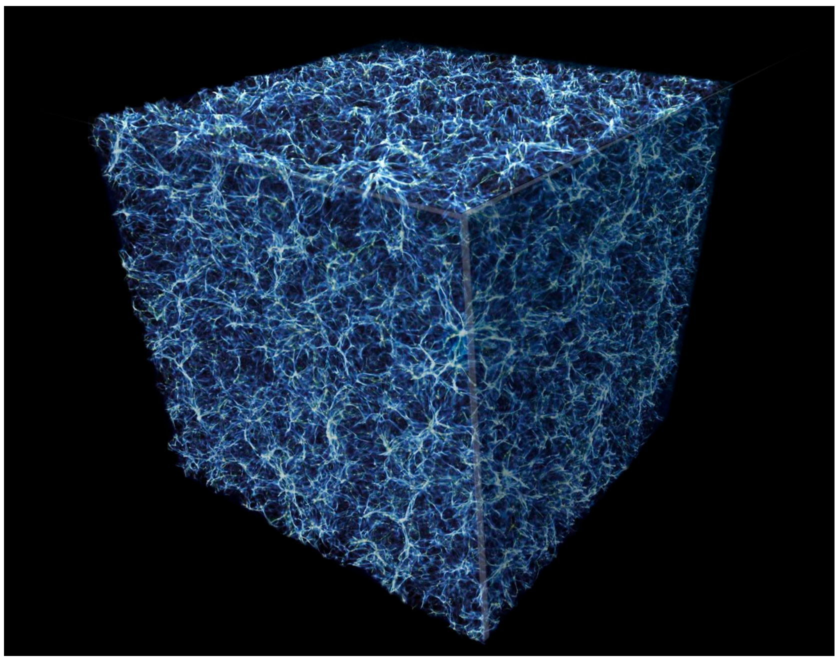
THE COSMOS*

(The Universe, What it is,

Origin, and the Future)



(see Page 2 for Photo details)

(An Historical Survey and Exploration of the Future)

by

Gerald F Pillay

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Gerald F Pillay
139A Lor 1A Toa Payoh
#01-48
Singapore 311139
gfpillay@singnet.com.sg

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Content
Matter distribution in a cubic section of the universe. The blue fibre structures represent the matter (primarily dark matter) and the empty regions in between represent the cosmic voids.

“This graphic represents a slice of the spider-web-like structure of the universe, called the "cosmic web." These great filaments are made largely of dark matter located in the space between galaxies.” Credit: NASA, ESA, and E. Hallman (University of Colorado, Boulder)

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WELCOME

Thank you for looking in.

One of my personal enjoyments is to keep a Brief of important areas of interest. It forces me to stay up to date.

In Science and Technology, I have confined myself to four subjects (1) Quantum Mechanics, (2) The Human Genome, (3) Viruses and (4) Space Exploration.

It is a game of continual catch-up. I began my current reviews in 2019. It plunged me into momentous developments.

I completed Quantum Mechanics in Oct 2020. It proved the indispensable foundation to the other subjects.

I launched into Viruses with the onset of Covid-19 in Mar 2020, completing my review in Dec 2021 as the Delta variant peaked. In the process I had to cover the Human Genome and the current state of biology.

This has led to how the universe began and where we are heading, timed with the launch of the James Web Space Telescope in Dec 2021, and hopefully to be completed before the first substantive Mars landings.

* * *

ABOUT THIS BOOK

This book is an historical survey of man's discovery of the universe. It summarises what we know today, and looks to the future.

It ties in the discoveries sequentially, in terms of the epoch, the scientific background, the discover or inventor and its place in the evolving understanding of the universe. It includes what is still unknown.

It is written at the informed layman level. It is useful for the first-timer, both as a substantive introduction and as a factual summary-reference. It is extensively hyperlinked so it can be used as both.

There are still no answers to the big questions. .As the final chapters explain, we have a long way to go.

* * *

EDITORIAL NOTE

The saga falls clearly into three Parts, the Ancient World, The Age of Classical Science, and Age of Quantum Science.

The three phases of discovery fall into place neatly, as follows: (1) the astrological to geocentric, (2) the heliocentric, and the (3) space-centric stages of discovery.

The epochs are structured differently. The first is by civilisation, each subdivided into its history and its astronomy. The second is by the sequence of individual achievement. And the third is by technological progress. There is a certain lyricism in the collective whole.

I make no apology for the lengthy Ancient digressions, historical and philosophical. I had always wanted to check these out coherently. Having now done so, I have set them down for background. Cosmology is after all, a part of human history.

The book has been too extensive and took too much time for me to maintain strict editorial consistency and control. I apologise for the typographical lapses, and not always converting figures to comparable values.

In as far as the Ancient times is concerned, I have confined myself to the Babylonian-Greek-Hellenic-Roman mainstream. Writing up Chinese, Indian, Egyptian, Arabic, Inca, Stonehenge etc astronomy would have overbalanced the exercise.

* * *

TRIBUTE TO STEPHEN HAWKINGS

It was my good fortune to find Stephen Hawking's "A Brief History of Time" when I began. It was the original 1988 edition updated by him to 2017 (just before he died in 2018) and is therefore as summative as one could want. Let me quote:

"The eventual goal of science is to provide a single theory that describes the whole universe.

However, the approach most scientists actually follow is to separate the problem into two parts. First, there are the laws that tell us how the universe changes with time. (If we know what the universe is like at any one time, these physical laws tell us how it will look at any later time.) Second, there is the question of the initial state of the universe.

Some people feel that science should be concerned with only the first part; they regard the question of the initial situation as a matter for metaphysics or religion. They would say that God, being omnipotent, could have started the universe off any way he wanted. That may be so, but in that case he also could have made it develop in a completely arbitrary way. Yet it appears that he chose to make it evolve in a very regular way according to certain laws.

It therefore seems equally reasonable to suppose that there are also laws governing the initial state."

A Brief History of Time – Stephen Hawking. Chapter 1

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DEDICATION

To

CHRISTIAN LOWEN PILLAY

Only grandson of Mabel and myself
Who will be 17 this coming 6 Oct 2023

Outcome of the Big Bang,
Born in Space-time,
The Earth is your inheritance
And your responsibility.

Christian,

You will see some predictions at the end
Make them happen.
The universe may then be yours as well.

If there is a 100,000 qubit quantum computer
around by then, say hello to it for me
And upload a copy of this book for it to read.

LOVE, Grandpa.

* * *

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Preface

It is the science and technology of each epoch that determines its astronomy, and the jump from to the next epoch. But, it has been the inventive power of the human mind that has led the way. I rate the invention of trigonometry in BC 500 as one of the great turning points of this history.

It was likewise the invention of the telescope and Newtonian physics that gave the classic age the breakthroughs, to confirm the heliocentricity of the earth and the details of the Solar System.

They were also the first to venture a formulation of the structure and the composition of the universe. They made the first charts of the galactic quadrants, notwithstanding that their telescopes were not yet able to distinguish the individual stars of the Milky Way.

It was relativity and quantum mechanics at the turn of the last century that finally enabled man to understand that energy and matter are the same and that the behaviour of these constituted the totality of the phenomenon known as the universe. Einstein and Planck opened our doors to cosmology with elementary particles, gravity and space-time.

We went on to discover that electro-magnetic radiation (EMR) was the bloodstream of the universe, which could be diagnosed to tell us what is going on in every corner of the visible world – right from the beginning of time.

Lemaitre gave us the Big Bang and Hubble the expanding universe.

It was essentially gravity that told us there was also a much larger dark invisible world, and it was Dirac's obscure mathematics that told us there was antimatter, which we went on to prove existed.

Quantum science has also provided us a whole package of new technologies, especially microelectronics and information technology, to help us leap into the future.

We know how through fusion and fission of elementary particles, we could tap one source of the energy we need – hopefully to travel far in space.

Through the quantum computer and AI we shall finally discover the entire universe and (hopefully) travel around in it.

The following Table 1 provides a simplified over-view of man's encounter with the universe, our subject

Terminology

"universe", means all the that entity comprising the matter-energy set existing in space-time of which we are part, inclusive of galaxies, voids stars, interstellar space, solar systems, planets and living things. There is only the one.

"space" is technically that empty area outside or beyond the universe, but in context it also means the areas around and between the physical objects in the universe, such as the galactic voids on the one hand, and the area between the Earth and the Moon on the other.

“cosmos” means the universe as a well-ordered working whole, including the principles or rationale on which it operates, and encompassing its origin, evolution and end.

“cosmology” is the study of the above.

* * *

“Astronomy” is the study of physics of al the objects in the universe from (and therefore excluding) the Earth.

“Astrology” is that body of studies concerned with interpreting the positions, movements, eclipses and interactions of stars, constellations and other celestial phenomena, as predictions, omens and influences on mundane events and human behaviour. Astrology was the first application of astronomy.

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PART I

The Ancient World

Introduction

This Part provides the background of what Man did in the pre-scientific ages.

I have focussed on the Sumerian-Babylonian, Greek-Ptolemaic and Medieval-Renaissance astronomic histories, as they are continuous and constitute the linear development to modern times. ,

With strings of empires and kingdoms, it has been necessary to interweave an historic continuum to flesh out the people, bring out the boundary lines and connect the whole.

Beginnings

Man began to study the world as soon as he had need to manage its effects. Nothing would have had more impact on his daily life than the Sun and the Moon. And his tools were simply observation and measurement. He soon discovered night and day, the months, the seasons, and the year.

As man progressed from hunting to agriculture, and then urbanised life, he would, among other things, learn to write, develop mathematics and begin to record events. His astronomical data, his processes of observation, his calculation methods and the application of his results form the subject of interest in this present review.

He would soon identify the planets, record their changing positions, and even predict their movements. He would then proceed to study the stars. He would map their locations and groups them into patterns, giving them names. Finally he would divide the celestial hemisphere into quadrants to better navigate around.

Beyond that man would inevitably relate and mythologise the heavens with his beliefs, his religion and a world view.

* * *

Chapter One
Mesopotamia

Mesopotamia occupied the Fertile Crescent, the “land between the rivers”, the Tigris and the Euphrates. The present-day Bagdad separates the southern half stretching to the Persian Gulf from the northern half stretching to Turkey and Syria. It may well have been the cradle of civilisation. Among the ancient civilisations, the Mesopotamians were the pioneers of modern astronomy.

Overview

Mesopotamia had a long history, the recorded portion being about 2,500 years. The first people were the Sumerians. who spread both to the north and south and developed as independent city-states with loose interchanging hegemonies.

In their last millennium, there were five major empires, who occupied the whole land and or parts of each other in turn, and or were periodically conquered by neighbours. This table summarises the history:

Table 2

Major Empires of Mesopotamia

Dates (BC)	Empire	Originating Location	Dynasty	Conquered by
3100-2334	Sumer	North and South	Sumerian	Akkadians in BC 2334
2600-745	Assyrian	North Conquered Persia to Turkey and Egypt Periodic invasion of South	Early, Old and Middle Assyrian Kingdoms	Longest empire World’s greatest army and empire Conquered by Neo Babylon in BC 745
2334-2100	Akkadia	North. Conquered whole	Akkadian	Last UR III in BC 2100
2100-2004	Sumer (Revived)	South Conquered whole	Ur III	Elamites (foreign) sacked Ur in BC 2004. Amorites took over.
1894-1595	Babylonia (Old Kingdom)	Foreign. Conquered south	Amorite	Hittites (foreign) in BC 1595
1570 - 1155	Babylonia (Middle Kingdom)	Foreign Conquered south	Kassite	Assyrians in BC 1155

1250-1100				Bronze Dark Age
745-612	Neo-Assyrian	North Conquered whole	Assyrian	Neo-Babylonians and Medes in BC 612
612-539	Neo-Babylonian	South Conquered whole	Chaldean	Archaemenid (Persian) in BC 539

After the fall of the Akkadian Empire (BC 2100), the peoples of Mesopotamia coalesced into two major Akkadian-speaking nations: Babylonia in the south and Assyria in the north. But basically, they developed as one civilisation with a common culture and forms of worship, and collectively made a remarkable astronomic contribution to posterity.

There was complete continuity in Mesopotamian astronomy from Sumerian through to Neo-Babylonian times, notwithstanding the fragmented political occupation of both Mesopotamia and Babylonia. Where the Sumerians left off, it was the Babylonians who continued to build, both in terms of astronomy and its applications, particularly astrology. Where not specifically stated, I use the term Babylonian synonymously with Mesopotamian.

As the first Sumerians looked to the sky to improve day-to-day life, like the days, the climate and the seasons, they developed the basic skills of observation, measurement and recording.

Outstandingly, they invented clay-tablet writing and cuneiform. Among. Other things, they , also acquired a passion for recording their astronomical observations.

Early Sumerian astronomy was mainly the observation and recording of celestial objects, and their application to life.

Temple-Religious Framework

In parallel, the Sumerians developed a polytheistic mythology. They believed in many gods with different functions, inhabiting the different parts of the heavens. Their culture attributed the gods as having a very direct role in human life. From early on, they practised divination, inter alia by inspecting the entrails of sacrificed animals.

They soon coupled celestial events with human happenings, as acts of the gods. An eclipse was a bad omen, and in time they learnt to predict them. And, finally, they devised systems for consulting the stars for good fortune through astronomy. Thus, astrology became an inseparable part of astronomy, indeed the major component of the latter. The two became the dominant features of Mesopotamian civilisation.

The temple priests would be among those who looked at the heavens most. Therefore, they were mostly likely to be the first astronomers, and would have doubled as scribes. They would also probably function as the first astrologers.

Not surprisingly, astronomical activity centred in the temple, tied if by nothing else by the common use of Sumerian to record observations. The temple was also where the data would be kept and safeguarded..

The temple was in turn inextricably tied to the ruler. The latter ruled by divine right or favour. The worship-system would have been part of the state infrastructure. As the astrological system developed, the rulers depended increasingly on their predictive functions. The last

Assyrian ruler, for instance, called for weekly forecasts from the temple to plan his activities. The temples were a source of political power.

There may or may not have been a system of sharing celestial information among temples. My impression would be that each ruler would have jealously guarded his own temples' secrets. I suspect a prime objective of conquering a rival kingdom or empire might have been capturing their temples.

Thus, the major temples concentrated around the king. From the time of king Hammurabi of the Old Babylonian Kingdom, Babylonia noticeably emerged as the lead intellectual and cultural centre of Mesopotamia, reaching pre-eminence under the Neo-Babylonian empire. Likewise Babylon (the city) emerged to become a strong centre of astronomy. The priest-astronomers of Babylon likewise became the most influential of the astronomer-priests. A late Babylonian document gives the names of 43 temples in Babylon, followed by 55 shrines of Marduk. This could explain how the Achaemenians (Persians) made a clean haul of all Babylonian astronomy when they conquered them in BC 539.

It might be pointed out that Nippur, not quite 200 Km from Babylon across the Tigris, became the centre of Babylonian religious worship, vide

> "In Sumerian mythology Nippur was the home of Enlil, the storm god and representation of force and the god who carried out the decrees of the assembly of gods that met at Nippur. Enlil, according to one account, created man at Nippur. Although a king's armies might subjugate the country, the transference to that king of Enlil's divine power to rule had to be sought and sanctioned. The necessity of this confirmation made the city and Enlil's sanctuary there especially sacred, regardless of which dynasty ruled Mesopotamia."
> Encyclopaedia Britannica."
> https://www.britannica.com/place/Nippur

This suggests that, allowing for local and regional differences, Mesopotamian kingdoms and empires enjoyed a common pantheon of gods and institutions of worship. It seemed all the kings and conquerors in Mesopotamian history, local and foreign, by and large respected the same temple institutions, and fostered and protected them.

Priests-Astronomers

Not surprisingly, the priests-astronomers became a common elite across the land. I could not determine whether they formed an independent power group, laid down their own rules, carried out common training of recruits, transferred about among themselves, and shared astronomical resources as well as temple knowledge. There must have been some of this.

The fact that both religious and astronomic activity began and continued in the Sumerian language would have narrowed the participation and assured the continuity in the select community of priests-astronomers..

It seems commonly accepted that the temples and astronomy became the preserve of a group called the Chaldeans. While this was probably true in the Neo-Babylonians empire (see further on), I could not confirm that all temples and astronomical activity throughout Mesopotamia were run by Chaldeans, or who exactly they were.

Chaldea was the region in which the Sumerians originated, near Ur in the south. The Neo-Babylonian Empire, the third and last, was also founded by the uprising of a new Chaldean people, presumably from the south. In fact the empire was also known as the Chaldean Empire. Apparently, this second group also spoke a kind of Chaldean-Sumerian.

Remembering that all temple activities, including astronomy, were historically run in Sumerian, it is understandable that the new ruling elite and the temple elite of Neo-Babylon should have reinforced each other. This may account for the depth and historical purity of Babylonian astronomy-astrology and the preservation of their tablets.

Between half a million and two million cuneiform tablets are estimated to have been excavated in modern times, of which only approximately 30,000-100,000 have been read or published. Our knowledge of the Mesopotamian world is still fragmentary. Apart from lack of completeness and continuity, one other difficulty is identifying whether a finding of inforrmation, where first discovered in one epoch, was new or belonged to an earlier epoch and re-discovered . I have placed the relevant facts in the time frames of the empires by first mention, but plead that a lot may be inherited from intermediates.

I apologise for the length of the historical portions. I assure you, they are very brief compared to the full story of this very fractious part of the world.

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(A) Sumer (3100 – 2334 BC)

The people of Sumer go back to the 6th millennium BC, before the bronze and Iron ages. The Sumerians occupied southern Mesopotamia in the region west of the mouth of the Euphrates, known as Chaldea. .

When they emerged into recorded history, from about the early 3rd millennium BC, we find that they had developed into a remarkably sophisticated urbanised civilisation – among the most advanced in the world at that time[1].

Firstly, the origin of writing on clay tablets has been traced back to them, to about the end of the 4th millennium BC. The creation of language, using the cuneiform script, written on clay tablets, became their outstanding contribution to mankind, being the world's earliest language recording system[2]. It went on to be universally adopted in the Near East (then the centre of the world) for the next three millennia, until the last dated record in AD 75.

Secondly the Sumerians achieved a considerable level of mathematical competence. By 3000 BC, they developed a complex system of metrology, and from 2600 BC they were writing multiplication tables on their clay tablets and dealt with geometrical exercises and division problems. The earliest traces of the Babylonian numerals date back to this period.

Thirdly, the Sumerians were avid record-keepers. They kept voluminous meticulous records of their activities, down to taxes. The clay tablets preserve well, and have been instrumental in transmitting their knowledge and maintaining their presence in the region down the centuries.

And fourthly, it would appear that the specialisation in astronomical matters by scribes-priests and priests-astronomers must have begun with them. These would have been the parties devoted to studying the heavens, developing the necessary observational mathematics, and for the extensive records of celestial movements passed down by them. This would account for the close tie-up of astronomy with the temples – and later to astrology and divination. The Sumerians are said to be the first astronomers, and probably the first astrologers.

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[1] Archaeology has shown that in about 2500 BC the ruling elite in the city of Ur went to their final resting place surrounded by their wealth and the attendant bodies of their court personnel.

[2] Cuneiform characters were imprinted on a wet clay tablet with a stylus often made of reed (reed pen), and then baked

Sumer laid the foundations of a civilisation that went on in the next millennia to provide the world with many other firsts besides astronomical achievements: first legal codes, court system, schools, proverbs, moral and ethical ideas, and technological innovations. The oldest epic tale in the world was written 1500 years before Homer wrote the Iliad. “The Epic of Gilgamesh” tells of the Sumerian Gilgamesh, the hero king of Uruk, and his adventures.

Not much of their own clay tablets have survived to today. We learn more about them from what their layers of successors knew and practised, making judgements what was invented by them and what was passed down to them.

The Sumerians were the first and earliest peoples of Mesopotamia. They spread out over much of Mesopotamia, including the north, forming smallish semi-independent kingdoms.. The scenario becomes mixed later by periodic intrusions, conquests and settlement by neighbouring peoples. In this form, Sumer continued for over 1,000 years. They were first conquered by Sargon the Great of Akkadia, a Semitic people, in 2334 BC, to form the first of the historically great Mesopotamian empires.

Sumerian Astronomy

The Sumerians developed a sexagesimal system of measurement (base 60) which became universal in Mesopotamia. They divided a circle into 360 sections, thus providing an angle measurement system especially suited to plot cosmological phenomena, and is still in use today. Without this they could not have charted the sky.

The Sumerians divided night and day into 12 equal hours each, whose length varied with the seasons as the length of the daylight hours changed. They also divided the astronomical day (our 24 hours) into 12 equal hours, and each hour into 30 smaller units, making a total of 360 units for each day.

The number 12 was an important number to the Sumerians. it was the number of lunar cycles in a year and the number of constellations of the Zodiac. Day and night were each divided into 12 periods, and the 24-hour day was born. The Sumerians were the first to create a calendar by counting 12 lunar months as a year The lunar calendar was synchronized with the solar year (the seasons) by interspersing a leap month every few years. It is of course a factor of 60
.
In ancient Sumer, there were two seasons– a “summer” season, which began with the Vernal Equinox and a “winter” season which began with the Autumnal Equinox.

Not surprisingly, the Sumerians tracked the planets, five at that point visible to the naked eye - Mercury, Venus, Mars, Jupiter and Saturn. They bequeathed centuries of tablets recording these planetary movements to later generations. They even developed predictive skills.

The Sumerians inevitably looked at the visible firmament beyond the planets. They mapped the stars and set out the constellations, many of which have survived to this day.

The theory of the ecliptic as representing the course of the Sun through the year, divided among twelve constellations with a measurement of 30° to each division, is of Babylonian origin, as has now been definitely proved; but it does not appear to have been perfected until after the fall of the Babylonian empire in .

Sumerians believed that the universe consisted of a flat disk enclosed by a dome. In contrast, later Babylonian cosmology suggested that the cosmos revolved around circularly with the heavens and the earth being equal and joined as a whole.

The Babylonian pantheon of gods began with the Sumerians, and many of these gods were tied to the planets, a tradition carried on by the Greeks and Romans. They believed that the king god was Marduk, patron of Babylon. One source enumerated some 2,100 deities of various orders of importance counted out of known tablets so far.

The Sumerians i3ntified the five planets in their god identities: Jupiter (Marduk), Venus (Ishtar), Saturn (Ninurta), Mercury (Nabu) and Mars (Nergal).

The Sumerians believed in a plurality of heavens and earths. This idea dates back to Sumerian spells of the 2nd millennium BC, which refers to the existence of seven heavens and earths, perhaps chronologically linked to the creation by seven generations of gods..

The practice of identifying and naming constellations also went back to the Sumerians. The people marked the seasons for harvesting or planting by the orientation of the constellations. Some constellations provided an accurate clock with which to measure time

Sumerian scribe-priests and their chief clients, the kings, were the end-users and custodians of astronomy, a very common trait in the region and one that defined the history of astronomy. It is remarkable how much of the subsequent sophistication was built up on Sumerian origins.

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(B) Akkadia (2334 – 2100 BC)

The first empire to rule all of Mesopotamia was the Akkadian Empire. The Akkadians lived in northern Mesopotamia. The empire It lasted for around 200 years, from 2300 BC to 2100 BC. At its greatest extent, the empire reached as far as Anatolia in the north, inner Iran in the east, Arabia in the south, and the Mediterranean in the west.

Babylon was then a small town on the banks of the Euphrates, some 80 Km south of present day Bagdad, founded around 2300 BC by Akkadian-speaking peoples.

The consolidation of the city-states of Sumer and Akkad reflected the growing economic and political power of Mesopotamia. The empire's breadbasket was the rain-fed agricultural system and a chain of fortresses was built to control the imperial wheat production.

Sargon showed special deference to the Sumerian deities, particularly Innanna (Ishtar), his patroness, and Zababa, the warrior god of Kish. His daughter was installed as a priestess to Nanna at the Sumerian temple in Ur.

After the fall of the Akkadian Empire, the people of Mesopotamia coalesced into two major Akkadian-speaking nations: Babylonia in the south and Assyria in the north.

Akkadian gradually replaced Sumerian as a spoken language in the area from around 2000 BC, but Sumerian continued to be used as a sacred, ceremonial, literary and scientific language in fact until the 1st century AD.

Akkadian Astronomy

Despite much searching I found little trace of Akkadian astronomy as such. Perhaps nothing has yet been discovered in tablets by modern scholars. More probably, the Akkadians left it to the Sumerian priest-scribes in those still early days, and the latter kept things close to their chest.

(C) Rise of Babylon
(2100 - 612 BC)

Sumer UR III Dynasty

(2100-1994 BC)

In 2100 BC the Sumerian city of Ur rose back into power under Ur Dynasty III. It re-conquered Akkadia and indeed much of the original Sumer. It was eventually conquered by the Amorites in around 2004 BC. This was succeeded by a transitional period of Amorite states before the rise of Babylonia from 1894 BC.

Amorites

(2004 – 1595 BC)

From the 21century BC, a large-scale migration of Amorite tribes infiltrated Mesopotamia, There was no Amorite invasion as such, but Amorites ascended to power in many locations, especially during the reign of the last (Sumerian) king of the Ur-III Dynasty.

Amorites progressively assumed power in various cities, including Babylon. The Elamites, a warring neighbour from Persia, sacked Ur in 2004 BC, ending Sumerian history, and were in turn ousted by the Amorites in 1894 BC, beginning the “Amorite Period” of Mesopotamian history.

Amorites were originally a Semitic nomadic people. They came to dominate the region for 400 years, and the most famous Amorite king was the great *Hammurabi* of Babylonia.

Their rise to power brought about significant changes in Mesopotamian civilisation. The division into kingdoms replaced the city-state system. Men, land, and cattle ceased to be owned by various gods, temples, or kings. The new monarchs endowed or let out for an indefinite period numerous parcels of royal or temple lands, and freed the inhabitants from taxes and forced labour. This encouraged a new society to emerge, featuring large farms, free citizens, and enterprising merchants. This new system was to last throughout the centuries.

The priests, who had previously ruled on behalf of their gods, continued in the service of their deities and their people's spiritual welfare, but the economic life of the country was no longer nearly exclusively in their hands.

Religion continued its evolution from many local deities to a regional pantheon of major and minor gods. The storm-god, Marduk, came to assume the role of chief deity.

There were at least seven principal Amorite dynasties, including the last, Babylonia. This era ended with the sack of Babylon in 1595 BC by the Hittites, a people from Anatolia. This brought new ethnic groups - particularly Kassites - to the forefront in Mesopotamia.

Amorite Babylonia

(First Babylonian Empire)
(Old Babylonian Kingdom)
(1894-1595)

A small Amorite-ruled state emerged in 1894 BC which came to be known as Babylonia, and included the minor port town of Babylon.

In the early 18th century BC, the state expanded to become the First Babylonian Dynasty of the Amorites, and Babylon grew to be a major capital city. Its sixth king was *Hammurabi,* who ruled from 1782 to 1750 BC. He conquered Elam and the surrounding city states, and ousted the king of Assyria in the north, bringing almost the whole of Mesopotamia under Babylonian rule. The Babylonian Empire rapidly fell apart after the death of Hammurabi and reverted to a small kingdom.

Hammurabi gave the region stability, transforming what had been an unstable collection of city-states into an empire that spanned the fertile crescent. A great literary revival followed. One of the most important works of this time was the compilation of a code of laws, made by his order, known as the Code of Hammurabi - only found in 1901. This code was one of the first written codes of law in recorded history. It gave Babylonia the edge over the other kingdoms.

The Babylonian state retained the written Akkadian language (the language of its native populace) for official use and the Sumerian language for religious use. Though many cultures co-existed in Mesopotamia, Babylonian culture gained a degree of prominence among the literate classes throughout the Middle East.

Hammurabi turned Babylon into a rich, powerful and influential city. The Code of Hammurabi helped Babylon surpass other cities. Babylonia, however, was short-lived. The empire fell apart after Hammurabi's death and reverted back to a small kingdom for several centuries.

Under the rules of Hammurabi's successors, the Babylonian Empire was weakened by military pressure from the Hittites who sacked Babylon in 1595 BC. However, it was the Kassites who eventually next conquered Babylon and ruled Mesopotamia for 400 years, adopting parts of the Babylonian culture, including Hammurabi's code of laws.

First Babylonian Astronomy

The earliest mathematical texts available from Mesopotamia written about 1800 BC mention the so-called "Pythagorean triples" and so, by inference, the Pythagorean theorem. It seemed to be the most ancient and widespread mathematical development after basic arithmetic and geometry, long before Pythagoras in the 6th century BC or Euclid's Proposition No 47.

The astronomy bequeathed to the Babylonians was essentially the recording and study of celestial objects. From 1800 BC, the evidence is that the Old Babylonians upgraded this. They meticulously plotted the movement of the sun and the moon, using them to track the procession of the seasons. Nothing much else recently discovered dates specifically to this period, the main glory of which rests with Hammurabi.

Kassite Babylonia

(Middle Babylonian Kingdom)
1570 – 1155 BC)

The Kassites controlled Babylonia from 25 years after the Hittites sacked Babylon, from 1570 BC until 1155 BC. They established a dynasty based first in Babylon (city) and later in Dur-Kurigalzu. They went on to conquer the southern part of Mesopotamia, roughly corresponding to ancient Sumer. This period is sometimes called the Middle Babylonian Empire, although ruled by foreigners. The Kassites it seemed were content for their emp[ire to remain known as Babylonia.

The Kassites were members of a small military aristocracy but were efficient rulers and locally popular, and their 400-year reign laid an essential groundwork for the development of subsequent Babylonian culture. The chariot and the horse, first came into use in Babylonia at this time. Several Kassite leaders and deities bore Indo-European names.

The transformation of southern Mesopotamia into a territorial state, rather than a network of allied or combative city states, made Babylonia an international power. Kassite kings established trade and diplomacy with neighbouring kingdoms, and the Kassite royal house intermarried with their royal families. There were foreign merchants in Babylon and other cities, and Babylonian merchants were active in Egypt, Assyria and Anatolia. Over the centuries, however, the Kassites were absorbed into the Babylonian population. Eight among the last kings of the Kassite dynasty had Akkadian names, Their success was built upon the relative political stability that the Kassite monarchs achieved.

At one point, the. Assyrians briefly took the Kassite state over because of a family feud. The Elamites finally conquered Babylonia in 1155 BC, ending the Kassite state.

Bronze Dark Age

(1250-1100 BC)

The entire Mesopotamian and Near East region next entered what is called the Bronze Age Collapse. For 150 years, from 1250 to 1100 B.C. all the Near East civilizations—the Egyptians, Greeks, Cyprians, Syrians, Mesopotamians—disintegrated to a certain extent, except for the Assyrians. It is believed this was reflected in (if not accentuated by) a general degeneracy of the priest-scribe society.

Middle Babylonian Astronomy

The Kassite kings conservatively practised Babylonian's priest-scribe temple culture. There are important re-discovered records dating back to this period. ,

At some stage, the Babylonians began to compile lists of visible stars, grouped by constellations. The first formal compendia of star lists were the *Three Stars Each* texts, which appeared in the late Kassite period from about the 12th century BC. They represent a tripartite division of the heavens: the northern hemisphere belonged to the Sumerian god *Enil,* the equator belonged to *Anu,* and the southern hemisphere belonged to *Enki.* The boundaries were at 17 degrees North and South, so that the Sun spent exactly three consecutive months in each third. The enumeration of stars in the *Three Stars Each* catalogues includes 36 stars, three for each month.

Centuries of Babylonian observations of celestial phenomena were recorded in the series of cuneiform tablets known as *Enuma Anu Enlil* (EAE).The series was probably compiled in its canonical form during the Kassite period, but there was certainly some form of prototype current in the Old Babylonian period. It continued in use well into the 1st millennium, the latest datable copy being written in 194 BCE.

Enuma Anu Enlil is a major series of 68 or 70 tablets dealing with Babylonian astrology. The subject matter of the EAE tablets unfold in a pattern that reveals the behaviour of the moon first, then solar phenomena, followed by other weather activities, and finally the behaviour of various stars and planets.

The bulk of the work is a substantial collection of omens, estimated to number between 6500 and 7000, which interpret a wide variety of celestial and atmospheric phenomena in terms relevant to the king and state. The EAE was the principal source of omens used in the regular astrological reports that were sent to the Neo Assyrian king by his entourage of scholars. There are over 500 such reports. A majority simply list the relevant omens that best describe recent celestial events and many add brief explanatory comments concerning the interpretation of the omens for the benefit of the king. An astronomical report to the king *Esarhaddon,* king of Assyria – then ruling the Middle Babylon kingdom - concerning a lunar eclipse of January 673 BC showed how the ritualistic use of substitute kings, or substitute events, combined an unquestioning belief in magic and omens with a purely mechanical view that the astrological event must have some kind of correlate within the natural world.

The oldest significant astronomical text that we possess is Tablet 63 of the series, the *Venus Tablet of Ammisaduga* which recorded the first and last risings of Venus over 21 years. The Babylonians were fully aware of the regularity and periodicity of planetary phenomena.

According to the method described in four of the tablets, Babylonian astronomers plotted a 60-day portion of Jupiter's wandering path across the sky on a graph, with time plotted on one axis and velocity — how many degrees Jupiter's path shifted each day.

Babylonian astrology developed within the context of divination. A collection of 32 tablets with inscribed liver models, dating from about 1875 BC, are the oldest known detailed texts of Babylonian divination, and these demonstrate the same interpretational format as that employed in celestial omen analysis. Blemishes and marks found on the liver of the sacrificial animal were interpreted as symbolic signs which presented messages from the gods to the king.

Assyrian Late Middle Babylonia

(745-612 BC)

The Middle Babylonian kingdom, with many weak kings, collapsed internally and the resulted in the Neo Assyrian Empire intervening militarily in 745 BC and incorporating Babylonia into its empire in 729 BC.

Assyrian control of Babylonia was neither stable nor continuous and the century of Assyrian rule included several unsuccessful Babylonian revolts. The latter finally broke free defeating the Assyrians at Nineveh in 612 B.C, forming the Neo Babylonian Empire.

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(D) Neo-Babylonian Empire (Chaldean Empire) (612 – 539 BC)

The Middle Babylonian kingdom, with many weak kings, collapsed internally and the resulted in the Neo Assyrian Empire[3] intervening militarily in 745 BC and incorporating Babylonia into its empire in 729 BC. The latter finally broke free defeating the Assyrians with their allies the Medes from northern Persia at Nineveh in 612 B.C, forming the Neo Babylonian Empire.

The population of Babylonia in the preceding Middle Babylonian period comprised two main groups, the natives - composed of the descendants of the Sumerians, Akkadians and the assimilated Amorites and Kassites- and more recent arrivals - Arameans, Chaldeans and unassimilated tribesmen from the Levant.

By the 7th century, the native Babylonians had lost their old identities and had assimilated into a unified "Babylonian" culture. At the same time, the Chaldeans, though retaining their

[3] I have placed coverage of the Neo Assyrian Empire last, for better reading connectivity of Babylonian Astrology.

tribal structure and way of life, were becoming more "babylonised". All the major Chaldean tribes produced at least one Babylonian king.

The Neo-Babylonian Empire became the most powerful state in the world. It was also known as the Second Babylonian Empire and the Chaldean Empire. It was the last of the Mesopotamian empires to be ruled by monarchs native to Mesopotamia.

The Neo-Babylonian Empire was a period of cultural renaissance in the Near East. The Babylonians built many beautiful and lavish buildings and preserved statues and artworks from the earlier Babylonian Empire.

The period thus saw unprecedented economic and population growth throughout Babylonia and a renaissance of culture and artwork, with the Neo-Babylonian kings conducting massive building projects, especially in Babylon itself, and bringing back many elements from the previous 2,000 or so years of Sumerian-Akkadian culture. *Nebuchadnezzar's* reign was the golden age that transformed Babylonia into the greatest empire of its time.

The Neo-Babylonian Empire and its ruling Chaldean Dynasty were short-lived. Their final king, *Nabonidus*, favoured the moon god *Sin* over Babylon's patron deity *Marduk* eventually providing a *casus belli* for the Achaemenid king, *Cyrus the Great*, to invade Babylonia in 539 BC, portraying himself as a champion of *Marduk*

Neo-Babylonian Astronomy

During the 8th and 7th centuries BC, Babylonian astronomers refined their understandings about the operations of the universe, leading to an increasingly predictive approach to planetary study.

It developed alongside and out of the beliefs that since the gods in the heavens ruled man's fate and the motions of the stars and planets controlled the fate of people on earth. the stars could reveal fortunes. The priests-scribes became "inspectors" for ascertaining or divining the will and intention of the gods through celestial omens – in addition to divination by inspecting the entrails of slaughtered animals. Thus was Babylonian celestial astrology born.
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Prior to the 7th century BC the practitioners' understanding of astronomy was fairly rudimentary. By the 4th century, however, their mathematical methods had progressed enough to calculate future planetary positions with reasonable accuracy, at which point extensive ephemerides (calculation-tables) began to appear.

MUL.APIN

This is the point at which we introduce the MUL.APIN, the most comprehensive Babylonian compendium of astronomy. It deals with many diverse aspects of Babylonian astronomy and astrology. It is in the tradition of earlier star catalogues, the Three Stars Each lists, but represents an expanded version based on more accurate observation. The text lists the names of 66 stars and constellations and further gives a number of indications, such as rising, setting and culmination dates, that help to map out the basic structure of the Babylonian star map.

The text is preserved in a 7th-century BC copy on two tablets, named after their first constellation of the year, APIN, The Plough. The earliest copy of the text so far discovered was made in 686 BC; however the majority of scholars now believe that the text was originally compiled around 1000 BC. The latest copies of MUL.APIN are currently dated to around 300 BC.

The text runs to two tablets and possibly a third auxiliary tablet, and is organised as follows:

Tablet I – Description of the static sky				
List 1	I i 1	to	I ii 35	catalogue of asterisms (inventory of the sky)
List 2	I ii 36	to	I iii 12	dates of heliacal rises in the Babylonian calendar
List 3	I iii 13	to	I iii 33	simultaneous rises and settings
List 4	I iii 34	to	I iii 48	time intervals between heliacal risings
List 5	I iv I	to	I iv 30	*ziqpu*-asterisms
List 6	I iv 31	to	I iv 39	asterisms in the path of the Moon

Tablet II – Changes in the sky				
List 1	II i 1	to	II i 8	motion of planets in the lunar path
List 2	II i 9	to	II i 24	determining cardinal points of the year
List 3	II i 25-37	and	II i 68-71	heliacal risings and wind direction
List 4	II i 38	to	II i 67	planets – visibilities
List 5	II ii 1	to	II ii 20	intercalary rules
List 6	II ii 21	to	II ii 42	shadow lengths of the sundial
List 7	II ii 43	to	II iii 15	water clock

List 8	II iii 16	to	II iv 12	omens

Constellations

The path of the Moon as given in MUL.APIN consists of 17 or 18 stations, corresponding to constellations as we know them:

No.	MUL.APIN name	Translation	Constellation (IAU)	associated god according to List 1
1	MUL.MUL	Many Stars (or: Star Cluster)	Pleiades (Taurus)	Anu
2	GU_4.AN.NA	Bull of Heaven	Taurus	Anu
3	SIPA.AN.NA	True Shepherd of Anu	Orion	Anu
4	ŠU.GI	Old Man (Enmešarra, the last of Enlil's primeval ancestors)	Perseus	Enlil
5	GAM	Crook	Auriga	Enlil
6	MAŠ.TAB.BA.GAL.GAL	Great Twins (Lugalirra and Meslamta'ea, a pair of netherworld gods)	Gemini (north of ecliptic)	Enlil
7	AL.LU	Cancer	Cancer	Enlil
8	UR.GU.LA	Leo	Leo	Enlil
9	AB.SIN	Furrow	Virgo (north of Spica)	Šala
10	RIN	Balance	Libra and the part of Virgo south of Spica	Anu
11	GIR.TAB	Scorpion	Scorpius (maybe plus southern parts of Ophiuchus)	Ea
12	PA.BIL.SAG	Pabilsang (city god of Larak, who was identified with Ninurta, particularly in his role as the	Sagittarius	Ea

		husband of the healing-goddess Gula)		
13	SUḪUR.MEŠ	Goat-Fish	Capricornus	Ea
14	GU.LA	The Great One (a common by-name of the god Ea/Enki)	Aquarius	Ea
15	KUN^{MUŠ} (ša)[6]SIM.MAḪ	Tails of the Great Swallow	Pisces	Anu/ Ea
16	^{Dingir}Anunitu	Goddess Anunitu	the eastern one of the two fishes in Pisces plus parts of Andromeda (β And)	Anu
17	^{LU}HUN.GA	Hired Man (or: Loan Worker) (Dumuzi, the mythical lover of Inanna/Ištar who is imagined as a shepherd)	Aries and Triangulum	Anu

MUL.APIN was comprised in the general time frame of the Astrolabes and he *Enuma Anu Enlil* evidenced by similar themes, mathematical principles, and occurrences.

Astrology - Planets and gods

There is speculation that astrology of some form appeared in the Sumerian period in the 3rd millennium BC, but the isolated references to ancient celestial omens are sufficient to demonstrate a system of astrology. The history of celestial divination is therefore generally reported to begin in Old Babylonia. (c. 1800 BC), and continuing through the Middle Babylonian periods (c. 1200 BC).

The Babylonians used a horoscopic astrology. By observing the seasonal movement of the sun, moon, and planets, they connected their beliefs of divine intervention in everyday life to celestial movements.. They would forecast their future circumstances by relating ominous events, such as a lunar eclipses, to social, political, and environmental problems, even aspects of their everyday lives, such as giving birth to deformed children.

The Babylonians associated and created their beliefs around planets based on the Benefic or Maleic nature of the god associated with it. Planets were believed to have influences and provide guidance to humans

The movements of the Sun, Moon and five planets were regarded as representing the activity of the five gods in question, together with the moon-god/goddess *Sin* and the Sun-god *Shamash* , in preparing the occurrences on earth. If, therefore, one could correctly read and interpret the activity of these powers, one knew what the gods were aiming to bring about. Astrology was also applied in the practice of astral medicine.

In the later Babylonian Empire, the priest-astronomers in addition to continuing to use the old star catalogues also developed mathematical models capable of anticipating astronomical events without consulting the registers. Thanks to this ability to “predict the future” they enjoyed positions of great power and respect

Zodiac

The path of the 17 or 18 stations of the Moon in the MUL/APIN are recognizable as the direct predecessors of the 12 constellations of the. zodiac. when the Sun at vernal equinox was close to the Pleiades in Taurus in the 23rd century BC.

The division of the ecliptic into the zodiacal signs originated in Babylonian astronomy during the first half of the 1st millennium BC. The zodiac (a Greek word meaning “circle of animals”) was devised by the Neo-Babylonians. The 12 signs of zodiac correspond to 12 of the constellations which the sun passes through in successive months and are more or less directly overhead at noon on the equator in the course of year.

In the reign of *Nabonassar (*747 - 733 BC), there was an upgrade in the systematic coverage and quality of celestial observations. As a result the Babylonians went on to discover that lunar eclipses were locked in to a nineteen year cycle. Other contributions were the naming of the zodiacal signs along the ecliptic plane, which passed into the Roman system and is still used by modern astrologers and astronomers to divide the night sky.

It appears most of Babylonian astronomers were concerned mainly with ephemerides (observational data) and not with theory. Their predictive models were strictly empirical and arithmetical, and did not involve cosmology or geometry. Uniform circular motion was not an element in their universe. The ancient Babylonians were able to advance our understanding of astronomy without ever using a telescope.

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(E) Assyria

Early Assyria (2600–2025 BC),
Old Assyria (2025–1364 BC),
Middle Assyria (1363–912 BC
Neo-Assyrian (911–612 BC)

The Assyrian people developed cotemporally with the Sumerians in northern Mesopotamia, from the 23rd century BC. They existed as a city-state from the 21st century BC to the 14th century BC, then as a territorial state, and eventually as an empire from the 14th century BC to the 7th century BC. They survived for another 800 years after final conquest by the Neo-Babylonia and the Medes in BC 609.

Assyrian history divides into Early Assyrian (2600–2025 BC), Old Assyrian (2025–1364 BC), Middle Assyrian (1363–912 BC), Neo-Assyrian (911–609 BC) and post-imperial) (609 BC–AD 240) periods. Assur, the first Assyrian capital, was founded c. 2600 BC but there is no evidence that the city was independent until the collapse of Ur III in the 21st century BC.

The city underwent several periods of foreign rule and domination before Assyria rose in the 14th century BC as the Middle Assyrian Empire.

In the Middle and Neo-Assyrian periods Assyria was one of the two major Mesopotamian kingdoms, alongside Babylonia.

Assyria was at its strongest in the Neo-Assyrian period, when the Assyrian army was the strongest military power in the world. From 744 BC to 612 BC, Assyria had a string of powerful and capable rulers such as *Tiglath-Pileser* III, *Sargon II, Sennacherib*, *Esarhaddon* and *Ashurbanipal.* They conquered and ruled the then largest empire in world history, spanning from modern-day Iran in the east to Egypt in the west.

The Assyrian Empire fell in the late 7th century BC, conquered by Babylonians, who had lived under Assyrian rule for about a century, allied with the Medes from the northern mountains. Assyrian culture and traditions continued to survive for centuries throughout the post-imperial period.

The ancient Assyrians primarily spoke and wrote the Assyrian language, a Semitic language. Aramaic grew in importance and from the 9th century BC onwards became the lingua franca of the Neo-Assyrian Empire The Sumerian language was sometimes used in ancient Assyria as a language of scholarship and culture, and in written form in the temples for worship and astronomy.

Two things that made the Assyrians great warriors were their deadly chariots and their iron weapons. Their chariots could strike fear in the hearts of their enemies. *Tiglath-Pileser III* created the first professional standing army of Assyria and made it into the most effective military force in history up until that time.

The last great Assyrian king, *Ashurbanipal,* constructed the great *Nineveh Library*. He collected clay tablets from all over Mesopotamia. These included the stories of Gilgamesh, the Code of Hammurabi, and more. Much of our knowledge of the ancient civilizations of Mesopotamia comes from the remains of this library. According to the British Museum in London, just over 30,000 tablets have been recovered. These tablets make up around 10,000 different texts.

Assyrian Astronomy

I found nothing specifically Assyrian in my searches. We might remember that from 744 BC to 612 BC, they conquered and ruled over Babylonia (Middle Kingdom). They shared and practised the same astronomical-astrological temple-based culture as the Babylonians. There are stories (see further on) of at least two Assyrians kings calling on the (presumably) Babylonian temple priests for regular astrological forecasts. Thereafter the Assyrians were part of the Neo-Babylonian empire from 612 BD to 539 BC.

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(F) Neo- Babylon, The Marvellous (612-539 BC)

It is now timely to sketch in a picture of Babylon as we cross the horizons of three empires that transformed the world.

So far, I have identified the Babylonian (Mesopotamian) temple complex as the focal point of the astronomy-astrology component of Babylonian (Mesopotamian) development.

It was the rich surplus agricultural yields of the Fertile Crescent that enabled the Mesopotamians to nurture and build their great urban civilisations, including cities, kings, temples and armies.

Initially, the majority of the land was owned by the palace and the temples, but in the 18th century BC, large swathes of land were privatized and leased by them to family smallholdings family. In reverse, the farmers were required to pay taxes to the king and the temple. The rates depended on the needs of the country, and would invariably be increased when required to raise an army or recruit mercenaries, to build a temple, for building projects like a canal, and or just for the avariciousness of the king or others in charge.

Needless to say, the other source of wealth was conquest. The prizes would include, besides the visible riches, the palace and temple treasuries, taxes and granaries, and last but not least skilled manpower (including slaves), the last being the most valuable in advanced urban communities.

Babylon (Mesopotamia) was therefore made up many cities with temples and interconnecting roads, and with intensive agriculture supported by irrigation canals. Some cities would have palaces and ziggurats. The system made for opulent wealth.

The ziggurat was massive square or rectangular three tiered structure, on the top tier of which was the temple dedicated to the presiding or patron god of the city. The original "Anu Ziggurat", at Uruk, ante dates the first Pyramid. It goes back to the Sumerians around 4000 BC, and the White Temple on it was built circa 3500 BC.

Approximately 25 ziggurats are known, being equally divided among Sumer, Babylonia, and Assyria. No ziggurat is preserved to its original height. Perhaps the largest ziggurat was the one at Babylon. Recorded dimensions show that it had seven levels and reached a height of nearly 300 feet. It was also 300 feet by 300 feet square at its base. In fact, the ziggurat at Babylon was known as Etemenanki[4], which means "House of the foundation of heaven and earth" in Sumerian.

The Mesopotamian ziggurats were not places for public worship or ceremonies. They were believed to be dwelling places for the gods. Only priests were permitted on the ziggurat or in the rooms at its base, and it was their responsibility to care for the gods and attend to their needs.

Nabopolassar (620-605 BC) founded the Neo-Babylon empire in 639 BC by defeating the Neo-Assyrian empire. Nebuchadnezzar II[5] (605-562 BC) was the eldest son and succeeded him on his death, reigning for 43 years with outstanding contributions. In the 580s BC, Nebuchadnezzar engaged in a successful string of military actions in the Levant against the vassal states in rebellion there, likely with the ultimate intent of curbing Egyptian influence in the region. In 587 BC, Nebuchadnezzar destroyed the Kingdom of Judah and its capital. Jerusalem, which led to the Jew's Babylonian captivity. Through the capture of the Phoenician city of Tyre and other campaigns in the Levant, he completed the Neo-Babylonian transformation into the new great power of the ancient Near East.

Nebuchadnezzar is also remembered as a great builder-king. His building inscriptions record work done to numerous temples, notably the restoration of the Esagila, the main temple of Babylon's national deity Marduk , and the completion of the Etemenanki , the great ziggurat dedicated to Marduk. The temple was located south of Etemenanki, and it measured 660 feet (200 m) on its longest side, and its three vast courtyards were surrounded by intricate chambers. The whole complex reflected centuries of building and rebuilding by the Babylonian kings, especially Nebuchadnezzar The tremendous wealth of Esagila was recorded by the Greek historian Herodotus who is believed to have visited Babylon in the 5th century BC.

Among the most impressive efforts was the work done surrounding the city's northern ceremonial entrance, the Ishtar Gate. The projects included restoration of the South Palace inside the city walls, the construction of a completely new North Palace on the other side of the walls facing the gate, as well as the restoration of Babylon's

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[4] Some scholars have sought to identify this with the Tower of Babel.

[5] Nebuchadnezzar I (1121–1100 BC), was the fourth king of the Second Dynasty of Isin and Fourth Dynasty of Babylon.

Processional Street, and the Gate itself. The latter is one of the Seven Wonders of the Ancient World.

And there were also the fabled Hanging Gardens of Babylon, another of the Seven Wonder of the Ancient World. They were described as a remarkable feat of engineering with an ascending series of tiered gardens containing a wide variety of trees, shrubs, and vines, resembling a large green mountain constructed of mud bricks. According to one legend, the Hanging Gardens were built by Nebuchadnezzar alongside a grand palace known as The Marvel of Mankind, for his Median wife Queen Amytis because she missed the green hills and valleys of her homeland.

The other great building projects by Nebuchadnezzar included the Nar-Shamash, a canal to bring water from the Euphrates close to the city of Sippar. He also began work on the Royal Canal, a great canal linking the Euphrates to the Tigris which in time completely transformed the agriculture of the region, but the structure was not completed until the reign of Nabonidus (556 to 539 BC), who ruled as the last king before conquest by the Achaemenids.

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(G) Achaemenian Empire (Persia)

The empire had its beginnings in the 7th century BC, when the Persians settled in the southwestern portion of the Iranian plateau in the region of Persis. From this region, Cyrus The Great (590-529 BC) rose and defeated the Median Empire as well as Lydia, following which he conquered Babylonia (with Assyria) in 539 BC.

Cyrus then formally established the Achaemenid Empire, also called the First Persian Empire, in 550 BC.

The Achaemenid Empire reached its greatest extent under Xerxes 1 (519-465 BC) who conquered most of northern and central Greece (including Macedonia!) . At its greatest territorial extent, the Achaemenid Empire stretched from the Balkans and Eastern Europe to the Indus Valley, the largest in history up to then. There were long drawn out Greco-Persian wars from 499-429 BC, waged by Darius The Great, against the Greek city states, which finally halted the Persians' Greek aspirations. They conquered Egypt in 341 BC.

The Achaemenid Empire was known for a successful model of centralised control but devolved administration via the use of satraps (viceroys). It was also known for its multicultural policy, for good infrastructure, such as road systems, and a postal system, the use of an official language (Old Persian) across its territories, and the development of a civil service and a large professional army.

Cyrus also created standardised gold and silver coins, thus transitioning the empire from a barter economy into a money economy. It is said his rule greatly influenced the thinking of Aristotle, Alexander the Great, and later the Roman Empire. The empire's capital was Persepolis.

The empire was conquered in 331 BC by Alexander The Great, who burnt down Persepolis, it is said in retribution for Xerxes' occupation of Macedonia.

Astronomy under Archaemenid Empire

As far as I can infer, the earliest Persian interest in the celestial universe took the same lines as the early Mesopotamians, working out the practical effects upon life of the Moon, Sun and planets – and in due course the stars. They also developed a polytheistic faith, believed the stars held both good and evil power and linked the two.

In astrology, the Royal Stars of Persia were Aidebaran, Regulus, Antares and Formalhaut. The Persians believed that the sky was divided into four districts with each district being guarded by one of the four Royal Stars. The stars were believed to hold both good and evil power and the Persians looked upon them for guidance in scientific calculations of the sky, such as the calendar and lunar/solar cycles, and for predictions.

The old Persians adopted a Persian cuneiform based on the Sumerians'. However, I nowhere found that they developed special mathematics or recorded their celestial observations. I think much could remain to be re-discovered

A significant feature of the Persian people was that their religion was Zoroastrianism. It is believed that the religion had been founded very much earlier in the 1st millennium by the prophet Zoroaster, also known as Zarathustra (1500-1000 BC). Cyrus was a devout Zoroastrian, it was the religion of the Achaemenid empire and it would become so for both the Parthian and the Sassanid empires that succeeded it. The central tenet of the religion was monotheism, one God, who was *Ahura Mazda*. This was the first monotheist religion in the world. The Persians had earlier built up a polytheist pantheon. My understanding is that the latter have since been accommodated in the realms of mythology, while some dozen of them are treated as emanations of the one God. The Royal Stars are mentioned in the Bundahishn a major collection of works on Zoroastrian cosmogony.

I could not find specific information about the Magi, except they appeared to have originated as priests in early Persia and seemed to have instituted themselves as priests in the Zoroastrian system. It is not clear whether Gaspar, Melchior and Balthazar of the Bible were magi. If they were, it seems they had a pretty sharp eye for unusual movements among "royal stars". Judea had just been conquered by the Romans but culturally belonged to the multi-religious, multi-ethnic, internationalised Hellenic world of the Seleucid empire. The arrival in Jerusalem during the Passover of three regal looking foreigners with their impressive entourages would not have raised any unusual attention. Probably Magi, someone might have said, on a pilgrimage, They must have shown Herod the Great some proof for the latter to have massacred the innocents.

Cyrus the Great was immortalised in the *Cyrus Cylinder*, a clay cylinder inscribed in 539 BC with the story of how he conquered Babylon. Together with other inscriptions, it contained the following: "He freed the slaves, declared that all people had the right to choose their own religion, and established racial equality." He is immortalised in the Bible for releasing the Jews from their bondage along the Rivers of Babylon.

Babylon under the Achaemenid empire.

Under Cyrus and the subsequent Persian king Darius I, Babylon became the capital city of the 9th Satrapy (semi-autonomous province) of Mesopotamia. It continued as a centre of learning and scientific advancement. Babylonian astronomy and mathematics were revitalized, and Babylonian scholars completed maps of constellations. The city became the administrative capital and remained prominent for over two centuries. The Achaemenids simply took over the system of land administration and taxation.

From the preceding it is apparent that the Babylonians were conquered by a tolerant and progressive civilisation, with religious freedom. They would have been allowed to practice their own religion. The temples could continue. There was no persecution or forced conversion. I am not sure about discrimination. I imagine there would in fact have been active interest to learn about things Babylonian.

Although his grandfather Cyrus had been a friend to Babylon, Xerxes I subjugated the city and melted down the golden statue of Murdak. This was a particular affront to the dignity and tradition of Babylon because one of the religious duties of a ruler was to grasp the hands of the statue of Marduk at the New Year's festival in order to ensure continued prosperity throughout the land; Babylon thus enjoyed a prestige among the cities as the site of this ritual.

Cyrus had been diligent in officiating at this festival, as had Darius, the Great, The early Persian kings attempted to maintain the religious ceremonies of Marduk. But Xerxes considered it a matter of little consequence. He ignored the established relationships. Babylon revolted against him twice before he lay siege to it and crushed the rebellion.

In the end, over-taxation and the strain of numerous wars led to a deterioration of Babylon's main shrines and canals, and the destabilization of the surrounding region. Inevitably, this led to numerous attempts at rebellion. However, these revolts were quickly repressed and Babylon remained under Persian rule until conquest by the Macedonians in 331 BC.

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(H) Alexander The Great
(354-323 BC)

The father of Alexander The Great was Phillips II, King of Macedonia. After defeating the Greek city-states of Athens and Thebes in 338 BC, he worked towards establishing a federation of Greek states under him known as the League of Corinth for a planned invasion of the Achaemenid Empire of Persia. Following his assassination by a bodyguard, Alexander took over in 336 BC. He had a ready army.

After crushing various revolts among the Greek and Balkan states, he proceeded with the invasion, leaving Antipater, a senior general, in charge of Macedonia and Greece as regent. .

Alexander's army crossed the Hellespont in 334 BC with 48,100 soldiers, 6,100 cavalry and a fleet of 120 ships with crews numbering 38,000, drawn from Macedon and the Greek city-states, mercenaries, and feudally raised soldiers.

He took Asia Minor in 333 BC, and Syria/Levant and Egypt by 331 BC. In that same year he took Upper Mesopotamia, and entered Babylon.

After the decisive Battle of the Persian Gate against Darius III Codomannus in 330 BC, Alexander entered Persepolis, the Persian capital, and burnt it down. Then he conquered east Persia by 329 BC.

Thereafter he turned his attention to India, where won the Indus Valley at the Battle of Jhelum in Punjab against King Porus in 326 BC. If his troops had not revolted, he would have marched on. Alexander had the idea of “reaching the waters on the other side”. At that point, the Greeks had already surmised the world was probably round.

In eight years, Alexander had conquered that largest empire ever. He returned to Babylon where had died unexpectedly in 323 BC, only three years later.

Alexander and Babylon

This section is paraphrased[6] from the Roman author Quintus Curtis Rufus, who based his account on earlier Greek sources:

"Alexander was met by Mazaeus[7] who had taken refuge in the city after the battle. He came as a suppliant with his grown-up children to surrender himself and the city. Alexander was pleased at his coming, for besieging so well-fortified a city would have been an arduous task and, besides, his example was likely to induce the others to surrender. Accordingly Alexander gave him and his children a courteous welcome.

Nevertheless, Alexander put himself at the head of his column, which he formed into a square, and ordered his men to advance into the city as if they were going into battle.

A large number of the Babylonians had taken up a position on the walls, eager to have a view of their new king, but most went out to meet him. including the man in charge of the citadel and royal treasury, Bagophanes. He had carpeted the whole road with flowers and garlands and set up at intervals on both sides silver altars heaped not just with frankincense but with all manner of perfumes.

Following him were his gifts - herds of cattle and horses, and lions, too, and leopards, carried along in cages.

Next came the Magians (Maji) chanting a song in their native fashion, and behind them were the Chaldeans, then the Babylonians, represented not only by priests but also by musicians equipped with their national instrument.

At the rear came the Babylonian cavalry, their equipment and that of the horses suggesting extravagance rather than majesty.

Surrounded by an armed guard, the king instructed the townspeople to follow at the rear of his infantry; then he entered the city on a chariot and went into the palace. The next day he made an inspection of Darius' furniture and all his treasure,"

Alexander was concerned with forming a lasting harmony between his Macedonian and Persian subjects. He maintained the basic forms of community life and the general structure of government. He adopted Persian dress and customs in court, not always approved by his fellow Macedonians. Alexander held a mass marriage of his senior officers to Persian and other noblewomen at Susa, but few of those marriages seem to have lasted much beyond a year. He even gave Persians command posts in the army and conferred Macedonian military titles upon Persian units.

Alexander understood the sophistication of the Mesopotamians. It was his desire to make their wealth of knowledge available to the Greek philosophers and the Hellenic world. He intended to make Babylon his capital. He stayed at one of Nebuchadnezzar' places.

Alexander founded more than 20 cities named after him, including Alexandria in Ptolemic Egypt, which became the most famous city in the Hellenic world.

Break up of Alexander's empire

Alexander died in after a short illness on 13 June 323, some speculate due to typhoid, some due to an infected would.

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[6] https://www.livius.org/sources/content/curtius-rufus/alexander-the-great-enters-babylon/

[7] Achaemenid general, earlier defeated at Battle of Gaugamela, son in law of Darius III Codomannus, and reportedly satrap of Babylon.

The big problem was that he had not named his successor. His own child was not yet born. and there was the claim of his half-brother Philip Arrihidaeus' intellectually disabled son as the legal successor (Phillip III).

At the Partition of Babylon in June 323 BC, his closest family and generals subscribed to these general arrangements. A final decision on succession would await until Alexander's wife, Roxana8, who was pregnant, had given birth. If the child was a boy, then the child be chosen as the new king. Meanwhile, Perdiccas, the supreme commander of the army would be the regent responsible for both the children and effectively the ruler of Alexander's empire until the king was selected and old enough to rule on his own.

Despite misgivings the other generals accepted the proposal. Meanwhile Perdiccas allocated that the other generals would look after the empire as satraps or super-satraps.

Nobody was happy. The whole Grecian civilised world, the largest, possibly the richest, empire ever put together in history, was at stake. Without the blood and sweat of their men and the generals themselves, it would not have existed. It was their empire.

The options for succession were unacceptable: a half-barbarian child or a mentally deficient child, and all that conquered world to be ruled indefinitely by a regent, with no safeguards he would not grab it all for himself. Imagine Eisenhower, MacArthur, Mountbatten, Montgomery and de Gaulle in the same situation at the end of World War II.

After the assassination of Perdiccas in 321 BC, the generals met again at the Partition of Triparadisus in the same year. Meanwhile, Roxana had given birth to a son (Alexander IV). This time the generals chose Arridaeus' son, Philip III, as the king, and Antipater as regent.

The records are confusing how the satrapies[9] were further sub-divided among the generals. Suffice it to say that they or some were not satisfied, while others decided on military action to correct the distribution. They had the armies.

Macedonian unity collapsed, and after four "Successors Wars" among them and their families (the Diadochi Wars) the Hellenistic world settled into four power blocs:

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[8] Roxana was the daughter of Bactrian (Afghan) chief Oxyartes, whom he married in 327 BC. He would subsequently marry Statira, Darius III's daughter at Susa in 324 BC , and later Parysatis II , the daughter of Artaxerxes III. In due course, Roxana would put these two to death, and she would give birth a boy (Alexander IV). At a subsequent stage, she and both the bosy, Alexander IV and Philip Arridaeus, would also be put to death. In addition, Alexander The Great's mother, Olympia, would also be murdered, among several others, including Perdiccas.

[9] A satrapy is a governorship of a territory, which pays the appropriate taxes to the king or as in this case presumably the general allocated the satrapy.

Table 5
Breakup of Alexander's Empire

Territory	Partition Disposition	Final Disposition of Territory	Eventual Successor
Alexander's Successor	Philip IV Arridaeus	Nil. Philip IV was murdered. Alexander IV was murdered.	End of Alexander's dynasty
Macedonia, Greece	Antipater	Macedonian Dynasty of Antipater	Cassander, son of Antipater.
Egypt, Levant	Ptolemy 1	Ptolemaic Egyptian Empire	Ptolemy 1
Asia Minor,	Antigonus Monophthalmos	Antigonid Kingdom	Antigonus II Gonatas, grandson of Antigonus
Mesopotamia, Persia, part of India	Seleucus 1 Nicator	Seleucid Empire	Seleucus, II, son of Nicator
Thrace	Lysimachus	Kingdom of Attalid-Pergamon	Philetaerus

Alexander and Hellenisation

Alexander was a pupil of Aristotle, from whom he absorbed the intellectual and. social values of Classical Greece, including the desire to spread and share Greek civilisation to the world. In his short reign, he projected the former as the norms and the latter as the objective of his new empire. Even as the empire broke up, Hellenism remained a core constituent of the fragmented empire - even among conquered peoples who later became independent and others who conquered parts of his former empire.

It is amazing that Koine Greek, which developed as the lingua franca of Alexander's Hellenic world, became the language of the Roman and Byzantine empires for the next 1000 years. It was the language in which the Bible was written, and is still used by a sizeable part of Christendom. Nothing compares with this except the Westernisation and Anglicisation of the modern world. I wonder whether he ever imagined that Cleisthenes' "democratia" would be constituted the international foundation of all human rights in future.

As far as our Mesopotamian story goes, it ends here, The cultural Hellenisation of the Middle and Near East by the conquests of Alexander created the route and means by which the astronomic-astrological riches of the Babylonians (and Persians) became known by the neighbouring parts of the world and onward to today. This was the world in which astronomy would take the next decisive steps in the next 1000 years, from Alexandria in fact.

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Chapter Two
Ancient Greece

Ancient Greece (Hellás) was a north-eastern Mediterranean civilisation which emerged after the Greek Dark Ages (12th-9th centuries BC). It comprised a loose collection of culturally and linguistically related city-states and other territories.

Greek civilisation developed as a coherent culture in four phases, (1) Archaic Greece (800-600 BC), (2) the Pre-Classic Period (600-479 BC), the Classica Age (480-323 BC) and (4) the Hellenic Period (323-30 BC). The city states were unified only once, for 13 years, under Alexander The Great (336-323 BC). At the end, Greece was totally absorbed within the Roman empire.

The attainments by the Greek civilisation in philosophy, literature, the arts, mathematics (including astronomy) and science have gone on to form the seminal culture of the modern world. They peaked in the Classical Age.

Homeland

Ancient Greece, the homeland of the Greek people, comprised three components, (1) the southern peninsular extension of the Balkans (Pindus Mountains) forming the mainland or central landmass, (2) the southern Peloponnese "island" extension of the latter connected by the Isthmus of Corinth, and (3) the myriads of islands in the Aegean Sea bordering the mainland on the east.

Athens was (is) located at the southern tip of the mainland , Sparta was (is) located in the south of the Peloponnese, and Thebes, next to Athens. The northern boundary was formed by Thessaly. Beyond that lay Macedonia.

Predecessor civilisations

The Greeks had two major Bronze age "ancestor" civilisations, which are mentioned here for the record only, as they do not feature in our story.

Minoan Civilisation

The first was the Minoan civilisation (3500-1100 BC.) in Crete and other Aegean islands. The centre was Knosses. It was the first advanced civilization in Europe, leaving behind massive building complexes, sophisticated art, and writing systems. The level of religious and mythology development has not yet been fully uncovered, but apparently independent of the Greek pantheon. The name Minoan comes from King Minos of Knossos, whom (Greek) legend has it built the Labyrinth (at Knossos) to confine the Minotaur that Theseus had to fight. Minoan civilisation collapsed suddenly. The causes have not been fully uncovered, but are believed to include Mycenaean in-roads.

Mycenaean Civilisation

The second was the Mycenaean civilisation (1750-1050 BC). It represented the first advanced and distinctively Greek civilisation in mainland Greece, with its palatial states, urban organisation, works of art, and writing system. The Mycenaeans extended their influence throughout the Peloponnese in Greece, and are named after their chief city there of Mycenae in the Argolid. They occupied many of the later-day city states, including Athens, Thebes and Thessaly, and across the Aegean from Crete to the Cycladic islands. Mycenaean-influenced settlements also appeared on the coasts of Asia Minor, the Levant, Cyprus and Italy. Trade over the Mediterranean was essential for the Mycenaean economy.

In terms of beliefs, they had advanced close to the later Greeks, with gods and heroes. The Mycenaean period became the historical setting of much ancient Greek mythology and literature, including the Trojan Cycle which was a war between Troy and Mycenae. Mycenaean Greece perished with the collapse of Bronze Age culture in the eastern Mediterranean. Various theories have been proposed for the end of this civilization, among them Dorian invasion or activities of the "Sea Peoples" (Egyptians).

Greek Ancestral Tribes

The Mycenaeans were followed by the so-called Greek Dark Ages (1100-800 BC), a recordless transitional period, but one of the leading features of which was the birth of the Iron Age.

During this time (and probably before) the Greek mainland was already populated by ancient tribes who were widely dispersed over the Greek peninsula. They have been classified into four major groups. There were the Dorians in the Peloponnese and west coast, and on the east coast the Atticans-Ionians in Attica and Euboea, the Aeolians in Thessaly and Boeotia, and the Achaeans in central mainland.

Quite apart from ease of expansion by sea, historians believe the mainland was already densely populated, if not overpopulated, leading to the next cycle of growth of the Greeks to be by colonisation. The Dorians were the prime movers, after occupying the most territory on the mainland. In time, the Ionians-Atticans and Aeolians would colonise much of the opposite Asia Minor. As they entered the Iron age, they also adopted in common the city-state formula,

Time-Line

For convenience of readers, we provide a simple time-line to follow the narrative, in Table 2:

Table 4
Time-line of Ancient Greece History

Date	Age	History	Personalities/Event
3500- 1100 BC	Pre-historic Greece	Collapse of Bronze Age Minoan civilisation (3500-1100 BC) Mycenaean civilisation (1750-1050 BC) Greek Dark Ages (1100-800 BC) Iron Age (1100-800 BC)	Troy Destroyed (1184 BC)
800- 600 BC	Archaic Greece	Greek colonisation (800-600 BC) First Olympics (776 BC)	Writing developed (800 BC) Homer (750 BC) Hesiod (650 BC)
600–479 BC	Pre-Classic Greece	Rise of city states Rise of Athens Democracy Rise of Sparta (and Peloponnesian League) Greco-Persian Wars (499-449 BC)	The Pre-Socrates Philosophers:- Thales Pythagoras
479-323 BC	Classic Greece	Rise of Delian League Rise of Athenian Empire	Socrates Plato

		Pentecontaetia Peloponnesian Wars (431-401 BC) Gold Age of Athens Rise of Macedonia Macedonia conquers Greece (338 BC) Macedonia and Hellenic League Alexander conquers Egypt, Persian empire and India (BC 334-323) Death of Alexander (BC 323)	Aristotle
323–146 BC	Hellenic Greece	Seleucid Empire (312 BC) Ptolemic Empire (305 BC Antigonid Kingdom (305 BC) Macedonia-Greece Kingdom (305 BC) Rome conquers Greece and Macedonia (186 BC) Rome annexes Greece and Macedonia (146 BC) Rome conquers Ptolemic Egypt (30 BC)	Aristarchus of Samos (310-230 B.C.) Seleucus of Seleucia Eratosthenes of Cyrene (276-194 BC) Hipparchus (190-120 BC) Ptolemy (100-180 BC)
E			

Classical Greek culture especially philosophy, had a powerful influence on ancient Rome, which carried it throughout the Mediterranean and Europe For this reason, Classical Greece is generally considered the cradle of Western civilisation.

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(A) Archaic Greece

Expansion in the Archaic age

The archaic period experienced a massive increase in the population. The mountainous terrain, many islands, rugged shorelines and tight fertile valleys, favoured small or limited communities. Scholars suggest that one other cause of pressure on the land was the tendency of the aristocracy and wealthy landowners to hog what was available. It seems that, pushed out from competing for the hinterland, the Greeks resorted to colonisation in settlements in the islands and shores in the lands around. The sea was the enabling factor.

The Greeks settled around the Aegean Sea, the Sea of Mamara, the Black Sea and the Mediterranean, the latter including Sicily, southern Italy and southern France (Magna Graecia). Scholars report that there were some 1,500 to 2,000 settlements, presumably towards the later part of the period.

By the end of the archaic period they were part of a maritime trade network that spanned the entire Mediterranean, coming into contact with the Phoenicians on the east, and possibly even the early Romans[10] and Libyans on the west.

Estimates of their total population by historians vary, reaching from seven to 10 million, with a lower limit of four to six million. Athens was the largest and said to have 431,000 people, Spartan 20,000-30,000 people. The typical city-state was 10,000. At this point, Greece was a people united by the sea.

By the end of the archaic period, they would have been close to peak as a cohesive people. After the wars of the Classical age and growth of Hellenic Greece, they would acquire a different complexion and be spread out beyond the Mediterranean.

[10] Rome was founded in 753 BC by Romulus and Remus, and became a republic in 509 BC

I could not resist inserting this snippet from Wikipedia describing the population of Greece, broadly at the end of the Archaic period.

Ancient Greece and Greek colonies[11] (edited)

"From around 800 BC, Greek city-states began colonizing the Mediterranean and Black Sea coasts. Suggested reasons for this dramatic expansion include overpopulation, severe drought or an escape for vanquished people (or a combination). The population of the areas of Greek settlement from the western Mediterranean to Asia Minor and the Black Sea in the 4th century BC has been estimated at up to 7.5-10 million.

Estimates of the Greek-speaking population in the coast and islands of the Aegean Sea during the 5th century BC vary from 800,000 to over 3,000,000. In Athens and Attica in the 5th century BC, there were up to 150,000 Athenians of the citizen class, around 30,000 aliens, and 100,000 slaves, most residing outside the city and port. though precise numbers remain unknown and estimates vary widely.

The geographical definition of Greece has fluctuated over time. The ancient kingdom of Macedonia was a distinct entity and even though the Macedonian language was a part of Greek dialect continuum, it was not considered as a part of Greece by some Athenian writers.

On the other hand Ionia, now part of Turkey, from the 1st millennium BC Ionia was densely populated by Greek-speaking people and an important part of Greek culture.

The ancient Roman province of Cyrenaica in the eastern region of present-day Libya was home to a Greek, Latin and native population in the hundreds of thousands. Originally settled by Greek colonists, five important settlements (Cyrene, Barca, Euesperides, Apollonia, and Tauchira) formed a pentapolis. The fertility of the land, the exportation of silphiumand, and its location between Carthage and Alexandria made it a magnet for settlement."
https://en.wikipedia.org/wiki/Classical_demography

Rise of the City-State

The settlements would have grown from agricultural roots. Then, they would have developed with maritime inter-colonial and then foreign trade. Despite their growth by dispersion, the Greeks were able to preserve a common unadulterated culture, and identity.

The Greek practice was that the settlements and cities elected their own leaders. Here and there, the latter grew to be kings, autocrats (tyrants) or oligarchs according to preference, power play, available leaders and need, But, generally, where they lost the consent of the people they would be overthrown and replaced.

By the dawn of the archaic age, Greece was a people of many independent city-states and most of these city-states practised people-based forms of self-government (democratia).

In the. interim, they had become urbanised societies, in townships and cities. While supported by a still largish agricultural sector, with external trade, they achieved an urban infrastructure with a craft based economy.

The townships and cities in both the heartland and the colonies became progressively knitted together and grouped as continuous political city-states with regional identities. The bigger city-states enjoyed considerable civic sophistication. They proceeded to develop the highest levels of education, intellectual and scientific discourse and the arts, The stage was set for the Classical age.

11 https://en.wikipedia.org/wiki/Classical_demography

By the end of the archaic period, the major city-states were Athens (founded in 1790 BC), Ionia (1000 BC), Sparta (900 BC), Thebes (unknown BC) and Corinth (700 BC.). These would lead in the next age to the development of that unique Greek institution, the “polis” or democratic civic community.

Aside from Sparta, there were no hereditary kingdoms at the end of the archaic period. Of significance was the Kingdom of Macedonia (808 BC), which occupied the northeast corner of the Greek peninsula, but at this point in time it was not Greek, and would not be until the Hellenic age.

Greek Gods

Each city-state worshiped its god or a goddess. For example, Sparta’s deity was Athena, the goddess of wisdom. The gods worshipped in archaic and classical Greece were those worshipped by their Mycenaean predecessors.

The ancient Greeks did not have a word for 'religion' in the modern sense. Likewise, no Greek writer had classified either the gods or the cult practices into separate 'religions'. Instead, they had, to quote Herodotus, "common shrines of the gods and sacrifices, and the same kinds of customs.". “Religious” practices encompassed a collection of beliefs, rituals and mythology that formed both popular public religion and cult practices. There were 12 major Olympian gods and goddesses, in complex familial relationships, but no sense of a transcend deity.

The most significant change of the eighth century was the development of permanent temples. The seventh century further saw the appearance of monumental stone temple buildings, beginning with the temple of Apollo at Corinth, as well as cult images and cult sanctuaries.

The enormous explosion in cultic activity in Olympia in the Peloponnese peninsula coincided with the establishment of the Olympic Games. According to Greek tradition the first games had been established by Herakles (Hercules) but these had fallen out of practice, until they were revived in 776 BC.

Another famous site going back to archaic times was Delphi on the slopes of Mount Parnassus in central mainland Greece. It had been continuously occupied from the Bronze Age. The first evidence of its revival as a religious centre and a cult sanctuary was in the eighth century BC. In due course, votives and offerings came from across Greece, to patronise the Oracle at the Temple of Apollo. In 560 BC, the Sphinx of Naxos was built there.

After the Mycenaean period, the art of writing was lost. The present Greek Alphabet developed from the Phoenician in the eighth century BC, and by the sixth century surviving inscriptions included public records such as law codes, lists of officials, and records of treaties.

Homer

As the city-states matured, the archaic period saw the flowering of poetry as an oral tradition, both lyric poetry at the popular level, as well as heroic and didactic poetry.

The earliest surviving works of the literature are by Homer. His two epic poems, the Iliad and the Odyssey, are the foundational works of Greek culture, and he is regarded as one of the greatest and most influential authors of all time. Homer incorporated the Greek gods and heroes permanently as part of the firmament of Greek culture.

The poems were composed around the late eighth to early seventh century. Most researchers believe that the poems were originally composed and transmitted orally. The use of writing became widespread in Greece about the same time, and it seems that the poems were also set down for the first time during this period. But it is clear that the poems contain features preserved from the pre-writing age. They are 15,693 lines and 12,109 lines respectively. Homer's life is unknown and shrouded in legend, which among other things had him as blind.

Hesiod

Hesiod was an archaic poet generally thought to have been active between 750 and 650 BC, around the same time as Homer. He is often called the father of Greek didactic poetry. A native of Boeotia, in central Greece, he may have been initially a "raphsodes", ie. a professional reciter of poetry. Two complete epics of his have survived. His more important work was Theogony.

The Theogony Of Hesiod was a poem describing the origins and genealogies of the Greek gods, composed circa 700 BC. It is a synthesis of the Greek traditions concerning the gods, organised as a coherent narrative. It tells how they came to be and how they established permanent control over the Cosmos. It was the first Greek mythical cosmogony.

Theogony was the first expression of that part of the Greek psyche which embodied the desire to articulate reality as a whole, which would become the dominant impulse in the classic age. Aristotle believed that the question of first causes may have started with Hesiod.

His second work, Works and Days, described peasant life and expressed his views on the proper conduct of men. The Theogony has 1,022 lines and the Works and Days 828 lines.

Astronomy in Archaic Greece

It is clear the Greeks had early figured out the essentials of the day, calendar and seasons and the position of the stars from pre-historic times.

The Minoans of Crete were an example of a Greek civilisation whose palaces and mountaintop sanctuaries exhibited features that aligned with the rising sun on the equinoxes as well as the rising and setting of particular stars.

However, in the archaic period we find no reference to an astronomical tradition as such.

The Greek archaic period approximates in time-frame to the expansion of Phoenician seafaring in the Mediterranean and the population transfers carried out by the Neo-Assyrian empire, among the latter of thousands of Babylonians to the Levant and North Syria. The Greeks would have made contact with this burbling international milieu, with the inevitable transfer of knowledge about things navigational and celestial, among others.

Not surprisingly, in Homer's epics we find he noted several astronomical phenomena, including the constellations, the star clusters Hyades and the Pleiades, the Dog Star Sirius, and solar eclipses. In Homer's Odyssey, Calypso tells Odysseus to keep the Bear (Ursa Major) on his left hand side and at the same time to observe the position of the Pleiades, the late-setting Bootes, and the Orion as he sailed eastward from her island Ogygia traversing the Ocean

It has even been suggested that Hesiod's theogony and cosmogony were the Greek versions of two Phoenician myths, and the Odyssey of Homer was inspired by the Epopee of Gilgamesh[12].

It is more reasonable to infer that whatever Homer and Hesiod reflected came from the Oriental people they rubbed shoulders with in Lefkandi[13], the centre of Greek culture at that time.

Every ancient civilisation had its own set of names for the planets, then only five visible to the naked eye, and they tended to be the names of deities. Most people even today know that the Greek names for Jupiter was Zeus, Saturn was Cronos, Mars was Ares, Mercury was Hermes, and Venus was Aphrodite. I have the impression (I have not read the Theogony) that Hesiod rightly placed his pantheon of gods in the heavens above. However, despite some searching among commentators, I could not find any association by him anywhere between a god and a planet. My conclusion has to be that in archaic Greece, the planets were not named by gods and Hesiod had no interest in making the association.

Sailors navigating in the Mediterranean made use of several techniques to determine their location, including staying in sight of land and understanding of the winds and their tendencies. The Minoans made sea voyages to the island of Thera and to Egypt, which would have had them traveling by night across open water. The sailors would have used particular stars, especially those of the constellation Ursa Major to orient the ship in the correct direction. The pole stars were used to navigate because they did not disappear below the horizon and could be seen consistently throughout the night. However, there were not as yet clear traditions of either observational or theoretical astronomy. These would come soon in the classical age.

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(B) Pre-Classical Period

As the Greeks entered the classical age, the city-states progressed in political and social maturity. These developments led to the first flowering of the mighty “pre-Socratic” Greek philosophers – and beginnings of astronomy. We examine these aspects briefly, with particular interest in their democracy, leading into the Classical Age.

The latter period then saw the conquest of the Greek settlements in Asia Minor by the Achaemenid empire - for 50 years, followed by invasion of the Greek homeland in two Greco-Persian wars.

For the first time, the city-states banded together as allies to support the Ionian revolt and later to repel the Persians from the mainland, and eventually free all the Greek city states in Asia Minor.

Social and Political Background

Political Structure

The term “Greece” refers to the Greek people (rather than to a country or nation), spread out around the Mediterranean. who shared one language, one culture and a common history. The term did not include the Kingdom of Macedonia, yet.

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12 See for reference the work of M.L. West et W. Burkret.

13 On Euboea Island in the Aegean, now a famous archaeological site.

As we enter the pre-classic age, most if not all the Greek people were politically organised as city-states. These were grouped within geographical territories or regions of distinct identity (their original tribal territories). One region, say Boeotia or Thessaly, would have a number of self-managing cities and townships..

Scholars estimate that there were over 1,000 city-states at this time. Apart from Athens and Sparta, the others were small scale. Even the next biggest, Corinth and Thebes had around 15.000 people only.

The standard framework of their political organisation was the autonomous city-state (polis). It could be a township but probably not a village The political or "electoral" boundary was the city, and citizenship meant belonging to a city, ie, being an Athenian.

While cities would share religious and cultural activities and even enter into alliances for mutual protection, there seemed to be no compulsion for higher levels of political aggregation. The city was their natural limit of political organisation. This seemed mainly because of size, but perhaps because it was the model that worked for them. I was not able to determine the cut-off, ie. to what extent the smaller settlements, particularly agricultural settlements, were self-governing or brought within the administration of their neighbouring towns and cities. (I noted that the alliances formed against the Persians were at the city level, but included the participation and defence of all of "their " territories and people. There was no political entity encompassing the Greeks as a country or nation in the modern sense. In fact some of the overseas city-states were at various times parts of other empires, and the Persians declared war on a city by city basis.

Athens was their largest city, a mega city-state. It was the lead city not only in size and prosperity, but also in the development of democratic institutions. We look briefly at the latter.

Athens

Attica was the peninsular region in south eastern mainland Greece bordered on the Aegean Sea. Historically, its maritime settlements were prosperous, driven by the kingdom and later city of Athens. Athens went as far back as Minoan and Mycenaean times.

The first king of Athens was the semi-mythical Cecrops, who ruled from 1556 to 1506 BC. He was followed by 16 others, ending with Codrus in 1068 BC. King Theseus, who killed the Minotaur to free the Athens, ruled from 1234 to 1205 BC. Attica had 12 small communities under the reign of Cecrops. All these towns were incorporated in an Athenian state during the reign of Theseus.

After Codrus, Athens was ruled under a system of three archons[14] (magistrates) appointed by the Areopagus (judicial council). As the latter were composed of aristocrats and elitists, the archons were the same, and the appointments soon became hereditary, until 753 BC when it was made non-hereditary. Appointments then were for 10 years initially, but became annual in 683 BC. As retired archons were still appointed to the Areopagus for life, there was no tangible change in the occupancy of the archonite.

While the archonite framework was the accepted system, from time to time, when things got too bad, the citizenry did in fact over-ride it and choose a leader who would assume power as

[14] In Athens a system of three concurrent archons evolved, the three office holders being known as the archon eponymous, the chief magistrate, the polemarch, who was head of the armed forces, and the archon basileus who was responsible for the civic religious arrangements. The archon eponymos remained the titular head of state under democracy . Ex-archons were automatically enrolled as life members of the Areopagus

an autocrat (tyrant [15]) to carry out corrections, and sometimes as a general (strategio) to defend against external threats. The seventh century BC witnessed the decline of the old aristocratic order and the rise of the tyrant.

Draco was the first recorded legislator of Athens. In 621 BC, he replaced the prevailing system of oral law and family feuds by a written code to be enforced by a court of law. But Draco's laws were characterised by their harshness

Conditions in Athens continued to deteriorate. I can do no better than quote from the Britannica:-

> "The early 6th century was a troubled time for the Athenians in other ways as well. Society was dominated by an aristocracy of birth, the eupatridae, who owned the best land, monopolized the government, and were themselves split into rival factions. The poorer farmers were easily driven into debt by them and when unable to pay were reduced to the condition of serfs on their own land and, in extreme cases, sold into slavery. The intermediate classes of middling farmers, craftsmen, and merchants resented their exclusion from the government. These social, economic, and political evils might well have culminated in a revolution and subsequent tyranny (dictatorship), as they had in other Greek states."
> https://www.britannica.com/biography/Solon

Solon's Reforms

It was at this point that Solon (630-560 BC) was appointed eponymous archon (chief magistrate). He was a member of the nobility, descended from the last king. He believed in moderation and in an ordered society, in which each class had its proper place and function.

He held office in 594-593 BC, and was then appointed a member of the Areopagus. Athenians of all classes accepted him and turned to him in hope. He did not however have full power to carry out his reforms until 20 years later.

Under Solon's reforms, all debts were abolished and all debt-slaves were freed. He redeemed all the forfeited land and freed all the enslaved citizens, by fiat. The status of serfdom was also abolished, and he prohibited all loans secured on the borrower's person.

But he refused to go to the length demanded by the poor, which was to redistribute the land. Instead, he passed measures designed to increase general prosperity and to provide alternative occupations for those unable to live by farming, which did considerably alleviate poverty.

Solon's new political constitution abolished the monopoly of the eupatridae (Greek well-born) and substituted for it government by citizens according to their wealth, a system called timokratia (timocracy). Citizens were divided into four classes based on their land production. Henceforth, political privilege was allotted on the basis of these divisions, without regard to birth.

All citizens were entitled to attend the general Assembly (Ecclesia). It became the chief consultative body. In fact, it was the sovereign body, entitled to pass laws and decrees, elect officials, and hear appeals from the most important decisions of the courts. All but those in the poorest group might serve, a year at a time on a new Council of Four Hundred (Boule), which was responsible for preparing business for the Assembly.

The higher governmental posts were reserved for citizens of the top two income groups. But a strong conservative element remained with retention of the Areopagus, the ancient Council

[15] The term has no ill connotations, a benevolent dictator (my favourite form of government – with me as dictator). Pericles was one.

of the Hill of Ares), and the people themselves for a long time preferred to entrust the most important positions to members of the old aristocratic families.

Solon's legislation in effect granted to the first three of these four classes a vote in the election of responsible officers, and only to the first class the power of election to the highest offices, such as that of archon.

The first three classes were bound to serve as hoplites (soldiers). The cavalry was raised out of the first two, while the fourth class was only employed as light-armed troops or on the fleet, and apparently for pay. The others served without pay. The holders of office in the State were also unpaid. The fourth class had the right of taking part in the trials by jury which Solon had instituted.

Solon re-wrote Draco's code, except for homicide, and made Athenian law altogether more humane. They were given validity for 100 years and posted for all to see on revolving wooden tablets.

Solon was also Athens's first poet. His poetry was the instrument of his statesmanship. He was in time named one of the Seven Wise Men of Greece.

Pisistratus

The archon Pisistratus who assumed power as a tyrant and ruled for most of 561-508 BC, did much to implement Solon's prescriptions and went further. His unified Attica. His economic and cultural improvements laid the groundwork for the later pre-eminence of Athens. He confiscated the lands of the aristocrats and gave them to the poor.

Cleisthenes

Cleisthenes (570-508 BC) was appointed archon for the term 525-524 BC. He belonged to the rival noble family of the Alcmaeonidae, and was popular due to his calls for a more democratic system. Again, because of the rivalries and changes of archons, his reforms were not implemented until 508-507 BC.

Cleisthenes shifted the basis of the political organisation from the four traditional tribes which formed the basis of the upper class Athenian political power network, into ten tribes according to their area of residence (demes), which became the basis of a new democratic power structure. He further divided the Athens into three regions: the city region, the coastal region and the inland region, and allocated the 139 demes accordingly. .

Through Cleisthenes' reforms, the people of Athens introduced equal rights for all citizens as the working principal of their institutions, though only men were citizens. He also established the random selection of citizens to fill government positions rather than kinship or heredity, a true test of real democracy.

He reorganized the Boule to have 500 members, 50 from each tribe,. He made it the role of the Boule to propose laws to the assembly, who convened in Athens around forty times a year for this purpose. The bills proposed could be rejected, passed or returned for amendments by the assembly.

Until the 6th century BC, aristocratic families lived independently in the suburbs. However, after the laws of the tyrant Pisistratus and the reforms of Cleisthenes, all these local communities lost their independence and were united under the central government of Athens.

The reforms of Cleisthenes, the Areopagus kept its power as 'Guardian of the Laws', which meant that it could veto actions it deemed unconstitutional. Pericles finally stripped the Areopagus of its role in supervising and controlling the other institutions.

Cleisthenes' life after his reforms is unknown as no ancient texts mention him thereafter. He has been called the father of democracy.

Social System

Athens

The Athenian social structure may be taken as representative of the of the other city states, with the exception of Sparta which will be touched on further down.

The population fell into the following categories: (a) – Citizens. Male, adult, born or acquired; (b) - Women and children (of Citizens); (c) – Non-Citizen Greeks (Metics). Usually imported for skilled and similar jobs; (d) – Slaves, including their families; and (e) – Foreigners (periokoi). Non-citizens, their families and their retinue.

Citizenship was acquired by birth or descent or was granted. Only adult male Athenian citizens who had completed their military training had the right to vote in Athens. The percentage of the population that actually participated in the government was 10% to 20% of the total number of inhabitants. Women were excluded from civic rights, and could even restricted in movement. Metics were a class of free non-citizens, often employed on more menial, but nevertheless vital, tasks - including trireme (ship) building, rowing and maintenance. Metics were usually Greeks from other city-states. Foreigners were basically restricted to visitors' rights and obligations.

Slavery was an accepted institution going back to Mycenaeans times. For Aristotle slaves were "living property". They were deployed principally in agriculture, but also in construction, and as craft workers[16], shop assistants and as domestic servants. They were privately owned. Their wives and children were also slaves. Slaves originated by conquest or capture. They could be bought and sold, sometimes sold due to poverty.

Athens had strict laws to protect slaves. They enjoyed considerable freedom of association and movement. Athenian families grew up with their slaves. Some could live independently and even earn an income. Those sent to the mines suffered worst. Slaves could be freed and became metics. Slaves were not use as fighting forces, but in supporting roles, one of which was as oarsmen in fighting ships.

In Athens in the 5th century BC, there were up to 150,000 Athenians of the citizen class, around 30,000 aliens, and 100,000 slaves, most of the latter residing outside the city.

Sparta

Sparta was the only different city-state, in that they had an oligarch of two kings, who were hereditary going back to the original ruling families. Their power was counter-balanced by an elected board of ephors (who only served a single one-year term). There was also a Council of Elders (Gerousia), each member of which was over the age of 60 and could serve for life. The duties of the kings were primarily religious, judicial, and militaristic.

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[16] During classical times, slave labour was the main workforce in the craft production industry. Most of the craft factories belonged to wealthy politicians. One of these factories produced swords and had about 30 slaves. Another a shield factory had 120 slaves producing the intricate weapons

Spartans believed they were descended from Herakles (Hercules) who supposedly conquered Sparta two generations after the Trojan War. Sparta was unusual among the Greek city-states in that it maintained its kingship past the archaic age. It was even more unusual in that it had two kings simultaneously, who were called the archagetai, coming from the twins Eurysthenes and Procies, descendants of Herakles.

Sparta's social system was unique. It was supposedly constituted by their semi-mythical legislator Lycurgus, to maximize their military proficiency as the prime social objective. Like other Greeks, the inhabitants of Sparta were stratified as citizens with full rights, free non-Spartans and slaves. The latter were known as helots.

Men were separated from their families as children. They devoted their entire lives to serving the army, beginning at age seven, and women were responsible for raising physically fit children to serve as future soldiers. Work was done by the helot population, with the native Spartans rejecting wealth and luxury. Even their food and clothing were regimented, simple and basic.

Spartan men underwent a rigorous training regime known as the agoge, The Spartan agoge, a thirteen-year training course, was one long rite of passage that transitioned a young Spartan male from childhood to puberty to youth, and finally into manhood. The education-training was comprehensive. Besides physical training, athletics, games and dancing, it included education and personality and social development. Fitness was prized above all. There was no fat Spartan. Basically, they grew up in male communes from childhood, bonded within groups at each stage and under senior mentors.

A Spartan man graduated from the agoge at age 30, at which time he was permitted to have a family. He would also receive a kleros, an allotment of land farmed by helots. At age 30, he became a full citizen of Sparta, provided he had served honourably. He was required to continue serving the military until age 60.

Spartan women were also required to keep fit, but had more freedom than women elsewhere in the Greek world. To outside contemporaries Spartan women had a reputation for promiscuity and controlling their husbands. Unlike their Athenian counterparts, Spartan women could legally own and inherit property and they were usually better educated.

Helots were state-owned slaves, ie enslaved non-Spartan locals. They were required to wear demeaning clothes to distinguish them, and generally treated with contempt. Their living conditions were inhumane and humiliating. Even killing a helot was not a punishable act. To keep their numbers up, Spartans encouraged helots to breed amongst themselves, and they were allowed to have some form of a family unit. Spartans would also procreate with helot women to bulk up the numbers of the state's servants. Those resulting children would be called nothoi, ranking somewhere between a slave and a free man. Nothoi usually served in the citizen army or worked in some low-level public service job. Girls, however, would simply be discarded. Helots were not used as fighting forces but in supporting roles.

At its peak Sparta had around 20,000-35,000 free Spartans. It is usually thought that there was one Spartan for every seven non-citizen and slave, in a population of around 200,000 .Of these only the citizens lived in the city itself , the rest would be living in the outskirts. Herodotus thought slaves formed up to 80% of the population of Sparta.

Spartan citizenship was inherited by blood. The separation of the males for much of their fertile lives would have inhibited the reproduction rate. Sparta faced a helot population that vastly and increasingly out-numbered its citizens. The alarming decline of Spartan citizens was one of their problems. Sparta was the only city-state that experienced a slave revolt. It is interesting that over their history Sparta only founded one colony.

There are legends about the prowess of the Spartans in battle. One report had it that they stood over seven feet in their armour. Researchers have established that they were indeed of ordinary height, mainly under six feet. However, there is no doubt that man for man they were fearsomely fit and skilled in battle. They had also developed two military assets: the long spear and shield, and the phalanx fighting formation. These in combination gave their soldiers considerable tactical advantage.

Hoplites

The standard Greek city-states did not have standing armies. Instead they had citizens-soldiers, known as hoplites. These formed the core of the Greek armies. All defined classes of citizens were required to undergo training and do their turn as soldiers.

Alliances, War and Division

Peloponnesian League

In its early history, Sparta expanded by conquering Laconia and Messenia and reducing their population into slavery (as helots), but the subjugation of Tegea on its northern border failed. Following this defeat, Spartan adopted a diplomatic strategy, known as the "bones policy", by appropriating the relics of the mythical hero Orestes from Tegea. This enabled it to present itself as the natural successor of the mythical Achaean kingdom of Agamemnon. Tegea then signed an alliance treaty with Sparta, which became the starting point of the Peloponnesian League. By 540s BC, Sparta had concluded alliances with all the Peloponnesian cities, apart from Argos and Achaean cities on the northern shore.

A major change in the organisation of the League took place c.506 BC, when Sparta attempted to capture Athens. A full army of the League was called and marched on Athens, but the Corinthians pulled out when they discovered the purpose of the expedition. The campaign therefore failed, and as a result Sparta had to concede the creation of a congress of the League, where members could vote on war and peace, in theory at least.

The League was a Spartan hegemony. It was controlled by the council of allies which was composed of two bodies: the Assembly of Spartans and the Congress of Allies. Each allied state had one vote in the Congress, regardless of that state's size or geopolitical power. No tribute was paid except in times of war when one third of the military of a state could be requested. Only Sparta could call a Congress of the League. And although each state had one vote, League resolutions were not binding on Sparta. In addition, the "one state, one vote" principle allowed Sparta to often ensure a formal majority through the smaller towns it could dominate directly.

Thus, the Peloponnesian League was not an "alliance" in the strictest sense of the word (nor was it wholly Peloponnesian for the entirety of its existence). Other members could hold influence comparable to Sparta herself, especially Corinth, due to its wealth and navy.
The League provided protection and security to its members. It was a conservative alliance which supported oligarchies and opposed tyrannies and democracies.

Thus, Sparta came to control some 8,500 km² of territory making the polis or city-state the largest in Greece and a major player in Greek politics. The conquered peoples of Messenia and Laconia had no political rights in Sparta and were often made to serve with the Spartan army.

Greco-Persian Wars

The Greco-Persian Wars (also called the Persian Wars) were a series of conflicts between the Achaemenid (or Persian) Empire and the Greek city-states that started in 499 BC and lasted until 449 BC.

First Hellenic League

The wars brought about the final stage of alliances and united action among the city-states, most particularly Athens and Sparta, cementing their oneness as a people. The League was expanded into the Hellenic League, and included Athens and other states. The Hellenic League was led by Pausanias of Sparta, and after he was recalled, by Cimon of Athens. Sparta had the most powerful army and Athens the most powerful navy.

After the Persian Wars, Sparta withdrew from the Hellenic League, reforming the Peloponnesian League with its original allies.

Ionian Revolt

In 547 BC, Cyrus the Great of Persia conquered the Ionian cities - some seven years **before** formation of the Peloponnesian League and **eight years before Cyrus conquered Babylon.** The Persians appointed tyrants (satraps) to rule each of them. In 499 BC, the tyrant of Miletus incited all of Hellenic Asia Minor to rebel against the Persians. Athens and Eretria joined in support, and in 498 BC they forces helped to capture and burn the Persian regional capital of Sardis. In 494 BC, the Persians regrouped and attacked the epicentre of the revolt in Miletus. The rebellion collapsed in 493 BC.

First Persian Invasion of Greece

Darius, the successor Persian king, decided to conquer Greece and punish Athens and Eretria for the burning of Sardis. He launched the first Persian invasion of Greece in 492 BC. First, they subjugated Thrace and Macedonia.

The following year, Darius sent ambassadors to all the cities of Greece, demanding their submission. He received it from almost all of them, except Athens and Sparta, both of whom instead executed the ambassadors. In 490 BC Darius launched a second force to Greece, across the Aegean Sea. They subjugated the Cyclades, destroyed Naxos, and island-hopped to Eretria, which they also conquered and enslaved.

The Persians next sailed down the coast of Attica, landing at the bay of Marathon, roughly 40 kilometres (25 mi) from Athens. The Athenian army marched to block the two exits from the plain of Marathon. After five days, the Persians decided to continue onward (by sea) to Athens, and began to load their troops and cavalry back onto the ships. Then, 10,000 Athenian soldiers descended from the hills around the plain, and crushed the weaker Persian foot soldiers The remnants of the Persian army fled to their ships and left the battle. Herodotus recorded that 6,400 Persian bodies were counted on the battlefield; the Athenians lost only 192 men.

The Battle of Marathon[17] was a watershed in the Greco-Persian wars, showing the Greeks that the Persians could be beaten. It also highlighted the superiority of the more heavily armoured Greek hoplites, and showed their potential when used wisely.

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17 Legend has it that Pheidippides, a, Athenian courier (professional runner, ran from Marathon to Athens (26 miles, 42 km) to deliver the news of the victory.

Second Persian Invasion of Greece

Darius died in 486 BC and responsibility for the Grecian conquest passed on to his son Xerxes In 480 BC, Xerxes personally led the second Persian invasion of Greece with one of the largest ancient armies ever assembled.

Xerxes achieved simultaneous successes in mid-August, with a famous victory over the allied Greek forces at the Battle of Thermopylae and the withdrawal of some 271 ships of the allied navy at the Battle of Artemisium. These allowed the Persians to overrun most of Greece. Athens was evacuated by the allied fleet to Salamis. She fell to the Persians, and **Xerxes ordered the burning of Athens**. .

The Peloponnesian allies began to prepare a defensive line across the isthmus of Corinth. At the same time, the Greek allies hoped, by destroying the Persian fleet, they could prevent the conquest. Even after Athens fell, the allied fleet remained off the coast of Salamis, trying to lure the Persian fleet to battle. The navies finally met in Sep 480 BC in the cramped Straits of Salamis. Seizing the opportunity, the allied fleet attacked, and scored a decisive victory, sinking or capturing at least 200 Persian ships, therefore ensuring the safety of the Peloponnesus.

Xerxes retreated to Asia with the bulk of the army, leaving one of his generals to complete the conquest with a hand-picked group of troops. As the latter wintered in Boeotia and Thessaly, the Athenians were thus able to return to their burnt-out city.

Eviction of Persians from Greece.

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There was tension among the allies. The Athenians, who were not protected by the Isthmus, but whose fleet was the key to the security of the Peloponnesus, felt that they had been treated unfairly, and so they refused to join the Allied navy in the spring, while the allies refused to send an army outside the Peloponnesus.

The Persians sought to divide the Greeks, and offered peace to the Athenians. The Athenians made sure that a Spartan delegation was on hand to hear the Athenians reject the Persians' offer. **Athens was thus evacuated again**, and the Persians marched south and re-took possession of it.

The Persians next offered peace terms to the Athenians and other refugees in Salamis. Athens and the. others sent emissaries to Sparta demanding assistance, threatening to accept the Persian terms. In response, the Spartans summoned a large army from the Peloponnese cities and marched to meet the Persians.

They opposing forces clashed at Plataea, near Boeotia in Jun 479 BC. The Persian infantry proved no match for the heavily armoured Greek hoplites, and the Spartans broke through to the general’s bodyguards and killed him. After this the Persian force dissolved in rout. Some 40,000 troops managed to escape via the road to Thessaly, but the rest fled to the Persian camp where they were trapped and slaughtered by the Greeks, finalising the Greek victory.

Expulsion of Persians from Asia Minor and Europe

The allied Greeks followed up their success by destroying the rest of the Persian fleet at the Battle of Mont Mycale (479 BC) off the Ionian coast, before expelling Persian garrisons from Sestos (479 BC) and Byzantium (478 BC). Following the Greek victory at Mycale, Macedon and the city-states of Ionia regained their independence.

Delian League

After Byzantium (479 BC), Sparta was eager to end its involvement in the war. The Spartans feared the rise of the Athenians as a challenge to their power. Additionally, the Spartans were of the view that, with the liberation of mainland Greece, and the Greek cities of Asia Minor, the war's purpose had already been achieved. The colonies in Asia Minor were not theirs.

This marked the point at which the leadership of the Greek alliance effectively passed to the Athenians. With the Spartan withdrawal it became explicit.

The loose alliance which had fought against Xerxes's invasion had been dominated by Sparta and the Peloponnesian League. With the withdrawal of these states, a congress was called on the holy island of Delos to institute a new alliance to continue to fight the Persians; hence the modern designation "Delian League".

The members numbered between 150 and 330, and were given a choice of either offering armed forces or paying a tax to the joint treasury; most states chose the tax. League members swore to have the same friends and enemies.

Over time, especially with the suppression of rebellions, Athens exercised hegemony over the rest of the league. The Athenians were very severe and exacting. The Athenians also arranged for the other members to pay their share of the expense in money instead of in ships and men. Thus, while Athens was increasing her navy with the funds they contributed, a revolt always found itself without enough resources or experienced leaders for war.

The League treasury was initially held in the temple at Delos, until Pericles, the then Athenian general, moved it to Athens in 454 BC. Athens began to use the League's funds for its own purposes, which led to conflicts between Athens and the less powerful members of the League. It is generally considered that this unilateral action sealed the League's growing transformation into an Athenian empire.

Expulsion of Persians from Asia Minor

In the meantime, the Delian League expelled the Persians from Europe at Thrace-Chersonese by 465 BC, and finally the Aegean at the Battle of Eurymedon in Asia Minor in 469 BC and Salamis-in Cyprus in 450 BC. Historians differ whether there was in fact a Peace Treaty of Callias in 449 BC.

We have reached the end of Greece's social and political evolution to full maturity, as they reached the Classic Age. In the next 150 years, Greece, and Athens in particular, will blossom to the peak of its civilisation, notwithstanding that the city-states, again Athens in particular and Sparta, will continue internal fighting until so weakened that the whole of Greece will be conquered by Macedonia by 338 BC. The latter history will be related later in its proper sequence.

(Back to TOC)

(C) The Classical Age

Pentecontaetia

Pentecontaetia, "the period of fifty years", is the term used to refer to the period between the defeat of the Persians in 479 BC and the beginning of the Peloponnesian Wars in 431 BC.

The Pentecontaetia was marked by the rise of Athens as the dominant state in the Greek world, a period also known as the Gold Age of Athens.

Athens assumed the leadership of the Delia League, which effectively completed the expulsion of the Persians from Europe in 449 BC, and with the transfer earlier in 454 BC of its treasury from Delos to Athens, the League functioned virtually as the Athenian empire.

Age of Pericles

Judging by their age ranges, this period saw the most famous men of Greece located in Athens practising their arts: , Aeschylus (525-455 BC), Sophocles (496-406 BC) and Euripides (480-406 BC) the dramatists, Pindar (518-438 BC) the poet, Phidias (480-430 BC) the sculptor and builder of the Parthenon (n 447 BC), and Anaxagoras(500-428 BC) and Socrates (469-399 BC) the philosophers. It was the Classic or Golden Age of Greece.

And there was Pericles (495-429 BC), the Athenian statesman largely responsible for the full development, in the later 5th century BC, of both Athenian democracy and the Athenian empire, making Athens the political and cultural focus of Greece. It was also known as the Age of Pericles. He served from 461 to 429 BC.

Pericles promoted the arts and literature. It is said it was principally through his efforts that Athens acquired the reputation of being the educational and cultural centre of the Greek world. He started an ambitious project that generated most of the surviving structures on the Acropolis, including the Parthenon and Propylaea 437. This project beautified and protected the city, exhibited its glory and gave work to its people. It is generally agreed that Pericles dipped freely into the League treasury to finance these projects.

Pericles[18] fostered Athenian democracy to such an extent that critics called him a populist. His political faction was the people-based (democrat) party. Their leader, Ephialtes[19], was elected strategos (general) in 465 BC and was assassinated n in 461 BC, whereon Pericles assumed his role as democratic leader. The unchallengeable leader of the democratic party became the unchallengeable ruler of Athens He was elected strategos almost continuously from 448 BC. Although Athens had a new archon appointed by the Areopagus almost every year, he remained (by popular support) in actual power until his death in 429 BC.

He stripped the (still) aristocratic Areopagus of its powers, and handed decision-making to the people via the Boule and the Assembly – including his own appointment. He kept his seat by sheer popularity, public works and a judicious war now and again. He maintained a strictly anti-Spartan foreign policy.

The Delian League comprised mainly the city states on both sides of the Aegean. Therefore, the Athenian power-base was its navy (for which all Delian members paid money contributions). The Peloponnesian League on the other hand comprised the states of that peninsula and some non-Delians of the mainland. Therefore the power-base of Sparta was

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18 Pericles was of the same family as Cleisthenes

19 Ephialtes was the leader of the democratic movement. In the late 460s BC, he oversaw reforms that diminished the power of the Areopagus a traditional bastion of conservatism, which marked the beginning of radical democracy for which Athens would become famous. These powers included the scrutiny and control of office holders, and the judicial functions in state trials. He introduced pay for public officeholders, reduced the property qualifications for holding a public office, and created a new definition of citizenship. Ephialtes was elected strategos in 465 BC, but was assassinated in 461 BC, and the political leadership of Athens passed to his deputy, Pericles.

the League's land army. A number remained neutral. Athens had the largest navy and Sparta the largest army. Conquest as a means of expansion was now the preferred option, and defence a necessity

When Athens and Sparta went to war against one another, or when one member was invaded from the opposite side, all members would aligned as allies, voluntarily or otherwise. When one League member was invaded by another from the same side or a neutral party, it was open season. Somebody always had some score to settle, a grudge to account, or a reason to go to war, even among third parties who joined in; or even just for the spoils or to free some of their citizens previously captured and sold into slavery – if not to capture some new enemy slaves of their own. The underbelly of glorious Greece was not very pretty.

The Pentecontaetia was characterised by continuous fractions, even after the Persians were expelled. Athens and Sparta signed a Thirty Years' Peace Agreement in in 445 BC. It was broken in five years. Let it be said, Pericles was not the greatest of generals. He won some, and he lost some.

Peloponnesian War

The Peloponnesian War (431–404 BC) was fought between Athens and Sparta, along with their respective League allies. Historians have traditionally divided the war into three phases.

In the first phase, the Archidamian War, Sparta launched repeated invasions of Attica, while Athens took advantage of its naval supremacy to raid the Peloponnesian coast and suppressed signs of unrest in its empire. This period concluded in 421 BC, with the signing of the Peace of Nicias. That treaty, however, was soon undermined by renewed fighting in the Peloponnese.

The second phase began when Athens launched a massive expeditionary force, known as the Sicilian Expedition in 415 BC, against Sparta, Syracuse and Corinth. (After Pericles, democracy was not working so well. There was strife and discord in the decision-making and command.)

The Athenians achieved early successes, before the arrival of back up in the form of the Spartan forces. A massive reinforcing armada from Athens briefly gave the Athenians the upper hand once more, but a disastrous failed assault on a strategic high point and several crippling naval defeats damaged the Athenian soldiers' ability to continue fighting and also their morale. The Athenians attempted a last-ditch evacuation from Syracuse. The evacuation failed, and nearly the entire expedition were captured or destroyed. The expedition ended in 413 BC in a devastating defeat for the Athenian forces. Two hundred ships and thousands of soldierswere lost in a single stroke. The city's enemies on the mainland and in Persia were encouraged to take action, and rebellions broke out in the Aegean. Some historians consider the defeat to have been the turning point in the war.

This ushered in the final phase of the war, generally referred to either as the Decelean War, or the Ionian War. In this phase, Sparta, now receiving help from the Achaemenid empire supported rebellions in Athens's subject states in the Aegean Sea and Ionia, undermining Athens's empire, and, eventually, depriving the city of naval supremacy. The destruction of Athens's fleet in the Battle of Aegospotami effectively ended the war. After the siege of Athens, they surrendered in the following year.

Sparta's Peace Terms

After the siege of Athens in 404 BC, Athens and Sparta struck a peace deal establishing Spartan hegemony over the Greek world. The Corinthians and Thebans, both Spartan allies, wanted to destroy Athens and enslave its citizens. The Spartans rejected this due to Athens being a major factor in holding up the balance of power. Instead Sparta imposed the following terms: the Athenian walls and fortifications were to be destroyed, the Athenian fleet was to be decommissioned except for twelve ships, Athenian exiles were to be allowed back to the city, and Athens was to acknowledge Spartan leadership and join the Spartan alliance network, allowing Sparta to dictate its foreign policy.

The Delian League was dissolved upon the war's conclusion in 404 BC under the direction of Lysander, the Spartan commander.

Corinthian War

Sparta's former allies turned against it in 395 BC, with Thebes instigating a Spartan attack that would lead to the Corinthian War, in which Sparta would face a coalition of Athens, Thebes, Corinth, and Argos, backed by Persia.

The Persians emerged the dominant victorious party, so much so that they dictated the terms of the King's Peace (387 BC), which was guaranteed by the Persian King Artaxerxes II. Under it, all Greek cities in Asia Minor as well as the island of Cyprus would revert to Persia, with the exceptions of Lemnos, Imbros, and Scyros which would belong to Athens, and they would guarantee the independence of all other Greek cities. By authority of the Persian King, Sparta was established as the head among Greek states. In effect Greece was placed under the suzerainty of Persia. Greek historians have called this the most disgraceful event in their history.

One result of this war was to re-empowered Athens, who had scored some success for the victorious side for the first time since the end of the Peloponnesian War, to rebuild their previously decommissioned fortifications and navy.

Second Athenian League

With Ionia and the Asian Minor colonies abandoned to the Persians, and both Athens and Sparta muzzled by Persia, the old historic political entities jostled to occupy the power vacuum, forming and changing alliances: Boeotia (Thebes), Argolis (Corinth) and Arcadia (Mantineia), and Elis, among others

The Second Athenian League was a maritime confederation of Aegean city-states from 377 to 355 BC, headed by Athens, primarily for self-defence against the growth of Sparta and secondly for insulation from the Persian empire.

The formation of the League was stimulated by three major events that caused relations between Athens and Sparta to deteriorate. The first event was a Spartan intervention in a factional conflict within Thebes in 382 BC in flagrant violation of the Peace of Antalcidas. The second event was the outbreak In 378 BC of the Boeotian (Theban) War, directly caused by the Spartan intervention in Thebes. The third event was the invasion of Piraeus, the Athenian port in Attica, in the winter of 378 BC. The Spartan commander was acquitted by Sparta. This caused Athens to seek alliances against Sparta, so they reached out to Aegean cities under harsh Spartan control. Ominously, Thebes, the major city state of Boeotia, left the League in 371B.

The Last Dance, Two Theban Tangos!

In 371 BC, under their illustrious general Epaminondas[20], Thebes and its Arcadian League defeated Sparta at the Battle of Leuctra in Boeotia, to shatter Sparta's Persian-supported hegemony and control over the Peloponnesian peninsula. In the process, he broke Spartan military power with his victory at Leuctra and liberated the Messinian helots, a group of Peloponnesian Greeks who had been enslaved under Spartan rule for some 230 years.

Athens decided to support the Spartans, as she resented the growing Theban power. An Athenian army was sent by sea to join the Spartan-led forces, in order to avoid being intercepted on land by Theban forces.

The Theban army marched into the Peloponnese and re-established Theban/Arcadian hegemony over the peninsula by forming the Arcadian League – having beaten both Sparta and Athens who had both dominated them from the beginning.

In July 362 BC, the Thebans, supported by the Arcadian and the Boeotian Leagues, decisively defeated Sparta. This time the Spartans had on their side Athens and the Elians as well as the Mantineans, who both defected from the Arcadian League.

The losses in material strength and prestige sustained by the Spartans at Leuctra and Mantinea were key in depriving them forever of their supremacy in Greece. Sparta was deprived of its former prominence and was reduced to a second-rate power among the Greek city-states.

Theban supremacy in Greece was short-lived, as it had subsequently to face the Macedonians.

Macedonian Conquest

C2

In the end Phillip II of Macedonia subjugated the whole of mainland Greece by 336 BC. Alexander The Great, his son, finished the job in 335 BC and led the League of Corinth as a federation of all Greek city-states with him as commander-in-chief, backed by a unanimous decision by the League, to go to war against the Achaemenid empire. For more see next Chapter.

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(C1) Philosophers and Astronomers

The Classical Age (479-336 BC) was a time when the Greeks achieved new heights in art, architecture, theatre, and philosophy. Much of these achievements took place in Athens, which experienced its Golden Age during this period.

Philosophy in Greek meant love of wisdom. In ancient times, it covered thought in all realms of study, including the sciences, ethics, mathematics and cosmology. Astronomy emerged as a branch of mathematics.

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[20] Epaminondas (419–362 BC) was a Greek general of Thebes and statesman of the 4th century BC who transformed that city-state, leading it out of Spartan subjugation into a pre-eminent position in Greek politics called the Theban Hegemony.   Epaminondas supervised the construction of entire cities. He was also militarily influential and invented and implemented several major battlefield tactics

Greek philosophy attained its full greatness beginning with Socrates (460-399 BC), centred in Athens. We may distinguish an earlier overlapping "pre-classical[21] era of philosophy (585-350 BC), also known as "pre-Socratic" philosophy, centred at Miletus, Ionia. The pre-Socratics were in fact the first Greek philosophers.

The common distinguishing feature of the philosophers from the pre-Socratics onwards was that they sought explanations based on reason, observation and the finding of natural law, rather than in the actions of the gods. But, in the early, especially pre-Socratic stages, they relied mainly on speculation, as the empirical sciences had yet to develop..

My enquiry is about astronomy. As the Greeks philosophers ranged widely in their search for wisdom and truth, I had to draw strict boundaries. I have avoided all curiosity about the art, sculpture, literature, drama and architecture of Greece. I have also not tried to include everyone. I have however added bits of historical, social and personal information to give a sense of the people and the times involved.

What will emerge is that in Greece we shall be talking about the achievements of individuals, whereas in Babylon we talked about the discoveries of the civilisation. It is also fascinating that the leading lights among the pre-Socratics wrote in verse, as did Solon and Cleisthenes,

The word "cosmos" is Greek, and means the universe. This was my point of attention. Initially, their cosmology embraced everything, from the primary building-blocks of matter to the prime mover and operating laws of the universe. The monists reduced things to a single substance and/or cause. The pluralists argued for a mix of materials with or without a cause. Mainly, the philosophers remained in the metaphysical domain. Mathematics and astronomy would come in later. The immediate post-Socratic age that followed would go further to grapple with the physical shape and size of the immediate universe. It will take the Hellenic period after that to postulate the first full physical design of the world.

Editorial Note

As the typical Greek philosopher[22] at that time would investigate everything that came his way - and write a treatise about it, I have strictly confined myself to those who made landmark contributions to cosmology and astronomy, and then only to key persons, and then only to their contributions, except for mentioning (where I cannot resist doing so) others of their achievements of paramount interest:

Except that when it came to Pythagoras, Plato, Aristotle, and Archimedes, who cardinally shaped Greek and world philosophy, mathematics and science, I could not resist capturing a fuller picture of their contributions.

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(C2) Pre-Socratic Philosophers

Greek speculative and philosophical thinking first found fertile ground in the ancient Greek world of Ionia. This was likely because of their close exposure to neighbouring civilisations and the rise of their autonomous city-states. Ionia came before Athens.

[21] The more common term is "Pre-Socratic". I find it clumsy for my purpose.
[22] Every practicing intellectual was a philosopher. No one had yet invented the term "specialist". I did not read of a philosopher who called himself a "scientist", although they mostly were, at least mathematicians.

Ionia

Ionia was a region on the western coast of Asia Minor. The name Ionia was first applied to this coast when Ionian[23] Greek refugees migrated eastward across the Aegean Sea about 1000–900 BC.

Ionia was a coastal strip, with a breadth varying from 60 to 90 kilometres (40 to 60 miles), and not exceeding 150 kilometres (90 miles) in length from north to south. To this must be added the peninsula of Mimas together with the two islands, Chios and Samos. Ionia enjoyed the reputation in ancient times of being the most fertile of all the rich provinces of Asia Minor.

With prosperity, there grew to be twelve city-states. These were banded together in an Ionian League, which was based on their sharing common religious and cultural practices, in particular the festival of Panionium.

Miletus was one of the most important commercial cities of Greece. After 700 BC, seamen of Miletus and Phocaea became active in and around the Black Sea. area and along the Mediterranean coasts of France and Spain, planting numerous colonies. Miletus alone is said to have been the mother of 90 cities.

By the end of the 7th century the Ionian cities had achieved great prosperity through their trading enterprises, their colonisation efforts, and their manufacture of ceramics, textiles, and metalware.

Because of their juxtaposition to Mesopotamia-Persia and Egypt among others, and their open asses to these by sea, Ionians were widely exposed to the intellectual interests, technical skills and philosophic content of these civilisations.

Ionian Language

Ionic Greek acquired prestige among Greek speakers because of its association with the language used by both Homer and Herodotus. In the Athenian writing reforms in 403 BC, the old Attic alphabet was replaced by the Ionic alphabet, as used by the city of Miletus This alphabet eventually became the standard Greek alphabet, its use becoming uniform during the Koine era. It was also the alphabet used in the Christian Gospels and the book of the Acts.

The Ionic dialect of Greek became the language of literature and learning, and Ionic architecture, sculpture, and bronze casting were also influential.

Pre-Socratic Schools of Thought

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In the 8th and 7th centuries down to about 500 BC, the pre-classical or pre-Socratic philosophers of Ionia dominated the intellectual life of Greece.

The pre-Socrates focussed on explanations of the cosmos. They shared the intuition that there was a single explanation that could explain both the plurality and the singularity of the whole, and how, if any, change occurred.

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[23] The four original tribes into which Greeks divide themselves are: Aetolian, Ionian, Achaean and Dorian. Each spoke their own dialect of Greek.

The pre-Socratics divided into three phases. The first phase of pre-Socratic philosophy, mainly the Milesians, looked for the primal substance or building block making up the universe (materialist monism). The second phase was that of the Eleatics. They rejected material monism and maintained that the true explanation of things lay in the conception of a universal unity (metaphysical monism). In the third phase, the post-Eleatics were a heady mix, seeking the truth by combining the naturalism of the Milesians, the Eleatics' ultimate incorporeal operating principle or cause (logos), and first approaches to applying observation and mathematics. There was pluralism and there was atomism. Then, we have the enigmatic Pythagoras, who bestrode the pre-classical and the classical eras, and made contributions down to the Hellenic age. And finally, there was Philolaus, perhaps the first true astronomer.

Milesian School

Thales

Among the most renowned was Thales of Miletus (624-545 BC). Contemporary with Solon in Athens, he has been recognised as the first Greek philosopher. He was the first to use reason, to use proof, and to generalise. He created the word cosmos, the word to describe the universe. He preceded Socrates (460-399 **)** by over a century.

What marked Thales out was that he posed the fundamental philosophical questions about the origin and the substance of the world, while providing an answer based on empirical evidence and reasoning.

He propounded that the essence (arche) of all matter was water. The universe was made up of one substance. He added that the Earth was a flat disk floating on a vast sea.

Thales' attempted to explain nature by searching for causes within nature itself rather than in the caprices of the gods. Thales was important in bridging the worlds of myth and reason.

Thales visited the neighbouring civilisations, Mesopotamia, Crete, Phoenicia, and Egypt where geometry was well practised. Thales advanced geometry with his abstract deductive reasoning and universal generalisations. Considering the role geometry played in Greek philosophy subsequently, I rate this an important first of his.

His contemporaries, the philosophers Anaximander and Anaximenes, both of Miletus, were, the first to develop a cosmological view of the world.

Anaximander

Anaximander (610–545 BC) was a pupil or associate of Thales. **He was the first to conclude that the earth was not flat** and made instruments to mark time, something like a clock.

He set up a gnomon (a shadow-casting rod) at Sparta to demonstrate the equinoxes, the solstices and the hours of the day and drew a map of the known world

In response to Thales, he postulated as the first principle an undefined, unlimited substance without qualities (apeiron), out of which the primary opposites, hot and cold, moist and dry, became differentiated.

He proclaimed that the earth was not situated in another structure but lay unsupported in the middle of the universe. Anaximander described a cyclical Earth suspended in the centre of the cosmos surrounded by rings of fire.

Further, he developed a rudimentary evolutionary explanation for biodiversity in which constant universal powers affected the lives of animals.

Anaximander was the first to **conceive a universe governed by laws**, which idea shaped the philosophical thinking of centuries to come.

Anaximenes

Anaximes (585–525 BC) was also a pupil of Thales. Anaximenes thought air was the primary substance that held the universe together.

He believed that air was infinite and divine. The primary difference in the forms of air as matter was the degree of condensation and density. He attributed condensation to cold/wet air and rarefaction to the interaction of hot/dry air.

Anaximes said that the earth, which was table-like, behaved like a leaf floating on air. He believed that the sky was a dome, and day and night were caused by celestial bodies being carried North until they were no longer seen. He thought of stars being similar to nails stuck in a transparent shell. He proposed that the earth let out an exhalation of air that rarefied, ignited and became the stars.

Similarly, he considered the moon and sun to be flat and floating on streams of air. The sun was not composed of rarefied air like the stars, but rather of earth like the moon; its burning comes not from its composition but rather from its rapid motion.

While his cosmology might sounds like a Van Gogh vision of the science involved, Anaximes' influenced many philosophers and scientists down the generations

Xenophanes

Xenophanes (570–478 BC), from Colophon, Ionia, was a philosopher, poet and theologian, who travelled widely. Xenophanes is seen as one of the most important pre-Socratic philosophers. His was a multi-dimensional approach to his cosmos,

At the natural physical level, he sought explanations for physical phenomena such as clouds or rainbows without reference to divine or mythological intervention, but instead based on first principles.

As a social philosopher, he believed in moderation and piety in civic, social and personal conduct.

At the theological level, Xenophanes espoused a belief that God was one eternal being, spherical in form, comprehending all things within himself, He was of absolute mind and thought, therefore intelligent, and moved all things. He did not intervene in human affairs.

As an early proponent of epistemology, he distinguished between different forms of knowledge and belief. Xenophanes held that there actually existed a truth of reality, but that humans as mortals were unable to know it

Xenophanes' understanding of divine nature as separate and uninvolved in human affairs motivated him to come up with naturalistic explanations for physical phenomena

In his cosmology, there was only one boundary to the universe, the one "seen by our feet". Xenophanes believed that the earth extended infinitely far down, as well as infinitely far in every direction. A consequence of his belief in an infinitely extended earth was that rather than having the sun pass under the earth at sunset, Xenophanes believed that the sun and the moon travelled along a straight line westward, after which point a new sun or moon would be reconstituted after an eclipse.

Xenophanes concluded from his examination of fossils of sea creatures found on land that water once must have covered all of the Earth’s surface. He used this evidence to conclude the cosmic principle that there was a tide flowing in and out between wet and dry, or earth and water. These two extreme states would alternate, at which point human life would become extinct, then regenerate (or vice versa).

Heraclitus

Heraclitus (535-475 BC), Greek philosopher was a native of the city of Ephesus, which was then part of the Achaemenid empire. He is remembered for his cosmology in which fire formed the basic material principle of an orderly universe.

Contrary to the others of the Milesian School, who posited one stable element as the arche, Heraclitus taught that everything flows, the closest element to this eternal flux being fire. All things came to pass in accordance with Logos, which must be considered as the "plan" or "formula" of the cosmos.

The hallmark of Heraclitus' philosophy was flux. Heraclitus wrote: “This world-order…no god nor man did create, but it ever was and is and will be: ever-living fire, kindling in measures and being quenched in measures”. He posited that all things in nature were in a state of perpetual flux. His image of the river, with ever-changing waters, was well known. From fire all things originated and all things returned to it again in a process of eternal cycles.

He also posited a unity of opposites, expressed through dialectic, which structured this flux, such as that seeming opposites in fact were manifestations of a common substrate to good and evil itself. Heraclitus called the oppositional processes "strife", and hypothesised that the apparently stable state of "justice" was the harmonic unity of these opposites.

Eleatic School

The Eleatic School was named after Elea, an ancient Greek town in Magna Graecia on the southern Italian Peninsula. The primary philosophers associated with the Eleatic doctrines were Parmides and Zeno (495-430 BC) both of Elea, and Melissus of Samos. Parmides was considered to be the founder.

The Eleatics advocated a strict metaphysical view of monism, in response to the materialist monism advocated by their predecessors and the theory of f Heraclitus that all existence could be summed up as perpetual change. They believed that only one substance existed and formed the cosmos, and everything else was just a transformation of it. The Eleatics rejected the validity of sense experience and instead took logical standards of clarity and necessity to be the criteria of truth.

The Eleatics maintained that the true explanation of things lay in the conception of a universal unity. It was by thought alone that we could arrive at the knowledge of being, at the fundamental truth that the "All is One". The Eleatics' focus on Being through means of logic initiated the philosophical discipline of ontology.

Parmides

The Eleatic School adhered to the central doctrine of Parmenides (515-? BC) that reality was a single, unchanging whole. “What-is”, according to Parmenides, was a physical sphere that was unborn, unchanged, and infinite. This was a monist vision of the world, far more radical than that of Heraclitus. As all things are One, and nothing can be changed or altered. Hence, all the things that we think to be true, even ourselves, are false representations. He is regarded as the founder of ontology and would influence Plato and Aristotle.

He was interested in many fields, such as biology and astronomy. He was the first person to deduce that the earth was spherical, on metaphysical grounds.

Melissus

The main contribution of Melissus (500-? BC) was a treatise of systematic arguments supporting the Eleatic philosophy. Like Parmenides, he argued that reality was ungenerated, indestructible, indivisible, changeless, and motionless. In addition, reality was infinitely extended in all directions.

Since he said no more about the natural order of the cosmos, where our Interest lies, I will not dwell on him further.

Zeno

Zeno (495–430 BC) was a philosopher of the Eleatic school. He was the inventor of the dialectic, and the method of argument “reductio ad absurdum”. He was best known for his paradoxes. He was the first philosopher who dealt with mathematical infinity.

Zeno was a precursor of the line of philosophy that culminated in Pyrrhonism and became a central concept of Aristotelian ethics: “an ability which suffices for living well, perfection in respect of virtue and resources sufficient for a living creature” (eudaemonia).

Since he said no more about the natural order of the cosmos, where our Interest lies, I will not dwell on him further.

Third Phase: Pluralism

Anaxagoras

Anaxagoras (500 –428 BC) was born in Clazomenae, Persian empire, and moved to Athens. According to Anaxagoras all things existed from the beginning, but originally in infinitesimally small fragments of themselves, endless in number and inextricably combined throughout the universe. All things existed in a confused and indistinguishable form, of both homogeneous as well as heterogeneous parts.

The work of arrangement, the segregation of like from unlike and the summation of the whole into totals of the same name, was the work of “Nous” (the cosmic mind) Mind stood pure and independent, a thing of finer texture, alike in all its manifestations and everywhere the same. possessed of all knowledge and power. The only manifestation of it was Motion. It gave distinctness and reality to the aggregates of like parts.

He gave scientific accounts of natural phenomena. From the fall of meteorites, he recognised the force later known as gravity. He was the first to give a correct explanation of eclipses, and was both famous and notorious for his scientific theories, including the claims that the Sun was a mass of red-hot metal, that the Moon was earthy, and that the stars were fiery stones. He thought the Earth was flat and floated supported by 'strong' air under it and disturbances in this air caused earthquakes. He introduced the notion of panspermia, that life existed throughout the universe and could be distributed everywhere.

Empedocles

Empedocles (490?-430 BC) was a citizen of Akragras, Sicily and lived in Athens. He was the last philosopher to write in verse. His brilliant oratory, penetrating knowledge of nature, and reputation for marvellous powers (including curing of diseases and averting epidemics), produced many myths and stories. He is said to have been magnanimous in his support of the poor, severe to overbearing oligarchs and even declined the sovereignty of the city when offered to him.

In cosmology, Empedocles established four ultimate elements[24], namely Water, Earth, Fire and Air. He called these four elements "roots". The different proportions in which these four indestructible and unchangeable elements were combined produced different structures. The aggregation and segregation of elements arising constituted the real process of growth, ie. increases or decreases. Nothing new came or could come into being. The only change that could occur was a change in the juxtaposition of element with element. This theory of the four elements became the standard dogma for the next two thousand years.

He also hypothesised that the four elements were eternally brought into union and parted from one another by two divine powers, Love and Strife. Love was responsible for the attraction of different forms of what we now call matter, and Strife was the cause of their separation. Love and Strife were plainly observable in human behaviour, but also pervaded the universe. The two forces waxed and waned in their dominance, but neither force ever wholly escaped the imposition of the other.

There was a time when the pure elements and the two powers co-existed in a condition of rest and inertness in the form of a sphere. The elements existed together in their purity, without mixture and separation, and the uniting power of Love predominated in the sphere: the separating power of Strife guarded the extreme edges of the sphere. Since that time, strife gained more sway and the bond which kept the pure elementary substances together was dissolved. The elements became the world of phenomena we see today, full of contrasts and oppositions, operated on by both Love and Strife. The sphere being the embodiment of pure existence was the embodiment or representative of God. Empedocles assumed a cyclical universe whereby the elements returned and prepared the formation of the sphere for the next period of the universe. In his details of aggregation, he was prophetic of evolution
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In natural science, Empedocles is credited with the first comprehensive theory of light and vision. He put forward the idea that we see objects because light streamed out of our eyes and touched them. While flawed, this became the fundamental basis on which later Greek philosophers and mathematicians like Euclid would construct some of the most important theories of light, vision, and optics.

Empedocles preached a new religion which sought to secure release from the 'wheel of birth' by purity and abstinence, echoing reincarnation. All living things were on the same spiritual plane. Plants and animals were links in the same chain where humans were links too, and Empedocles believed in the transmigration of the soul between humans, animals and even plants. One's behaviour during his lifetime would determine his next incarnation, until they

[24] Empedocles never used the word "element", which was first used later by Plato.

exit to the freedom from the cycle of reincarnations, after which they are able to rest in happiness for eternity[25].

Third Phase II: Atomism

With atomism we are back in the stream of natural philosophy. The pre-Socratic Greek atomists in this phase theorised that nature consisted of two fundamental components: atoms and the void. Clusters of different shapes, arrangements, and positions gave rise to the various macroscopic substances in this world.

Leucippus

Leucippus (5th century BC) and Democritus (460– 370 BC) both lived in Abdera, a city in an. Ionian colony in Thrace. They were famous for their atomic cosmology even though their thought included many other fields of philosophy, such as ethics, mathematics, aesthetics, politics, and even embryology.

Leucippus has been generally regarded as the propounder of the idea, that everything was composed entirely of various imperishable, indivisible elements called atoms. It has been difficult for historians to determine which contributions to atomism came from Democritus and which from Leucippus. Some sources claim that around 440 BC or 430 BC Leucippus founded a school at Abdera, with which his pupil, Democritus, was closely associated. His writings did not survive, historians paid him scant attention and there was even dispute that he existed.

On the other hand, Democritus wrote extensively, and a massive number of fragments and quotations of his writings have survived to this day. He visited Egypt, lived there five years and praised their mathematicians He became acquainted with the Chaldean Ostanes, one of the magi accompanying Xerxes, and was said to have taught him. His has been taken as the authentic exposition of atomism. We review his theory as representative of both. Many consider Democritus to be the "father of modern science".

Democritus

Democritus's argument for the existence of atoms hinged on the idea that it was impossible to keep dividing matter to infinity and that matter must therefore be made up of extremely tiny particles. The atomistic theory aimed to remove the distinction which the Eleatics drew between the Absolute or the only real existence, and the world of change around us.

Democritus believed that atoms were too small for human senses to detect, were infinitely many, came in infinitely many varieties, and had always existed. They floated in a vacuum, which he called the “void”. Democritus wrote that atoms and the void were the only things that existed.

Atoms varied in form, order, and posture and were constantly moving and colliding into each other.. The objects humans see in everyday life were composed of many atoms united by random collisions and their forms and materials were determined by what kinds of atom make them up.

Likewise, human perceptions were caused by atoms as well. Bitterness and sweetness were caused by atoms of different character and shape passing across the tongue.

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[25] Lord Buddha lived from 563 to 483 B.C, almost overlapping. There is no indication hat their paths crossed.

In philosophical atomism, nothing really existed: the only things that really existed were the atoms ricocheting off each other mechanistically in an empty void. Atomism stood in contrast to a substance theory, wherein a prime material continuum remained.

The atomic theory of Leucippus and Democritus was a response to the Eleatic school, who held that motion was not possible because everything was occupied with What-is. Democritus and Leucippus reverted the Eleatic axiom, claiming that since motions existed, What-is-not must also exist; hence void existed.

One conclusion of the Atomists was determinism - that all events were determined completely by previously existing causes. As Leucippus said, "Nothing comes to be random but everything is by reason and out of necessity."

Without any basis, it is remarkable how close Leucippus and Democritus came to the quantum world of Max Planck.

Orphism (The Lyrical poem)

A more detailed description about the cosmos can be found in Orphism, a lyric poem of the 5th century BC. We can find the remarkable information there that the Earth was round, had an axis and moved around it in one day, had three climate zones and that the Sun magnetised the Stars and planets.

The Orphic religion first appeared in Thrace. Orpheus its legendary founder taught that soul and body were united by a compact unequally binding on either. The soul was divine, immortal and aspired to freedom, while the body held it in fetters as a prisoner. Death dissolved this compact, but only to reimprison the liberated soul after a short time, for the wheel of birth revolved inexorably. Thus the soul continued its journey, alternating between a separate unrestrained existence and fresh reincarnation, round the wide circle of necessity, as the companion of many bodies of men and animals. To these unfortunate prisoners Orpheus proclaimed the message of liberation—that they stood in need of the grace of redeeming gods (Dionysius)—and called on them to turn to the gods by ascetic piety and self-purification: until the soul completed the spiral ascent of destiny to live forever as a God from whom it came. Such was the teaching of Orphism, which appeared in Greece about the 6th century BC

Pythagoreanism

Pythagoras (570 – 495 BC) lived about the same time as Cleisthenes of Athens. Pythagoras was born in, Samos, Ionia. Greek philosopher, mathematician, and founder of the Pythagorean brotherhood that, although religious in nature, formulated principles that influenced the thought of Plato and Aristotle and contributed to the development of mathematics and Western rational philosophy. Pythagoras developed a school of philosophy that was dominated by both mathematics and mysticism.

As a young man, Pythagoras went to Egypt and Babylon. He emigrated to southern Italy in about 532 BC, apparently to escape Samos' tyrannical rule, and established his ethico-political academy at Croton (now Crotone). Because of anti-Pythagorean feeling in Croton, he fled that city in 510 BC for Metapontum (now Metaponto) in Italy, where he died. He was something of a Hellenist before his time. No writings of his survive. What is known about Pythagoras comes from the fourth century BC, about 150 years after his death.

Pythagoras displayed an interest in metaphysic as did his naturalistic Ionian predecessors. But he claimed to find its key in mathematical form rather than in any substance.

Mathematical Form

He introduced the concept of form as distinct from matter, and that the physical world was an imitation of an eternal mathematical world. These ideas were very influential on Heraclitus, Parmenides and Plato.

Pythagoras believed that behind the appearance of things, there was the permanent principle of mathematics. The forms of things were based on a transcendental mathematical relation of numbers. There was a correspondence between mathematics and musical harmony.

Number

Pythagoras held that all things were Number, and the cosmos came from numerical principles. Everything consisted of numbers: the universe was made by numbers and everything was a reflection of analogies and geometrical relations. A large following of Pythagoreans adopted and extended his doctrine.

Numbers, music and philosophy, all interlinked, could comfort the beauty-seeking human soul. One of his most famous saying was: “There is geometry in the humming of the strings, there is music in the spacing of the spheres.”

Quadrivium

Pythagoras placed astronomy among the four mathematical arts (along with arithmetic, geometry and music). The study of Number, comprising the four mathematical arts, he later called the Quadrivium. Basically, astronomers sought to create geometrical models that could imitate the appearances of celestial motions.

Cosmology – First Concept of Spherical Earth

It was around 500 B.C. that Pythagoras first proposed a spherical Earth, mainly on aesthetic grounds. Like many Greeks, he believed the sphere was the most perfect shape.

He studied the stellar heavens, but with the possible exception of the theory of musical intervals in the cosmos, made no new contributions to astronomy.

Immortality and Re-incarnation

Pythagoras believed in the immortality of the soul and in re-incarnation (or metempsychosis), and the ultimate union with the divine. He advocated a way of life living based on ascetic ideals, purgation, and respect for all animal life. Further. popular cults and beliefs in the 6th century BC including the tenets of Orphism introduced him to the notions of occultism and ritualism.

Pythagoreans perceived the world as perfect harmony, dependent on number, and aimed at inducing humankind likewise to lead a harmonious life, including ritual and dietary recommendations

Pythagoreanism interweaved rationalism and irrationalism more inseparably than did any other movement in ancient Greek thought.

Pythagoreanism represented a soul-directed subjectivism alien to the mainstream of pre-Socratic Greek thought. It is interesting that the Lord Buddha was seven years younger than Pythagoras. There is no reported connection between the two.

Pythagoras himself wrote no books. His original teachings included:(1) the metaphysic of number, and the conception that reality was, at its deepest level, mathematical in nature; (2) the use of philosophy as a means of spiritual purification; (3) the heavenly destiny of the soul, and the possibility of its rising to union with the divine; (4) the appeal to certain symbols, sometimes mystical, and the harmony of the spheres; (5) various mathematical contributions, including the Pythagorean Theorem, and (6) the demand that members of his order should observe strict loyalty and secrecy.

Scholars have found it difficult to distinguish Pythagoras's teachings from those of his disciples. Suffice it to say he strongly influenced the philosophers of the classical age. On the one hand, he installed mathematics (and astronomy) as a branch and tool of learning, which would soon bear fruit. On the other, he started a spiritual and moral movement that continued to flower into the Hellenic age and after.

First Fruits of Astronomy.

Geocentricity of Planets.

The planets did not escape the observations of the pre-classical philosophers. The term "planet" came from the Greek meaning "wanderer". The five planets could be seen with the naked eye. So, they gave them Greek names: Hermes, Aphrodite, Ares, Zeus and Cronus. They did argue whether the Sun and Moon should be added in. So, sometimes, there were a total of seven.

Even then, they fumbled with Venus. They initially had Hesperus for the evening star and Phosphorous for the morning star. It took Pythagoras to put them right. The latter point also confirmed the then accepted view of their geocentricity in relation to the Earth.

Philolaus –Heliocentricity of Universe

Philolaus, (470-385 BC) was a pre-Socratic philosopher. He was born in Croton, Magna Graecia, in Italy and migrated to Greece. Philolaus was the successor of Pythagoras.

Philolaus was the most outstanding figure in the Pythagorean school. Most of what is known today about the Pythagorean astronomical system is derived from Philolaus's views. He argued that at the foundation of everything was the part played by the limiting and the limitless, which combined in a harmony.

With his assertion that the Earth was not the centre of the universe (geocentrism), he is credited with the earliest concepts in the development of heliocentrism, namely that the Sun was the centre of the known universe. In his way of thinking, the universe revolved around an hypothetical astronomical object he called the Central Fire.

In Philolaus's system, a sphere of the fixed stars, the five planets, the Sun, the Moon, and the Earth all moved around the Central Fire. Philolaus added a tenth unseen body, as the Pythagorean Number theory required a tenth.

Pre-Socratic Round-Up

The pre-Socratic intellectual revolution is widely considered to have been the first step towards liberation of the human mind from the mythical world and initiated a march towards reason and scientific thought, that led to modern western philosophy and science.

The pre-Socratics were the first to seek for a unitary arche of the world, whether arche meant the beginning, the origin, the main principle or the basic element. Thales focussed on the natural law and asserted the primacy of empiricism, and may be regarded as the pro-genitor of Aristotle. Anaximander offered the principle of sufficient reason, a revolutionary argument that would also yield the principle that nothing comes out of nothing. The two philosophers Heraclitus and Parmenides, along with Pythagoras, began the metaphysical tradition that strongly influenced Plato and Aristotle, and continues today. The latter incorporated the quadrivium into philosophy, and astronomy into the quadrivium.

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(C3) The Classical Philosophers

Socrates

Socrates (470–399 BC) was a Greek stonemason, social critic and philosopher from Athens. He lived at the height of the latter's period of glory, from the victories of the Greco-Persian Wars to Pericles and the First Peloponnesian War.

He is credited as the founder of western philosophy. He caused Greek philosophy to pivoted round a major corner, from looking at the external world to human conduct. He was among the first moral philosophers of the ethical tradition.

Socrates believed that philosophy should achieve practical results for the greater well-being of society. He did not found a school as such, but taught in the public places wherever people gathered to learn from him.

He attempted to establish an ethical system based on human reason rather than theological doctrine. Socrates pointed out that human choice was motivated by the desire for happiness.

Socrates believed that knowledge was the ultimate good and that pursuing knowledge was vital to living a good, virtuous life. Socrates argued that good and evil were absolute and that only through pursuing knowledge could we learn the difference.

Socrates did not write anything and is known mainly through the accounts of his students Plato and Xenophon, The former were written as dialogues, immortalising the literary genre of the Socratic Method or Dialogue.

He cared nothing for convention, class distinctions or `proper behaviour', and spoke easily with all classes and ages. His liberal attitude got him into trouble. In 399 BCE Socrates was charged with impiety, which read as follows: "Socrates is guilty, firstly, of denying the gods recognized by the state and introducing new divinities, and, secondly, of corrupting the young." He was sentenced to death by the (democratic) Assembly. He refused exile, and died by self-administering hemlock (poison).

Socrates' sayings included the following: ""Strong minds discuss ideas, average minds discuss events, weak minds discuss people." He said nothing about astronomy.

Plato

Plato (428–348 BC) was a Greek philosopher born in Athens . He was a generation younger than Socrates, and his pupil. He lived through the same period of glory, overlapping into the second Peloponnesian War. He lived on further, through the subsequent wars between the Athenian empire (the Delos League) and the Spartan empire (the Peloponnesian League), the conquest of Athens by the latter in 404 BC and the rule of the Thirty Tyrants imposed by the Spartans on Athens, and the final defeat of Sparta in 371 BC. He saw both the rise and disintegration of Athens.

Plato was born into a prominent Athenian family. However, the short-lived Spartan oligarchy of the Thirty Tyrants (404-403 BC) and the trial and execution of his mentor Socrates led Plato to become disgusted with the Athenian political life. He devoted himself instead to teaching and philosophical inquiry. To that end, he founded the Academy around 385 BC, which lasted in some form until 527 AD, and was the prototype for the western university system. Aristotle was his most famous student.

Plato's entire body of work is believed to have survived. These works consist of a set of 41 "Dialogues" plus a collection of 13 letters and a book of Definitions. Our knowledge of Socrates, his mentor, stems mostly from Plato's Dialogues. Plato never speaks in his own voice in his Dialogues, and speaks as Socrates in all but the Laws.

Philosophy

The foundations of Plato’s philosophy are threefold – dialectic thought, ethics and physics, the central point of unison being the theory of forms. For him, the highest of forms was that of The Good, which he took as the cause of being and knowledge. Plato’s philosophy is known as Platonism, also Platonic Realism and Platonic Idealism. Much of Plato’s philosophy is metaphysical in nature.

Plato wrote one of the first and most influential works on politics, The Republic, which described an ideal or Utopian society. Plato was a critic of democracy. Plato is regarded as the father of political science.

Theory of Forms

. The central tenet underlying Plato’s philosophy was his Theory of Forms. It was, among other things, Plato’s solution to the problem of universals[26],

In Plato’s philosophy, our senses were imperfect. The world that can be perceived with the five senses was less real than that of their essential forms. Unchanging and eternal, essential forms were the only true objects of knowledge. An essential form was an invisible, intelligible principle that was unified and unalterable. A good analogy is a scientific law of nature or a mathematical rule: it will still exist in its perfectly unchanged form long after everything physically perceiving is gone.

Thus, the reality of the world was to be found in their Perfect Forms. These were only accessible through pure thought. Our senses offered us only an illusion of reality. Plato believed that our knowledge or awareness of Perfect Forms was innate to us. Through intellectual effort and reason, we could unlock this true knowledge.

[26] Universals are qualities and relations in two or more entities. if all cup holders are circular in some way, circularity may be considered a universal property of cup holders. Many properties can be universal: being human, red, male or female, liquid or solid, big or small, etc. Philosophers agree that human beings can talk and think about universals, but disagree on whether universals exist in reality beyond mere thought and speech.

The Intelligible World

The Intelligible World corresponded to the states of knowledge (episteme) and thinking (dianoia) in man. The “World of Appearances,” that of visible things and images, corresponded to the lesser states of belief (pistis) and imagining (eikasia) in man.

Plato put forth a scenario in which a group of humans were born into a chamber within a cave. The cave dwellers were chained in a position such that they only saw what was directly before them. And what was before them were silhouettes on a wall made by shadows cast from puppet masters in front of a fire to their rear. The whole reality of these imprisoned cave dwellers, therefore, was the movements of the shadows on the wall before them.

The Good

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Plato proclaimed that The Good was the highest object of the “Intelligible World,” which was composed of essential forms and mathematics. The Good was the highest object of knowledge. The Good made the world intelligible. And the apprehension of it was a revelation which could only follow a long intellectual training, like that of the philosopher. \

He said that the objects of knowledge were made visible and nourished by “Goodness” in the same way light from the sun enables sight and knowledge of objects on the Earth. In this way, the objects of knowledge derived their very being from The Good. Therefore, Goodness was not the same as being, but surpassed it.

God

In his Dialogues, he uses the names of various gods, as well as the singular “God,” and “universe” interchangeably. “God” is the benevolent creator of all things, and man’s evil is a product of his misdirected will or illusion. For Plato, the highest of forms was that of The Good, which he took as the cause of being and knowledge.

Soul

Every human person has a soul in Plato’s philosophy. And each soul has three parts: the rational, the irrational, and the spirited. The rational is “reflective,” meaning it seeks knowledge, order, and discipline. The irrational satisfies appetite and impulse, and can distract the rational. The third part, the spirited element, animates either of the first two. Ideally, it should be what Plato calls the “auxiliary of the rational.”

For Plato, the soul was that which gave life. See this brief exchange from the Phaedo: "What is it that, when present in a body, makes it living? — A soul." Plato advocated a belief in the immortality of the soul, and several dialogues end with long speeches imagining the afterlife.

Reincarnation

Among the most interesting was his professed belief in reincarnation. Plato referred to a “wheel of birth” that the “purified soul” could escape from to “dwell with the gods forever”.

Virtue

Virtue was a prerequisite for knowledge. And true knowledge, as opposed to mere belief, was man’s closest link to the divine.

To be virtuous one must lead a just life. Plato asserted that a just person enjoyed "internal order". Justice was the sum of all virtues. Virtue was happiness, and the route to escape re-incarnation.

Politics

Plato is regarded as the father of political science. Plato was sceptical of democracy. He proposed that nations should be ruled by "philosopher kings," or high-minded individuals dedicated to the pursuit of justice and learning. The philosopher king, after having attained a certain degree of wisdom from study and reflection, would seek to inspire the governed to equally pursue virtue.

Unity, another theme pervasive throughout Plato's philosophy, was essential to the health of the state. Citizens should be so closely bound by institutions that they all wanted the same things.

Contrary to Greek culture, he believed woman to be man's equal, and that no opportunity should be denied to her on the basis of sex.

Justice

The Greek term for "justice" "dikaiosune" embraced both individual justice and the justice that informed societies. Plato was able not only to inform metaphysics, but also ethics and politics with the question: "What is the basis of moral and social obligation?"

Plato's well-known answer rested upon the fundamental responsibility to seek wisdom, wisdom which led in turn to an understanding of the Form of the Good. Plato argued that such understanding of Forms produced and ensured the good communal life.

The latter was ideally structured when under a philosopher king in a society with three classes (philosopher kings, guardians, and workers) that neatly mirrored his triadic view of the individual soul (reason, spirit, and appetite). Justice is attained when knowledge of how to fulfil one's moral and political functions in society was put into practice.

The Beautiful

Like "Goodness", at its essence, The Beautiful was unified, unchanging, and eternal. Recognising a manifestation of beauty in a person or thing was not knowledge of its essence. It was only belief in an isolated manifestation.

Like The Good, The Beautiful was the highest form or manifestation of being or the divine. And, again like The Good, it illuminated and transcended wisdom, truth and justice.

Mathematics

The objects of pure thought were numbers and forms. Therefore, mathematics earned its place in the higher, intelligible world. Facility with abstract mathematical concepts increased the aptitude for attaining knowledge of the essential forms.

In the dialogue Timaeus, Plato associated each of the four classical elements (earth, air, water an fire) each with a regular solid (cube. octahedron, icosahedron and tetrahedron) due to their shape, the so-called Platonic solids. The fifth regular solid, the dodecahedron was supposed to be the element which made up the heavens.

Although he was not a creative mathematician, Plato included the quadrivium as the basis for philosophical education in the Republic..

Cosmology

Quadrivium

Plato included the "quadrivium" (ie. the subjects of arithmetic, geometry, music, and astronomy) as basic constituents of a philosophical education.

Two-Sphere Model of Earth

Plato's main books on cosmology were the Timaeus and the Republic. In them he proposed a two-sphere model of a geocentric earth. The model divided the cosmos into two regions, a spherical Earth, central and motionless, and a spherical heavenly realm centred on the Earth, which might contain multiple rotating spheres made of ether.

Plato proposed that there were eight circles or spheres carrying the seven planets and the fixed stars. He proposed that the seemingly chaotic wandering motions of the planets could be explained by combinations of uniform circular motions centred on a spherical Earth - a novel idea in the 4th century BC.

Plato is reported to have posed a question for the Greek mathematicians of his day: "By the assumption of what uniform and orderly motions can the apparent motions of the planets be accounted for. He encouraged a younger mathematician, Eudoxus, to develop a system of Greek astronomy. Eudoxus would take him up on this, see later on.

Around this time Greek philosophers had begun to believe the world could be explained by natural processes rather than invoking the gods, and astronomers began making physical measurements

Aristotle

Aristotle (384–322 BC) was a Macedonian, who became the most famous Greek philosopher of all time. He born in Stagira, Chalcidice, an Ionian settlement in central Macedonia, founded in 655 BC. His father was the physician to King Amyntas III (393-370 BC) of Macedonia, the grandfather of Alexander The Great/..

After his father died in 367 BC, at 17-18 years of age, Aristotle migrated to Athens and joined Plato's Academy. He remained there 20 years, until the age of 37 (c. 347 BC).

Meanwhile Phillip II (359-336 BC) became king of Macedonia and embarked on an expansionist policy, targeting the whole of Greece, Thrace and Epirus and ultimately the Achaemenid Empire. The political atmosphere was therefore marked by intrigues, change of allegiances, and episodes of friction and peace. It could not have been comfortable for Macedonians living in Athens. Philip II finally conquered Greece (except Sparta) at the Battle of Chaeronea in 338 BC, against a coalition of Athens, Thebes, and Corinth and their allies. When Plato died, about 348 BC, his nephew, Speusippus, became head of the Academy, and Aristotle left Athens.

He migrated to Assus, another ancient Ionian settlement on the north-western coast of Anatolia (then under the Persian king) where Hermias, a graduate of the Academy, was ruler. Aristotle became a close friend of Hermias and eventually married his ward Pythias. Aristotle helped Hermias to negotiate an alliance with Macedonia, which angered the Persian king, who had Hermias put to death about 341 BC.

Aristotle next moved to Mytilene on Lesbos, seven miles off shore from Assus. At both Assus and Mytilene, he began his monumental scientific work investigating the natural world, in particular zoology and marine biology.

In 343 or 342 Aristotle was summoned by Philip II to the Macedonian capital at Pella to act as tutor to Philip’s 13-year-old son, the future Alexander the Great. Little is known of the content of Aristotle’s instruction.

Philip II was assassinated by his bodyguard during a wedding feast and succeeded by Alexander in 336 BC, who proceeded to implement his father’s plan to conquer and was able to launch the invasion at the head of a combined Grecian army.

By 326, Alexander had made himself master of an empire that stretched from the Danube to the Indus and included Libya and Egypt. Ancient sources report that during his campaigns Alexander arranged for biological specimens to be sent to his tutor from all parts of Greece and Asia Minor.

When it fell under Macedonian rule, and while Alexander was conquering Asia, Aristotle, now 50 years old, moved back to Athens in 335 BC. Just outside the city boundary, he established his own school in a gymnasium known as the Lyceum.

During Aristotle’s years at the Lyceum, his relationship with his former pupil Alexander apparently cooled. Alexander became more and more megalomaniac, finally proclaiming himself divine and demanding that Greeks prostrate themselves before him in adoration.

Opposition to this demand was led by Aristotle’s nephew Callithenes (c. 360–327 BCE), who had been appointed historian of Alexander’s Asiatic expedition on Aristotle’s recommendation. For his heroism Callisthenes was falsely implicated in a plot and executed.

Following Alexander's death, anti-Macedonian sentiment in Athens was rekindled. In 322 BC, Aristotle was reportedly denounced for impiety, prompting him to flee to his mother's family estate in Chalcis on Euboea, at which occasion he was said to have stated: "I will not allow the Athenians to sin twice against philosophy"– a reference to Socrates. He died on Euboea of natural causes later that same year.

Tradition has it that the natives of Stagira transferred Aristotle's relics to the city, buried it there, and founded a festival in his honour which was called “Aristoteleia.

Aristotelian Perspectives

For Aristotle, philosophy was the first form of scientific thought, since it tried to give answers to our questions using the observation of natural phenomena, elaborating hypotheses and thinking rationally.

Aristotle was Plato's student, but he argued that we could discover truth not just by contemplating the Realm of Ideas, but also by examining the physical world. He believed that people’s concepts and all of their knowledge were ultimately based on perception.

Such was the case of the study of the heavens, which today we call astronomy, but which at the beginning of philosophy was one of its objects of study.

The Ultimate Philosopher

Ab initio, Aristotle grappled with the subject of realty. While Plato conceived of the world as an imperfect reflection of a higher realty that existed outside space and time, Aristotle concluded that reality was inherent in things, and knowable. He initiated, even established, the systems of inquiry across all the major domains. He was the father of the physical and theoretical sciences and of the modern disciplines of metaphysics, political science and ethics. Ultimately, Aristotle's contribution was to establish a rational framework for the comprehensive exploration of the world - and in time the universe and the cosmos. He went further to examine our reasoning processes, and in his landmark work Logic gave us a set of tools of inquiry that has been the foundation of our intellectual achievement since.

He turned us round our first corner of enlightenment, enabling us to breakthrough in our quest to know our world, like Einstein would do again later.

Framework of Knowledge

Aristotle was the proto-type of the present-day (dying) species the classical or "liberal arts" scholar. He had a "helicopter" (he might have said "olympian") vision. He wanted to knit together everything in a comprehensive understanding, and he had the genius to undertake the task. Aristotle made philosophy in the broad sense co-extensive with reasoning, that included "science" as we understand it - and indeed astronomy.

His output was to lay the first rational and all-encompassing ground plans for the organisation and pursuit of our knowledge of the world.

Next he classified the domains of knowledge into (a) metaphysical philosophy, (2) natural philosophy, which included the sciences as we know it, and (3) practical philosophy[27].

Speculative Philosophy[28]

1. Metaphysics

Metaphysics is the branch of speculative philosophy[29] that studies the fundamental nature of reality, the first principles of being, identity and change. It has been suggested that the term might actually have been coined by a first century editor who assembled various small selections of Aristotle's works into the treatise now known as Metaphysics (After/Before Physics).

First Philosophy

Aristotle called it the "first philosophy", and distinguished it from mathematics and natural science (physics), as the contemplative philosophy which was "theological" and studied the divine. He wrote[30]:

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[27] We shall not look at this further.

[28] A theoretical as opposed to demonstrative philosophy, founded upon intuitive or a priori insight and especially insight into the nature of the Absolute or Divine; broadly a philosophy of the transcendent or one lacking empirical bases (Merriam-Webster.)

[29] It is one of the main branches of philosophy, along with epistemology (how knowledge arises), ontology, logi, ethics and politics.

[30] https://en.wikipedia.org/wiki/Aristotle

> "if there were no other independent things besides the composite natural ones, the study of nature would be the primary kind of knowledge; but if there is some motionless independent thing, the knowledge of this precedes it and is first philosophy, and it is universal in just this way, because it is first. And it belongs to this sort of philosophy to study being as being, both what it is and what belongs to it just by virtue of being."
> **Metaphysics (1026a16**).

Forms

For Plato, Forms[31] were the perfect exemplars or ideal types of the properties and kinds of things found in the world. Thus the properties "beautiful" and "black" corresponded to the Forms the Beautiful and the Black. A person was courageous and generous because he or she participated in the Forms of Courage and Generosity, and so on. For Plato, Forms were abstract objects, existing completely outside space and time Thus they were knowable only through the mind, not through sense experience.

For Aristotle, forms did not exist independently of things—every form was the form of something, and was directly knowable. A "substantial" form attributed to a thing was that without which that thing would be a different thing or would cease to exist altogether. "Black Beauty is a horse" attributes a substantial form, horse, to a certain thing, the animal Black Beauty. Unlike substantial forms, "accidental" forms could be lost or gained by a thing without changing its essential nature. "Black Beauty is black" attributes an accidental form, blackness, to a certain animal, who could change colour without ceasing to be itself.

Substance

Aristotle concluded that substance was a combination of both matter and form. For example, the matter of a house was the bricks, stones, timbers, etc., or whatever constituted the potential house, while the form of the substance was the actual house.

Essence was the term for the property or set of properties that made an entity or substance what it fundamentally was. Essence was contrasted with accident, a property that the entity or substance had contingently, without which the substance could still retain its identity.

Potentiality and Actuality

Aristotle defined change as "coming to be", which he said was when nothing persists of which the resultant was a property. Change could arise from (1) growth and diminution (change in quantity), (2) locomotion (change in space),and (3) alteration (change in quality).
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Potentiality was what a thing was capable of doing or being acted upon to do or be, if the conditions were right and it was not prevented by something else. For example, the seed of a plant was potentially a plant. Actuality was the fulfilment of the potentiality. Because the end was the principle of every change, actuality was the end. According to Aristotle, the potential being (matter) and the actual one (form) were one and the same

3. Epistemology

Like Plato, Aristotle's philosophy recognised the universal. But he placed the universal within and as part of each thing itself. Aristotle argued that all universals were "instantiated" at some point in time, and that there were no universals that were unattached to existing things. So, the universal of apple was immanent within each apple.

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[31] When used to refer to forms as Plato conceived them, the term "Form" is conventionally capitalized. The term is lowercased when used to refer to forms as Aristotle conceived them.

Aristotle's immanent realism meant that epistemology (study of the processes of knowledge acquisition) must necessarily be based on the study of things that existed or happened in the world, rising to knowledge of the universal. **He established observation as the bedrock of scientific study.**

4. Ontology

God

Sticking true to his empirical methodology, from the available observations of the planets and stars and speculating on the causes of their concentric circular motions, Aristotle inferred the existence of an Unmoved Mover. Aristotle concluded the unmoved mover was God.

> . "Hence it is actuality rather than potentiality that is held to be the divine possession of rational thought, and its active contemplation is that which is most pleasant and best. If, then, the happiness which God always enjoys is as great as that which we enjoy sometimes, it is marvellous; and if it is greater, this is still more marvellous. Nevertheless it is so. Moreover, life belongs to God. For the actuality of thought is life, and God is that actuality; and the essential actuality of God is life most good and eternal. We hold, then, that God is a living being, eternal, most good; and therefore life and a continuous eternal existence belong to God; for that is what God is."
> **Metaphysics 12 1072b**

In his Metaphysics, he claimed that there must be a separate and unchanging being that is the source of all other beings.

Aristotle made God passively responsible for change in the world in the sense that all things sought divine perfection. God imbued all things with order and purpose, both of which could be discovered and point to his (or its) divine existence.

Soul

De Anima, On the Soul[32], was a major treatise of Aristotle that discussed the different kinds of souls possessed by different kinds of living things. Thus plants had the capacity for nourishment and reproduction, and had their own kind of soul. Lower animals had, in addition, the powers of sense-perception and self-motion (action), and their own kind of soul.

A soul, Aristotle said, was "the actuality of a body that has life." If one regards a living substance as a composite of matter and form, then the soul was the form of the living body. The soul was not a substance distinct from the body. It was the soul that made an organism what it was. A body without a soul was unintelligible – or dead.

The human being, additionally, performed the function of thinking. His soul accordingly possessed the extra faculty of the intellect. Aristotle posited further that man's rational soul incorporated two components, a storage facility (he named possible intellect) and a thinking component (he named the agent intellect One contained all the mind's ideas, and another which brought them into action.

Aristotle also argued that the mind (only the agent intellect) was immaterial, able to exist without the body, and immortal. He argued that some parts of the soul — the intellect — could exist without the body, but most could not.)

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32 https://en.wikipedia.org/wiki/On_the_Soul

He argued that since the active principle in our mind acted with no bodily organ, it could exist without the body. And if it existed apart from matter, it therefore could not be corrupted. And therefore there existed a mind which was immortal. How the human soul related to this immortal mind remained undefined.

5. Logic

Aristotle is credited with the earliest study of formal logic, and his conception of it was the dominant form of western logic until 19th-century advances in mathematical logic. The works of Aristotle on Logic were compiled into a set of six books called the Organon around 40 BC by Andronicus of Rhodes

These go from the basics, the analysis of simple terms in the Categories, the analysis of propositions and their elementary relations in On Interpretation, to the study of more complex forms, namely, syllogisms in the Analytics and dialectics in the Topics and Sophistical Refutations. The first three treatises form the core of the logical theory : the grammar of the language of logic and the correct rules of reasoning.

Fundamentally, inferences were steps in reasoning. Deduction was inference deriving logical conclusions from premises known or assumed to be true. Induction was inference from particular evidence to a universal conclusion.

This process of logical deduction was invented by Aristotle, and perhaps lies at the heart of all his famous achievements. His most famous thinking tool was the syllogism.

6. Ethics

For Aristotle, like Plato, the central problem of ethics was the achievement of happiness. Happiness meant a good human life, or a life of human flourishing (eudaimonia). The means by which happiness was acquired was through virtue.

Plato suggested that virtue was a kind of knowledge, and that virtuous action (or the desire to act virtuously) followed necessarily from having such knowledge.

In Plato’s later dialogue Republic, the just or completely virtuous person was the one whose soul was in harmony, because each of its three parts—Reason, Spirit, and Appetite—desired what was good and proper for it and acted within proper limits.

For Aristotle, happiness was not merely a condition of the soul but a kind of right activity. The good human life, he held, must consist primarily of whatever activity was characteristically human, and that was reasonable. The good life was therefore the rational activity of the soul, as guided by the virtues. Aristotle recognized both intellectual virtues, chiefly wisdom and understanding, and practical or moral virtues, including courage and temperance. The underlying principle was moderation.

The man who possessed character excellence would tend to do the right thing, at the right time, and in the right way. Bravery, and the correct regulation of one's bodily appetites were examples of character excellence or virtue. So acting bravely and acting temperately were examples of excellent activities.

In his Nicomachean Ethics, Aristotle held that happiness was the practice of philosophical contemplation in a person who had cultivated all of the intellectual and moral virtues over much of a lifetime.

In the Eudemian Ethics, happiness was the exercise of the moral virtues specifically in the political realm, though again the other intellectual and moral virtues were presupposed.

7. Politics

Plato's Republic declared that only philosophers should rule. He was hostile towards democracy, or rule by the many.

Plato's Republic drew the analogy between the three parts of the soul (Reason, Spirit, and Appetite) and the three classes of an ideal state - Rulers, Soldiers, and Producers (e.g., artisans and farmers). In the just state, the three parts performed the functions proper to them and in harmony. In particular, the Rulers would understand not only the good of the state but, necessarily, the Good itself, the result of years of rigorous training to prepare them for their leadership role.

In one of his last works, the Laws, Plato outlined a mixed constitution incorporating monarchy and democracy. It seemed the state of the Republic remained Plato's ideal, or utopia, while that of the Laws represented the best that could be achieved in realistic circumstances.

Aristotle was famous for observing that "man is a political animal," meaning that human beings naturally formed political communities. Indeed, it was impossible for human beings to thrive outside a community, and the basic purpose of communities was to promote human flourishing.

Aristotle classified states according to the number of their rulers and their interests. Rule by one person in the interest of all was monarchy; rule by one person in his own interest was tyranny. Rule by a minority in the interest of all was aristocracy; rule by a minority in the interest of itself was oligarchy. Rule by a majority in the interest of all was "polity"; rule by a majority in its own interest—i.e., mob rule—was "democracy."

In theory, the best form of government was monarchy, and the next best was aristocracy. However, because monarchy and aristocracy frequently devolved into tyranny and oligarchy, respectively, in practice the best form was polity.(It is interesting to speculate whether he had one eye on Alexander and one eye on the Athenian boule.)

Natural Philosophy

Aristotle's natural philosophy (science) stressed biology, instead of mathematics like Plato. He believed the world was made up of individuals (substances) occurring in fixed natural kinds (species). Each individual had built-in patterns of development, which helped it grow toward becoming a fully developed individual of its kind.

Further, Aristotle divided the sciences into three kinds: productive, practical, and theoretical. The productive sciences included not only engineering and architecture, but also disciplines such as strategy and rhetoric. The practical sciences, most notably ethics and politics, were those that guided behaviour. The theoretical sciences—physics, mathematics, and theology—were those that had no product and no practical goal but in which information and understanding were sought for their own sake. There was also poetical science, which meant the study or practice of the fine arts, including poetry, but we shall not be concerned with that.

Finally, Aristotle cross-classified knowledge into three types, i.e. Episteme which meant scientific knowledge, Techne which meant knowledge of craft, and Phronesis which meant ethical knowledge.

Aristotle, unlike Plato, was an empiricist — that is, he described what he was seeing, rather than stating what he thought it should be.

It is impossible reflect his contributions in the different areas of science. Suffice it to say that Aristotle has been called "the father of logic", "the father of biology", "the father of political science", "the father of zoology", "the father of embryology", "the father of natural law", "the father of scientific method", "the father of rhetoric", "the father of psychology", "the father of realism", "the father of criticism", "the father of individualism", "the father of teleology", and "the father of meteorology".

1. Zoology and Marine Biology

We may look at the above as an example. While in Assus and during the subsequent few years lived on the island of Lesbos, Aristotle carried out extensive scientific research, particularly in zoology and marine biology. This work was summarized his book History of Animals to which he added two short treatises, On the Parts of Animals and On the Generation of Animals.

Although Aristotle did not claim to have founded the science of zoology, his detailed observations of a wide variety of organisms were quite without precedent. Some of the features of insects that he accurately reported were not again observed until the invention of the microscope in the 17th century.

The scope of Aristotle's scientific research was astonishing. Much of it was concerned with the classification of animals into genus and species. More than 500 species figured in his treatises, many of them described in detail. These included myriads of items about the anatomy, diet, habitat, modes of copulation, and reproductive systems of mammals, reptiles, fish, and insects, a melange of minute investigation. In some cases his unlikely stories about rare species of fish were proved accurate many centuries later. In other places he stated clearly and fairly a biological problem that took millennia to solve, such as the nature of embryonic development.

Despite an admixture of the fabulous, Aristotle's biological works must be regarded as a stupendous achievement. His inquiries were conducted in a scientific spirit, and he was always ready to confess ignorance (a Socratic virtue) where evidence was insufficient. Whenever there was a conflict between theory and observation, he trusted observation.

2. Cosmology

Round Model of Earth

Aristotle was possibly the first to propose a spherical Earth based on actual physical evidence. He listed several arguments for a spherical Earth: (1) ships disappeared hull first when they sailed over the horizon, (2) the Earth cast a round shadow on the moon during a lunar eclipse, and (3) different constellations were visible at different latitudes.

Aristotle however maintained that the Earth was the centre of the universe (the geocentric model), around which the sun, moon, and planets revolved in a circular motion. Because they seemed to float in air, they must be composed of some element lighter than earth but differing from water, air, or fire which he believed only related to the Earth. This other element he defined as "ether" which was changeless and perfect. These perfect heavenly spheres, owing to their nature, revolved in absolutely perfect circles at a constant speed.

Aristotle also speculated that each of them was endowed with a moving principle which sought to emulate and was governed by a central transcendent Unmoved Mover (see under God)

Aristotle's Legacy

Lyceum

Aristotle returned to Athens in 335 BC and established a school in one of the buildings of the Lyceum[33], lecturing there as well as writing most of his books and collecting books.

He established a Library in the Lyceum which helped him to produce many of his hundreds of books on papyrus scrolls. Though Aristotle wrote many elegant treatises and dialogues for publication, only around a third of his original output has survived.

Aristotle's surviving works amounted to about one million words, though they probably represent only about one-fifth of his total output. Aristotle had always been a book collector and the library grew with the books Alexander sent him.

Aristotle gathered around him a group of brilliant research students, called "Peripatetics", from the name of the cloister (peripatos) in which they walked and held their discussions. The Lyceum was not a private club like the Academy. Many of the lectures there were open to the general public and given free of charge.

Throughout his conquests of various regions, Alexander also collected plant and animal specimens for Aristotle's research, allowing Aristotle to develop the first museum, zoo and botanical gardens in existence. It is also suspected that Alexander donated what would be the equivalent of more than 4 million dollars to the Lyceum..

In 322 BCE, Aristotle was forced to flee Athens with his family when the political leadership reacted against the Macedonians again, and his previously published works supporting Macedonian rule left him a target. He passed on his Lyceum to Theophrastus, and died later that year in Chalcis, near his hometown.

Theophrastus headed the Lyceum for 36 years, between Aristotle's exile from Athens in 322 BC until his own death in 286 BC. The school was closed for a year (306 BC) when all foreign philosophers were required to leave Athens. It seemed to have gone into decline from about 300 BC, and to have more or less disintegrated sometime after 225 BC when its last certain scholar Lyco of Troas died and left the Lyceum not to one man but to all his colleagues. The Lyceum fell with the rest of Athens in 86 BC to the Romans.

The Library

Aristotle established a Library in the Lyceum which helped him to produce many of his hundreds of books on papyrus scrolls. Though Aristotle wrote many elegant treatises and dialogues for publication, only around a third of this output has survived

Aristotle's surviving works amounted to about one million words, though they probably represent only about one-fifth of his total output. Aristotle had always been a book collector

[33] The Lyceum was used at a location for philosophical discussion before Aristotle's school was founded there, among others by Socrates.

and the library grew with the books Alexander sent him. It was the first library of its kind in the western world.

Theophrastus ran the Lyceum for 36 years. He placed a provision in his will that left the Lyceum library to his supposed successor Neleus. The collection at that point included both his and Aristotle's work as well as students' research, philosophical historical texts and histories of philosophy, reportedly totalling some 10,000 rolls of papyrus.

Upon his retirement, Neleus divorced the Lyceum from its library and took all of the books with him to Skepsis in Mysia. At least some of the books were sold to the library in Alexandria. The library then disappeared for several centuries from record. They were bought from Neleus's heirs in the 1st century and returned to the Lyceum, which it appears had continued to operate.

The Lyceum was destroyed when Sulla conquered Athens in 86 BC. The library books were commandeered by the Roman commander and taken to Rome, where they were edited and published about 60 BC by Andronicus of Rhodes, the last head of the Lyceum.

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(C4) The Classical Astronomers

We may say that Pythagoras and Philolaus launched the fraternity of the Greek astronomers independently of the classical philosophers. These over-lapped with the classical greats, and merged with the mathematician-philosophers who followed, to form a continuous philosophic tradition into the Hellenic Age.

Once they disengaged themselves from their mythical heritage, they rationalised their metaphysical and empirical approaches. Their characteristic methods were empirical observation and mathematics, particularly geometry, with judicious deduction and reasoning to bridge the gaps. They could further be expected to meld with the knowledge and experience of the civilisations around, with whom they were increasingly in contact through the Ionian networks.

We narrate their contributions in this Section together, for greater coherence in viewing the development of astronomy. Needless to say, the Greeks would already have acquired all the necessary astronomical knowledge governing life on the planet, including the seasons, the cycles of the Sun and the Moon; and the planets. By the 5th century BC, they would have learnt much advanced information from neighbouring civilisations, including practical knowledge for navigation, etc. As we begin our story, they were conducting close observations of the heavens, and speculating whether the Earth was spherical and whether the universe was geocentric or heliocentric.

Meton of Athens

Meton, the son of Pausanias and a native of Athens, was a Greek mathematician, astronomer, geometer and engineer, who lived in Athens in the 5th century BC.

He studied astronomy with Phaeinus of Athens, who made astronomical observations from his observatory on Lycabettus Hill (432 BC).

Meton set up his observatory behind the Pnyx, Athens' historic venue of democracy, within site of the Parthenon, where also he constructed a solar clock (433 BC). He designed and built a number of waterworks, including the Colonos aqueduct.

Meton found the dates of the equinoxes and solstices by observing sunrise from his observatory. He was assisted in his work by his pupil Euctemon, and together they made observations of the position of the sun at the equinox in relation to visible topographical features.

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At that time, the Greek city-states used their own calendars, for different purposes. Athens had settled on the lunisolar Attic calendar, which incorporated the solar and lunar calendars with the supplementary lunar month. Meton's contribution was the lunar Meton cycle, which he introduced in 432 BC into the lunisolar Attic calendar.

The Metonic calendar incorporated knowledge that 19 solar years and 235 lunar months were very nearly of the same duration. Consequently, a given day of a lunar month will often occur on the same day of the solar year as it did 19 years previously.

Meton's cycle is still used to determine the date of Easter, since every 19 years the phases of the moon recur on the same days of the solar year.

One of the craters on the moon has been named "Meton" in his honour. None of his written work has survived.

Eudoxus of Cnidus

Eudoxus (408-355 BC) was born in Cnidus, on the Carian Chersonese, adjacent to Ionia. He was a mathematician, astronomer, philosopher, inventor, meteorologist, geographer, physician, rhetorician, and lawmaker.

Eudoxus has been considered the founder of mathematical astronomy. He was the first to introduce the concept of celestial bodies and explain their movement using a geometric model based on mathematic principles

Eudoxus studied mathematics with Archytas (Pythagoras' successor) in Sicily and at the age of 23 he enrolled in Plato's Academy, where he studied medicine. He travelled to Egypt where he was taught astronomy by the priests of Heliopolis and later founded the Eudoxian Observatory. He returned to Greece where he founded the School of Cyzicus and a school in Athens. On Plato's request he became a professor of sciences in Plato's Academy and taught there for most of his life, until he moved back to Cnidus and founded an observatory.

Eudoxus' work on mathematics was titanic. He was credited by Archimedes as the founder of the Archimedean Property or Eudoxian Theorem on the Axioms of Continuity, which today dominate in modern higher mathematics. The Eudoxus Axiom forms the basis of calculus, which was first discovered by Eudoxus and later developed by Newton and Leibnitz. The discovery of the Method of Exhaustion belonged to Eudoxus. With it he was able to calculate areas and volumes of geometrical shapes which were unknown at the time.
He developed the theory of irrational magnitudes and made important discoveries on the Theorem of the Golden Ratio. He was acknowledged as one of the greatest mathematicians of antiquity, second only to Archimedes and Apollonius of Perga.

He rose to Plato's challenge by assigning to each planet a set of concentric spheres. By tilting the axes of the spheres, and by assigning each a different period of revolution, he was able to approximate their celestial "appearances."

His Theory of the Homocentric Spheres interpreted the movement of the planets using complex geometric curves, an invention of Eudoxus that formed the basis of mathematical astronomy.

He created a planetary system consisting of rotating spheres depicting the 7 planets Mercury, Venus, Earth, Mars, Zeus, Saturn, the Moon and the Sun. In addition, Eudoxus included a sphere for the fixed stars, giving a total of 27 spheres. Thus, he was the first to attempt a mathematical description of the motions of the planets

His geocentric planetary system achieved considerable acclaim, was accepted by Aristotle and by the scientific community, and was later perfected by his student Calippus.

With his observations of the star sky, he described the constellations, their position, the dates when the stars were visible, and the weather associated with each of their phases. Moreover, he researched the sizes of the Sun, the Moon and the Earth, and introduced the eight-year cycle calendar with 365 days of the year, which was adopted by Julius Cesar later.

Since all his own works are lost, our knowledge of Eudoxus is obtained from secondary sources. Among them, a general idea of the content of On Speeds, his book on the planets, can be gleaned from Aristotle’s Metaphysics, and a commentary by Simplicius on his De Caelo. Aristotle described both systems, but insisted on adding "unrolling" spheres between each set of spheres to cancel the motions of the outer set; without unrollers, the outer motions would be transferred to the inner planets.

Callippus of Cyzicus

Callippus (370-300 BC) was a Greek philosopher ,born in Cyzicus, an Ionian colony at the Sea of Mamara going back to 756 BC. He studied under Eudoxus of Cnidus at the Academy of Plato. He also worked with Aristotle at the Lyceum, which meant that he was active in Athens prior to Aristotle's death in 322 BC.

He observed the movements of the planets using Eudoxus' scheme of connected spheres. However, he found that 27 spheres was insufficient to account for the planetary movements, and so he added seven more for a total of 34. According to the description in Aristotle's Metaphysics, he added two spheres for the Sun, two for the Moon, and one each for Mercury, Venus, and Mars.

Callippus made careful measurements of the lengths of the seasons, finding them to be 94 days, 92 days, 89 days, and 90 days. This variation in the seasons implied a variation in the speed of the Sun, called the "solar anomaly".

Callippus expanded on the work of Meton, proposing what is now called the Callippic Cycle which runs for 76 years, or four Metonic cycles. Callippus refined the lunisolar calendar, deducting one day from the fourth Metonic cycle in each Callippic cycle, so as to better keep the lunisolar calendar synchronised with the seasons of the solar year.

One of the craters on the Moon has been named "Callippus" in his honour.

Heraclides Ponticus

Heraclides Ponticus (390-322 BC) was a philosopher and astronomer from Heraclea Pontica, Bithynia, Black Sea, a Greek colony going back to 560 BC.

He studied in the Academy of Athens where he became one of Plato’s students and briefly in charge of it when Plato went to Sicily. He was later a student of Aristotle in the Lyceum. In the Academy he befriended Speusippus, the successor headmaster of the school, and was defeated upon the latter’s death as a candidate for the post in 339 BC. He returned to Heraclea where he founded his own philosophic school.

Heraclides possessed profound knowledge on Pythagorean philosophy and was a proponent of Democritus' theory of the atom. Heraclides was active primarily in astronomy.

Heraclides is best remembered for being the first to propose that the Earth rotated on its axis, from west to east, once every 24 hours. He is also hailed as the originator of the heliocentric theory, although this is doubted by some.

He proposed the mixed helio-geocentric model of the cosmos according to which the sun, the moon and the planets of the solar system rotated around the Earth, except from Venus and Mercury, which orbited the Sun.. He was also the first philosopher to hold such a belief.

Heraclides was a prolific writer. Like most of his contemporaries, he wrote a book On Nature, a treatise on physics. Furthermore, he wrote the philosophical books On the Pythagoreans, On Hades and on Uranus, On Findings and Zoroaster, books on the philosophy of physics, literary critiques, books on mysticism and books on theurgy or medicine. As a Platonic philosopher, Heraclides endorsed the concept of the immortality of the soul as well as reincarnation. According to him, the soul was made of light and aether.

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Chapter Three
Hellenic Greece

(A) Ancient Macedonia

Prefatory Note:

I had always wanted to know how in some detail this most remarkable segment of history:

. – How Phillip II, the king of the small "country cousin" kingdom of Macedonia, from about 353 BC, conquered all the city states of Greece, uniting them for the first and only time in their history under his command in the League of Corinth; and how he proceeded to build the mightiest fighting army of his time to conquer the Persian Empire; in a decade and a half;

. – How Alexander The Great, his son, upon Philip's assassination in 336 BC, led the same army to conquer the Persian Empire (including Babylon) and much of the rest of known world from Egypt to the Indus valley, setting up the greatest empire of his time by 323 BC, before his sudden death, all in a little less than a decade and a half; and

. – How, partitioned into four, this empire continued for almost the next three hundred years to stamp its identify and influence on the world (and astronomy) as Hellenic Greece.

I have captured the second part, the story of Alexander The Great, earlier in the historical component covering Mesopotamia - where it is most in context in relation to Babylon. This Chapter covers the third part further on.

This section covers the first part, on Phillip II. It is an intricate and absorbing story of diplomacy, intrigues, marriage alliances, assassinations and wars. I make no apology for recording my notes fairly extensively, both for my own satisfaction and because it is difficult to summarise it further. Those who prefer may with this prefatory note proceed straight to the section on the Hellenic Age – but I do recommend you read this section.

Historic Macedonia

Macedonia occupied the north-western corner-coastline of the Greek peninsula and Aegean Sea. The original) Macedonia was situated in the river valleys north of Mount Olympus in the central Greek mainland. It was established In the 7th century BC by peoples of Greek origin migrating north-eastwards along the mainland, with their capital at Aigai (Vergina). They expanded, mainly after the 4th century BC, into Upper Macedonia, inhabited by other Greek tribes and peoples from the neighbouring regions of Thrace and Illyria, and Paeonia.

Hesiod mentions Makednos as the mythical founder of Macedonia. Like Sparta, they developed on the kingship model. Their first king (possibly fictional) was Karanos (808-778 BC). Perdiccas I (700- 678 BC) is recognised as the founder of the Argead dynasty, that would reign unbroken until Alexander IV (323-310 BC.

Macedonia was made a vassal state by Cyrus the Great as part of Persian Asia Minor, from 547 to 498 BC, when it was interrupted by the Ionian Revolt. It was fully re-subordinated to

Persia from 492 – 479 BC , when it was liberated by the Greek Alliance. In the first Greco-Persian war, Macedonian troops fought on the Persian side.

The Macedonians originally spoke a variant of the original Greek language. However, by the inter-mixing in the 5th century onwards, they had acquired the contemporary Greek language, forms of literacy and culture.

They were however conscious of being the "country cousins" and not so cultured, indeed considered somewhat "barbaric" by the southern Athenians and Thebans, etc. They were aware of their record of being a conquered people under the Persians for long periods, as compared with the Greeks' record of victories in the Greco-Persian Wars and after. All this would engender the desire to emulate and square up with, if not out-do, both the Greeks and the Persians. As it was, the Macedonians had not yet put their house in order due to rivalries. And they had yet to deal with their northern neighbours' incursions and invasions.

On the other hand, the Macedonian king wielded absolute power and commanded all state resources, such as gold and silver. Macedonian rulers also assumed roles as high priests and patrons of religious cults. Their authority was theoretically limited only by the institution of the army. Some municipalities (cities) enjoyed a high degree of autonomy, with democratic governments and popular assemblies. They were poised for a strong man.

Phillip II, King of Macedonia

Ascension to Power

Philip II of Macedon (382–336 BC) was the King (Basileus) of the ancient Kingdom of Macedonia from 359 BC until his death. He was a member of the Argead dynasty, founders of the ancient kingdom, and the father of Alexander the Great.

Philip was himself the youngest of the three sons of King Amyntas III (392-370 BC), who was succeeded on demise by his eldest son, Alexander II (370-368 BC).

When Alexander II was away at war in Thessaly, Ptolemy of Aloros, reportedly brother of his mother (Eurydice), rose up as an usurper, and one report had it that he secured Philip as a hostage and sent him to be held in Illyricum. Another account relates that one Pelopidas[34], who was called into mediate and took with him to Thebes several hostages, among them Phillip.

Alexander II was assassinated after two years in 368 BC by Ptolemy of Aloros. He was in turn succeeded by his second brother (aged 18) as Perdiccas III, (386-368 BC) with Ptolemy of Aloros as regent. In 364 BC, on reaching his majority, Perdiccas III assassinated Ptolemy and took over.

On his own demise in 359 BC, he was succeeded by his infant son, as Amytas IV. Before his death, the king had appointed his youngest brother, Phillip, as regent. Phillip had the young king killed in short order took over as Phillip II.

Under the reign of Phillip II (359–336 BC), the Kingdom of Macedonia, initially at the periphery of classical Greek affairs, came to dominate ancient Greece in the span of 25 years, largely thanks to the personality and policies of its king.

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[34] Pelopidas was an important Theban statesman and general in Greece, instrumental in establishing the mid-fourth century Theban hegemony.

Greek Education and Training

While in Thebes, Philip was placed as hostage in the care of Pammenes[35] by Epaminondas[36], and received a military and diplomatic education from the latter. He lived with Pammenes who was an enthusiastic advocate of the Sacred Band of Thieves[37]. It is reported that he may have been a male-lover of Pammenes.

After eight years, He returned to Macedonia in 364 BC fully steep in the understanding of Greek ways, their civil, cult and league discords, and in the very latest in Greek military politics, military thinking and military practices.

He also saw clearly Macedonia's route to the subjugation of Greece, and the long sought-for revenge conquest of the Achaemenid empire for their years of subjugation.

Macedonian Army[38]

Phillip II now understood that the balance of power lay in having the best possible army. Previously Macedonia had been regarded as a second-rate power. The latest innovations in weapons and tactics were adopted and refined by Philip II.

By introducing military service as a full-time occupation, Philip was able to drill his men regularly, ensuring unity and cohesion in his ranks..

Tactical improvements included the latest developments in the deployment of the traditional Greek phalanx, such as made by men like Epaminondas of Thebes and Iphicrates[39] of Athens. Philip II improved on these military innovators by using both Epaminondas' deeper phalanx and Iphicrates' combination of a longer spear and smaller and lighter shield.

The Macedonian king also innovated; he introduced the use of a much longer spear, the two-handed pike. The Macedonian pike, the sarrisa, gave its wielder many advantages both offensively and defensively. For the first time in Greek world, cavalry became a decisive arm in battle.

The Macedonian army perfected the co-ordination of different troop types, an early example of combined arms tactics — the heavy infantry phalanx, skirmish infantry, archers, light cavalry, heavy cavalry, and siege instruments, each troop type being used to its own particular advantage in mutual support.

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[35] .Pammenes was a Theban general of considerable fame who lived during the 4th century BC . In a remarkably short time, he created one of the finest military machines of the ancient world. He was connected with Epaminondas by political ties and ties of friendship. When Philip, the future king of Macedonia was sent as a hostage to Thebes, he was placed under the care of Pammenes.

36 Epaminondas (419–362 BC) was a top general and statesman of Thebes of the 4th century. who transformed that city-state, leading it out of Spartan subjugation into a pre-eminent position in Greek politics called the Theban Hegemony.

[37] The **Sacred Band of Thebes** was a troop of select soldiers, consisting of 150 pairs of male lovers who formed the elite force of the Theban army in the 4th century BC.

[38] I quote substantially from this source. https://en.wikipedia.org/wiki/Ancient_Macedonian_army.

[39] Iphicrates (418 BC – c. 353 BC) was an Athenian general, who flourished in the earlier half of the 4th century BC. He is credited with important infantry reforms that revolutionised ancient Greek warfare by regularising light-armed peltasts.

The new Macedonian army was an amalgamation of different forces. Macedonians and other Greeks (especially Thessalian cavalry) and a wide range of mercenaries from across the Aegean and Balkans were employed by Phillip. By 338 BC, more than a half of the army for his planned invasion of the Achaemenid empire came from outside the borders of Macedon.

After Philip's death, his successor, Alexander the Great, led the army to conquer the world.

Frontier Stability

One of Philip's primary aims was to secure Macedon's eastern flank, which bordered Thrace. One such objective was the independent city-state of Amphipolis. One of his first steps as to capture it in 357 BC. Originally colonised by the Athenians in 437 BC, Amphipolis was a major strategic point where it controlled the only crossing point on the lower reaches of the border river, and therefore access to and from Thrace. Eastwards expansion of his kingdom required that Philip control Amphipolis. Amphipolis was close to forests needed for shipbuilding, and controlled the gold and silver mines of Mount Pangaion. Phillip used this gambit to run a decade of war of attrition and negotiation against Athens, weakening their hold of their upper Aegean and Hellespont settlements and allies, while critically denying them their immediate naval vital resources. In the same way, the Thracian Chersonese, which controlled the Dardanelles, became the focus of a bitter territorial dispute between Athens and Phillip who sought possession. It was eventually ceded to him in 338 BC. He was also allied to the other major Greek power in the region, the Chalcidian League.

Much of Philip's expansion was at the nominal expense of the Athenians, who considered the north Aegean coast as their sphere of influence, and Philip was at war with Athens from 357–346 BC

Philip II was equally preoccupied by wars with his marauding neighbouring Illyrians and Thracians. In a series of campaigns stretching from 356 to 340 BC, Philip II managed to subjugate them. His prime objective was the conquest of Greece.

Conquest of Greece

Third Sacred War

Thessaly

The Third[40] Sacred War (356–346 BC) was fought among the forces of Delphic Amphitryonic League principally represented by Thebes on one side and the Phocians on the other, and the Thessaly League mainly remaining with Thebes. The war was caused by a large fine imposed in 357 BC on the Phocians for the offense of cultivating sacred land. Refusing to pay; the Phocians instead seized the Temple of Apollo and used its accumulated treasures to fund large mercenary armies. Thus, they were able to continue the war for many years, until eventually all parties were nearing exhaustion. The Thessalonians eventually called on Phillip II for help.

When Philip answered the call for help, he became fully engaged on the Theban side of the Third Sacred War. His interventions eventually resulted in the defeat of Phocis at the Battle of Crocus Field in 352 BC and the Thessalian defectors around 353 BCE and he was elected

[40] The First and Second Sacred Wars were fought earlier among Amphictyonic League members and do not concern us here. (The Delphic Amphictyony, or the Great Amphictyonic League as it was was set up in about 1100 BC and consisted of all the Greek tribes that surrounded the oracle of Delphi)

president (archon) of the Thessalian League. Being entrusted with this position for life, Philip got control of the levies and revenues of the Thessalian Confederation and was able to unite the resources and manpower of both Macedonia and Thessaly in order to create a powerful alliance that gave him tremendous influence over the Greek city-states. However, Philip did not intervene further in the Sacred War until 346 BC

Most importantly, this invitation opened the door for Phillip's forces to enter (in effect take over) Thessaly, and he would proceed to establish Macedonian garrisons as necessary, as he encroached on other Greek territory. He used effective diplomacy and marriage alliances[41] and founded new cities to keep his allies and frontiers stable.

Phocis

Early in 346 BC, the Thebans, who had borne the brunt of the Sacred War, together with the Thessalians, asked Philip to assume the "leadership of Greece" and join them in fighting the Phocians. Philip's power was by now so great that ultimately the Phocians did not even attempt to resist, and instead surrendered to him. Philip was thus able to end a particularly bloody war without any further fighting.

Philip allowed the Amphitryonic council the formal responsibility of punishing the Phocians, but ensured that the terms were not overly harsh. Nevertheless, the Phocians were expelled from the League, all their cities were destroyed, and they were resettled in villages of no more than fifty houses. No doubt Phillip established more garrisons.

Thebes and Fall of Sparta

Thebes had rivalled Argolis as a centre of Mycenaean power until its palace and walls were destroyed shortly before the Trojan War (1200 BC). Immigration produced a mixed Boeotian stock, and an oligarchy of large estates regulated by laws passed about 725 BC. In the 6th century a league of Boeotian cities was formed; it was dominated by Thebes from the 5th century. Hostility to Athens (their neighbours) led in the 5th century to Theban collaboration with Sparta in the Peloponnesian War. A Theban suggestion at the end of the latter (404 BC) that the Spartans annihilate the Athenians was rebuffed. The latter had been defused as a major power by the war, but helped keep Thebans in check..

In 395 BC, Thebes instigated an attack on Sparta that would lead to the Corinthian War, in which Sparta would face a coalition of Thebes, Corinth and Argos, backed by Persia, and this time also with Athens. However, Persia emerged the dominant victorious party. In their King's Peace, (387 BC), Spartan was designated the head Greek city-state , while all the others were guaranteed their independence by the Persian King.

Persian peace enforcement was non- existent. The two powers clashed again, and Sparta, winning, disbanded the Boeotian League (386 BC) and occupied Cadmea (382 BC). Thebes joined the Athenian Second League against Sparta in 377BC, but left in 371 BC.

Revolting after 379 BC, Thebes reorganised the Boeotian League and defeated Sparta at Tegyra (375 BC) and Leuctra (371 BC).

For the next 10 years Thebes was the first military power in Greece. Its commander Epaminondas invaded the Sparta and the Peloponnese (370–362 BC) and, notwithstanding that Thebes was victorious, he died at the Battle of Mantineia (362 BC).

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[41] Phillip II had eight wives, from Illyria, Thrace (2), Thessaly (2), Epirus (Olympia, mother of Alexander the Great), and Macedonia (2)

Epaminondas's death marked a rapid decline in Thebes' capability. With Phillip's friend and mentor gone, Thebes would confront Macedonia twice again, at the Battle of Chaeronea (338 BC) and the Battle of Thebes (335 BC) and be destroyed (see further on).

Athens

Athens had formed a Second Athenian League against Sparta in 377 BC, without the naval resources to achieve their former clout. They ended up in a Social War among members, between 357 and 355 BC, further weakening themselves.

Athens was still a significant naval power, whilst Macedon had no real navy to speak of. Conversely, Macedon had a very powerful army, especially with the addition of the Thessalians after 352 BC, which Athens could not hope to match. The Athenians could therefore prevent Philip attacking Athens by sea, but not by land—unless they could occupy Thermopylae in time. This pass between Phocis and Boeotia was the gateway to central and south Greece - and Athens. Unfortunately, the Phocis did not agree to co-operate, preferring to negotiate terms with Phillip.

Peace of Philocrates

By 346 BC, the Athenians were war-weary, unable to match Philip's strength, and had begun to contemplate the necessity of making peace. Thus, while poised to launch a direct assault on Athens in 346 BC, the Macedonian king was met with an Athenian embassy that arranged the Peace of Philocrates. As a result, Macedonia and Athens became allies, yet Athens was forced to relinquish its claims to Amphipolis.

Member of Amphitryonic Council,

With Phocis negotiating terms of settlement on one side and the Athenians terms of peace concluded on the other, Philip applied the coup de grace by occupying Thermopylae, and by garrisoning the closest town to Thermopylae, Nicaea, with Thessalian troops.
Finally, he settled the peace arrangements with the parties engaged in the Third Sacred War (of which he was the principal now) – with the Athenian peace delegation all present together. Basically, he let the council deal the terms for Phocis, mediating for moderation.

In return for ending the war, Macedon was made a member of the Amphitryonic council, and given the two votes which had been stripped from Phocis. This was an important moment for Philip, since membership of the Amphictyony meant that Macedon was now no longer a 'barbarian' state in Greek eyes.

Philip presided over the Amphitryonic festival in the autumn, and then, much to the surprise of the Greeks, he went back to Macedon and did not return to Greece for seven years.

Philip returned to Macedon, not only having gained a reputation for piety and superb generalship, but also having made considerable preparations for the increase of power that was destined to be his. For he wished to be appointed the commander-in-chief of Greece and to wage war against the Persians.

Coming to a separate peace with Athens was a bonus. Philip was, through his membership of the Amphitryonic council, now legitimised as a "true" Greek; and by the prestige he had gained for his pious conduct on behalf of Apollo, and by his military strength, he was now the de facto leader of the Greek city-states.

There has been much debate amongst historians about Philip's motives and aims in 346 BC, with particular regard to Athens. Even when in possession of Thermopylae, he made no hostile moves towards Athens, and still prevented any punishment being meted on Athens by the Amphitryonic council. Why was Philip so lenient towards Athens? It is suggested that Philip was already beginning to contemplate the campaign against Persia in 346 BC, for which purpose he desired the use of the powerful Athenian navy; hence his request for alliance, and his on-going patience with Athens. This may also provide another explanation for Philip's use of the Amphitryonic council to formally settle the Sacred War; if he was to campaign in Asia, he needed Greece to be peaceful, and a peace imposed through a pan-Greek organisation was more likely to succeed than one directly imposed by Macedon.

The Peace of Philocrates eventually broke down as hostilities reignited between Athens and Macedonia. Demosthenes, an Athenian statesman who was partially responsible for engineering the peace treaty encouraged his fellow Athenians to oppose Philip.

Breakdown of the Peace

Philip's continually improving financial situation had allowed him to start building a navy by 342 BC, something that did not pass undetected in Athens. Philip's new navy had occupied the small island of Halonesus in the northern Aegean after expelling the pirates who had seized the island, which Athens disputed.

In 341 BC, Athens sent out new settlers to the Thracian Chersonese who proceeded to ravage the territory of Cardia, an ally of Philip.

Finally, Athens sent an embassy to the Persian king, requesting money for a forthcoming war with Macedon, much to Philip's anger, but was sharply rebuffed by the Persians.

Fourth Sacred War

Philip's campaign in Greece became linked with a new, fourth, Sacred War. The citizens of Amphissa in Ozolian-Locris (next to Phocis) had begun cultivating land sacred to Apollo south of Delphi, and the Amphitryonic council decided to declare sacred war. A Thessalian delegate proposed that Philip should be made leader of the council forces, which gave him the pretext to campaign further in Greece.

Philip arrived in Phocis in November 339 BC. Philip's relatively lenient treatment of the Phocians in 346 BC now bore fruit. He ordered Elatea, their main city, to be re-populated and the whole Phocis confederation restored. This provided Philip with a base in Greece, and new, grateful allies in the Phocians.

The decisive phase of the campaign did not occur until August 338 BC. During this period Philip settled the situation in Amphissa. He took Amphissa and expelled its citizens, turning it over to Delphi. He probably also engaged in diplomatic attempts to try to avoid further conflict in Greece, although if so, he was unsuccessful. The Amphictyony council decided to hold a special session two or three months later. The Athenians and the Thebans did not send envoys.

At the start of the 339 BC, the Thebans had seized the town of Nicaea near Thermopylae, which Philip had garrisoned in 346 BC. It presented him with a significant problem, blocking the main route into Greece. However, a second route into central Greece was available. The Greeks had either forgotten the existence of this road, or believed that Philip would not use it; the subsequent failure to guard this road allowed Philip to slip into central Greece unhindered.

The Battle of Chaeronea

When news first arrived that Philip was in Elatea, just three days march away, there was panic in Athens. Demosthenes counselled that the Athenians should seek an alliance with the Thebans. Philip had also sent an embassy to Thebes, requesting that the Thebans join him, or at least allow him to pass through Boeotia unhindered. Since the Thebans were still not formally at war with Philip, they could have avoided the conflict altogether. However, in spite of Philip's proximity, and their traditional enmity with Athens, they chose to ally with the Athenians, in the cause of liberty for Greece. The Athenian army had already pre-emptively been sent in the direction of Boeotia, and was therefore able to join the Thebans within days of the alliance being agreed.

Thus, history approached the final showdown at the Battle of Chaeronea, located between Phocis and Boeotia, fought in August 338 BC between an alliance of central and southern Greek city states, led by Thebes and Athens, and Phillip of Macedonia.

The allied Greek army included contingents from Achaea, Megara, Corinth, Chalcis, Epidaurus, Troezen, with the majority of troops being supplied by Athens and Thebes, thus making it an army of allied cities of southern Greece, that had been traditionally self-governed for centuries.

Philip took command of the right wing of the Macedonian wing and placed his 18-year-old son Alexander in command of the left wing, accompanied by a group of Philip's experienced generals.

The modern view is that the allied Greek numbers were approximately equal to those of the Macedonians, who numbered roughly 30,000 infantry and 2,000 cavalry.

There were certainly some preliminary skirmishes; Demosthenes alludes to a "winter battle" and "battle on the river" in his speeches, but no other details are preserved. Finally, in August 338 BC, Philip's army marched straight down the main road from Phocis to Boeotia, to assault the allied Greek army defending the road at Chaeronea.

Details of the battle itself are scarce. Young Alexander, "his heart set on showing his father his prowess" (so a commentator says) succeeding in rupturing the allied Greek line aided by his companions, and eventually put the allied Greek right wing to flight; meanwhile, Philip advanced in person against the allied Greek left and also put it to flight. Some modern historians propose the following synthesis of the battle. After the general engagement had been in progress for some time, Philip had his army perform a wheeling manoeuvre, with the right wing withdrawing, and the whole line pivoting around its centre. At the same time, wheeling forward, the Macedonian left wing attacked the Thebans on the allied Greek right and punched a hole in the allied Greek line. On the allied Greek left, the Athenians followed Philip, their line becoming stretched and became disordered; the Macedonians then turned, attacked and routed the tired and inexperienced Athenians. The allied Greek right wing, under the assault of the Macedonian troops under Alexander's command, then were also routed, ending the battle. More than 1000 Athenians died in the battle, with another 2000 taken prisoner, and that the Thebans fared similarly.

This was one of the most decisive battles in ancient history; since there was now no army which could prevent Philip's advance, the war effectively ended.

Aftermath

Philip had no intention of besieging any city, nor indeed of conquering Greece. He wanted the rest of the Greeks as his allies for his planned campaign against the Persians, and he wanted to leave a stable Greece in his rear when he went on campaign; further fighting was therefore contrary to his aims.

Philip marched first to Thebes, which surrendered to him; he expelled the Theban leaders who had opposed him, recalled those pro-Macedonian Thebans who had previously been exiled, and installed a Macedonian garrison. He also ordered that the Boeotian cities which Thebes had destroyed in previous conflicts, be re-founded. Generally, Philip treated the Thebans severely, making them pay for the return of their prisoners, and even to bury their dead. He did not, however, dissolve the Boeotian confederacy.

By contrast, Philip treated Athens very leniently indeed; although the Second Athenian League was dissolved, the Athenians were allowed to keep their colony on Samos and their prisoners were freed without ransom. He needed to remain on good terms with the Athenians.

Philip also made peace with the other combatants, Corinth and Chalcis, which controlled important strategic locations; both received Macedonian garrisons.

He then turned to deal with Sparta, which had not taken part in the conflict, but was likely to take advantage of the weakened state of the other Greek cities to try to attack its neighbours in the Peloponnese. The Spartans refused Philip's invitation to engage in discussions, so Philip ravaged Lacedaemonia, but did not attack Sparta itself.

League of Corinth

Philip moved around Greece in the months after the battle, making peace with the states that opposed him, dealing with the Spartans, and installing garrisons; his movements also probably served as a demonstration of force to the other cities, lest they oppose him.

Phillip camped near Corinth, and began the work to establish a league of the Greek city-states, which would guarantee peace in Greece, and provide Philip with military assistance against Persia. The result, the League of Corinth, was formed in the latter half of 337 BC at a congress organised by Philip. All states signed up to the league, with the exception of Sparta.

The principal terms of the concord were that all members became allied to each other, and to Macedon, and that all members were guaranteed freedom from attack, freedom of navigation, and freedom from interference in internal affairs. Philip, and the Macedonian garrisons installed in Greece, would act as the 'keepers of the peace'. At Philip's behest, the League declared war on Persia, and voted Philip as Strategos for the forthcoming campaign.

An advance Macedonian force was sent to Persia in early 336 BC, with Philip due to follow later in the year. However, Philip was assassinated before he could begin the campaign, a task that instead fell to his son and successor, Alexander the Great.

At his death, many Greek cities rejoiced and some rose up to expel, or attempt to expel, their Macedonian garrisons. This revolt resulted in an invasion of the plain of Peneus by Alexander. Faced with the Macedonian army suddenly appearing behind them, and having had little time to organise any resistance, the League surrendered and elected Alexander archon in his father’s place

After a massacre and almost total destruction in a fruitless uprising (336 BC) against his successor Alexander the Great, Thebes was finally subdued.

Accession of Alexander

Alexander began his reign by having his potential rivals to the throne murdered. He had his cousin, the former Amytas IV, executed, as well as two Macedonian princes. Olympias had Cleopatra Eurydice and her daughter by Philip, Europa, burned alive. Alexander spared the life of his half-brother Arrhidaeus, who was by all accounts somewhat mentally disabled, possibly as a result of poisoning by Olympias.

Confirmation as Hegemon

News of Philip's death roused many states into revolt, including Thebes, Athens, Thessaly, and the Thracian tribes to the north of Macedon. When news of the revolts in Greece reached Alexander, he responded quickly. Though his advisors advised him to use diplomacy, Alexander mustered the Macedonian cavalry of 3,000 men and rode towards Thessaly, Macedon's neighbour to the south. When he found the Thessalian army occupying the pass between Mount Olympus and Mount Ossa, he had the men ride over Mount Ossa. When the Thessalians awoke the next day, they found Alexander in their rear, and promptly surrendered, adding their cavalry to Alexander's force, as he rode down towards the Peloponnesus.

Alexander stopped at Thermopylae, where he was recognised as the leader of the Amphitryonic League, before heading south to Corinth. Athens sued for peace and Alexander received the envoy and pardoned anyone involved with the uprising. At Corinth, he was given the title Hegemon, and like Philip, appointed commander of the forthcoming war against Persia.

The organisation was the first time in history that the Greek city-states (with the notable exception of Sparta (which would join only later under Alexander's terms) would unify under a single political entity.

The League was governed by the hegemon in a military context, and the council and the judges otherwise.. The League maintained an army levied from member states in proportion to their size, while Philip established “Hellenic garrisons” in Corinth, Thebes and Pydna (in Macedonia).

Destruction of Thebes

After having been made Hegemon of the League of Corinth, Alexander had marched to the north to deal with revolts in Illyria and Thrace. The garrison in Macedonia was weakened and Thebes declared its independence.

The decision for the destruction of Thebes as transgressor of the oath was taken by the council of the League of Corinth by a large majority. Beyond the violation of the oath, the council judged that the Thebans were thus finally punished for their betrayal of the Greeks during the Persian Wars.

The Thebans refused to submit on merciful terms. The Battle of Thebes was a battle that took place between Alexander and the Greek city state of Thebes in 335 BC immediately outside of and in the city proper. Alexander assaulted the city, razed it to the ground, and sold all the survivors into slavery.

With the destruction of Thebes, mainland Greece again acquiesced in Alexander's rule. Alexander was now finally free to undertake the Persian campaign which had been planned for so long by his father.

The Greek contribution of soldiers to Alexander's Asian campaign was neither significant nor dependable, and the league's major action seems to have been the condemnation of the Thebans to slavery and the distribution of their territory among neighbouring states following their revolts (336 and 335 BC).

Subjugation of Sparta

Alexander launched the Persian campaign in 334 BC. In the autumn of 333 BC, the Spartan King Agis III had met with the Persian commanders in the Aegean Sea with plans for a war against Alexander - in Greece. The Persians agreed to provide limited support. Agis also recruited the Greek mercenary survivors who had served in the Persian army – a force of 8,000 veterans.

In the summer of 331 BC, Agis defeated the Macedonian general in command of the Peloponnese and the Corinth garrison. Agis asked for help from the Peloponnesians and Athens, though Athens refused to help the Spartans.

Antipater, Alexander's regent in Macedonia, after resolving a rebellion in Thrace, marched against Agis. Antipater had recruited a large force, over 40,000 strong, with a core of Macedonian troops and substantial numbers of tribal warriors from the northern fringes of Macedonia, reinforced with troops from his Greek allies. Antipater received aid from Alexander of 3,000 talents to support the Lacedaemonian (Spartan) War.

The final battle, fought near Megapolis in Arcadia, ended in defeat for the Spartans. In the end it was the sheer weight of numbers that brought victory to the Macedonians. It is written that 5,300 died on the Spartan side, though it may have been as little as 1,000 for the Macedonians, For the Spartans that meant a death toll of over 25 percent.

After the battle, Antipater left it to the Peloponnesians to organise their own peace terms The Spartans were forced to send ambassadors to Alexander.

Sparta appealed to Alexander for terms, to which he agreed on condition that the Lacedaemonians now joined the League of Corinth.

During the Asiatic campaign, Antipater was appointed deputy hegemon of the League while Alexander personally recommended that the Athenians turn their attention to things; in case something happened to him, Athens would take over the power in Greece.

The league broke up after Alexander's death (323 BC).

Empire of Alexander The Great

The empire of Alexander The Great stretched from the Balkans to the Indus, and lasted form 334 to 323 BC, when he died in Babylon. He launched the Hellenic age.

The setting up the Hellenic empires have been described earlier as part of the post-Babylonic coverage, for the greater continuity at that point.

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(B) The Hellenic Age

Hellenic Kingdoms

Macedonian unity collapsed after the death of Alexander The Great, and after four “Successors Wars” among his generals and their families lasting two decades (the Diadochi Wars) the Hellenic world settled into four stable power blocs by the beginning of the third century BC (300 BC):

.(1) - the Ptolemaic Kingdom of Egypt ,
.(2) - the Seleucid Empire in the Middle East,
.(3) - the Kingdom of Pergamon in Asia Minor, and
.(4) - the Kingdom of Macedonia, (including Greece)

Territorially, Hellenic Greece extended across the above, briefly unified by the conquests of Alexander the Great. Although these dynasties were not politically united afterwards, they did share a great deal in common. It is these commonalities, their essential “Greek-ness”, that historians refer to when they talk about the Hellenic or Hellenistic Age.

The situation was far from static. In the east, Seleucid empire would cede the Indus back to the Indian Mauryan empire, and soon be invaded by the Parthians, who from 141 BC would conquer Persis, Mesopotamia, Ctesiphon, down to Armenia. By 63 BC the empire was essentially left with Syria and bits of the Levant, with the jewel of its capital Antioch. In the west, apart from constantly warring among themselves, Pergamon and Macedonia (the latter included Greece) would be progressively encroached by the growing Roman empire, see further on. Only Ptolemic Egypt remained stable, and grew the most prosperous and illustrious, with Alexandria dominating the Hellenic world.

The Hellenic states were ruled absolutely by kings. (By contrast, the classical Greek city-states, or polis, reverted to being governed democratically by their citizens.) These kings had a cosmopolitan view of the world, and were particularly interested in amassing as many of its riches as they could. As a result, they cultivated commercial relationships throughout the Hellenistic world. They imported ivory, gold, ebony, pearls, cotton, spices and sugar (for medicine) from India; furs and iron from the Far East; wine from Syria and Chios; papyrus, linen and glass from Alexandria; olive oil from Athens; dates and prunes from Babylon and Damascus; silver from Spain; copper from Cyprus; and tin from as far north as Cornwall and Brittany.

They also put their wealth on display for all to see, building elaborate palaces and commissioning art, sculptures and extravagant jewellery. They made huge donations to museums and zoos and they sponsored libraries (the famous libraries at Alexandria and Pergamum, for instance) and universities.

Hellenic Culture

The Hellenistic period was characterised by Greek colonisation which eventually established Greek cities in their newly conquered empire. This resulted in the export of Greek culture and language to these new realms, spanning as far as modern-day India. These new domains were also influenced by the indigenous cultures, adopting local practices. This mixture gave rise to a common Attic-based Greek dialect, known as Koine Greek, which became the lingua franca throughout the Hellenic world.

During the Hellenic period the importance of Greece proper declined sharply. The great centres of culture were now Alexander and Antioch, capitals of Ptolemaic Egypt and Seleucid Syria. The conquests of Alexander greatly widened the horizons of the Greek world, making the endless earlier conflicts between the city-states seem petty and unimportant. It led to a steady emigration, particularly of the young and ambitious, to the new Hellenic world.

The Hellenic age saw a dissociation from traditional religion. The rise of philosophy and the sciences had removed the gods from many of their traditional domains. While there was a substantial decline in religiosity, this was mostly reserved for the educated classes.

There was a general unbuckling of the intelligentsia from traditional norms and values. This led to a whole host of quasi philosophies, attitudes of individualism and practices. The sophists advocated agnosticism and the centrality of humanity nature. The epicureans eschewed the principles of the Greek polis (democracy), and advocated instead atomism and hedonism. The sceptics rejected everything.

In the century after his death (490 BC), the Pythagorean community at Croton evolved into two streams: (1) the *akousmatikoi* (the esoterics) and the *mathmatikoi* (the scientific).

The first group became ritualistic, rule bound, concerned with interpretation of the master's saying, and mendicant. With the ascetic Apollonius of Tyana, about the middle of the 1st century , a distinct Neo-Pythagorean trend appeared of the ideal of a Pythagorean life—of occult wisdom, purity, universal tolerance, and approximation to the divine. Th sage felt himself to be a reincarnation of Pythagoras. They all blended well into the liberal Hellenic world.

The second group were concerned with the scientific aspects of Pythagoreanism. Philolaus (480-405 BC) published a summary of Pythagorean philosophy and science in the late 5th century, and was a sometime teacher of Archytas of Tarentum, (400–350 BC), Greek scientist, philosopher, and major Pythagorean mathematician. Plato was the latter's close friend and made use of his work in mathematics. There is evidence that Euclid also borrowed from him. After the 380s BC there was a give-and-take between the school of Archytas and the Academy of Plato, a relationship that makes it almost impossible to disentangle the original achievements of Archytas from joint involvements.

People, like goods, moved fluidly around the Hellenic kingdoms. Almost everyone in the former Alexandrian empire spoke and read the same language: koine, or "the common tongue," a kind of colloquial Greek. Koine was a unifying cultural force: No matter where a person came from, he could communicate with anyone in this cosmopolitan Hellenic world.

At the same time, many people felt alienated in this new political and cultural landscape. Once upon a time, citizens had been intimately involved with the workings of the democratic city-states; now, they lived in impersonal empires governed by professional bureaucrats. Many people joined "mystery religions," like the cults of the goddesses Isis and Fortune, which promised their followers immortality and individual wealth.

Hellenistic philosophers, too, turned their focus inward. Diogenes the Cynic lived his life as an expression of protest against commercialism and cosmopolitanism. (Politicians, he said, were "the lackeys of the mob", and the theatre was "a peep show for fools.") The philosopher Epicurus argued that the most important thing in life was the pursuit of the individual's pleasure and happiness. And the Stoics argued that every individual man had within him a divine spark that could be cultivated by living a good and noble life.

In Hellenic art and literature, this alienation expressed itself in a rejection of the collective demos and an emphasis on the individual. For example, sculptures and paintings represented actual people rather than idealized "types." Famous works of Hellenistic Art include “Winged Victory of Samothrace,” “Laocoön and His Sons,” “Venus de Milo,” “Dying Gaul,” “Boy With Thorn” and “Boxer at Rest,” among others.

End of Hellenic Greece[42]

Macedonia and Greece

Macedonia and Greece were left in the charge of one of Alexander’s most senior generals, Antipater. In 322 BC most cities of the Corinthian League, under leadership of Athens, attempted to shake off Macedonian control, but failed. In the aftermath Antipater consolidated his influence over Greece by making each of the cities make separate treaties with Macedonia. Athens was forced to renounce her democratic constitution and restrict political decision-making to the richer citizens (Antipater felt that the Athenian mob had been led to rebel by a populist demagogue called Demosthenes – who committed suicide at this time).

In the power vacuum which followed Alexander’s death it was inevitable that the Successors, who now controlled different parts of Alexander’s empire, should fall to fighting one another. The wars between them would drag on for two decades, with many twists and turns. At different times various Successors, leading powerful armies, gained control of different parts of Greece, with the small Greek city-states powerless to prevent them. Areas quickly changed hands as the fortunes of war changed. Meanwhile, Macedonia fell into the hands of Cassander, Antipater’s son (the latter had died in 320 BC).

In 310 BC, Cassander, Antipater’s son, had Alexander the Great’s son, Alexander IV, and his widow, Roxanne, murdered, bringing to a brutal end the Argead dynasty. Soon after this the survivors amongst Alexander’s Successors began proclaiming themselves kings, and Cassander became king of Macedonia. He died in 297 BC, and the country experienced a sequence of struggles as claimants for the throne fought each other.

Revival of the Greek Leagues

In Greece, many of the city-states were banding themselves together into leagues to defend themselves against the marauding armies of the Successors. The Aetolian League was the first to form. It constituted itself into a permanent political and military league sometime before 290 BC. The Achaean League, similarly, had existed for centuries as a loose religious association before it reformed itself in 280 BC, on the same lines as the Aetolian League. Other cities, notably Athens and Thebes, fell under the control of a general, Demetrius, who was also king of Macedonia for a short time, and then his son Antigonus Gonatus.

Antigonid dynasty

Antigonus founded the Antigonid dynasty which would rule Macedonia until its conquest by the Romans. In the short term, however, he had to deal with invasions from the neighbouring kingdom of Epirus, under its brilliant king Pyrrhus, who succeeded in occupying most of the country, leaving Antigonus with only the coastal towns in the east. Antigonus to re-consolidated in Macedonia, then pursued Pyrrhus into Greece; there, after several twists and turns, Pyrrhus was killed in a confused melee in Argos in 272 BC. A little later Pyrrhus’s son, Alexander II, repeated his father’s feat of almost occupying Macedonia, but was soon expelled. Thereafter Antigonus was secure in his rule of Macedonia.

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42 Much of this section taken from https://www.timemaps.com/encyclopedia/macedonia-and-greece-after-alexander-the-great/

Antigonus' efforts to extend Macedonian influence in Greece met with resistance from the Aetolian and Achaean Leagues. These had been expanding as new members joined them – the large city of Corinth joined the Achaean League in 243 BC. Antigonus' son, Demetrius II (239-229 BC), however, defeated an alliance of the Leagues soon after his accession, and conducted an aggressive policy of expansion in those parts of Greece not under the control of the Leagues.

Demetrius was killed fighting against the Dardanians, a people from the north who had invaded his kingdom, leaving his throne to a nine year old boy, Philip. His uncle, Doson, was made regent, and he pushed the Dardanians back over the borders.
Sparta resurgent

In Greece, meanwhile, Sparta, under its remarkable king Cleomenes III (reigned 235-222 BC), had undertaken a reform of its institutions which enabled it to rebuild its military strength. It then began expanding its power, with a view to reconstituting the ancient Peloponnesian League. This posed a major challenge to the Achaean League, whose forces were hard put to it to resist the Spartans. The League therefore called on the Macedonians for aid. Doson (who had been acclaimed king as Antigonus III) forged an alliance with other Greek states, as well as the Achaeans, to form a broad-based league under his leadership and overwhelmed the Spartan army at the battle of Sellasia (222 BC). This greatly strengthened Macedonian influence throughout Greece.

The coming of the Romans

The Roman Republic had come to dominate almost all Italy, and had inflicted their first defeat on Carthage (in the long First Punic War of 264-241 BC), acquiring their first overseas provinces, Sicily, Corsica and Sardinia, as a result.

During Rome's second struggle with Carthage (218-202 BC), the youthful king of Macedonia, Philip, took the opportunity to flex his muscles. Feeling himself to be the natural leader of the Greek world against Rome, Philip allied himself with Carthage (215 BCE) in the First Macedonian War. With the Romans unable to spare many forces from their life-and-death struggle with Carthage, much of the fighting was left to the Aetolians, who allied themselves with the Romans. However, the war was desultory and indecisive.

Once Carthage had been decisively defeated, the Romans prepared for a more substantial reckoning. Again allied with the Aetolian League, the Romans declared war (the Second Macedonian War) on Macedon in 200 BC. This ended with a decisive Roman victory in 197 BC. The Romans imposed a harsh peace on Macedonia, returning her to her ancient borders and effectively ending her status as a major power in the Mediterranean. Philip was forced to abandon all possessions in southern Greece, Thrace and Asia Minor. The Romans then withdrew.

Seleucid Defeats

In the aftermath of this war the Achaeans went on to defeat Sparta and take control of the whole of southern Greece, the Peloponnese.

The Aetolians, meanwhile, fearing Rome's growing influence in the region, called on the Seleucid king, Antiochus III ("the Great") (222-187 BC), who at this point still ruled much of Alexander's empire stretching from Asia Minor to Iran, to lead them against their former allies. Antiochus III crossed over into Greece, but was heavily defeated at the battle of Thermopylae (191 BC). Having crossed back into Asia Minor he was again defeated at the battle of Magnesia (190 BC). The Aetolian League were forced to sign a peace treaty with Rome which made it a permanent Roman ally. Thereafter the league continued to exist in name only.

These defeats by Rome marked the decline of the Seleucid empire after Antiochus III.

Final dissolution

In 179 BC, King Philip IV of Macedonia died. A generation later, the Macedonians, under Philip's son Perseus, were ready for to try to re-assert their power and end Roman influence in Greece. Rome declared the Third Macedonian War on Macedon in 171 BC.

Most of the war was fought in Macedon as well as neighbouring Thessaly, where the Roman troops were stationed. After some years of campaigning, Rome decisively defeated the Macedonian forces at Battle of Pydna (168 BC).

The Romans then abolished the kingdom of Macedonia altogether, the first of the Hellenistic kingdoms to suffer this fate. In its place they set up four autonomous republics, which were required to pay an annual tribute to Rome.. Epirus was also absorbed into this arrangement.

This arrangement produced a state of chronic disorder in Macedonia, however, and in 152 BC a pretended son of Perseus, Andriscus, tried to re-establish the Macedonian monarchy, thus provoking the Fourth Macedonian War (149–148 BC).

The Romans crushed the rebellion with relative ease, and in 146 BC Macedonia was made a Roman province. It was in fact the first province of the rising Roman Empire. The province incorporated the former kingdom of Macedonia with the addition of Epirus, Thessaly, and parts of Illyria, Paeonia and Thrace.

In 146 BC the Achaean League tried one final time to rid Greece of Roman influence. The league was defeated; its largest city, Corinth, was razed to the ground and its citizens sold into slavery. The league was dissolved and both Greece and Macedonia were now absorbed into Roman empire, forming two provinces (Achaia and Macedonia).

End of Seleucid empire

The Seleucid empire was a major centre of Hellenic culture, which maintained the pre-eminence of Greek customs and manners over the indigenous cultures of the Middle East. A Greek-speaking Macedonian aristocratic class dominated the Seleucid state throughout its history, although this dominance was most strongly felt in the urban areas.

Early on the Seleucid empire ceded the Indus territories back to the Indian Mauryan empire. It would then would suffer its most serious invasions by the Parthians, who also originated in the Median highlands. From 224 BC, the latter progressively conquered Persis (Persia) in 141 BC, Babylonia and Mesopotamia in 129 BC, and Ctesiphon in 58 BC; and invaded Armenia in 52 BC.

The Seleucid king Antiochus III, the 6th ruler of the empire, reigned from 222 to 187 BC. He ruled over Syria and Western Asia. Antiochus gained several military victories and substantially expanded the empire's territory. A militarily active ruler, Antiochus restored much of the territory of the Seleucid Empire, before suffering a serious setback, towards the end of his reign, in his war against Rome.

Declaring himself the "champion of Greek freedom against Roman domination", in 196 B.C., he crossed the Hellespont and added Thrace to his empire. This brought him into direct contact with the dominant Mediterranean power. Antiochus waged a four-year war against the Roman Republic. In 190 BC, the Roman soldiers first set foot in Asia. In 189 BC, Antiochus was decisively defeated by the Romans at the Battle of Magnesia, losing Turkey (Anatolia).

By the time of the first defeat of the Seleucids by the Romans in BC 189. the Aegean Greek cities had thrown off the Seleucid yoke, Cappadocia and Attalid Pergamum had achieved independence, and other territories had been lost to the Celts and to Pontus and Bithynia. By the middle of the 3rd century, Parthia, Bactria, and Sogdiana had gained their independence.

By 141 BC all lands east of the Euphrates were gone, and attempts by Demetrius II (141 BC) and Antiochus VII (130 BC) could not halt the rapid disintegration of the empire.

The last king of the Seleucids was Phillip II Philoromaeus (r. 65-63 BC) about whom little is known outside of a hopeless attempt to maintain his position, which exemplifies the Seleucid monarchy on the whole after Antiochus III. Once Seleucid I's grand vision of a vast, multi-cultural empire living in peace had been lost – starting with the reign of Antiochus IV Epiphanes - the rest of the empire's royal history was marked by arrogance, neglect of the people, and petty power-grabs which finally left them with nothing. When in 64 BC Pompey The Great (106-48 BC) captured Syria and Cilicia, that ended the Seleucid empire.

Resistance to Greek cultural hegemony had peaked earlier during the reign of Antiochus IV (175–163 BC), whose promotion of Greek culture had culminated in his raising a statue to Zeus in the Temple at Jerusalem. He had previously ordered the Jews to build shrines to idols and to sacrifice pigs and other unclean animals and had forbidden circumcision—essentially prohibiting, on pain of death, the practice of the Jewish law. This persecution of the Jews sparked the Maccabean Revolt (167 -141 BC). Simon Thassi established the Hasmonaean dynasty in 141 BC, two decades after his brother Judas Maccabeus defeated the Seleucid army during the Revolt, and created an independent Judea in Palestine. The Hasmonean dynasty had survived for 103 years. In the late 2nd century BC, the Hasmonean Kingdom conquered most of Palestine and parts of neighbouring regions but the kingdom gradually became a vassal of Rome, which annexed the area in 64 BC. In the same year, Pompey entered Jerusalem.

In 53 BC, the Parthians met the Romans at the Battle of Carrhae (upper Mesopotamia, now Turkey), defeated them and captured and executed Crassus. and in 40–39 BC, Parthian forces captured the whole of the Levant except Tyre from the Romans.

In 37 BC, the Romans appointed Herod, the Idumean (73 BC-4 AD), to be King of Judea, and provided him with an army to secure his appointment. The installation of Herod the Great (an Idumean) as king in 37 BC made Judea a Roman client state and marked the end of the Hasmonean dynasty.

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End of Ptolemaic Dynasty

The Ptolemaic dynasty, sometimes referred to as the Lagid dynasty, was a Macedonian Greek royal dynasty which ruled the Ptolemaic Kingdom in Ancient Egypt during the Hellenic period. Their rule lasted for 275 years, from 305 to 30 BC. The Ptolemaic was the last and longest dynasty of ancient Egypt.

Alexander the Great conquered Egypt from the Archaemenid empire in 322 BC. At his death it devolved on Ptolemy, who was one of Alexander's most trusted generals and confidants and who in due course declared himself pharaoh (king) in 305 BC.

Alexandria, a Greek polis, founded by Alexander, became the capital city and a major centre of Greek culture, learning, and trade for the next several centuries. Following the several Syrian Wars with the Seleucid empire, the Ptolemaic Kingdom expanded its territory to include eastern Libya, the Sinai, and northern Nubia.

To legitimise their rule and gain recognition from native Egyptians, the Ptolemies adopted the title of the pharaoh and had themselves portrayed on public monuments in Egyptian style and dress; otherwise, the monarchy rigorously maintained its Hellenistic character and traditions. The kingdom had a complex government bureaucracy that exploited the country's vast economic resources to the benefit of a Greek ruling class, who dominated military, political, and economic affairs, and which rarely integrated into Egyptian society and culture.

Native Egyptians maintained power over local and religious institutions, and only gradually accrued power in the bureaucracy, provided they were Hellenised. The Ptolemies began to adopt Egyptian customs, such as marrying their siblings, and participating in Egyptian religious life. New temples were built, older ones restored, and royal patronage was lavished on the priesthood. From the mid third century BC, Ptolemaic Egypt was the wealthiest and most powerful of Alexander's successor states, the leading example of Greek-Hellenic civilisation.

Beginning in the mid second century BC, dynastic strife and a series of foreign wars weakened the kingdom, and it became increasingly reliant on the Roman Republic Under Cleopatra VII, Egypt became entangled in a Roman civil war, which ultimately led to its conquest by Rome at the Battle of Actium in 31 BC. That year, Octavian defeated Mark Anthony's Ptolemaic fleet. Capture of Alexandra followed in 30 BC. Octavian took the name Augustus and became the first Roman emperor

Egypt became one of Rome's richest provinces and a centre of Hellenistic culture, with Greek remaining the main language of government until the Muslim conquest in 641 AD. Alexandria remained one of the leading cities of the Mediterranean well into the late Middle Ages.

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(C) Astronomers and Mathematicians

The sciences which received the major attention in the Hellenic Age were astronomy, mathematics, geography, medicine, and physics. Chemistry as a pure science was practically unknown.

Aristarchus.

Aristarchus of Samos, Ionia, (310 – 230 BC) was an astronomer and mathematician. He was a student of Strato of Lampsacus who was the third head of Aristotle's Peripatetic School at the Lyceum in Athens.

He presented the **first known heliocentric model** that placed the Sun at the centre of the known universe, with the Earth revolving around the Sun once a year and rotating about its axis once a day. He was influenced by the concept presented by Philolaus of Croton (470 – 385 BC) of a fire at the centre of the universe, but Aristarchus identified the "central fire" with the Sun and he put the other planets in their correct order of distance around the Sun. He also created two separate sundials; one that is a flat disc and one that was hemispherical.

I did not find any evidence that Aristarchus knew or met Heraclides Ponticus who earlier(?) proposed a mixed heliocentric universe. It seems likely he was junior to the latter at the Lyceum and might have picked up the idea on campus, and worked on it.

Aristarchus estimated the sizes of the Sun and Moon as compared to Earth's size. He also estimated the distances from the Earth to the Sun and Moon. He is considered one of the greatest astronomers of antiquity.

A problem the earlier Greek astronomers had grappled with was why the planets seemed to move randomly, sometimes forward or backwards, sometimes appearing brighter or dimmer. Aristotle had resolved the issue by claiming this was caused by their circular motion. A planet was brighter as it drew nearer to the Earth and dimmer as its motion carried it further away. Aristotle's arguments seemed so convincing that his model was accepted as an accurate representation of the universe and so other models which contradicted it were rejected.

The most famous example of this is the work Aristarchus of Samos. Since this **contradicted Aristotle's model, it was rejected** and when Hipparchus of Nicea investigated Aristarchus' proposal, he basically dismissed it for this reason. A heliocentric universe did not fit the established model of ethereal planets revolving in perfect circles.

After realizing that the Sun was much larger than the Earth and the other planets, Aristarchus concluded that planets revolved around the Sun.

Aristarchus of Samos (310-230 B.C.) is sometimes called the "Hellenistic Copernicus." As a result of his discovery that the apparent immobility of the "fixed" stars was due to their vast distance from the earth, he was the first to have any adequate conception of the enormous size of the universe.

But his chief title to fame comes from his deduction that the earth and the other planets revolved around the sun. Unfortunately this conflicted with the teachings of Aristotle and with the anthropocentric ideas of the Greeks. It was also not in harmony with the beliefs of the Jews and other Orientals who made up a large a percentage of the Hellenistic population.

Aristotle was the first to offer simple proof that the Earth was spherical, and this was propounded by a pupil (Aristarchus) at his Lyceum not long after his death. But this brilliant insight, it turned out, was too much for the philosophers of the time to swallow and astronomy had to wait 2000 years for Copernicus to find the right path.

Euclid

Euclid, was the most prominent mathematician of Hellenic antiquity. He taught at Alexandria at the time of Ptolemy I Soter who reigned over Hellenic Egypt from 323 to 285 BC. About 300 BC, he revolutionised geometry, by his Treatise on Geometry, Elements (Books I of XIII), widely considered the most successful and influential textbook of all time. He introduced mathematical rigour through the axiomatic method: that of definition, axiom, theorem, and proof. Although most of the contents of the Elements were already known, Euclid arranged them into a single, coherent logical framework. He did not influence stronomy directly, but his mathematics would have.

Archimedes

Archimedes (287-211 BC), was a Greek mathematician, engineer, astronomer, and inventor, born in Syracuse, the then principal Greek city-state in Sicily. He died in that same city when the Romans captured it following a siege that ended in either 212 or 211 BCE. Archimedes probably spent some time in Egypt early in his career, but he resided for most of his life in Syracuse, where he was on intimate terms with its king, Hieron II. He is considered to be the greatest mathematician of ancient Greece and one of the greatest of all time.

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Mathematician

Archimedes anticipated modern calculus and analysis. Archimedes' other mathematical achievements include deriving an approximation of pi, devising a system of exponentiation for expressing very large numbers, and the beginnings of trigonometry..

He was also one of the first to apply mathematics to physical phenomena, founding hydrostatics and statics. Archimedes' achievements include proof of the principle of the lever, the concept of centre of gravity and the law of buoyancy[43.]

Inventor

He is credited with designing innovative machines, such as the screw pump, compound pulleys and defensive war machines, such as the Claw Arm. This was a weapon that he is said to have designed in order to defend the city of Syracuse. Also known as "the ship shaker", the claw consisted of a crane-like arm from which a large metal grappling hook was suspended. When the claw was dropped onto an attacking ship the arm would swing upwards, lifting the ship out of the water and possibly sinking it.

Astronomer

Archimedes was also known as an astronomer: his observations of the solstices were used by Hipparchus, the foremost ancient astronomer.

His treatise the Sand-Reckoner revealed his keen astronomical interest and practical observational ability. There has been handed down a set of numbers attributed to him giving the distances of the various heavenly bodies from Earth which has been shown to be based not on observed astronomical data but on a “Pythagorean” theory associating the spatial intervals between the planets with musical intervals.

In the Sand Reckoner, Archimedes set out to calculate the number of grains of sand that the universe could contain. In this treatise, also known as Psammites, Archimedes mentions the heliocentric theory of the solar system proposed by Aristarchus of Samos as well as contemporary ideas about the size of the Earth and the distance between various celestial bodies. By using a system of numbers based on powers of the myriad, Archimedes concludes that the number of grains of sand required to fill the universe is 8×1063 in modern notation.

The introductory letter states that Archimedes' father was an astronomer named Phidias. The Sand Reckoner is the only surviving work in which Archimedes discusses his views on astronomy.

Eratosthenes

Most Greeks began to believe that Earth was round, not flat. But they had no idea how big the planet was until Eratosthenes of Cyrene (276-194 BC) estimated its circumference around 240 BC.

Born in Libya, he studied at Athens at the Lyceum, and was a famous scholar. King Ptolemy III of Alexandria appointed him chief librarian of the library of Alexandria. Eratosthenes was produced impressive works in astronomy, mathematics, geography, philosophy, and poetry, and is now well known for developing the sieve of Eratosthenes, a method of finding prime numbers.

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[43] The most widely known anecdote about Archimedes tells of how he invented a method for determining the volume of an object with an irregular shape. According to Vitruvius, a votive crown for a temple had been made for King Hiero II of Syracuse, who had supplied the pure gold to be used; Archimedes was asked to determine whether some silver had been substituted by the dishonest goldsmith.[30] Archimedes had to solve the problem without damaging the crown, so he could not melt it down into a regularly shaped body in order to calculate its density

Eratosthenes' most famous accomplishment is his measurement of the circumference of Earth. He recorded the details of this measurement in a manuscript that is now lost, but his technique has been described by other Greek historians and writers.

Eratosthenes had heard from travellers about a well in Syene (now Aswan, Egypt) where at noon on the summer solstice, the sun illuminated the entire bottom of this well, without casting any shadows, indicating that the sun was directly overhead. Eratosthenes then measured the angle of a shadow cast by a stick at noon on the summer solstice in Alexandria, and found it made an angle of about 7.2 degrees, or about 1/50 of a complete circle. He immediately realised (Eureka!)[44] that if he knew the distance from Alexandria to Syene, he could calculate the circumference of Earth.

The rest is history. So Eratosthenes hired bematists, professional surveyors trained to walk with equal length steps. They found that Syene was about 5000 stadia from Alexandria. Eratosthenes then used this to calculate the circumference of the Earth to be about 250,000 stadia. Modern scholars disagree about the length of the stadium used by Eratosthenes. Values between 500 and about 600 feet have been suggested, putting Eratosthenes' calculated circumference between about 24,000 miles and about 29,000 miles. The Earth is now known to measure about 24,900 miles around the equator, slightly less around the poles.

He produced the most accurate map that had yet been devised, with the surface of the earth divided into degrees of latitude and longitude. He propounded the theory that all of the oceans are really one, and he was the first to suggest the possibility of reaching India by sailing west. One of his successors divided the earth into the five climatic zones which are still recognized, and explained the ebb and flow of the tides as due to the influence of the moon.

Other Greek scholars repeated the feat. Posidonius (135-51 BC) used the star Canopus as his light source and the cities of Rhodes and Alexandria as his baseline. But because he had an incorrect value for the distance between Rhodes and Alexandria, he came up with a value for Earth's circumference of about 18,000 miles, nearly 7,000 miles too small. Ptolemy included this smaller value in his treatise on geography in the second century. Later explorers, including Christopher Columbus, believed Ptolemy's value and became convinced that Earth was small enough to sail around.

Apollonius of Perga

Apollonius Pergaeus (240 –190 BC) from Perga, Asia Minor, was a Greek geometer and astronomer.

He is known for his work on conic sections. Beginning from the contributions of Euclid and Archimedes on the topic, he brought them to the state prior to the invention of analytic geometry

Apollonius worked on numerous other topics, including astronomy. His hypothesised eccentric orbits to explain the apparently aberrant motion of the planets   The Apollonius crater on the moon is named in his honour.

Apollonius of Perga (262 BC–c. 190 BC) is sometimes mentioned as the actual inventor of the astrolabe. His critical contribution included introducing two new mechanisms that allowed a planet to vary its distance and speed: the deferent and epicycle. The deferent is a circle carrying the planet around the Earth. An eccentric deferent is slightly off-centre from Earth. In

[44] With apologies to Archimedes, for this anachronism.

a deferent and epicycle model, the deferent carries a small circle, the epicycle, which carries the planet. His deferent-and-epicycle model mimicked the Sun's eccentric orbit and explained retrogration which happens when planets appear to reverse their motion through the zodiac for a short time.

Hipparchus of Nicea

Hipparchus of Nicaea (190 120 BC) was a Greek astronomer, geographer and mathematician, who was born in Nicaea, Bithynia and probably died in Rhodes. He is considered the founder of trigonometry, although it was known in Babylon.

He is considered the greatest of the Greek astronomers. He was known to have been a working astronomer between 162 and 127 BC, and was most famous for his discovery of the precession of the equinoxes. He created accurate models for the motion of the planets, the first star chart, and developed mathematical principles for calculating astronomical events.

Although he was working from the then inaccurate (geocentric) model of the solar system, Hipparchus' calculations and observations were still accurate. He drew on the earlier work of the Babylonians and Egyptians but mathematically tested their conclusions to confirm them rather than simply accepting them as a given truth. He did the same with the works of the mathematician Archimedes and the polymath Eratosthenes. He calculated the mean lunar month at 29 days, 12 hours, 44 minutes, 2 ½ seconds (which differs by less than a second from the present accepted figure!), made correct estimates of the sizes and distances of the Sun and Moon,

Hipparchus compiled a catalogue of some 850 stars; he was the first to state the position of these stars in terms of latitude and longitude (in relation to the ecliptic). He wrote a treatise in twelve books on Chords in a Circle, equivalent to a table of trigonometrical sines. For calculating arcs in astronomy from other arcs given by means of tables he used propositions in spherical trigonometry.

Many of his conclusions are still recognized as sound in the present day, especially the discovery he is most famous for, the precession[45] of the equinoxes. The term refers to axial precession, the change in a celestial body's rotational axis, as applied to earth. By measuring the longitude of certain known stars and comparing the measurements with those from earlier astronomers, then comparing how long it takes the Sun to return to an equinox and to an identifiable star, Hipparchus concluded that the rate of precession was around one degree in a century and so a full cycle would be completed in approximately 36,000 years.

Establishing the precession of the equinoxes made the universe more accessible and understandable. Planets did not move randomly but according to their nature. His discovery enabled him to better map the heavens and predict when various astronomical events were likely to take place. which could be calculated mathematically.

Hipparchus is said to have invented or improved upon a number of astronomical instruments, among them his celestial globe. According to Ptolemy, the globe rested within a flat plane and was encircled by a scale from which a grid divided it into lines of 24 hours. He is thought to have used the globe to work out the precession of the equinoxes and determine planetary movements as well as calculating the length of a year (which was accurate to within 6.5 minutes).
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[45] In astronomy, axial precession is a gravity-induced, slow, and continuous change in the orientation of an astronomical body's rotational axis. In particular, it can refer to the gradual shift in the orientation of Earth's axis of rotation in a cycle of approximately 23,000 years. This is similar to the precession of a spinning top, with the axis tracing out a pair of cones joined at their apices.

As he charted the skies, he developed various instruments to assist him, one of which may have been the famous Antikythera Mechanism (see further on).

Hipparchus is considered one of the most important Greek astronomers, because he introduced exact prediction into Greek astronomy. Hipparchus was the father of trigonometry. His chief contributions were the mathematics of the astrolabe, the best chart of the heavens then known, the approximately correct calculation of the diameter of the Moon and its distance from the earth, and the discovery of the precession of the equinoxes. Somehow he had access to Babylonian observations or predictions, and used them to create better geometrical models.

Hipparchus also compiled a star catalogue. So that later generations could tell whether other stars came to be, perished, moved, or changed in brightness, he recorded the position and brightness of the stars.

The following quote assesses Hipparchus' contribution well:

> "Hipparchus played a major role in introducing Babylonian numerical into Greek astronomy. Indeed, an important shift in Greek attitudes toward astronomy occurred about this time. The Babylonian example served as a sort of wake-up call to the Greeks. Previous Greek planetary thinking had been more about getting the right big picture, based on philosophical principles and geometrical models (whether using Eudoxus's concentric spheres or Apollonius epicycles and eccentrics). The Babylonians had no geometrical models but instead focused on devising arithmetical theories that had real predictive power. Hipparchus achieved numerically successful geometrical theories for the Sun and the Moon, but he did not succeed with the planets. He contented himself with showing that the planetary theories then in circulation did not agree with the phenomena. Nevertheless, Hipparchus's insistence that a geometrical theory, if it is true, ought to work in detail, marked a major step in Greek astronomy."
> https://www.britannica.com/biography/Hipparchus-Greek-astronomer

To measure angles in the sky, Hipparchus employed the ancient Babylonian practice, still in use today, of dividing a circle into 360 degrees, and each degree into 60 arc minutes. Hipparchus's catalogue, one of the earliest successful attempts to chart the heavens, lists the positions of 850 stars across the sky with a precision of about one degree (about twice the angular size of the full Moon). He was able to attain this precision exclusively with naked-eye observations and the few instruments available at the time – gnomons, astrolabes, and armillary spheres. Hipparchus also created the magnitude system for describing the brightness of stars, which is still in use today, and studied the relative distance of the Sun and the Moon from Earth.

His fame was eventually overshadowed by the reputation of Ptolemy of Alexandria, the last of the Hellenistic astronomers, but he laid the foundations that enabled the later to uplift Greek astronomy to the next platform level.

Seleucus of Seleucia (Mesopotamia)

Seleucus of Seleucia (190-?BC) was a Hellenic astronomer, from Seleucia, Mesopotamia, capital of the Seleucid empire, and is best known as a proponent of the heliocentrism and for his theory of the origin of tides.

Seleucus is known to have supported the heliocentric theory of Aristarchus of Samos. He was a contemporary of Hipparchus.

Seleucus was the first to demonstrate the heliocentric system through reasoning but it is not known what arguments he used. Seleucus may have constructed his heliocentric theory by determining the constants of a geometric model and by developing methods to compute planetary positions using this model. According to the Greek geographer Strabo, Seleucus was the first to assume the universe to be infinite.

Seleucus' arguments for a heliocentric theory were probably related to the phenomenon of tides. The annual cycle of tides (which was studied by Seleucus) can indeed hardly be explained in a geocentric system. Seleucus correctly theorized that tides were caused by the Moon, explaining that the interaction was mediated by the pneuma (primaeval air component) He noted that the tides varied in time and strength in different parts of the world. Seleucus ascribed tides both to the Moon and to a whirling motion of the Earth. which could be interpreted as the motion around the Earth-Moon mass.

Seleucus was the first to state that the height of the tides depends on the Moon's position relative to the Sun.

Strabo lists Seleucus as one of the four most influential "Chaldean astronomers". Babylonian astrologers and astronomers were often called "Chaldaeans." Strabo calls them "the so-called Chaldaeans". Their writings were translated into Greek and used by later authors. The "Chaldaean" astronomers mentioned by Strabo are Kidenas, Naburianos, Sudines and Seleucus. The first two are also known from astronomical cuneiform texts under their Akkadian names Nabu-Rimannu and Kidinnu.

Posidonius

Posidonius (135 - ?BC) born in Apmea, Syria, advanced the theory that the Sun emanated a vital force which permeated the world. He attempted to measure the distance and size of the Sun. In about 90 BC, Posidonius estimated the distance from the Earth to the Sun to be 9,893 times the Earth's radius.

Geminus

Geminus (100 -?BC) was believed to be from Rhodes. The only work of Geminus to survive is his Introduction to the Phenomena often just called the Isagoge. This introductory astronomy book, based on the works of earlier astronomers (such as Hipparchus) was intended to teach astronomy for beginning students in the subject. In it, Geminus described the zodiac, the motion of the Sun, the constellations, the celestial sphere, days and nights, the risings and settings of the zodiacal signs, luni-solar periods and their application to calendars, phases of the Moon, eclipses, star phases, terrestrial zones and geographical places, and the foolishness of making weather predictions by the stars.
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Antikythera Mechanism

It is a 37-gear mechanical computer which computed the motions of the Sun and Moon, including lunar and solar eclipses, predicted on the basis of astronomical periods believed to have been learned from the Babylonians.

It was an astronomical observational device, the first ancestor of an astronomical computer. It was discovered in an ancient shipwreck off the Greek island of Antikythera off Crete in 1901.

Remarkably, the Antikythera Mechanism performs calculations based on both the Metonic and Callippic calendar cycles, with separate dials for each.

The device became famous for its use of a differential, previously believed to have been invented in the 16th century, and the miniaturization and complexity of its parts, comparable to a clock made in the 18th century.

The device worked by turning a crank on the side which caused a series of gears to move and a pointer to shift to the positions one was attempting to calculate. All one needed to know was the present year to enable accurate predictions of future celestial events

Hipparchus is thought to have had a hand in its invention.

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(D) Ptolemy

Ptolemy or Claudius Ptolemaeus (100-170 AD) was an astronomer, mathematician and geographer who flourished in Alexandria during the 2nd century, when the Ptolemic empire had already become a Roman province.

In several fields his writings represent the culminating achievement of Greco-Roman science, particularly his geo-centric model of the universe now known as the Ptolemaic system. Virtually nothing is known about his life except what can be inferred from his writings. Ptolemy wrote in ancient Greek, and can be shown to have utilized Babylonian astronomical data. He might have been a Roman citizen, but was ethnically either a Greek or a Hellenised Egyptian. He was not related to Ptolemy I Soter, Alexander's general, who was the founder of the Ptolemaic Egyptian Empire.

Ptolemy wrote about a dozen scientific treatises, three of which were of importance to the next developments in science. The first was the Almagest, originally entitled the Mathēmatikē Syntaxis or Mathematical Treatise, and later known as The Greatest Treatise. The name Almagest arose as an Arabic corruption of the Greek word for "greatest". The second was his Geography, which is a thorough discussion on maps and the geographic knowledge of the the Greco-Roman world. The third was the astrological treatise in which he attempted to adapt horoscopic astrology to the Aristotelian natural philosophy of his day, sometimes known as the Apotelesmatika, but more commonly known as the Tetrabiblos or Four Books or by its Latin equivalent Quadripartite.

Almagest

The Almagest, was completed about 150 CE and contained reports of astronomical observations that Ptolemy had made and collated from different sources over the preceding quarter of a century. Ptolemy concluded therein that the universe was geocentric, ie revolved with the earth in the centre. It served as the basic guide for Islamic and European astronomers until about the beginning of the 17th century. Ptolemy placed the planets in the order that would remain standard until it was displaced by the heliocentric system.

The Almagest was translated into Arabic in the late 8th and early 9th centuries and then from Arabic to Latin in the last half of the 12th century. Beginning in the 15th century, the Greek text circulated widely in Europe, although the Latin translations from Arabic continued to be https://www.worldhistory.org/Seleucid_Empire/ more influential.

Although Babylonian astronomers had developed arithmetical techniques for calculating and predicting astronomical phenomena, these were not based on any underlying model of the heavens. Early Greek astronomers, on the other hand, provided qualitative geometrical models of celestial phenomena without the ability to make any predictions. The earliest person that attempted to merge these two approaches was Hipparchus who produced geometric models that not only reflected the arrangement of the planets and stars but could be used to calculate celestial motions.

Ptolemy, following Hipparchus, derived each of his geometrical models for the Sun, Moon, and the planets from selected astronomical observations over more than 800 years; however, many astronomers have suspected that some of his models' parameters were adopted independently of observations. In the Almagest, Ptolemy explained how to predict the behaviour of the planets, which Hipparchus could not, with the introduction of a new mathematical tool, the equant[46].

The Almagest is divided into 13 books. Book 1 gives arguments for a geocentric spherical cosmos and introduces the necessary trigonometry. Book 2 uses spherical trigonometry to explain cartography and the astronomical phenomena of various localities, such as the length of the longest day. Book 3 deals with the motion of the Sun and how to predict its position in the zodiac at any given time, and Books 4 and 5 treat the more difficult problem of the Moon's motion. Book 5 also describes the construction of instruments to aid in these investigations. Book 6 deals with lunar and solar eclipses. Books 7 and 8 mainly concern the fixed stars, giving ecliptic coordinates and magnitudes for 1,022 stars. This star catalogue relies heavily on that of Hipparchus. These two books also discuss the construction of a star globe that adjusts for precession. The remaining five books, the most original, set forth in detail geometric models for the motion of the five planets visible to the naked eye, together with tables for predicting their positions at any given time.

In the Ptolemaic system, the Earth was at the centre of the universe with the Moon, the Sun, and five planets circling it. The circle of fixed stars marked the outermost sphere of the universe and beyond that would be the philosophical "aether" realm. The sphere carrying the Moon is described as the boundary between the corruptible and changing sublunary world and the incorruptible and unchanging heavens above it. The heavens were defined as incorruptible and unchanging based on theology and mythology of the past.

The aether is the area that describes the universe above the terrestrial sphere. This component of the atmosphere is unknown and named by philosophers.

The Almagest introduced the idea of the sphericity of the heavens. The aether was used to affirm the sphericity of the heavens. The latter was further confirmed by the belief that different shapes had an equal boundary, that those with more angles were greater, the circle was greater than all other surfaces, and a sphere was greater than all other solids. Therefore, through physical considerations, and heavenly philosophy, the heavens must be spherical.

The differences in the hours across a globe would be proportional to the distances between the spaces at which they were observed. Therefore, the Earth must be spherical because they change in time-zones across the world occurred in a uniform fashion, as with the rotation of a sphere.

Finally, the Almagest suggested that the Earth was at the centre of the universe. The basis of this was the fact that six zodiac signs could be seen above Earth, while at the same time the other signs were not visible. The increase and decrease of daylight would be different if the Earth was not at the centre of the universe. Though this view later proofed to be invalid, this proposition remained in place for over 1000 years.

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[46] The equant is used to explain the observed speed change in different stages of the planetary orbit. This planetary concept allowed Ptolemy to keep the theory of uniform circular motion alive by stating that the path of heavenly bodies was uniform around one point and circular around another point.

"Although the Ptolemaic scheme may appear cumbersome compared to the modern understanding of the universe, the reason that it dominated science for so long was that it actually worked. With the detailed information that Ptolemy had to work from, he was able to use the scheme as a basis for monitoring and predicting the positions of the planets with great accuracy."

Life and Work of Ptolemy, Deborah Houlding
http://www.skyscript.co.uk/ptolemy.html

Geōgraphikḕ Hyphḗgēsis,

Ptolemy was probably as famous as a geographer as an astronomer. His work, Geōgraphikḕ Hyphḗgēsis, The Geography, also known by its Latin names Geographia and the Cosmographia, was a gazetteer, an atlas and a treatise, compiling the cartographic and geographical knowledge of the 2nd-century Roman empire. Originally written by Ptolemy in Greek around AD 150, the work was a revision of a now-lost atlas by Marinus of Tyre, using additional Roman and Persian gazetteers and new principles. It was translated into Arabic in the 9th century and Latin in 1406 and was highly influential on the geographical and cartographic traditions of Islam and medieval and Renaissance Europe.

The Geography consisted of three sections, divided among 8 books. Book I was a treatise on cartography, describing the methods used to assemble and arrange Ptolemy's data. From Book II through the beginning of Book VII, a gazetteer provided longitude and latitude values for the then known world. The rest of Book VII provided details on three projections to be used for the construction of a map of the world, varying in complexity and fidelity. Book VIII constituted an atlas of regional maps.

Maps based on scientific principles had been made in Europe since the time Eratosthenes in the 3rd century BC. Ptolemy improved the treatment of map. He provided instructions on how to create his maps in the first section of the work.

The gazetteer section of Ptolemy's work provided latitude and in degrees of an arc from the equator, the same system that is used now, though Ptolemy used fractions of a degree rather than minutes of arc. His Prime Meridian (0 degrees Longitude) ran through the Fortunate Islands, the westernmost land recorded, at around the position of El Hiero in the Canary Islands The maps spanned 180 degrees of longitude from the Fortunate Isles to China.

Ptolemy's work included a single large and less detailed world map and then separate and more detailed regional maps. The first Greek manuscripts compiled after rediscovery of the text had as many as 64 regional maps. The standard set in Western Europe came to be 26: 10 European maps, 4 African maps, and 12 Asian maps.

Ptolemy's most important geographical innovation was to record longitudes and latitudes in degrees for roughly 8,000 locations on his world map, making it possible to make an exact duplicate of his map. Hence, we possess a clear and detailed image of the inhabited world as it was known to the Roman Empire - a world that extended from the Shetland Islands to the Nile and from Atlantic to China.

Ptolemy also devised two ways of drawing a grid of lines on a flat map to represent the circles of latitude and longitude on the globe. His grid gave a visual impression of Earth's spherical surface and also, to a limited extent, preserves the proportionality of distances. The more sophisticated of these maps using circular arcs anticipated later area-preserving projections.

Tetrabiblos

Ptolemy was the author of one of the oldest complete manuals of astrology, - the Tetrabiblos (Greek), or Quadrapartitium (Latin) meaning 'Four Books'.

Ptolemy did not invent the methods of astrology. His contribution was orchestrating the mass of Eastern star lore into an organized and reasoned exposition. The Tetrabiblos offered a detailed explanation of the philosophical framework of astrology, enabling its practitioners to answer critics on scientific as well as religious grounds.

As a leading intellectual of his day, Ptolemy's patronage and approval of astrology added to its academic respectability. He spoke of astrology with authority and lucidity, establishing the Tetrabiblos as the definitive reference for astrological students. It was used extensively by Arabic scholars, who regarded Ptolemy as the final word on the subject, and later by European ones when it was translated back into Latin in the 12th century.

Ptolemy reveals no interest in magic, superstition or ideas which fall beyond the realm of reason. He adheres to the scientific views of his era and in harmony with Aristotelian philosophy.

His perspective rests upon the belief that planetary influences derive from the planets' relationship with the Sun (the source of heat and light) and the Earth (the source of moisture). In this way the Moon is regarded as a 'cool and moist' planet. Saturn is 'cold and dry' because it is furthest from the warmth of the Sun and, again, from the moisture of the Earth. Planetary characteristics are defined by these humoural temperaments. In nature, warmth and moisture promote health and vitality whilst cold and dryness are conducive to decay. Hence Saturn becomes the principal agent of destruction and death; the 'Greater Malefic'.

Through this hypothesis Ptolemy explains how the constant movement of the planets creates an ever-changing atmosphere to which all the Earth's creatures are sensitive. Just as two similar seeds grow differently as a result of their environment, so is each soul affected by the celestial atmosphere at the time of its birth. In sympathy and antipathy, the aspects and movement of the stars continue to produce favourable or injurious conditions, as determined by the individual's personal disposition.

To Ptolemy, therefore, astrology is a scientific study because it operates according to natural law. Although he maintains the importance of the angles of a chart, the Tetrabiblos shows a noticeable lack of interest in the houses, whilst other elements of astrology were considered to be completely unworthy of mention, either because they were too unscientific, too reminiscent of fortune telling, or defied any kind of rational explanation:

Ptolemy was concerned to defend astrology by defining its limits, compiling astrological data that he believed was reliable and dismissing practices (such as considering the numerological significance of names) that he believed to be without sound basis.[47]

The Hellenistic period saw the rise of New Comedy, Alexandrian poetry, the Septuagint, and the philosophies of Stoicism, Epicureanism, and Pyrrhonism.

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[47] http://ircamera.as.arizona.edu/NatSci102/NatSci102/text/extptolemy.htm

Alexandria

Hellenistic culture produced seats of learning throughout the Mediterranean. Hellenistic science differed from Greek science in at least two ways: first, it benefited from the cross-fertilization of Greek ideas with those that had developed in the larger Hellenistic world; secondly, to some extent, it was supported by royal patrons in the kingdoms founded by Alexander's successors. Especially important to Hellenistic science was the city of Alexandria in Egypt, which became a major centre of scientific research in the 3rd century BC. Hellenistic scholars frequently employed the principles developed in earlier Greek thought: the application of mathematics and deliberate empirical research, in their scientific investigations.

Astrology[48]

Hellenistic astrology was a tradition of horoscopic astrology that was developed and practiced in the late Hellenistic period in and around the Mediterranean Basin region, especially in Egypt. The texts and technical terminology of this tradition of astrology were largely written in Greek (or sometimes Latin).

Astrology was a central feature of Greek and Roman culture. A knowledge of astrology's claims, practices, and world view is essential for a full understanding of religion, politics, and science in the Greek and Roman worlds.

Astrology is the name given to a series of diverse practices based in the idea that the stars, planets, and other celestial phenomena possessed significance and meaning for events on Earth. It assumed a link between Earth and sky in which all existence, spiritual, psychological, and physical, is interconnected.

Most pre-modern cultures practiced a form of astrology. A particularly complex variety of it evolved in Mesopotamia in the first and second millennia BC from where it was imported into the Hellenistic world from the early 4th century BC onward.

There it became attached to three philosophical schools, those pioneered by Plato, Aristotle and the Stoics, all of which shared the assumption that the cosmos was a single, living, integrated whole. Hellenistic astrology also drew on Egyptian temple culture, especially the belief that the soul could ascend to the stars.

By the 1st century AD, the belief in the close link between humanity and the stars had become democratized and diversified into a series of practices and schools of thought which ranged across Greek and Roman culture. It was practiced at the imperial court and in the street. It could be used to predict individual destiny, avert undesirable events, and arrange auspicious moments to launch new enterprises. It could advise on financial fortunes or the condition of one's soul. It was conceived of as natural science and justified by physical influences or considered to be divination, concerned with communication with the gods and goddesses.

In some versions, the planets were neither influences nor causes of events on Earth, but timing devices, which indicated the ebb and flow of human affairs, like the hands on a modern clock. Astrology had a radical view of time in which the future already existed, at

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[48] This summary Is substantially extracted from https://oxfordre.com/planetaryscience/view/10.1093/acrefore/9780190647926.001.0001/acrefore-9780190647926-e-46

least in potential, and the astrologer's task was to intercede in time, altering the future to human advantage. In this sense astrology was a form of "participation mystique" in which time and space were conceived of as a single entity and individual and social benefits were to be derived from engaging with it.

There was no one single version of astrology and there were disputes about what it was and what it could do, for example, whether it could make precise predictions about individual affairs or merely general statements.

From the early 4th century it went into a progressive decline, facing challenges from Christianity and the fragmentation of classical culture, especially in Western Europe. It survived in Persia, exerted a powerful influence on Indian astrology, and was transmitted to the Islamic world, from where it was reimported into the Latin West in the 12th century.

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Magic was practiced widely, and this, too, was a continuation from earlier times. Throughout the Hellenistic world, people would consult oracles and use charms to deter misfortune or to cast spells.

The Hellenic world also developed a complex system of astrology which sought to determine a person's character and future in the movements of the Sun, Moon and the planets. Astrology was widely associated with the cult of Tyche. (luck, fortune), which grew in popularity during this period. Tyche was the presiding tutelary deity who governed the fortune and prosperity of a city. .

Other Scientific Advances

Medicine, which was dominated by the Hippocratic tradition, saw new advances under Praxagoras of Kos (3430-? BC), who theorised that blood travelled through the veins. Herophilus (335–280 BC) was the first to base his conclusions on dissection of the human body and animal vivisection, and to provide accurate descriptions of the nervous system. A major step was the emergence of the empiric school of medicine.
Bolos of Mendes made developments in alchemy, Theophratus was known for his work in plant classification, and Cretuas wrote a compendium on botanic pharmacy. The library of Alexandria included a zoo for research and Hellenistic zoologists include Archelaos, Leonidas of Byzantion, Apollodoros of Alexandria and Bion of Soloi. Hero of Alexandria described the first-recorded steam engine.

Concluding Remarks

I can do no better than quote the following, which must be an essential reading for anyone pursuing the subject further:

> "Of all the sciences created in Antiquity, astronomy is second in importance only to medicine in its impact on human lives. And, for this reason, like medicine, it achieved remarkable sophistication. The development of astronomy in Greco-Roman culture from a qualitative science in the late fourth century bce to a fully quantitative and predictive science in the second century ce that was the paradigm of human knowledge and a rival to philosophy is truly astounding. So there is no denying the historical importance of astronomy as a basis for insight into the Greek and Roman worlds of that time."
> Hellenistic Astronomy
> Editors: Alan C. Bowen and Francesca Rochberg
> Brill's Companions to Classical Studies, Feb 2020
> https://brill.com/view/book/edcoll/9789004400566/front-6.xml?language=

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Chapter Four
The Roman World

The conquest of Hellenic Greece by the emergent Roman Republic was related towards the end of the last chapter's historical coverage of the preceding era, for better continuity of the background of the astronomic developments that took place.

In particular, Ptolemy was Hellenic Greek, represented the pinnacle of Greek astronomic achievement, and worked in Alexandria, which was still the beacon of Greek Hellenic civilisation notwithstanding its capture by the Romans in BC 30.

At the same time, Ptolemy was a Roman (probably a citizen) and lived from 100-170 AD in the Roman Empire, and his astronomy was wholly compiled in Romantimes, and therefore Roman. In fact in the 1300 years that followed, Ptolemy's conception of the universe as a geocentric system dominated the Roman and post Roman world, until the Renaissance.

This chapter briefly infills the development of Roman civilisation and the evolution of Roman science, astronomy, and astrology.

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(A) The Roman Kingdom
(753 - 509 BC)

According to legend, Romulus and Remus were the twin sons of the God of War, Mars, born to princess Rhea Silvia, daughter of King Numitor of the Latin state of Alba Longa. Romulus killed Remus and founded the Kingdom of Rome as its first king. It was located on the Palatine Hill, one of the Seven Hills of Rome, beside the River Tiber.

At that time, much of Italy was already dominated by the kingdom of Etruria (the Etruscans) to the north and west, by various Latium (Italics) peoples over much of the south and east, and by maritime settlers, including Greeks in the coastal south. The original Romans were of Latium (or Latini or Latin) extraction. The latter in turn claim ancestry from the Trojans, via Aeneas.

The Kingdom of Rome was therefore contemporaneous with the Greek Archaic Age when the latter's city-states evolved. It was ruled by seven kings, before the monarchy was overthrown and the Roman Republic was born in BC 509.

Historians differ in detail, but one. version is that the kings were elected by the people sitting as a Curiate Assembly from among candidates nominated by a Senate, which was oligarchic and aristocratic-based. Candidates could be anyone. The elected monarch had absolute power.

Historical records ae poor. Seven kings are said to have ruled Rome until 509 BC. These kings ruled for an average of 35 years. The last two kings were Etruscans.

The last king, Lucius Tarquinius Superbus, ruled badly and was overthrown by the ancestors of Brutus. Extraordinarily, this happened at the same time Cleisthenes set up democracy in Athens.

One traditional history has it that the monarchy was terminated through military defeat and foreign intervention. Rome was a site highly prized. The king of Etruscan Clusium defeated the Romans and expelled Tarquinius Superbus. Before he could establish himself as monarch, the Romans replaced the kingship with two annually elected magistrates called consuls, inaugurating the republic.

Modern historians think Tarquin was expelled from Rome because his son had raped a noblewoman, and her husband and family had mustered support from the Senate and the Roman army to force the monarch into exile in Etruria. The Senate then decided to have no more kings.

Much of the kingdom-period was taken up with small-scale internal conflicts and adjustments among the states of Italy, to accommodate a growing Rome. Like in Greece, there was a Latin League with changing membership which featured in much the same way as its many Greek counterparts did.

There were no authors, philosophers, astronomer, scientists or generals of note during this period.

The last king of Rome, Lucius Tarquinius Superbus, was overthrown following a coup d'etat led by Lucius Junius Brutus, who. Founded the Roman Republic.

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(B) The Roman Republic (509 – 27 BC)

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Political System

From kingdom days through the early years of the republic, Rome's aristocrats, who were the land-owners or patricians, were the dominant force in politics and society. The patricians were divided into 30 curiae or local groups, and their assembly was the Comitia Curiata, at that time the sole representative of the Roman populus. They monopolised Rome's Senate, the magistracies, state priesthoods and senior military posts.

Consuls

When the Senate ratified to abolish kingship. most of the former functions of the king were transferred to two newly created appointments of Consul. These consuls were elected by the people for a term of one year, and each was capable of acting as a "check" on the other through the power of veto. In modern parlance, they would be co-executive heads of state. Among other things, ach was responsible for raising the necessary (originally draft)) citizen army for the protection of his territory of responsibility. In times of military emergency, a dictator might be elected by the people, who however could not hold supreme military command for longer than six months (ie, they were elected for a specific campaign.). This was extraordinarily like the Athenian system of archons and strategos.

The consuls presided over the Senate and the Roman Assemblies, and had the ultimate responsibility to enforce the policies and laws enacted by both institutions. The consuls carried out business with foreign nations, and facilitated interactions between foreign ambassadors and the Senate. Upon an order by the latter, the consuls were responsible for raising and commanding an army. While the consuls had supreme military authority, they had to be provided with financial resources by the Senate. While abroad, the consuls had absolute power over their soldiers, and over any Roman province.

Senate

The Senate, the top political institution of the Romans, existed from kingdom days, when it was appointed by the king, and was largely advisory. Following the coup d'état, it became de facto the senior over-arching body, if not authority, in the land, and adjudicator of last resort. In practice, the Senate's principal role was as an advisory council to the consuls on matters of foreign and military policy, and it exercised a great deal of influence over consular decision-making. The Senate also resolved disputes between magistrates and oversaw the allocation of public resources to magistrates.

In the early Roman republic, Senate members were appointed by the consuls. By the late 4th century BC, the consul's power to control Senate membership was transferred to Censors. They held appointment for life, and numbered about 500.

Censors

Censors were introduced earlier in BC 443. They numbered two, and were also elected by the people for terms originally of five years, and subsequently reduced to o eighteen months. The censorship was regarded as the highest dignity in the state, with the exception of the dictatorship. It was a "sacred magistracy" due to the important duties of control over the conduct and morals of the citizens. Only they could impeach a senator. They were regulated solely by their own views of duty, and were not responsible to any other power in the state. Usually only former consuls were elected to be censors.

Technically they outranked all other ordinary magistrates (including consuls and praetors). Censors could enrol citizens in the senate, or purge them from the senate. A censor had the ability to fine a citizen, or to sell his property, which was often a punishment for either evading the census or having filed a fraudulent registration.

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Magistrates

Magistrates were the elected officials of the Roman republic. Each magistrate was vested with a degree of power. The dictator, when there was one, had the highest level of power. Below the dictator was the censors, and then consuls, and then the highest ranking ordinary magistrates. These were the praetorship, plebeian tribunate, aedileship, quaestorship, and military tribunate. These generally were elected for same terms as that of the consuls there served. Priests were also elected magistrate officials, elected originally for life.

Below the consuls were the praetors, who administered civil law, presided over the courts, and commanded provincial armies. They possessed the imperium, and in the absence of a consul could exercise his duties.. They be governors and procurators who controlled the provinces. Romans were eligible to be a praetor at the age of 40.

Curule aediles were officers elected to conduct domestic affairs in Rome, who were vested with powers over the markets, public games, and shows. Every year, two curule aediles and two plebeian aediles were elected.

Finally, at the bottom of magistrate rankings were the quaestors, who usually assisted the consuls in Rome and the governors in the provinces with financial tasks.

Plebeian tribunes and plebeian aediles were considered representatives of the people, and acted as a popular check over the Senate through use of their veto powers, thus safeguarding the civil liberties of all Roman citizens.

The most significant constitutional power a magistrate could hold was that of imperium or command, which was held only by consuls and praetors. This gave the magistrate in question the constitutional authority to issue commands, military or otherwise.

Election to a magisterial office resulted in automatic membership in the Senate for life, unless impeached.

Once a magistrate's annual term in office expired, he had to wait at least ten years before serving in that office again, unless extended..

Plebeians

The vast majority of Roman citizens were commoners of various social degrees. They were the plebeians, had little direct political influence or say over the Senate's decisions or the laws it passed.

In time, the plebeians emerged as a self-organised, culturally distinct group of commoners, with their own internal hierarchy, laws, customs, and interests. in **494 BC**, they rose in protest at their abusive treatment through labour strikes. The patrician Senate was compelled to give them direct access to the written civil and religious laws and to the electoral and political processes. To represent their interests, the plebs elected tribunes, who had veto over the passage of legislation.

The Senate passed decrees that were called senatus consulta, ostensibly "advice" from the senate to a magistrate. Legislation was enacted by the Assemblies

There were two types of legislative assemblies. The first was the comitia ("committees"), which were assemblies of all Roman citizens. The second was the concilia ("councils"), which were assemblies of special interest groups. We will not both abut the latter.

In time, the Roman republic's democratic framework came to consist of the Senate and two different legislative Assemblies, the Comitia Centuriata or centuriated assembly and the Comitia Plebis Tributa or tribal assembly.

The Comitia Centuriate, instituted in about 450 BC, was a military assembly, and decided issues of war and peace, enacted legislation, elected consuls, praetors, and censors, and considered the appeals of Roman citizens convicted of capital crimes. The comitia included plebeians as well as patricians. However, its organisation gave greater influence to the rich. All Roman were assigned to classes and centuriae (centuries) according to their wealth and the equipment they could provide for military service. Voting started with the wealthier centuries, whose votes outweighed those of the poorer.

The Comitia Plebis Tributa was originally formed in 471 BC as the Concilium Plebis, a relatively small and informal advisory assembly, After the passage of the Lex Hortensia (287 BC) its resolutions had the force of law and were binding upon all Roman citizens. The assembly became, in effect, the Comitia Plebis Tributa, and was presided by the consul. Its simpler procedures and the availability of tribunes made this comitia an important legislative body of the middle and later periods of Republican Rome. Its judicial functions, however, were basically limited to fines for noncapital offenses.

The comitia centuriata was the assembly of the centuries (soldiers), and they elected magistrates who had imperium powers (consuls and praetors). The comitia tributa, or assembly of the tribes (the citizens of Rome), was presided over by **a consul** and composed of 35 tribes.

The Comitia Populi Tributa was founded around 357 BC in imitation of the Comitia Plebis Tributa, but it differed from the former in that it was an assembly of the whole Roman people, both plebeians and patricians organized by tribe. This comitia elected the minor magistrates (including questors and military tribunes), held minor trials, and eventually became a regular organ for (non-military) laws passed by the whole people.

Both the Comitia Plebis Tributa and the Comitia Populi Tributa became increasingly influenced by radical tribunes or other demagogic leaders from about 130 BC) onward.

As the Roman citizens voted for their consuls, they also voted for other bureaucrats. Once a year, they chose 8 praetors, 4 aediles, and 20 quaestors.

The quaestorship became the first magistracy sought by an ambitious young man. Later in the century it was decreed that plebeians could hold the office, and the number of quaestors was increased.

In 451 BCE Rome received its first written law code, inscribed upon 12 bronze tablets and publicly displayed in the Forum This Law of the Twelve Tablets was to form the basis of all subsequent Roman private law.

The politics of Rome resolved itself into a two party democratic parliamentary-style scenario, with the optimates and populares representing aristocratic conservative faction and the those advocating the needs of the people.

Mainland Consolidation

Toward the end of the 5th century BC, the Romans began to expand at the expense of the Etruscan states, possibly propelled by population growth. A marauding Gallic tribe swept down and sacked Rome in 390 BC; the invaders departed, however, after they received a ransom in gold. Forty years of hard fighting in Latium and Etruria were required to restore Rome’s power. When Rome became increasingly dominant in the Latin League, the Latins took up arms against Rome to maintain their independence. The ensuing Latin War (340–338 BCE) was quickly decided in Rome’s favour. At the Battle of Populania in 282 BC , Rome finished off the last vestiges of Etruscan power in the region. Rome also secured their position against the immediate threat posed by the nearby Apennine hill tribes.

Rome was now the master of central Italy and spent the next decade pushing forward its frontier through conquest and colonisation. After three wars against the Samnites in the north (the third in 298–290 BC) and the Pyrrhic War (280–275 BC) against Greek towns in the south, Rome was the unquestioned master of Italy. It had taken over 200 years.

The Punic Wars

Rome’s success led it into conflict with Carthage, the ancient Phoenician settlement and the established commercial power in northern Africa, for control of the Mediterranean. The ensuing battles, known as the Punic Wars spanned over a century (264–146 BC).

The first Punic Wars broke out in Sicily in 264 BC as a result of Rome's expansionary posture combined with Carthage's objective of securing the island as its major Mediterranean outpost. The fighting lasted 23 years, until 241 BC, when after immense losses on both sides the Carthaginians were defeated. Carthage paid large reparations and Sicily was annexed as a Roman province

The Second Punic War began in 218 BC. After battling the Romans in Spain, Hannibal, the Carthaginian general, crossed the Alps and invaded Italy, inclusive of 37 elephants. They ravaged the country for 14 years , but without taking Rome. before the survivors withdrew. The successful Roman invasion of the Carthaginian homeland in Africa in 204 BC led to Hannibal's recall. He was defeated by the Roman consul and general Scipio Africanus The Elder, at the Battle of Zama in 202 BC. Carthage ceased to be a military threat.

Rome started the Third Punic War in BC 149. fought entirely on Carthage's territories and centred on the siege of Carthage. In 146 BC the Romans stormed the city, slaughtered most of its population and completely demolished it. The Carthaginian territories were taken over as the Roman province of Africa. Carthage ceased to be.

Conquest of the Mediterranean

After the defeat of Carthage, the Romans set their sights on the entire Mediterranean area. To the east, the Romans defeated Syria, Macedonia, Greece and Egypt, all of which had until then been part of the decaying Hellenic empire. The Romans also destroyed the Archean League and burnt Corinth (146 BC).

The newly acquired lands and the diverse peoples populating them proved a challenge to govern effectively. The Romans organised the conquered peoples into provinces, under the control of appointed governors with absolute power over all non-Roman citizens—and stationed troops in each.

Roman Army

From mid Roman kingdom times, the Roman army was raised by the levy (ie draft or conscription) of citizens for obligatory terms of six years, and divided into five classes according to what fighting equipment they could bring. The patricians formed the eques (horse-mounted) and heavy infantry, the commoners the rank and file. The army was essentially short-term, raised when a war was declared. The commanding officer was the king.

After the coup d'état, the commanding position was given to the consuls, "who were charged both singly and jointly to take care to preserve the Republic from danger.

The tradition of social class determining military duty continued, despite structural changes – the rich equestrians continued to serve together in the equites (cavalry) for instance – but the lower ranks became based upon a mix of social class, age and military experience rather than social class alone. For non-citizens, 25 years in the army was a guaranteed way of gaining citizenship for them and their family.

Amongst the commanders a process began of politicising military command. Military service became a pre-requirement for a number of political posts, Intended initially to ensure that all political leaders had shown dedication and duty serving in the military. The effect was to cause military experience to become of paramount importance to a Roman's political career, with the eventual consequence that armies would become tools for the political goals of their generals, rather than neutrally aligned forces of the state.

During the middle republic period when they had conquered most of Italy, while maintaining the levy system, the Romans bound all the other peninsular Italian states into a permanent military alliance in 264 BC. The latter were required to supply (collectively) roughly the same number of troops as the Romans to joint forces under Roman command. The legions in this phase were always accompanied on campaign by the same number of allied alae (Roman non-citizen auxiliaries), units of roughly the same size as legions. After the Social Wars (91-87 BC), the whole of Italy was Romanised, everybody was Italian, and Roman citizenship (and military obligations) were extended to all equally.

After the Second Punic War (218–201 BC), the Romans acquired an overseas empire, which necessitated standing forces to fight lengthy wars of conquest and to garrison the provinces. The army's character mutated from a temporary force based entirely on short-term conscription to a standing army. The conscripts were supplemented by a large number of volunteers willing to serve for much longer than the legal six-year limit. These volunteers were mainly from the poorest social class, who did not have plots to tend at home and were attracted by the modest military pay and the prospect of a share of war booty. The minimum property requirement for service in the legions was increasingly ignored.

Roman armies were now also accompanied by units of non-Italian mercenaries, who provided specialist functions that Roman armies had lacked, such as adequate cavalry, archers, and slingers.

Gaius Marius (157-86 BC), the Roman general and statesman, who held the office of consul an unprecedented seven times, instituted landmark reforms of the army in 107 BC, which consolidated the trends. He enlarged the legions for greater tactical effectiveness in the changing scales and conditions of warfare. These now contained approximately 4,800 men (as against 3,000 originally) made up of 10 cohorts, each with 6 centuries of 80 men. He also improved the pilum, a javelin, and made large-scale changes to the logistical structure of the Roman army.

Gaius Marius' reforms transformed legions into standing units, which could remain in being for several years, or even decades. This became necessary to garrison the republic's now far-flung territories. Legions started large-scale recruiting of volunteer soldiers enlisted for a minimum term of six years and a fixed salary, although conscription was still practiced. The property requirements were abolished by Marius, so that the bulk of recruits were henceforth from the landless citizens, who would be most attracted to the paid employment and land offered after their service. He set the precedent for the shift from the militia levies of the middle republic to the professional soldiery of the late republic.

Although the officer corps was still composed largely of Roman aristocrats, the rank-and-file troops all were lower-class men. Serving in the legions became less every citizen's traditional civic duty, and more a means of rising in society. This trend was accelerated by the huge influxes of slaves. Freemen with or without land could not compete with slave (free) labour. Signing up with a legion allowed the possibility of loot and land enfranchisement.

The reforms also meant that legions were now more-or-less permanent formations, not just temporary armies deployed according to need (the Latin word 'legion' is actually their word for 'levy'). They were more effective fighting forces. More importantly, they engendered lasting loyalties to their commanders, rather than to Rome.

The Roman legions were invariably stationed outside Rome, originally to defend against invading neighbours and border Gallic tribes and then to conquer new ones. In time, some were stationed in the conquered territories, while others were deployed to defend their new frontiers. Finally, an increasing proportion were mobilised in campaigns for new conquest. It was a sacred principle that the Roman army was never to march into Rome

Late Republican Political Scenario

The Roman economy began to depend on the inflow of wealth from new conquests as against productivity - from external natural resources, provincial taxes and the inflow of slaves. Spending on war became necessary.

The distribution of wealth and standards of living grew even more askew. The patricians and the rich could afford the luxuries, and poor and landless lived oppressed. Social instability increased accompanied by populares demands. A major issue was the allocation of land for war veterans, returning after decades of service and looking for just rewards. The Senate on the other hand needed money to sanction more wars.

As their campaigns grew the army needed more legions. Increasing numbers of legionaries, auxiliaries and mercenaries were recruited from the Italian territories, provinces, newly allied conquered countries, and mercenaries, who only knew their general. This, in turn, meant that troops identified themselves more to their commanders than to the Senate or Rome, which empowered the generals The latter became meganauts of power.

The consuls commanding remained two. The 1-year consular system began to break down, but the generals served for longer durations. Rome acquired a polarised two army two general situation. This would tip the course of Roman history hereon

In Rome proper, the majority of citizens suffered the consequences of living in a nation pre-occupied with its external territories, Roman farmers were unable to raise crops to compete economically with produce from the provinces, and many migrated to the city. For a time the common people were placated with bread and circuses, as the authorities attempted to divert their attention from the gap between their standard of living and that of the aristocracy Slavery fuelled the Roman economy, and its rewards for the wealthy turned out to be disastrous for the working classes.

By the early first Century, the power structure looked ominous. There were two large standing armies, each under a consul, who was also the general in command. The consul(s) were elected by the Comitia Curiata, who were mainly military in composition. The Comitia Curiata was in turn presided over by the consul(s

With a permanent army, it stood to reason that the consul-general jn command should hold office for longer tenure that one year. It was not clarifiable whether a consul was elected ipso facto to be general by the comitia, or whether the latter was an assignment by the Senate. The point however is mute: the consul(s) chaired the Senate. The picture was that the generals were being appointed for longer terms , and the annual tenure of consulship was breaking down.

Iit might. Be noted that the other people’s assembly, the Comitia Plebs Tributa (basically non-military) was also presided over by a consul. It has also not been clarifiable how the two consuls shared the chairmanship of the Senate or the comitiae. One might say, if the two consul colluded, there would be a virtual dictatorship. If they did not, there could be civil war.

In the last century of the republic , consuls and proconsuls governing frontier provinces became increasingly powerful. Their command of standing legions in distant and arduous military campaigns resulted in the allegiance of those units transferring from the Roman state to themselves. They raised many legions that were not authorised by the Senate, sometimes having to use their own resources. As civil wars were resolved, many of these "private" units would be disbanded, only for more to be raised to fight the next war. By the time the republic ended in 31 BC, over 50 legions were in existence, many of which were subsequently disbanded.

The ensuing period of unrest and revolution marked the transition of Rome from a republic to an empire.

Civil Wars

Sulla's Revolt

Gaius Marius (c. 110 – 82 BC) was general who was elected consul seven times. Besides reforming the army, he was a leader of the plebeian reforms.

Lucius Cornelius Sulla Felix (138–78 BC), held office as consul twice. He was the general with the more victories, over the Numidians, Germanic tribes and other Italian states. He sought to maintain senatorial supremacy against the populist reforms.

In a dispute over the command of the war against the Kingdom of Pontus, Sulla marched on Rome in an unprecedented act and defeated Marian forces in battle. The populares seized power once he left with his army for Pontus. He returned victorious in 82 BC, marched a second time on Rome, crushed the populares and their Italian allies, and revived the office of dictator. He restored the primacy of the Senate and limited the power of the tribunes of the plebs. Resigning his dictatorship in 79 BC, Sulla retired to private life and died the following year.

Sulla's military coup was ironically enabled by Marius' military reforms that bound the army's loyalty with the general rather than to the republic, and permanently destabilized the Roman power structure.

First Triumvirate

The First Triumvirate was an informal political alliance among three prominent politicians Gaius Julius Caesar (100-44 BC), Gnaeus Pompeius Magnus (106-48 BC) and Marcus Licinius Crassus (140-53 BC) formed in BC 60.

Marcus Licinius Crassus began his public career as a military commander under Sulla. Following Sulla's assumption of the dictatorship, Crassus amassed an enormous fortune through real estate speculation. Crassus rose to political prominence following his victory over the slave revolt led by Spartacus in 73-71 BC. He also served under Caesar as questor in the Gallic Wars and in various other elected positions. He was consul in BC 55, together with Pompey. He was then appointed governor of Syria in 54 BC, that new province having been conquered by Pompey in the year before.

Julius Caesar was born into an ancient patrician family. His father governed the province of Asia and the latter's sister, Caesar's aunt, married Gaius Marius. Following Sulla's final victory, Caesar's connections to the old regime made him a target for the new one. He left Rome and joined the army, in Asia and Cilicia.

On Sulla's death in 78 BC, Caesar felt safe enough to return to Rome and was elected military tribune. He was further elected questor in 69 BC, and went to serve his quaestorship in Hispania. In 62 BC, Caesar was appointed to govern Hispania Ulterior as propraetor. He was acclaimed "imperator" in 60 BC by his troops for victories in the field.

In 60 BC, Caesar sought election as consul for 59 BC, To stand for the election he had to lay down his command and enter Rome as a private citizen. He won the election. A that point, Caesar was a politician in need of influence and in debt, and soon found a political and financial friend in Crassus.

Gnaeus Pompeius Magnus @ Pompey was a member of the senatorial nobility. Pompey entered into a military career while still young. He rose to prominence serving the dictator Sulla as a commander in the civil war of 83-82 BC. In 84 BC, on Sulla's second march on Rome, Pompey raised three legions to support his march against Marius.
Pompey's success as a general while young enabled him to advance directly to his first Roman consulship without following the traditional cursum honorum. He was elected as consul on three occasions.

He celebrated three Roman triumphs as a commander in three wars and in various other military campaigns. Pompey's successes earned him the honorific "Th Great".

In 60 BC Pompey returned to Italy after his eastern campaign of three years, disbanding his army on arrival at Brindisium. On the streets, he was as popular as ever. In the Senate, Pompey was both admired and feared. His eastern victories earned him his third triumph, which he celebrated on his 45th birthday in 61 BC, seven months after his return to Italy, when he marched in victory parade into Rome.

Plutarch wrote that it surpassed all previous triumphs, taking place over an unprecedented two days. Much of what had been prepared could not find a place in the procession. Inscriptions indicated the nations he defeated (Pontus, Armenia, Cappadocia, Paphlagonia, Media, Colchis, Caucasian Iberia, Caucasian Albania, Syria, Cilicia, Mesopotamia, Phoenicia, Judea and Nabataea) and claimed that 900 cities, 1,000 strongholds, 800 pirate ships and 1,000 pirates were captured, and that 39 cities were founded – including the re-building of Corinth. The captives led in the triumph included the kings of Judea and Comagene, the royal families of Pontus and Armenia, the leaders of the pirates, and hostages. He brought back masses of tributes and increased the Roman treasury immensely.

It could not have been by pure happenstance that these three political super-powers should have converged in Rome and gravitated towards one other. They needed to come to terms or annihilate one another. In 60 BC, Pompey joined Crassus and Caesar in the military-political alliance known as the First Triumvirate Pompey married Caesar's daughter, Julia which helped secure this partnership.

The constitution of the Roman republic had many veto points. They forged the alliance to support each other to overcome opposition in the Senate against their proposals. it emerged publicly during Caesar's first consulship in 59 BC, when they pushed through legislation for the three allies, Caesar secured passage of an agrarian law which helped resettle Pompey's veterans, a law ratifying Pompey's settlements after the Third Mithridatic War against Pontus and legislation on provincial administration and tax collection. Caesar also was placed in a long-term governorship in Gaul. Together, the three men dominated the Roman political system. The alliance triggered substantial political backlash.

After his consulship, Caesar was appointed governor of the vast region of Gaul (north-central Europe) in 58 B.C., where he commanded a large army.

While Caesar and Crassus were lifelong allies, Crassus and Pompey disliked each other and Pompey grew increasingly envious of Caesar's spectacular successes in the Gallic Wars.

The alliance was restabilised in 56 BC at the Luca Conference, which was actually located then in Cisalpine Gaul, Caesars's newly conquered territory. As this was something akin to the famous Yalta Conference[49], I quote Wikipedia's simple summary of the conclusions:

> They agreed that Pompey and Crassus would again stand for the consulship in 55 BC. The elections would be postponed until the winter so that Caesar could support them by sending soldiers home to Rome to vote for them. Once elected, they would extend Caesar's command in Gaul by five years. At the end of their joint consular year, Crassus would get the influential and lucrative governorship of Syria, to use as a base for a grand campaign to conquer Parthia. Pompey would keep Hispania in absentia.
>
> In this way, since after their consulship Pompey and Crassus could expect major provincial commands, all three men would have armies and formal imperium for the next few years.
>
> With an army of his own, Crassus gained the opportunity to rival Caesar's and Pompey's military achievements.
>
> Pompey was also satisfied. More than either of the others he had appeared in recent months to have been drifting away, but in the end he would not have been as well off if the triumvirate had been broken.
>
> As part of the bargain, Cicero was to be obliged to end his criticisms and become a loyal spokesman for the alliance."
> https://en.wikipedia.org/wiki/Luca_Conference

By the use of naked force and political disruption they delayed and intimidated the comitia into electing Pompey and Crassus again as consuls in 55 BC. Caesar's command in Gaul was then renewed for another five years; plum provincial commands placed Pompey in Spain and Crassus in Syria.

Following his second consulship, Crassus as governor of Syria launchpad a military campaign against the Parthan empire, Rome's long-time eastern enemy. Crassus' campaign was a disastrous failure, ending in his defeat and death at the Battle of Carrhae in 53 BC.

Caesar and Pompey, the two remaining allies, maintained friendly relations for a few years, even after Pompey's assumption of a sole consulship in 52 BC and the death of Julia (Caesar's daughter and Pompey's wife).

Through a string of military victories in the Gallic Wars, completed by 51 BC, he greatly extended Roman territory, including the invasion of Britain and building a bridge across the Rhine. These achievements and the support of his veteran army threatened to eclipse the standing of Pompey, who had realigned himself with the Senate after the death of Crassus. A build-up of tensions started in late 49 BC, with both Caesar and Pompey refusing to back down .

On 1 January 49 BC, Caesar stated that he would be willing to resign if other commanders would also do so but, "would not endure any disparity in their [Caesar and Pompey's] forces". Mark Anthony met with senatorial leaders with a more conciliatory message, with Caesar willing to give up Transalpine Gaul if he would be permitted to keep two legions and the right to stand for consul without giving up his imperium (and, thus, right to triumph), but these terms were rejected by the opposition led by Cato, the Younger.

[49] Between Roosevelt, Churchill and Stalin, in 1945. at Yalta, Crimea

The Senate was persuaded on 7 January 49 BC) – while Pompey and Caesar continued to muster troops – to demand Caesar give up his post or be judged an enemy of the state. A few days later, the Senate stripped Caesar of his permission to stand for election in absentia and appointed a successor to Caesar's proconsulship in Gaul. The pro-Caesarian tribunes vetoed these proposals, but the Senate ignored it and moved by resolution empowering the magistrates to take whatever actions were necessary to ensure the safety of the state. Pompey and his allies induced the Senate to demand Caesar give up his provinces and armies. The Senate ordered Caesar to step down from his military command and return to Rome.

Caesar openly defied the Senate's authority and on 10 January 49 BC he crossed the rubicon and marched towards Rome at the head of his army. This began Caesar's Civil War.

Caesar went to Gaul in 58 BC with 4 legions and returned in 49 BC with 11 legions. His auxiliaries were primarily Gallic but included elements such as Germanic cavalry.
Much of the Roman public hated the senators for the assassination., It led to the formation of the Second Triumvirate, the Liberators' civil war, and ultimately to the formation of the Roman empire.

Pompey assembled his troops into nine legions, and could count on two additional legions from Syria, led by Metellus Scipio. Pompey's total strength was roughly 36,000 infantry, with as many as 7,000 cavalry and another 4,200 archers and slingers.

Caesar's Civil War

The war was a four-year-long politico-military struggle, fought in Italy, Illyria, Greece, Egypt, Africa, and Hispania.

Caesar captured Rome and forced Pompey and his allies to withdraw from Italy. He then defeated Pompey's legates in Spain. Caesar was appointed dictator in Rome; he presides over his own election as consul and resigns after eleven days.

In the campaign season for 48 BC, Caesar crossed the Adriatic and advanced on Dyrrachium in Epirus-Macedonia. Pompey pursued, seeking to spare Italy from invasion by concluding the war on Greek soil, and to prevent Caesar from defeating Metelius Scipio's forces arriving from Syria .Pompey defeated Caesar at the Battle of Dyrrhachiium.

Caesar withdrew into Thessaly, in central Greece, where he decisively defeated Pompey at the Battle of Pharsalus. Many former Pompeiians, including Marcus Junius Brutus and Cicero, surrendered after the battle, while others including Metellus Scipio and Cato the Younger went on. Pompey fled to Egypt, where he was assassinated on arrival by agents of the Egyptian Pharaoh Ptolemy XIII.

In 48-47 BC, Caesar intervened in an on-going Egyptian civil war, installing Cleopatra VII as co-pharaoh. He and Cleopatra became lovers, and had a. son, Caesarion, who became Ptolemy XV Caesar, the last king of the Ptolemaic dynasty.

In 47 BC he attacked North Africa, where he defeated Scipio in 46 BC. Scipio and Cato (his principal opponent in the Senate) committed suicide shortly thereafter.

The following year, 46 BC, Caesar defeated the combined armies of the last of the Pompeiians under his former lieutenant Titus Labienus in the Battle of Munda, leaving him in a position of near unchallenged power and influence in 45 BC

He was made dictator perpetuo (dictator in perpetuity or dictator for life) in 44 BC.

After assuming control of government (in 49 BC), Caesar began (presumably as dictator) a programme of social and governmental reforms, including the creation of the Julian calendar. He gave citizenship to many residents of far regions of the Roman republic. He initiated land reform and support for veterans. He centralised the bureaucracy of the republic, and was eventually proclaimed "dictator for life" (dictator perpetuo) in 44 BC.

Mark Anthony

Marcus Antonius (83–30 BC), commonly known as Mark Antony, was a Roman politician and general who played a critical role in the transformation. He was born a member of a ancient Antonia family with patrician and plebeian roots. His mother was a third cousin of Julius Caesar.

In 57 BC, Antony began his military career as chief of the cavalry of Aulus Gabinius, proconsul of Syria. Antony achieved his first military distinctions after securing important victories quelling a Judean rebellion against Hyrcanus, Pompey's Rome client-ruler, in 56 BC.

The following year, in 55 BC, Gabinus intervened in another rebellion, in Ptolemaic Egypt. With Rome's client king restored, he garrisoned two thousand Roman soldiers in Alexandria. Antony claimed years later to have first met Cleopatra, the then 14-year-old daughter of Ptolemy XII, during this campaign..

Antony was a relative and supporter of Julius Caesar. He secured a position on Caesar's military staff in 54 BC, joining his campaign in Gaul. Antony demonstrated excellent military leadership. Despite a temporary alienation later in life, Antony and Caesar developed friendly relations which would continue until Caesar's assassination in 44 BC.

After a year of service in Gaul, Caesar dispatched Antony to Rome to formally begin his political career with election as quaestor in 52 BC, as a member of the populares faction. Assigned to assist Caesar, Antony returned to Gaul and commanded Caesar's cavalry. Following his year in office, Antony was promoted by Caesar to the rank of Legate and assigned command of two legions. Antony remained on Caesar's military staff until 50 BC, helping mopping-up actions across Gaul to secure Caesar's conquest.

With the war over, Antony was sent back to Rome to act as Caesar's protector against Pompey and the other Optimates. Antony was appointed the College of Augurs, an important priestly office responsible for interpreting the will of the gods by studying the flight of birds. All public actions required favourable auspices, granting the college considerable influence. Antony was then elected as one of the ten tribunes plebeian for 49 BC. In this position, Antony could protect Caesar from his political enemies, by vetoing any actions unfavorable to his patron.

Antony summoned a meeting of the Senate to resolve the conflict: he proposed both Caesar and Pompey lay down their commands and return to the status of private citizens, which was not agreed. Antony then made a new proposal: Caesar would retain two of his eight legions and the governorship of Illyricum, if he was allowed to stand for the consulship in absentia. This was rejected and Anthony was expelled from the senate meeting by force. Antony fled Rome, fearing for his life, and returned to Caesar's camp on the banks of the Rubicon.

Caesar used Antony as a pretext for marching on Rome. As tribune, Antony's person was sacrosanct, and so it was unlawful to harm him or to refuse to recognize his veto. Three days later, on 10 January, Caesar crossed the Rubicon. During the southern march, Caesar placed Antony as his second in command.

During the. Civil War, Antony was appointed administrator of Italy while Caesar eliminated political opponents in Greece, North Africa, and Spain. Antony joined Caesar in Greece by March 48 BC commanding his naval resources.

Post-Assassination Republic

His populist and authoritarian reforms angered the elites, who began to conspire against him. On the Ides of March (15 March 44 BC), Caesar was assassinated by a group of rebellious senators led by Marcus Junius Brutus and Gaius Cassius Longinus, who stabbed him to death on the steps of the Forum.

Much of the Roman public hated the senators for the assassination. A wax statue of Caesar was erected in the Forum displaying the 23 stab wounds. A crowd who had amassed there expressed their anger at the assassins by burning the Senate House.

Two days after the assassination, Mark Antony summoned the Senate and managed to work out a compromise in which the assassins would not be punished for their acts, but all of Caesar's appointments would remain valid. Antony hoped to avoid large cracks in government as a result of Caesar's death. Simultaneously, Antony diminished the goals of the conspirators.

The result unforeseen by the assassins was that Caesar's death precipitated the end of the Roman Republic. The Roman lower classes, with whom Caesar was popular, became enraged that a small group of aristocrats had sacrificed Caesar. Antony capitalized on the grief of the Roman mob and threatened to unleash them - perhaps with the intent of taking control of Rome himself.

Brutus and Cassius fled Italy and were massing an enormous army in Greece. Antony needed soldiers, money and legitimacy for any action he took against them.

Second Triumvirate

To Anthony’s surprise and chagrin, when his will was read, Caesar had named his grandnephew Gaius Octavius his sole heir, bequeathing him the immensely potent Caesar name as well as making him one of the wealthiest citizens in the republic.

Gaius Octavius (63 BC–AD 14), also known as Octavian, and later Augustus Caesar, came from a Roman equestrian family. His father had been governor of Macedonia and his mother was the niece of Julius Caesar.

Upon hearing of his adoptive father's death, Octavius abandoned his studies in the Greek city of Apollonia in Illyria and sailed across the Adriatic Sea to Brindisium.

Arriving in Rome on 6 May 44 BC, Octavian found consul Mark Antony, Caesar's former colleague, in an uneasy truce with the dictator's assassins. They had been granted a general amnesty on 17 March 44 BC, yet Antony had succeeded in driving most of them out of Rome with an inflammatory eulogy at Caesar's funeral, mounting public opinion against the assassins.

Unlike Sulla, Julius Caesar failed to revert power to the state when the threat of Pompey had been removed. Not just keeping his position as de factor ruler of the state, immediately on his return from defeating Pompey, he namied his grand-nephew Gaius Octavius (Octavian) as the heir to his title, a wholly unconstitutional act. In everything but name, the army had placed the first emperor on the throne of Rome.

Octavius adopted the name of became Gaius Julius Caesar Octavianus or Octavian, the son of the great Caesar, and inherited the loyalty of much of the Roman populace. Octavian, aged only 18, proved to have considerable political skills, and quickly gained the support and admiration of Caesar's friends and supporters, and even optimates who saw him as the lesser of two evils (compared to ambitious Anthony), Among the latter was Cicero.

Antony had lost the support of many Romans and supporters of Caesar when he initially opposed the motion to elevate Caesar to divine status. Anthony attempted without success to secure Senate approval to be given Cisalpine Gaul, which instead was awarded to Decimus Julius Brutus Albinus, one of the conspirators. When his consulship was over, Mark Anthony returned to Cisalpine Gaul, and sought to take it by force. He became a public enemy. The Senate sent the two consular armies. While they won, they were themselves both killed.

Meanwhile, with Cicero's influence, Octavian was inducted into the Senate in 43 BC. Octavian was at the same time building up a private army in Italy by recruiting Caesarian veterans. He also won over two of Antony's legions with the enticing offer of monetary gain. He was granted the imperium to command, to assist the incumbent consuls against Anthony, but more importantly legitimising his command of his own troops.

Anthony was defeated by senate's forces in Apr 43 BC. Octavian then refused to aid any further offensive against Antony. In July, he sent an embassy of centurions, who demanded the two consulships left vacant and also that the decree should be rescinded which declared Antony a public enemy. When this was refused, Octavian marched on the city with eight legions. He encountered no military opposition in Rome and on 19 August 43 BC was elected consul with his relative Quintus Pedius as co-consul.

Meanwhile, Antony formed an alliance with Lepidus. **Marcus Aemilius Lepidus** (89–12 BC), was a Roman general and statesman. He was a close ally of Julius Caesar. He was also the last elected chief priest (pontifex maximus) of the republican era, and Caesar's last Master of the Horse (magister equitum).

Octavian moved quickly to enact legislation confirming Octavian's adoption as Caesar's heir and establishing courts to condemn Caesar's assassins in absentia. They also repealed the declaration of Antony as a public enemy. Octavian then moved north to treat with Antony under Lepidus' protection. With the Caesarian soldiers' urging, Octavian and Antony reconciled. And Octavian would marry Antony's step-daughter, Clodia.

The three men then established themselves as the triumviri rei publicae constituendae (the latter words indicate a causa or commission for the reconstitution of the republic.).The triumvirate however emerged as a force to reassert Caesarian control over the western provinces and wage war on the liberatores led by the men who assassinated Julius Caesar.

On 27 November 43 BC the **lex Titia** was passed that established the Triumvirate of Octavian, Mark Anthony and Lepidus for five years, until the end of 38 BC. It was renewed in 37 BC for another five years before expiring in 32 BC, and was ultimately extended to 27 BC.

The Second Triumvirate was an extraordinary commission and magistracy conferring on the three triumvirs practically absolute power, that overrode those of all the other magistrates, both in Rome and the provinces, including .The law also provided that the triumvirs would exercise their powers sine provacatione (ie without appeal to the people). This gave them power over the life and limb of all Roman citizens. In BC 42, Caesar was deified as Divus Julius, and Caesar Octavian became Divi filius ("Son of the Divine").

The Second Triumvirate brought back proscription. It engaged in the legally sanctioned murder of a large number of its opponents, pursuing the senatorial and equestrian orders.

They used this authority to engage in the largest proscriptions in Roman history. Their aims were to avenge Julius Caesar's assassination, eliminate political enemies, and acquire their properties.. There were 2,000 names on the list in total, and a handsome reward for information on where someone on the list was hiding. Anyone who tried to save people on the list was added to the list. Pertinently, the material belongings of the dead victims were to be confiscated.

Plutarch described the proscriptions as a ruthless and cutthroat swapping of friends and family among Antony, Lepidus, and Octavian. Octavian allowed the proscription of his ally Cicero, Antony the proscription of his maternal uncle Lucius Julius Caesar, and Lepidus his brother, although only Cicero would ultimately be killed as a result of these concessions.[10] The triumvirate also divided the western Roman world: (1)Antony would receive Cisalpine and Transalpine Gaul, (2) Lepidus would receive Narbonensis and Spain, and (3) Octavian (then the junior partner) would receive Africa, Sardinia, and Sicily.

Octavian and Antony were pushed to cooperation, in part by their soldiers, and the triumvirs had their legal arrangement renewed for another five years in 37 BC.

Octavian and Antony then prepared to wage war on the liberatores with forty total legions. After the murder of Caesar, Brutus and Cassius (the two main conspirators, also known as the Liberatores) left Italy and taken control of all the Eastern provinces (from Greece and Macedonia to Syria, and of the allied Eastern kingdoms. In Rome the three main Caesarian leaders (Antony, Octavian and Lepidus) controlled almost all the Roman army in the west.

The triumvirs decided to leave Lepidus in Italy, while the two main partners moved to Northern Greece with their best troops (28 legions).They defeated Caesar's killers, the Liberatores, at the Battle of Philippi in Macedonia, in 42 BC. Brutus and Cassius committed suicide.

They then divided the government of the republic between themselves, and ruled as defacto dictators.. Antony was assigned Rome's eastern provinces, including the client kingdom of Egypt (ruled by Cleopatra) and given command of the war against Parthia. Octavian took the west, including Rome. Lepidus was left with a corner of Africa.

Eventually, after Antony's defeat in Parthia and Octavian's victory over remnant Pompeiians in Sicily, Octavian forced Lepidus from the triumvirate in 36 BC.

Antony married Octavian's sister, Octavia. Despite this marriage, Antony carried on a love affair with Cleopatra, who bore him three children., further straining Antony's relations with Octavian. In 33 BC disagreements between Antony and Octavian caused a split between the remaining triumvirs. Antony, meanwhile, married Cleopatra, intending to use the fabulously wealthy Egypt as a base to dominate Rome.

In 31 BC, the Senate, at Octavian's direction, declared war on Cleopatra and proclaimed Antony a traitor. Later that year, Antony was defeated by Octavian's forces at the Battle of Actium, on the west coast of Greece Antony and Cleopatra fled to Egypt where, having again been defeated at the Battle of Alexandria in 30 BC. they committed suicide.

Augustus Caesar, Princeps Civitas

Gaius Julius Caesar Octavianus (later known as Augustus Caesar) was the great-nephew, adopted son and heir of Julius Caesar. On accepting Caesar's will, he became by far the wealthiest person in Rome.

With Antony dead, Octavian became the undisputed master of the Roman world. He adopted the name of Gaius Julius Caesar Octavianus. In 27 BC, Octavian was granted the ancient title of Augustus (meaning “exalted ” or “venerable”, a name incorporating a deity status.. He would thenceforth be simply “Augustus” or “Augustus Caesar”.

Although dynastic pretences crept in from the start, formalising this in a monarchic style remained politically perilous. Octavian worked instead through established republican forms to consolidate his power.

After the demise of the Second Triumvirate, Augustus restored the outward façade of the free republic, with governmental power vested in the Roman Senate, the executive magistrates and the legislative assemblies. He maintained autocratic authority by having the Senate grant him lifetime tenure as a Roman Consul, combined with those of a tribune o the plebs; later he added the role of the censor and finally became pontifex maximus (chief priest) as well.

He rejected monarchical titles, and called himself Princeps Civitatis (First Citizen) juxtaposed with his title Augustus. He never claimed the title “emperor” for himself. He finally adopted the title “Imperator Caesar Augustus” - Imperator meant commander. This was pretty much the same as “Emperor” in the Roman context.

The Roman Empire began with the “reign of Augustus Caesar. History calls him “Emperor Augustus “ from this time. The power of the Senate was limited and became an organ to support the emperor.

Augustus's official name was Imperator Caesar Divi Filius Augustus. There is no Latin word for “Emperor”. The translation would be “Imperator”. Over time, “Caesar” came to be an equivalent form of address during the Augustan lineage, eg. “Hail Caesar!”

Augustus dramatically expanded the empire, inter alia annexing Egypt and completing the conquest of Hispania. Beyond the frontiers, he secured the empire with a buffer region of client states and made peace with the Parthian empire through diplomacy. He reformed the Roman system of taxation, developed a network of roads, with an official courier system, established a standing army and the Praetorian Guards, as well as official police and fire-fighting services for Rome, and he rebuilt much of the city during his reign.

He remained as the sole master of the Roman world and proceeded to establish the Principate as the first Roman "Emperor".

Augustus died in AD 14 at age 75, probably from natural causes. He was succeeded as emperor by his adopted son Tiberius, his wife’ Livia's son, and also former husband of Augustus' only biological daughter Julia.

Pax Romana

The Pax Romana (Roman peace) was a roughly 200-year-long timespan identified the Golden Age of Roman history of increased as well as sustained imperialism, of relative peace and order, of prosperous stability and hegemony and regional despite several revolts and. wars, and continuing competition with. Parthia It is traditionally dated as commencing from the accession of Augustus in 27 BC and concluding in 180 AD with the death of Marcus Aurelius, the last o the five “Good Emperors”. The Roman achieved its greatest territorial extent and its population reached a maximum of up to 70 million people.

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The Roman Empire
(27 BC –476 AD)

The period between Augustus and Diocletian is called High Empire, while the Low Empire is the era between Diocletian and the fall of the Roman Empire in the West. This period is further divided into the following periods: the Principate and the Dominate.

High Roman Empire
(27 BC – 305 AD)

The Principate.

The Principate was characterised by the reign of a single emperor (princeps) and an effort on the part of the early emperors to preserve the illusion of the formal continuance, in some aspects, of the Roman Republic.

The Julio-Claudian dynasty (14-68). Between the years 14 and 68 the heirs of Augustus succeeded him: Tiberius, Caligula, Claudius and Nero. This dynastic succession was interrupted when emperor Nero died and a civil war broke out in the year 68. Jesus Christ was born in 4 BC and Judea was annexed as a province of Rome in AD 6, under Augustus.

Year. Of the Four Emperors(68-69). Four emperors fought for the power and finally the war was won by Vespasian, part of the Flavian dynasty.

The Flavian dynasty (69-96). They comprised Vespasian, Titus and Domitian, which period of stability and expansion, including the destruction of Jerusalem and the Jews.

The Antonines dynasty (96-193). This the generic name given to Nerva, Trajan, Hadrian, Antoninus Pius, Marcus Aurelius and Commodus. These emperors had a very similar policy to the Flavians. The Roman empire reached its greatest extent during this period.

Year of the Five Emperors (193). When Commodus was murdered, there were five claimants for the title of Roman emperor: Pertinax and Didius Julianus held office for two months each, both killed, to. be succeeded by Septimus Severus.

The Severan dynasty (193-235) Septimius Severus reigned for 17 years, and was succeeded by four members of his lineage, who together ruled for 23 years, and two outsiders who together ruled fo one year. All were murdered, executed or lynched, except Septimus who died of natural causes.

Crisis of the Third Century (235-285). The power of Rome, capital of the Empire, was weakened over time. Between 235 and 300 Rome's only priority was to defend its borders from the continuous attacks by the Barbarians and from the Sasanians (from Persia).

The pressure of these raids prompted the army to assume power in 235. This era is known as the Military Anarchy and lasted about fifty years.

As a consequence of these constant wars the army was very expensive to maintain, and thus the Empire became crippled with debts. This in turn impoverished the population and many lost their identity and values. Many put in doubt their religious beliefs, especially with the arrival of Christianity.

In the 50 years, there were 29 emperors. Of these 18 were murdered or died suspiciously, Only two died of natural causes and one of suicide, while five were killed in action, with. one unknown.

The average term in office was 1,85 years, 12 served for less than a year, the record being 22 days. The two longest-serving were Quintillus (17 years), and Valerian and Probus (both 6 years.) Nine were proclaimed by their armies, and most of the rest were the sons or relatives incumbents nominated by them i(n case they died)and declared by the Senate.

Successful usurpers were usually either provincial governors, commanders of a large grouping of Roman legions, or prefects of the Praetorian Guards. The problem of usurpation seems to have lain in the lack of a clear tradition in law and popular will of an agreed method of ensuring succession, and also in the maintenance of large standing armies .
The greater the manpower a provincial governor had under his command, the greater the temptation to make a bid to the throne.

Dominate (284-476)

This second phase of the Roman empire is best characterised by the empire being divided into west and east, with two emperors or caesars, one ruling each, and the republican trappings of the Senate and magistry virtually disappearing.

It began with the reign of Diocletian in AD 284, following the Third Century Crisis of AD 235–284, and ended in the west with the fall of the Western Roman Empire in 476, while in the east its end is disputed, as either occurring at the close of the reign of Justinian (565) 565) or of Heraclius (641). (We are not going into the history of the east in this exercise.)

The Tetrarchy (284-324). Gaius Aurelius Valerius Diocletianus, also known as Diocletian (23-311) was born to a family of low status in the province of Dalmatia. He rose through the ranks of the military early, eventually becoming a cavalry commander for the army of Emperor Carus. After the deaths of Carus and his son on a campaign in Persia, he was proclaimed emperor by the troops, taking the name Diocletian.

Diocletian's reign ended the Crisis of the Third Century. He served for 20 years and reformed the empire. During his rule he inaugurated the Dominate period, by instituting the Tetrarchy.

He appointed fellow officer, Maximian, as co-emperor in 286. Diocletian reigned in the east and Maximian reigned in the west On 1 March 293, Diocletian delegated further, appointing Galenus and Constantius as junior co-emperors (each with the title “caesar”) under himself and Maximian, respectively. Under the Tetrarchy or "rule of four", each emperor would rule over a quarter-division of the empire.

Diocletian abdicated in 305, and Maximian did likewise. A total of eight other emperors and caesars held office during the Tetrarchy, with this difference that now the incumbent caesar elevated his successor.

Diocletian was a strong and able leader and effectively split the empire into two parts. Provinces were slowly divided into smaller units to avoid concentration of power and military capacity in the hands of one man.

Diocletian secured the empire's borders and purged it of all threats to his power. Galerius, aided by Diocletian, campaigned successfully against Sassanid Persia, the empire's traditional enemy. In 299, he sacked their capital, Ctesiphon. Diocletian led the subsequent negotiations and achieved a lasting and favourable peace.

Diocletian separated and enlarged the empire's civil and military services and reorganised the empire's provincial divisions, establishing the largest and most bureaucratic government in the history of the empire. He established new administrative centres closer to the empire's frontiers.

Bureaucratic and military growth, constant campaigning, and construction projects increased the state's expenditures and necessitated a comprehensive tax reform. From at least 297 on, imperial taxation was standardised, made more equitable, and levied at generally higher rates.

The Diocletian Persecution (303–312), the empire's last, largest, and bloodiest official persecution of Christians failed to eliminate Christianity in the empire.

Diocletian's reforms fundamentally changed the structure of Roman imperial government and helped stabilise the empire economically and militarily, enabling the empire to remain essentially intact for another 150 years despite being near the brink of collapse in Diocletian's youth.

Weakened by illness, Diocletian left the imperial office on 1 May 305, becoming the first Roman emperor to abdicate the position voluntarily. He lived out his retirement on the Dalmatian coast.

Although effective while he ruled, Diocletian's tetrarchic system collapsed after his abdication under the competing dynastic claims of the sons of Maximian and Constantius.

The Low Empire

(305 AD – 476 AD)

Constantinian dynasty (306-363)

Flavius Valerius Constantinus, known as Constantine The Great [50](27-337), was the son Constantius one of the four rulers of the Tetrarchy His mother was St Helena. Constantine served with distinction under the Roman emperors Diocletian and Galenus After his father's death in 306, Constantine became emperor. He eventually emerged victorious against the other co-emperors to become the sole ruler of the Roman empire by 324.

Constantine enacted numerous reforms to strengthen the empire. He restructured the government, separating civil and military authorities. To combat inflation, he introduced the solidus, a new gold coin, became the standard for more than a thousand years. The Roman army was reorganised to consist of mobile units and garrison troops to better counter internal threats and barbarian invasions. He created the appointment of "magister militum". It referred to the senior military officer or war theatre commander, the emperor remaining the supreme commander, like the Greek strategos. Constantine pursued successful campaigns against the tribes on the and resettled territories abandoned by his predecessors.

Constantine abolished all laws limiting the Christians' civil rights, by the Edict of Milan.. He forbade the branding of slaves on the forehead, abolished penalties for celibacy, and offered financial support to poor parents to discourage infanticide. He banned gladiator games. Unilateral divorce was limited to cases of serious crimes.

Constantine developed a system of client states along the Danube and Rhine taking advantage of the neighbouring tribes' dependence on commerce with the empire.

50 https://en.wikipedia.org/wiki/Constantine_the_Great

He appointed his three sons, Constantine II, Constantius II, and Constans, caesars between 328 and 333, but none of them was promoted to Augustus during his lifetime. In effect, Constantine reintroduced the principle of lineage for succession to the emperorship.

Constantine died on 22 May 337. In Sep 337, the three brothers assumed the title of Augustus and divided the empire at a meeting in Pannonia: Constantine II received the western, Constans the central, and Constantius the eastern regions.

Constantine was to be the last emperor of the unified empire. He legalised Christianity as a religion of the empire.

The capital of the empire was moved to the ancient city of Byzantium from 324, which had been reconstructed by him, was consecrated and renamed Constantinople in 330, and continued to be the capital of the Byzantine empire thereafter. .The capital of the west had been moved earlier in 286 by Diocletian to Milan - and remained so util 402 when it was moved to Ravenna.

Constantine convened the First Council of Nicaea, Bithynia in 325, a landmark council of Christian bishops which drew up original the Nicene Creed. It defined the agreed articles of faith of orthodox Christianity. Constantine was baptised a Christian on his deathbed in 337.

Valentinian dynasty (364–392)

The Valentinianic or Valentinian dynasty was a ruling house of five generations of dynasts, including five emperors, from 364 to 392 and from 425 to 455, with an interregnum (392–423) during which the Theodosian dynasty ruled and eventually succeeded them. The Theodosians intermarried into the Valentinian house, and ruled concurrently in the east after 379.

Under the Valentinians, dynastic rule was consolidated and the division of the empire into west and east became increasingly entrenched. The empire was subject to repeated incursions along its borders, with the Danube frontier eventually collapsing in the northeast and barbarian invasions in the west eventually reaching Italy, and culminating with the sack of Rome in 410

Theodosian dynasty (379–457)

The Theodosian dynasty was a Roman imperial family that produced five reigning emperors from 379 to 457. The dynasty's patriarch was Theodosius The Elder, an outstanding and highly decorated commander under the Valentinians, whose son,Theodosius I (also called Theodosius The Great I), was made emperor of the east in 379, and ruled for 15 years until his death (by natural causes) in 395.

After the death of its incumbent Valentinian II in 392, Theodosius I became emperor of the west as well, uniting the halves for the last time. He proceeded to appoint his two sons emperors, Arcadia to the east and Honorius to the west.

Theodosius's daughter, Galla Placidia, became an empress by marriage to Constantinus III, emperor of the west, a had a son who also became west emperor Valentinian III. The dynasty of Theodosius married into, and reigned concurrently with, the ruling Valentinian dynasty (364–455)

Arcadia would rule in the east for 13 years (395-408) followed by his son, Theodosius II for 42 years (408-450; followed by his son-n-law, Marcian for 7 years (450-457),), or 55 years in all. leading into the Byzantine empire. Honorius would rule for 28 years (395-423), unfortunately leading to the fall of the west.

Theodosius I passed away in 395 of pedema.The rule of the Theodosian dynasty saw the final East-West division of the Roman Empire

(Back to TOC)

(C2) Turning Points

Christian Persecution

The persecution of Christians began with Nero in 64 AD. Christians had been subject to intermittent local discrimination in the empire, but emperors prior to Diocletian were reluctant to issue general laws against the religious group. In the 250s under the reigns of Decius and Valerian, Roman subjects including Christians were compelled to sacrifice to Roman gods or face imprisonment and execution, but there is no evidence that these edicts were specifically intended to attack Christianity. After Gallienus' accession in 260, these laws went into abeyance.

The Diocletian or Great Persecution was the last and most severe persecution of Christians in the Roman empire. In the years 303-306, the emperors Diocletian, Maximian, Galerius and Constantinus issued a series of edits rescinding Christians' legal rights and demanding that they comply with traditional religious practices. Later edicts targeted the clergy and demanded universal sacrifice, ordering all inhabitants to sacrifice to the gods. The persecution varied in intensity, weakest in Gaul and Britain where only the first edict was applied, and strongest in the Eastern provinces. The persecutory laws were nullified by different emperors (Galerius' edict of 311) at different times, but the Edict of Milan in 313 by emperors Constantine and Licinius has traditionally marked the end of the persecution.

Persecutory policies varied in intensity across the empire. Whereas Galerius and Diocletian were avid persecutors, Constantius was unenthusiastic. Later persecutory edicts, including the calls for universal sacrifice, were not applied in his domain. His son, Constantine, on taking the imperial office in 306, restored Christians to full legal equality and returned property that had been confiscated during the persecution.

Galerius ended the persecution in the East in 311, but it was resumed in Egypt, Palestine and in Asia Minor in by his successor, Maximinus. Constantine and Licinius, Severus's successor, signed the Edict of Milan in 313, which offered a more comprehensive acceptance of Christianity than Galerius's edict had provided. Licinius ousted Maximinus in 313, bringing an end to persecution in the East.

The persecution failed to check the rise of the Church. By 324, Constantine was sole ruler of the empire, and Christianity had become his favoured religion. Although the persecution resulted in death, torture, imprisonment, or dislocation for many Christians, the majority of the empire's Christians avoided punishment.

Theodosius I and Christianity.

While born into a Christian family, Theodosius was not baptised until 380, when a serious sickness occurred.. During his reign Theodosius, while holding strictly to the orthodox tenets of the Nicene Creed, attempted to be conciliatory with the heretical parties but was not successful.

The reputation of Theodosius I as a “Great” likely stemmed in part from his devotion to Christianity and his impact on the faith’s development in the Empire. His defence of his

Christian beliefs and practices have been seen as central to his legacy, and justification of his wars against imperial usurpers of opposing views.

Theological debates had surrounded the Christian religion particularly in the tensions between the Nicene and Arian Christological factions. The Nicene Creed was adopted at the Council of Nicaea in 325, called by Constantine to sort things out. While open-minded, Constantine himself leant toward Arianism and was finally baptised on his deathbed by an Arian-inclined bishop.

All emperors after Constantine were Christian, either Nicene or Arian, except Julian "The Apostate" (361-363), the last pagan emperor. He rejected Christianity and tried to restore the earlier imperial Hellenic religion.

Christianity had spread massively in the empire. Scholars estimate that by 300, they made up 22% of the population of the empire. In legalising Christians, Constantine not so much allowed them as acknowledged them. By Theodosius I's ascension (in fact earlier by 350) the constituted some 33 million or more than half of the empire's. population of 60 millions[51]. They were concentrated in Italy, but were spread far and wide in the empire. The Nicene faith held sway in Italy and the east, but the west provinces, including the Germanic populations northward were mainly Arian.

Theodosius I remained a firm adherent of the Nicene doctrines. On 27 Feb 380, Theodosius I, emperor of the East, together with Gratian and Valentinian II, co-emperors of the West, jointly
Issued the Edict of Thessalonica, which made the catholic orthodoxy the Nicene Creed the state religion of the Roman empire, and condemned belief in other Christian creeds as heresies and authorised their punishment. The creed was further finalised at the First Council of Constantinople by Theodosius I in May-JuL 381. Because it was so unique and monumental, I quote it here in full:

> "EMPERORS GRATIAN, VALENTINIAN AND THEODOSIUS AUGUSTI EDICT TO THE PEOPLE OF CONSTANTINOPLE
> It is our desire that all the various nations which are subject to our Clemency and Moderation, should continue to profess that religion which was delivered to the Romans by the divine Apostle Peter, as it has been preserved by faithful tradition, and which is now professed by the Pontiff Damasus and by Peter, Bishop of Alexandria, a man of apostolic holiness. According to the apostolic teaching and the doctrine of the Gospel, let us believe in the one deity of the Father and of the Son and of the Holy Spirit, in equal majesty and in a Holy Trinity. We order the followers of this law to embrace the name of Catholic Christians; but as for the others, since, in our judgment they are foolish madmen, we decree that they shall be branded with the ignominious name of heretics, and shall not presume to give to their conventicles the name of churches. They will suffer in the first place the chastisement of the divine condemnation and in the second the punishment of our authority which in accordance with the will of Heaven we shall decide to inflict.
> GIVEN IN THESSALONICA ON THE THIRD DAY FROM THE CALENDS OF MARCH, DURING THE FIFTH CONSOLUTE OF GRATIAN AUGUSTUS AND FIRST OF THEODOSIUS AUGUSTUS."
> **Codex Theodosianus xvi, 1,2** [52]

Acknowledgment of the Nicene doctrine is made the test of State recognition. The citation of the Roman See as the yardstick of correct belief is significant The last sentence of the Edict indicates that the Emperors contemplate the use of physical force in the service of orthodoxy; this is the first recorded instance of such a departure

[51] https://www.a2schools.org/cms/lib/MI01907933/Centricity/domain/2403/hum-pdf/Growth-of-Chr.pdf
[52] https://en.wikipedia.org/wiki/Edict_of_Thessalonica

Theodosius cracked down on pagan religious practices. A series of decrees issued between 389 and 391 effectively sounded the death knell of Paganism. Temples were closed, the sacred fire at the Temple of Vesta in Rome was extinguished and the order of Vestal Virgins disbanded, and the many prominent pagan sites were attacked. In 391, Theodosius refused the restoration of the Altar of Victory in the Roman senate. He also put an end to the Olympic games.

Theodosius I launched the transformation of the Roman empire into the Christian Roman empire, as it continued for the next 1000 years in the East. There had been 35 Popes before him, and they now installed the emperor in. office

Barbarians in the Roman Army

From the time of Augustus, the Roman army comprised legions and auxiliaries. The former were exclusively Roman citizens, but extended to common folk volunteering for long-service careers – as against the earlier system of annual conscription based on class distinctions. The auxiliaries comprised second-class citizens as well but included foreigners or “barbari”, voluntarily recruited or contracted into cohorts of infantry, cavalry or mixed, and attached to legions.

In the early 3rd century, the Roman military was organised into several provincial armies under the command of the provincial governors, a smaller reserve under the command of the emperor, A Third component of field armies comprised temporary formations . They were composed of reserve and/or provincial detachments. However, due to the frequent wars, they remained for several years and came under the command of the emperor, with their own recruitment systems.

By the 4th-century the army was became increasingly dependent on barbarian recruitment, which took various forms:

. – From Augustan days, it had been and continued to be the practice to establish barbarian military settlements, as a source of recruits for the army. Rome in fact subsidised these communities in return for military service. Groups of Germanic or Sarmatian tribespeople were granted land to settle in the empire, in return for military service. Most commonly each community was under a treaty obligation to supply a specified number of troops to the army each year. .

. – In the 4thCentury, the establishment of military settlements was more systematic and on a much larger scale. **“Foederati**” were peoples and cities bound by a treaty, known as foedus, with Rome. During the Roman empire it was used to describe foreign states, client kingdoms or barbarian tribes to which the empire provided benefits in exchange for military assistance. The term was also used for groups of barbarian mercenaries of various sizes who were allowed to settle within the empire.

.- The term foederati was extended to the practice of subsidising entire tribes, including the Franks, Vandals and Visigoths in exchange for providing warriors to fight in the Roman armies. Alaric I began his career leading a band of Gothic foederati.

. - Over a period, the Roman army comprised a sizable numbers of long-service foederati, many promoted and honoured through the ranks. Many irregular and allied units would have been converted to regular units. Many of these would be due for retirement and looking to settle down on the expected allocation of land. Scholars report a large number of barbarian names in late 4th century in army nominal rolls, as well as units with barbarian names and even dress.

. – Inevitably, there was also the emergence of significant numbers of senior officers with barbarian names in the regular army, and eventually in the high command itself. In the early 5th century, the Western Roman forces were often controlled by barbarian-born generals or generals with some barbarian ancestry. According to an analysis, about a quarter of the sample of army officers was barbarian-born in the period 350–400.

. - A minority of barbarian recruits were enlisted by compulsion, namely barbarians who surrendered and tribes who were defeated by the Romans, and obliged, as a condition of peace, to undertake military service.

In contrast to Roman recruits, the majority of barbarian recruits were volunteers, drawn by conditions of service and career prospects – and ultimately citizenship.

At the civil war Battle of Philippi, the Triumvirs had 19 legions and the Republicans 17 legions, totalling over 200,000 troops altogether, inclusive of auxiliaries.

In the time of Septimus Severus (193-211) the Roman army reached around 500,000 total individuals, with 33 legions (182,000 legionaries) and more than 400 auxiliary units of around 250,000 auxiliaries. Of the latter, around 75,000 served as cavalry.

An estimate[53] of the size of the Roman army under Constantine I in 337 had 67 legions (350,000 troops) plus 226,00 auxiliaries plus 18, 000 garrison forces, and a navy of 64,000, giving a total of 645,000 in the armed forces. No figure of non-citizens or foederati was available. By the 5th century, the Roman army would be divided into East and West.

The Goths

The Goths were a major Germanic people of many tribal groups, who migrated from the Scandinavian-Baltic region southwards into central and eastern Europe in the course of the 1st to 4ht centuries, impinging on the Rhine-Main-Danube borders of the Roman empire.

These invasions were of two types: (1) migrations of whole peoples with their complete German patriarchal organisations intact and (2) bands, larger or smaller, of emigrants in search of land to settle, without tribal cohesion but organized under the leadership of military chiefs. The Goths were of the first type, heavily dependent on finding food and other living resources, and therefore less sedentary, more menacing and more mobile.

One mainstream migrated south-eastwards across central Europe. Over time, they broke up into two great divisions, the Ostrogoths and the Visigoths. Around 215, they appeared around the Black Sea and settled in the Danubian lands. to the east and the west respectively, but united as a nation.

The attacks of the Goths on the Roman empire in the East began about 247. They then destroyed the army of emperor Decius, killing him in 251, and continued to maraud the cities of the Black Sea and the Aegean until decisively defeated by Claudius II in 269..

But meanwhile the Goths began the dismemberment of the empire by penetrating and ultimately occupying one of its provinces - the province of Dacia, north of the Danube, which had been conquered nearly a hundred and fifty years before by Trajan. It was the last European province to be acquired by Rome; it was the first to fall away. The Roman period ended about the year 270.

53 https://en.wikipedia.org/wiki/Size_of_the_Roman_army

In the 4th century the pressure of the Germanic advance was increasingly felt on the frontiers, and this led to a change in the government of the empire which was to have notable consequences. In May 330 Constantine I transferred the capital from Rome to Constantinople, but the empire, continued to be administered successfully from a single centre. This would not remain the case for long,

Constantine the Great endeavoured to secure the lower Danube frontier by fortified camps and castles. He built a wall in the north-east corner of Thrace. Towards the end of his reign Constantine concluded a forced treaty with the Visigoths. They became **foederati** (federates) of the empire; that is, they undertook to protect the frontier and to supply a certain contingent of soldiers to the imperial army in case of wars. In return for this they received subsidies which, theoretically a supply of corn, was actually paid in money.

Through this treaty, Dacia became nominally a dependency of the empire, and Constantine might boast that he had in a sense recovered Dacia. The peace lasted for a generation, and during this time the Visigoths, unable to press from the southward or westward, took to more settled habits and began to learn the arts of agriculture.

The Visigoths held Dacia, and also parts of what are now Moldavia and Walachia; the Ostrogoths lived in the steppes beyond the Dniester. These two peoples remained independent of each other.

The German tribes as a whole, including the Goths, had undergone massive technological, social, and economic changes after four centuries of contact with the Roman empire. From the first to fourth centuries, their populations, economic production, and tribal confederations grew, and their ability to conduct warfare increased to the point of challenging Rome. They were no longer barbarians, but mature societies.

Historians report that The Visigoths had no king. Their constitution was republican.
The gaus (polity) acted in common, and the gaus chiefs had a predominant influence in guiding the council of the nation and were recognised as natural leaders in the case of war. On the other hand, the Ostrogoths had a king

After this peace in the reign of Constantine there is a pause for a generation in the hostilities between the Empire and the Danubian Goths.

The Danubian Gothic peoples began to face internal strife and increasing intrusion and attacks by the emergent Huns in the late 4th century, which destabilised them.

As a result, several groups sought refuge within the Roman empire. The pace of the Germanic incursions increased dramatically during the reigns of the emperor Valens and his successors. Soon after, starvation, high taxes, hatred from the Roman population, and governmental corruption turned the Goths against their hosts.

Visigoths

The Visigoths swarmed. In a successful invasion of the Roman empire, beginning in 376, they first delivered a crushing defeat of the Roman army, including the death of the emperor Valens, at the Battle of Adrianople in 378, in the province of Thracia, not far from Constantinople, The rebellion was led by their gaus chieftain, Fritigern, and involved two major groups of Visigoths, largely the Thervings as well as the Greutungs.

In 380, the Greuthungs invaded the Western province of Pannonia History is unclear whether; they were defeated by the forces of Gratian, who was then emperor of the West, or they were peaceably signed a deal that settled them in Pannonia.

The Thervings went south into Macedonia and Thessaly, provinces of the Eastern empire.. Theodosius I marched to meet them but was unsuccessful and his army defeated.. Having ended the invasion of Pannonia, Gratian directed his generals to help drive the Goths back into Thrace, which they successfully accomplished by the summer of 381.

After years of war, the defeat of two Roman armies and continued stalemate, Theodosius I sanctioned peace negotiations, and peace was declared on 3 October 382.

In the peace, the Romans recognised no overall leader of the Goths and the Goths were nominally incorporated into the Roman empire. The Goths would be drafted into the Roman army and in special circumstances could be called upon to field full armies for the Romans. What differed from traditional Roman practice was that the Goths were given lands inside the Roman empire itself, in the provinces of Scythia, Mœsia and possibly Macedonia, under their own authority and were not dispersed. This allowed them to stay together as a unified people with their own internal laws and cultural traditions. To seal the agreement, Theodosius threw the Goths a large feast.
.
Roman commentators, while acknowledging that the Goths could not be militarily defeated, applauded the peace as a victory for the Romans who had won the Goths over to their side and turned them into farmers and allies.

The Goths, like many barbarian peoples, had earlier been converted to Arianism. The settlement paved the way for Theodosius I to expand Nicene Christianity, the official religion of the empire.

Fritigern died around 382. Possibly in 391, a Gothic chieftain named Alaric was declared king by the Visigoths. He then led an invasion into Eastern Roman territory outside of the Goths' designated lands. Alaric was defeated by Theodosius I and his general Flavius Stilicho in 392, who forced Alaric back into Roman vassalage.

In 392, Theodosius I was made emperor of the west as well, on death of Gratian. But there was a usurper, Eugenius. In 394, Alaric led a force of Visigoths as part of the Western army of Theodosius I against the usurper. At the Battle of Frigidus, around half the Visigoths died fighting. Theodosius army won the battle, and Alaric was given the title comes (count) for his bravery. However, tensions between the Goths and Romans grew as it seemed clear that the Roman generals had sought to weaken the Goths by making them bear the brunt of the fighting and exulted in their heavy losses. Alaric was also enraged he had not been granted a higher office in the imperial administration. He expected promotion to the position of magister militum and command of regular Roman units. He persuaded his people to "seek a kingdom by their own exertions rather than serve others in idleness." Alaric mutinied and began to march against Constantinople.

The Empire Splits

On 17 January 395, Theodosius I died of an illness, leaving the empire finally and firmly divided between his two young sons Arcadia (18 years) to the East and Honorius (6 years) to the West, leaving the latter under the guardianship of Flavius Stilicho his half-Gothic magister militum in the West, while Flavius Rufinus, his Eastern counterpart, proceeded to exercise the same role in respect of Arcadia in the East. They behaved in every way like supremos ,or consuls but in name.
As could be expected the two hated one another and disputed the division of territory. They manipulated the young emperors and events accordingly, not the least Alaric and the Visigoths.

After his rejection of Stilicho's terms, Alaric invaded Greece in 395-6, marauding down to the Peloponnese and plundering Athens in the process. Then he sued for peace. There is the suggestion that Rufinus colluded with the Goths, to forestall a threatened invasion by the West. Stilicho did in fact arrive by sea and pushed back the Goths to Epirus.

There is a curiously worded report[54] that Stilicho was then forced to send "some of his Eastern forces home". As far as can be made out, there were in fact Eastern forces in the field at that time fighting Alaric under the command directly of Arcadia, whether or not alongside Stilicho is not clear, and comprising or at least including Gothic "mercenaries". Apparently Arcadia ordered the recall of part or all of the latter, under their commander Gaines, also a Goth.

On reaching Constantinople, Gaines murdered Rufinus. The latter was succeeded by Eutropius, an Assyrian-born eunuch, who in turn appointed Gaines magister militum for Thrace. Alaric returned to his ho

While Stilicho carried on an indecisive invasion, Alaric continued to oppose him. In 396, Eutropius declared Stilicho a public enemy, and in 399 appointed Alaric magister militum for Illyricum. This restored to Alaric the entitlement to gold and grain for his followers and negotiations were underway for a more permanent settlement.

In 399, Eutropius fell from power. The new Eastern regime now felt that they could dispense with Alaric's services and in 401 they nominally transferred Alaric's province to the West. This administrative change removed Alaric's Roman rank and his entitlement to legal provisioning for his men, leaving his army—the only significant force in the ravaged Balkans—as a problem for Stilicho.

When the eastern government stopped their supplies in 401,Alaric and his men, desperate for provisions, moved into northern Italy, where they were held at bay by Stilicho at the battles of Pollentia and Verona during the spring and summer of 402.

Stilicho now changed his tactics and began to use the Goths as allies in his aim to secure Illyricum for the western empire. Alaric received the insignia of magister utriusque militiae for Illyricum not from Arcadius but from the western court. The Goths moved back to their former possessions in Epirus, from which they threatened Thessalonica.

in 405, another substantial body of Goths and other barbarians, this time from outside the empire, crossed the middle Danube under their leader Radagaisus, and advanced into northern Italy, where they plundered the countryside and besieged cities and towns Although the imperial government was struggling to muster enough troops to contain these barbarian invasions, Stilicho cornered Radagaisus near Florence and starved the invaders into submission.

Meanwhile, Alaric awaited as Stilicho faced further difficulties from more barbarian. Sometime in 406 and into 407, more large groups of barbarians, primarily Vandals, Sueves, and Alans, crossed the Rhine and invaded Roman Gaul

About the same time a rebellion occurred in Roman Britain, under a common soldier who was declared co-emperor by his soldiers Constantine III, which rebellion spread to Gaul and was not successfully checked by Stilicho's' forces.
Stilicho's position was weakened. . During this crisis in 407, Alaric again marched on Italy, taking a position in Noricum (modern Austria), where he demanded a sum of 4,000 pounds of gold to buy off another full-scale invasion.

[54] https://en.wikipedia.org/wiki/Alaric_I

Stilicho paid Alaric the 4,000 pounds of gold nevertheless. This agreement, sensible in view of the military situation, fatally weakened Stilicho's standing at Honorius's court.

In the East, Arcadius died on 1 May 408 and was replaced by his son Theodosius II. Stilicho seems to have planned to march to Constantinople, and to install there a regime loyal to himself. He may also have intended to give Alaric a senior official position and send him against the rebels in Gaul. Before Stilicho could do so, a bloody coup against his supporters took place at Honorius's court led by Honorius's minister, Olympius. Agents of Olympius promised Stilicho his life, but instead betrayed and killed him, also in 408 .

Alaric was again declared an enemy of the emperor. Olympius's men then perpetrated a massacre of thousands of barbarians who were quartered in Italy, including women and children. Up to thirty thousand of the survivors sought protection and redress by joining Alaric in Noricum. Italy was left without effective indigenous defence forces thereafter.

As a declared 'enemy of the emperor', Alaric was denied the legitimacy that he needed to collect taxes and hold cities without large garrisons, which he could not afford to detach. He again offered to move his men, this time to Pannonia, in exchange for a modest sum of money and the modest title of comes (count), but he was refused because Olympius's regime regarded him as a supporter of Stilicho.

Alaric’s Siege of Rome

When Alaric was rebuffed, he led his force of around 30,000 men—many newly enlisted and understandably motivated—on a march toward Rome to avenge their murdered families. He moved across the Julian Alps into Italy, bypassing the imperial court at Ravenna and in September 408 he menaced the city of Rome, imposing a strict blockade. No blood was shed this time; After much bargaining, the famine-stricken citizens agreed to pay a ransom of 5,000 pounds of gold, 30,000 pounds of silver, 4,000 silken tunics, 3,000 hides dyed scarlet, and 3,000 pounds of pepper. Alaric also recruited some 40,000 freed Gothic slaves.

Honorius was again dissuaded from making an agreement by Olympius. Instead five legions were summoned from Dalmatia to protect Rome in future. Their commander, Valens, engaged Alaric in open warfare and lost his whole force.

The terms offered by Alaric for lifting the blockade, included his expectation of being named head of the Roman army, which Honorius was not prepared to grant.

Alaric, then proceeded to not only besiege Rome again in late 409, but also to proclaim a leading senator, Piscus Attilus, as a rival emperor, from whom Alaric then received the appointment. he desired. Then, Attalus—accompanied by Alaric—marched on Ravenna and after receiving unprecedented terms and concessions from the legitimate emperor Honorius, refused him and instead demanded that Honorius be deposed and exiled. Fortunately for him, ships carrying 4,000 troops arrived from Constantinople, restoring his safety. Alaric deposed Attalus, perhaps to re-open negotiations with Ravenna.

Negotiations were carried out between Iovius, Honorius' praetorian prefect, and Alaric. The latter scaled down his demands to the point that he would be satisfied with land in the two Norican provinces, which lay exposed to the Danubian frontier and paid little tax to the treasury. He would take any grain that could be made available to his hungry people and dropped his demands for gold. On these modest terms there could be friendship between his people and the Romans. Iovius rejected even these conditions.

A renegade Gothic force, led by Sarus, attacked Alaric. He interpreted it as bad faith from Honorius. As his patience had reached its end, he marched on Rome for a third and final time. The city was captured by assault on August 24, 410, and given over for three days for the Gothic forces to plunder.

Roman booty was not the focus of Alaric's sack of Rome; he came for needed food supplies. The invaders were not gentle in their treatment of property as substantial damage was evident and the Roman world was shaken by the fall. There is a parallel report saying during the sack the population took refuge in the city's churches and were in large part spared by the Goths, who were themselves Christian.

Other reports say that many other Italian communities beyond the city of Rome itself fell victim to the forces under Alaric. They destroyed all the cities which they captured, especially those south of the Ionian Gulf. And they killed all the people, as many as came in their way, both old and young alike, sparing neither women nor children.

But for Alaric the sack of Rome was an admission of defeat. Everything he had hoped for, had fought for went up in flames. Imperial office, a legitimate place for himself and his followers inside the empire, these were now forever out of reach. When the looting was over Alaric's men still had nowhere to live and fewer future prospects than ever before.

Three days after the sack, Alaric marched his men south to Campania, from where he intended to sail to Sicily—probably to obtain grain and other supplies—when a storm destroyed his fleet. During the early months of 411, while on his northward return journey through Italy, Alaric took ill and died at Consentia in Bruttium. His cause of death was likely fever.

Alaric was succeeded in the command of the Gothic army by his brother-in-law, Ataulf, who married Honorius' sister, Gala Placida three years later. Alaric's Goths remained together inside the empire, going on to settle in Gaul. There, in the province of they put down roots and created the first autonomous barbarian kingdom inside the frontiers of the Roman empire. Honorius granted the once Roman province to them, sometime in 418 or 419.

Not long after Alaric's exploits, there was a rapid emergence of Germanic barbarian groups in the West who began controlling many western provinces. These peoples included the Vandals in Spain and Africa, Visigoths in Spain and Aquitaine, Burgundians along the upper Rhine and southern Gaul, and Franks on the lower Rhine and in northern and central Gaul.

Vandals

The Vandals were a Germanic who first inhabited southern Poland. They migrated and settled in Silesia Expanding into Dacia, the Vandals received permission to settle in Pannonia by Constantine The Great in 330. Pushed by raids by the Huns from the east the Vandals migrated west crossing the Rhine into Gaul in 406 and in 409, they crossed the Pyrenees into the Iberian peninsula, settling in Gallaecia (northwest) and Baetica. (south-central Iberia).

In 429, under king Genseric (r 428–477), the Vandals entered North Africa, and by 439 they established a kingdom which included the Roman province of Africa, Sardinia and Sicily, among others. They fended off several Roman attempts to recapture the African province. Removal of the African provinces seriously cut Rome’s food chain, as well as taxes, weakening it further.

Arising from some betrayal over the proposed linking of the royal house on both sides, the Vandals sacked the. city of Rome for fourteen days, historically giving the definition to the term “vandalism”.

Attila, the Hun

The Huns were a nomadic people who lived in Central Asia, the Caucasus, and Eastern Europe between the 4th and 6th centuries. By 370, the Huns had arrived on the Volga, and by 430, they had established a vast, if short-lived, dominion in Europe, conquering thw Goths and many Germanic peoples the living outside Roman borders, and causing many others to flee into Roman territory.

Attila (c. 406–453), frequently called Attila the Hun, was the ruler of the Huns from 434 until his death in 453. Under him, the Huns crossed the Danube twice, and plundered the Balkans. This was followed in 441 by an invasion of the Eastern Roman empire, the success of which emboldened Attila to invade the West, conquering many Gothic peoples in these areas, including the Ostrogoths. He also attempted to conquer Roman Gaul crossing the Rhine in 451 and marching as far as Aurelianum (Orleans), before being stopped in the Battle of the Catalaunian Plains in 451.

In 452, Attila launched an invasion of Italy, passing through Pannonia into Venetia, where he laid siege to Aquileia. Since Aetius, the Roman general, had been unable to blockade the Julian Alps, he instead reinforced the city garrison to force Attila into a siege, or otherwise risk Roman forces cutting off his potential retreat. The siege lasted for some time, and Attila was considering withdrawing, when the city fell in a renewed assault and he razed it to the ground. Aquileia had been a centre of government (with an imperial residence), commerce and finance (with a mint), military defence, and Christianity. Attila then followed up with an unimpeded ravaging of the province of Venetia.

Attila then proceeded to raid Italy, with Aetius able to do little more than harass Attila at best. He invaded the northern provinces, but was unable to take Rome. It was only when an embassy including Pope Leo (400-461) arrived that Attila finally ended his invasion. Some hisorias suggest it was as likely also a result also of famine, disease, and an Eastern Roman Army approaching the Hunnic settlements near the Tisza.

He planned for further campaigns against the Romans but died in 453. After Attila's death, the Goths led a revolt against Hunnic rule, after which the Hunnic Empire quickly collapsed.

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(C3) Fall of the Western Roman Empire

In the East, Arcadia died in 408, and was succeeded by Theodosius II, who was then a boy of seven, and ruled for 42 years. The role of guardian (and number one in the empire) was taken up by the prefect of the East, Anthemius, a benign leader who even cemented relations between east and west and was for a while cross-appointed on the throne of the West by the Eastern emperor Theodosius II. The latter’s reign was generally stable and constructive, and ended in 450, when he fell off a horse and died. The Theodosian dynasty continued a while longer with Marcian, Arcadian’s son-in-law, for. six years until 457 and was followed by Leo I of the Leonid dynasty. This began the Byzantine empire which lasted nearly 1000 years until 1453, and which fades out of this exercise at this point. The East passes out of our story at this point.

In the West, Honorius passed away in 423, after ruling for 28 years. We might notice however that , from 407 to 411, the Roman army in Britain had declared Constantine III emperor, and Honorius recognised him as co-emperor in 409. We are already aware that from 409 to 410, Priscus Attalus was emperor, declared by Alaric, the Goth. We might notice that Honorius also made Constantius III, son-in-law of Theodosius I, co-emperor for six months in 421, before he died of illness; he had been defacto ruler since 411. There was yet another usurper, Johannes, a general, who was elevated to emperor by reigning consul during the vacancy in 423-424. Theodosius II of the East contested the appointment with force and installed Valentine III, grandson of his own father, as emperor of the West in 425. The latter ruled for 29 years to 455, and ended the dynasty in the West.

The western command structure differed substantially from the eastern. In the West, after 395, the emperor was no longer in direct command of his diocesan military chiefs, who instead reported to a military generalissimo, known as the magister utriusque militiae (literally "master of both cavalry and infantry"). This officer was additionally n direct command of the single but large western imperial escort army based near Milan.

This anomalous structure had arisen through the ascendancy of the half–Vandal military strongman Stilicho. After Stilicho's death in 408, a succession of weak emperors ensured that this position continued, under Stilicho's successors until the dissolution of the Western empire in 476.

The West was losing control of its vast provinces. The Goths and other barbarians were on the move, invading the empire at will, and the Roman frontier had effectively collapsed. Roman townships were fortified. Honorius had moved the capital to Ravenna in 406 because it was a very well-defended city. The Roman army proper was significantly non-Roman, even a good proportion of the officers, while it relied on its auxiliaries for force of numbers, and these were mainly foederati and barbarians under terms. By the invasion of Attila in 441 Rome hardly any indigenous defence force.

Olympius, successor to Stilicho in 408 was killed in 410 by his successor. Among the latter, mention must made of **Aetius** (390-454). As a boy, Aetius was at the service of the imperial court. Between 405 and 408 he was kept as hostage at the court of Aetius, after which he was sent to the court the Huns, where he would stay throughout much of the reign of Charaton who died in 420. He was able to bring an army of Huns to support Johannes, whose service he had joined. After he sent back the Huns, he was made comes et magister militum per Gallias (or Gaul).

He was the most influential man in the Western empire for two decades (433–454). He managed the many attacks and negotiated the many settlements of the barbarian foederati throughout the west. Notably, he was able to muster a large Roman and allied (foederati) army in the Battle of the Catalaunian Plains, ending a devastating invasion of Gaul by Attila in 451. For two decades he brought stability lo Gaul. He has been called the "last of the Romans". He was not able however able to prevent the invasion of Italy by Attila in 452

Aetius was murdered by the emperor Valentinian III in September 454, and this event marked the sunset of Roman political power. Six months later Valentinian was slain by two of Aetius's retainers, and the throne of the Western empire became the stake in the next cycle of intrigues.

Last of the Western Emperors (455-476)

In the last 21 years o the West empire, there were nine emperors listed, with five reigning for 15 months or less, one of these a boy of five or six. Five were murdered, two died of illness, one (the boy) abdicated, and two fate unknown. Only effective emperor was Anthemius, elevated to the post out of desperation by the Eastern emperor, who ruled for five years (467-472) and was himself murdered.

Flavius Ricimer (418-472) was a Romanised Germanic general who effectively ruled the remaining territory of the Western from 461 until his death in 472, with a brief interlude in

which he contested power with Anthemius. Deriving his power from his position as magister militum, Ricimer exercised political control through a series of puppet emperors
The inside story discloses that almost all were emplaced in office and manipulated by their magister militum, who by virtue of their commanding position, had acquired enormous power.

According to a source, Ricimer served under Aetius alongside Majorian whom he befriended.

A power vacuum was created in the Western empire after the events of 454 and 455, which saw the consecutive murders of Aetius and Valentine III. The Roman senator Petronnius Maximus proclaimed himself emperor. Petronius, however, was killed by a Roman mob immediately prior to the Vandal sacking of the city in 455. After the sack, the Visigothic King Theodoric II proclaimed as as emperor, Avitus, the Roman military commander in Gaul. In return for Theodoric's support, Avitus agreed to allow the Visigoths to enter Suevi-controlled Hispania. The new emperor, with the Visigoths under his command, marched on Rome to secure the throne. Avitus named the Visigoth Remistus as magister militum, a position which had been vacant since Aetius's death.

Avitus subsequently appointed Ricimer as a comes or count of the empire, a prominent military position. By this point, however, the Western empire encompassed only the Italian Peninsula and portions of southern Gaul.

Ricimer raised an army and navy from the Germanic mercenaries, and commenced campaigns directed against "barbarian" tribes in conflict with the empire. Ricimer achieved his first important victory in 456, when he defeated the Vandals in the Battles of Agrigentum and Corsica.
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After his Mediterranean victory, Ricimer was appointed by Avitus as magister militum praesentalis. Ricimer used his new position to assist his colleague Majorian in plotting against Avitus, who had not yet been recognised as emperor of the West by Marcian, the Eastern emperor. Ricimer and Majorian raised a military expedition against Avitus. The two defeated an imperial force commanded by Remistus, who was executed. Avitus fled to Gaul to gather support and an army from his Visigoth and Gallic followers. A month later Avitus returned but was heavily defeated by Ricimer. The emperor was captured and finally executed.

With the Western throne vacant, the new Eastern Emperor, Leo I, granted Ricimer the title of patrician and the rank of magister militum in 457, and appointed Majorian to replace Ricimer in his Italian command. Without a Western Emperor, Leo hoped to use Ricimer as his effective viceregent in the West.

Being Germanic and Arian faith, Ricimer was ineligible for the imperial throne he was left with the options of dissolving the Western empire and ruling as an official viceroy of Leo or exerting his power through a puppet emperor. Majorian led his field army north defeating the Alamanni and was proclaimed emperor by his troops. Realizing Majorian's potential as a puppet, Ricimer induced Leo to give his consent to this arrangement.

Majorian proved to be a capable ruler and soon distanced himself from his magister militum. Majorian next waged war against the Vandals under Genseric, and was defeated in Spain. During his absence, Ricimer convinced the senate to turn against the emperor, who soon disbanded his army and returned to Italy. Ricimer arrested him, tortured and finally beheaded him in 461.

Ricimer ruled the West without an emperor for three months. Facing pressure from the senate and Italian aristocracy, Ricimer named the undistinguished senator Libius Severus as his puppet emperor. Though Severus was recognized by the senate, the Eastern Emperor Leo I refused to recognize him as his Western counterpart.

The Vandals had continuously raided the Italian coast since 455, wreaking havoc upon the Italian economy. Because Leo did not recognise Severus, he refused to provide assistance to the Western government. Constantinople had made peace with Genseric in 462, but had refused to intervene in the Vandal raids.

Due to diminished tax revenues and with the key armies of the West under generals in opposition since the murder of Majorian, Severus, despite his docile nature, represented an obstacle to Ricimer's power. Upon Severus' death in 465 (rumoured to have been poisoned by Ricimer,) he proceeded to rule the West for eighteen months without an emperor as he waited for Leo to name Severus' successor.

In 467 Leo, faced with increased Vandal impingement, named Anthemius,the commanding general of the Illyrian Army, as Western emperor. Leo sent Anthemius to Italy with an army led by the commanding general of the Dalmatian Army, Marcellinus, who had previously rebelled against Ricimer. Anthemius was to secure the Western throne and recapture North Africa from the Vandals. Needing the support of the Eastern empire, Ricimer was forced to accept the appointments. Ricimer diplomatically married Anthemius' daughter and for some time lived in peace with Anthemius.

Anthemius granted Marcellinus the rank of patrician, in an effort to counterbalance the authority of Ricimer. (In the East, it was established practice for there to be two supreme commanders). Both Leo and Anthemius had seen the difficulty Western emperors had in maintaining control over the Western military with the existence of a single unchallenged supreme commander.

In 468, Leo organised a grand campaign against the Vandals in North Africa, to which the East and West would commit substantial forces. The commanding general of the Thracian army, brother-in-law of Leo, assumed supreme command over the joint East-West assault, with Marcellinus commanding the Western forces. Ricimer, under the overall command of Marcellinus, commanded a large portion of the Western forces.. Ricimer's behaviour raised suspicions that he secretly wanted the expedition to fail, which it ultimately did following the disastrous Battle of Cape Bon. Most of the joint armada was destroyed, with Marcellinus himself being assassinated by his own soldiers while in Sicily, perhaps at the instigation of Ricimer.

The failed joint expedition against the Vandals bankrupted the Western and Eastern Empires and greatly reduced their military might. Upon hearing of the disastrous defeat, the Visigoths resumed their wars of expansion against the West and the Vandals resumed raids on Italy. Ricimer was left as the sole Supreme Commander of the West. Marcellinus' death served to widen the divide between the emperor and Ricimer.
Open warfare broke out between Ricimer and Anthemius in 472. Ricimer, along with his barbarian mercenary units (including the soldiers of Odoacer) marched on Rome. The siege lasted for five months. Ricimer finally entered the city and succeeded in starving the supporters of the emperor. Both sides appealed to the field army in Gaul, but the Burgundian commanding general of Gaul, Gundobad, supported his uncle Ricimer. Anthemius was beheaded on July 11, 472. Ricimer then proclaimed Olybrius as emperor in 473, the candidate for emperor that he and Genseric had once favoured, who died of dropsy within seven months.

Ricimer's rule lasted until his death from a haemorrhage on 19 August 472, six weeks after deposing Anthemius. His title of patrician and position as supreme commander were assumed by his nephew Gundobad. According to one source, Gundobad executed Anthemius on his uncle's orders.

Once in power, Gundobad elevated Glycerius, a general with the title the count of the domestics , to the position of emperor. Not long after, Gundobad left for Burgundy where his father, Gundioc, had died; to claim the kingship thereof.

Gundobad's departure may have been connected with the arrival of a new emperor, Julius Nepos, who had the support of the Roman Emperor in Constantinople. Once Julius Nepos landed he deposed Glycerius in 474, whom he made a bishop.

In 475, Julius Nepos appointed Orestes as a patrician and his magister militum. By 28 August 475, Orestes, at the head of the foederati, managed to take control of the government in Ravenna. Julius Nepos fled to his home, Dalmatia, where he continued to reign until his assassination in 480.

Orestes was born of an aristocratic Roman family from Pannonia. After Pannonia was ceded to Attila, Orestes joined Attila's court, reaching high position as a secretary (notarius) in 449 and 452. In 449 Attila sent him twice to Constantinople with his ambassador.

With the emperor far away, Orestes elevated his son Romulus to the rank of Augustus so that the last Western Roman emperor was known as Romulus Augustus. He was only a child, somewhere between 12 and 15 years old, at the time he became emperor in 475.

However, Nepos reorganised his court in Salona, Dalmatia and received homage and affirmation from the remaining fragments of the Western empire beyond Italy and, most importantly, from Constantinople, which refused to accept Augustulus, Zeno having branded him and his father as traitors and usurpers.

Duc Italiae

Odoacer

Odoacer was of Gothic origins, associated with the Germanic people of Gaul. By 470, Odoacer had become an officer in what remained of the Roman army, on the side of Ricimer When Orestes was made magister militum in 475 by Julian Nepos, Odoacer became head of the Germanic foederati (the Scirian–Herulic foederati) of Italy.

About this time the foederati, who had been quartered in Italy all of these years,petitioned Orestes to reward them for their services, by granting them lands and settling them permanently in Italy". Orestes refused their petition, and they turned to Odoacer to lead their revolt against Orestes.

Orestes was killed along with his brother outside Ravenna. The Germanic foederati, as well as a large segment of the Italic Roman army, then proclaimed Odoacer rex ("king") on 23 August 476. Odoacer then advanced to Ravenna and captured the city, compelling the young emperor Romulus to abdicate on 4 September. Odoacer was moved by Romulus's youth and his beauty to not only spare his life but give him a pension of 6,000 solidi and sent him to Campagna to live with his relatives.
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Upon hearing of the accession of Zeno to the throne, the senate in Rome sent an embassy to the Eastern emperor and bestowed upon him the Western imperial insignia. The message was clear: the West no longer required a separate Emperor. Zeno accepted their gifts and this essentially brought to end any puppet emperors in the West.

The Eastern emperor then conferred upon Odoacer the title of patrician and granted him legal authority to govern Italy in the name of Rome, as **dux Italiae**.

Zeno also suggested that Odoacer should receive Nepos back as Emperor in the West. Although he accepted his titles, Odoacer did not invite Julius Nepos to return to Rome, and the latter remained in Dalmatia until his death. Odoacer was careful to observe form, however, and made a pretence of acting on Nepos's authority. Following Nepos's murder in 480, Zeno became sole emperor.

Odoacer retained the Roman administrative system, and his rule was efficient and successful. He evicted the Vandals from Sicily in 477. Upon Nepos's murder in 480, Odoacer invaded Dalmatia to punish the murderers. He did so, executing the conspirators, but within two years also conquered the region and incorporated it into his domain.

Odoacer ruled autonomously and introduced few important changes into the administrative system of Italy. He had the support of the Roman senate, and was able to distribute land to his followers without much opposition. Unrest among his warriors led to violence in 477–478, but no such disturbances occurred during the later period of his reign. Odoacer was an Arian Christian and rarely intervened in the affairs of Nicene church.

When the master of soldiers of the Eastern empire asked for Odoacer's help in 484 in his struggle to depose Zeno, Odoacer invaded Zeno's westernmost provinces. The emperor responded first by inciting the Rugii of Dacia to attack Italy. During the winter of 487–488 Odoacer crossed the Danube and defeated the Rugii in their own territory.

Zeno also appointed Theodoric The Great, king of the who was menacing the borders of the Eastern empire, to be king of Italy, turning one troublesome ally against another. Theodoric invaded Italy in 489 and by August 490 had captured almost the entire peninsula, forcing Odoacer to take refuge in Ravenna. The city surrendered on 5 March 493. Theodoric invited Odoacer to a banquet of reconciliation; instead of forging an alliance, Theodoric killed the unsuspecting king

Theodoric the Great

Many Gothic tribes had been brought under the Hunnic empire during the latter's expansion under Attila. The progressively gained their independence in the latter 5th century, most importantly the Ostrogoths under their king Theodoric the Great,

The Ostrogoths were the eastern branch of the Goths, settled and established a powerful state in Dacia. After the collapse of the Hunnic empire in 454, large numbers of Ostrogoths were settled by Emperor Marcian in the Roman province of Pannonia as foederati. Unlike most other foederati formations, the Goths were not absorbed into the structure and traditions of the Roman military but retained a strong identity and cohesion of their own.
In 460, during the reign of Leo I because the payment of annual sums had ceased, they ravaged Illyricum. In previous years, a large number of Goths had entered service in the Roman army and were a significant political and military power in the court of Constantinople. The period following saw a complex struggle among the Goths and the new Eastern Emperor Zeno. In this conflict, alliances shifted regularly, and large parts of the Balkans were devastated by it.

In the end, in 481, Zeno came to terms with Theodoric. Parts of Moesia and Dacia were ceded to the Goths, and Theodoric was named magister militum and consul for 484. Barely a year later, Theodoric and Zeno fell out, and again Theodoric's Goths ravaged Thrace. It was then that the thought occurred to Zeno and his advisors to kill two birds with one stone, and direct Theodoric against another troublesome neighbour of the Empire - the Italian kingdom of Odoacer. Theodoric invaded Odoacer's kingdom and eventually conquered Italy.

The Ostrogothic Kingdom, officially the Kingdom of Italy existed under the control of the Germanic Ostrogoths in Italy and neighbouring areas from 493 to 553. Under Theodoric, its first king, the Ostrogothic kingdom reached its zenith, stretching from modern southern France in the west to the modern western Serbia in the southeast. Most of the social institutions of the late Western Roman empire were preserved during his rule. Theodoric called himself Gothorum Romanorumque rex ("King of the Goths and Romans"), demonstrating his desire to be a leader for both peoples.

Starting in 535, the Byzantine empire invaded Italy under Justinian I The Ostrogothic ruler at that time, Witiges, could not defend the kingdom successfully and was finally captured when the capital Ravenna fell. The Ostrogoths rallied around a new leader, Totila, and largely managed to reverse the conquest, but were eventually defeated. The last king of the Ostrogothic Kingdom was Teia

Transition to the Middle Ages

For a time, Theodoric, king of the Ostrogoths ruled a kingdom that included Italy, Gaul, and Spain. After his death in 526, the empire of the Ostrogoths was shattered, and changes took place which led to the rise of independent Germanic kingdoms in Gaul and Spain. In Gaul Clovis, the king of the Franks, had already established his power, and in Spain a Visigoth kingdom with its capital at Toledo now asserted its independence.

Under Justinian (527–565), the Byzantine[55] empire seemed in a fair way to recover the Mediterranean supremacy once held by Rome. The Vandal kingdom in Africa was destroyed, and in 552 the Byzantines shattered the power of the Ostrogoths in Italy, The "exarchate of Ravenna" was established as an extension of Byzantine power, the Ostrogoths were forced to give up the south of Spain, and the Persians were checked.

With the death of Justinian, however, troubles began. In 568 the Lombards appeared in Italy, which they overran as far south as the Tiber. In Asia, the emperor broke Persian power and succeeded even in extending Roman dominion. However, Italy, save for Ravenna itself and a few scattered seacoast towns, was thenceforth lost to the empire of which in theory it still formed a part.

The withdrawal of Byzantine influence from Italy produced one result the importance of which it is impossible to exaggerate: the development of the political power of the. papacy. At the beginning of the 6th century, Rome, under Theodoric, was still the city of the Caesars, and the tradition of its ancient life was yet unbroken. By the end of the century, Rome, under Pope Gregory the Great (590–604), had become the city of the popes. Along with the city, the popes laid claim to some of the political inheritance of the Caesars. The great medieval ; popes, in a truer sense than the medieval emperors, were the representatives of the idea of Roman imperial unity.

Until the late Middle Ages, leading to the Renaissance, no developments of significance occurred in the realms of astronomy (or astrology as a matter of fact) and we will go no further historically.

Editor's Note:
I apologise for the extent to which I have indulged in Roman history. This has been the first time I have had the opportunity to go through it all, considering the muddle of personalities, territories, factions, usurpations, treacheries, assassinations, wars and kings involved.

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[55] Throughout its history it remained the Eastern Roman empire (or the Roman empire). It was first given the name "Byzantine empire" only in 1557, when the German historian Hieronymus Wolf published his work Corpus Historiæ Byzantinæ,

(D1) Of Roman Gods and Men

Some introductory remarks are in order before we proceed with Roman Science, Astronomy and Astrology. We are concerned with Rome of the pre-Christian era, and therefore as reflected in the culture, civitas and psyche of the High Roman empire, also referred to as Ancient Rome.

The Romans were if nothing else a practical people. Their national objective was conquering the world, and they formula was to combine their knowledge and skills with ensuring the gods were on their side, a technological civilisation fortified with a practising religious culture. They were convinced that their success was due to not neglecting the gods, and therefore depended on learning to read their portents correctly.

At the mythological, cultural and popular levels, the Romans derived their heritage from both the Etruscans and the Greeks, combined with their own pre-historical beliefs. They believed in the same pantheon of gods and the same Olympian community as the Greeks. Both peoples believed that the gods specialised in various areas of governance, and it was beneficial to invoke their protection or help if done in the right way. The Romans gave them their own names and invested them with the Roman variations of their powers and responsibilities. There were 12 major Roman gods :

Table 6
Roman Gods

Gods	Province	God	Province
1.Jupiter	King of the gods, and god of thunder and lightning	7. Apollo	god of music, archery, healing, poetry and truth
2. Juno	Wife of Jupiter; goddess of women and fertility	8, Diana	goddess of hunting, archery, and animals
3. Mars	god of war	9. Minerva	goddess of wisdom, learning, arts, and industry
4. Mercury	god of travellers and tradesmen	10. Ceres	goddess of agriculture, harvest, and the seasons
5. Neptune	god of the sea	11.Vulcan	god of blacksmiths and volcanoes
6. Venus	Goddess of love and beauty	12. Vesta	goddess of the hearth, home and city

While in their classical period the Geek philosophers, intellectuals and scientists clarified many areas of misconception and superstition about the supernatural – which corpus of learning was also transmitted down to their Roman counterparts - there remained among both peoples, at the popular and civitas levels, a shared core of believe in the involvement of the gods in daily life.

Religious worship was accordingly a state institution, more so in fact among the Romans. In the latter, there was an official religion, with temples, priests, and vestal virgins (keepers the sacred fires), etc. The military formations carried religious insignias. There were both official and private professional augurs, and there were oracles and festivals. In the homes and privately, Romans worshipped various domestic gods, in addition to participation at the temples an oracles. .The “pontifex maximus” (Latin for "supreme pontiff") was the chief high priest of the College of Pontiffs (Collegium Pontificum) in ancient Rome. He was appointed by the Senate. This was the most important position in the ancient Roman religion.

At the popular level, both the Greeks and the Romans believed the gods augured or expressed their designs, desires and decisions by means of signs and portents. The practice of reading the will of the gods became known as augury, and the process “divination. It became part of religious activity, bracketed with propitiation and supplication. Professional augurers also read signs and meanings, for a fee, from various other things, such as the flight of a bird, the sky a sunset, etc. To the extent that divination revealed the. future, it became fortune-telling. or a predictive activity.

It was therefore in the psyche of the Roman to look for signs of the gods' will and favour. What was more natural than to look to the sky, their divine abode, or indeed the planets and stars, their ancient personification. What was even more inviting was the living and cyclic movements of these celestial phenomena which showed correspondence with events on earth and re-enforced the sky-earth link..

As Astronomy and Astrology dawned upon the Romans, these studies were pursued by the Romans with the same alacrity as other things. The Romans understood quite clearly that astronomy dealt with the scientific understanding of the universe – nothing to do with gods, while astrology dealt with the divination of events on earth from the motion of celestial objects.

It was difficult however sometimes to discern whether Roman astrology essentially addressed the gods for guidance and favours through the stars, or was simply a mechanistic way to ascertain the (natural) interactions of the sky and the Earth and predict favourable timings and course of action. The line between astrology and religious practice was very blurred, more so since the practitioners of astrology were the augurers and priests of the instituted state religion. It appears there was both a non-religious astrology and a religious astrology.

To give them their exact meanings, Astronomy is the study of the composition of the universe and how it is structured and works, while Astrology is the study of the movements of the planets, sun, moon, and stars in the belief that these movements can have an influence on people's lives, and which can be interpreted to predict events. (When astronomy veers into issues like how things began and how the universe will end, we stray into the realms of Cosmology.

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(D2) Of Roman Science and Engineering

The Romans were the proud inheritors of all that Ancient and Hellenic Greece had to bequeath. While they made significant new contributions in specific areas, their overall achievements lay in engineering, in the practical application of technologies that helped them, broadly speaking, to “civilise the world” and upgrade the quality of human life. A few examples will serve to give the range, nature and flavour of their technological influence.

The Romans seemed to emerge less as pure inventors than as creators of highly efficient engineering applications of technologies borrowed from the Greeks, Etruscans, Celts, and others. With limited sources of power, the Romans managed to build impressive structures, some of which survive to this day.The Romans studied past scientific achievements and keenly observed, tested, and refined their existing ideas to create new ideas.

Medicine

The Romans acquired their medical science from the Greeks. Their early cohorts of medical people were Greeks, Greek salves or others with Greek medical education.

Pre-eminent in this field was Aelius Galenus or Claudius Galenus (129-216), known as Galen of Pergamon, who lived in Roman times. He was a Greek physician, surgeon, and philosopher, recognised as one of the most accomplished of all medical researchers of antiquity. Galen influenced the development of various scientific disciplines, including antinomy, pathology and pharmacology. Born in Pergamon (now in Turkey) Galen settled in Rome, where he became the personal physician to several emperors.

Galen's views dominated and influenced Western medical science for more than 1,300 years. His anatomical reports were based on the dissection of apes and later other animals, because human vivisection was strictly forbidden. Galen's theory of the physiology of the circulatory system remained unchallenged until 1242 when Arab science discovered pulmonary circulation. His anatomical reports remained the substantive knowledge until refined in the mid-sixteen century.

The biggest industry in the Roman world was warfare. After Augustus Caesar established service with the armed forces as a professional career for the citizen, the legions numbered p to 50-60, or a quarter of a million men at any one time – double that if auxiliaries were included. It became essential and the norm to have permanent field hospitals and medical corps. The Romans pioneered battlefield medicine, from front-line wound dressings, to arrow extraction, to amputation, to tooth aches, including the surgical tools and techniques, medications, post-infection care, essential standards of hygiene and waste disposal, etc. It was said the soldier had the prospect of a longer healthier life than the man in the street. There were however no public hospitals until the time of the Christians. Needless to say Galen’s influence pervaded these developments.

Architecture

In architecture we have the highest synthesis of the arts and the sciences of a civilisation. In Roman architecture we encounter many of the practical Roman inventions and elements which combine with their aesthetics to make up their civilised world.

Marcus Vitruvius Pollio (80-15 BC) was a Roman architect and military engineer during the 1st century BC, known for his multi-volume work entitled **De Architectura**. It was dedicate to his patron Augustus Caesar as a guide to building projects.

He originated the idea that all buildings should have three attributes: firmitas, utilitas, and venustas ("strength", "utility", and "beauty"), principles later widely adopted in Roman architecture[56]. As a military engineer, he specialised in the construction of war machines for sieges.

As the only treatise on architecture to survive from antiquity, it has been regarded since the Renaissance as the first book on architectural theory. It is as well as a major source on the canon of classical architecture. It contains a variety of information on Greek and Roman buildings of the time, as well as prescriptions for the planning and design of military camps, cities, and structures both large (aqueducts, buildings, baths, harbours) and small (machines, measuring devices, instruments).

Written between 30-20 BC, it combines the knowledge and views of many antique writers, Greek and Roman, on architecture, the arts, natural history and building technology

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[56] His discussion of perfect proportion in architecture and the human body led to the famous Renaissance drawing of the “Venuvian Man” by Leonardo di Vinci.

De Architectura – Ten Books on Architecture.
. – 1.Town Planning, in general and qualifications of the architect or civil engineer.
. - 2. Building Materials
. – 3. Temples and the order of architecture.
. – 4. Civil buildings
. – 5. Domestic Buildings
. – 6. Water Supplies
. – 7. Pavements an decorative plasterwork
. – 8. Water Supplies and aqueducts
. – 9. Sciences influencing architecture
. – 10 Use of construction machines. Drainage, hoisting, pneumatics, etc.

Roman architects were skilled in engineering, art, and craftsmanship combined. Under Serial 9 above, Vitruvius included astronomy and astrology.

Civil Engineering

Concrete

Concrete was invented before the Romans. However, concrete was the Roman empire's construction material of choice. It was used in monuments such as the Pantheon in Rome, in buildings, for making the roads that linked the empire, and the aqueducts that carried its fresh water, and in urban pavements and drainage.

Instead of Portland cement, the Romans used a mix of volcanic ash and lime to bind rock fragments to form their concrete. Stronger than stone, it could be used to design huge arches and domes.

Roads

"All roads lead to Rome," as the saying goes. One of the greatest scientific feats of Rome was the concrete road. Nearly 30 military highways, all made of stone, exited the great city. At one point, 372 roads connected 113 provinces, totalling over 50,000 miles. Due to their concrete structure, many of these roads survived more than a thousand years.

The Romans improved their design and perfected the construction to the extent that many of their roads are still in use today. Their accomplishments surpassed most other civilisations of their time, and after their time, and many of their structures have withstood the test of time to inspire others.

The Romans utilised different engineering techniques to survey, clear and level land suitable for direct paths between cities. Additionally, tunnels and bridges were built for their roads along with paths for pedestrians. Due to the extensive network of roads, military personnel were able to cover ground extremely fast. Citizens could easily travel due to directional signage, and goods were traded efficiently.

The Roman road network was used as a tool to help conquer and hold onto a vast empire, , and their engineering techniques have been used as a basis for many modern roads.

Aqueducts

The Romans loved water. Eleven aqueducts serving the city supplied over 1.1 million cubic metres of water per day. Per capita water usage in ancient Rome matched that of modern-day cities like New York City or modern Rome. Most water was for public use, such as baths and sewers.

Across the empire they built tunnels and arched bridges carrying fresh spring water from the mountains into the cities. Today, Rome's drinking fountains (eg. the Trevi fountain) continue to provide its people with abundant, clean drinking water

De Aquaeductu was the definitive two volume treatise on 1st century aqueducts of Rome, written by Frontinus. **Sextus Julius Frontinus** (40-103) was a prominent civil engineer, author, soldier and senator. He was a general commanding forces in Roman Britain, and on the Rhin and the Danube. He was consul three times. he is best known to the post-classical world as an author of technical treatises, especially that on the aqueducts of Rome.

Frontinus's work was a description of the water-supply of Rome, including the laws relating to its use and maintenance. He provided the history, sizes and discharge rates of all of the aqueducts, and he described the quality of water delivered by each, mainly depending on their source, be it river, lake, or spring.

Roman aqueducts were designed to approach the city at a deteriorating angle, called a gradient. The slope of these aqueducts had to be calculated from a very great distance with and they had to be executed perfectly regardless of the terrain. For this to be possible, Roman engineers dug tunnels through mountains in higher terrain and crafted stone walls for the pipes to run through deeper land.

Roman aqueducts were built to remarkably fine tolerances. Powered entirely by gravity they transported very large amounts of water very efficiently.

The aqueducts could stretch from 10–100 km long, and typically descended from an elevation of 300 m (1,000 ft) above sea level at the source, to 100 m (330 ft) when they reached the reservoirs around the city.

Roman engineers worked to make the routes of aqueducts as practical as possible. This meant aqueducts followed the ground level or flowed below surface level, as these were more cost effective options. Most aqueducts were constructed below the surface with only small portions above ground supported by arches. Only 5 percent of the water transported along the aqueduct systems travelled by way of bridges. Sometimes, where depressions deeper than 50 metres had to be crossed, they used inverted siphons force water uphill.

The longest Roman aqueduct, 178 km in length, was that which supplied the city of Carthage. The complex system built to supply Constantinople had its most distant supply drawn from over 120 km away along a sinuous route of more than 336 km.
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Water theft from the aqueducts was a frequent problem which led to difficulties in estimating the amount of water flowing through the channels.

To prevent the channels from eroding, a plaster known as opus signinum was used. The plaster incorporated crushed terracotta in the typical Roman mortar mixture of pozzolana rock and lime.

In 312 BC, Appius Claudius built the first aqueduct for the city of Rome. The Romans were still a tightly knit body of citizens whose lives cantered on the seven hills within the city wall beside the Tiber river.

Plumbing

Once the water supply reached a city, it would be transferred to various holding tanks that supplied citizens with drinking water, public bathing water and the wealthy with private water supplies

The Roman plumbing system was a legendary achievement in civil engineering, bringing fresh water to urbanites from hundreds of kilometres away. Wealthy Romans had hot and cold running water,. The Rome system was the proto-type, and the model was adapted in other towns, military encampments, and wealthy homes.

When the water from an aqueduct reached the city, it would be stored in a tank, cistern or distributing reservoir called a castellum, which then supplied the public baths as well as the public fountains, the imperial palaces and private houses.

The distribution was done by earthenware or terra cotta plumbing, sometimes stone or concrete or encased in concrete. At one stage Romans used lead pipe, until they identified its poisonous effects. Vitruvius commented that they removed the practice. Rainwater was deemed the purest water. and terra cotta provided the best filtration.

The Romans were the first to seal pipes in concrete to resist the high water pressures developed in siphons and elsewhere

In overall terms, fresh water delivered by the aqueducts was used for drinking, for the private and public baths and for the fountains, and the used water flushed the latrines and removed human and other waste through the sewage system, in a continuous eco-cycle.

The best waters were reserved for potable drinking supplies, and the second quality waters would be used by the baths, the outfalls of which connected to the sewer network under the streets of the city. The continuous supply of running water helped to remove wastes and keep the sewers clear of obstructions. Aqueduct water also supported mining operations, milling, farms, and gardens.

Sewerage

The Cloaca Maxima was one of the world's earliest sewerage systems. It carried city effluent to the River Tiber. t began as an open air canal, but it developed into a much larger sewer over the course of time. Sewers in fact became cavernous enough to drive a carriage through. By the first century all eleven aqueducts were connected to this sewer, and it became the city's main storm drain as well. Eventually, the sewer could not continue growing to keep up with the expanding city. From 31 BC to 192 manholes would be used to access the sewer, which was traversed by canal at this point

In the first century AD, the Roman sewage system was very efficient. In his Natural History, Pliny remarked that of all the things Romans had accomplished, the sewers were "the most noteworthy things of all"..

Water Power

The Romans were among the first civilisations to harness the power of water. They built some of the first watermills outside of Greece and spread the technology. A famous example occurs in southern France, where no fewer than 16 mills built into the side of a hill were worked by a single aqueduct, the outlet from one feeding the mill below in a cascade.

They were also skilled in hydraulic mining, building reservoirs and aqueducts to supply water used in extracting metal ores. They were also capable of building and operating dewatering machines, ie water extractor pumps.

Ancient Rome's plumbing connected the expansive republic and its vast population to a steady water supply brought in through aqueducts and flushing waste out through cavernous sewers. Some of the first flushing toilets and indoor plumbing systems were used in Rome. Some Roman homes contained sewer systems that carried waste to the Tiber River.

Pipes were not only made of terracotta, lead, stone, and clay, but also of wood or leather. The use of all four has also been found in aqueducts. Terracotta was the most common, followed by lead and then stone.

Arches

The Romans learned the arch from the Etruscans, refined it and were the first builders in Europe to tap its full potential for above ground buildings. They Romans were perhaps the first in the world to fully appreciate the advantages of the arch, the vault and the dome. Their engineers erected arch structures, such as bridges, aqueducts, and gates using the arch. They introduced the triumphal arch as a military monument. Vaults began to be used for roofing large interior spaces such as halls and temples, a function that was also assumed by domed structures from the 1st century BC onwards. They were also routinely used in house construction.

The Romans used the idea of the arch to create architecture that has continued to inspire builders even today. The discovery that the arch shape allowed weight to be distributed evenly allowed the Romans to create amazing buildings and homes. Arches were also used when developing aqueducts to deliver water to citizens all over Rome. Eleven aqueducts measuring nearly 220 total miles carried water across valleys and aided in the area's.

Naturalis Historia

Gaius Plinius Secundus (23-79), called **Pliny the Elder** ,was a Roman author,naturalist, philosopher, naval and army commander, and a friend of the emperor Vespasian. He wrote the encyclopaedic **Naturalis Historia** (Natural History, the first encyclopaedia ever written. And the earliest encyclopaedia to survive. It merits mention here because it gives broadside access to the world as the Romans saw it – including astronomy.

The Natural History consisted of 37 books. The table below is a summary based on modern names for the topics.

Table 7
Pliny's Naturalis Historia

Volume	Books	Contents
1	**1**	Preface, Contents, Authorities
	2	Astronomy, meteorology
II	**3-6**	Geography and ethnography
	7	Anthropology and Human physiology
III	**8-11**	Zoology, includ mammals, snakes, marine animals, birs and insects
IV_VII	12-27	Botany, includ agriculture horticulture and medicine.
VIII	28-32	Pharmacology, magic, water, aquatic life
IX-X	33-37	Mining and Mineralogy, includ materials as applied to art, statuary, sculpture and precious stones.

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(D3) Of Roman Astronomy

Pliny's Overview

The first topic covered in Naturalis Historia is Astronomy in Book II, written about 77. The following is a convenient extract of Wiki's summary:

"Pliny starts with the known universe, roundly criticising attempts at cosmology as madness, including the view that there are countless other worlds than the Earth. He concurs with the four (Aristotelian) elements, fire, earth, air and water, and records the seven "planets" including the sun and moon. The earth is a sphere, suspended in the middle of space. He considers it a weakness to try to find the shape and form of God, or to suppose that such a being would care about human affairs. He mentions eclipses, but considers Hipparchus' almanac grandiose for seeming to know how Nature works. He cites Posidonius' estimate that the moon is 230,000 miles away. He describes comets, noting that only Aristotle has recorded seeing more than one at once.

Book II continues with natural meteorological events lower in the sky, including the winds, weather, whirlwinds, lightning, and rainbows. He returns to astronomical facts such as the effect of longitude on time of sunrise and sunset the variation of the sun's elevation with latitude (affecting time-telling by sundials), and the variation of day length with latitude."
https://en.wikipedia.org/wiki/Natural_History_(Pliny)

The Geocentric Universe

Ptolemy or Claudius Ptolemaeus (100-170 AD) was an astronomer, mathematician and geographer who flourished in Alexandria during the 2nd century, when the Greek Ptolemaic empire had already become a Roman province.

In several fields his writings represent the culminating achievement of Greco-Roman science, particularly his **geocentric model of the universe** now known as the Ptolemaic system. The complete review of his work, including the Ptolemaic System of Astronomy, has been placed more appropriately in context under Hellenic Greece. It is essential reding.

Here we provide a summary of his astronomical world view, which was the dominating Roman and indeed the substantive understating of the world for the next 1,000 years. It was contained in his masterwork, the Almagest, written in. Greek..

The Almagest, was completed about 150 and contained reports of astronomical observations that Ptolemy had made and collated from different sources over the preceding quarter of a century. Ptolemy concluded therein that the universe was geocentric, ie revolved with the earth in the centre. It served as the basic guide for Islamic and European astronomers until about the beginning of the 17th century. Ptolemy placed the planets in the order that would remain standard until it was displaced by the heliocentric system.

Although Babylonian astronomers had developed arithmetical techniques for calculating and predicting astronomical phenomena, these were not based on any underlying model of the heavens. Early Greek astronomers, on the other hand, provided qualitative geometrical models of celestial phenomena without the ability to make any predictions. The earliest person that attempted to merge these two approaches was Hipparchus.

Ptolemy, following Hipparchus, derived each of his geometrical models for the Sun, Moon, and the planets from selected astronomical observations over more than 800 years; In the Almagest, Ptolemy explained how to predict the behaviour of the planets, which Hipparchus could not, with the introduction of a new mathematical tool, the equant[57].

In the Ptolemaic system, the Earth was at the centre of the universe with the Moon, the Sun, and five planets circling it. The circle of fixed stars marked the outermost sphere of the universe and beyond that would be the philosophical “aether” realm. The sphere carrying the Moon is described as the boundary between the corruptible and changing sublunary world and the incorruptible and unchanging heavens above it. The heavens were defined as incorruptible and unchanging based on theology and mythology of the past.

The aether is the area that describes the universe above the terrestrial sphere. This component of the atmosphere is unknown and named by philosophers.

The Almagest introduced the idea of the sphericity of the heavens. The aether was used to affirm the sphericity of the heavens. The latter was further confirmed by the belief that different shapes had an equal boundary, that those with more angles were greater, the circle was greater than all other surfaces, and a sphere was greater than all other solids. Therefore, through physical considerations, and heavenly philosophy, the heavens must be spherical.

The differences in the hours across a globe would be proportional to the distances between the spaces at which they were observed. Therefore, the Earth must be spherical because they change in time-zones across the world occurred in a uniform fashion, as with the rotation of a sphere.

Finally, the Almagest suggested that the Earth was at the centre of the universe. The basis of this was the fact that six zodiac signs could be seen above Earth, while at the same time the other signs were not visible. The increase and decrease of daylight would be different if the Earth was not at the centre of the universe. Though this view later proofed to be invalid, this proposition remained in place for over 1000 years.

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[57] The equant is used to explain the observed speed change in different stages of the planetary orbit. This planetary concept allowed Ptolemy to keep the theory of uniform circular motion alive by stating that the path of heavenly bodies was uniform around one point and circular around another point.

The Planets

Like the Greeks (and everybody else), the Romans only knew the visually observable planets, which including the Moon and the Earth totalled seven. They also adopted their Greek identities, namely the gods of Greek mythology, but gave them their own counterpart names, as follows

	Greek	Roman		Greek	Roman
1	Hermes	Mercury	4	Zeus	Jupiter
2	Aphrodite	Venus	5	Cronos	Saturn
3	Ares	Mars	6	Gaia	Terra
			7	Selene	Luna

Except among astrologers, the Greeks largely dissociated their gods and planets from human affairs. The Romans, however, retained their gods and planets as actively involved and influencing daily human and terrestrial happening (see further on.)

The Roman calendar

Two hundred years before Ptolemy, in 46 BC Julius Caesar reformed the calendar system. Based on advice by astronomer Sosigenes of Alexandria, the Julian calendar included one leap day every four years to account for the fact that an Earth year is slightly more than 365 days long. The question here is whether Ptolemy used Caesar’s calendar as a basis for anything.

Before Julius Caesar created his calendar, the Roman year was thought to have 10 months. The prefixes sept, oct, nov, and dec meaning seventh, eighth, ninth, and tenth come from Latin. July and August are named after Caesar and emperor Augustus. As early as 600 BC 2 extra months (January and February) were added and the calendar counted 355 days. Every 2 years, a month was added after February as a leap month with the same amount of days. February was given a leap day. At first this day happened every 3 years, this was later changed to every 4 years. The Julian calendar was used until 1582 when Pope Gregory XIII introduced his calendar, making minor changes to the Julian calendar

Constellations and Zodiac

In the early astronomy, after the planets, the first pattern recognitions would have been of the constellations. These were groupings of stars by familiar patterns, given names for recognition during stellar navigation. This was practiced and shared by all civilisations and inherited by the Romans from the Greeks who inherited it from the Babylonians . The practice has continued to modern times, and the IUA today has 88 officially listed constellations on catalogue. Many bear Roman names.

Over time, civilisations, and the Babylonians in particular, discovered the zodiac. They passed the knowledge on to the Greeks who passed it onto the Romans. The zodiac is the belt-shaped region of the sky that extends approximately 8° north or south of the ecliptic, which is the apparent path of the Sun across the sky over the course of the year. The paths of the Moon and visible planets are within the belt of the zodiac. The zodiac overlays and overlaps the constellations, and includes some but not all the constellations.

The modern zodiac, inherited from the Greco-Roman zodiac is divided into twelve signs each occupying 30° of celestial longitude and roughly corresponding to the following star constellations: Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius Capricorn, Aquarius, and Pisces.

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(D4) Of Roman Astrology

Astrology is the study of the movements of the planets, sun, moon, and stars in the belief that these movements can have an influence on people's lives.

Astrology developed while man's knowledge of the celestial world was limited to what could be seen with the naked eye. The observations on which astrology developed were therefore based on the planets, the constellations and the zodiac.

Again, tit was the Babylonians (and the Sumerians their predecessors) who were among the earliest to develop the knowledge and skills to "read" the stars to predict events. They then passed this on to the Greeks and the Romans.

The Romans took up this subject with alacrity for its practical value. This "Babylonian" or "Chaldean wisdom" was immediately recognised as another route of divination - through the planets and the stars.

Roman Astrological Inheritance

Most pre-modern cultures practiced a form of astrology. A particularly complex variety of it evolved in Mesopotamia from where it was imported into the Hellenistic and Roman worlda from the early 4th century BC onward.

There it became attached to three philosophical schools, those pioneered by Plato, Aristotle and the Stoics, all of which shared the assumption that the cosmos was a single, living, integrated whole. Hellenistic astrology also drew on Egyptian temple culture, especially the belief that the soul could ascend to the stars.

By the 1st century AD, the belief in the close link between humanity and the stars had become popularised and diversified into a series of practices and schools of thought which ranged across Greek culture.

It was practiced at the imperial court and in the street. It could be used to predict individual destiny, avert undesirable events, and arrange auspicious moments to launch new enterprises. It could advise on financial fortunes or the condition of one's soul. It was conceived of as natural science and justified by physical influences or considered to be divination, concerned with communication with the gods and goddesses.

In some versions, the planets were neither influences nor causes of events on Earth, but timing devices, which indicated the ebb and flow of human affairs, like the hands on a modern clock. Astrology had a radical view of time in which the future already existed, at least in potential, and the astrologer's task was to intercede in time, altering the future to human advantage. In this sense astrology was a form of "participation mystique" in which time and space were conceived of as a single entity and individual and social benefits were to be derived from engaging with it.

There was no one single version of astrology and there were disputes about what it was and what it could do, for example, whether it could make precise predictions about individual affairs or merely general statements.

The Hellenic world also developed a complex system of astrology which sought to determine a person's character and future in the movements of the Sun, Moon and the planets. Astrology was widely associated with the cult of Tyche. (luck, fortune), which grew in popularity during this period. Tyche was the presiding tutelary deity who governed the fortune and prosperity of a city. .

From the early 4th century it went into a progressive decline, facing challenges from Christianity and the fragmentation of classical culture, especially in Western Europe.

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Magic was practiced widely, and this, too, was a continuation from earlier times. Throughout the Hellenistic world, people would consult oracles and use charms to deter misfortune or to cast spells.

Tetrabiblos

Ptolemy sought to give astrological a scientific basis. While defining the structure mechanics of our universe in the Almagest, he addressed the enormous work in astrology bequeathed by the Babylonians.

Ptolemy was the author of one of the oldest complete manuals of astrology, - the Tetrabiblos (Greek), or Quadrapartitium (Latin) meaning 'Four Books'. Again, you are invited to read the full review of this subject under Hellenic Greece.

His main contribution was orchestrating the mass of Eastern star lore into an organised and reasoned exposition. The Tetrabiblos also offered a detailed explanation of the philosophical framework of astrology, enabling its practitioners to answer critics on scientific as well as religious grounds.

Ptolemy's patronage and approval of astrology added to its academic respectability.. Ptolemy revealed no interest in magic, superstition or ideas which fall beyond the realm of reason. In looking at astrology, he adhered to the scientific views of his era and in harmony with Aristotelian philosophy.

His perspective rested upon the belief that planetary influences derive from the planets' relationship with the Sun (the source of heat and light) and the Earth (the source of moisture). The Moon was regarded as a 'cool and moist' planet. Saturn was 'cold and dry' because it was furthest from the Sun and, again, from the moisture of the Earth. Planetary characteristics were defined by these humoural temperaments. In nature, warmth and moisture promoted health and vitality whilst cold and dryness were conducive to decay.

Through this hypothesis Ptolemy explained how the constant movement of the planets created an ever-changing atmosphere to which all the Earth's creatures were sensitive. Each soul was affected by the celestial atmosphere at the time of its birth. The aspects and movement of the stars continued to produce favourable or injurious conditions, as determined by the individual's personal disposition.

To Ptolemy, therefore, astrology operated according to natural law. He compiled astrological data that he believed was reliable and dismissed practices (such as considering the numerological significance of names) that he believed to be without sound basis.

Astrology was a central feature of Greek and Roman culture. A knowledge of astrology’s claims, practices, and world view was essential for a full understanding of religion, politics, and science in the Greek and Roman worlds.

Roman Practice

Roman astrology was a series of diverse calculations and practices related to the idea that the stars, planets, and other celestial phenomena possessed significance and meaning for events on Earth. It assumed a link between in the Earth and sky in which all existence, spiritual, psychological, and physical, was interconnected. In practice, astrology subsisted in both a religious and secular context.

The Romans thought of themselves as highly religious, and attributed their success as a world power to their collective piety (pietas) in maintaining good relations with the gods. Religion in ancient Rome consisted of varying imperial and provincial religious practices, which were followed both by the people of Rome as well as those who were brought under its rule.

Roman religion was practical and contractual, based on the principle of "do ut des" –"I give that you might give". Religion depended on knowledge and the correct of prayer, rite, and sacrifice, not on faith or dogma.

The belief in astrology flowed into the Roman Empire which succeeded the Republic. The Roman emperors used astrology as one means of justifying their rule. The first emperor Augustus used his sign (Capricorn) on his coins and claimed that his elevation was foretold by his horoscope. It was standard practice for Roman emperors to call for daily horoscope, and have a full divination before any important undertaking or event. All this was in fact the standard practice of all ancient kings and emperors from the Babylonians down.

For ordinary Romans, religion was a part of daily life. Each home had a household shrine at which prayers and libations to the family's domestic deities were offered. Neighborhood shrines and sacred places such as springs and groves dotted the city. The Roman calendar was structured around religious observances.
As the Roman empire expanded, migrants to the capital brought their local cults, many of which became popular among Italians. Christianity was introduced early in the 1st century and became the state religion in 380.

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PART II

Modern Astronomy

Editorial Note

In this Part , the focus is on the Discoveries - the personalities and their inventions not the history or description of the discovered universe. The latter is compiled together in Part IV – Stuff Of The Universe.

Chapter Five
Renaissance

Late Medieval to Renaissance

Astronomy entered a relatively static era in Western Europe from the fall of Roman era (431) through the 12th century. Recent investigations, however, have revealed a more complex picture.

Western Europe entered the Middle Ages with great difficulties that affected intellectual life. The advanced astronomical treatises of classical antiquity were written in Greek and with the decline of knowledge of that language, only simplified summaries and practical texts were available for study. The most influential writers to pass on this ancient tradition in Latin were Macrobius, Pliny, Martianus Capella, and Calcidius. In the 6th century Bishop Gregory of Tours complained he had learned his astronomy from reading Martianus Capella, and went on to employ this rudimentary astronomy to describe a method by which monks could determine the time of prayer at night by watching the stars.

In the 7th century the English monk Bede of Jarrow published an influential text on the Reckoning of Time, providing churchmen with the practical astronomical knowledge needed to compute the proper date of Easter using a procedure called the computes. His text remained an important element of the education of clergy from the 7th century until well after the rise of the universities in the 12 century.

The range of surviving ancient Roman writings on astronomy and the teachings of Bede and his followers began to be studied in earnest during the revival sponsored by the emperor Charlemagne By the 9th century rudimentary techniques for calculating the position of the planets were circulating in Western Europe.

Building on this astronomical background, in the 10th century European scholars such as Gerbert of Aurilllac began to travel to Spain and Sicily to seek out learning which they had heard existed in the Arabic-speaking world. There they first encountered various practical astronomical techniques, most notably the astrolabe. Soon scholars were writing texts in Latin on the uses and construction of the astrolabe and others were using the astrolabe to observe the time of eclipses in order to test the validity of computistical tables.

By the 11th century, most of Europe had become Christian; stronger monarchies emerged; borders were restored; technological developments and agricultural innovations were made, increasing the food supply and population. Classical Greek texts were translated from Arabic and Greek into Latin, stimulating scientific discussion in Western Europe.

By the 12th century, scholars were traveling to Spain and Sicily to seek out more advanced astronomical and astrological texts. The arrival of these new texts coincided with the rise of the universities in medieval Europe.

In the 14th century, Nicole Oresme, later bishop of Liseux, showed that neither the scriptural texts nor the physical arguments advanced against the movement of the Earth were demonstrative and adduced the theory that the Earth moves, and not the heavens. In the 15th century, Cardinal Nicholas of Cusa suggested in some of his scientific writings that the Earth revolved around the Sun, and that each star is itself a distant sun.

Universities

An intellectual revitalisation started with the birth of the medieval universities in the 12th century. These urban institutions grew from the informal scholarly activities of learned friars who visited monasteries and consulted libraries and conversed with other fellow scholars. A friar who became well-known would attract a following of disciples, giving rise to a brotherhood of scholars or collegium. If the number of scholars within a collegium grew too large, they would opt to settle in a town instead. As the number of collegia within a town grew, the collegia might request that their king grant them a charter that would convert them into a universitas. Many universities were chartered during this period, with the first in Bologna in 1088, followed by Paris in 1150, Oxford in 1167, and Cambridge in 1231.

The granting of a charter meant that the medieval universities were partially sovereign and independent from local authorities. Modern academic concepts and practices such as freedom of inquiry are remnants of these medieval privileges.

Many of the Masters yearned for the complete original texts of the Ancient Greek philosophers, mathematicians, and physicians, which were not available to them at the time. These Ancient Greek texts were to be found in the Byzantine Empire and the Islamic World. Contact with the Byzantine Empire and with the Islamic world during the Spanish.
At the beginning of the 13th century, there were reasonably accurate Latin translations of the main works of almost all the intellectually crucial ancient authors, allowing a sound transfer of scientific ideas via both the universities and the monasteries.

By then, the natural philosophy in these texts began to be extended by scholastics such as Robert Grosseteste, Roger Bacon, Albert Magnus and Duns Scotus. Not surprisingly, the church fund itself obliged to issue strings of condemnations against the slew of unassimilated new ideas. Their net effect was to advance the new intellectual attitudes towards the coming scientific revolution.

In 1348, the Black Death and other disasters sealed a sudden end to philosophic and scientific development. Yet, the rediscovery of ancient texts was stimulated by the Fall of Constantinople in 1453, when many Byzantine scholars sought refuge in the West.

We might mention the greatest of the medieval inventions. Goldsmith and inventor Johannes Gutenberg began experimenting with printing in Strasbourg, France in 1440. He returned to Mainz and by 1450 had a printing machine perfected and ready to use commercially.
The introduction of printing was to have great effect on European society. The facilitated dissemination of the printed word democratized learning and allowed ideas to propagate more rapidly. It paved the way for the scientific revolution to come. Paper, invented in China in 105, had already reached Toledo, Spain via the Arabs in 1150.

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Copernicus.

Nicolaus Copernicus (1473 1543) was born in Poland, He was the child of German-speaking parents and grew up with German as his mother tongue, and eventually returned to Poland die there. He was a Renaissance polymath, active as a mathematician and astronomer, and as a Catholic canon.

Between 1491 and about 1494 Copernicus studied liberal arts—including astronomy and astrology at the University of Cracow. Like many students of his time, he left before completing his degree, resuming his studies in Italy at the University of Bologna (1496–

1500). In the latter period, for a short time, Copernicus lived in the same house as the principal astronomer at the university, Domenico Maria de Novara. The latter had the responsibility of issuing annual astrological prognostications for the city, forecasts that included all social groups but gave special attention to the fate of the Italian princes and their enemies. Copernicus, as is known from Rheticus, was "assistant and witness" to some of Novara's observations, and his involvement with the production of the annual forecasts means that he was intimately familiar with the practice of astrology.

In 1501 he stayed briefly in Frauenburg, Poland, but soon returned to Italy to continue his studies, this time at the University of Padua, where he pursued medical studies between 1501 and 1503. At this time medicine was closely allied with astrology, as the stars were thought to influence the body's dispositions. Thus, Copernicus's astrological experience at Bologna was relevant training.

In May 1503, Copernicus finally received a doctorate—like his uncle, in canon law—but from an Italian university where he had not studied: the University of Ferrara.

In 1497 Copernicus had been appointed by his uncle and ward, Bishop Lucas Watzenrode of Frauenburg, a canon of the Ermland Chapter of Warmia Cathedral. When he returned to Poland (1503), Bishop Watzenrode arranged a sinecure for him: an in absentia teaching post at Wroclaw. Copernicus's actual duties at the bishopric palace, however, were largely administrative and medical. As a church canon, he collected rents from church-owned lands; secured military defences; oversaw chapter finances; managed the bakery, brewery, and mills; and cared for the medical needs of the other canons and his uncle. Despite serving as a canon, Copernicus did not become a priest.

The peace which Copernicus wished, however, was not easy to find in a period of frequent wars. The fortifications of Frauenburg that became Copernicus's home had been built to protect the town which had been captured by various opposing groups over the years.
In 1516 Copernicus was given the task of administering the districts of Allenstein (also known as Olsztyn) and Mehlsack. He lived for four years in Allenstein Castle while carrying out these administrative duties.

Lucas Watzenrode died in 1512 and following this Copernicus resumed his duties as canon in the Ermland Chapter at Frauenburg. Copernicus's astronomical work took place in his spare time, apart from these other obligations. He now had more time than before to devote to his study of astronomy, having an observatory in the rooms in which he lived in one of the towers in the town's fortifications.

Copernicus was an economist of no mean ability. In 1517 he derived a quantity theory of money - a key concept in economics—and in 1519 he clearly defined the economic principle that later came to be called Gresham's law.

Copernicus Theory: Heliocentric Universe

Copernicus is famed for formulating a model of the universe that placed the Sun rather than the Earth at its centre. In all likelihood, Copernicus developed his model independently of Aristarchus of Samos (310-230 BC), who proposed the same over 1,000 years earlier.

Copernicus probably hit upon his main ideas sometime between 1508 and 1514, and during those years he wrote a manuscript usually called the Commentariolus ("Little Commentary"). However, the book that contains the final version of his theory De Revolutionibus Orbium Coelestium, (*On the Revolutions of the Celestial Spheres*) was published just before his death in 1543.

Copernicus proposed that the planets had the Sun as the fixed point to which their motions were to be referred; that Earth was a planet which, besides orbiting the Sun annually, also turned once daily on its own axis; and that very slow long-term changes in the direction of this axis accounted for the precession of the equinoxes. This representation of the heavens is usually called the heliocentric or “Sun-centred,” system.

The Copernican system gave a truer picture than the older Ptolemic system, which was geocentric, or centred on Earth. It correctly described the Sun as having a central position relative to Earth and other planets. Copernicus retained from Ptolemy, although in somewhat altered form, the imaginary clockwork of epicycles and deferents (orbital circles upon circles), to explain the seemingly irregular movements of the planets in terms of circular motion at uniform speeds.

Copernicus's Commentariolus, circulated around 1514, summarised his heliocentric theory. It listed the "assumptions" upon which the theory was based, as follows:

.1 - There is no one centre of all the celestial circles or spheres.

.2 - The centre of the earth is not the centre of the universe, but only the centre towards which heavy bodies move and the centre of the lunar sphere.

.3 - All the spheres surround the sun as if it were in the middle of them all, and therefore the centre of the universe is near the sun.

.4 - The ratio of the earth's distance from the sun to the height of the firmament (outermost celestial sphere containing the stars) is so much smaller than the ratio of the earth's radius to its distance from the sun that the distance from the earth to the sun is imperceptible in comparison with the height of the firmament.

.5 - Whatever motion appears in the firmament arises not from any motion of the firmament, but from the earth's motion. The earth together with its circumjacent elements performs a complete rotation on its fixed poles in a daily motion, while the firmament and highest heaven abide unchanged.

.6 -What appear to us as motions of the sun arise not from its motion but from the motion of the earth and our sphere, with which we revolve about the sun like any other planet. The earth has, then, more than one motion.

.7 - The apparent retrograde and direct motion of the planets arises not from their motion but from the earth's. The motion of the earth alone, therefore, suffices to explain so many apparent inequalities in the heavens.

In the Commentariolus, Copernicus then postulated that, if the Sun is assumed to be at rest and if Earth is assumed to be in motion, then the remaining planets fall into an orderly relationship whereby their sidereal periods increased from the Sun as follows: Mercury (88 days), Venus (225 days), Earth (1 year), Mars (1.9 years), Jupiter (12 years), and Saturn (30 years). This theory did resolve the ordering of the planets but, in turn, raised new problems. One had to abandon much of Aristotelian natural philosophy and develop a new explanation for why heavy bodies fall to a moving Earth. In addition, Copernicus was working with many observations that he had inherited from antiquity and whose trustworthiness he could not verify. Any of these considerations alone could account for Copernicus’s delay in publishing his work.

When a description of the main elements of the heliocentric hypothesis was first published, in the Narratio Prima or “First Narration” (1540 and 1541)it was not under Copernicus’s own name but jointly under that of the 25-year-old Geor Rheticus. Rheticus, a Lutheran, from the

University of Wittenberg, Germany, stayed with Copernicus at Frauenburg for about two and a half years, between 1539 and 1542. The Narratio prima was a “trial balloon” for the main work. It presented Copernicus as following admiringly in the footsteps of Ptolemy even as he broke fundamentally with his ancient predecessor. It also provided what was missing from the Commentariolus: a basis for accepting the claims of the new theory.

Both Rheticus and Copernicus knew that they could not definitively rule out all possible alternatives/ But they could underline what Copernicus’s theory provided that others could not: a singular method for ordering the planets and for calculating the relative distances of the planets from the Sun. The theories of his predecessors, he wrote, were like a human figure in which the arms, legs, and head were put together in the form of a disorderly monster. His own representation of the universe, in contrast, was an orderly whole in which a displacement of any part would result in a disruption of the whole. In effect, Copernicus advanced a new criterion of scientific adequacy together with the new theory of the universe.

When Rheticus left Frauenburg to return to his teaching duties at Wittenberg, he took the manuscript with him in order to arrange for its publication. Rheticus was unable to remain and supervise. He turned the manuscript over to Andreas Osiander (1498–1552), a theologian experienced in shepherding mathematical books through production. In earlier communication with Copernicus, Osiander had urged him to present his ideas as purely hypothetical and he now introduced certain changes without the permission of either Rheticus or Copernicus. What Osiander did was to write a letter to the reader, inserted in place of Copernicus's original Preface following the title page, in which he claimed that the results of the book were not intended as the truth, rather that they merely presented a simpler way to calculate the positions of the heavenly bodies. A casual reader would be confused about the relationship between this letter and the book’s contents. Rheticus, having trusted Osiander, was enraged. The printed book was reportedly presented to Copernicus on his deathbed, and he died in peace – unaware of the change. No public revelation of Osiander’s role was made until Kepler revealed it in his Astronomia Nova (New Astronomy) in 1609. In addition, the title of the work was changed from the manuscript’s “On the Revolutions of the Orbs of the World” to “Six Books Concerning the Revolution of the Heavenly Orbs - a change that appeared to mitigate the book’s claim to describe the real universe.

Ironically, Osiander’s “letter” made it possible for the book to be read as a new method of calculation, rather than a work of natural philosophy, and in so doing may even have aided in its initially positive reception. Some are appalled at this gigantic piece of deception by Osiander, as Rheticus was at the time, others feel that it was only because of Osiander's Preface that Copernicus's work was read and not immediately condemned.

It was not until Kepler that Copernicus’s cluster of predictive mechanisms would be fully transformed into a new philosophy about the fundamental structure of the universe. Its other notable defenders included Galileo while theoretical evidence for the Copernican theory was provided by Newton’s theory of universal gravitation around 150 years later.

Catholic Church

The immediate result of the 1543 publication of Copernicus's book was only mild controversy. At the council of Trent (1545–63) neither Copernicus's theory nor calendar reform (which would later use tables deduced from Copernicus's calculations) were discussed.

It is equally clear that his fame as an astronomer was well known for when the Fifth Lateran Council decided to improve the calendar, which was known to be out of phase with the seasons, the Pope appealed to experts for advice in 1514, one of these experts was Copernicus. Many experts went to Rome to advise the Council, but Copernicus chose to respond by letter. He did not wish to contribute more to the discussions on the calendar since he felt that the motions of the heavenly bodies was still not understood with sufficient precision.

It was not until six decades after the publication of De Revolutionibus that the Catholic Church took any official action against it. Catholic side opposition only commenced seventy-three years later, when it was occasioned by Galileo. Those prohibitions were finally dropped from the 1835 Index.

Other Reactions

Rheticus could have been Copernicus's successor, but did not rise to the occasion. Erasmus. Reinhold could have been his successor, but died prematurely. The first of the great successors was Tycho Brahe (though he did not think the Earth orbited the Sun), followed by Johannes Kepler who had collaborated with Tycho in Prague and benefited from Tycho's decades' worth of detailed observational data.

Copernicus's theory was originally slow to catch on. Scholars hold that sixty years after the publication of The Revolutions there were only around 15 astronomers espousing Copernicanism in all of Europe.

The intellectual climate of the time remained dominated by Aristotelian philosophy and the corresponding Ptolemaic astronomy. At that time there was no reason to accept the Copernican theory, except for its mathematical simplicity. Tycho Brahe's system, that the earth was stationary, the sun revolved about the earth, and the other planets revolved about the sun also directly competed with Copernicus's.

It was only a half-century later with the work of Kepler and Galileo that any substantial **evidence** defending Copernicanism appeared, starting from when Galileo formulated the principle of inertia...[which] helped to explain why everything would not fall off the earth if it were in motion. It was not until after Newton formulated the universal law of gravitation and the laws of mechanics in1687, which unified terrestrial and celestial mechanics, was the heliocentric view generally accepted.

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Tycho Brahe

Tycho Brahe (1546–1601) was born in Scania, which became part of Sweden. Tycho was well known as an astronomer, astrologer, and alchemist. He was described as "the first competent mind in modern astronomy to feel ardently the passion for exact empirical facts. His observations were generally considered to be the most accurate of his time.

An heir to several of Denmark's principal noble families, Tycho received a comprehensive education. He took an interest in astronomy and in the creation of more accurate instruments of measurement. Tycho worked to combine what he saw as the geometrical benefits of Copernican heliocentrism with the philosophical benefits of the Ptolemaic system into his own, the Tycho System.

His system correctly saw the Moon as orbiting Earth, and the planets as orbiting the Sun, but improperly considered the Sun to be orbiting the Earth. He was the last of the major astronomers to work **without telescopes.** This was one of the systems people believed in when they did not accept heliocentrism, but could no longer accept the Ptolemaic system.
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Although one of astronomy's great minds, Tycho Brahe, rejected heliocentrism – because he could not find the proof of it.

However, from his base in Denmark, Brahe made great strides in observational astronomy. on the island of Hven, located in present-day Sweden, where Brahe built Uraniborg, the greatest astronomical observatory before the invention of the telescope. With the aid of large quadrants and sextants, he compiled a catalogue with the positions of about 1000 stars. Completed in 1598 and published in 1627, Brahe's catalogue had a precision of about one arc minute – a huge leap forward, and the first major improvement on stellar catalogues that stretched back seventeen centuries.

The heliocentric system revived the debate about stellar parallaxes. The parallax is an apparent movement of a foreground object with respect to its background owing to a change in the observer's position. Also known as triangulation, this method is used to assess distances to faraway objects on Earth. Astronomers had tried to apply it to determine the distance to the stars, but no baseline on Earth was big enough to detect stellar parallax because of the immense distances involved.

In his De Nova Stella (On the New Star) of 1573, his precise measurements indicated that "new stars" (stellae novae, now called supernovas), in particular that of 1572 (SN1572) lacked the parallax expected in sublunar phenomena and were therefore not tail-less comets in the atmosphere, as previously believed, but were above the atmosphere and beyond the Moon. Using similar measurements, he showed that comets were also not atmospheric phenomena, as previously thought, and must pass through the supposedly immutable the celestial spheres.

He worked at Uraniborg until disagreement with the new Danish king, and went into exile. He was then invited by the Bohemian king and Holy Roman Emperor Rudolph II to Prague, where he became the official imperial astronomer. He built an observatory at Benatky nad Jizerou. There, from 1600 until his death in 1601, he was assisted by Johannes Kepler, who later used Tycho's astronomical data to develop his three laws of planetary motion.

Tycho was most known for his highly accurate observations of the stars and the solar system. In Prague he was at work on the Rudophine Tables, that were not finished until after his death. The Rudolphine Tables was a star map designed to be more accurate than either the Alfonsine Tables made in the 1300s, and the Prutenic Tables, which were inaccurate.

After Copernicus suggested that Earth revolves around the Sun, astronomers realised that it was possible to exploit the much larger baseline offered by Earth's orbit to measure stellar parallaxes. So Brahe pushed towards the observational limits of his time, in search of stellar parallax. Unfortunately, he could not detect it. Incorrectly assuming that stars cannot be so distant that their parallax would not be within the reach of his measurements, Brahe rejected Copernicus's model and proposed his own hybrid system, which incorporated both geocentric and heliocentric features.

There was no way for Brahe to know, at the end of the sixteenth century, that stars are indeed so far away that his measurements would not be sufficient to detect parallax even for the closest stars to the Sun. At a distance of just over four light-years, our nearest neighbouring stars have a parallax smaller than one arc second[58]. The invention of the telescope and two centuries of diligent astronomy would be required before the first distance to a star could be measured. It was early in the nineteenth century, before we began to comprehend the true immensity of the cosmos.

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58 The parsec is the fundamental unit of distance in astronomy and a parallax of 1 arcsecond is called a parsec. A star with a parallax of 1 arcsecond has a distance of 1 parsec. (3.26 light-years).

Johannes Kepler

Johannes Kepler (1571-1630) was a German astronomer, mathematician, and writer on music. He is best known for his laws of planetary motion. His books Astronomia, Harmonice Mundi, and Epitome Astronomiae Copernicanae provided the foundations for Newton's theory of universal gravitation.

Kepler was a mathematics teacher at a seminary school in Graz (Austria), where he became an associate of Prince Hans Ulrich von Eggenberg. Later he became an assistant to the astronomer Tycho Brahe in Prague, and eventually the imperial mathematician to Emperor Rudolf II and his two successors. He also taught mathematics in Linz, and was an adviser to General Wallenstein.

Kepler lived in an era when there was no clear distinction between astronomy and astrology, but there was a strong division between astronomy (a branch of mathematics) and physics (a branch of natural philosophy). Kepler incorporated religious arguments and reasoning into his work, motivated by the religious conviction and belief that God had created the world according to an intelligible plan that is accessible through the natural light of reason.

Kepler described his new astronomy as "celestial physics", as "an excursion into Aristotle's Metaphysics" and as "a supplement to Aristotle's On the Heavens, transforming the ancient tradition of physical cosmology by treating astronomy as part of a universal mathematical physics.

After the death of Brahe, Kepler was deemed his successor and was given the job of completing Brahe's uncompleted works, like the Rudolphine Tables. He completed the Rudolphine Tables in 1624, although it was not published for several years.

Laws of planetary motions

Johannes Kepler is considered the founder of astronomy, because he was the first to attempt to derive mathematical predictions of celestial motions **from assumed physical causes.**

While Galileo was extending his observation of the planets, Kepler formulated his law of planetary motions, the first two in 1609 and the third in 1618. As assistant to the most accurate astronomical observer of the time, Tycho Brahe, he was able to use Brahe's data to show that planets moved in ellipses around the Sun (Kepler's First Law), that planets moved proportionally faster in their orbits when they were nearer the Sun (Kepler's Second Law), and that more distant planets took proportionally longer to orbit the Sun (Kepler's Third Law).

The three Kepler's laws of planetary motion may be state as follows:

.1 - The orbit of a planet is an ellipse with the Sun at one of the two foci.

.2 - A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.

.3 - The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit.

With these laws, he gave more credibility to the heliocentric model, because they adequately explained all the key features of our planetary movements, and provided more reliable predictions.

Before this, the Copernican model was just as incomplete as the Ptolemaic model. This improvement came because Kepler realised (from Brahe's data) that their orbits were not perfect circles, but ellipses.

Kepler lived during the time of discovery of the telescope. He was one of the few vocal supporters of Galileo's discoveries and the Copernican system of planets orbiting the Sun instead of the Earth.

Kepler's three laws of planetary motion can be stated as follows: (1) All planets move about the Sun in elliptical orbits, having the Sun as one of the foci. (2) A radius vector joining any planet to the Sun sweeps out equal areas in equal lengths of time. (3) The squares of the sidereal periods (of revolution) of the planets are directly proportional to the cubes of their mean distances from the Sun.

In 1684–85, Kepler's laws proved a crucial input to Newton when he considered the application of his law of gravity between the sun and the planets. He concluded that gravity applied to all objects anywhere in the universe. The motion of bodies subject to a central gravitational force need not always follow the elliptical orbits specified by the first law of Kepler. It could be in parabolic or hyperbolic orbits, depending on the total energy of the body. Thus, an object of sufficient energy—e.g., a comet could enter the solar system and leave again without returning. From Kepler's second law, he observed further that the angular momentum of any planet about the sun was unchanging.

Newton concluded that an invisible force, namely a gravitational force, acts between the sun and its planets. He stated that every object in the universe attracts every other object with a force that operates through empty space and that it varies with the masses of the objects and the distance between them. The stars do not fall into one another because these forces balance out. His law of gravity was brilliantly successful in explaining the Kepler's laws of planetary motions.

In Newton's time it was known that no matter what the mass of an object, it fell to the earth at the same acceleration (ignoring air resistance) of 9.8 metres per second squared. Newton postulated two types of mass: inertial mass, which resists motion and is governed by his general laws of motion, and gravitational mass, which enters into his equation for the force gravity. He showed that, if the two masses were equal, then all objects would fall with that same gravitational acceleration.

In classical times, the technology for space observation was still limited. The prevailing view was that the universe was in stable steady state, having thus been created, and would continue so in time. Science still had no knowledge of anything below the atomic or much beyond the canopy of the Milky Way.

It may be worth noting that Newton also defined space and time, taking both to be absolutes that are unaffected by anything external. Time, he wrote, "flows equably," while space "remains always similar and immovable".

Given the knowledge of the times, Newton's mechanics and the law of gravity, along with his assumptions about the nature of space and time, were wholly successful in explaining the dynamics of the universe, from motion on earth to cosmic events.

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Galileo

Galileo di Vincenzo Bonaiuti de' Galilei (1564-1642), commonly referred to as Galileo, was an Italian astronomer, physicist, and engineer, sometimes described as a polymath, from the city of. Pisa, Florence. Galileo has been called the "father" of observational astronomy, modern physics, the scientific method and modern science.

Principles of Motion

Galileo studied speed, velocity, gravity, free fall, the principle of relativity, inertia, and projectile motion. He laid down the first accurate laws of motion for masses. Galileo measured that all bodies accelerate at the same rate regardless of their size or mass. He developed the concept of motion in terms of velocity (speed and direction) through the use of inclined planes. He developed the idea of force as a cause for motion, and he determined that the natural state of an object is rest or uniform motion, i.e. objects always have a velocity, sometimes that velocity has a magnitude of zero = rest. Finally, objects resist change in motion, which is called inertia.

He also worked in applied science and technology, describing the properties of pendulums and hydrostatic balances. He invented the thermoscope and various military compasses, and finally he used the telescope for scientific observations of celestial objects, with dramatic results for mankind.

Telescope

Hans Lippershey, (1570-1619), spectacle maker from the United Netherlands, is traditionally credited with inventing the telescope (1608). He applied for a 30-year patent for his instrument, which he called a kijker (“looker. Two other claimants to the invention came forward, Jacob Metius and Sacharias Jansen. No patent was granted because so many people knew about it and the device was so easy to copy. However, the State General granted Lippershey 900 florins for the instrument but required its modification into a binocular device. His telescopes were made available before the end of 1608. The potential importance of the instrument in astronomy was recognized by, among others, Jacques Bovedere of Paris; he reported the invention to Galileo, who promptly built his own telescope. He was among the first to use a telescope to observe the sky, after constructing a 20x refractor telescope.

Galileo’s Observations

He discovered the four largest moons of Jupiter in 1610, which are now collectively known as the Galiliean moons in his honour. This discovery was the first known observation of satellites orbiting another planet. He also found that our Moon had craters and observed, and correctly explained, sunspots, and that Venus exhibited a full set of phases resembling lunar phases. Galileo argued that these facts demonstrated incompatibility with the Ptolemaic model, which could not explain the phenomenon and would even contradict it. With the moons it demonstrated that the Earth did not have to have everything orbiting it and that other parts of the solar system could orbit another object, such as the Earth orbiting the Sun. In the Ptolemaic system the celestial bodies were supposed to be perfect so such objects should not have craters or sunspots. The phases of Venus could only happen in the event that Venus' orbit is insides Earth's orbit, which could not happen if the Earth was the centre.

The observations made by Galileo would open up the way for fundamental discoveries. Along with the laws of planetary motion formulated by the German astronomer Johannes Kepler, Galileo's work laid the foundations for the theory of universal gravitation. This theory, developed by English physicist and mathematician Isaac Newton, and published in 1687, removed any lingering doubt that the Earth revolved around the Sun.

Heliocentrism and the Catholic Church

Galileo's championed Copernican heliocentrism. This was met with opposition from within the Catholic Church and from some astronomers. The matter was investigated by the Roman Inquisition in 1615, which concluded that heliocentrism was foolish, absurd, and heretical since it contradicted Holy Scripture.

On the orders of Pope Paul V Cardinal Robert Bellarmine gave Galileo prior notice that the decree was about to be issued, and warned him that he could not "hold or defend" the Copernican doctrine. The corrections to De Revolutionibus, which omitted or altered nine sentences, were issued four years later, in 1620.

Galileo later defended his views in Dialogue Concerning the Two Chief World Systems (1632), which appeared to attack Pope Urban VIII and thus alienated both the Pope and the Jesuits who had both supported Galileo up until this point. He was tried by the Inquisition, found "vehemently suspect of heresy", and forced to recant. He spent the rest of his life under house arrest.

In due time, at the instance of Roger Boscovich (1711-1787) physicist, astronomer, mathematician, philosopher, diplomat, poet, theologian and Jesuit priest who lived in Italy and France, the Catholic Church's 1758 Index of Prohibited Books omitted the general prohibition of works defending heliocentrism, but retained the specific prohibitions of the original uncensored versions of Copernicus' De Revolutionibus and Galileo's Dialogue.

The transition from the earlier observational processes of "natural philosophy" came about from a build-up of causes. There was the recovery of the philosophical, speculative and mathematical learning of the ancient world, that broke the medieval intellectual freeze. Then, there was the initial growth of higher secular learning at the universities, expanding later to wider public education. Then there was greater exploration, travel and sharing of knowledge, not the least due to the arrival of printing.

And finally, there was the evolution of the social milieu in the form of greater belief, curiosity and the upsurge of a new scientific awareness.

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Chapter Six

First Generation
Classical Age

Age of Exploration

It was an age of exploration and discovery in Europe. While sailors and merchants set off to cross the oceans and chart the globe, scientists embarked on their own journeys,- to probe the infinitely great and invisibly tiny

These investigations became possible at the turn of the seventeenth century with the invention of the telescope and the microscope, both credited to Dutch lens makers.

Shortly after the invention of the telescope, Italian astronomer Galileo Galilei built his own version and was the first to observe the sky with an 'enhanced' eye in 1609. This inaugurated a new era in observational astronomy and fostered the development of propositional , experimental study. The telescope allowed astronomers to gather ample evidence to test the heliocentric view of the universe that had been proposed a few decades earlier by the Polish astronomer Nicolaus Copernicus.

Along with the laws of planetary motion formulated by the German astronomer Johannes Kepler, Galileo's work laid the foundations for the theory of universal gravitation.

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(The above is extracted from European Space Agency, https://sci.esa.int/web/gaia/-/53197-seeing-and-measuring-farther).

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The Scientific Revolution

The Scientific Revolution began in Europe towards the second half of the Renaissance. With the rediscovery of ancient Greek learning and a the growing social and intellectual sophistication of the times, there grew the need for increased concrete knowledge of the physical world to improve the quality of human life. The Greeks had largely left this frontier of learning underexplored, and without any investigative methodology to speak of. This was the genesis of the Scientific Revolution.

The Scientific Revolution saw “natural philosophy”, the study of the physical world (which was started by Aristotle on the beaches of Lesbos) take its full place alongside philosophy and theology – overpowering all else with its continuous development to become the lead factor driving modern civilisation. Accompanied by a new utilitarian attitude, it transformed the world we live in through technology.

The first spark of the revolution started with Astronomy, the known and apparent facts of which had been the longest observed in history, and comprehensively summed up by Ptolemy. Interestingly, astronomy was classified as mathematics; the Greeks were quite hazy what was science. After checking out the geocentric model against his observations, Copernicus' in 1543 in his "De Revolutionibus" (On the Revolutions of the Heavenly Spheres) proposed a heliocentric system. This marked the first eruption of the New Science. Galileo would confirm it with further observations in 1609.

The Renaissance was a period of great vitality, the flowering of a re-surgent humanism (belief in Man as the centrality of things) and the liberation of the intellect. There was a willingness to question previously held truths and search for new information and answers. It resulted in a period of major scientific advancements, now known as the Scientific Revolution,. which led to the emergence of a New Science. It was a period of great fecundity which gave us Leonardo di Vinci and Vasco de Gama would give us William Shakespeare, Descartes and, among others, Francis Bacon.
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Francis Bacon

Francis Bacon (1561-1626), commonly regarded as one of the founders of the Scientific Revolution.

He defined the emergent utilitarian scientific ethos and helped establish the scientific method, whereby the laws of science were discovered by gathering and analysing data from experiments and observations, rather than by using logic-based arguments.

.His Novum Organum was published in 1620. He argued that man is "the minister and interpreter of nature", and that "knowledge and human power are synonymous". By the knowledge of nature and the using of instruments, man could govern or direct the natural work of nature to produce definite results. Therefore, that man, by seeking knowledge of nature, can reach power over it—and thus re-establish the "Empire of Man over creation", In this way, he believed, would mankind be raised above conditions of helplessness, poverty and misery, while coming into a condition of peace, prosperity and security.

Bacon developed his scientific method, consisting of procedures for isolating the formal cause of a phenomenon through eliminative induction. The enquirer should proceed through inductive reasoning from fact to axiom to physical law.

Bacon considered that science should work for the bettering of mankind's life by bringing forth new inventions, having even stated that "inventions are also, as it were, new creations."

Despite his influence on scientific methodology, he himself rejected correct novel theories of Copernicus's heliocentrism, and Kepler's laws of planetary motion – because at that point they were still to be proved by scientific methodology.

The Scientific Revolution that followed was a series of events that marked the emergence of a new science. Developments in mathematics, physics, astronomy, biology (including human anatomy) transformed man's understandings and the views of society about nature.

Christiaan Huygens was the first person to transfer the results of mathematical inquiry to describe unobservable physical phenomena. William Gilbert did some of the earliest experiments with electricity and magnetism, establishing that the Earth itself was magnetic. The Scientific Revolution is considered to have culminated in the 1687 with Isaac Newton's publication of his Principia, which formulated the laws of motion and universal gravitation, thereby completing the synthesis of a new cosmology.

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Classical Science

The Scientific Revolution saw "natural philosophy", the study of the physical world (which was started by Aristotle on the beaches of Lesbos) take its full place alongside philosophy and theology – overpowering all else with its continuous development to become the lead factor driving modern civilisation. Accompanied by a new utilitarian attitude, it transformed the world we live in through technology.

The new science initiated what would become the first stage of a universal quest for a common complete understanding of the physical world, and it progressively evolved the required set of scientific methodologies to do so.

Out of the ferment there arose a new view of science, bringing about the following transformations: the reliance on common sense instead of abstract reasoning, and on quantitative information for a qualitative view of nature. The object and criteria of scientific inquiry was was on the workings of nature (the "how" rather than the "why") with a view to trapping the laws behind them. The cutting edge was a new experimental approach, that sought definite answers to certain limited questions couched in the framework of specific theories;

The growing flood of (experimental) information that resulted from the Scientific Revolution needed to be shared and cumulatively used. This led to new social and intellectual attitudes, and institutions, and the new science became the bedrock of a new Enlightened Age.

The new science that emerged through the Age of Enlightenment and beyond in the 18th and 19th centuries , in turn became the first stage in the foundation of Modern Science. The latter happened with the birth of Relativity and Quantum Mechanics. I find it convenient therefore to refer to the whole of this first stage as the Age of Classical Science

By the end of the 19th century, man had in fact substantially established our basic knowledge (of the "truth") of the physical world across all the known realms of science, within the level of technology obtaining at that time. This meant defining the building blocks of matter, their physical, chemical and electrical properties, and the laws that governed them in the different physical domains.

To my mind, the determining requirement was getting down to the laws. That meant defining the set of operations that applied in all physical situations which that science studied, that could be used to identify new incidence of the same, and could be the basis for extending hypothesis and investigation to new areas, and forming new laws. Some people bandy the word empiricism. To me, it is what one looks at that matters. The achievement of the Scientific Revolution was establishing the operating baselines of our physical world.

Scientific enquiry became pervasive and cumulative. New canons of reporting were devised so that experiments and discoveries could be reproduced by others. This required new precision in language and a willingness to share experimental or observational methods.

As a result, there were better tools, better techniques and processes of investigation, the establishment of universally accepted criteria, and the increasing availability of shared data and experience. The scientific community reached the stage familiar to moderns: the more you share and know, the more you find there is to learn.

The result was the emergence of science as the lead driving factor of civilisation. Not the least was that the sciences now became the servant of mankind through technology, changing the world manifold for the better. The catch word was progress. There were a string of critical breakthroughs and inventions. Among the latter were the telescope and the microscope. Underpinning everything, deriving from the deeper and deeper needs for analysis and hypothesis, was the most remarkable development of mathematics in all its dimensions - the sine qua none of the scientific revolution. And, thank God, the world was gifted with some of the most brilliant minds of the century.

The scientific revolution (and technological explosion) bred a host of other revolutions: the exploration and colonisation of the “rest” of our planet, the discovery of new natural resources, the revolutions of economics and international trade that followed, the growth of education and democracy, and finally broadening out into the dawn of the Age of Enlightenment. At one level, it represented the challenge of the new sciences to the traditional views held in philosophy and theology. In its widest terms, it was the cross-fertilisation of the widened intellectual scientific attitudes to all dimensions of human endeavour.

Thus, the scientific revolution replaced slavery with technology as the economic foundation of our civilisation. The Christian churches found new worlds to preach their message to, with the means to do so.. the scientific revolution expanded the intellectual approaches of both philosophy and theology, broadening the meaning of Enlightenment.

Lastly, the scientific revolution also gave us the theory of evolution, and led inevitably to the theory of relativity, which in turn has put us within reach of the stars

Scientific and Academic Societies

Science during the Classical Age was dominated by scientific societies and academies which had largely replaced universities as the lead centres of scientific development and the maturation of the scientific profession.

The Accademia dei Lincei was founded in Rome in 1603 by Prince Federico Cesi and three other scholars: Historical sources report that the arms and the name “Lyncei” arose from their love of science and the desire to see into the secrets of nature with a perception as acute as that of the lynx. Their dedication to the study of natural sciences and their approach to science based on the new experimental methods made the Accademia dei Lincei the first scientific academy in the world. One of the first illustrious members was Galileo Galilei, whose most important scientific works were published by the Academy during the first part of the 17th century. After various phases of its history, the Accademia Nazionale dei Lincei is today the Italian national academy.

The German National Academy of Sciences Leopoldina is the national academy of Germany, and is located in Halle (Sa Tale). Founded in 1652, based on academic models in Italy, it was originally named the Academia Naturae Curiosorum until 1687 when Emperor Leopold I raised it to an academy and named it after himself. In 2007, it was declared to be Germany's National Academy of Sciences.

The Royal Society was formed in 1660, after a lecture at Gresham College, London, by Christopher Wren, the then professor of astronomy at the college. The tweleve men present resolved to set up “a college for the promoting of Physico-Mathematical Experimental Learning.” Those present intended that the new body should to become a truly national society devoted to the promotion of science. The charter of incorporation was granted by Charles II in 1662. Isaac Newton was its President from 1703 to 1727.

The French Academy[59] of Sciences (Académie des sciences) is a learned society, founded in 1666 by Louis XIV. Its aim was to encourage and protect the spirit of French scientific research. It examines the political, ethical and societal issues surrounding the current and future scientific topics

The Society of Sciences of the Elector of Brandenburg was founded in 1700 by Gottfried Wilhelm Leibniz (1646–1716) under Elector Frederick III of Brandenburg. From the start, this institution united the natural sciences and the humanities. It was the precursor of the Berlin-Brandenburg Academy of Sciences and Humanities of today, which boasts 80 Nobel Laureates; we need say no more..

In these societies and others like them all over the world, “natural philosophers” of the Scientific Revolution gathered to examine, discuss, and criticize new discoveries and old theories.

Astronomical Observatories

The Royal Observatory Greenwich was the oldest scientific research institution in Great Britain. It was founded for navigational purposes in 1675 by Charles II. Greenwich is most famous as the home of the Prime Meridian.
This was hugely beneficial when it came to mapping the night sky, with separate observation points able to be recorded in terms of their distance from the Prime Meridian. Until its closure in 1998, its primary contributions were in practical astronomy—navigation, timekeeping, determination of star positions, and almanac publication. The institution’s equipment and operations were consolidated under the UK Astronomy Technology Centre, headquartered at the Royal Observatory Edinburgh.

The Paris Observatory, French Observatoire De Paris, the national astronomical observatory of France, under the Academy of Sciences, was founded by Louis XIV in 1667. Gian Domenico Cassini was the first of four generations of his family to hold the post of director of the observatory. The observatory now houses the headquarters of the International Time Bureau, which standardizes the time determinations of the world’s observatories.

This is a good point to indicate that hereon we shall stick with Astronomy, and leave Astrology behind.

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Measuring The Earth

Jean Picard

Jean Picard (1620-1682) was a French astronomer and priest who studied at the Jesuit College Royal Henry-Le-Grand.

Picard was the first person to measure the size of the Earth to a reasonable degree of accuracy in an arc measurement survey conducted in 1669–70. Picard achieved this by measuring one degree of latitude along the Paris Meridian using from Paris to a clocktower in Amiens. His measurements produced a result of 110.46 km for one degree of latitude which gave a corresponding terrestrial radius of 6328.9 km. Newton was to use this value in his

[59] To be distinguished from the French Academy, Académie Française, the illustrious French literary academy, established by Cardinal Richelieu in 1634.

theory of universal gravitation. Picard's was an error only 0.44% less than the modern value of. just over 6,357 km[60]. His methodology was also a breakthrough in cartography.
Picard was the first to attach a telescope with crosswires to a quadrant, and one of the first to use a micrometre screw on his instruments. These refinements among others accounted for his level of accuracy.

Picard also developed what became the standard method for measuring the right ascension of a celestial object. In this method, the observer records the time at which the object crosses the observer's meridian. Picard made his observations using the precision pendulum clock that Christian Huygens had recently developed.

Henry Cavendish

Henry Cavendish (1731-1810) was an English natural philosopher and scientist who was an important experimental and theoretical chemist and physicist. He is noted for his discovery of hydrogen; Lavoisier reproduced Cavendish's experiment and gave the element its name.

His experiment in 1797 to measure the density of the Earth (which, in turn, allowed the gravitional constant to be calculated) has come to be known as the Cavendish experiment.

He measured the gravitational attraction between two iron balls of known mass. The balls, when released from a grip, caused a slight twist in a thread connecting them. By measuring how much the thread twisted Cavendish calculated the force between the balls, and thus the value of the gravitational constant (since he knew all of the other terms in the expression for gravitational force). Thus, he could "weigh the Earth" and determined that its mass was 5.972×10245.972×1024 kg.

Gravitation states that any two masses are attracted to one another. This attractive force is directly proportional to the masses and inversely proportional to the square of the distance between them and is written F = G M m / d2, where F denotes the force of attraction, M and m are the masses, and d is the distance between the object's centres. G is a constant that must be determined experimentally. G tuned out to be incredibly small, 0.0000000000667310 Nm2/kg2. (G is known only to the six decimal places.)

With the Cavendish constant, it became possible to calculate the mass (weight) of the Earth (M_e), Using (say) a person's weight (m), the distance to the Sun (which was known) (d), and the Cavefish constant (G) , we can find the Force (F) between the two objects m and Me from the following formula [F=GM_em/d2]. Their respective masses would proportional to their distances from the centre of the Earth.

The mass of the Earth worked out to $6x10^{24}$ (6 trillion trillion) kilograms, which converted to 13 trillion trillion pounds (lbs) for weight.(2.2 lbs=1kg)

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Discovering The Solar System

With discovery of the telescope and Kepler's use of it, astronomy became a science. He figured the heliocentricity, proportions and constituents of the solar system, but did not know its size and why stayed up there and revolved in place.

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60 The Earth's shape is actually an oblate spheroid There is a small flattening at the poles and bulging around the equation due to its rotation. The equatorial diameter is 43 kilometres (27 mi) larger than the pole-to-pole diameter.

Rene Descartes

René Descartes (1596-1650) was a French philosopher, mathematician, scientist and lay Catholic, who spent much of his life in the Dutch Republic. He is widely regarded as one of the founders of Enlightenment philosophy, and he dabbled as well in astronomy.. Descartes' best known philosophical statement is "cogito, ergo sum" ("I think, therefore I am").

Descartes is largely seen as responsible for laying the foundation of Rationalism, the view that "regards reason as the chief source and test of knowledge" or "any view appealing to reason as a source of knowledge or justification". It exerted an immense and profound influence on modern Western thought, with the birth of the two rationalistic philosophical systems of Descartes (Cartesianism) and Spinoza (Spinozism)

Descartes' influence in mathematics is equally apparent in the Cartesian coordinate system. He is credited as the father of analytic geometry, used in the discovery of infinitesimal calculus and analysis.

The vortex theory

Because of his philosophical beliefs, Rene Descartes proposed in 1644 that no empty space (aether) exist and that space must consequently be filled with matter. The parts of this matter tend to move in straight paths, but because they lie close together, they cannot move freely, which according to Descartes implies that every motion is circular. So the aether must filled with vortices.

Descartes also distinguishes between different forms and sizes of matter in which rough matter resists the circular movement more strongly than fine matter. Due to centrifugal force, matter tends towards the outer edges of the vortex, which causes a condensation of this matter there. The rough matter cannot follow this movement due to its greater inertia, so due to the pressure of the condensed outer matter those parts will be pushed into the centre of the vortex.

According to Descartes, this inward pressure is nothing other than gravity. He compared this mechanism with the fact that if a rotating liquid-filled vessel is stopped, the liquid goes on to rotate. Now, if one drops small pieces of light matter (e.g. wood) into the vessel, the pieces move to the middle of the vessel.

Isaac Newton

It began, so the story goes, with this apple falling off a tree. It took a Newton to conclude why the Moon did not fall to the Earth - for the same reason; and why everything else behaved as they did above us.

Sir Isaac Newton (1642-1726) was an English mathematician, physicist, astronomer, alchemist, theologian, and natural philosopher, widely recognised as one of the greatest mathematicians and physicists, and among the three[61] most influential scientists of all time. He was a key figure in the Scientific Revolution.

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[61] My list in historical order : Newton, Darwin, Einstein

Principia

His book Philosophiae Naturalis Principia (Mathematical Principles of Natural Philosophy), first published in 1687, established the laws of motion and gravity that unified the scientific framework for both terrestrial and celestial investigation. .

Laws of Motion

Firstly, Newton's laid down three laws of motion, which are the foundations of classical Mechanics. They describe the relationship between the motion of an object and the forces acting on it. These laws can be paraphrased as follows:

Law 1. A body remains at rest, or in motion at a constant speed in a straight line, unless acted upon by a force.

Law 2. When a body is acted upon by a force, the time rate of change of its momentum equals the force.

Law 3. If two bodies exert forces on each other, these forces have the same magnitude but opposite directions.

Newton's first law - a body tends to move at constant speed in a straight line - had been hinted at by Galileo in his law of inertia, and expressed in a more definite way by French philosopher Rene Descartes.

Newton's third law - if body A exerts a force on body B, then B exerts force on A equal in magnitude but opposite in direction - was well supported by work of Dutch mathematician Christian Huygens and others.

Newton's second law - the force impressed on a body is equal to the body's mass times its acceleration - represented a fresh way of thinking about motion. The idea of an inverse-square law for gravity had been toyed by other physicists and astronomers, but they had been unable to assemble all the necessary concepts—the law of attraction, the concept of motion under an impressed force, and the linking mathematics—into a finished product.

Law of Universal Gravitation

In the Principia, Newton also laid down the law of universal gravitation. It is usually stated as follows: that every particle attracts every other particle in the universe with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres. It is also called the "inverse-square law".

Most profoundly, Newton found that all objects on Earth and all celestial bodies were governed in common by the same laws of motion and the law of gravity.

The publication of the theory has become known as the "first great unification", as it marked the unification of the previously described phenomena of gravity on Earth with known astronomical behaviours.

Given the still nascent state of the sciences (in 1687), it was mind-boggling that anyone could announce that that all matter (apples) obeyed the same laws of motion and gravitation whether in the heaven or on earth.

Newton's laws have since been superseded by Albert Einstein's theory of general relativity. but it continues to be excellent approximation of the effects of gravity in most applications on our planet. Relativity is required only when there is a need for extreme accuracy, or when dealing with very strong gravitational fields, massive and dense objects, or at small distances.

Proofs of Heliocentric Earth

Newton used his mathematical description of gravity to verify and prove that Kepler's laws of planetary motion were correct and therefore that the solar system was as he asserted it to be heliocentric. .Newton went on to account for tides, the trajectory of comets, the precession of the equinoxes and other phenomena. He thereby provided the mathematical proof of what up to then had been a collection of hypotheses: the heliocentricity of the solar system. He supplied the why – it was gravity that kept \t everything in place.

In the Commentariolus, Copernicus had postulated that, if the Sun is assumed to be at rest and if Earth is assumed to be in motion, then the remaining planets fall into an orderly relationship whereby their sidereal periods increased from the Sun as follows: Mercury (88 days), Venus (225 days), Earth (1 year), Mars (1.9 years), Jupiter (12 years), and Saturn (30 years). This theory did resolve the ordering of the planets but, in turn, raised new problems, among others why they stayed up there and revolved as they did. Newton confirmed the disposition of the planets and supplied the missing force – gravity. However, this distance between planets was yet to come.

Newton's law of universal gravitation encountered some resistance, especially on the French-speaking continent. The idea that one body could reach out across empty space and affect another seemed to some to be a throwback to animism. It did not help that Newton could not explain the mechanism by which gravity acted.

Other Discoveries

His book, the Principia established classical mechanics, most of it terrestrially applicable and applied today.

Newton built the first practical reflecting telescope and developed a sophisticated theory of colour based on the observation that a prism separated white light into the colours of the visible spectrum. His work on light was collected in his highly influential book Opticks, published in 1704.

He also formulated an empirical law of cooling, made the first theoretical calculation of the speed of sound, and introduced the notion of a Newtonian fluid.

In addition to his work on calculus, as a mathematician, Newton contributed to the study of power series, generalised the binomial theorem to non-integer exponents, developed a method of approximating the roots of a function, and classified most of the cubic plane curves.

Newton also made seminal contributions to optics. He shares credit with Leibniz for developing infinitesimal calculus. .

Jean Richer

The inverse-square law was subjected to several dramatic tests. The first concerned Earth's shape. Newton had argued that Earth's rapid rotation on its axis must cause it to depart from perfect sphericity. Instead, Earth should be an oblate spheroid—that is, flattened at the poles like an onion. For evidence, Newton pointed to the example of Jupiter which showed such a noticeable flattening.

Proofs of Spheroid Earth

Jean Richer (1630-1696) French astronomer was sent by the French Government in 1671-73 to Cayenne, French Guiana, where he made observations that the beat of a pendulum was slower at Cayenne than at Paris. This meant that gravity must be weaker at Cayenne than at Paris. Newton and Dutch mathematician Christiaan Huygens used this discovery to prove that the Earth was not a sphere but actually flattened at the poles (an oblate spheroid), ie Cayenne was farther than Paris from Earth's centre. In 1672 he again found a pendulum clock near Earth's equator ran slightly slower than an identical clock in Paris.

In 1730s the French Academy of Sciences sponsored two expeditions—one to Lapland and one to equatorial South America - to settle this question. Careful geodetic and astronomical measurements were made to determine the length of a degree of the meridian for a place near the pole and a place near the equator. The results of the Lapland expedition showed decisively that Earth was flattened at the poles.

Christiaan Huygens

Christiaan Huygens, (1629-1695) was a Dutch mathematician, physicist, engineer, astronomer and inventor, who is regarded as one of the greatest scientists of all time and a major figure in the Scientific Revolution.

Rings of Saturn

As an astronomer Huygens is chiefly known for his studies of the rings of Saturn.. He discovered the first of Saturn's moons, Titan, and was the first to explain Saturn's strange appearance as due to "a thin, flat ring, nowhere touching, and inclined to the ecliptic".

Theory of Light

In physics, Huygens made ground-breaking contributions in optics and mechanics. In optics, he is best known for his wave theory of light, which he proposed in 1678 and described in his Traite de la Luniere (1690). His mathematical theory of light was initially rejected in favour of Newton's, until Augustin-Jean Fresnel adopted his principle to give a complete explanation of the rectilinear propagation and diffraction effects of light, in 1821. Today this principle is known as the Huygens-Fresnel principle.

Telescope

As an engineer and inventor, he improved the design of telescopes. In 1655, Huygens began grinding lenses with his brother Constantijn to build refracting telescopes for astronomical research. In 1662 Huygens developed what is now called the Huygenian eyepiece, a telescope with two lenses, which diminished the amount of dispersion.

Pendulum Clock

Huygens invented the pendulum clock, a breakthrough in timekeeping and the most accurate timekeeper for almost 300 years. Huygens invented the pendulum clock in 1657, which he patented the same year. His research in horology resulted in an extensive analysis of the pendulum in his Horologium (1673), regarded as one of the most important 17th century works on mechanics.

Mathematical Physics

An exceptionally talented mathematician and physicist, Huygens was the first to idealise a physical problem by a set of parameters then analyse it mathematically, and the first to fully mathematise a mechanistic explanation of an unobservable physical phenomenon. For these reasons, he has been called the first theoretical physicist and one of the founders of mathematical physics.

Huygens first identified the correct laws of elastic collision in his work De Motu Corporum ex Percussione, completed in 1656 but published posthumously in 1703. In 1659, Huygens derived geometrically the standard formulae for centrifugal force in his work De vi Centrifuga, a decade before Newton. That brilliant work contained a theory on the mathematics of curvatures, as well as complete solutions to such problems of dynamics as, the derivation of the formula for the time of oscillation of the simple pendulum, the oscillation of a body about a stationary axis, and the laws of centrifugal force for uniform circular motion.

In 1666 Huygens became one of the founding members of the French Academy of Sciences. which granted him a pension large.

Forgotten until the early 19th century, these latter appear today as one of the most brilliant and original contributions to modern science and will always be remembered by the principle bearing his name.

Huygens-Descartes Vortex Model

Following the basic premises of Descartes, Christiaan Huygens between 1669 and 1690 designed a much more exact vortex model. This model was the first theory of gravitation which was worked out mathematically. He assumed that the aether particles were moving in every direction, but were thrown back at the outer borders of the vortex and this caused (as in the case of Descartes) a greater concentration of fine matter at the outer borders. So also in his model the fine matter presses the rough matter into the centre of the vortex.

Huygens also found out that the centrifugal force was equal to the force which acted in the direction of the centre of the vortex (centripetal force). He also posited that bodies must consist mostly of empty space so that the aether can penetrate the bodies easily, which is necessary for mass proportionality. He further concluded that the aether moved much faster than the falling bodies.

At this time, Newton developed his theory of gravitation which was based on attraction, and although Huygens agreed with the mathematical formalism, he said the model was insufficient due to the lack of a mechanical explanation of the force law.

Newton's discovery that gravity obeyed the inverse law, surprised Huygens and he tried to take this into account by assuming that the speed of the aether was smaller at greater distances.

Newton objected to the theory because drag must lead to noticeable deviations of the orbits which were not observed. Another problem was that moons often moved in different directions, against the direction of the vortex motion. He devoted most of Book II of the Principia to the refutation of Descartes' vortex theory. Also, Huygens' explanation of the inverse square law was circular, because this meant that the aether obeyed Kepler's third law. But a theory of gravitation had to explain those laws and not presuppose them.

The telescopes of the classical age were basically limited to the solar system. It would be close to the 20th century before bigger telescopes and new technology would enable astronomers could measure distances of the nearest stars.

Giovanni Cassini

When in Guyenne in 1671-3, Jean Richer made observations of the planet Mars, especially its parallax at its zenith or. "opposition". Comparison of Richer's Mars observations with those made elsewhere made it possible to determine the distances of Mars and the Sun from Earth, leading to the first reasonably accurate calculations of the dimensions of the solar system.

Parallax

The parallax is the trigonometrical angle of a distant object which subtends the earth measured from two points. The parallax formula states that the distance to the object (say a planet) is equal to 1 divided by the parallax angle, p, where p is measured in arc-seconds, and d is parsecs[62]. **d=p1**.

The parallax (angle) of an object gets smaller with increasing distance. The parallax method therefore depends on how far and accurately the instruments can read small measurements of angle. During classical times, their instruments were not refined enough to measure the parallax of stars (ie stellar parallax).

As for the circumference of the earth, Erasthones (276-176 BC) had shown how to calculate it using trigonometry. It's modern measurement is 40,075 km or 25.000 miles)[63].

Size of the Solar System

In 1672, **Giovanni Cassini** (1625-1712) used Richer's observations and a method involving the parallax to find the distance to Mars and the distance between the Earth and the Sun. He is given the credit to be the first to do so, as he used rigorously acceptable scientific methodology and data. He obtained a value of 1.4×101^{1} m, (as against the modern value of 1.496×10^{11} m).

Once the distance between Earth and Sun is known, one can calculate all the other parameters. We know that the Sun, as seen from Earth, has an angular diameter of about 0.5 degrees. Again, using trigonometry, the radius or diameter of the Sun can be calculated. Also, since we know the time taken by the Earth to go once around the Sun (P = 1 year), and the distance travelled by the Earth in this process (approximately $2\pi a$, since Earth's orbit is nearly circular), we can calculate the average orbital speed of Earth as $v = (2\pi a)/P$.

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62 Parsec = the unit for expressing distances to stars and galaxies outside the solar system. It represents the distance at which the radius of Earth's orbit subtends an angle of one second of arc. approximately equal to 3.26 light years or 206,265 astronomical units (AU) The parsec unit is obtained by the use of parallax and trigonometry, and is defined as the distance at which 1 AU subtends an angle of on arc second arc-second (1/3600 of a degree. The nearest star, Proxima Centauri, is about 1.3 parsecs (4.2 light-years) from the Sun. Most stars visible to the naked eye are within a few hundred parsecs of the Sun, with the most distant at a few thousand. "kpc" stands for kilo parsecs (1,000 parsecs)

63 The circumference of the Earth is just its average diameter, 7915 miles, times the number pi, where pi is 3.14159. This gives us about 25,000 miles for the Earth's circumference

The relevant numbers are:
. - Earth-Sun distance, a = roughly 150 million km, defined as one Astronomical Unit (AU)
. - Radius of the Sun, Rsun = roughly 700,000 km
. - Orbital speed of Earth, v = roughly 30 km/s

Ole Roemer

In 1676, the Danish astronomer **Ole Roemer** (1644-1710) became the first person to measure the speed of light.

Working at the Paris Observatory, he was compiling observations of the orbit of Io, the innermost of the four big satellites of Jupiter discovered by Galileo. By timing the eclipses of Io by Jupiter, Roemer hoped to determine a more accurate value for the satellite's orbital period. A table of these orbital motions would provide a kind of "clock" in the sky.

Orbit of Io

The satellite was eclipsed by Jupiter once every orbit, as seen from the Earth. By timing these eclipses over many years, Roemer noticed that that when the Earth was nearest to Jupiter (at E1), eclipses of Io would occur about eleven minutes earlier than predicted based on the average orbital period over many years. And 6.5 months later, when the Earth was farthest from Jupiter (at E2), the eclipses would occur about eleven minutes later than predicted.

Speed of Light

In a brilliant insight, he realised that the time difference must be due to the finite speed of light. Roemer estimated that light required twenty-two minutes to cross the diameter of the Earth's orbit. The speed of light could then be found by dividing the diameter of the Earth's orbit by the time difference.

he Dutch scientist Christiaan Huygens, who first did the arithmetic, found a value for the speed of light equivalent to 131,000 miles per second. The correct value is 186,000 miles per second. More important than the exact answer, Roemer's data provided the first quantitative estimate for the speed of light,

Edmond Halley

Edmond Halley (1656-1742) was an English astronomer, geophysicist, mathematician, meteorologist and physic, the second Astronomer Royal in Britain, succeeding John Flamsteed in 1720.

From an observatory he constructed on Saint Helena in 1676-77, Halley catalogued the southern celestial hemisphere and recorded a transit of Mercury across the Sun.

Proper motion

In 1718, he discovered the proper motion of "fixed stars". It is the astronomic measure of the observed changes in the apparent places of celestial objects in the sky as seen from the centre of the solar system -compared to the abstract background of the more distant stars.

Over the centuries, stars appeared to maintain nearly fixed positions with respect to each other, so that they formed the same constellations over historical time. However, precise long-term observations showed that the constellations changed shape, albeit very slowly, and that each star had an independent motion.

Any proper motion is a two-dimensional vector and bears two quantities or characteristics: (1) its position angle, which is the direction of the proper motion on the celestial sphere (with 0 degrees meaning the motion is north, 90 degrees meaning the motion is east, and so on), and (2) the second is its magnitude, typically expressed in arc-second per year. Proper motion may alternatively be defined by the angular changes per year in the star's right ascension (μα) and declination (μδ) with respect to a constant\ (often J2000).

Knowledge of the proper motion, distance, and radial velocity will in time allow calculations of an object's motion from our star system and its motion from the galactic frame of reference, namely the Milky Way

Halley's Comet

From observations Halley made in 1682, he used Newton's Laws of Motion and Gravity to compute the periodicity of the comet Halley in his 1705 Synopsis of the Astronomy of Comets.

Halley had argued that the comet(s) of 1531, 1607, and 1682 were one and the same and predicted a return for late 1758 or early 1759, but he did not live to see it happen. It was named after him upon its predicted return in 1758.

As the time approached for the expected reappearance, in Paris, astronomer Jerome Lalander and Nicole Lepauté, the wife of a well-known instrument maker, calculated the motion of the comet, including the planetary perturbing forces acting upon it, the most ambitious programme of numerical calculation ever undertaken up to that time. When the comet reappeared within their announced one-month window of error, it was seen by many as a triumph of calculation, as well as of the law of universal gravitation.

I was so intrigued by this anecdote from Quora that I decided to include it here:

> "Newton actually calculated, using a lot of obscure geometry and limiting concepts, the orbits that various force forms would generate. One of those forms was the inverse square force. If you want to know what the others were, find a copy of the Principia and wade through it.
>
> The result wasn't published until Edmund Halley asked Newton if he knew the nature of the force (our modern wording) that would cause something to have a repeating orbit. Halley was investigating the possibility that sightings of a bright comet every 76 years could possibly be the same comet. Newton immediately responded that it was an inverse square force.
>
> Halley was shocked with the quick answer. Newton had worked out the math for various forces out of curiosity and never told anyone. Halley forced him (with his financial backing) to publish the results.
>
> Newton's reasoning was that the same force which gave an object weight (or gravitas, from the Latin) was the same force which kept the moon in orbit around the Earth and the Earth around the Sun, etc.
>
> Quora
> https://www.quora.com/How-did-Newton-calculate-the-distance-between-the-Earth-and-the-Sun-to-calculate-the-mass-of-the-Earth

John Flamsteed

John Flamsteed, (1646-1719), was a British astronomer and member of the Royal Society, whose report to the latter on the need for a new observatory resulted in the founding of the Royal Greenwich Observatory in 1675. He was appointed its first director and hence the First Astronomer Royal of England.

Flamsteed was a clergyman. He found that he himself had to supply all the instruments at Greenwich, apart from a few gifts; he was forced to take private pupils to augment his income. A small inheritance from his father, who died in 1688, provided the means to construct a mural arc, a wall-mounted instrument for measuring the altitudes of stars as they passed the Prime Meridian.

Uranus

Flamsteed accurately calculated the solar eclipses of 1666 and 1668. He was responsible for the earliest recorded sightings of Uranus in 1690, which however he mistook for a star. .

Comets

In 1681 Flamsteed proposed that the two comets observed in November and December 1680 were not separate bodies, but rather a single comet travelling first towards the Sun and then away from it.

Newton at first disagreed with Flamsteed, but he later came to agree with him - and theorised that comets, like planets, moved around the Sun in large, closed elliptical orbits. Flamsteed later learned that Newton had gained access to his observations and data through Edmond Halley, his former assistant.

Historia Coelestis Britannica

His main achievements were the preparation of a 3,000-star catalogue, the Catalogus Britannicus, and a star atlas called the Atlas Coelestis, both published posthumously

As Astronomer Royal, Flamsteed spent some forty years observing and making meticulous records for his star catalogue, which would eventually triple the number of entries in Tycho Brahe’s sky atlas. Unwilling to risk his reputation by releasing unverified data, he kept the incomplete records under seal at Greenwich. In 1712, Newton, then President of the Royal Society and Halley again obtained Flamsteed's data and published 400 copies of the pirated star catalogue edited by Halley. Flamsteed managed to gather 300 of the printings and burned them. The data from the pirated catalogue were used by a London cartographer to produce star charts in the 1720s before Flamsteed's own charts were ready.

In 1725, Flamsteed's own version of Historia Coelestis Britannica was published posthumously, edited by his wife, Margaret. This contained Flamsteed's observations, and included a catalogue of 2,935 stars to much greater accuracy than any prior work. It was considered the first significant contribution of the Greenwich Observatory. Flamsteed's numerical designation are still use for some stars. In 1729 his wife published his Atlas Coelestis.

James Bradley

James Bradley, (1693-1762) was an English astronomer who in 1728 announced his discovery of the aberration of starlight, an apparent slight change in the positions of stars caused by the yearly motion of the Earth. That finding provided the first direct evidence for the revolution of the Earth around the Sun. Bradley was one of the first post-Newtonian observational astronomers who led the quest for precision

After Copernicus in 1543, it became increasingly imperative for astronomers to be able to observe and measure the parallactic displacement of a star —the change in a star's position over a six-month period—to confirm the orbital motion of the Earth around the Sun. Such information would provide the evidence needed to augment the conceptual and mathematical arguments thitherto advanced for the idea that the Sun does not revolve around the Earth. In the absence of such evidence, Tycho Brahe had not been favourably disposed to Copernican theory. Ole Roemer had measured an apparent displacement of the stars Sirius and Vega in the 17th century, but his observations were found to be erroneous.

In 1725, Bradley observed that Gamma Draconis ha shifted south in position by an astonishing 1 degree of arc in three days— in the wrong direction and by too large an amount to be accounted for by parallax. He concluded that the apparent stellar shift was brought about by the aberration of light[64] which was a result of the finite speed of light and the forward motion of the Earth in its orbit. On the basis of his quantitative observations of aberration, Bradley confirmed the velocity of light to be 295,000 kilometres (183,000 miles) per second and gave a proof for the Copernican theory.

Bradley's star measurements in 1727–32 also revealed what he called the "annual change of declination in some of the fixed stars," which could not be accounted for by aberration. He concluded that this was caused by the slight and uneven nodding motion of the Earth's axis (nutation) that resulted from the changing direction of the gravitational pull of the Moon. For this achievement the Royal Society of London, to which he had been elected, awarded him the Copley Medal in 1748.

The German mathematician Friedrich Bessel analysed and organized his data, correcting for the small errors in Bradley's instruments, and then computing star positions.

Joseph-Louis Lagrange

Joseph-Louis Lagrange (1736-1813) was an Italian French mathematician who made great contributions to number theory and analytic, and celestial mechanics.

[64] Aberration of light is a phenomenon which produces an apparent motion of celestial objects about their true positions, dependent on the velocity of the observer. It causes objects to appear to be displaced towards the direction of motion of the observer compared to when the observer is stationary. In the case of "stellar" or "annual" aberration, the apparent position of a star to an observer on Earth varies periodically over the course of a year as the Earth's velocity changes as it revolves around the Sun. Aberration is distinct from parallax which is a change in the apparent position of a relatively nearby object, as measured by a moving observer, relative to more distant objects that define a reference frame. The amount of parallax depends on the distance of the object from the observer, whereas aberration does not.

Stability of the Moon

By 1761 Lagrange was already recognized as one of the greatest living mathematicians. In 1764 he was awarded a prize offered by the French Academy of Sciences for an essay on the libation of the Moon (i.e., the apparent oscillation that causes slight changes in position of lunar features on the face that the Moon presents to the Earth). In this essay he used the equations that now bear his name. His success encouraged the academy in 1766 to propose, as a problem the theory of the motions of the satellites of Jupiter, which challenge was taken up by Laplace see next section).

In 1766, Lagrange succeeded Euler (Europe's most famous mathematician – but not an astronomer) as the director of mathematics at the Prussian Academy of Sciences in Berlin, where he stayed for over twenty years, producing volumes of work and winning several prizes of the French Academy of Sciences.

Analytic Mechanics (100 years after Newton)

His most important book, Mécanique analytique, Analytic Mechanics (1788), 2 Volumes, was written in Berlin and first published in 1788. It offered the most comprehensive treatment of classical mechanics since Newton, and formed a basis for the development of mathematical physics in the 19th century.

In 1787, at age 51, he moved from Berlin to Paris and became a member of the French Academy of Sciences.

Leonhard Euler

Leonhard Euler (1707-1783) was a Swiss mathematician, physicist, astronomer, geographer, and engineer who founded and made pioneering and influential discoveries in many branches of mathematics, He introduced much of modern mathematical terminology and notation.   He was also known for his work in mechanics, dynamics, optics, astronomy and music theory.
Euler is held to be one of the greatest mathematicians in history and the greatest of the 18th century.

What may be one of the most important discoveries for future space travel, Euler discovered the three collinear Lagrange points (L1, L2, L3) around 1750, a decade before Joseph -Louis Legrange discovered the in which he demonstrated both the collinear and the equilateral (L4 and L5) points for any three masses with circular orbits

Lagrange Points

There are five locations around a planet's orbit where the gravitational forces and the orbital motion of a spacecraft, Sun and the planet interact to create a stable location from which to make observations. These points are known as Legrange or the Lagrangian or 'L' points, after Lagrange.

The Lagrange points (also known as libration points) are points of equilibrium for small-mass objects under the influence of two massive orbiting objects.

Normally, the two massive bodies exert an unbalanced gravitational force at a point, altering the orbit of whatever is at that point. At the Lagrange points, the gravitational forces of the two large bodies and the centrifugal force balance each other. This makes Lagrange points an excellent location for satellites and. harbour for spacecraft, as few orbital corrections are needed to maintain their desired orbit.

The Hubble Space Telescope was placed in Earth orbit some 540 Km up in April 1990, opening up our view of the extragalactic universe. Its successor. In Jan 2022, the James Web Telescope was placed in orbit at L2 Earth-Sun Legrange point, some 1.5 million miles up, with promise of untold discoveries to come.

An every planet has its set of Legrange points, these are step-ladders to the Milky Way, where there will be other Legrange points.

Pierre-Simon Laplace

Pierre-Simon, marquis de Laplace (1749–1827) was a French scholar and polymath whose work was important to the development of engineering, mathematics, astronomy, physics, statistics and philosophy. Laplace is sometimes referred to as the Newton of France. He is best known for his investigations into the stability of the solar system..

Laplace showed his mathematical ability at the military academy at Beaumont. In 1766 Laplace entered the University of Caen, but he left for Paris, apparently without taking a degree. He arrived with a letter of recommendation and secured a professorship at the École Militairea where he taught from 1769 to 1776.

Stability of the Solar System

It was a major unsolved puzzled in astronomy at that stage that as every planet was attracted not only by the Sun but also (much more weakly) by all the other planets, its orbit cannot really be the simple ellipse of Kepler. The mutual gravitational interactions (known as perturbations) within the solar system were so complex that a mathematical solution seemed impossible; indeed, Newton had concluded that divine intervention was periodically required to preserve the system in equilibrium

In the 18th century new mathematical methods were developed, largely in France, which treated the problem more efficiently. The key figures in this work were Joseph-Louis Lagrange and Laplace.

In 1773 Laplace began his major lifework—applying Newtonian gravitation to the entire solar system—by taking up a particularly troublesome problem: why Jupiter's orbit appeared to be continuously shrinking while Saturn's continually expanded.

In 1773, Laplace announced the invariability of planetary mean motions (average angular velocity). This discovery, the first and most important step in establishing the stability of the solar system, was the most important advance in physical astronomy since Newton. It won him associate membership in the French Academy of Sciences.

Returning to his astronomical investigations of the entire subject of planetary perturbations Laplace in 1786 proved that the eccentricities and inclinations of planetary orbits to each other would always remain small, constant, and self-correcting. The effects of perturbations were therefore conservative, periodic but not cumulative and disruptive. He proved that the solar system was inherently quite stable.

Laplace also removed the last apparent anomaly from the theoretical description of the solar system, with the announcement that lunar acceleration depended on the eccentricity of the Earth's orbit. Although the mean motion of the Moon around the Earth depended mainly on the gravitational attraction between them, it was slightly diminished by the pull of the Sun on the Moon. This solar action depended in turn on changes in the eccentricity of the Earth's orbit resulting from perturbations by the other planets. As a result, the Moon's mean motion was accelerated as long as the Earth's orbit tended to become more circular; but, when the reverse occurred, this motion was retarded. The inequality was therefore not truly cumulative, Laplace concluded, but was of a period running into millions of years. The last threat of instability thus disappeared from the theoretical description of the solar system.

Celestial Mechanics

His Traité de Mécanique Celeste (Celestial Mechanics), appearing in five volumes between 1798 and 1827, summarized the results obtained by his mathematical development and application of the law of gravitation. It offered a complete mechanical interpretation of the solar system by devising methods for calculating the motions of the planets and their satellites and their perturbations, including the resolution of tidal problems. The book made him a celebrity. This work translated the geometric study of classical mechanics to one based on calculus.

Nebular Hypothesis

In 1796 Laplace published Exposition du Système du Monde (The System of the World), a semi-popular treatment of his work in celestial mechanics and a model of French prose, which appeared in several editions up to1824. In this work Laplace explained for the lay reader all the phenomena of the solar system in terms of universal gravitation. This was followed by a brief history of astronomy from ancient times down to Laplace's own day.

The book ended with a brief account of what is now called Laplace's nebular hypothesis, a theory of the origin of the solar system. Laplace imagined that the planets had condensed from the primitive solar atmosphere which originally extended far beyond the limits of the present-day system. As this cloud gradually contracted under the effects of gravity, it first formed rings and then amalgamated into planets.

Newton had seen in the regularities of the solar system a sign of the wisdom and beneficence of the Creator. For example, the fact that all the planets travel around the Sun in the same direction and more or less in the same plane could be explained only by divine providence. Laplace, looking at the same facts, instead regarded them as evidence about the prehistory of the solar system.

The nebular hypothesis, although only sketchily worked out, was important as an early example of an evolutionary theory in natural science, and it is notable that evolutionary thinking entered astronomy before it became important in the life sciences. He was one of the first scientists to postulate the existence of black holes and the notion of gravitational collapse.

Other Contributions

During 1784–85 Laplace worked on the attraction between spheroids. He explored the attraction of any spheroid upon a particle situated outside or upon its surface. Through his discovery of the attractive force of a mass upon a particle regardless of direction, Laplace laid the mathematical foundation for the scientific study of heat, magnetism, and electricity.

in mathematical physics Laplace formulated Laplace's equation and pioneered the Laplace transform, a field that he took a leading role in forming. The Lapacian differential operator widely used in mathematics, is also named after him in 1780. applying quantitative methods to a comparison of living and non-living systems, Laplace and Lavoisier showed respiration to be a form of combustion.

In 1814 Laplace published a popular work for the general reader, Essai Philosophique sur les Probabilités (A Philosophical Essay on Probability). This work was the introduction to the second edition of his important earlier work Théorie Analytique des Probabilités (Analytic Theory of Probability), first published in 1812, in which he described many of the tools he invented for mathematically predicting probabilities, not only to the ordinary problems of chance but also to the inquiry into the causes of phenomena, vital statistics and future events, while emphasizing its importance for physics and astronomy. Laplace proved that the distribution of errors in large data samples from astronomical observations can be approximated by a Gaussian or normal distribution.

Probably because he did not hold strong political views and was not a member of the aristocracy, he escaped imprisonment and execution during the French Revolution. Afterwards, Laplace was president of the Board of Longitude, and aided in the organisation of the metric system.

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Peeking Beyond The Solar System

Galileo was able to make out mountains and craters on the moon, as well as a ribbon of diffuse light arching across the sky -- which would later be identified as our Milky Way galaxy. After Galileo's and, later than Newton's time, astronomy flourished as a result of larger and more complex telescopes.

Astronomers discovered many faint stars and the calculation of stellar distances. In the 19th century, using a new instrument called a spectroscope, astronomers gathered information about the chemical composition and motions of celestial objects

Charles Messier

Charles Messier (1730-1817) was a French astronomer, famous for his Catalogue des Nébuleuses et des Amas d'Étoiles (Catalogue of Nebulae and Star Clusters) published in 1781-84, an astronomical catalogue of 103 entries which came to be known as the Messier objects. Messier's interest was in comets, and he ultimately identified 13 of them. He purpose in recording the catalogue was to distinguish between permanent and transient objects in the sky. The entries are now known to comprise 39 galaxies, four planetary nebule, seven other types of nebulae, and 55 star clusters. Other astronomers, using side notes in Messier's texts, eventually filled out the list up to 110 objects.

The first version of Messier's catalogue contained 45 objects which were not yet numbered. Eighteen of the objects were discovered by Messier, the rest being previously observed by other astronomers.

Messier did his observing with a 100 mm (four-inch) refracting telescope in downtown Paris, in the area of the sky Messier could observe, from the north celestial pole to a declination of about −35.7° . This catalogue of objects is one of the most famous lists of astronomical objects, and many Messier objects are still referenced by their Messier numbers. The catalogue includes most of the astronomical deep-sky objects in the northern hemisphere.

Frederick William Herschel

Frederick William Herschel (1738-1822) was a German-born British astronomer. He frequently collaborated with his younger sister and fellow astronomer Caroline Herschel (1750–1848). He emigrated to Great Britain in 1757 at the age of nineteen.

Herschel constructed his first large telescope in 1774, after which he spent nine years carrying out sky surveys to investigate double stars. Herschel published catalogues in 1802 (2,500 objects) and in 1820 (5,000 objects). The resolving power of the Herschel telescopes revealed that many objects called nebulae in the Messier catalogues were actually clusters of stars.

Uranus

On 13 March 1781 he made note of a new object in the constellation of Gemini. This would, after several weeks of verification and consultation with other astronomers, be confirmed to be a new planet, eventually given the name of Uranus. This was the first planet to be discovered since antiquity, and Herschel became famous overnight.

As a result of this discovery, George III appointed him Court Astronomer. He was elected to the Royal Society and grants were provided for the construction of new telescopes.

Herschian Telescope

The most common type of telescope at that time was the refracting telescope, which involved the refraction of light through a tube using a convex glass lens. . This design was subject to chromatic aberration, a distortion of an image due to the failure of light of different wavelengths to converge.

In 1668, Newton invented the reflector telescope which used a single concave rather than a convex lens. This avoided chromatic aberration. The concave mirror gathered more light than a lens, reflecting it onto a flat mirror at the end of the telescope for viewing. A smaller mirror could provide greater magnification and a larger field of view than a convex lens. Newton's first mirror was 1.3 inches in diameter; such mirrors were rarely more than 3 inches in diameter.

Because of the poor reflectivity of mirrors made of speculum metal, Herschel eliminated the small diagonal mirror of the Newtonian model from his design and tilted his primary mirror so he could view the formed image directly. This "front view" design has come to be called the Herschian telescope.

The 40 foot Telescope

The creation of larger, symmetrical mirrors was extremely difficult. Herschel, determined to make his own. This was no small undertaking, especially the casting. He was assisted by his sister Caroline and other family members.

Herschel is reported to have cast, ground, and polished more than four hundred mirrors for telescopes, varying in size from 6 to 48 inches in diameter. Herschel and his assistants built and sold at least sixty complete telescopes of various sizes. Commissions for the making and selling of mirrors and telescopes provided Herschel with an additional source of income.

An essential part of constructing and maintaining telescopes was the grinding and polishing of their mirrors. This had to be done repeatedly, whenever the mirrors deformed or tarnished during use. The only way to test the accuracy of a mirror was to use it.

The most famous of Herschel's telescopes was a reflecting telescope with a 49½-inch-diameter (1.26 m) primary mirror and a 40-foot (12 m) focal length, at that time, the largest scientific instrument that had been built.

In 1785 Herschel received £4,000 from George III. Without royal patronage, the telescope could not have been created. As it was, it took five years, and went over budget.

A 40-foot telescope tube had to be cast of iron. The tube was large enough to walk through. Mirror blanks were poured in almost four feet (1.2 m) in diameter and they weighed 1,000 pounds (454 kg). When the first disk deformed due to its weight, a second thicker one was made with a higher content of copper. The mirrors had to be hand-polished, a painstaking process. A mirror was repeatedly put into the telescope and removed again to ensure that it was properly formed. A huge rotating platform was built to support the telescope, enabling it to be repositioned by assistants as a sweep progressed. A platform near the top of the tube enabled the viewer to look down into the tube.

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In 1789, shortly after this instrument was operational, Herschel discovered a new moon of Saturn, Mimas, only 250 miles (400 km) in diameter. Discovery of a second moon, Enceladus, followed, within the first month of observation.

The 40-foot (12.2-metre) telescope proved very cumbersome, and in spite of its size, not very effective at showing clearer images. Herschel's technological innovations had taken him to the limits of what was possible with the technology of his day.

The 40-foot would not be improved upon until the Victorians developed techniques for the precision engineering of large, high-quality mirrors. Herschel was disappointed with it. Most of Herschel's observations were done with a smaller 18.5-inch (47 cm), 20-foot-focal-length (6.1 m) reflector. Nonetheless, the 40-foot caught the public imagination.

Distribution Of Stars

Herschel was the first astronomer to attempt to determine the distribution of stars in the sky. During the 1780s, he established a series of gauges in 600 directions and counted the stars observed along each line of sight. From this he deduced that the number of stars steadily increased toward one side of the sky, in the direction of the Milky Way core. His son, John Herschel, repeated this study in the southern hemisphere and found a corresponding increase in the same direction.

Binary Stars

Herschel is noted for his discovery that some stars do not merely lie along the same line of sight, but are physical companions that form binary star systems.

Other Discoveries

Herschel pioneered the use astronomical spectroscopy, using prisms and temperature measuring equipment to measure the wavelength distribution of stellar spectra. In the course of these investigations, Herschel discovered infra-red radiation. Other work included an improved determination of the rotation period of Mars, the discovery that the Martian polar caps vary seasonally, the discovery of Titiana and Oberon (moons of Uranus).

Herschel was the first President of the Royal Astronomical when it was founded in 1820. He died in August 1822

Johann Daniel Titius (Bode's law)

Johann Daniel Titius (1729-1796) a Prussian astronomer, physicist, and biologist whose law (1766) expressing the distances between the planets and the Sun was popularized by German astronomer John Elert Bode in 1772, also known as Bode's law.

There was a long tradition that went all the way back to Plato and Pythagoras of trying to tie planetary distances to numerical sequences. An influential new scheme was proposed in 1766 by Titius.

Titius proposed his law of planetary distances in an unsigned interpolation in his German translation of a work by a Swiss philosopher. Titius fixed the scale by assigning 100 to the distance of Saturn from the Sun. On this scale, Mercury's distance from the Sun was approximately 4. Titius therefore proposed that the sequence of planetary distances (starting from Mercury and moving outward) had the form: 4, 4 + 3, 4 + 6, 4 + 12, 4 + 24, 4 + 48, 4 + 96.

There was an empty place at distance 28, or 4 + 24 (between Mars and Jupiter) which, Bode asserted, the Founder of the Universe surely had not left unoccupied. Titius's sequence stopped with Saturn, the most distant planet. His law was reprinted, without credit, by Bode in the second edition of his Clear Guide to Knowledge of the Starry Heaven. In later editions, Bode did credit Titius, but this mostly escaped notice, and during the 19th century the law was usually associated with Bode's name.

The Titius-Bode law proved to be accurate in accounting for the average distance between the Sun and the first asteroids (discovered in 1801), which were found in the gap at distance 28 and also for the distance between the Sun and Uranus (discovered in 1781). Herschel's discovery of Uranus at distance 192 (where the law predicted 196) seemed an uncanny confirmation of the law. It did not, however, accurately predict the distance of Neptune.

Friedrich Wilhelm Bessel

Friedrich Wilhelm Bessel (1784-1846) was a German astronomer, mathematician, physicist, and geodesist. He was the first astronomer who determined with reliable values the distance from the Sun to another star by use of the **stellar parallax**. His rigorous methods of observation (and correction of observations) took astronomy to a new level of precision.

Bessel was born in Westphalia, Germany. He studied the principles of navigation, which led him to astronomy and mathematics. In 1804 he wrote a paper on Halley's Comet . A German astronomer who read it proposed Bessel as assistant at the Lilienthal observatory of the celebrated lunar observer J.H. Schröter.

After Bessel had spent only four years at Lilienthal, the Prussian government charged him with the construction at Konigsberg of the first big German observatory. In 1810 he was appointed professor of astronomy at the University of Konigsberg, directing the observatory from its completion in 1813 until the end of his life.

Refraction of Light

Bessel made the first precise measurements of the refraction of light by the Earth's atmosphere. As a result, he produced tables of atmospheric refraction[65], that won him the Lalande Prize from the French Academy of Sciences in 1811. His tables of refraction allowed observers to measure star positions to an unprecedented accuracy of less than a tenth of a second of arc (the size of a small coin as seen from a mile away).

Meridian Circle

Starting in 1819, Bessel determined the position of over 50,000 stars using a meridian circle[66] specially made for him by Georg von Reichenbach, the instrument maker. For many years, transit timings were the most accurate method of measuring the positions of heavenly bodies, and meridian instruments were relied upon to perform this painstaking work. The measuring of positions (and the deriving of orbits and astronomical constants) was the major work of observatories.

Heliometer

The later achievements of Bessel were possible only because he first established the real framework of the universe by making accurate measurements of the positions and motions of the nearest stars with a heliometer[67] built by German physicist Joseph von Fraunhofer, making corrections for various measuring errors caused by imperfections in his telescopes and by disturbances in the atmosphere. He reduced, or systematised, the observations of the English astronomer James Bradley. Correcting the positions of 3,222 stars and he published the results in his Fundamenta Astronomiae (1818); this work marked the beginning of modern astrometry (positional astronomy). The uniform system of reduction that Bessel established in Tabulae Regiomontanae (the Königsberg Tables) in 1830, long remained standard.

First Parallax of a Star

Bessel is credited with being the first to use the stellar parallax in calculating the distance to a star. The heliometer's most notable discovery happened in 1838 when Bessel used it to perform the first measurement of the parallax of a star, and hence its distance from earth. Bessel was the first to publish a reliable measurement of parallax.

Having established the exact positions of thousands of individual stars, Bessel was ready to observe exceedingly small but highly significant motions, relative to one another, among them. Choosing 61 Cygni, a star barely visible to the naked eye and known to possess a

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[65] **Atmospheric refraction** is the deviation of light or other electromagnetic wave from a straight line as it passes through the atmosphere due to the variation in air density as a function of height. Astronomical or celestial refraction causes astronomical objects to appear higher above the horizon than they actually are. In the visible spectrum, blue is more affected than red.

[66] The **meridian circle** is a telescope instrument for timing of the passage of stars across the local meridian, while at the same time measuring their angular distance. Meridian telescopes rely on the rotation of the sky to bring objects into their field of view.

[67] **Heliometer** = An astronomical instrument used to measure the angle between two objects in the sky viewed by an observer from the same location and at the same time. In the case of two stars, the distance the two lenses must be moved in order to superimpose the two images together can be used to derive their angular separation The first heliometers were designed by British scientist Servington Savery in 1743 and French scientist Pierre Bouguer 1748.

relatively high velocity in the plane of the sky, Bessel showed that the star apparently moved in an ellipse every year. This back and forth motion, called the annual parallax, could only be interpreted as being caused by the motion of the Earth around the Sun. Bessel was the first to demonstrate it accurately. This was the conclusive proof of Copernicus' theory (that the Earth moved round the Sun), also confirming James Bradley's earlier evidence of the same.

Bessel detected an annual shift in the position of a star 61 Cygni amounting to 0.314 arc-seconds, measured against the diameter of the Earth's orbit[68] around the Sun by triangulation. It placed the star at a distance of about 10.3 light-years, though Bessel did not express it this way. Bessel was honoured for this achievement by the Royal Astronomical Society and others.

Bessel also used the speed of light[69] to measure the distance between the Earth and 61 Cygni. Though he did not explicitly mention the word 'light year', he explained that light would take 10.3 years to reach from 61 Cygni to Earth. It became the standard measure. (He was slightly off: the contemporary measurement is 11.4 light years.) Nowadays, 61 Cygni is known to be a binary star system, with parallax values of 0.287 and 0.286 arc-seconds for the two stars.

Sirius B and Procyon B

Bessel's measurements using the meridian circle allowed him to notice deviations in the motions of Sirius and Procyon which he deduced must be caused by the gravitational attraction of unseen companions. His announcement of Sirius's "dark companion" in 1844 was the first correct claim of a previously unobserved companion by positional measurement, and eventually led to the discovery of Sirius B and Procyon B.

Neptune

An important share in the discovery of the planet Neptune also belongs to Bessel. In a paper read in 1840, he called attention to exceedingly small irregularities in the orbit of Uranus, which he had observed and concluded were caused by an unknown planet beyond.

Sirius

Sirius, or the Dog Star, was known as Sothis to the ancient Egyptians who believed its first heliacal rising (i.e., rose just before sunrise) of the year caused the Nile floods. They also discovered that the heliacal rising of the star occurred at intervals of 365.25 days, which became the Roman calendar. As it brought on the hottest part of the year, it was called the Dog Star. For the Polynesians, mostly in the southern hemisphere, the rising star marked the coming of winter and it was an important reference for their navigation around the Pacific Ocean.

Bessel got down to measuring it at some stage, and in 1844 announced that it was a binary star. He had observed that the bright star was pursuing a slightly wavy course among its neighbours in the sky and concluded that it had a companion star, with which it revolved in a period of about 50 years. The companion was first seen in 1862 by Alwan Clark, an American astronomer and telescope maker.

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[68] One complete orbit takes 365.256 days (1 sideral), during which time Earth travels 940 million km (584 million mi). The orbit is slightly elliptic. Maximum diameter is 299 million km (185.8 million miles); actual depends on timing.

[69] Speed of light= 300 million km/s, found by Ole Roemer in 1676.

Other Contributions

Bessel laid the foundations for a better determination than any previous method had allowed of the scale of the universe and the sizes of stars, galaxies and clusters of galaxies. He made fundamental contributions to accurate positional astronomy, celestial mechanics, and to the study of size and shape of the Earth.(geodesy).

Further, he enlarged pure mathematics by his introduction of what are now known as Bessel functions to investigate, inter alia, planetary perturbations.

Friedrich Georg Wilhelm von Struve

Friedrich Georg Wilhelm von Struve, Russian (1793-1864) founded the modern study of binary stars. In 1813 he became professor of astronomy and mathematics at the University of Dorpat (now Tartu, Estonia), and later he was appointed director of the Dorpat Observatory.

In 1824 he obtained a Fraunhofer refracting telescope with an aperture of 24 cm (9.6 inches), at that time the finest ever built, and used it in a binary-star survey of unprecedented scope. In his survey of 120,000 stars from the north celestial pole to 15° S declination, he measured 3,112 binaries, more than 75 percent of which were previously unknown. He published his findings in the catalogue Stellarum Duplicium Mensurae Micrometricae (1837), “Micrometric Measurement of Double Stars”), one of the classics of binary-star astronomy. In 1839, he became director of the Pulkovo Observatory in Russia

In 1835 that Struve began efforts to measure the parallax of Vega, a star he had selected for its brightness and large proper motion, which suggested that it might be near the Earth. In 1837, using the Fraunhofer telescope, Struve announced a parallax for Vega of one-eighth (1.25) of a second of arc, which was close to the modern value (25.05 light-years.). Bessel would become more famous because of the higher precision of his observations.

Thomas Henderson

Thomas Henderson, (1798-1844), a Scottish astronomer who was royal astronomer at the Cape of Good Hope (1831–33) and made measurements of the stars in the southern hemisphere.

He conducted his measurements in the early 1830s, but only published the results in 1839. He reported a parallax of one arc-second for the star Alpha Centauri. Now known to be a binary system, the best current estimates of the parallaxes of the two stars are 0.755 and 0.797 arc-seconds. The binary system of Alpha Centauri, along with the companion Proxima Centauri, are the nearest stars to the Sun, the latter the closest at a distance 4.246 light-years,

The measurements were a triumph. Knowledge of astronomical distances allowed astronomers to calibrate their observations and to estimate physical parameters of stars, such as their luminosity and size, for the first time. The true immensity of the universe was finally becoming apparent .

FOR INFORMATION.According to the review by Reid and Honna (2014)[70] the most distant source with a VLBI-based trigonometric parallax is the star forming region W49N. The source

[70] https://arxiv.org/abs/1312.2871

has a parallax of 90±690±6 micro arc-seconds and a corresponding distance of 11.1±0.811.1±0.8 kpc or “kilo parsec”(where 1kpc = 1,000 par-secs) which I calculate to be 36,203.36 light-years.

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Some Stellar Neighbours

VEGA: PORTRAIT

Vega is the brightest star in the northern constellation of Lyra. This star is only 25 light-years from the Sun, the fifth brightest star in the night sky and the second brightest in the northern hemisphere, after Arcturus (36.66 light years)..

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Vega has been termed "arguably the next most important star in the sky after the Sun". Vega was the northern pole star around 12,000 BC and will be so again around the year 13,727, when its declination will be +86° 14′.

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Vega is only about a tenth of the age of the Sun, but since it is 2.1 times as massive, its expected lifetime is also one tenth of that of the Sun; both stars are at present approaching the midpoint of their life expectancies. Vega is also a variable star, that is it varies slightly in brightness. It is rotating rapidly with a velocity of 236 km/s at the equator. This causes the equator to bulge outward.

Based on an observed excess emission of infrared radiation, Vega appears to have a circumstellar disk of dust This dust is likely to be the result of collisions between objects in an orbiting debris disk. Stars that display an infrared excess due to dust emission are termed Vega-like stars.

ALPHA CENTAURI: PORTRAIT

Alpha Centauri is a gravitationally bound system of stars and planets, closest to the Solar System, at 4.37 light years (1.34 parsecs) from the Sun. It is a triple star system, consisting of α Centauri A (officially Rigil Kentaurus), α Centauri B (officially Toliman), and the closest star α Centauri C (officially Proxima Centauri).

The first two together form the binary star Alpha Centauri AB. To the naked eye, the two components appear to be a single star, the brightest star in the southern constellation of Centaurus, and the third brightest in the night sky after Sirius and Canopus.

Alpha Centauri A has 1.1 times the mass and 1.5 times the luminosity of the Sun, while Alpha Centauri B is smaller and cooler, at 0.9 times the mass and less than 0.5 times its luminosity. The pair orbit around a common centre with an orbital period of 79 years. Their elliptical orbit is eccentric, so that the distance between A and B varies from 35.6 AU[71] or about the distance between Pluto and the Sun, to 11.2 AU, or about the distance between Saturn and the Sun.

Alpha Centauri C, or Proxima Centauri, is a small faint red dwarf. Though not visible to the naked eye, Proxima Centauri is the closest star to the Sun at a distance of 4.24 light-years slightly closer than Alpha Centauri AB. Currently, the distance between Proxima Centauri

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[71] An astronomical unit (AU) is the mean distance between **centres** of the Earth and the Sun = 93,000,000 miles = 150,000,000 km = 8.3 light-minutes. 1 light year = 63241 AUs.

and Alpha Centauri AB is about 13,000 AU (0.21 light-years), equivalent to about 430 times the radius of Neptune's orbit.

Proxima Centauri has three known planets: Proxima b, an Earth-sized planet in the habitable-zone discovered in 2016; Proxima c, a super-Earth 1.5, which is possibly surrounded by a huge ring system discovered in 2019; and Proxima d, a candidate sub-Earth[72] which orbits very closely to the star, announced in 2022.

Alpha Centauri A may have a Neptune-sized habitable-zone planet, still to be confirmed.

SIRIUS, THE DOG STAR: PORTRAIT

Sirius is the brightest star in the night-sky. The star is designated α Canis Majoris. Sirius is a binary star, consisting of a mainstream star Sirius A, and a faint white dwarf companion. termed Sirius B. Sirius and its companion revolve together in orbits of considerable eccentricity. The distance between the two varies between 8.2 and 31.5 AUs as they orbit every 50 years. The companion star is about as massive as the Sun, though much more condensed, and was the first white dwarf to be discovered.
Sirius appears bright because of its intrinsic luminosity and its proximity to the Solar System, At a distance of 2.64 parsecs (8.6 light-years), the Sirius system is one of Earth's nearest neighbours. Sirius is gradually moving closer to the Solar System, so it is expected to increase in brightness slightly over the next 60,000 years. After that time, its distance will begin to increase, and it will become fainter, but it will continue to be the brightest star in the Earth's night sky for approximately the next 210,000 years, before Vega, more luminous than Sirius, becomes the brightest star.

Sirius is in the constellation Canis Major. It is known more commonly as the Dog Star. Sirius B is a white dwarf, a celestial object that will be left behind, once our own Sun reaches the end of its life.

Sirius A is is a blue-white star about twice as massive and 25 times as luminous as the Sun. The system is between 200 and 300 million years old. It was originally composed of two bright bluish stars. The initially more massive of these, Sirius B, consumed its hydrogen fuel and became a red giant before shedding its outer layers and collapsing into its current state as a white dwarf around 120 million years ago.

61 CYGNI: PORTRAIT

61 Cygni is a binary star system in the constellation Cygnus, consisting of a pair of dwarf stars that orbit each other in a period of about 659 years. They can be seen with binoculars in city skies or with the naked eye in rural areas.

61 Cygni was the first star to have its stellar parallax measured. Among all the listed stars or stellar systems 61 Cygni has the seventh-highest proper motion, and the highest among all visible stars or systems.

Over the course of the twentieth century, several different astronomers reported evidence of a massive planet orbiting one of the two stars, but recent high-precision observations have shown that all such claims were unfounded. No planets have been confirmed in this stellar system to date.

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[72] Sub-Earth= a planet substantially smaller than the Earth or Venus.

Climbing Jacob's Ladder (Technologies)

(A) Optical Telescopes

At first, astronomers mainly used long refracting telescopes, designed around a glass lens. Technology was still non-existent. Apart from weak magnification, the lens refracted the light with spectral or chromatic aberration.

Reflecting Telescopes

A Scottish mathematician, **James Gregory** (1638-75),proposed a reflecting telescope in his 1663 book Optica Promota. It featured a primary mirror with a parabolic curvature. It would reflect light to an elliptical secondary mirror, which reflected it back down through a hole in the primary to the astronomer's eye. The Gregorian design would eventually become the predominant design for reflecting telescopes. But at the time, opticians could not polish mirrors in curves that were not spherical

In 1668, **Isaac Newton** devised a reflecting telescope. Instead of a lens, it used a single curved main mirror, together with a smaller flat mirror. Newton presented his design to the Royal Society in 1672., He had succeeded in making a mirror with a spherical curvature, with a magnification of about 40. Above this primary mirror Newton placed a small flat secondary mirror at a 45-degree angle, to reflect the light into an eyepiece mounted in the side of the telescope tube.

The problem was there was no technology yet to grind mirrors of regular curvature. Adding to the problem, the metal mirror tarnished and had to be repolished every few months.

John Hadley (1682-?) a Fellow of the Royal Society, began to experiment with the grinding and polishing of metal. He used speculum, a combination of bronze and silver used for mirrors since ancient times. By 1721, he had succeeded in making a 6-inch-diameter Newtonian telescope with a focal length of 62 inches.

Hadley managed to polish his metal mirror so that it had an approximately parabolic shape, avoiding the distortion in previous telescopes with spherical curves.

To track objects across the sky as the Earth turns, Hadley developed what is now called an altitude-azimuth mount. With an alt-az mount, an astronomer had to move the telescope along two axes simultaneously to keep an object in view, but this was compensated by its relatively compact size.

Hadley's telescope was tested by two English astronomers in 1722 by observing Saturn. They saw four of the planet's satellites (the largest in transit across the face of the planet), and the divisions in Saturn's rings. Although they judged its images not as bright as those in Huygens's 123-foot aerial (refracting) telescope, Hadley's design was far easier to use.

William Herschel, directed his first efforts toward building refracting telescopes. But the lengthy tubes annoyed him, and he turned his attention to mirrors. By the late 1770s, Herschel had built several reflectors. His most successful one had a 6-inch mirror and was 7 feet long. He used this telescope to compile the first substantial catalogue of double stars and, in 1781, to discover the planet Uranus.

Herschel spent the next several years perfecting an even bigger telescope. It featured a mirror nearly 19 inches in diameter, encased in a tube 20 feet long on an alt-az mount. Like other early telescope mirrors, it was made of metal (mostly copper and tin) and tarnished quickly, so it had to be repolished often.

Herschel's 20-foot telescope was the best of his instruments. In 1785, he began to design one twice as large, which could collect four times as much light. He began using this 40-foot telescope in the fall of 1789, and quickly found two more satellites of Saturn (Mimas and Enceladus).

However, the long telescope tube tended to bend, while the frequent need to re-polish the main mirror limited its usefulness. Herschel used this cumbersome giant only occasionally, preferring the more manageable 20-foot instrument.

Herschel made his last observation with the 40-foot telescope in 1815. He noted "Saturn was very bright and considerably well-defined. The mirror is extremely tarnished." Such tarnishing was one of several severe limitations for large reflectors, and over the next several decades their popularity declined. Advances in optical design and glassmaking were revitalising the refracting telescope as a tool for research.

Refracting Telescope

The 19th century saw an expanded scope for telescopes using lenses (refractors). As optical technology improved, the refracting telescope became a rugged and precise instrument.

The triumph of the refracting telescope as a serious research tool depended on technological progress. Glassmakers had to perfect the manufacture of high-quality optical glass, and opticians had to figure out ways to avoid the smearing of colours by lenses (chromatic aberration). Until the early part of the twentieth century, glassmaking was more a craft than a science. Optical glass in particular had to be exquisitely free of defects and residual colour. For example, iron impurities in the sand used for glassmaking could tint the glass, while tiny bubbles or other defects could render the glass useless for lenses

A major advance in overcoming the chromatic aberration inherent in refracting lenses came in the 1750s. An English optician, **John Dolland** (1706-1761) combined a concave lens made from a leaded ("flint") glass with a convex lens made from a glass with a slightly lower density. The colours dispersed by the first lens were bent back together by the second. These came to be called achromatic lenses. Dolland received a patent for his design, but the poor quality of the flint glass available at the time limited its usefulness.

In the late 1790s, Pierre Louis Guinand (1748-1824), a Swiss craftsman, was able to make high-quality lenses as large as six inches. He introduced new stirrers made of clay, which brought unwanted bubbles to the surface and mixed the glass to produce a nearly flawless material.

Guinand joined a German optical firm, where he passed on his secret to **Joseph Fraunhofer** (1727-1826). After he moved back to Switzerland, Fraunhofer continued to experiment with glassmaking and lens design. Fraunhofer's efforts bore fruit in several excellent refractors, built before his death in 1826 at the age of 39.

One of these was a 9.5-inch 14 foot long telescope at Russia's Dorpat Observatory, installed in 1824 by Wilhelm Struve. His "Great Dorpat Refractor" was noted not only for the high quality of its lenses but also for its equatorial mounting. It was the first example of what became known as equatorial mounting. It had a "polar" axis, together with a "declination" axis at a right angle to the polar axis. This allowed the telescope to be rotated toward any part of the sky. Further, the polar axis was continuously rotated by a clock mechanism at precisely the rate that counteracted the apparent daily movement of the stars across the sky. Thus the telescope tracked stars automatically. Fraunhofer's innovation became part of the standard design of telescopes in the 19th century. The clock-driven equatorial mounting proved essential when photography was introduced into astronomy in the latter part of the 19th century, for it made possible lengthy exposures of photographic plates.

Late 19th Century onwards

Techniques for making high-quality glass and lenses spread to France and England. Meanwhile, Fraunhofer's success in making astronomical instruments helped create a German optics industry which led the world for more than half a century

The first observatories built in the US. were equipped with telescopes from Europe. An example was the new 15-inch refractor dedicated in 1847 at the Harvard College Observatory. Dubbed the "Great Refractor," it was the largest refractor in the world for twenty years. The Harvard instrument (like a similar one at Russia's Pulkovo Observatory) was made by a German firm[73].

The first telescope to surpass the Russian and Harvard 15-inch telescopes was made not by a European firm, however, but by **Alvan Clark & Sons**, an American firm. It became the world's preeminent makers of telescopes in the second half of the 19th century. Their company built instruments for almost every American observatory as well as some overseas. Five times the Clarks beat their own record by making the lens for the world's biggest refracting telescope. Some are still in operation today.

The 18.5-inch (470 mm) Dearborn telescope was commissioned in 1856 by the University of Mississippi. In 1873 they built the 26-inch (660 mm) objective lens for the refractor at the US Naval Observatory, and in 1883, they build (another) the 30-inch (760 mm) telescope for the Pulkovo Observatory in Russia.
The biggest commission came in 1880. The purchaser was **James Lick**, a San Francisco businessman who decided to immortalise himself by funding the world's biggest telescope. After Lick's death in 1876, Mount Hamilton near Santa Cruz, California, was chosen as the site for Lick's monument. Alvan Clark & Sons were given the contract to produce a 36-inch lens for the giant telescope. A French company made the blank glass discs (it took them 19 tries over three years). The grinding and polishing was finished in 1885. The telescope's dome was advanced for its time, with a design that compensated for the expansion and contraction of metal with changes in temperature. The circular floor of the dome could rise and descend through approximately seventeen feet to follow the eyepiece of the 58-foot-long telescope tube.

The Lick 36-inch refractor was completed and dedicated in 1887. The excellent quality of the 36-inch telescope, combined with Mount Hamilton's excellent observing conditions, helped **Lick Observatory** become one of the world's premier astronomy institutions.

George Ellery Hale was perhaps the greatest American science entrepreneur of his time. He inspired, organised, and helped find funding for three of the most important observatories in the history of astronomy.

In 1892, Hale visited the offices of Charles T. Yerkes, a Chicago tycoon who had made his fortune through streetcar and railroad franchises, and was interested in his social position and legacy. Hale left Yerkes' office with a mandate to build "the largest and best. telescope in the world and send the bill to me."

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[73] I could not find the name of the company, under which Utzschneider (the original proprietor) and Fraunhofer manufactured all the telescopes.

Alvan Clark & Sons had a partly finished lens, 40 inches in diameter, left over from another telescope project. Alvan Graham Clark arrived in Chicago and agreed to finish the 40-inch lens for the new observatory. The noted instrument firm Warner and Swasey would make the telescope mount.

Alvan Clark & Sons finished the lens (actually an achromatic pair, one lens of crown glass and one of flint glass) in 1895. It weighed 500 pounds and had a focal length of 62 feet. In 1897, the lens was shipped to Williams Bay, Wisconsin, the chosen site of the new observatory. The telescope with its moving parts and counterweights weighed over 20 tons, yet it was so well-balanced that small motors could easily move it to point at any part of the sky. As at Lick, astronomers could raise and lower the entire floor of the observatory in order to reach the eyepiece. Astronomers who used the new telescope were delighted with its quality.

The 40-inch (1,000 mm) lens for the **Yerkes Observatory** refractor, in 1897, was only ever exceeded in size by the lens made for Great Paris Exhibition Telescope of 1900 (for exhibition purposes only in the end).

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(B) The Electromagnetic (EMR) Spectrum

Electromagnetic Radiation (EMR), of which light is the visible spectrum, could be described the single most important physical component of the universe. It pervades everything form the sub-atomic to the cosmic ,and carried the past into the future. Astronomy is therefore substantially the study of EMR in all its forms and manifestations and interactions with matter, across the universe.

Light was intensively studied from the beginning of the 17th century, in association with invention of the telescope. Starting in 1666, Newton was the first to show that white light comprised a range of colours when split through a prism, and that these colours were intrinsic to light and could be recombined into white light. A debate arose over whether light had a wave nature or a particle nature. Around 1801, **Thomas Young** (1773-1829) measured the wavelength with his famous two-slit experiment.

In 1800, William Herschel discovered infrared radiation, and the next year, Johannes William Ritter identified the existence of ultraviolet rays. Then, in 1820, **Hans Christian Oersted** (1777-1851) discovered that electric currents produced electromagnetism. And, in 1845, Faraday (1791-1867) noticed the polarisation of light travelling through a magnetic field.

Finally in the 1860s **James Clark Maxwell** (1831-1879) developed the famous four Maxwell equations for the electromagnetic field. In his formulation, Maxwell described light as a propagating wave of electric and magnetic fields. More generally, he predicted the existence of electromagnetic radiation: coupled electric and magnetic fields traveling as waves at a speed equal to the known speed of light.

Maxwell realised that the waves must travel at a speed that was about the (then known) speed of light. This led Maxwell to make the inference that light itself was a type of electromagnetic wave.

Maxwell's equations predicted an **infinite** range of frequencies of electromagnetic waves all traveling at the speed of light, the first indication of the existence of the entire electromagnetic spectrum. Maxwell had also predicted waves at very low frequencies compared to infrared.

In 1886, **Heinrich Rudolf Hertz (**1857-1894), a brilliant German physicist, built an apparatus to generate and detect what are now called radio waves. Hertz found that the waves (by measuring their wavelength and multiplying it by their frequency) travelled at the speed of light. Hertz also demonstrated that the new radiation could be both reflected and refracted in the same manner as light. Hertz was honoured by his name being attached to the unit of frequency, a cycle per second is one hertz.

It took a bit longer for scientists to discover the higher-energy (shorter wavelength) light in the electromagnetic spectrum. The discovery of the ultraviolet radiation with wavelengths below 200 nm, named "vacuum ultraviolet" because it is strongly absorbed by the oxygen in air, was made in 1893 by another German physicist **Victor Schumann** (1841-1913).

in 1903 **Ernest Rutherford** (1871-1937) identified emissions fundamentally different from charged alpha and beta (radiation) some called particles and named them gamma-rays. In 1914, he and Edward measured their wavelengths, and found that gamma rays were similar to X-rays, but with shorter wavelengths. In progressive stages, the EMR spectrum was uncovered, and their individual study began.

In the coming Quantum era, Max Planck and Einstein would contribute the quantum nature of radiant energy and confirm that light (al EMR) travelled at the speed of light. The dual Particle-Wave theory would become a central tenet of the new physics.

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(C) The Doppler Effect

The Doppler effect or Doppler shift is the change in frequency of a wave in relation to an observer who is moving relative to the wave source. It is named after the Austrian physicist **Christian Doppler (1803-1853)** who described the phenomenon in 1842.
A common example of Doppler shift is the change of pitch heard when a vehicle sounding a horn approaches and recedes from an observer. Compared to the emitted frequency, the received frequency is higher during the approach, identical at the instant of passing by, and lower during the recession.

The reason for the Doppler effect is that when the source of the waves is moving towards the observer, each successive wave crest is emitted from a position closer to the observer than the crest of the previous wave. Hence, the time between the arrivals of successive wave crests at the observer is reduced, causing an increase in the frequency. The distance between successive wave fronts is reduced, so the waves "bunch together". Conversely, if the source of waves is moving away from the observer, each wave is emitted from a position farther from the observer than the previous wave, so the arrival time between successive waves is increased, reducing the frequency. The distance between successive wave fronts is then increased, so the waves "spread out".

For waves that propagate in a medium, such as sound waves, the velocity of the observer and of the source are relative to the medium in which the waves are transmitted. The total Doppler effect may therefore result from motion of the source, motion of the observer, or motion of the medium.

For waves which do not require a medium, such as electromagnetic waves or gravitational waves, only the relative difference in velocity between the observer and the source needs to be considered

The Doppler effect has become one of the crucial techniques in astronomy for studying the distance and directions of motion of celestial objects, through its application in the redshift principle (see next Part).

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(D) Astro-Photography

The development of astro-photography as a scientific tool was pioneered in the mid-19th century .

Because of the very long exposures needed to capture relatively faint astronomical objects, many technological problems had to be overcome. These included making telescopes rigid enough so they would not sag out of focus during the exposure, developing ways to accurately keep a telescope aimed at a fixed point over a long period of time, and building clock drives that could rotate the telescope mount at a constant rate. Early photographic processes also had limitations. The daguerreotype process was far too slow to record anything but the brightest objects, and the wet plate collodion process limited exposures to the time the plate could stay wet.

John William Draper (1811-1882), physician and scientific experimenter, managed to make the first successful photograph of the moon in 1840, taking a 20-minute-long daguerreotype image, using a 5-inch (13 cm) reflecting telescope.

The Sun's solar corona was first successfully imaged in 1851 by **August Ludwig Busch** (1804-55) and a daguerreotypist named Johann **Julius Friedrich Berkowski** (unavailable). The telescope used by Berkowski was attached to 6.5 inch (17 cm) heliometer and had an aperture of only 2.4 in (6.1 cm), and a focal length of 32 in (81 cm).

In 1863 the English chemist **William Allen Miller** (1817-1870) and English amateur astronomer **William Huggins** (1824-1910) used the wet collodion plate process to obtain the first ever photographic spectrogram of a star, Sirius and Capella.

With the introduction of dry plate, in 1880 Henry Draper used the new process with photographically corrected an 11 in (28 cm) refracting telescope to make a 51-minute exposure of the Orion Nebula, the first of a nebula ever made.

The beginning of the 20th century saw the worldwide construction of refracting telescopes and sophisticated large reflecting telescopes specifically designed for photographic imaging. Towards the middle of the century, giant telescopes such as the Hale Telescope were pushing the limits of film photography.

Some progress was made in the field of photographic emulsions, cryogenic cooling, and light amplification, but starting in the 1970s after the invention of the CCD[74], photographic plates were gradually replaced by electronic imaging. Telescopes now used many configurations of CCD sensors, including linear arrays and large mosaics of CCD elements equivalent to 100 million pixels, designed to cover the focal plane of telescopes that formerly used 10–14 inch (25–36 cm) photographic plates.

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74 A charge-coupled device **(CCD)** is a light-sensitive integrated circuit that captures images by converting photons to electrons. A CCD sensor breaks the image elements into pixels. Each pixel is converted into an electrical charge whose intensity is related to the intensity of light captured by that pixel.

The late 20th century saw advances in astronomical imaging take place in the form of new hardware, with the construction of giant multi-mirror and segmented mirror telescopes. It would also see the introduction of space-based telescopes.

Astro-Cartography (Mapping the Skies)

With astro-photography, astronomers could directly capture a map of the sky on a photographic plate rather than looking through a telescope and transcribing their observations. This produced stellar catalogues that were much larger and more precise than had ever been possible.

In 1901, Dutch astronomer **Jacobus Kapteyn** (1851-1922), used photographic observations to assemble a catalogue with the position and distances (obtained from parallax) of 58 stars; the catalogue grew rapidly to comprise 365 stars by 1910. At this time, other astronomers were performing even larger photographic surveys, among them the famous Carte du Ciel, reporting the positions of millions of stars, although with less precision.

Many more stellar surveys based on photographic observations, often taken with wide angle dedicated Schmidt telescopes based in both hemispheres, were assembled throughout the twentieth century, providing an ever more precise map of the entire sky. These remarkable data sets are the outcome of astrometry's long history, which had begun thousands of years earlier and made a phenomenal surge in the nineteenth century.

As the twentieth century dawned, the measurement of stellar distances laid the foundations for even greater discoveries to come, ranging from the structure and nature of our galaxy, the Milky Way, to the origin and evolution of the entire Universe.

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(E) Astro-Spectroscopy

In the latter half of the 19th century, with astro-photography opening the doors to ever widening and deepening space, astronomers began to embrace the techniques of spectroscopy. For the first time, scientists could investigate what the universe was made of. This was a major turning point in the development of astronomy, as astronomers were able now to record and document not only where the stars were but what they were made of as well.
Astronomical spectroscopy captures and measures the spectrum of electromagnetic radiation from stars and other celestial objects, including visible light, ultraviolet light, infrared, and radio waves that radiate.

Such a spectrum can through spectroscopy reveal many properties of the celestial object such as their chemical composition, temperature, density, mass, distance and luminosity. Spectroscopy can also show the velocity of motion towards or away from the observer by measuring the Doppler shift. Spectroscopy studies the physical properties of many types of celestial objects besides stars, such as planets, nebulae, galaxies, and active galactic nuclei.

Astronomical spectroscopy started off as an off-shoot of chemists' attempts to analyse materials on Earth as well as scientists' interest in the nature of colour. There were some early forays into spectroscopy before 1850. Joseph Fraunhofer, for example, mounted a prism in front of the objective lens of a small telescope, making a crude spectroscope. He found that when light from the sun and bright stars like Sirius was analysed there were characteristic absorption lines present in the spectrum produced. Fraunhofer, however, died before he could study this phenomenon more fully.

A major advance was made in 1859 by Gustav Kirchhoff (1824-1887) and Robert Bunsen (1811-1899) of Bunsen burner fame. Bunsen reported to a colleague that Kirchhoff had made "a totally unexpected discovery." He had identified the cause of the dark lines seen in the solar spectra by Fraunhofer and others. When certain chemicals were heated in Bunsen's burner, characteristic bright lines appeared. In some cases these were at exactly the same points in the spectrum as Fraunhofer's dark lines. The bright lines were light coming from a hot gas, whereas the dark lines showed absorption of light in the cooler gas above the Sun's surface.

The two scientists found that every chemical element produces a unique spectrum. This provided a sort of "fingerprint" which could confirm the presence of that chemical. Kirchhoff and Bunsen recognized that this could be a powerful tool for "the determination of the chemical composition of the Sun and the fixed stars." Throughout the 1860s, Kirchoff managed to identify some 16 different chemical elements among the hundreds of lines he recorded in the Sun's spectrum. From this data, Kirchoff speculated on the Sun's chemical composition as well as its structure.

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(F) Spectral Analysis

.The advent of the 20th century saw the coupling of astro-photography and astro-spectroscopy, which magnified the scope, depth, scale and flow of the image (data) capture available (not only for stellar mapping but) for spectroscopic analysis. **It put the universe within reach of spectroscopy, which was already able to put a name to any chemical by its spectrograph**

The final step came with the full understanding of the structure of the atom in 1913, the immortal contribution of **Max Bohr (1885 -1962),** the Danish physicist and co-father of quantum mechanics. Without this we could never unravel the universe. **John William Nicholson** (1881-1955), an English physicist, contributed an essential component to the model of the atom, namely the different levels of energy states to which electrons were excited under external energetic impulse. Nicholson was the first to create an atomic model that quantized angular momentum. Nicholson was also the first to create a nuclear and quantum theory that explained spectral line radiation as electrons descended (in energy states) toward the nucleus, identifying hitherto unknown solar and nebular spectral lines.

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(G) Classifying the Stars

In time, astronomers began to turn their attention to the myriad of other stars available for study. Scientists like William Huggins gathered as many spectra as possible and spent a considerable amount of time placing them into classification schemes. Three basic groups emerged: blue and white stars, yellow (or solar-type stars), and red stars.

In 1885, **Edward C. Pickering** (1846-1919) at the Harvard College Observatory undertook an ambitious program of stellar spectral classification using spectra recorded on photographic plates. By 1890, a catalogue of over 10,000 stars had been prepared that grouped them into thirteen spectral types.

Annie Jump Cannon (1863-1941) expanded the catalogue to nine volumes and over a quarter of a million stars by 1924 and developed a system of ten spectral types - O, B, A, F, G, K, M, R, N, S - that astronomers accepted for world-wide use in 1922.

Advent of Information Age

None of the preceding developments would have taken place if the Classical Age had not at the same time laid the foundation for the Information Age. The latter happened with quantum mechanics, which led to the development of micro-electronics, telecommunications, supercomputing, the massed data-bases and the internet. These are the foundations of the Information age.

.Without microprocessors, computers and telecommunications yoked to our astronomical tools, we could not build or operate the telescopes we now have, capture, store and process the masses of data and images we have, or analyse their spectra, classify the results and store them. We would not be in space.

I marvel that Max Planck, Einstein, Schrodinger and Dirac (and for that matter Hubble and his generation) laid out the universe for us without having heard of a microchip or a handphone.

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Chapter Seven
Second Generation - Quantum Age

Quantum Science

At the beginning of the 20th Century, Science exploded in a double theoretical revolution, the Theory of Relativity and Quantum Mechanics (QM). From these emerged Quantum Science, which totally transformed our understanding of the physical world and opened unprecedented forms of technology.

Enabled by the new science, astronomy surged in the 20th century to master new dimensions of knowledge of the universe. Today, we think we know how it began and how it could possibly end. We are on the verge of exploring it, and searching for both other habitable planets and intelligent life forms.

As we ended the Classical Age we were still with a visual view of the universe, and astronomy was still in observational mode. Nonetheless, credit must be given for the solid and outstanding achievements of our predecessors. They had developed the telescope, mapped the visual universe, and harnessed both astro-photography and spectroscopy to capture and unpacked the information stored on the celestial images. They had discovered the electromagnetic radiation (EMR) spectrum and fully exploited the visible wavebands. They developed the use of the parallax and discovered redshift. And, finally they substantially studied the Solar System.

Within the limits of their technology, the Classic Age profoundly understood that the entire universe was made of the same matter, and that the whole of the universe was held together by gravity. They even discovered EMR, the lifeblood of the universe, but not quite how it worked.

For them, the atom was the smallest particle of matter and the Milky Way was the only galaxy forming the upper limit and ceiling of the world. And the universe was essentially static.

The first outcome of the new Quantum Science was to empower astronomy with a fundamentally new understanding of matter. And the second was to establish in detail that the entire universe was a single entity, made of the same matter and subject to the same laws.

Then, beginning from the first half of the century, with scientific mastery, application and exploitation of the new physical sciences, we acquired incredibly new technology, from aviation and telecommunications to nuclear energy, to the minutest levels of sub-atomic investigative instrumentation, and to the massive fabricative precision of a Saturn 5 rocket.

And In the last third of the century, we created the undreamed of capabilities of the computer, Information Technology (IT) and the Internet, which have gone on to transform all forms of technology, including astronomy. And then we had Space Flight.

Under the impact of the preceding, astronomy has proceeded to develop in a number of components, which converged towards the end of the century.

Astronomy has been, and always will be, a long distance observational science. Therefore, its primary tool will always be the telescope. Building on the solid foundations of the Classical age, astronomy extended its depth of penetration by refinements to the parallax. And. astronomy continued, especially through spectroscopy and astro-photography, to increases exploitation of the Visible spectrum, and refining the tools of post-capture image processing, storage and analysis of data. Visible observation is still the most important component of astronomy and is today highly computerised.

In 1923, operating in the Visible spectrum, **Edwin Powell Hubble** (1889-1953) discovered the Cepheid Variable (a species of pulsating star) - and the astronomical world was turned upside down. Using it as a distance marker and applying the known principles of redshift, he discovered the Andromeda Galaxy beyond the Milky Way, and went on to establish that there was indeed an extragalactic universe filled with galaxies.

In 1927 **Georges Henri Joseph Édouard Lemaître** (1894-1966) independently derived the conclusion that the extragalactic universe was expanding at the outer edges, and the further that proportionally the further away they were the faster was their recessional velocity. in 1929, Hubble supported this thesis with further findings. It became the Lemaitre-Hubble law, which states: that galaxies are moving away from Earth at speeds proportional to their distance and according to the Hubble constant.

In 1931, Lemaitre proposed the Big Bang theory, that as the universe was expanding it must have started in a Big Bang, “with a primeval atom”. This is still the currently accepted thesis.

All this was done before the age of the computer and with investigations based essentially on the Visible spectrum . The 20th century had entered a new phase of astronomy.

Radio emission from space was first discovered in 1931. A photographic image of the universe captured in the radio frequencies (indeed in every constituent set of frequencies in the EMR spectrum) revealed different information about the object studied. This opened a new window. Fortunately, radio emissions were receivable from the ground. However, because they were hampered by water-vapour, reception had to be in dry areas and high ground-altitudes. Radio astronomy has since developed into a major branch of the science. Radio astronomy has its own telescopes, can operate in arrays, even cross-continentally, and can target different subjects of observation complementing the other data streams. Needless to say, radio astronomy is highly computerised today.

But, observational astronomy hit a snag. It was found that EMR frequencies (or wavelengths) of infrared and those above the Visible spectrum could not penetrate the Earth’s atmosphere and were not satisfactorily detectable by ground-based observation. Developments in reading information from these wavebands were delayed until the first telescopes were put in orbit.

The first telescopic forays into space occurred with NASA’s Orbital Solar Observatory series (OSO 1-7) in 1962-75, focussing on the Sun. The Soviet Orion-1 telescope aboard the space station Salyut 1 was successfully launched in 1971. These developments culminated in 1990 with the launch of the Hubble Space Telescope, which was designed as a general purpose observatory, meant to explore the universe in the visible, ultraviolet and infrared wavelengths.

Hubble was the first of NASA’s Great Observatories series of four telescope satellites launched at the. turn of the century, built with different technologies to examine specific wavelengths and regions of the EMR spectrum:

.- The Hubble Space Telescope (HST), primarily to observe the visible light and near-ultraviolet wavelengths of the spectrum, launched in 1990 into low-Earth orbit

(586.47–610.44 km). Hubble gave us our first insights into the depths of outer space. It was the biggest spin-off of visual astronomy.

.- The Compton Gamma Ray Observatory (CGRO), primarily to observe gamma-rays, extended into hard X=rays as well, launched in 1991 into low-Earth orbit (362–457 km). It was de-orbited in 2000 after a gyroscope failed.

.- The Chandra X-Ray Observatory (CXO), primarily to observe soft X-rays, launched into an elliptical high-Earth orbit (9,942–140,000 km). It was initially named the Advanced X-ray Astronomical Facility (AXAF). It is still up there and working.

.- The Spitzer Space Telescope (SST) , primarily to observe the infrared spectrum, launched in 2003 into an Earth-trailing Solar orbit (0.98–1.02 AU). Depletion of its liquid helium coolant in 2009 reduced its functionality, leaving it with only two short-wavelength imaging modules. It was removed from service and placed into safe-mode on January 30, 2020.

Update, some 95 space satellites have been launched, 91 targeting the EMR spectrum and 4 other radiation, and 32 remain functional. The early ones were in low-earth and high-earth orbits. Altogether 12 have been placed in an heliocentric or solar earth-trailing orbit.[75]

We have discovered that there is both direct and cosmic EMR radiation. The latter originated with the Big Bang. We have also identified non-EMR radiation in the universe. It has also emerged that there is more "invisible" Dark Matter" making up the universe than represented by the "visible" universe. We will look at these in the Final Part on the 21 century.

It is inevitable that man should move from the Observational to the Exploratory stage of astronomy. The full technology is not there yet. But man has begun. There have been a multiplicity of unmanned probes around the Solar System and beyond. Voyagers 1 & 2, launched in 1977 are now the furthest man-made objects in deep space, some 12 billion miles (19 billion km) away, having crossed the heliopause in 2012. Man landed on the Moon in 1969 and there have been a number of space stations. The largest, the International Space Stations (ISS) was launched in 1998, and has been in continuous operation since.

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(A) Relativity

Relativity was a theoretical framework formulated by **Albert Einstein** (1879-1955). It was first propounded in his Theory of Special Relativity in 1905, and enlarged in his Theory of General Relativity in 1915. We might note two central features. First, all motion (speed) must be defined relative to its frame of reference, ie as between the relative motions of the observer and the observed. Secondly, the laws of relativity applied in the same way throughout the universe, both in space and in sub-atomic matter.

Special Relativity

In 1905, in his theory of Special Relativity, he propounded the most famous equation in all human history, $\mathbf{E = mc^2}$. This translates to "energy is equal to mass times the speed of light

[75] https://en.wikipedia.org/wiki/List_of_space_telescopes

squared." In other words, energy (E) and mass (m) are interchangeable. They are, in fact, just different forms of the same thing.

But they are not easily exchanged. Because the speed of light is already an enormous number, and the equation demands that it be multiplied by itself (or squared). A small amount of mass contains a huge amount of energy.

As an object's mass increases, so does the energy required to keep accelerating it; thus, it would take infinite energy to accelerate a material body to the speed of light For this reason, it is thought that no material object can reach the speed of light, which is the speed limit for the universe. (Light itself can attain this speed because the rest mass of the quantum particle of light (photon) is zero. This is the origin of the fact that mass and energy are the same physical entity and can be changed into each other).

Spacetime

To have the speed of light constant, the theory required that space and time change in a moving body according to its speed, as seen by an outside observer. The body becomes shorter in its direction of motion, that is, its length contracts. On the other hand, time intervals become longer, or time dilates, that is time runs more slowly (dilates) in a moving body. The further logical consequence of the above was the inseparable joining of the four dimension of space and time, hitherto assumed as independent.

In his theory of Special Relativity, Einstein had showed that space and time were interwoven as a single structure he dubbed (4-dimensional) **spacetime.** According to him, you need to describe where you are not only in three-dimensional space — length, width and height — but also in time. Time is the fourth dimension.

General Relativity

Einstein proposed his Theory of General Relativity in 1915, dealing with the theory of gravity, particularly as it manifested itself in space. He showed that mass and energy curved the flat fabric of spacetime into a manifold, like a bowling balling would on a taught trampoline. If you then attempted to roll a marble around the edge of the trampoline, the marble would spiral inward toward the body, pulled in much the same way that the gravity of a planet pulls at rocks in space.

Instead of being an invisible force that attracted objects to one another, gravity was the curving or warping of spacetime. The more massive an object, the more it warped the spacetime around it. **There was no such thing as a force of gravitation, only the structure of spacetime itself.** (However, for our sanity, we shall continue to refer herein to this force as "gravity").

Spacetime was no longer a static background, but actively interacted with the physical systems that it contained. Spacetime curved in the presence of matter, could propagate waves, bent light, and exhibited a host of other phenomena.

Einstein combined his redefinition of time and space with the two powerful principles of the conservation of energy and conservation mass, which state that the total amount of each remains constant in a closed system

Macroscopic Features of Gravity

Under Quantum Mechanics, gravity is one of the four fundamental forces in the universe, which means both at the sub-atomic and in space. Little is known about gravity in the former, where the other fundamental forces predominate. Einstein's General Relativity describes its large-scale dynamics as affects the contents of the universe.

.(A) Gravitational Lensing

Gravity acts as a lens, capable of bending light between a distant light source and an observer. This effect is known as gravitational lensing. Gravitational lenses act equally on all kinds of electromagnetic radiation, not just visible light, and also on non-electromagnetic radiation, like gravitational waves.

A strong lens can produce multiple images, and there will be a relative time delay between two paths: that is, in one image the lensed object will be observed before the other image. In extreme cases, a star in a distant galaxy can act as a microlens and magnify another star much farther away.

Weak lensing effects have been found in the cosmic microwave background as well as in galaxy surveys. More commonly, where the lensing mass is complex (such as a galaxy group), the source will resemble partial arcs scattered around the lens. The observer may then see multiple distorted images of the same source.
Astronomers routinely use gravitational lensing methods to study stars and galaxies behind massive objects.

.(B) Gravitational Time Dilation

Gravitational time dilation is an actual difference of elapsed time between two events as measured by observers situated at varying distances from a gravitating mass, The lower the gravitational potential (the closer the clock is to the source of gravitation), the slower time passes..

.(C) Gravitational Waves

Gravitational waves are disturbances or ripples in the curvature of spacetime, generated by (differentially) accelerated masses, that propagate as waves outward from their source, at the speed of light. Gravitational waves transport energy as gravitational radiation, a form of radiant energy similar to electromagnetic radiation (but not the same thing).

. (D) Gravitational Geodesics

The curvature of spacetime (say near a star) defines the shortest natural path, known as the geodesic, much as the shortest path between any two points on the earth is a great circle. In Einstein's theory, spacetime geodesics define the deflection of light and the orbits of planets. As someone said: matter tells spacetime how to curve, and spacetime tells matter how to move.

.(E) Gravitational Singularity

A gravitational singularity is a condition under general relativity in which gravity is so intense that spacetime itself breaks down. A singularity can be defined by the scalar invariant curvature becoming infinite, or by a geodesic being incomplete. Equations for these physical theories predict that the ball or mass involved becomes infinite or increases without limit.

In a situation of a contracting universe, this condition would obtain at the “big crunch”, (see further on, under Big Crunch). The initial state of the universe is also thought to have been a singularity, but in conditions of explosive expanding conditions, (see further on, under Big Bang.) At present, gravitational singularities are mainly observable where density becomes infinite as at the centre of a black hole, which themselves are formed by collapsing galaxies. (See further on, under Black Holes).

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(B) Quantum Mechanics

Quantum Mechanics (QM) came into being early in the last century to study the workings of matter at the sub-atomic level, the details of which were not known. They also understood, but needed to prove, that the sub-atomic universe was a microcosm of the larger universe.

Matter and Energy

Underling QM is that the entire universe is made up of the same matter, which in turn is made up of the same fundamental particles. The latter originate as pure energy in the first instance, at cosmic events such as the big bang. In appropriate conditions, the energy transforms into matter in its many composite features. In appropriate conditions, matter can in turn transform into energy.

Quantum Electrodynamics (QED)

When matter goes active (ie is excited by new energy), it manifests itself as electromagnetism (EM**).** One output of electromagnetism is electromagnetic radiation (ER), which is energy moving as a flow of photons. ER is the pervasive working tool that keeps both nature and our world ticking. At the cosmic level, ER transmits to us the replenishing energy of the sun (for photosynthesis), new-born elementary particles, and heat. At the sub-atomic level, it is one of the fundamental forces that mediates the responses of elementary and atomic sub-particles arising from changes of energy.

QM further found that all bodies not only radiate electromagnetic energy, but emit this radiation at all wavelengths. The maximum energy radiated at a wavelength depends on the temperature of the body; the hotter the body, the shorter the wavelength.

The ER spectrum is classified from low to high frequency into radio, microwave, infrared, visible, ultraviolet, X-rays and gamma rays. Light is electromagnetic energy radiating in the visible spectrum.

Quanta (Photon)

On 14 Dec 1900, **Max Planck** (1858-1947), a German physicist, published his ground-breaking study of the effect of radiation on a “blackbody” substance, and the quantum theory of modern physics was born. He made the breakthrough when he confirmed that all matter moved as discrete individual packets or quanta.

Energy therefore was *quantised.* This meant its operations were measurable. As energy pervaded all levels of the universe, this was Aladdin’s “open o sesame” to studying both the universe and the elementary particles in the subatomic world. The operations of elementary particles became known as *quantum mechanics*. This was the beginning of the Quantum Revolution.

In 1905, Einstein discovered the photoelectric effect, which is the emission of electrons by a metal surface when it is irradiated by light or more-energetic EMRs. The above confirmed (1) that light was composed of packets or photons, and (2) that an atom in the metal could absorb either a whole photon or nothing. He proposed that a beam of light was not a wave propagating through space, but a swarm of discrete energy packets, known as photons. This experiment confirmed Planck's discovery.

Wave-Particle Duality

It had been earlier understood that when energy radiates, it does so as a wave. QM established that energy is both a wave and a particle. The **wave-particle duality theory** is one of the central tenets of QM: energy is matter and flows in as particles in waves. This was the work of the mathematician **Erwin Schrodinger** (1887-1961). EMR waves can be isotopic (omni-directional) but generally travel along the direction of propagation of the energy. Of QM's many features, ER has been most widely applied, from the transistor to the qubit.

Elementary Particles

Today, QM and astronomy have confirmed that the world from the sub-atomic level up to the stars is made of the same elementary particles.

One of QM's first achievements was to define in measurable detail the structure and behaviour of the **atom.** It was **Niels Bohr (**1885-1962) who was in 1913 responsible for this. QM further defined the elementary particles that make up the electron, the proton and neutron, and the forces that bound them together as an atom..

At the same time, QM confirmed and re-defined the classical **Periodic Table of Elements** to delineate the chemicals in exact element composition right down to the location of the last valence electron, and explained how the elementary particles operate in chemical reactions.

Perhaps the central achievement of QM was to establish what these elementary particles were, in the **Standard Model of Particle Physics**. A lepton or quark is a fundamental building block. A boson is a particle that mediates (handles or works) the fundamental forces. Quanta could be a single quark; or they could comprise more than one, in which case they are known as hadrons. An electron is a quark. A photon is a bosun. Protons and neutrons are baryons.

Four Fundamental Interactions

QM has also identified that there are **Four Fundamental Interactions (or Forces)** that apply across nature, big and small - fundamental meaning forces than could not be further broken down. It was known earlier that gravity and electromagnetism operated in space (as well as on earth). QM now found that they also functioned at the sub-atomic level. The other two fundamental forces, the strong and the weak, are sub-atomic.

Although, these four forces are related, QM has so far not been able to integrate them into a single relationship. The role of gravity is still hanging loose. If and when QM successfully integrates the four fundamental forces applicable at all levels of the universe, it will have subsumed Einstein's theory of general relativity.

Heisenberg's Uncertainty Principle

Science is all about measurement. To predict the future position and velocity of a particle, one has to measure its present position and velocity accurately. The obvious way is to shine light on the particle - the minimum according to Planck being one photon or one quantum.

In 1926, another German scientist, **Werner Heisenberg**, (1901-1976) formulated the uncertainty principle. He said that the quantum will disturb the particle and change its velocity in a way that cannot be predicted. Some of the waves of light will also be scattered by the particle. One will therefore not be able to determine the position of the particle more accurately than the distance between the wave crests of the light.

The more accurately one measures the position, the shorter the wavelength of the light required and hence the higher the energy of the single quantum required. The velocity of the particle will accordingly be disturbed by a larger amount. In other words, the more accurately you try to measure the position of the particle, the less accurately you can measure its speed, and vice versa.

Quantum State

Heisenberg's uncertainty principle emerged as a fundamental property of matter.
This led Heisenberg, Erwin Schrodinger, and Paul Dirac (1902-1984) in the 1920s to reformulate quantum mechanics based on the uncertainty principle. Particles no longer had separate, well-defined positions and velocities that could not be observed, Instead, they had a quantum state, which was a combination of position and velocity.

Today, quantum mechanics does not predict a single definite result for an observation. Instead, it predicts a number of possible outcomes and tells us how likely each of these is. QM introduced the probabilistic into science. Taking into account that it studies matter at the nanoscale, this is quite satisfactory.

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Towards a Quantum Theory of Everything

The recent confirmation of the Higgs boson is thought to point to a "Higgs field, which is thought might extend as a or be the common continuum of matter in spacetime in the universe. It would form an important constituent of a unified theory of gravity.

QM is presently discovering that there are further sub-layers or refinements of elementary particles. There is much talk of quasiparticles, positrons, preons, anyons, etc, not to mention the pervasive presence of neutrinos. At some stage QM will find need to find the ultimate "particle".

In fact, it is now being theorised that at the big bang when pure energy at very high temperatures cooled, it first formed particles of matter paired with particles of antimatter. Where they "annihilated" each other, the result was a particle of matter. Where they did not, the result would be antimatter. The slight preponderance of the former (neutrinos to be precise) at the big bang was what is thought to have led the universe to be formed fractionally more of matter, The rest went on to form dark matter and dark energy which pervade the invisible universe. So far it has not been possible to generate the necessary temperatures in the colliders to replicate and prove the theory.

One of the problems to applying concepts of spacetime at the particle level is the small scales of observation or measurability involved. A quark is 10^{-18} metre or a million times smaller than a grain of sand. And there could be smaller dimensions, before one reaches the common ground. At those scales, gravity would be proportionately minute compared to the other fundamental forces whose terrain the sub-atomic is.

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Key Astronomical Technologies

(A) Redshift

One of the critical features of a celestial object to determine is its speed and its direction of motion. This is done by applying the Doppler effect in the redshift technique. When applied at the cosmological level, it can tell us the rate of expansion of the universe.

For waves which do not require a medium, such as electromagnetic waves or gravitational waves, only the relative difference in velocity between the observer and the source needs to be considered.

In astronomy, a redshift is an increase in the wavelength, and corresponding decrease in the frequency and photon energy of electromagnetic radiation (such as light). The opposite change, a decrease in wavelength and simultaneous increase in frequency and energy, is known as a negative redshift, or blueshift. The terms derive from the colours red and blue which form the extremes of the visible light spectrum.

The three main causes of electromagnetic redshift are

.- The radiation travels between objects which are moving apart (" relativistic" redshift or Doppler effect).

.- The radiation travels towards an object in a weaker gravitational potential, ie towards an object in less strongly curved spacetime (gravitational redshift).

.- The radiation travels through expanding space (cosmological redshift),

Astronomers know of three sources of redshift-blueshift: Doppler shifts; gravitational redshifts, (due to light exiting a gravitational field); and cosmological (where space itself stretches). Gravitational waves, which travel at the speed of light, are also subject to the same redshift phenomena. Redshift is also used to measure the expansion of space: known as cosmological redshift. Doppler effects on cosmological scales, which, if incorrectly interpreted as cosmological in origin, lead to the observation of redshift-space distortions.

The Doppler effect is in widespread use in astronomy to measure the speed at which stars and galaxies are approaching or receding from us, resulting in so called a blueshift or redshift , respectively. Positive radial velocity means the star is receding, negative that it is approaching.

This may also be used to detect if an apparently single star is in reality a close binary, to measure the rotational speed of stars and galaxies, or to detect exoplanets.

The use of the Doppler effect in astronomy depends on knowledge of the precise frequencies of discrete lines in the spectra of stars.
The value of a redshift is often denoted by the letter z, corresponding to the fractional change in wavelength (positive for redshifts, negative for blueshifts), and by the wavelength ratio 1 + z (which is >1 for redshifts, <1 for blueshifts).

(B) Planck's Law

Spectroscopy studies the interactions of electromagnetic waves with matter. Planck's Law is the basis of spectroscopy, which is in turn the primary tool to unpack information about a star from its radiation.

Accelerating charged particles produce electromagnetic radiation. The power radiated is proportional to the square of the acceleration. Higher rates of velocity result in higher frequency radiation. Higher frequency results in shorter wavelength. And vice-versa.

The Planck Radiation Law gives the intensity of radiation emitted by a blackbody as a function of wavelength for a fixed temperature. The Planck law gives a distribution which peaks at some wavelength for the temperature The peak shifts to shorter wavelengths for higher temperatures, and the area under the curve grows rapidly with increasing temperature. And vice-versa. By observing the continuous distribution of the radiation emitted by an object, we can learn its **temperature**.

When light passes through or reflects or scatters matter, it interacts with the atoms and molecules. Atoms and molecules have characteristic resonance frequencies. They preferentially interact with light waves of exactly those frequencies. When excited in collisions, atoms and molecules emit light with a set of characteristic frequencies. This results in a **line spectrum**. Only light with a discrete set of wavelengths is produced and the spectrum is not continuous, but consist of a set of emission lines. That set characterizes the atoms and molecules which produced it and can be used to identify those atoms and molecules and their environment.

When light with a continuous distribution of wavelengths passes through a low-density material, the atoms and molecules of the material absorb light waves with the same set of characteristic frequencies that appear in their emission spectrum. This produces an **absorption spectrum**, a nearly continuous spectrum with missing lines. The absorption spectrum can also be used to identify those atoms and molecules and their environment.

A blackbody is a body that absorbs all the radiation that falls onto it. It does not reflect any radiation. When it reaches thermal equilibrium with its surroundings, it emits exactly as much radiation as it absorbs.

In radiometry radiant flux or radiant power is the radiant energy emitted, reflected, transmitted, or received per unit time, and spectral flux or spectral power is the radiant flux per unit frequency or wavelength, depending on whether the spectrum is taken as a function of frequency or of wavelength.

(C) Luminosity[76]

In astronomy, luminosity is the total amount of electromagnetic energy emitted per unit of time by a star, galaxy or other astronomical object. Luminosity is an intrinsic measurable property of a star independent of distance.

In astronomy, luminosity may be given in terms of the astronomical magnitude system. The absolute magnitude is a logarithmic measure of the luminosity within some specific wavelength or filter band.
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[76] Luminosity is an absolute measure of the radiant power emitted by a light-emitting object over time. In SI units, luminosity is measured in joules per second, or watts..

Values for **luminosity** are given in the terms of the luminosity of the Sun, L. The IAU has defined its standard to be one Solar Mass or one **nominal solar luminosity,** as equal to 3.828×1026 W (watts), to promote use of consistent and comparable values in units of the solar luminosity.

The absolute magnitude corresponds to the brightness of a star or other celestial body as seen if it would be located at a standard interstellar distance of 10 parsecs.

In contrast, the term **brightness** in astronomy is generally used to refer to an object's apparent brightness: that is, how bright an object appears to an observer. Apparent brightness depends on both the luminosity of the object, the distance between the object and observer, and on any absorption of light along the path from object to the observer.

A star's luminosity can be determined from two stellar characteristics: size and effective temperature[77]. The former is typically represented in terms of solar radii, R while the latter is represented in kelvins (K) but in most cases neither can be measured directly. To determine a star's radius, two other metrics are needed: the star's angular diameter and its distance from Earth. Both can be measured with great accuracy in certain cases. Since the effective temperature is merely a number that represents the temperature of a blackbody that would reproduce the luminosity, it cannot be measured directly, but it can be estimated from the spectrum.

An alternative way to measure stellar luminosity is to measure the star's apparent brightness and distance. A third component needed to derive the luminosity is the degree of interstellar extinction present, a condition that usually arises because of gas and dust present in the interstellar medium (ISM) of the Earth's atmosphere, and circumstellar matter. Extinction can only be measured directly if the actual and observed luminosities are both known, but it can be estimated from the observed colour of a star, using models of the expected level of reddening from the interstellar medium.

By measuring the width of certain absorption lines in the stellar spectrum, it is possible to assign a certain luminosity class to a star without knowing its distance. Thus a fair measure of its absolute magnitude can be determined without knowing its distance nor the interstellar extinction.

Photometry is a technique used to measure the luminosity of astronomical objects. This light is measured through a telescope often using electronic devices such as a CCD photometer or a photo-electric photometer that converts light into an electric current.. When calibrated against standard stars (or other light sources) of known intensity and colour, photometers can measure the brightness or apparent magnitude of celestial objects. Several different photometric systems exist.

Finally, the absolute bolometric [78]magnitude (Mbol) of an object is a logarithmic measure of its total energy emission rate

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[77] The effective temperature of a body such as a star or planet is the temperature of a blackbody that would emit the same total amount of electromagnetic radiation as it receives. Effective temperature is often used as an estimate of a body's surface temperature when the body's emissivity curve (as a function of wavelength) is not known.

[78] A bolometer is the instrument used to measure radiant energy over a wide band (by absorption) and measurement of heating.

In practice bolometric magnitudes are measured by taking measurements at certain wavelengths and constructing a model of the total spectrum that is most likely to match those measurements. In some cases, the process of estimation is extreme, with luminosities being calculated when less than 1% of the energy output is observed.

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International Astronomical Union (IAU)

The International Astronomical Union (IAU)'s mission is to promote and safeguard the science of astronomy in all its aspects, including astronomical research, outreach, education, and development, through global cooperation. It is a non-governmental organisation founded in 1919 and is based in Paris.

The IAU is composed of individual members who are professional astronomers active in research, education and outreach in astronomy, as well as junior members, and national members, such as professional associations, national societies, or academic institutions. As of 2018, the Union had over 13,700 individual members, spanning 90 countries, and 82 national members. Individual members are organised into divisions, committees, and working groups centred on particular subdisciplines, subjects, or initiatives..

The Union is the leading authority in assigning official names and designations to astronomical objects and for setting uniform definitions for astronomical principles.

The scientific and educational activities of the IAU are organized by its 9 Scientific Divisions and, through them, its 38 specialized Commissions covering the full spectrum of astronomy, along with its 46 Working Groups.

The key activity of the IAU is the organisation of scientific meetings. Every year the IAU sponsors 9 international symposia. Every three years the IAU holds a General Assembly, which offers 6 symposia, some 15 focus meetings, and individual business and scientific meetings.

Among the other tasks of the IAU are the definition of fundamental astronomical and physical constants; unambiguous astronomical nomenclature and informal discussions on the possibilities for future international large-scale facilities.

The IAU has been responsible for the naming and nomenclature of planetary bodies and their satellites since the early 1900s. Such decisions and recommendations are not enforceable by any national or international law; rather they establish conventions that are meant to help our understanding of astronomical objects and processes.

The IAU typically creates a committees to gather opinions from a broad range of scientific interests, with inputs from professional astronomers, planetary scientists, historians, science publishers, writers and educators. On the scientific side, IAU avoids arbitrary cut-offs simply based on distances, periods, magnitudes, or neighbouring objects.

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Beyond the Milky Way

Edwin Hubble (1889-1953), an American astronomer, played a crucial role in establishing the field of extragalactic astronomy, and is generally regarded as the leading observational cosmologist of the 20th century.

IN 1914, he entered the University of Chicago and embarked on graduate studies in astronomy. Hubble conducted his observational research at the Yerkes Observatory. After military service in World War I, he joined the Mount Wilson Observatory in Pasadena California, which had a 100-inch (254-cm) telescope.

At Mount Wilson, Hubble returned to the problem of the so-called spiral nebulae, which he had investigated for his doctorate and the status of which was then unclear. There had been a Great Debate on 26 April 1920 at the Smithsonian between the astronomers Harlow Shapley and Herbert Curtis on the nature of so-called spiral nebulae and the size of the universe. Shapley believed that these nebulae were relatively small and lay within the outskirts of the Milky Way (then thought to be the entire universe), while Curtis held that they were in fact independent galaxies, implying that they were exceedingly large and distant.

Galaxies

In 1923 Hubble found Cepheid Variable stars in the Andromeda Nebula, a very well-known spiral. The fluctuations in light of these stars enabled Hubble to determine the nebula's distance. Hubble's distance estimate placed the Andromeda Nebula approximately 900,000 light-years away[79]. If Hubble was right, the Nebula clearly lay far beyond the borders of the Milky Way Galaxy (the largest estimates of its size then put its diameter at around 300,000 light years). The Andromeda Nebula therefore had to be a galaxy and not within the Milky Way. Hubble's finds in the Andromeda Nebula and in other relatively nearby spiral nebulae swiftly convinced the great majority of astronomers that the universe contained a myriad of galaxies.

Within a few years, Hubble decided to tackle the outstanding puzzle that the vast majority of the (external) galaxies (or extragalactic nebulae, as Hubble always called them) seemed to be moving away from Earth if the redshifts in their spectra were to be interpreted as the result of the Doppler effect.

Redshifted Galaxies

Another Mount Wilson astronomer, **Milton L. Humason** (1891- 1972) measured the spectral shifts of the galaxies and Hubble focused on determining their distances. In 1929 Hubble published his first paper on the relationship between redshift and distance. He tentatively concluded that there was a linear redshift-distance relationship; that is, if one galaxy was twice as far away as another, its redshift was twice as large. Two years later Hubble and Humason presented what astronomers and cosmologists widely judged to be very convincing evidence that the relationship was indeed linear, and hence that a galaxy's redshift was indeed directly proportional to its distance.

The redshift-distance relation established by Hubble and Humason was quickly meshed by various theoreticians with the general relativity-based theory of an expanding universe. By the mid-1930s the redshift-distance relationship was generally interpreted as a velocity-distance relationship, such that the spectral shifts of the galaxies were a consequence of their motion. But Hubble throughout his career resisted the definite identification of the

[79] The current distance estimate of the Andromeda Nebula—now known as the Andromeda Galaxy—is 2.48 million light-years

redshifts as velocity shifts. He declined to choose between a static and a non-static model of the universe, but he did not definitely rule out an expanding universe.

Hubble did much to lay down the methods and techniques that extragalactic astronomers would follow or have to take into account for decade. Hubble was therefore the central figure in the establishment of extragalactic astronomy in the 1920s and ’30s.

Cepheid Variables

Henrietta Swan Leavitt (1868-1921) was an American astronomer, worked at the Harvard College Observatory, tasked with examining photographs to measure and catalogue the brightness of stars. After studying thousands of photographic plates of the Magellanic Cloud, this work led her to discover the relation between the luminosity and the period of Cepheid variables. Leavitt's discovery provided astronomers with the first “standard candle” with which to measure the distance to faraway galaxies.

A standard candle is an object whose luminosity is known. The apparent brightness can be measured, and the distance can be calculated according to the inverse square law. The inverse square law states that the intensity of light decreases with the square of the distance from the source. Given the great distances involved, many objects are too dim to use them as standard candles.

A Cepheid variable is a type of star that pulsates radially, varying in both diameter and temperature and producing changes in brightness with a well-defined stable period and amplitude[80]. A strong direct relationship between a Cepheid variable's luminosity and pulsation period established Cepheids as important cosmic benchmarks for scaling galactic and extragalactic distances. The true luminosity of a Cepheid can be found by simply observing its pulsation period. This in turn allows one to determine the distance to the star, by comparing its known luminosity to its observed brightness.

Before Leavitt’s discovery, the only techniques available to astronomers for measuring the distance to a star were based on parallax and triangulation. Such techniques could only be used for measuring distances up to hundreds of light-years. Leavitt's work allowed astronomers to measure distances up to about 20 million light years.

As a result of this, it is now known that the Milky Way has a diameter of about 100,000 light years. After Leavitt's death, Hubble used Leavitt's period-luminosity relation, together with the galactic spectral shifts measured at Lowell Observatory, to establish that the universe is expanding.

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Lemaitre-Hubble Law

The notion of the universe expanding at a calculable rate was first derived from general equations by **Alexander Alexandrovich Friedmann** (1888-1925), a Russian mathematician, who published a set of equations, now known as the Friedmann equations, in 1922.

In 1927, **Georges Henri Joseph Édouard Lemaître** (1894-1966), a Belgian a Catholic priest, theoretical physicist, mathematician and astronomer and professor of physics at the Catholic University of Louvain, independently derived that the universe might be expanding, observed the proportionality between recessional velocity of and distance to distant bodies,

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[80] The term Cepheid originates from Delta Cephei , in the constellation Cepheus, the first of its type identified in 1784.

and suggested an estimated value for the proportionality constant. Lemaître also proposed the **Big Bang** theory of the origin of the universe calling it the "hypothesis of the primeval atom" and later calling it "the beginning of the world".

A decade before, the American astronomer, Vesto M. Slipher (1875-1969), had provided the first evidence that the light from many of the distant nebulae was strongly red-shifted, indicative of high recession velocities

Hubble continued his work determining the distances of galaxies using a combination of radar, parallax, and Cepheid variables. In this way, he was able to measure the distances of over 20 extra-galactic nebulae. He would also measure the redshift in the spectrum of these galaxies., From the redshift, the radial velocity of the galaxy could be determined. In an article published in 1929, Hubble provided evidence that the recessional velocity of a galaxy increased with its distance from the Earth, confirming Lemaitre's findings. This property is now known as the Lemaitre-Hubble Law. The law implies that the universe is expanding. The motion of astronomical objects due solely to this expansion is known as the **Hubble flow.**

The expansion of the universe is the increase in distance between any two given gravitationally unbound parts of the observable universe with time. It is an intrinsic expansion whereby the scale of space itself changes. The universe does not expand "into" anything and does not require space to exist "outside" it. It can be measured by observing the wavelength shifts of spectral lines emitted by the object, known as the object's cosmological redshift.

Another way of looking at it: all sufficiently distant light sources show redshift corresponding to their distance from Earth. A greater redshift means that the emitter is moving away at a greater velocity, and the more distant galaxies are moving away from the Earth at a greater rate.

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Big Bang Theory

The Hubble-Lemaitre law implied that all galaxies were moving away from the Milky Way (ie us). However, the galaxies are not really moving through space. The space between the galaxies is increasing, causing an apparent velocity that increases with distance. Thus, the observations provided the first observational support for an expanding universe.

If the universe is expanding, it followed that at some point in the past it was smaller. This led to the Big Bang theory, which states that the universe began as a singularity before it began expanding in all directions. This is the widely accepted theory of how the universe began.

Hubble's Constant

Hubble's constant can be expressed mathematically as $v=H_0 \times d$, where v is the speed of recession (generally given in kilometres per second,) d is the distance in megaparsecs and H_0 is the Hubble constant with units of kilometres per second per megaparsec. The Hubble constant describes the relationship, which is linear, between the velocity and the distance of an object. **This constant also gives the speed at which the universe is expanding.**

Hubble estimated the constant as 500 km/s/Mpc. Modern techniques have been used to measure distances and, as a result, the accepted value of the Hubble constant has changed. There is still not a consensus for the Hubble constant, although most agree that the value is between 70−74km/s/Mpc.

Derived from Hubble's Constant there are several other units:

.- Hubble time: the age of the universe if the expansion of the universe had been linear, the inverse of the Hubble constant.

.- Hubble length: the length scale of the universe, determined by multiplying Hubble time by the speed of light.

.- Hubble volume: the volume around an observer beyond which objects would recede at the speed of light, the size of the volume is determined by the Hubble length.

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Temperature of Stars

Cecilia Helena Payne-Gaposchkin (1900-1979) was a British-born American astronomer and astrophysicist who proposed in her 1925 doctoral thesis that the stars were composed primarily of hydrogen and helium, later confirmed by other eminent scientists.

Cecilia Payne's discoveries led to the understanding that most of the mass of the visible universe is made of hydrogen and the rest mainly helium, including our Sun, are all basically made of the same stuff, helium and hydrogen. She was ahead of her time.

But more importantly, Payne's discovery meant that a star's spectrum really told us more information about the temperature of the star than its chemical composition - since the star was made of the same stuff anyway. Therefore, stars with similar spectra must have similar temperatures. A spectrum was a result of the dispersion of a beam of electromagnetic radiation such that its components are spread out in order of wavelength.

The Balmer Thermometer

The Balmer Thermometer is often used in astronomy to measure the temperature of stars. Cecilia Payne developed a method for determining the temperature of stars by using their spectra that is now known as the Balmer Thermometer. The Balmer Thermometer uses the spectral lines of hydrogen visible to the human eye, called **Balmer lines**, to estimate stellar temperatures.

A spectral line is a line in a spectrum located at a specific wavelength when a specific atom absorbs or emits a characteristic amount of energy. When energy is absorbed in the form of a photon of light, a dark absorption line will form in a continuous spectrum.

Since the light that actually forms any given spectrum of a star comes from the outer layers of a star, a spectrum is only representative of those layers and its temperatures, and so, the strength of the Balmer lines is dependent upon the temperature of the star's surface layers.

Confusingly enough, medium-temperature stars are the ones that have the stronger Balmer lines, while hot and cold stars have weaker Balmer lines. The gases in a star needs to be just the right temperature to happily absorb photons in the Balmer series because Balmer absorption lines can only be produced by atoms that have electrons in their second energy level.

Relatively hot stars will have way too many violent collisions between atoms. This will cause most of the atoms in such a hot gas to have their electrons in energy levels higher than the second one. Such energy levels are too high to form Balmer absorption lines, and so, these stars will have weak Balmer absorption lines in their spectrum.

On the other hand, a relatively cold star will have too few collisions between atoms strong enough to excite an atom's electrons away from the lowest energy level, the ground state. This means such unexcited atoms won't be able to absorb photons in the Balmer series either, and so, the Balmer absorption lines in the spectra of these stars will also be weak.

However, stars around 10,000 Kelvin have just the right amount of collisions happening between their atoms to excite their electrons to their second energy level. At this temperature and energy level, hydrogen gas can absorb photons with wavelengths in the Balmer series well, producing nice and strong dark (absorption) spectral lines as a result.

A spectral line is a line in a spectrum located at a specific wavelength when a specific atom absorbs or emits a characteristic amount of energy. Balmer absorption lines can only be produced by atoms that have electrons in their second energy level, which means stars that are too hot or cold will have weak Balmer lines. But because weak Balmer lines in a spectrum can be indicative of a hot or cold star, spectral lines of other elements are used to clue an astronomer in to the actual temperature of the star.

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Part III

CLIMBING JACOB'S LADDER II & III

Chapter Eight
Climbing Jacob's Ladder II

The main source of information about celestial bodies has been, and still is, visible light. However, with modern science, much of our new information comes from our readings across the entire electromagnetic radiation (EMR) spectrum.

Historically, astronomy consisted of observations in the visible wavelengths with the naked eye. Then, with the discovery of optics during the Classical era , they were made with refractor and later reflector telescopes. Optical astronomy laid the foundations of the science. It enabled the identification and classification of the celestial objects, locate and map them, navigate about among them, and measure their distances and movements. The Solar System was unravelled at this stage. The discovery of how to measure the stellar parallax (the distance of a star) was the great technical leap forward.

The next stages involved developments in the technology and instrumentation of astronomy. The first was applying photography to capture what the telescopes searched out and saw. This greatly increased the scope of capture and limit of resolution Today, astro-photography is married to the CCD-camera, providing data and enabling classification of incredible detail about the stars.

Newton had opened the pandora's box when his prism refracted light into its constituent colours and their frequencies. This deepened the understanding of what was visible. It led to discovery of the whole electromagnetic radiation (EMR) spectrum, opening whole new windows for observation. EMR became our umbilical cord.

Before long, various specialised instruments in various specialised telescopes were capturing EMR radiation across all wavebands, dedicated particularly to the higher end ultra-violet, X-ray and gamma-ray, as well as the lower end microwave and radio wave, emissions.

Astronomical spectroscopy developed as the study of the EMR spectrum. It has been able to reveal many properties of stars, such as their chemical composition, temperature, density, mass, distance and luminosity. Spectroscopy can show the velocity of motion towards or away from the observer. Spectroscopy has helped reveal the structure of the universe, and the physical properties of the many types and parts of celestial objects such as planets, nebulae, galaxies, active galactic nuclei, and black holes.

On the scientific side, at the beginning of the mid-20th century, quantum mechanics and relativity gave us a unified understanding of matter, which enabled us to comprehend the earth and the universe as one. Quantum science went on, through its technology, to empower us with undreamed of precision in research tools and investigative capability.

In parallel, there has been the wave of brilliant theoretical astrophysicists (such as Hubble), whose mathematics enabled us to speculate, probe and unravel the mysteries of the universe - even before the first eprom was invented.

And then came the power of the computer: first the desktop, then the mainframe, then the networked computers, and presently the supercomputer[81]. This was in turn accompanied by

[81] And already, the incipient quantum computer.

the development of the incredible software of today - for diagnostics, problem analysis, data management, simulation, and now even the beginnings of AI. In fact, today, scientists' prime tool of investigation is no longer observation but, based on what they have captured, to model predictions of the possible and the probable in space and time, and programme searches and probes to verify their propositions. Needless to say, astro-photography, astro-spectrography and the telescope, are now totally computerised.

One of the issues was that the frequency ranges outside the optical window and the radio window could not penetrate or were distorted by the Earth's atmosphere, in particular those of the shorter wavelengths, namely Ultra-violet, X-rays and gamma-rays. The last breakthrough came when man could put a telescope in space.

Today, improvements in instrumentation have enabled astronomers to study non-EMR vectors of space, including neutrinos, neutrons, cosmic rays and gravitational waves.

On the non-technical side, in view of the levels of financing involved (not to mention political and security considerations), governmental agencies, such as NASA and the European Space Agency (ESA), have today come to monopolise the research of the visible universe. In fact all other branches of astronomy have moved into the hands of highly specialised technological institutions and agencies. Barring the International Space Station (ISS), many of the activities launched are still on a project by project basis.

On the professional side, the most important event was probably the formation of the The International Astronomical Union (IAU) in 1919, a nongovernmental organisation with the objective of advancing astronomy in all aspects, through global cooperation. It has become th governing body of astronomy. Among others, it establishes the galactic quadrants and galactic coordinate system, defines celestial objects and their classification, registers new discoveries, approves the proper names of stars and constellations, and even sets criteria for such things as measuring luminosity, etc.

It is only fitting to mention here the European Organization for Nuclear Research(CERN), the site of the Large Halidron Collider (LHC), the world's largest and highest-energy particle collider, established in 1954. It is the leading edge of Quantum Science, where they run particles of matter to the zillionth degree of temperature and near speeds of light, to discover how elementary particles were made and behaved in the Big Bang.

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Ground-Based Astronomy

There are three ways to know the universe: (1) Observation, (2) Analyse the stuff that reaches us, and (3) Go there - explore. This Part reviews the incredible achievements under the first two together. They are inseparable.

We have landed on the Moon, but are still fumbling in the sub-orbital; and we are basically still in the probe stages of the third. We review our exploration activities under the Next Stage

(A) Optical Observatories

Since astronomy began, we have studied the heavens with our feet firmly planted on the ground, and before Galileo with only our naked eye - supported by a keen sense of mathematics and imagination. In fact we only grasped the astronomical (no pun intended) informational potential of non-visual EMR at the turn of the last century when our telescopes had reached their present day sophistication.

In Classical times, no respectable astronomer was without his observatory and telescope, usually privately funded. Joseph Fraunhofer, a German optician, who was successful in making astronomical instruments, helped create a German optics industry which led the world for more than half a century.

The first observatories built in the US. were equipped with telescopes from Europe. The new 15-inch refractor dedicated in 1847 at the Harvard College Observatory was the largest refractor in the world for twenty years and, like a similar one at Russia's Pulkovo Observatory, was made by his German firm.

However, by 1897, the 40-inch lens for the Yerkes Observatory refractor at Williams Bay, Chicago was built by the US firm Alvan Clark & Sons, and was the apex of achievement in the 19th century.

The Hale Telescope is a 200-inch (5.1 m), reflecting telescope at the Palomar Observatory, California, named after astronomer George Ellery Hale. With funding from the Rockefeller Foundation, he orchestrated the planning, design, and construction of the observatory, which was ground-breaking for its time, with many new technologies in the design and fabrication of its "honeycomb" low mirror. It was completed in 1949 and is still in active use. The Hale Telescope represented the technological limit in building large optical telescopes for over 30 years. It was the largest from its construction in 1949 until the Soviet BTA-6 was built in 1976.

The 20th century saw the proliferation and increasing sophistication of observatories. Still mainly optical, their telescopes and instrumentation included capabilities to read the whole EMR spectrum. Observatories added on-site post-capture processing facilities and on-line storage and back-end research, becoming astronomical complexes.

Late in the late last and in this century, observatories evolved further. They became now inked with one another for wider baselines and for interferometric work, and they moved underground for noise insulation in particle and gravitational work.

Current Generation

Wikipedia[82] has a list of all astronomical observatories as at 2021. Excluding space and airborne categories, those dedicated for specialised purposes, as well those defunct, I found that the number of ground-based basically optical observatories set up since 1950 was 408, of which 170 were set up in this century and the remaining 238 dated back to the preceding half century. The total numbers inclusive of all categories was 489.

82 https://en.wikipedia.org/wiki/List_of_space_telescopes

Table 8
Most Famous Observatories[83]

No	Observatory	Information	Year
1	Mauna Kea Observatory, (MKU), Hawaii, USA	Located on Hawaii's Big Island, on the summit of Mauna Kea mountain, the MKO is the world's largest array of optical, infrared, and sub-millimetre astronomical equipment. The Mauna Kea **Observatory** houses more telescopes than any other single mountain peak Keck Observatory, astronomical observatory located near the 4,200-metre (13,800-foot) summit of Mauna Kea, a dormant volcano on north-central Hawaii Island, Hawaii, U.S.Keck's twin 10-metre (394-inch) telescopes, housed in separate domes, constitute the largest optical telescope system of the burgeoning multi observatory in the world At 13,600 feet above sea level, near the summit of Mauna Kea, reside the two largest telescopes in the United States. The twin Keck telescopes each measure 10 meters across but use a unique design	1968
2	Very Large Telescope (VLT), Chile	The Very Large Telescope is a **telescope** operated by the European Southern **Observatory**. It is located on Cerro Paranal in the Atacama Desert, northern Chile. The VLT actually consists of four individual telescopes which are generally used separately but can be used together to achieve very high angular resolutions	1998
3	South Pole Telescope (SPT) Antarctica	A **telescope** of 10 metre in diameter located at the Amundsen-Scott South Pole Station in Antarctica. Funded by grants from multiple sources—the National Science Foundation, the US Department of Energy, and the Kavli and Moore foundations	2007
4	Yerkes Observatory, Wisconsin, USA	The Yerkes Observatory is often described as "the birthplace of modern astrophysics". The observatory's main dome houses a 40 in-diameter (102 cm) doublet lens refracting telescope, the largest refractor ever successfully used for astronomy. Two smaller domes house 40-inch (102 cm) and 24-inch (61 cm) reflecting telescopes.	1897

The largest optical telescopes by aperture, again according to Wikipedia, were:

. - The Large Binocular Telescope (LBT), 469 inches, multiple mirrors, at Mount Graham International Observatory , Arizona, USA.

. – The Gran Telescopio Canaris (BTC), 409 inches, segmented mirrors, at Roque de los Mucharchos Oaaseervatory (ORM), Canary Islands, Spain.

. - The Hobby-Eberly Telescope (HET), 394 inches, segmented mirrors, at McDonald Observatory, Fort Davis, Texas, USA.

. – The Keck 1 and 2, twins, 394 inches each, segmented mirrors, at Mauna Kea, Hawaii, USA.

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[83] https://10mosttoday.com/10-best-observatories-in-the-world/

Galileo would have been pleased to that the Vatican Advanced Technology Telescope (VATT) is located on Mt. Graham, Arizona, and is part of the Mount Graham International Observatory, operated by the Vatican Observatory Research Group (VORG) on a 25% shared basis.

The information to be extracted from the visible spectrum is far from exhausted, and optical astronomy is still a major component of astronomical activity. In the end, everything must be united in the visible dimension, the ultimate challenge They must be visible and transparent at the same time. There is no point having map of darks matter if they cannot be seen.

Satellites are carrying more instruments for more purposes, observational instruments are becoming more integrated, and projects are increasingly multi-tasked and multi-spectral. Nevertheless, it is meaningful to look at the activity in the different spectral realms.

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(B) Radio Astronomy

Radio Waves

In 1887, German physicist Heinrich Hertz demonstrated the reality of Maxwell's electromagnetic waves by experimentally generating radio waves in his laboratory, showing that they exhibited the same wave properties as light: standing waves, refraction, diffraction, and polarisation.

Human-made radio waves are generated when electrons, which are negatively charged, move back and forth within an antenna. This movement of charged particles creates a field that radiates out from the antenna at the speed of light. The radio portion of the electromagnetic spectrum is divided into wavebands. Guglielmo Marconi: an Italian inventor, sent and received his first radio signal in Italy in 1895.

Radio waves radiate at the lowest frequencies of the EM spectrum,100 kHz to 300 GHz. Radio waves accordingly have a wavelength of about two or three metres. An FM station broadcasting at a frequency of 90 MHz is broadcasting at a wavelength of 3.3 metres. The sub-category microwave, the most frequently used in astronomy, operates at closer to wavelengths of 10 cm to 1mm. Visible light is at about 0.0000006 metres.

Discovery of Radio Astronomy.

Karl Guthe Jansky (1905-1950) was an American physicist and radio engineer who in 1933 first announced discovery of radio waves emanating from the Milky Way, from the constellation Sagittarius He is considered one of the founding figures of radio astronomy.

Grote Reber (1911-2002), an American radio engineer, was instrumental in investigating and extending Jansky's pioneering work. He singlehandedly built a radio telescope in his Illinois back yard in 1937 and did the first systematic sky-survey of astronomical radio frequencies, and conducted the first sky-survey in the radio frequencies. For nearly a decade he was the world's only radio astronomer. In his third attempt, at 160 MHz, he was successful in 1938, confirming Jansky's discovery.

He turned his attention to making a radio-frequency sky map, which he completed in 1941 and extended in 1943. His data, published as contour maps showing the brightness of the sky in radio wavelengths, revealed the existence of extensive radio sources.

The standard theory of radio emissions from space was that they were due to black-body radiation. Reber demonstrated that there was a considerable amount of low-energy radio signal. It was not until the 1950s that the explanation for these emanations was found to be the result of standard **synchrotron** radiation when electrons orbit magnetic fields.

Radio astronomy developed as, and remains essentially conducted, at ground-based observatories, using **radio telescopes.** One principle reason is that radio telescopes have to be larger than their optical counterparts, for angular resolution is a function of the diameter of the target in proportion to the wavelength being observed**.** For example, a one metre diameter optical telescope is two million times bigger than the wavelength of light observed giving it a resolution of roughly 0.3 arcsecs, whereas a radio telescope "dish" may have to be many times that size depending on the longer wavelength observed.

However, at low frequencies or long wavelengths, transmission is limited by the ionosphere, which reflects waves with frequencies less than its own characteristic plasmic frequencies. Further, water vapour interferes with radio astronomy at higher frequencies. Finally, transmitting devices on Earth may cause interference.

Thus, radio observatories tend to conduct observations at millimetre (microwave) end of their wavelengths, located at very high and distant dry sites the Earth's surface. They are enhanced by use of multiple linked telescopes utilising the techniques of radio interferometry and aperture synthesis.

During the late 1960s and early 1970s, as computers became capable of handling the intensive computations required, astronomers at Cambridge UK mapped the radio sky, producing the Second and Third Cambridge Catalogues of Radio Sources.

Radio Interferometry-Aperture Synthesis

The difficulty in achieving high resolutions with single radio telescopes led to radio interferometry, developed by British radio astronomer Martin Ryle and Australian engineer and radio astronomer Joseph Lade Pawsey and radio-physicist, Ruby Payne-Scott in 1946, and based on war-time radar experience. The first use of a radio interferometer was carried out by the Australian group, who further laid out the principles of aperture synthesis in a ground-breaking paper published in 1947.

The use of interferometry allows radio astronomy to achieve high angular resolution, as the resolving power of an interferometer is set by the distance between its components, rather than the size of its components. It consists of widely separated radio telescopes observing the same object, that are connected together using co-axial cable, waveguide fibre optic or other transmission line. This not only increases the total signal collected, it can also be used in a process called aperture synthesis to vastly increase resolution.

This technique works by superposing ("interfering") the signal waves from the different telescopes, on the principle that waves that coincide with the same phase will add to each other while two waves that have opposite phases will cancel each other out. This creates a combined telescope that is the size of the antennas furthest apart in the array.

In order to produce a high quality image, a large number of different separations between different telescopes are required, as many different baselines as possible are required in order to get a good quality image.

An astronomical interferometer offers a resolution equivalent to that of a telescope of diameter equal to the largest separation between its individual elements.

VLBI Interferometry

Beginning in the 1970s, improvements in the stability of radio telescope receivers permitted telescopes from all over the world (and even in Earth orbit) to be combined to perform Very Long Base Line Interferometry. (VLBI)

Instead of physically connecting the antennas, data received at each antenna is paired with timing information, usually from a local atomic clock and then stored for later analysis on magnetic tape or hard disk. At that later time, the data is correlated with data from other antennas similarly recorded, to produce the resulting image. Using this method it is possible to synthesise an antenna that is effectively the size of the Earth. The large distances between the telescopes enable very high angular resolutions to be achieved, much greater in fact than in any other field of astronomy. At the highest frequencies, synthesised beams less than one milli-arcsec are possible.

Radio astronomy has led to substantial increases in astronomical knowledge, particularly with the discovery of several classes of new objects, including pulsars, other supernova remnants, quasars, active galactic centre (AGNs), and radio galaxies. Such objects represent some of the most extreme and energetic physical processes in the universe. It has particularly been instrumental in investigating Sagittarius A*, the galactic centre of the Milky Way, thought to be a radio wave emitting supermassive black hole.

The cosmic microwave background radiation, a blackbody radio-microwave emitter, was also first detected using radio telescopes. Radio telescopes have additionally been used to investigate the Sun, solar activity and to map the planets. Merging galaxy clusters often show diffuse radio emission.

Radio Observatories

Wikipedia reported over 100 radio telescopes[84] in all continents, many in remote locations, including the Pacific, Arctic and the Antarctic. In a separate list[85] of theirs, I counted 42 extant radio observatories. Seems about right.

We might take a peek at a few of these wonders:

[84] https://en.wikipedia.org/wiki/List_of_radio_telescopes
[85] https://en.wikipedia.org/wiki/List_of_astronomical_observatories

Table 9
Selected Radio Observatories

No	Observatory	Information	Year
1	Five Hundred Meter Aperture Spherical Telescope (FAST)	Located in the Dawodang depression, a natural basin in Guizhou, SW China Pingtung, Guizhou, China FAST has a single 500 m (1,600 ft) diameter full dish. It has an active surface made of 4,500 panels to form a moving parabola of metal panels in real time. The cabin containing the feed antenna suspended above the dish, can move automatically to steer the instrument to receive signals from different directions. It observes at wavelengths of 10 cm to 4.3 m.	2020
2	Atacama Large Millimetre Array (ALMA)	ALMA) is an astronomical of 66radio telescopes in the Atacama Desert, Chile, which observes in the milimeter-sub-millimetre wavelengths. The array has been constructed on the 5,000 m (16,000 ft) elevation Chajnantor plateau., near the Liano de Chagnantor observatory and the Atacama Pathfinder experiment station. ALMA is expected to provide insight on star birth during the early Stelliferous era. ALMA is an international partnership amongst US, Europe, Canda, Japan, South Korea , Taiwan and Chile.	2013
3	Karl G. Jansky Very Large Array (VLA)	The VLA is a centimetre wavelength radio astronomy observatory located in central New Mexico on the Plains of San Augustin, Socorro, USA. The VLA comprises twenty-eight 25-meter radio telescopes deployed in a Y-shaped array and all the equipment, instrumentation, and computing power to function as an interferometer, capable of giving 351 independent baselines at once. It is the largest facility of its kin. Each of the massive telescopes is mounted on double parallel railroad tracks, so the radius and density of the array can be transformed to adjust the balance between its angular resolution and its surface brightness sensitivity. The VLA stands at an elevation of 6,970 feet (2,120 m) above sea level. It is a component of the national Radio Astronomy NRAO) which is a facility of the National Science Foundation (NSF).	2007

Global VLBI.

The pre-eminent VLBI arrays operating today are the Very Long Based Array (VLBA) with 10 25metre telescopes located across North America from Hawaii to Virgin Island, and the European VLBI Network (EVN) with telescopes in Europe, China, South Africa and Puerto Rico. Each array usually operates separately, but occasional projects are observed together producing increased sensitivity.

There are also VLBI networks operating in Australia and New Zealand called the LBA (Long Baseline Array) and arrays in Japan, China and South Korea which observe together to form the East-Asian VLBI Network (EAVN).

The availability today of worldwide high-bandwidth networks makes it possible to do VLBI in real time. This technique (referred to as e-VLBI) was originally pioneered in Japan, and more recently adopted in Australia and in Europe by the EVN (European VLBI Network).

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Orbital-Based Observatories

By the end of the Second World War, astronomy had substantially identified the ambit of its concerns based on the visual universe. Astronomy had developed the telescope as the umbilical cord to the universe, and learnt to read the EMR, the bloodstream of the universe . And astronomy had done all this with the technology of the time, and based from the ground.

Astronomers also realised that they were impeded from proceeding with the next steps by the Earth's atmosphere, which was blocking receipt of much of the EMR radiation from space on both sides of the visual spectrum. The remedy was, next, to position ourselves astronomy in space. The first step is orbital. Fortunately, parallel developments in technology have enabled this, some old, some new.

Besides obtaining a first clear window into space, there was also much still to be studied about the Sun, the Solar System, and the Milky Way from the previously inaccessible wavelengths of the EMR.

(A) Scaling The Suborbital

Hot Air Balloons

The first hot air balloons carrying meteorological instruments (weather. balloons) went up in France in 1892. Meteorologist needed to learn about the atmosphere, before astronomers did about stars. We may assume that Phileas Fogg and Passepartout brought a telescope along in 1872, although I suspect to look at the ground not the stars.

The original hot air balloon used a single-layered, fabric gas bag (the lifting "envelope"), with an opening at the bottom called the mouth or throat. Attached to the envelope was a basket, or gondola for carrying the passengers and or payload. Mounted above the basket was the "burner", fuelled by propane, which injected a flame into the envelope heating the air within. As the balloon ascended, the pressure of its environment decreased, and the balloon expanded. Pilots controlled their ascent and descent by heating the air with "burns" or slowly releasing air allowing the heated air to cool off, or by using a variety of vents. Some balloons used hydrogen or helium; no burners but with different steering principles, including use of ballast to rise.

The balloons for weather and other research purposes varied with purpose. A standard version had the balloon rise and continue expansion until the balloon burst. Such balloons remained in flight for up to two hours before exploding. This typically could occur at altitudes between of 30 and 35 km, just below or in the stratosphere (above the weather dominated troposphere). The payload would then float back on a parachute, as much for up to 17 hours and 200 Km away giving vertical as well as latitudinal real-time profiling. In some recent examples, the instruments would radio readings all the way up and back,

As the cost of air balloon operations is negligible, and the payload is often re-usable, balloons are most suitable for testing new theories, designs, instruments and propositions , or when searching for something or just checking out unknown territory. It could also be launched from remote locations, eg. the south pole. It is therefore still very much a continuing part astronomical activities.

Balloon-borne Telescopes

The Statoscopes were two balloon-borne astronomical telescopes which flew from the 1950s to the 1970s and observed in the optical and infrared regions of the spectrum. Both were controlled remotely from the ground

Stratoscope I was the first balloon-borne astronomical telescope flown in 1957. It was a 12-inch telescope which took photographic images of the sun, showing granulation features. In 1959 it was flown again, this time with a television transmitter

Stratoscope II, a 36-inch reflecting telescope, flew from 1963 to 1971. This larger project was managed by NASA as a beginning of its scientific ballooning program. The gondola it was mounted on weighed 3.5 tons. It studied planetary atmospheres of the planets, the red giant stars and the galaxies. On early flights of Stratoscope II, photographic film was used, but this was soon replaced by television detectors.

Wikipedia lists 12 balloon programmes up to 2015. The Spider telescope launched in the latter year looked for gravitational waves.

ASTHROS

NASA is currently planning the largest ever high altitude balloon observatory with a 400 foot balloon and 2.5 metre telescope, known as ASTHROS (Astrophysics Stratospheric Telescope for High Spectral Resolution Observations at Submillimetre-wavelengths)., it will launch from the Antarctic and is envisioned to last three weeks

NASA's Astrophysics Stratospheric Telescope for High Spectral Resolution Observations at Submillimetre-wavelengths (ASTHROS), seen in this illustration, is a high-altitude balloon mission for studying astrophysical phenomena.

Scheduled to launch no earlier than December 2023 from in Antarctica, ASTHROS will aim to fly for 21 to 28 days at an altitude of about 130,000 feet (24.6 miles or 40 kilometres). At that altitude, ASTHROS can observe wavelengths of light blocked by Earth's atmosphere.

When fully inflated, the 40 million-cubic-foot helium balloon will be about 400 feet (150 metres) wide, or roughly the size of a football stadium.

The ASTHROS telescope features a lightweight 8.4-foot (2.5-metre) primary mirror to collect far-infrared light – one of the largest to ever fly on a high-altitude balloon mission.

The mission's main science goal is to study the process by which living stars disperse and reshape clouds of gas and dust that may eventually form new stars. ASTHROS will look at several star-forming regions in our galaxy where feedback takes place, and at distant galaxies containing millions of stars to see how feedback plays out in different environments.

Balloon Satellites

A balloon satellite is inflated with gas after it has been put into orbit, usually low orbit. Apart from its longer flight duration and greater payload, it can be large and painted bright, and can be visibly tracked from the ground.

The first flying body of this type was Echo 1, which was 30 metres in diameter, and was operated in a 1,600-kilometer (990 mi) high orbit from1960 to 1968 by the US at an angle of

47o. It served for testing as a "passive" communications and geodesic. Its successor was the similarly built Echo 2, in 1964 to 1969.

Taking part in the Echo orbit checks to analyse disturbances in its orbit and in the Earth's gravitational field were thirty to fifty professional earth stations, as well as around two hundred amateur astronomers,

Sounding Rockets

German V-2 rockets captured after World War II were fired by the US as sounding rockets into the Earth's upper atmosphere) for a programme of atmospheric and solar investigations from the White Sands Missile Range (WSMR). The V-2 sounding rocket investigations started in 1949 and continued until 1952. They developed telemetry to transmit the instrument readings during flight. On the first flight, X-rays from the Sun were detected by the experiment on board.

A sounding rocket (sometimes called a research rocket or a suborbital rocket) is designed to take measurements and perform scientific experiments during sub-orbital flight. The rockets reach from 48 to 145 km (30 to 90 miles) above the surface of the Earth, the altitude generally between weather balloons and satellites - the maximum altitude for balloons is about 40 km (25 miles) and the minimum for satellites is approximately 121 km (75 miles). The trajectories generally carried the rocket about 30 miles (48 km) horizontally from the launch site.

Larger, higher altitude rockets have two to three stages to increase efficiency and payload capability. The rocket consumes its fuel on the rising part of the flight, then separates and falls away. The freefall part of the flight is an elliptic trajectory. The average flight time is less than 30 minutes, usually between five and 20 minutes.

The payload continues into space after separation, and begins conducting the experiments. When the experiments are completed, the payload re-enters the atmosphere and a parachute is deployed, bringing the payload gently back to Earth. The payload is then retrieved and can be refurbished (or parts of it) and flown again).

Sounding rockets are advantageous because of their low cost, short lead time, and the ability to conduct research in areas inaccessible to either balloons or satellites. The smaller size of a sounding rocket also makes launching from temporary sites possible, even in the middle of the ocean, if fired from a ship.

Sounding rockets are commonly used for measurements of the upper atmosphere, ultraviolet and X-ray astronomy, and for microgravity research - which benefits from a few minutes of weightlessness.

NASA currently uses 15 different sounding rockets, in a variety of sizes from the single-stage which stands about 7 ft (3 m) tall to the four-stage Black Brant XII, which stands 65ft (20m) tall. These rockets can carry payloads of various weights to altitudes from 48 km to more than 1200 km.

An Aerobee 150 rocket launched by US on June 19, 1962 (UTC) detected the first X-rays emitted from a source outside our solar system (Scorpius X-1), starting a new field of astronomy.

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(B) Orbital (Satellite) Observatories

Satellite-Telescopes

In this review, a satellite with a telescope is a space observatory. A satellite is by definition orbital. A telescope on a satellite is both a space telescope and an orbital telescope. The satellite-borne telescope is the backbone of astronomy as of today. For some time to come, satellites will be our prime space-based astronomical observatories.

Their primary function is to enable the space telescope(s) to read the non-visible EMR of the universe not possible from the ground. Because of the depth of penetration possible from a satellite, the latter are also used to capture incredibly rich pictorial harvests for mapping and cataloguing the universe. Their third role is to measure up, help unravel the history of and support the exploration of the universe. .

Space telescopes avoid the atmospheric filtering and distortion (scintillation) of electromagnetic radiation and avoid light pollution. As a result, the angular resolutions of space telescopes are much higher than a ground-based telescope with a similar aperture.

Satellites can generally be commanded remotely from the ground. However, by and large, they cannot be re-supplied or maintained (or retrieved) from the ground. Therefore they are planned with a short lifespan.

Satellites are divided into two types: those which map the entire sky (astronomical survey), and satellites which focus on selected astronomical objects or parts of the sky for specific capture or enquiry.

Update, some 95 space satellites have been launched, 91 targeting the entire EMR spectrum, and 4 other forms of radiation, and 32 remain functional.

Milestones

Herewith some milestones[86]:

.- The first space telescope that was launched was Orbiting Astronomical Observatory 2 (OAO-2). It was launched Dec 1968, and it remained in space for one month.

. – The first satellite launched for the sole purpose of collecting data about X-Ray astronomy was Uhuru (also known as X-ray Explorer Satellite, SAS-A, SAS 1 or Explorer 42). It reached space on Dec 1970. It remained active for 3 years.

. – The first space gamma-ray telescope. SAS 2 (Explorer 48), was launched in 1972.
. - The first space observatory to map the entire sky at infrared wavelengths was the Infrared Astronomical Satellite (IRAS) launched in Jan 1983, a joint-project of space agencies from the US, Netherlands and UK . its mission lasted ten months.

. - The first telescope that was focused on Infrared and Submillimetre light was Submillimetre Wave Astronomy Satellite (SWAS) from 1998.

. - Microwave observation of space was done with just 4 space telescopes: (1) The Cosmic

[86] http://www.historyoftelescope.com/telescope-facts/facts-about-space-telescopes/

Background Explorer (COBE, 1989-1993), (2) The Odin (2001- still on-going)), (3) The Wilkinson Microwave Anisotropy Probe (WMAP), (2001 to 2010) which measured temperature differences across the sky in the Cosmic Microwave Background (CMB) and (4) The Planck Satellite (2009-2013), with multiple objectives including creating a catalogue of galaxy clusters.

. - Radio astronomy was done with two probes (1) The HALCA (1997-2005), which conducted various engineering experiments including deployment of large antenna and VLBI interference experiments before successfully making VLBI observations, and (2) The RadioAstron (2011-2019) was a Russian space based radio telescope, which worked together with Earth based radio telescopes to give interferometer baselines extending up to 350,000 km, enabling VLBI,

.- The first the mission to look for planets orbiting distant stars was the Kepler Mission launched by NASA in 2009 It retired in 2018.

To the preceding should be included the following four major space telescope launches under NASA's Great Observatories series in 1999-2003, built with different technologies to examine specific wavelengths and regions of the EMR spectrum:

.- The Hubble Space Telescope (HST), primarily to observe the visible light and near-ultraviolet wavelengths of the spectrum, launched in 1990.
Hubble gave us our first insights into the depths of outer space and the immensity of the universe.

.- The Compton Gamma Ray Observatory (CGRO), primarily to observe gamma-rays, extended into hard X-rays as well, launched in 1991. It was de-orbited in 2000 after a gyroscope failed.

.- The Chandra X-Ray Observatory (CXO), primarily to observe soft X-rays, launched in 1999). it is still operational.

.- The Spitzer Space Telescope (SST), primarily to observe the infrared spectrum, launched in 2003 and the first to be placed in a halo or Earth-trailing orbit. Depletion of its liquid helium coolant in 2009 reduced its functionality, leaving it with only two short-wavelength imaging modules. It was removed from service and placed into safe-mode in Jan 2020.

Some Optical Satellite Telescopes of Note

High Precision PARallax COllecting Satellite (Hipparcos)

Hipparcos was a scientific satellite pf the ESA launched in 1989 and operated until 1993. It was the first space experiment devoted to precision astrometry, the accurate measurement of the positions of celestial objects on the sky, to remove the unavoidable imprecisions due to the atmosphere.

This permitted the first high-precision measurements of the intrinsic brightness, proper motion and parallaxes of stars, enabling better calculations of their distance, tangential velocity, etc. When combined with the highly precise orders of measurements from spectrography, etc astrophysicists were able to finally measure all six quantities needed to determine the motion of stars.

The resulting Hipparcos Catalogue, a high-precision catalogue of more than 118,200 stars, was published in 1997. The lower-precision Tycho Catalogue of more than a million stars was published at the same time, while the enhanced Tycho-2 Catalogue of 2.5 million stars was published in 2000.

HUBBLE Space Telescope

The Hubble Space Telescope (HST or Hubble) marked the culmination of the astronomical endeavours of the last century in the optical realm, and set the standards for the next generation.

Hubble was the largest and most versatile space telescope, launched into low Earth orbit in 1990 and remains in operation. Hubble formed the visible light component of NASA's Great Observatories programme, and launched the series of flagship satellite telescopes. It was followed by Compton (1991), the Chandra (2001) and the Spitzer (2003.) Hubble was funded and built by the NASA with contributions from the European Space Agency (ESA) .

Hubble featured a 2.4 m (7 ft 10 in) mirror, and its five main instruments observe in the ultraviolet, visible, and near infrared regions of the electromagnetic spectrum. Hubble's orbit allowed it to capture extremely high-resolution images with substantially lower background light than ground-based telescopes. It has recorded some of the most detailed visible light images, allowing a deep view into space. Many Hubble observations have led to breakthroughs in astrophysics, such as the determining the rate of expansion of the universe.

Hubble was (and still is) the only telescope designed to be maintained in space by astronauts. Instruments and limited life items were designed as orbital replacement units. Hubble was designed to accommodate regular servicing and equipment upgrades. Five Space Shuttle missions repaired, upgraded, and replaced systems on the telescope, including all five of the main instruments, the last in 2009. In fact, its main mirror had been ground incorrectly, resulting in spherical aberration that compromised the telescope's capabilities. The optics were corrected by the first servicing mission in 1993. Hubble completed 30 years of operation in April 2020and is predicted to last until 2030–2040.

Hubble accommodates five science instruments at a given time, plus the Fine Guidance Sensors which are mainly used for aiming the telescope but are occasionally used for scientific astrometry measurements. Early instruments were replaced with more advanced ones during the Shuttle servicing missions.
Since the final servicing mission in 2009, the four active instruments have been ACS, COS,

STIS and WFC3. NICMOS is kept in hibernation, but may be revived if WFC3 were to fail in the future.
. – Advanced Camera for Surveys (ACS; 2002–present)
. – Cosmic Origins Spectrograph (COS; 2009–present)
. – Corrective Optics Telescope Axial Replacement (COSTAR; 1993–2009)
. – Faint Object Camera (FOC; 1990–2002)
. – Faint Object Spectrograph (FOS; 1990–1997)
. – Fine Guidance Sensors (FGS; 1990–present)
. - Goddard High Resolution Spectrograph (GHRS/HRS; 1990–1997)
. – High Speed Photometer (HSP; 1990–1993)
.- Near Infrared Camera and Multi-Object Spectrometer (NICMOS; 1997–now, hibernating since 2008)
. – Space Telescope Imaging Spectrograph (STIS; 1997–present (non-operative 2004–2009))
. – Wide Field Planetary Camera (WFPC; 1990–1993)
. – Wide Field and Planetary Camera 2 (WFPC2; 1993–2009)
. – Wide Field Camera 3 (WFC3; 2009–present)

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From Observation to Research

Hubble launched the transition from observation to research, enabled let it be said by the increasing insights of quantum science, the power of information technology and advances in instrumentation. Astronomy moved into targetted investigation, co-ordinated projects and integrating the outcomes from different modes and spectra.

Although Hubble is nearing the end of its life, there are still major projects scheduled for it.

. – ULLYSES. The current Ultraviolet Legacy Library of Young Stars as Essential Standards project (2022) will last for three years to observe a set of high- and low-mass young stars and will shed light on star formation and composition.

. – CANDLES. The Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey is designed to document the first third of galactic evolution from z = 8 to 1.5 via deep imaging of more than 250,000 galaxies. It will also find the first Type Ia SNe beyond z > 1.5 and establish their accuracy as standard candles for cosmology.

. - FRONTIER FIELDS PROGRAM. The programme, officially named "Hubble Deep Fields Initiative 2012", is aimed to advance the knowledge of early galaxy by studying high-redshift galaxies in blank fields with the help of gravitational lensing.

. – COSMOS. The Cosmic Evolution Survey (is an astronomical survey designed to probe the formation and evolution of galaxies as a function of both cosmic time (redshift) and the local galaxy environment. The survey covers a two square degree equatorial field with spectroscopy and X-ray to radio imaging by most of the major space-based telescopes and a number of large ground based telescopes, making it a key focus region of extragalactic astrophysics.

COSMOS was launched in 2006 as the largest project pursued by the Hubble Space Telescope at the time, and still is the largest continuous area of sky covered for the purposes of mapping deep space.

The COSMOS scientific collaboration that was forged from the initial COSMOS survey is the largest and longest-running extragalactic collaboration, known for its collegiality and openness.

Kepler Space Telescope

The Kepler space telescope is a retired visual space telescope launched by NASA in 2009 to discover Earth-size planets orbiting other stars. It was placed in an Earth trailing orbit round the Sun

Kepler was designed to survey a portion of Earth's region of the Milky Way, to discover Earth-sized exoplanets in or near habitable zones. Its parallel mission was to estimate how many of the billions of stars in the Milky Way have such planets.

Kepler's sole scientific instrument is a photometer that continually monitored the brightness of approximately 150,000 Main Sequence Stars in a fixed field of view. The data was transmitted to Earth to analyse the periodic dimming caused by exoplanets that cross in front of their host star. Only planets whose orbits were seen edge-on from Earth could be detected. Kepler observed 530,506 stars and detected 2,662 planets. The technical setup was incredibly simplistic for its mission, all the more so considering the orbit selected.

After nine and a half years of operation, the telescope's reaction control system fuel was depleted, and NASA announced its retirement in Oct 2018.

My impression is that it was a low-budget, technically poor in conception and objectives, carried out by a second division team, and hence unimpressive in results. For these reasons, it was poor thinking to put it in a heliocentric (Legrange point) orbit.

Transiting Exoplanet Survey Satellite (TESS)

Transiting Exoplanet Survey Satellite (TESS, Explorer 95 or MIDEX-7) was a space telescope of NASA's Explorer programme designed to search for exoplanets using the transit method, in an area 400 times larger than that covered by the Kepler. It was launched in Apr April 2018, and was placed into a highly elliptical 13.70-day Earth orbit.

The primary mission objective for TESS was to survey the brightest stars near the Earth for transiting exoplanets. Over the course of the two-year primary mission, TESS was expected to ultimately detect about 1,250 transiting exoplanets orbiting the targeted stars, and an additional 13,000 transiting planets orbiting additional stars in the fields that TESS would observe.

As of 16 October 2022, TESS had identified 5,931 candidate exoplanets, of which only 266 had been confirmed. After the end of the primary mission around 4 July 2020, data from the primary mission for planets continues to be searched, while the extended mission continues to acquire additional data.

On 18 July 2019, after the first year of operation, the southern portion of the survey was completed, and the northern survey was started. The primary mission ended with the completion of the northern survey on 4 July 2020. The spacecraft is now in an extended mission.

The sole instrument on TESS is a package of four wide-field-view charge-coupled device (CCD) cameras. Each camera features four low-noise, low-power 4 megapixel CCDs.The four CCDs are arranged in a 2 x 2 detector array for a total of 16 megapixels per camera, an and 16 CCDs for the entire instrument. Each camera has a 24° × 24° field-of-view, a 100 mm (3.9 in) effective pupil diameter, a lens assembly with seven optical elements, and a bandpass range of 600 to 1000 nm.

The TESS satellite uses this array of wide-field cameras to perform a survey of 85% of the sky. With TESS, it is possible to study the mass, size, density and orbit of a large cohort of small planets, including a sample of rocky planets in the habitable zones of their host stars.

TESS provides prime targets for further characterisation by the James Webb Space Telescope (JWST), as well as other large ground-based and space-based telescopes of the future.

While previous sky surveys with ground-based telescopes have mainly detected giant exoplanets and the Kepler mostly found planets around distant stars too faint for characterisation, TESS finds many small planets around the nearest stars in the sky. TESS records the nearest and brightest Main Sequence Stars hosting transiting exoplanets.

TESS uses a novel highly elliptical orbit around the Earth with an apogee approximately at the distance of the Moon and a perigee of 108,000 km (67,000 mi). TESS orbits Earth twice during the time the Moon orbits once. The orbit is expected to remain stable for a minimum of ten years.

TESS is designed to carry out the first spaceborne all-sky transiting exoplanet survey. It is equipped with four wide-angle telescopes and associated CCD) detectors. Science data are transmitted to Earth every two weeks. Full-frame images with an effective exposure time of two hours are transmitted as well, enabling scientists to search for unexpected, transient phenomena, such as the optical counterparts to gamma-ray bursts.

On 17 May 2018, the spacecraft underwent a gravity assist by the Moon at 8,253.5 km (5,128.5 mi) above the surface, and performed the final period adjustment burn on 30 May 2018. It achieved an orbital period of 13.65 days in the desired 2:1 resonance with the Moon, at 90° phase offset to the Moon at apogee, which is expected to be a stable orbit for at least 20 years, thus requiring very little fuel to maintain.

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(A) Infrared Astronomy

Infrared (IR)

The infrared (IR) component of the electromagnetic spectrum is also called radiant heat. All objects give off infrared radiation. The radiation comes from the thermal motion of molecules. The warmer an object is, the more infrared radiation it emits. An object that absorbs more infrared radiation than it releases becomes warm

The wavelength range for infrared is taken to extend from the nominal red edge of the visible spectrum at 700 nanometres (nm) to 1 millimetre (mm). This range of wavelengths corresponds to a frequency range of approximately 430 THz down to 300 GHz.

The detection and analysis of infrared radiation, that is wavelengths longer than red light and outside the range of our vision, is useful for studying objects that are too cold to radiate visible light, such as planets, circumstellar disks, or nebulae whose light is blocked by dust.

Their IR radiation can penetrate clouds of dust that block visible light to reach us, allowing the observation of young stars embedded in molecular clouds in their host star-clusters, as well as the cores of galaxies. Some molecules radiate strongly in the infrared. This allows the study of the chemistry of space; more specifically it can detect water in comets.

As infrared radiation is heavily absorbed by the atmosphere or masked, as the atmosphere itself produces significant infrared emission, observatories have to be located in high, dry places on Earth or in space.

In 1800, William Herschel discovered infrared radiation. He did so with a simple experiment in which he dispersed sunlight through a prism and placed a thermometer at the location of each colour.

In 1878, Samuel Pierpoint Langley created the first bolometer, an instrument that could electrically detect incredibly small changes in temperature in the infrared spectrum. In the 1950s, scientists used lead-sulphide detectors to detect the infrared radiation from space.

Between 1959 and 1961, Harold Johnson created a near-infrared photometer, which allowed scientists to measure thousands of stars. In 1961, Frank Low invented the first germanium bolometer. This invention led the way for current infrared telescope development.

Infrared telescopes may be ground-based, air-borne, or space based. They contain an infrared camera with a special solid-state infrared detector. The uniqueness (and problem) of an infrared detector is that it must be **cooled to cryogenic** temperatures to operate.

Ground-based telescopes have limitations because water vapour in the atmosphere absorbs infrared radiation. Ground-based infrared telescopes therefore tend to be placed on high mountains and in very dry climates.

In the 1960s, scientists used balloons to lift infrared telescopes to higher altitudes. In 1967, infrared telescopes were placed on rockets. These were the first air-borne infrared telescopes. Since then, aircraft have been adapted to carry infrared telescopes. Placing infrared telescopes in space completely eliminates the interference from the Earth's atmosphere.

Infrared Space Observatories of Note

Two-Micron All-Sky Survey (2MASS)

The Two Micron All-Sky Survey, or 2MASS, was an ground-based survey of the whole sky in infrared light. It is included here to show the complementary importance of ground survey work alongside satellite studies. It took place between 1997 and 2001, from two different high altitude locations, in Arizona and in Chile, each using a 1.3-metre telescope for the Northern and Southern Hemisphere respectively and conducted across three distinct frequeny bands.

2MASS produced an astronomical catalogue with over 300 million observed objects, from minor planets of the Solar System to low-mass stars , star clusters and galaxies. In addition, 1 million objects were catalogued in a 2MASS Extended Source Catalogue (2MASX) survey.

Infrared Astronomical Satellite (IRAS)

One of the most significant infrared projects was the Infrared Astronomical Satellite (IRAS) launched in 1983, a satellite telescope joint-project of space agencies from the US, Netherlands and UK . its mission lasted ten months.

IRAS was the first observatory to perform an all-sky survey at infrared wavelengths. It mapped 96% of the sky four times at differing wavelengths. It discovered about 350,000 sources, many of which are still awaiting identification.

About 75,000 of those are believed to be starburst galaxies still in their star formation stage. Many other sources were normal stars with disks of dust around them, possibly the early stage planetary systems, New discoveries included a dust disk around Vega, and the first images of the Milky Way’s core.

IRAS's life, like that of most infrared satellites that followed, was limited by its cooling system. The on-board supply of liquid helium was depleted after 10 months causing the telescope temperature to rise and preventing further observations. The spacecraft continued to orbit the Earth.

SPITZER Space Telescope

The Spitzer Space Telescope was the fourth of the four flagship space telescope launches under NASA’s Great Observatories series in 1999-2003,

The Spitzer Space Telescope, launched by NASA in 2003, was the third space telescope dedicated to infrared astronomy. It carried an Infrared Array Camera (IRAC), which operated simultaneously on four wavelengths, an Infrared Spectrograph (IRS), an infrared spectrometer with four sub-modules, and a Multiband Imaging Photometer for Spitzer (MIPS), three detector arrays in the mid- to far-infrared range. At its launch in 2003, NASA's Spitzer Space Telescope was the most sensitive infrared space telescope in history.

It was the first spacecraft to use an Earth-trailing orbit, ie heliocentric orbit, later used by the Kepler planet-finder. The planned mission was five or slightly more years until the onboard liquid helium supply was exhausted – which occurred in 2009. However, the two shortest-wavelength modules of the Infrared Array Camera (IRAC) continued to operate on a “warm mission” into early 2020.

Its 16-year lifetime revolutionised our view of the cosmos. Spitzer made discoveries from inside our solar system to nearly the edge of the universe.

In Jun 2008, scientists unveiled the largest, most detailed infrared portrait of the Milky Way, created by stitching together more than 800,000 snapshots taken from the Spitzer.

In its 16 years of operation, Spitzer discovered among other things a giant ring of Saturn, revealed a system of seven Earth-size planets around a star 40 light-years away, and studied the most distant known galaxies. In March 2016, Spitzer and Hubble were used to discover the most distant-known galaxy, GN-z211. This object was seen as it appeared 13.4 billion years ago

Herschel Space Observatory

The Herschel Space Observatory was built and operated by the European Space Agency (ESA). It was active from 2009 to 2013, and was the largest infrared until the launch of the James Webb Telescope in 2021.

This observatory was also placed In a halo orbit at the Lagrange Point 2 (L2) of the Earth-Sun System, 1,500,000 kilometres (930,000 mi) from Earth.

Herschel carried a 3.5-metre (11.5 ft) mirror and instruments sensitive up to the submillimetre wavebands,(55–672 μm

The observatory was capable of seeing the coldest and dustiest objects in space; for example, cool cocoons where stars form and dusty galaxies just starting to bulk up with new stars. The observatory sifted through star-forming clouds—the "slow cookers" of star ingredients—to trace the path by which potentially life-forming molecules, such as water, form.

The Rosetta Nebula region of our Milky Way galaxy was observed in three infrared wavelength ranges. Stars were seen forming in large numbers, sending out shock waves into their turbulent surroundings lit up by heated dust grains emitting infrared radiation.

The telescope continued to operate until Apr 2013, when Herschel ran out of coolant.

WISE

NASA presently also has an infrared satellite telescope called the Wide-field Infrared Survey Explorer (WISE). It was launched in Dec 2009, and placed in hibernation in 2011, before being re-activated in 2013 and renamed the Neo-Earth Orbit Wide-field Infrared Survey Explorer (NEOWISE).

WISE also performed an all-sky astronomical survey capturing images across multiple infrared wavebands, over ten months using a 40 cm (16 in) diameter telescope in Earth orbit.

After its coolant depleted, a four-month mission extension called NEOWISE was conducted to search for near-Earth objects.

In Aug 2013, NASA announced it would reactivate the WISE telescope for a new three-year mission to search for asteroids that could collide with In Jul 2021, NASA extended the NEOWISE mission until at least Jun 2023.

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(B) Ultraviolet Astronomy

The ultraviolet universe looks quite different from the familiar sky. Most stars are relatively cool objects emitting much of their electromagnetic radiation in the visible or near-infrared part of the spectrum. Ultraviolet radiation is the signature of hotter objects, typically in the early and late stages of their evolution.   In the Earth's sky seen in ultraviolet light, most stars would fade in prominence. Some very young massive stars and some very old stars and galaxies, growing hotter and producing higher-energy radiation near their birth or death, would be visible. Clouds of gas and dust would block the vision in many directions along the Milky Way[87].

Ultraviolet (UV) waves operate in the range from 0.40 μm down to 1 nm. UV light at those wavelengths is absorbed by the Earth's atmosphere, requiring observations at these wavelengths to be performed from the upper atmosphere or from space.

UV Spectroscopy

In astronomy, the main advantage of UV, compared to the optical or infrared or X-ray, lies in spectroscopy. **UV spectroscopy enables the study of the elements** through their absorption lines on spectrographs. Except for a very few elements (e.g., sodium, calcium, potassium , and ionised calcium), all other atoms transition (start to radiate) in the UV wavelengths when in their ground state. All the fundamental atoms in the universe (hydrogen, carbon, oxygen, nitrogen) are in their ground state.

In the atmospheres of stars, however, the densities are high, and likewise the rates of collision among atoms. They become substances in “higher” excited states. For the most part these atoms make their transitions in the visible spectrum. For this reason, stellar spectra have a rich selection of lines that can be visually observed from the ground. But the atmosphere of Earth is opaque to UV. The incoming ultraviolet light interacts strongly with the atmosphere, is mostly absorbed, and cannot get from space to the ground.

In interstellar (or intergalactic) medium (ISM), on the other hand, atoms largely exist in their ground states. Collisions with other atoms are very infrequent. They are accordingly visible in UV. It means that, once into space, it becomes possible to see all those atoms and really understand the **physics of matter**. Most of the universe is in fact in the ultraviolet. As far as molecular physics goes, the key molecule seen in the UV is **molecular hydrogen**, generally considered to be the basis for all interstellar molecular chemistry.

In addition, other galactic and extragalactic objects and features evince (very bright) UV radiation in characteristic moments of their life cycles. Study of these phenomena (from the remotest past) opens the **cosmological book** to the origins of galaxies and the universe.

There has been a long history of ultraviolet spectroscopes put into space following the early successes with rockets and balloons but not many ultraviolet imagers.

[87] https://en.wikipedia.org/wiki/Ultraviolet_astronomy

UV Objectives

UV astronomy is best suited to the study of thermal radiation and spectral emission lines[88] from young hot blue stars. These stars are hot, massive stars of spectral types O or early-type B that form in loosely organised groups called OB associations. They are short lived, and thus do not move very far from where they formed. During their lifetime, they emit much ultraviolet radiation, which rapidly ionises the surrounding interstellar gas of the molecular cloud in the H II region[89] in which the stars are formed.

O-type stars are very hot and extremely luminous, with most of their radiated output in the UV range. These are the rarest of all main-sequence stars. Only about 1 in 3,000,000 (0.00003%) of the main-sequence stars are O-type stars. B-type stars are also very luminous and blue

Ultraviolet (UV) line spectrum measurements are used in spectroscopy to study both the temperature and composition of these hot young stars and to discern the chemical composition, densities, and temperatures of the interstellar medium. These observations provide critical information about the evolution of galaxies.

The H II regions may be of any shape, because the distribution of the stars and gas inside them is irregular. Some are several hundred light-years across, and are associated with giant molecular clouds. H II regions may give birth to thousands of stars over a period of several million years. In the end, supernova explosions and strong stellar winds will disperse the gases of the H II region, leaving behind a cluster of stars which have formed.

Spiral and irregular galaxies contain many H II regions, while elliptical galaxies are almost devoid of them. In spiral galaxies, including our Milky Way, H II regions are concentrated in the spiral arms, while in irregular galaxies they are distributed chaotically.

Other objects commonly observed in ultraviolet light include planetary nebulae, and supernova remnants, and active galactic nuclei. However, as ultraviolet light is easily absorbed by interstellar dust, ultraviolet measurements must be adjusted.

Lastly, the study of the Sun, the Solar System and their impact on our day to day lives has been, must be, and always will be the prime consideration of astronomy. Although 95% of it is filtered off by the ozone layer, what gets to us remains dominant factor of life on this planet.

UV exploration

Ultraviolet (UV) light was discovered in 1801 by Johann Wilhelm Ritter (776-1810), a German chemist and philosopher. He noticed that invisible light beyond the optical region of the electromagnetic spectrum darkened silver chloride. He split sunlight using a prism and then measured the relative darkening of the chemical as a function of wavelength. Man-made UV went on to have an extensive history of applications in medicine, forensics, public health, war and day to day life.

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[88] A spectral line is a dark or bright line in an otherwise uniform and continuous spectrum, resulting from emission or absorption of light in a narrow frequency range, compared with the nearby frequencies. Spectral lines are often used to identify atoms and molecules. These "fingerprints" can be compared to the previously collected ones, and are thus used to identify the atomic and molecular components of strs and planets, which would otherwise be impossible.

[89] The H II region is a region within a galaxy, of interstellar atomic hydrogen, in which stars are born,

After the second world war, interest in understanding space resulted in the use of instrumentation-borne sounding rockets. One of the most robust, versatile, and cost-effective flight programmes at NASA, for over 40 years, the Sounding Rocket Programme has provided critical scientific technical, and educational contributions and is still being used. The first moderate-resolution UV spectra of stars were obtained with small spectrographs flown on sounding rockets, and before it was known how to successfully make pointing and control systems operate in the space environment.

Copernicus

Initially known as Orbiting Astronomical Observatory (OAO) C, it became OAO 3 once in orbit. It was also renamed Copernicus. It was launched in 1973.

Fitted with the largest ultraviolet telescope ever orbited to date as well as four co-aligned X-ray instruments, Copernicus was arguably NASA's first dedicated multiwavelength astronomy observatory. Learning to point and hold an orbiting telescope on a star long enough for the detectors to capture its light proved much more difficult than expected. Copernicus flew with a new inertial reference unit (IRU). The primary instrument aboard Copernicus was the Princeton Experiment Package, which captured UV light using a 32-inch (0.8 meter) mirror about a third the size of Hubble's.

Copernicus returned UV and X-ray observations for 8.5 years before its retirement in 1981, and it still orbits Earth today. Its instruments studied some 450 unique objects.

International Ultraviolet Explorer (IUE)

The International Ultraviolet Explorer (IUE) or Explorer 57, formerly SAS-D), was the first space observatory primarily designed for UV. Launched in 1978, the satellite was a collaborative project between NASA, ESA and the United Kingdom.

The mission lifetime was initially set for 3 years, but in the end it lasted 18 years, with the satellite being shut down in 1996. The switch-off occurred for financial reasons, while still functioning at near original efficiency.

It was the first space observatory to be operated in real time by astronomers who visited the ground stations. Astronomers made over 104,000 observations using the IUE, of objects ranging from Solar System to distant quasars. Among the significant scientific results from IUE data were the first large scale studies of stellar winds.When the mission ended, it was considered the most successful astronomical satellite eve.

The IUE was fired it into its planned geosynchronous orbit. The orbit was inclined by 28.6° to the Earth's equator, and the satellite's distance from Earth varied between 25,669 km (15,950 mi) and 45,887 km (28,513 mi). It was centred at a longitude of approximately 70° West.

Far Ultraviolet Spectroscopic Explorer (FUSE)

The Far Ultraviolet Spectroscopic Explorer (FUSE, Explorer 77, and MIDEX-0) represented NASA' next generation, high-orbit, ultraviolet space observatory covering the wavelength range of 90.5–119.5 nm. It was launch in 1999 and resides in in low Earth orbit.

FUSE detected light in the far UV spectrum which was mostly unobservable by other telescopes. Its primary mission was to characterise universal **deuterium,** an isotope of

hydrogen, in an effort to learn about the stellar processing times of deuterium left over from the Big Bang.
The FUSE observatory was designed for an operational lifetime of three years, although it was hoped that it might remain operational for as long as ten years. It stopped functioning in 2007.

The satellite had to operate on its own most of the time, moving from target to target, identifying star fields, cantering objects in the spectrograph apertures, and performing the observations. The scientific data, which was stored in digital form, was radioed to the ground during contact with the ground station.

Because of the large number of atomic absorption and emission lines in the far-ultraviolet, FUSE enabled many studies of galactic, extragalactic, and intergalactic chemistry and chemical evolution.

Extreme Ultraviolet Explorer (EUVE)

The Extreme Ultraviolet Explorer (EUVE or Explorer 67) was a NASA space telescope, a part of the Explorer series, launched in June1992. With instruments for UV radiation between 7 and 76 nm, the EUVE was the first satellite mission especially for the short-wave ultraviolet range. The satellite compiled an all-sky survey of 801 astronomical targets before being decommissioned in Jan 2001.

Galaxy Evolution Explorer (GALEX)

Galaxy Evolution Explorer (GALEX or Explorer 83 or SMEX-7) was a NASA orbiting space UV telescope launched I Apr 2003, designed to measure the history of star formation. The space telescope allowed astronomers to uncover mysteries about the early universe and how it evolved, as well as better characterise phenomena like dark matter and black holes.

The mission was extended three times over a period of 10 years before it was decommissioned in Jun 2013.

The Galaxy Evolution Explorer (GALEX) explored the origin and evolution of galaxies, and the origins of stars and heavy elements over the redshift range of Z between 0 and 2.

GALEX conducted an all-sky imaging survey, a deep imaging survey, and a survey of 200 galaxies nearest to the Milky Way. As well, GALEX performed three spectroscopic surveys over the 135-300 nm band.

Solar Dynamics Observatory (SDO)

The space-based Solar Dynamics Observatory (SDO), a NASA mission observing the Sun since 2010 also has a UV telescope, which provides continuous full-disk observations of the solar chromosphere and corona in seven extreme UV channels over a range of solar temperatures.

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(C) X-ray Astronomy

X-ray emits radiation at the ultra-short wave range of 1nm to 1 pm (picometre 1×10^{-12} m). As X-ray radiation is absorbed by the Earth’s atmosphere, instruments to detect X-rays must be taken to high altitude by balloons, sounding rockets[90], and satellites. X-ray cannot be detected with an optical telescope; but with an X-ray telescope.

Typically, X-ray radiation is produced by synchrotron emission (the result of electrons orbiting magnetic field lines.) X-ray is also produced from astronomical objects that contain extremely hot gases at temperatures from about a million kelvin (K) to hundreds of millions of kelvin (MK).

The layer of ionized gas high in the Earth's thermosphere[91] suggests a strong extra-terrestrial source of X-rays. Although theory predicted that the Sun and the stars would be prominent X-ray sources, there was no way to verify this because Earth's atmosphere blocked most extra-terrestrial X-rays. Since the vast majority of X-rays are not detectable from Earth, space-based telescopes were required to make these observations.

Sources of X-ray

The first cosmic (beyond the Solar System) X-ray source was discovered by a sounding rocket in 1962 in the constellation Scorpius. The X-ray emission of Scorpius X-1 was 10,000 times greater than its visual emission, whereas that of the Sun is about a million times less. Additional flights uncovered more cosmic sources, including Cygnus X-1, long suspected and now known to host a stellar-mass black-hole. Many thousands of X-ray sources have since been discovered.

The inter-stellar medium (or ISM) is the gas and cosmic dust that pervade interstellar space: the matter that exists between the star systems within a galaxy. It fills interstellar space and blends smoothly into the surrounding intergalactic medium. The interstellar medium consists of an extremely dilute (by terrestrial standards) mixture of ions, atoms, molecules larger dust grains, cosmic rays and (galactic) magnetic fields. The energy that occupies the same space volume, in the form of electromagnetic radiation, is the interstellar radiation (ER) field.

Of interest is the hot ionised medium (HIM) consisting of a coronal cloud ejection from star surfaces at 106-107 K, which emits X-rays. Stars are born deep inside in molecular clouds, typically a few parsecs in size. During their lives and deaths, the stars interact physically with the ISM. Stellar winds from young clusters of stars, as well as supernova shockwaves, inject enormous amounts of energy into their surroundings, which lead to hypersonic turbulence. The resultants are stellar wind bubbles and super-bubbles of hot gas. The Sun is currently traveling through the Local Interstellar Cloud, a denser region in the low-density Local Bubble.

In addition, intergalactic spaces, between galaxies and galactic clusters, have also been found to be filled with a hot, but very dilute gas, at a temperature between 100 and 1000 Megakelvins (MK). The total amount of hot gas is five to ten times the total mass in the visible galaxies.

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[90] Sounding rockets were rockets sent up on a one-way trip of short duration with instruments to capture specific information, usually using war surplus stock.

[91] The **thermosphere** is the layer in the Earth's atmosphere directly above the mesophere and below the exosphere. Within this layer of the atmosphere, UV radiation causes photoionisatioin/photoassociation of the molecules, creating ions. The thermosphere thus constitutes the larger part of the ionosphere. The thermosphere is uninhabited with the exception of the International Space Station, which orbits the Earth within the middle of the thermosphere between 408 and 410 kilometres (254 and 255 mi) and the Tiangong space station, which orbits between 340 and 450 kilometres (210 and 280 mi).

Discovery of X-ray

W.C. Röntgen (1845-1923), a German mechanical engineer and physicist, reported the discovery of X-rays in 1895, and won the inaugural Nobel Prize for it. He named them X-rays to underline the fact that their nature was unknown.

It was not until ways of sending instrument packages to high altitude were developed that these X-ray sources could be studied

The first sounding rocket flights for X-ray research were accomplished with a V-2 in Jan 1949. X-rays from the Sun were detected.

An Aerobee150 rocket launched on Jun 1962 detected the first X-rays emitted from a source outside our solar system (Scorpius X-1). It is now known that such X-ray sources are compat stars, such as neutron stars or black-holes. Material falling into a black hole may emit X-rays, but the black hole itself does not. The energy source for the X-ray emission is gravity. Infalling gas and dust is heated by the strong gravitational fields. .

Some X-Ray Satellites of Note

X-Ray Explorer Satellite (Uhuru)

Uhuru was the first satellite launched specifically for the purpose of X-ray astronomy. It was also known as the X-ray Explorer Satellite, SAS-A (for Small Astronomy Satellite A, being first of the three-spacecraft SAS series), SAS 1, It was launched in Dec 1970 into low Earth orbit and the mission ended in Mar 1973. Uhuru was a scanning mission, with a spin period of 12 minutes, and performed the first comprehensive survey of the entire sky for X-sources..

The main objectives of the mission were to survey the sky for cosmic X-ray sources, to study the structure of extended sources of complex regions and to determine gross spectral features and variability of X-ray sources.

Uhuru mapped more than 300 sources, showed that many are neutron stars or black holes fuelled by gas streaming from stellar companions, and discovered X-rays from the hot gas in galaxy clusters.

Uhuru achieved several outstanding scientific advances, including the discovery and detailed study of pulsing accretion-powered binary X-ray sources, the identification of Cygnus X-1, the first strong candidate for an astrophysical black-hole.

The Uhuru Catalogue was issued in four successive versions, the last being the 4U catalogue, the first comprehensive X-ray catalogue contains 339 objects and covers the whole sky.

Chandra X-ray Observatory (CXO)

On July 23, 1999, the Chandra X-ray Observatory (CXO) was launched into orbit aboard the Space Shuttle Columbia. Chandra was a flagship class satellite, one of NASA's four "Great Observatories," along with the Hubble Space Telescope, the Spitzer Space Telescope, and the Compton Gamma Ray Observatory. Chandra is in a 64-hour Earth satellite orbit, and its mission is ongoing as of 2022. Its mission is similar to that of ESA’s XMN-Newton spacecraft, also launched in 1999, but the two telescopes have different design foci. Chandra has much higher angular resolution

Chandra consists of four pairs of mirrors and their support structure. X-ray telescopes must be very different from optical telescopes. Because of their high-energy, X-ray photons penetrate into a mirror much as bullets slam into a wall, requiring they be polished and ground to the smoothness of a few atoms and aligned parallel to incoming X-rays – or they will ricochet. The incoming X-rays are focused by the mirrors to a tiny spot (about half as wide as a human hair) on the focal plane, about 30 feet away. The two focal plane science instruments (ACIS and HRC), are well matched to capture the sharp images formed by the mirrors and to provide information about the incoming X-rays: their number, position, energy and time of arrival.

Two additional science instruments provide detailed information about the X-ray energy, the LETG and HETG spectrometers. These are grating arrays which can be flipped into the path of the X-rays just behind the mirrors, where they redirect (diffract) the X-rays according to their energy.

The X-ray position is measured by HRC or ACIS , so that the exact energy can be determined. The science instruments have complementary capabilities to record and analyse X-ray images of celestial objects and probe their physical conditions with unprecedented accuracy.

Chandra is sensitive to X-ray sources 100 times fainter than any previous one, enabled by the high angular resolution of its mirrors. It's equipment include these features: a High Resolution Camera (HRC), an Advanced CCD Imaging Spectrometer, a High Energy Transmission Grating Spectrometer and a Low Energy Transmission Grating Spectrometer.

The data gathered by Chandra has greatly advanced the field of X-ray astronomy. Some random examples typify the range of its contributions:

. – The first glimpse of the centre of a supernova remnant, probably a neutron star or black hole. (2000)

.- The first X-ray emission seen from the super-massive black hole, Sagittarius A, at centre of the Milky Way (2001)

.- The first time seen in Perseus A the shadow of a small galaxy as it is being cannibalised by a larger one

.- data suggesting that stars previously thought to be pulsars, might be even denser objects: **quark stars**. These results are still debated.

.- The Hubble constant was measured to be 76.9 km/s/Mpc

.- There was strong evidence that dark matter exists by observing super cluster collision.

.- A large halo of hot gas was found surrounding the Milky Way.

In September 2016, it was announced that Chandra had detected X-ray emissions from Pluto, the first detection of X-rays from a Kuiper belt object.

In 2020, Chandra reportedly may have made an observation of an exoplanet in the Whirlpool Galaxy, which would be the first such planet discovered beyond the Milky Way

In April 2021, NASA announced findings from the observatory in a tweet saying "Uranus gives off X-rays, astronomers find".

Copernicus

The three X-ray telescopes aboard Copernicus experienced significant challenges in its shutters. In Jun 1973, scientists sent a final command made it through – and the sticky shutter stuck closed, blinding the instruments.

A fourth detector unattached to a telescope continued working for the duration of the mission. This X-ray counter measured radiation from 1 to 3 angstroms over a wide field of view — 2.5 by 3.5 degrees, about 40 times the apparent area of a full Moon.

Copernicus performed long-term monitoring of other pulsars and bright sources, and observed Nova Cygni in 1975, an explosion on the white dwarf in a close binary system. The experiment discovered curious dips in X-ray absorption at Cygnus X-1, likely caused by cool, dense clumps in the gas flowing away from the star.

And the satellite recorded varying X-rays from the black-hole powered galaxy Centaurus A , located about 12 million light-years away.

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XMM-Newton space observatory

In June 2021, one of the largest X-ray surveys using the European Space Agency's XMM-Newton space observatory published initial findings, mapping the growth of 12,000 supermassive black holes at the cores of galaxies and galaxy clusters

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(D). Gamma-ray Astronomy

Gamma-rays emit radiation at the shortest wave length of the ER spectrum, of less than 1 pm (picometre) (1x10-12). As Gamma-ray radiation is absorbed by the Earth's atmosphere, instruments must be taken to high altitude by balloons, sounding rockets, and satellites.

Most gamma-ray emissions are **gamma-ray bursts** (GRBs), observed in distant galaxies, from objects which only produce gamma radiation for a few milliseconds to some hours before fading away. Most observed GRBs are thought to be released during a supernova or super-luminous supernova, as a high-mass star implodes to form a neutron star or a black hole.

Gamma-ray bursts are immensely energetic explosions. They are the most energetic and luminous electromagnetic events since the Big Bang. A typical burst releases as much energy in a few seconds as the Sun will in its entire 10-billion-year lifetime. Bursts typically produce photon energies above 100 keV. Radiation below 100 keV is classified as X-rays or other.

The mechanisms emitting gamma rays are diverse, mostly identical with those emitting X-rays but at higher energies. They include electron-positron annihilation, and in some cases the decay of radioactive material, reflecting matter under extreme primal (and terminal) conditions - in fact the very phenomena QM scientists are probing to penetrate the origins of matter in our accelerators.

The sources of most GRBs are billions of light-years away, implying that the explosions are both extremely energetic and extremely rare (a few per galaxy per million years). After an initial flash of gamma-rays, a longer-lived "afterglow" is usually emitted at longer wavelengths from X-ray to radio waves.

Only 10% of gamma-ray sources are non-transient sources. These steady gamma-ray emitters include pulsars, neutron stars and black hole candidates such as active galactic nuclei.

A subclass of GRBs (the "short" bursts) appear to originate from the merger of binary neutron stars. The cause some of these short events may be the development of a resonance between the crust and core of such stars, as a result of the massive tidal forces experienced in the seconds leading up to their collision, causing the entire crust of the star to shatter.

All observed full-blooded GRBs have originated from **outside the Milky Way galaxy**. It has been hypothesised that a gamma-ray burst in the Milky Way, pointing directly towards the Earth, could cause a mass extinction event.

There is however a related class of phenomena within the Milky Way, soft gamma repeater flares, which are associated with magnetars. Like neutron stars, magnetars are around only 20 km (12 mi) in diameter, but have a mass about 1.4 solar masses. They are formed by the collapse of a star with a mass 10–25 times that of the Sun. Magnetars are differentiated from neutron stars by having even stronger magnetic fields, and by their rotating more slowly in comparison. A magnetar's magnetic field gives rise to very strong and characteristic bursts of X-rays and gamma rays. The active life of a magnetar is short compared to other celestial bodies.

Discovery of Gamma-rays

Scientists had known theoretically that the universe should be producing gamma-rays. However, it was not until the 1960s that our ability to actually detect these emissions came to pass.

The first gamma-ray telescope carried into orbit, on the Explorer 11 satellite in 1961, picked up fewer than 100 cosmic gamma-ray photons. They appeared to come from all directions in the Universe, implying some sort of uniform "gamma-ray background". Such a background would be expected from the interaction of cosmic rays (very energetic charged particles in space) with interstellar gas. Gamma-rays were detected in 1967 by the (Vela) satellites designed to detect covert nuclear weapons tests. Little information was available to verify them.

Not surprisingly, the study of sporadic radiation from the Earth’s solar flares generated in the MeV range was among the first streams now classified as gamma rays . The gamma-ray line observations were from NASA’s OSO 3 (Orbiting Solar Observatory 3), 1968-69, and later the OSO 7 (1971-74) and in the Solar Maximum Mission (1980-89). It was found that a solar flare created massive amounts of radiation across the electromagnetic spectrum, including gamma-rays. Gamma-ray emission from our galaxy (the Milky Way) was also first detected by the OSO3 satellite, some 621 detected events attributable to cosmic gamma rays.

Gamma-ray astronomy took a leap forward with NASA’s the Small Astronomy Satellite 2 (SAS 2) (1972-79) and the COS-B satellite, the first European Space Research Organisation (ESRO) mission to study cosmic and gamma-ray sources. These two satellites provided an exciting view into the high-energy universe (sometimes called the 'violent' universe), that produced gamma rays. They confirmed the earlier findings of the gamma-ray background, produced the first detailed map of the sky at gamma-ray wavelengths, and detected a number of point sources. However the resolution of the instruments was insufficient to identify most of the point sources with specific visible stars or stellar systems.

Some Gamma-ray Satellites of Note

Compton Gamma Ray Observatory (CGRO)

The Compton Gamma Ray Observatory (CGRO) was a satellite space observatory in low Earth orbit from 1991 to 2000. CGRO was the second of the four projects in NASA's "Great Observatories" programme to be launched, after Hubble.

The first mission in the programme was the Hubble Space Telescope launched in 1990. Compton was followed by the Chandra X-ray Observatory in 1999 and the infrared-sensitive Spitzer Space Telescope in 2003. All of them have remained operational except Compton, which was deliberately de-orbited in 2000 following the failure of one of its gyroscopes.

CGRO was an international collaboration, and additional contributions came from the European Space Agency (ESA), various universities, and the US Naval Research Laboratory.

At the time, the 17-ton observatory was the heaviest astrophysical payload ever flown, a record not broken until the launch of NASA's Chandra X-ray Observatory and its propulsion stage in 1999

The observatory featured four main telescopes in one spacecraft, covering the entire electromagnetic spectrum. It included an Imaging Atmospheric (or Air) Cherenkov Telescope or Technique (IACT) (see further below).

Compton's many findings included the discovery of a new class of galaxies powered by supermassive black holes, the surprising detection of gamma rays from thunderstorms on Earth, and the most persuasive evidence to date that gamma-ray bursts (GRBs) were the most distant and powerful explosions in the cosmos.

It was quickly evident GRBs were distributed all over the sky instead of in a pattern reflecting the structure of our Milky Way galaxy, strongly suggesting the bursts were originating far beyond our cosmic neighbourhood. Proof of this came in 1997 when ground-based observatories were able to rapidly perform follow-up studies of GRBs seen by the Italian-Dutch satellite BeppoSAX. These bursts were extraordinary explosions located millions to billions of light-years away, usually a result of the deaths of massive stars or mergers of neutron stars and black holes.

Its scientific legacy continues with the Fermi, Swift and other space observatories exploring the universe's highest-energy light and the extreme phenomena producing it.

International Gamma-Ray Astrophysics Laboratory (INTEGRAL)

Successors to CGRO include the ESA's International Gamma-Ray Astrophysics Laboratory (INTEGRAL). It was launched by the ESA into Earth orbit in 2002, and achieved a 3-day elliptical Earth orbit with an apogee of nearly 160,000 km and a perigee of above 2,000 km, hence mostly beyond radiation belts which would otherwise lead to high instrumental backgrounds from charged-particle activation.

It was designed to provide imaging and spectroscopy of gamma-rays from cosmic sources In the MeV energy range. Photons in INTEGRAL's energy range are emitted by relativistic and supra-particles in violent sources, radioactivity from unstable isotopes produced during nucleosynthesis. and from X-ray binaries.

The spacecraft's instruments have very wide fields of view, which is particularly useful for detecting gamma-ray emission from transient sources as they can continuously monitor large parts of the sky.

As of October 2021, INTEGRAL continues to operate despite the loss of its thrusters through the use of its reaction wheels and solar radiation pressure.

INTEGRAL has far exceeded its 2+3-year planned lifetime, and is set to enter Earth atmosphere in 2029 as a definite end of the mission.

Neil Gehrels Swift Observatory (Swift Gamma-Ray Burst Explorer)

NASA's Swift Gamma-Ray Burst Explorer, a three-telescope space satellite for GRBs and monitoring the afterglow in X-ray, and UV/Visible light at the location of a burst was launched in Nov 2004 in low Earth orbit.

Swift discovered approximately 100 bursts per year. The Burst Alert Telescope detects GRBs and accurately determines their positions on the sky. Swift then relays a 3 arcminute position estimate to the ground within 20 seconds of the initial detection

Neil Gehrels Swift Observatory, previously called the Swift Gamma-Ray Burst Explorer, was developed in a joint partnership by an international consortium from the United States, United Kingdom, and Italy

Swift had a burst detection sensitivity 3 times fainter than the BATSE detector aboard the Compton and was launched with a nominal on-orbit lifetime of two years. Swift was operated as part of NASA's Medium Explorer Program (MDEX). It was the third to be launched, following IMAGE (2000), the first spacecraft dedicated to imaging the Earth's magnetosphere and WINAPS (2001), the first to study the microwave background..
While originally designed for the study of gamma-ray bursts, Swift now functions as a general-purpose multi-wavelength observatory, particularly for the rapid follow up and characterisation of astrophysical transients of all types. As of 2020, Swift received 5.5 Target of Opportunity observing proposals per day, and observes about 70 targets per day, on average

Fermi Gamma-ray Space Telescope (FGST)

NASA's Fermi Gamma-ray Space Telescope (FGST) , formerly called the Gamma-ray Large Area Space Telescope (GLAST), was launched into low Earth orbit in Jun 2008.

The mission was a joint venture of NASA and government agencies in France, Germany, Italy, Japan, and Sweden, becoming the most sensitive gamma-ray telescope on orbit, succeeding INTEGRAL .

Its main instrument was the Large Area Telescope (LAT) intended to perform an all-sky surveys, including active galactic nuclei, pulsars, other high-energy sources and dark matter.

The LAT is an imaging gamma-ray detector which detects photons with energy from about 20 million to about 300 billion electronvolt (20 MeV to 300 GeV), with a field of view of about 20% of the sky; it may be thought of as a sequel to the EGRET instrument on the Compton.

Another instrument aboard Fermi, the Gamma-ray Burst Monitor (GBM; formerly GLAST Burst Monitor), was intended for study of gamma-ray bursts, and solar flares.

The GBM consists of 14 scintillation detectors for the 8 keV to 1 MeV range and with sensitivity from 150 keV to 30 MeV) and can detect gamma-ray bursts in that energy range across the whole of the sky not occluded by the Earth.

By peering at the cosmos from low Earth orbit, Fermi has detected the most powerful gamma-ray blast astronomers have ever seen: **a mysterious source glowing with more energy than 9,000 supernovas.** Fermi also discovered the first gamma-ray pulsar and gamma-ray "bubbles" around the Milky Way.

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Chapter Nine
Climbing Jacob's Ladder III

First Steps into Space

Moon

The nearest object in space, the Moon, became the common target of the US and the Soviet Union, the main protagonists, in the Cold War.

. - On 4 Oct 1957, the Soviet Union successfully launched the first artificial satellite, Sputnik 1, (23 inches diameter) into a low Earth orbit. It sent radio signals for 21 days, and decayed after three months.

. – On 12 Apr 1961, the Soviet Union successfully launched the spacecraft Vostok 1, with astronaut Yuri Gagarin aboard, making it the first human flight in space. The total flight was a single orbit of about 9 minutes. Gagarin ejected and landed by parachute in the last stage of the retrun. On August 6, 1961, Soviet cosmonaut Gherman Titov flew in orbit for a full day under the Vostok 2 programme.

. - On 5 May 1961, Alan Shepherd became the first American in (sub-orbital) space, as part of Project Mercury. On 30 Feb 1962, US astronaut John Glenn made three orbits around the Earth.

. – On 20 Jul 1969, Neil Armstrong and Buzz Aldrin became the first people to land on the Moon and walk on the lunar surface, under the Apollo 11 programme. They were followed by 10 others during 1969 -1972, under Apollo 12-17. Anther 12 astronauts orbited the Moon, during various stages. These were the first flights beyond the Earth's and into another orbit.

. – On 15 Oct 2003, the first Chinese taikonaut, Yang Liwei, went into space as part of Shenzhou 5 programme, the first Chinese human spaceflight.

As of 2021, humans had not travelled beyond low Earth orbit. since the Apollo 17 lunar mission in December 1972.

Saturn V

Saturn V was the super-lift launch vehicle developed by NASA under the Apollo programme for exploration of the Moon It was flown from 1967 to 1973. It was used for nine crewed flights to the Moon, and to launch Skylab, the first American space station.

Saturn V holds records for the heaviest payload launched and the largest payload capacity to low Earth orbit: 310,000 lb (140,000 kg), which included the third stage and unburned propellant needed to send the Apollo command and service module and the Lunar module to the Moon. As of 2022, the Saturn V remains the only launch vehicle to carry humans beyond low Earth orbit (LEO). The rocket is now retired.

Space Shuttle

The Space Shuttle programme, carried out by NASA aimed at creating a regular(reusable) Space Transportation System (STS). The shuttles operated from 1981 to 2011 and provided routine space station transportation for Earth-to-orbit crew and cargo, as well as launched satellites into space. It flew 135 missions and carried 355 astronauts from 16 countries, many on multiple trips. They were launched vertically by rocket.

The space shuttle was the only winged and crewed spacecraft built. It comprised an orbiter (space plane) launched with three rocket engines into low orbit, and equipped with two reusable boosters It carried up to eight astronauts and a payload of up to 50,000 lb (23,000 kg) When its mission was complete, the orbiter would re-enter the Earth's atmosphere and land like a glider. Each vehicle was designed with a projected lifespan of 100 launches, or 10 years' operational life.

Six orbiters were built for flight. They had a checked history and the programme was terminated in 2011, with a total casualty rate of 15 astronauts and four cosmonauts:

. – Enterprise (1977) was the first and the test vehicle and disassembled after completion of critical testing..
. - Columbia (1981) was the first space-worthy orbiter. In 2003, it disintegrated during e-entry on its 28th flight.
. – Challenger (1983) also disintegrated in 1986 73 seconds after its launch on its tenth mission.
. – Discovery (1984) flew 39 missions, and was NASA's "Return to Flight" vehicle, following the earlier accidental destructions. Discovery completed its last mission in 2011.
. – Atlantis (1985) flew 33 spaceflights including the final Space Shuttle mission in July 2011.
. – Endeavour (1992) flew 25 spaceflights, the final launched on May 16, 2011.

Commercial Space Transport Services

The Space Shuttle programme involved carrying large payloads to various orbits including the International Space Station (ISS), providing crew rotation for the space station, and performing service missions on the Hubble Space Telescope.

Since the Shuttle's retirement in 2011, many of its original duties are performed by an assortment of government and private vessels. By 2012, cargo to the International Space Station was already being delivered commercially under NASA's Commercial Resupply Services by SpaceX's partially reusable Dragonn spacecraft, followed by Orbital Sciences' Cygnus spacecraft in late 2013.

Crew service to the ISS is currently provided by the Russian Soyuz and, since 2020, by the SpaceX ‘s Dragon 2 crew capsule, launched on the company's reusable Falcon rocket , as part of NASA's Commercial Crew Development programme.

Space Stations

International Space Station (ISS)

The International Space Station (ISS) is the largest modular space station in low Earth orbit. It is a multinational collaborative project involving five participating space agencies: NASA (United States), Roscosmos (Russia) JAXA (Japan), ESA (Europe), and CSA Canada).

The station serves as a microgravity and spare environment research laboratory. The ISS is suited for testing the spacecraft systems and equipment required for possible future long-duration missions to the Moon and Mars.

The ISS is the ninth space station to be inhabited by crews, following the Soviet and later Russian Salyut, Almaz and Mir stations and the American Skylab. It is the largest artificial object in space and the largest satellite in low Earth orbit, regularly visible to the naked eye from Earth's surface.

The ISS was taken into space piece-by-piece and gradually built in orbit using spacewalking astronauts and robotics. Most missions used NASA's space shuttle to carry up the heavier pieces, although some individual modules were launched on single-use rockets.

It maintains an orbit with an average altitude of 400 kilometres (250 mi) by means of re-boost manoeuvres using the engines of the Zvezda Service Module or visiting spacecraft. The ISS circles the Earth in roughly 93 minutes, completing 15.5 orbits per day.

The first ISS component was launched in 1998, and the first long-term residents arrived on November 2000 . The station has since been continuously occupied for 21 years and 345 days, the longest continuous human presence in low Earth orbit.
In January 2022, the station's operation authorisation was extended to 2030, with funding secured within the United States through that year. There have been calls to privatize ISS operations after that point.

ISS astronomical observations

The ISS rotates with an orbital velocity resulting in a view change with an angular velocity of 3.88 arc-degrees per second to keep the same side facing the Earth (and away from the Sun). Therefore it is not suitable for astronomical observation.

There is a telescope (Celestron brand) on board that can be moved around inside the space station to look through any window, used to observe the Earth.

There had been an Alpha Magnetic Spectrometer (AMS-02) installed from 2011 to 2015, a particle physics experiment module. This detector measured antimatter in cosmic rays.

Tiangong Space Station

The Tiangong Space Station is a space station being constructed by China in low Erth orbit between 340 and 450 km (210 and 280 mi) above the surface. Tiangong will have a mass between 90 and 100 tons (200,000 and 220,000 lb), roughly one-fifth the mass of the ISS. The first module, the Tianhe core module, was launched on in April 2021 and two more major modules have been added in Sep and Oct in 2022.

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Interplanetary Probes

Probes

A probe is a space vehicle shot out of Earth's orbit on a planned trajectory with a specific mission. A space vehicle placed in orbit around the Earth (or other celestial entities) is, on the other hand, called a satellite. (A probe may inter alia be navigated into orbit around another planet, moon or even the Sun, either temporarily or in residence, as a satellite.)

Except for the manned activities related to the conquest of the Moon in the 1960s-early 70s, probes have been unmanned.

Such a space probe is remotely piloted. It carries instruments to measure and otherwise gather information about the atmosphere, composition and other physical properties of outer space or celestial bodies other than Earth.

When such a probe is tasked with gathering samples and returns-delivers these back to Earth, it would generally be called a spacecraft.

Launch Vehicles

Satellites and probes became reality when their launch vehicles (rockets) could clear “7Gs”, (the Earth escape velocity of 6.95 km/s), which happened with Sputnik 1 on 4 Oct 1957. By the time of the Lunar landings (1969-72), rockets could take sizable payloads into space. Apollo 15’s payload in 1971 was 47.7 tons.

The earliest probes were essentially one shot one-way point to point affairs. Their payload and destinations governed their escape velocity. The standard lift off propulsion vehicle was the 3-stage rocket. The firs two stages would lift the probe up and place it in Earth orbit. The third stage would shoot the off to their target at the escape velocity required.

Regardless of payload weight, a launch vehicle requires to reach a speed of 11.2 km/second (25,053.69 mph) to attain escape velocity from the Earth. This would be necessary to go into Earth orbit.

Gravity Assist

Gravity assist was (and is) a vital component of space navigation. In orbital mechanics, a gravity assist, a gravitational slingshot, or swing-by is the use of the relative movement (e.g. orbit around the Sun) and gravity of a planet or other celestial body to alter and manage the path and or speed of a spacecraft.

The gravity assist manoeuvre was first used in 1959 when the Soviet probe Luna photographed the far side of Earth's Moon. It has been used by interplanetary probes from the Mercury flyby in 1973 onwards.

Gravity assistance can be used to accelerate or decrease its speed or redirect its path. The "assist" is provided by the motion of the gravitating body as it pulls on the spacecraft Any gain or loss of kinetic energy and velocity by a passing spacecraft is correspondingly lost or gained by the gravitational body, in accordance with Newtonian laws.

Profile of a Probe

At the initial planetary visit stages, the minimum objective would be a flyby and successful transmission of pictures and data, before crash landing – with the prize always a few closeup shots before the latter.

Later ones would orbit their targets, and perhaps string a few targets together, and at some stage a few would soft landings. No interplanetary probe has so far returned.

Space probes carried special cameras and measuring instruments, mainly commanded remotely, those being the days before even microprocessor chips and on-board data storage.

The probe carried its own power source, an early radioisotope thermoelectric generator (RTG), which converted the heat generated from the natural decay of its radioactive fuel into electricity, for radio transmitting of its data back.

There was also a minimal load of fuel (hydrazine) to operate its mechanical devices, boosters and thrusters, for micro-navigation and positioning.

Space probes varied a lot in size. Satellites often weighed in the range of 8 tons, but the larger spacecraft rarely weighed more than 1 ton.

Solar System Probes

The probe programme under review here represents the first round contact of the Solar System. Probes were launched to study the planets and other constituents of the Solar System (including the Sun).

Early space probes were exploratory, the instrumentation minimal, and the failure rates high. By the end of the last century, though, the major planets of the Solar System had bad been visited, photographed and investigated.

Among the early probes were those launched to the Moon. So far, manned landings and safe returns have only occurred with the Moon. As the facts are well-known, I exclude coverage of it in this review, and come back to the subject in Chapter Fifteen – 21st Century.

I have also reserved mention of the current planned manned expeditions to Mars (and excursions to passing asteroids and comets) to Chapter Fifteen – The 21st Century.

Selected Firsts

The following summary table provides an overview of the pioneer rocket activity in the first generation of the exploration of the Solar system:

Table 9
Selected Firsts in Unmanned Space Probes

Spacecraft	Country	Target	Year	Type	Spacecraft	Country
Lunar1	USSR	Moon	Jan 59	flyby	Partial success	
Pioneer 4	USA	Moon	Mar 59	flyby	Partial success	
Mariner 2	USA	Venus	Aug 62	flyby	First planetary encounter	
Ranger 7	USA	Moon	Feb 64	impactor	Pix before impact.	
Mariner 4	USA	Mars	Nov 64	flyby	First successful	
Venera 3	USSR	Venus	Nov 65	impactor	First planetary impact landing	
Lunar 9	USSR	Moon	Jan 66	lander	First Lunar lander	
Surveyor 5	USA	Moon	Jan 68	lander	Soft landing. Prepare for Apollo.	
Apollo 8	USA	Moon	Dec 68	orbiter	First crewed orbiter	
Apollo 11	USA	Moon	Jul 69	lander	First Man on Moon and return.	
Venera 7	USSR	Venus	Aug 70	lander	First probe landing on another planet.	
Pioneer 10	USA	Jupiter	Mar 72	flyby	First flyby	
Pioneer 11	USA	Saturn	Apr 73	flyby	First flyby	
Mariner 10	USA	Mercury	Nov 73	flyby	First flyby	
Venera 9	USSR	Venus	Jun 75	lander	First surface pix	
Viking 1	USA	Mars	Aug 75	lander	Frist surface pix	
Voyager 2	USA	Uranus	Jan 86	flyby	Enroute space	
Voyager2	USA	Neptune	Aug 89	flyby	Enroute space	
New Horizons	USA	Pluto	Jul 15	flyby	enroute Kuiper Belt	

Unmanned Space probes were initiated as early as 1959, and the first planetary success (to Venus) was in Aug 62.

By Aug 75, the first probe descent on Mars had taken place, completing the visits to the Inner Planets. Mercury proved the most difficult. Despite several probes, there was only one that crash-landed.

Conquest of the Outer Planets began with Jupiter when Pioneer 10 arrived on 3 Dec 1973 after a 21 month journey from Earth. It was followed by Pioneer 11, Voyager 1 and Voyager 2. The Jupiter flyby was necessary for the probes to rev up their speeds by gravity assist to achieve the escape velocity to leave the Solar System. All the outer planets were visited in this way, and the probes are now in interstellar space.

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Interstellar Probes

Gravity assist

No rocket has been built that can achieve the escape velocity directly out of the heliosphere, namely 42.0 kps or 94,000 mph[92].One of the great achievements has been to successfully apply gravity assist in space to boost our probes to the necessary speeds and execute the necessary course corrections to get to interstellar space – in a pre-computer age.

One had only to get to Jupiter halfway and that massive planet's momentum was available to do the rest. So far the instellar probes have only gone one way.

There have been and are five interstellar probes, all launched by NASA, three of which have entered interstellar space.

A gravitational slingshot, gravity assist manoeuvre, or swing-by is the use of the relative movement (e.g. orbit around the Sun) and gravity of a planet or other celestial object to alter the path and speed of a spacecraft.

Gravity assistance can be used to increase or decrease its speed or redirect its path. The "assist" is provided by the motion of the gravitating body as it pulls on the spacecraft.

The gravity assist manoeuvre was first used in 1959 when the Soviet probe Luna photographed the far side of Earth's Moon and it was used by interplanetary probes from Mariner 10 onwards., including the two Voyager probes' notable flyby's of Jupiter and Saturn.

2018 On Oct. 3, Parker Solar Probe successfully completed its flyby of Venus at a distance of about 1,500 miles during the first Venus gravity assist of the mission.

Pioneer 10

Pioneer 10 was the first spacecraft to pass through the asteroid belt, and then cross the gulf from the Earth to Jupiter.

[92] Once the second stage of the Saturn V reached a speed of 15,500 miles-per-hour, Saturn V's single engine third stage ignited, burning for about two minutes to place the Apollo spacecraft into orbit at 115 miles and a speed of almost 17,500 miles-per-hour. After a checkout, the engine reignited and burned for 5-112 minutes reaching the lunar transfer velocity of 25,000 miles per hour, enough to escape earth orbit.

Weighing 250 kg (640 lbs,) Pioneer 10 was launched on 2 Mar 1972 on top of a 3 stage Atlas/Centaur/TE364-4 launch vehicle. The third stage was required to rocket Pioneer 10 to the speed of 32,400 mph needed for the flight to Jupiter.

On 15 Jul1972, Pioneer 10 entered the asteroid belt, located between the orbits of Mars and Jupiter. It passed safely through the belt, emerging on the other side about 15 Feb 1973, taking seven months to do so.

It arrived at Jupiter on 3 Dec 1973, some 21 months later. It was not until after Pioneer 10 had cleared the asteroid belt that NASA selected a trajectory towards Jupiter that offered the slingshot effect that could eventually send the spacecraft out of the Solar System. Pioneer 10 was the first spacecraft to attempt such a manoeuvre, and became a proof of concept for the missions that would follow.

Pioneer 10 rendezvoused with Jupiter on 3 Dec 1973. At the closest approach it was 200,000 km (124,000 miles) from the outer atmosphere of Jupiter, reaching the velocity of 82,000 mph. The spacecraft flew round the back of the planet, and flew by its planets . First-ever close-up images and atmospheric readings were obtained.

On 1 Jan 74, Pioneer 10 ended its Jupiter mission and was sling-shotted towards Pluto, which was then a planet, while the Kuiper Belt and the other KBOs had not yet been identified. It was the first vehicle placed on a trajectory to escape the Solar System into interstellar space.

It first crossed the orbit of outer planets Saturn in 1976 and of Uranus in 1979. Then, it crossed the orbit of Pluto (then nearer the Sun) on 25 Apr 1983.

On 13 Jun 1983, Pioneer 10 crossed the orbit of Neptune, becoming the first human-made object to travel beyond the planets, in this case the Kuiper Belt. But that spacecraft did not visit any of the icy worlds in the region.

On 31 Mar 1997, Pioneer 10 ended its mission, travelling forward into space, and only maintaining contact through telemetry. The last signal was received on 23 Jan 2003.

On its 50th Anniversary, Pioneer 10 was some 131.46 Aus (19.67 billion km or 12.22 billion miles)) from Earth. Light would have taken 18 hours, 13 minutes and 21.2579 seconds to travel from Pioneer 10 and arrive on Earth.

In 2016, its speed was measured at 12.04 k/s or 27,000 mph (relative to the Sun). At its current speed, it will be more distant than the red dwarf Proxima Centauri in 26,118 years. Its course is pointed in the direction of the star Aldebaran, the “eye” of the Taurus constellation at a distance of 68 light-years which it will reach in two million years.

Well before that, in about 90,000 years, Pioneer 10 will pass about 0.75 light-years of HIP 117795. This is the closest stellar flyby in the next few million years of all the four Pioneer and Voyager spacecrafts, which are leaving the Solar System.

Pioneer 11

Pioneer 11, weighing some 260kg (570 lbs) was launched by NASA on 5 Apr 1973, on an Atlas-Centaur rocket equipped with an additional upper stage to provide the required velocity to send the spacecraft on a direct trajectory to Jupiter.

Pioneer 11 was launched to study the asteroid belt, the environments around Jupiter and Saturn, solar winds, and cosmic rays. It was the first probe to encounter

Saturn. Later, Pioneer 11 became the second to achieve an escape velocity to leave the Solar System.

In May 1974, Pioneer was re-targeted to fly past Jupiter on a north–south trajectory, enabling a Saturn flyby in 1979. The manoeuvre increased Pioneer 11's speed by 230 km/h (143 mph).

Pioneer 11 flew past Jupiter in November and December 1974. During its closest approach, it passed 42,828 km (26,612 mi) above the cloud tops. The probe obtained detailed images, transmitted the first images of the immense polar regions, and determined the mass of Jupiter's moon Callisto.
.
Pioneer 11 entered the Saturnian system on 1 Sep 1979, at a distance of 21,000 km (13,000 mi) from Saturn's cloud tops.

By this time, Voyager 1 and Voyager 2 had already passed Jupiter enroute to Saturn.. So, it was decided to target Pioneer 11 to pass through the Saturn ring plane at the same position that the soon-to-come Voyager probes would use in order to test the route before the Voyagers arrived. If danger were detected, then the Voyager probes could be re-routed further away from the rings, but missing the opportunity to visit Uranus and Neptune.

Pioneer 11 imaged and nearly collided with one of Saturn's small moons, passing at a distance of no more than 4,000 km (2,500 mi). After the Voyager flybys, it became known that there were two similarly sized moons (Epimetheus and Janus) in the same orbit. Pioneer 11 encountered Janus on 1 Sep and Mimas on the same day at 103,000 km. (64,000 km).

Pioneer 11's instruments located another previously undiscovered small moon and an additional ring, charted Saturn's magnetosphere and magnetic field and found its planet-size moon, Titan, to be too cold for life. The probe also sent back pictures of Saturn's rings.

Pioneer 11 exited the Saturnian system and began its interstellar mission on 5 Oct 1979. On 25 Feb 1990, Pioneer 11 became the 4th man-made object to pass beyond the orbit of the planets. It took 11 years to do so.

By 1995, Pioneer 11 could no longer power any of its detectors, so the decision was made to shut down routine contact on 30 Sep 1995 Scientists received a few minutes of good engineering data on 24 Nov 1995, but then lost final contact once Earth moved out of view of the spacecraft's antenna

As of October 20, 2022, Pioneer 11 was estimated to be 109.49 AU (1.6380657×1010 km; 1.0178468×1010 mi) from Earth, traveling at 11.18 km/s (40,260 km/h; 25,010 mph) (relative to the Sun) and traveling outward at about 2.36 AU per year.

The spacecraft was heading in the direction of the constellation Scutum, close to Messier 26. In 928,000 years, it will pass within 0.82 light years of the K dwarf TYC 992-192-1, and will pass near the star Lambda Aquilae in about four million years.

Pioneer 11 has now been overtaken by the two Voyager probes launched in 1977, and Voyager 1 is now the most distant object built by humans.

Voyager 1

Voyager 1 is a space probe launched by NASA on 5 Sep 1977. Like its twin, its It was delivered to space aboard the 3-stage Titan-Centaur rocket. The spacecraft's weight, at launch was 815 kg, and it was launched on a faster, shorter trajectory to Jupiter.

The spacecraft's mission was to locate and study the regions and boundaries of the outer heliosphere, and to begin exploring the interstellar medium, with a three-fold agenda: (1) flyby-photograph-take instrumental readings of the Jupiter system including Titan, (2) to do likewise for the Saturn system, and thereafter (3) proceed to explore the outer heliosphere and interstellar space.

Voyager 1 entered the asteroid belt on 10 Dec 1077 and took nine months to exit it, on 8 Sep 1978.

Voyager 1 reached Jupiter on 5 Mar 79, some 18 months after leaving Earth. and on closest flyby was 349,000 km (219,000 miles) above the clouds. It exited the Jovian system on 12 Apr 1979, a little over a month.

Voyager 1 reached the Saturnian system on 12 Nov 1980 and spent two days there, exiting the system on 14 No 1980, benefitting from the earlier exploration of Pioneer 11.It is noteworthy that Voyager was at that point had a velocity of 79,000 kpm (49,100 mph) well in excess of Saturn's escape velocity of 30,400 mph (49,000 km/h) and no gravity assist was required.

Voyager 1 began its space exploration thereafter and on 17 Feb 198, it overtook Pioneer 10.

On 17 Dec 2004, Voyager 1 crossed the Termination Shock and on 23 Aug 2012 it crossed the heliopause into interstellar space. As of 8 October 2022, it was about 157.77 AU (2.360×10^{10} km), the farthest man-made object, from Earth.

As of 2017, the probe was moving with a relative velocity to the Sun of about 16.95 km/s (37,916 mph). Voyager 1 could reach the Oort Cloud in about 300 years.

In 1990, Voyager 1 powered down its cameras. As of early 2020 the spacecraft was still operating, but no longer had the capability to take images.

Voyager 1 remains in contact with Earth through the Deep Space Network, to receive routine commands and to transmit data. Signals from Voyager 1 take over 21 hours to reach Earth. Real-time distance and velocity data is provided by NASA.

Voyager 1's extended mission is expected to continue until about 2025, when its radioisotope thermoelectric generators (RTGs) will no longer supply enough electric power to operate its scientific instruments. After 2036, the probe will be out of range of the Deep Space Network.

Voyager 2

Voyager 2 is the twin space probe to Voyager 1, launched by NASA (earlier) on 20 Aug 1977, on a longer first-part outer planetary exploration mission before joining the later in space on its extended mission. Voyager 2 spacecraft's weight at launch was 825 kg. Voyager 1 overtook it on 19 Dec 77.

As of Oct 2022, it had reached a distance of 131.44 AU (12.218×10^{10} mi) from Earth. As of 2017, the probe was moving with a relative velocity of 15.341 km/s (34,320 mph) relative to the Sun.

Like its twin, the spacecraft's extended mission was to locate and study the regions and boundaries of the outer heliosphere, and to begin exploring the interstellar medium, but with different specifications for the planetary visits as follows: (1) flyby-photograph-take (more) instrumental readings of the Jupiter system (2) to do first-time likewise for the Saturn system, the Uranian system, and the Neptunian system, and thereafter (3) proceed to explore the outer heliosphere and interstellar space.

It was launched 16 days before its twin, on a trajectory to reach the gas giants Jupiter and Saturn and enabled further encounters with ice giants Uranus and Neptune. Voyager 2 remains the only spacecraft to have visited either of the ice giant planets.

Voyager 2 successfully fulfilled its primary mission of visiting the Jovian system in 1979, the Saturnian system in 1981, the Uranian system in1986 and the Neptunean system in 1989. On 2 Oct 1989, Voyager 2 began its interstellar mission.

Some 18 years on, on 30 Aug 2007, Voyager 2 passed the crossed the Termination Shock and then entered into the heliosheath, approximately 1 billion mi (1.6 billion km) closer to the Sun than Voyager 1 did. This was due to the instellar magnetic field of deep space being stronger, for the southern hemisphere of the Solar System's heliosphere was being pushed in.
On 5 Nov 2018, Voyager 2 finally reached interstellar space. Voyager 2 began to provide the first direct measurements of the density and temperature of the interstellar plasma.

Voyager 2 remains in contact with Earth through the NASA Deep Space Network . In 2020, maintenance work to the Deep Space Network cut outbound contact for eight months. Contact was re-established on Nov 2020, when a series of instructions was transmitted, subsequently executed, and relayed back with a successful communication message. On February 12, 2021, full communications with the probe were restored after a major antenna upgrade that took a year to complete.

For those thrilled by absolutely virginal information (as I am) herewith from a Wiki report: "in October 2020, astronomers reported a significant unexpected increase in density in the space beyond the Solar System as detected by the Voyager 1 and Voyager 2 space probes. According to the researchers, this implies that "the density gradient is a large-scale feature of the VLISM (very local interstellar medium) in the general direction of the heliospheric nose". Actually I query "unexpected": surely one would expect this at the front of any considerable moving object, in this case the whole Sola System.

In 2023, Voyager 2 is expected to pass Pioneer 10 to become the second furthest spacecraft from the Sun at a distance of around 12.4 billion miles.

Voyager 2 is not headed toward any particular star, although in roughly 42,000 years, it will have a close approach with the star Ross 248 at a distance of a few light-years. If undisturbed for 296,000 years, Voyager 2 should pass by the star Sirius at a distance of 4.3 light-years.

After 2036, both Voyagers will be out of range of the Deep Space Network.

New Horizons

New Horizons was launched by NASA on 19 Jan 2006 directly into a hyperbolic escape trajectory headed for (then) Pluto and thereafter the Kuiper Belt, with a stop-over at and for a gravitational assist from Jupiter enroute.

The goal of the mission was to understand the formation of the Plutonian system, the Kuiper Belt, and the transformation of the early Solar System

On 24 Aug 2006, the International Astronomical Union (IAU) announced it had re-classified Pluto as a dwarf planet within the Kuiper Belt.

The questions for the mission to answer focussed on Pluto and its binary Charon . They included the composition, surface temperatures and behaviour of their atmospheres, and their surface and large geological structures, also feedback about solar wind particles and the presence of unknown rings, satellites and features.

The spacecraft flew by Jupiter for a gravity assist manoeuvre with the closest approach on 28 Feb 2007. The encounter increased its velocity by about 14,000 kph (9,000 mph) shortening its trip to Pluto by three years. During the flyby, New Horizons carried out a detailed set of observations over a period of four months in early 2007.

After the Jupiter encounter, New Horizons was put in hibernation mode starting 28 Jun 2007. The second, third, and fourth hibernation cycles were Dec 2008, Aug.2009, and Aug 2014. New Horizons passed the halfway point to Pluto on 25 Feb 2010.

On 6 Dec 2014, ground controllers revived New Horizons from hibernation for the last time to initiate its active encounter with Pluto. At that time, it took four hours and 25 minutes for a signal to reach Earth from the spacecraft.

The spacecraft began its approach phase toward Pluto on 15 Jan 2015, and its trajectory was adjusted with a 93-second thruster burn on 10 March. Two days later, with about four months remaining before its close encounter, New Horizons finally became closer to Pluto than Earth is to the Sun. It achieved flyby of Pluto on 14 Jul 2015 at 7,800 km (4,800miles) above the surface and Charon at 28,800 km (17,900 miles), at a distance of 44 AU from the Sun.

New Horizons also observed Pluto's other satellites, Nix, Hydra, Kerberos, and Styx. Three days later mission scientists concluded that Pluto was about 2,370 km (1,470 miles) and Charon 1,208 km (about 750 miles) in diameter.

The download of the entire set of data collected during the encounter with Pluto and Charon – about 6.25 gigabytes – took over 15 months and was completed by 25 Oct 2016. Such a lengthy period was necessary because the spacecraft was roughly 4.5 light-hours from Earth and it could only transmit 1-2 kilobits per second.

Target Arrokoth

In the fall of 2015, after its Pluto encounter, mission planners began to redirect New Horizons for a Jan. 1, 2019, flyby of 2014 MU69, a Kuiper Belt Object that was approximately 4 billion miles (6.4 billion Km from Earth. The object was called Ultima Thule later officially named Arrokoth.

The goal of the encounter was to study the surface geology of the object, measure surface temperature, map the surface, search for signs of activity, measure its mass, and detect any satellites or rings.

Four course corrections were implemented in the fall while a fifth was carried out on 1 Feb.2017. Halfway from Pluto to its new target New Horizons was placed in hibernation mode, when much of the vehicle remained in an unpowered mode for "a long summer's nap" that lasted until 11 Sep 2017.

It was the farthest object in the Solar System ever to be visited by a spacecraft.

On 1 Jan 2019, New Horizons flew past Arrokoth. Moving at a speed of 51,500 km/h (858 km/min; 14.3 km/s; 32,000 mph), New Horizons passed by Arrokoth at a distance of 3,538 km (2,198 miles), equivalent to a one third of the distance of the spacecraft's closest encounter with Pluto. Closest approach occurred on 1 Jan 2019, at which point it was 43.4 AU from the Sun. At this distance, the one-way transit time for radio signals between Earth and New Horizons was 6 hours.

The science objectives of the flyby include characterising the geology and morphology of Arrokoth, and mapping the surface composition (searching for ammonia, carbon monoxide, methane, and water ice). Surveys of the surrounding environment to detect possible orbiting moonlets, a coma, or rings, were conducted

The object had no detectable atmosphere, and no large rings or satellites larger than 1.6 km (1 mi) in diameter. Arrokoth appeared to be made up of two individual orbiting objects (a contact-binary).

End to end, the overall shape of Arrokoth measured about 22 miles (35 Km) long, about 12 miles (20 Km) wide and by 6 miles (10 Km) thick. The larger lobe was found to be “lenticular,” which means it’s flattened and shaped like two lenses placed back to back. The smaller lobe was more rounded.

The New Horizons was deep in the Kuiper Belt, and speeding away from the Earth and Sun at a rate of about 300 million miles per year. The spacecraft was put into hibernation mode on 1 Jun 2022, and will remain in hibernation until 1 Mar 2023, to save fuel, and wear and tear. On the spacecraft.

If New Horizons can reach the distance of 100 AU, it will be traveling at about 13 km/s (29,000 mph), around 4 km/s (8,900 mph) slower than Voyager 1 at that distance.

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Part IV
Stuff Of The Universe

Introduction

This Part confines itself to be an outline of what we know about the main celestial objects in the universe, drawing towards the end of the 20th century. We shall look at the present century in a separate Part.

It becomes meaningful at this point to distinguish some terms, which are those commonly in use. Unless otherwise connotated by its context: .

“macro universe” is a collective term embracing the “extragalactic universe” and the “galactic universe”.

“extragalactic universe” is the universe beyond the Milky Way galaxy, as discovered by Hubble, etc from 1927 onwards.

“galactic universe” comprises the Milky Way galaxy and all within it, including the Solar System, as understood before discovery of the extragalactic world.

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Chapter Ten
The Macro Universe

Big Bang Theory

Thanks to Relativity, Quantum Science and the Lemaitre-Hubble law, we have been able to theorise that the universe originated in a Big Bang. And thanks to the further extensive advances since in astronomic technology and the astrophysical sciences , it is still the working proposition, with inclusions, refinements and still significant reservations, as at the end of the 20th century.

In 1927, Georges Lemaitre (1894-1966), a Belgian Catholic priest and professor of physics at the University of Louvain, first noted that an expanding universe could be traced back in time to an originating single point, which he called the "primeval atom".

In the years 1927-29, an American astronomer Edwin Hubble (1889-1853), by plotting the distance of eighteen galaxies against their red shifts, discovered that galaxies were moving away from earth at a rate proportional to their distance from us. Hubble's discovery was not just unexpected. It wa monumental.

For several decades, the scientific community was divided between supporters of the Big Bang and the rival steady-state theory which both offered explanations for the observed expansion; however, the steady-state model stipulated an eternal universe in contrast to the Big Bang's finite age.

In 1964, the cosmic microwave background (CMB) was discovered which convinced many cosmologists, for the Big Bang theory also predicted a uniform background radiation throughout the universe.

The Big Bang theory postulates that the universe originated[93] from small fluctuations (gravitational ripples) at a singularity in space. This triggered a cosmic inflation of spacetime, at a factor of the order of $10^{26,}$ over a time of the order of 10^{-36} to 10^{-32} seconds, with radiation energy peaking at 10^{15} GeV, creating a super-heated elemental soup. The observable universe was thought to have a radius of 300 light-seconds at that point. (The point of origin must have been truly infinitesimal.)

As the primordial goo cooled down to about 10^{10} degrees, quantum effects operated to release the fundamental forces, unpackage matter and antimatter, and progressively form quarks, , hadrons and leptons, within a time frame of the first 10 seconds. Many as yet unidentified sub-sub elementary particles are also thought to have been formed at this time; the neutrino was one of them, decoupled at about the first second The observable universe is thought to have been about 10 light-years at this point. This was the Radiation dominated era.

Next, the Big Bang went into Nucleosyntheses in the time frame of the order of 10^3 seconds, with protons and neutrons (baryons) forming atomic nuclei. The universe consisted of a plasma of nuclei, electrons and photons. Most of the energy was still electromagnetic. Baryonic density increased. The observable universe grew to a radius of 300 light-years.

In the next epoch, Recombination took place in a time frame of the order or of 100,000 years, as electrons bonded with atomic nuclei to form neural atoms. As the universe cleared

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93 https://en.wikipedia.org/wiki/Chronology_of_the_universe

of electrons and became more transparent to photons, the latter began to radiate (as light), becoming the beginnings of the cosmological background radiation (CMB). The observable universe grew to a radius of 42 million light-years by this stage. This was the Matter dominated era.

The universe went into a “dark age” thereafter, as the CMB redshifted into the microwave wavelengths and no longer transmitted as light. This lasted 150 million years until the first stars were formed. This was the Dark Energy dominated era.

Detailed measurements of the expansion rate placed the Big Bang singularity at an estimated 13.8 billion years ago, which is considered the age of the universe.

The first galaxies were formed around 300-400 million years after the Big Bang. This became the Stelliferous era, down to our day.

The Big Bang theory offered a comprehensive explanation for a broad range of observed phenomena, including the morphology of the large-scale structures and galaxies, the abundance of light elements, EMR radiation, and the CMB.

The Lemaitre-Hubble Law

Crucially, the Big Bang theory provided the framework for an expanding universe. The discoveries led to the **Hubble-Lemaitre law**, which stated that the universe was in fact still expanding after the Big Bang, or to put it more correctly from the perspective of the observer (the Earth) receding. What was discovered precisely was that at any one point in cosmological time the velocity of recession was proportional to the galaxy’s distance from the observer. The farther away a galaxy was, the greater was its velocity moving away from Earth.

Hubble’s Constant

The rate of expansion or the speed of recession has come to be known as known (somewhat confusingly) as **Hubble’s constant**. What this means is that the rate of expansion is constant (the same) at all locations throughout the universe at any one point in cosmological time, but this rate of expansion changed (increased) with time. It is constant in space, but **changed with time**. The obvious corollary is that the radius of the **Hubble sphere** (the universe) varies with time. In the present frame of cosmic evolution, the expansion rate is positive (increases) with cosmological time.

Over time, the expansion will be proportionate to distance and the rate. Hubble’s findings indicated that the rate of expansion also increased proportionately. This implied the universe was not only expanding, but accelerating.

Hubble’s constant has been refined several times and is currently around 73 km/s/Mpc (megaparsec[94]). This means If a galaxy is 10 Mpc away today, it recedes at ~700 km/s; if it is 1,000 Mpc away, it receded at 70,000 km/s. The rate of acceleration will be found by subtracting the two constants in time. This will also be proportional to distance.

The motion of the galaxies due solely to the expansion of the universe is called the **Hubble Flow.**

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94 Mpc = megaparsec = 3.26 light-years = 206,265 AU. One parsec corresponds to the distance at which the mean radius of the earth's orbit subtends an angle of one second of arc.

Expanding Universe

It is now understood that the expansion of the universe is inherent in the fabric or metric of spacetime itself, an intrinsic expansion whereby the scale of space itself changes.

Observable Universe

The observable universe is a spherical region of the universe observed by an observer anywhere in the universe, in our case the Earth. It is subject to the performance of our telescopes and instruments and to the luminosity of the object. But, because the universe is so immense, there is a third factor: the time light takes time to travel from the object. The physical limit is created by the speed of light. No signal can travel faster than light, hence there is a maximum distance (called the **particle horizon**) beyond which nothing further away can be detected, as the signals could not have reached us yet.

Objects within spacetime cannot travel faster than light, but this limitation does not apply to the effects of changes in the metric of spacetime itself. Objects that recede beyond the observable limit of light, known as the **event horizon**, will become unobservable, as no new light from them will be capable of overcoming the universe's expansion.

The universe therefore extends beyond the observable. If it is expanding, there must be a boundary, albeit a moving boundary. What lies "outside" the universe is unknown, if there is an outside. We can only be concerned with the observable universe[95].

Size of the Universe

"Conmoving distance" measures the relative distance between an observer and an object at the moment of observation, both being conmoving. "Proper distance", on the other hand, measures the distance where the object would actually be after a segment of cosmological time, taking into account the expansion of space. The comoving distance is in fact the difference in the proper distances of the object and its observer along the line of sight. The "observable distance" is the comoving distance at the present time.

Astronomers calculate that, at a conmoving radial distance of 13.8 billion light years (from the Earth), if inflation occurred at a constant rate through the life of the universe since the Big Bang (3.8 billion years ago), the proper distance of the current observable edge of the universe would over 46.5 billion light-years away today. This would make **the proper diameter of the observable universe a sphere of around 93 billion light-years.**

They further calculate that the full size of the universe's diameter beyond the observable horizon in proper distance terms could be 260 billion light-years.

For our purposes, suffice it that we have a very large universe, if only within observable reach. There is no centre point of the universe. Every location has its own observable universe **The conmoving diameter of our universe today, observable from the Earth, is a likely 27.6 billion light years** – when we make the telescope to see it.

Assuming that space is roughly flat, this size corresponds to a comoving volume of about 4.22×10^{5} giga-light-year^{3} or 3.57×10^{80} m3.

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95 https://en.wikipedia.org/wiki/Observable_universe

Current Observable limit

Conventionally, distances in space is measure by light-years, the distance light takes to travel in one year[96] at 300,000 km/s. The Sun is 8 minutes away, Alpha Centauri, the nearest star, is 3.26 light-years away, and it takes 27,700 light-years or so to get to the Milky Way.

On 22 Jun 2022, the new James Webb Space Telescope recorded viewing a most distance galaxy, GLASS Z-13, which had a light-travel distance (lookback time) of 13.4572 billion years, anda present proper distance of 33.205 billion light-years. The age of the universe has been calculated to be 13.8 billion years. We were therefore viewing the galaxy only 342 million years after the Big Bang, at 97.5% of the observable limit..

Critical Density

Critical density is the energy of the universe at which the expansion of the universe is poised between continued expansion and collapse. At this density, the universe will be flat.

If the matter of the universe is above critical density, the universe will stop expanding, contract, and end in a Big Crunch. If it equals exactly critical density, the universe will stop expanding, and slow down infinitely towards zero without ever reaching it. If it below critical density, the cosmological constant (Hubble's constant) will prevail.

The present position is that by making observations of fluctuations in the cosmic microwave background, astronomers have shown that the Universe is 'flat'. This means that its density should be close to the critical density and the cosmological constant zero. However, the universe is not just expanding but accelerating.

The current expansion rate indicates that the actual critical density of the universe is about 9×10-27 kg $m^{-3,}$ One of the major mysteries is to account for the energy generating this expansion, or conversely to account for the deficit in matter or density necessary to produce the countervailing or missing gravity – if indeed anything is missing.

Composition of the Universe

It has been perhaps the most outstanding achievement of man to have established that the entire universe is made of the same matter, and is governed by the same set of physical laws.

Until 1933, it was thought that the visible universe was all there was and substantially made of ordinary visible matter. The newly discovered extragalactic universe, the voids, and the expansion of the galaxies completely transformed the picture.

To account for the present critical density plus the acceleration, it is now estimated that the matter makes up only 31.4% of the mass-energy of the universe, of which only 4,9% is composed of ordinary matter and 26.5% of invisible dark datter, and the balance of 68.6% is ascribed to dark energy.

[96] Year –Earth year

Ordinary Matter

The visible universe is composed of ordinary matter, which is matter that interacts with electromagnetic radiation (EMR) across its full frequency range, inclusive of light, and is therefore visible.

Ordinary matter is also called baryonic matter, because all the atoms making up ordinary matter are composed mainly of protons and neutrons, which are baryons. The latter is a class of sub-atomic of matter made up of quarks which react to the strong fundamental force.

Until now, our entire understanding of the universe has been based on our understanding of ordinary matter.

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Dark Matter

In 1933, Fritz Zwicky (1896-1974) a Swiss astronomer measured the visible mass of a cluster of galaxies and found that it was much too small to prevent the galaxies from escaping the gravitational pull of the cluster to which it belongs. Something else was acting like glue to hold clusters of galaxies. He called it dark matter. In the 1970s, Vera Rubin and Kent Ford measured the rotation speeds of individual galaxies and found evidence that dark matter was keeping the galaxies from flying apart.

In the 1970s. it was found that the speed with which stars orbited the centre of their galaxy was either constant or increased slightly with distance, rather than drop off as might be expected. To account for this, the mass of the galaxy within the orbit of the stars must increase linearly with the distance of the stars from the galaxy's centre. However, no light was seen from this inner mass—hence the name "dark matter."

Dark matter was postulated in order to account also for other gravitational effects observed in very large-scale structures, such as the "flat" rotational curves of galaxies; the gravitational lensing of light by galaxy clusters, and enhanced clustering of galaxies, that cannot be accounted for by the quantity of ordinary matter. The calculations showed that many galaxies would behave quite differently if they did not contain a large amount of unseen matter. Other evidence throughout the years has confirmed the existence of this dark matter.

Dark matter does not interact with EMR at any wavelength – or does so very weakly. This means it does not absorb, reflect or emit light, making it extremely hard to spot. It is , therefore, invisible and cannot be spectrographed and studied. It also does not react to the fundamental forces, except gravity. The latter is the only way we know where it is.

Because dark matter does not interact electromagnetically, we cannot touch it, see it, or manipulate it using conventional means. One could, in principle, manipulate dark matter using gravitational forces.

Researchers have been able to infer the existence of dark matter only from the gravitational effect (pull) it has on ordinary or visible matter. If it has gravity, it has mass, volume and energy. It is matter. The evidence shows that dark matter is fives more plentiful that visible matter.

Currently, dark matter is hypothesised to be mainly non-baryonic, ie it consists of matter other than protons and neutrons (and electrons, although electrons are not baryons).

Neutrinos are excluded, being non-baryonic but not cold. Dark matter might consist of as yet unidentified subatomic particles

Dark matter can refer to any substance which interacts predominantly via gravity with ordinary matter (e.g., stars and planets). Hence in principle it need not be composed of a new type of fundamental particle. It could, at least in part, be made up of standard baryonic matter. We do not yet know.

Matter is generally classified as "cold," "warm," or "hot" according to its velocity (more precisely, its free streaming length). In this case, dark matter has been regarded as “cold”. Cold refers to the fact that dark matter does not radiate energy and moves slowly compared to the speed of light.

In the cold dark matter (CDM) theory, structure grows hierarchically, with small objects collapsing under their self-gravity first, and then merging in a continuous hierarchy to form larger and more massive objects.

Information is still incomplete, but here we may note that implicit in the Big Bang theory is that dark matter could have been formed in the earliest stages together with ordinary matter. A recent study shows that dark matter may have been produced during an era known as the cosmic inflation when space was expanding very rapidly.

Dark matter is dissipationless: it cannot cool by radiating photons. And it is collisionless: dark matter particles interact with each other and other particles only through gravity and possibly the weak force. Its velocity is far less than the speed of light.

Researchers theorise that it could be made up of sub-sub elementary particles which have very light gravity fields, and react at most only to the weak force. Proposed candidates include weakly interacting massive particles (WIMPS).

Little information seems available about how it works at the terrestrial and atomic levels. Dark matter particles can penetrate all other forms of matter, which means that they may even be able to traverse right through our planet and our bodies. On the other hand, their impact with ordinary matter may hamper them slightly, resulting in a loss of energy.

So far, dark matter has been observed operating in the context of large scale structures, mainly by its gravitational lensing. It has been suggested that as a result of gravitational interactions within itself, dark matter formed filaments that intersected in a complex, three-dimensional meshwork. The additional gravitational pull at the points where filaments intersected would draw in regular matter, leading to the first galaxies.

The rates at which galaxies and large structures composed of galaxies are calculated to have coalesced in the early universe indicate that nonbaryonic dark matter was relatively “cold,” or “nonrelativisitic,” meaning that the backbones of galaxies and clusters of galaxies were made of heavy, slow-moving particles

If dark matter is composed of weakly-interacting particles, does not interact with the strong force and lacks an efficient means to lose energy (radiation), the .obvious question is whether in fact it can form objects equivalent to planets, stars or black holes. Historically, the answer has been it cannot.

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Lambda-CDM Model

The Lambda-CDM Model or ΛCDM (Lambda-Cold Dark Matter) or is a parametrisation of the Big Bang theory which seeks to explain the origin and constituents of our universe. It derives from Einstein's original propositions and broadly conforms with them. It is based on his Theory of General Relativity, including the following of his premises: (1) that the universe is isotopic (uniform in all directions) and homogeneous, (2) that space is not empty (has vacuum energy) and new space can come into existence, and (3) the universe is "flat" (all measurements are true).

Einstein's model dealt with only the visible universe. Dark matter (CDM) was incorporated into the ΛCDM only after its discovery in 1933, by others. CDM fitted into the model alongside visible atter, although how it was formed and many details about it have still not yet been cleared.

Einstein had originally introduced a cosmological constant into his equations, to provide a balancing quantum to obtain a steady-state universe. He never could satisfactorily account for. Later he removed it when dark matter doing the same thing. It would re-emerge at a later date.

The name of the model (ΛCDM) indicates its two principal ingredients: Lambda refers to a cosmological constant (identified with Dark Energy) of the vacuum, and CDM stands for Cold Dark Matter .

The Lambda-CDM has successfully predicted a wide variety of observations related to the cosmological background radiation, large scale structure, gravitational lensing, and other critical areas of cosmology. As a result, it has reached the status of a paradigm, and it is often referred to as the Standard Model of Cosmology (SMC). Like all good models, it also functions as the thinking tool to test hypothesis, show up inconsistencies and missing elements.

The Lambda-CGM model has enabled us to theorise to a reasonable degree of certitude that it was the mutual annihilation of matter and antimatter in the superheated primeval soup that created dark and ordinary matter together and in the proportions we know, and man was cast out on the desolate shores of the latter. We further theorise that the lighter baryonic matter took off first to shape the visible universe. The cold (non-radiant) heavier dark matter followed behind, and condensed at the centres of the galaxies and as other nodes.

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Dark Energy

Why Dark Energy

It has been calculated that after 7 billion years, the continuing propulsive force of the Big Bang should have been counterbalanced by the combined gravity or the universe's ordinary and dark matter and it should be decelerating. Therefore, there must be another missing energy component to explain the continuing expansion of space, not to mention its acceleration. and it must be gravitationally negative or repulsive..

In 1998, two international teams that included American astronomers Adam Riess and Saul Perimutter and Australian astronomer Brian Schmidt embarked on a Dark Energy Survey (DES) study. It focussed among other things on how light received from Type 1a

Supernovae[97] changed with distance-time. Their calculations allowed the supernovae to be used to measure accurately distances to faraway galaxies. The team found that the supernovae that exploded when the universe was younger were fainter and farther away than expected. This implied that the expansion rate of the universe was faster now than it was in the past, it was accelerating.

The acceleration of the universe was a startling result that completely changed cosmology.. In fact the missing energy was double the quantum of dark matter, and it was propulsive or gravity negative. The majority of the universe's mass-energy was of a completely unknown nature. Riess named officially named it "dark energy".

Features of Dark Energy

Dark energy, in contrast to both forms of other matter, is thought to be relatively uniform in time and space within the volume it occupies.

The only element in common with dark matter is that both are non-reactive (transparent) to EMR, and therefore cannot be "seen" or be spectrographed. Dark energy is additionally not known to interact through any of the fundamental forces, except gravity. The only external evidence of the latter - and of its actual existence - so far is the reported incidence of its (weak) gravitational lensing of light in the supernovae studies.

Further, the above DES studies also found that there was evidence of progressive retardation in the formation of galaxies and large scale structures over cosmological time.. This could only be due to the presence of massive repulsive gravitational forces such as dark energy. To account for an accelerating universe, dark energy must in fact exert net progressively increasing negative gravity. The corollary is that it would have been negligible in the beginning..

Source of Dark Energy

Dark energy can be thought of as an intrinsic property of spacetime rather than as (the familiar stress-energy tensor) matter that is the source of spacetime curvature. The energy is deemed to be inherent in the metric of spacetime. An expression sometimes used is that it is the "vacuum energy" of space.

In ΛCDM model terms, dark energy occupies the role of Einstein's cosmological constant, the missing component that accounts for the "balance" (or otherwise) of the universe.

Dark energy is quite rarefied and un-massive. Its density is roughly 10^{-27} kg/m3, and therefore undetectable in the laboratory. It is theorised that this density is constant. However the quantum of **dark energy increases proportionately with the expansion of spacetime**.

To account for the expansion of space, dark energy must exercise a repulsive force, or negative gravity. To account for acceleration, dark energy must be growing.

Under the ΛCDM model, the original propulsive force of the Big Bang would abate at some point and gravity would exert contraction. The model further provided that at equilibrium the universe would be flat. If it thereafter contracts, the universe would go into a Big Crunch. Recent CMB observations have suggested that that the universe is flat at present. The

[97] Since 2000, professional and amateur astronomers have been finding several hundred supernovae a year (572 in 2007, 261 in 2008, 390 in 2009; 231 in 2013).

problem is therefore to account for the expansion. The ΛCDM model has had to accommodate an expanding universe and since 1998 an accelerating universe.

Astronomers calculate that to produce the expansion rate, **dark energy must make up some 68.6% of the energy-matter of the universe.** Further, apart from being negative, it must be homogeneous and uniformly fill otherwise empty space.

All scientific efforts are now concentrated on determining what this massive unknown component might be.

One present postulate is that, like everything else, dark energy is took off as an integral component of spacetime. This could be the genesis of its propulsive force; and as the Big Bang slowed down, dark energy continued to grow filling the expanding space in spacetime.

The density of matter decreased as the universe expanded, because inter alia the volume of spacetime increased. The density of dark energy however remained constant as spacetime increased, but the total energy increased, exercising a growing repulsive pressure against gravity or negative gravity. At some point, the propulsive force of dark energy cancelled out the gravitational force of the universe, and the universe expanded and accelerated. Over time, dark energy will dominate the energy budget of the universe.

This postulate implies that nature designed that the universe will accelerate for ever, until it matter thins out and cools down – and become totally dark. What happens to dark energy at that point with non-operational matter will need to be worked out. Either that, or dark energy has to be re-conceptualised to slow-down at some stage, whether or not leading to contraction and a Big Crunch.

It is calculated that at the outer edges, the universe is already travelling faster than the speed of light. No one has yet measured whether the rate of acceleration itself is declining

Genesis of Dark Energy

Some researchers point out that, from the postulates about inflation, the period of time before the Big Bang was extremely cold, almost at absolute zero, and it was empty of everything except empty space. And yet, empty space had delivered this dark energy that stretched the universe to its enormous size before the Big Bang. Researchers concluded that the energy was inherent to the fabric of space itself.

It has been suggested that dark energy could arise through a common physical process from the quantum level. The proposal[98] here is that the creation of spacetime and matter results at the same time in independent metric expansion around mass points in the quantum matrix. The former results in the usual curvature of spacetime due to stress-energy sources of the gravitational field. This latter is the source of dark energy which fills the growing space homogeneously, variously thought of as akin to the zero-point radiation of "vacuum energy" of the cosmological constant.

Other suggestions conceive of dark energy as the emanation of underlying quantum fields, being dynamic quantities having energy densities that vary in time and space.

I shall go no further that quote Britannica on this point:

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[98] This 2018 article is worth reading, see https://www.frontiersin.org/articles/10.3389/fphy.2018.00071/full

> "The simplest and oldest explanation for dark energy is that it is an energy density inherent to empty space, or a "vacuum energy." Mathematically, vacuum energy is equivalent to Einstein's cosmological constant. Despite the rejection of the cosmological constant by Einstein and others, the modern understanding of the vacuum, based on quantum field theory, is that vacuum energy arises naturally from the totality of quantum fluctuations (i.e., virtual particle-antiparticle pairs that come into existence and then annihilate each other shortly thereafter) in empty space. However, the observed density of the cosmological vacuum energy density is ~10^{-10} ergs per cubic centimetre; the value predicted from quantum field theory is ~10^{110} ergs per cubic centimetre. This discrepancy of 10^{120} was known even before the discovery of the far weaker dark energy. While a fundamental solution to this problem has not yet been found, probabilistic solutions have been posited, motivated by string theory and the possible existence of a large number of disconnected universes. In this paradigm, the unexpectedly low value of the constant is understood as a result of an even greater number of opportunities (i.e., universes) for the occurrence of different values of the constant and the random selection of a value small enough to allow for the formation of galaxies (and thus stars and life).
> https://www.britannica.com/science/dark-energy

Some experts believe that a revised and more accurate treatment of the structures on all scales in the real universe may do away with the need to invoke dark energy.

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Chapter Eleven
Extragalactic Universe

Not much more than 100 years ago, the Milky Way was believed to be the only galaxy around, and substantially the upper limit of the celestial hemisphere, with individual smudges of stars and other cloudy patches in the distance.

Even the size of our galaxy had not been measured beyond a few hundred light-years. Thus, Hubble's discoveries in 1923 of the universe beyond the Milky Way became known as "extragalactic", while "galactic" is still used for the Milky Way and its constituents. We keep to this convention for sentimental reasons.

Shape of the Universe

Einstein's Theory of General Relativity allowed three possible shapes to the universe; a flat universe (Euclidean or zero curvature), a spherical or closed universe (positive curvature) or a hyperbolic or open universe (negative curvature

Although the exact shape of the universe is still debated among scientists, observations of the CMB radiation have revealed that the universe has a curvature of zero, meaning that the universe is flat. A flat universe is still three dimensional. Furthermore, the universe could be so large that any attempts to determine its shape are pointless. After all, a large universe that has curvature will appear indistinguishable from one that does not, assuming it is large enough.

The experimental data from various independent sources, the Wilkinson Microwave Anisotropy Probe (WMAP)[99], the BOOMERanG (Balloon experiment)[100], and the Planck Spacecraft[101] for example, confirm that the universe is flat with only a 0.4% margin of error.

This suggests that the universe is infinite in extent; however, since the universe has a finite age, we can only observe a finite volume of the universe.

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Large Scale Structures

Under present models, the structure of the visible universe was formed in the following stages:

Very early universe

In this stage, cosmic inflation was responsible for establishing the initial conditions of the universe: homogeneity, isotropy, and flatness.

It also would have amplified minute quantum fluctuations (pre-inflation) into slight density ripples of over-density and under-density (post-inflation).

99 https://en.wikipedia.org/wiki/Wilkinson_Microwave_Anisotropy_Probe
100 https://en.wikipedia.org/wiki/BOOMERanG_experiment
101 https://en.wikipedia.org/wiki/Planck_(spacecraft)

Growth of structure[

The early universe was dominated by radiation. Density fluctuations larger than the cosmic horizon would grew proportional to the scale factor, as the gravitational potential fluctuations remained constant. Structures smaller than the horizon remained essentially frozen due to radiation domination impeding growth.

As the universe expanded, the density of radiation dropped faster than matter. This led to a crossover called matter-radiation equality at about 50,000 years after the Big Bang.

After this, all dark matter ripples could grow freely, forming seeds into which the baryons could later fall.

As for baryonic matter, the primordial hydrogen and helium were fully ionized into nuclei and free electrons. The radiation (photons) could not travel far before scattering off an electron.

Finally, at a little less than 400,000 years after the Big Bing', it became cool enough (around 3000 K) for the protons to capture negatively charged electrons, forming neutral hydrogen atoms. (helium atoms formed somewhat earlier due to their larger binding energy).

CMB fluctuations

Once nearly all the charged particles were bound in neutral atoms, the photons no longer interacted with them and were free to propagate for the next 13.8 billion years; we currently detect those photons redshifted down to 2.725 K as the Cosmic Microwave Background Radiation (CMB), filling today's universe.

The CMB appears very nearly uniformly the same in every direction. However, several space-based missions have detected very slight variations in the density and temperature of the CMB. However, these slight temperature variations of the order a few parts in 100,000 were of enormous importance, for they essentially were early "seeds" from which all subsequent complex structures in the universe developed.

The COBE satellite (Cosmic Background Explorer) provided the first detection of the intrinsic fluctuations in the CMB in the 1990s.These perturbations were found to have a very specific character: very nearly to the values predicted by the simplest and most robust models of inflation.

COBE was the second cosmic microwave background satellite, following RELIKT-1, a Russian satellite in 1983. It was followed by two more advanced spacecraft: the Wilkinson Microwave Anisotropy Probe (WMAP) operated from 2001 to 2010 and the Planck Spacecraft from 2009 to 2013.

On 21 Mar 2013, the European-led research team behind the Planck probe released the mission's all-sky map of the cosmic microwave background. This map suggested the universe was slightly older than thought: according to the map, subtle fluctuations in temperature were imprinted on the deep sky when the universe was about 370,000 years old. The imprint reflected ripples that arose as early in the existence of the universe as the first nonillionth (10^{-30}) of a second. It is theorised that these ripples gave rise to the present vast cosmic web or galactic clusters and dark matter.

According to the Planck team, the universe was 13.798±0.037 billion-years-old, and contained 4.82±0.05% ordinary matter, 25.8±0.4% dark matter and 69±1% dark energy. The Hubble constant was also measured to be 67.80±0.77 (km/s)/Mpc.

Structure Formation

Dark matter plays a crucial role in structure formation because it feels only the force of gravity: the gravitational instability which allows compact structures to form is not opposed by any force, such as radiation pressure. As a result, dark matter begins to collapse into a complex network of dark matter halos well before ordinary matter, which is impeded by pressure forces. Without dark matter, the epoch of galaxy formation would occur substantially later in the universe than is observed.

The theory of what happened after the universe's first 400,000 years is one of hierarchical structure formation: the smaller gravitationally bound structures such as matter peaks containing the first stars and stellar clusters formed first, and these subsequently merged with gas and dark matter to form galaxies, followed by groups, clusters and superclusters of galaxies

While the simulations appear to agree broadly with observations, their interpretation is complicated by the understanding of how dense accumulations of dark matter spur galaxy formation. In particular, many more small haloes form than we see in astronomical observations as dwarf galaxies and globular clusters. Most account for it as an effect in the complicated physics of galaxy formation, but some have suggested that it is a problem with the model of dark matter and that some effect, such as warm dark matter, prevents the formation of the smallest haloes.

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Filaments and Walls

Galaxies were not just strewn randomly throughout the universe. Along huge strands of hydrogen, galaxies collect into larger groupings of massive filaments, separated by giant voids of nearly empty space.

Filaments are the largest known structures in the universe, thread-like structures with a typical length of 50 to 80 megaparsecs that form the boundaries between the voids.

With thicknesses of only ~20 million light years, galactic filaments are partially responsible for the 'honey-comb' appearance of the extragalactic universe (through our telescopes).

Research suggests that, after the universe was born in the Big Bang, much of the hydrogen gas that made up most of its matter collapsed to form colossal sheets. These sheets then broke apart to form the filaments of a vast cosmic web.

The filaments may be thought of as the wombs of the universe. The smaller gravitationally bound structures such as matter peaks containing the first stars and stellar clusters formed first therein, and these subsequently merged with gas and dark matter to form galaxies, followed by groups, clusters and superclusters of galaxies

Each filament is in turn basically a wall of galaxies, stretching for hundreds of millions of light-years. They are the next biggest structures in the known universe. Put together, these walls make up the cosmic web.

Stars are organised into galaxies, which in turn form galax groups, galaxy clusters, superclusters , walls and filaments. which are separated by immense voids, creating a vast foam-like structure sometimes called the "cosmic web".

Hercules–Corona Borealis Great Wall

The Hercules–Corona Borealis Great Wall or simply the Great Wall is the largest known LSS structure, measuring approximately 10 billion light years in length.

This massive superstructure is a region of the sky seen in the mapping of gamma-ray bursts GRBs found to have an unusually higher concentration of similarly distanced GRBs. The over-density lies at the Second, Third and Fourth Galactic Quadrants (NQ2, NQ3 and NQ4) of the sky. Thus, it lies in the Northern Hemisphere, cantered on the border of the constellations of Draco and Hercules. The entire clustering consists of around 19 GRBs with the redshift ranges between 1.6 and 2.1.

Indeed, the clustering crosses over 20 constellations and covers 125 degrees of the sky, or almost 15,000 square degrees in total area, which translates to about 18 to 23 billion light-years (5.5 to 7 gigaparsecs) in length.

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Cosmic Web

The current picture is that the universe was first formed by the extrusion of dark matter into space, accompanied by ordinary matter basically occupying the interstices. This process would result in forming long filaments and networks of filaments across the voids.
The end-result would be creating cosmic webs enclosing dark energy and matter, the whole wrapped in screens of primal gasses and molecular cloud.

Astronomers believe that matter in intergalactic space is distributed in a vast network of interconnected filamentary structures known as the cosmic web. The long filaments of matter are themselves separated by voids.

Astronomers think that on the largest scale the earliest structures resembled a "foam", comprising filaments and sheets of galaxies in 3D, hanging about and surrounding huge voids.

The filaments coalesced within themselves further into strings of clusters and superclusters of galaxies. The latter in turn further condensed within themselves into nebulae of molecular gases and particles, which further condensed into stars within the galaxies.

Astronomers believe that matter in intergalactic space is distributed in a vast network of interconnected filamentary structures known as the cosmic web. The long filaments of matter are themselves separated by voids. Nearly all the atoms in the universe reside in this web, vestigial material left over from the Big Bang.

The term "cosmic web" was coined in 1996 to describe a tangled structure of clumps and filaments naturally formed by dark matter left to experience the pull of gravity.

The cosmic web is the building block of the cosmos -- consisting primarily of dark matter and laced with gas, on which galaxies were built.

In the standard model of the evolution of the universe, galactic filaments form along and follow web-like strings of dark matter—referred to as the galactic web or cosmic web. It is thought therefore that dark matter dictates the structure of the universe on the grandest of scales.

A few hundred million years after the Big Bang, the distribution of matter in the universe had produced very dense knots at the intersections of the sheets and filaments that make up the cosmic web. In these knots, the density of ordinary matter was so high that the formation of stars and galaxies became possible.

Over time, gravity attracted more and more matter together, clustering the universe further and further. At the same time, dark **energy** acted to slow down this process of gravity creating large structures.

Today, we know that the observable universe is nearly 27 billion light-years across, and contains not less than 100 billion galaxies. The Large Scale Structures (LSS) refer to the patterns of galaxies and other groupings of matter across the extragalactic universe.

The LSSs are millions-to-billions of light years away and across. Astronomers study them indirectly by observing how they selectively absorb the light coming from faraway sources known as quasars and gamma=ray bursts (GRBs).

Cosmological Void

Simulations suggest that the universe is composed largely of voids whose densities might be as low as one-tenth the cosmological mean. Voids, vast expanses of nearly empty space, account for about 80 percent of the observable universe.

The cosmological evolution of the void regions differs drastically from the evolution of the universe as a whole: there is a long stage when curvature dominates, which prevents the formation of galaxy clusters and massive galaxies. Hence, although even the emptiest regions of voids contain more than 15% of the average matter density of the universe, the voids look almost empty for an observer.

Voids typically have a diameter of 10 to 100 Mpcs (30 to 300 million light years; particularly large voids, defined by the absence of rich superclusters, sometimes called supervoids. They were first discovered in 1978.

Voids are believed to have been formed by baryonic acoustic oscillations[102] in the Big Bang. Regions of higher density collapsed more rapidly under gravity, eventually resulting in the large-scale, foam-like structure or "cosmic web" of voids and galaxy filaments seen today. Voids located in high-density environments are smaller than voids situated in low-density spaces of the universe.

Voids appear to correlate with the observed temperature of the cosmic microwave background (CMB). Colder regions correlate with voids and hotter regions correlate with filaments. As the correlation is only significant if the universe is dominated by radiation or dark energy, the existence of voids is significant in providing physical evidence for dark energy.

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[102] Baryon acoustic oscillations (BAO) are fluctuations in the density of the visible baryonic matter (normal matter) of the universe, caused by acoustic density waves in the primordial plasma of the early universe. BAO provides a length scale in cosmology, the maximum distance the acoustic waves could travel before the plasma cooled to the point where it became neutral atoms "freezing" them into place. The length of this standard ruler is 490 million light years in today's universe.

The Sloan Digital Sky Survey (SDSS)[103] data combined with previous large-scale surveys now provide the most complete view of the detailed structure of cosmic voids. Voids have contributed significantly to the modern understanding of the cosmos.

Few galaxies exist in voids. Many void galaxies are connected through void filaments or tendrils, lightweight versions of the regular galaxy filaments that surround voids. These filaments are often straighter than their regular counterparts due to the lack of influence by surrounding filaments.

Dark energy

The simultaneous existence of the largest-known voids and galaxy clusters requires about 70% dark energy in the universe today, consistent with the latest data from the cosmic microwave background. Voids act as bubbles in the universe that are sensitive to background cosmological changes. This means that the evolution of a void's shape is in part the result of the expansion of the universe.

Since this acceleration is believed to be caused by dark energy, studying the changes of a void's shape over a period of time can help refine the working models of the universe. Voids offer opportunities to study the strength of intergalactic magnetic fields. For example, a 2015 study concludes, based on the deflection of blazar gamma-ray emissions that travel through voids, that intergalactic space contains a magnetic field of strength at least 10-17 G. The specific large-scale magnetic structure of the universe suggests primordial "magneto-genesis", which in turn could have played a role in the formation of magnetic fields within galaxies, and could also change estimates of the timeline of recombination in the early universe.

The insides of voids often seem to adhere to cosmological parameters which differ from those of the known universe. Due to the observation that larger voids predominantly remain in a linear regime, with most structures within exhibiting spherical symmetry in the underdense environment, the underdensity leads to near-negligible particle-particle gravitational interactions that would otherwise occur in a region of normal galactic density.

Boötes void

The Boötes void is an approximately spherical region of found in the vicinity of the constellation Bootes contains very few galaxies. It is enormous, with a radius of 62 Mpcs.

At nearly 330 million light years in diameter, the Boötes void is one of the largest known voids in the universe, and is referred to as a supervoid. Its discovery was reported in 1981 as part of a survey of galactic redshifts. The centre of the Boötes void is approximately 700 million light-years from Earth.

By 1997, the Boötes void was known to contain 60 galaxies in a space that would usually roughly have 2000. The scale of the void is such that if the Milky Way had been in the centre of the Boötes void, we would not have known there were other galaxies until the 1960s.
It has been theorised that the Boötes void was formed from the merging of smaller voids, much like the way in which soap bubbles coalesce to form larger bubbles. This would account for the small number of galaxies that populate a roughly tube-shaped region running through the middle of the void.

[103] The Sloan Digital Sky Survey or SDSS is a major multi-spectral imaging and spectroscopic redshift survey using a dedicated 2.5-m wide-angleooptical telescope at Apache Point, New Mexico.The project began in 2000.

Size of the Universe

"Comoving distance" factors out the expansion of the universe. It gives the relative distance between an observer and an object as at the moment of observation in cosmological time. "Proper distance" corresponds to the actual distance of an object after a segment of cosmological time, taking into account the expansion of the universe. The observable distance is the comoving distance at the present time.

Scientists calculate that, at a conmoving radial distance of 13.8 billion light years (from the Earth) if inflation occurred at a constant rate through the life of the universe since the Big Bang 13.8 billion ago, the proper distance of the current observable edge of the universe would over 46;5 billion light-years away today. This would make the proper diameter of the observable universe a sphere of around 93 billion light-years. They further calculate that the full size of the universe's diameter (beyond the observable horizon) in proper distance terms could be 260 billion light-years.

For our purposes, suffice it that we have a very large universe, if only within observable reach. There is no centre point of the universe. Every location has its own observable universe The conmoving diameter of our universe today, observable from the Earth, is a likely 27.6 billion light years.

Hubble 's constant

The new estimate of the Hubble constant is 74 kilometres (46 miles) per second per megaparsec. This means that for every 3.3 million light-years farther away a galaxy is from us, it appears to be moving 74 kilometres (46 miles) per second faster, as a result of the expansion of the universe. The number indicates that the universe is expanding at a 9% faster rate than the earlier prediction of 67 kilometres (41.6 miles) per second per megaparsec, which comes from the earlier Planck Spacecraft observations.

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Superclusters

A supercluster is a large group of smaller galaxy clusters or galaxy groups. They are among the largest known structures in the universe. The large size and low density of superclusters means that they, unlike clusters, expand with the Hubble expansion. The number of superclusters in the observable universe is estimated to be 10 million.

The existence of superclusters indicates that the galaxies in the universe are not uniformly distributed; most of them are drawn together in groups and clusters, with groups containing up to some dozens of galaxies and clusters up to several thousand galaxies. Those groups and clusters and additional isolated galaxies in turn form even larger structures called superclusters. Their existence was first postulated in 1958.

Interspersed among superclusters are large voids of space where few galaxies exist. Superclusters are frequently subdivided into groups of clusters called galaxy groups and galaxy clusters.

Astronomers now believe superclusters fill perhaps 10 percent of the volume of the universe. Most galaxies, groups, and clusters belong to superclusters, the space between superclusters being relatively empty. The dimensions of superclusters range up to a few times 10^8 light-years.

For larger scales the distribution of galaxies is essentially homogeneous and isotropic—that is, there is no evidence for the clustering of superclusters. This fact can be understood by recognizing that the time it takes a randomly moving galaxy to traverse the long axis of a supercluster is typically comparable to the age of the universe. Thus, if the universe started out homogeneous and isotropic on small scales, there simply has not been enough time for it to become inhomogeneous on scales much larger than superclusters. This interpretation is consistent with the observation that superclusters themselves look dynamically unrelaxed—that is, they lack the regular equilibrium shapes and central concentrations that typify systems well mixed by several crossings.

Galactic Clusters

A galaxy cluster, or cluster of galaxies, is a structure that consists of anywhere from hundreds to thousands of galaxies that are bound together by gravity, with typical masses ranging from 10^{14} -10^{15} solar masses. They are the second largest known structure in the universe after galactic filaments - until the 1980s, when superclusters were discovered. Small aggregates of galaxies are however referred to as galaxy groups rather than clusters of galaxies.

Spherical clusters are dense and consist almost exclusively of elliptical and lenticular galaxies. They are enormous, having a linear diameter of up to 50 million lightyears. Spherical clusters may contain as many as 10,000 galaxies, which are concentrated towards the cluster centre.

The biggest single entity that scientists have identified in the universe is a supercluster of galaxies called the Hercules-Corona Borealis Great Wall. It's so wide that light takes about 10 billion years to move across the entire structure.

Warm–hot intergalactic medium (WHIM)

The warm–hot intergalactic medium (WHIM) is the sparse, warm-to-hot (105 to 107 K) plasma that is said to exist in the spaces **between** galaxies and to contain 40–50% of the baryonic normal matter' in the universe at the current epoch. The WHIM can be described as a web of hot, diffuse gas stretching between galaxies, and consists of plasma, as well as atoms and molecules in contrast to dark matter.

Circum-Galactic Medium

Conceptually similar to WHIM, the Circum-Galactic Medium (CGM) is a halo of gas surrounding galaxies that is diffuse, and nearly invisible. Current thinking is that the CGM is an important source of star-forming material, and that it regulates a galaxy's gas supply. If visible, the CGM of the Andromeda Galaxy (1.3-2 million light years) would stretch 3 times the size of the width of the galaxy, and even bump into the next (Milky Way) CGM.

Intra-Cluster Medium (ICM)

One of the key features of clusters is the Intra-Cluster Medium (ICM). The ICM consists of heated gas between the galaxies and has a peak temperature between 2–15 keV, dependent on the total mass of the cluster

Large clusters of galaxies often exhibit extensive X-ray emission from intergalactic gas heated to tens of millions of degrees. Also, interactions of galaxies with each other and with the intra-cluster gas may deplete galaxies of their own interstellar gas.

Galaxy Groups (including Local Group)

The groups class is composed of small compact groups of 10 to 50 galaxies of mixed types, spanning roughly five million light-years. An example of such an entity is the Local Group, which includes the Milky Way Galaxy, the Magellanic Clouds, the Andromeda Galaxy

Some Large Scale Structures

Laniakea Supercluster

The Laniakea Supercluster encompasses approximately 100,000 galaxies stretched out over 160 Mpc (520 million light years). It has the approximate mass of 10^{17} solar masses, or 100,000 times that of our galaxy. It consists of four subparts, which were known previously as separate superclusters:

. – Virgo Supercluster, in which the Milky Way resides.
. – Hydra-Centaurus Supercluster, which includes.
. (a) The Great Attractor, Laniakea's central gravitational point near the Norma Antlia Wall,
. (b) The Hydra Supercluster.
. (c) The Centaurus Supercluster
. - Pavo-Indus Supercluster
.- Southern Supercluster
. (a) Formax Cluster, and
. (b) the Dorado and Eridanus clouds.

The entire supercluster consists of approximately 300 to 500 known galaxy clusters and groups. The real number may be much larger because some of these are traversing an area of the sky that is partially obscured by gas and dust from the Milky Way

Within a given supercluster, most galaxy motions will be directed inward, toward the centre of the mass. In the case of Laniakea, this gravitational focal point is called the Great Attractor. and influences the motions of the Local Group of galaxies, where the Milky Way galaxy resides. Unlike its constituent clusters, Laniakea is not gravitationally bound and is projected to be torn apart by dark energy.

Confirmation of the existence of the Laniakea Supercluster emerged only in 2014, although early studies in the 1980s had already suggested its existence.

Laniakea is itself a constituent part of the Pisces-Cetus Supercluster Complex, a galaxy filament.

KBC Void

The KBC Void is an immense, comparatively empty region of space, named after astronomers who studied it in 2013. The existence of a local underdensity has been the subject of many pieces of literature and research articles. The underdensity is proposed to be roughly spherical, approximately 2 billion light years (600 Mpcs) in diameter. It is not completely empty but contains part of the Laniakea Supercluster, the Virgo Super Cluster, the Local Group, the Milky Way and the Earth. The Milky Way is within a few hundred million light-years of the void's centre..

Discovery of the LSSs

It was commonly assumed that galaxy clusters were the largest structures in existence, distributed more or less uniformly throughout the universe in every direction. However, since the early 1980s, more and more structures have been discovered.

In 1983, a large quasar was identified consisting of 5 quasars. The discovery was the first identification of a larger-scale structure.

In 1987, the Pisces-Cetus-Supercluster Complex was identified, the galaxy filament in which the Milky Way resided. It was about 1 billion light-years across.

That same year, an unusually large region with a much lower than average distribution of galaxies was discovered, the Giant Void, which measures 1.3 billion light-years across. In 1989, the Great Wall was discovered, a sheet of galaxies more than 500 million light years-long and 200 million light-years wide, but only 15 million light-years thick.

The existence of this structure escaped notice for so long because it required locating the position of galaxies in three dimensions, which involved combining location information about galaxies with distance information from redshifts.

Two years later, the Clowes-Campusano Large Quasar Group was measuring two billion light-years at its widest point. In 2003, another large-scale structure was discovered, the Sloan Great Wall.

In 2007, a possible supervoid was detected in the constellation Eridanus, which coincided with a "CMB cold spot", a cold region in the microwave sky that was highly improbable under the currently favoured cosmological model. This supervoid could cause the cold spot, but to do so it would have to be improbably big, possibly a billion light-years across, almost as big as the Giant Void mentioned above.

In 2011, a large quasar group was discovered, measuring about 2.5 billion light-years across. On January 11, 2013, another large quasar group, the Huge-LQG was discovered, which was measured to be four billion light-years across, the largest known structure in the universe at that time.

In November 2013, astronomers discovered the Hercules-Corona Borealis Great Wall, an even bigger structure to cross, about 10 billion light years.. It was defined by the mapping of gamma-ray bursts.

In 2021, the American Astronomical Society announced the detection of the Giant Arc, a crescent-shaped string of galaxies that spanned 3.3 billion light-years in length, located 9.2 billion light years from Earth in the constellation Boötes.

Intergalactic gas

The most barren regions of the universe are the far-flung corners of intergalactic space. In these vast expanses between the galaxies there are only a few atoms per cubic meter – a diffuse haze of hydrogen gas left over from the Big Bang. Viewed on the largest scales, this diffuse material nevertheless accounts for the majority of atoms in the universe, and fills the universe. Intergalactic gas is so tenuous that it emits no light of its own.

Neutrinos

Neutrinos, due to their very small mass and extremely weak interaction with other matter, will free-stream in and out of voids which are smaller than the mean-free path of neutrinos. This has an effect on the size and depth distribution of voids, and is expected to make it possible with future astronomical surveys to measure the sum of the masses of all neutrino species by comparing the statistical properties of void samples to theoretical predictions.

Gamma-Ray Bursts (GRBs)

Gamma-ray bursts (GRBs) are immensely energetic explosions that have been observed in distant galaxies. They are the most energetic and luminous electromagnetic events since the Big Bangg. Bursts can last from ten milliseconds to several hours. After an initial flash of gamma-rays, a longer-lived "afterglow" is usually emitted at longer wavelengths (from X-ray to radio.)

The intense radiation of most observed GRBs is thought to be released during a supernova or super-luminous supernova, as a high-mass star implodes to form a neutron star or black-hole.

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Chapter Twelve
Galaxies

Galaxies are sprawling systems of dust, gas, dark matter and anywhere from a million to a trillion stars (ordinary matter) that are held together by gravity. Nearly all large galaxies are thought to also contain supermassive black holes at their centres

Galaxies are thought to begin as small clouds of stars and dust swirling through space. As other clouds get close, gravity sends these objects careening into one another and knits them into larger spinning packs

A star is formed and born in a galaxy. A galaxy may be thought of as the nursery of the stars. A galaxy is therefore any of the systems of stars and interstellar matter that make up the universe. Galaxies usually exist in clusters, some of which measure hundreds of millions of light-years across

Most galaxies are between 10 billion and 13.6 billion years old, formed when the universe was quite young! Astronomers believe that our own Milky Way galaxy is approximately 13.6 billion years old. The newest galaxy we know of formed only about 500 million years ago.

The light that we see from each of these galaxies comes from the stars inside it.

Classification

The Hubble sequence is a morphological classification scheme invented in 1926. It is often known colloquially as the “Hubble tuning-fork” because of the shape in which it is traditionally represented. Hubble's scheme divides galaxies into three broad classes based on their visual appearance:

. – **Elliptical galaxies** have smooth, featureless light distributions and appear as ellipses in images. They are denoted by the letter "E", followed by an integer n representing their degree of ellipticity on the sky.

Elliptical galaxies are among some of the largest known. Their stars are on orbits that are randomly oriented within the galaxy (i.e. they are not rotating like disk galaxies). A distinguishing feature of elliptical galaxies is that the velocity of the stars does not necessarily contribute to flattening of the galaxy, such as in spiral galaxies. Elliptical galaxies have central super-massive black-holes.

Elliptical galaxies contain mostly older stars. That means they often are not as bright as spiral galaxies. They also have very little dust and gas. Elliptical galaxies are the largest and most common galaxies observed. They make up about 20% of nearby galaxies.

. – **Spiral galaxies** consist of a flattened disk, with stars forming a (usually two-armed) spiral structure, and a central concentration of stars known as the bulge, which is similar in appearance to an elliptical galaxy. Spirals are often surrounded by a much fainter halo of stars, many of which reside in globular clusters.

Spiral galaxies are named by their spiral structures that extend from the centre into the galactic disc. The spiral arms are sites of ongoing star formation and are brighter than the surrounding disc because of the young, hot that inhabit them. Roughly two-thirds of all spirals are observed to have an additional component in the form of a bar-like structure, extending from the central bulge, at the ends of which the spiral arms begin

Spiral galaxies look like giant pinwheels. The arms of the pinwheel are made up of stars and lots of gas and dust. Gas and dust are some of the main ingredients needed to form new stars. Young stars burn much hotter than older stars, so spiral galaxies are often some of the brightest in the universe. About 60% of nearby galaxies are spirals. The Milky Way is a very good example of one.

Together with irregular galaxies spiral galaxies make up approximately 60% of galaxies in today's universe. They are mostly found in low-density regions and are rare in the centres of galaxy clusters.

. – **Lenticular galaxies** also consist of a bright centra bulge surrounded by an extended, disk-like structure but, the disks of lenticular galaxies have no visible spiral structure and are not actively forming stars in any significant quantity.

They consist mainly of aging stars (like elliptical galaxies). Despite the morphological differences, lenticular and elliptical galaxies share common properties like spectral features and scaling relations. Both can be considered early-type galaxies that are passively evolving, at least in the local part of the universe.

These broad classes can be extended to enable finer distinctions of appearance and to encompass other types of galaxies, such as **irregular galaxies**, which have no obvious regular structure (either disk-like or ellipsoidal).

. - **Irregular galaxies** are among the smallest galaxies observed. However, they can also be very bright. Like spiral galaxies, irregular galaxies are often filled with gas, dust, and lots of bright young stars. About 20% of nearby galaxies are irregular galaxies.

The Hubble sequence, still in use today, is often represented in the form of a two-pronged fork, with the ellipticals on the left (with the degree of ellipticity increasing from left to right) and the barred and unbarred spirals forming the two parallel prongs of the fork. Lenticular galaxies are placed between the ellipticals and the spirals, at the point where the two prongs meet the “handle”.

The de Vaucouleurs system is a widely used extension to the preceding, first described in 1959.

The de Vaucouleurs system introduced a more elaborate classification system for spiral galaxies, based on three morphological characteristics:

. - Bars. Galaxies are divided on the basis of the presence or absence of a nuclear bar. De Vaucouleurs introduced the an intermediate class, containing weakly barred spirals. Lenticular galaxies are also classified as unbarred or barred, with a notation for those galaxies for which it is impossible to tell.

. - Rings. Galaxies are divided into those possessing ring-like structures

. - Spiral Arms. As in Hubble’s original scheme, spiral galaxies are assigned to a class based primarily on the tightness of their spiral arms. The de Vaucouleurs scheme extends the arms of Hubble’s tuning fork to include several additional spiral classes:

Visually, the de Vaucouleurs system can be represented as a three-dimensional version of Hubble's tuning fork, with stage (spiral-ness) on the x-axis, family (barred-ness) on the y-axis, and variety (ringed-ness) on the z-axis

. – Disc Galaxies is a collective term referring to galaxies with discs, generally spiral and lenticular galaxies.

Galaxies generally divide into blue star-forming galaxies that are more like spiral types, and red non-star forming galaxies that are more like elliptical galaxies.

The majority of giant galaxies contain a supermassive black-holes in their centres, ranging in mass from millions to billions of times the mass of our Sun. The black hole mass is tied to the host galaxy bulge or spheroid mass.

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Galactic Components

Galactic Disc (or Disk)

A galactic disc, a component of disc galaxies, consist of a stellar component (composed of most of the galaxy's stars) and a gaseous component (mostly composed of cool gas and dust).

The stellar population of galactic discs tend to exhibit very little random motion with most of its stars undergoing nearly circular orbits about the galactic centre. Discs can be fairly thin because the disc material's motion lies predominantly on the plane of the disc (very little vertical motion). The Milky Way's disc, for example, is approximately 1 kilo light year thick.

Most of a galaxy's gas lies within the disc. Both cool atomic hydrogen (HI) and warm molecular hydrogen (HII) make up most of the disc's gaseous component. This gas serves as the fuel for the formation of new stars in the disc. Atomic hydrogen is distributed fairly uniformly throughout the disc. Like the stars within the disc, clumps or clouds of gas follow approximately circular orbits about the galactic centre. The circular velocity of the gas in the disc is strongly correlated with the luminosity of the galaxy.

Stellar Population

Bluer stars are strongly associated with the spiral arms, and yellow stars dominate near the central galactic bulge and within globular star clusters. The two main divisions were defined as Population I and Population II, with another newer, hypothetical division called Population III added in 1978.These three simple population classes usefully divided stars by their chemical composition or metallicity.

By definition, each population group shows the trend where decreasing metal content indicates increasing age of stars. Hence, the first stars in the universe (very low metal content) were deemed population III, old stars (low metallicity) as population II, and recent stars (high metallicity) as population I. The Sun is considered population I, a recent star with a relatively high 1.4% metallicity. Astrophysics nomenclature considers any element heavier than helium to be a "metal", including chemical non-metals such as oxygen

Three stellar components with varying scale heights can be distinguished within the disc of the Milky Way. The young thin disc is a region in which star formation is taking place and contains the youngest stars and most of its gas and dust. The scale height of this component is roughly 100 pc. The old thin disc has a scale height of approximately 325 pc, while the thick disc has a scale height of 1.5 kpc. Stars in the thin disc tend to have higher metallicities compared to the stars in the thick dis.

Active Galactic Nucleus (AGN)

An active galactic nucleus (AGN) is a compact region at the centre of a galaxy that has a much-higher-than-normal luminosity indicating that the luminosity is not produced by stars. Such excess non-stellar emission has been observed variously across all the EMR bands. A galaxy hosting an AGN is called an "active galaxy". The non-stellar radiation from an AGN is theorized to result from the accretion of matter by a supermassive black-hole at the centre of its host galaxy.
Numerous subclasses of AGN have been defined based on their observed characteristics; the most powerful AGN are classified as quasars.

Quasars

Quasars are compact areas in the centre of a galaxy. They give off enormous amounts of energy. Quasars are actually some of the brightest objects in the universe. There are no quasars near our Milky Way

Inter -Stellar Medium (ISM)

The Inter-stellar Medium (ISM) is matter that exists in the space between star systems and a galaxy, including the gas plasma, minute solid particles, dust and cosmic rays, and beyond the galactic disc or ovoid, or but within the galaxy's radius influence.

The interstellar medium is filled primarily with hydrogen gas and a relatively significant amount of helium, along with smaller percentages of other elements and molecular substances. In addition, primary cosmic rays travel through interstellar space, and magnetic fields thread their way across much of the region. Such matter accounts for about 5 percent of the Milky Way's galactic mass

In a spiral galaxy the interstellar medium makes up 3 to 5 percent of the galaxy's mass, but within the arm the mass fraction increases to about 20 percent. Much of the rest of the mass within a galaxy is concentrated in visible stars, but there is also some form of dark matter that accounts for a substantial fraction of the mass in the outer regions.

Nebula

A nebula ('cloud' or 'fog') is a distinct luminescent part of the ISM, which can consist of ionized, neutral or molecular hydrogen and also cosmic dust. In these regions, the formations of gas, dust, and other materials "clump" together to form denser regions, which attract further matter, and eventually will become dense enough to form stars. The remaining material is then believed to form planets and planetary systems and objects.

Most nebulae are of vast size; some are hundreds of light years in diameter. The Orion Nebula, the brightest nebula in the sky and occupying an area twice the angular diameter of the full Moon, can be viewed with the naked eye. Although denser than the space surrounding them, most nebulae are far less dense than any vacuum created on Earth – a nebular cloud the size of the Earth would have a total mass of only a few kilograms. Usually nebulae are visible due to fluorescence caused by embedded hot stars and T Tauri stars. Today the term nebula generally refers exclusively to the interstellar medium.

Galactic Mergers

Elliptical galaxies are more likely found in crowded regions of the universe (such as galaxy clusters). Astronomers now see elliptical galaxies as some of the most evolved systems in the universe. It is widely accepted that the main driving force for the evolution of elliptical galaxies is mergers of smaller galaxies. Many galaxies in the universe are gravitationally bound to other galaxies, which means that they will never escape their mutual pull. If the galaxies are of similar size, the resultant galaxy will appear similar to neither of the progenitors, but will instead be elliptical.

Mergers between such large galaxies are regarded as violent, and the frictional interaction of the gas between the two galaxies can cause gravitational shock waves which are capable of forming new stars in the new elliptical galaxy.

By sequencing several images of different galactic collisions, one can observe the timeline of two spiral galaxies merging into a single elliptical galaxy.

Global Clusters (of Stars)

A globular cluster is a spheroidal conglomeration of stars, bound together by gravity, with a higher concentration of stars towards their centres. They can contain anywhere from tens of thousands to many millions of member stars.

Globular clusters are found in nearly all galaxies, In spiral galaxies, like the Milky Way, they are mostly found in the outer spheroidal part of the galaxy – the galactic halo. They are the largest and most massive type of star cluster, tending to be older, denser, and composed of lower abundances of heavy metals than open clusters which are generally found in the discs of spiral galaxies. The Milky Way has more than 150 global clusters, and there may be many more.

Star clusters were formerly thought to consist of stars that all formed at the same time from one star-forming. Nebula, but nearly all globular clusters contain stars that formed at different times, or that have differing compositions. Some clusters may have had multiple episodes of star formation, and some may be remnants of smaller galaxies captured by larger galaxies.

The origin of globular clusters and their role in galactic evolution are unclear. Some are among the oldest objects in their galaxies and even the universe.

Examples of major galaxies

IC 1011 is a barred spiral galaxy with apparent magnitude of 14.7, and with a redshift of z=0.02564 or 0.025703, yielding a distance of 100 to 120 megaparsecs. Its light has taken 349.5 million years to travel to Earth. IC 1011's calculated age is approximately 12.95 billion years.

IC 1101 is a supergiant lenticular galaxy at the centre of the Abell 2029 galaxy cluster. It has an isophotal diameter at about 123.65 to 169.61 kiloparsecs (400,000 to 550,000 light years).

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Black-Holes

Black holes are points in space that are so dense they create deep gravity sinks. Beyond a certain region, not even light can escape the powerful tug of a black hole's gravity. And anything that ventures too close will be stretched and compressed like putty in a theoretical process known as spaghettification. A black hole is a region of spacetime where gravity is so strong that nothing – no particles or even electromagnetic radiation such as light – can escape

Some black holes are born when a dying star collapses in on itself. Others through mergers. And some may have started off in an even weirder way. There are four types of black-holes: stellar, intermediate, supermassive, and miniature.

Stellar Black-Holes

The most commonly known way a black-hole forms is by stellar death. As stars reach the end of their lives, most will inflate, lose mass, and then cool to form white dwarfs. But the largest of these fiery bodies, those of at least 10 to 20 solar masses, are destined to become either super-dense neutron stars or so-called stellar-mass black-holes.

In their final stages, enormous stars go out with a bang in massive explosions known as supernovae. Such a burst flings star matter out into space but leaves behind the stellar core. In the stellar remnants of a supernova, there are no longer forces to oppose gravity, so the star core begins to collapse in on itself. If its mass collapses into an infinitely small point, a **stellar black hole** is born.

Supermassive Black-Holes

When a massive star reaches the end of its life and implodes, it collapses in on itself. If the imploding star is between about eight and 20 times the mass of the Sun, however, it will not form a black-hole. Instead, the collapsing material will rebound off its core, causing it to erupt as a supernova, eventually becoming a neutron star.

But if the collapsing star is greater than about 20 times the mass of the Sun, its core is not strong enough to stop the implosion. In fact, there is no mechanism that can prevent such a star from collapsing into a black-hole. Depending on the initial size of the imploding star, the resulting stellar-mass black hole can reach up to about 100 or more times the mass of the Sun.

Black-holes tend to grow larger and larger through mergers into **supermassive black-holes** One of the most compelling theories is that they grow so large through a runaway chain reaction of colliding stars and black-holes. In this scenario, the seed of the supermassive black hole continually merges and gobbles up more and more material, eventually getting so massive it “sinks” toward the centre of its galaxy. Along the way, the black-hole might join up with more stellar- and intermediate-mass black-holes, growing even more massive. But eventually, it will make it to the galaxy’s core (if it did not already start there) and continue to gorge on whatever material strays too close. Over billions of years, this process might enable a black hole to grow to millions times the mass of the Sun

Supermassive black-holes, predicted by Einstein's general theory of relativity, can have masses equal to billions of suns; these cosmic monsters likely hide at the centres of most galaxies. The Milky Way hosts its own supermassive black hole at its centre known as Sagittarius A* that is more than four million times as massive as our sun, detected only in the early 2000s.

Miniature or Primordial Black-Holes

The tiniest members of the black hole family are, so far, theoretical. These **miniature or primordial black-holes**, small vortices of darkness, may have swirled to life soon after the universe formed with the big bang, some 13.7 billion years ago, and then quickly evaporated. This was a time long before stars, galaxies, and other black holes existed.

They would have popped into existence when the newly created universe was not yet homogenous and evenly distributed. At this point, some scientists think that certain parts of the universe were unbelievably rich in energy. Tiny insanely energetic points in space could have theoretically collapsed directly into primordial black holes. And depending on just how soon after the Big Bang these first black-holes formed, they could have ranged from about 0.00001 times the mass of a paperclip to about 100,000 times the mass of the Sun.

Intermediate Black-Holes

An intermediate black hole (IMBH) is a class with mass in the range 102–105 solar masses, significantly more than stellar black-holes. Several candidate objects have been discovered in our galaxy and others nearby, based on indirect gas cloud velocity and accretion disk spectra observations of various evidentiary strength.

Intermediate-mass black holes are thought to form when multiple stellar-mass black-holes undergo a series of mergers with one another. These mergers frequently happen in crowded areas of galaxies, like global clusters, and grew with consecutive mergers.

There are three postulated formation scenarios for IMBHs. The first is the merging of stellar holes and other compact objects by means of accretion. The second one is the runaway collision of massive stars in star clusters and the collapse of the collision product into an IMBH. The third is that they are primordial formed in the Big Bang. Thousands of these may lurk within the Milky Way galaxy.

The energy release for (stellar) black holes and neutron stars are of the same order of magnitude. Black-holes and neutron stars are therefore often difficult to distinguish, quite apart from classifying them.

No matter their starting size, black holes can grow, slurping gas and dust from any objects that creep too close. Anything that passes the event horizon, the point at which escape becomes impossible, is in theory destined for spaghettification. Objects must creep fairly close to one to lose the gravitational tug-of-war. For example, if the Sun was suddenly replaced by a black hole of similar mass, its planetary family would continue to orbit unperturbed, if much less warm and illuminated.

Objects can orbit a black-hole, and astronomers look for stars that seem to orbit nothing to detect a likely candidate. Black-holes are also messy eaters, which often betrays their locations. As they sip on surrounding stars, their massive gravitational and magnetic forces superheat the infalling gas and dust, causing it to emit radiation. Some of this glowing matter envelops the black-hole in a whirling region called an **accretion disk**. Even the matter that starts falling into a black hole is not necessarily there to stay. Black holes can sometimes eject infalling star dust, etc, laden with radiation.

Near a black hole, the slowing of time is extreme. From the viewpoint of an observer outside the black hole, time stops. For example, an object falling into the hole would appear frozen in time at the edge of the hole.

Wormholes are shortcuts in spacetime, popular with science fiction authors and movie directors. They've never been seen, but according to Einstein's general theory of relativity, they might exist.

Black holes are freezing cold on the inside, but incredibly hot just outside. The internal temperature of a black hole with the mass of the Sun is around one-millionth of a degree above absolute zero.

Hawking Radiation

Forty years ago Stephen Hawking, the world's foremost expert on black holes, announced that they evaporate and shrink because they emit radiation Black hole evaporation. When particles escape, the black hole loses a small amount of its energy and therefore some of its mass. Consequently, an evaporating black hole will have a finite lifespan.
For all their extraordinary power, black holes are not immortal. They have a life cycle.

Over time they shrink down to nothing and simply pop away in a flash of energy. It's not exactly fast. A good size black hole — say, a few times more massive than the sun — will take about 10^{100} years to eventually evaporate through this process, known as Hawking Radiation.

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The Milky Way

The Milky Way is the galaxy that includes our Solar System, with the name describing the galaxy's appearance from Earth: a hazy band of light seen in the night sky formed from stars that cannot be individually distinguished by the naked eye. From Earth, the Milky Way appears as a band because its disk-shaped structure is viewed from within.

Until the early 1920s, most astronomers thought that the Milky Way contained all the stars in the universe. Since then, the Milky Way has been found to be just one of many galaxies.

The Milky Way is a barrel spiral galaxy, with an estimated visible diameter of 100,000–200,000 light-years. Recent simulations suggest that a dark matter area, also containing some visible stars, may extend it up to a diameter of almost 2 million light-years.

The Milky Way has several satellite galaxies, and is part of a Local of galaxies, which form part of the Virgo Supercluster, which is itself a component of the Laniakea Supercluster.
I
t is estimated to contain 100–400 billion stars and at least that number of planets. The Solar System is located at a radius of about 27,000 light-years from the Galactic Centre, on the inner edge of the Orion Arm, one of the spiral-shaped concentrations of gas and dust.

The stars in the innermost 10,000 light-years form a bulb and one or more bars that radiate from the bulge. The galactic centre is an intense radio source known as Sagittarius A*, a supermassive black of 4.100 (± 0.034) million solar masses Stars and gases at a wide range of distances from the Galactic Center orbit at approximately 220 km/s.

The constant rotational speed appears to contradict the laws of Keplerian dynamics and suggests that much (about 90%) of the mass of the Milky Way is invisible to telescopes, neither emitting nor absorbing electromagnetic radiation. This conjectural mass has been termed “dark matter”. The rotational period is about 240 million years at the radius of the Sun.

The Milky Way as a whole is moving at a velocity of approximately 600 km per second with respect to extragalactic frames of reference. The oldest stars in the Milky Way are nearly as old as the universe itself and thus probably formed shortly after the Big Bang.

Galactic Co-ordinate System

The galactic coordinate system locates objects within the Milky Way by 'latitude' and "longitude". The current definition of the galactic coordinate system was finalised by the IAU in 1959.

The galactic plane or galactic is similar to the celestial equator of the equatorial coordinate system. It is the great circle of the celestial sphere made by the plane of the disk of our Galaxy.

The galaxy is commonly divided into four quadrants, **the Alpha Quadrant, the Beta Quadrant, the Gamma Quadrant and the Delta Quadrant**. Most astrometric representations of the Milky Way depict the border of the Alpha and Beta Quadrant running through the Solar System.

The northern zodiac constellations – Pisces, Aries, Taurus, Gemini, Cancer and Leo – are located in the eastern celestial hemisphere, while the southern – Virgo, Libra, Scorpius, Sagittarius, Capricornus and Aquarius – are found in the west.

Local Group

The Local Group is a galaxy group of closely bound galaxies, that includes the Milky Way. It has a total diameter of roughly 10 million light years and a total mass of the order of 2×10^{12} solar masses. It consists of two collections of galaxies in a "dumbbell" shape: the Milky Way and its satellites form one lobe, and the Andromeda Galaxy and its satellites constitute the other. The two collections are separated by about 800 kpc (3 million light years) and are moving toward one another with a velocity of 123 km/s, They are expected to collide in less than five billion years. .

The group itself is a part of the larger Virgo Supercluster which is a part of the larger Laniakea Supercluster. The exact number of galaxies in the Local Group is unknown as some are occluded by the Milky Way; however, at least 80 members are known, most of which are dwarf galaxies. The two with masses of about 10^{12} solar masses each have their own system of satellite galaxies. The Andromeda Galaxy has 12 satellite systems, with several more barely visible. The Milky Way has 15 satellite systems, with several more barely visible.

The Triangulum Galaxy (M33) is the third-largest member of the Local Group, and is the third spiral galaxy. It is unclear whether the Triangulum Galaxy is a companion of the Andromeda Galaxy; the two galaxies are 750,000 light years apart, and experienced a close passage 2–4 billion years ago. which triggered star formation across the Andromeda's disk.

The fourth largest member of the Local Group is the Magellanic Spiral Galaxy, the only member of the Magellanic Cloud in the group. In addition there are at least over 70 irregular, dwarf and at least one elliptic galaxy attached to the three main members.

The Milky Way and the Andromeda Galaxy are a binary system. The mass of the entire Milky Way is estimated to be only half the mass of the Andromeda Galaxy. Current measurements suggest the Andromeda Galaxy is approaching the Milky Way at 100 to 140 km/s (220,000 to 310,000 mph). In 4.3 billion years, there may be a collision, depending on the importance of unknown lateral components to the galaxies' relative motion. The chance of individual stars colliding with each other is extremely low, but instead the two galaxies will merge to form a single elliptical galaxy or perhaps a large disk galaxy over the course of about six billion years.

Features of Milky Way

The Milky Way consists of a bar-shaped core region surrounded by a warped disk of gas, dust and stars. The mass distribution within the Milky Way classifieds it as a spiral galaxy with relatively loosely wound arms.

The Milky Way has an estimated diameter of 87,500 light years (27 kpc), but only about 1,000 light years thick at the spiral arms (more at the bulge). Recent simulations suggest that a dark matter area, also containing some visible stars, may extend its diameter to almost 2 million light-years (613 kpc). The Milky Way has several satellite galaxies. It is estimated to contain **100–400 billion stars** and at least that number of planets.

As viewed from Earth, the visible region of the Milky Way's galactic plane occupies an area of the sky that includes 30 constellations .

The galactic plane is inclined by about 60° to the ecliptic (the plane of the Earth's orbit). Relative to the celestial equator (same as Earth's equator, it passes as far north as the constellation of Cassiopeia and as far south as the constellation of Crux, indicating the high inclination of Earth's equatorial plane and the plane of the ecliptic relative to the galactic plane

The oldest stars in the Milky Way are nearly as old as the universe itself and thus probably formed shortly after the dark ages of the Big Bang. The Milky Way as a whole is moving at a velocity of approximately 600 km/s with respect to extragalactic frames of reference.

Galactic Bulge

The stars in the Milky Way's innermost diameter of 10,000 light-years comprise a dense concentration of mostly old stars in a roughly spheroidal shape called a Bulge, with one or more bars that radiate from the bulge. Some estimates give as many as 10 million stars populating the Milky Way's galactic bulge. The bulge contains mostly reddish stars. Many of them are relatively old -- ten billion years or more

The bulge at the centre of the galaxy lies somewhere in the middle (the Galactic Centre). At the very centre of the bulge is a supermassive black hole, but it does not have much of an effect outside of its immediate vicinity.

Galactic Centre

The Galactic Center is the rotational centre, the barycentre, of the Milky Way galaxy. It lies in the direction of the constellation Sagittarius, where the Milky Way is brightest. The Galactic Centre of the Milky Way is an intense radio source known as Sagittarius* - a supermassive black-hole of 4..1 million solar masses.

Spiral Arms

Outside the gravitational influence of the Galactic bar, the structure of the interstellar medium and stars in the disk of the Milky Way is organised into four spiral arms. Spiral arms typically contain a higher density of interstellar gas and dust than the Galactic average as well as a greater concentration of star formation.

The Milky Way's spiral structure is uncertain, and there is currently no consensus on the nature of the Milky Way's arms. Estimates of the pitch angle of the arms range from about 7°

to 25°.There are thought to be four spiral arms that all start near the Milky Way Galaxy's centre. These are named as follows

. – 1. Near 3kpc Arm and Perseus Arm
. – 2. Norma and Outer Arm
. - 3.Scutum-Centaurus Arm
. - 4 Carina-Sagittarius Arm
Two Smaller ones
. - 5 Orion-Cygnus Arm (which contains the Sun and Solar System)

Observers suggest that the Milky Way possesses only two major stellar arms: the Perseus arm and the Scutum–Centaurus arm. The rest of the arms contain excess gas but not excess old stars. In December 2013, astronomers found that the distribution of young stars and star-forming regions matched the four-arm spiral description of the Milky Way. Thus, the Milky Way appears to have two spiral arms as traced by old stars and four spiral arms as traced by gas and young stars.

The bulk of the stars in a spiral galaxy are located either close to a single plane (the galactic plane) in more or less conventional circular orbits around the Galactic Centre, or in a spheroid orbit around the Galactic Bulge.

Stars and gases at a wide range of distances from the Galactic Centre orbit at approximately 220 km/s. The constant rotational speed appears suggests that much (about 90%) of the mass of the Milky Way is invisible to telescopes, neither emitting nor absorbing electromagnetic radiation. This conjectured mass has been termed “dark Matter”. The rotational period is about 212 million years at the radius of the Sun.

Galactic Halo

The disk of stars in the Milky Way does not have a sharp edge beyond which there are no stars. Rather, the concentration of stars decreases with distance from the centre of the Milky Way. For reasons that are not understood, beyond a radius of roughly 40,000 light years (13 kpc) from the centre, the number of stars per cubic kpc drops much faster with radius.

Surrounding the galactic disk is a spherical galactic halo of globular clusters, open clusters, star associations and stars that extends farther outward, but limited in size by the orbits of two Milky Way satellites, the Large and Small Magellanic Clouds whose closest approach to the Galactic Centre is about 180,000 light years (55 kpc). At this distance or beyond, the orbits of most halo objects would be disrupted by the Magellanic Clouds. Hence, such objects would probably be ejected from the vicinity of the Milky Way.

They differ primarily in age and in the number of member stars.The largest and most massive star clusters are the globular clusters, so called because of their roughly spherical appearance. The Milky Way contains more than 150 globular clusters.

The orbital behaviour of these stars is disputed, but they may exhibit retrograde or highly inclined orbits, or not move in regular orbits at all. Halo stars may be acquired from small galaxies which fall into and merge with the spiral galaxy—for example, the Sagittarius Dwarf Spheroid Galaxy is in the process of merging with the Milky Way and observations show that some stars in the halo of the Milky Way have been acquired from it.

Unlike the galactic disk, the halo seems to be free of dust, and in further contrast, stars in the galactic halo are of Population II, much older and with much lower metallicity than their Population I cousins in the galactic disk (but similar to those in the galactic bulge).

Satellite Galaxies

The Milky Way has a number of satellite galaxies, but the biggest one is the Large Magellanic Cloud. It is about 163,000 light years away and around 1/100th the size of the Milky Way. It lacks a clean spiral shape. Some scientists think that is because the Milky Way and other galaxies are pulling and warping it.

In terms of distance, there are two contenders for closest satellite galaxy. One group of stars is small enough that astronomers consider it a dwarf galaxy. The other group is so close that they still debate whether or not it is part of the Milky Way or its own dwarf galaxy. Astronomers have named the first as the Sagittarius Dwarf Spheroidal Galaxy. It is about 50,000 light-years away from the Milky Way centre. It orbits over the top and down below the disk of the Milky Way like a ring over a spinning top.

But there is something even closer to our Milky Way—a cluster of stars named by some to be the Canis Major Dwarf Galaxy. Scientists estimate that it contains around a **billion** stars. It is so close to the edge of the Milky Way that it is closer to our solar system than to our galaxy's centre. It's about 25,000 light-years away from Earth.

Satellite Galaxies

The satellite galaxies surrounding the Milky way are not randomly distributed, but seem to be the result of a break-up of some larger system producing a ring structure 500,000 light-years in diameter and 50,000 light-years wide. Close encounters between galaxies over time can coalesce to form dwarf galaxies in a ring at an arbitrary angle to the main disk.

In 2014 researchers reported that most satellite galaxies of the Milky Way lie in a very large disk and orbit in the same direction. This came as a surprise: according to standard cosmology, the satellite galaxies should form in dark matter halos, and they should be widely distributed and moving in random directions. This discrepancy is still not fully explained.

Two smaller galaxies and a number of dwarf galaxies in the Local Group orbit the Milky Way. The largest of these is the Large Magellanic Cloud with a diameter of 14,000 light-years. It has a close companion, the Small Magellanic Cloud. The Magellanic Stream is a stream of neutral hydrogen gas extending from these two small galaxies across 100° of the sky. The stream is thought to have been dragged from the Magellanic Clouds in tidal interactions with the Milky Way.

Some of the dwarf galaxies are the Canis Major Dwarf (the closest), Sagittarius Dwarf Elliptical Galaxy, Ursa Minor Dwarf, Sculptor Dwarf, Sextans Dwarf, Formax Dwarf and the Leo I Dwarf.

The smallest dwarf galaxies of the Milky Way are only 500 light-years in diameter. These include the Carina Dwarf, Draco Dwarf and the Leo II. There may still be undetected dwarf galaxies that are dynamically bound to the Milky Way, which is supported by the detection of nine new satellites of the Milky Way in a relatively small patch of the night sky in 2015. There are also some dwarf galaxies that have already been absorbed by the Milky Way, such as the progenitor of Omega Centauri.

Warped Disk

In January 2006, researchers reported that the heretofore unexplained warp in the disk of the Milky Way had been mapped and found to be a ripple or vibration set up by the Large and Small Magellanic Clouds as they orbitted the Milky Way, causing vibrations when they passed through its edges. Previously, these two galaxies, at around 2% of the mass of the Milky Way, were considered too small to influence the Milky Way. However, in a computer model, the movement of these two galaxies has creates a dark matter wake that amplifies their influence on the larger Milky Way.

Inter Stellar Medium (ISM)

In addition to the stars, there is also interstellar gas, comprising 90% hydrogen and 10% helium by mass, with two thirds of the hydrogen found in the atomic form and the remaining one-third as molecular hydrogen. The mass of the Milky Way's interstellar gas is equal to between 10% and 15% of the total mass of its stars. Interstellar dust accounts for an additional 1% of the total mass of the gas.

Local Interstellar Cloud (LIC)

The Local Interstellar Cloud (LIC), also known as the Local Fluff, is roughly 30 light years (9.2 pc) across, through which the Solar System is moving. This feature overlaps a region around the Sun referred to as the Solar Neighbourhood. It is unknown whether the Sun is embedded in the Local Interstellar Cloud, or is in the region where the Local Interstellar Cloud is interacting with the neighbouring G-Cloud.

Like the G-Cloud and others, the LIC is part of the Very Local Inter Stellar Medium (ISM), which begins where the Sun's heliosphere and the Inter Planetary Medium (IPM) end.

Solar System

The Solar System is located at a radius of about 27,000 light-years (8.3 kpc) from the Galactic Centre, on the inner edge of the Orion Arm, one of the spiral-shaped concentrations of gas and dust.

The Solar System is located within a structure called the Local Bubble, a low-density region of the galactic ISM. Within this region is the Local Interstellar Cloud (LIC), an area of slightly higher hydrogen density. It is estimated that the Solar System entered the LIC within the past 10,000 years. It is uncertain whether the Sun is still inside of the LIC or has already entered a transition zone between the LIC and the G-Cloud. A recent analysis estimates the Sun will completely exit the LIC in no more than 1900 years.

The LIC has a temperature of about the same as the surface of the Sun. It is not very dense, with 0.3 atoms per cubic centimetre (4.9/cu in). This is less dense than the average for the interstellar medium of the Milky though six times denser than the gas in the hot, low-density Local Bubble which surrounds the local cloud.

The Sun, and thus the Solar System, is located in the Milky Way's galactic habitable zone (I should think so!)

The apex of the Sun's way, or the solar apex, is the direction that the Sun travels through space in the Milky Way. The general direction is towards the star Vega near the constellation Hercules, at an angle of roughly 60 sky degrees to the direction of the Galactic Centre.

The Sun's orbit about the Milky Way is expected to be roughly elliptical with the addition of perturbations due to the Galactic spiral arms and non-uniform mass distributions.

In addition, the Sun passes through the galactic plane approximately 2.7 times per orbit. These oscillations were until recently thought to coincide with mass life-form extinction periods on Earth.

Dark Matter

Much of the mass of the Milky Way seems to be dark matter. A dark matter halo is conjectured to spread out relatively uniformly to a distance beyond 326,100 light years (100 kpc) from the Galactic Center. In March 2019, astronomers reported that the virial mass of the Milky Way galaxy is 1.54 trillion solar masses, within a radius of about 130,000 light years (39.5 kpc) and suggesting that about 90% of the mass of the galaxy is dark matter

The least-understood component is the giant massive (dark?) halo that is exterior to the entire visible part. All that can be said with any certainty is that the halo extends considerably beyond a distance of 100,000 light-years from the centre and that its mass is several times greater than the mass of the rest of the Galaxy taken together. It is not known what its shape is, what its constituents are, or how far into intergalactic space it extends

A 2020 study predicted the edge of the Milky Way's dark matter halo being around 1 million light years (330 kpc) (which translates to a diameter of 2 million light years (660 kpc). The Milky Way's stellar disk is also estimated to be approximately up to 4,000 light years 1.35 kpc) thick.

The nature of the dark matter in the Galaxy remains one of the major questions of galactic astronomy. Many other galaxies also appear to have such undetected matter.

Exoplanets

On November 4, 2013, astronomers reported, based on the Kepler space mission data, that there could be as many as 40 billion Earth-sized planets orbiting in the habitable zones of Sun-like stars and red dwarfs within the Milky Way. 11 billions of these estimated planets may be orbiting Sun-like stars. The nearest exoplanet may be 4.2 light-years away, orbiting the red dwarf Proxima Centauri according to a 2016 study. Such Earth-sized planets may be more numerous than gas giants.

An exoplanet is also called an “extrasolar planet” - both terms simply mean a planet which is in orbit around another star .

X-rays/Gamma Rays

Since 1970, various gamma-ray detection missions have discovered 511 keV gamma-rays coming from the general direction of the Galactic Centre. NASA and ESA satellite observations indicated these gamma rays were are produced by positrons (antielectrons) annihilating with electrons, both emanating from X-ray binaries. The 1970 gamma ray detectors found that the emitting region was about 10,000 light-years across with a luminosity of about 10,000 suns.

In 2010, two gigantic spherical bubbles of high energy gamma-emission were detected to the north and the south of the Milky Way core, using data from the Fermi Gamma-ray Space Telescope. The diameter of each of the bubbles was about 25,000 light-years (7.7 kpc) or about 1/4 of the galaxy's estimated diameter.

Subsequently, observations at radio frequencies identified polarised emission that is associated with the Fermi bubbles. These observations are best interpreted as a magnetized outflow driven by star formation in the central 640 light years (200 pc) region of the Milky Way.

Active Galactic Nuclei and Supermassive Black Holes

Active Galactic Nuclei (AGN) are located at the centre of large galaxies, and they are viewed usually visible from Earth as point sources of radiation, as most AGN are so far away that the host galaxy is not easily visible. Light from an AGN that is 10 billion light years away has taken 10 billion years to reach us, and we view the AGN as it looked 10 billion years ago. At this time the universe was young; many galaxies were still forming and had lots of gas spread throughout them.

AGN are powered by Supermassive Black Holes (SMBH). The light does not come from within the SMBH, but rather from the surrounding accretion disk. An accretion disk is a swirling disk of material that is falling into the SMBH. The material in this disk is heated to insanely hot temperatures by friction, causing the disk to glow so brightly that they are considered to be the most luminous objects in the universe.

Today, scientists believe that all large galaxies have a SMBH at their core. A galaxy is considered "active" when that SMBH at the centre has an accretion disk and matter is falling into it. Not all galaxies are active. For example, the Milky Way has a SMBH at its core, but it is not currently accreting a significant amount of material.

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Quasars

More than one million quasars have been found since their discovery in 1962 by Dutch astronomer Maarten Schmidt. They have been discovered using radio surveys, visible observations and X-ray surveys. Quasars are strong emitters almost uniformly across the entire electromagnetic spectrum.

Quasars are known for their incredibly high luminosities. They are among the most luminous objects in the universe. They were far more luminous than any known galaxy. They are more than one trillion times brighter than the Sun. The most luminous quasars are called “blazars”.

Quasars are believed to be powered by gravitational accretion on supermassive blackholes. Gravitational accretion is the accumulation of particles into a massive object by gravitational attraction. Gas particles are attracted by the gravitational pull of the blackhole, and form what is known as an accretion disc.

Quasars are also incredibly compact. Far more luminous than any known galaxy, they are less than a few light-days across. They can have masses one million times greater than the Sun.

Several theories were developed to try and explain the observed phenomena of quasars. One explanation was that they were not as distant as measurements indicated. Another explanation was chain reactions set off by supernovae. A supernova in a dense star cluster could set off a chain reaction in which many stars would explode. More exotic explanations include: quasars were composed of some form of stable antimatter, and quasars were white holes at the end of a wormhole. It is now widely accepted that quasars are in fact distant and incredibly luminous objects.

The first black hole was identified in 1971, and led to an explanation for how quasars could be small, while also being massive and luminous. A model was developed that quasars are powered by matter from an accretion disc falling onto a supermassive black hole. Many galaxies have a black hole in the centre. Some of these galaxies have regions of extremely high luminosity at their centre. These are known as active galaxies and the region in the centre is known as an Active Galactic Nucleus (AGN) . The most powerful active galactic nuclei are called quasars.

It was observed that some do not have strong radio emissions. This led to quasars being classified as radio-loud and radio-quiet. Radio emission from quasars is due to highly collimated jets of radiation that are produced by the accretion disc. Quasars radiate energy most strongly in the direction of the jet. The most luminous quasars have beams that are pointed directly at the Earth. These are known as blazars. If the jet is perpendicular to Earth, it appears as a “radio galaxy” - a galaxy that is very luminous in radio frequencies.

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Chapter Thirteen
Stars

A star is a massive ball of hot, glowing matter in space. That substance is known as plasma. Gravity holds stars together. A star is any massive self-luminous celestial body of gas that shines by radiation derived from its internal energy sources. Of the tens of billions of trillions of stars in the observable universe, only a very small percentage are visible to the naked eye.

Stars are huge celestial bodies made mostly of hydrogen and helium that produce light and heat from the churning nuclear forges inside their cores.

It is convenient to think of the stars as the primary components or building blocks of the observable universe. They are born in nebulae, and mature and die in life cycles, within larger clusters, galaxies and galaxy-clusters.

As a star grows, it enters one of two pathways of life. Depending on its size, the star becomes either an average star or a massive star. The average star then becomes a red giant, a planetary nebula, and ends its life as a white dwarf. The massive star turns into a red supergiant, goes supernova, and ends up as a neutron star or a black hole. Some stars are much smaller than the Sun.

A star is a luminous spheroid of plasma, held together by gravity. At any one time, all stars in the universe will be in different stages of their life cycle

A star's life begins with the gravitational collapse of a gaseous nebula, of material composed primarily of hydrogen along with helium and trace amounts of heavier elements. A star shines for most of its active life due to the thermonuclear fusion of hydrogen into helium in its core.. At the end of a star's lifetime, its core becomes a stellar remnant, a white dwarf, a neutron star or, if massive enough a black hole.

Stella nucleosynthesis in stars or their remnants creates almost all the naturally occurring chemicals heavier than lithium. Stellar mass loss or supernova explosions return this chemically enriched material to the interstellar medium. These elements are then recycled into new stars.

The observable universe contains an estimated 10^{22} to 10^{24}stars. Still, most are invisible to the naked eye from Earth, including all individual stars outside our galaxy, the Milky Way

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Constellations

Since ancient times, the more prominent clusters and groups of visible stars have been identified as constellations (and asterisms),

A constellation is an area of the celestial sphere in which a group of visible stars form a perceivable pattern or outline, typically representing an animal, mythological subject, or inanimate object. Since ancient times, astronomers of different civilisations have named, catalogued and mapped. The celestial hemispheres were divided into quadrants, and systems of co-ordinates applied to locate and navigate by them, as well as by all other stars. Many prominent stars were also given proper names. In a separate system, the Sun and planets moved back and forth in an annual cycle straddling the zodiac belt, which overlapped 13 of the constellations.

Before modern science (the telescope) this was the celestial world, and the principal means on navigation on land and sea, and still in use. In 1922, the IAU formally accepted the modern list of 88 constellations and in 1928 adopted their celestial boundaries. The IAU has also officially approved 227 proper names of stellar designations.

Other star patterns or groups called asterisms are also used by observers to navigate the night sky. Asterisms may be several stars within a constellation, or they may share stars with more than one constellation.

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Classification of Stars

A star can be classified into one of seven groups according to its properties, or spectral attributes. Some of these properties are size, colour, temperature, and stage in their life cycle. All suns, including our Sun, are stars. It looks so much bigger than other stars because it is much closer to Earth than all the other stars.

Astronomers can determine stellar properties—including mass, age, chemical composition, variability, distance and motion through space by carrying out observations of a star's apparent brightness, spectrum, and the changing position over time.

Spectral Classification

The spectral sequence is a temperature sequence used to classify stars and arranges them according to temperature based on a star's spectrum.

There are seven main types of stars, and they are grouped by a system called spectral classification. This system organises stars into groups by their temperature, colour, and luminosity (brightness). So far, the system has been based on the Visible spectrum.

These groups are the O, B, A, F, G, K, and M-class stars. The hottest stars are the blue-colored O-class stars, with an average temperature of more than 28,000 degrees Kelvin. The coolest stars are the red-colored M-class stars with an average temperature of fewer than 3,500 degrees Kelvin. M-class stars are still very hot, just not as hot in comparison to O-class stars.

O-Class Stars

O-class stars are the hottest stars with surface temperatures that range from approximately 30,000 degrees Kelvin and higher. These stars are blue and are very bright. Even though O-class stars are very young, there are not many of them compared to other stars in our universe. Their life cycles are usually shorter than other stars. This is because of the intensity of their heat and the immense amount of mass they have. These two factors cause O-class stars to exhaust their fuel more quickly and experience supernova events which result in the star becoming either a neutron star or a black hole.

B-Class Stars

B-class stars have surface temperatures that range from approximately 20,000 to 30,000 degrees Kelvin. These stars are blue-white and very bright. Like O-class stars, these stars are young and rare in our universe. B-class stars burn so quickly that they use up all their energy in a very short amount of time. As a result, their life cycles are rather short.

A-Class Stars
A-class stars have surface temperatures ranging from 10,000 to 20,000 degrees Kelvin and are white. They are relatively young and make up less than 1% of stars in the universe. These stars are very bright, making them visible to the unaided eye. This means you can see them without the aid of a telescope or other type of technology.

F-Class Stars
F-class stars have surface temperatures ranging from approximately 7,000 to 10,000 degrees Kelvin. They are whitish-yellow, are relatively bright, and are closer to the middle of their life cycles than O, B, or A-class stars. Approximately 3% of the main-sequence stars in our universe are classified as F-class stars.

G-Class Stars
The surface temperature of G-class stars is approximately 6,000 to 7,000 Kelvin. These stars are yellow in colour, large, and have an average brightness. They are sometimes called yellow stars and almost 8% of the stars in the universe fall into this category. G-class stars are just about in the middle of their life cycle. The most famous yellow star is **our sun**. Since their mass is not as immense as O, B, or A-class stars, the life span of G-class stars can last for billions of years.

K-Class Stars
K-class stars have a surface temperature that is less than our Sun but that does not mean they are cold. With an average range of about 5,000 to 6,000 degrees Kelvin, these orange-colored stars do not shine as brightly as the others. These stars are relatively old in their life cycles.

M-Class Stars

M-class stars are the coolest stars having surface temperatures less than 5,000 degrees Kelvin. They are large red stars and are often called **red giants**. These stars are old and are nearing the end of their lifecycle. Even though they are not very bright, they can still be seen as twinkling red dots in the night sky. Making up approximately **75% of the stars, M-class** stars are the most abundantly found type of star in our universe.

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Types of Stars by Size

Stars are also classified by their size.

Supergiants
Supergiant stars are enormous and contain an immense amount of mass. To put that in perspective, over one million of our Earths could fit into our Sun, and the mass of these supergiants can range anywhere between 10 to 70 times more the Sun. They can be found at opposite ends of the spectral classification. Blue supergiants have temperature ranges from 10,000 degrees Kelvin to over 50,000 degrees Kelvin. Red-orange supergiants have lower temperatures ranging from around 3,500 to 5,000 degrees Kelvin. These massive stars burn through their energy more quickly than other types of stars. As a result, supergiants have relatively short life-spans, ranging from 10 million to 50 million years. These stars are rare in our universe because of their short life spans.

Giant Stars

Giant stars are not as big as supergiants, their masses can range up to 70 times more than the Sun, and they are similar in life span and size, depending on where they fall in their spectral classification. Giant stars are K and M-class stars with temperatures between 3,500 to 5,000 degrees Kelvin. Even though their temperatures are considered low, they are still very bright stars. These stars are not abundant in our universe.

Main-Sequence

Main-sequence stars are the most abundantly found star in the universe. The Sun is a main-sequence star. These stars have the most variety in characteristics with spectral classifications from O-class to M-class stars.

White Dwarf Stars

The white dwarf is a main sequence star. White dwarf stars have very high temperatures that exceed 100,000 degrees Kelvin and are very bright. They are small in comparison to other stars, averaging a size similar to that of Earth, but have a much greater density. Their large densities contribute to their strong gravitational pull.

Brown Dwarf Stars

Technically, a brown dwarf is a substellar celestial object with too low a mass for nuclear fusion reactions. Brown dwarfs are objects that began their lives as stars but they just never got big enough to sustain nuclear reactions. This is because when an object like a brown dwarf has a mass less than about 0.08 solar masses, it's not large enough to allow for hydrogen fusion (that is to say, nuclear reactions) to take place.

Brown dwarfs give off little energy, making them less luminous than other stars. Because most of their energy is radiated out in infrared because of their low temperatures, they are mainly a very dim reddish-orange colour to our eyes. So dim, that we didn't find the first one until 1995! But astronomers now believe there may be as many brown dwarfs as stars in our galaxy.

Brown dwarf stars have been called "failed stars" due to their inability to reach temperatures high enough to perform hydrogen fusion. This leaves the star in a state of permanence as a brown dwarf.

Brown dwarfs form alongside stars in clusters, so there are a huge number of brown dwarfs out there. The researchers determined that the minimum number of brown dwarfs in the Milky Way is somewhere between **25 billion to 100 billion** – slightly less that red dwarfs.

Brown dwarfs do not have enough mass to ignite the nuclear fusion of ordinary hydrogen. After their deuterium is gone, brown dwarfs glow in the invisible light of infrared waves for billions of years, their insides churned and warmed by the bubbling of escaping heat as they slowly collapse under their weight. Brown dwarf stars will eventually cool down and become dark balls of cold gas.

Some scientists do not consider brown dwarfs to be true stars because they do not have enough mass to ignite the nuclear fusion of ordinary hydrogen.

Brown dwarfs are stars that can often be mistaken for a planet. However, 0.013 solar masses, about 13 times the mass of Jupiter, is generally considered to be a reasonable estimate for the lower-end mass of a brown dwarf. They are close in size to the planet Jupiter, but the differences lie with their mass, luminosity, temperature, and energy. Jupiter would need to weigh 13 times its current mass to become a brown dwarf, and about 83 to 85 times its mass to become a low-mass star.

L, T, & Y Dwarfs

Brown dwarfs consist of three spectral types: the L dwarfs, T dwarfs, and Y dwarfs. This is a temperature sequence, not according to their mass.

Cool dwarf stars and warm brown dwarfs look similar in their spectra even though their masses are different. Since it's hard to distinguish between the two solely based on spectra, the warmer brown dwarfs may actually fall into spectral type M. M-type objects will have a surface temperature from 2100 Kelvin to 3500 Kelvin, with the warmest (and thus youngest) brown dwarfs having temperatures as high as 2800 Kelvin. Brown dwarfs will use up their energy in only a matter of millions of years, getting colder and darker as they age until they fade away and turn black.

Cooler than the M-type brown dwarfs, more distinguishable as brown dwarfs based on their spectra alone, are the L dwarfs, which have temperatures of around 1300-2100 Kelvin.

Even colder than that are the T dwarfs (aka methane dwarfs), with surface temperatures between about 800 Kelvin and 1300 Kelvin.

And the Y-types, or Y dwarfs, have temperatures ranging down to 300 Kelvin. That means that the coolest of these brown dwarfs (the Y dwarfs) are colder than our own body!

Black Dwarf

A black dwarf is the end stage of a white dwarf, one with a low temperature.

There are no black dwarfs around today. The universe is simply far too young for it. In fact, the coolest white dwarfs have, to the best estimates, lost less than 0.2% of their total heat since the very first ones were created in this Universe.

Red Dwarf

In modern usage, the definition of a red dwarf varies. When explicitly defined, it typically includes late K- and early to mid M-class stars, but in many cases it is restricted just to M-class stars. In some cases all K stars are included as red dwarfs, and occasionally even earlier stars.

A red dwarf is the smallest and **coolest** kind of star on the **Main sequence**. Red dwarfs are by far the most common type of star in the Milky Way but because of their low luminosity, from Earth, not one star that fits the stricter definitions of a red dwarf is visible to the naked eye. Proxima Centauri the nearest star to the Sun, is a red dwarf, as are fifty of the sixty nearest stars. According to some estimates, red dwarfs make up three-quarters of the stars in the Milky Way.

Red dwarf stars form just like other Main Sequence Stars. They can form out of a molecular cloud of dust and gas for example. Gravity pulls the swirling gas and dust together, and it begins to rotate. The material clumps in the centre, and when it reaches the critical temperature, fusion begins.

A red dwarf cannot be a giant star because it cannot develop a helium core surrounded by unprocessed hydrogen (hydrogen shell). Red dwarfs actively convert hydrogen to helium through nuclear fusion in their core, whilst red giants are unable to convert hydrogen within their core as all of it has been converted.

Red dwarfs burn hydrogen more slowly, live for a hundred billion years or more on the main sequence, but will eventually use up all of their hydrogen. When they do, the **red dwarfs become white dwarfs**

The coolest red dwarfs near the Sun have a surface temperature of 2,000 K and the smallest have radii of 9% that of the Sun, with masses about 7.5% that of the Sun. Objects smaller than red dwarf stars are called brown dwarfs, and these critically do not shine through the thermonuclear fusion of hydrogen.

These red dwarfs have spectral classes of L0 to L2. Since some of them lack the internal layers that Sun-like stars have, their churning guts and fast rotation make them prone to extreme magnetic activity, such as flares.

Low-mass red dwarfs develop very slowly, maintaining a constant luminosity and spectral type for trillions of years, until their fuel is depleted. Because of the comparatively short age of the universe **no red dwarfs yet exist at advanced stages of evolution.**

Lighter stars are much more plentiful than heavier stars, and red dwarfs are thus the most numerous type of star, estimated at three quarters of all stars.

Observations indicate 40% of red dwarfs have a "super-Earth" class planet orbiting in the habitable zone where liquid water can exist on the surface. Computer simulations of the formation of planets around low-mass stars predict that Earth-sized planets are most abundant, but more than 90% of the simulated planets are at least 10% water by mass, suggesting that many Earth-sized planets orbiting red dwarf stars are covered in deep oceans.

Modern evidence suggests that planets in red dwarf systems are extremely unlikely to be habitable. First, planets in the habitable zone of a red dwarf would be so close to the parent star that they would likely be tidally locked; this would mean that one side would be in perpetual daylight and the other in eternal night: the perpetual night zone would be cold enough to freeze the main gases of their atmospheres, leaving the daylight zone bare and dry.

Variability in stellar energy output may also have negative impacts on the development of life. More recent research suggests that these stars may be the source of constant high-energy flares and very large magnetic fields, diminishing the possibility of life as we know it.[

OGLE-TR-122b

The smallest known star right now is **OGLE-TR-122b**, a red dwarf star that's part of a binary stellar system. This red dwarf the smallest star to ever have its radius accurately measured; 0.12 solar radii. This works out to be 167,000 km. That's only 20% larger than Jupiter

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Types of Stars by Life Cycle

Stars can be classified by what stage in their life cycle they are.

Protostars are the first stage of a star's lifecycle and neutron stars are the last. Stars form when gravity begins to pull objects towards one another. As gas and dust combine, they form a large round shape that will eventually perform a nuclear fusion of hydrogen and become a star. After billions of years of burning through their hydrogen, stars begin to collapse on themselves, and the end of their life cycle has begun.

Protostar

The first stage in a star's life cycle is the protostar stage. This is the stage where gravity and inertia work to pull in gas and dust from space. When gravity's pull is stronger than the force of inertia, the gas and dust will begin to spin forming a large spherical ball. The force of gravity causes pressure on the core of the sphere preparing the star for the next stage in its life cycle. It takes a protostar approximately 100,000 years to make it to the next stage.

T Tauri Star

This is the second stage in a star's life cycle. T Tauri stars get their energy from the massive amount of gravitational pressure exerted on them. Even though there are large amounts of gravitational pressure, T Tauri stars cannot yet perform nuclear fusion. It will take an average of 100,000 million years to reach the next stage in its life cycle.

Main-Sequence Star

A star in its third stage of life is called a main-sequence star. In this stage, the star begins nuclear fusion, and the temperature of the star increases. The balance between the gravitational force and the gas pressure causes main-sequence stars to have very long life cycles that are in a state of equilibrium. How long a star will stay in this stage of life depends on how massive the star is. Stars with more mass tend to burn through their energy much faster than lower mass stars. This results in main-sequence stars having an average life span between 20 billion to 100 billion years.

Red Giant Star

When nuclear fusion of hydrogen stops, a star has reached the fourth stage in its life cycle. The equilibrium between the gravitational pull and gas pressure no longer exists. The hydrogen core begins to burn, and the star begins to grow much larger. These red giants can be as much as 100 times bigger than they were when they were main-sequence stars. This stage will last about one million years because of how quickly red giants burn through their energy resources.

White Dwarf Star

The fifth, and last, stage in a star's life cycle is the white dwarf star stage. These stars are no longer able to perform nuclear fusion. These stars will use up any remaining energy they have to create heat and light. Once their reserve is spent, they will begin to cool down and become black dwarfs with no energy to give off heat and light.

Supernova

Not all stars will become white dwarfs. In some cases, a star will experience a supernova event. If the star is large enough to continue nuclear fusion as it grows, the star may eventually explode outward. This is a supernova event leaving an immensely dense core behind that contains only neutrons

Stars which are about eight times or more massive than the Sun - whether they are red giants or red supergiants end their lives in this spectacular way. A supernova is an explosion that occurs when the star runs out of fuel and fusion stops. Without the outward pressure from the fusion in the core there is nothing to counteract the inward pressure of gravity.

First, the outside of the star swells into a red supergiant. The core of the star begins shrinking and grows hotter and denser. For a while, a new series of nuclear reactions, that turn the core to iron occur, temporarily stops the collapse of the core. When the core contains mostly iron, it has nothing left to fuse, and fusion in the core ceases.

In less than a second, the star begins the final phase of its collapse. The temperature in the core rises to over 100 billion degrees as the iron atoms are crushed together. There are a lot of forces going on at this point - some repulsive, some compressive - until finally the whole star explodes and produces a shock wave that forces the matter from the star into space.

All that remains of the original star is a small, super-dense core composed almost entirely of neutrons. This is a neutron star. If the original star was extremely big, even the neutrons don't survive, and the core collapses further forming a black hole.

Neutron Star

A neutron star is the collapsed core of a massive supergiant star, which normally has a total mass of between 10 and 25 solar masses

If the collapsed or remnant star has a mass of around 2 solar masses, the combination of degeneracy pressure and nuclear forces is insufficient to support the neutron star and it continues collapsing to form a black hole.

Most of the basic models for these objects imply that neutron stars are composed almost entirely of neutrons (subatomic particles with no net electrical charge and with slightly larger mass than protons; the electrons and protons present in normal matter combine to produce neutrons at the conditions in a neutron star.

Neutron stars have a radius on the order of 10 kilometres (6 mi) and a mass of about 1.4 solar masses. They result from the supernova explosions that compresses the core past white dwarf star density to that of atomic nuclei. Except for black holes, neutron stars are the smallest and densest currently known class of stellar objects.

Neutron stars that can be observed are very hot and typically have a surface temperature of around 600000 K. Once formed, they no longer actively generate heat, and cool over time; however, they may still evolve further through collision or accretion .

Neutron star material is remarkably dense: a normal-sized matchbox containing neutron-star material would have a weight of approximately 3 billion tonnes.

Their magnetic fields are between 10^8 and 10^{15} times stronger than Earth's magnetic field. The gravitational field at the neutron star's surface is about 2×10^{11} (200 billion) times that of Earth's gravitational field.

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Main Sequence Stars

Stars have mass, density, and luminosity that can vary depending on one or the other. An **H-R diagram** plots a star's luminosity vs. surface temperature. It's called the **main sequence band**. Here, stars are grouped from least massive, all the way down at the bottom right, to most massive, all the way at the top left.

Mass-Luminosity Relation

Luminosity is a rate of the total radiant energy output of a star. It is the intrinsic brightness of a star stretched over the entire electromagnetic spectrum, not just the portion that includes visible light The luminosity of a main-sequence star is based on its mass with a simple equation: L=M3.5 where L= luminosity, and M-Mass.

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Mass-Density Relation

The average density of a star is its mass divided by volume. Stars are not uniformly dense throughout their diameter. They are more like a fluffy ball of cotton candy around a centre made of a jawbreaker. Their centres are much denser than their outer layers.

For example, giants and super-giants, albeit much more massive than white dwarfs, are far less dense than the white dwarfs. A giant is basically one humongous cotton candy ball and thus has a very large volume of space that it occupies and, on average, not very dense. On the flipside, a white dwarf is just a jawbreaker with no cotton candy twirled around it, making it, on average, far denser than a giant despite its small mass. Most stars, however, are main-sequence stars with a density closer to that of our sun.

The relationship between mass and a main sequence star's luminosity is far more straightforward. The more massive the star on this band, the more luminous it will also be.

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Pulsar

A pulsar is called by that name because it appears to be a pulsating star. Pulsars are a subdivision of neutron stars. This means that they are built of conglomerates of neutrons created by exploding stars or supernovas. Pulsars are incredibly dense and small.

All pulsars emit a wide range of electromagnetic radiation. Emissions of pulsars include visible light, radio waves, x-rays, and gamma rays.

Pulsars rotate rapidly, which causes the appearance of light pulsation. The rate of their rotation is around thirty rotations per second

The term "pulsating star," which is frequently used to describe pulsars, is somewhat a misnomer. The star only appears to pulsate. Pulsation does not actually take place. The pulsar continuously rotates. Therefore, interactions between the light and electromagnetic rays caused by this rotation cause the appearance of pulsation. This effect occurs because electromagnetic rays go across the sky periodically.

Other neutron stars do not pulse but have extremely magnetic fields, called magnetars.

Pulsars were first discovered by Jocelyn Bell in 1967. An astrophysicist working to advance the field of radio astronomy. Bell discovered pulsars through the use of a radio telescope that she invented. She noticed that some of these transmissions appeared at regular intervals. With the help of Anthony Hewish, she discovered that radio emissions were generated by the stars rotating rapidly. Before long, they began to find different regular patterns of radio emissions.

Pulsars are comparatively few. Approximately 500 pulsars exist in the Milky Way. There are around 1,500 pulsars in the entire universe..

Pulsars are offset. This means that the axis of a pulsar does not go straight up and down. Additionally, the magnetic field generated by pulsars does not align with this axis. One view is that the the combination of these two non-alignments creates the pulses.

No one can give a definitive answer as to what the power source for the pulsars is. One theory states that rotation powers itself. Pulsars have electromagnetic fields, which are known to generate energy when they move. It is thought that this energy is somehow transferred to the core of the pulsar and supports continued rotation.

The rotation of pulsars gradually decreases. When a pulse period, or the time between pulses, is lengthened to around four seconds, the pulsar will appear to die. In reality, it still exists. However, the light is not able to reach the Earth. When the rotation slows enough, pulsars die in a massive supernova.

The range of pulsars' electromagnetic radiation is inconsistent from object to object. Some pulsars have a full range of electromagnetic radiation. Others have smaller ranges. A specific type of pulsar only emits x-rays or gamma rays. These are known as "radio-quiet" pulsars.

Pulsars move at incredible speeds through space, leaving a trail of visible particles. This pulsar, known as the Mouse, has a tail that extends for 55 light years.

Pulsars can spin so quickly without damage because of their mass distribution. They are very dense, small, and compact. Neutron stars are the only visible objects that can do this.

The mass of most neutron stars is around 1.4 times that of the Sun. They can be about 1.2 to 2 times the Sun's mass. Typical pulsars have a diameter of around twelve miles.

How are Pulsars Formed

Pulsars owe their characteristics to the method through which they have been created. They are created in a supernova event. A supernova event occurs when a large star becomes unstable. It loses all of the fuel in its core. Therefore, it implodes or collapses on itself. In the energy release created by the supernova, pulsars are created.
The neutrons that were inside the original star combine to create small, compact, rotating stars. Neutrons at the ends of this cluster gradually decay. They are transformed into protons and electrons. As the pulsar creates a magnetic field, these protons and electrons are the sources of electromagnetic waves. The light produced by these waves is generated when the pulsar reaches its peak speed.

As the star's core collapses, its rotation rate increases and newly formed neutron stars hence rotate at up to several hundred times per second. Some neutron stars emit beams of electromagnetic radiation that make them detectable as pulsars. Indeed, the discovery of pulsars by in 1967 was the first observational suggestion that neutron stars exist.

The radiation from pulsars is thought to be primarily emitted from regions near their magnetic poles. If the magnetic poles do not coincide with the rotational axis of the neutron star, the emission beam will sweep the sky, and when seen from a distance, if the observer is somewhere in the path of the beam, it will appear as pulses of radiation coming from a fixed point in space (the so-called "lighthouse effect").

The fastest-spinning neutron star known is PSR J1748-2446ad, rotating at a rate of 716 times a second or 43,000 revolutions per minute giving a linear speed at the surface of nearly a quarter the speed of light.

There are thought to be around one billion neutron stars in the Milky Way,   and at a minimum several hundred million. However, most are old and cold and radiate very little; most neutron stars that have been detected occur only in certain situations in which they do radiate, such as if they are a pulsar or part of a binary system. Slow-rotating and non-accreting neutron stars are almost undetectable.

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Chapter Fourteen
The Solar System

The Solar System comprises the Sun and a total of eight planets, surrounded on the outside by the Kuiper Belt. Beyond that will be found the heliosphere, the heliopause and the Oort Cloud which begins interstellar space.

The Solar System is distributed as follows

. – **Inner Planets**: Mercury: Mercury, Venus, Earth and Mars in that order of distance from the Sun. Mercury is closest with a solar radius of 37 million km (0.2 AU) and Mars is furthest at 220 million km (AU 1.5). The Earth is in between at 150 million km (= 1Astronomical Unit (AU) (Between the Inner and Outer Planets there is a discontinuous belt of asteroids.)

. – **Outer Planets**: Jupiter, Saturn, Uranus, and Neptune in that order of distance from the Sun. Jupiter is first with a solar radius of 780 million km (5.2 AU), Saturn next at 1,429 million km (9.5 AU), Uranus next at 2,870 million km (19.1 AU), and lonely Neptune at 4,500 million km (30 AU.)

. –**Kuiper Belt.** The Kuiper Belt is a doughnut-shaped circumstellar ring of icy objects around the outer edge of the Sun's heliosphere, extending from beyond the orbit of Neptune, from about 30 to 55 AU (about 3.750 to 8.250 billion km) and about 10 AU thick (1.500 billion mi).

While asteroids are composed of rock and metal, most Kuiper Belt Objects (KBOs) are composed of frozen volatiles (termed "ices"), such as methane, ammonia and water. The belt is home to most of the objects known as dwarf planets, including Pluto. Some comets are thought to originate there. The vast majority of objects are small bodies. More than 100,000 KBOs of 100 km (62 mi) or more in diameter are believed to exist. Many KBOs have moons of their own.

. – **Pluto** was originally classified as the Earth's nineth planet when discovered in the 1930s, but was declassified as a dwarf planet by the IAU in 2006. It is 1,881.3 km (1,176 mi) in diameter, only slight bigger than the Moon, and has five moons of its own, of which Charon is its binary companion. Pluto orbits the Earth, once in 247.68 Earth years.

The heliosphere is the area under the influence of the Sun. Beyond that is interstellar space. The Kuiper Belt and Neptune may be treated as a marker of the extent of the Solar System, or heliosphere.

. - **Oort Cloud.** Interstellar space starts with the Oort Cloud. The latter is a gigantic sphere (like an ice-ball) encasing the entire Solar System (with Kuiper Belt) and extending all around it in a spherical radius of trillions of km from the Sun.

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Components of Solar System

Sun

The Sun is the star around which the Solar System revolves. It is a nearly perfect ball of hot plasma heated to incandescence by nuclear fusion in its core, and radiating energy mainly in the light, ultraviolet, and infrared wavebands. The temperature varies from around 15 million degrees Celsius at the core to about 5,500 degrees C at the surface.

The Sun's radius is about 695,000 Km or 109 times that of Earth. Its mass is about 330,000 times that of the Earth, comprising about 99.86% of the total mass of the Solar System. Roughly three-quarters of the Sun's mass consists of hydrogen, and the rest mostly helium with much smaller quantities of heavier elements.

The Sun is a G-type main sequence star (G2V), commonly referred to as a yellow dwarf (its light is actually white). It formed approximately 4.6 billion years ago. Most of the matter gathered in the centre, whereas the rest flattened into an orbiting disk that that became the Solar System. The central mass became so hot and dense that it eventually initiated nuclear reaction.

When hydrogen fusion in its core has diminished to the point at which the Sun is no longer in hydrostatic equilibrium, its core will undergo a marked increase in density and temperature while its outer layers expand, eventually transforming the Sun into a red giant, engulfing Mercury and Venus, and making Earth uninhabitable - but not for about five billion years. After this, it will shed its outer layers and become a dense type of cooling star known as white dwarf.

Earth

Since Erasthones in BC 310 we knew the Earth was round and since Kepler in 1682 that it was heliocentric. Today we know that its axis is tilted at an angle of 23.5 degrees, it rotates on its axis once a day, is slightly flattened at the poles, and it goes round the Sun once a year or in 365.256 days.

The Earth's radius is 6,371 km, its diameter is 12,742 km and its circumference 40,075 Km. Its orbit around the Sun is elliptical and its average distance (radius) from the Sun is 149.60 million km. The total orbital distance round the Sun is 940 million km.

The Earth's mass is 5.9736×10^{24} kg or 5.9 sextillion tonnes, and it is the third planet from the Sun, and the fifth biggest in the Solar System . It has a human population of 8.0 billion.

Planets

The Solar System comprises eight planets and an assortment of other associated celestial objects. All planets orbit anti-clockwise:

Table 10
Solar System

Position from Sun	Name	Mass (1=Earth)	Solar Radius (m=million km)*	Solar Orbit (Earth days)	Mean Surface Temp (Celsius)	Orbital speed (km/s)	Moons (m) Rings
1	Mercury	0.06	37m	87.97	67°	47 km/s	
2	Venus	0.82	108m	224.7	464°	35 Km/s	
3	Earth	1.00	*150m	365.2	14°	30 km/s	
4	Mars	0.11	220m	689.0	-60°	24 km/s	Phobos and Deimos, planets
	Asteroid belt		340m to 490m				Ceres, largest dwarf planet 4,70m
5	Jupiter	318.00	780m	4332.6	-108.95°	13 km/s	80 known satellites Three rings, and an outer gossamer ring.
6	Saturn	95.00 14.536	1.429m	10,591.7	-197.2°	6.8 km/s	27 known satellites Ring system
c7	Uranus	14.54	2,870m	30,679.3	-197.2°	6.8 km/s	27 known satellites Ring system
8	Neptune	17.00	4,500m	60,263.0	-201°	5.43 km/s	14 known satellites Several minor planets (trojans)
9	Kuiper Belt		4,500m -7,500m 3-5 AUs				Myriads of celestial objects, including Pluto.
	Pluto	0.002	4,500m -7,500m 3-5 AUs	90,560.0	-229°	4.73 km/s	Dwarf planet 5 known moons
10	Oort Belt		AUs 2,000-100,000 AUs				
	Helioshock/ Heliosheath		AUs 280 -300				
	Heliopause		AUs 24,000				
	Interstellar space						

* Inter-stellar distances are expressed in Astronomical Units (AUs), **1AU= 150 million Km** (Distance Earth-Sun). I Light-Year= 63,241.1 AUs

Asteroids Belt

An asteroid is a minor planet of the inner Solar. System. Sizes and shapes vary significantly, ranging from 1-metre rocks to a dwarf planet. They are metallic or rocky bodies with no atmosphere.

Of the roughly one million known asteroids, the greatest number are located between the orbits of Mars and Jupiter, approximately 2 to 4 AUs from the Sun, in the main asteroid belt.

The sizes of asteroids varies greatly; the largest, Ceres is almost 1,000 km (600 mi) across and qualifies as a dwarf planet. The total mass of all the asteroids combined is less than that of Earth's Moon. The majority of main belt asteroids follow slightly elliptical, stable orbits, revolving in the same direction as the Earth and taking from three to six years to complete a full circuit of the Sun.

Near-Earth asteroids can threaten all life on the planet; an asteroid impact resulted in the Cretaceous-Paleogene extinction.

Kuiper Belt

The Kuiper Belt is a circumstellar disk around the outer Solar System, extending from the orbit of Neptune at 30 AUs to approximately 50 AU from the Sun. It is similar to, but is far larger—20 times as wide and 20–200 times as massive as the asteroid belt. Like the asteroid belt, it consists mainly of small bodies or remnants. While many asteroids are composed primarily of rock and metal, most Kuiper Belt Objects (KBOs) are composed largely of frozen volatiles (termed "ices"), such as methane, ammonia and water. The Kuiper Belt is also home to dwarf planets, including Pluto and Eris.

Overlapping the outer edge of the Kuiper Belt is a second region called the “scattered disk”, which continues outward to nearly 1,000 AU, with some bodies on orbits that go even farther beyond – into the Oort Cloud region..

Pluto and Eris

Pluto is a dwarf planet in the Kuiper Belt. It is the ninth-largest and tenth-most massive known object to directly orbit the Sun, slightly less massive than Eris. Pluto is made primarily of ice and rock. Pluto has only one sixth the Moon’s mass and one third its volume. Light from the Sun takes 5.5 hours to reach Pluto at its average distance of 39.5 AU [5.91 billion km; 3.67 billion mi]). Pluto's eccentric orbit periodically brings it closer to the Sun than Neptune.

Pluto was discovered in 1930, the first object in the Kuiper belt. It was immediately hailed as the ninth planet. Following discovery of additional objects in the Kuiper belt, in 2006 the IAU formally defined a new class of dwarf planets, to include Pluto.

Pluto has yet to complete a full orbit of the Sun since its discovery, as one Plutonian year is 247.68 years long.

Pluto has five known moons of its own: Charon the largest, whose diameter is just over half that of Pluto.. Pluto and Charon are sometimes considered a binary system. The New Horizons mission was the first spacecraft to visit Pluto and its moons, making a flyby on 14 July 2015 and taking detailed measurements and observations.

In Jul 2005, scientists announced the discovery of a KBO, later named Eris, which orbited the Sun once every 560 years, its distance varying from about 38 to 98 AU. Recent measurements show it to be slightly more massive but smaller than Pluto. It has been classified a dwarf planet, and has one moon, named Dysnomia.

Heliosphere

The heliosphere is the region around the Sun dominated by it. The outer boundaries occur where its solar winds collides with the interstellar medium, which may be thought of as at around 200 AU. The Kuiper Belt is essentially in the heliosphere.

The heliosphere comprise three major sections from the Sun to its edge. They are (1) the termination shock, (2) the heliosheath, and (3) the heliopause. A type of particle called an energetic neutral atom (ENA) has been observed to have been produced from its outer edges.

Except near obstacles such as planets or comets, the heliosphere is dominated by material emanating from the Sun. Originating at the extremely hot surface of the Sun's corona, solar wind particles reach escape velocity, streaming outwards at 300 to 800 km/s or 1 to 2.9 million km/h (671 thousand to 1.79 million mph). As it begins to interact with the interstellar medium, its velocity slows to a stop. The point where the solar wind becomes slower than the speed of sound is called the termination shock.

Here the wind slows dramatically, condenses and becomes more turbulent, forming a great oval structure known as the heliosheath. This structure has been theorised to look and behave very much like a comet's tail, extending outward for a further 40 AU on the upwind side but tailing many times that distance downwind. Evidence has suggested that it is forced into a bubble shape by the constraining action of the interstellar magnetic field, but the actual shape remains unknown

The solar wind continues to slow as it passes through the heliosheath leading to a boundary called the heliopause, where the interstellar medium and solar wind pressures balance.

The final boundaries (at the heliopause) are shaped by two forces, the solar wind and the Sun's gravity. The limit of the solar wind's influence is roughly four times Pluto's distance from the Sun. This, the heliopause, is the outer boundary of the heliosphere and is considered the beginning of the interstellar space.

Beyond the heliopause, at around 230 AU, lies the bow shock, a plasma "wake" left by the Sun as it travels through the Milky Way.

Underlying the above forces is the Sun's retarding gravity which operates throughout. The effective range of its gravitational dominance, known as the Hill sphere, is thought to extend into interstellar space, up to a thousand times farther and encompasses the hypothetical Oort Cloud.

Voyager 1 and voyage 2 passed the termination shock and entered the heliosheath at 94 and 84 AU from the Sun, respectively. Voyager 1 was reported to have crossed the heliopause in August 2012, and Voyager 2 in December 2018.

Stellar-Wind Bubble

A stellar-wind bubble is a cavity (of light years across) in space filled with hot gas blown into the interstellar medium by the high-velocity (several thousand km/s) stellar winds from a single massive star of type O or B. Weaker stellar winds also blow bubble structures, which are also called astrospheres. The Sun's heliosphere, within which all the major planets of the Solar System are embedded, is a small example of a stellar-wind bubble.

Stellar-wind bubbles have a two-shock structure. The freely-expanding stellar wind hits an inner termination shock, where its kinetic energy is thermalised, producing X-ray emitting plasma. The hot, high-pressure, shocked wind expands, driving a shock into the surrounding interstellar gas. If the surrounding gas is dense enough, the swept-up gas radiatively cools far faster than the hot interior, forming a thin, relatively dense shell around the hot, shocked wind.

Sedna

In Mar 2004, astronomers announced discovery of a trans-Neptunian object orbiting the Sun at an extreme distance, in one of the coldest known regions of our solar system. Named Sedna, it approaches the Sun only briefly during its 10,500-year solar orbit. It never enters the Kuiper Belt. Instead it travels in a long, elliptical orbit between 76 and nearly 1,000 AU from the Sun. Since Sedna's orbit takes it to such an extreme distance, its discoverers have suggested that it is the first observed body belonging to the inner Oort Cloud.

Oort Cloud

The Oort cloud is a hypothetical spherical cloud of up to a trillion icy objects that is thought to be the source for all long-period comets and to surround the Solar System at roughly 50,000 AU (1 light-year) and possibly to as far as 100,000 AU (1.87 light-years). It is thought to be composed of comets that were ejected from the inner Solar System by gravitational interactions with the outer planets. Oort cloud objects move very slowly, and can be perturbed by infrequent events, such as collisions, the gravitational effects of a passing star, or the galactic tide exerted by the Milky Way.

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More Galactic Neighbours

The Sun resides in one of the Milky Way's outer spiral arms, known as the Orion-Cygnus Arm or Local Spur about 27,000 light-years from the Galactic Centre

The Solar System lies well outside the star-crowded galactic centre. Its orbit is close to circular, at roughly the same speed as that of the spiral arms. Therefore, the Sun passes through arms only rarely. Because spiral arms are home to a far larger concentration of supernovae, gravitational instabilities, and radiation that could otherwise disrupt the Solar System this has given Earth long periods of stability for life to evolve. However, the changing position of the Solar System relative to other parts of the Milky Way (as it orbits) could explain periodic extinction events.

Local Bubble

Solar System resides in the region known as the Local Bubble, which is within 300 light-years of the Sun, and part of the stellar structure of the Local Spur. The feature is an hourglass-shaped cavity or super-bubble in the interstellar medium (ISM) roughly 300 light-years across. The bubble is suffused with high-temperature plasma, suggesting that it may be the product of several recent supernovae. Within the Local Bubble lies the Local Interstellar Cloud (LIC). The Solar System is currently passing through it

Local Interstellar Cloud (LIC)

Within ten light years of the Sun are relatively few stars, the closest being the triple star system Alpha Centauri which is about 4.4 light-years away and may be in the Local Bubble's G-Cloud. Alpha Centauri A and B are a closely tied pair of Sun-like stars, whereas the **closest star** to Earth is the small red dwarf, **Proxima Centauri**, which orbits the pair at a distance of 0.2 light-years. In 2016, a potentially habitable exoplanet was found to be orbiting Proxima Centauri. Called Proxima Centauri b, it is the closest confirmed exoplanet to the Sun.

The next closest to the Sun are the **red dwarfs** (also known fusors[104]), Barnard's Star (at 5.9 light years), Wolf 359 (at 7.8 light years) and Lalande 21185 (8.3 light years).

Barnard's Star is in the constellation of Ophiuchus in the northern hemisphere, about 14% of the Sun's mass. Despite its proximity, the star is invisible to the naked eye. it is much brighter in the infrared spectrum. At 7–12 billion years of age, Barnard's Star is considerably older than the Sun, which is 4.5 billion years old, among the oldest stars in the Milky Way galaxy. Barnard's Star has lost a great deal of rotational energy, and rotates on its axis once in 130 days as against th Sum's once in 27 days.

Wolf 359 is located in the constellation Leo. It can only be seen with a large telescope. Wolf 359 is one of the faintest and lowest-mass stars known. Wolf 359 is a relatively young star with an age of less than a billion years. Two planetary companions are suspected, but as yet unestablished.

The next are **brown dwarfs**. The nearest brown dwarfs belong to the binary **Luhman 16** system at 6.6 light years away (2.0 pc). It is another binary system in the southern constellation Vela discovered in 2014 The masses of Luhman 16 A and B are 33.5 and 28.6 Jupiter masses, respectively, and their ages are estimated to be 600–800 million years. They orbit each other at a distance of about 3.5 AU approximately every 27 years.

The closest known rogue or free-floating planetary-mass object at less than 10 Jupiter masses is the W0855 a sub-brown dwarf 7.4 light years (2.3 pc) from Earth, the discovery of which was also announced in 2014 using data from the Wide-Field Infrared Survey Explorer (WISE). It is also the coldest object of its type found in interstellar space, having a temperature in the range 225 to 260 K.

Just beyond at 8.6 light years lies Sirius, the brightest star in the sky with roughly twice the Sun's mass, orbited by the closest **white dwarf** to Earth, **Sirius B**.

Other stars within ten light-years are the binary red-dwarf system Luyten 726 at 8.7 light years and the solitary red dwarf Ross 154 at 9.7m light years.

The closest **solitary star** to the Solar System is **Tau Chen** at 11.9 light-years. It has roughly 80% of the Sun's mass but only about half of its luminosity in the constellation Cetus. it is a relatively stable and the closest solitary G-class star. It can be seen with the unaided eye with an apparent magnitude of 3.5.

Observations have detected more than ten times as much dust surrounding Tau Chen as is present in the Solar System. Since December 2012, there has been evidence of at least four planets—all confirmed as super-Earths with two of these being potentially in the habitable zone. There are an additional four unconfirmed planets, one of which is a Jovian planet

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[104] Fusors are hydrogen burning or fusion stars. Any object that achieves core fusion during its lifetime may be called a fusor.

between 3 and 20 AU from the star. Tau Chen is consistently listed as a target for the Search for Extra Terrestrial Intelligence (SETI).

Edge of the Local Bubble

The nearest and unaided-visible **star group** beyond the immediate celestial neighbourhood is the **Ursa Major Moving Group** at roughly 80 light-years, which is within the Local Bubble.

One of the closest **star-forming region**s is the **Taurus Molecular Cloud** at 430 light years (140 pc), just beyond the Local Bubble, in the constellations Taurus an Auriga. This cloud hosts a stellar nursery containing hundreds of newly formed stars The newly formed stars in this cloud have an age of 1–2 million years. It has been important in star formation studies at all wavelengths.

Scholz's Star (WISE 0720−0846) is a dim binary system at 22 light years (6.8 pc) in the constellation Monoceros, discovered in 2013. The system **passed through the Solar System,** at about 0.82 light-years or 52,000 AUs (0.25 pc) from the Sun roughly 70,000 years ago.

Comets perturbed from the Oort cloud would require roughly two million years to get to the inner Solar System. A star is expected to pass through the Oort cloud every 100,000 years or so. An approach as close or closer than 52,000 AU is expected to occur about every 9 million years.

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The Earth

Orbit

Earth orbits the Sun at an average distance of about 150 million km (93 million mi) every 365.2564 mean solar days, or one sideral year. This gives an apparent movement of the Sun eastward with respect to the stars at a rate of about 1°/day. Due to this motion, on average it takes 24 hours for Earth to complete a full rotation about its axis.

The orbital speed of Earth averages about 29.78 km/s (107,200 km/h; 66,600 mph), which is fast enough to travel a distance equal to Earth's diameter, about 12,742 km (7,918 mi), in seven minutes, and the distance to the Moon, 384,000 km (239,000 mi), in about 3.5 hours.

The Moon and Earth orbit a common barycentre every 27.32 days relative to the background stars. When combined with the Earth-Moon system's common orbit around the Sun, the period of the synodic month is 29.53 days.

Viewed from a vantage point above the Sun and the Earth's north poles, Earth orbits in a counter-clockwise direction about the Sun.

The orbital and axial planes are not precisely aligned: Earth's axis is tilted some 23.44 degrees from the perpendicular to the Earth-Sun plane and the Earth-Moon plane is tilted up to ±5.1 degrees against the Earth-Sun plane. Without this tilt, there would be an eclipse every two weeks, alternating between lunar and solar eclipses

Hill sphere

The Hill sphere or the sphere of gravitational influence, of Earth is about 1.5 million km (930,000 mi) in radius. This is the maximum distance at which Earth's gravitational influence is stronger than the more distant Sun and planets. Objects must orbit Earth within this radius, or they can become unbound by the gravitational perturbation of the Sun.

Galactic orbit

Earth, along with the Solar System, is situated in the Milky Way and orbits about 28,000 light-years from its centre. It is about 20 light-years above the galactic plane in the Orion Arm. The Solar system completes one orbit every 220-250 million years. We have been to the other side of the Milky Way 17 time since the Earth was formed.

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Earth’s Atmosphere

Earth's atmosphere is composed of about 78% nitrogen, 21% oxygen, and one percent other gases. These gases are found in layers (troposphere, stratosphere, mesosphere, thermosphere, and exosphere) defined by unique features such as temperature and pressure.

Troposphere

The troposphere is the lowest layer of the atmosphere. Starting at ground level, it extends upward to about 10 km (6.2 miles or about 33,000 feet) above sea level. We live in the troposphere, and nearly all weather occurs in this lowest layer. Most clouds appear here, mainly because 99% of the water vapor in the atmosphere is found in the troposphere.

Most of the mass (about 75-80%) of the atmosphere is in the troposphere. Almost all weather occurs within this layer. The troposphere is by far the wettest layer of the atmosphere (all of the other layers contain very little moisture).

The height of the top of the troposphere varies with latitude (it is lowest over the poles and highest at the equator) and by season (it is lower in winter and higher in summer). It can be as high as 20 km (12 miles or 65,000 feet) near the equator, and as low as 7 km (4 miles or 23,000 feet) over the poles in winter.

Air gets colder as one rises through the troposphere. Air pressure and the density of the air also decrease with altitude. The boundary between the troposphere and the stratosphere is called the "tropopause"

Stratosphere

The next layer up is called the stratosphere, which extends from the top of the troposphere to about 50 km (31 miles) above the ground. The ozone layer is found within the stratosphere. Ozone molecules in this layer absorb high-energy ultraviolet (UV) light from the Sun, converting the UV energy into heat.

Unlike the troposphere, the stratosphere actually gets warmer the higher you go. That trend of rising temperatures with altitude means that air in the stratosphere lacks the turbulence and updrafts of the troposphere beneath. Commercial passenger jets fly in the lower stratosphere. The jet stream flows near the border between the troposphere and the stratosphere.

The bottom of the stratosphere varies with latitude and with the seasons. The lower boundary of the stratosphere is called the tropopause; the upper boundary is called the stratopause.

It is Ozone, an unusual type of oxygen molecule relatively abundant in the stratosphere, that heats this layer as it absorbs energy from incoming ultraviolet radiation from the Sun..

Air is roughly a thousand times thinner at the top of the stratosphere than it is at sea level. Because of this, jet aircraft and weather balloons reach their maximum operational altitudes within the stratosphere.

Due to the lack of vertical convection in the stratosphere, materials that get into the stratosphere can stay there for long times. Such is the case for ozone-destroying chemicals called CFCs (chlorofluorocarbons). Large volcanic eruptions and major meteorite impacts can fling aerosol particles up into the stratosphere where they may linger for months or years, sometimes altering Earth's global climate. Rocket launches inject exhaust gases into the stratosphere, producing uncertain consequences.

Mesosphere

Above the stratosphere is the mesosphere. It extends upward to a height of about 85 km (53 miles) above our planet. Most meteors burn up in the mesosphere. Unlike the stratosphere, temperatures once again grow colder as you rise up through the mesosphere. The coldest temperatures in Earth's atmosphere, about -90° C (-130° F), are found near the top of this layer. The air in the mesosphere is far too thin to breathe (the air pressure at the bottom of the layer is well below 1% of the pressure at sea level and continues dropping as you go higher).

Weather balloons and other aircraft cannot fly high enough to reach the mesosphere. **Satellites orbit above the mesosphere** and cannot directly measure the traits of this layer. Scientists use instruments on sounding rockets to sample the mesosphere directly, but such flights are brief and infrequent.

Most meteors vaporize in the mesosphere. Some material from meteors lingers in the mesosphere, causing this layer to have a relatively high concentration of iron and other metal atoms.

At the mesopause (the top of the mesosphere) and below, gases made of different types of atoms and molecules are thoroughly mixed together by turbulence in the atmosphere. Above the mesosphere, in the thermosphere, and beyond, gas particles collide so infrequently that the gases become somewhat separated based on the types of chemical elements they contain.

Various types of waves and tides in the atmosphere influence the mesosphere. These waves and tides carry energy from the troposphere and the stratosphere upward into the mesosphere, driving most of its global circulation.

Thermosphere

The layer of very rare air above the mesosphere is called the thermosphere. High-energy X-rays and UV radiation from the Sun are absorbed in the thermosphere, raising its temperature to hundreds or at times thousands of degrees. However, the air in this layer is so thin that it would feel freezing cold to us. In many ways, the thermosphere is more like outer space than a part of the atmosphere. **Many satellites orbit Earth within the thermosphere**

The thermosphere is next directly above the mesosphere. Variations in the amount of energy coming from the Sun exert a powerful influence on both the height of the top of this layer and the temperature within it. Because of this, the top of the thermosphere can be found anywhere between 500 and 1,000 km (311 to 621 miles) above the ground.

Temperatures in the upper thermosphere can range from about 500° C (932° F) to 2,000° C (3,632° F) or higher. The aurora, the Northern Lights and Southern Lights, occur in the thermosphere.

The boundary between the thermosphere and the exosphere above it is called the thermopause.

Although the thermosphere is considered part of Earth's atmosphere, the air density is so low in this layer that most of the thermosphere is what we normally think of as outer space. In fact, the most common definition says that space begins at an altitude of 100 km (62 miles), slightly above the mesopause at the bottom of the thermosphere. **The space shuttle and the International Space Station both orbit Earth within the thermosphere**

In the thermosphere and above, gas particles collide so infrequently that the gases become somewhat separated based on the types of chemical elements they contain. Energetic ultraviolet and X-ray photons from the Sun also break apart molecules in the thermosphere. In the upper thermosphere, atomic oxygen (O), atomic nitrogen (N), and helium (He) are the main components of air.

Much of the X-ray and UV radiation from the Sun is absorbed in the thermosphere. When the Sun is very active and emits more high-energy radiation, the thermosphere gets hotter and expands or "puffs up". Because of this, the height of the top of the thermosphere (the thermopause) varies. Satellites occasionally need to be boosted higher to offset the effects of the drag force.

High-energy solar photons also tear electrons away from gas particles in the thermosphere, creating electrically-charged ions of atoms and molecules. Earth's ionosphere, composed of several regions of such ionized particles in the atmosphere, overlaps with and shares the same space with the electrically neutral thermosphere.

Like the oceans, the Earth’s atmosphere has waves and tides within it. These waves and tides help move energy around within the atmosphere, including the thermosphere. Winds and the overall circulation in the thermosphere are largely driven by these tides and waves. Moving ions, dragged along by collisions with the electrically neutral gases, produce powerful electrical currents in some parts of the thermosphere.

Finally, the aurora (the Southern and Northern Lights) primarily occur in the thermosphere. Charged particles (electrons, protons, and other ions) from space collide with atoms and molecules in the thermosphere at high latitudes, exciting them into higher energy states. Those atoms and molecules shed this excess energy by emitting photons of light, which we see as colourful auroral displays.

Exosphere

Some experts consider the exosphere to be the uppermost layer of our atmosphere, the actual "final frontier" of Earth's gaseous envelope. The "air" is very, very, very thin, making this layer even more space-like than the thermosphere. In fact, the air in the exosphere is constantly - though very gradually - "leaking" into outer space. Different definitions place the top of the exosphere somewhere between 100,000 km (62,000 miles) and 190,000 km (120,000 miles) above the surface of Earth. The latter value is about halfway to the Moon.

The boundary directly below the exosphere is called the thermopause. The bottom of the exosphere is also referred to as the exobase. The altitude of the lower boundary of the exosphere varies.

At the higher distances, radiation pressure from sunlight exerts more force on hydrogen atoms than does the pull of Earth's gravity. A faint glow of ultraviolet radiation scattered by hydrogen atoms in the uppermost atmosphere has been detected at heights of 100,000 km (62,000 miles) by satellites. This region of UV glow is called the **geocorona.**

The air in the exosphere is so thin that collisions are very rare. Gas atoms and molecules in the exosphere move along "ballistic trajectories". Most gas particles in the exosphere zoom along curved paths without ever hitting another atom or molecule, eventually arcing back down into the lower atmosphere due to the pull of gravity. However, some of the faster-moving particles fly off into space instead! A small portion of our atmosphere "leaks" away into space each year in this way.

Many satellites, including the International Space Station (ISS), orbit within the exosphere or below. The average altitude of the ISS is about 330 km (205 miles), placing it in the thermosphere below the exosphere! Although the atmosphere is very, very thin, there is still enough air to cause a slight amount of drag force. The ISS loses about 2 km (1.2 miles) in altitude each month to such "orbital decay", and must periodically be given an upward boost by rocket engines to keep it in orbit.

Ionosphere

The ionosphere is not a distinct layer. Instead, it is a series of regions in parts of the mesosphere and thermosphere where high-energy radiation from the Sun has knocked electrons loose from their parent atoms and molecules. The electrically charged atoms and molecules that are formed in this way are called ions, giving the ionosphere its name and endowing this region with some special properties.

High-energy X-rays and ultraviolet (UV) "light" from the Sun are constantly colliding with gas molecules and atoms in Earth's upper atmosphere. Some of these collisions knock electrons free from the atoms and molecules, creating electrically charged ions (atoms or molecules with missing electrons) and free electrons. These electrically charged ions and electrons move and behave differently than normal, electrically neutral atoms and molecules. Regions with higher concentrations of ions and free electrons occur at several different altitudes and are known, as a group, as the ionosphere.

There are three main regions of the ionosphere, called the D layer, the E layer, and the F layer. These regions do not have sharp boundaries, and the altitudes at which they occur vary during the course of a day and from season to season. The D region is the lowest, starting about 60 or 70 km (37 or 43 miles) above the ground and extending upward to about 90 km (56 miles). Next higher is the E region, starting at about 90 or 100 km (56 or 62 miles) up and extending to 120 or 150 km (75 or 93 miles). The uppermost part of the ionosphere, the F region, starts about 150 km (93 miles) and extends far upward, sometimes as high as 500 km (311 miles) above the surface of our home planet.

The regions of the ionosphere are embedded within the standard atmospheric layers. The D region usually forms in the upper part of the meso, while the E region typically appears in the lower thermo and the F region is found in the upper reaches of the thermosphere.

The height, fraction of ionized particles, and even the existence of the different regions of the ionosphere varies over time. The ionosphere is very different in the daytime versus night. During the day, X-rays an UV light from the Sun continuously provides the energy that knocks electrons free from atoms and molecules, producing a continuous supply of ions and free electrons. At the same time, some of the ions and electrons collide and re-combine to form normal, electrically neutral atoms and molecules. During the day, more ions are created than are destroyed, so the number of ions in the three regions increases. At night, the number of ions drops or the D region disappears

Before communication via satellites became common, the operators of radio communication systems often used the ionosphere to extend the range of their transmissions. The curvature of the Earth limits the range of radio transmissions to stations that are over the horizon. However, some frequencies of radio waves bounce or reflect off of the electrically charged particles in certain ionosphere layers. Pre-satellite radio communications often took advantage of this phenomenon, bouncing radio waves off of the "sky" to extend the range of the signals.

The ionosphere regions can absorb or dampen radio signals, or they can bend radio waves, as well as reflecting the signals as described above. The specific behaviour depends on both the frequency of the radio signal as well as the characteristics of the ionosphere region involved. Since Global Positioning System (GPS) satellites use radio signals to determine locations, the accuracy of GPS can be severely reduced when those signals bend as they pass through ionosphere regions. Similarly, some radio communications can be disrupted if the frequency used is one that an ionosphere layer dampens or absorbs entirely, resulting in a weakened signal or even total loss of communications. Scientists constantly measure and produce computer models of the ever-changing ionosphere so that people in charge of radio communications can anticipate disruptions.

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Part V

Next Generation

Chapter Fifteen
Twenty-First Century

In This Part, we highlight some landmark exploratory programmes and missions, which mark the exciting directions of astronomy in this century. In the Next Part we look at the fundamental Issues we must still address.

Enter the Spacecraft

At this point we may introduce the first generation spacecraft. A spacecraft is a vehicle designed to fly in outer space. In orbiting configuration it is a type of artificial satellite. Otherwise, it is a vehicle propelled off the ground by rocked, on a predetermined trajectory and speed to its target. On the way, it is navigated by fly-bys of other celestial bodies, taking advantage of their gravity assist, both as to course and speed.

The earlier ones were referred to as probes, and were usually one-way, eventually crashing or becoming derelict. More recently, spacecraft sent on a mission to trough and collect space material, have been navigated back to Earth to return the samples.

The last stage of the Earth return is still mainly by aerobraking. Only in the case of the now decommissioned Shuttle and still operational the Russian Soyuz capsule servicing the astronauts of the ISS is a soft landing employed

The Artemis programme will operate “lander” spacecraft, ie. vehicles that will execute “soft landings” on the Moon, delivering both humans and cargo. They will incorporate or be complemented by a re-ascent or return module to convey to its mothership payload (astronauts and samples) for return to Earth.

In Jan 2019, China's robotic Chang'e-4 spacecraft soft-landed landed on the far side of the Moon, and Yutu-2, a small rover it was carrying, began exploring through a crater there. Both US and China have also achieved soft-landing probes on Mars,

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Conquest of the Moon

As we cross over into the 21 Century , the Conquest of the Moon must remain unquestionably among man’s greatest achievements, a glowing inspiration of what we may yet achieve, and as it still stands unequalled after 50 years.

Apollo Programme

Under the Apollo programme conducted by NASA, 24 astronauts flew to the Moon over nine missions between Dec 1968 and Dec 1972. During six successful two-man landing missions, 12 men walked on the lunar surface. Three of these 12 men have been to the Moon twice, one only orbited both times, while the other two landed once apiece. The first man to set foot on the Moon had been Neil Armstrong under the Apollo Mission 11, on 20 Jul 1969. The last man to step on the Moon did so under the Apollo 17 Mission which took place on 7-19 Dec 1972.

The Apollo spacecraft had been a pioneer model and proto type of future space vehicles for manned flight. Apollo 17 consisted of a Command Module (CM), a Service Module (SM), and a Lunar Module (LM). The last three missions also had a Lunar Roving Vehicle (LRV) to increase the range of investigative and collection work. The descent (and re-assent) was executed by the Lunar Module, while the spacecraft orbited the Moon. The Apollo 17 CM arrived safely by parachute after re-entry over the South Pacific.

Artemis Programme

Artemis is mankind's next programme to re-establish a human presence on the Moon. The programme's long-term goal is to establish a permanent base, and to facilitate missions to Mars.

The Artemis programme is a collaboration, led by NASA, ESA, CSA and JAXA, of governmental space agencies and private spaceflight companies, joined for the purpose in an a set of Artemis accords. As of December 2022, twenty-three countries and one territory have signed the accords, including the British Space Agency and those of emerging space powers such as Brazil, South Korea, and the United Arab Emirates. (We might note Russia an China are not mentioned anywhere.)

The mission comprises a series of main launches, Artemis 1 to 11, supported by a host of additional logistic and support launches planned over 12 years

On 16 Nov 2022, Artemis 1 was successfully launched from the Kennedy Space Center and successfully completed its mission on 11 Dec 2022, The goal of the Artemis 1 mission was to place Orion into a lunar orbit, and then return it to Earth. The flight was un-crewed. When Orion spacecraft splashed down in the Pacific Ocean, west of Baja California, it had travelled more than 1.4 million miles on a path around the Moon and back. The splashdown occurred 50 years to the day to the last astronaut missioned to touch down on the lunar surface.
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Components of Artemis

The major components of the Artemis programme are the Space Launch System (SLS), the Orion Spacecraft, the Lunar Gateway space station, and the Commercial Human Landing Systems (CHLSs)

. - Space Landing System (SLS).

The SLS is the launch rocket that powers and uplifts the Artemis. The first stage Block is comprises by one central core rocket-engine with two outboard solid rocket boosters. All SLS Blocks share a common core stage design, while they differ in their upper stages and boosters according to payload requirements.

Block 1 is intended to be capable of lifting 209,000 lb (95 tons) to Low Earth Orbit (LEO including the weight of the Interim Cryogenic System (ICPS) as part of the payload. At the time of SLS core stage separation, This trajectory ensured safe disposal of the core stage. The ICPS then performs the Earth orbital insertion, and proceeds to a subsequent trans-lunar injection burn to send Orion towards the Moon. The ICPS will be human-rated for future t crewed Artemis 2 and 3 flights.

.- Orion Spacecraft

The Orion spacecraft consists of a Crew Module (CM) space capsule, capable of supporting a crew of six beyond LEO. Orion is equipped with solar panels, an automated docking system, and glass interfaces. It has a single engine for primary propulsion, and others including reaction control system engines. Orion is launched atop an SLS, sitting forward of the ICPS component.

.- The Gateway

The Gateway will be a mini-space station in lunar orbit, to serve as a solar-powered communication hub, science laboratory, short-term habitation module, and holding area for rovers and other robots. While the project is led by NASA, the Gateway is meant to be developed, serviced, and utilised in collaboration with the commercial and international partners:

The Gateway Logistics Services programme will provide cargo and other supplies to the station, even when crews are not present. As of 2022, the only supply vehicle, known as Dragon XL has been finalised..

The Gateway will be resupplied and supported by launches of the Dragon XL spacecraft launched by the Falcon Heavy lift-off rocket . Each will remain attached to Gateway for up to six months, and will not return to Earth but will be expended in spacecraft.

The Gateway will be parked at an Earth-Moon Legrange point in a near-rectilinear halo orbit (NRHO) (see next section) where it will require little energy for station-keeping or to manoeuvre into other cislunar orbits.

The first two Gateway modules, the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO) will be delivered to the NRHO in a single launch, planned for availability before Artemis 4

.- Commercial Human Landing Systems (CHLSs)

The transport and logistics programmes in support of Artemis include delivery of Gateway modules, Gateway logistics, delivery of the HLS (see below), and delivery of elements of the Moon base. Most of these missions will be executed under NASA contracts to commercial providers.

Under the Commercial Lunar Payload (CLPS) programme, several robotic landers will deliver scientific instruments and robotic rovers to the lunar surface after Artemis 1. Additional CLPS missions are planned throughout the Artemis program to deliver payloads to the Moon base. These include habitat modules and rovers in support of crewed missions.

. - Human Landing System (HLS)

The Human Landing System (HLS) is a critical component of the Artemis mission. The HLS is a spacecraft that can convey crew members from NRHO to the lunar surface, support them on the surface, and return them to NRHO. This system will act as a lunar habitat.

Each crewed landing needs one HLS, although some or all of the spacecraft may be reusable. Each HLS must be launched from Earth and delivered to NRHO in one or more launches.

The initial commercial contract has been awarded to SpaceX for two Starship HLS missions, one un-crewed and one crewed as part of Artemis 3. These two missions each require one HLS launch and multiple fuelling launches., all on

. – Robotic landers.

A lander is a spacecraft that. makes a “soft landing after which it and its payload remain functional. Lander services will be contracted out commercially, to ferry rovers, equipment and other supplies and stuff to and from the Moon, including samples.. The Artemis programme includes robotic landers to make independent scientific researches.

.- Base Camp

The Artemis Base Camp is the prospective lunar base to be established by the end of the 2020s. It would consist of three main modules: the Foundational Surface Habitat, the Habitable Mobility Platform (the Lunar Cruiser) , and the Lunar Terrain Vehicle.

It would support missions of up to two months and be used to study technologies to use on Mars.

Currently Shackleton Crater is the prime target for this outpost due to its wide variety of lunar geography and water ice.

Artemis Mission Programme

Artemis is an ambitious multi-component 12 year, with the first human landing to take place in 2025, the Gateway to be completed in 2029 and the Lunar Base by 2034.

Table 11

Artemis Programme Current Time-Line

Mission	Launch date	Duration	Goal
Artemis 1	16 November 2022	25 days	Un-crewed. Lunar orbit and return
Artemis 2	May 2024	≈10 days	4-person lunar flyby
Artemis 3	2025	≈30 days	4-person lunar orbit with 2-person lunar landing
Artemis 4	2027	≈30 days	4-person lunar orbit, lunar landing, and delivery of the first module to the Gateway
Artemis 5	2028	≈30 days	Lunar landing with the Lunar Terrain Vehicle and delivery of the Refuelling Module to the Gateway
Artemis 6	2029	≈30 days	Lunar landing with the delivery of the Gateway Airlock Module

Provisional Time Line

Mission	Launch date	Duration	Goal (proposed)
Artemis 7	2030	≈30 days	Lunar landing with the delivery of the Habitable Mobility Platform to surface
Artemis 8	2031	≈60 days	Lunar landing with the delivery of lunar surface logistics and the Foundational Surface Habitat
Artemis 9	2032	≈60 days	Lunar landing with the delivery of lunar surface logistics

Mission	Launch date	Duration	Goal (proposed)
Artemis 10	2033 (planned)	<180 days	Expect a lunar landing, a long-term stay with the delivery of lunar surface logistics.
Artemis 11	2034 (planned)	~365 days	Delivery of lunar surface base logistics and shift.

Artemis 1 was successfully executed and the un-crewed Orion capsule was safely returned on 11 Dec 2022.

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Legrange Points

We have conquered the Moon, our nearest celestial neighbour. It is no longer satisfactory for us to remain positioned, or our telescopes, in orbit at the Earth. We need to be further out in space to conduct the next stages of our investigations.

In celestial mechanics, the Lagrange points (or libration points) are points of equilibrium for small-mass objects under the influence of two massive orbiting bodies. This finding was the contribution of the illustrious 18th Century Italian-French mathematician and astronomer, Joseph Louis Legrange.

Lagrange points are positions in space where the gravitational forces of a two-body system like the Sun and Earth produce enhanced regions of attraction and repulsion. These can be used by spacecraft as “parking spots” in space, to remain in a fixed position with minimal fuel consumption .Small objects placed in orbit at Lagrange points are in equilibrium in at least two directions relative to the centre of mass of the large bodies.

Lagrange points are analogous to geostationary orbits in that they allow an object to be in a fixed position in space rather than an orbit in which its relative position changes continuously.

For any combination of two orbital bodies there are five Lagrange points, L1 to L5, all in the orbital plane of the two large bodies. There are five Lagrange points for the Sun–Earth system, and five different Lagrange points for the Earth–Moon system. L1, L2, and L3 are on the line through the centres of the two large bodies, while L4 and L5 each act as the third vertex of an equilateral triangle formed with the centres of the two large bodies.

In a two-body system of sufficient substance, as is the case with the Sun-Earth system, the L4 and L5 Legrange are more stable and tend to pull objects to them to park and orbit around them. Several planets have “trojan asteroids” near their L4 and L5 points with respect to the Sun. Jupiter has more than one million of these trojans. For various reasons, Earth astronomers generally prefer to use L1 and L2. In the latter case the Legrange point is shielded from the Sun by the Earth.

In the Earth-Sun system the first (L1) Lagrangian point occurs some 1,500,000 km (900,000 miles) from Earth, toward the Sun. The second (L2) Legrange point occurs at the same distance from the Earth on the opposite side of the Earth, away from the Sun, giving a distance of 3.0 million km (1.8 million miles) between the two points.

A Lagrange point orbits the Sun at the same rate as the Earth. Thus a spacecraft placed at a Legrange point is said to be in **heliocentric orbit,** as it follows the Earth round the Sun on its annual cycle.

Each planet in the Solar System has its own Lagrangian points. The islands of equilibrium get bigger farther from the Sun and the more massive the planets. The ones associated with Sun-Earth are each roughly 800,000 Km (500,000 miles) wide.

The Moon rotates round the Earth in a radius of 384,400 km (238.900 miles), and therefore “inside” the two L1 and L2 Legrange points. Both the Legrange points are (each)about four times more distant from the Earth than the Moon. Moving operations to a Legrange point is a major step into space. It takes about a month to get there.

The Earth-Sun L1 a point of gravitational balance is located approximately 0.99 AU from the Sun and 0.01 AU from the Earth.

Lissajous/Halo orbits

In orbital mechanics, a Lissajous orbit , named after Jules Antoine Lissajous, is an orbital trajectory that an object can follow around a Lagrange point without requiring any propulsion. **Lissajous orbits** include components in the plane of the two primary bodies and perpendicular to it, and follow a Lissajous curve. They are nonperiodic, or at best said to be quasi-periodic.

A **halo orbit**, like the Lissajous orbit, is another (or alternative) orbit, that a visiting spacecraft can be placed in at a Legrange point. In this case, it is a periodic three-dimensional orbit within L1, L2 or L3 Legrange points.. A halo orbit also includes components perpendicular to the plane of the main bodies, but unlike Lissajous orbits Halo orbits are periodic.

These orbital characteristics can be thought of as resulting from an interaction between the gravitational pull of the two planetary bodies and the Coriolis and centrifugal force on a spacecraft.

Continuous “families” of both northern and southern halo orbits exist at each Lagrange point. Because halo orbits tend to be less stable, station-keeping may be required to keep a spacecraft on the orbit.

Further Up Jacob’s Ladder

Finally we may note that a spacecraft or satellite parked at a Legrange point is four times beyond the Moon, our last point of true achievement, and significantly deeper in the heliosphere and space. It opens new vistas of research into the nature of space and its elements and affords the parking place from which to do so.

It is within range for sending our space vehicles and instruments into position, for remote control and targeting of work, central communications and data relay. We are already able to bring our spacecraft back to Earth, and therefore (soon) to bring back samples, and increasingly we shall be able to park our first line stock up there, and carry out LAD remote re-fuelling, resupply and maintenance. The Sun-Earth Legrange points could be our first prototype space operations centre.

From the Le grange points we shall be able to support exploration of our neighbouring planets. Like gravity assist, Le grange points are to be found all over the Solar System, and possibly in nearby interstellar space – why not with dark matter, when we learn about their makeup.

The Legrange points provide harbours or zone of safety at which spacecraft can park with minimal station-keeping for long years. They exist all over the Solar System: all planets and their moons have them..

They are the potential stepping of man's exploration of space, including interstellar space when we find them beyond the Solar system We may be on to the next series of steps in Jacob's ladder.

Early Legrange Missions

We briefly reflect the first exciting explorations at the Sun-Earth's Legrange points to convey the flavour and possibilities of the new researches. They provide the backdrop to the major observational, research and formulative projects that have already and will be launched to take us up the next steps in man's space odyssey.

ISEE-3 (ICE)

The first spacecraft to use the Sun-Earth Legrange points was the (third) International Sun-Earth Explorer-3 (ISEE-3) satellite, a joint NASA/ESA project to study the interaction between the Earth's magnetic field and the solar wind. It was launched in Aug 1978. It travelled to the Sun–Earth L1 point and remained there for several years. It was the first spacecraft to be placed in a halo orbit

Redesignated as the International Cometary Explorer (ICE), it became the first spacecraft to visit a comet, passing through the plasma tail of comet, Giacobin-Zinner, within about 7,800 km (4,800 mi) of the nucleus on 11 Sep 1985.

NASA suspended routine contact with ISEE-3 in 1997, and made brief status checks in 1999 and 2008. In Jul 2014, the project team initiated an alternative plan to use the spacecraft to "collect scientific data and send it back to Earth", but on in Sep 2014, contact was lost.

SOHO

The second mission to use a Legrange point was a Solar and Heliospheric Observatory (SOHO), also a joint NASA/ESA project to study the Sun. It was launched on 2 Dec 1995 and began operations at Sun–Earth L1 in May 1996 , It was the first entered in a Lissajous orbit.

SOHO was part of the International Solar Terrestrial Physics Program (ISTP). Originally planned as a two-year mission, SOHO continues to operate after over 25 years in space. SOHO has already discovered over 4,000 comets. The mission has been extended until 2025, subject to review.

In addition to its scientific contributions, SOHO is distinguished by being the first three-axis-stabilised spacecraft to use its reaction wheels as a virtual gyroscope.

ACE

The third mission to use a Legrange point was the Advanced Composition Explorer (ACE or Explorer 71). It was a NASA space exploration mission, to study energetic particles from the solar wind, the interplanetary medium and and other sources.

The ACE robotic spacecraft was launched in 25 Aug 1997, and entered a Lissajous orbit at Sun-Earth L1 on 12 Dec1997. As of 2021, the spacecraft was still in generally good condition, and was projected to have enough propellant to maintain its orbit until 2024.

WIND

The Global Geospace Science (GGS) Wind satellite was a NASA science spacecraft launched on 1 Nov 1994. It was deployed to study radio waves and plasma that occurred in the solar wind and the Earth's magnetosphere. The spacecraft's original mission was to orbit the orbit the Sun at the L1, but this was delayed to study the magnetosphere and near lunar environment when SOHO and ACE were sent to the same location. Wind has been at L1 continuously since May 2004, As of Mar 2021, it had enough fuel to last over 50 more years. Wind has continued to collect data.

DEEP IMPACT

Deep Impact was a NASA space probe launched on 12 Jan 2005, designed to study the interior composition of the comet Tempel 1 (9P/Tempel), by releasing an impactor into the comet. On 4 Jul 2005, the Impactor successfully collided with the comet's nucleus. The impact excavated debris from the interior of the nucleus, forming an impactor crater, and showed the comet to be more dusty and less icy than had been expected.

Previous space missions to comets were able to photograph and examine only the surfaces of cometary nuclei from considerable distances. The Deep Impact mission was the first to eject material from below a comet's surface.

Upon the completion of its primary mission Deep Impact flew by Earth on 31 Dec 2007, on its way to an extended mission, with a dual purpose to study extrasolar planet and comet Hartley 2 (103P/Hartley). Communication was unexpectedly lost in August 2013 while the craft was heading for another asteroid flyby.

GENESIS

Genesis was a NASA sample-return probe that was designed to collect samples of solar particles and return them to Earth for analysis., the first mission to return material since the Apollo programme and the first from beyond the orbit of the Moon.

Genesis was launched on 8 Aug 2001, and the sample return capsule crash-landed on 8 Sep 2004, after a design flaw prevented the deployment of its droque parachute. The crash contaminated many of the sample collectors. Although most were damaged, some of the collectors were successfully recovered.

STARDUST

Stardust was a robotic space probe launched by NASA earlier on 7 Feb 1999. Its primary mission was to collect dust samples from the coma of the comet Wild 2 as well as samples of cosmic dust , and return them to Earth for analysis The primary mission was successfully completed on 15 Jan 2006 when the sample return capsule returned to Earth – after the disaster of Genesis. It was the first successful sample-return of its kind. Enroute to comet Wild 2, it flew by and studied the asteroid 5535 Annefrank.

A mission extension, codenamed NexT, culminated in Feb 2011 with Stardust intercepting comet Tempel1 previously visited by Deep Impact in 2005. Stardust ceased operations in

Mar 2011. On 14 Aug 2014, scientists announced the identification of possible interstellar dust particles from the Stardust capsule returned to Earth in 2006

DSCOVR

Deep Space Climate Observatory (DSCOVR) was a National Oceanic and Atmospheric Administration (NOAA) was space weather, space climate and Earth observation satellite. It was launched on 11 Feb 2015, and reached Sun-Earth L1 on 8 Jun 2015.

WINAP

Wilkinson Microwave Anisotropy Probe (WMAP), originally known as the Microwave Anisotropy Probe (MAP and Explorer 80), was a NASA spacecraft operating from 2001 to 2010 at L2 which measured temperature differences across the sky in the cosmic microwave background.

HERSCHEL

The Herschel Space Observatory was a space observatory of the ESA, with NASA as partner, launched in May 2009 and sent to L2. It was the largest infrared telescope ever launched until the launch of the JWST in 2021.The observatory was capable of seeing the coldest and dustiest objects in space; for example, cool cocoons where stars form and dusty galaxies just starting to bulk up with new stars. The observatory sifted through star-forming clouds—the “slow cookers” of star ingredients—to trace the path by which potentially life-forming molecules, such as water, form.

The telescope's continued to operate until 29 April 2013, when Herschel ran out of coolant. NASA was a partner in the Herschel mission.

PLANCK

Planck was a space observatory operated by the ESA which mapped the anisotropies of cosmic microwave background(CMB) at microwave and infrared frequencies.

Since the end of its mission, Planck has defined the most precise measurements of several key cosmological parameters, including the average density of ordinary matter, and dark matter, and the age of the in the universe.

Planck was launched in May 2009. It reached the Sun-Earth L2 by July 2009. In March 2013, the mission’s first all-sky map of the cosmic microwave background was released. It was deactivated in Oct that year and put into heliocentric sleep.

The mission substantially improved upon observations made by the NASA Wilkinson Microwave Anistropy Probe (WMAP) which operated earlier from 2001 to 2010, also form L2.

Queqiao,

In May 2018, China placed the first communications relay satellite, Queqiao, into a halo orbit around the Earth-Moon L2 point. In Jan 2019, the Chang’e 4 spacecraft landed on the far side of the Moon, using the Queqiao relay satellite to communicate with the Earth.

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Present Frontiers

Stellar Census (Gaia)

Global Astrometric Interferometer for Astrophysics (GAIA) is a European Space Agency (ESA) astronomical observatory mission launched in 2013. The spacecraft is designed for **astrometry**: measuring the positions, distances and motions of stars with unprecedented precision.

Gaia is part of ESA's Horizon+ long-term scientific programme. The spacecraft currently operates at the Sun-Earth Legrange point L2 in a Lissajous orbit. Extended beyond its original life-line 2019, it is expected to operate until 2025.

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Its goal is to create by far the largest and the most precise three-dimensional map of the Milky Way . The astronomical objects surveyed will be mainly stars, but also include planets, comets, asteroids and quasars, among others

To study the precise position and motion of its target objects, the spacecraft monitored each of them about 70 times over the five years of the nominal mission (2014-2019), and continues to do so during its extension. Gaia targets objects brighter than magnitude 20 in a broad photometric band that covers the extended visual range between near-UV and near infrared; such objects represent approximately 1% of the Milky Way population.
Gaia will detect and very accurately measure the motion of each star in its orbit around the centre of the galaxy.

Each of the 1 billion stars that Gaia studies will be observed an average of 70 times over five years to create a record of the brightness and the position of each star over time.

The Gaia mission will create a precise **three-dimensional map** of astronomical objects throughout the Milky Way, and will map their motions, which encode the origin and subsequent evolution of the Milky Way.

Additionally, the spectrophotometric measurements will provide the accompanying detailed physical properties of all stars observed, by then - in radio, infrared, visual and UV perspectives.

These measurements will, characterise their luminosity, effective temperature, gravity AND elemental composition (fantastic!).

Additionally, Gaia is expected to detect thousands to tens of thousands of Jupiter-sized exoplanet beyond the Solar System, 500,000 quasars outside this (Milky Way) galaxy and tens of thousands of known and new asteroids and comets within the Solar System.

This massive **stellar census** will provide the basic observational data to analyse a wide range of important questions related to the origin, structure and evolutionary history of the Milky Way galaxy – and the universe.

Gaia Data Release 1 (DR1)

Gaia DR1 was the first data release of the spacecraft based on the first 14 months of observations was made in Sep 2015. The data release included positions and magnitudes in a single photometric band for 1.1 billion stars using only Gaia data and the positions and magnitudes for more than 2000 extragalactic sources used to define the celestial reference frame.

The second data release (DR2), which occurred in April 2018, was based on 22 months of observations, and included data for about 1.3 billion stars, and contains data for over 14,000 selected Solar System objects.

The first part of the third data release (DR3) was in Dec 2020. The full DR3 was expected in 2022, and the final Gaia catalogue is expected to be released three years after the end of the Gaia mission.

Hipparcos

Gaia is the successor to ESA's Hipparcos mission, operational 1989–1993, which helped create the first modern predecessor database (catalogue) of 1,058,332 stars

USNO-B1.0

Today, the catalogue most often used is USNO-B1.0 an all-sky catalogue that tracks proper motions, positions, magnitudes and other characteristics for over one billion stellar objects. During the past 50 years, 7,435 Schmidt camera plates were used to complete several sky surveys that make the data in USNO-B1.0 accurate to within 0.2 arcsec.

Celestial GPS

And when we get our first 10,000-qubit quantum computer, we shall be able to load all this in and have a miniscule (but hopefully sufficient) slice of our universe as an on-line model, to test our theories and plan our journeys thereto.105

A famous Pillayism states: "You get nowhere without a map". When we break the time barrier, we shall need first a Milky Way and then an inter-galactic GPS.

Asteroid Hunting (OSIRIS-Rex)

OSIRIS-Rex passed near the Sun-Earth L4 point and performed a survey for asteroids in Feb 2017.

OSIRIS-Rex was launched by NASA on 8 September 2016, flew past Earth on 22 September 2017, and rendezvoused with Asteroid 01955 Bennu on 3 December 2018 after a two-year journey.

Asteroid 01955 Bennu is a carbonaceous asteroid in the Apollo group discovered in Sep1999. It is listed on the Sentry List Table106 and has the highest cumulative rating on the Palermo Technical Impact Hazard Scale[107], It has a cumulative 1-in-1,800 chance of impacting Earth between 2178 and 2290 – with the greatest risk being on 24 September

[105] Read the last chapter fo my book "Quantum Mechanics", 2020, at https://geraldpillay.wordpress.com

[106] **Sentry** is a highly automated impact prediction system operated by NASA. It continually monitors the most up-to-date asteroid catalogue for possibilities of future impact with Earth over the next 100+ years.

[107] The **Palermo Technical Impact Hazard Scale** is a logarithmic scale used by astronomers to rate the potential hazard of impact of a near-Earth object (NEO). It combines two types of data—probability of impact and estimated kinetic yield—into a single "hazard" value.

2182. Bennu has a mean diameter of 490 m (1,610 ft; 0.30 mi) and has been observed extensively

It orbited the asteroid and mapped out Bennu's surface in detail, seeking 351pprox.351al sample collection sites. Analysis of the orbits allowed calculation of Bennu's mass and its distribution. The spacecraft spent the next several months analysing the surface to find a suitable site. On 20 October 2020, OSIRIS-Rex **touched down on Bennu** and successfully collected a sample. Though some of the sample escaped when the flap was jammed open by larger rocks, NASA was confident that they were able to retain between 400 g and over 1 kg of sample material, well in excess of the 60 g (2.1 oz) minimum target mass.

On 10 May 2021, OSIRIS-Rex successfully completed its departure from the Bennu asteroid while still carrying the sample. OSIRIS-Rex is expected to return with the sample to Earth on 24 September 2023.

It will subsequently start its new mission as OSIRIS-APEX to study Asteroid 99942 Apophis, another near Earth potentially hazardous asteroid, arriving at that asteroid in 2029.

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Eye in the Sky (James Webb Space Telescope)

The James Webb Space Telescope (JWT) was launched on 25 December 2021 and arrived at the Sun-Earth L2 Lagrange point on its heliocentric orbit on 22 January 2022.

Webb will make one orbit of the L2 point **every six months**, with the thrusters firing at approximately 21-day intervals to keep it aligned.

Webb was launched from the Guiana Space Centre (Le Centre Spatial Guyanais, CSG) in Kourou, French Guiana, onboard an Ariane 5 rocket provided by the European Space Agency.

At a whopping 6,161.4 kg (13,584 lb) or 6.8 (US) tons, and measuring 20x114 metres. It is the largest telescope in space.

It is a project of joint collaboration between the space agencies of US, Europe, and Canada, namely NSA, ESA and CNSA. The James Webb Space Telescope has four key goals:

. – to search for light from the **first** stars and galaxies that formed after the Big Bang,
. – to study galaxy formation an evolution ,
. _to understand star and planet formation, and
. – to study planetary systems and the origins of life.

Because of the "age" of the phenomena under investigation, these goals can be accomplished more effectively by **observation in near-infrared** light rather than light in the visible part of the spectrum. For this reason, JWST's instruments will not measure visible or ultraviolet light like the Hubble Telescope, but will have a much greater capacity to perform infrared astronomy. Its high infrared resolution and sensitivity will allow it to conduct observations of the first stars and the formation of the first galaxies.

The Webb and Hubble missions are expected to overlap, providing complementary science. Hubble will continue its mission as long as its instruments are functioning.

Webb will also provide detailed atmospheric characterisation of potentially habitable planets. It will be able to tell if an exoplanet has methane in its atmosphere, allowing astronomers to determine whether or not the methane is a biosignature.

It is targetted to operate for five and a half years, and thereafter continue functioning on a delaying basis for up to 20 years. It first images were released on 11 July 2022.

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Webb needs to be kept very cool to measure the heat from objects in the universe. Low Earth orbit, where Hubble resides, is too close to heat coming off the Earth and Moon, which would interfere with Webb's precise measurements. Webb had accordingly to be provided with a sunshield. The 5-layered shiny silver shield measured 21.2x14,2 metres (69.5 feet long by 46.5 feet wide) when fully deployed — far too large to fit inside the protective payload. So it was designed to launch in a highly compact configuration and then unfold once Webb got to space.

Likewise, Webb's Korsche telescope has a diametre of 6.5 metres (21 ft) and a collecting area of 25.4 metres (273 sq ft), It's primary mirror had therefore to be manufactured in 18 (gold-plated) segments. Once aloft, they had to be assembled and focussed individually into a smooth surface that could acquire a single sharp image instead of 18 fuzzy ones. Each of the 18 segments has seven actuators on the back to change the shape.

Webb's deployment in space involved unfolding the sunshield and mirrors, a process that was carefully conducted over nearly a month.

Needless to say the remote unpackage, assembling, positioning, calibrating, testing and functionally integrating these two prime components of the spacecraft were extraordinary feats of engineering.

Webb carries a suite of four instruments, which are housed in the Integrated Science Instrument Module (ISIM).

. - **NIRSpec** (Near Infrared Spectrograph),
. – **MIRI** (Mid-Infrared Instrument),
. – **NIRCam** (Near-Infrared Camera), and
. – **FGS/NIRISS** (Fine Guidance System/Near-InfraRed Imager and Slitless Spectrograph),

The four science instruments are sensitive over a wide wavelength range from the optical to the mid-infrared (0.6 – 28.3 microns).

Webb has a larger collecting area and can capture longer wavelengths in infrared. Both its cameras take "deep field" images, pictures with long exposure times (12½ hours in Webb's case) that allow even the most faint form of incoming light to be seen.

Webb's MIRI instrument carries detectors that need to be at a temperature of less than 7 kelvin to operate properly. This temperature is not possible on Webb by passive means alone, so Webb carries an innovative "cryocooler" that is dedicated to cooling MIRI's detectors and the spacecraft bus was filled with 369 pounds (168 kilograms) of hydrazine fuel and 292 pounds (133 kilograms) of dinitrogen tetroxide oxidizer..

Webb is not designed to be serviced. Webb's orbit location is much farther than Hubble, beyond the Moon. To ensure the five-year mission, NASA has engineered Webb so that all critical subsystems are dual or will degrade gracefully with age. Webb has enough fuel for 10 years of manoeuvres at its location.

NASA's Webb Science and Operations Center at the Space Telescope Science Institute has the ability to change the operations of the observatory to maximize its scientific potential as it ages - just like Hubble, NASA's Chandra X-ray Observatory, and NASA's Spitzer Space Telescope.

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Conquest of Mars

Mars is the fourth planet of the Solar System, our nearest neighbour away from the Sun. It is the second brightest star (planet) in the sky after Venus, and has been known from ancient times as the Red Star, because of its distinctly red luminosity. Somewhat unexpectedly, it is only half the size of the Earth with only 11% of its mass.

With Mercury and Venus, our other neighbours closer to the Sun, being totally inhospitable for that reason, Mars has become our automatic target of choice for our travel ambitions. It is the next closest and compatible among our quartet of Inner Planets.

Few people have a clear profile of Mars. In Table 12 we reflect some comparative data of Mars, with Earth – and our two other neighbours, Venus and Mercury, who together form the set of Inner Planets of the Solar System:

Table 12
The Inner Planets - Relative Scales

Data	Mercury (1)	Venus (2)	Earth (3)	Mars (4)	Scale
Diameter	0.38	0.949	1.00	0.53	1=Earth
Mass	0.06	0.82	1.00	0.11	1=Earth
Solar Radius (Av Distance from Sun)	37m	108m	150m	220m	m=million km
Mean Surface Temp	167°	464°	14°	-60°	Celsius
Surface Temp Range	430° to -180°	462° (constant)	-25° to 45°	20° to -125°	Celsius
Length of Day	175.9	116.8	1.00	1.03	1=Earth
Gravity	0.38	0;91	1.00	0.38	1=Earth
Escape Velocity	0.38	0.93	1.00	0.45	1=Earth (11.2 km/s)
Solar Orbit	87.97	224.7	365.2	689.0	Earth days
Orbital speed	47	35	30	24	km/s
Moons (m)	0	0	1	2	

The data above favours Mars as possessing the set with the nearest compatibility to Earth. The next nearest choice would be Jupiter, 741 mill km away with a double-freeze surface temperature averaging -150° Celsius \.

That both Mars and Earth were born together in the same Solar System life-cycle encourages the possibility that they may share common evolutionary features, paleoethology, and resources supportive of life. The most dramatic expectation would be of finding signs of life or life forms on Mars, either existing or in the past, and whether or not evolved from the same elemental bases as man. The preceding would make Mars a primary target for extra-terrestrial settlement.

First Stage Exploration

Not surprisingly, Mars has been intensively probed and investigated. The first successful flyby was on 14–15 July 65, by NASA's Mariner 4. On 14 Nov 71, Mariner 9 became the first space probe to orbit another planet when it entered into orbit around Mars. The Soviet Union's Mars 3, which landed on 2 Dec 71, was the first successful Mars landing, followed by the US' Viking 1 on 20 Jul 76.

Mars has a reputation as a difficult space exploration target; only 25 of the 55 missions through to 2019, or 45.5%, have been fully successful, with a further three partially successful and three partially failures. However, of the sixteen missions since 2001, twelve have been successful and eight of these are still operational.

The **Mars Exploration Program (MEP)** has been a long-term effort funded and led by NASA. Started in 1993, MEP has made use of orbital spacecraft, landers, and Mars rovers to explore the possibilities of life on Mars as well as the planet's climate and natural resources. Most of the activities have come under this programme.

The NASA **Mars Global Surveyor** achieved orbit in 1997. After a year and a half trimming its orbit from a looping ellipse to a circular track around the planet, the spacecraft began its primary mapping mission in Ma 1999. It observed the planet from a low-altitude, nearly polar over one complete Martian year, the equivalent of nearly two Earth years. It completed its primary mission in Jan 01, and several extended mission phases until communication was lost in 2007. Global Surveyor took pictures of gullies and debris flow features that suggested there may be current sources of liquid water at or near the surface of the planet.

The NASA **Mars Pathfinder**, carrying a robotic exploration vehicle **Sojourner** landed in the summer of 1997, returning many images. The mission studied the entire Martian surface, atmosphere, and interior, and returned more data about the red planet than all previous Mars missions combined.

In 2001, **NASA's Mars Odyssey** orbiter arrived at Mars, to hunt for evidence of past or present water and volcanic activity. In 2002, it was announced that it had detected large amounts of hydrogen indicating that there are vast deposits of water ice in the upper three meters of Mars' soil within 60° latitude of the south pole

ESA's **Mars Express Orbiter** entered orbit on Dec 2003 – but its lander-rover, Beagle 2, failed. The Mars Express Orbiter confirmed the presence of water ice and carbon dioxide ice at the planet's south pole, while NASA had previously confirmed their presence at the north pole of Mars.[

In Jan 2004, NASA's **Mars Exploration Rover Mission (MER)** landed on Mars. It was a robotic space mission involving two rovers, **Spirit** (MER-A) and **Opportunity**, (MER-B) that explored the Martian surface geology. The mission's scientific objective was to search for and characterize a wide range of rocks and soils that hold clues to past water activity on Mars. Among the most significant scientific returns has been conclusive evidence that liquid water existed at some time in the past at both landing sites. Spirit rover (MER-A) was active until 2010., In Mar 2006, NASA's **Mars Reconnaissance (MRO) probe** arrived in orbit to conduct a two-year science survey. The orbiter began mapping the Martian terrain and weather to find suitable landing sites for upcoming lander missions. It tested a new telecommunications system that enabled it to send and receive information at an unprecedented rate and allowed it to serve as an important relay satellite for other missions.

In Aug 2012, NASA's **Mars Science Laboratory (MSL)** mission delivered the **Curiosity** rover on the surface of Mars. The mission goals included an investigation of the Martian climate and geology, assessment of whether the selected field site inside Gale had ever offered environmental conditions favourable for micro-life, the role of water, and planetary habitability studies in preparation for human exploration Curiosity was larger and more advanced than the Mars Exploration Rovers, with a velocity of up to 90 metres per hour (295 feet per hour). The rover carried instruments designed to look for past or present conditions relevant to habitability. Experiments included a laser chemical sampler that could deduce the composition of rocks at a distance of seven metres. The rover is still operational, and as of 10 Nov 22, Curiosity had been active on Mars for 3,648 sols (10 years, 96 days) since its landing.

The Indian Space Research Organisation's (**ISRO) Mars Orbiter Mission** (MOM was inserted into Mars orbit on 24 Sep 14. India's ISRO is the fourth space agency to reach Mars, after the Soviet space program, NASA and ESA.

In-depth Exploration

INSIGHT 2018

InSight, which stands for Interior Exploration using Seismic Investigations, Geodesy and Heat Transport, was NASA's next generation Mars lander. Equipped with a heat flow probe and seismometer, its mission is to determine the deep interior structure of Mars.

InSight touched down on Mars on 26 Nov 18. The lander plunged through the thin Martian atmosphere, heatshield first, and used a parachute to slow down. It fired its retro rockets to slowly descend to the surface of Mars, and landed on the smooth plains of Elysium Planitia.

InSight is designed to give the Red Planet its first thorough check up since it formed 4.5 billion years ago. It is the first outer space robotic explorer to study in-depth the "inner space" of Mars: its crust, mantle, and core.

It is worth noting the incredible scope of it mission[108];

. – (a) To understand how rocky planets formed and evolved, InSight will study the interior structure and processes of Mars, the size of the core, what it is made of, and whether it is liquid or solid; the thickness and structure of the crust, the structure of the mantle and what it is made of, and how warm the interior is and how much heat is still flowing through.

. – (b) To determine how tectonically active Mars is today, and how often meteorites impact it. It will measure: how powerful and frequent internal seismic activity is on Mars, and where it is located within the structure of the planet, and how often meteorites impact the surface of Mars.

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[108] https://mars.nasa.gov/insight/spacecraft/about-the-lander/

PERSERVERENCE 2020

The Mars 2020 mission was a part of NASA's programme that included the rover **Perseverence,** the small robotic, coaxial helicopter **Ingenuity**, and associated delivery vehicles. After traveling over the course of more than six months, Perseverance successfully landed in the Martian crater Jezero on 18 Feb 21.The scientific payload is focused on astrobiology.

Unlike older rovers that relied on solar power, Perseverance is nuclear powered, to survive longer than its predecessors in Mars' harsh, dusty environment The car-size rover weighed about 1 ton, with a robotic arm that reached about 7 feet (2.1 m), zoom cameras, a chemical analyser and a rock drill. The rover also employs nineteen cameras and two microphones, allowing for audio recording of the Martian environment.

Perseverance will investigate an astrobiologically relevant ancient environment on Mars, its surface geological processes and history, including assessment of its past habitability the possibility of past life on Mars and the potential for preservation of bio-signatures within accessible geological materials.

As of Oct 21, Perseverance had captured the first sounds from Mars. Recordings consisted of five hours of Martian wind gusts, rover wheels crunching over gravel, and motors whirring as the spacecraft moves its arm. The sounds give researchers clues about the atmosphere, such as how far sound travels on the planet

Importantly, it will cache sample containers along its route for retrieval by a potential future Mars sample-return mission.

HOPE

The Emirates Mars Mission launched its orbiter Hope in Jul 20, which went into orbit around Mars on 9 Feb 21 It was the first in the series of three space missions sent toward Mars during the Ju 20 Mars launch window.

The mission design, development, and operations are led by the Mohamed bin Rashid Space Centre (MBRSC) and at the Universities of Colorado and California Berkeley.

The spacecraft was launched from the Tanegashima Space Centre in Japan, with a Japanese rocket, the Mitsubishi Heavy Industries H-IIA launch vehicle.

The space probe will study the daily and seasonal weather cycles, weather events in the lower atmosphere and how the weather varies in different regions of the planet. It will also add to knowledge about Mars atmospheric hydrogen and oxygen loss and other possible reasons behind the planet's drastic climate changes.

TIANWEN-1 (TW-1)

The Tianwen-1 mission was the second of three Martian exploration missions launched during the Jul 20 Mars launch window, after UAE's Hope orbiter, and before NASA's Perseverence the rover with the attached Ingenuity helicopter drone.

Tianwen-1 (TW-1) was an interplanetary mission by the China National Space Administration (CNSA), which sent a robotic spacecraft mission to Mars, consisting of 6 components: an orbiter, two deployable cameras, a lander, a remote camera, and the **Zurong** rover. The spacecraft, with a total mass of nearly five tons, was one of the heaviest probes launched to

Mars, and carried 14 scientific instruments. It was the first in a series of planned missions undertaken by CNSA as part of its Planetary Exploration of China programme

The mission's scientific objectives included: investigation of Martian surface geology and internal structure, search for indications of current and past presence of water, and characterisation of the space environment and the atmosphere of Mars.

After seven months in transit the spacecraft entered Martian orbit on 10 Feb 21. For the next three months the probe studied the target landing sites from a reconnaissance orbit. On 14 May 21, the lander/rover portion of the mission successfully touched down on Mars, making China the second nation to make a soft landing on and establish communication from the Martian surface, after the United States.

Pending

The optimum “launch windows” to Mars circle round every 2 to 3 years, the next being 2023-24 and 2026.and .

NASA plans to collaborate with the Japanese space agency (JAXA), Canadian Space Agency (CSA), and the Italian Space Agency (ISA) to send an orbiting craft to Mars to map out water ice resources on the planet, targetted for early 2026..

The Indian Space Research Organisation (ISRO) plans to launch its Mars Orbiter Mission, MOM 2 (Mangalyaan-2) by 2025.It trial orbiter MOM1 was sent up earlier in 2013 and operated until 2022. The mission will include a hyperspectral camera, a high resolution panchromatic camera and a radar, to understand the early Martian crust, recent basalts and boulder falls. The mission will be followed by another, including a soft in 2030

Current Status

As of Dc 2022, there were three operational rovers on the surface of Mars, two operated by NASA and one by China. There were seven orbiters surveying the planet, which have contributed massive amounts of information about Mars. In all, there were 11 probes surveying Mars including the Inequity, the robotic helicopter.

The proposed NASA-ESA Mars Sample Return to pick up he samples currently being collected by the Perseverance rover has been delayed to 2033. If the necessary laboratory resources, robotic or human, can be put down on Mars, this mission may not be that crucial.

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Search for Life

All levels of investigation are ultimately driven by the same question: is there life, in any form besides Man, in the universe? Nailing the answers to the questions how the universe began (and will end) may tell us how life, as we know it, began, and give us a clue whether other life forms exist. On this dimension, we must wait till we get there.

The big question comes with an ironic asterisk: we do not have a universally accepted definition of life itself. That said, we might not need one. We need only detect the tell-tale signs of life.

At this point our investigations, we have not the slightest evidence of life in any form, besides ourselves. No aliens have been in touch with us. And we are light years from visiting the closest star. In fact, until we break the speed of light, we do not have any hope of even getting near the Milky Way. So we must work around ourselves , with what we know and at long distance.

Studying the habitable zones of stars is the primary strategy. We have rightly started with our own Inner Planets. For obvious reasons, Mars is our best prospect. The investigations going on are heavily focussed on finding traces of life. We are now also into comet and asteroid bashing, but have found none – not even a worm.

Heaven forbid we find viruses nearby, or anywhere in space. We may have to revise our definition of life[109].

Habitable Stars

Sun- ike stars are classified as G stars; stars less massive and cooler than our Sun are K dwarfs; and even fainter and cooler stars are the reddish M dwarfs.

K Stars, slightly cooler and less luminous than our Sun (also called orange dwarfs) are considered potentially better prospects for advanced life. They can burn steadily for tens of billions of years. This opens up a vast times-cape for biological evolution to pursue an infinity of options for yielding robust life forms. And, for every star like our Sun, there are three times as many orange dwarfs in the Milky Way.

K dwarfs, are considered the ”Goldilocks” stars. K-dwarf stars are in the ‘sweet spot,’ with properties intermediate between the rarer, more luminous, but shorter-lived solar-type stars (G stars) and the more numerous red dwarf stars (M stars). The K stars, especially the warmer ones, have the best of all worlds. K stars are three to four times more abundant than G stars.

Habitable Zones

The “habitable zone” of a habitable star is the circumferential area around it neither too close nor too far from the star.

The definition of “habitable zone” is the distance from a star at which liquid water could exist on orbiting planets’ surfaces.

This is the area around a star in which liquid water could exist on planets over geological timescales and where its atmosphere could contain the right balance of gases that could support life.

Habitable Planets

Needless, life, if to be found, would exist on the planets circulating within the habitable zone. It has of course to be the right type of planet.

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109 Readers may like to look at my separate review on this subject “Virus* - Biological Predator” (2021) at https://geraldpillay.wordpress.com

Exoplanets

An exoplanet is any planet beyond the Solar System. Most orbit other stars, but free-floating exoplanets, called rogue planets, orbit the galactic centre and are untethered to any star. Exoplanets are very hard to see directly with telescopes. They are hidden by the bright glare of the stars they orbit.

The first exoplanet to burst upon the world stage was 51 Pegasi b, a “hot Jupiter” orbiting a Sun-like star 50 light-years away. The watershed year was 1995.

So far scientists have categorised exoplanets into the following types: Gas giant, Neptunian, super-Earth and terrestrial. The mass cannot be greater than approximately 13.6 Jupiter masses because then the planet would start burning deuterium and become a brown dwarf. In order from smallest to biggest, they are rocky planets, super-Earths, mini-Neptunes, ice giants; and gas giants.

There are five different methods to detect exoplanets, including direct imaging, astrometry, radial velocity, transit event observation, and microlensing. Few exoplanets to date have highly accurate measures for both mass and radius, limiting the clues as to what materials they are made of and their formation history.

Kepler Space Telescope

In the 1980s and ’90s ground-based observatories took the reins, providing the historic first burst of exoplanet discovery. Lifting our telescopes above the Earth’s atmosphere revealed a dazzling universe across the light spectrum.

The Kepler Space Telescope made history with its discovery of thousands of exoplanets. In its first mission, from 2009 to 2013, In 2014, it began its second mission, dubbed K2, and continued discovering exoplanets despite its diminished directional capability. Decommissioned in 2018, Kepler remains credited with discovering the most exoplanets of any mission so far – more than 2,600. Researchers are still finding planets in Kepler’s data. The bulk of exoplanets found so far are hundreds or thousands of light-years away.

TESS

The Transiting Exoplanet Survey Satellite (TESS) is a NASA space telescope designed to search for exoplanets using the transit method in an area 400 times larger than that covered by the Kepler mission.

It was launched on 18 Apr 18, and was placed into Earth orbit. TESS uses a novel highly elliptical orbit with an apogee of the distance of the Moon and a perigee of 108,000 km (67,000 mi). TESS orbits Earth twice during the time the Moon orbits once.

TESS has picked up where Kepler and K2 left off, again conducting a grand survey of the sky. But while Kepler took deep, penetrating looks into small patches, TESS’s star pictures are painted in broad strokes.

TESS’s mission is a near all-sky survey in sequential segments, first the dome of stars that would be seen from the Southern Hemisphere, then the Northern. TESS is designed to survey more than 85% of the sky (an area of sky 400 times larger than covered by Kepler).

However, its focus is to search for planets around **nearby** stars (within about 200 light-years). TESS stars are typically 30-100 times brighter than those surveyed by Kepler. Its prime technique is to find planets around these brighter, closer stars, by searching for their shadows - the incredibly tiny subtraction of light from a star when a planet crosses in front of it.

With TESS, it is possible to study the mass, size, density and orbit of a large cohort of small planets, including a sample of rocky planets and in the habitable zones of their host stars. The primary mission objective for TESS was to survey for the transiting exoplanets, over a two-year period, While ground-based telescopes have mainly detected giant exoplanets and the Kepler has mostly found planets around distant stars that are too faint for characterisation, TESS will find many small planets around the nearest stars in the sky.
On 18 Jul 19, after the first year of operation, the southern portion of the survey was completed, and the northern survey was started. The primary mission ended with the completion of the northern survey on 4 Jul 20. The spacecraft entered a second extended mission in Sep 22 which should last for another three years.

As of 5 Nov 22, TESS had identified 5,969 candidate exoplanets, of which only 268 had been confirmed and 1720 had been dismissed as false positives..

TESS provides prime targets for further characterisation by the James Webb Telescope (JWST), as well as other large ground-based and space-based telescopes of the future.
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CHEOPS

Cheops is ESA's Characterising ExOPlanet Satellite. It is the first mission dedicated to studying bright, nearby stars that are already known to host exoplanets, in order to make high-precision observations of the planet's size as it passes in front of its host star.

CHEOP was launched on 18 Dec 19, the first Small-class mission in ESA's Cosmic Vision science programme. It was placed into a Sun-synchronous Earth orbit of about 700 km altitude.

For the planned mission duration of three to five years, CHEOPS is to measure the size of known transiting exoplanets orbiting bright and nearby stars, as well as search for predicted transits of exoplanets previously discovered via radial velocity.

These exoplanets will be the prime targets for future observatories such as James Webb Space and the next generation of ELTs

Extremely Large Telescopes (ELTs)

Finally, we come back to Earth where it all began. The next generation of ground-based telescopes will included these Extremely Large Telescopes (ELTs) among others currently under construction, for the near-red/visible/near-UV spectra, which will enable us to glare at the exoplanets:

. – The Extremely Large Telescope (ELT) at Cerro Amazones Obs, Chile, with aperture 39.3 m, due 2027.

. – The Thirty Metre Telescope (TMT) at Mauna Kea, Hawaii, with aperture of 30.0 m due 2027

.- Giant Magellan Telescope (GMT) at Las Campanas Obs, Chile, with aperture of 24.5 m, due in 2029

Telescopes for radio wavelengths can be much bigger physically, such as the 300 metres (330 yards) aperture fixed focus radio telescope of the Arecibo Obs, Puerto Rico.

TRAPPPIST – 1

The most studied planetary system, aside from our own solar system, lies about 40 light-years away.

In 2017, NASA announced the discovery of the most Earth-sized planets found in the habitable zone of a single star, called TRAPPIST-1, a system of seven rocky worlds–all of them with the potential for water on their surface

A 2018 study suggested that some could harbor far more water than the oceans of Earth, in the form of atmospheric water vapor for the planets closest to their star, liquid water for others, and ice for those farthest away

A 2021 study revealed that the planets are likely made of similar stuff, but different than Earth. That could mean they all contain about the same ratio of materials thought to compose most rocky planets, like iron, oxygen, magnesium, and silicon. But the TRAPPIST-1 planets are about 8% less dense than they would be if they had the same makeup as Earth.

Gliese 486b

In Oct 21, CARMENES consortium and the Max Planck Institute for Astronomy reported the discovery of a hot rocky super-Earth orbiting a nearby red dwarf star, Gliese 486. Despite its small separation from the parent star, the planet designated **Gliese 486b** had possibly retained a part of its original atmosphere. Therefore, at a distance of only 26 light-years, Gliese 486b was uniquely suited for examination by the next generation of space-borne and ground-based telescopes.

The newly discovered Gliese 486b is a super-Earth with a mass 2.8 times biggrt. It is also 30% bigger than Earth. The scientists have employed both transit photometry and radial velocity spectroscopy to obtain their results. By calculating the planet's mean density from the mass and radius measurements, its composition appears similar to Venus and Earth, including a metallic core. Anyone standing on Gliese 486b would feel a gravitational pull that is 70% stronger than what we experience on our world.

Although the star Gliese 486 is much fainter and cooler than the Sun, the irradiation is so intense that the planet's surface heats up to at least 700 Kelvin (430 °C). In this sense, Gliese 486b's surface probably looks more like Venus than Earth, with a hot and dry landscape interspersed with glowing lava rivers.

However, unlike Venus, Gliese 486b possibly has a tenuous atmosphere if any. Model calculations may be consistent with both scenarios because stellar irradiation tends to evaporate atmospheres. At the same time, the planet's gravity helps to retain it. Figuring out the balance of those contributions is difficult.

One great advantage to us is that Gliese 486b traverses the view between us and surface of the host star periodically. Whenever this happens, a tiny fraction of the stellar light shines through the thin atmospheric layer before it reaches Earth. The various compounds in the atmosphere absorb light at specific wavelengths, leaving their footprint in the signal. By using spectrographs, the astronomers split up the light according to wavelengths and look for absorption features to derive the atmospheric composition and dynamics. This method, known as transit spectroscopy, is the most fundamentally important tool we have.

Proxima Centauri

And finally, we come to our nearest neighbouring star, Proxima Centauri. It has been found to possess at least one planet – probably a rocky one. It's about 4 light-years away – more than 25 trillion miles (40 trillion kilometres). No doubt telescopes and instruments will be focussed on It. After Mars, this is our nearest bet.

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SETI

When the current invasion of Mars is finished, we would be happy to know if a microbe lives or lived on the planet, quite apart from intelligent life.

Meanwhile, the Search for Extraterrestrial Intelligence (SETI) is a collective term for scientific searches for intelligent extraterrestrial intelligence – not just life.

Scientific investigation began shortly after the advent of radio in the early 1900s, and focused around monitoring the electromagnetic wavelengths for signs of transmission from civilisations on other planets.

A landmark was the SETI Institute, a no-for-profit I research organisation incorporated in 1984 in US. Its mission was to explore, understand, and explain the origin and nature of life in the universe, and to share this knowledge with the public.

The Institute's Carl Sagan Center is devoted to the study of life in the universe. The Carl Sagan Center is home to over 80 scientists and researchers organised around six research thrusts: astronomy and astrophysics, exoplanets, planetary exploration, climate and geoscience, astrobiology and SETI. Most of the research undertaken within the Carl Sagan Center is funded by grants from NASA, while SETI endeavours are funded exclusively by private philanthropy.

In 1992, the US government funded an operational SETI programme, in the form of the NASA Microwave Observing Program (MOP). MOP was planned as a long-term effort to conduct a general survey of the sky and also carry out targeted searches of 800 specific nearby stars. The US Congress cancelled it one year after its start. In 1995 the SETI Institute resurrected the MOP programme, backed by private sources of funding.

SETI Institute's Center for SETI Research (CSR) uses ATA[110] in the search for extraterrestrial intelligence, observing 12 hours a day, 7 days a week. From 2007 to 2015, the ATA has identified hundreds of millions of technological signals. So far, all these signals have been assigned the status of noise or radio frequency interference.

In 2015, Stephen Hawkins and Israeli billionaire Yuri Milner announced a project called Breakthrough Listen. It was a ten-year initiative with $100 million funding to actively search for intelligent extraterrestrial communications in a substantially expanded way, It has been described as the most comprehensive search for alien communications to date.

[110] ATA = SETI Institute collaborated with Berkeley's SETI research centre to develop a specialized radio telescope array for SETI studies, something like a mini-cyclops array, known as the Allen Telescope Array..

In Oct 2019, Breakthrough Listen started a collaboration with scientists from the TESS team to look for signs of advanced extraterrestrial life. Thousands of new planets found by TESS will be scanned for techno-signatures by Breakthrough Listen partner facilities across the globe. Data from TESS monitoring of stars will also be searched for anomalies

In a 2021, an astronomer described for the first time how one could search for quantum communication transmissions sent by extraterrestrial using existing telescope and receiver technology. He also provided arguments for why future searches of SETI should also target interstellar quantum communication networks. My contribution: check out gravity.

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Chapter Sixteen

Cosmology: Where Do We Stand?

Achievements

There is no doubt that the greatest achievement of science has been to establish that the entire visible universe, the Earth, the stars and the galaxies, are made of the same matter, are governed by the same physical laws, and share the same evolutionary life cycle. In fact they share this common identity as constituents of the same spacetime.

On the one hand, matter in all locations is made up of the same elementary particles as found in the standard table of elementary particles on Earth, and respond to the same four. fundamental forces.

Critically, all matter above 0° Kelvin, no matter where (or when), constantly radiate, absorb and exchange energy across the electromagnetic (EMR) frequencies depending on their actual temperature. The universe is awash with energy, and EMR is the bloodstream. Without light, there would be no life on Earth

Critically all matter is bound together by the same gravitational forces. And lastly, nothing can travel faster than light (pure energy). Incredibly, we understand that all of the visible universe exists as a unity in spacetime. The same processes that operate in our sub-atomic world operate in the larger world

With the science of Quantum-Relativity, technology like the CERN Large Hadron Particle Collider and instrumentation like the Hubble and James Webb Space Telescopes,, man has unravelled not only the composition of our universe but its evolutionary history as well. We have seen light from 13.4 billion years ago and looked down in time to our world from the near 3% from the beginning of the universe's life cycle. Our observable diameter is 27.4 billion light-years in conmoving time and 93 million light-years in proper time..

We know the chemistry of the whole universe. Stars, including our Sun, comprise mainly hydrogen with a smaller proportion on helium, depending on age. The stars convert hydrogen into helium by nuclear fusion, producing heat and light. With astro-spectrography and spectrometry, we can tell the presence of any element anywhere in the universe by the absorption lines in their spectrograph.

Sometimes astro-photography is taken for granted. The modern high-precision digitalised (CCD) camera coupled to a modern telescope of unprecedented amplitude and focal length can capture millions of stars and their locations. We are currently in the process of completing surveys which will map much if not all of the observable universe

Sometimes, our enormous telecommunications and computing capability, developed only in the last fifty years, is also taken for granted. Today, a whole array of observatories around the world can be hooked up to scan a quadrant of the sky at the same instant, with the data downstreamed on-line to a base computer for processing, resolution and storage. With a quantum computer, we should be able to model the universe, interrogate it for a whole new dimension of information, and prepare a GPS. .

And all the preceding has been achieved without man stepping beyond the Moon – and that in 1969. The James Webb Space telescope is already positioned 150 million km in space on a Solar Orbit at Legrange point 2. The Artemis programme should see us place a human habitat on it by the end of this decade. The Conquest of Mars should be on course by then. But, basically, space travel awaits the development of many more things.

We understand that our universe could have started from a singularity in a Big Bang and we are mid-course on our way to a termination as yet to be fully uncovered. Evolving within the fabric of its own spacetime, it has extended massively, with a still active life-cycle and with various possible terminations still to be understood. Depending on whether the universe remains in steady-state, expands or contracts, the geometry of spacetime will remain flat, contract and end in a Big Crunch or continue expanding to a Big Rip. There are still many Cosmic Unknowns to finding out.

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Cosmic Unknowns

Once again, the famous saying rings true: the more you know the more you know you don't know. Astronomy is at a serious cross-roads. Some think we may even want to re-examine whether what think we know, including our science, is correct.

Missing Matter

As soon as astronomers began examining the extragalactic universe newly discovered by Hubble beyond the Milky Way, they found something very wrong. The mass of ordinary matter making up the visible world was far short of what was necessary to generate the gravity to keep the galaxies together and not fly apart. Calculations showed the missing matter to be of the order of five to one. Fritz Zwicky who first discovered the missing matter in 1933, named it Dark Matter,

Dark matter did not react to light or any form of EMR, and it was therefore both invisible and undetectable at all frequencies. The latter meant it could not be spectrographed and studied. It did not interact with ordinary matter, in fact lit largely passed right through the latter. And it did not respond to the four fundamental forces of matter, or only weakly, except for gravity. It is by its gravitational effects that we know its whereabouts, and that only on the macro scale clumped in the centre of galaxies. We know next to nothing about their behaviour on the terrestrial and sub-atomic scale.

It is nearly a century now, but we are still running extended checks against our in-depth knowledge of ordinary matter, to establish it profile by its similarities and differences. So far, we know it has mass and therefore is matter. it is not clear if its matter-energy-temperature profile is the same as ordinary matter. It is heavier (denser) than ordinary matter, and moves more slowly. Some researchers think it may be made of Weakly Interacting Massive Particles (WIMPS), a class of particles that do not absorb or emit light, do not interact with other particles and annihilate one another,

Until disclosed otherwise, we presume it is part of our universe and our spacetime, and subject to the speed of light. We do not know if forms unseen galaxies, dark stars and black holes, with life cycles of their own. For that matter, we do not know if there are invisible men.

We presently hypothesise that dark matter was created in the Big Bang with ordinary matter and pursued its own course alongside us. We do not know if there is dark anti-matter. We do not know if it is expanding or contracting. Our assumption it is a fixed proportion of matter.

Expanding Universe

By the logics of the Big Bang, the original propulsive force should have abated at some stage and been overhauled by gravity, leading to deceleration and contraction. Astronomers calculate this might in fact have happened about 7 billion years ago.

A second astonishment facing astronomy was the simultaneous revelation, now enshrined in the Lemaitre-Hubble law of 1929, that the universe as we know it was expanding. The discovery implied the existence of an additional propulsive force, negative or repulsive to gravity

Critical Density

Under the Lambda-CDM model, critical density is the mass-energy of the universe at which the expansion of the universe is poised between continued expansion and collapse. At this density, the universe (ie. spacetime) will be flat.

If the universe is below critical density, the universe (spacetime) will stop expanding, contract, and end in a Big Crunch. If it exactly equals critical density, the universe will stop expanding, and slow down infinitely towards zero without ever reaching it. If it below critical density, the cosmological constant (Hubble's constant) will prevail to keep it at equilibrium or the universe will contract into a Big Bang. It Rip

Extensive studies of the Cosmological Microwave Background (CMB) originating from the Big Bang indicate that the universe is currently flat. This means we should in equilibrium, neither expanding or contracting. It should also mean that its density should be close to the critical density and the cosmological constant zero.

However, the universe is expanding, in fact accelerating. The expansion indicates that the actual density is higher than critical. One of the major mysteries is to account for the mass-energy propelling. and accounting for the continuing expansion.

Geometry of Space

In Einstein's model of the universe, he introduced a "cosmological constant " (a kind of unknown) as a balancing factor to obtain a stable and perpetual universe and in which the dynamics of spacetime would resolve in a "flat" universe (as in Euclidean geometry).

The ACDM model, which is based on both Einstein and the more recent CMB studies, indicates that to maintain a flat universe and account for the expansion at the current rate, the total mass-energy of universe must comprise all of three components, as follows: 4.9% ordinary matter, 26.5% dark matter and an additional whopping 68.6% of a new unknown entity called dark energy.

Dark energy was immediately thought to be the cosmological constant, except of course it was not constant, but constantly growing. This opened up whole problem areas.

Dark Energy

The ordinary universe had already enlarged enormously with discovery of the extragalactic world. We had suddenly understood the observable diametre of the world to be 27.6 million light years instead of a few hundred thousand light years when Einstein first put out the General Relativity Theory. We are now told this visible world is only 4.9% of our universe.

With dark matter, spacetime, homogeneity and isotopism thrown in, our matter-based world is still only 31.4% of our actual world. The new parametrics of dark energy and dark matter challenge whether our astronomy, based on the visible universe, can still validly conceptualise everything.

Our response has been to interpret the new features with our existing knowledge. As far as we can know, dark matter is made up only of energy. There is only the presence of energy, and a huge and growing amount. It poses the issue whether this energy derives from the mass-energy relationship as per Einstein, or is another thing altogether. The name energy may a misnomer.

Astronomers suggest that dark energy can be thought of as an intrinsic property of spacetime rather than as related to conventional matter that is the source of spacetime curvature. The source of the energy is thought to be external to our universe, but inherent in the fabric of spacetime. The energy is deemed to be inherent in the metric of spacetime..

One (naïve) way of looking at it is that the expansion of our universe drives the expansion of spacetime, which generates new (dark) energy which drives our universe forward.

In this view, the energy generates a propulsive force in the direction of motion, overcoming gravity, and making our universe an “open system”, Other versions speak of negative energy, repulsive force and negative gravity, which seem the same thing, but these lead into technicalities beyond me.

Expansion Rate (Acceleration)

It is clear to me that astronomers do not know the current or starting speed or velocity of the universe. There is no frame of reference to do so. Hubble and company can only calculate the average acceleration rate over distance, in this case the megaparsec (3.26 million light years) and the change of the acceleration rate over time, namely per megaparsec. On this basis they declare presently that the “rate of expansion” , revised a few times, is 73 km/s per megaparsec. For convenience I use this term, referring to acceleration when necessary in context.

Only one commentator on the Internet, namely the correspondent in the BBC Sky At Night Magazine, Feb 2023 issue[111] has attempted to answer the question “Does the universe expand faster than light?” He calculates and I quote: “At the current growth rate of the Universe, their distance will increase by 0.007% (corresponding to 1.4 million lightyears) in one million years, which is clearly faster than light. I have to say the arithmetic is beyond my hand calculator. One million years is not a long time, actually, only 7% of the age of the universe. Even our Sun will be very much around. The question is where will we be, if the acceleration continues, in 4.5 billion years when the Sun dies out. Will we have left light behind somewhere?

It seems to me sufficient that in the current epoch, we are not hurtling away faster than light. In fact our current “speed” (acceleration) at 73 km/s is woefully slower than the 300,000 km/s of light.

Life-Cycle of the Universe

The above has led astronomers to speculate whether the universe can in fact travel faster than light. It has been said everywhere and by everyone (including Einstein) than nothing in spacetime can exceed the speed of light. Our universe is and is in the spacetime. So it

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should not be possible. Perhaps Einstein will be right, again. In any case we shall have to wait (a long time) to see if t happen.

For the present, we still need to think through what happens within current speed limits and known variables.

In an (hypothetical) stable state, with no expansion (or acceleration) and space-geometry is flat, ordinary matter will burn out and thin out towards the end of their galactic-stellar life cycles, and probably be absorbed in black holes.

We have no idea what the life-cycle of dark matter is. In fact, as our perceptions are that they populate the galaxy centres and are denser, they should be the first to fall into the black holes, whether into common black holes or their own. In fact a bright astronomer has suggested that black holes are nothing more than sink-holes of black matter, and have functioned as such from early in the life of the universe to clear away failed galaxies.

As for dark energy, we do not yet clearly know if it will keep growing as an independent prime mover, or slow down as the matter-universe thins out and is supplanted by black holes. We may note that gravity becomes infinite in black holes. In the end it seems we shall be left with black holes and. dark energy, an inviting combination for speculation. Perhaps black holes will stop dark energy in the end, in which case we are looking at a very big Big Crunch in the end.

In the alternate scenario, where the universe keeps accelerating, space-geometry will go convex and force lines diverge. If there is no black hole intervention, the universe will go into a Big Rip. This is still speculative cosmology

IN the third scenario of a contracting universe, for whatever the cause, the universe will contract into a Singularity, generally called the Big Crunch, presumably dark energy and all. This also is very much speculation.

Since that is how we began, some theorise that the Singularity will re-cycle everything in the next Big Bang. They still have to take into account Hawkins radiation, which is the “evaporation” or de-materialisation of matter at the event horizon of black holes and can make big black holes smaller and small black holes disappear.

Genesis of Dark Matter

One present postulate is that, like everything else, the dark energy process began with and as an integral component of spacetime. This could be the genesis of its propulsive force; and as the Big Bang slowed down, dark energy continued to grow drawing in and filling an expanding volume in the matrix of spacetime. It might be noted that the mass-density of dark energy remains constant as it is distributed evenly over time in space, but the quantity and volume of the dark energy increases.

It has also been suggested that dark energy could arise through a common physical process from the quantum level. The proposal here is that the creation of spacetime and matter resulted at the same time in independent metric expansion around mass points in the quantum matrix. The former resulted in the usual curvature of spacetime. This latter however is the source of the dark energy which fills the growing space homogeneously - variously thought of as akin to the zero-point radiation of “vacuum energy” of the cosmological constant.

Notwithstanding the massive propulsive force involved, the matter-energy density of dark energy is very low, about 9×10-27 kg m^{-3},, lower than ordinary and dark matter. This accounts for its volume having to be so large as to equate to 68.6% of our universe.

Yet other researchers theorise that ,based on quantum field theory. vacuum energy arises naturally from the totality of quantum fluctuations in empty space, like virtual particle-antiparticle pairs that come into existence and then annihilate each other shortly thereafter. However, the observed density discrepancies are wide. Other probabilistic solutions have also been posited, motivated by string theory and the possible existence of a large number of disconnected universes.

Quintessence is a significant theoretical development. It is a hypothetical form of dark matter, more precisely a scalar quantum field, postulated as an explanation of the accelerating rate of expansion. Invented by Aristotle, quintessence means something like the essence or perfect form of …in this case energy. The concept has been expanded to more general types of time-varying dark energy It has been proposed by some physicists to be a fifth fundamental force. Quintessence is dynamic, that is, it changes over time, unlike the cosmological constant which, by definition, does not change. Quintessence can be either attractive or repulsive depending on the ratio of its kinetic and potential energy. Those working with this postulate believe that quintessence became repulsive about ten billion years ago, about 3.5 billion years after the Big Bang.[112]

For the broad run of cosmologists who have been studying the issue closely, the supernova result was the last key observation to fall into place. Now it can be said that a cosmological model based on the big bang, inflationary cosmology, and a universe that is composed of one-third matter and two-thirds dark energy is consistent with all current astrophysical and cosmological measurements. For the broader scientific community and the public-at-large, the discovery that the universe is accelerating came as a stunning surprise.

So far, no one has dared entertain the possibility that the universe is not homogeneous and isotropic, the original simplifying assumptions. Taking this possibility together with a variable dark energy like quintessence, we should have a real pickle of options

Finally no one seems to have accounted for the propulsive direction of the force of dark energy, or if one prefers whether repulsive or negative gravity.

Gravity

Newton's Law of Gravitation

Newton's law of gravitation is still the neatest statement of it: that any particle of matter in the universe attracts any other with a force varying directly as the product of the masses and inversely as the square of the distance between them.

Gravity is one of the four fundamental forces (interactions) of matter, which causes mutual attraction between all things with mass or energy in the universe. Fundamental forces are those that govern all matter, and cannot be reduced to further laws.

Gravity was the first fundamental forces to be discovered, by Newton, in 1687. The electromagnetic force was discovered in 1814, the weak nuclear force was discovered in 1933, and the strong force 1935.

Gravity is, by far, the weakest of the four fundamental forces. It interacts with all objects in the universe and its range is infinite.. It is approximately 10^{38} times weaker than the strong force, which however has a range of only 10^{-15} m (diametre of an atomic nucleus). It is

[112] https://en.wikipedia.org/wiki/Quintessence_(physics)

10^{36} times weaker than the electromagnetic force (EMF), which also has an infinite range, and it is 10^{29} times weaker than the weak force, which has a range of 10^{-18} m (tenth of a proton).

As a result, gravity has no significant influence at the level of subatomic particles. However, gravity is the most significant interaction between objects at the macroscopic scale and it determines the motion of planets, stars, galaxies, and even light. On Earth, gravity gives weight to physical objects.

The gravitational attraction between the original gaseous matter in the universe allowed it to coalesce and form stars which eventually condensed into galaxies. It is responsible for the large-scale structures in the universe. Gravity has an infinite range, although its effects become weaker as objects get farther away.

Like the gravitational force, the electromagnetic force is an inverse square law. However, the electromagnetic force does not exist between any two objects of mass, only those that are charged.

As a result, at astronomical scales, gravity is the dominant one because it has the longest range and because there is no negative mass.

Einstein and Gravity

Einstein dealt with gravity in its macroscopic role.. The General Theory of Relativity visualises gravity not as a force, but as the curvature of spacetime caused by the uneven distribution of mass causing masses to move along geodesic lines. The most extreme example of this curvature of spacetime is a black hole from which nothing—not even light—can escape once past the black hole's event horizon Gravity is a result of the warping of space-time..

He theorised that a mass impacts space.. It can warp it, bend it, push it, or pull it. Gravity was just a natural outcome of a mass's existence in space. Instead of exerting an attractive force, each object curves the fabric of space and time around them, forming a sort of well that other objects — and even beams of light — fall into. Gravity is just a natural outcome of a mass's existence in space. Einstein's ideas have been supported by evidence and are widely accepted today

The effect called gravity is simply how objects move in a spacetime that is itself curved. A mass does not shoot out gravitational force field lines. Rather, mass warps space and time, and when an object travels in a straight line through a warped spacetime, the object seems to be acted on by a force.

Einstein’s Equivalence Principle

According to Einstein, the laws of physics are identical in all non-accelerating (that is, inertial) frames of reference. An inertial reference frame is one that drifts in gravity-free space without undergoing rotation or being accelerated.

Einstein's equivalence principle for a uniform gravitational field states that the motion of an object in an inertial reference frame is indistinguishable from the motion of the object in the absence of this field but with respect to a suitable uniformly accelerated reference system. Translated, it means that inertial and gravitational forces are similar in nature and usually indistinguishable.

An immediate consequence of the equivalence principle is that gravity bends light. To visualize why this is true imagine a photon crossing the elevator accelerating into space. As the photon crosses the elevator, the floor is accelerated upward and the photon appears to fall downward.

Einstein Gravity, Space and Cosmic Expansion

On the scale of groups of galaxies and smaller, there is enough localized mass present to make spacetime act like traditional gravity. On these scales, General Relativity almost exactly reproduces the Newtonian law of gravity and acts like good old-fashioned gravity.

On scales larger than galaxy groups, the mass of stars, planets, moons, and space dust gets too sparse and too non-localized on average to make spacetime continue acting like traditional gravity. On these scales, spacetime looks mostly empty, mostly uniform, and mostly flat.

According to General Relativity with the cosmological constant included, two distant galaxies in such a spacetime no longer move towards each other. They move away from each other. It's not that the two galaxies are actively repelling each other. Rather, the nature of spacetime is such that when it is mostly empty, uniform and flat, it expands.

New space is continually created between distant galaxies, so that the distance between galaxies in different galaxy groups is continually growing.

Furthermore, the nature of spacetime is such that, on large scales, this expansion is accelerating in time. Galaxies in different groups are not only moving farther apart, they are also moving farther apart at an increasing rate.

Scientists call this behaviour of spacetime on the largest scale by the names "cosmic expansion" or "metric expansion". Cosmic expansion has been confirmed experimentally many times using many different approaches.

The key concept for our discussion here is that the accelerating expansion of the universe is an innate property of spacetime itself on scales where spacetime no longer acts like traditional gravity.

In summary, the influence of gravity only extends to the edge of each gravity group. Beyond that, spacetime no longer behaves like gravity. It's not that the gravitational attraction of a star simply gets too weak to notice when you leave its galaxy group. Rather, the gravitational attraction goes completely away outside of the galaxy group. Spacetime simply does not behave at all like attractive gravity on cosmic scales. For this reason, gravity fundamentally does not extend beyond gravitationally-bound groups of galaxies.

Quantum Mechanics and Gravity

General relativity and quantum mechanics have been repeatedly validated in their separate fields of relevance. Since the usual domains of applicability of general relativity and quantum mechanics are so different, most situations require that only one of the two theories be used.

Quantum Field Theory (QFT) is the general framework in Quantum Mechanics (with several associated theories) embracing the many elementary particles, fundamental forces, and energy states that make up matter at the subatomic.

QFT has also served as the basis, so far credibly, for understanding the beginnings and early evolution of the universe, and for contemplating its future – on the subatomic scale. It is the framework within and around which efforts are being made to develop quantum gravity as a unifying theory incorporating general relativity and quantum mechanics.

Quantum mechanics is at present incompatible with general relativity. QFT centres on the activities of matter at the sub-atomic in a high energy environment, where elementary particles interact with fundamental forces exchanging well-defined quanta that behave both as a particle and as a wave. General relativity on the other hand deals with the disposition, behaviour, movement and life-cycle of matter on a mass scale in spacetime in a low energy environment. What is thought of as gravity in quantum mechanics is in general relativity the force of macro matter moving through spacetime.

On the one hand, the graviton, the hypothetical force carrier of gravity in quantum mechanics, has not yet not been discovered. Apparently, one of the problems is that the existing facilities for particle acceleration cannot attain the high energies required. This means it has not yet been proved that gravity is quantum. I take it, the fact that its comparative strength has been so finely calculated proves that as the fourth fundamental force it does in fact exist as quantum force. So far, aside from physical proof and its negligible strength, gravity has still to be fully theoretically integrated with the other forces.

On the other hand, the identification and naming of the force keeping the universe together as gravitation took place well before quantum mechanics was invented. Newton did not concern himself with its genesis. It was a low energy scenario dealing with matter at the macro level. Einstein refined its the physics as four-dimensional spacetime to explain the nature of the force. He also did not deal with the underlying genesis of the forcesor the force carrier involved, While Einstein separately help discover the quantum (photon), he did not associate gravity with it.

There is a gap. Even today, gravity is essentially Newtonian-Einsteinian. Quantum mechanics has to prove it is theirs, and gravity is quantum, like light is photonic.

Most theoretical physicists hope to extend (complete) the Standard Model of Particle Physics with an added component called quantum gravity. They are convinced that quantum reality must envelope all the elementary particles and forces at all scale of nature, including gravity.

Unification Theories

A quantum theory of gravity is needed in order to reconcile general relativity with the principles of quantum mechanics, but difficulties arise when one attempts to apply the prescriptions of quantum theory to the force of gravity. The major focus of research therefore is on quantum gravity. This is today a major open end of cosmology

String Theory

In string theory, the gravitational field is not quantised; rather, a distinct theory is quantised which happens to coincide with general relativity at low energies

In string theory the point-like particles of particle physics replaced by one-dimensional objets calle strings. . String theory describes how strings propagate through space and interact with each other. In a given version of string theory, there is only one kind of string, which may look like a small loop or segment of ordinary string, and it can vibrate in different ways. On distance scales larger than the string scale, a string will look just like an ordinary particle, with its mass, charge and other properties determined by the vibrational state of the string. In this way, all of the different elementary particles may be viewed as vibrating strings. One of the vibrational states of a string gives rise to the graviton, a quantum mechanical particle that carries gravitational force.
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String theory posits that at the beginning of the universe (up to 10−43 seconds after the Big Bang), the four fundamental forces were once a single fundamental force. According to string

theory, every particle in the universe, at its most ultramicroscopic level consists of varying combinations of vibrating strings (or strands) with preferred patterns of vibration. String theory further claims that it is through these specific oscillatory patterns of strings that a particle of unique mass and force charge is created (the electron is a type of string that vibrates one way, while the up quark is a type of string vibrating another way, and so forth).

String theory proposes six or seven dimensions of hyperspace in addition to the four common dimensions, for a ten- or eleven-dimensional spacetime. Another important property of string theory is its supersymmetry which together with extra dimensions are the two main proposals for resolving why gravity is so much weaker than any other force. The extra-dimensional solution involves allowing gravity to propagate into the other dimensions while keeping other forces confined to a 4-dimensional spacetime, an idea that has been realised with explicit stringy mechanisms.

There are several versions of string theory: The different theories allow different types of strings, and the particles that arise at low energies exhibit different symmetries. For example, the type I theory includes both open strings (which are segments with endpoints) and closed strings (which form closed loops), while types IIA and IIB include only closed strings.

Superstring Theory

Another important theoretical idea that plays a role supersymmetry. This is a mathematical relation that exists in certain physical theories between a class of particles called bosons and a class of particles called fermions. Roughly speaking, fermions are the constituents of matter, while bosons mediate interactions between particles. In theories with supersymmetry, each boson has a counterpart which is a fermion, and vice versa. When supersymmetry is imposed as a local symmetry, one automatically obtains a quantum mechanical theory that includes gravity. Such a theory is called a supergravity theory.

At low energies, the superstring theories are approximated by supergravity in ten spacetime dimensions.

A theory of strings that incorporates the idea of supersymmetry is called a superstring theory. There are several different versions of superstring theory

Branes

In string theory and related theories such as supergravity theories, a brane is a physical object that generalises the notion of a point particle to higher dimensions.

For example, a point particle can be viewed as a brane of dimension zero, while a string can be viewed as a brane of dimension one. It is also possible to consider higher-dimensional branes. In dimension p, these are called p-branes. Branes are dynamical objects which can propagate through spacetime according to the rules of quantum mechanics.

They can have mass and other attributes such as charge. A p-brane sweeps out a (p + 1)-dimensional volume in spacetime called its worldvolume. Physicists often study fields (analogous to the electromagnetic field) which live on the worldvolume of a brane. The word brane comes from the word "membrane" which refers to a two-dimensional brane.

Much of the current research attempts to better understand the properties of these branes

M-Theory

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M-theory is a theory in physics that unifies all consistent versions of superstring theories. It was first proposed by Edward Witten (1951-) in 1995. Witten's announcement initiated the “second superstring revolution”.

Prior to Witten's announcement, string theorists had identified five versions of superstring theory. Although these theories initially appeared to be very different, work by many physicists showed that the theories were related in intricate and nontrivial ways.

Physicists found that apparently distinct theories could be unified by mathematical transformations (called S-duality and T-duality) Witten's conjecture was based in part on the existence of these dualities and in part on the relationship of the string theories to a field theory called eleven-dimensional supergravity.

Although a complete formulation of M-theory is not known, such a formulation should describe two- and five-dimensional branes and should be approximated by eleven-dimensional supergravity at low energies.

Investigations of the mathematical structure of M-theory have spawned important theoretical results in physics and mathematics. More speculatively, M-theory may provide a framework for developing a unified theory of all of the fundamental fores of nature.

Each of the string theories arises as a special limiting case of M-theory. This theory, like its string theory predecessors, is an example of a quantum theory of gravity. It describes a force just like the familiar gravitational force subject to the rules of quantum mechanics
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Theory of Everything (TOE)

A theory of everything may be defined as a comprehensive theory that, in principle, would be capable of describing all physical phenomena in this universe.

Solving the missing link of quantum gravity would go a big way to unifying general relativity and quantum mechanics to this end They are also considered incompatible particularly in common regions of extremely small scale such as those that exist within a black hole or during the beginning stages of the universe (i.e., the moment immediately following the Big Bang) . A theoretical framework revealing a deeper underlying reality, unifying gravity with the other three interactions, must be discovered to harmoniously integrate the realms of general relativity and quantum mechanics into a seamless whole.

At the macro level, new aspects are constantly emerging. There is still the question of dark matter, which needs to be fully integrated with both QFT and spacetime. At the same time, the source of dark energy is attributed to be inherent in the fabric of spacetime. However the source of the energy (if it is energy) and the cause and mechanics are not known. And the link between dark energy, gravity and the expanding universe needs likewise to be established.

At present dark energy is hypothesised as negative gravity. This is another macro feature of spacetime. No doubt this is being taken into account in the various theories.

At the event horizon, Hawking realised in 1974, one particle in a pair can fall into ta black hole while the other escapes. As the black hole radiates such particles, it loses energy and mass, until it evaporates completely. Such "Hawking radiation" is too feeble to observe, but few scientists doubt its existence. The implications of this phenomenon for QT on the one hand and the life cycle of spacetime on the other need to be found out. One vexing issue is the question of the “black hole information box” for with evaporation of the black hole, the preservation of information presents another inscrutable problem. The same issue of course arises in a Big Crunch

Whatever terminal end is visualised for the universe, it must also be rationalise with the second law of thermodynamics and the entropic end of the world.

At the subatomic level, QFT must pursue the many new areas emerging in Quantum mechanics, such as the full place and role of antiparticles and antimatter generally. Ultimately, QFT must determine the subject of Singularities and how a quiet empty estate of space produced the Big Bang.

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Chapter Seventeen

Destination Mars

Given the limits of our present scientific, technological, and exploratory achievements, man is close to making a first human attempt to travel to another planet. Without question, that planet has to be Mars. It is our nearest neighbour, with the nearest comparable environment to Earth. The conquest of Mars is the first step to travel further afield. This Chapter reviews our readiness and prospects.

Home Front

The Sun can sustain life on Earth for the next 1-1.5 billion years before the oceans boil up. It is good to know it will be here if we return this way.

The world's population was 7.91 billion in 2020 with an average density of 52 p/km^2. and will peak at 11.0 billion in 2100 at a density of 72 p/km^2. Thereafter it is expected to decline. If we find a cure for aging, we could grow to the trillions, and maybe need to find additional accommodation

Of the earth's surface of 514 million miles^2, some 29 % is land, of which 71% is habitable. The sea level is projected to rise by up to 1.1 – 2.1 m by 2100, or by 0.23%. Low countries will suffer flooding, and many (island countries) will disappear. The net habitable area will reduce as we peak.

UN have warned that, even if current pledges for action by 2030 are delivered in full, there is likely to be a mean rise in global heating of about 2.5° Celsius, a level that would condemn the world to climate breakdowns. If continued to 2100, conditions would be catastrophic and affect long-term habitability.

There is reason therefore for us to look to the sky for habitability. However, if we manage ourselves properly, there is no reason not to think of Earth as our home for many years to come, whether or not we settle afield.

The immediate motivation is simply to beat the challenge: Have Rocket Will Travel. The subtler motive is: to give the successful parties whatever geopolitical and economic advantage may accrue.

Are We Ready?

Going to Mars has only emerged into possibility in the last half century of years. It is meaningful to re-cap our journey so far to sum up our readiness,

Climbing Up Jacob's Ladder (Reprise)

Step One - Conquering Earth's Orbit.

The first sub-orbital flight took place (with Sputnik) on 4 Oct 57 and the first flight of man in space (Yuri Gagarin) on 12 Apr 61.

The first communications satellite, Telstar 1, orbited on 12 Jul 62. As of 1 Sep 21, there were 4,550 earth satellites in orbit, belonging to 75 countries (of which Singapore is one with 11) and some 85% of which are in private ownership. The satellites are tightly integrated with ground stations into comprehensive telecommunications platforms, supporting a world- and space-wide communications, including NASA's Deep Space Network. Communication with Mars is the first prerequisite.

Step Two – Conquering the Moon

The first human (Neil Armstrong) stepped on the Moon under the Apollo 11 Mission on 20 Jul 69. During six successful two-man landing missions, 12 men walked on the lunar surface. The last man to step off the Moon did so on 18 Dec 72.

We are currently preparing for the next series of visits to the Moon under NASA's Artemis programme. It is specifically to refine our skills for Mars.

Step Three – Space Stations and Shuttles

Salyut 1 was the world's first space station launched by the Soviet Union on 19 Apr 71. The first uplift was un crewed.

The first successful delivery of crew by the Russian space shuttle Soyuz 10 (see further on), performed experiments for 23 days aboard. However, they were killed by asphyxia caused by failure of a valve just prior to Earth re-entry. Salyut 1's mission was terminated in Oct 71.

Skylab was NASA's first space station launched on 14 May 73. It was developed on a Saturn V Moon rocket.

Three subsequent missions delivered three-astronaut crews: Skylab 2 in May 73 for 28 days, Skylab 3 in Jul 73 for 59 days , and Skylab 4 in Nov 73 for 84 days. As the Space Shuttle was not ready until 1981, the programme was cancelled. Skylab's orbit eventually decayed in Jul 79,

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MIR was a space station operated from 1986 to 2001 by the Soviet Union and later Russia. MIR was the first modular space station assembled in orbit.

MIR, launched in 1986, was the first continuously inhabited long-term research station in orbit. It was occupied for a total of twelve and a half years out of its fifteen-year lifespan, having the capacity to support a resident crew of three, or larger crews for short visits. MIR was de-orbited in Mar 01 after funding was cut off.

The **International Space Station (ISS)** was and remains the largest modular space station in Earth orbit. It is a multinational collaborative project involving five participating space agencies: NASA (United States), Roscosmos (Russia) JAXA (Japan), ESA (Europe), and CSA Canada).

The first ISS component was launched in 1998, and the first long-term residents arrived on 2 Nov 00. The station has since been continuously occupied for 21 years and 345 days, the longest continuous human presence in Earth orbit. In Jan 22, the station's operation authorisation was extended to 2030.

The ISS was taken into space piece-by-piece and gradually built in orbit using spacewalking astronauts and robotics. Most missions used NASA's space shuttle to carry up the heavier pieces, although some individual modules were launched on single-use rockets.

The ISS is suited for testing the spacecraft systems and equipment required for possible future long-duration missions to the Moon and Mars. The longest a person has stayed continuously onboard in space was 437 days.

The **Space Shuttle** programme, carried out by NASA, aimed at creating a regular(reusable) Space Transportation System (STS). The shuttles operated from 1981 to 2011 and provided routine space station transportation for Earth-to-orbit crew and cargo, as well as launched satellites into space. It flew 135 missions and carried 355 astronauts from 16 countries, many on multiple trips. They were launched vertically by rocket.

The space shuttle was the only winged and crewed spacecraft built. It comprised an orbiter (space plane) launched with three rocket engines into low orbit, and equipped with two reusable boosters It carried up to eight astronauts and a payload of up to 50,000 lb (23,000 kg) When its mission was complete, the orbiter would re-enter the Earth's atmosphere and land like a glider. Each vehicle was designed with a projected lifespan of 100 launches, or 10 years' operational life.

Six orbiters were built for flight. They had a checkered history and the programme was terminated in 2011, with a total casualty rate of 15 astronauts and four cosmonauts:

. – Enterprise (1977) was the first and the test vehicle and disassembled after completion of critical testing.
. - Columbia (1981) was the first space-worthy orbiter. In 2003, it disintegrated during e-entry on its 28th flight.
. – Challenger (1983) also disintegrated in 1986, 73 seconds after its launch on its tenth mission.
. – Discovery (1984) flew 39 missions, and was NASA's "Return to Flight" vehicle, following the earlier accidental destructions. Discovery completed its last mission in 2011.
. – Atlantis (1985) flew 33 spaceflights including the final mission in July 2011.
. – Endeavour (1992) flew 25 spaceflights, the final launched on May 16, 2011.

Soyuz, the Russian space shuttle, served as the only means to ferry crew to or from the ISS after the retirement of the Space Shuttle, until 2020. Soyuz started in Nov 66, and is considered the world's most successful shuttle service, having carried cosmonauts and cargo to and from the Salyut 1, MIR and the ISS for over 50 years. At least one Soyuz spacecraft is docked to the ISS at all times for use as an escape craft in the event of an emergency.

Several **Commercial Space Transport Services** companies now ship crew and cargo to the ISS - spurred by NASA's Commercial Resupply Services and its Crew Development programme. The lead corporation is Space Exploration Technologies Corp (SpaceX) who are playing a major role in the preparations for Mars.

The **Tiangong Space Station** is the most recent space station put up by China. The core module, was launched on in Apr 21 and two more major modules have been added in Sep and Oct in 22. The Shenzhou 15 mission launched successfully carried three taikonauts (astronauts) to the Tiangong on Nov 22,.

Step Four –Exploring the Solar System

The first fly-by of a planet by a probe was by Mariner 2. This was of Venus in Aug 62. Since then all the **Inner Planets** have been visited one or more times, the last being Mars, by Aug 75. All visits were uncrewed and on a no-return basis, with varying performance configurations, ie fly-by, orbit, impact landing, landing, and collecting a wealth of data and photographs as available.

The first probe to the **Outer Planets** was Pioneer 10, to Jupiter in Mar 72. The remaining planets, Saturn, Uranus and Neptune were variously studied by Pioneer 11 and Voyagers 1 & 2, by Aug 89. New Horizons penetrated beyond and studied Pluto and the Kuiper Belt In Jul 15,

A major achievement of the probes to the Outer Planets was perfecting the technique of **Gravitational Assist**. By precise interplanetary navigation, a probe could use the gravitation of planets or other bodies enroute to "slingshot" it towards its destination, whether directly or in tandem - or slow itself down. It was the key opening. The door to outer space.

A second achievement was successfully identifying and exploiting the **Legrange Points** at the heliosphere. Mathematically, there are five points of gravity equilibrium (L1 to L5) between every set of bodies in orbit relative to one another. These are excellent parking zones for satellites, and spacecraft that need to work from one spot - and with an unparalleled view of the universe. There have been over 20 satellites parked at Sun-Earth L2 this century, including the James West Space Telescope, 150 million km up. Artemis will be parking the Gateway for the next Moon mission at Moon-Earth L2, and a similar option is available at Mars if they decide on a gateway there.

The third major achievement has been the precision of the observational instruments aboard these probes, among others for astro-photography and spectrographic capture. As a result we can profile the make-up of every planet in depth, and can focus further research with precision to find out what we really need to know (like water on Mars). Tangentially, robotic vehicles have been developed to carry these instruments on the surface of these planets for eye-level investigation.

Investigation of Mars

It takes traveling 471 million km to reach Mars, over more than six months, depending on the optimum launch window, which occurs every 2-3 years only.

Mars has had a reputation as a difficult space exploration target; just 25 of 55 missions through to 2019, or 45.5%, have been fully successful, with a further six partially successful. The Soviet Union's Mars 3, which landed on 2 Dec 71, was the first landing, followed by the US' Viking 1 on 20 Jul 76. Of the 16 missions since 2001, some 12 have been successful and eight of these are still operational.

The Robotic Onslaught

It is nearly half a century since man stepped on the Moon, and there has been a revolution in microelectronics, telecommunications, data-processing, robotics, instrumentation and laboratory analysis, not to mention launch and landing technology.

Substantially, NASA's Mars Science Laboratory (MSL) mission in Aug 2012 was a major breakthrough. It delivered **Curiosity**, the robotic rover, on the surface of Mars. The mission goals included an investigation of the Martian climate and geology, assessment of whether the selected field sites had ever offered environmental conditions favourable for micro-life, the role of water, and planetary habitability studies in preparation for human exploration.

Curiosity was larger and more advanced than the Mars Exploration Rovers (of 2004), with a velocity of up to 90 metres per hour. The rover carried instruments designed to look for past or present conditions relevant to habitability. Experiments included a laser chemical sampler that could deduce the composition of rocks at a distance of 7 meters. The rover is still operational, and as of Nov 22, Curiosity has been active on Mars for 3,648 sols (10 years, 96 days) since its landing.

InSight, which stands for Interior Exploration using Seismic Investigations, Geodesy and Heat Transport, was NASA's next generation Mars lander. Equipped with a heat flow probe and seismometer, its mission was to determine the deep interior structure of Mars. InSight touched down on Mars on 26 Nov 2018. It was the first outer space robotic explorer to study in-depth the "inner space" of Mars: its crust, mantle, and core.

The Mars 2020 mission was a part of NASA's programme that included the rover **Perseverence,** the small robotic, coaxial helicopter **Ingenuity,** and associated delivery vehicles. Perseverance successfully landed in the Martian crater Jezero on 18 Feb 21.The scientific payload was focused on astrobiology. As of Oct 21, Perseverance had captured the first sounds from Mars.

The Emirates Mars Mission launched its orbiter **Hope** in Jul 2020, which went into orbit around Mars in Feb 21, The space probe, launched from Japan, will study the daily and seasonal weather cycles and the possible reasons behind the planet's drastic climate changes.

The **Tianwen-1** mission was the second of three Martian exploration missions launched during the Jul 2020 Mars launch window, after UAE's Hope orbiter, and before NASA's Perseverence. On 14 May 21, the lander/rover portion of the mission successfully touched down on Mars, making China the second nation to make a soft landing on and establish communication from the Martian surface, after the United States.

ExoMars (Exobiology on Mars) is an astrobiology programme of the European Space Agency (ESA), to search for signs of past, investigate how the Martian water and geochemical environment varies, investigate atmospheric trace gases and their sources and by doing so demonstrate the technologies for a future Mars Sample-Return mission.

The first part of the programme was a mission launched in 14 Mar 16 that placed the **Trace Gas Orbiter** (TGO) into Mars orbit while lander crashed on the planet's surface. The TGO proceeded to map the sources of methane (CH4) and other trace gases present in the Martian atmosphere that could be evidence for possible biological or geological activity.

The second part of the programme was planned for Jul 20, when a Russian lander would have delivered the **Rosalind Franklin rover** on the surface, supporting an extensive mission that was expected to last into 2022 or beyond. On 12 Mar 20, it was announced that the second mission was being delayed, inter alia due to the Ukraine war..

NASA plans to collaborate with the Japanese space agency (JAXA), Canadian Space Agency (CSA), and the Italian Space Agency (ISA) to send an orbiting craft to Mars to map out water ice resources on the planet.

Current Status

As of 2023, Mars is host to thirteen functioning spacecraft. Eight are in orbit: 2001 Mars Odyssey, Mars Express, Mars Reconnaissance Orbiter, MAVEN, ExoMars Trace Gas Orbiter, the Hope orbiter, and the Tianwem-1 orbiter, Another five are on the surface: the Mars Science Laboratory Curiosity rover, the Perseverence rover, the Ingenuity helicopter, the Tianwen-1 lander, and the Zhurong rover..

Planned missions to Mars include the Rosalind Franklin rover mission, designed to search for evidence of past life, which was intended to be launched in 2018 but has been repeatedly delayed, with a launch date pushed to 2024 at the earliest, with a more likely one sometime in 2028.

The proposed NASA-ESA Mars Exon Sample Return to pick up the samples currently being collected by the Perseverance rover has been delayed to 2033.

We have established a robotic foothold on Mars, albeit we have only scratched the surface in a few places.. The next section will reflect how much we do know, while also identifying further critical gaps about Mars. A huge area still to be covered is our own human biological adaptation to travelling in space and living in the Martian environment. This includes creating the kind of spaceships and ground habitats humans can survive in for reasonably long periods if not to settle in permanently.

It will lead us to the three next milestones (1) establishing a dependable transport and communications framework between Earth and Mars, (2) marshalling Mars' resources to support human life and economic activity and settlement and (3) selected suitable sites for the initial outpost if not settlements.

The NASA Authorization Act of 2017 directed NASA to study the feasibility of a crewed Mars mission in the early 2030s. The resulting report eventually concluded that this would be unfeasible. In 2021, China was planning to send a crewed Mars mission in 2033.

A private company, SpaceX, has proposed plans to settle humans on Mars within this decade., The moon Phobos has also been proposed as an anchor point for a space elevator.

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The Mars Environment

Mars has half the radius of Earth, one-tenth the mass, and only 38% of Earth's gravity. It has to be established can man can adapt in the long term, and indeed survive the many bodily dysfunctions already known from his limited low gravity exposures so far.

Planetary History

Red Planet

The Sun formed in the Milky Way about 4.6 billion years ago in a giant, spinning cloud of gas and dust called the Solar Nebula. When a temperature of about 15,000,000° K was reached, nuclear reaction (fusion) began at the core of the Sun, and the solar system settled into its current layout. About 4.5 billion years ago, Mars formed when gravity pulled swirling gas and dust in to become the fourth planet of the Sun.

Mars is about 220 million km from the Sun (as against Earth 's 150 million km). It is about half the size of Earth, is 11% of its mass and has a gravity of only 38% that of Earth's. Mars has a radius of 3,900 km.

Mars can be viewed from Earth with the naked eye, distinguished by its reddish colour which has led to it often being called the Red Planet. Mars has two small, irregularly shaped moons, Phobos and Deimos. A journey to Mars from Earth is about 480 million km, and takes six months at current technological speeds.

Core and Surface

Like Earth, Mars differentiated into a dense metallic core, overlaid by less dense materials forming a rocky mantle, and a solid crust. materials. The core consists primarily of iron and nickel with about 16–17% sulphur. The core is surrounded by a silicate mantle that formed many of the tectonic and volcanic features on the planet. The average thickness of the planet's crust is about 50 km with a maximum thickness of 125 km. By comparison, Earth's crust averages 40 km. Elements with comparatively low boiling points are much more common on Mars than Earth.

In 2021, it was reported that based on eleven low-frequency marsquakes detected by the InSight lander the core of Mars was indeed liquid and had a temperature of around 1,900–2,000° K. The Martian core has a radius of about 1,830 km, abnormally large, accounting for more than half the radius of Mars and about half the size of the Earth's core. The core of Mars is overlaid by the rocky mantle, which does not however have a thermally insulating layer analogous to the Earth's lower mantle. The Martian mantle appears to be solid down to the depth of about 500 km, where the low-velocity zone begins. Below the velocity of seismic waves starts to grow again; and at the depth of about 1,050 km lies the boundary extending down to the core.

Mars is a terrestrial planet, with a surface that consists of minerals containing silicon and oxygen, metals and other elements that typically make up rock. The Martian surface is primarily composed of basaltic, although parts are more silica-rich. Much of the surface is deeply covered by finely grained iron oxide dust, which gives he planet its colour.

Late Heavy Bombardment (LHB)

After the formation of the planets, all were subjected to the so-called Late Heavy Bombardment (LHB)113. About 60% of the surface of Mars shows a record of impacts from that era, whereas much of the remaining surface is probably underlain by immense impact basins caused by those events. There is evidence of an enormous impact basin in the northern hemisphere of Mars, spanning 10,600 by 8,500 km, the largest impact basin yet discovered. This theory suggests that Mars was struck by a Pluto-sized body about four billion years ago. The event is thought to be the cause of the Martian hemispheric dichotomy and to have created the smooth Borealis Basin that covers 40% of the upper half of the planet.

Magnetosphere

Thanks to the numerous missions we now know that in its early infancy, up until around 4 billion years ago (Gya), Mars had a strong magnetic field, created, just like Earth's, by convection currents of molten metals in the planet's core. But, unlike Earth, Mars cooled enough internally to switch off this mechanism, and the planet ended up with no global magnetic field. Without this magnetic field, the planet was less protected from the solar wind – the stream of energetic charged particles flowing from the Sun.

The solar wind stripped away most of the Martian atmosphere in only a few hundred million years after the planet lost its magnetic field. This process was quick because the Sun rotated much faster in its youth, which made the solar wind more energetic. The loss of a large

[113] The **Late Heavy Bombardment (LHB)** is a hypothesized event thought to have occurred approximately 4.1 to 3.8 billion years (Gya) ago, at a time corresponding to the Neohadean and Eoarchean eras on Earth. According to the hypothesis, during this interval, a disproportionately large number of asteroids and comets collided with the early terrestrial planets in the inner Solar System, including. These came from both post-accretion and planetary instability-driven populations of impactors. Although widely accepted, it remains difficult to prove conclusively

fraction of its atmosphere to space was the major cause of Mars's transition from a warm, wet climate to today's cold, dry one.

New studies link the disappearance of the Martian magnetic dynamo to the Late Heavy Bombardment, The cooling action of the mantle draws heat from the core, keeping it churning. Without that flow, core convection would cease.The subsisting theory is that a massive collision could and did warm Mars's mantle, disrupting core convection. Further, the date of heavy bombardment, about 3.9 billion years ago, corresponds to the death of Mars's dynamo.

Mars was hit by at least five particularly large asteroids during the bombardment. Any one of the super-giant impacts could have shut off [the dynamo.

Observations show that parts of the planet's crust have been magnetized, confirming the pre-existence of the magnetic mantle.

Earth likely suffered the same onslaught, but at twice the radius of Mars, it probably had a strong enough dynamo to withstand or recover from huge impacts. Not all scientists however are on board with the analysis

Topography

The most obvious geomorphic feature of Mars is the dichotomy between its northern lowlands and southern highlands.

Mars is "bald" at the top, except for the polar ice-cap. The Northern Hemisphere comprises relatively low land making up some 40% of the planet's total surface. There is a theory that something big like an unstable planet came by and ripped off the top in its early life.
The Northern Lowlands consists mainly of the vast Vastitas Borealis plain.

The Southern Hemisphere, on the other hand, is wholly encircled by highland, which stretches down to and includes the south pole, comprising components of different geological eras. The pole is ice-capped. The west is volcanic and includes Olympus Mons, the highest mountain in the Solar System. There are three huge craters basins, the Argyre and Hellas in the south and the Isidis Basins on the equator. Much of the rest of southern highlands is heavily pock-marked by small impact craters.

The most conspicuous feature is the Valies Marineris, one of the largest canyons in the Solar System. It Is more than 4,000 km long, 200 km wide and up to 7 km deep, surpassed in length only by the oceanic rift valley systems of Earth. Valles Marineris is located along the equator of Mars, and stretches for nearly a quarter of the planet's circumference.

It has been suggested that Valles Marineris is a large tectonic "crack" in the Martian crust. Most researchers agree that this formed as the crust thickened in the mountainous region to the west, and was subsequently widened by erosion. Near the eastern flanks of the rift, there appear to be channels that may have been formed by water or carbon dioxide or by the erosion of lava flows.

Atmosphere

The atmosphere of Mars is colder than Earth's. Owing to the larger distance from the Sun, Mars receives less solar energy and has a lower effective temperature, which is about −63 °C. The average surface emission temperature of Mars is just −58 °C, which is comparable to inland Antarctica.

The atmosphere of Mars is much thinner than Earth's. The average surface pressure is only about 0.088 psi which is less than 1% of the Earth's value. The currently thin Martian atmosphere prohibits the existence of liquid water on the surface, but many studies suggest that the Martian atmosphere was much thicker in the past.

The atmosphere of Mars is primarily composed of carbon dioxide 95%), molecular nitrogen (2.8%), and argon (2%). It also contains trace levels of water vapour, oxygen, carbon mono oxide, oxygen and hydrogen and the noble gases.

The highest atmospheric density on Mars is equal to the density found 35 km above the Earth's surface and is 0.02 kg/m3.

The atmosphere of Mars has been losing mass to space since the planet's core slowed down, and the leakage of gases still continues today. The density during spring and fall is reduced by 25% during the winter when carbon dioxide partly freezes at the pole caps.

The atmosphere is quite dusty, containing particulates about 1.5 μm in diameter which give the Martian sky a tawny colour when seen from the surface. It may take on a pink hue due to iron oxide particles suspended in it.

Seasons

Of all the planets in the Solar System, the seasons of Mars are the most Earth-like, due to the similar tilts of the two planets' rotational axes. The lengths of the Martian seasons are however about twice those of Earth's, because Mars's greater distance from the Sun leads to the Martian year being about two Earth years long.

The planet is 1.52 times as far from the Sun as Earth, resulting in just 43% of the amount of sunlight. Martian surface temperatures vary from lows of about −110 °C to highs of up to 35 °C in equatorial summer. The wide range in temperatures is due to the thin atmosphere, the low atmospheric pressure, and the low thermal inertia of Martian soil.

The comparatively large eccentricity of the Martian orbit has a significant effect. Mars is near perihelion when it is summer in the Southern Hemisphere and winter in the north, and near aphelion when it is winter in the Southern Hemisphere and summer in the north. As a result, the seasons in the Southern Hemisphere are more extreme and the seasons in the northern are milder than would otherwise be the case. The summer temperatures in the south can be warmer than the equivalent summer temperatures in the north by up to 30 °C.

Cosmic Radiation

Cosmic radiation consists of high-energy charged particles, x-rays and gamma rays produced in space. The universe is awash with cosmic radiation, from the cosmic background radiation (CMB) of the Big Bang to the galactic cosmic rays (GCRs) of the extra galactic universe and the Milky Way.

GMCRs are now known to originate from a wide range of sources, eg. supernovae, quasars, active galactic nuclei, and gamma-ray bursts – and for our purposes, mostly stars, and that means suns.

Space radiation is harmful to humans and therefore exercises a limit on space travel. It can alter the cardiovascular system, damaging the heart, eliminate some of the cells in linings of the blood vessels, and lead to cardiovascular disease. The major concern is the long term effects which include an increased chance of cancer, and sterility. Some health effects can skip a generation and appear in the descendants of the exposed individual, being passed on by mutated genes.

The Earth's atmosphere and magnetic shield protect us from cosmic radiation in general and the Sun's cosmic rays in particular. Earth's magnetic shield is strongest at the equator and weakest near the poles. The magnetic shield diverts most of the radiation around the Earth. The charged particles react with the Earth's atmosphere to produce secondary radiation, which reaches the earth.

With the magnetosphere of Mars switched off eons ago, man cannot survive there without artificial protection, whether it be in a spacesuit, habitat or a rover. Man must have cosmic ray protection as soon as his spaceship leave the Earth's atmosphere.

Solar Wind

The Earth and Mars, located close in among the Inner Planets in the heliosphere, are subject to cosmic radiation continuously emitted from the Sun. This has led scientists to call it the 'solar wind'.

An equally serious consequence of the disappearance of its global magnetic field was the loss of Mar's protective shield against cosmic radiation, or in this case solar wind. In time, Mars also lost most of its atmosphere, compounding its problems.

Close-up, the solar wind is a stream of charged particles from the upper atmosphere of the Sun called the corona. . The plasma consists of electrons, protons, and alpha particles. The composition of the solar wind's plasma also includes trace amounts of heavy ions, atomic nuclei and isotopes.

These particles can escape the Sun's gravity because of their high energy resulting from the high temperature of the corona.

The solar wind varies in density, temperature and speed. At a distance of more than a few solar radii from the Sun, the solar wind reaches speeds of 250–750km/s moving faster than the speed of the magnetosonic wave. Beyond the termination shock, it ceases, marking the boundary of the heliosphere and Sun's influence. The heliosphere is a bubble defined by the solar wind, outside of which is interstellar space.

The magnetic field carried by the solar wind as it flows past Mars can generate an electric field, which accelerates electrically charged gas atoms, called ions, in Mars' upper atmosphere and shoots them into space. Thus, Mars' was and continues to be stripped of its atmosphere

Present Climate

It is freezing cold and bone-dry on the planet Mars. The daily range of temperature in the lower atmosphere is huge due to the low thermal inertia; it can range from −75 °C to near 0 °C near the surface in some regions.

It never rains on Mars, and there are no large standing bodies of liquid water on the planet's surface.

This is firstly so because the ambient temperatures at the surface are sub-freezing. Further, the atmospheric pressure averages just around 0.088 psi, a figure under average Martian conditions slightly below the triple point of water - the minimum pressure at which liquid water can exist.

(Warming water on the Martian surface would sublime it, meaning cause its transition directly from solid to vapour (ie cross the boiling point). Conversely, cooling water would deposit it, meaning cause its transition directly from vapour to solid).

Thus, on the surface, only in sub-surface pockets, such as in a deep crater, where the ambient temperature may rise briefly, some liquid water may be found. A point of possible interest is that the presence of salts in water can separate the triple points of the water. There is invariably a trace of water vapour in the atmosphere.

While it lacks liquid water, Mars has lots of ice at the polar caps and buried widely around beneath the surface.

Dust Storms

Mars has the largest dust storms in the Solar System, reaching speeds of over 160 km/h. These can vary from a storm over a small area, to gigantic storms that cover the entire planet. They tend to occur when Mars is closest to the Sun, and have been shown to increase the global temperature

Dust devils and dusts storms are prevalent on Mars, and sometimes observable by telescopes from Earth, and in 2018 even with the naked eye as a change in colour and brightness of the planet. Planet-encircling dust storms (global dust storms) occur on average every 5.5 Earth years (every 3 Martian years) on Mars. It has been suggested to be loosely related to gravitational influence of both moons, somewhat similar to the creation of tides on Earth.

Wetter Earlier Climate

When Mars lost its magnetosphere, it lost its atmosphere and with it its “greenhouse” effects, like higher surface heat retention, higher levels of moisture in the atmosphere, more loud, more rain and more liquid water on the surface. The central cause was the loss of atmospheric pressure.

From current evidence, before about 3.8 billion years ago, Mars is believed to have had had a denser atmosphere and higher surface temperatures, allowing vast amounts of liquid water on the surface, possibly a large ocean covering one-third of the planet. Water has also apparently flowed across the surface for short periods at various intervals more recently in Mars' history

Landforms visible on Mars strongly suggest that liquid water has existed on the planet's surface. Huge linear swathes of scoured ground, known as outflow channels, cut across the surface in about 25 places. These are thought to be a record of erosion caused by the catastrophic release of water from subsurface aquifers, though some of these structures have been hypothesized to result from the action of glaciers or lava.

One of the larger examples, Ma’adim Vallis, is 700 km long, much greater than the Grand Canyon, with a width of 20 km and a depth of 2 km in places. It is thought to have been carved by flowing water early in Mars's history. The youngest of these channels are thought to have formed only a few million years ago.

Elsewhere, particularly on the oldest areas of the Martian surface, finer-scale, dendritic network of valleys are spread across significant proportions of the landscape. Features of these valleys and their distribution strongly imply that they were carved by runoff. Along crater and canyon walls, there are thousands of features that appear similar to terrestrial gullies.

Deltas and alluvial fans preserved in craters are further evidence of warmer, wetter conditions, which require the widespread presence of crater lakes across a large proportion of the surface, for which there is independent mineralogical, sedimentary and geomorphological evidence.

Researchers suspect much of the low northern plains of the planet were covered with an ocean hundreds of metres deep, the size of the Arctic Ocean, though this theory remains controversial. Martian climate models have not yet shown that the planet was warm enough in the past to support bodies of liquid water

ICE

Recent researches have established one thing for certain. There is plenty of “water ice”(ie. water in the form of ice) on Mars. The two polar ice caps appear to be made largely of water ice. The volume of water ice in the south polar ice cap alone, if melted, would be enough to cover the entire surface of the planet with a depth of 11 metres.

Abundant water ice is also present beneath the permanent carbon dioxide ice cap at the south pole and in shallow sub-surfaces at more temperate conditions. In fact, more than 5 million km3 of ice have been detected at or near the surface of Mars enough to cover the whole planet to a depth of 35 metres. Even more ice is likely to be locked away in the deep subsurface.

Some liquid water may occur transiently on the Martian surface today, but limited to traces of dissolved moisture from the atmosphere and thin films, which are challenging environments for known life.

Large quantities of ice are thought to be trapped within the thick cryosphere114 of Mars. Radar data show large quantities of ice at both poles, and at middle latitudes The Phoenix lander directly sampled water ice in shallow Martian soil .

In 2018, scientists reported the discovery of a sub-glacial lake 1.5 km below the southern polar ice cap with a horizontal extent of about 20 km, the first known stable body of liquid water on the planet, but subsequent work has questioned this detection.

In September 2020, scientists confirmed the existence of several large salt-water lakes under ice in the southern polar region. The only place where water ice is visible at the surface is at the north pole ice cap

In March 2021, researchers reported that a considerable amount of water on ancient Mars has remained, but, for the most part, has likely been sequestered into the rocks and crust of the planet over the years

Even larger ice sheet on south polar region sheet is suspected to have retreated in ancient times that may have contained 20 million km3 of water ice, which is equivalent to a layer 137 m deep over the entire planet.

Surrounding the polar caps are many smaller ice sheets inside craters, some of which lie under thick deposits of sand or dust. The 81.4 km wide Koralev Crater is estimated to contain approximately 2,200 km3 of water ice. The surface of Korolev's floor lies about 2 km below the rim, and is covered by a 1.8 km deep central mound of permanent water ice, up to 60 kilometres in diameter.

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[114] The cryosphere is an all-encompassing term for those portions of Earth’s surface where water is in solid form, including sea ice, lake ice, snow, and frozen ground (which includes permafrost).

Ice Caps

During a pole's winter, it lies in continuous darkness, chilling the surface and causing the deposition of 25–30% of the atmosphere into slabs of carbon dioxide (dry ice).When the poles are again exposed to sunlight, the frozen carbon dioxide sublimes. These seasonal actions transport large amounts of dust and water vapor, giving rise to Earth-like frost and large cirrus clouds.

Frozen carbon dioxide accumulates as a comparatively thin layer about one metre thick on the north cap in the northern winter only, whereas the south cap has a permanent dry ice cover about eight metres thick.

The northern polar cap has a diameter of about 1,000 km and contains about 1.6 million km^3 of ice. This compares to a volume of 2.85 million km^3 for the Greenland ice-sheet.

The southern polar cap has a diameter of 350 km^3 and a thickness of 3 km. The total volume of ice in the south polar cap plus the adjacent layered deposits has been estimated at 1.6 million km^3.

Minerals

In 2004, NASA's Mars rover Opportunity detected the mineral jarosite. This forms only in the presence of acidic water, showing that water once existed on Mars. In 2007, the Spirit rover found concentrated deposits of silica that indicated wet conditions in the past, and in 2011 the mineral gypsum, which also forms in the presence of water, was found by Opportunity on the surface.

As more and more of the surface of Mars has been imaged by the modern generation of orbiters, it has become gradually more apparent that there are probably many more patches of ice scattered across the Martian surface. Many of these putative patches of ice are concentrated in the Martian mid-latitudes (≈30–60° N/S of the equator).

It is estimated that the amount of water in the upper mantle of Mars, represented by hydroxyl ions within Martian minerals, is equal to or greater than that of Earth at 50–300 parts per million of water, which is enough to cover the entire planet to a depth of 200–1,000 metres. A definitive conclusion about the presence, extent, and role of liquid water on the Martian surface remains elusive.

Mars Sample Return Programme

NASA is launching two more mini helicopters to Mars in its effort to return Martian rocks and soil samples to Earth. Under the plan NASA's Perseverance rover will do double duty and transport the cache to the rocket that will launch them off the red planet a decade from now.

NASA and ESA, partners in the Mars Sample Return Programme, have established a new group of researchers to maximise the scientific potential of Mars rock and sediment samples that would be returned to Earth for in-depth analysis. The researchers will function as a science resource for the Mars's project teams as well as for related Earth-based ground projects involving sample recovery and curation. They will build the roadmap by which science for this historic endeavour is accomplished – including establishing the processes for sample-related decision-making and designing the procedures that will allow the worldwide scientific community to become involved with these first samples from another world.

Original Source of Mar's water

Just like Earth, Mars likely got its water from asteroids and comets that bombarded its surface. Conditions may have been right for the red planet to be habitable from 4.1 to 3 billion years ago. During that time, life could have taken hold in global oceans, rivers, and lakes.

The same processes that put water on our planet operated on Mars. Research suggests that the water on Earth came from asteroids and heavy clouds of gas and dust, soon after the formation of the Sun. Earth's atmosphere was filled with oxygen, which joined with deuterium and hydrogen to create water - the condensation of hydrogen and oxygen into water as the primordial gas cloud collapsed into a star.

Evidence of Life

To date, no proof of past or present life has been found on Mars. Cumulative evidence suggests that during the ancient Noachian time period[115], the surface environment had liquid water an may have been habitable for microorganisms, but habitable conditions do not necessarily indicate life.

Mars has remained almost unchanged for more than 3.5 billion years, and it could have been habitable since 4.48 billions of years ago, 500 million years before the earliest known Earth lifeforms. Mars may thus hold the best record of the prebiotic conditions leading to life, even if life does not or has never existed there.

Although the surface of Mars was periodically wet and could have been hospitable to microbial life billions of years ago, the current environment at the surface is dry and subfreezing, probably presenting an insurmountable obstacle for living organisms. In addition,

Critically, Mars lacks a thick atmosphere, ozone layer and protective magnetic field, allowing solar and cosmic radiation to strike the surface unimpeded. The damaging effects of ionizing radiation on cellular structure is a prime limiting factors on the survival of life on the surface. Therefore, the best potential locations for discovering life on. Mars may be in subsurface environments.

Following the confirmation of the past existence of surface liquid water, the army of rovers started searching for evidence of past life. The search for fossils and organic compounds is now a primary objective.

Currently, the surface of Mars is bathed with ionizing radiation and the Martian soil is toxic to microorganisms. The consensus is that if life exists - or existed - it could be found or is best preserved in the subsurface

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Noachian period: Formation of the oldest extant surfaces of Mars, 4.5 to 3.5 billion years ago. Noachian age surfaces are scarred by many large impact craters.
Hesperian period: 3.5 to between 3.3 and 2.9 billion years ago. The Hesperian period is marked by the formation of extensive lava plains.
Amazonian period: between 3.3 and 2.9 billion years ago to the present. Amazonian regions have few meteorite impact craters but are otherwise quite varied
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In June 2018, NASA announced the detection of seasonal variation of methane levels on Mars. Methane could be produced by microorganisms or by geological means. The European ExoMars GTO orbiter started mapping the atmospheric for methane in Ap 18 Several previous missions and ground-based telescopes detected unexpected levels of methane in the Martian atmosphere, which may even be a biosignature. However, the interpretation of the measurements is still highly controversial and lacks a scientific consensus

Habitable Zones

The Mars environment is harsh to extreme, with many factors at critical margins of human life requirements, and lacking many essential resources

. – (a) Mars has half the radius of Earth, one-tenth the mass, and only 38% of Earth's gravity. It has to be established can man can adapt in the long term, and indeed survive the many bodily dysfunctions already known from his limited low gravity exposures so far.

. - (b) Atmospheric pressure on Mars is far below that at which humans can survive without pressure suits. Habitable structures would need to be pressurised.

. – (c) The atmosphere is toxic to humans Most of it consists of carbon dioxide (95%), nitrogen (3%), argon (1.6%), oxygen (.0.16%) and traces totalling less than 0.4% of other gases. Further, the thin atmosphere does not filter out UV light, which causes instability in the molecular bonds between atoms.

. - (d) The amount of solar energy entering its upper atmosphere is only around 43.3% of what reaches the Earth's upper atmosphere. Mars is a lot colder, with mean surface temperatures between -87° and −5 °Celsius.

Due to the thinness of the atmosphere, the temperature difference between day and night is much larger than on Earth, typically around 70 °C. One effect of this is that Mars' atmosphere can react much more quickly to a given energy input than Earth's atmosphere. As a consequence, Mars is subject to strong thermal tides produced by solar heating rather than a gravitational influence. These tides can be significant, being up to 10% of the total atmospheric pressure.

. – (e) Due to the thinner atmosphere, a higher fraction of the solar energy reaches the surface as radiation. Mars has no magnetosphere, like the Earth, which is capable of mitigating or blocking the effects of solar or cosmic radiation and thereby protects all living organisms. Radiation exposure is a real hazard.

. - (f) Mars is dry and liquid water is scarce, with the roves finding less than there is in Earth's driest deserts. Mars has no rain and virtually no clouds, so although cold, it is permanently sunny

. - (e) Mars' landscape is barren and covered with a fine dust. The atmosphere is thick enough to cause dust storms. Global storms are common throughout the year and can cover the entire planet for weeks, blocking sunlight from reaching the surface and causing temperatures to drop for several months after the storm.

. (f) The Martian soil is toxic due to relatively high concentrations of chlorine and associated compounds, which are hazardous to all known forms of life. Generally, Earth plants and animals cannot survive the ambient conditions on the surface of Mars.

Life Support Resources

To achieve the goal of usable water on Mars, NASA requires a system capable of removing water from the soil. This system must be capable of operating reliably and maintenance free for at least 500 hours, storing the water, and must be powered by solar energy. Liquid water is unstable over much of the planet. There is no shortage of ice.

Opportunities to generate electricity via wind, solar and nuclear power using resources on Mars are however considered poor. Energy wil be a critical factor inn the end. However, manufacturing rocket fuel from local resources appears feasible and is critical component to the transport system.

Economic Resources

Perhaps the most promising economic feature is Mars' close proximity to the Asteroid Belt which is known to be rich in mineral resources, making Mars a first class base for the exploitation of the same. Mining the asteroid belt from Mars and its moons could help in the colonisation of Mars. Thee could be another "California" and "Klondike", with a host of spacecraft moored alongside asteroids in the belt each of the latter dotted with prospectors' Martian habitats.

Living on Mars

Living around the equatorial regions of Mars is like moving to Antarctica, sub-zero down to –125o Celsius. (A standard kitchen freezer on Earth is set at -10o C). Surface water on Mars evaporates at 10o C, below that it freezes immediately. Even penguins will not like Mars, because it is bone dry, less water than in our driest desserts.

There are vast reserves of frozen water at both poles. But Mars water is heavily mineralised, and undrinkable. Small groups of humans can survive with strict regimes and recycling of their supplies, as at the ISS. Larger communities must make their own water.

For humans, even a 5–8% decrease in total body water causes fatigue and dizziness, and a 10% decrease leads to physical and mental impairment . Through experience and training, astronauts on the ISS have shown it is possible to use less, and that 70% of what is used can be recycled. Absence of liquid water is not a "fatal flaw:, but must worked around.

A major problem with the water found on Mars is that it's salty, possibly just as salty as Earth's oceans. And the water is highly toxic if ingested in sufficient amounts. This too must be worked around.

When the temperature is below water's triple point, water vapour will freeze into ice. Exceptions to this are in the low-lying areas of the planet, most notably in the Hella impact basin, the largest such crater on Mars. It is so deep that the atmospheric pressure at the bottom reaches 1155 Pa. and the temperature exceeds 0 °C liquid water could exist there. Presumably there is also less radiation down there. I have no doubt this option of underground living will be examined in detail as a future way of life.

Many people have suggested terra-forming Mars, to change the climate to make it more habitable to humans. Notably, Elon Musk has suggested detonating nuclear weapons on the ice caps of Mars to release the water vapour and carbon dioxide, which would warm the planet enough to make it habitable for humans. No doubt we will be insurable against radiation (by an Elon Musk company), or someone (Elon Musk again) will invent a radiation cream. Unless one finds a mountain of molten gold this may not be a feasible alternative on a planetary scale. On the other hand, limited hot-housing could be an option in suitable craters and pockets. Someone (Elon Musk again?) might even invent something to amplify sunlight in a crater, while filtering out radiation – an UV machine might do it.

Living in low gravity is another long-term issue. The longest space flight by any one astronaut was 437 days, by the Russian doctor Valeri Polyakov on board MIR in 1994-95. His ailments included vestibular dysfunction, weight loss, increase in height, upward fluid shift, anaemia, cardiovascular deconditioning, muscle atrophy, and bone loss. Almost all of these alterations can be attributed to the absence of gravitational force. Air pressure (the barometer reading) is proportional to gravity. Presumably someone has already thought that this principle might be applied in our future habitats. I am surprised though Elon Musk has not suggested increasing gravity on Mars on a planet level – it would eliminate human ailments and release liquid water all at the same time – unless of course it involved releasing a nuclear bomb to do so.

So far, no one has found viruses on Mars. Heaven forbid that we Import them into Mars. So far I have not heard any discussion how we will keep them out. Perhaps we could have a portable version of the anti-covid radiator so popular in recent years. My understanding is that we will need bacteria even on Mars - so probiotics are all right.

I am sure someone else (if not Elon Musk again) will realise that if the water on Mars could be heated up a few degrees in selected craters, we could ship out a few loads of our favourite seafoods and start a fishing industry there, with Mars' ready-made sea water, salted to perfection. The organic off-cuts would make excellent manure to start high-quality market farming.

Landing on Mars is, if nothing else, its own ultimate human satisfaction. There is always that significant proportion of humanity for whom this and the mysterious are sufficient reasons, regardless of the costs. And happily, man's faith in himself to overcome the unexpected is boundless.

Other mundane motivations include the potential to discover more about the universe, the economic resources, and the romantic possibility that settlement on another planet would decrease our chances of extinction.

(Back to TO)

Preparing to Land

Target Mars

NASA is under presidential orders to land humans on Mars by 2033. NASA's own appraisal is that this not likely to happen – by the target date. The good thing is that it has and will set everybody scrambling to beat it. The worst scenario is that they will compete to do so, committing (and wasting) the astronomical investments involved. The desirable development is that countries will collaborate to make it happen as early as possible, for their benefit mutually and for mankind.

The Political-Economic Front

Conquering Mars is too massive to be pursued under conventional inter-government arrangements. It requires to be a global consortium to drive and manage the process

Fortunately, there are increasing signs of national space agencies and institutions cooperating, sharing, and engaging in joint missions. It is recognition that the scales involved are beyond individual entities or even countries.

Ultimately insurance lies in joint ownership and collective but independent control. Creating such an entity may in fact prove to more difficult in the end than landing a man on Mars. We have the lessons of our WHO Covid-19 failures to learn from,[116] From my four years' experience as a telecommunications administrator, I always though the ITU was among the better working models for world level management..

One of the factors that can bog down development is the cost. The public sector is not the venues to ensure cost-effectiveness. For example, NASA's new SLS rocket is a completely expendable single-use system. NASA's inspector general estimates the ARTEMIS campaign will cost $93 billion between 2012 and 2025, $4.1 billion for a single launch. We cannot afford to go to live on the Moon on this basis, let alone Mars..

The techno-economic components must be farmed out to the international private sector to enjoy the benefits of entrepreneurial competition and the participation of venture capital, the latter that most fecund of economic drivers.

The transfer of human life and its living civilisation to another planet in fact requires the involvement of all sectors of society, not just the political and economic sectors. But it is beyond the scope of this review to go into all that.

The Techno-Commercial Front.

Therefore, it is most promising that, by and large, most national governments and space agencies, given the limits of their political and defence safeguards have fostered international co-operation , joint research and the sharing of knowledge. The benefits to work together will in time emerge, especially in the remote valleys of Mars.

It is equally heartening that most national governments and space agencies have recognised how essential it is to involve the private sector in the growth of this new industrial frontier, and have fostered the participation of both their anchor as well as their new and emergent industries. In the last two decades alone, there has been an unparalleled upsurge.

The space economy comprises a long value-added chain, starting with exploration, research and development and the manufacture of space hardware and software, and ending with the providers of space-enabled products and services to final users. The satellite industry is now substantially privatised. We are looking at space proper.

A quick look at Wikipedia[117] reveals that there has already been astonishing private sector space industry development, with one or more pushing the national agencies if not ahead of them. Some of the major groupings are:

. - (a) – Launch Vehicles Manufacturers (include rockets of various sizes): 16 companies active, 22 launch vehicles operational and 28 projects under development.

. - (b) Cargo Transport Vehicles: 4 companies active, 2 operational vehicles, plus 1 under development

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116 https://geraldpillay.files.wordpress.com/2021/12/virus-biological-predator-an-investigative-review-of-covid-19-zz.pdf
117 https://en.wikipedia.org/wiki/List_of_private_spaceflight_companies

. - (c) Crew Transport Vehicles: 4 companies, 1 operational, and 4 projects under development

. –(d) Propulsion Manufacturers: 6 companies, 8 products and 14 under development

. - (e) Lander, Rovers, Orbiters: 17 companies active, 14 projects under development, 3 testing, and 3 proposed.

The other groupings with active companies include Research craft and Tech Demonstrators, Satellite launchers, Space Manufacturers, Space Mining, Space Stations, Space Component manufacturers, and Space-liner companies (there are three - tourist oriented)

NASA-SpaceX Tango

Space Exploration Technologies Corp. (SpaceX) is an American spacecraft manufacturer, launcher, and a satellite corporation. It was founded in 2002 by the industrial visionary Elon Musk, when the satellite industry had taken off on its own, and the Shuttle was having problems servicing the ISS. SpaceX stated, tactically, that its goal was reducing space transportation costs (immediately attractive) to enable the colonisation of Mars (ultimately irresistible.).

Its timing was impeccable. NASA would soon be looking for options to the Shuttle, while under threat by the Russians at a price of US 70 million per seat on the Soyuz to shuttle US crew to and from the ISS. The NASA's partnership with SpaceX was an excellent example of initial irisk-sharing and early stage commercialisation of the new “monster” industry.

SpaceX had proceeded to develop its first orbital launch vehicle, the Falcon1, at that stage an expendable two-stage small up-lift-to-obit rocket. In 2005, SpaceX announced plans to simultaneously pursue a human-rated commercial space programme through the end of the decade. The preliminary step would be a cargo spaceship.

Cargo Dragon

In 2006, SpaceX won a NASA Commercial Orbital Transportation (COTS) Phase 1 contract to demonstrate cargo delivery to ISS, with a possible contract option for crew transport. Designed to provide "seed money" through Space Act Agreements for developing new capabilities, NASA paid SpaceX US$396 million to develop the cargo configuration of their Dragon spacecraft, while SpaceX developed the Falcon 9 launch vehicle with their own resources. NASA took risks. At that point, the. Falcon 1 had not been successfully tested and would make its maiden flight in 2008. In the end, the formula saved NASA millions of dollars in development costs, making rocket development 4–10 times cheaper than if produced by NASA. In May 12, SpaceX's Dragon spacecraft successfully berthed with the ISS.

The Commercial Resupply Services (CRS) comprised a series of contracts awarded by NASA from 2008 to 2016 for delivery of cargo and supplies to the ISS on commercially operated spacecraft. The first CRS contracts were signed in 2008, and awarded US$1.6 billion to SpaceX for 12 cargo transport missions, covering deliveries to 2016.

The first of the 12 planned CRS resupply missions in Oct 12, achieved orbit, berthed and remained on station for 20 days, before re-entering the atmosphere and splashing down in the Pacific Ocean. The CRS missions have flown approximately twice a year to the ISS since then.

After 2015, NASA extended the contracts for a total of twenty further cargo missions to the ISS. The final Dragon 1 mission departed the ISS in Apr 20, and it was subsequently retired from service.

A Second Phase of contracts was awarded in Jan 16 with SpaceX as one of the awardees. SpaceX would fly up to nine additional CRS flights with an upgraded Drago 2 spacecraft. The commercialisation of cargo transport was complete.

In Mar 20, NASA contracted SpaceX to develop the DragonXL spacecraft to send supplies to the Lunar Gateway under the Artemis programme

Falcon 9

in 2005, SpaceX proceeded with the development of the Falcon 9, a heavier lift vehicles. incorporating a reusable first stage. . Development was accelerated by NASA which committed to purchasing several commercial flights if specific capabilities were demonstrated. The overall contract award was US$278 million to provide development funding for the demonstration launches of Falcon 9 with the Dragon.

The first operational Dragon/Falcon 9 spacecraft was launched in Dec 10, and safely returned to Earth after two orbits, completing all its mission objectives. The rocket evolved through several versions. The Falcon 9/Full Thrust, Block 5 is the current version first launched in 2015, and has been operational since May 18.

The Falcon 9 rocket's first stage booster is capable of landing vertically to facilitate reuse. SpaceX has successfully landed boosters over 100 times.
Falcon 9 is human-rated for transporting NASA astronauts to the ISS. Falcon 9 is certified for the National Security Space Launch (NSSL) programme and NASA Launch Services Program (LSP) as "Category 3", which can launch the most expensive, important, and complex NASA missions.

As of January 2021, Falcon 9 had the most launches among US rockets. It is the only US rocket certified for transporting humans to the ISSIt is the only commercial rocket to ever launch humans to orbit. On 24 Jan 21, Falcon 9 set a record for the most satellites launched by a single rocket, carrying 143 satellites.

Crew Dragon

In April 2011, as part of its second-round Commercial Crew (CCDev) programme, NASA issued a US$75 million contract for SpaceX to develop an integrated launch integrated system for Dragon in preparation for human-rating it as a crew transport vehicle to the ISS.

In Sep 11, NASA released a draft request for proposals (RFP) under their Commercial Crew integrated Capability (CCiCap) programme. For this phase, NASA wanted proposals to be complete, end-to-end concepts of operation, including spacecraft, launch vehicles, launch services, ground and mission operations, and recovery, with closing submissions by Mar 12.

The selected proposals, announced in Aug 12, were those of Sierra Nevada Corporation (US$212.5 million), SpaceX: US$440 million - for Dragon/Falcon 9 - and Boeing (US$460 million).

NASA awarded a series of competitive fixed-price contracts to private vendors starting in 2011. In Aug 12, NASA awarded SpaceX a fixed-price agreement to produce a detailed design of the crew transportation system

Operational contracts to fly astronauts were awarded in Sep 14, to SpaceX and Boeing. Each company performed an uncrewed orbital test flight in 2019, and operational flights started in Nov 20. In all cases, the spacecraft returned by splashdown.

SpaceX completed five flights under its first Commercial Crew Program (CCP) contract It is contracted with NASA for fourteen operational flights in total to the ISS.

Falcon Heavy

Falcon Heavy (FH) is a super-lift variant of the Falcon 9, comprising three Falcon 9 first stages: a reinforced centre core, and two additional side bosters. All three boosters are designed to be recovered and reused, although expendable flights are possible to increase the payload capacity.

Falcon Heavy's lift-off thrust equals approximately that of eighteen 747 aircraft at full power. Falcon Heavy can lift the equivalent of a fully loaded 737 jetliner—complete with passengers, luggage and fuel—to orbit

SpaceX successfully launched the Falcon on 6 Feb 18, **delivering a payload comprising Musk's personal Tesla Roadster on to a trajectory reaching the orbit of Mars.**
Falcon Heavy has since been certified for NSSL programme.

As of 24 March 2023, the Falcon 9 and Falcon Heavy have been launched 218 times, resulting in 216 full mission successes, one partial success, and one in-flight failure.

Falcon Heavy was designed to be able to carry humans into space but SpaceX does not intend to transport people on Falcon Heavy. Both Falcon Heavy and Falcon 9 are expected to eventually be superseded by the in-development Starship launch system.

Starship

The SpaceX Starship, under development, is intended to be a fully re-usable space vehicle, capable of delivering new generation scales of payloads to Earth's orbit and beyond,

Standing at 120 m (390 ft) tall, it is designed to be the tallest and most powerful launch vehicle ever built, and the first capable of total reusability.

The Starship launch vehicle is made up of the first-stage booster and a second stage which functions as a self-contained spacecraft for carrying crew or cargo once in orbit.

Both stages are powered by SpaceX's own designed Raptor engine that cryogenically burn liquid oxygen and liquid methane propellants in a highly efficient full-flow staged combustion power cycle. Both rocket stages are designed to be reused by landing vertically at the launch pad.

The SpaceX Super Heavy booster, with 33 Merlin power units aboard, produces roughly 70% more thrust off the launch pad than the Soviet N1 and counterpart of the Saturn V with more than twice the thrust of the latter. Even the US space agency Nasa's new mega-rocket, the Space Launch System (SLS), which flew for the first time back in Nov 22, is dwarfed by the capability being built into Starship.

In its fully reusable configuration, Starship is planned to have a payload capacity of 150 tonnes (330,000 lb) and is designed to be flown multiple times, to spread out the cost of the spacecraft. Other variants can transport more than 100 passengers.

SpaceX routinely returns the first stage of Falcon 9 and Falcon Heavy rockets after orbital launches. The rocket flights and land to a predetermined landing site using only its own propulsion systems. When propellent margins do not permit a return to launch site, rockets return to floating landing platform in the ocean, called autonomous spaceport drone ships. SpaceX also plans to introduce floating launch platforms.

As specifically designed for the Mars conquest, the delivery package will be a fully re-usable super heavy-lift two stage launch vehicle, both stages recoverable, with the second stage a fully functional and navigable spacecraft (the Starship) as payload. Starship will be refuelled in Earth orbit from a separate tanker, and self-launched off to Mars, where it will execute a soft landing by vertical propulsion. On Mars it will be leveraging Mars' natural H2O and CO2 (and still to be confirmed methane resources) to refuel on the surface, then ascend to Mars orbit and return to Earth.

Reusable parts have drastically lowered the costs of a launch, in turn lowering the barrier of access to space. Starship launches have an estimated cost of $10 million, while NASA's Space Launch System is expected to cost $4.1 billion, per launch.

SpaceX started manufacturing the first prototypes of Starship in 2019. The first successful suborbital flight and landing of a full Starship prototype was achieved in May 21.
Recently, Musk announced that the new date for man to finally set foot on Mars would be 2029 - exactly 60 years after the first moon landing was achieved in 1969.
Applications of the Starship can include regular crewed and cargo launches for building orbit stations and platforms. SpaceX is currently establishing a space-based Internet communications network with over 3,000 satellites called Starlink. It is thought that the complementary support of the Starship will reduce the cost of the Internet.

There is even talk that a fully re-usable Starship can be deployed to perform point-to-point terrestrial cargo space flights.

SpaceX's Starship spacecraft rocket systems represent an integrated and fully reusable launch, propellant delivery, rendezvous, planetary lander and return system with robust capabilities and safety features uniquely designed to deliver these essential building blocks[118].

Space Investment

Over the past decade, the space sector has experienced massive growth in investment activity. Between 2012 and 2021, total annual investment grew to more than $10 billion, from $300 million

SpaceX had operated on a total **funding** of approximately $1 billion over its first. It is estimated that up to 85% was funded by the federal government, mostly through his NASA awards, with the remaining funding split between Elon Musk and other private investors

SpaceX was awarded $2.2 billion and $2.8 billion in federal contracts in 2021 and 2022, respectively, the majority of which came from NASA, according to public records.

NASA recently announced it has awarded five more astronaut missions to Elon Musk's SpaceX, with a contract worth an additional $1.4 billion to the company.

Not to be blinded by the scale of investment above, SpaceX makes the bulk of its money by launching satellites into orbit. Commercial businesses pay SpaceX a fee to launch

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[118] On 17 Apr 2023, after this was written, SpaceX carried out its first trial flight of the Starship but it failed.

satellites that they can use for their businesses. SpaceX uses a flat rate model to charge commercial customers a launch fee for a basic launch. The fee is $62 million per service

ARTEMIS

Artemis is mankind's next programme to re-establish a human presence on the Moon. The programme's long-term goal is to establish a permanent base, and to facilitate missions to Mars.

The Artemis programme is a collaboration, led by NASA, ESA, CSA and JAXA, of governmental space agencies and private spaceflight companies, joined for the purpose in a set of Artemis accords. As of December 2022, twenty-three countries and one territory have signed the accords, including the British Space Agency and those of emerging space powers such as Brazil, South Korea, and the United Arab Emirates. (We might note Russia an China are not mentioned anywhere.)

The mission comprises a series of main launches, named Artemis 1 to 11, backed by a host of additional logistic and support launches, planned over 12 years

On 16 Nov 22, Artemis 1 was successfully launched from the Kennedy Space Center, and it completed its mission on 11 Dec 22, The goal of the Artemis 1 mission was to place Orion, its spacecraft, into a lunar orbit, and then return it to Earth.

The major components of the Artemis programme are the Space Launch System (SLS), the Orion Spacecraft, the Lunar Gateway space station, and the Commercial Human Landing Systems (CHLSs)

The Orion spacecraft consists of a Crew Module (CM) space capsule, capable of supporting a crew of six. Orion is equipped with solar panels, an automated docking system, and glass interfaces.

The Gateway will be a mini-space station in lunar orbit, to serve as a solar-powered communication hub, science laboratory, short-term habitation module, and holding area for rovers and other robots. While the project is led by NASA, the Gateway is meant to be developed, serviced, and utilised in collaboration with the commercial and international partners. The Gateway Logistics Services programme will provide cargo and other supplies to the station, even when crews are not present. The Gateway will be parked at an Earth-Moon Legrange point.

The Commercial Lunar Payload (CLPS) programmes include delivery of Gateway modules and logistics, the Human Landing System (HLS), and elements of the Moon base. Several robotic landers will deliver scientific instruments and robotic rovers to the lunar surface after Artemis 1. Additional CLPS missions are planned to deliver payloads to the Moon base. These include habitat modules and rovers in support of crewed missions.

The Human Landing System (HLS) is a spacecraft that can convey crew members from Gateway to the lunar surface, support them on the surface, and return them to the Gateway. This system will act as a lunar habitat.

The initial commercial contract has been awarded to Space Exploration Technologies Corp (SpaceX) belonging to Elon Musk for two Starship HLS missions, one un-crewed and one crewed as part of Artemis 3.

Lander services will also be contracted out commercially, to ferry rovers, equipment and other supplies and stuff to and from the Moon, including samples.. The Artemis programme includes robotic landers to make independent scientific researches.

The Artemis Base Camp is the prospective lunar base to be established by the end of the 2020s. It would consist of three main modules: the Foundational Surface Habitat, the Habitable Mobility Platform (the Lunar Cruiser) , and the Lunar Terrain Vehicle. Artemis will support missions of up to two months, and be used to study technologies to use on Mars.

Starship for Artemis

NASA has modified its contract with SpaceX to further develop the Starship human landing system as a **lunar** lander capable of carrying astronauts between lunar orbit and the surface of the Moon as part of NASA's Artemis III mission. SpaceX will now support a second human landing demonstration as part of NASA's Artemis IV mission. Additionally, SpaceX will demonstrate Starship's capability to dock with Gateway to support both lunar and deep-space exploration, accommodate four crew members, and deliver more supplies, equipment, and science payloads that are needed for extensive surface exploration.

DearMoon Mission

Japanese entrepreneur Yusaku Maezawa has announced that ten crewmembers, including two backups, who will join him on the dearMoon mission. The dearMoon crew will be the first humans Starship will launch, fly around the Moon, and safely return to Earth.

Colonisation of Mars

Economic drivers

Colonisation on Mars will be possible when the necessary methods become cheap enough.

There is some prospect of a radical reduction to launch costs in the 2020s, with a bench-mark published price by SpaceX of US$62 million per launch of up to 22,800 kg (50,300 lb) payload to low Earth orbit, or 4,020 kg (8,860 lb) to Mars. If SpaceX is successful in developing reusable technology, it could be expected to have a major impact on the cost of access to space.

Colonisation requires the establishment of permanent habitats that have the potential for self-expansion and self-sustenance, Before any people are transported to Mars, a number of robotic cargo missions would be required first in order to transport the requisite equipment, habitats and supplies., including robotic machines to produce fertilizer, methane and oxygen from Mars' atmosphere and subsurface water ice, as well as construction materials to build transparent domes for initial agricultural areas. .

The path to a human colony could be prepared by robotic systems. These systems could help locate resources, such as ground water or ice, that would help a colony grow and thrive. The lifetimes of these systems would be years and even decades, it may be that these systems will involve private as well as government ownership. These robotic systems also have a reduced cost compared with early crewed operations, and have less political risk.

Establishing power, communications, shelter, heating, and manufacturing basics can begin with robotic systems, if only as a prelude to crewed operations.

Robotic systems might lay the groundwork for crewed landings and bases, by producing the various needed consumables including fuel, oxidizers, water, and construction materials.

A major development would be producing solar power for the colony. The thin atmosphere allows almost all of the available energy to reach the surface as compared to Earth, where the atmosphere absorbs roughly a quarter of the solar radiation. A machine that could use this power would be the most valuable item on that planet.

ISRU

in Situ Resource Utilisation (ISRU) is the practice of collection, processing, storing and use of materials found or manufactured in space locations (eg, the Moon, Mars, asteroids, etc.) that replace materials that would otherwise be brought from Earth.

ISRU could provide materials for life support, propellants, construction and energy. It is now common to harness use solar panels as part of missions. The use of ISRU for material production has not yet been implemented in a space mission, but will be the basis of Mars colonisation.

Extensive research and testing is going on in several possibilities, and will be carried on under Artemis on the Moon.

The. most immediately relevant one is SpaceX's objective to manufacture its rocket propellant on Mars for the return trip of the Starship – a sine qua none of its Mars colonisation project as presently put together. It is understood they will base the technology on the "Sabatier process", which produces methane and water from a reaction of hydrogen and carbon dioxide in the presence of a nickel catalyst. The raw materials are available on Mars. The propellants will be stored cryogenically on site, for refuelling the spaceships as and when.

A similar reaction proposed for Mars is the reverse water-gas shift reaction. This reaction takes place in the presence of an iron-chrome. Again, hydrogen is recycled from the water by electrolysis. The net result of this reaction is the production of oxygen, to be used as the oxidizer component of rocket fuel. Another reaction proposed for the production of oxygen and fuel is the electrolysis of the atmospheric carbon dioxide,

It has been suggested that buildings on Mars could be made from basalt, as it has good insulating properties. An underground structure of this type would be able to protect life forms against radiation exposure.

All of the resources required to make plastics exist on Mars. Many of these complex reactions are able to be completed from the gases harvested from the Martian atmosphere. Hydrogen and oxygen can be made by the electrolysis of water, carbon monoxide and oxygen by the electrolysis of carbon dioxide and methane by the Sabatier reaction of carbon dioxide and hydrogen. These basic reactions provide the building blocks for more complex reaction series which are able to make plastics. Ethylene, which is used to make plastics, and can be made from carbon monoxide and hydrogen:

Some scientists think that cyanobacteria could play a role in the development of self-sustainable crewed outposts on Mars. They propose that cyanobacteria could be used directly for various applications, including the production of food, fuel and oxygen. They foresee products from their culture could support the growth of other organisms, opening the way to life-support biological processes based on Martian resources.

Human survival on Mars would require living in artificial habitats. One key aspect would be water processing systems. Potential access to on-site water (frozen or otherwise) via drilling has been investigated by NASA. The practical requirements of the huge energy supply needed has still to be worked out.

The biological survival of humans outside the Earth has still to be fully evaluated and provided for. Scientists have hypothesized that many different biological functions can be negatively affected by the environment of Mars colonies. Due to higher levels of radiation, there are a multitude of physical side-effects that must be mitigated. In addition, Martian soil contains high levels of toxins which are hazardous to human health.

The difference in gravity may negatively affect human health by weakening bones and muscles, and affect the cardiovascular system. On the skeletal system which is important to support our body's posture, long space flight and exposure to microgravity cause demineralisation and atrophy of muscles. During re-acclimation, astronauts were observed to have a myriad of symptoms including cold sweats, nausea, vomiting and motion sickness. Once on Mars, these health effects would be a serious concern. Upon return to Earth, recovery from bone loss and atrophy is a long process and the effects of microgravity may never fully reverse.

Dangerous amounts of radiation reach Mars' surface. There are two main types of radiation risks to traveling outside the protection of Earth's atmosphere and magnetosphere: galactic cosmic rays (GCR) and solar energetic particles (SEP). Earth's magnetosphere protects from charged particles from the Sun, and the atmosphere protects us against uncharged and highly energetic GCRs. There are ways to mitigate solar radiation, but without much of an atmosphere, the only solution to the GCR flux is heavy shielding amounting to roughly 15 centimetres of steel, 1 meter of rock, or 3 meters of water, limiting human colonists to living underground most of the time.

Various ideas have been put forth of terraforming Mars to allow a wide variety of life forms, including humans, to survive unaided on Mars' surface. So far, none would be able to bring the entire planet into the Earth-like habitat pictured in science fiction. It remains to be seen if limited human habitats (when we get there) can become the nucleus for terra forming efforts. We can rely on permanent residents to do so pretty quickly.

If climate change goes downhill as it has, the first populations to need an alternative homeland will be our penguins. If they could be acclimatised to the gravity and the radiation (or shielded from these) they might be delighted with vast expanses of ice and snow on Mars – provided we cultivated some local fish (and a walrus or two) as well. Elon Musk might find the Eskimos and Yupighyt excellent folk to recruit as penguin farmers

Minimum size of a colony

For long term planning, it is necessary to conceive a settlement of minimum size for survival. To be self-sustaining, a colony would have to be large enough to provide all the necessary living services. These include

- **Ecosystem management**: producing appropriate gases, controlling air composition pressure and temperature, collecting and producing water, growing food and processing organic wastes.
- **Energy production**: this includes extracting methane for vehicles and if photovoltaic cells are used to produce energy this would include the extraction and processing of silicates, to augment or replace any original equipment.
- **Industry**: extracting and processing appropriate ores, manufacturing tools and other objects; producing clothes, medicine, glass, ceramics, plastics.
- **Building**: even if the base is constructed before arrival, it will need frequent adaptation according to the evolution of the settlement as well as inevitable replacement.

- **Social activities**: this includes raising children and educating them, health care, preparing meals, cleaning, washing, organizing the work and making decisions. Time for sport, culture and entertainment can be minimized but not eliminated
- **Government**: Benevolent dictatorship, ideally with me as the dictator. My first edit would be: no apple trees.

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The future colonists may turn with benefit to early Athens and look for an eponymous archon like Solon. Here, I quote myself:

> "It was at this point that Solon (630-560 BC) was appointed eponymous archon (chief magistrate). He was a member of the nobility, descended from the last king. He believed in moderation and in an ordered society, in which each class had its proper place and function.
>
> He held office in 594-593 BC, and was then appointed a member of the Areopagus. Athenians of all classes accepted him and turned to him in hope. He did not however have full power to carry out his reforms until 20 years later."
> Page 46, Herein.

By mathematical modelling of the time spent by people on these issues and by keeping things simple, Jan Marc Salotti[119] concludes that the minimum number for a colony on Mars is 110. This is close to other studies of the genetic problems involved in the longer journey to the nearest star, Proxima Centauri (4.26 light-years away).

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Target Date Mars

NASA is under presidential orders to land humans on Mars by 2033. I read their estimate that this date is unlikely. Under their Artemis programme, they estimate man's re-landing on the Moon in stage IV by 2026. They are not going anywhere near Mars live, until after that and the necessary time for full extraction of the lessons therefrom. The critical factor is the human survival package.

Elon Musk targets an uncrewed Starship visit to Mars iin 2026, and a human landing in 2029.I suspect the latter w ill not be a joint NASA involvement. The Starship will be ready, possibly too a short-term "excursionary" human survival package. SpaceX is working closely with NASA on Artemis. It is interesting whether the latter can and will morph into Target Mars and achieve the target of 2033.

I would say Elon Musk needs to work on a new propulsion system: 33 Merlin rockets wired up together for an lift of a 39-storey Starship, refuelling in orbit and 6 months for a one way journey to Mars sound like pretty old technology to me. Even our submarines have been nuclear -powered for many years and can travel around without surfacing for over two years at a time. If he can cut the round-trip to two months , the human survival package can be ready in a shorter time.

It will be some way after the first Mars landing to the first settlement of Scalotti. Under present technology, I would say not earlier than 2038.

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[119] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7297723/

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Chapter Eighteen

Destination Space: Are We Ready?

Unmanned Space Flights

To leave the Solar System from Earth, the escape velocity has to be 42 km/s or 151,300 kph (94,000 mph). Up to today, we have not attained this take-off speed. By and large we do 11.6 km/s, which attains Earth orbit

All flights, even to the Outer Planets and beyond, generally t incorporate a “sling-shot” gravity assist manoeuvre, by flying-by one or more of the distant planets, invariably the “half-way house” giant Jupiter.

Solar System

The first generation attempts at conquering space were simple one-shot unmanned probes to our planets. They comprised fly-bys, impactors, landers and orbiters. Mariner 2 was the first (to crash-land) on Venus in Aug 62. The first probe to Mars , a lander, took place in Aug 75, completing the visits to the Inner Planets.

Conquest of the Outer Planets began with Jupiter when Pioneer 10 arrived on 3 Dec 73, after a 21 month journey from Earth. It was followed by Pioneer 11, Voyager 1 and Voyager 2. The Jupiter flyby was necessary for the probes to rev up to go further and ultimately leave the Solar System.

The primary mission of visiting the Jovian system was completed in 1979, the Saturnian system in 1981, the Uranian system in1986 and the Neptunean system in 1989.

Kuiper Belt

Beyond Neptune, lies the Kuiper Belt, The former planet Pluto, reclassified a dwarf planet in 2006, was finally visited in 2015 by the New Horizons probe, marking the highpoint of man’s Solar exploration achievements.

The Kuiper Belt is a circum-Solar disk extending from the orbit of Neptune at 4.4 billion kms (30 AUs[120]) to approximately 7.3 billion kms (50 AUS), at which distance it crosses over into the Oort Cloud and the beginning of interstellar space.

The Kuiper Belt consists mainly of small bodies of frozen volatiles (termed "ices"). It is the home of most of the dwarf planets and some 100,000 other KBOs (Kuiper Belt objects). . .

New Horizons was launched by NASA on 19 Jan 06 directly headed for **Pluto**, with a stop-over at and for a gravitational assist from Jupiter.

After the Jupiter encounter, New Horizons was put in hibernation mode starting 28 Jun 07. The second, third, and fourth hibernation cycles were Dec 08, Aug.09, and Aug 14.

[120] AU=Astronomical Unit, the distance between Earth and the Sun, 150 million km or 93 million miles.

On 6 Dec 2014, ground controllers revived New Horizons for the last time to initiate its active encounter with Pluto. At that time, it took four hours and 25 minutes for a signal to reach Earth from the spacecraft.

The spacecraft began its approach phase toward Pluto on 15 Jan 2015, and its trajectory was adjusted with a 93-second thruster burn on 10 March. New Horizons achieved flyby of Pluto on 14 Jul 15 at 7,800 km above the surface and Charon at 28,800 km, at a distance of 6.6 billion kms (44 AU) from the Sun. New Horizons also observed Pluto's four other satellites.

The download of the entire set of data collected during the encounter with Pluto and satellites – about 6.25 gigabytes – took over 15 months and was completed by 25 Oct 16. Such a lengthy period was necessary because the spacecraft was roughly 4.5 light-hours from Earth and it could only transmit 1-2 kilobits per second.

After its Pluto encounter, mission planners redirected New Horizons for a 1 Jan 19 flyby of a KBO object, 2014 MU69, approximately 6.4 billion km from Earth, also named **Arrokoth.**

Five course corrections were implemented and halfway from Pluto New Horizons was placed in hibernation mode, until 11 Sep 17. It was the farthest object in the Solar System ever to be visited by a spacecraft.

In earthling terms, New Horizon is the ultimate feat in navigational technology and performance, to have remotely steered a 478 kg spacecraft over three missions (including work done at Jupiter) across six billion km over four years to rendezvous with an object 35km times 20 km, measure it, and photograph it.

Interstellar Probes

All the five above Solar probes have been sent onwards into interstellar space. Their on-board instrumentations are mainly past their life span, and they are out of reach of telecommunications control, but we can continue to glean information from such telemetry as can reach us. They are the furthest man has reached in space, and their current is as follows:

. - (a) Pioneer 10 (1024 kg)

On its 50th Anniversary (2020), Pioneer 10 was some 19.67 billion km (131.46 AUs) from Earth. In 2016, its speed was measured at 12.04 km/s relative to the Sun).

Pioneer 10 will be more distant than the red dwarf Proxima Centauri (Earth's nearest neighbour at 4.2 light-years) in 26,118 years.

In about 90,000 years, Pioneer 10 will pass within 0.75 light-years of HIP 117795, a red star in our the Milky Way. This is the closest stellar flyby among the probes out there.

Pioneer 10 is pointed in the direction of the star Aldebaran, the "eye" of the Taurus constellation at a distance of 68 light-years, which it w ill reach in two million years.

. (b) Pioneer 11 (260kg)

It exited the Saturnian system and began its interstellar mission on 5 Oct 79. On 25 Feb 90, Pioneer 11 became the 4th man-made object to pass beyond the orbit of the planets.

By 1995, Pioneer 11 could no longer power any of its detectors, so the decision was made to shut down routine contact on 30 Sep 95 Scientists received a few minutes of good engineering data on 24 Nov 95.

As of Oct 22, Pioneer 11 was estimated to be 16.4 billion km (109.5 AUs) from Earth, traveling at 11.18 km/s outward.

The spacecraft was heading in the direction of the constellation Scutum, close to Messier 26. In 928,000 years, it will pass within 0.82 light years of the K dwarf TYC 992-192-1, and will pass near the star Lambda Aquilae in about four million years.

. - (c) Voyager 1 (815 kg)

Voyager 1 reached Jupiter on 5 Mar 79, some 18 months after leaving Earth and exited the Saturnian system on 14 No 80.

Voyager 1 began its space exploration thereafter and on 17 Feb 81, it overtook Pioneer 10. **Voyager 1 is now the most distant object built by humans.** As of 2017, the probe was moving at 16.95 km/s.

As of Oct 2022, it had reached a distance of 20.0 billion km (131.44 AUs) from Earth. Voyager 1 would reach the Oort Cloud in about 300 years.

. - (d) Voyager 2 (825 kg)

Voyager 2, the twin space probe to Voyager 1, was launched on 20 Aug 77 before that latter.

Some 18 years on, on 30 Aug 07, Voyager 2 passed the crossed the Termination Shock and then entered into the Heliosheath, approximately 1.6 billion km closer to the Sun than Voyager 1 did. This was due to the instellar magnetic field of deep space being stronger, for the southern hemisphere.

On 5 Nov 18, Voyager 2 finally reached interstellar space. Voyager 2 began to provide the first direct measurements of the density and temperature of the interstellar plasma.

Voyager 2 remains in contact with Earth through the NASA Deep Space Network . On 12 Feb 21, full communications with the probe were restored after a major antenna upgrade that took a year to complete.

For those thrilled by absolutely virginal information (as I am) herewith from a Wiki report: “in October 2020, astronomers reported a significant unexpected increase in density in the space beyond the Solar System as detected by the Voyager 1 and Voyager 2 space probes. According to the researchers, this implies that “the density gradient is a large-scale feature of the VLISM (Very Local Interstellar Medium) in the general direction of the heliospheric nose”.

In 2023, Voyager 2 is expected to pass Pioneer 10 to become the second furthest spacecraft from the Sun.

Voyager 2 is not headed toward any particular star, although in roughly 42,000 years, it will have a close approach with the star Ross 248 at a distance of a few light-years. In 296,000 years, Voyager 2 should pass by the star Sirius at a distance of 4.3 light-years.

After 2036, both Voyagers will be out of range of the Deep Space Network

. - (e) New Horizons (1,024kg)

New Horizons was launched on 19 Jan 06 directly into a hyperbolic escape trajectory headed for Pluto and the Kuiper Belt, with a stop-over at and for a gravitational assist from Jupiter enroute.

The New Horizons was deep in the Kuiper Belt, and speeding away from the Earth and Sun at a rate of about 480 million miles per year. The spacecraft was put into hibernation mode on 1 Jun 22, and sent our into space, and will remain in hibernation until 1 Mar 23, to save fuel, and wear and tear.

If New Horizons can reach the distance of 100 AU, it will be traveling at about 13 km/s, We await to learn what lies beyond.

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Space Travel (ST)

The first problem with Space Travel (ST) is that space is too big. We are looking at an observable radius of 46 billion light years, and a diametre twice that.

The second problem is that we travel far too slow. I have described our interstellar probes so far to highlight how puny our efforts are. Our speeds range from 11-15 km/s, carrying an average load of 790 kg.

Even the much vaunted Starship, currently being prototyped by SpaceX for Mars, is projected to de-orbit Earth for Mars also at around 11.6 km/s – Earth's escape velocity into orbit, in this case with a payload of 400 metric tonnes

We have not reached the Earth's direct escape velocity into interstellar space of 42 km/s. Even then we shall be 7,143 times slower than the speed of light at 300,000 km/s.

It takes light 4.26 years to reach Proxima Centauri, our nearest star. At Earth escape velocity, it will take us 30,400 years to do the same.

For the present, man's life-span is about 100 years, effectively less. And nothing can travel at or faster than the speed of light. Even if (impossibly) man did reach half the latter, he would not get much farther than to a few of the neighbouring stars in a life-time, not to mention getting in a return trip home.

Habitable Planets

While the primary problem of ST is distance, it makes sense to examine the other related issues, just in case we can travel, and more particularly in case we need to find alternative or additional places for mankind to settle in.

Firstly, any other location, whether for a visit or for settlement, must be habitable.. We evolved on Earth, and within tolerable limits need our sunshine, atmosphere, water and our gravity. Astronomers initially identified that K dwarfs, or orange stars were those most likely to be the habitable stars, ie to possess the 'sweet spot' for a habitable zone, Our Sun is a middle-aged yellow star.

The definition of "habitable zone" is the distance from a star at which liquid water could exist on orbiting planets' surfaces over geological timescales and where its atmosphere could contain the right balance of gases that could support life. Habitable zones, also known as

Goldilocks' zones, must be neither too hot nor too cold for life. They will also be rocky or terrestrial, rather than gaseous or frozen.

Life means anything and everything on a planet, dead or alive. Roughly human would be great, but we would need to check him out. Even finding a prokaryotic cyanobacterium would be the culmination of success.

Planets or exoplanets[121] exist where there are stars, which is everywhere, but they are hard to see or study, being smallish and generally blinded out by their brighter parent stars. The first exoplanet was discovered only in 1995, some 50 light years away, 51 Pegasi b.

The Kepler Space Telescope, in its two missions (2009-2018), recorded more than 2,600 exoplanets in deep space. NASA's Transiting Exoplanet Survey Satellite (TESS) in its three missions (2018 - ongoing), focussing on stars in the 200 light year range, has identified 5,969, with 248 confirmed and 1720 false positives. With these data-bases, the James Webb Space Telescope (JWST), launched in Dec 2021, can carry out pin-point examination of targets with its new generation technology. These can view, photograph and spectro-analyse targets on a planet across the EMF visible spectra down to molecule level.

A host of exoplanets are now being vigorously studied. JWST's most exciting find has been discovery of an exoplanet orbiting within the habitable zone of the red dwarf star Proxima Centauri, our close neighbour. Still, it is 4.26 light-years away, and take us 30,400 years to get there at Earth escape velocity of 42km/s. At our current interstellar speeds of about 11.2 km/s, it will take us 118.000 years.

For sure, our present prospect of ST is firmly based within the Solar System, with Mars as our best option. For present our radius is limited to a return trip.

Search for Extra Terrestrial Intelligence (SETI)

Here, we are concerned with sentient or intelligent life. If they exist, live in the same space-time as us, are like us, and are developed to a level comparable to us, there should be signs of them. If they are more developed than us, they should have found us.

The search which very broad-ranging, has been going on since 1984 by the SETI Institute. It's Center for Research ran a programme of monitoring EMF (radio-related) wavebands from 2007- 2015 without success. It is currently tied up with TESS in a Breakthrough Listen project focussing on nearby planets classified to have habitable zones.

Together with the JWST, this renewed attack on the quest looks promising. What we have here is a combination, on the one hand, of intelligence watch across a wider spectrum of the EMR particularly the IR, and, on the other, microscopic analysis of the same wavelengths to ascertain whether the composition of their planets can support life. We should sniff out life if there is any.

One problem is that if life evolved in a totally different environment, say sulphur based, we shall never detect them. Likewise, if they did not use EMR for communication, lived outside the visible spectra, or travelled outside space-time, we should also not find them or the us.

We have only one model of evolution, that of Earth, and only the human way of thinking. We even invest our lower orders of life with rationalised behaviour similar to ours. . Aliens, however, may have been put together quite differently, quite apart from their acquired culture and social values. We may not understand one another.

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[121] Planets outside the Solar System

Assuming the universe is uniform (as Einstein did) , we may a priori assume that aliens in our universe have evolved in the same time-frame (same age) as us, but from different material combinations and conditions. Assuming that evolution operates everywhere in the same way, again subject to local conditions and materials, we may all be of the same "age" or level of development. There is no reason not to suppose as above, and that we may as a result be looking out for one another at this point in time. There may even be a degree of kindred ship when we meet.

What this also means is that they too will be facing the problem of distance, and adapting themselves to ST.

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Increasing Our Capability

On-Board Power

Nuclear power is of course already incorporated in many on-board space activities, Man's success in harnessing this power at the micro level has been critical to his space achievement so far.

Space exploration missions require safe, reliable, long-lived power systems to provide electricity and heat to spacecraft and their science instruments.

Developed in the early 1960s, the radioisotope thermoelectric generator (RTG) - or radioisotope power systems (RPS) - provide electricity and heat that can enable spacecraft to undertake scientific missions to environments beyond the capabilities of solar power, chemical batteries and fuel cells.

In a typical RTG, solid-state thermoelectric couples convert heat produced by the natural decay of radioisotope Plutonium-23 to electricity. It is essentially a nuclear battery that reliably converts heat into electricity. The output of the first RTGs was about 2.5 W.

From about 1961, for more than fifty years, RTGs have been the main power source in space. Sometimes a radioisotope heater unit (RHU) is used to keep components from becoming too cold.
.
Over 40 have been used globally, principally by US and USSR, on satellites, spacecraft, orbiters, landers, rovers and mission devices, in latter stages modified and or with new components. Currently, the top-end RTG is the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)

The RTGs led in the US' to development of the Systems for Nuclear Auxiliary Power (SNAP) programme. The SNAP Experimental Reactor (SER) was the first reactor to be built by the specifications established for space satellite applications in Sep 59.

The odd-numbered series were essentially developments of RTG technology. The even-series aimed to developed compact minitiarised fission reactors for space use, in effect RTG systems assisted by subcritical nuclear reactions.
,
The GPHS-RTG or the general-purpose heat source is a US Department of Energy designed radioactive heat source for use with RTGs or other radioisotope generators. It is meant as a component for space applications and is packaged as a stackable module. Each module has a temperature of over 600 degrees Celsius, delivers 250 watts and weighs 1.44 kg each.

With safety in mind, the GPHS employs iridium-clad plutonium-238 dioxide pellets. The pellets are encased within nested layers of carbon-based material and placed within an aeroshell housing to comprise the complete module. The modules can withstand extreme conditions including a launch-pad explosion or a high-speed re-entry. Each GPPHS-RTG can have several modules.

RTGS of different generations can be found still working in space. The RTG-SNAP 27s can be found working in the research equipment left on the Moon's surface by the Apollo missions. The Pioneers 10 and 11 each have four RTG-SNAPP 19s and 12 RHUs, the two Voyagers three MHW-RTG and nine RHUS, and the New Horizons one GPHS-RTGs. The Perseverence on Mars has the MMRTG.

BES-5 was a Soviet thermoelectric generator used to power 31 satellites in a US surveillance project between 1967 and 1988. The Soviet Union also developed TOPAZ reactors which utilized thermionic converters instead.

There are a number of sources of local power in space, such as solar panels and sunshields, which have been use effectively and specifically, not the least on James Web Space Telescope, though I could not confirm the latter does double up as solar panels. I do not go into these. There are many locales in space with no sun.

Propulsion Power

Chemical Propulsion Systems

The space propulsion system in use for uplift today derives from WW2 v2 rocketry. It is a fuel or chemical propulsion process. The principles are the same for all variants. The propellant (say liquid hydrogen) is combined (combusted, burnt) with liquid oxygen at high temperatures in a central chamber, generating light and more heat, and releasing the by-product: water. The latter, overheated and over pressured in the chamber, is jetted out via a nozzle or nozzles, providing the desired thrust. Until today it is the primary mechanism of rocket propulsion, using different fluids or fluid mixes, solid propellants and water, whether or not kept cryogenically cold, and whether for the main uplift rocket or the booster rockets for navigation.

The chemical propulsion system has emerged with the following advantages, namely, that it is simple and reliable, and it is the lowest in cost compared to other systems. It also has lower contamination of exhaust gases, and there is of course no problem of radiation. The trade-off is that it has It has relatively low thrust and impulse bit capability, and needs to be big. Again, the use of fossil fuel is a serious disadvantage. It was the natural choice in the early days mainly for small satellites. The monster among them was the Saturn V rocket, which was used to send the first man to the Moon.

With various refinements, it is still the sole propulsion system in use. However, with bigger payloads and more ambitious space journeys and objectives being pursued, the relative thresholds of risks, costs and performance of other options are being seriously evaluated one against another.

The SLS

The 10 year Artemis programme of NASA, launched last year, for the return of man to the Moon and this time to establish a base habitat there is also a rehearsal and preparation for the Conquest of Mars. It envisages a Gateway and landers, as well as the regular support of human and cargo spacecraft from Earth.

The Space Launch System rocket (SLS) used fto launch Artemis 1 stood at 321 feet tall, provided 8.4 million pounds of thrust at lift-off, weighed 5.5 million pounds, carried 154,000 pounds of payload and used 700,000 gallons (2.6 million litres) of liquid hydrogen and oxygen. The SLS was 15% more powerful than the Saturn V, meaning it was the most powerful rocket ever successfully launched.

Starship

Elon Musk of SpaceX has announced plans to achieve the first man-landing on Mars by (about) 2029. The spaceship being built by his company for the purpose is called Starship.

Unlike others, in which the spacecraft sits atop a rocket or launch vehicle of another manufacturer, SpaceX builds both, eg. the Falcon Cargo atop the Falcon 9. In this case, the first stage Super Heavy rocket booster and the second stage spacecraft proper (the payload) are identified as one, called Starship. Both stages are capable of returning back to Earth in soft landings and being reusable.

While the first recoverable on soft landing after being jettisoned, the second stage is designed for onward flight after refuelling in Earth orbit, and again being refuelled again at the destination for the return journey.

The Super Heavy is powered by 33 Raptor engines using sub-cooled liquid methane as propellant and liquid oxygen as oxidiser.

They are able to generate 16 million pounds of thrust at full throttle, almost twice that delivered by the SLS, and making the Starship the most powerful rocket when it goes operational Standing at 119 m (390 ft) tall, it is designed to be the tallest launch vehicle ever built, Starship had its successful inaugural test yesterday on 20 Apr 2023.

Starship has a payload capacity of 100-150 tonnes, which is about 100 people. And because it is fully reusable, Starship could greatly reduce the cost of launching payloads to orbit.

NASA is paying SpaceX to build a version of the vehicle to carry astronauts from lunar orbit to the moon's surface for the. Artemis III and IV missioins. For one reason, they are cheaper.

Given its technological start, and cost cuttings due to reusability, chemical propellant propulsion may stay competitive. It will be interesting whether SpaceX can retain the monopoly of methane manufacture on Mars. SpaceX's Starship shares should hit the sky.

No Demand for Nuclear Propulsion

A technology not fully exploited for propulsion is nuclear power. This sounds surprising at first sight, considering we had nuclear power stations going in 1954, nuclear-powered submarines since 1954, and we have sometimes two nuclear reactors aboard an aircraft-carrier, such as the Gerald F Ford, pushing 100,000 tonnes in the water and powering the mightiest air-naval warfare system afloat space to-date. Yet, today, we have not exploited nuclear power for our space propulsion systems.

Interestingly, we also have 1300 ICBMS world-wide, nuclear-armed, but using conventional rocket delivery. And a quick check informs me that while there are bombers and fighters carrying nuclear weapons, but none of them are nuclear powered. One issue seems to be the safety of the airmen.

From the preceding review, because of its risks, it seems we have not yet found the need to look at nuclear energy for our space rocketing, perhaps not until now.

Nuclear Thermal Propulsion

A nuclear thermal rocket (NTR) is a type of thermal rocket where the heat from a nuclear reactor, usually fission, replaces the chemical energy of standard propellant rocket. In an NTR, a working fluid , usually liquid hydrogen, is heated to a high temperature in a nuclear reactor and then expands through a rocket nozzle to create a thrust. The external nuclear heat source theoretically allows a higher exhaust velocity and is expected to double or triple payload capacity compared to chemical propellants that store energy internally. Although more than ten reactors of varying power output have been built and tested, as of 2023, no nuclear thermal rocket has flown.

Nuclear thermal rockets have their problems. First and foremost, the exhaust tends to carry radioactive particles with it, which poses environmental hazards if the engine fires in an atmosphere (which is does , massively). The reactor itself is also radioactive. A nuclear reactor only emits low levels of harmful radiation when powered down. However, when operating at criticality as an engine or as a power generator, it is extremely radioactive. The other disadvantages are the higher cost to develop, install, operate and maintain, the reactor requires very dense shielding, the social issues, and that fact that NTR technology is at a lower stage of readiness and maturity.

The following are the advantages of NTR propulsion:
. (a) Higher thruster specific impulse (It is 2 to 10 times that of a chemical system).
. (b) Lower Specific Mass in Kg/KW
. (c) Higher Power which allows high thrust.
, (d) Any propellants can be used, and
. (e) It has reduced radiation in some instances.

On 25 Jan 23, NASA and the Défense Advanced Research Projects Agency (DARPA) announced a collaboration to demonstrate a nuclear thermal rocket engine in space, described as an enabling capability for NASA crewed missions to Mars. NASA and DARPA will partner on the Demonstration Rocket for Agile Cislunar Operations (DRACO) programme. NASA will work with DARPA to develop and demonstrate advanced nuclear thermal propulsion technology as soon as 2027.

With the help of this new technology, astronauts could journey to and from deep space faster than ever – a major advance for crewed missions to Mars, etc. Longer trips require more supplies and more robust systems. Other benefits include increased science payload capacity and higher power for instrumentation and communication.

Electric Space Propulsions Systems

Electric propulsion uses electrostatic or electromagnetic fields to accelerate mass to high speed and thus generate thrust . The propulsion system is controlled by power electronics.

Electric thrusters typically use much less propellant than chemical rockets because they have a higher exhaust speed than chemical rockets. Due to limited electric power the thrust is much weaker compared to chemical rockets, but electric propulsion can provide thrust for a longer time.

I see no special advocacy of electric propulsion as such which involves electronic management of electrical power. and so I have not explored the subject. I set down its advantages and disadvantages as I found them neatly summarised in a tutorial site:

Advantages of Electrical Spacecraft Propulsion System

Following are the advantages of Electrical Spacecraft Propulsion System:
. - It offers very flexible layout and hence will have 30% reduction in volume compare to mechanical drive system. .
. It offers load diversity due to single central power generation.
. It offers greater benefits to the environment due to reduction in fuel consumption by 14000 tons per year.
. It generates less noise as electric motor has low vibration characteristics.
. The system is designed to be highly automated and self-monitoring.
. It has very low emissions.
. It offers flexibility in the space.
. It offers safety.
. It offers redundancy.

Following are the disadvantages of Electrical Spacecraft Propulsion System:
. It is expensive system.
. It has lesser efficiency compare to other systems.
. It is a complex system due to more equipment.

Electric propulsion, when compared with chemical propulsion, is not limited in energy, but is only limited by the available electrical power on-board the spacecraft. Therefore it is suitable for low-thrust (micro and milli-newton levels) long-duration applications on board spacecrafts. The propellant used varies with the type of thruster and can be a rare gas (i.e. xenon or argon), a liquid metal or, in some cases, a conventional propellant. It seems to me it can be useful for on-board requirements.

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Breaking Down Our Limits

It has been only in the last 50 years that we have become aware that the visible word we know is only 5% of the universe or space-time as we define it. Dark energy and dark matter , that we calculate gravitationally to exist and infer to share the same material laws and characteristics of our visible world, comprise the balance of 95%, about which we actually know nothing. We are either wrong about the dark world or we are naïve in assuming it is the same, only non-interactive to EMR and therefore invisible. If we cannot explain our whole universe – and find new ways of travel and survival - we may need to look again at our fundamental concepts..

So far, in our 5% world, nothing is within travelling distance, and there is nothing we have found livable in or worth visiting. We have not found anything alive out there, and no one has visited us. For all practical purposes, we seem to be alone and space travel means mucking around in the Solar System, with the Moon and Mars offering some challenges.

Yet, man is the inveterate explorer and ultimate optimist. In the belief that we will some day find the human t limits.

Speed of Light

By our own definition, the primary restriction on space travel is the speed of light. Nothing in space-time can travel faster than the speed of light, which is 300,000 km/s. The second restriction is ourselves – we evolved that way. Our lifespan is short, and we are not designed anatomically to live outside the Earth. Thirdly, it is pure distance. It will take us 27,700 years at the speed of light to get to the Earth's baryonic centre at the near edge of the Milky Way, our birth-place. If we can rev up to 42 km/s, the escape velocity from Earth, it will still take us 198 million years to get there. At present we can manage 11.6 km/s. I shall not bother to calculate how long that will take us – about 3.75 times longer. Even at the speed of light, it is out of scale.

Human Limits

Gs

Rapid acceleration and deceleration can be lethal to the human organism. The reason is inertia. The classical concept was famously expressed in Newton's first law of motion as "an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an outside force".

The cause is G-forces, otherwise called gravitational forces, or even simply Gs. These are units of accelerative force upon a mass, such as a human body. One G is equal to the pull of Earth's gravity toward the planet's centre at 9.8 metres per second per second (or second^2 , at sea level.

G-forces are experienced vertically, from head to toe or vice versa. Blood pools in the heads of those undergoing negative Gs (going up), causing an engorged sensation. "Red out" sets in as blood-swells and the lower eyelids rise up to cover the pupils.

Conversely, when acceleration is positive (going. down), the eyes and brain become starved of oxygen as blood collects in the lower extremities. Dimmed vision called "grey out" occurs, followed by total vision loss, or "blackout". These high Gs can progress to outright faints, dubbed G-induced loss of consciousness (GLOC). Many aviation deaths result from pilots blacking out and crashing.

The average person can withstand a sustained force of about five Gs from head to toe before slipping into unconsciousness. Pilots wearing special high-G suits and trained to flex their torso muscles can still operate their aircraft at about nine Gs. For short periods, the human body can take much higher than nine Gs, but not to sustain that for long period of time.

Astronauts experience fairly high Gs – between three and eight on take-offs and re-entries, respectively. These G-forces are mostly benign front-to-back Gs, as the astronauts are strapped facing their direction of travel. Once at a steady cruising speed of about 26,000kph in orbit, astronauts do not feel their speed more than on a commercial airplane.

Space Bombardment

In space, missiles, small space rocks or "micrometeoroids" can be a real hazard.. These grain-size bits can reach devastating speeds of nearly 300,000km/h. To protect the vessel and its crew, the Orion (of the Artemis mission) has a protective outer layer varying in places from 18 to 30cm thick, plus other shielding and clever equipment placement.

At several hundreds of millions of kilometres per hour, every mote in space, from stray hydrogen gas atoms to micrometeoroids, becomes in effect a high-powered bullet ploughing into a ship's hull.

Although only present at a density of around one atom in a cubic centimetre, the cosmos's ambient hydrogen would translate into a bombardment of intense radiation. The hydrogen would shatter into subatomic particles that would pass into the ship, irradiating both crew and equipment.

Heat

At speeds around 95% of light, the heat exposure would be near-instantly deadly. The star ship would heat up, too, to melting temperatures, while water in the crew's bodies would promptly boil.

One scientist estimates that, barring some sort of magnetic shielding to divert the lethal hydrogen rain, star ships could go no faster than about half of light speed without killing their human occupants.

Radiation

Ionizing radiation (IR) in deep space can be the single most limiting factor to human space exploration.

Radiation exposure is 10 times higher in low orbit than it is on land. As insulating lead is too heavy for spacecraft, astronauts receive toxic doses of radiation every second. The damage to the retina, the thyroid, and the brain, along with the body's most sensitive tissues, is permanent.

Any residence in space would require massive shielding of housing and mobile units, along with clothing—making Mars or lunar colonists relatively stationary.

Unanticipated solar flares produce fatal radiation doses in minutes, even through the walls of spacecraft. In one measured solar storm, the surface level of radiation on the planet Mars doubled.

No fetus could be conceived in this low gravity and high radiation environment. Most likely they would be stillborn, due to the 9-month exposure to radiation in the womb, and/or deformed upon delivery.

The eyes are particularly sensitive, and a higher incidence of radiation-induced cataracts in astronauts has been noted. Alzheimer's and other degenerative brain diseases are accelerated in the astronauts who have travelled into space so far.

Radiation weakening of the immune system. Chromosomal changes in lymphocytes have been noted, and the T-Cell function required for the immune system is reduced.

Space agencies need to assess the radiation environment by prior exploratiion, adequately reduce the exposure risks, and mitigate the negative effects of IR.

Gravity

Too much Gs are bad. The lack of gravitational force is also deadly to humans.

The cerebrospinal fluid does not circulate properly in low gravity states, causing brain swelling and cerebral motor dysfunction. While loss of balance may be obvious, all types of proprioception are affected—some perhaps permanently. Changes in the brains of astronauts noted by MRI suggest premature aging—and the trips so far have been relatively short.

Normally the body's fluids are pulled down by gravity and our systems adjust. In low gravity, the fluids redistribute. Faces, eyes, and brains all swell, overloading the cardiovascular system. Cardiac atrophy, with weakening heart muscle activity, will eventually disable all humans in space.

Bone formation depends on resistance exercises. The loss of bone mineral essentially ages astronauts by decades and makes fragility fractures a huge risk. Bone loss accelerates from 3% cortical loss per year to 1% per month.

It simply is not possible to exercise enough while in space. The osteoclasts cells that break bone down are ramped up more than the bone-forming cells, leading to an overload of calcium in the system.

Long-haul astronauts experience a decreased production of red blood cells. The proprioception system that relies on the senses. The inner ear and blood pressure are so disturbed that all astronauts develop nausea for varying periods of time. A single episode of vomiting in a space suit can be fatal.

Depression

People confined indoors with no exposure to fresh air (e.g., prisoners) display depression and multiple other health issues. The sense of taste is reduced, and foods do not taste the same. Smells freed from gravity permeate the shared living space, diminishing the quality of life. Combined with claustrophobia, lack of biodiversity, lack of privacy, no family, and reduced opportunities for social engagement, extended time in space is a prescription for mental disease.

Infection

Microbes and viruses become more virulent in space, possibly leading to food poisoning, antibiotic resistance, and hard-to-treat infections. A likely confluence of microbiomes—interacting without medical services, a hospital environment or advanced testing facilities to control and treat infectious agents—risks complete spaceship or a colony wipe out from a single antibiotic-resistant organism.

Survival

Resources such as air, water and food are needed for astronauts to survive. These must be provided or substituted to desirable levels of need and comfort. .

The high likelihood of cancer formation from radiation, blood pressure elevations from lack of gravity, and the stress of living in confined quarters will lead to complex health challenges ,while only basic emergency care is available. The expected lifespan of extraterrestrial inhabitants will be shockingly short.

Like humans, machines are impacted by gravity, propulsive forces, radiation, gases, toxins, chemically caustic environments, static discharge, dust, extreme temperatures, frequent temperature variations and more. The longer the journey, the more critically the spaceship's environment must be equipped to cater for the above.

Even if a small colony could survive, they could not innovate, manufacture or farm at scale if cut off. They would probably have to re-invent many things, including the computer. There could be no interstellar civilisation of humans without telecommunications.

Speed

The current human speed record is shared equally by the trio of astronauts who flew Nasa's Apollo 10 mission. On their way back from around the Moon in 1969, their capsule hit a peak of 24,790 mph (39,897km/h) relative to planet Earth. Speed in itself is not the problem, so long as it is relatively constant and in one direction.

We feel speed when we change speeds. Ie. accelerate or decelerate, or change direction-location. Even then it affects us beyond a certain tolerance.

Therefore, scientist argue that humans could – in theory – be able to travel at rates just short of the universe's speed limit[122], the speed of light, if we accelerate slowly enough – and live long enough.

Scientists helpfully say we might survive if we make it to half-light speed. We are still far short of a reasonable acceleration speed. To be realistic we also need to extend our life span.

Extending our Life-Span.

To achieve ST, extending our life-span has to be a central strategy. It is essential if we wish to think of interstellar living. As a first working yardstick, we might aim to stretch our lives to 300 years, the first hundred for up-curve learning in all dimensions, the second century devoted to effective work-travel life, and the last century for travel, holidays, philosophy, and other forms of life fulfilment.

I have no master-plan for this need, except to suggest, we start with the youngest. By the time our first interstellar argosies are ready, the first generation can safely accelerate to and travel at one quarter the speed of light, and will be ready and able to breed in space.

I have not looked into what is going on .currently among scientists in this frontier. Let other who think this a serious idea, follow up.

Off hand, one can think of the following courses to pursue:

. – Genetics, keep improving the human species as is, as the foundation of the future man
. – Cryonisation, find -526° Kelvin for a start for long sleeps between destinations
. – Go Bionic, re-in force, perpetuate, or substitute key organs with electronic devises
. – Go Mechanical, frankensteinise and grow taller, bigger, and stronger physically
. – Computerise the brain, with plug-in to processors and databases
. – Safeguard our key natural asset, the Reproductive process. Allocate women and men and compulsory time for this. Artificial reproduction may be necessary, but as a last resort, for the species may be weakened at source by this..

To the extent the preceding or similar developments do not happen, we can safely forget about ST much beyond Mars. The bottom line is that, we must remove all the human limitations listed,. especially the effects of gravity and radiation.

The First ST Odyssey

Let us also be aware of the fact that travelling at the rate of half-light will still take us eight years to get to Proxima Centauri at a constant speed. Before we get to half-light speed, we

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122 By their own mathematics, our mass will become infinite at the speed of light, will require infinite energy to move, and time will stan still.

have to accelerate up to it. Someone has kindly calculated this would take 19 years at 9Gs. We may assume the time taken to decelerate at the distant end would be the same. Then there is the cruise period in between.

The actual distance to Proxima Centauri is 36.84 trillion km or 4 light years. It would take 8 years at half-light speed for the whole distance. Unfortunately, I do not have the distances travelled during acceleration and deceleration. Let us assume each segment could take 10% of the distance, then the main cruise, 80%, would take 6.4 years. On this basis, the whole journey would take 19+6.4+19=44.4 years..

It will be a. one-way trip, in effect a migration, Moses might say, yea, we did that in about the same number of years, but he did have Help and a Promised Land.

The scale will be big. To be viable we will have to assemble a task force of mutually supporting spaceships, like the US Seventh Fleet. with I suggest a “mothership” carrying smaller reconnaissance, etc spacecraft. The people must be of the new generation, capable of withstanding 9Gs for 19 years up and the same down, and giving birth after that. We shall need a new vintage of the wagon train giants, John Wayne and Wallace Beery, with Captain James T Kirk and Spock to do the technical work.

The exodus will also need to bring along HAL or and his high-end AI descendants, preloaded with everything necessary, including the GPS of the universe, The fleet should be substantially operated and maintained by AIs, with powerful versions acting as ship’s officers engineers and navigators. Each spaceship should have an hospital, staffed by qualified Ai doctors, with a specialist hospital on the mothership (of humans and Ais) caring for extreme health and doing research. On the main run, it should be possible to have ferries and shuttle services between spacecraft. I would say 50 spaceships and 10,000 people would be about right

It will be foolhardy to send out a task force before several reconnaissance trips by Ais. It will be essential to have communications, to benefit from these missions. It will be necessary to establish intermediate relay stations, There must be a working link all the way to Proxima Centauri, perhaps a series of satellites at various Lagrange points. It might be necessary to invent new technology to achieve this. We cannot have telecommunications that take light years to get across.

I rate telecommunications the first “infrastructure” to work on. Perhaps it will be the first set of imprints of man on the universe: a telecommunications “highways”, signposted with directional arrows and “milestones from Earth“ alongside. Among other things, it will be an outstanding achievement if a ST mission can be in. touch with Earth all the time – the first basis of an interstellar civilisation - and tourism. No doubt, a hot-dog stand, a refuelling station, and a cigarette vending machine will come up alongside, perhaps a sauna hut, and a “honky-tonk” brauhaus or two.
“
Even if we travel at half-light speed to Proxima Centauri, we are not really achieving much. The Milky Way will still be only 27,000 light years beyond, And our next nearest galaxy, Andromeda, will still be 68 **million** light years further away.

Untapped Propulsion Sources

While still possibly the most economical way, Elon Musk has set the current limits of ST travel. His Starship to Mars will have a payload of 100 people and 150 tonnes of supplies. His 33 Raptor engines will need 4,500 million tonnes of fuel to blast off, and a further 1500 tonnes of refuel in Earth orbit before heading for Mars. He will do the journey at a blindingly (slow) speed of 11.6 km/second and take 6 months. He will soft-land on Mars, but will have to refuel again to return to Earth.

Fusion

Fission energy has already been successfully incorporated extensively in scientific instrumentation and technological equipment including on board satellites an spacecraft.

Fusion, the superior source of energy but also the technologically more complex, has still to be mastered for space. NASA and DARPLA have now initiated proposals to develop fusion for power to launch vehicles. When we get a fusion reactor aboard a spacecraft, I would say we can blast off and we can live in space for short spells. ST might then become viable in and around the Solar System.

But, even if fusion propulsion systems could accelerate a vessel up to 10% of the speed of light, a cool 30,000 km/second, within tolerable Gs, we would still be short of the half-light speed necessary to use our highway to Proxima Centauri..

Antimatter

Some scientists think that the best prospects for powering fast spacecraft is antimatter. According to quantum science, antimatter exists, and when matter and antimatter make contact, they obliterate each other as pure energy. The last fact is the point of interest to space travellers.

Antimatter is defined as matter, but composed of the antiparticles (or "partners") of their corresponding particles of "ordinary" matter.

In particle physics, every type of particle is associated with an antiparticle with the same mass, but with opposite physical characteristics. Every particle has its antiparticle.

In particle physics, in association with the conservation laws which govern the behaviour of physical particles, Charge conjugation (C), Parity (P) and Time (T) combine to constitute a fundamental symmetry called “CPT invariance”. These define a particle.

Antimatter is thought of as matter with reversed features of Charge, Parity, and Time (known as “CPT reversal”[123]). It is the opposite of matter..

Scientists have then proceeded to apply this scenario of understanding at the birth of the universe. The Big Bang theory would or should have produced equal amounts of matter and antimatter. The two equal and opposite components would or should have been created in CPT reversal, and should have proceeded to annihilate each other completely, leaving a universe empty except for radiation.

We have no idea, not to say proof, of what actually happened, whether there creation of a matter and an antimatter world. If there was but no mutual annihilation, where is the antimatter world? If there was no antimatter world as supposed, what are the traces of antimatter we find and in fact can create, and which we describe as violations of CPT reversal?

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[123] Charge conjugation(C): reversing the electric charge and all the internal quantum numbers. Parity (P): space inversion; reversal of the space coordinates, but not the time. Time reversal (T): replacing t by -t. This reverses time derivatives like momentum and angular momentum.

The on-going research so far indicates that, at the hyper-measurements being taken at the sub-sub-particle (kaons, mesons) level, there seems to be little violation of CPT reversal, which is the pre-condition of CT asymmetry. The latter is thought to be the cause or the under-pinning basis for the higher proportional difference in the annihilation of antimatter as against matter. If only the antimatter component was annihilated, it must have been almost as big as the baryonic world. Where is the energy now which would have been produced.?

We still far from establishing any relationship between antimatter, gravity, dark matter and dark energy. Speculative theories include the existence of an entire anti-universe somewhere else.

We did not theorise antimatter or discover annihilation as such.

in 1928, Paul Dirac developed a theory that combined quantum mechanics and Einstein's special relativity, to provide a more complete description of electron interactions. The equation he derived turned out to have two solutions, one for the electron and one that seemed to describe something with the opposite charge (in fact, it was the positron). Then in 1932, the positron (antimatter) was found occurring naturally in cosmic rays.

Antimatter has since been confirmed to occur in natural processes like cosmic ray collisions with the atmosphere. It is also produced in certain types of radioactive decay. However, the quantities are fractional. If not for Dirac's dual matter hypothesis, I doubt we would be look for half missing universes.

For the past 50 years and more, laboratories like CERN have routinely produced antiparticles, and in 1995 CERN became the first laboratory to create anti-atoms artificially. But no one has ever produced antimatter without also obtaining the corresponding matter particles

There are therefore, presently, only two places where antimatter exists. One is inside our ultra-powerful particle colliders: when we turn them on and blow up some subatomic stuff, jets of both normal and antimatter pop out. The other place is in cosmic rays: cosmic rays are streams of high-energy particles streaking in from across the cosmos and hitting our atmosphere. They come from ultra-powerful processes in the universe, like supernovae and colliding stars, where the same physics cause their ejection.

At the same time, there is strong evidence that the observable universe is composed almost entirely of ordinary matter, as opposed to an equal mixture of matter and antimatter. The process by which this inequality between matter and antimatter particles is thought to have developed is called baryogenesis.

Just as pairs are produced in perfect symmetry in fundamental interactions, they are destroyed in symmetry as well. When a particle meets its antiparticle they annihilate each other completely. Antimatter particles only annihilate when they come in contact with their own opposites or partners

Similarly, because charge is conserved, it is not possible to create an antiparticle without destroying another particle of the same charge. These conditions obtain when antiparticles are produced naturally via beta decay, and at the collision of cosmic rays with Earth's atmosphere. The same holds true in the simultaneous creation of both a particle and its antiparticle in a particle accelerator.

It has been further established that a collision between any particle and its anti-particle partner, which leads to their mutual annihilation, in fact gives rise in detail to various proportions of intense photons (gamma rays), neutrinos, and sometimes less-massive particle–antiparticle pairs. The majority of the total energy of annihilation emerges in the form of ionising radiation. If surrounding matter is present, the energy content of this radiation will be absorbed and converted into other forms of energy, such as heat or light. The amount of energy released is usually proportional to the total mass of the collided matter and antimatter, in accordance with $E=mc^2$.

According to the Standard Model of particle physics, the Big Bang should have produced matter and antimatter in equal amounts. But if so, the entire contents of the cosmos would have annihilated itself through collisions over time, leaving the universe a very empty place today.

We have as yet no idea what happened at the Big Bang, except that we have the baryonic world (with us in it) whileantimatter exists or remains only as trace amounts, with no apparent on-going role or place in the arrangements of things.

Several accelerator, decelerator and particle research centres world-wide have been reverse engineering the exact happenings at the Big Bang. They have even successfully bound anti-particles together in experiments to form antiatoms. However, only minuscule numbers of antiparticles can be generated. The total artificial production has been only a few nanograms. No macroscopic amount of antimatter has ever been assembled due to the extreme cost and difficulty of production and handling.

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It has further been found that antiparticles bind with each other to form antimatter, just as ordinary particles bind to form normal matter. For example, a positron (the antiparticle of the electron) and an antiproton (the antiparticle of the proton) can form an antihydrogen atom. The nucleus of an antihelium has been artificially produced, albeit with difficulty, and are the most complex anti-nuclei so far observed. **Physical principles indicate that complex antimatter atomic nuclei are possible, as well as anti-atoms corresponding to the known chemical elements.**

We appear to have moved to a position of near-proving that an antimatter world is a plausibility, but not yet if there was one at the Big Bang.

The discovery of **charge parity violations** has helped to shed light on this problem, by showing that CPT symmetry, originally thought to be perfect, was only approximate. Some particles, such as the photons, are their own antiparticle.

CPT asymmetry is the only difference between matter and antimatter found so far. To produce a baryonic matter-dominated Universe like the one we live in, an excess of matter must have formed and survived the hypothesised annihilation. But to produce such an excess, some difference between matter and antimatter must be present: enter CP asymmetry.

James Cronin and Val Fitch did their experiment with particles called neutral K-mesons, or "kaons" in the 1960s.. The types of kaons they chose to study can be regarded to consist of one half ordinary matter and the other half antimatter (not that I know what that means). It is not clear to me from the available narratives what they discovered or disproved. They were awarded the Nobel Prize in 1980 for their discovery, for it seemed, by then, that they must have opened a significant gateway in a significant direction[124.] I take it they discovered the possible existence of CPT asymmetry.

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[124] See Nobel Prize press release, which to me is quite obscure, at https://www.nobelprize.org/prizes/physics/1980/press-release/

Unfortunately, the amount of CP asymmetry present in the Standard Model of particle physics is not enough to explain the observed antithetic composition of the universe, driving extensive studies and searches of antimatter and or other sources of CP asymmetry.

Physicists now believe that the laws of nature obey a fundamental symmetry that if all the matter in the universe were replaced with antimatter, left and right inverted as if looking into a mirror, and the flow of **time** reversed, this “anti-world” would be indistinguishable from our real matter world. Antimatter atoms should weigh exactly the same as their matter.There is no mention of gravity.

Experimental groups are producing antimatter atoms artificially to explore the fundamental symmetries between matter and antimatter at their identity level. The following extract from Max Plank’s Masaki Hori, lead scientist of the CERN-Paul Sherer Institute research group sums up the main position still:

> “Experiments on antimatter are particularly exciting with regards to the fundamental laws of physics," says Masaki Hori, team leader from MPQ. For example, the Standard Model of particle physics - the basis of scientists' current understanding of the structure of the universe and the forces acting within it - requires that particles and their antiparticles differ in the sign of their electric charge. An antiproton - the counterpart of the positively charged proton, a building block of atomic nuclei - carries a negative charge. According to the Standard Model the other properties are identical. "In our past experiments, we have found no evidence that the masses of protons and antiprotons differ in the slightest," notes Hori. "If any such difference could be detected, however small, it would shake the foundations of our current view of the world.”
> https://www.psi.ch/en/num/featured/antiprotons-in-superfluid-a-new-way-for-sensitive-measurements-of-antimatter

Perhaps a most remarkable development of the above group has been mixing the (low temperature) antiprotons with liquid helium cooled to a a few degrees above absolute zero, trapping a small part of the antiprotons in atoms of helium. The antiproton replaced one of the two electrons that normally surround a helium atomic nucleus - forming a hybrid structure stable to study. There was no report what the CPT symmetry status was. It seems to me near zero temperature is a factor in sub atomic activity.. I wonder the group di not try to boil the mixture. We might have had an annihilation, proved the Big Bang hypothesis, and opened the door to a new source of power for ST.

Based on $E=mc^2$, the calculated energy output of a 1 kg-to-1kg matter-antimatter annihilation would be around 43 megatons of TNT, about the biggest bomb detonated. It is said the energy released by antimatter annihilation is greater than that of fusion, fission, and chemical combustion. However, it still is not possible to formulate the technology of the reactor fully to produce, manage and apply the released energy. Anyone with 1 kg of antimatter is a walking bomb, and should be dipped in sub-zero helium hyper fluid..

I have dealt with antimatter in some depth as there is more than possibility it is real and not a research dream. I therefore include a useful Wikki reference[125]..

I note Dirac’s original inquiry has not been answered: how does his second equation related to gravity – and there are other open ends, like dark matter and dark energy, black holes and missing universes. Who knows, antimatter might open a new door to these.
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125 https://en.wikipedia.org/wiki/Antimatter#:~:text=The%20modern%20theory%20of%20antimatter,positrons%20from%20%22positive%20electron%22.

Superluminal Travel

One ingenuous idea is to surf spacetime, and thereby travel at faster-than-light (superluminal) speeds).

This intriguing faster-than-light scenario works like the “warp drive” of Star Trek. Called an Alcubierre drive, it involves compressing the normal spacetime of Einstein physics in front of a starship, while expanding it behind. In essence, the ship resides within a chunk of spacetime – a “warp bubble” – that moves faster than the speed of light. The ship, however, remains at rest within its pocket of normal spacetime, avoiding any violation of the universal light-speed limit. The Alcubierre drive will carry the ship like a surfer riding on the crest of wave on a surfboard.

The concept requires an exotic form of matter possessing a negative mass to contract and expand spacetime. Physics does not forbid negative mass but there are no examples of it seen it in nature.

As we look for more power, we find ourselves at the boundaries of present day science. I am told, if we learned to manipulate inertia even for a fraction of a second, it could allow a rapid, effortless acceleration, after which point inertia could return and we could cruise at a constant, high velocity.

(Back to TOC)

Faster-Than-Light Travel

For the despairing Earth-bound I have saved FTL for the last option.

Since one might not travel faster than light, one might conclude that a human can never travel further from the Earth than 40 active light-years or so. A traveller would then never be able to reach more than the very few star systems.

FTL

This is a mistaken conclusion. Because of time dilation the traveller can travel thousands of light-years during their 40 active years.

This is how it is done. If the spaceship accelerates at a constant 1 g (in its own changing frame of reference), it will, after 354 days, reach speeds a little under the speed of light (for an observer on Earth).

Time dilation will increase the traveller’s lifespan to thousands of Earth years, seen from the reference system of the Solar System, but the traveller's subjective lifespan will not thereby change.

If they were then to return to Earth, the traveller would arrive on Earth thousands of years from the time when he originally left.

His travel speed would not have been observed from Earth as being supraluminal—neither for that matter would it appear to be so from the traveller’s perspective.

But the traveller would instead have experienced a length contraction of the universe in his direction of travel.

After the traveller reverses course, the Earth will seem to experience much more time passing than the traveller does.

So while the traveller's (ordinary) coordinate speed cannot exceed c (speed of light), his proper speed or distance travelled from the Earth's point of reference divided by proper can be much greater than c.

Technical Explanation[126]

If a space ship travels at a constant acceleration over interstellar distances, it will approach the speed of light for the middle part of its journey when viewed from the Earth's planetary frame of reference.

The most important effect is that time will appear to pass at different rates in the ship frame and the planetary frame, and this means that the ship's speed and journey time will appear different in the two frames.

From the planetary frame of reference, the ship's speed will appear to be limited by the speed of light — it can approach the speed of light, but never reach it. If a ship is using 1 g constant acceleration, it will appear to get near the speed of light in about a year, and have travelled about half a light year in distance. For the middle of the journey the ship's speed will be roughly the speed of light, and it will slow down again to zero over a year at the end of the journey.

As a rule of thumb, for a constant acceleration at 1 g, the journey time, as measured on Earth will be the distance in light years to the destination, plus 1 year. This rule of thumb will give answers that are slightly shorter than the exact calculated answer, but is reasonably accurate.

From the frame of reference of those on the ship the acceleration will not change as the journey goes on. Instead the planetary reference frame will look more and more relativistic. This means that for voyagers on the ship the journey will appear to be much shorter than what planetary observers see.

At a constant acceleration of 1 g, a rocket could travel the diameter of our galaxy in about 12 years ship time, and about 113,000 years planetary time. If the last half of the trip involves deceleration at 1 g, the trip would take about 24 years.

Aging

Thanks to Einstein, we know that the faster you go, the slower time passes. Five years on a ship traveling at 99 percent the speed of light (2.5 years out and 2.5 years back) corresponds to roughly 36 years on Earth.

This means astronauts on the International Space Station get to age just a tiny bit slower than people on Earth.

Research has shown that spending time in space causes bone density loss, immune dysfunction, cardiovascular issues, and loss of skeletal muscle mass and strength. These changes resemble aging in people age on Earth, but happen more quickly in space.

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126 https://en.wikipedia.org/wiki/Faster-than-light

Future Tourism

At our present stage, we still have major problems to sort out before we can institute regular round trips to the Moon and Mars. I imagine that, additionally, as soon as we sort out the best nuclear, anti-matter or anti-gravity modus of propulsion would suit our purpose, we could be into future tourism travel.

Travelling in space for three years at close to the speed of light would equal five years on Earth. If the trip is merely to the nearest star, Proxima Centauri, 4.26 light years away, with deceleration tin he last half of the way, it would take (ship time) 3.6 years., plus something for a stopover. The tour would cover 38.34 trillions km. Mars would be a cinch.

The Milky Way however would take 24 years, inclusive of stopover, in an Earth planetary frame of reference of 113,000 years. Re-inserting the returning travellers so far in the Earth's future may be a problem. It could of course be a selling point for those who want also want to see the future (and migrate to it).

I may be anticipating myself, but I think it would be a great idea t send A1s out on these acceleration trips to explore, survey for habituality and videograph these potential tourist sites .

(Back to TOC)

Re-sizing the Universe

This section tries to round up a layman's perceptions of the present status of our understandings of the Cosmos, after a serious study of the subject. Where my facts or conclusions are wrong, I would apricate being corrected.

My overall conclusion is that our current understandings no longer adequately encompass the new facts that have emerge since Edwin Hubble.

According to our conception, the universe exists in space-time, and travel within this universe is limited by the fact that nothing can travel faster than the speed of light. All forms of energy, including gravity, electricity and telecommunications travel automatically at the speed of light - which is itself a form of energy. In fact, if we do travel faster than light, we will go back in time.

If we accelerate beyond the speed of light, we shall be leaving behind all our light, telecommunications, Internet and our data behind, and will be talking with our yesterday, unless we also invent a way to take them along at our speed. At this point, we should not assume that matter and information are the same. (There is in fact a very big difference, the subject of my next enquiry possibly.)

Perhaps we have reached the point for another deep-think about our material universe, like Einstein and Planck did a century ago. It is in the nature of the scientific ethic, and indeed of all learning, from time to time to assemble all the known chips of knowledge and cast them out in the most meaningful new pattern that best explains them all, while allowing new facts to emerge. Periodically, when the working postulates can no longer accommodate the new facts, it is time for a re-synthesis.

Even at the level of fundamental matter, we still lack a unifying theory that ties up the elementary particles of sub-atomic matter with the gravitational forces that hold and move the universe. It is not even clear that we have found the last smallest sub-sub-sub-atomic building block of matter, as we go deeper to find the common links, whether it be the muon, the gluon, the neutrino, peon or the pion, and which ones mediate gravity at different scales.

Then, there are the already serious loose ends to the big picture. Among others, we are completely in the dark about two-thirds of our universe, which we describe as dark energy, not to mention, the remaining third being mostly dark matter. Our current knowledge only relates to the baryonic world of matter, which makes up 5% of the universe. It is quite tenuous to apply it to the whole.

We are also quite at a loss to understand the continued expansion of the universe after the big bang – and that the universe is expanding faster than the speed of light. We are left calculating both our conmoving and our proper distances to decide where we are. Thus the CMB has travelled 13.7 billion light years in actual time, but is 40 billion light years from its point of origin. There is the further unanswered question where we are heading, to entropy or a big crunch.

While physicists firmly declare that all particles must conform to their respective fundamental symmetries called their "CPT invariance", we find that every particle also has an antiparticle, which is the opposite. Worse, when the opposites come into contact, they annihilate each other. Modern science has not yet explained how our world of matter came to remain behind, while the world of anti-matter disappeared except for traces in cosmic rays and radioactive decay. There is no clue so far what proportions of what got zapped and what remained, if anything in fact got zapped.

There is the further apparent fact that the missing anti-matter got converted to energy. I have not come across any scientific persuasion rationalising why there had to be antimatter, what indispensable role it played in the scheme of evolution, and in fact how the anthesis evolved – not even to account for the Big Bang. If not, where is that energy? Is it dark energy? As a matter,where did dark energy come from?

independently of antimatter, we do not know how the energy was built up in the singularity which has been deemed so far to be accountable for the Big Bang. The question may be wrongly put, but there should be valid answers to it.

One fact has been established, however. Antimatter exists, Our scientists have made the stuff, and actually have a store of it – in nanogram quantities. Not only that, but they are building anti-matter atoms and hybrid-matter atoms. Let me quote again their current perceptions: "Physical principles indicate that complex antimatter atomic nuclei are possible, as well as anti-atoms corresponding to the known chemical elements." No doubt they shall soon have a standard model of antiparticles and clarify whether anti-matter is EMF sensitive, gravitational positive or negative, etc.

Finally, our universe is like Harry Belafonte's bucket, with a hole (many holes) in it, Galaxies are dropping into Black Holes, with still a string of hypotheses what happens inside or at their event horizons, not to mention where the dark world fits in or for that matter whether anti-matter exists therein. I have not gone into Black holes in detail, and have questions about Hawking's radiation, and wormhole passages. . A controversial new theory suggests that supermassive black holes that lurk at the heart of most large galaxies could be the source of dark energy, the mysterious force driving the accelerating expansion of the universe.

I am told, if a regular black hole and an antimatter black hole got married in space, they would not vanish. Feeding in antimatter is just like regular matter or energy. It only makes the black hole more massive. Perhaps that is where all that antimatter went, if indeed they were annihilated and were subject to (positive) gravity. It also implies antimatter was part of our space-time.

I have not seen much discussion of using gravity for powering spacecraft, besides "gravitational assist". Quantum scientists have been looking for bosons as gravity force carriers in the particle world, and found some. Instead of looking to "unify" them with macro-gravity through a common continuum, perhaps we might recognise them for what they are, namely evolutionary loose ends with no functional value in the larger universe.

We might look again at gravity for what it is: not just the resultant of changes in spacetime curvature, but the active principle or force governing the macro world, distributing matter and energy, dark and otherwise in space. A theory that does not include negative gravity or explain the expansion of the universe cannot stand on its own. Perhaps in future we can be riding on - 500 Gs outside of space-time, instead of fighting it..

Gravity is sometimes poetically described as a great "vacuum service" sweeping all space discards into Black Holes – for recycling. I am very inclined to it. Negative gravity would be the ambient condition on the outside - perhaps for un-recyclables.

As a result of the preceding, our model of the universe is breaking down. There are already whisperings that the first pictures from the James Webb Space Telescope, due any day, will confirm or challenge many of our premises.

Even if we perceive our universe to comprise several physical dimensions of existence or as cycling from big bang-to-crunch-to big bang- again, we need to establish scientifically how it began, and if not whether in fact we can know scientifically how it began.

The same issue arises with life, which I have left out of this exercise, although life is matter and energy and some would say is the highest product or expression of physical evolution. I have left out consciousness and intelligence as phenomena beyond the physical, about which we still have no clear dear at the macro scale.

As I see it, there is no need to discard the Big Bang yet t this point. Perhaps, we need to have a layered (perhaps multiple layers of) micro world and macro world systems, and not tie up everything with symmetries and superstrings. Perhaps the Big Bang can no longer be the over-arching system.

As I proceeded with this Chapter, I became aware of stunning new pictures taken by the James Webb Space Telescope of the early universe recently released by NASA. They revealed huge fully matured galaxies in the first 500 million years after the Big Bang, when according to the latter theory there should not have been any in the still nascent universe. If verified, they would contradict the prevailing theory.

Rather than get embroiled, I decided to leave my survey as it is, simply report this additional discovery, and await the spectrometric and other analyses that must follow to establish the details. Needless to say it adds another element to be taken in to the Big Bang theory. I have added the full published report in a **Postscript** at the end of this book.

Quantum Computer

One major frontier of quantum technology is the quantum computer. It is the leading edge which will define ST.

We are currently looking at a leap in scale comparable to Hubble's first comprehension of the extragalactic universe. I quote from IBM's description of its current front-runner the Osprey 433 qubit:

> "IBM's new 433-quantum bit (qubit) processor has the potential to run complex quantum computations well beyond the capability of any classical computer. For reference, IBM said the

> number of classical bits that would be necessary to represent possible states on the IBM Osprey processor far exceeds the total number of atoms in the known universe.' https://techhq.com/2022/11/ibm-just-unveiled-its-most-powerful-quantum-computer-yet-a-433-qubit-machine/

IBM's Condor is due in 2023, with 1,211 qubits. , which means a processing power of $2x10^{1211}$ cycles/s.

Looking at a quantum computer is like Adrian Hubble discovering the extragalactic universe. An earlier 63 qubit assembly, which equates with $9.2x10^{18}$ bits on a classical computer, will hold one Exabyte[127] of data in RAM and complete one scheduled run 97.5 years faster than a (3 GHz) classical computer.

A 1,000 qubit machine has the equivalent of $1.1x10^{301}$ ordinary bits, and can load $1.x10^{282}$ bits in RAM. The universe contains 10^{80} hydrogen atoms. It would take six universes of hydrogen to load the quantum computer. The aforementioned classical computer would take $1.1x10^{284}$ years to run the same job. In fact, we would have to wait for our universe to complete six life cycles for the latter to complete the run[128].

Quantum Mechanics was the first subject I reviewed for myself in this series[129]. In the light of almost a year I took in the review, this is what I dared to say:

> "If we achieved the qubit scale in the preceding decade, there would not be any reason not to project a 100% a year straight- line growth from 2030 to 100,000 in 2040, and another round of say 50% a year straight line growth from the latter base in the decade following to 500,000 in 2050. From then, doubling in the decade following would probably seem straightforward. " https://geraldpillay.wordpress.com

It is almost unimaginable, but IBMS's and others' progress suggest 10,000 qubits by the end of this decade is possible, probably not longer than a decade later. It will happen when we break the "Noise Intermediate Scale Quantum Technology" (or NISQ) barrier, a major present hurdle[130]. Our processing power will be $2x10^{10000}$ cycles /second.

At that stage, we should have mastered the still considerable technical difficulties of building and operationalising a quantum computer. There is among others the problem of the rapid de-coherence of the result. Adding a qubit would be the least of the problems. In. fact, the next big hurdle will be Data Storage. For the quantum computer cannot store its own data and it produces tons of it (49,000 videos equivalent from one 49 qubit run). It is expected that DNA computing, the next new technology, will have to take over this problem. There will also be the problem of scalability, building progressively more manageable sizes for independent deployment.

Our requirement for quantum power for space will be progressive. Immediately there will need for a central integrated facility, complete with one or more front and back end computers, associated data storage facilities, i-cloud access, and links to the major land and space based observatories.

The primary task is to build the databases of the universe. We should, as soon as possible, have on-line a working model, map and GPS of the universe. We should progress to include dark matter and all 93 billion light years across the observable universe – and beyond to where the universe is racing. And we should have among other things a complete star

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127 - 1 Exabyte = 1,000 Petabytes =1 billion Gigabytes
128 https://vincentlauzon.com/2018/03/21/quantum-computing-how-does-it-scale/
129 https://geraldpillay.wordpress.com
130 See https://www.quintessencelabs.com/blog/current-quantum-computers-noisy

register with date of birth and galactic affiliation. At the sub-atomic w should have the complete listing of quantum particles, positive and anti, together with their CPF invariances.

There will of course be universe-wide telecommunications and the quantum Internet of All Things (I of T). While the quantum computer Is essentially a one run phenomenon, it must move to support full on-line functionality, simulation and AI level research In time, with availability of the databases ,every country will one for space research.

Artificial Intelligence

AI is the off-spring of Information Technology (IT), and the avatar of information processing. The first programmes were to instruct the computer what to do. As each generation of computers grew, the software deepened, incorporating human processes of thinking, and progressively the ability to focus on human preferences, interests and problems.

By the age of the supercomputer (1990s), there was computerisation of almost everything – and masses of data collected . With the laptop and smart hand-held device, the internet became the man-in-the-street's everyday working tool. People began to put personal data on the net. It became the world's daily newspaper. The world needed AI as a direct tool to use this information

The most important A! invention was the Search Engine, Yahoo in 1994 and Google in 1996. Today, the world is dependent on the Search Engine (Google to be exact) for the supply (and double-checking) of information. More, people are falling into the hands of marketeers who can match individuals with products. – and like it.

The world has been abuzz since the multiple resignations of Dr. Geoffrey Hinton, the well-known "Godfather of AI" of the current generation, that has spawned the chat-bots (like OpenAI, ChatGPT, and Google Board. He fears such like applications of AI can and may be used by "bad actors" to control the world.

When the tourism industry goes space-wide, and the Internet goes universe-wide, commercial AI may dominate use of our databases. Not until then.

Immediately AI will dominate in the areas of research, increasingly deepening its capability to extract information (and knowledge) from our enlarging worlds of data.

More importantly, AI will be incorporated increasingly in research tools that can be fielded when human cannot go, like the oceans and space. These robots will replace humans in such environments. It is quite conceivable that, in time, there can be spaceships under navigation by highly "intelligent" (human-like) robots, sent out on long exploration missions into deep space, armed with a battery of AI tools, feeding back information and pictures of 'far away places". There will be no need to travel to find out about the distant universe. The limit will be back communication with us.

Curiosity, our Mars rover, has been doing this since 2012 and reporting online at Twitter[131]. Perseverance, another rover landed on Mars in 2021,works with Ingenuity, a drone-helicopter, covering more ground. Perhaps the James Webb Telescope is our first true AI in space.

At some distant point, our model of the universe can and will be completed. If we have beaten the speed of light by then, or can live longer, we can look forward to becoming an interstellar species. It is also going to depend on whether our telecommunications and IoT can also beat the speed of light or bypass it. Who knows, we may have found alien friends.

In the end, we may be able to do an “under cut”. When our data bases are up, we might simply ask our master quantum computer: how do we travel faster than light? The answer might be: Schrodinger’s cat.

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THE END

POSTSCRIPT

NEW EVIDENCE
From the James Web Space Telescope

Tereza Pultarova
published February 23, 2023
SPACE.com[132]

The James Webb Space Telescope discovers enormous distant galaxies that should not exist

Giant, mature galaxies seem to have filled the universe shortly after the Big Bang, and astronomers are puzzled.

Nobody expected them. They were not supposed to be there. And now, nobody can explain how they had formed.

Galaxies nearly as massive as the Milky Way and full of mature red stars seem to be dispersed in deep field images obtained by the James Webb Space Telescope (JWST or Webb) during its early observation campaign, and they are giving astronomers a headache.

These galaxies, described in a new study based on Webb's first data release, are so far away that they appear only as tiny reddish dots to the powerful telescope. By analyzing the light emitted by these galaxies, astronomers established that they were viewing them in our universe's infancy only 500 to 700 million years after the Big Bang.

Such early galaxies are not in themselves surprising. Astronomers expected that first star clusters sprung up shortly after the universe moved out of the so-called dark — the first 400 million years of its existence when only a thick fog of hydrogen atoms permeated space.

But the galaxies found in the Webb images appeared shockingly big, and the stars in them too old. The new findings are in conflict with existing ideas of how the universe looked and evolved in its early years, and don't match earlier observations made by Webb's less powerful predecessor, the Hubble Space Telescope.

"We had specific expectations for the type of galaxies that live in the early universe: they are young and small," Joel Leja, assistant professor of astronomy and astrophysics at Penn State and one of the authors of the study, told Space.com in an email. "Previous studies of the early universe with Hubble and other instruments tend to find small, blue, baby galaxies at early times: objects which have just recently formed out of the primordial cosmic soup and are themselves building their early stars and structures."
Young stars in general shine bright blue. With age, stars develop a redder glow as they burn through their fuel and cool down. In ancient galaxies that Webb was built to spot,

[132] https://www.space.com/james-webb-space-telescope-giant-distant-galaxies-surprise

astronomers had not expected to see old red stars. They also had not expected to find galaxies more massive than perhaps a billion suns. But those reddish dots revealed in Webb's deep fields appear 50 times more massive than that, Leja said.

"The most massive galaxies in our sample are estimated to have masses [two to four times lower (higher?) than that of our own Milky Way," Leja wrote. "This was astounding — we're finding galaxy candidates as massive as our own galaxy when the universe was 3% of its current age."

Leja said that before astronomers start rewriting cosmology theories to explain how these galaxies came together so quickly after the Big Bang, they will have to ensure the odd red dots they are looking at are not something else. Most of the alternative explanations, however, also require entirely new concepts, Leja said.

"For example, stars in the early universe might emit light in exotic ways due to their lack of heavy elements, and perhaps we're not incorporating those in our models," Leja wrote. "Or alternatively, perhaps our understanding of how stars form locally, e.g. how many stars form from gas as a function of the mass of the stars, is totally inapplicable in the early universe. These things would also be exciting to discover and would also overturn our understanding of star formation in the early universe — just in a very different way."

The images that revealed these puzzling galaxies were obtained by Webb's Near Infrared Camera (NIRCam) as part of the Cosmic Evolution Early Release Science (CEERS) program. Astronomers plan to soon turn Webb's mirror to these galaxies again to, this time, obtain light spectra of those distant dots. Spectra break down the observed light according to its wavelength composition and thus reveal the chemical and physical properties of its source."

"The most important thing is that spectra give very precise distances to these objects," said Leja. "The "distance" and the "identity" of these objects is correlated: if we know the distance, we can pin down the identity, and vice versa. So a spectrum will pretty immediately tell us if our hypotheses are correct."

"We looked into the very early universe for the first time and had no idea what we were going to find," Leja said in a Penn University. "It turns out we found something so unexpected it actually creates problems for science. It calls the whole picture of early galaxy formation into question."

The study was published in the journal Nature on 22 Feb 2023.

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About Gerald F. Pillay

Gerald @ Toa Payoh

Family & Affiliations
Birthplace Malacca (now Melaka, Malaysia), 2 Dec 1934.
Son of Francis Joseph Pillay (@ Odiang), of Chetty Malacca descent, and Janet Thomas
Family settled in Singapore, since 13 Apr 1949
Married to Mabel Pillay nee Narayanasamy, on 6 Feb 1962
Two sons, Leslie Francis (b 1963) married to Deirdre Goh, and Carl Jeffrey (b 1964) married to Sharon Grace Loh. Latter have one son Christian Lowen Pillay (b 2006)
Roman Catholic, Singapore citizen.

Education
Yock Bin Chinese School, Malacca 1943-45
St Francis' Institution, Malacca 1941, 1946-49
St Joseph's Institution, Singapore 1949-53
University of Malaya, Singapore 1953-57. University Scholar, Economics Book Prize 1956, BA Hons Geography Upper II, 1957

Career
Singapore Administrative Service 1957 – 1974
ITB and VITB, predecessors of Institute of Technical Education, ITE) 1974-1989, retired as Deputy Director (Dy CEO) after 33 years in public service
Principal and Sole Proprietor, GFP Consultancy, 1989- 2006. Retired after 17 years' private practice in TVET Consultancy for the World Bank, UNESCO, ILO, and others.
G. F. Pillay CV_May 2020(click)

Others
Captain, Singapore Royal Artillery (Volunteers) SRA(V) and Aide-de-Camp (Extra) to Tun Yusof Ishak , Yang di Pertuan Negara, (Head of State) Singapore, 1961-64.
Lion, 1973 – 2008. Twice Club President and four times Cabinet Officer in Lions Clubs International District 308 A1 and predecessors
Secretary, Catholic Aids Response Effort (CARE), 2007 -2010.
Honorary Adviser, Peranakan Indian (Chitty Melaka) Association Singapore, 2016-2022

Current Activities
Internet research, see Publications.

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