ONLYIAS
BY PHYSICS WALLAH

BPSC WALLAH

PHYSICAL GEOGRAPHY

COMPREHENSIVE LEARNING SERIES FOR PRELIMS AND MAINS

CONTENTS

1 Evolution of Universe

BASIC INTRODUCTION TO GEOGRAPHY

Geography is a systematic study of the Earth, its features and phenomena that take place on it. Geography is derived from the words 'Geo', meaning 'Earth' and 'graphein', meaning 'to write'. Geography is an integrated discipline with applications across various subjects. **(Figure 1.1)**.

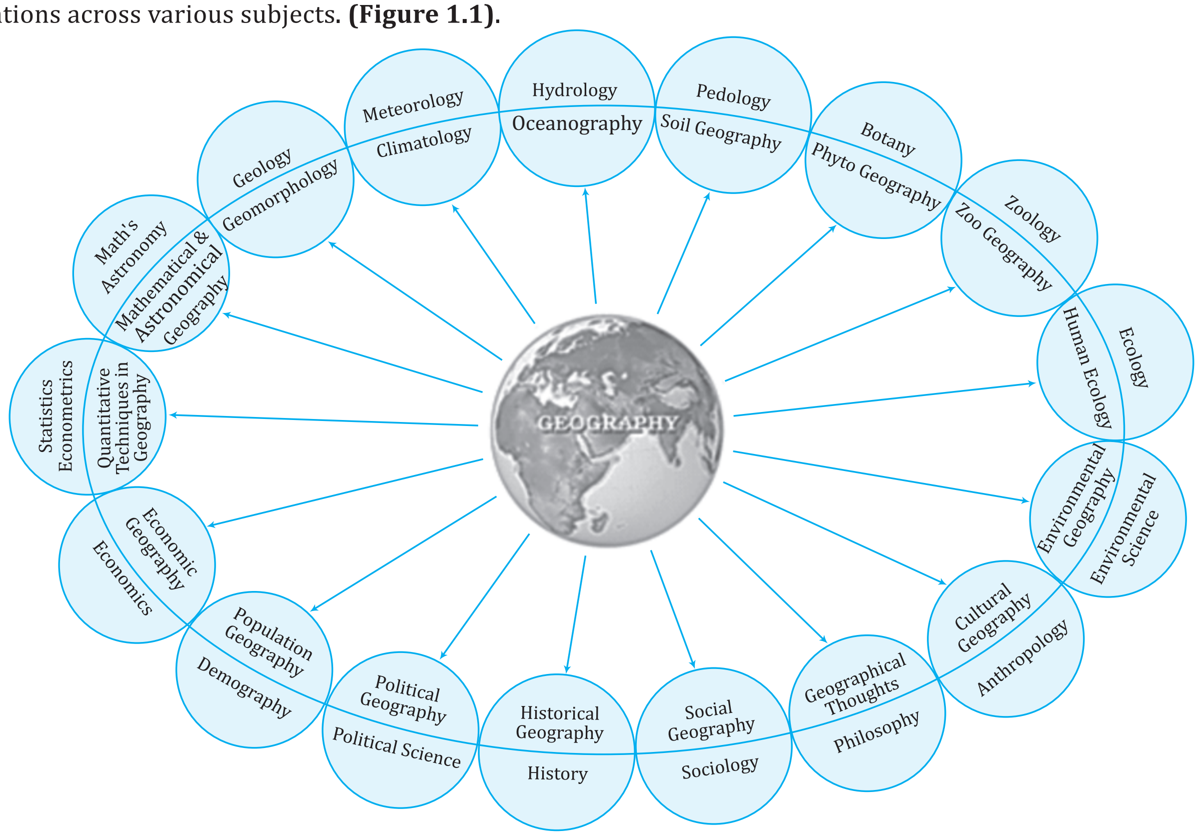

Fig.1.1: Geography and its Relation with Other Subjects

Geography has Two Main Branches

1. **Physical geography:** It describes the science behind Earth's development and focuses on natural events. **For instance**, the Evolution of Landforms, Systematic study of Earthquakes, Monsoon development, etc.
2. **Human geography:** It is a significant field centrally concerned with how **place, space and environment** are both the condition and, in part, the consequence of human activities. It concerns the interactive and dynamic relations between people and their physical environments.

Before studying the geography of the world and India in detail, we first need to understand the origin of the universe, solar system and earth briefly to get some necessary perspective.

Origin of the Universe

The universe is a vast cosmic system of mass and energy. It contains everything, from the tiniest subatomic particles to massive galactic superclusters. Astronomers estimate that the universe is home to around **100 billion galaxies.** Each of these galaxies, on average, holds approximately **100 billion stars.**

Various theories about the origin of the Universe have evolved. Let us explore them in detail.

Major Theories of Origin of the Universe

The origin of the universe has captivated human curiosity, prompting various theories. From the **Big Bang to cyclic models**, exploring these major theories unveils profound insights into cosmic beginnings.

The Steady-State Theory

- Bondi, Gold and Fred Hoyle formulated the Steady-State Theory.
- According to this theory universe is always expanding but maintains a constant average density, with matter being continuously created to form new stars and galaxies at the same rate that old ones become unobservable as a consequence of their increasing distance and velocity of recession.
- A steady-state universe has no beginning or end in time, and from any point within it the view on the grand scale i.e., the average density and arrangement of galaxies is the same.
- As a result, the total mass of the observable universe remains steady, preserving the universe's overall steady state.

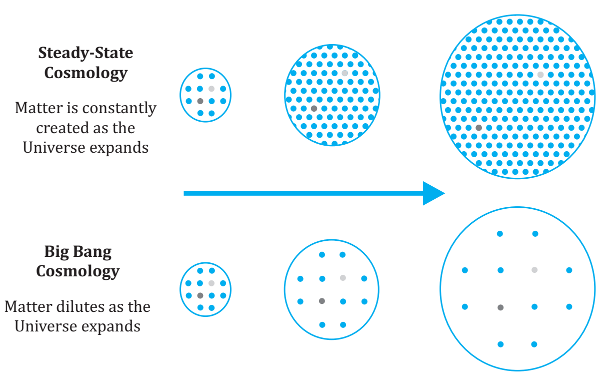

Fig 1.2: Steady State Theory

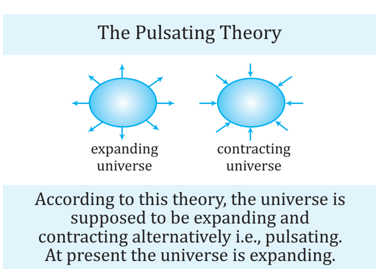

Fig 1.3: Pulsating Theory

The Pulsating Theory

- The Pulsating Theory suggests that the universe undergoes **cycles of expansion and contraction**, with the **current phase being 'expansion'.**
- Pulsating universes result from these alternating phases of expansion and contraction. **(Figure 1.3)**

The Big Bang Theory

- The Big Bang Theory is the prevailing cosmological model to explain the universe's birth. It is also called the **'expanding universe hypothesis'**.
- It was formulated by **Georges Lemaitre** in **1927.**
- His theory was strengthened by **Edwin Hubble's observations** and the discovery of **cosmic microwave background radiation** (CMB) by **Penzias and Wilson.**
- It states that **13.8 billion** years ago, all of space was contained in a 'tiny ball' of **infinite density, infinite temperature and a state of an unimaginably small volume** called the **'primeval atom'.**
- This atom explodes violently, leading to the **expansion of the Universe,** which continues to the present day.
- As the Universe grew, some **energy was converted into matter.**
- Within the **first three minutes** of the Big Bang event, the **first atom began to form.**
- Within **300,000 years** from the Big Bang, the temperature dropped to **4,500 Kelvin** and **gave rise to atomic matter (Figure 1.4).**

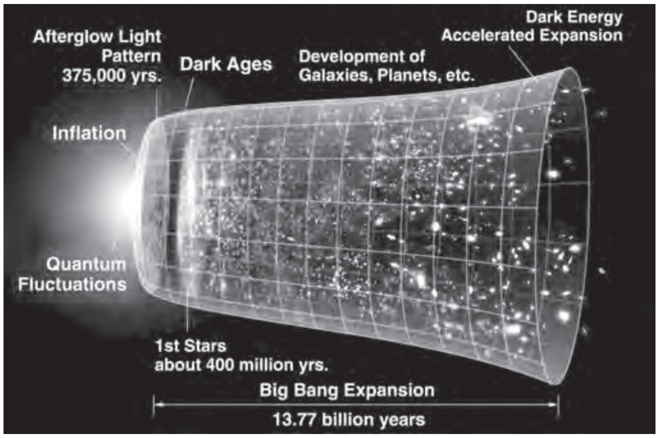

Fig. 1.4: Chronological Evolution of the Universe from the Big Bang

Singularity

- A **gravitational singularity, spacetime singularity, or simply singularity** is a condition in which **gravity is predicted to be so intense** that spacetime itself would break down catastrophically.
- At this point, due to infinite gravity and density, no object inside can escape, not even light.
- The **laws of physics break down at Singularity.**
- **Example**: The centre of a black hole, the starting point of the Big Bang.

Evidences of the Big Bang Theory

The Big Bang Theory, a cornerstone of cosmology, is supported by compelling evidence.

1. Redshift of Galaxies

- In 1929, **Edwin Hubble** provided the first observational evidence for the Big Bang.
- He discovered that most galaxies appear **'red shifted'**, indicating that they are moving away from us and that the universe is expanding.
- This red shift proves an expanding universe, which in turn proves an initial event that pushed all matter and energy outward from one point.

2. Cosmic Microwave Background

- Cosmic Microwave Background (CMB) refers to **remnant microwave radiation from the Big Bang,** a low-frequency radiation with a temperature of **2.725 K.**
- CMB is also Called **'Fossil' radiation,** released soon after the Big Bang.
- As the Universe grew exponentially in **size post the Big Bang**, the residual heat **left a "glow**" that filled the entire Universe.

3. Light Elements

- Elements like **Hydrogen** and **Helium** were created soon after the **Big Bang.**
- The percentage of light elements, such as hydrogen and helium, agree that the universe started in a hot and dense phase, as theorised by the Big Bang Theory.

4. Primordial Gravitational Waves

- According to **Cosmic Inflation Theory by physicist Alan Guth, primordial gravitational waves** are hypothesised to arise from **'cosmic inflation'**, a phase of **accelerated expansion** just after the Big Bang.

Criticisms of the Big Bang Theory

- It violates the **'First Law of Thermodynamics'**, which says you can't create or destroy matter or energy. According to critics, the Big Bang theory suggests the universe began out of nothing.
- The formation of stars and galaxies violates the **'law of entropy'**, which suggests systems of change become less organised over time.
- Scientists interpreted evidence like the redshift of celestial bodies and the cosmic microwave background radiation. Some cosmologists cite the **absence of exotic cosmic bodies that should have been the product of the Big Bang.**
- The early inflationary period of the Big Bang violates the **rule that nothing can travel faster than the speed of light.**

Recently, the Big Bang theory has been further strengthened because of distant galaxies discovered by the **James Webb telescope.**

James Webb Space Telescope is a space telescope jointly developed by **NASA**, the European Space Agency **(ESA)** and the Canadian Space Agency **(CSA)**. The James Web Space Telescope will not be in orbit around the Earth like the Hubble Space Telescope is – it will orbit the Sun, 1.5 million kilometres (1 million miles) away from the Earth

Key Concepts

Dark Matter

- Galaxies in our universe rotate at high speeds and the gravity generated by their observable matter isn't enough to hold them together.
- This led scientists to believe that we have yet to directly detect the 'dark matter' that is giving these galaxies extra mass, generating the extra gravity they need to stay intact.
- **Dark matter** is a **hypothetical** form of matter thought to be the predominant type of matter in the universe.
- Dark matter has not yet been observed directly.
- It is called "Dark" as it doesn't interact with light or electromagnetic fields; hence, it is invisible.
- **Evidence for dark matter** comes from many different angles, such as
  - Galaxy dynamics and formation,
  - Gravitational lensing.
  - Cosmic microwave background.
  - Astronomical observations of the observable universe's current structure.
- **Dark energy and dark matter** constitute **95%** of the total mass–energy content of the Universe.
- **Dark matter** constitutes **85%** of the total mass of the Universe.

Dark Energy

- Dark energy is an unknown form of energy primarily thought to be responsible for accelerating the expansion of the Universe.
- Dark energy makes up approximately **68%** of the universe and appears to be associated with the vacuum in space.

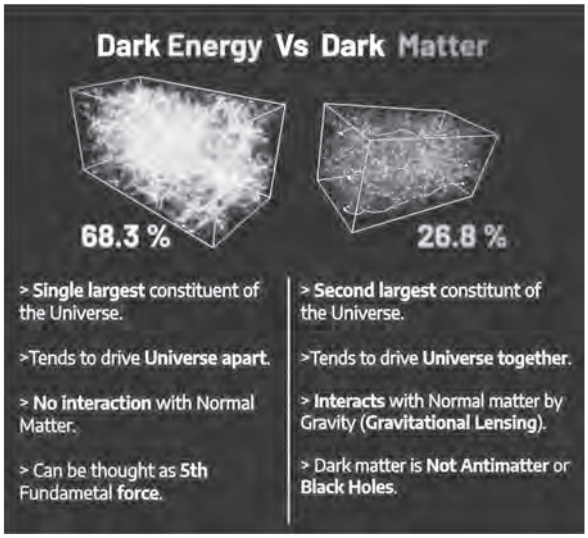

Fig. 1.5: Dark Energy vs Dark Matter

- **It is distributed evenly throughout the universe**, not only in space but also in time – in other words, **its effect is not diluted as the universe expands.**
    - The even distribution means that dark energy has no local gravitational effects but a global effect on the universe.
    - This leads to a repulsive force, accelerating **the universe's expansion.**
    - As is evident, our universe expands, indicating that **Dark Energy is more abundant than dark matter.**

General Theory of Relativity

- **General theory of relativity**, also known as **General relativity** and **Einstein's theory of gravity**, is the **geometric theory of gravitation** published by **Albert Einstein in 1915.**
- According to the theory, **matter causes space to curve.** This curvature of the space-time continuum is the reason for gravity.
- This Einstein's theory is the best description of how gravity works.
- **Newtonian physics** saw gravity as a force. At the same time, **Einstein, in the General Theory of Relativity,** viewed gravity as a **curved field** (an area of space under the influence of a force) in the **space-time continuum** created by the presence of mass.
- **General relativity has been experimentally verified by:**
    - Observations of **gravitational lenses**
    - **The orbit** of the planet Mercury, which is not predicted accurately by the Newtonian model.
    - **Dilation of time** in Earth's gravitational field.
    - **Gravitational waves** from merging Black Holes.

Gravitational Waves

Gravitational waves are waves of the intensity of gravity that are generated by the accelerated masses of binary stars and other motions of gravitating masses.

- Gravitational waves transport energy as **gravitational radiation** from their source **at the speed of light.**
- They were first proposed by **Oliver Heaviside** in 1893 and later by Henri Poincaré in 1905.
- In 1916, in his general theory of relativity, **Albert Einstein** predicted the existence of gravitational waves as **'ripples' in spacetime.**

Causes of Gravitational Waves

- Asymmetrical explosion of a star **(Supernova).**
- Orbital movement of two big neutron stars.
- Orbital movement and merging of Black Holes.

Importance of Gravitational Waves

- Many astrophysical phenomena are either very dim or utterly invisible in any form of light that astronomy has relied on for 400 years.
- Gravitational waves astronomy is a **powerful new probe of the Universe that uses gravity** instead of light to take measures of dynamic astrophysical phenomena.
- Studying gravitational waves gives enormous **potential for discovering the parts of the universe** that are invisible by other means, such as Black Holes and observing phenomena much farther back in time, like the Big Bang and other, as yet unknown, objects.
- The gravitational waves can work as sirens to measure the **expansion rate of the universe** and to understand the **origin and the future of the universe.**
- They can be used to infer data about the sources of gravitational waves such as:
    - Binary star systems composed of white dwarfs, neutron stars and Black Holes
    - Events such as **supernovae.**

LIGO (Laser Interferometer Gravitational-Wave Observatory)

LIGO is an international network of laboratories that detect the ripples in spacetime produced by the movement of large celestial objects like stars and planets. These ripples encapsulate our current understanding of how gravitation works. LIGO India, for which the government approval was given, would be the fifth node of this international network and will be located in the **Hingoli district of Maharashtra.**

eLISA

- eLISA stands for **Evolved Laser Interferometer Space Antenna.**
- It is a mission aiming at exploring the Gravitational Universe from space for the **first time**.
- It is a **space-based gravitational wave observatory**. It is designed to detect and study **gravitational waves,** which are ripples in spacetime caused by the motion of massive objects, such as **merging Black Holes or neutron stars**.
- It involves scientists from eight European countries – Denmark, France, Germany, Italy, The Netherlands, Spain, Switzerland and the UK – as well as the support of several US-based ones.
- eLISA would consist of **three spacecraft** flying in a **triangular formation** in space, with lasers slated to be used to measure the distances with extreme precision.
- This setup would enable eLISA to detect and study **low-frequency gravitational waves**, which cannot be observed by ground-based detectors like LIGO. **(Figure 1.10)**

- The mission aims to further our understanding of astrophysical phenomena and the nature of gravity itself.

Hence, Gravitational waves, predicted by Einstein in 1916, were confirmed by LIGO in 2015, ushering in a new era of astronomy. Initiatives like eLISA promise further insights, unveiling the invisible corners of the universe and revolutionizing our understanding of cosmic phenomena.

Gravitational Lensing

- Gravitational lensing occurs when a massive celestial body — such as a galaxy cluster or black hole — causes a sufficient curvature of spacetime for the path of light around it to be visibly bent, as if by a lens. The body causing the light to curve is called a **gravitational lens (Figure 1.6).**

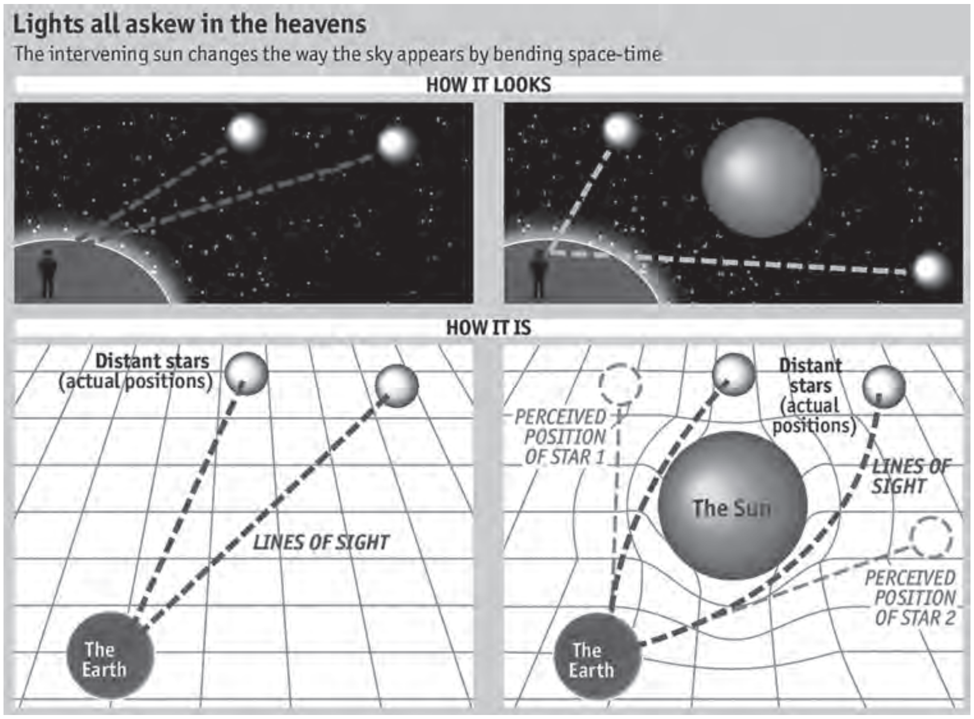

Fig. 1.6: Gravitational Lensing

- Einstein's theory of **general relativity** explains this effect – **Simply put, mass bends light**.
- The more massive the object, the stronger its gravitational field and greater the bending of light rays.
- Gravitational lensing observations by galaxies, clusters of galaxies and large-scale structures provided important results that **directly confirmed the existence of dark matter** and measured its distribution on both small and large scales.

Gravitational Microlensing

- Gravitational microlensing is an **observational effect** that was predicted in 1936 by **Einstein** using his General Theory of Relativity.
- Smaller objects, like individual stars, can also act as gravitational lenses when they pass in front of more distant stars.
- For a few days or weeks, light from the more distant star temporarily appears brighter because the gravity of the closer object magnifies it. This effect is known as **gravitational microlensing.**

Einstein Rings

- The simplest type of gravitational lensing occurs when there is a single concentration of matter at the centre, such as the dense core of a galaxy.
- The light of a distant galaxy is redirected around this core, often producing multiple images of the background galaxy.
- When the lensing approaches perfect symmetry, a complete or almost-complete circle of light is produced, called an **Einstein ring.**
- **Recently, the James Webb Space Telescope** has captured an image of an almost perfect "Einstein ring."

Black Holes

A black hole is an area of space with a gravitational field so strong that nothing, not even light, can escape it.

- Black holes usually cannot be observed directly, but they can be **"observed" by the effects of their enormous gravitational fields on nearby matter.**
- The concept of a black hole can be understood by thinking about how fast something needs to move to escape the gravity of another object – this is called

the **escape velocity**. Formally, escape velocity is the speed an object must attain to "break free" of the gravitational attraction of another body.

- Two things affect the escape velocity – **the mass of the object** and **the distance to the center of that object**. **For example**, a rocket must accelerate to **11.2 km/s** to escape Earth's gravity. If, instead, that rocket was on a planet with the same mass as Earth but half the diameter, the escape velocity would be 15.8 km/s. Even though the mass is the same, the escape velocity is greater, because the object is smaller (and more dense).

Types of Black Holes

- **Stellar-mass black holes** are formed when a massive star runs out of fuel and collapses. They are found scattered throughout the galaxy, in the same places where we find stars, since they began their lives as stars.
- **Supermassive black holes** are found at the center of nearly every large galaxy. Recent studies have shown that the size of the black hole is correlated with the size of the galaxy, so that there must be some connection between the formation of the black hole and the galaxy.

How are Black Holes Formed?

Black holes are expected to form via two distinct channels

1. According to the first pathway, they are stellar corpses, so they form when massive stars die. Stars whose birth masses are above roughly **8 to 10 times the mass** of our sun, when they exhaust all their fuel — their hydrogen and helium — explode and die.
2. **Chandrasekhar Limit:** The Chandrasekhar limit determines if a star dies as a white dwarf, or has the mass to exceed this, launching a supernova to create a black hole or neutron star. The Chandrasekhar value for a white dwarf star is generally considered to be 1.4 solar masses, according to The SAO Encyclopedia of Astronomy — that is 1.4 times the mass of the sun. It was First predicted by Subrahmanyan Chandrasekhar in 1931 and we are yet to find a white dwarf with a mass above 1.4 solar masses. Stars having mass above 1.4 solar masses, after their death can form neutron stars or black hole.
3. Another way that Black Holes form is from the direct collapse of gas, which is expected to result in more massive Black Holes ranging from 1000 times the sun's mass to even 100,000 times the sun's mass.

Do Black Holes Die?

Black holes do not die per se, but they are theoretically predicted to evaporate over extremely long time scales slowly.

Examples of Black Holes

- **Cygnus X-1:** A binary X-ray system consisting of a blue supergiant and an invisible companion 14.8 +/– 1 times the mass of the Sun (Solar Mass).
- **Sagittarius A***: A supermassive black hole that exists at the centre of the Milky Way Galaxy.
- In 2017, the **Event Horizon Telescope** obtained an image of the supermassive black hole at the centre of the **M87 galaxy**. It was **the first black hole to be imaged directly.**

CERN Experiment

- Founded in **1954**, the CERN laboratory sits astride the Franco-Swiss border near Geneva. It was one of Europe's first joint ventures and has 23 member states.
- Physicists and engineers at CERN study the basic constituents of matter – fundamental particles.
- The CERN experiment uses the **Large Hadron Collider**(LHC) to test the accuracy of the **Standard Model of Particle Physics** and to look for physics beyond the Standard Model, such as **supersymmetry, extra dimensions and others.**
- The **2013 Nobel Prize for Physics** was awarded to **François Englert** and **Peter Higgs** for the theoretical description of the Higgs Boson particle, famously known as the 'God particle'.

Large Hadron Collider

- The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator.
- It started on 10 September 2008 and remains the latest addition to CERN's accelerator complex.
- The LHC consists of a **27-kilometer ring of superconducting magnets** with a number of accelerating structures to boost the energy of the particles along the way.

Standard Model of Particle Physics

- Fundamental questions like "What is the world made of?" and "What holds it together?". The Standard Model is an attempt to explain these questions.
- The Standard Model explains how the basic building blocks of matter interact, governed by four fundamental forces - **Gravitational Force, Electromagnetic Force, Weak Force and Strong Force.**

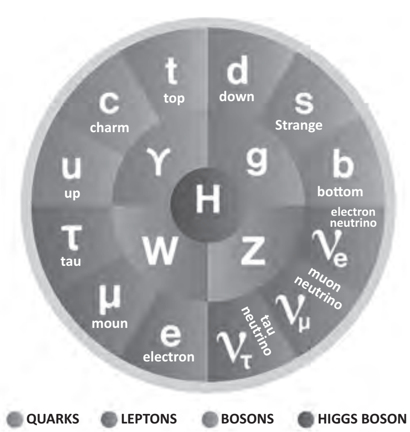

Fig 1.7: Subatomic particles as per standard model of Particle Physics

- According to it, all known matter comprises **fundamental particles called quarks and leptons.**
  - **Quarks** make up Protons and Neutrons.
  - **Leptons** make electrons. **(Figure 1.7)**
- The Standard Model explains **three** of the four fundamental forces that govern the universe: **electromagnetism, the strong force and the weak force.**

Higgs Boson (God Particle)

- Peter Higgs suggested that particles did not have mass just after the Big Bang. As the universe cooled and the temperature fell below a critical point, an invisible force field formed, termed the **Higgs Field.**
- Associated particles with the Higgs field have been termed the Higgs Boson.
- It has been theorised that any particle interacting with these Higgs Bosons got mass and those left out of the Higgs field remained massless.
- As these Higgs Bosons have the capability to grant mass, the primary condition for the existence of matter, they were termed the God particle.
- Recently, scientists at CERN observed the Higgs boson decaying into fundamental particles known as **bottom quarks**. For this, **Peter Higgs** was awarded the **Nobel prize in physics**.
- For weak and strong nuclear interactions to work, the Standard Model predicts the presence of a particle called the Higgs Boson.

Stellar Formations

- Stellar formation is the process by which dense regions within molecular clouds in interstellar space, sometimes called **"stellar nurseries" or "star-forming regions",** collapse and **form stars.**

Life Cycle of a Star

- All stars form in **nebulae,** which are huge clouds of gas and dust. Though they shine for thousands and even millions of years, stars do not last forever. The changes that occur in a star over time and the final stage of its life depend on a star's size **(Figure 1.8)**

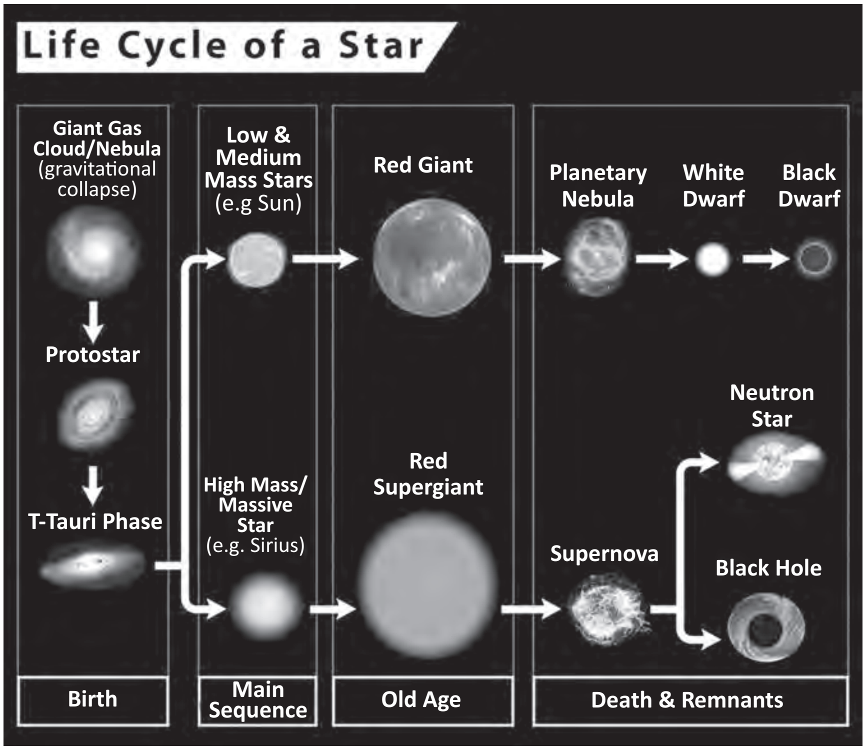

Fig. 1.8: Life Cycle of as Star

Birth

- **Nebula -** Giant interstellar cloud where stellar formation begins.
- **Protostar -** Heat energy produced from a nebula, which results in a warm lump of molecules called Protostar.
- **T-Tauri phase -** This phase begins when materials stop falling into the Protostar and further release tremendous energy. Mean Temperature of the Tauri star isn't sufficient to support nuclear fusion.

Revised Nebular Hypothesis of Laplace

- In 1796, mathematician **Pierre-Simon Laplace** revised Immanuel Kant's ideas with his hypothesis about the origin of our solar system.
- Laplace proposed that a Solar Nebula, primarily composed of hydrogen, helium and dust, surrounded the young Sun. **(Figure 1.9)**
- The collision and friction between particles in the nebula led to the development of a **flat, disk-shaped cloud.**
- Planets came into existence through a process called **Accretion**, where they formed from material associated with the young Sun.

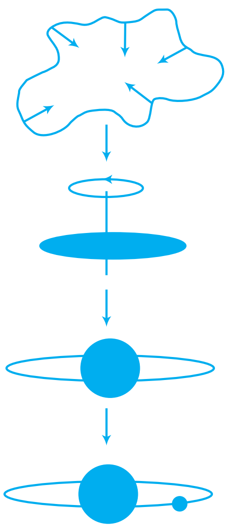

Fig 1.9: Nebular Hypothesis of Laplace

Constellations

- The stars forming a group that has a **recognisable shape** is called a **constellation.**
- Constellations help assist astronomers and navigators in locating certain stars.
- Today, there are **88** officially recognised constellations by the **International Astronomical Union.**
- Four well-known constellations are **Orion, Ursa Major, Ursa Minor and Cassiopeia.**

1. ORION

- Orion is one of the magnificent constellations in the sky.
- It has **seven** bright stars.
  - Four appear to be arranged as a quadrilateral and the other three form a straight line in the middle.
- One of the largest stars, known as **Betelgeuse,** is situated on one corner of this quadrilateral, while another bright star, called **Rigel**, is located on its opposite corner**(Figure 1.10)**

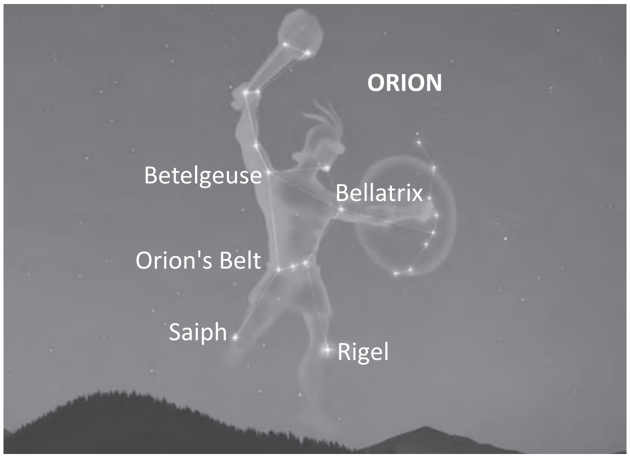

Fig. 1.10: Orion

- The arrangement of stars in this constellation resembles a hunter with a belt and a sword.
- This constellation is visible during the **winters in the northern hemisphere.**

2. URSA MAJOR

- It is also known as the **Great Bear, the Big Dipper or Saptarishi** and is visible in the northern sky.
- Ursa Major contains seven stars, making the pattern of a plough.

3. URSA MINOR

- It is also known as the **Little Bear or Little Dipper.**
- Ursa Minor also consists of **seven stars** arranged similarly to Ursa Major's. Still, the stars in this constellation are closer together and less bright than in the Ursa Major.
  - The last star in the handle of the Little Dipper is the **Pole star** itself.
  - Ursa Minor is also known as the **Pole star constellation.**
- This also is **visible in the summers.**

Galaxies

- A galaxy is a system of stars, stellar remnants, interstellar gas(nebulae), dust and dark matter **bound together by gravity.**
- The word is derived from the Greek 'galaxias', meaning 'milky'.
- They come in various sizes, with the smallest containing about 100,000 stars and the largest housing up to a staggering 3,000 billion stars.

Galaxy Characteristics

- Most galaxies have Black Holes at their centres that can produce significant energy.
- Some galaxies contain **quasars**, the most energetic bodies in the universe.

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ISBN 978-93-6034-523-5
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