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PHYSICAL GEOGRAPHY

COMPREHENSIVE LEARNING SERIES FOR PRELIMS AND MAINS

CONTENTS

Evolution of Universe

1

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.

Geography has two main branches:

- **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.
- **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.

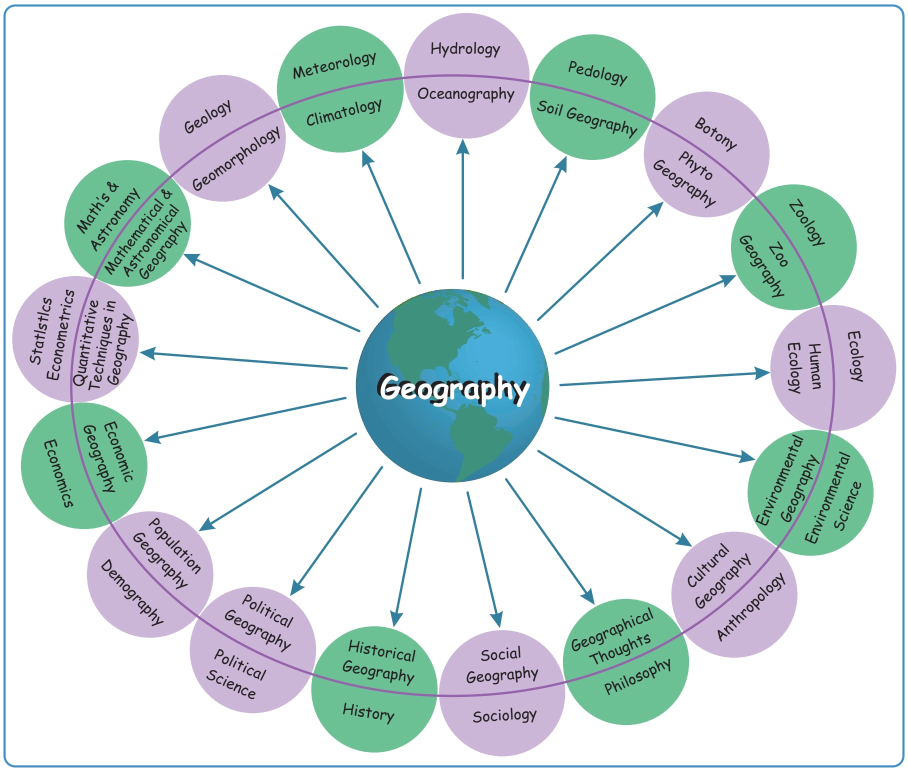

Fig. 1.1: Geography and its relation with other subjects

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 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 to 200 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, the number of galaxies in the observable universe remains constant.
- New galaxies continuously form from empty space to fill the gaps left by galaxies that exit the observable universe.
- As a result, the total mass of the observable universe remains steady, preserving the universe's overall steady state.

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.

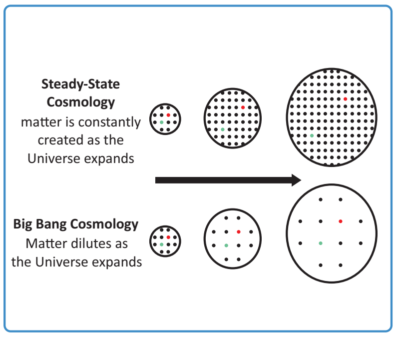

Fig. 1.2: Steady State Theory

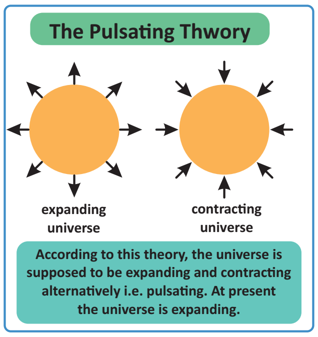

Fig. 1.3: Pulsating Theory

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 **13.7 billion** years ago, all of space was contained in a 'tiny ball' of **infinite density, infinite temperature, and an unimaginably small volume** called the **'primaeval atom'**.
- This atom exploded 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 of the Big Bang, the temperature dropped to **4,500 Kelvin** and **gave rise to atomic matter**.

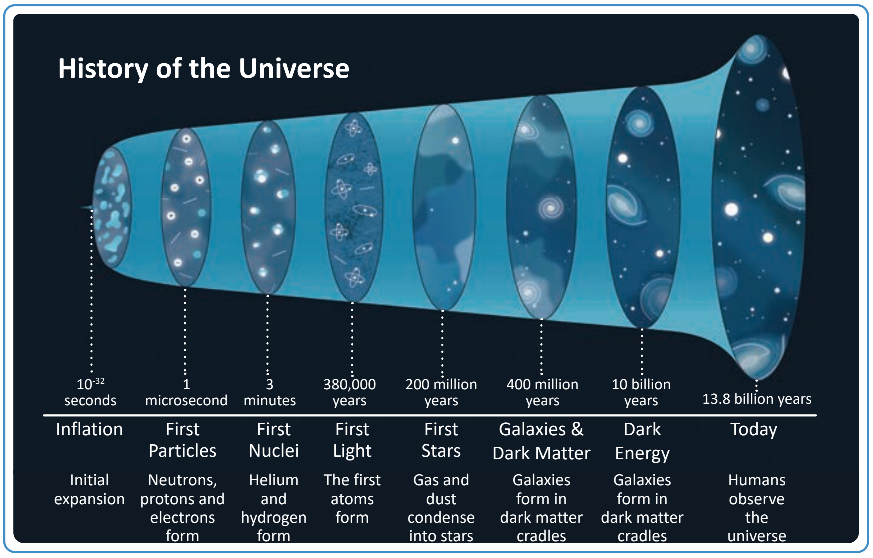

Fig. 1.4: Chronological Evolution of the Universe from the Big Bang

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 is 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.

- **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.
  - **Red Shift:**
    - Hubble noted that light from far-away galaxies appeared to be stretched to **longer wavelengths** or **reddened**, a phenomenon called **'redshift'**, based on the **Doppler Effect of Light**.

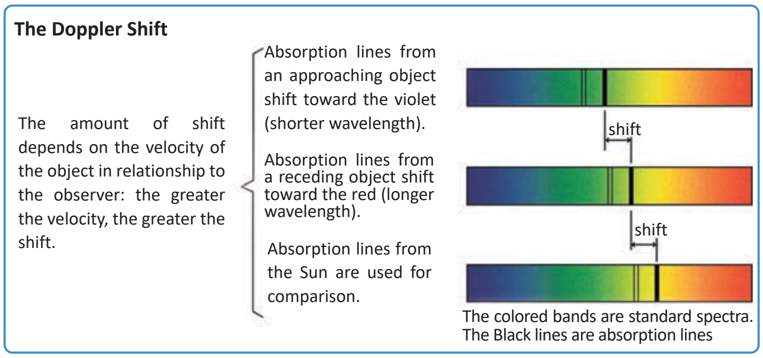

Fig. 1.5: Red Shift due to Doppler Effect

- 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.
  - The expansion rate and its acceleration can be measured by observations based on the Hubble-Lemaitre law.
    - According to this law, the galaxies are moving away from Earth at speeds proportional to their distance. In other words, the farther they are, the faster they move away from Earth.

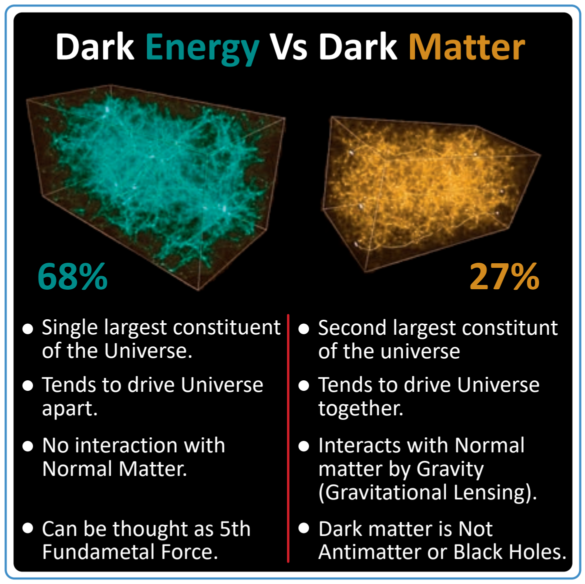

Fig. 1.7: Differences between Dark Energy and Dark Matter

IGNITE YOUR MIND

Dark matter and dark energy are two of the most mysterious and dominant components of the universe, yet they remain largely unknown. What are the current theories and experiments aimed at understanding the nature of dark matter and dark energy, and how do they challenge our current understanding of physics and cosmology?

General Theory of Relativity

- General theory of relativity, also known as General relativity or 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.

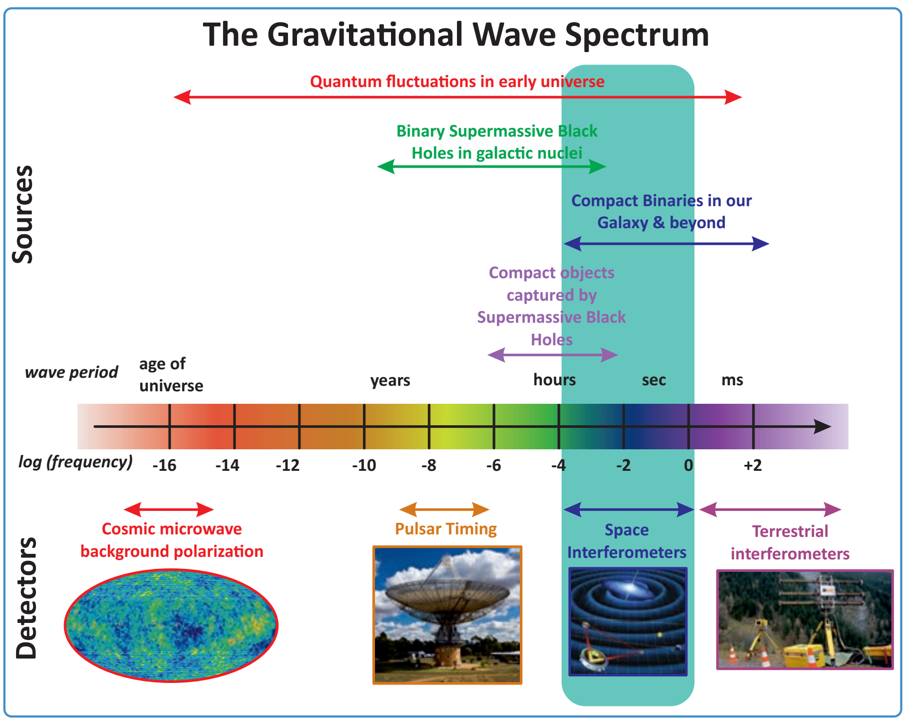

Fig. 1.8: Gravitational Waves Sources and Detectors

- Mathematical equations of Einstein's general theory of relativity, tested repeatedly, are currently the most accurate way to predict gravitational interactions, replacing those developed by Isaac Newton several centuries prior.

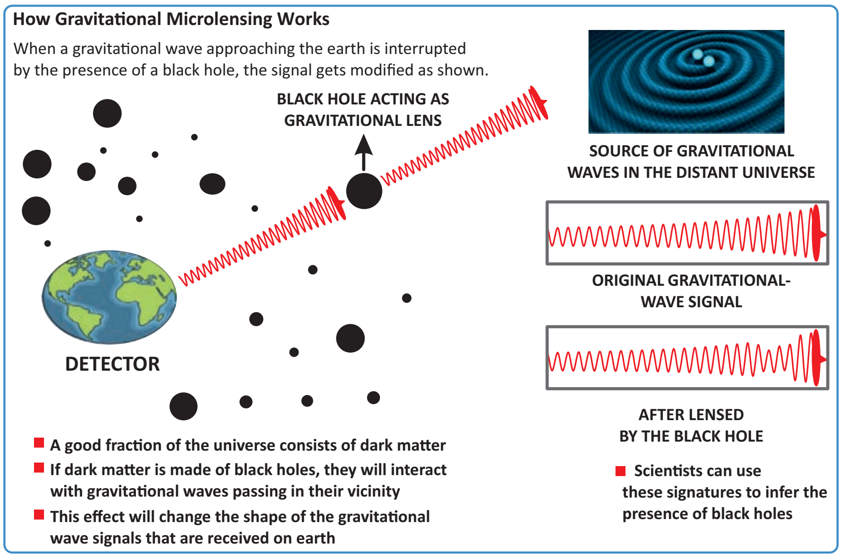

Fig. 1.12: Mechanism of Gravitational Microlensing

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**.

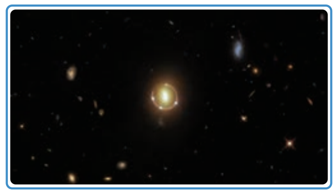

Fig. 1.13: Einstein Rings

- Recently, the James Webb Space Telescope has captured an image of an almost perfect "Einstein ring."

Importance of Gravitational Lensing

- Gravitational lensing helps probe the **distribution of matter in galaxies** and clusters of galaxies, thus enabling **observations of the distant universe**.
- Hubble's images of gravitational lensing have been used to create **dark matter maps** in galaxy clusters.

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.

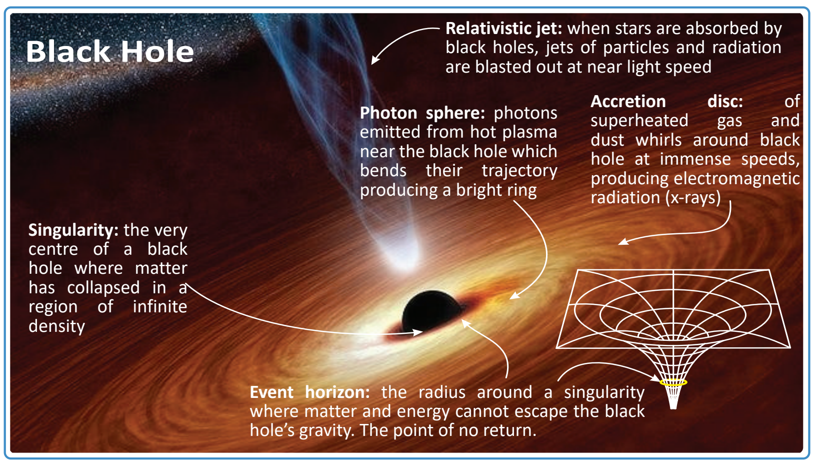

Fig. 1.14: Mechanism of Gravitational Microlensing

Anatomy of a Black Hole

- **Event Horizon:** The event horizon is the boundary surrounding a black hole beyond which nothing can escape. It is the point of no return. Anything that crosses the event horizon is inexorably pulled into the black hole.
- **Singularity:** The singularity is the theoretical point at the centre of a black hole where the gravitational forces become infinitely strong, and the laws of physics break down. **It is a point of infinite density**.

Examples of Black holes

- **Cygnus X-1:** A binary X-ray system consisting of a blue supergiant and an invisible companion 14.8 times the mass of the Sun.
- **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**.
  - That black hole has a mass equal to six and a half billion Suns but is only 38 billion km (24 billion miles) across.
  - It was the first black hole to be imaged directly.

IGNITE YOUR MIND

Stephen Hawking's groundbreaking work led to the theory of Hawking radiation, suggesting that Black Holes can emit radiation and potentially evaporate over time. How does Hawking radiation provide insights into the connection between quantum mechanics and general relativity, and what are its implications for the ultimate fate of Black Holes?

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 22 member states.
- Physicists and engineers at CERN study the basic constituents of matter – fundamental particles.
- Subatomic particles are made to collide a speed close to the speed of light using particle accelerators.
- **Particle accelerators** boost beams of particles to high energies before the beams collide with each other or stationary targets.
- Detectors observe and record the results of these collisions. The process gives us clues about how the particles interact and provides insights into the fundamental laws of nature.
- 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 September 10, 2008, and remains the latest addition to CERN's accelerator complex.
- The LHC consists of a 27-kilometre ring of superconducting magnets with a number of accelerating structures to boost the energy of the particles along the way.
- The LHC smashes tiny particles called hadrons together at really high speeds. It uses protons as particles and has a long circular pipe where they're accelerated.
- The beams inside the LHC are made to collide at four locations around the accelerator ring, corresponding to the positions of four particle detectors – **ATLAS, CMS, ALICE and LHCb**. ATLAS is the largest general-purpose particle detector experiment at the LHC.
- The LHC's goal is to test the Standard Model, the mathematical framework physicists use to describe all known fundamental particles in the universe and the forces through which they interact.

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**.
- The Standard Model of Particle Physics is scientists' current best theory to describe the most basic building blocks of the universe.

Main Sequence

- In this phase, the core temperature reaches the point where the fusion will commence.
- In this process, the protons of hydrogen are converted into atoms of helium in an exothermic reaction.
- Most of the stars in the universe, about 90 percent of them including the Sun, are main sequence stars.

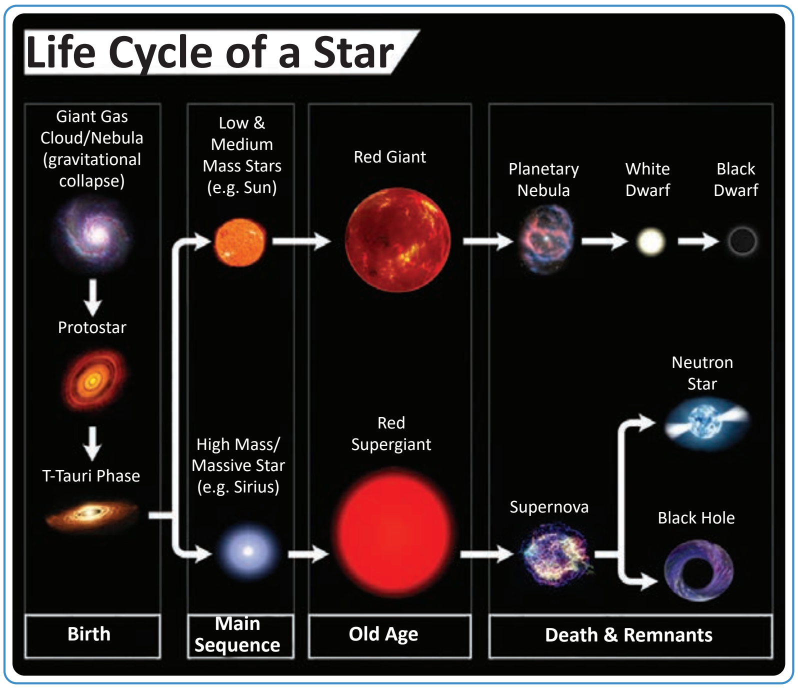

Fig. 1.17: Life Cycle of a Star

Old Age

- **Red Giant:**
  - A red giant is formed during the later stages of evolution as it runs out of hydrogen fuel at its centre. Its internal reaction stops, and as a result, the star contracts inward through gravity, causing it to expand.
  - As it expands, the star first becomes a subgiant star and then a red giant.
  - Red giants have cooler surfaces than the main-sequence star, and because of this, they appear red rather than yellow.
  - Red giants are hot enough to turn the helium at their core into heavy elements like carbon (this is how elements are formed one after the other). But most stars are not massive enough to create the pressures and heat necessary to burn heavy elements, so fusion and heat production stops.
- **Red Supergiant:**
  - An enormous red giant is often called Red Supergiant.
  - Red supergiant is a **massive, late-stage stellar evolutionary phase** that describes the fate of some high-mass stars.
  - These stars are characterised by their **enormous size and red colour**.
  - Red supergiants have **exhausted the hydrogen in their cores and have expanded significantly**.
  - Their **outer layers have cooled**, causing them to appear red.
  - These massive stars are often unstable and can eventually undergo a supernova explosion, resulting in the formation of a neutron star or a black hole, depending on their mass.
  - Red supergiants play a crucial role in the life cycle of stars, contributing to the enrichment of the universe through nucleosynthesis and the release of heavy elements.

Death & Remnants

- **Supernova:**
  - A supernova is the explosive death of a star and often results in the star obtaining the brightness of 100 million Suns for a short time.
  - It is a cataclysmic astronomical event in which **a massive star undergoes** dramatic and explosive destruction.
  - This explosion can briefly outshine entire galaxies and release an immense amount of energy.
  - During a supernova, **the star's core collapses and rebounds**, leading to the expulsion of outer layers into space.
  - Supernovae play a vital role in the universe as they **forge and distribute heavy elements**, and they can leave behind dense remnants, such as neutron stars or Black Holes.
  - The study of supernova explosions helps us understand **stellar evolution** and the formation of elements in the cosmos.
- **Neutron Star:**
  - A neutron star is a **highly dense and compact celestial object** that forms after the core of a massive star undergoes a supernova explosion.
  - Neutron stars are incredibly **small**, typically about 10-20 kilometres (6-12 miles) in diameter, yet they contain a mass roughly 1.4 to 2.1 times that of our Sun.

- 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.

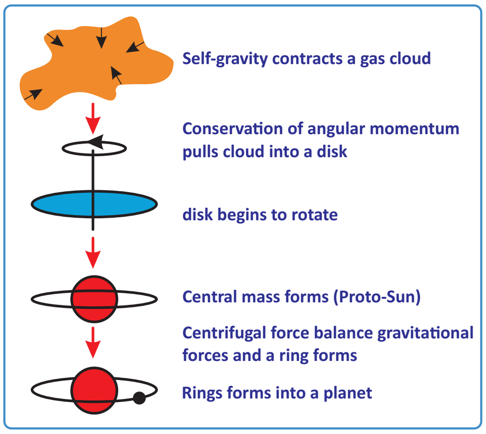

Fig. 1.19: Nebular Hypothesis of Laplace

Constellations

- The stars forming a group that has a recognisable shape are 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.

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

Fig. 1.20: Orion constellation

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.
  - A line drawn through the pointers of the plough leads us to the **Pole star or Polaris (Dhruv Tara)**.
  - This constellation is **visible during the summer**.
  - A straight line from the Ursa Major connects to Pole star of Ursa Minor.

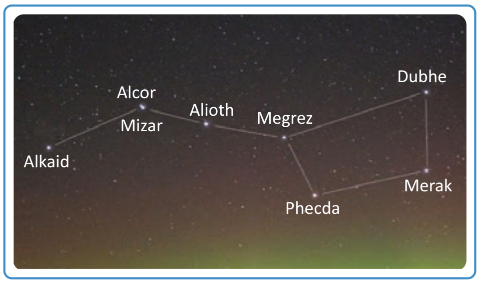

Fig. 1.21: Ursa Major Constellation

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 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 is also visible in the summer.

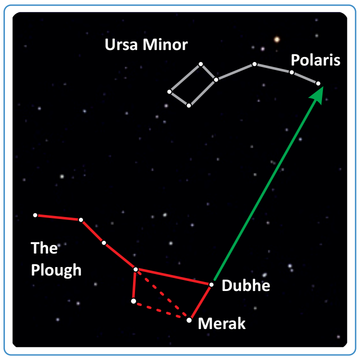

Fig. 1.22: Ursa Major and Ursa Minor through Pole Star

Importance of Constellations

- Known stars, such as those in well-known constellations, have been used to **navigate** since ancient times.
  - For centuries, sailors used stars to determine their location at sea. This is called **celestial navigation**.
  - NASA astronauts have also trained to use celestial navigation as a backup in case modern navigation systems have trouble.

- **Robotic spacecraft** also use **maps of the stars** to find their way.
  - They carry a **star map** in their onboard computers and compare these star maps to patterns of stars in images they take.

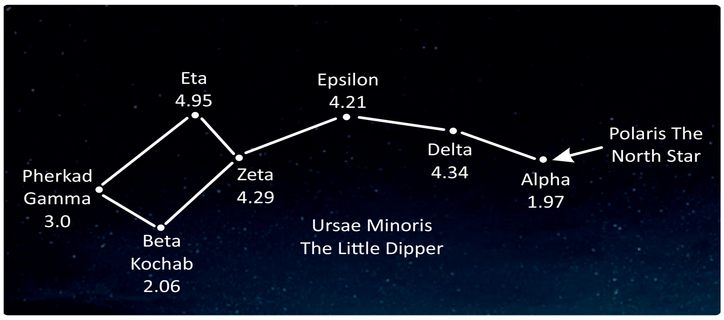

Fig. 1.23: Ursa Minor Constellation

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.
- Galaxies are classified by their shape, and each type has unique characteristics and evolutionary histories.

IGNITE YOUR MIND

Ancient mariners, including Polynesians, Greeks, Vikings, and Indians, mastered the art of star navigation. They utilized methods such as celestial navigation, identifying crucial constellations, and using instruments like astrolabes. How did these civilizations use the stars for oceanic and terrestrial navigation, and what was their impact on historical exploration and cultural exchanges?

Major Types of Galaxies

Based on shape, four major types of galaxies are there.

Spiral Galaxies

- They look like flat discs with many stars crowded near the centre.
- Some spiral galaxies are "barred spirals" with a bar structure in their centre.
- **About 60%** of all galaxies are spirals.
- Spiral galaxies have curvy arms where new, bright, and young stars are born.
- Examples of large spiral galaxies include **the Milky Way** and **Andromeda**.

Barred Spirals Galaxies

- Barred spiral galaxies feature a prominent central bar-shaped structure composed of stars, gas, and dust.
- These galaxies also have spiral arms that extend from the ends of the central bar, creating a pinwheel-like appearance.
- Barred spirals are a common type of galaxy, and they can be found throughout the universe, with the Milky Way being an example.
- The presence of a central bar can significantly influence a galaxy's evolution. The gravitational effects of the bar can funnel gas towards the centre, triggering star formation and impacting the galaxy's overall structure.

Irregular galaxies

- Irregular galaxies have irregular or chaotic shapes with no well-defined structure.

Elliptical Galaxies

- They are usually smaller than spiral galaxies.
- These galaxies are more round or oval-shaped, without any specific structure.
- Most stars in elliptical galaxies are very old, and **no new stars are forming in them**.
- Some are so small that we call them **"Dwarf Galaxies**, and approximately **one-thirds** of all galaxies are elliptical.
- They do not fit into the categories of spiral or elliptical galaxies.
- They can be further subdivided into "Irregular I" (Ir I) and "Irregular II" (Ir II) based on their appearance.

Peculiar Galaxies

- They are of unusual shape, size or composition.
- 5-10 % of known galaxies are of this type.
- They are further divided into two types: Active Galactic Nuclei and Interacting Galaxies.

There are also intermediate types and variations, such as **lenticular galaxies** (denoted as S0), which share some characteristics of both spiral and elliptical galaxies. These classification systems provide a way to categorise and describe the vast diversity of galaxies in the universe.

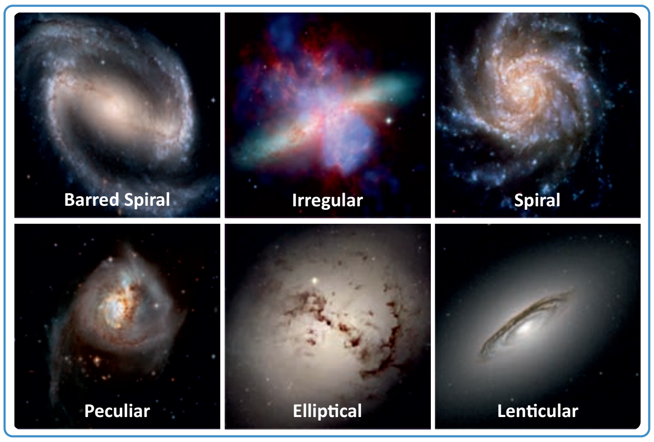

Fig. 1.24: Various types of Galaxies based on Shape

Milky Way Galaxy (Akash-Ganga)

- The Milky Way is a **spiral galaxy** and has the shape of a flat disc with a central bulge.
  - Its **diameter** is nearly a **hundred thousand light years.**
- In the **nucleus** (the central region), the **thickness** reaches **ten thousand light years**.
- In the **disc** (the flat part), the **thickness** is between **five hundred to two thousand light years**.
- Facts about the Milky Way Galaxy
  - Distance from the Sun to the Galactic Centre: Approximately 33,000 light-years
  - Size of the Milky Way: Enormous, spanning about 100,000 light-years across
  - Solar System's Location: Approximately one-third of the way from the Galactic Centre
  - Orbital Period of the Sun: About 230 million years to complete one full orbit around the Milky Way galaxy

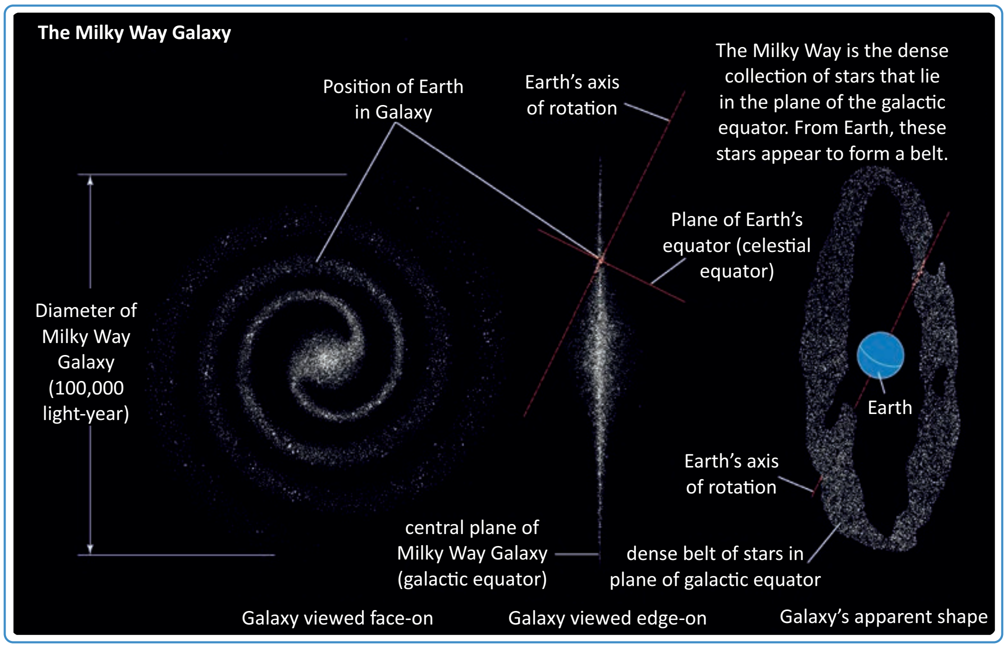

Fig. 1.25: The Milky Way Galaxy

Difference between Galaxy and Constellation

Galaxy	Constellation
1. It is a group of billions of stars.	1. It is a group of only a few stars.
2. It does not form a definite pattern.	2. The stars are arranged in definite, recognisable patterns.
3. There are billions of galaxies in the universe.	3. At present, we know of only about 88 constellations.
4. Very few galaxies are visible to the naked eye.	4. Many constellations are visible to the naked eye.

Our exploration of the universe's origin, the formation of stars, and the enigma of Black Holes has unveiled the intricate beauty of the cosmos. These processes, governed by the fundamental forces, continue to shape the universe and inspire an unending quest to understand the nature of existence in this vast and wondrous expanse.

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