

Big Bang Theory - Origin of Universe

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The **Big Bang theory** explains the **early development of the Universe**. According to this theory, the Universe **expanded** from an extremely small, hot, and dense state called **Singularity**. Since then, it has expanded and become less dense and cooler.

The Big Bang is the best model to explain the **creation of matter, space, and time** 13.7 billion years ago. The theory has several key features and predictions, which have been supported by various observations and experiments.

Evolution of the Big Bang Theory

The history of the Big Bang Theory can be traced back to several key developments in theoretical physics.

- **Einstein's General Theory of Relativity (1915):** Einstein's theory provided a foundation for understanding the **behaviour of space and time**, which would later be applied to the development of the Big Bang Theory.
- **Karl Schwarzschild's Solution (1916):** Schwarzschild found the solution for a **point-like mass**, which describes a **non-rotating black hole**.

- **Alexander Friedmann's Solution (1922):** Friedmann discovered the solution for an **isotropic** (same in all directions) and **homogeneous** (same at all locations) universe, where any and all types of energy, including matter and radiation, were present.
- In **1927-1931, Georges Lemaitre** (the **Father of the Big Bang Theory**) proposed the concept of an **initial point of concentrated mass**, suggesting the origin of space and time.

Formation of the Present Universe

The Big Bang theory proposes that the universe began from an infinitely **hot and dense single point**, known as a singularity, around 13.7 billion years ago.

Singularity

Singularity refers to a point where the concept of space-time breaks down and the laws of physics do not work. It is a point of **infinite density and gravity**. The centre of Black holes and the Big Bang are considered as the point of Singularity.

- **Big Bang singularity:** This Model predicts that the universe began from an extremely dense and massive point where **space and time did not exist**.
 - Hence, it is also hypothesised as the Big Bang singularity.
- **Planck Epoch:** Singularity represents the earliest period of the universe known as the Planck Epoch.
 - The physical theories of general relativity and quantum mechanics are not applicable before this epoch.
- **Instability:** Due to the extreme heat and density of matter, the state of the universe was **highly unstable**.

The Big Bang

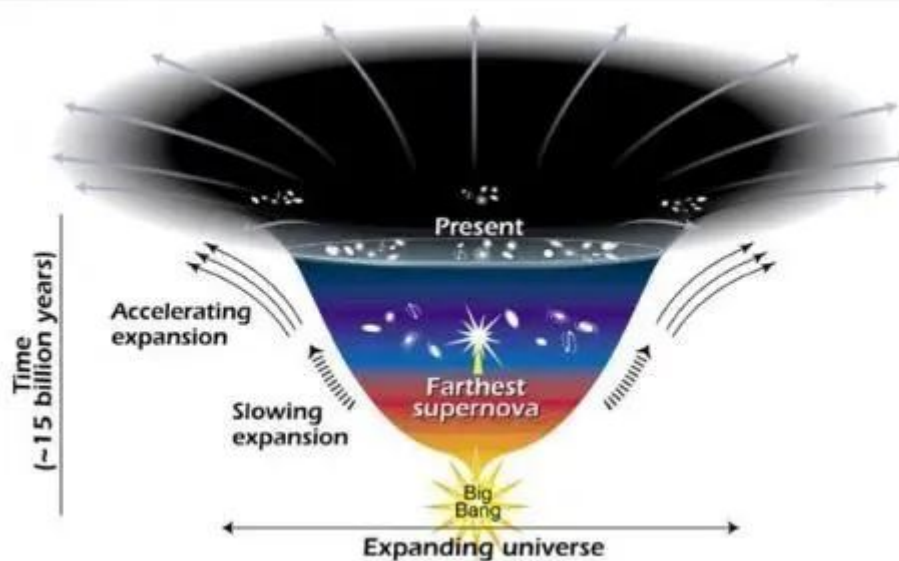
- **Cosmic inflation:** In the first instance for a fraction of a second (10⁻³² seconds) about 13.8 billion years ago, called cosmic inflation. This **period of rapid expansion** is believed to have set the stage for the Big Bang.
- **The Explosion:** Just after the inflation, the universe entered into a state of explosive expansion.
 - **Light and Present matter formed:** The driving energy of the Big Bang was converted to **matter** and **light**. The initial cosmic matter evolved into the building blocks of our present reality like atoms, molecules, etc.
 - **Fundamental Forces:** Along with matter and light, other fundamental forces of physics such as strong and weak **nuclear forces** and **electromagnetism** came into existence.
- **Evolution of the present universe:** With further cooling and expansion more complex structures like **stars, planets**, and **galaxies** emerged. This process continues to this day, with the universe still expanding and evolving.

Evidence supporting Big Bang Theory

The observations supporting the theory and its proposals include the present-day continuous **expansion** of the universe and the experiments performed through **CMBR**.

The Expanding Universe

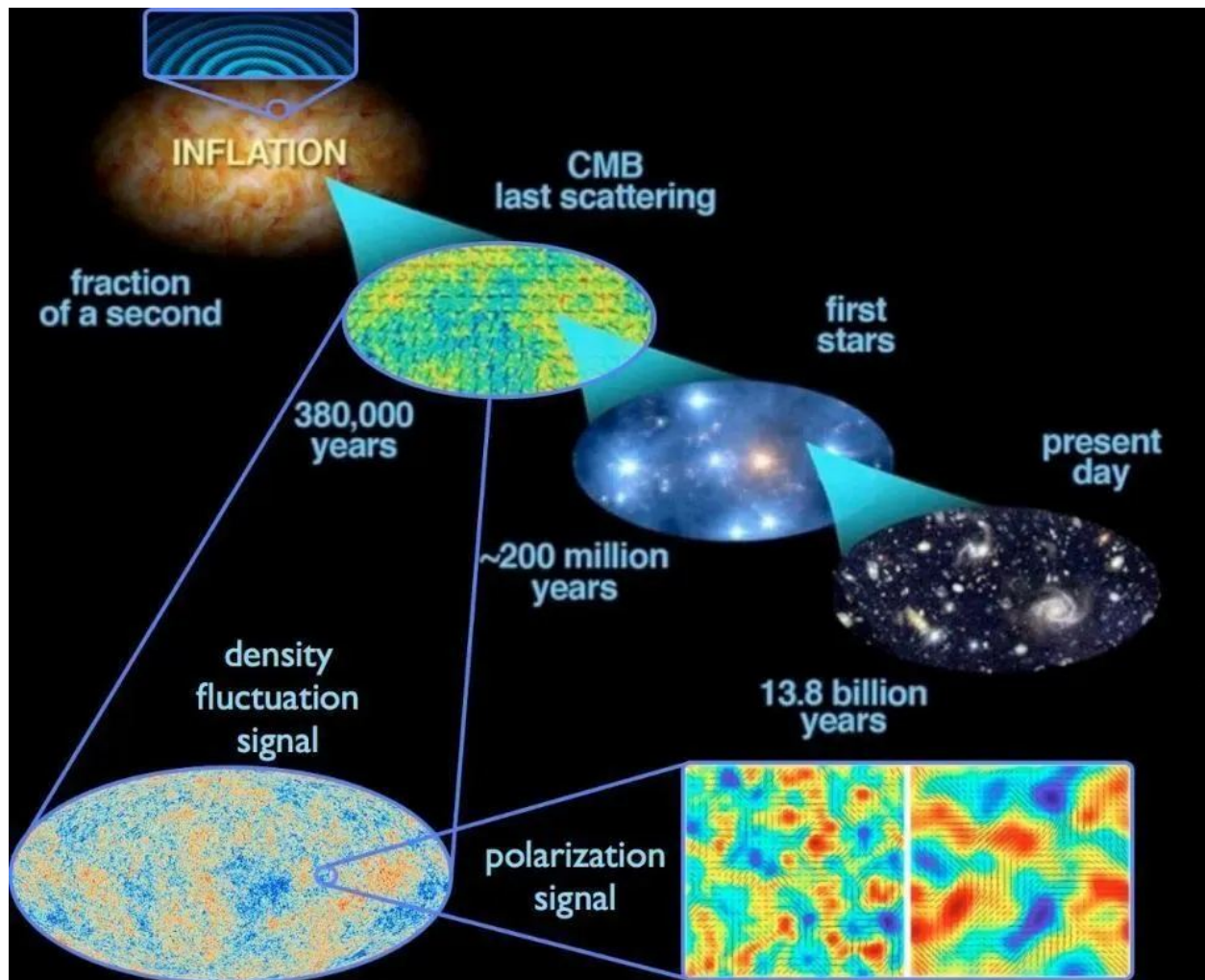
- **Hubble's Observations:** Earlier, it was believed that the universe was static. However, in 1924, astronomer Edwin Hubble revolutionised our understanding by measuring distances to remote celestial objects.
 - He revealed- galaxies are moving away from each other, and the farther they are, the faster they are receding.
- **Spatial Expansion Analogy: Hubble** used the analogy of dots on an **expanding balloon**. For example, two dots on a deflated balloon would be very close to each other but when we inflate the balloon those dots will move away.
 - If we choose a dot (representing a celestial object), all others are moving away, with those farther away receding more rapidly.
 - **Hubble's** discovery not only demonstrated the **universe's expansion** but also revealed the **existence of galaxies beyond our Milky Way**.



Cosmic Microwave Background Radiation (CMBR)

It was discovered by **Penzias and Wilson**, as the left-over heat radiation from the Big Bang.

- During the Big Bang, the heat and temperature would be extreme but currently, it is 2.7 Kelvin. This radiation permeates the entire universe. This **residual radiation** is recognised as evidence of the Big Bang.
- **Temperature variations:** Two probes (studies) were carried out to find the temperature variations, as a measure of the density differences in the universe.
- The **Cosmic Background Explorer (COBE)** and the **Wilkinson Microwave Anisotropy Probe (WMAP)** of NASA were instrumental in **studying variations in CMBR temperature**.
- **Based on the data acquired by these probes, a WMAP Survey was created.**
- The nearly **uniform distribution of CMBR** in all directions as per the Survey, with minute temperature variations, aligns with the Big Bang theory.



Evidence against Big Bang Theory

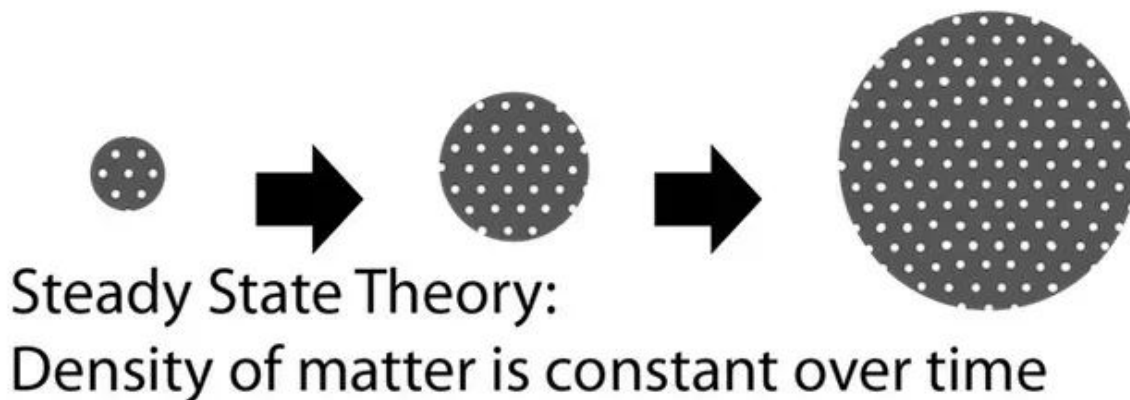
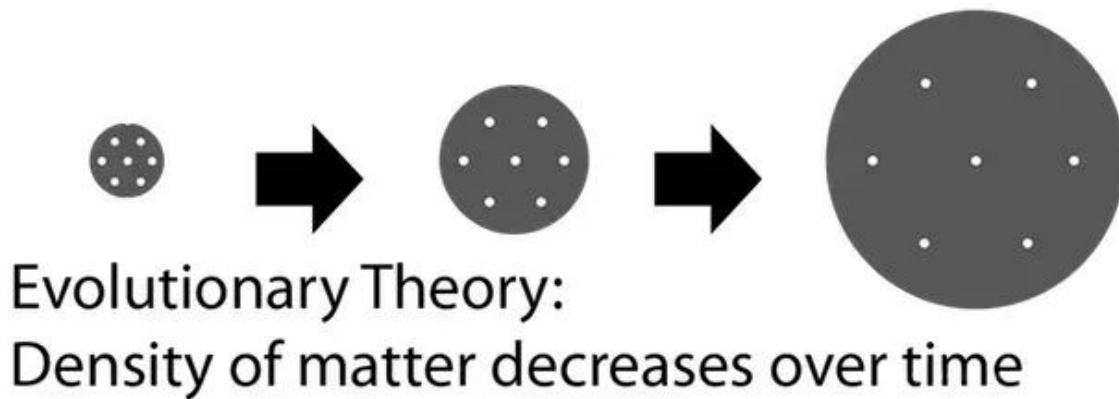
Though experiments support the Big Bang theory, there are multiple observations which are against its proposals such as,

- **Light Elements (Lithium and Helium):** The Big Bang should produce a specific amount of lithium and a large amount of helium. However, it was observed that older stars have less lithium than predicted, and nearby stars have less helium than expected.
- **Antimatter-Matter Annihilation:** The Big Bang should create equal amounts of matter and antimatter, leading to low matter density, but, the matter density is much higher than predicted, suggesting an unknown **asymmetry**.
- **Surface Brightness:** As the universe is expanding, it should cause distant objects to appear dimmer. However, the surface brightness remains constant with distance.
- **Cosmic Microwave Background (CMB) Anomalies:** CMB is a smooth relic of the initial Big Bang radiation. However, the anomalies in CMB are too small to align with predictions. Inflation theory introduces **unknown forces** to explain discrepancies.
- **Dark Matter:** The Big Bang requires the existence of dark matter. Multiple lines of evidence, including galaxy motions, dispute dark matter's existence. Earth experiments fail to detect dark matter particles.

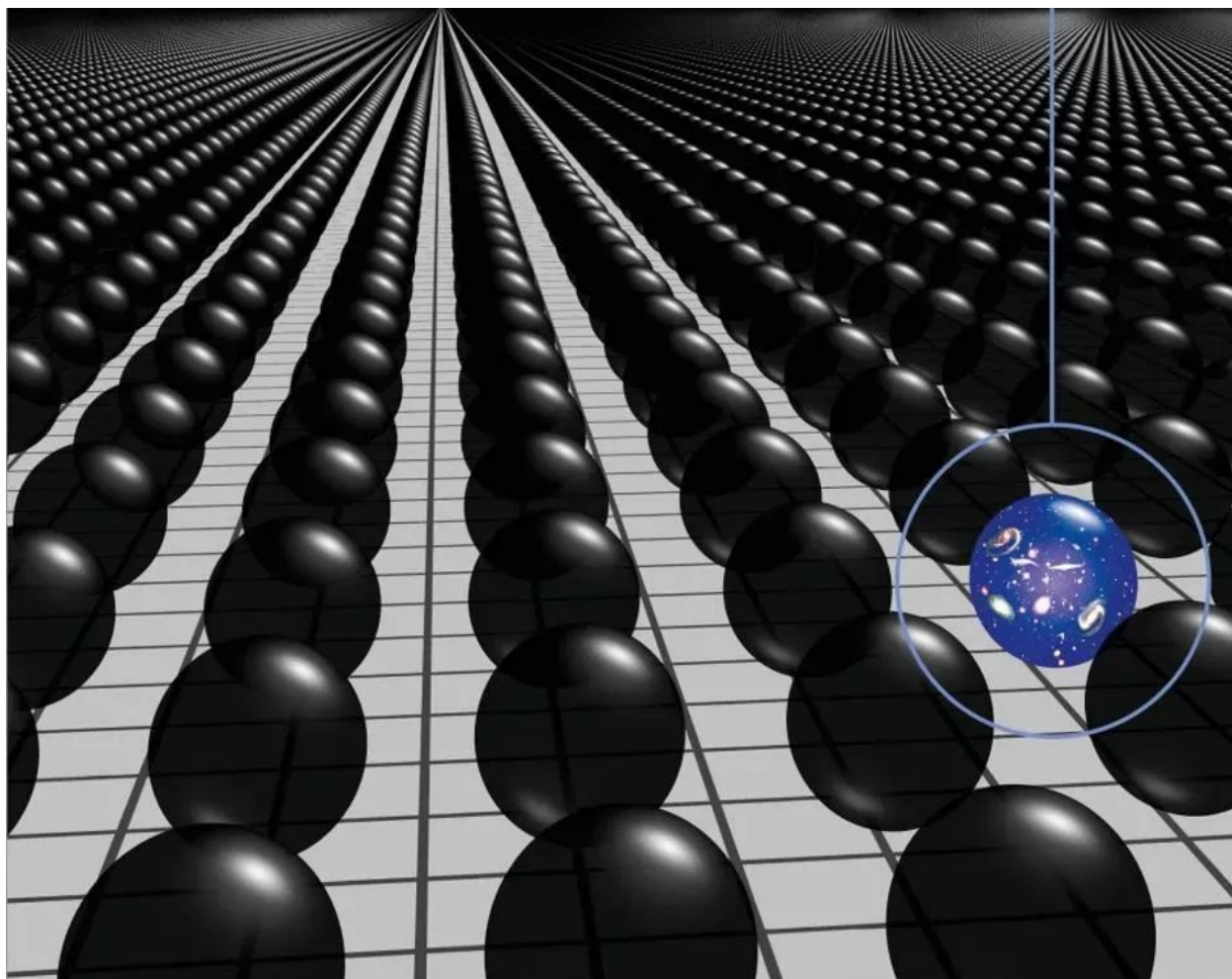
Alternative Theories of the Universe

While the Big Bang theory is the most widely accepted explanation for the origin and evolution of the universe, there are alternative theories that have been proposed by some theorists.

- **Steady State Theory:** An early rival to the Big Bang theory, Steady State proposes the continuous creation of matter throughout the universe to explain its apparent expansion.
 - However, this theory has been largely **discredited due to** the discovery of the cosmic **microwave background**, which provides strong evidence for the beginning of the universe.



- **Causal Set Theory:** Though major theories of the origin of the universe along with the Big Bang Theory consider space and time as continuous where two points can be as close to each other in space as possible. But the causal set theory reimagines space-time as a series of discrete chunks, or space-time "atoms."
 - This theory would place strict limits on how close events can be in space and time since they can't be any closer than the size of the "atom."
- **Multiverse:** The multiverse theory suggests that there are **multiple universes**, or bubbles of universes, each with its own set of physical laws.
 - It follows from the Big Bang theory and inflation theory, which predict the existence of more "**still-inflating**" space.
 - Some cosmologists propose that our Big Bang might be the rebirth of **one single quantum multiverse**, containing infinitely many different universes all occurring together.
 - In this view, the **Big Bang arises from almost nothing** and represents a physical universe, however empty.
 - The multiverse theory is **not a replacement** for the Big Bang theory, but rather an **extension of it**. It attempts to explain the fine-tuning of the universe and the existence of a set of conditions that led to the Big Bang.



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