

Lecture 7: Beginning to End

Overview

This lecture explores the **Big Bang Theory**, the **expansion of the universe**, and how our understanding of the universe's **past** gives insight into its **future**. It begins with a seemingly simple question: *Why is the night sky dark?* — and uses it to unpack the very structure and timeline of the cosmos.

Olbers' Paradox: Why is the Night Sky Dark?

- If the universe were **infinite** in space and time and filled with **infinite stars**, then the night sky should be **blindingly bright**.
- But it's not — and this leads to the paradox:

“In an infinite and eternal universe, every line of sight should end on a star.”

Implication:

This contradiction suggests:

- The universe is **not infinitely old**
- Or it's **not infinite in size**
- Or it doesn't have **infinite stars**

This opens the door to a **finite** universe that had a **beginning**.

The Expanding Universe

Doppler Shift & Spectroscopy

- Light from distant galaxies is **redshifted**, indicating they are moving **away** from us.
- This is not because we're the center of the universe — rather, **space itself is expanding**.

Edwin Hubble's Discovery:

- Distant galaxies move faster → **Velocity** ∝ **Distance**
- This relation is called **Hubble's Law**:

$$v = H_0 \times d$$

Where:

- v = recessional velocity
- d = distance
- H_0 = Hubble constant (~70 km/s/Mpc)

Consequence:

- The universe is **expanding**
- If we rewind time, all matter and energy condense to a **single point**

The Big Bang

- Rewinding the expansion leads to a beginning: the **Big Bang**
- Approximate **age of the universe**:

$$t \approx 1 / H_0 \approx 14 \text{ billion years}$$

This is not the origin of all existence, but rather the start of the **observable universe** and **space-time** as we know it.

Evidence for the Big Bang

1. Cosmic Microwave Background (CMB)

- Residual heat from ~400,000 years after the Big Bang.
- Universe cooled enough for **atoms to form**, allowing light to travel freely.

2. Primordial Nucleosynthesis

- Within the first **3 minutes**, the universe formed:
- Hydrogen (most common)
- Helium
- Trace amounts of Lithium, Beryllium
- These ratios **match predictions** and are found in stars and our own bodies.

*“You’re not just star stuff – you’re **Big Bang stuff**.”*

Henrietta Leavitt & Measuring Distance

- **Cepheid variable stars** used as standard candles.
- Leavitt’s Law (Period–Luminosity relationship) enabled measurements of galaxies beyond the Milky Way.

Edwin Hubble applied this:

- Discovered **Andromeda** is outside the Milky Way.
 - Cemented the **existence of other galaxies** and the **expansion of the universe**.
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Black Holes and the Far Future

- The Sun will die ~5 billion years from now.
- Eventually, all stars will die: universe filled with **white dwarfs, neutron stars, black holes**.

- After **10^{100} years**, even black holes may **evaporate** (via **Hawking Radiation**).

Final stages:

- The universe cools and dims toward **heat death**
 - Possibility of **quantum fluctuations** leading to **new universes**
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What Comes Next?

- We are now observing galaxies as they **were**, not as they **are**.
- The **cosmic horizon** limits what we can see: ~45 billion light-years away.

Open questions:

- Was there a universe **before** the Big Bang?
 - Are there **other universes**?
 - Are we **alone**?
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Final Thoughts

This lecture offers a sweeping cosmic narrative:

- From a paradox about darkness...
- To the realization of a universe with a **finite beginning**
- Supported by multiple lines of evidence
- And leading to profound questions about our **origins, existence, and destiny**