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Making a Big Bang: Understanding the observable Universe

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Storyline

- Time for some brain bending
- Questions about the Universe
- The discovery of expansion
- Big Bang Cosmology
- Matter & the Fate of the Cosmos
Cosmic questions...

- What is the Universe?
- How big is the Universe? Is it infinite, or finite?
- What is the shape of the Universe?
- What’s it doing now? How has it been changing?
- How old is the Universe? How did it get started?
- What is its ultimate fate?
Is the Universe infinite?

- Olber’s Paradox: *The sky is dark.*
- If the Universe is infinite, then in any direction I look, *I should eventually see a star.*
- *The sky should be ablaze with light!*
- *But the sky is dark!*
- Who solved this conundrum?
Solution

- Solution proposed by: Edgar Allan Poe in 1848, in *Eureka*:
  - *Universe is finite age*, so light hasn’t had time to reach us from every distant star

- Another solution: the *Universe is finite in size*, so there are not an infinite number of stars
Size of the Universe

- Special relativity tells us that there is an **Ultimate Speed Limit** — nothing can travel faster than light.

- Define the **OBSERVABLE UNIVERSE** to be the part of the Universe accessible at the speed of light during the Age of the Universe.

- If the Universe is of **finite age**, then the Observable Universe is of **finite size**.
Static Universe

- Things seem uniform and unchanging on large scales

- Once thought that the Universe should be **STATIC** (unchanging in time)

- Einstein proposed in General Relativity a **Cosmological Constant** to keep the Cosmos static.

- He later called this his “**greatest blunder**”
**Static Universe**

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Beginning in 1919, **Edwin Hubble** and **Milton Humason** began looking at galaxies with the 100” Hooker Telescope on Mount Wilson.

They measured **distance** and **redshift** (gives the speed the galaxy is moving).

In 1929 they announced one of the great discoveries of cosmology.

The galaxies are **all moving away from us**, and the farther away they are, the faster they are moving.
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Everything moving away from everything...

- Imagine a raisin bread. Measure the distance between all the raisins.
- Double the size of the loaf, and the distance between every raisin also doubles! They all appear to move away from one another!
- Can also do this with balloons.
Cinnamon Raisin Bread Recipe

**INGREDIENTS**
- 1 1/2 cups milk
- 1 cup warm water
- 2 (0.25 ounce) packages active dry yeast
- 3 eggs
- 1/2 cup white sugar
- 1 teaspoon salt
- 1/2 cup margarine, softened
- 1 cup raisins
- 8 cups all-purpose flour
- 2 tablespoons milk
- 3/4 cup white sugar
- 2 tablespoons ground cinnamon
- 2 tablespoons butter, melted

**DIRECTIONS**
- Warm the milk in a small saucepan until it bubbles, then remove from heat. Let cool until lukewarm.
- Dissolve yeast in warm water, and set aside until yeast is frothy. Mix in eggs, sugar, butter or margarine, salt, and raisins. Stir in cooled milk. Add the flour gradually to make a stiff dough.
- Knead dough on a lightly floured surface for a few minutes. Place in a large, greased, mixing bowl, and turn to grease the surface of the dough. Cover with a damp cloth. Allow to rise until doubled.
- Roll out on a lightly floured surface into a large rectangle 1/2 inch thick. Moisten dough with 2 tablespoons milk. Mix together 3/4 cup sugar and 2 tablespoons cinnamon, and sprinkle mixture on top of the moistened dough. Roll up tightly; the roll should be about 3 inches in diameter. Cut into thirds, and tuck under ends. Place loaves into well greased 9 x 5 inch pans. Lightly grease tops of loaves. Let rise again for 1 hour.
- Bake at 350 degrees F for 45 minutes, or until loaves are lightly browned and sound hollow when knocked. Remove loaves from pans, and brush with melted butter or margarine. Let cool before slicing.
Implications of the Expansion

- Imagine running the expansion **backward**...
- The **Universe shrinks down**!
- If its expansion is constant, it has been expanding for about a Hubble Time
- If it used to be very small, how did it get expanding so fast?
- We call the start of the expansion **THE BIG BANG**
What’s with the expansion?

- Let’s get right to it and ask the age old question:
  - If the Universe is expanding, what is it expanding into?

- Let me answer by asking another question:
  - What is the Universe?

- ANSWER: The Universe is everything that exists.

- SO: If the Universe is expanding into something, that something it is expanding into exists and is part of the Universe.

- The Universe isn’t expanding into anything — it is just expanding!
Starting from a small point...

- We talk about the Big Bang starting at a single point. **The Big Bang started at all points.**

- The **Observable Universe** that you see, started at one point, **centered on you**.

- The Observable Universe our friends see started **at another point**.
Observing the infant Cosmos

- How do we know what the Universe was like when it was very young?
- When you make things very small (planets, stars, the Cosmos) the compression energy makes them very hot
- Immediately after the Big Bang, the temperature was $10^{32}$ °C. That’s: $100,000,000,000,000,000,000,000,000,000,000,000$ °C
- Atoms (and other things you and I recognize as “matter”) can’t exist at these temperatures!
- As the Universe expands from the Big Bang, it cools down.
By 100 seconds after the Big Bang, the Universe has cooled to 10 billion °C. That’s: 10,000,000,000 °C

At this temperature, the nuclei of atoms can form: this is called **Nucleosynthesis**

**Nucleosynthesis** is extremely important because the Big Bang is the dominant source of **light elements** (Hydrogen, Helium, Lithium, etc.)

We observe the amount of light elements that exist today, and Big Bang calculations **correctly** predict abundances

**Observational evidence** in support of Big Bang model
What was made...

- For every 1,000,000,000 atoms:
  - 1 Lithium
  - 100,000 Helium
  - 1,000,000 Deuterium
  - 998,899,999 Hydrogen

- Hydrogen was the most common element in the Cosmos.
- Today it is STILL is the most common element in the Cosmos!
The Formation of Atoms

- Photons interact readily with loose charged particles like protons and electrons, and didn’t travel far.
- At ~300,000 years, the Universe cools to $T \sim 3000$ °C, and **neutral atoms** form, with electrons bound to nuclei. This is called **RECOMBINATION**.
- Photons can suddenly fly free, and expand out without interacting (much) with matter. This is called **DECOUPLING**.
- **The Universe fills up with light...**
Cosmic Microwave Background

- We can see this light today
- Nearly *uniform* background of microwave light coming from *every direction* on the sky
- Discovered at Bell Labs by Penzias & Wilson in 1965
- Nobel Prize in 1978
- Direct evidence that the Universe was *HOT and DENSE* before *Recombination* and *Decoupling*.
- Another indication that Big Bang calculations are correct
Cosmic Microwave Background Map
~1970s
Seeds of Today in the Past

- We know that about 400,000 years after the Big Bang, atoms formed in the Primordial Soup.

- How did those atoms get together after that?

- We think that the small differences we see in the Cosmic Microwave Background are indications of early groupings of the atoms when recombination and decoupling occurred.

- The beginning of Structure in the Cosmos
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- The beginning of Structure in the Cosmos.
Is that all there is?

- Suppose I count how much light I can see in the Cosmos (created by atoms)
- Suppose I count how much gravity I can see in the Cosmos
- Now suppose I compare these two numbers
- If atoms were all there was, these *should be the same*!

*Atoms are only 4% of all there is in the Cosmos.*
If 4% of the Universe is atoms, what about the other 96%?

- It is dark — it doesn’t emit light of any sort
- It interacts via gravity — it pulls and pushes on other stuff

I’ve now told you everything we are certain about with respect to dark matter and dark energy!
Why do I care?

- The Ultimate fate of the Cosmos in the distant future depends on the total matter content.

- There is just enough stuff (including **dark matter** and **dark energy**) so that gravity can slow the expansion of the Universe.

- Current CMB observations indicate that the Universe is close to **Flat** — it is slowly coasting, but never recollapsing.
More information, reading

- WMAP: map.gsfc.nasa.gov/

- THE FIRST THREE MINUTES (Stephen Weinberg)

- THE DAY WE FOUND THE UNIVERSE (Marcia Bartusiak)