Notes: The Big Bang Theory

Calvin and Hobbes

Isn't it weird how scientists can imagine all the matter of the universe exploding out of a dot smaller than the head of a pin, but they can't come up with a more evocative name for it than "the Big Bang"?

I've been reading about the beginning of the universe. They call it "the Big Bang."

Hmmm... that is better. Almost anything would be.

What would you call the creation of the universe?

"The Horrendous Space Kabloolie!"

And I think "Tyrannosaurus" should be changed to "Monstrous Killer Death Lizard."

We should lobby to change that.
Georges Lemaître (1894-1966)

- Belgian priest/astronomer.
- First to propose a specific model describe the start of the universe.
  - Said all matter was combined into one primordial atom that broke apart.
    - Those fragments broke apart further until they became the atoms of the universe.
- This hypothesis would eventually become the **Big Bang Theory**.
  - It was the first to describe an expansion of the universe.
  - It was not widely accepted.
    - Actually, the term “Big Bang” was coined as a joke.
Edwin Hubble (1889-1953):
- Provided observational evidence for the Big Bang:
  - While the work of others showed that galaxies were moving away from the Earth
  - He showed that galaxies moved away from the Earth faster the farther away they got.
- These observations imply that the universe is expanding.
  - The rate of expansion is known as the Hubble constant.
Describe Georges Lemaître model of the universe?
- One primordial atom broke apart until they became the atoms of the universe

What important discovery did Hubble make?
- Universe is still expanding
Misconceptions about the Big Bang

• It **does not** explain the creation of the universe.
  • It’s an attempt to **explain how the universe developed from a teeny, dense ball of matter into what we see today**.
  • It doesn’t attempt to explain what started expansion or what came before.
Misconceptions about the Big Bang

- There was no “BANG”.
- Instead, there was (and continues to be) an expansion.
  - Rather than imagining a balloon popping and releasing its contents, imagine a balloon expanding: an infinitesimally small balloon expanding to the size of our current universe.
Misconceptions about the Big Bang

- It started as a single point in space, a singularity.
- **Singularity**: a one-dimensional point which contains a huge mass in an infinitely small space, where density and gravity become infinite and space-time curves infinitely, and where the laws of physics as we know them cease to operate.
- **Space began inside of the singularity.**
  - Prior to the singularity, *nothing* existed, not space, time, matter, or energy - nothing.
White Board

- Does the Big Bang describe the creation of the universe or the development of the universe?
  - It does not attempt to explain the creation of the universe, only it’s development.
- Instead of a ‘Bang’ what was there?
  - Expansion
- How did the big bang start?
  - As a singularity that began to expand
Keys to the beginning

- Time begins **13.7 billion** years ago.
  - The universe is the size of a single atom.
  - At this time, all matter and space is created in a violent EXPANSION.

- 3 ideas that are key to the next steps:
  1. **The universe cools as it expands.**
     - At first it’s indescribably hot. By 0.01 seconds it’s a cool 180 trillion ° F.
     - By 3 minutes it’s about 1.6 billion ° F (70 times hotter than the core of the sun).
  2. **The early universe was so hot, it was made of mostly radiation, not matter.**
     - As these packets of energy (photons) collided, they could form matter.
     - Thanks to Einstein, we can calculate how much (remember $E=mc^2$).
     - It take A LOT of energy (heat) to create a universe, much more than most photons have today.
  3. **The hotter the universe, the more energy available to make matter.**
     - At a temperature of 11 billion ° F, the collision of two photons can make an electron and a positron (antimatter).
     - At temperatures above 1.8 trillion ° F you get protons.
     - If you have protons and electrons, you can get ATOMS.
The First 3 Minutes

- It is unknown what happened at the exact beginning.
  - We can follow what happened starting at $10^{-43}$ s.
    - That’s 0.0000000000000000000000000000000001 s.
    - Before that, it’s all so small and dense that we aren’t smart enough to describe it.

- $10^{-43}$ s to 0.01 s:
  - The universe is filled with energy and subatomic particles.

- 0.01 s:
  - Universe is no longer hot enough to produce protons or neutrons.
    - It could create electrons still.
  - Still way too hot for protons and neutrons to combine.

- 3 minutes:
  - The temperature drops to 1.6 billion ° F.
  - Protons and neutrons combine to form the first element, deuterium.
The Next 13.7 Billion Years

- **Several Hundred Thousand Years:**
  - Atoms form:
  - The universe becomes transparent.
    - Matter and radiation interacted much less frequently, allowing light to travel on its own.

- **One Billion Years:**
  - Stars and galaxies start to form.
  - The original energy of the big bang continues to cool.

- **4.6 Billion years AGO:**
  - Our solar system forms. So does the Earth.
White Board

- What happened at 3 seconds after the big bang?
  - The first element formed
- When did our solar system form?
  - 4.6 billion years ago
**Pillar #1: Redshift**

- The evidence supporting the Big Bang relies on 3 Pillars:
  - **Redshift**
  - **Cosmic Background Radiation**
  - **Elemental Abundances**

- **Redshift** is a phenomenon by which the light emitted from stars seems to be shifted towards the **RED** end of **ROY G BIV**.
  - It occurs because the wavelengths of light are being stretched because the source is **moving**.

Just like the chocolate chips move away from each other as the cake expands, so do the galaxies in the universe.
Pillar #2: Cosmic Background Radiation

• If the universe was initially super hot, there should be remnants of that.
  • Law of Conservation of Energy: Energy cannot be created nor destroyed.

• In 1965, Arno Penzias and Robert Wilson discovered a “noise” they couldn’t account for while calibrating communication satellites.
  • Discovered that the “noise” was actually free floating photons left over from the time when atoms first started to form.
    • When the universe was about 380,000 years old.

• This leftover radiation, called cosmic background radiation (CBR)
  • The CBR exists as microwaves.

• You can actually detect the CBR with an old antenna TV.

• Launched in 1989, the Cosmic Background Explorer (COBE) cemented the idea of the Big Bang theory.
  • It took a “picture” of the photons left behind from the Big Bang.
• This is the actual picture taken by COBE.
• The disk in the middle is the Milky Way galaxy as seen from Earth.
• The pink spots are the CBR.
Pillar #3: Elemental Abundances

- The Big Bang theory predicts that after 3 minutes, the universe would be too cold for any more fusion.
- This means that there would be an over abundance of light(weight) elements in the universe.
  - Lots of Hydrogen and Helium.
- It predicts that after 3 minutes, the elements in the universe would be:
  - 70% H, 29% He, 1% everything else.
    - AND it should stay that way.
- Observation shows that this is the ratio of elements in the universe today.
The Universe Today

Observable Universe

You are Here

Local Supercluster (Virgo Supercluster)
What is a redshift in terms of wavelength?
- Wavelengths are stretched because the light is moving farther away from us.

What is CBR?
- Left over photons from the big bang
- The big bang predicts this ratio of elements:
  - 70% H, 29% He, 1% everything else.
Accelerated Expansion?

- The expansion of the universe is **speeding up**.
- Why?
  - Because of **Dark Energy**.
- What is **dark energy**?
  - No one has any idea.
  - It acts like anti-gravity, pushing things apart.
  - It appears to make up 73% of the ENTIRE universe.
- What is dark matter?
  - ...not really sure
  - It is not energy or radiation
  - It acts like gravity, holding things together
Dark Matter vs Dark Energy

Big Crunch
Constant Dark Energy

Big Chill
Dark Matter wins over Dark Energy

Big Rip
Dark Energy wins over Dark Matter
The Composition of the Universe

- Suppose all the matter and energy in the Universe is $100 in your wallet.
- $73 would be **Dark Energy**.
  - It’s the mysterious energy that’s pushing the Universe apart faster and faster.
- $23 would be **Dark Matter**.
  - TOTALLY DIFFERENT from dark energy.
  - It’s matter that doesn’t give off any kind of radiation
  - We can’t see it – but it does have **gravity**. It holds things together.
  - So, you know $96 is there, but you can’t identify it.
- Only $4 would be **visible matter**.
  - The regular stuff we can see, like stars.
  - Of the visible matter ($4):
    - $0.40 cents are stars.
    - $0.60 are gas clouds and dust.
White Board

- Draw a pie chart of the composition of the universe

![Pie chart showing the composition of the universe: Dark Energy 72%, Dark Matter 23%, Atoms 4.6%]