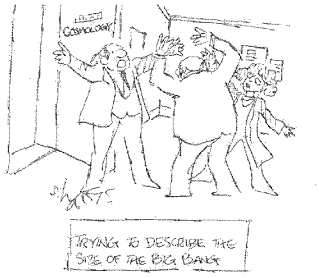
The Hot Big Bang



Monday, November 16

Hot Big Bang Theory:

Universe began expanding a finite time ago from a very dense, very hot initial state.

Dense = particles packed close together.
Hot = particles moving rapidly.

Hot Big Bang Theory (continued):

As space expanded, the universe became lower in density and colder.

Expansion of space has been continuous since the "Big Bang" (start of expansion).

Who invented the Big Bang Theory?

Idea of expanding space:
Aleksandr Friedmann (1922).

Observation of expansion:
Edwin Hubble (1929).

Idea of initial dense "primeval atom":
Georges Lemaître (1931).

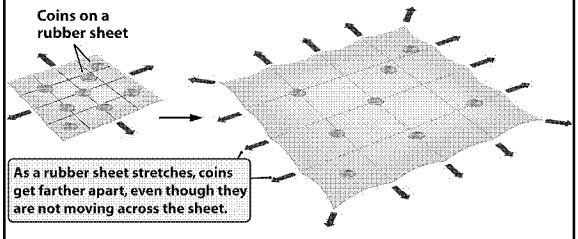
Coining of phrase "Big Bang":
Fred Hoyle (1949).

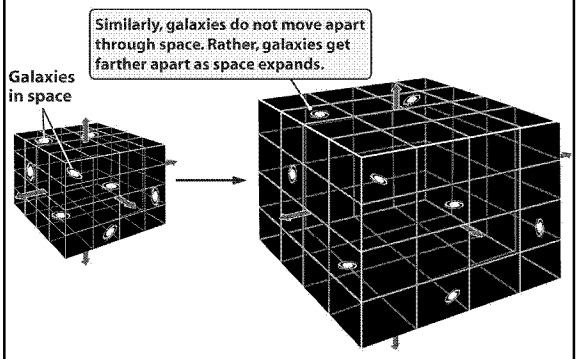
"**Big Bang**" is a misleading name.

Galaxies are not flying through space like shrapnel after an explosion.

They're moving apart along with expanding space.

The textbook laments that the name isn't "Expanding Space Theory".



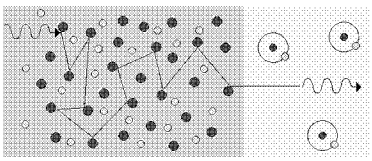


There are some special times during the expansion.

t = 0: Expansion starts.

t ≈ 3 minutes: Protons & neutrons combine to form nuclei (Big Bang Nucleosynthesis).

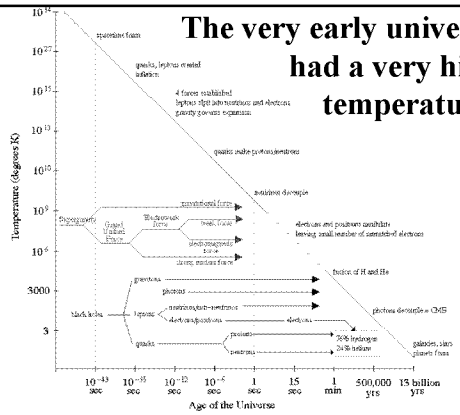
t ≈ 400,000 years: Protons & electrons combine to form hydrogen atoms. Universe becomes transparent. Photons **decouple** from matter.



Until t ≈ 400,000 yr, protons, electrons, He nuclei, & photons interacted frequently. Thus, they all had the **same** temperature.

Today's inhomogeneous universe is full of things with **different** temperatures.

The very early universe had a very high temperature.

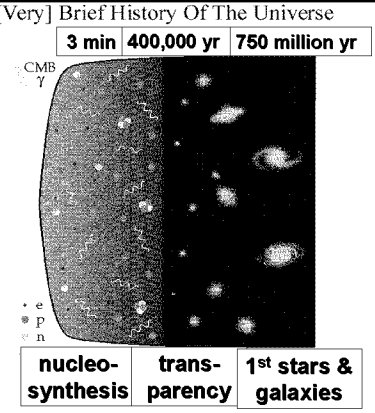


More special times.

t ≈ 750 million years: Formation of first stars and galaxies.

t ≈ 13.7 billion years: Intelligent life in at least one location in the universe.

[Very] Brief History Of The Universe

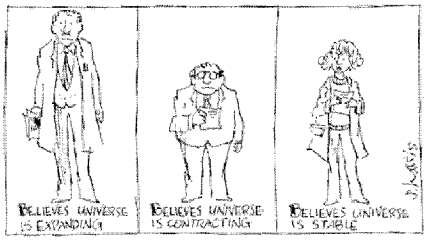


What **evidence** supports the Hot Big Bang Theory?

Before the 1920s, everyone on Earth thought space was not expanding.

Scientists generally don't accept radical new theories without strong proof.

Sometimes personality influences scientific beliefs….



…but today the Hot Big Bang is by far the favored theory.

Flashback: Top 3 pieces of evidence for the Hot Big Bang.

1) **Dark** night sky → Finite age for universe.

2) **Redshift** proportional to **distance** → Homogeneous & isotropic expansion.

3) **Cosmic Microwave Background** → Universe was hot & dense enough to be opaque.

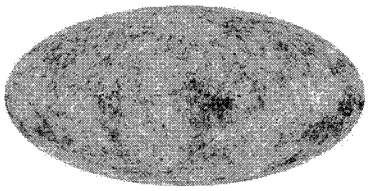
Other bits of evidence for the Hot Big Bang.

4) **¼ helium + ¾ hydrogen** → Universe was hot & dense enough for Big Bang Nucleosynthesis.

5) **Age measurements** of stars & planets are less than the Hubble time $1/H_0$.

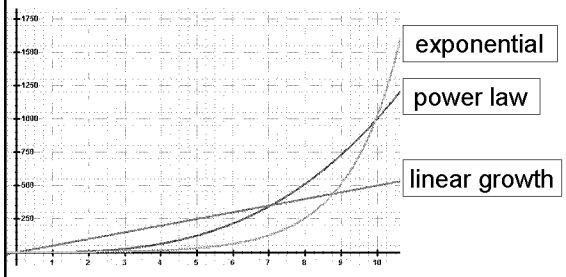
6) **Large scale structure** looks like that found in simulations of an expanding universe.

About large scale structure: We **know** what density fluctuations were present when the universe became transparent.

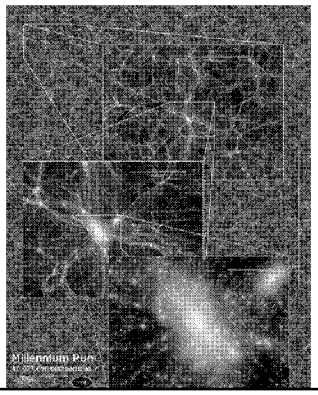


In a static universe, the fluctuations would grow **exponentially**.

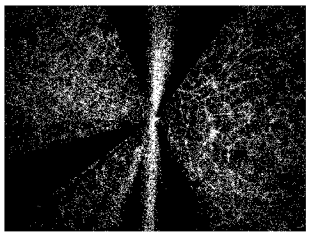
In an expanding universe, **gravity** tends to make dense regions **collapse**, **expansion** tends to **pull them apart**. **Growth is slow.**



Structure seen in a **simulation**:



Structure seen in **reality**:



Hot Big Bang explains:

Redshift & distribution in space of galaxies (t = 0.75 →13.7 billion years).

Existence of Cosmic Microwave Background (t ≈ 400,000 years).

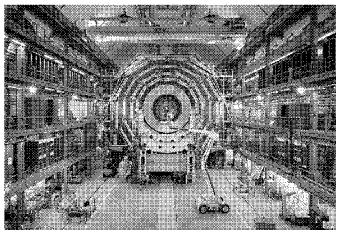
Production of ^{4}He, & a little ^{7}Li, by Big Bang Nucleosynthesis (t = 3 → 15 min).

Gosh! We understand what the universe was like when it was a few minutes old!

1) At t < 1 minute, things get more speculative.

2) Cosmologists love to speculate.

The Large Hadron Collider at CERN (between France & Switzerland)…



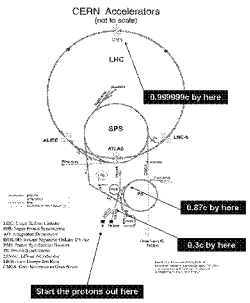
…is nicknamed the "Big Bang Machine". Why?

The LHC will accelerate protons until they have a kinetic energy of **2×10^{-6} joules**.

This is a **lot** of energy for one proton (mc^2 for a proton is 2×10^{-10} joules).

In the early universe, the temperature was high. **All** particles had lots of kinetic energy.

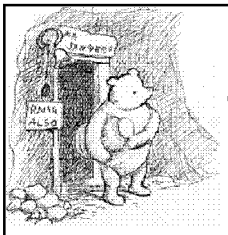
The particle energy produced by the LHC will be comparable to the particle energy **10^{-13} seconds** after the Big Bang.



Once they actually get it working.

If you like to speculate about the very early universe ($t < 3$ minutes), then section 11.2 is for you!!

quantum foam
Planck length
Planck time
quantum gravity
theory of everything
loop quantum gravity
M-theory
grand unified theory
baryogenesis
electroweak unification
quark-hadron transition



"…long words Bother Me."

I will continue to concentrate on things that are observable (stars, galaxies, CMB) and events that have directly observable consequences (BBN and helium-4).

Wednesday's Lecture:

Density of the Universe

Reading:

Chapter 11