Lecture 12

Cosmology

April 1 2003
8:00 PM
BPS 1420

This week's topics

- Cosmology
  - Static Universe
    - Oblers' Paradox
  - Expanding Universe
    - Hubble's Law
    - CMB
      - Horizon Problem
  - Accelerating Universe
- Gamma Ray Bursts

What is Cosmology?

- The study of the origin and evolution of the universe.
  - requires an understanding of all time, from big bang to $t \approx \infty$.
  - Large and exciting field, new discoveries change the field constantly.

Let's look at now:

What is the simplest model we can use for the universe right now? (Ignore a lot of the things that you may know about the current state of Cosmology.)

Let's look at now:

What is the simplest model we can use for the universe right now? (Ignore a lot of the things that you may know about the current state of Cosmology.)

Stationary, static infinite universe, filled with a uniform distribution of stars.

(This was favored by Newton among others.)

Static, Uniform Universe

- If the universe is infinite and static, then a uniform distribution of stars (think of it as the density of stars) implies an infinite number of stars.
  - This is bad.
  - Infinite number of stars with and infinite amount of time for their light to reach us yields a night sky that is quite bright indeed.

Olbers' Paradox

- Any direction we look in the night sky, our line of sight should fall upon a star
  - This works even if stars are not uniformly distributed since the universe is infinite
- Obviously isn't true since night sky is dark. So, what fixes the paradox?

Fixes to Olbers' Paradox

- Absorption
  - Yes, there is absorption, but if universe is infinite in size and sufficiently large, any dust would be heated to the point of emitting light as well.

Fixes to Olbers' Paradox

- Absorption
  - Yes, there is absorption, but if universe is infinite in size and sufficiently large, any dust would be heated to the point of emitting light as well.
- Redshift
  - Yes, this also occurs, but it turns out that this effect is too small to explain the night sky

Fixes to Olbers' Paradox

- Turns out that the Universe isn't unchanging, it had a beginning (Big Bang) and only a finite amount of time has passed since then.
  - Finite speed of light also, so not all of the light from all of the objects in the Universe has had time to get here.

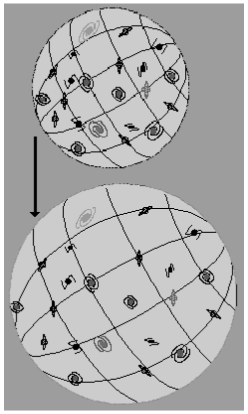
Hubble's Law

- In 1920's Hubble was studying spectra of galaxies
  - Nearly all of the galaxies studied seemed to show some redshift; this means that they are moving away from us
  - This begs the question, are we at the center of it all, as had been assumed so many times in history before this?
    - (Turns out no, no we aren't.)

The Expanding Universe

It is not an expansion of matter through space, but instead an expansion of space itself.

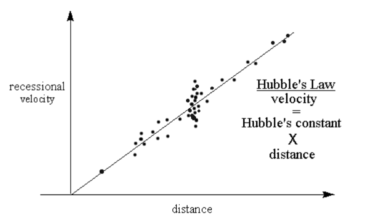
Imagine that all of the stars and galaxies are on the surface of a balloon that is being inflated. In this system, each object sees all of the others moving away from it, regardless of which object you chose to look at.

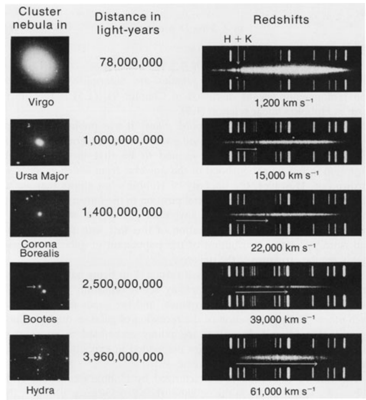


Hubble's Law

Hubble noticed that as you go out in distance, you find that things are moving away faster. This gives us a (mostly) nice straight line distribution.

$$v = H_0 * d$$





Consequences of Hubble's Law

- If everything is moving away from each other, then in the distant past everything was closer together
  - Seems trivial, but it implies that if you run time backwards, there was a time when everything was at the same point. (This is the concept of the Big Bang.)
  - This means that our static Universe is wrong.
  - It also means that the future of the Universe is uncertain. More on this later...

Einstein's Blunder

- The solution to Einstein's field equations for a dust filled isotropic, homogeneous universe of density rho is:

$$\left[\left(\frac{1}{R}\frac{dR}{dt}\right)^2 - \frac{8}{3}\pi G\rho - \frac{1}{3}\Lambda c^2\right] R^2 = -kc^2$$

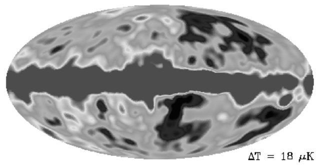
- The Λ term is referred to as the cosmological constant. It was put in to make the universe static.

Cosmic Microwave background Radiation

- Consider the CMBR
  - Observations have shown that the Universe contains residual radiation in the form of microwave background. Where did it come from and why is it a problem?

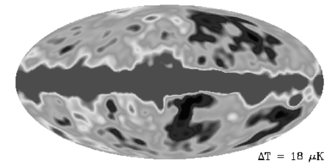
Discovery of the CMBR

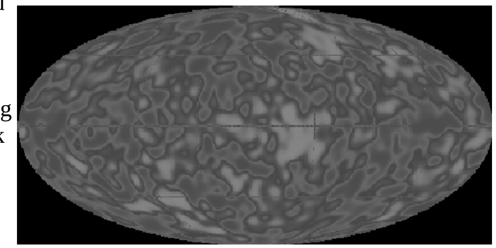
1964- Penzias and Wilson (of Bell labs) noticed an microwave signature in their radio telescope that wasn't coming from a local source. It was present no matter where they pointed their telescope. At the same time, Robert Dicke (of Princeton) was expanding on George Gamow's work that said that there should be a radiation field left over from the Big Bang.



Discovery of the CMBR

1964- Penzias and Wilson (of Bell labs) noticed an x-ray signature in their radio telescope that wasn't coming from a local source. It was present no matter where they pointed their telescope. At the same time, Robert Dicke and Jim Peebles (of Princeton) were expanding on George Gamow's work that said that there should be a radiation field left over from the Big Bang.

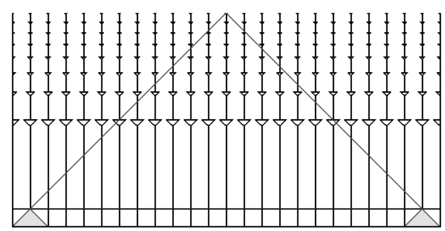


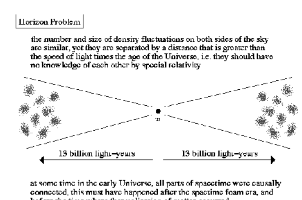


Problems from CMB

- If the Universe is roughly 14 billion years old, that means that from one point in the sky to the other is separated by 28 billion years. Why is it so smooth?
  - There is no way for stuff on one side of the Universe to have information about the other side.
  - But it all came from the Big Bang, so what is the problem?
    - Well, the CMB doesn't come from the BB itself, it comes from the era where matter could finally form. (Decoupling)

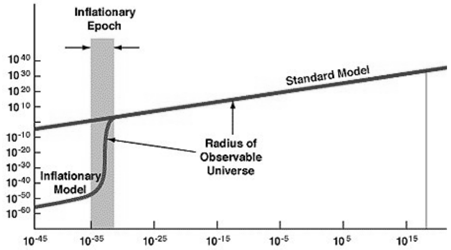
Problems from CMB





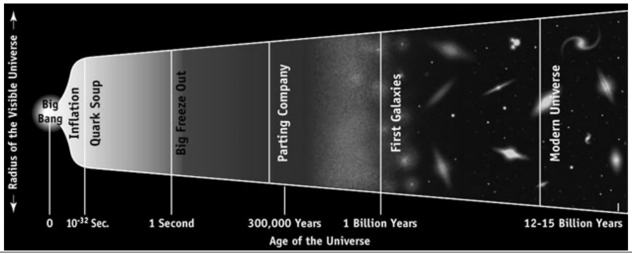
Horizon Problem

1979 Alan Guth proposed a solution. Suppose that at some point after the Big Bang and just before decoupling the universe suddenly expanded. In this model the initial Universe was much smaller than in the standard model and could be in thermodynamic equilibrium.



Current Picture

- The Universe is:
  - Expanding (we see redshift)
  - Isotropic (similar in all directions)
  - Homogeneous (of uniform structure)

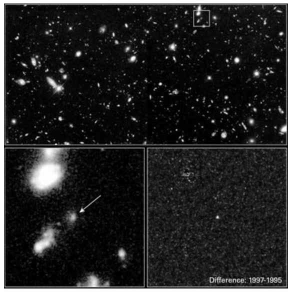


Accelerating Universe?

- Recall SN Ia as standard candles. You can get a distance from them if they all have a similar brightness.
- We can also get a distance using Hubble's Law.
  - Do these numbers agree?

Accelerating Universe?

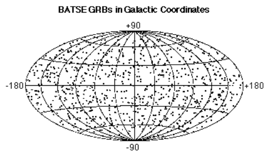
Turns out that distant supernovae seem to be too faint for their distance. This means that the Hubble constant may not be constant, it may instead change with time. In fact, it seems that the early Universe was expanding at a slower rate than we are today. This means that the Universe is accelerating. More on this later...



Gamma Ray Bursts

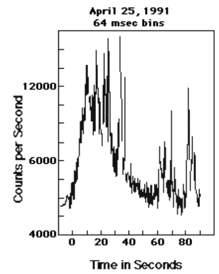
- About once per day, a gamma ray burst occurs
  - Energy output of a burst is greater than all other gamma ray sources in the Universe combined
  - They last from 30 ms to 1000s, although actual duration is unclear
- First detected in late 60's by a satellite that was searching for nuclear weapons detonations.
  - They saw large increases in gamma rays on several widely separated satellites, indicating that they were not from Earth.

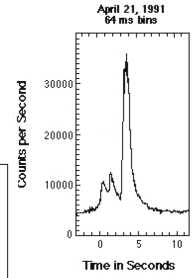
Gamma Ray Bursts



They are isotropic on the sky and therefore are not local to our galaxy. They have a fairly simple peaked shape.

But what causes them?

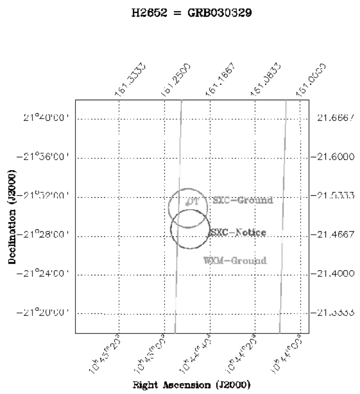




Gamma Ray Bursts

- They are believed to be the signature of the birth of a black hole
  - possibly the merger of two dense objects such as neutron stars
- The difficulty is that it is impossible to predict where the next one will come from, so observing them is difficult

GRB 030329



March 29, 2003:
The High Energy Transient Explorer (HETE-2) detected the closest and most energetic GRB to date. This may shed some light on the mystery.