Astronomy 210

This Class (Lecture 40):

The Big Bang

Next Class:

The end

HW #11 Due next Weds.

Final is May 10th.

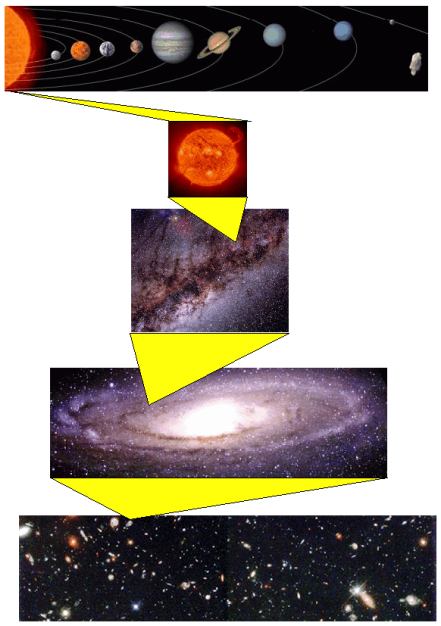
Review session: May 6th or May 9th?

Final

- Designed to be 2 hours long
- 1st half is just like the other 2 hour exams on the material after hour exam #2.
- 2nd half is review of the entire semester.
- You may bring a single sheet of paper with notes.
- Total exam will have 210 points, but graded out of 200 points.

Outline

- Quasars, Radio Galaxies
- The Big Bang
- Cosmic Microwave Background
- How Illinois is probing the early Universe



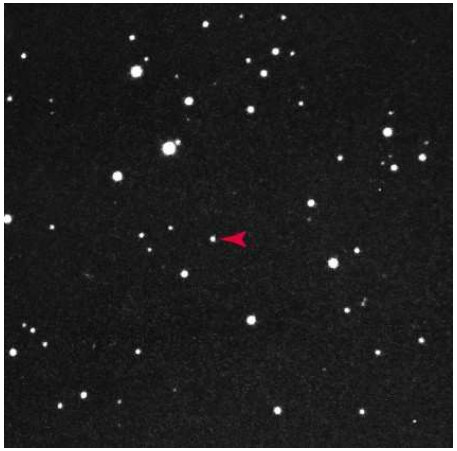
Astronomy: The Big Picture

Arguably, the biggest fish of all: *Cosmology*

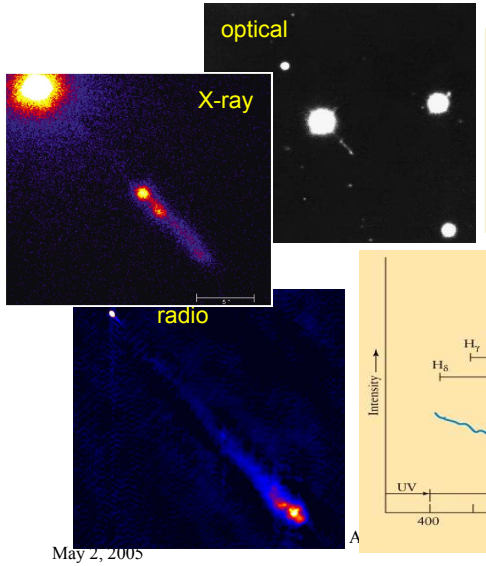
- What is the Universe made of?
- How big is it?
- How old is it?
- How did it form?
- What will happen to it?

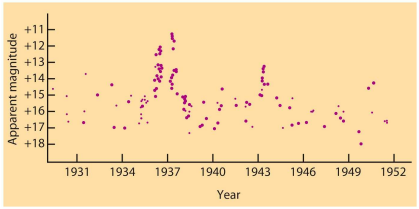
A Very Strange Star !?!

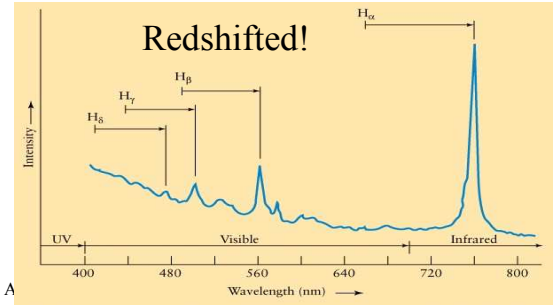
- Looked like a blue star, but had very odd spectrum lines
- Turned out it was simply greatly redshifted $\Rightarrow z = 0.16$
- That's 2 billion light years away!
- It must be 100 times brighter than the entire Milky Way!
- **Not** a star



The First Quasar Discovered: 3C 273





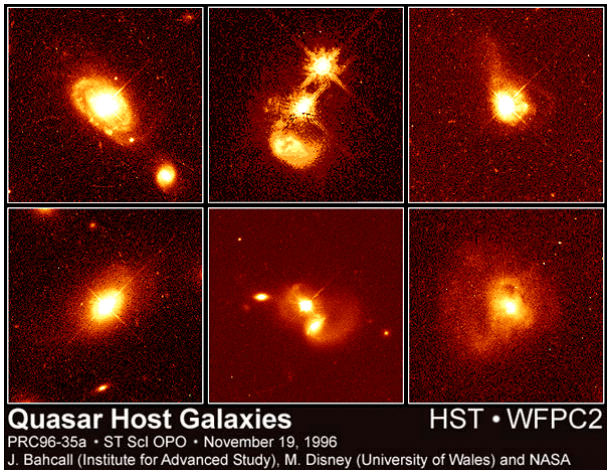


Quasars…

- These objects have a spectrum much like a dim star
  - But highly redshifted
  - Appear to moving away from us very fast!
- Dubbed **quasars** (quasi-stellar radio sources)
- The Hubble Law tells us that they are at "astronomical" distances
  - Up to 13 billion light years away!
- Great distances - must be very bright
  - Some 1 million times the brightness of our Galaxy!
- Highly variable
  - Must be small - about the size of our Solar System

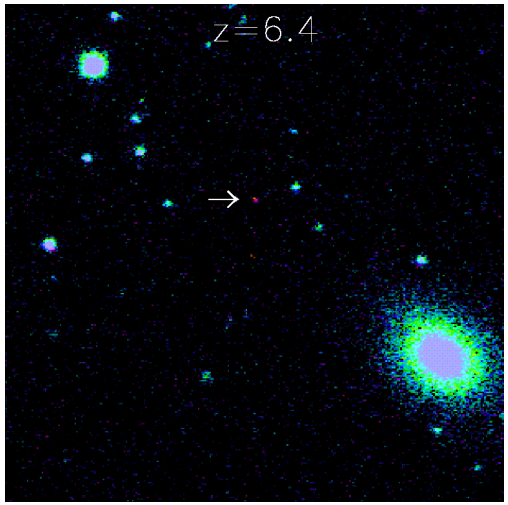
Quasar Host Galaxies

- Quasars live in distant galaxies
- They are *galactic nuclei!*



The Furthest Known Object

- Although there are now sources that may beat it, this galaxy is at z=6.4!
- That means only 800 Myrs after the Big Bang!
- Probably only current record holder.



http://www.sdss.org/news/releases/20030109.quasar.html

Are there quasars in the nearby Universe?

Active Galaxies

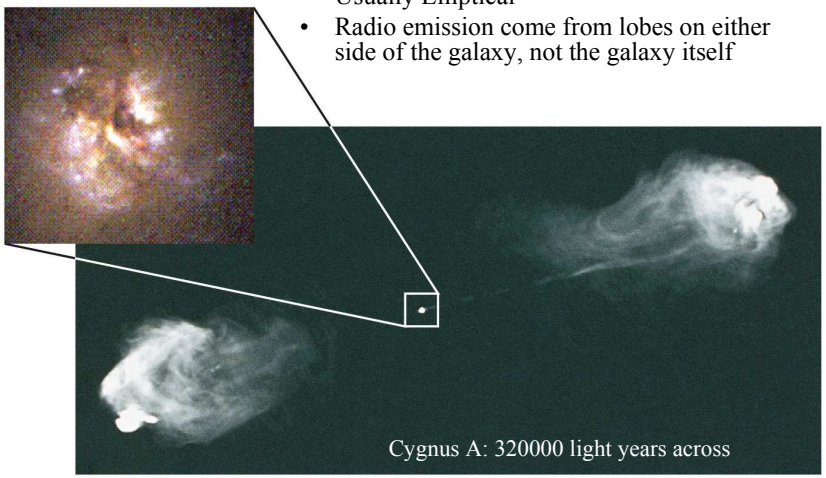
- There are no quasars in the nearby Universe *now*
- But there are some very energetic galaxies (about 1% of all galaxies)
  - Very bright, star-like nuclei
  - Often, energetic outflows of matter from the nucleus
- Called **active galaxies**
- Types of active galaxies
  - **Seyfert galaxies**
  - **Radio galalxies**
- Like quasars, but not as energetic

Seyfert Galaxies

- Look like normal spiral galaxies, but with incredibly bright nuclei
- Potentially as bright as a trillion Suns!
- Brightness varies tremendously
- Over a few weeks it's brightness can change by the ENTIRE brightness of the Milky Way

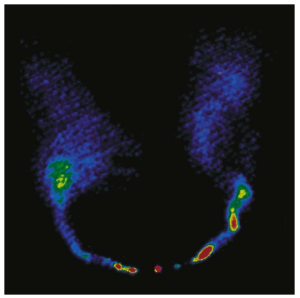
Radio Galaxies

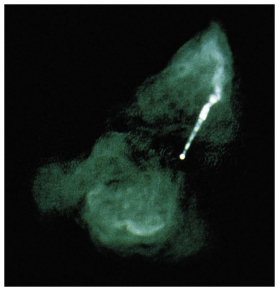
- Galaxies that emit large amounts of radio waves
- Usually Elliptical
- Radio emission come from lobes on either side of the galaxy, not the galaxy itself

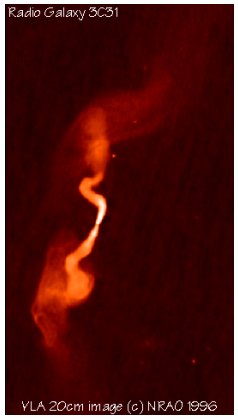


Radio Galaxies

- There are varying types of radio galaxies
- Called *radio loud* as they can be 10 million times as bright as the Milky Way at radio wavelengths

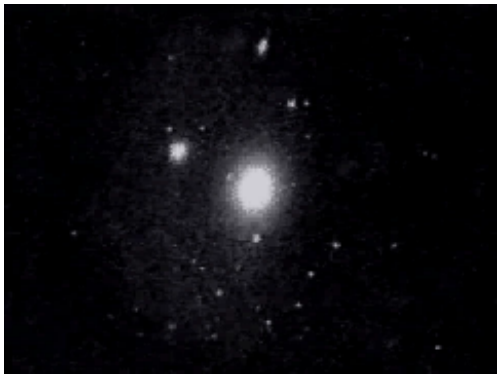






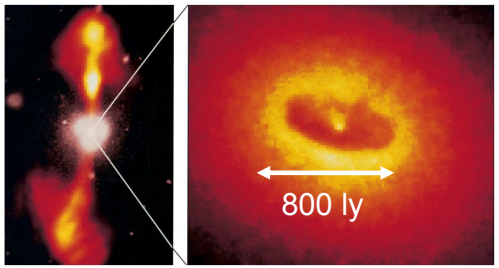
What is the power source for quasars and other active galaxies?

The Central Engine: Supermassive Black Holes



The Central Engine – Supermassive Black Holes

- Energy source for active galaxies
- Only thing compact enough and energetic enough

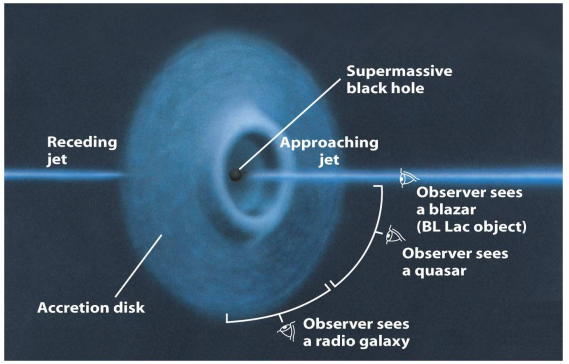


NGC 4261 in the Virgo Cluster

- Material falling into the black hole compresses and heats up
  - Emits tremendous amounts of energy
  - Some gas escapes via high-speed jets

A Unified Model

- Active galaxies and quasars have the same energy source (supermassive black holes)
- Orientation matters!



Quasars and Active Galaxies

- Supermassive black holes probably exist in most if not all galaxies' cores
- In the past, active galaxies were more common then now
- Were very powerful active galaxies at one time quasars?
- As the Universe evolved, the quasars calmed down
  - Turned off?
  - Became today's active galaxies?

TABLE 16-1 Galaxy and Quasar Luminosities

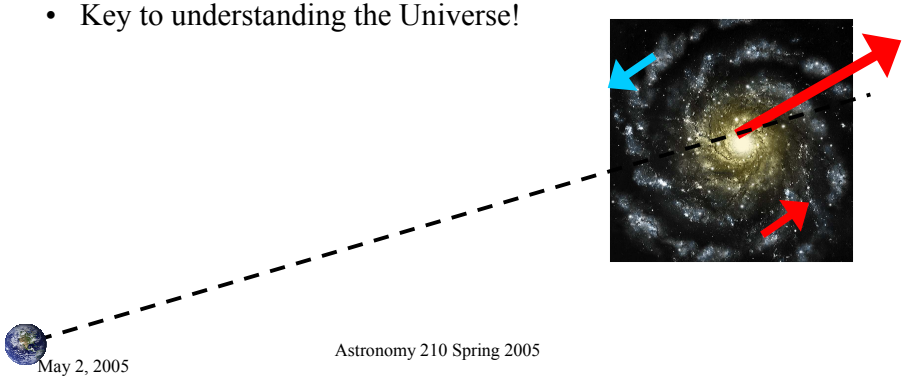
Object	Luminosity (watts)
Sun	4×10^{26}
Milky Way Galaxy	10^{37}
Seyfert galaxies	$10^{36} - 10^{38}$
Radio galaxies	$10^{36} - 10^{38}$
Quasars	$10^{38} - 10^{42}$

Think-Pair-Share

What would happen to our Galaxy if the supermassive black hole at the center were "fed"?

Redshift of Galaxies

- Most galaxies are moving away from us!
- The farther away, the faster they are moving away.
- What does this mean?
- Key to understanding the Universe!



What do you think?

- The Universe is expanding, how do you feel about that?

The 3rd Revolution

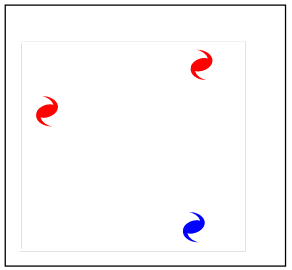
1. Copernicus and others: We are not the center of the solar system. The Earth is a typical planet.
2. Shapley and others: We are not the center of the Galaxy. The Sun is a typical star.
3. Hubble and others: We are not in the center of the Universe. The Milky Way is a typical galaxy.

Living in an Expanding Universe

Consider a large "box" containing many galaxies

- Total mass in box today: M_{today}
- Total volume in box today: V_{today}
- ***Density today*** $= M_{today} / V_{today}$

The Universe box



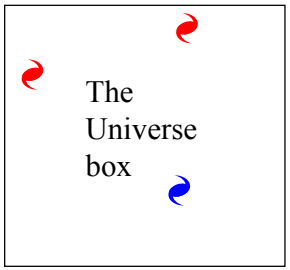
Tomorrow

How does the density of the Universe change with time?

Living in an Expanding Universe

How does the density of the Universe change with time? As the Universe expands:

- $M_{tomorrow}$ stays the same
- $V_{tomorrow}$ becomes larger
- Density $M_{tomorrow}/V_{tomorrow} \Rightarrow$ *smaller*



$$M_{tomorrow}/V_{tomorrow} < M_{today}/V_{today}$$

Density changes with time!

- Universe was denser the past
- Universe will be less dense in future

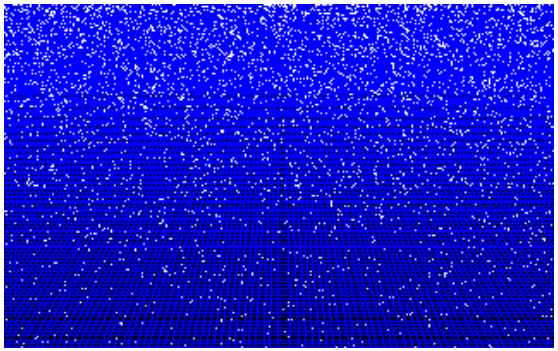
Putting it all together:

1. Earlier Universe was more dense
2. Earlier Universe was hotter.
3. The Universe is expanding.

The origin of the Universe can be described by the idea of the Big Bang. Where did the Big Bang happen? Remember the Universe is homog. & isotrop.

The Big Bang

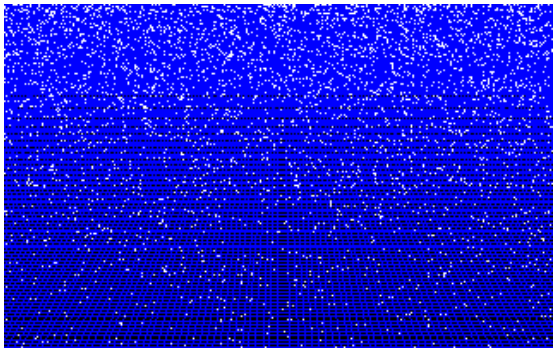
- No special points or locals
- Expansion of **all** space
- Big Bang has no center
- Happened everywhere
- Wherever you go, there was the big bang
- So as we talk about the very dense early universe, remember that we are talking about what happened not just far away, but right here! ...smooshed up small, but still right here!



http://www.anzwers.org/free/universe/bigbang.html

The Big Bang

- Occurred everywhere at once.
- Not an explosion into empty space.
- The Universe was suddenly filled with matter– hot and dense.
- A point, or infinite.
- The beginning of time and space.
- Expanding and cooling, eventually forming the stars and galaxies we see today.



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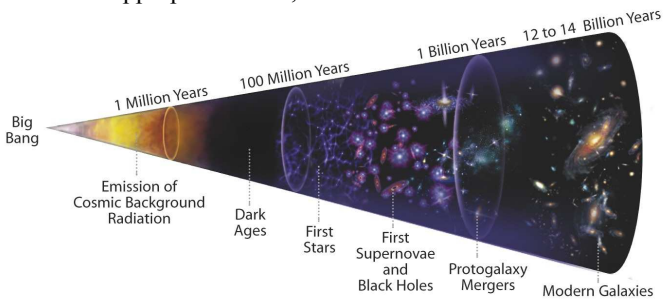
The Big Bang

- In the 1940s, extrapolating on Hubble's Law, George Gamow proposed the the universe began in a colossal "explosion" of expansion.
- In the 1950s, the term BIG BANG was coined by an unconvinced Sir Fred Hoyle who tried to ridicule it.
- In the 1990s, there was an international competition to rename the BIG BANG with a more appropriate name, but no new name was selected.



Living in an Expanding Universe

We know that galaxy spectra show redshifts
- Spectral lines shifted to red: longer wavelengths

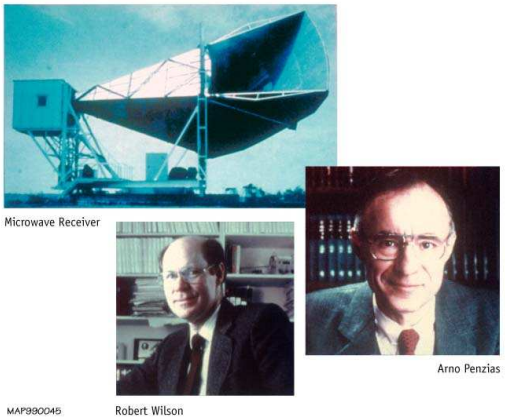
but: galaxy recession due to expansion of space
- "Doppler shift" not correct

Better to say that expansion stretches lengths
- Then, redshift comes from stretching of wavelength!

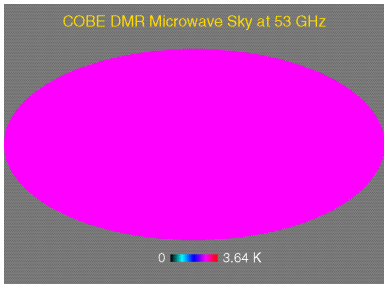
<u>What does this mean for photon energy?</u>
- Since wavelength increases
- And photon energy decreases with longer wavelength
- Photons lose energy as universe expands

The Early Universe was HOT!

- If the early Universe was so hot, we should be able to see it glowing. Right?
- Yep, we do! But, as the Universe expanded, it redshifted down to the microwave.
- Now it is called the Cosmic Microwave Background.
- First detected by Robert Wilson and Arno Penzias.

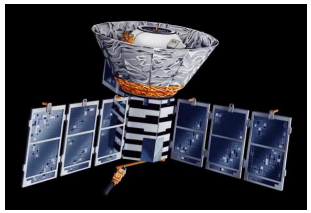


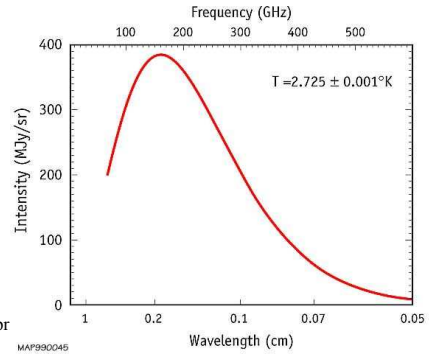
In Fact, a Rather Uniform Blackbody



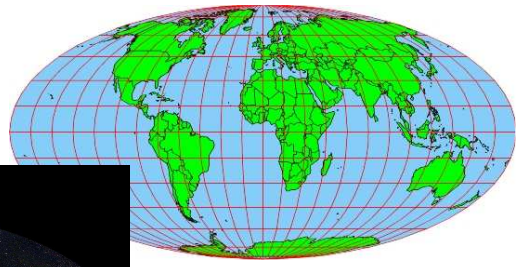
Cosmic Background Explorer (COBE) satellite (launched 1989)

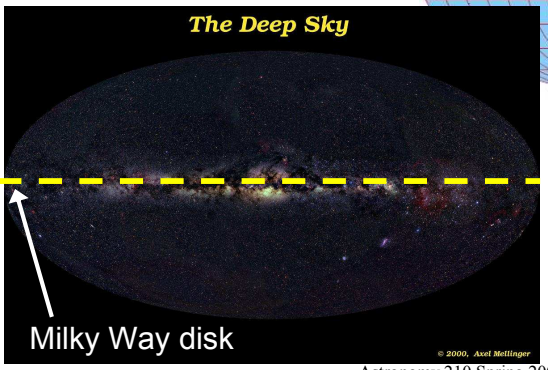
$$T \approx 3\ \mathrm{K}$$





How to Understand Sky Maps



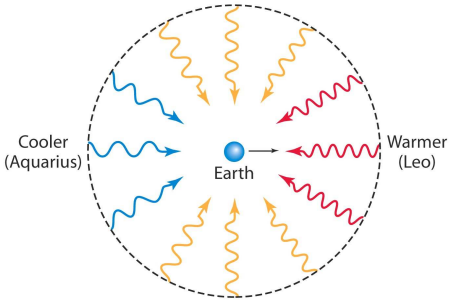


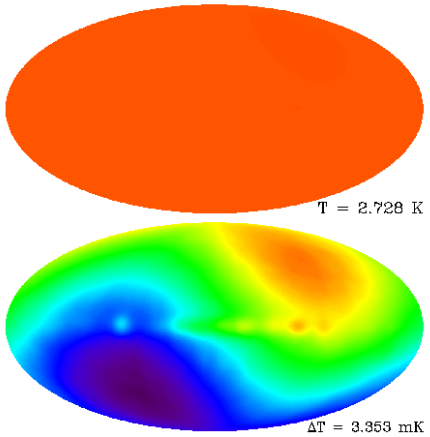
Small Scale Variations

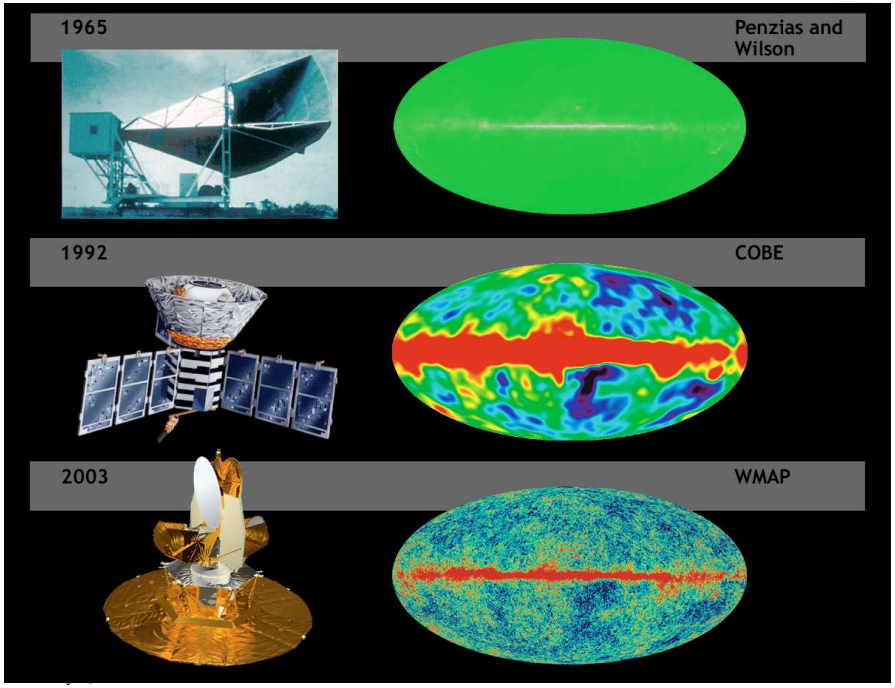
- There are small scale variations in the CMB
- Largest variations are due to motions
  - Motions of the Sun around the Galaxy
  - Motions of the Galaxy in the Local Group
  - Motions of the Local Group in our supercluster
- There are also Galactic sources of microwave radiation
- First, we have to remove these variations…
  - What is left is cosmological - from the Big Bang

Anisotropy

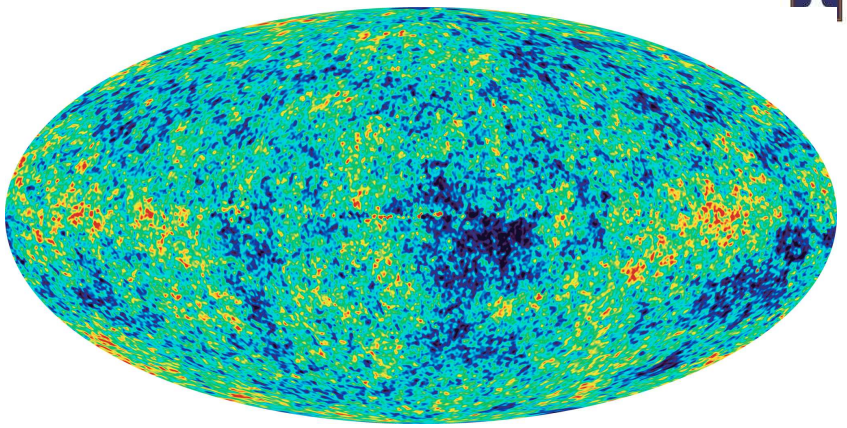
- Small scale variation, due to our movement with respect to the background.
- We are moving about 600 km/s or 1.3 million mph.
- Remove this and MW Galaxy component.



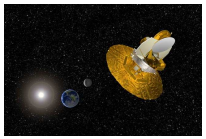




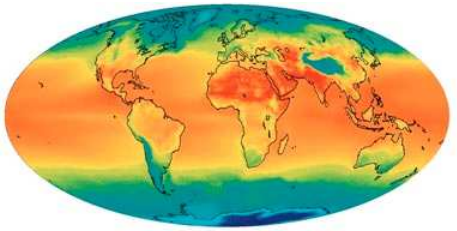
WMAP Results



All sky map from 2003. More sensitive and higher resolution than Cobe. Variation less than 1 part in 100,000.

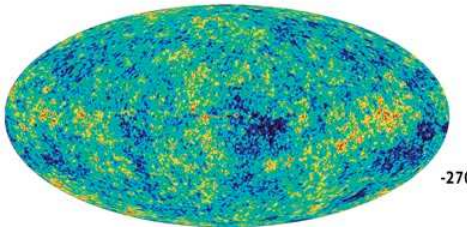


WMAP took a "baby picture" of the Universe– only 400000 yrs old.



Earth Temperatures

-63° -13° 37°
Centigrade
June 1992

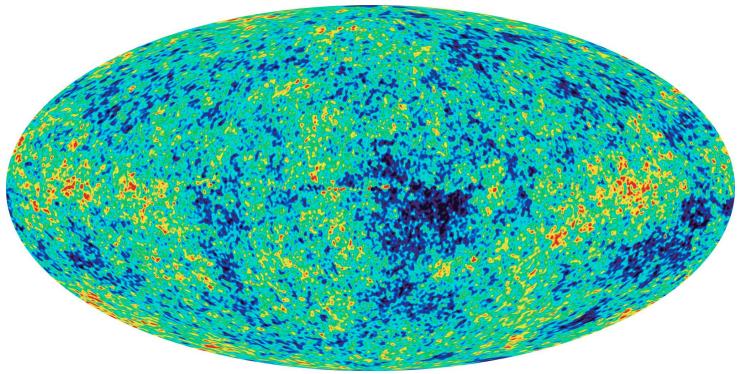


Microwave Sky Temperatures

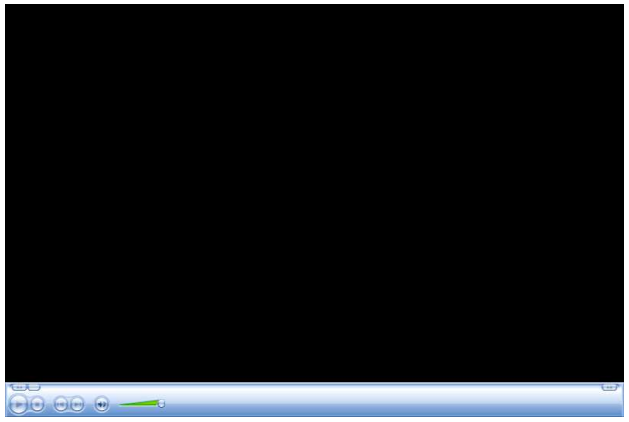
-270.4252° -270.4250° -270.4248°
Centigrade
380,000 Years after Big Bang

The Seeds of Galaxies

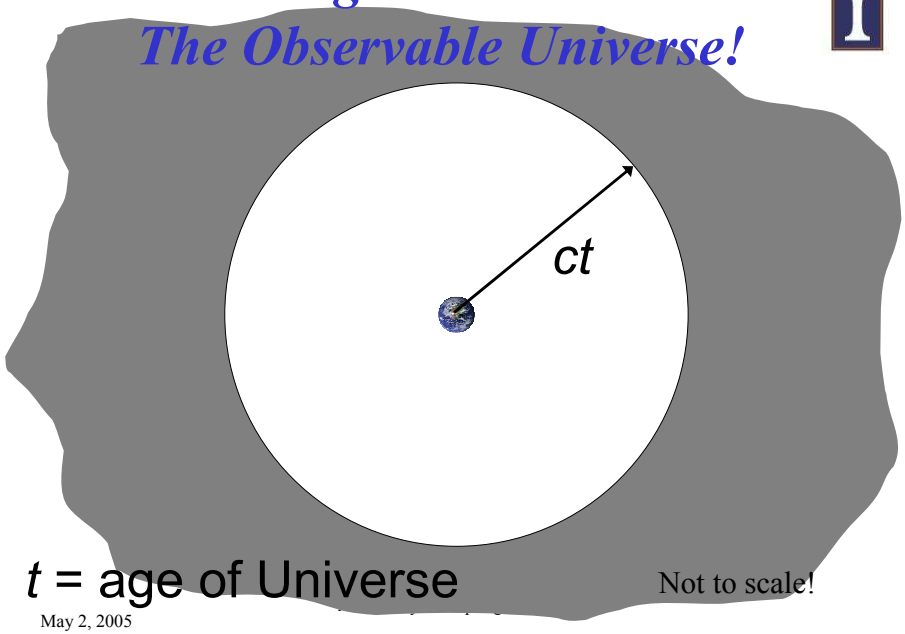
These small perturbations in temperature are the fluctuations that caused the large scale structures we see today. This is what formed the galaxies. All of this happened only 400,000 years after the Big Bang.



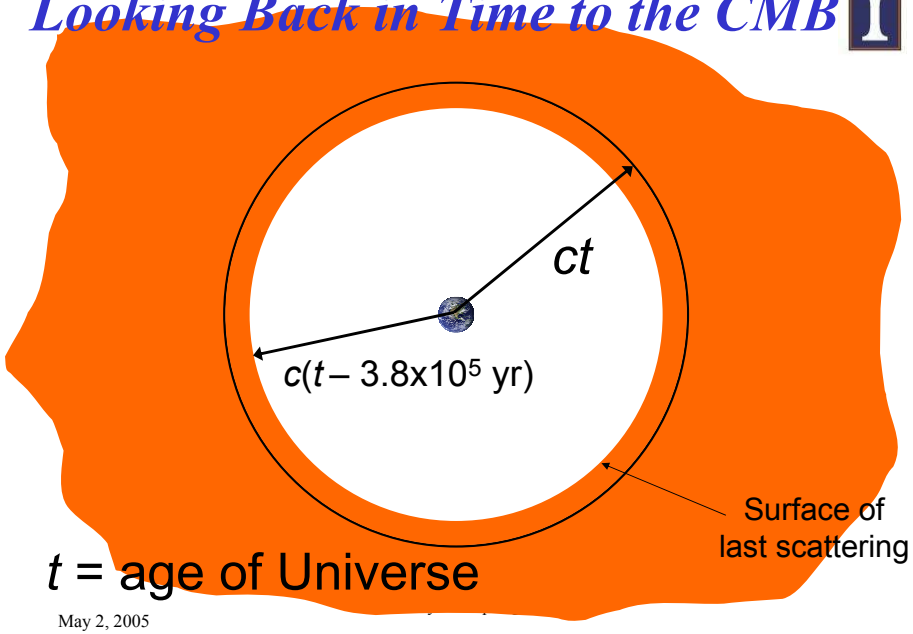
Galaxy Structure



Looking Back in Time: The Observable Universe!

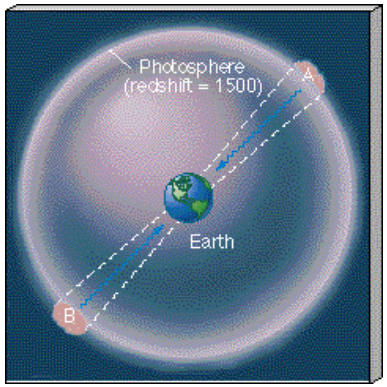


Looking Back in Time to the CMB



The Isotropy Problem

- The CMB looks very much the same all over the sky
- Thus, regions A and B were very similar to each other when the radiation we observe left them
- But there has not been enough time since the Big Bang for them ever to have interacted physically with one another
- Why then should they look the same?



THE VERY EARLY UNIVERSE

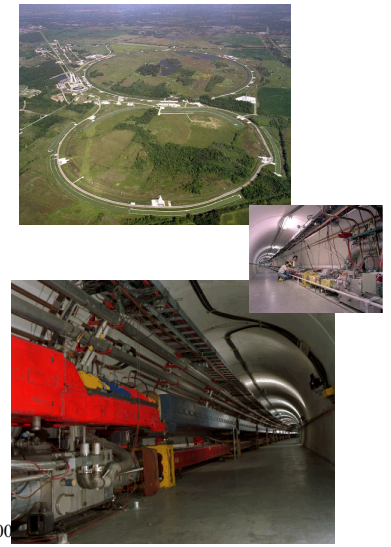
Since Big Bang works well so far, we have confidence to think about times earlier still:

t << 1 sec !

- Temperature and energies are ***ultrahigh***

Q: How to probe such high energies?
Hint: it's in the Great State of Illinois

Fermilab



INNER SPACE / OUTER SPACE

Fermilab is a telescope!

Probes conditions in Universe at 10^{-12} s

Universe was 10^{12} K hot!

…but also…

"The Universe is the poor man's accelerator"

Probes conditions inaccessible at laboratories