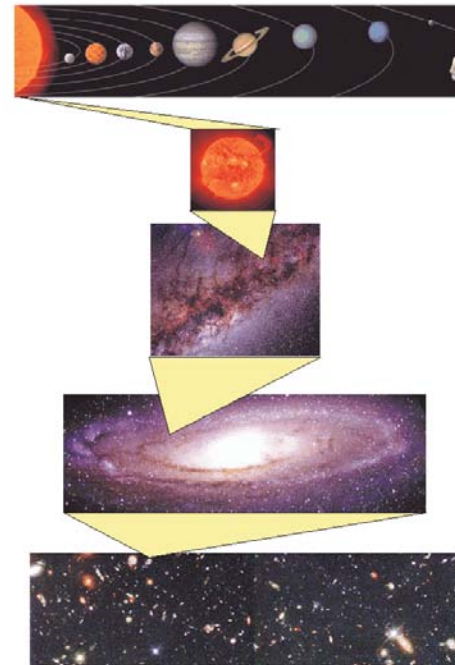




- Last Homework is due Friday– 11:50 am
- Honor credit– need to have those papers this week!
- Estimated grades are posted.
 - Does not include HW 8 or Extra Credit
- THE FINAL IS DECEMBER 15th: 7-10pm!

Dec 8, 2003

Astronomy 100 Fall 2003



Dec 8, 2003

Astronomy 100 Fall 2003

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?

Outline



- The Universe is expanding.
- The early Universe was dense.
- The early Universe was hot.
- The Big Bang explains the Early Universe.
- Age of the Universe is 13.7 billion years to about 1%.
- Cosmic Microwave Background
- Seeds of Galaxies.

Dec 8, 2003

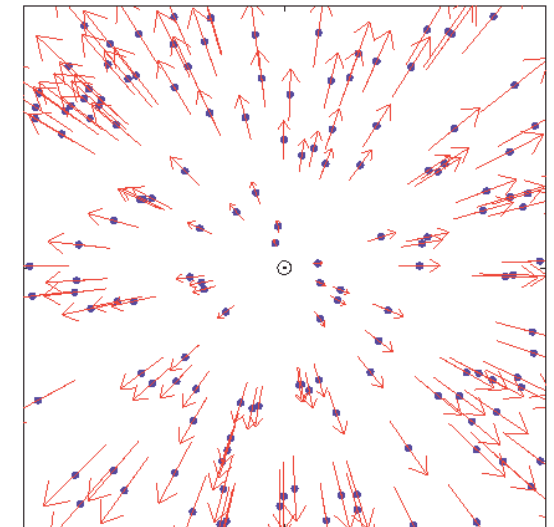
Astronomy 100 Fall 2003

What does Hubble's Law mean?



In a homogenous Universe, what does the farther away the faster they move away mean?

GALAXY MOTION: ARTIST'S CONCEPTION



☉ = YOU ARE HERE

Dec 8, 2003

Astronomy 100 Fall 2003

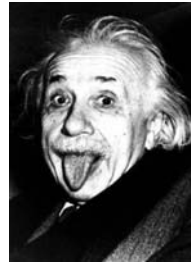
Interpretation: View of the Universe



Egoist view– We are at the center
of the Universe.



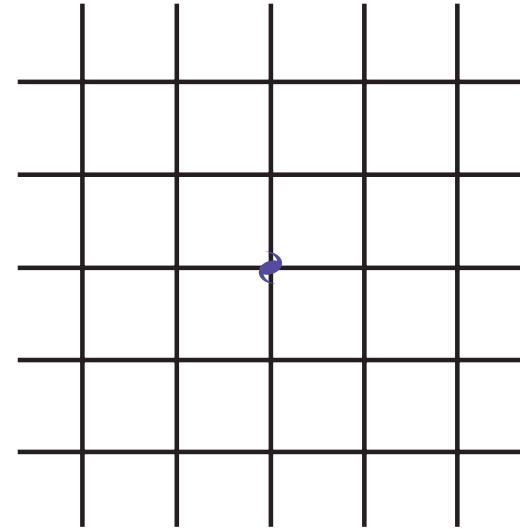
Einstein's view– The Universe is
expanding, and there is no center!



Dec 8, 2003

Astronomy 100 Fall 2003

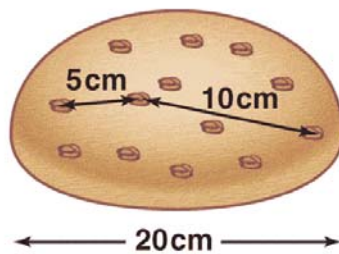
Dude, The Universe is Expanding.



Dec 8, 2003

Astronomy 100 Fall 2003

Analogy– Raisin Bread



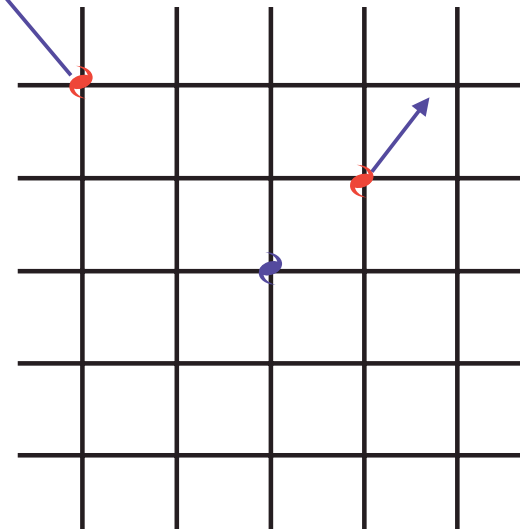
MAP890404

Raisins stay the same size.

Dec 8, 2003

Astronomy 100 Fall 2003

Wow. The Universe is Expanding.



Dec 8, 2003

Astronomy 100 Fall 2003



~~Expanding into What?~~

Dec 8, 2003

Astronomy 100 Fall 2003



Reality

- The analogies are just to help us visualize, don't get stuck in the specifics.
- The Universe has no center
- The Universe has no edge
- Concept of time and space began with the Universe, can not apply the concepts so easily.
- The Doppler Effect is not the real reason that galaxies are redshifted. As space expands, it stretches the light.

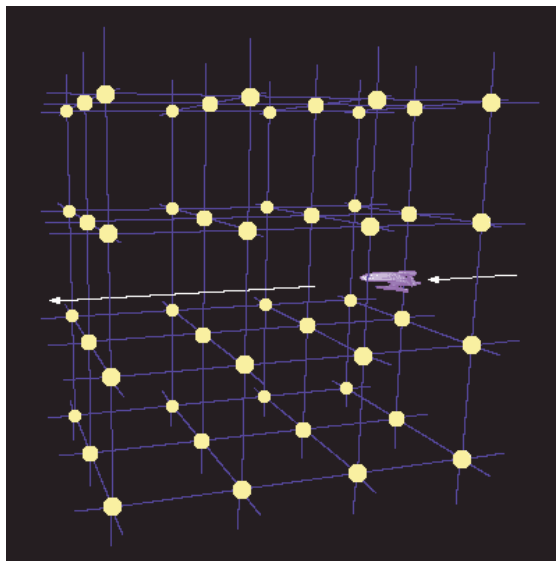
Dec 8, 2003

Astronomy 100 Fall 2003



The Edge of the Universe?

- If the Universe consisted of only 48 stars?
- The spaceship, would never really see the edge of the Universe.



Dec 8, 2003

Astronomy 100 Fall 2003

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



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 Milkyway is a typical galaxy.

Dec 8, 2003

Astronomy 100 Fall 2003

Living in an Expanding Universe



Consider a large “box” containing many galaxies

- Total mass in box today: M
- Total volume in box today: V_{today}
- $\text{Density today} = M/V_{\text{today}}$

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

- M stays the same
- V becomes larger
- Density M/V *smaller*

Density changes with time!

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

Dec 8, 2003

Astronomy 100 Fall 2003

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!**

What does this mean for photon energy?

- Since wavelength increases
- And photon energy decreases with longer wavelength
- Photons lose energy as universe expands

Dec 8, 2003

Astronomy 100 Fall 2003

Putting it all together:



1. Earlier Universe was denser.
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. Currently the best explanation.

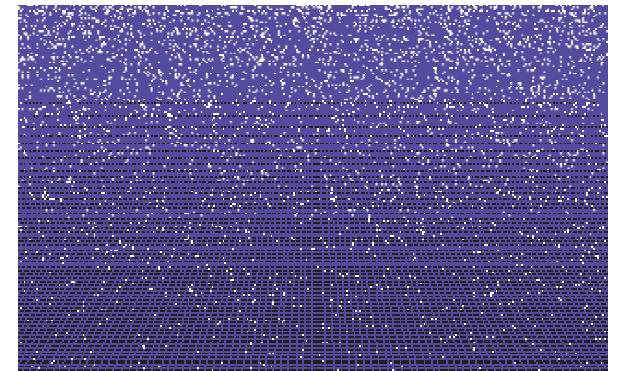
Dec 8, 2003

Astronomy 100 Fall 2003

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.

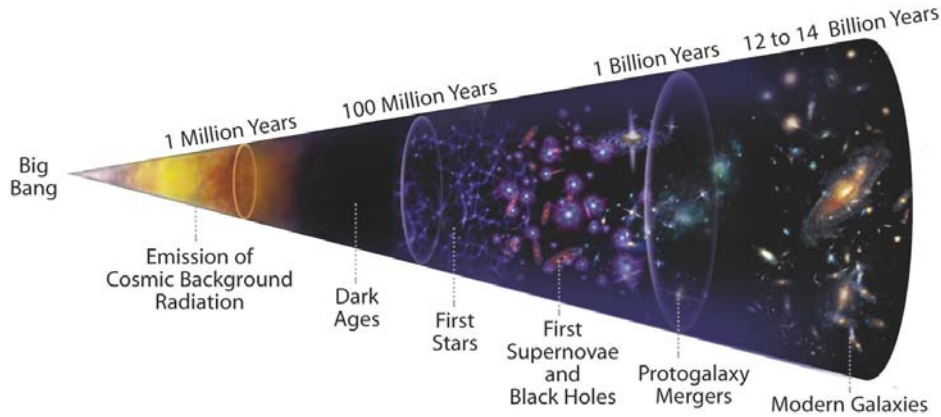


Dec 8, 2003

Astronomy 100 Fall 2003

<http://www.answers.org/free/universe/bigbang.html>

The Backward Ride



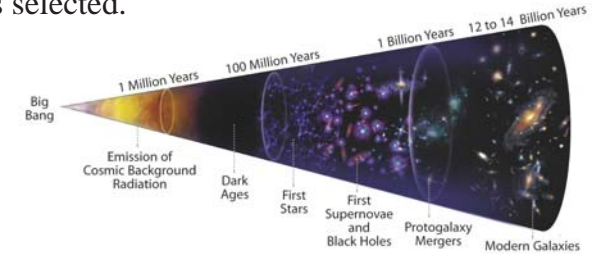
Dec 8, 2003

Astronomy 100 Fall 2003

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.



Dec 8, 2003

Astronomy 100 Fall 2003

The Age of the Universe



Expansion implies finite age ($\neq \infty$)

Hubble: $v = HD$

D: distance between 2 particles (galaxies)

If constant speed,
distance = speed x time
 $D = vt$

Put it all together:
 $v = HD = H(vt) = Htv$
so: $Ht = 1$

$$t = 1/H$$

"expansion age" of Universe

Dec 8, 2003

Astronomy 100 Fall 2003

The Age of the Universe



Other methods to date the Universe:

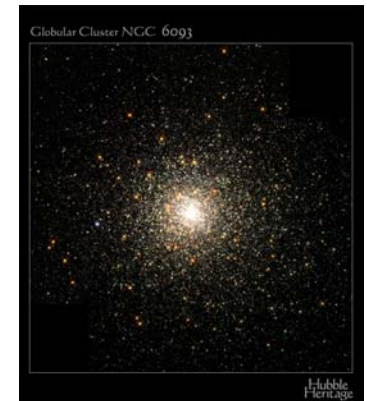
- Radioactivity in Rock
uranium decays to lead
decay is "clock": tells time since uranium made in star
age > 10 billion yrs



- Globular clusters
oldest stars
age about 13 billion years

Best estimate (WMAP good to 1%):

- Age $t = 13.7$ billion years



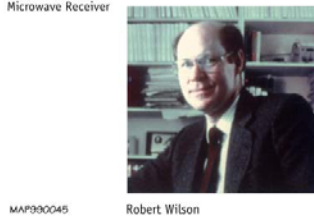
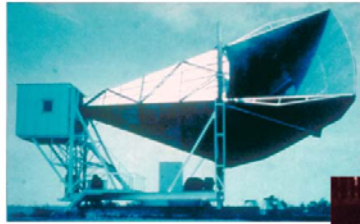
Dec 8, 2003

Astronomy 100 Fall 2003

But the Early Universe was *HOT*!



- If the early Universe was so hot, we should be able to see the blackbody radiation, redshifted. Right?
- Yep! It's redshift down to the microwave. Called the Cosmic Microwave Background.
- First detected by Robert Wilson and Arno Penzias.

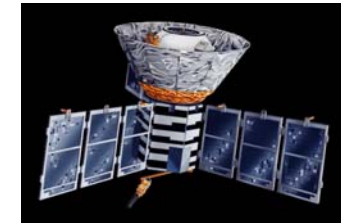
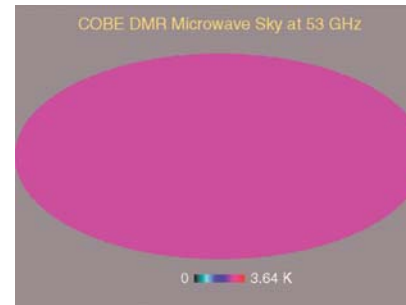


MAP990045

Dec 8, 2003

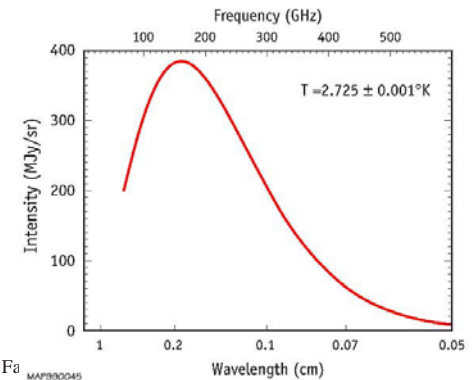
Astronomy 100 Fall 2003

In Fact a Rather Uniform Blackbody



Cosmic Background Explorer (COBE) satellite (launched 1989)

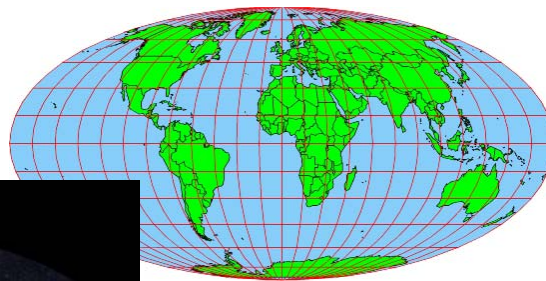
$$T \approx 3 \text{ K}$$



Dec 8, 2003

Astronomy 100 Fa

How to Understand Sky Maps



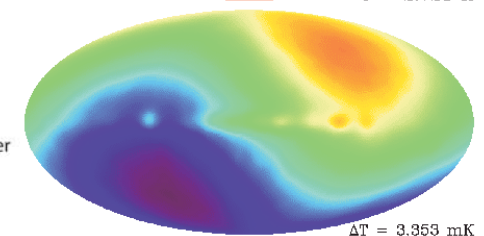
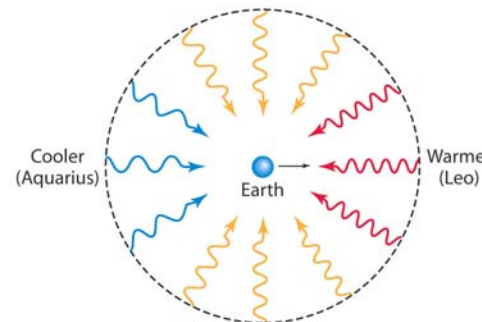
Dec 8, 2003

Astronomy 100 Fall 2003

Small 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.

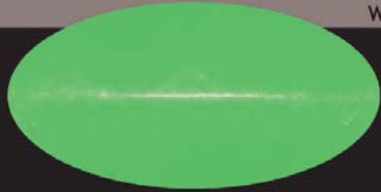


100 Fall 2003

1965



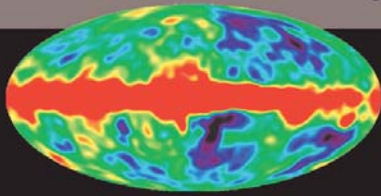
Penzias and
Wilson



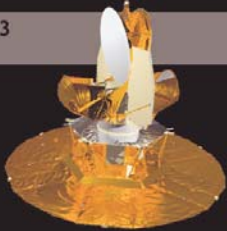
1992



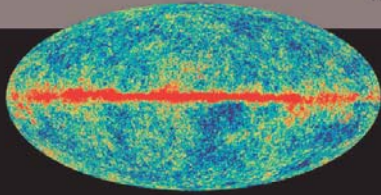
COBE



2003



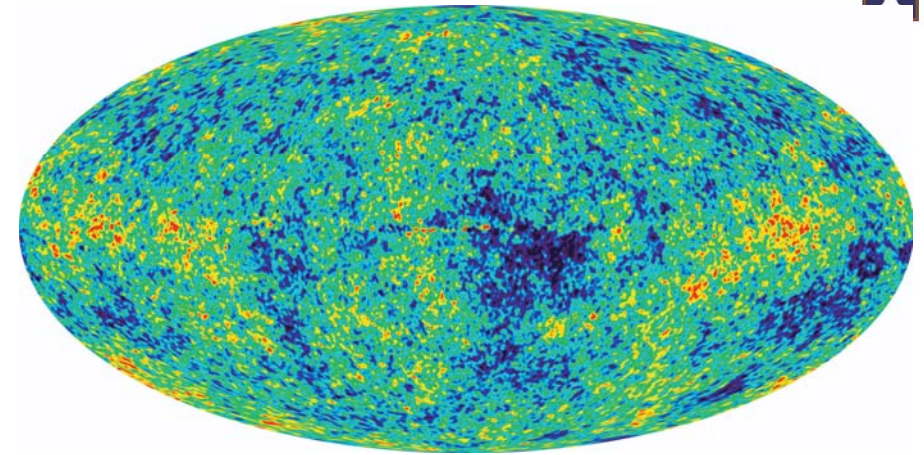
WMAP



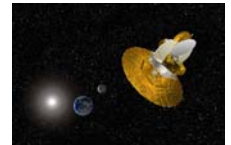
Dec 8, 2003

Astronomy 100 Fall 2003

WMAP Results



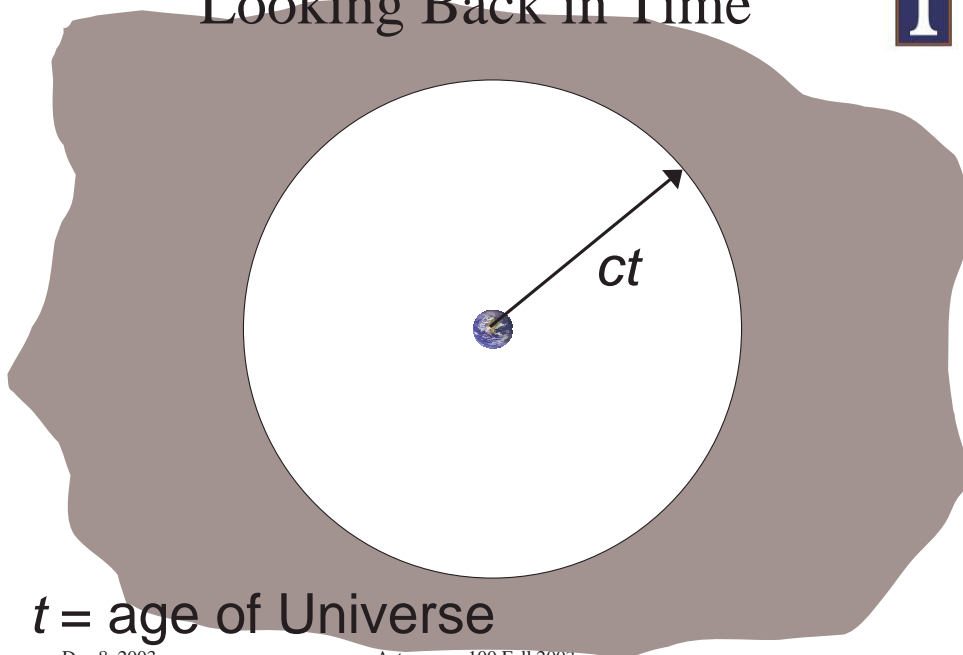
All sky map from this year. More sensitive and higher resolution than Cobe. Variation less than 1 part in 100,000.



Dec 8, 2003

Astronomy 100 Fall 2003

Looking Back in Time



Dec 8, 2003

Astronomy 100 Fall 2003

The Hubble Deep Field

Looking at the Baby pictures of the Universe.

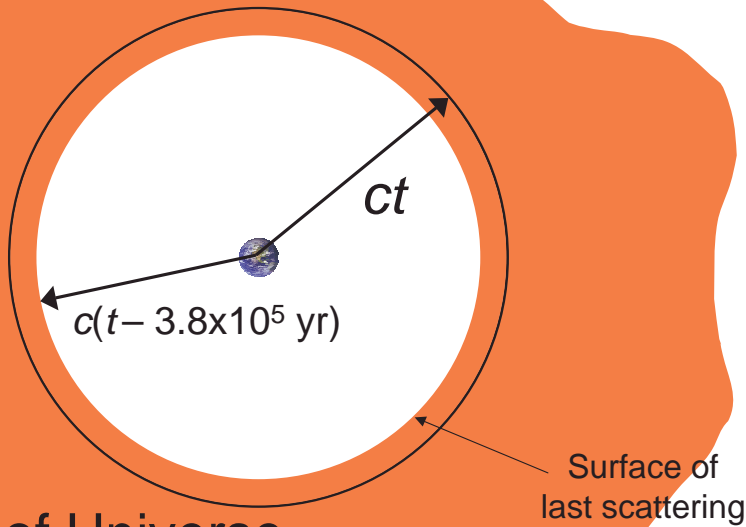
<http://osite.stsci.edu/pubinfo/pr/96/01/HDF.mpg>



Dec 8, 2003

Astronomy 100 Fall 2003

Looking Back in Time to the CMB



$t = \text{age of Universe}$

Dec 8, 2003

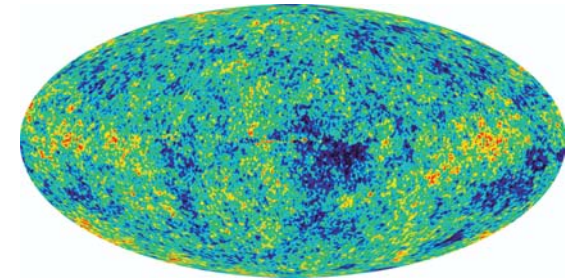
Astronomy 100 Fall 2003

The Seeds of Galaxies



These small perturbations are the fluctuations that caused the large scale structures we see today. All of this happened only 380,000 years after the Big Bang.

<http://map.gsfc.nasa.gov/mig/030651/030651b.mov>



Dec 8, 2003

Astronomy 100 Fall 2003