Astronomy 210

HW #11 Due next Weds.

Final is May 10th.

Review session is planned.

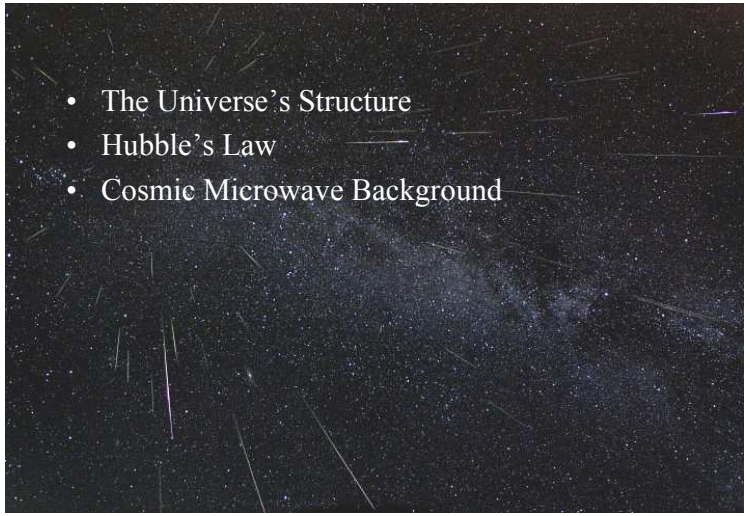
This Class (Lecture 39):

The Big Bang

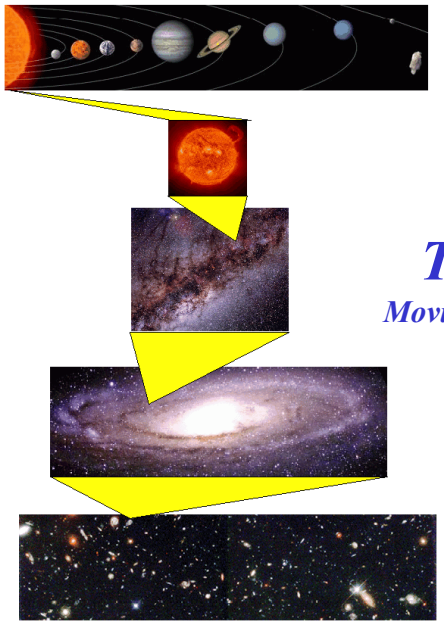
Next Class:

The Big Bang

Outline



- The Universe's Structure
- Hubble's Law
- Cosmic Microwave Background

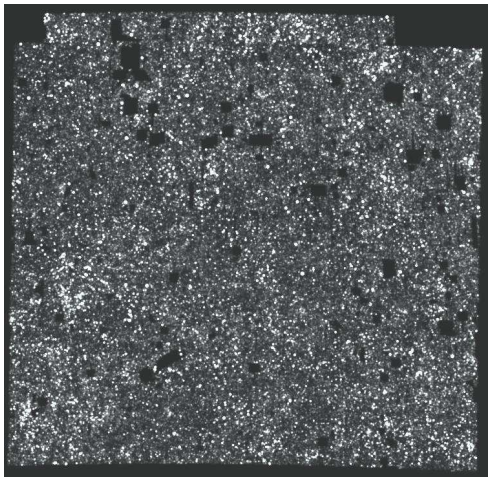


Astronomy: The Big Picture

Moving from our Galaxy outward!

The Universe

- On small scales– clumpy
- On large scale– smooth
  - 4 deg x 4 deg
  - Each point is a Galaxy
  - About 710,000

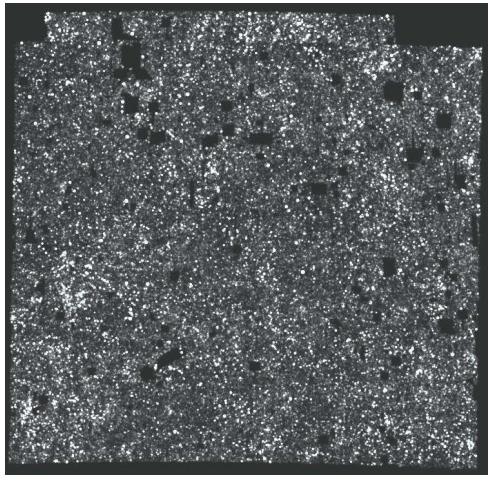


 http://www-int.stsci.edu/~postman/deeprange.html

The Universe

The Universe is

1. Homogeneous (gal's uniformly fill space)
2. Isotropic (looks same in all directions)
   - These are the starting points for our Cosmological journey



http://www-int.stsci.edu/~postman/deeprange.html

How are Galaxies Moving?

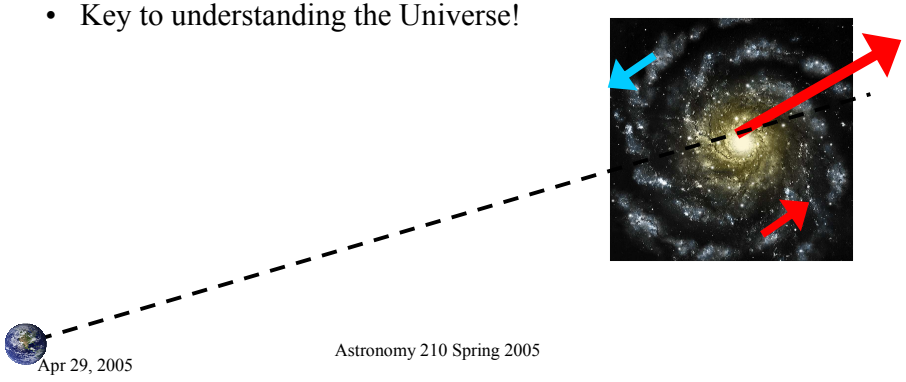
It's 1928 and Edwin Hubble is measuring how galaxies move by measuring the velocity WRT us.

What does he find?

a) More galaxies receding than approaching.
b) More galaxies approaching than receding.
c) About equal numbers of each.

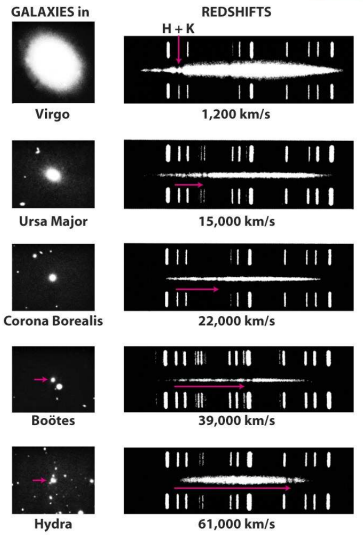
Redshift of Galaxies

- 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!



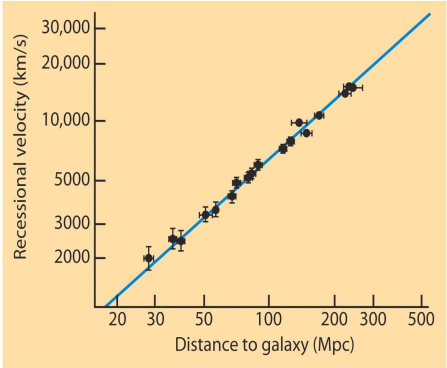
Redshifted Galaxies

- Hubble observed that the spectrum lines of most galaxies are **redshifted**
- Redshift: $z = (\lambda_{obs}-\lambda_{em})/\lambda_{em}$
- At low redshifts, z<<1, $v = cz$



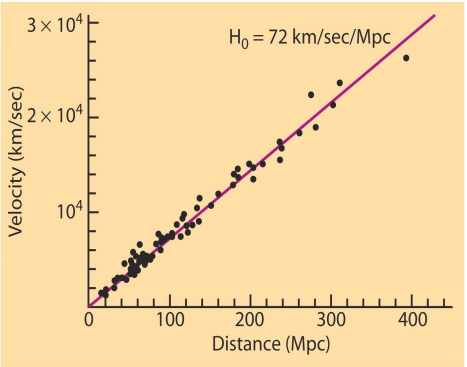
The Hubble Law

- Calculate velocity from Doppler and distance from Cepheid variables
- $V = H_o \times D$
  - Where v is velocity, d is distance, and H_o is the Hubble constant
- Current best value is H_o=72 km/s/Mpc



Redshift and Distance

- The Hubble Law gives us a new way of finding distances
- Remember,
  - $v=cz$
  - $v=H_o d$
- Therefore, $d=cz/H_o$!
- We can now measure distances to extremely distant galaxies!



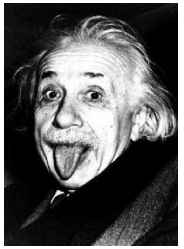
Apply it?

- In a homogenous Universe, what does the farther away the faster they move away mean?
- Draw it.

Interpretation: View of the Universe

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

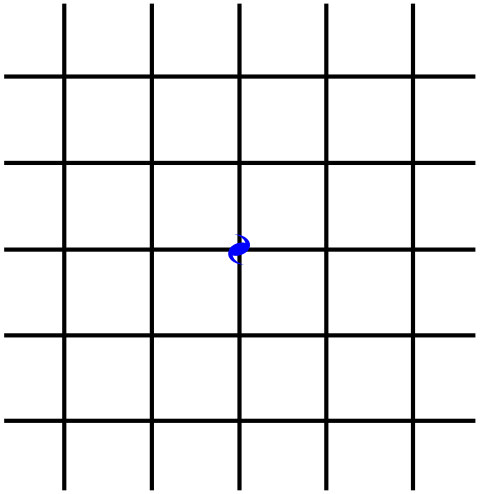
Einstein's view– The Universe is expanding, and there is no center!



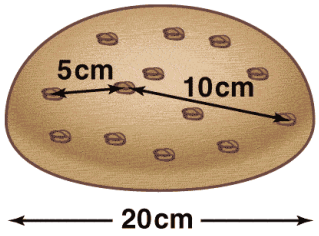
The Expanding Universe

- To describe the motion of all the galaxies in the Universe, we must use General Relativity (due to the gravity effects)
- General Relativity tells us that we live in an *expanding Universe*.
  - Einstein didn't buy it at first, so made a cosmological constant to get rid of it.
- In other words, space is stretching in all directions. This completely explains Hubble's Law.
- Overhead demo.

Dude, The Universe is Expanding.



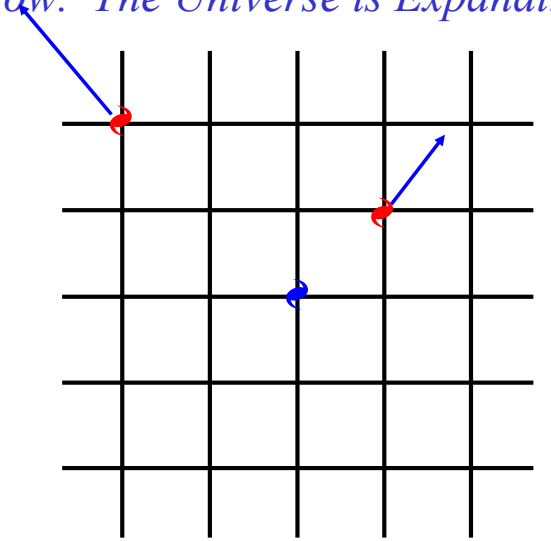
Analogy– Raisin Bread



MAP980404

Raisins stay the same size.

Wow. The Universe is Expanding.



What do you think?

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

~~Expanding into What?~~

Reality

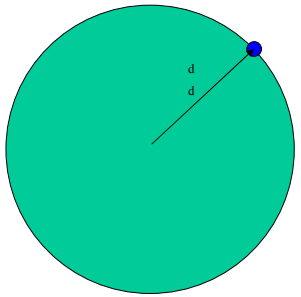
- The analogies are just to help us visualize, don't get stuck in the specifics.
- The Universe has no center.
- The Universe has no edge.
- Concept of time and space began with the Universe, can not apply the concepts so easily.

http://universe.gsfc.nasa.gov/images/reach-for-the-universe.jpg

How does the Universe Expand?

E_{tot} = KE + PE = const

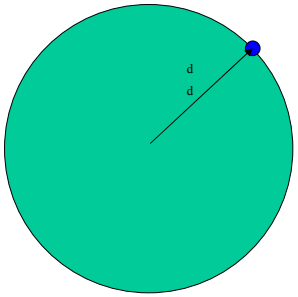
if < 0 then bound ⇒ collapse



and v = Hd

How does the Universe Expand?

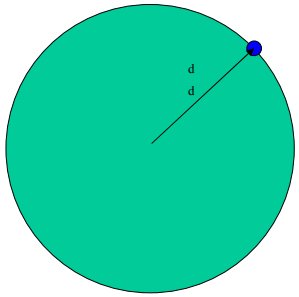
If d(t) = a(t) r, where r is the physical distance at some time t=0, then we can rewrite as



Also

How does the Universe Expand?

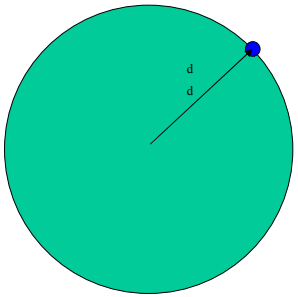
As



This is the Friedman equation of the Universe

How does the Universe Expand?

For borderline case, $E_{tot} = 0 \Rightarrow \kappa=0$



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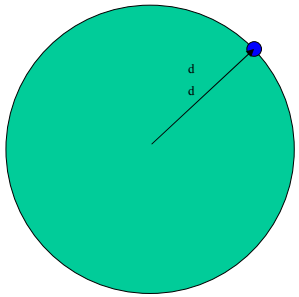
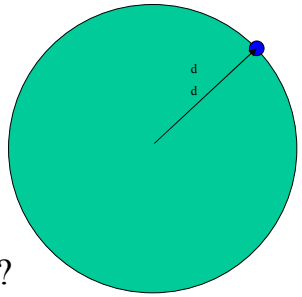


How does the Universe Expand?

Put $t = t_0$ for today.

Today we want to see a(t) = 1, so

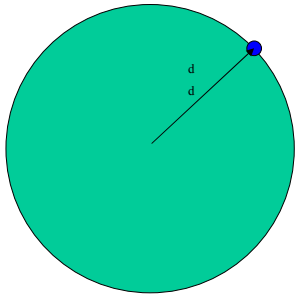


So, what is the age of the Universe?

$$\Rightarrow t = \frac{2}{3}\frac{1}{H} = 10 \text{ billion years}$$

How old?

Is 10 billion reasonable?



Age of the solar system?

4.5 billion

Age of globular clusters?

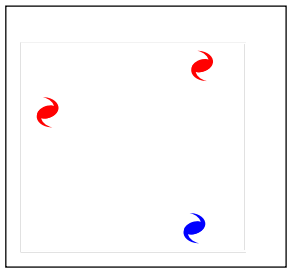
10-12 billion

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



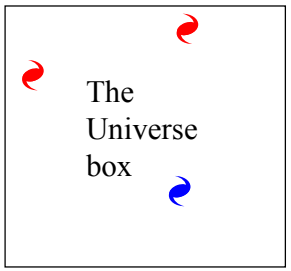
Tomorrow

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

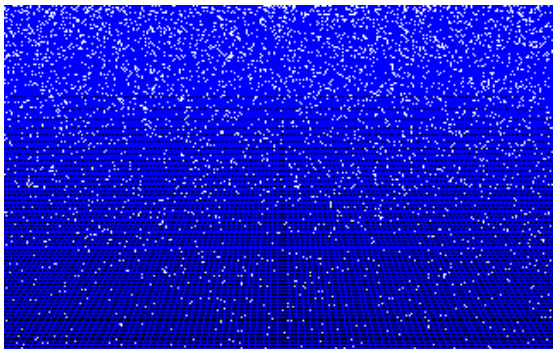
Putting it all together:

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

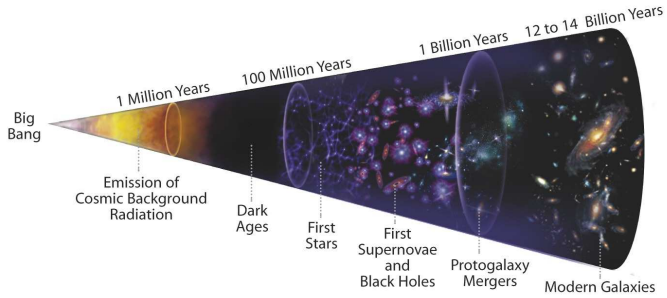
- Occurred everywhere at once.
- Not an explosion into empty space.
- The Universe was suddenly filled with matter– hot and dense.
- A point, or infinite.
- The beginning of time and space.
- Expanding and cooling, eventually forming the stars and galaxies we see today.



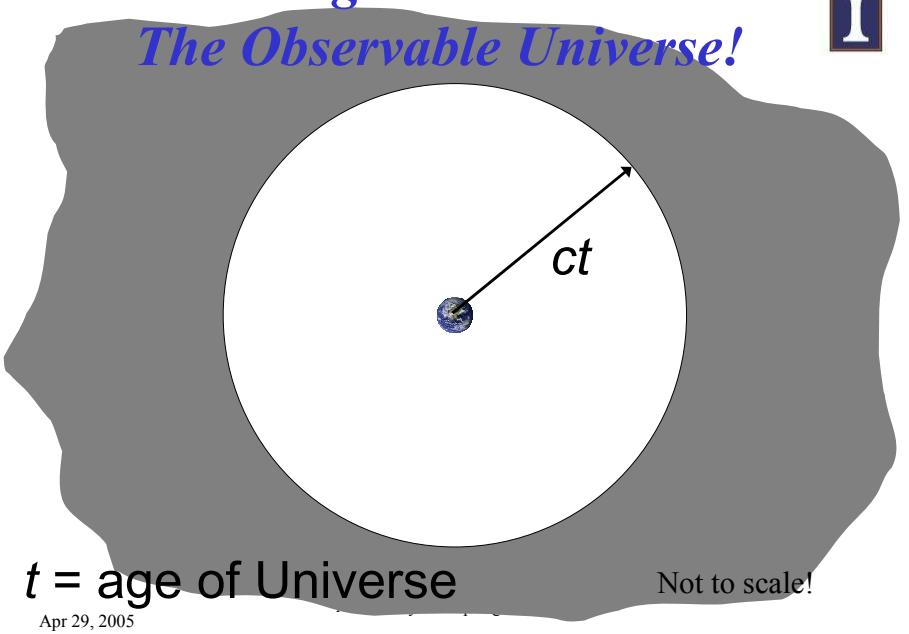
http://www.anzwers.org/free/universe/bigbang.html

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.



Looking Back in Time: The Observable Universe!

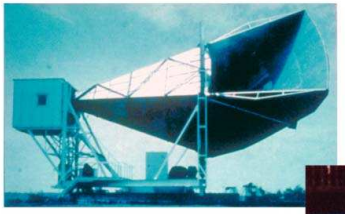


t = age of Universe

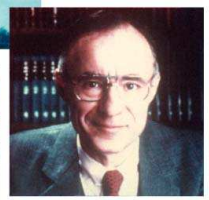
Not to scale!

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.


Microwave Receiver


Robert Wilson


Arno Penzias

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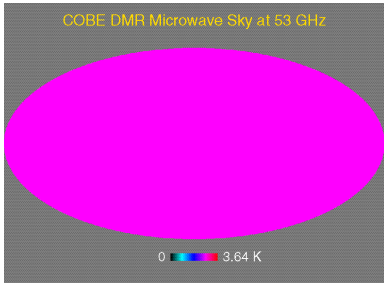
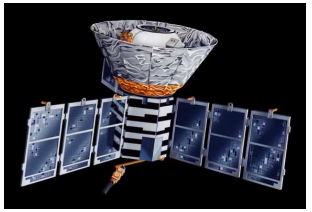
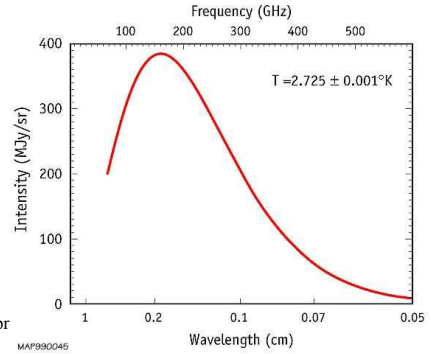
A Rather Uniform Blackbody

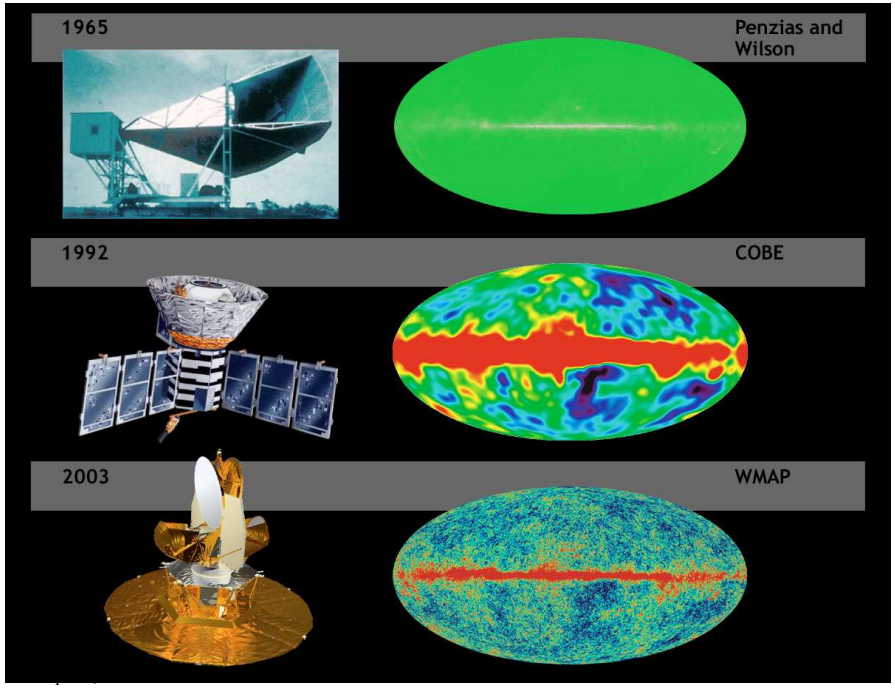




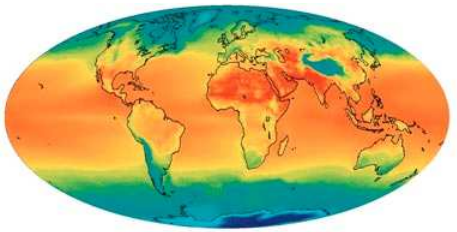
Cosmic Background Explorer (COBE) satellite (launched 1989)

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



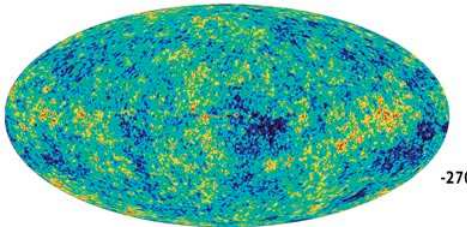


WMAP took a "baby picture" of the Universe– only 400000 yrs old.



Earth Temperatures

-63° -13° 37°
Centigrade
June 1992



Microwave Sky Temperatures

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