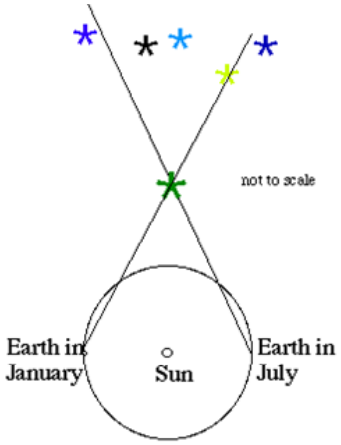
Today

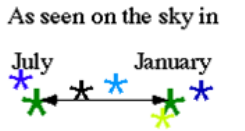
- Announcements:
  - No one got a perfect score on Exam #2, so I will make the exam out of 39
  - HW#8 is due 26 March at 8:00am.
  - Watch for the chance to vote on the Spring Break Stories.
- The size of the Universe
- The Big Bang

How do we determine distances?

- Radar – nearby things like the Sun
- Parallax – 1 arcsec motion 1 parsec (pc) = 3.24 ly
- Spectroscopic parallax – use location on the Hertzsrpung Russell diagram

Stellar Parallax





Star distances are measured in units of the distance from the Sun to the Earth, the Astronomical Unit. The nearer the star, the larger is the angle (called the parallax) between the January and the July observations.

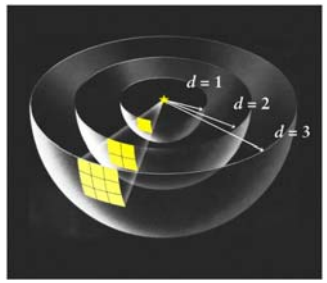
1 arcsec corresponds to a distance of 1 parsec (pc) = 3.24 ly

Distances to 300 ly can be measured this way

Why is there always r^2? I hate r^2.

Inverse square law

$$\text{intensity} = \frac{L[\text{Watts}]}{4\pi d^2}$$



If we know L the luminosity (measured in watts), and measure the intensity, we can determine d, the distance to the source

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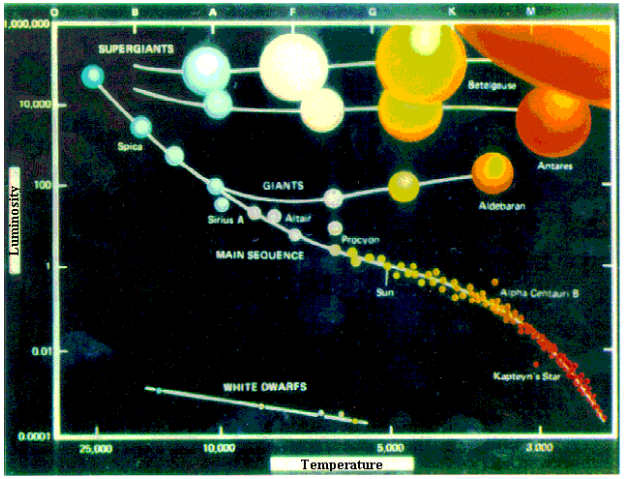
Hertzsprung-Russell Diagram



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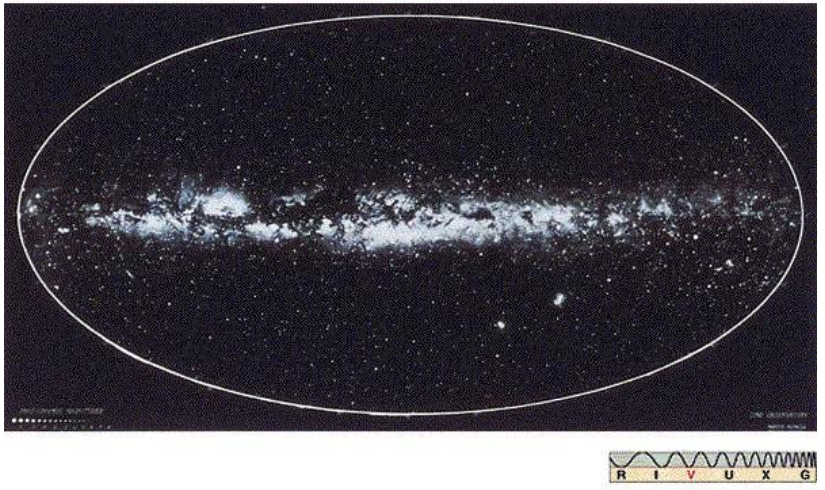
Map of the night time sky



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The Great Galaxy in Andromeda – M31

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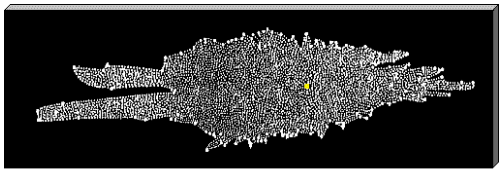
The Pace of Science

- Astronomers have studied the sky for thousands of years, but 90% of all astronomical information has been obtained obtained since 1900. For example, in 1900 scientists believed that the universe:
  - Was infinitely old
  - Was infinitely large
  - Contained only one galaxy (the Milky Way)
  - Did not change with time
  - Was uniform throughout (problem with Olber's paradox)
- All of these are false!

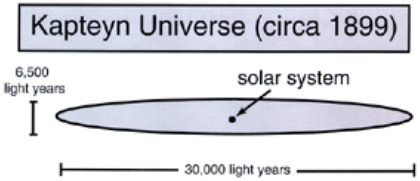
How do we know how far away galaxies are?

- Kypteyn Universe – study of visible stars



Map of all known stars- Distance guessed based on brightness

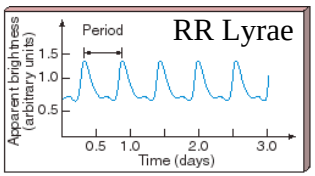
The picture people had until 1922

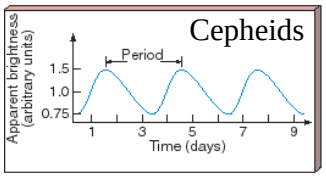


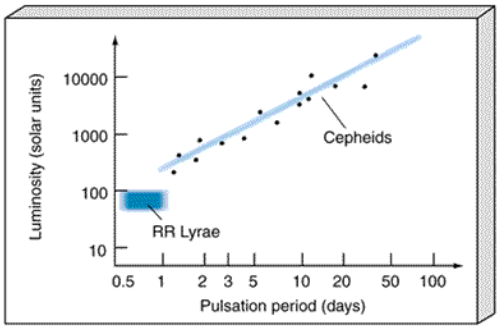
Edwin Hubble

- In 1922 Edwin Hubble measured the brightness of variable stars in the Andromeda galaxy.
- He discovered that the Andromeda galaxy was about 2.5 million light years away.
- He was the first person to demonstrate the size of the Universe and the the Milky Way is not the only galaxy.

Variable Stars – standard candles



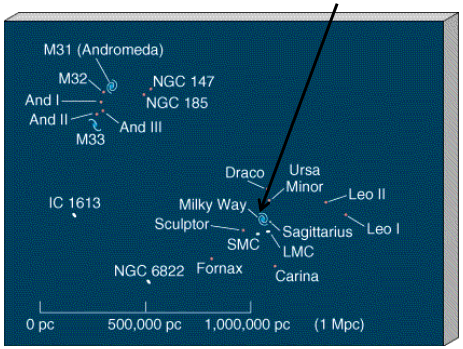


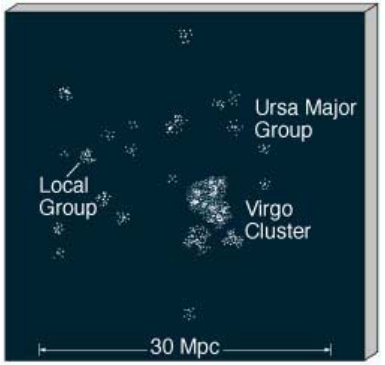


Once you find a variable star, you know how luminous it is.

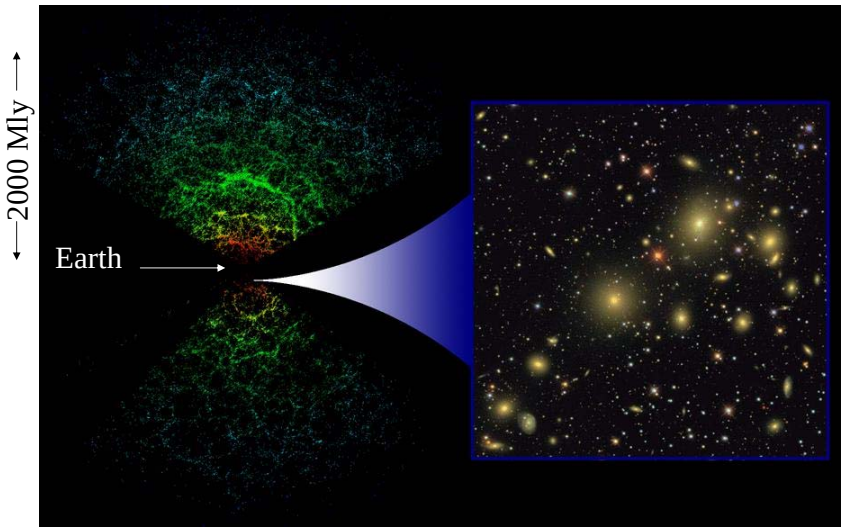
The structure of our local set of galaxies

You are here





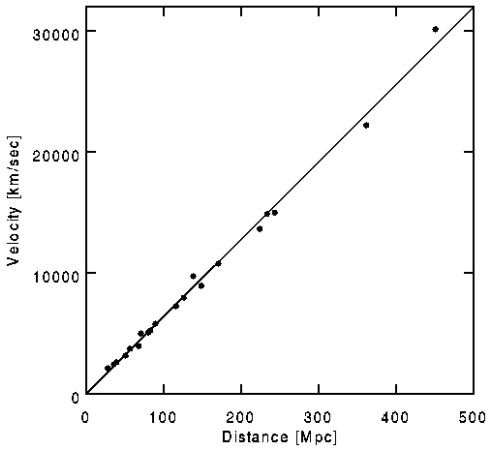
Sloan Digital Sky Survey of Galaxies



The Universe

- The Universe is not uniform.
- The 200 billion galaxies are clustered into large clumps with vase voids in between
- Why?
- Answer: It must have started that way and gravity is slowly pulling things together

Something Else!?! Hubble's Law



- The further away an object is, the faster it is receding.
- Speed = H_0 x d
- The Hubble Constant: H_0 = 77 km/s/Mpc

How Did the Universe Begin?

- It looks like the Universe started about 14 billion years ago and has been expanding (space stretching) ever since.
- The model of what happened is called the Big Bang.
- Why do we think so?
- There is a lot we don't understand. What came before? What caused the big bang? Why is there more matter than anti-matter in the Universe?

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Evidence for the Big Bang

- The expansion of the universe: All galaxies appear to be moving away from us.
- The abundances of the lightest elements produced in the Big Bang: the universe is mostly hydrogen and helium.
- The cosmic microwave background radiation: It looks like we are in the middle of a big oven with a temperature of ~3 Kelvin.

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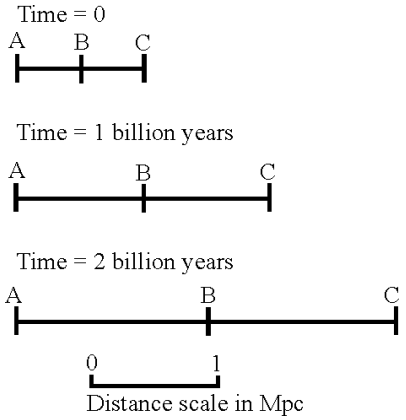
Hubble Expansion

- Because he was able to measure distance, Hubble observed that on average all galaxies seem to be moving away from us.
- The speed is related to distance. Galaxies farther away are moving faster.

No matter where you are, everything is moving away!



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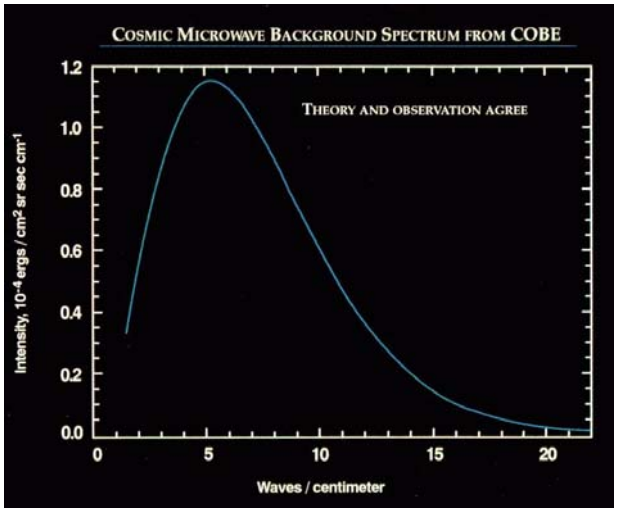
It looks like we are in the middle of an oven



The spectrum is identical to that of a blackbody at 3 Kelvin!

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Looking far away is like looking back in time.

What is we look very far back?

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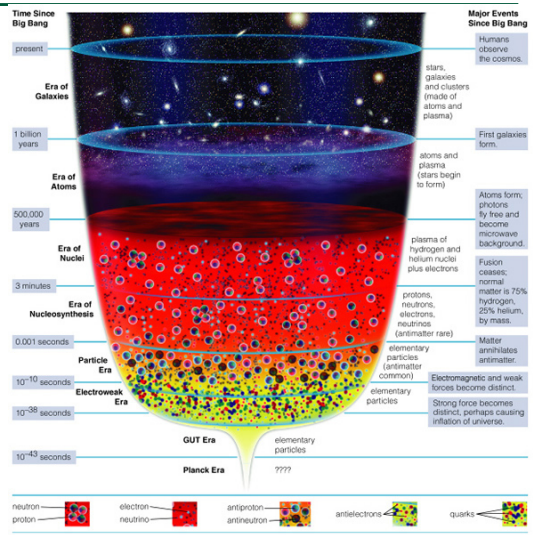
The History of the Universe

What we see as we look away from the Earth

We are effectively looking *back* in time.



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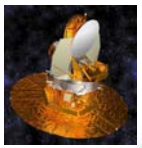
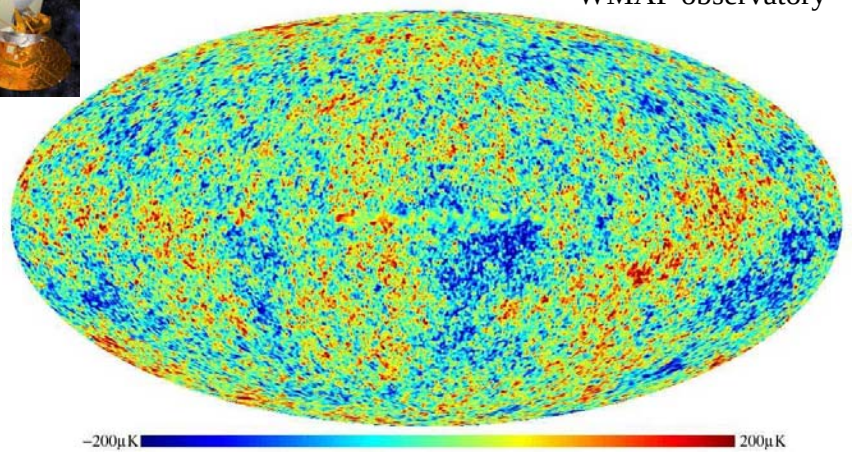
Picture of the Universe at 300,000 years old



WMAP observatory



The pattern indicates that the Universe is 13.7 billion years old.

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What about the future?

- Until very recently (past 5 years) we thought it was possible that the Universe might end in a Big Crunch.
- This would be the case if the mass of the Universe were large enough to halt the expansion and bring everything back together.
- In this model the Universe could be a never-ending cycle of Big Bangs and Big Crunches.
- The microwave background measured by WMAP points to an ever expanding Universe.

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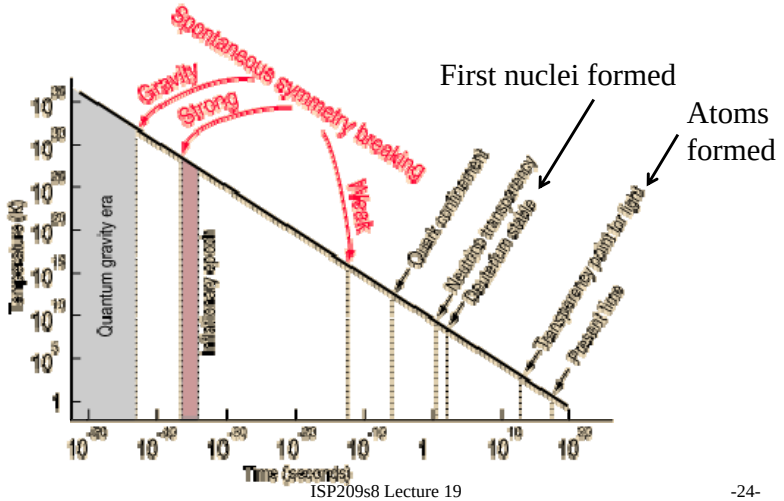
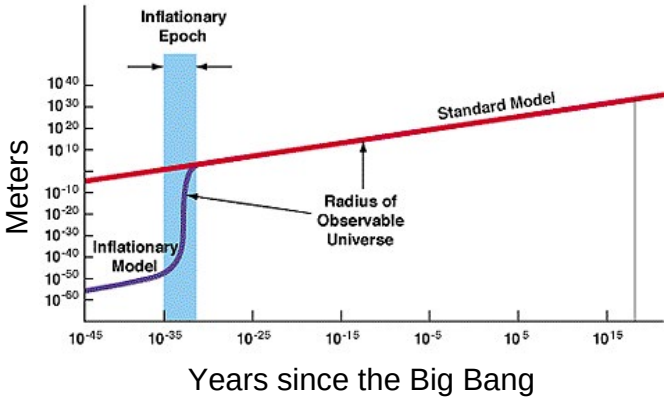
Big Bang Timeline (the early moments)



Inflation of the Universe



The existence of an unknown scalar field caused the rapid inflation of the Universe

Space stretched by 10^{50} times!

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Why does time always move in one direction?

- Inflation during the Big Bang resulted in a universe that had a very low entropy, much too low for its size. It was like the Universe started with all heads.
- Hence, everything in the universe moves toward reaching the correct amount of entropy.
- Time has a direction because going back in time would imply the entropy could be decreased. That is very improbable.
- The universe tends toward increasing entropy.
- What is time?