Today

- Announcements:
  - HW#10 is due Wednesday Nov. 23.
  - Extra credit project on Intelligent Design is available it will be due Dec. 2nd at 5:00pm. Please don't wait till the last minute.
- The average on the second exam was 32 (excellent). I think it was a relatively hard exam.
- The topics for today are how we measure distances, and the Big Bang

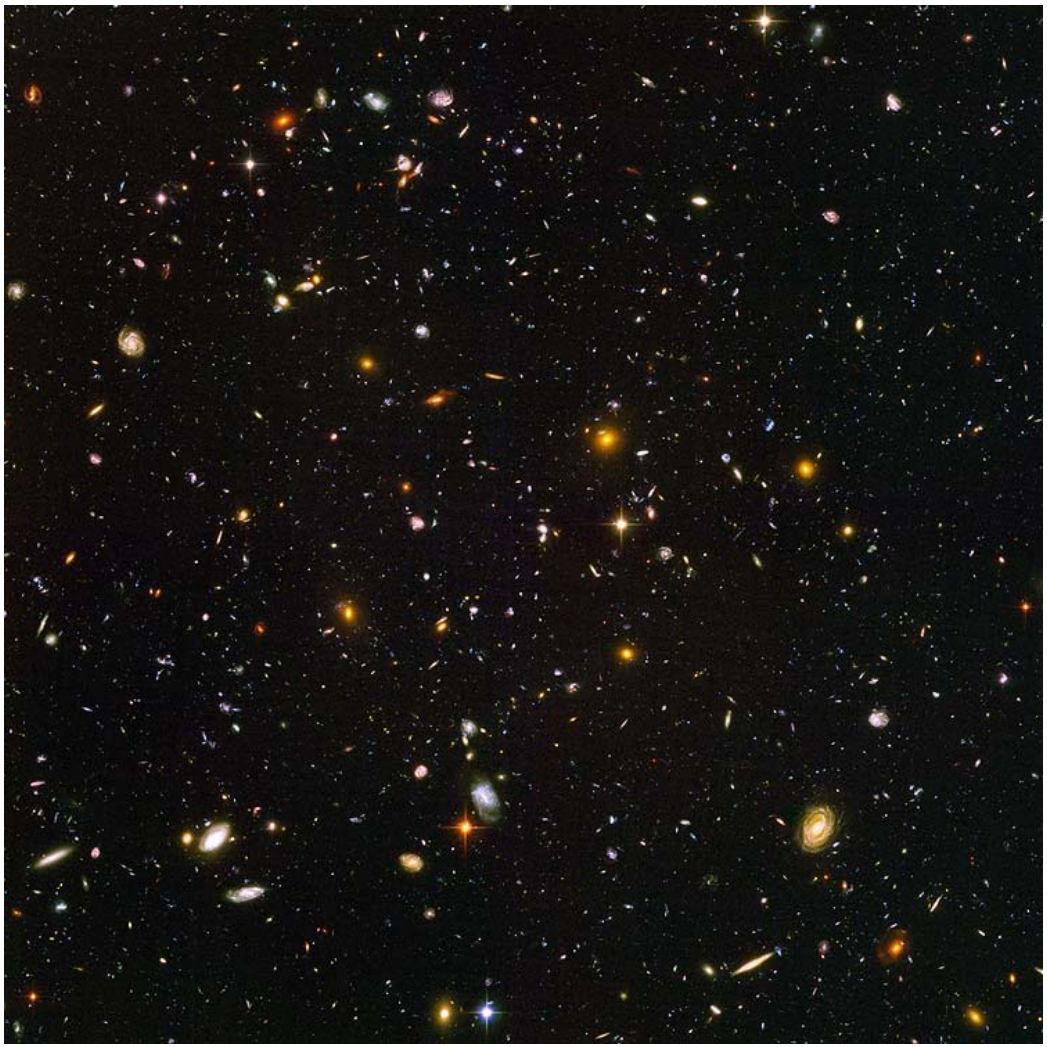
The Elegant Universe Videos

- Produced by PBS in 2002
- The primary author was Brian Green, who wrote the best selling book by the same name.
- Discussion of the videos…
- Is String Theory the "theory of everything?"

How did the Universe Begin?

- As we will discuss in this lecture, 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. We will discuss in this lecture why most people accept the Big Bang model.
- 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?

What do we know about the Universe?

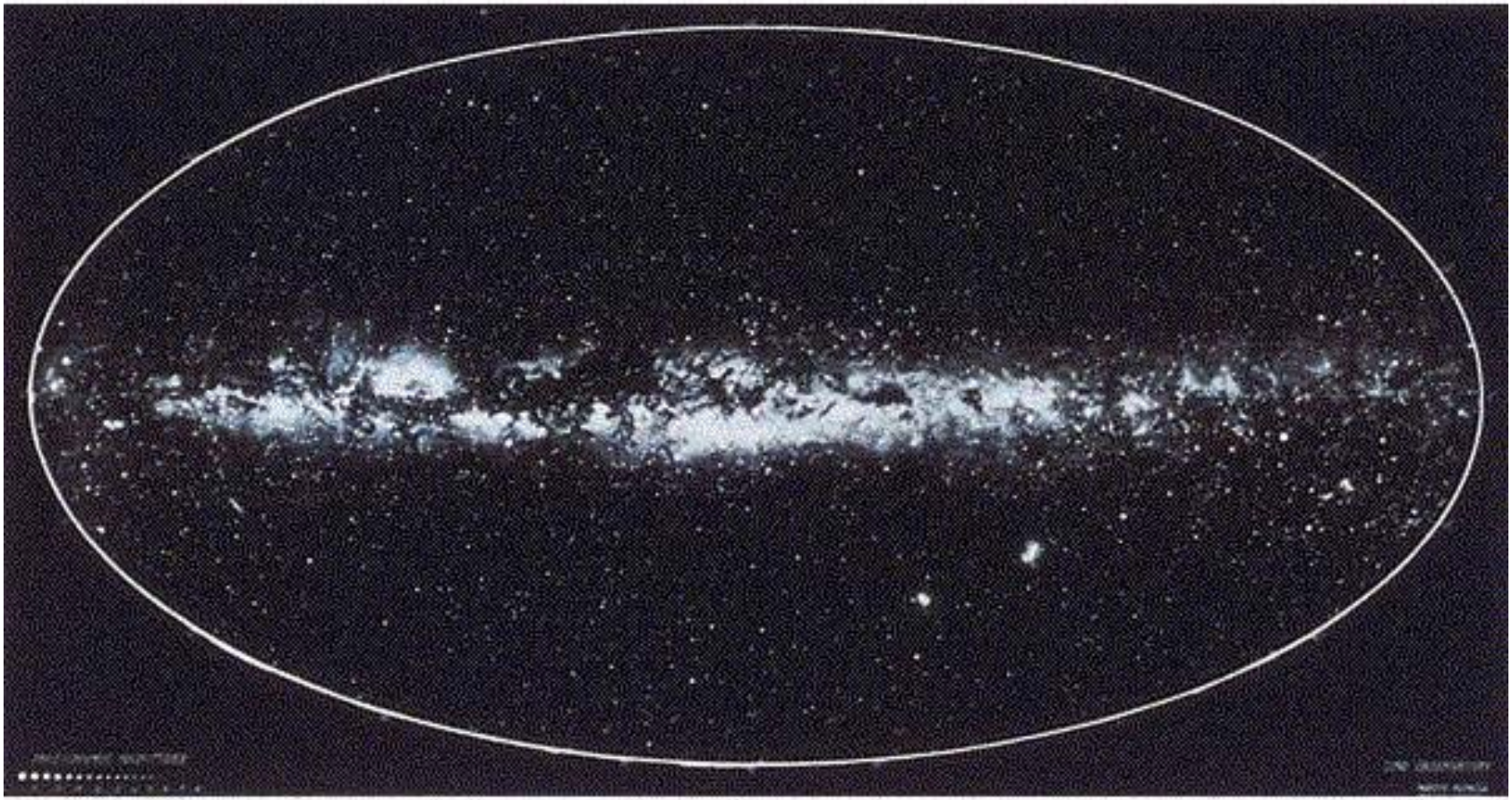


Picture of distant galaxies taken by the Hubble Space Telescope

There are approximately 200 billion galaxies

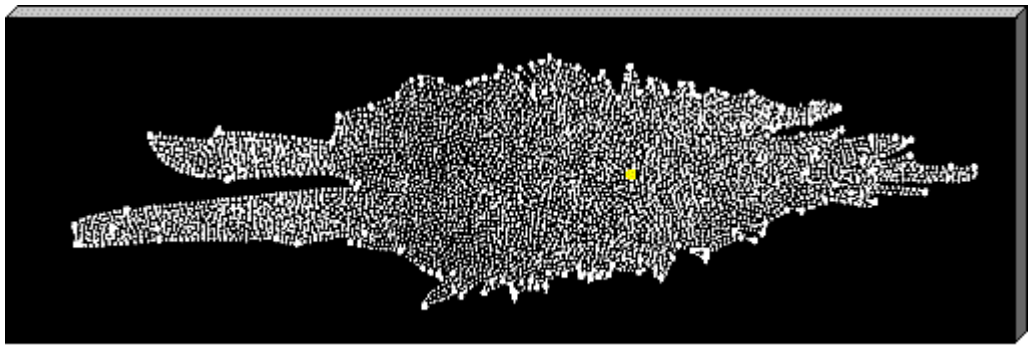
Looking at distant galaxies is like looking back in time.

Map of the night time sky



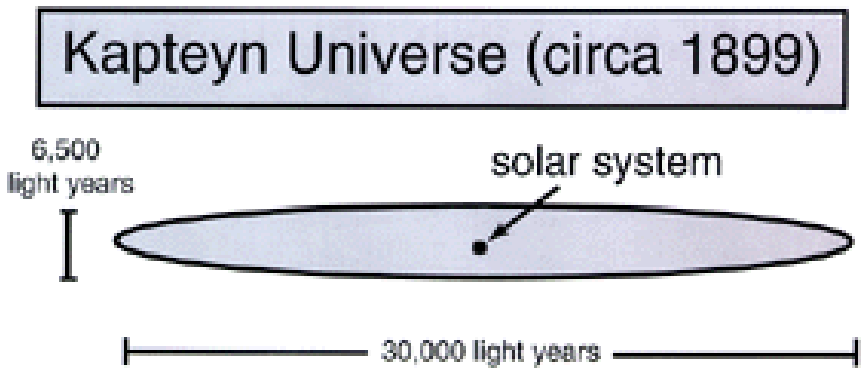
How do we know how far away galaxies are?

- Kypteyn Universe – study of visible stars



Map of all known stars- Distance guessed based on brightness

The picture people had until 1922

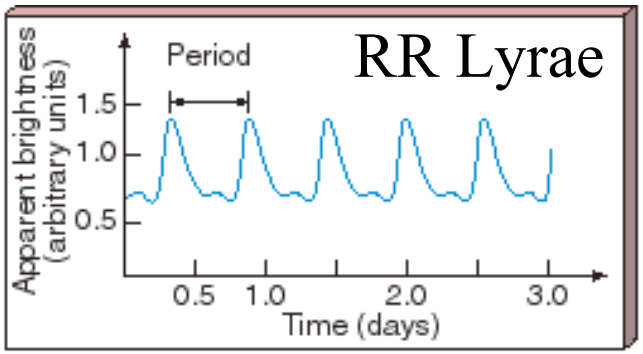


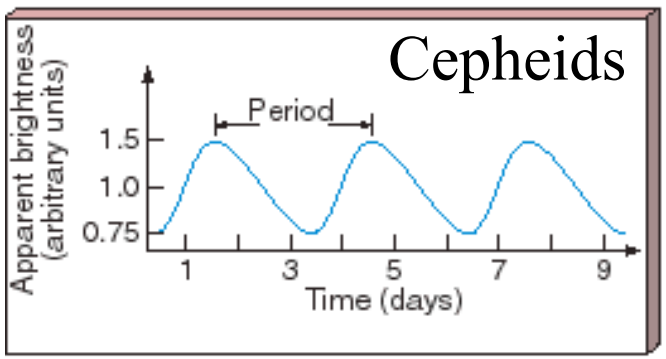
Edwin Hubble (1889-1953)

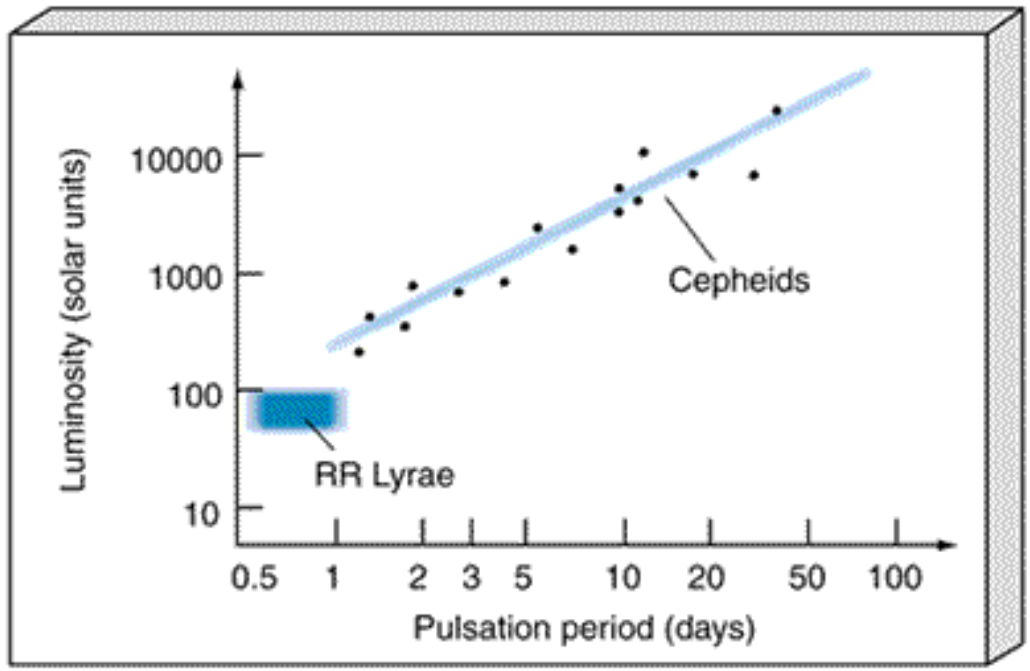
- In 1922 Edwin Hubble (of Hubble Space Telescope fame) measured the brightness of variable stars in the Andromeda galaxy.
- He discovered that the Andromeda galaxy was about 3 million light years away.
- He was the first person to demonstrate the size of the Universe and the the Milky Way is not the only galaxy.

The Great Galaxy in Andromeda – M31

Variable Stars – standard candles

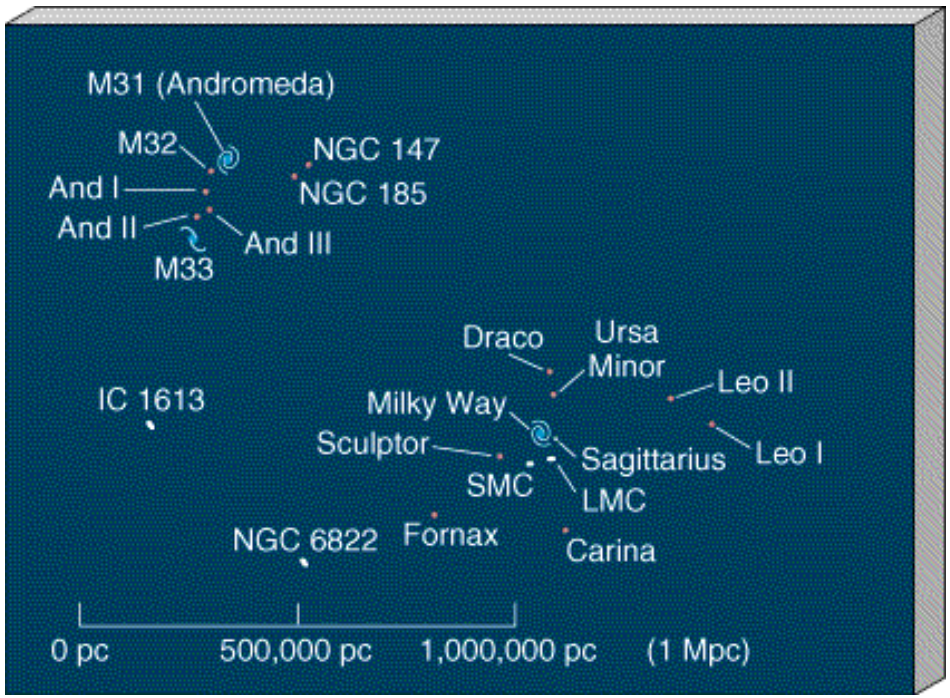


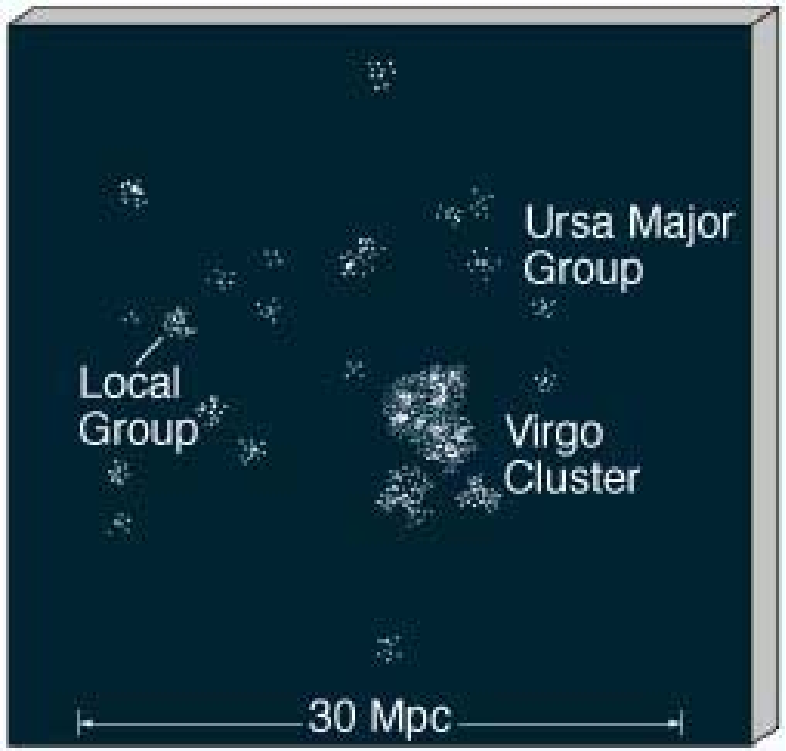




Once you find a variable star, you know how luminous it is.

The structure of our local set of galaxies





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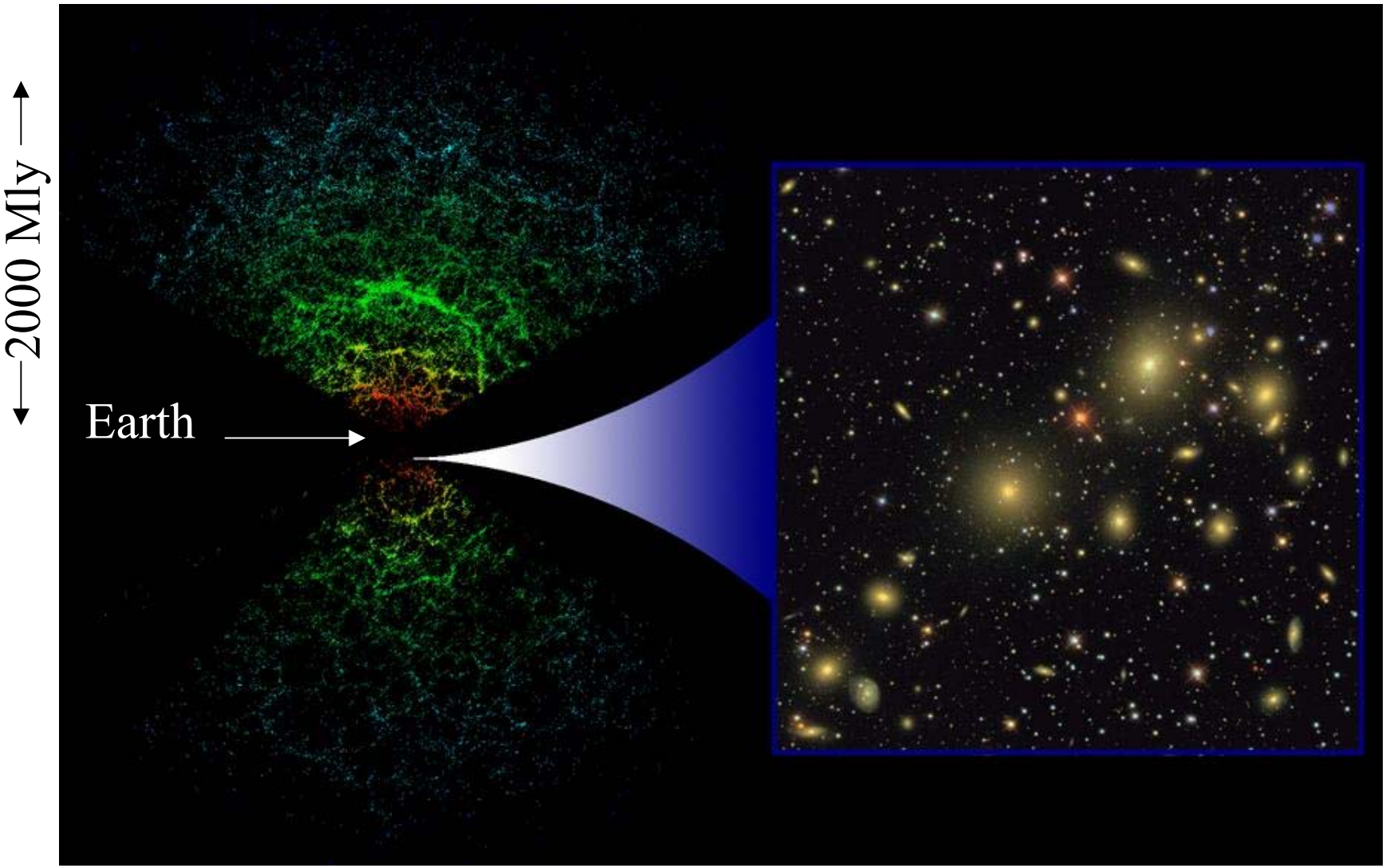
Sloan Digital Sky Survey of Galaxies



Hubble Expansion

- 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
- Hubble Law:

$$\text{velocity} = H_0 \cdot \text{distance}; H_0 = 20 \frac{km/s}{Mly}$$

- If a galaxy is observed to be moving away at 2000 km/s, we expect the galaxy is v/H_0=100 Mly away

How do we determine distances?

- Radar – nearby things like the Sun
- Parallax – 1 arcsec motion 1 pc = 3.24 ly
- Spectroscopic parallax – use location on the Hertzsrpung Russell diagram
- Variable stars – to nearby galaxies
- Supernova – to nearby clusters of galaxies
- Hubble Law – to farther galaxies and quasars
- Brightness of bright galaxies (Tully-Fischer Relation) to the farthest galaxy clusters.

Clicker Question

What is a useful way to measure the distance to nearby galaxies?

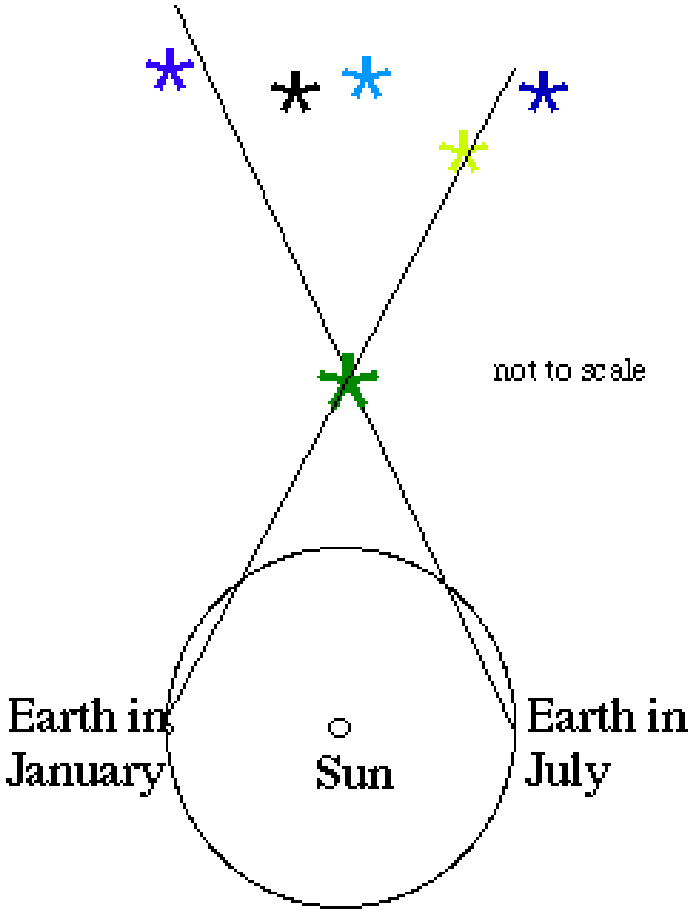
A) Hubble Law

B) Radar

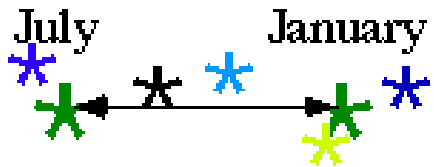
C) Brightness of the galaxy

D) Brightness of variable stars

Stellar Parallax



As seen on the sky in



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.

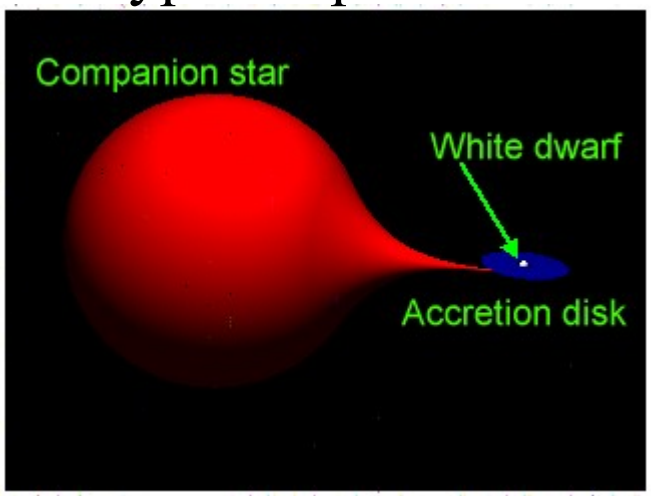
1 arcsec corresponds to a distance of 1 parsec (pc) = 3.24 ly

Distances to 300 ly can be measured this way

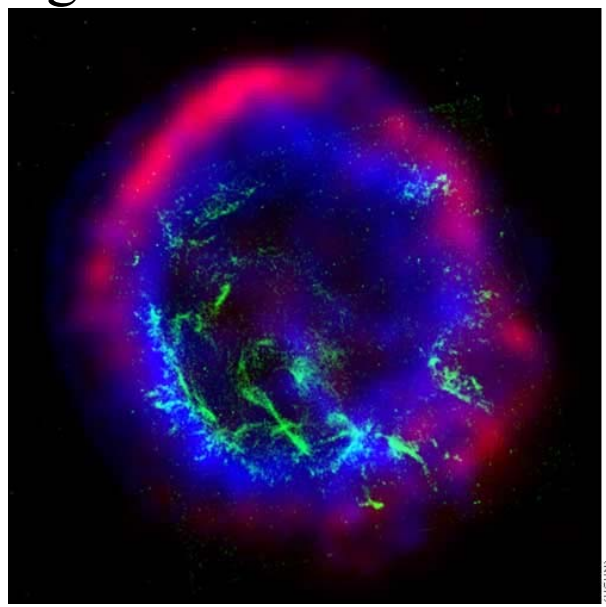
Supernovae

Type II: At the end of their lives massive stars (> 8 time that of the Sun) explode in a violent explosion called a type II supernova. The star becomes about 4 billion times brighter.

When a white dwarf collapses it explodes in a type I supernova

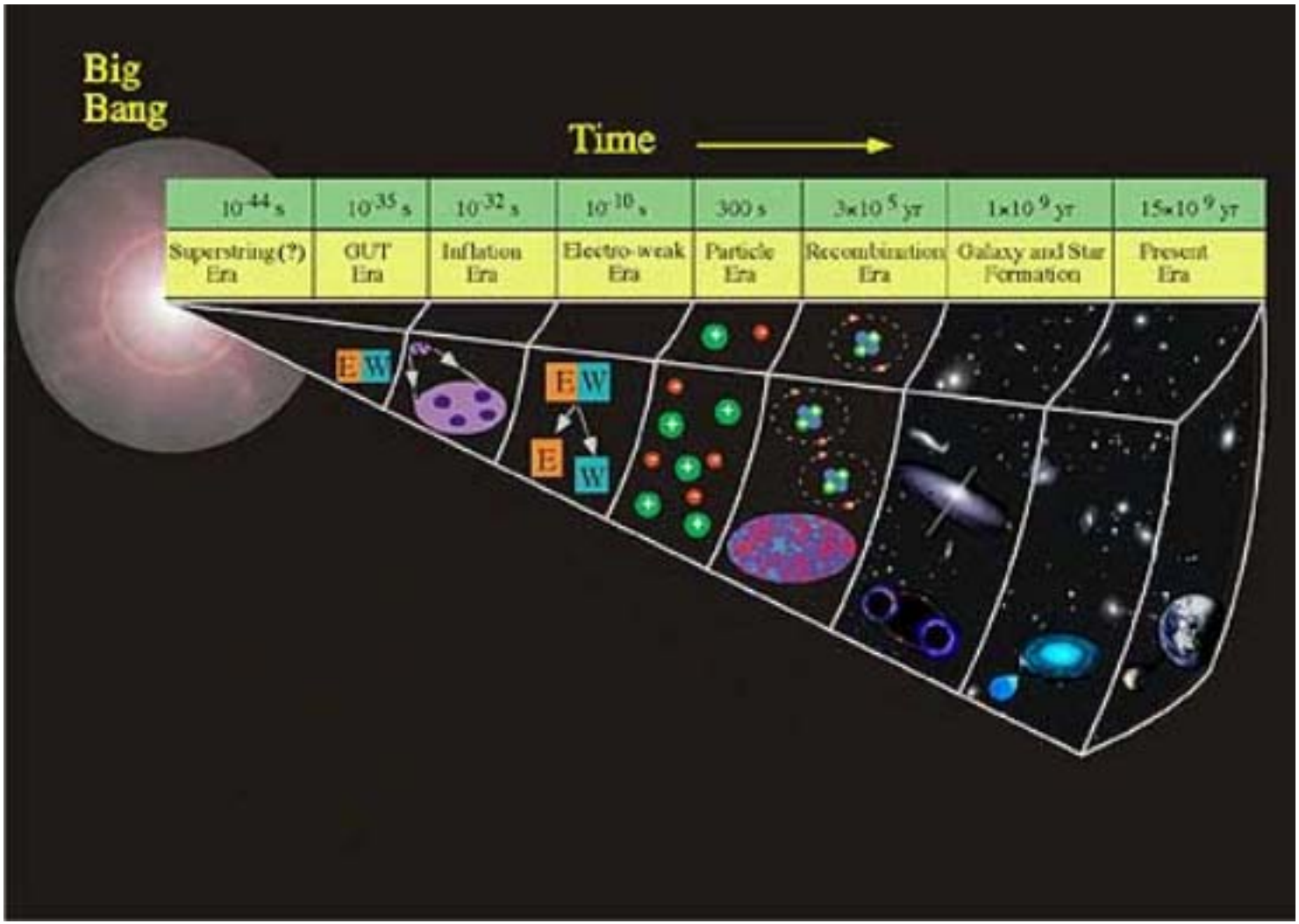


Prior to a Type I



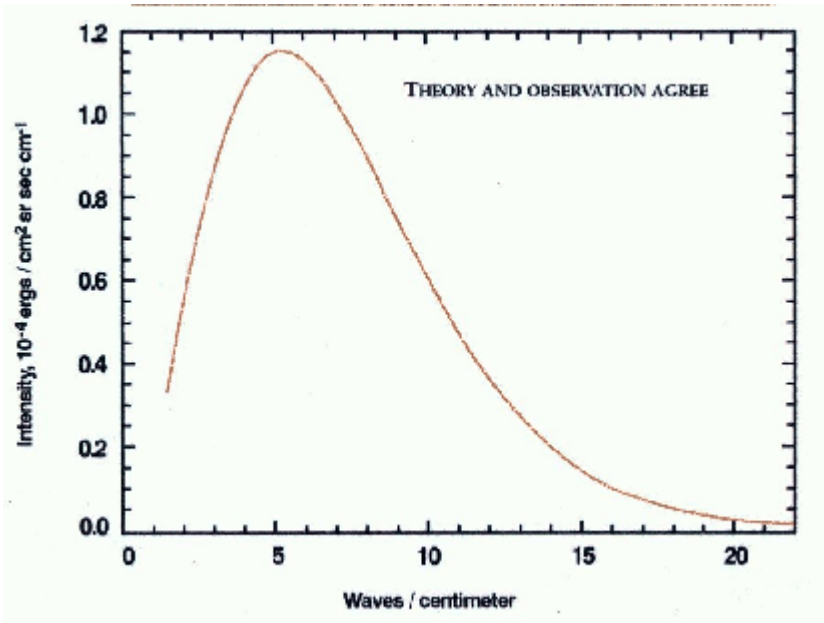
Type II

The Big Bang


Big Bang
Time
10^{-44} s
10^{-35} s
10^{-32} s
10^{-10} s
300 s
3×10^{5} yr
1×10^{9} yr
15×10^{9} yr
Superstring(?) Era
GUT Era
Inflation Era
Electro-weak Era
Particle Era
Recombination Era
Galaxy and Star Formation
Present Era
E W
E W
E W

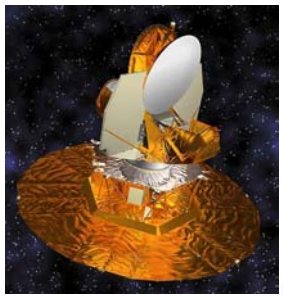
Evidence for the Big Bang

- The expansion of the Universe
- The abundances of the lightest elements produced in the Big Bang
- The cosmic microwave background radiation

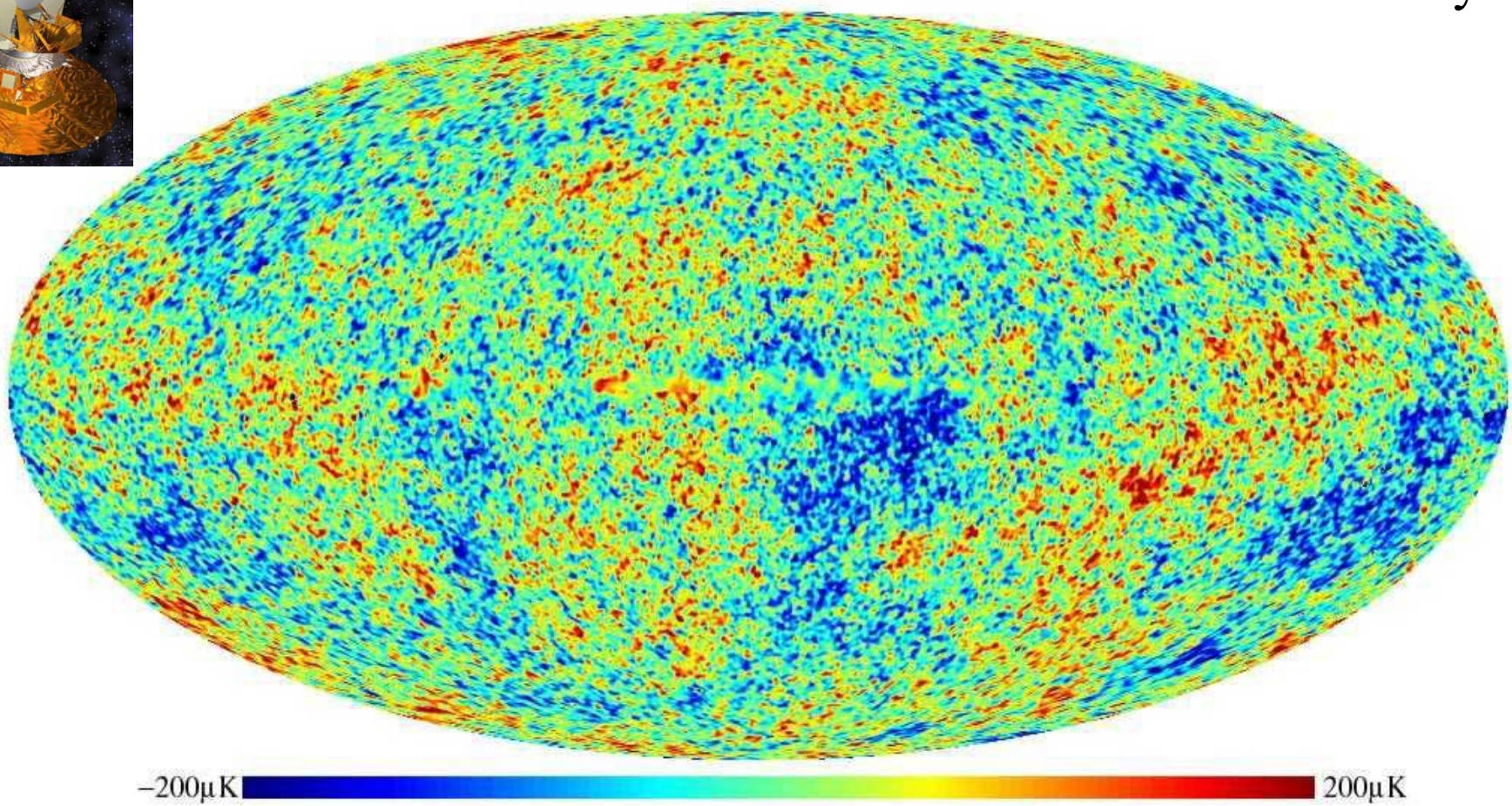


Temperature
2.738 Kelvin

Map of the microwave sky



WMAP observatory



Clicker Question

Choose the most correct statement:

A). Galaxies are evenly distributed in the Universe

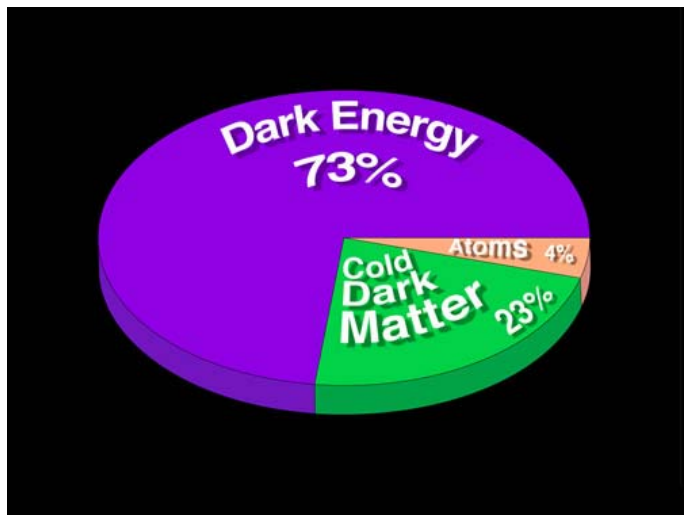
B). We look far away from Earth we can see the Universe as it was at a time about 100,000 years after the Big Bang

C). Many scientists doubt the Big Bang theory

D). The visible background radiation from Big Bang can still be detected.

What we have learned from WMAP

- The Universe is 13.7 billion years old
- The Universe is Flat and will continue to expand forever
- The Universe is made of mostly an unknown form of matter and an unknown form of energy (dark)



What is the Ultimate Fate

- 10^{100} years – all the stars will have used their fuel
- 10^{100} to 10^{150} years "dark ages"
- 10^{150} years all black holes will have evaporated
- 10^{1000} years the Universe will reach its lowest energy state
- The current age of the Universe is 13.7 billion years 10^{10} years