

Chapter 34: Cosmology

Did you read chapter 34 before coming to class?
 Yes
 No



According to the current models of stellar life cycle, our sun will eventually become a

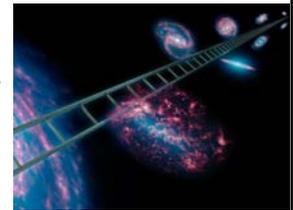
- a) Cloud of hydrogen gas
- b) Protostar
- c) Neutron star
- d) Black hole
- e) White dwarf

Cosmology: How the Universe Works

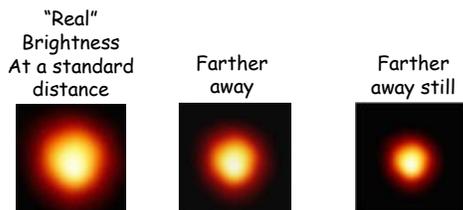
- Cosmology is the study of the structure and dynamics of the universe. To understand the universe we need to be able to tell
 1. Where things are
 2. How things are moving

The Astronomical Distance Ladder

- Methods for measuring distance
 - Radar ranging: works in the solar system
 - Triangulation: can be used up to 3,000 light years (nearest 120,000 stars)
 - Brightness-distance: works for any object where we can measure the brightness of the light arriving at earth and also have some way of knowing how bright the object "really" is (i.e. its brightness at a standard distance).



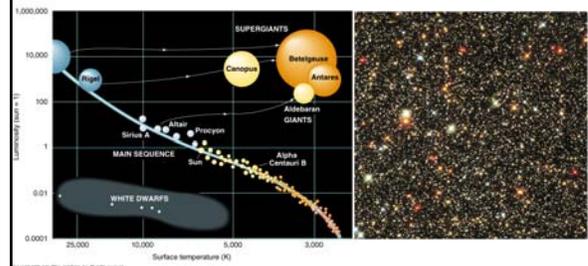
The Basic Idea Behind Finding Distances to Stars:



- We measure the brightness we see.
- We infer the real brightness.
- We calculate the distance from the difference between the apparent and absolute brightness.

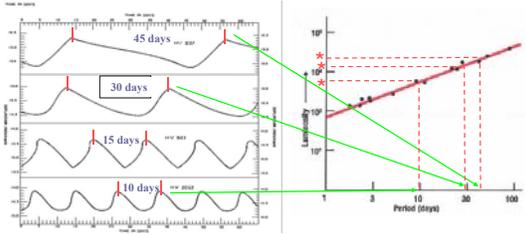
Color-Brightness Relation

- The Next Rung on the distance ladder is from the relation between brightness and color.
- Star colors and brightnesses are determined by their masses.



Variable Stars as Distance Indicators

- A class of very bright stars called Cepheids, have a tight relation between their real brightness and their pulsation periods.
 - Pulsation period \rightarrow real brightness
 - Compare measured brightness to real brightness \rightarrow distance
- The primary mission of the Hubble Space Telescope was to find distances to nearby galaxies using Cepheid variable stars.



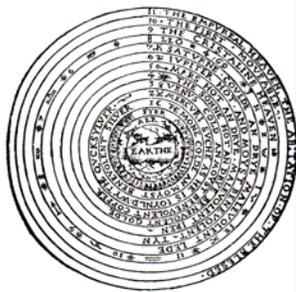
Type 1a Supernovae

- Certain types of supernovae have a predictable (very high) brightness. When we observe them we can tell how far their galaxy is from our own, even at very great distances.



A Vast Universe of Galaxies

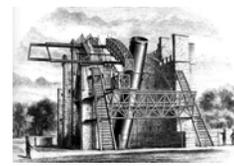
- Anciently mankind thought that the universe was the solar system inside a sphere of stars.
- By the 1900s we knew the sun was just one of billions of stars within the Milky Way galaxy.
 - At this time the Milky Way was thought to be the *entire* universe.



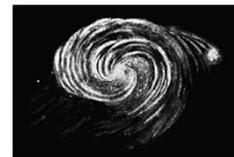
William Parsons studied external Galaxies, but thought they were solar systems forming in the Milky Way



William Parsons, 3rd Earl of Rosse



The "Leviathan of Parsonstown" Parson's 72-inch telescope



First Sketch of a galaxy, 1845

External Galaxies

- It wasn't until 1923 that we fully realized the universe consisted of more than the Milky Way.
- In 1923 Edwin Hubble determined that Cepheid variable stars in the Andromeda galaxy are 2.5 million light-years away.
- Since the Milky Way is only 100,000 light-years across, it became apparent that Andromeda was a separate system of stars.



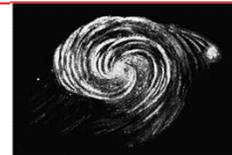
Andromeda (HST)



Edwin Hubble with his 200 inch telescope

We are not alone in the universe

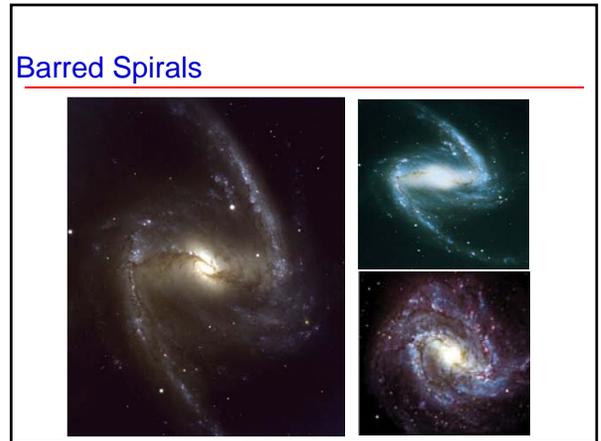
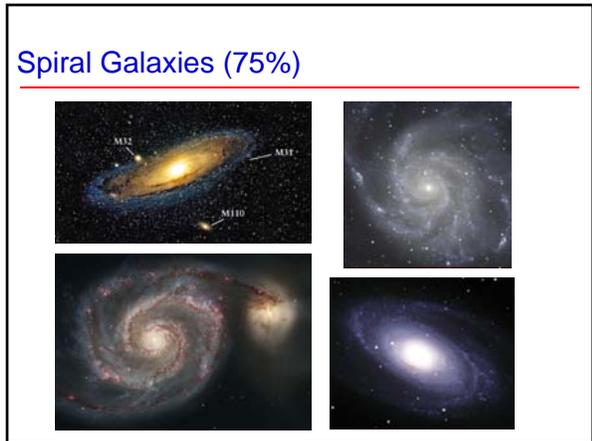
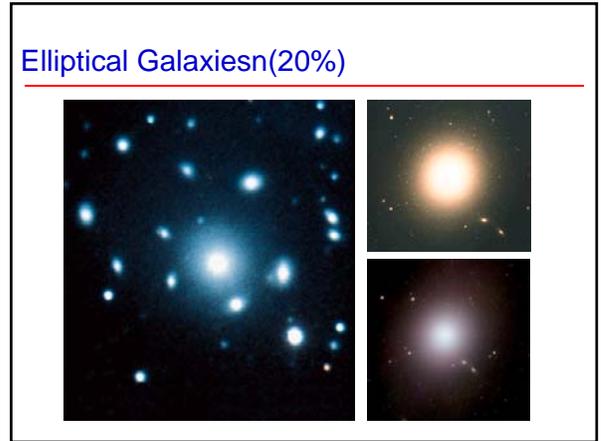
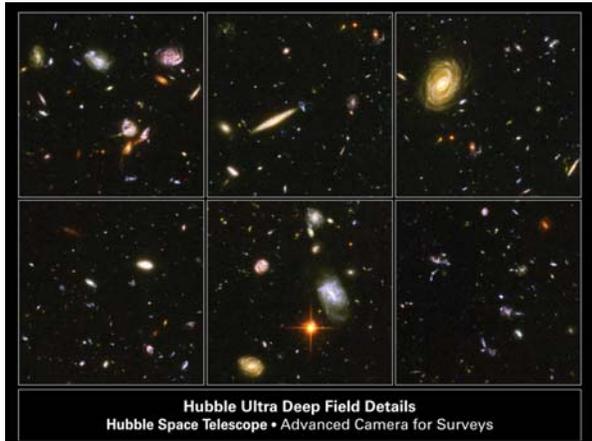
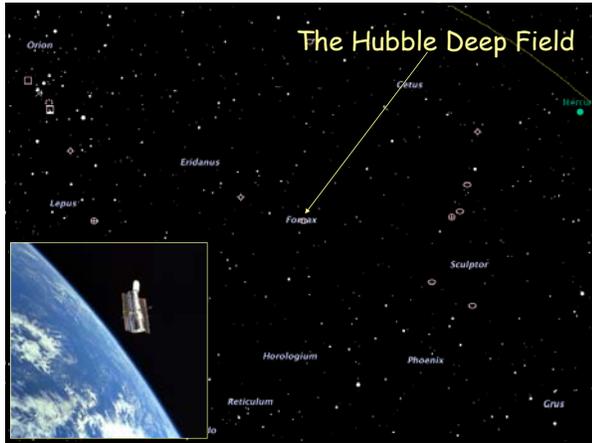
- Soon it was realized that the spiral-shaped "nebula" were galaxies of stars similar to the Milky Way.
 - On average over 100 billion stars per galaxy!
 - Huge! The universe itself is only 10^9 times larger than a typical galaxy.
 - At least 50 billion of them.



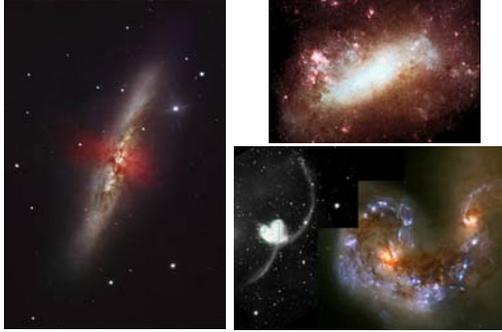
Sketch by William Parsons, 1845



HST photo of the "Whirlpool Galaxy" (data from NASA, ESA, and HST)

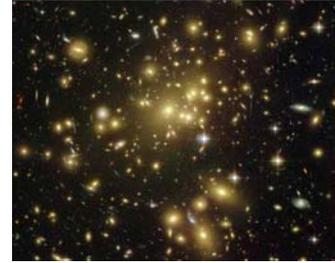


Irregular/Peculiar (5%)



Galaxy Clusters

- Galaxies are held together in small to large groups by gravity.

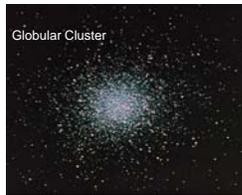


Harlow Shapley was able to point out that we are not at the center of the galaxy



Harlow Shapley

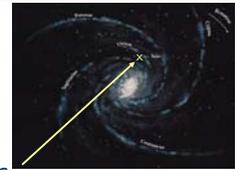
- He found the position by measuring distances to the *globular star clusters* that orbited about the center of the Milky Way.



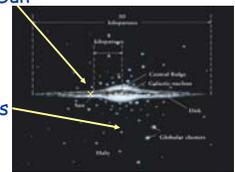
Globular Cluster

Position of the Sun in the Milky Way

- The sun is 2/3 the way from the galaxy center to the edge.
- Its position was found by measuring distances to the *globular star clusters* that orbited about the center of the Milky Way.
- Variable stars were used to find the distances.



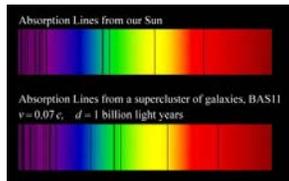
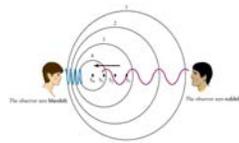
The Sun



Globular Clusters

Cosmological Redshift and The Doppler Effect

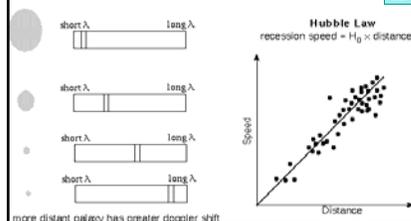
- A profound discovery of the early 1900s was that all distant galaxies have their absorption and emission spectral lines shifted to the red.
- The amount of the shift is related to the speed of the galaxy.
- Shift can be found because spectral emission lines have a characteristic pattern



Hubble Law

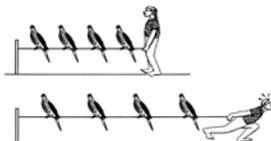
- The speed a galaxy moves away from us is proportional to its distance: The farther away the galaxy is, the faster it recedes.
- The Hubble Law is used to find distances to the farthest galaxies

radar ranging	within solar system
triangulation	nearest 10,000 stars in galaxy
distance-brightness	within our galaxy and nearby galaxies
cosmological redshift	beyond nearby galaxies



Because all distant galaxies are moving away from us (and hence are red-shifted) we know that the universe is expanding

- If the universe is expanding, the farther away two galaxies are, the faster they move apart.
- Also, all galaxies would appear to be moving away from all other galaxies so our view is not unique.

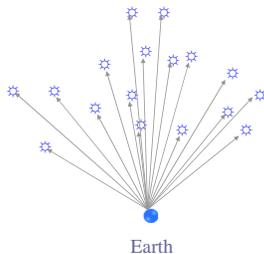


Types of Cosmologies

- Early ideas of the universe held that it was:
 - Infinitely old
 - Infinitely large
 - Unchanging in time
- But this cannot be true because
 - The universe is seen to be expanding and thus it is changing with time.
 - An infinitely large and old universe would never know darkness. This is *Olber's paradox*

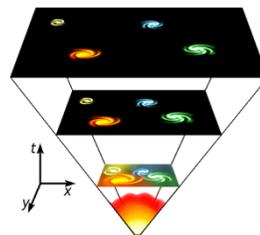
Olbers' Paradox

- All lines of sight end on a star! The sky should be ablaze with star light!
- The solution is that the universe has a time of creation
 - Light has not had time to reach us from the greatest distances
 - Glowing stars and galaxies have not always existed.



The observed expansion of the universe has led to the only currently viable cosmological theory: **The Big Bang**

- The universe was created about 13.7 billion years ago, and began as a great infusion of pure energy
- Space expanded from that point in time. The energy cooled into matter.



Fred Hoyle

- Fred Hoyle gave the Big Bang theory its name in a mocking manner, but it stuck
- Worked to disprove it, because it required an act of creation.
- To date, it is the best theory we have to describe the creation and development of the universe.



Experimental Evidence

- cosmological red shift
 - Everything is moving away from us
- helium/hydrogen ratio (25%/75%)
 - Fusion early after the big bang would produce that ratio of H to He

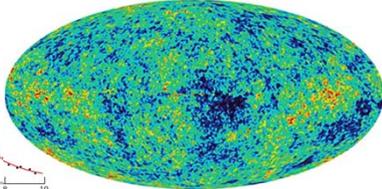
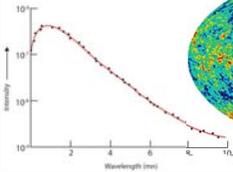
Big Bang																																																																																																					
Stellar Fusion																																																																																																					
Supernova																																																																																																					
H	He	Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Ba	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mendelevium	Nobelium	Lanthanum	Actinide Series

Evidence Supporting the Big Bang



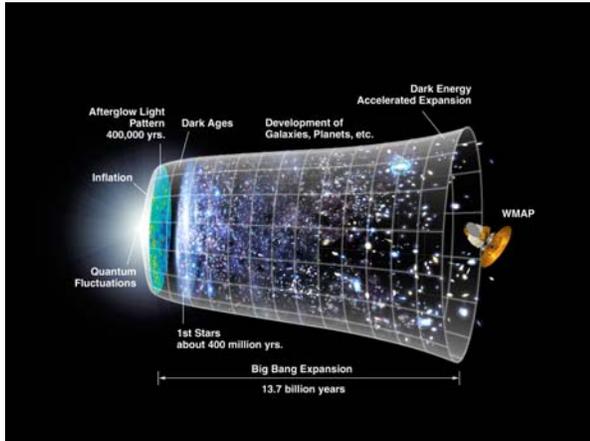
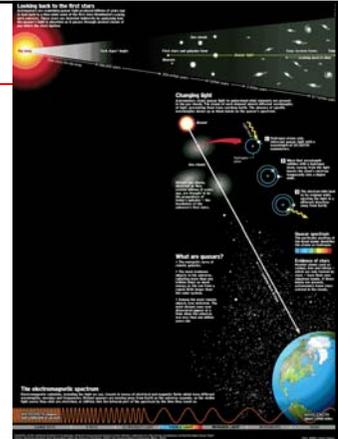
Arno Penzias and Robert Wilson

- We see a faint glow left from the original high temperatures
- Called the Cosmic Microwave Background or 3° K Background Radiation.



Looking back in time

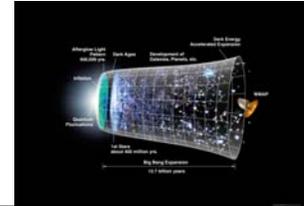
- A quasar is a supermassive black hole radiating through its accretion disk.
- They are formed by the collapse of supermassive stars that burned very quickly.
- Because they are so bright, they can be seen at extraordinarily large distances, and allow us to calibrate the age of the universe (about 13.7 billion years).



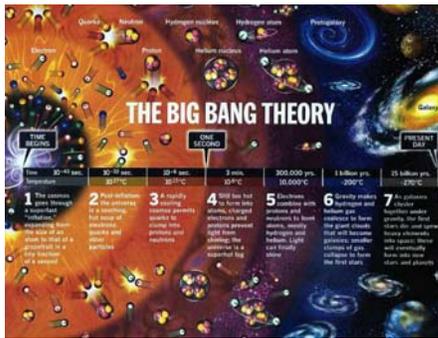
Big-Bang Theory

- universe began with an incredibly dense concentration of mass energy
- in the process of rapid expansion and cooling matter was formed
 - point-like particles (electrons, quarks, photons, etc.)
 - nucleons (protons and neutrons)
 - simple nuclei (hydrogen and helium)
 - more complex nuclei, atoms, and molecules

10 ⁻⁴³ sec	huge	???
10 ⁻³⁵ sec	10 ²⁶ deg	quarks, gluons, electrons, neutrinos, photons
.001 sec	10 ¹¹ deg	protons and neutrons
3 minutes	10 ⁹ deg	³ H, ³ He, ⁴ He nuclei
1/2 hour	10 ⁸ deg	² H nucleus
500,000 yrs	30000 deg	atoms



As the universe expanded, it would have cooled down



The Ultimate Fate of the Universe

- Gravity always pulls, never pushes, so the expansion must slow down unless there is another force pushing out.
- Not enough mass
 - open universe
- Just right
 - flat universe
- Too much mass
 - Closed universe (big crunch)
- Another force
 - Runaway universe.
 - This is what we think is happening as best we can observe!

