REVIEW last Class
Tuning Fork Diagram of Hubble:

Ellipticals

Ellipticals

SO or SBO Lenticular galaxy

Normal spirals

Sa

Sb

Sc

Irregulars

SBa

SBb

SBc

Barred spirals
How far are Galaxies?

Measuring Distances…

we need standard candle an object that lies in a galaxy and that we know its luminosity
For a Standard candle you want:
1. Luminous Object (so you can see it at great distances)
2. Be certain of it’s luminosity
3. Easily identifiable
4. Should be relatively common
Each technique can be used to calibrate the other...so a change in the distance-measuring techniques for nearby objects can also have substantial effects on distances to remote galaxies!
Redshift

• The redshift of a receding object:

\[ z = \frac{\lambda - \lambda_0}{\lambda_0} \]

Where \( \lambda_0 \) is the unshifted wavelength.

The more distant the galaxy... ...the greater its redshift and the more rapidly it is receding from us.
The Hubble law is \( v = H_0 d \)

The value of the Hubble constant, \( H_0 \), is not known with certainty but is close to 71 km/s/Mpc; each million parsecs to a galaxy, the galaxy’s speed away from us increase by 71 km/s. For example a galaxy located 100 million parsecs will be rushing away from us with a speed of 7100 km/s.
Galaxies have their Own Motion

- Not all galaxies are moving away from MW; the galaxies have their own motions relative to one another thanks to their mutual gravitational attraction—for distant galaxies the Hubble speed is much greater than any intrinsic motions that the galaxies might have.

- Because the value of $H_0$ is somewhat uncertain usually.
- We express the distance in terms of redshift $z$ (that can be measured very accurately).

- *The greater the redshift of a distant galaxy the greater its distance*
Galaxies are not scattered randomly but are found in clusters. Cluster is rich or poor depending on how many galaxies it contains!
A rich cluster contains hundreds or even thousands of galaxies.

A poor cluster, often called a group, may contain only a few dozen.

Poor clusters (which far outnumber rich ones) are often called groups.
Our Galaxy is a member of a poor, irregular cluster called the Local Group.

Local group contains more than 40 galaxies; most which are dwarf ellipticals. In recent years there were discovered a lot of dwarf elliptical galaxies in the Local Group.
The Nearest and Most Recent discovery is Canis Major Dwarf (8kpc from Earth - tidal forces exerted by the MW are causing Canis Major to slowly disintegrate (*animation*)
The nearest rich cluster is Virgo cluster (2000 galaxies) 3Mpc of diameter - center of Virgo three giant elliptical (each diameter of these giant elliptical is ~ size of entire Local Group!)
Clusters can be *regular or irregular*:

- A regular cluster has a nearly spherical shape with a central concentration of galaxies.
- In an irregular cluster, galaxies are distributed asymmetrically.

Example of rich, regular cluster is the **Coma cluster** (90Mpc; 300 million light-years away) containing 1000 galaxies. Most certainly it also contains many thousands of dwarf ellipticals, so it might contain 10,000 galaxies!
The overall shape of a cluster is related to the dominant type of galaxies

Rich, regular clusters: mostly elliptical and lenticular galaxies (e.g. Coma Cluster)
Irregular clusters: such as Hercules Cluster have a mixture of types

Hercules cluster
• Rich, regular clusters contain mostly elliptical and lenticular galaxies
• Irregular clusters contain spiral, barred spiral, and irregular galaxies along with ellipticals
• Giant elliptical galaxies are often found near the centers of rich clusters
The clusters are grouped together in Superclusters (over a region up to 45Mpc)

Local Supercluster
(sphere of 250Mpc centered in Earth)

The most massive cluster in the local universe is called the Great Attractor

Unlike clusters, superclusters are not bound by gravity
How superclusters are distributed in space?

Map of 1.6 million galaxies—superclusters are NOT randomly distributed but lie along *filaments*
The 2dF galaxy survey

There are enormous voids were very few galaxies are found (diameter 30-120 Mpc). Most galaxies are concentrated in void sheets (of 100 Mpc long) on the surfaces of between voids.

The sheets are the largest structures in the universe! On a scale larger than 100 Mpc the distribution is roughly uniform!

60,000 galaxies (each dot is a galaxy—until $z=0.25$ (corresponding to a velocity of 66,000 km/s—with $H_0=71 \text{ km/s/Mpc}$ correspond to 3 billion light-years from Earth)
Declinations bracketing $-30^\circ$

Solar system

Declinations bracketing $0^\circ$

Fields of view in the 2dF survey
Collision between Galaxies

(a) An X-ray image of Abell 2029 shows emission from hot gas.  
(b) A visible-light image of Abell 2029 shows the cluster’s galaxies.

Strong sources of X-rays—substantial amounts of hot intracluster gas ($10^7$-$10^8$ K)
Colliding galaxies produce starbursts, spiral arms, and other spectacular phenomena

When two galaxies collide, their stars pass each other, but their interstellar media collide violently, either stripping the gas and dust from the galaxies or triggering prolific star formation.

In a less violent collision or a near-miss between two galaxies, the compressed interstellar gas have more time to cool, allowing many protostars to form.

M81 and M82 (radio surveys show enormous streams of hydrogen gas connecting the three galaxies).

When two galaxies collide, their stars pass each other, but their interstellar media collide violently, either stripping the gas and dust from the galaxies or triggering prolific star formation.
A Starburst galaxy -> light of numerous newborn stars (surrounded by clouds of warm interstellar dust-indicating recent vigorous star birth)

Show the effects of strong winds from Young luminous stars
The gravitational effects during a galactic collision can throw stars out of their galaxies into intergalactic space.

As the galaxies pass through each other the two galaxies are severely distorted and throughout a pair of extended tails.
Extended tail (web link)

Close encounters between galaxies provide a third way of forming Spiral arms
Most of the matter in the universe has yet to be discovered.

The luminous mass of a cluster of galaxies is not large enough to account for the observed motions of the galaxies; a large amount of unobserved mass must also be present.

This situation is called the **dark-matter problem**.

We still have not detected the *true* Edges of these Galaxies.

Because we would have seen a decline in orbital speed (Kepler’s law).

There must be a considerable amount of dark matter that extends beyond the visible portion.

- The luminous mass of a cluster of galaxies is not large enough to account for the observed motions of the galaxies; a large amount of unobserved mass must also be present.
- This situation is called the **dark-matter problem**.
• Hot intergalactic gases in rich clusters account for a small part of the unobserved mass
• These gases are detected by their X-ray emission
• The remaining unobserved mass is probably in the form of dark-matter halos that surround the galaxies in these clusters
Gravitational lensing of remote galaxies by a foreground cluster enables astronomers to glean information about the distribution of dark matter in the foreground cluster.

This massive galaxy acts as a gravitational lens.

How gravitational lensing happens:

Without nearly perfect alignment, the second image of the background star is too faint to be noticeable.
If the alignment is slightly off-the image Of the distance galaxy is distorted as an arc
J. Anthony Tysonn of Bell Lab measuring The distribution of dark Matter: The overall arrangement Of visible galaxies Seems to trace the Location of dark matter

All of these blue arcs are images of the same distant galaxy.
Nature of Dark Matter:
faint low mass stars (0.2Ms or less)  
(none have yet been detected)  
WIMP (weakly interacting massive particles)  
MACHOs (massive compact halo objects)
How do galaxy form?

Galaxies formed from the merger of smaller objects

- Observations indicate that galaxies arose from mergers of several smaller gas clouds
- A large galaxy in a rich cluster may tend to grow steadily through galactic cannibalism, perhaps producing in the process a giant elliptical galaxy

Area only of 600kpc across (probably that the galaxy collided)

A portion of the constellation Hercules

3400 Mpc away
The blue color indicate a presence of young stars.

Observations indicate that the first stars were formed 13.5 billion years ago (when the universe was only about 200 million years old)
Formation of a spiral galaxy

The rate at which stars form within a protogalaxy may determine whether this protogalaxy becomes a spiral or an elliptical.
Formation of an elliptical galaxy

1. Stars form rapidly within a protogalaxy.
2. Gas is quickly consumed to make stars.
3. A elliptical galaxy results.
Whether a protogalaxy evolves into a spiral galaxy or an elliptical galaxy depends on its initial rate of star formation.

In an elliptical galaxy, there is a brief, intense burst of star formation, when the galaxy is young.

In a spiral galaxy, star formation continues at a more leisurely pace that extends over billions of years.

The stellar birthrate in galaxies.
The character of the galactic population changed over time.

In nearby rich clusters only 5% are spiral; but observations of rich clusters at redshift of $z=0.4$ show that about 30% were spirals.

Why were spiral galaxies more common in the past? Galactic collisions and mergers are probably responsible for that.