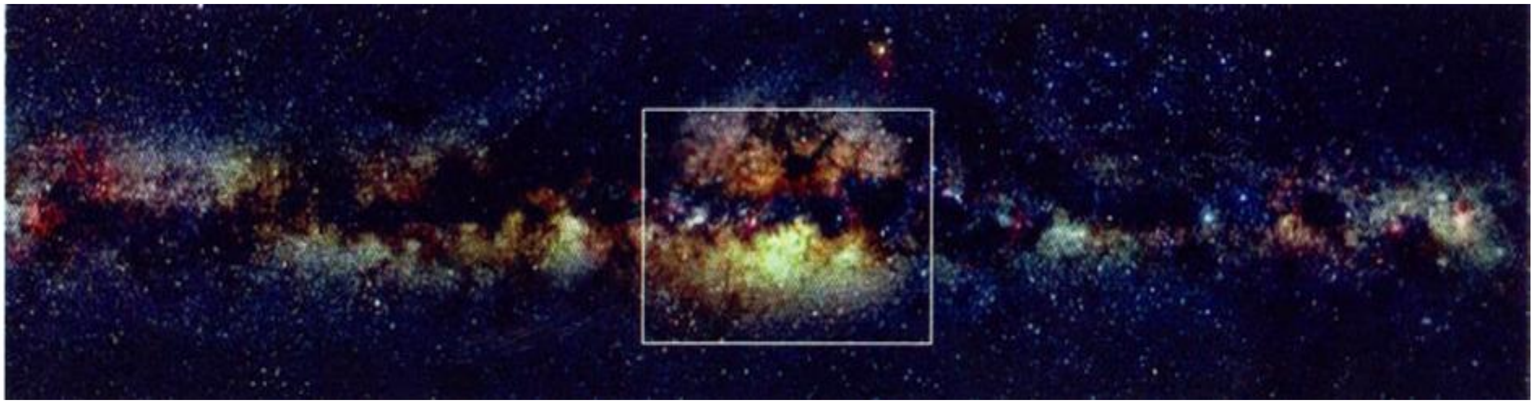
CHAPTER 16

The GALACTIC WORLD

A. The Milky Way and Our Galaxy

The Milky Way is a faint, irregularly shaped band of illumination girdling, or extending all the way around, the celestial sphere.

In 1609, Galileo Galilei, using a small telescope that he constructed, discovered that the Milky Way was in reality the combined light of millions of faint stars.



In 1784, Sir William Herschel, along with his son John**,** undertook a study of the distribution of stars in space around the Sun. They did so by counting the number of stars in a given direction at a given distance. (To do this, they assumed the distance of a star was related to its apparent brightness). They discovered that the Sun was located in a very large, disk-shaped aggregation or island of stars. At that time, this island of stars was believed to be the entire universe. This view became known as the **"Island Universe Theory".**

After Herschel's discovery, it was realized that the phenomenon that is called the Milky Way is our view, from the Earth, of the island or disk of stars in which we are embedded

The term **galaxy** did not come into use until the latter part of the 19th century. Herschel's disk of stars was then referred to as The Galaxy or the Milky Way Galaxy. Later it would be realized that this disk was just a part of a more complicated structure possessed by Our Galaxy.

Galaxy: A gravitationally bound system consisting of at least 1 million stars.

Galaxies have different sizes and shapes.

In addition to stars, some galaxies, such as ours, contain the following:

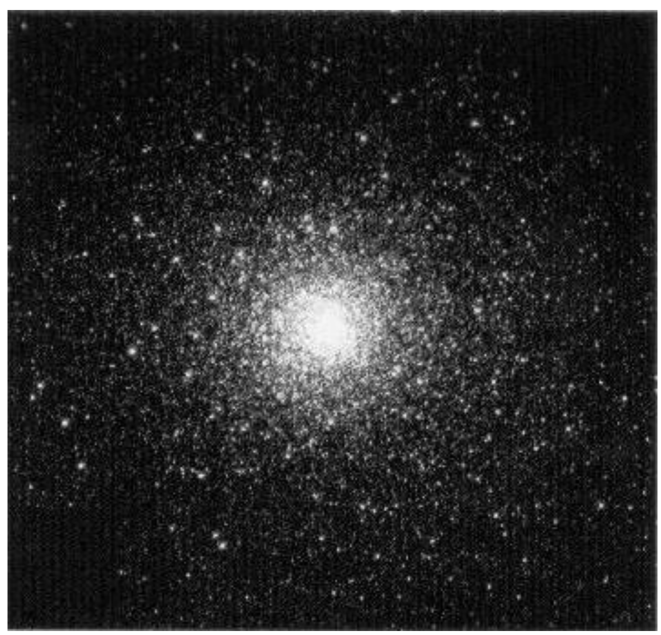
Nebulae: Clouds of gas and dust in space. Nebula is singular.

Nebulosity: a term referring to the presence of nebulae.

Interstellar Medium: the general distribution of gas and dust between and among the stars of our galaxy.

Star Clusters: There are 2 kinds.

Open Star Clusters and **Globular Star Clusters**

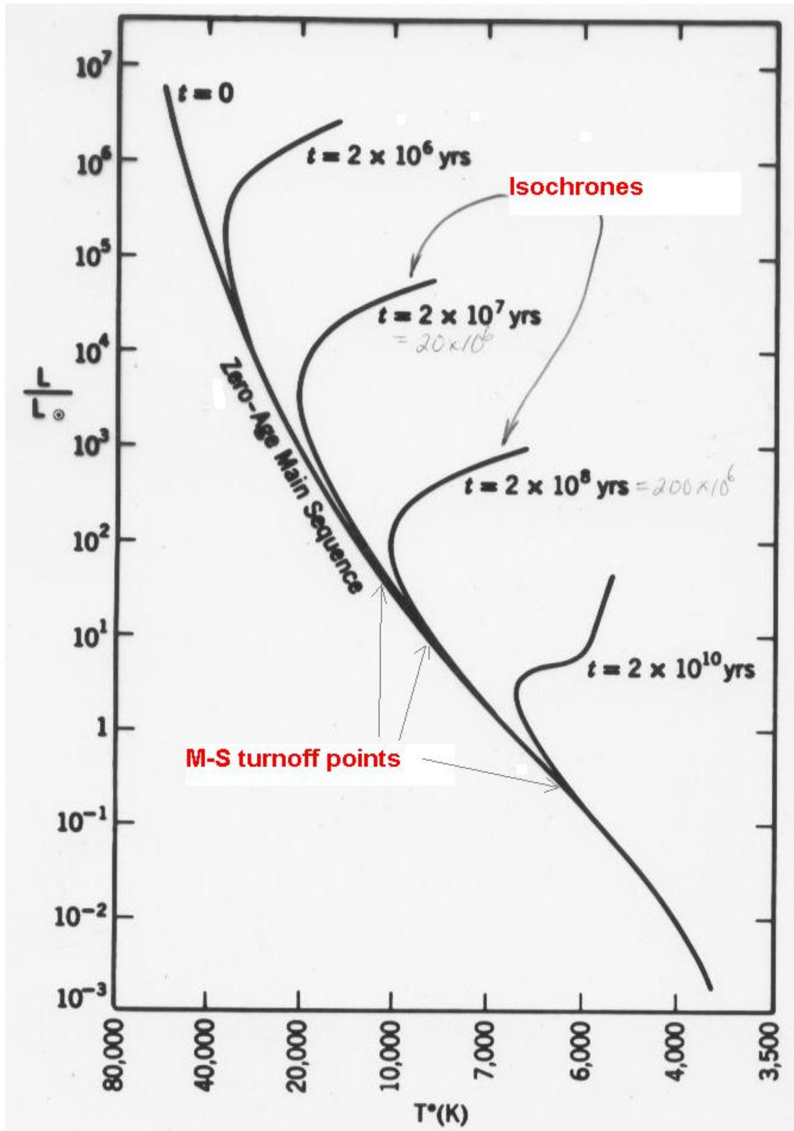


Globular Clusters are gravitationally bound systems comprised of several hundreds of thousands stars that are all very old.

Open Clusters may or may not be gravitationally bound. They contain at most several thousand stars. The stars in these clusters can be young or old.

Determining The Ages of Star Clusters

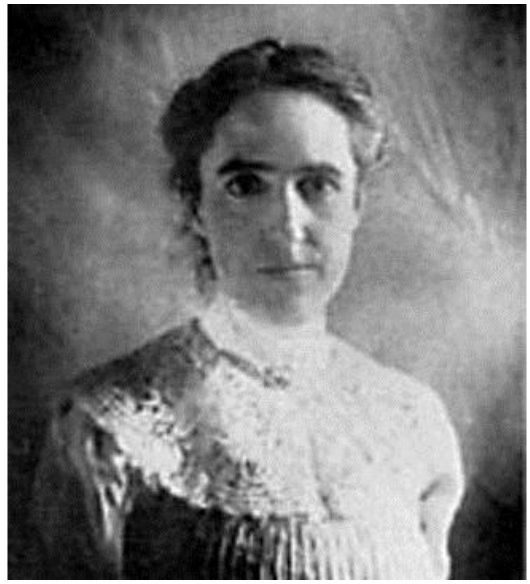
The age of a star cluster may be determined by first plotting a point in a temperature-luminosity diagram, as below, for each star in the cluster. These points will lie along a locus in the diagram. One then notes the temperature and luminosity position where stars are no longer found on the main sequence. This position on the main sequence is called the "turnoff point." Instead, stars with masses greater than that associated with this point lie along an isochrone that indicates these stars have already completed their main sequence stage of evolution. Now it is believed that all the stars in a given cluster are about the same age. Since the theories of stellar evolution indicate the main sequence lifetime for a star of a given mass, the turnoff point indicates the age of the cluster.



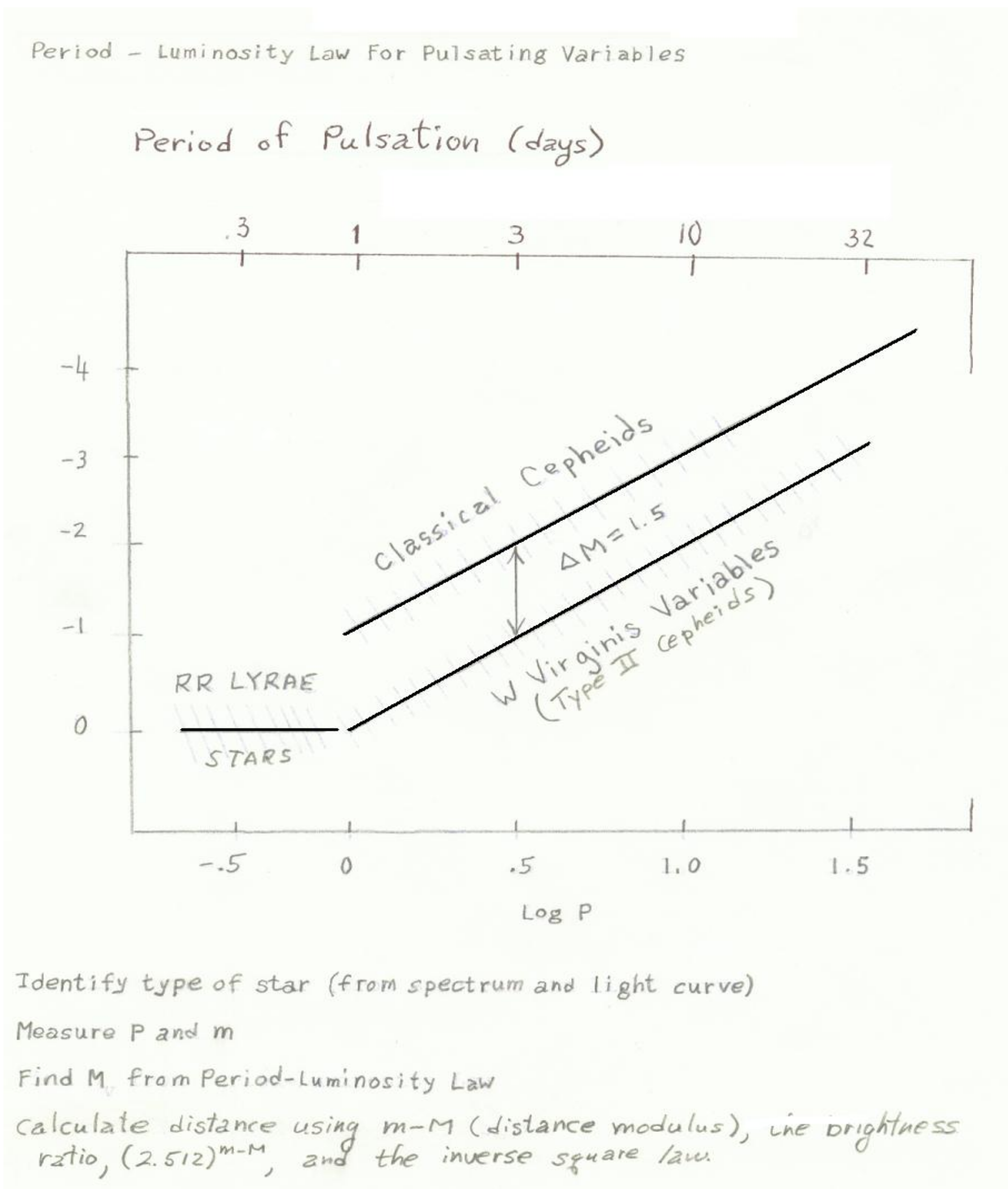
The Structure of our Galaxy:

The structure of our Galaxy and the location of the Sun within it, is the result of an investigation published in 1917 by H. Shapley. In this investigation, Shapley employed a method for measuring the distances of the globular clusters that are in our galaxy and thereby, was able to determine their distribution in the Galaxy relative to the Sun.

The method he employed makes use of what is known as the Period-Luminosity Law for pulsating variable stars. The latter was discovered by H. Leavitt in 1912 for stars in the Large Magellanic Cloud, a nearby irregular dwarf galaxy.



Since the distance of this stellar system was unknown, Leavitt presented the P-L Law in terms of relative brightness (apparent magnitudes) rather than intrinsic brightness (absolute magnitudes). Sometime later, H. Shapley was able to determine the absolute magnitudes for the short period pulsating stars called RR Lyrae stars and therefore, the absolute magnitudes for all the pulsating variables that make up the P-L Law. That is, Shapley was able to calibrate the P-L Law and make it a tool for determining distance.



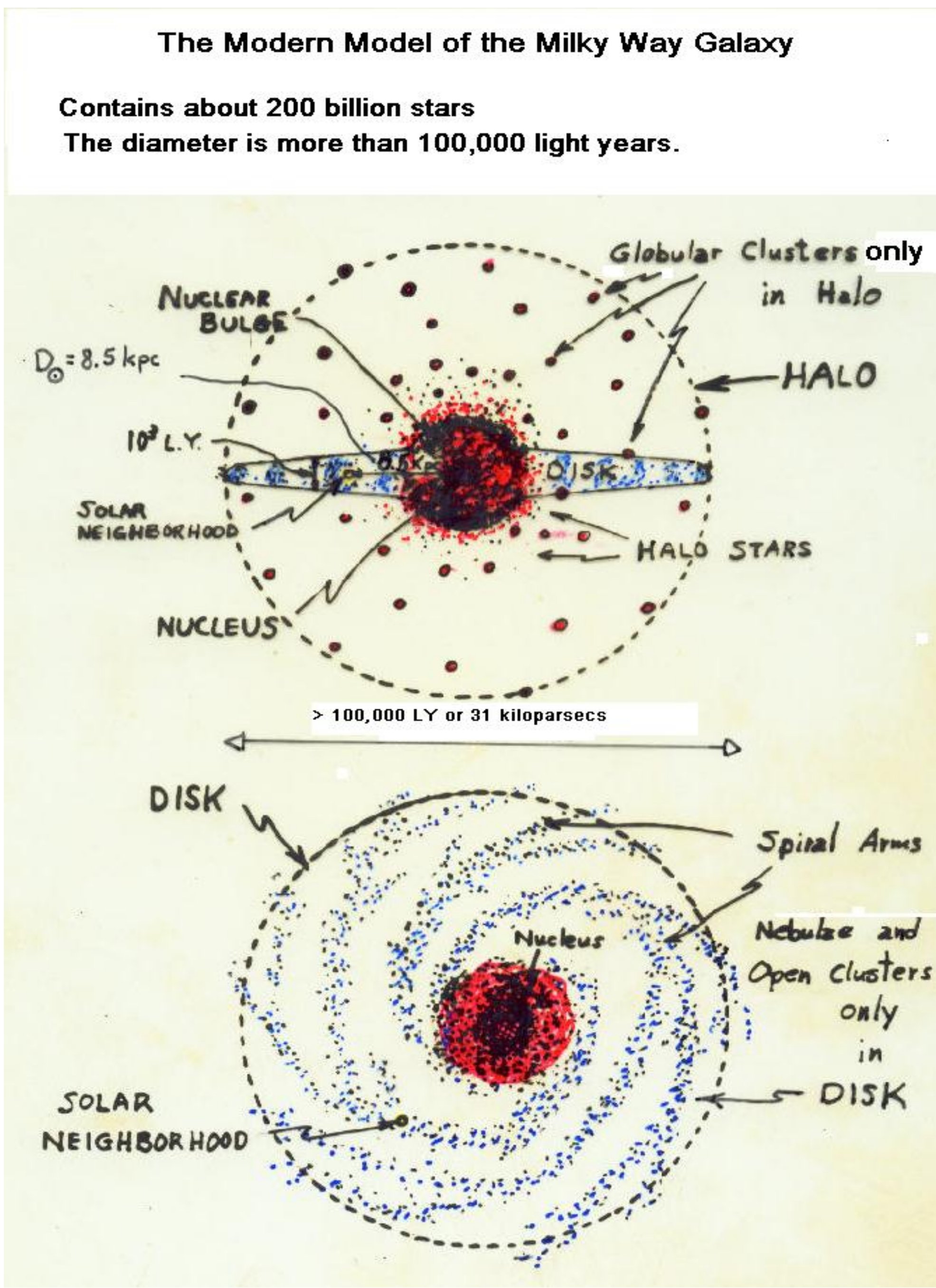
By measuring the periods of pulsation for some variable stars found in each globular cluster, Shapley was then able to determine their absolute magnitudes from the P-L Law and thereby, determine the distance of each cluster.

He discovered that the distribution of globular clusters was a spherical one, but not centered on the Sun. It was logical that the distribution was centered on the center of the galaxy and therefore, the Sun was not at the center of the galaxy. Instead, the Sun was displaced from the center by about 0.6 of the distance from the center to the edge of the disk. Since Shapley's work, there have been many other studies of the structure of our galaxy, which are summarized below.

Properties of the Milky Way Galaxy:

1. The **disk** of our galaxy has a spiral structure and is more than 100 thousand LY in diameter and, more than likely, it is 150 thousand LY in diameter. Most of the interstellar medium is confined to the disk of a galaxy.

2. All the globular clusters form a spherical halo around the center of The Galaxy. The halo also contains **halo stars**, which are also old stars. The latter are concentrated towards the center of the halo and eventually merge into what is called the



nuclear bulge of the galaxy.

3. The central region of the galaxy is called the **nucleus.** It is believed there is a dormant, supermassive black hole at the very center.

4. The open clusters are found only in the disk of the galaxy, which is dominated by young stars

5. Our galaxy contains nearly 200 billion stars and many gas and dust clouds in the disk.

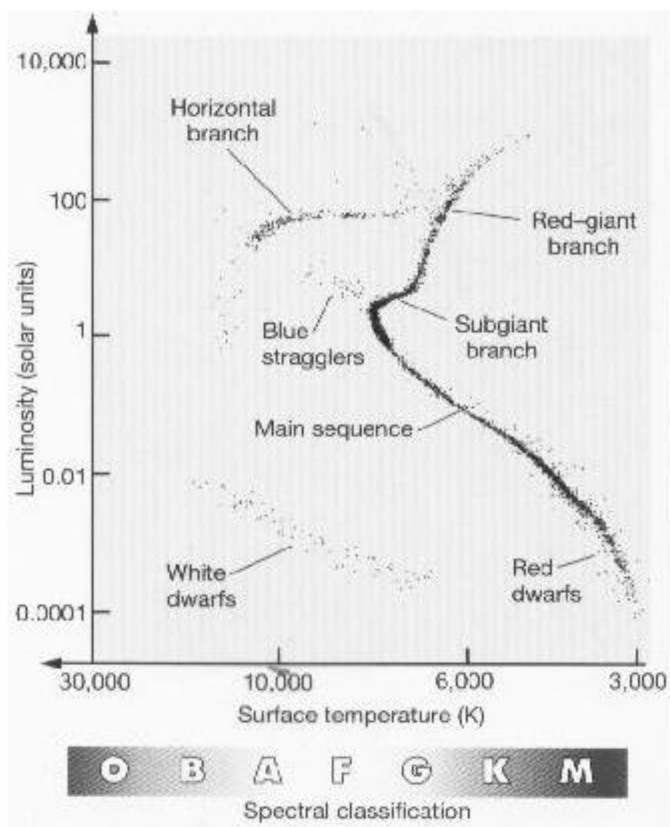
6. Each star in a galaxy moves in orbit around the center of the galaxy. The sun orbits the center of Our Galaxy at 250 km/sec and takes 200 million years to orbit once.

7. The solar system is located in the disk on the inner edge of a spiral arm at a distance of about 8.5 kpc from the center.

Another advance in understanding our Galaxy was made in 1943 by W. Baade. His study of the stars in different galaxies indicated that there are two distinct stellar populations comprising a galaxy. He designated these two populations as Population I and Population II.

Population I stars:

1. These stars are found in the spiral arms of a galaxy.
2. They are young stars.
3. The brightest stars are the hot blue stars of the upper main sequence or blue giants.
4. Often found in open clusters
5. Associated with nebulosity.
6. Have higher metal abundances.



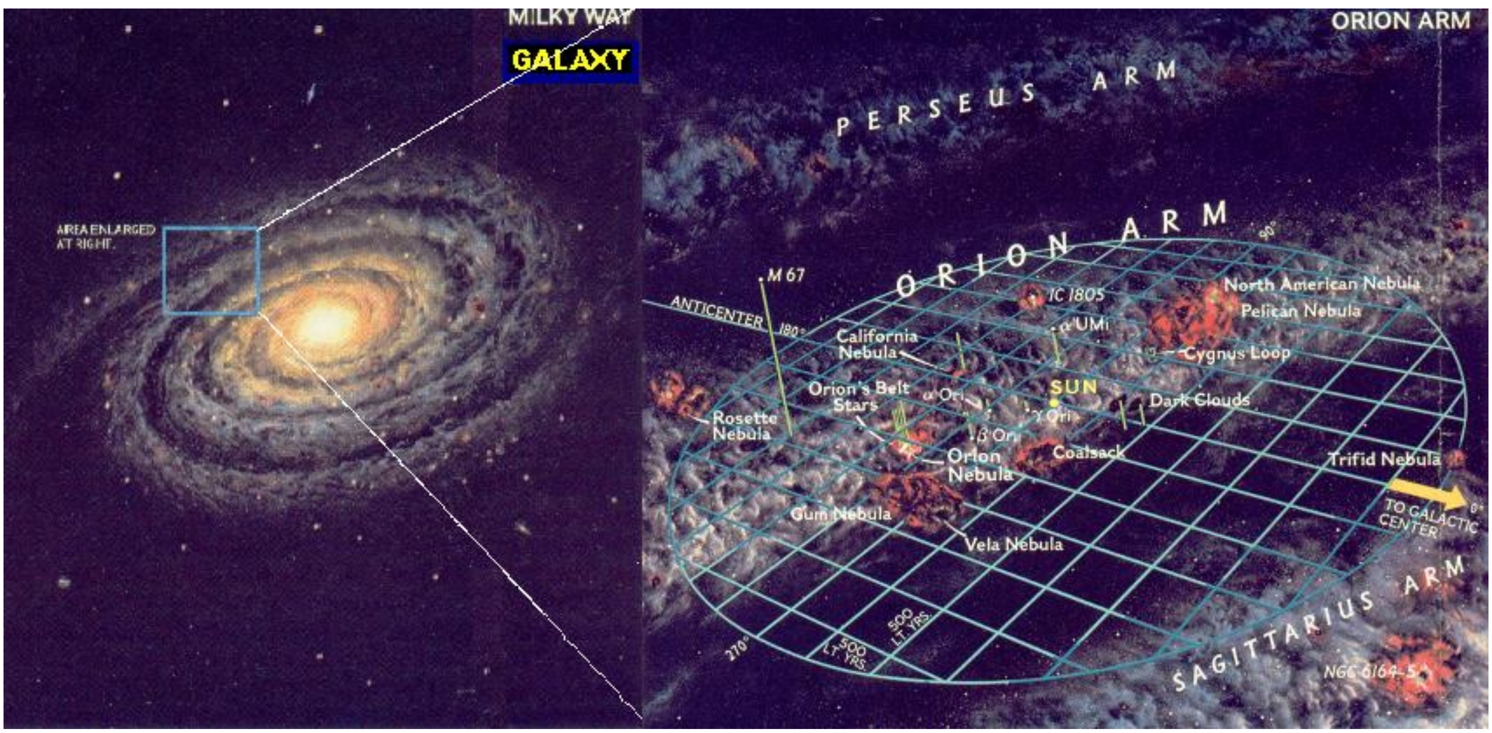
Population II stars:

1. These stars are in the globular clusters, the halo stars, and the nuclear bulge.

2. These stars are very old: more than 10 billion years old.
3. They are not associated with clouds of gas & dust.
4. This population has no blue giants and the brightest stars are red giants and supergiants.
5. The main sequence for such stars is truncated with a turnoff point indicative of their old age.
6. The stars have low metal abundances.

By measuring the 21-cm radiation emitted by neutral hydrogen atoms, radio astronomers have been able to map the clouds of hydrogen gas in our galaxy. This actually delineates the spiral arms of the galaxy, since the hydrogen clouds are confined to the spiral arms.

We now have a much better understanding of the location of the Sun within our galaxy. This is shown in the following figure, which shows the Sun to be located on the edge of what is known as the Orion Arm of the galaxy.



B. Beyond Our Galaxy

From about 1845, astronomers, using large telescopes, began to see things that were called **"spiral nebulae."** These were believed to be pinwheels of gas located in the Island Universe. However, others began to suspect that these things were not spiral nebulae but other island universes, or galaxies, far away from ours.

The true nature of the spiral nebulae and the existence of other galaxies was a matter of debate in the early twentieth century, since the distances of the spiral nebulae had not be determined.

It was in 1924, that E. Hubble discovered photographically that the "Great Spiral Nebula in Andromeda, M31," contained stars and therefore was not a nebula at all.

Some of the individual stars that Hubble was able to detect in the Andromeda System turned out to be pulsating variables. In 1926, Hubble published a paper wherein he describes how he used the P-L Law to determine the distance to the great spiral nebula in Andromeda. His results indicated that it was farther away (1 million LY) than the diameter of Our Galaxy and therefore, it was outside our Galaxy and even larger than our galaxy. Today, this number has been revised to be 2 million LY.

Edwin Hubble inspecting a photographic plate. (Courtesy of Hale Observatories and Bert Shapiro.)

Hence, the Andromeda System was another galaxy, and the question about the nature of the spiral nebulae and the existence of other galaxies had been answered.

We now know that M31 is a member of the Local Group.

Hubble also studied other galaxies and classified them according to their morphology. Galaxies are of different shapes and sizes. Small galaxies are called dwarf galaxies and may contain as few as a million or so stars. In terms of morphology there are:

1. **Spiral galaxies (Our Galaxy is a normal spiral, but there is now evidence that it may be a barred spiral),**
2. **Barred Spirals,**
3. **Giant and dwarf elliptical galaxies (they have no spiral arm structure), and**
4. **Irregular galaxies, which tend to be dwarf ones.**

All spiral galaxies are fairly large. Elliptical galaxies range from very large galaxies to dwarf-sized galaxies that contain only a million or so stars. Irregular galaxies tend to be small systems.

Below is a photograph of a normal spiral galaxy that is about 200 million light years distant. It is outside the Local Group.

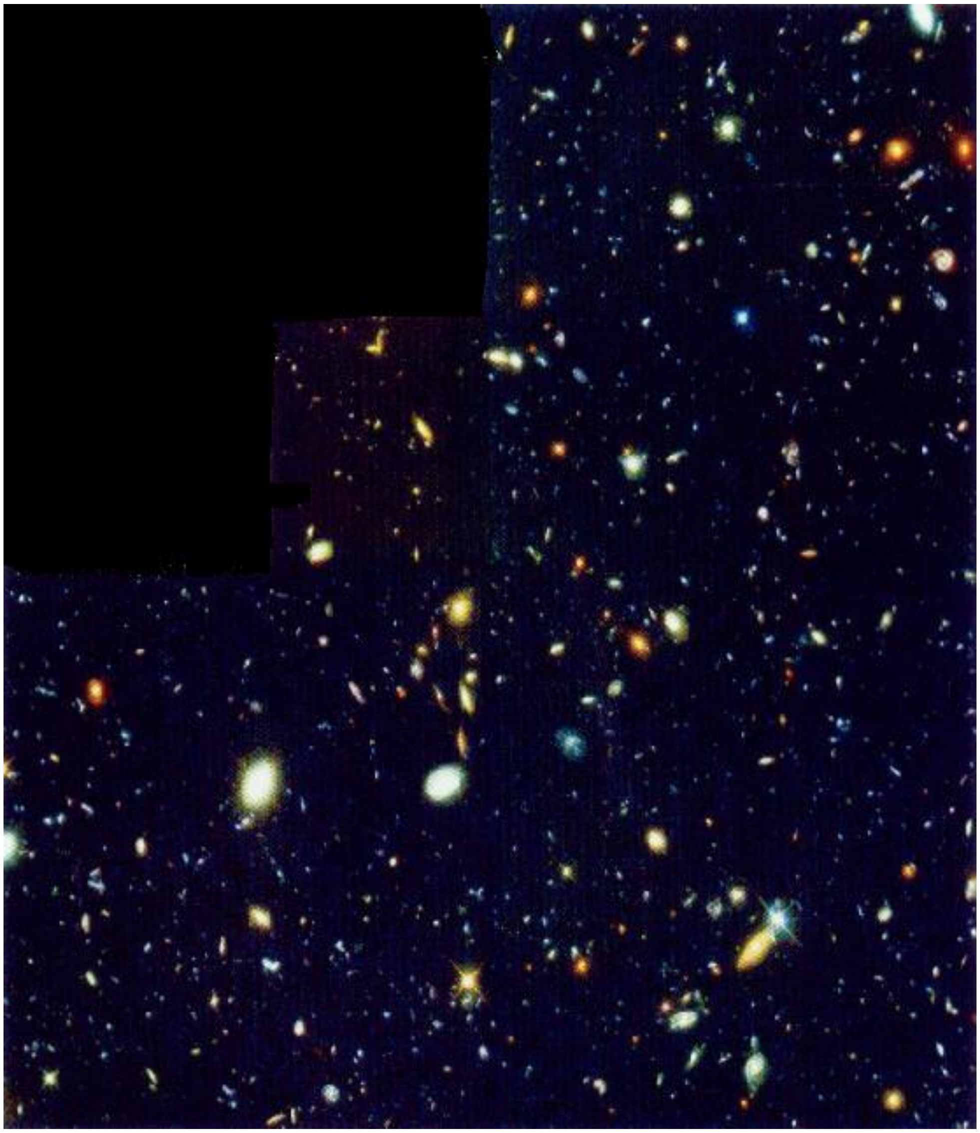
The Sombrero Galaxy, M104, in Virgo

To the right is a photograph of M33, a normal spiral galaxy located in Triangulum. M33 is a member of the Local Group.

Below are examples of barred spirals:

(a) NGC 3992 Type SBa (b) NGC 1365 Type SBb (c) NGC 6872 Type SBc

We now realize that the universe contains billions of galaxies extending to the limit of visibility. Below is a Hubble Telescope image of very deep space and is courtesy of NASA:

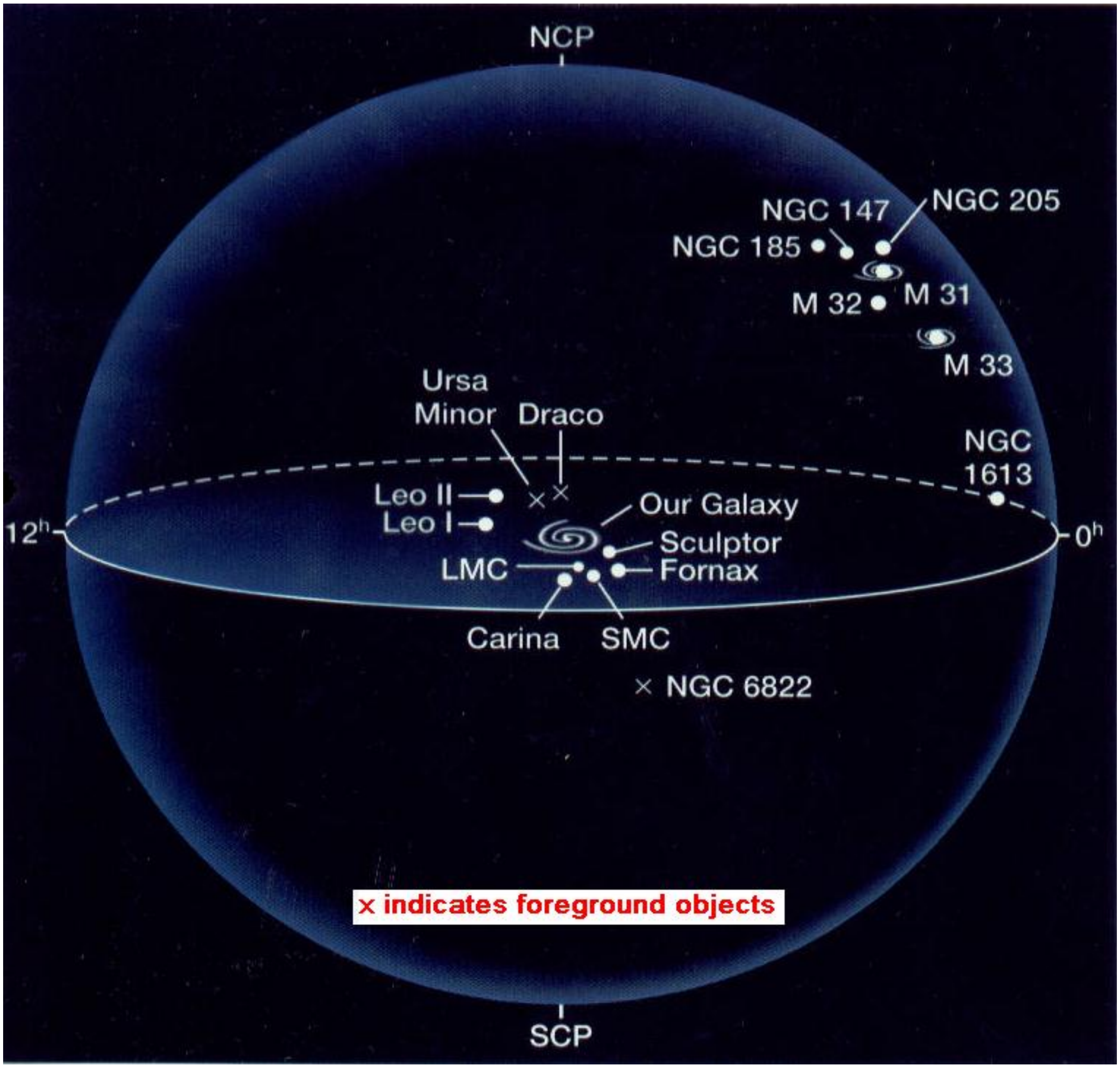


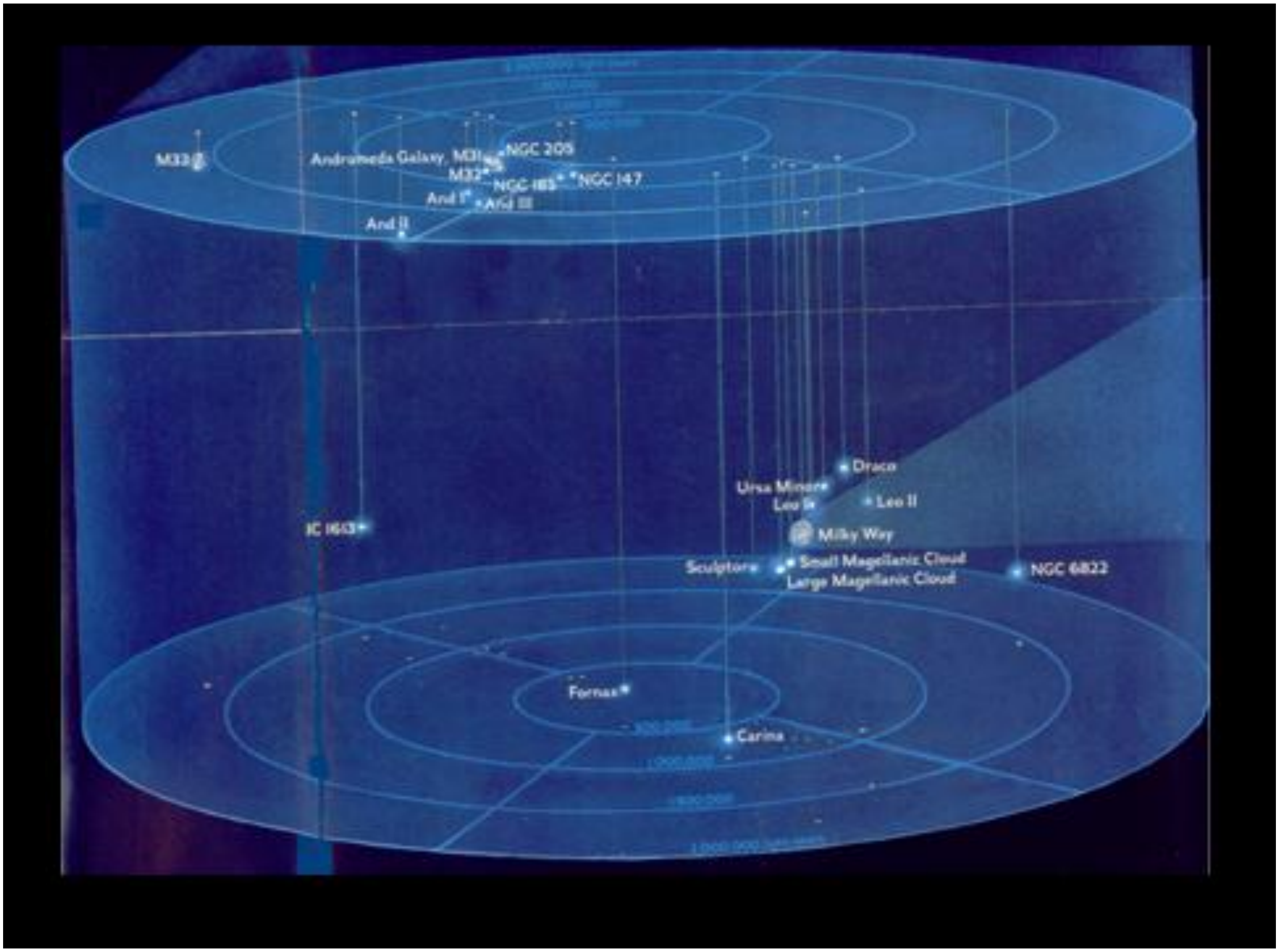
Magellanic Clouds: These are two dwarf, irregular galaxies which move in orbit around our galaxy at a distance of about 180 thousand light years. Observationally, they were first recorded as clouds detached from the Milky Way by Magellan in 1521. Of course, he did not know what they really were.

It appears that our galaxy is tearing the Magellanic Clouds apart with gravitational tidal forces and pulling these dwarf galaxies into itself.

It is now realized that, in general, large galaxies grow larger by absorbing, "eating, cannibalizing, or ingesting" smaller galaxies through gravitation interaction.

Local Group: An apparently gravitationally bound system of about 45 galaxies, including Our Galaxy.





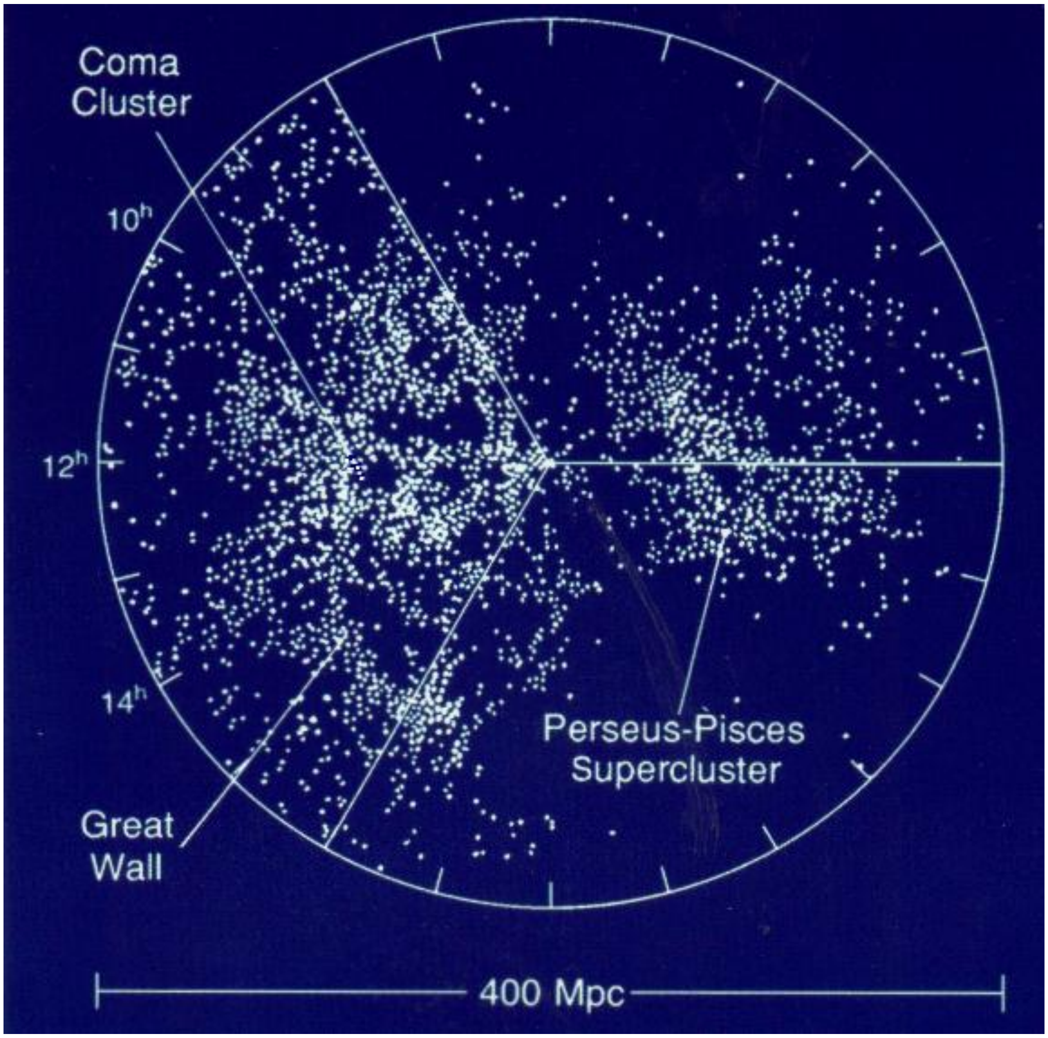
C. Galactic Clusters

Galaxies are organized into clusters, and the clusters are organized into superclusters throughout the visible universe.

Our Local Group is a relatively small cluster of galaxies that is located on the edge of a supercluster called the Virgo supercluster. This name comes from the fact that the center of the Virgo supercluster is located in the sky within the boundaries of the constellation Virgo.

The galaxies and clusters of galaxies are distributed throughout the universe in a frothy or random lace-like manner. That is, there are large voids in the universe where no galaxies are found.

These voids are similar to the large bubbles of air in soap suds. The galaxies define the surfaces of these voids. That is, the galaxies are like the soap itself.



The most distant cluster of galaxies is about 13.5 billion light years away. This sets a lower limit on the size of the visible universe.

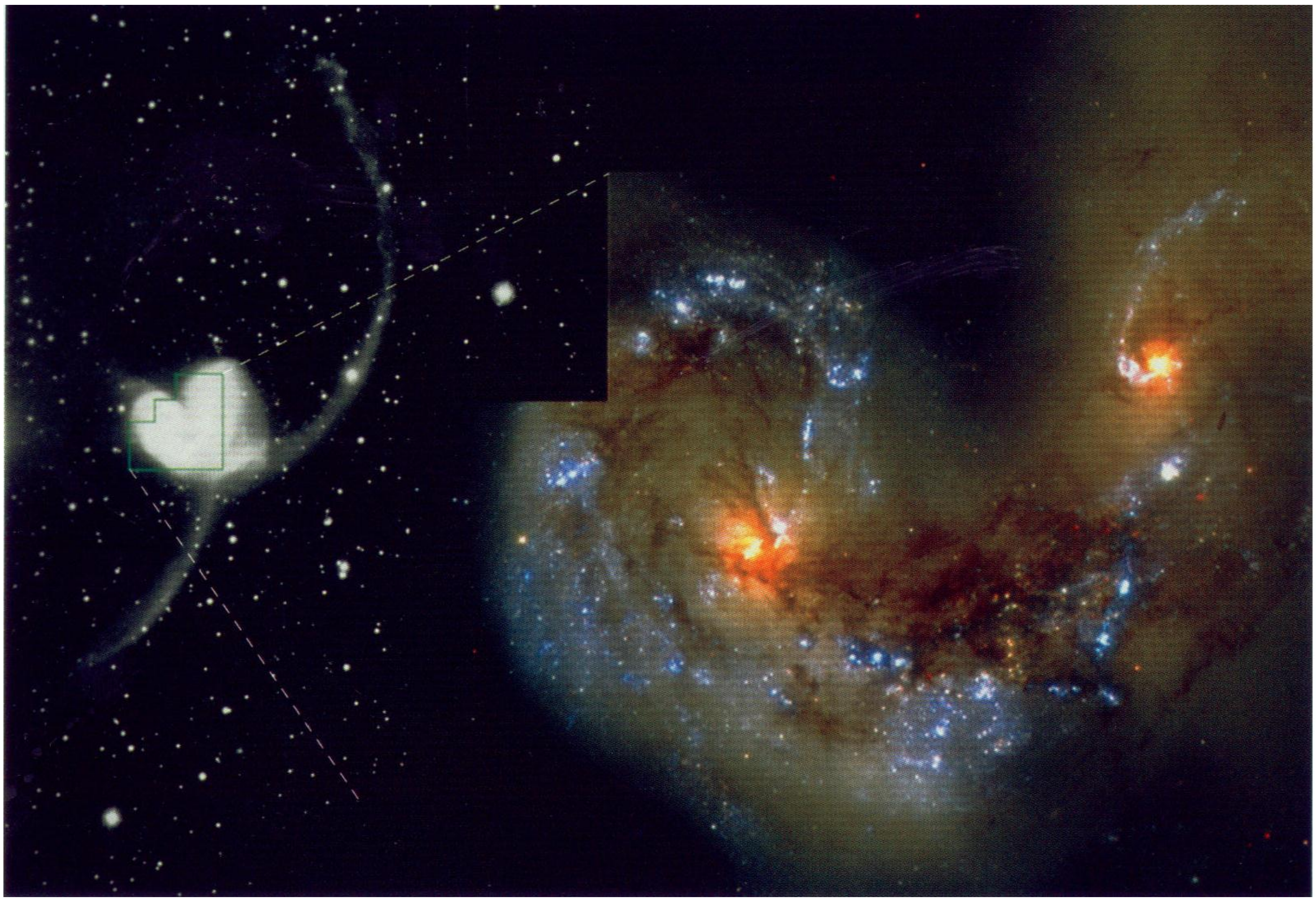
D. Galactic Interactions

As the galaxies in a cluster move about, they often get sufficiently close to one another that gravitational tidal forces distort the shapes of the galaxies.

At other times 2 galaxies might actually collide with one another and merge together.

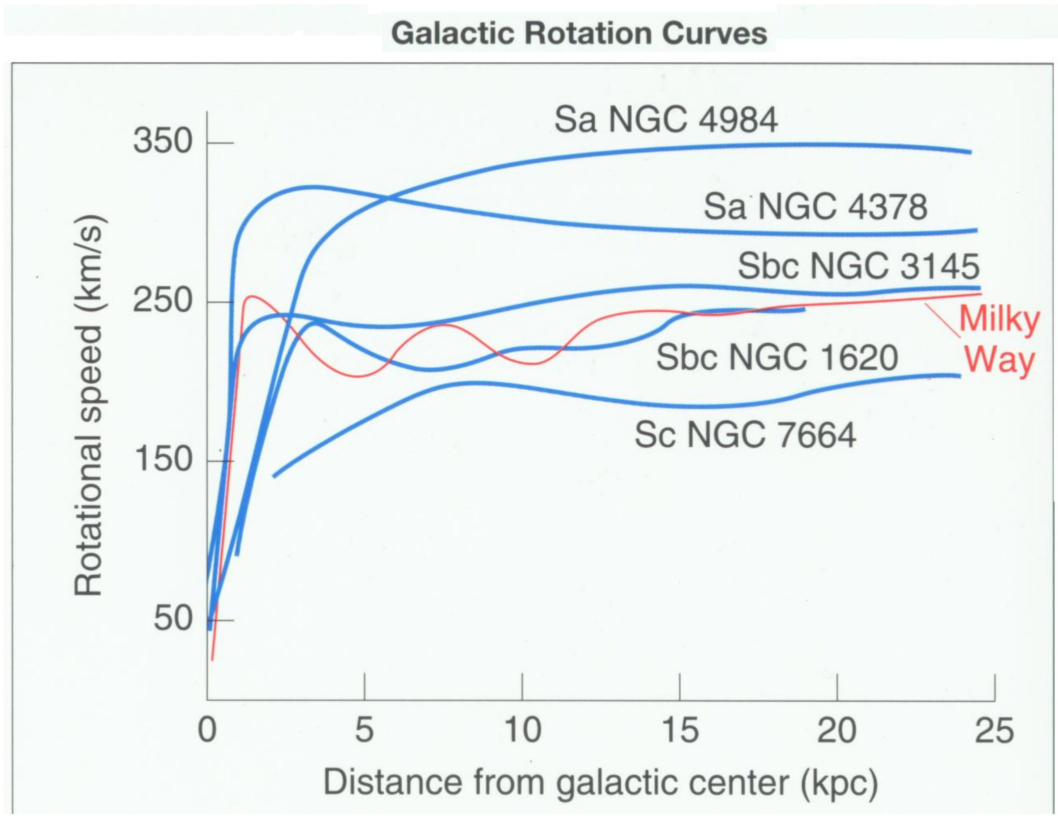
Although a collision of two galaxies will wreak havoc on the large scale structure of the galaxies, it has no effect on the stars they contain.

This is because stars are spaced about a parsec apart, which is millions of times greater the size of a typical star. So the stars in the galaxies just glide past one another.



E. DARK MATTER

Studies of the motions of stars in galaxies indicate that galaxies have a lot of unseen matter or non-luminous matter. This is called "dark matter." The evidence for this is summarized in the diagram below: The diagram shows that the rotational speeds of the galaxies levels off at a distance of about 3 to 4 kpc from the center of the galaxy, whereas it should decrease with distance from the center of the galaxy in accord with Kepler’s Third Law of Planetary Motion.



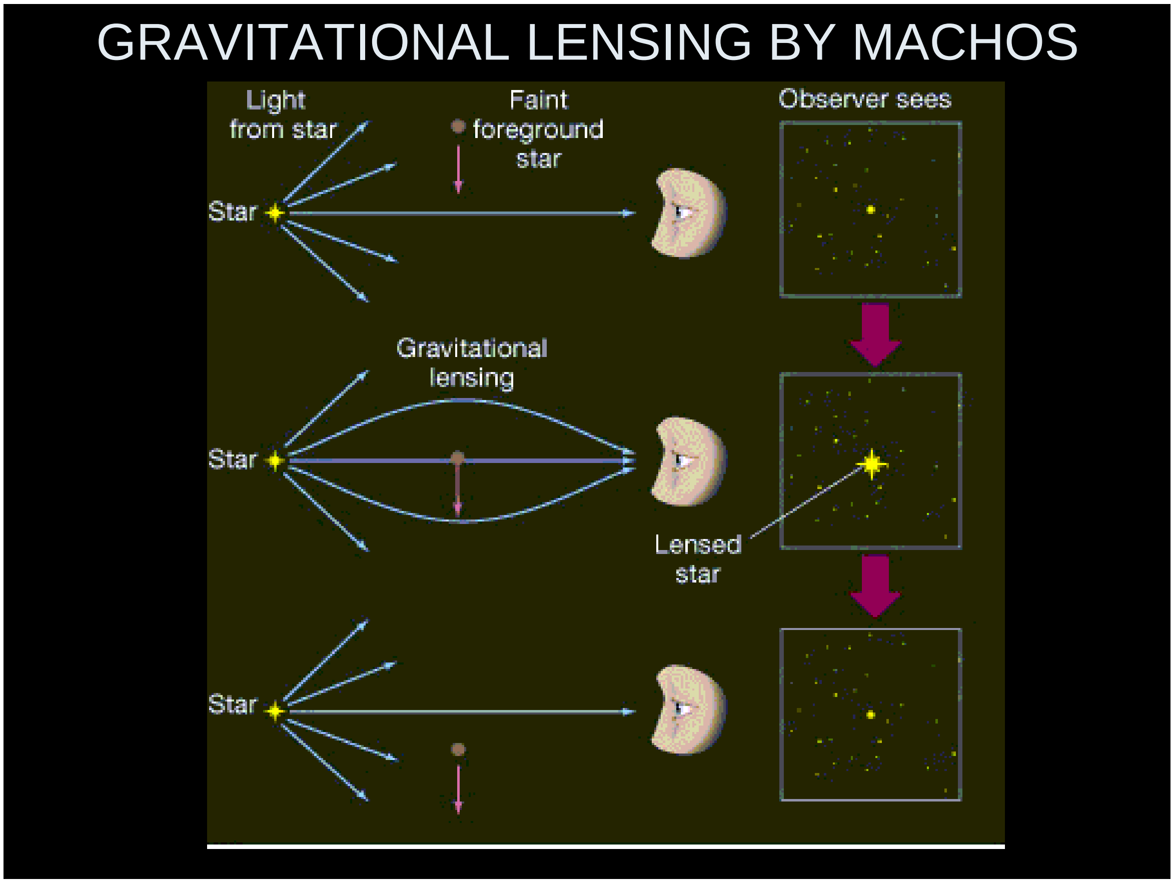
The only to explain these rotational curves is that there must be a large amount of dark matter that is distributed almost uniformly throughout the halos of the galaxies.

One of the frontiers of investigation today is to determine what the form of this dark matter is. However, it known that dark matter makes up more than 90% of the matter in the universe. Some matter may not really be dark, but just intrinsically faint so that it is not detectable at great distances.

However, we shall also classify this kind of matter as "dark matter." The different possible kinds of dark matter in the universe are then:

1. Very faint red dwarf stars
2. Very faint white dwarf stars
3. Black Holes and neutron stars
4. Brown dwarfs. These are believed to exist in large quantities.
5. Dust, which is not believed to make a major contribution to the amount of dark matter in the universe.

6. MACHOS (massive compact halo objects.). These cause gravitational lensing effects, by which they have been detected. Many are believed to be white dwarfs.



7. Neutrinos (These come from TNF reactions and flood the universe, but the mass of these subatomic particles is extremely small and has not been well determined).
8. WIMPS (weakly interacting massive particles). Such things are predicated to exist according to the theories of particle physics. Recently there have been some reports that such particles have been detected in the laboratory, but the data are not conclusive.

The End