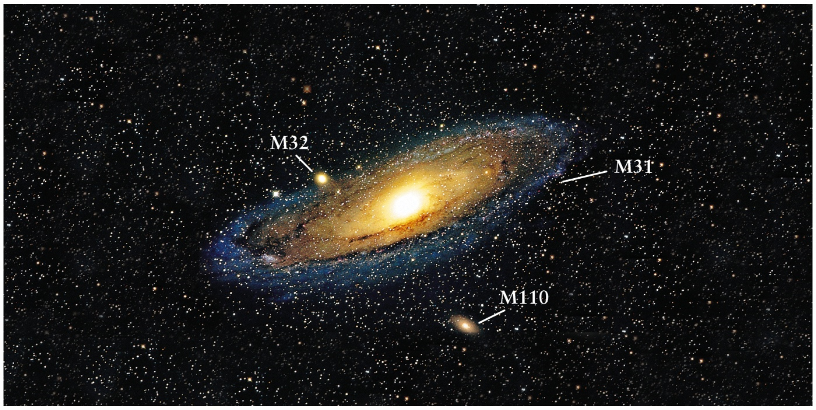
Clustering of Galaxies

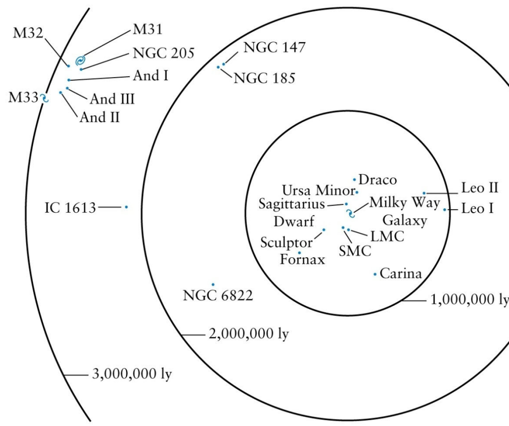


The Local Group

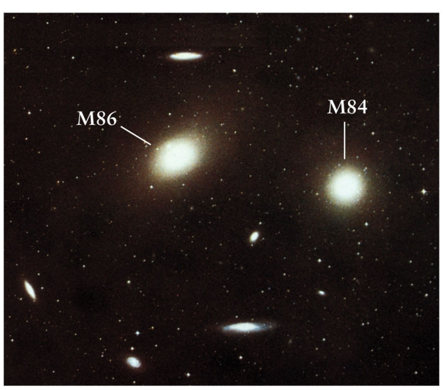
The Milky Way is a member of a small group of galaxies called the **Local Group**. It is spread over about a million parsecs and contains at least 26 members. There are 3 large spiral galaxies (our own, the Andromeda Galaxy, and M33), at least 9 dwarf irregulars, 2 intermediate ellipticals, and 12 known dwarf ellipticals.

The radial velocities of some of the Local Group galaxies have been measured. Most of the apparent radial velocities are due to the motion of our Galaxy in the Local Group. We find the Galaxy is moving at about 100 to 150 km/s in the Local Group. The total mass is about 5×10^{12} solar masses, and much of it is in the form of **dark matter**.

The Local Group



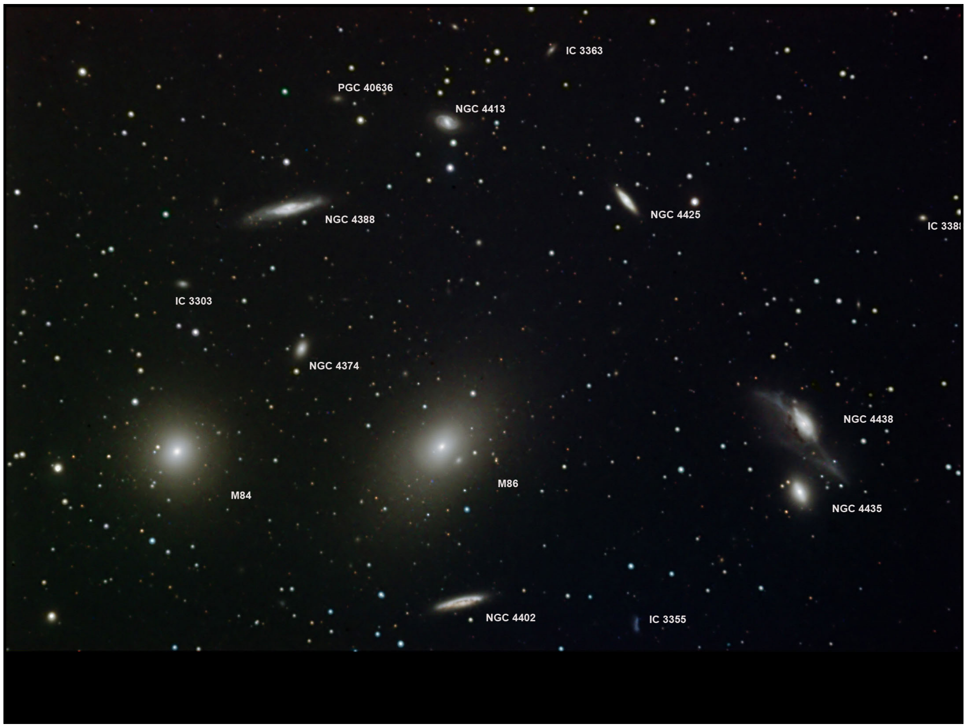
Neighboring Groups and Clusters



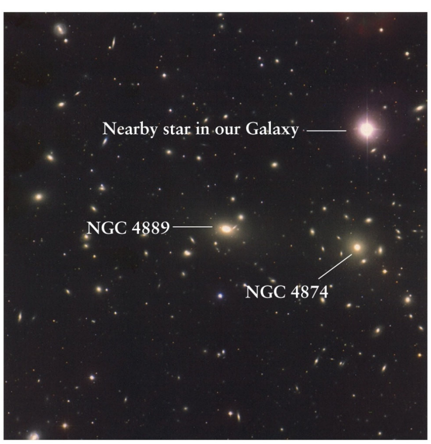
The nearest moderately rich cluster is the Virgo Cluster, which has a 1000 members. It contains a concentration of mostly elliptical galaxies that includes M87, which is both a radio and an X-ray source.

Within several degrees of M87 are many spirals as well as ellipticals and very many dwarfs.

The distance to M87 is about 15 Mpc (50,000,000 ly). Its linear diameter is1.5 Mpc (5,000,000 ly).


IC 3363
PGC 40636
NGC 4413
NGC 4388
NGC 4425
IC 3303
NGC 4374
NGC 4438
M84
M86
NGC 4435
NGC 4402
IC 3355

Neighboring Groups and Clusters



The Coma Cluster has a linear diameter of at least 3 Mpc (10,000,000 ly) and has thousands of galaxies. The cluster is centered on two giant ellipticals.

The total number may be tens of thousands of galaxies, with a total mass of 4 x 10^{15} solar masses.

Rich clusters like Coma usually show spherical symmetry and high central concentration. **They contain few, if any, spiral galaxies in the cluster core, and are dominated by ellipticals and S0 galaxies.**

The Coma Galaxy Cluster

Neighboring Groups and Clusters

Irregular clusters, such as the Hercules Cluster, are much less dense than the Coma Cluster.

These clusters contain many spiral galaxies, often associated in pairs and small groups.

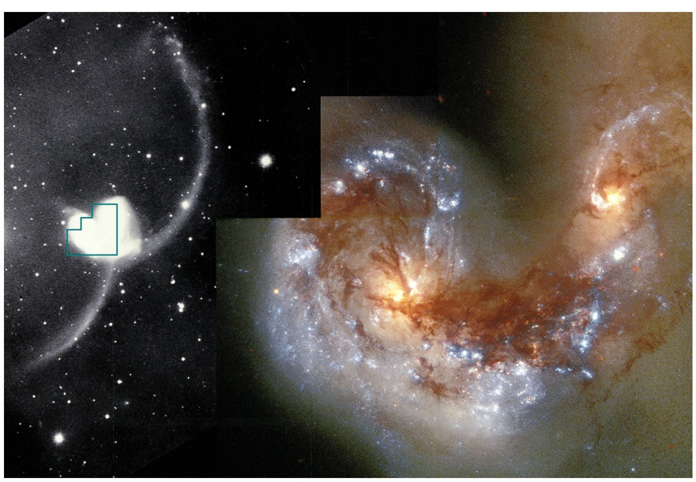
Environmental Influence

The surrounding environment may be the dominant factor in determining what types of galaxies are formed.

Observations show that about 80 to 90 percent of the galaxies in the high-density environments in the **centers** of clusters of galaxies are **ellipticals** (and disk-shaped galaxies that have very little gas, no spiral arms, and no recent star formation).

Conversely, isolated galaxies found in the **periphery** of clusters, where the density is low, are mostly **spirals**.

Colliding Galaxies



Interacting Galaxies

Fundamental Properties of Tidal Interactions

1. The tidal force is proportional to the inverse cube of the separation of the galaxies.

2. Tidal forces on an object tend to elongate it; thus there are tidal bulges on both the near and the far sides of each galaxy with respect to the other.

3. The perturbed galaxies are generally rotating before the tidal encounter, and the subsequent distributions of their material must reflect the conservation of their angular momenta.

Interacting Galaxies

We might expect a tidal interaction between two galaxies to pull matter out of each toward the other. Such bridges of matter may form between the galaxies, but also there are "tails" of material that string out away from each galaxy in a direction opposite to that of the other.

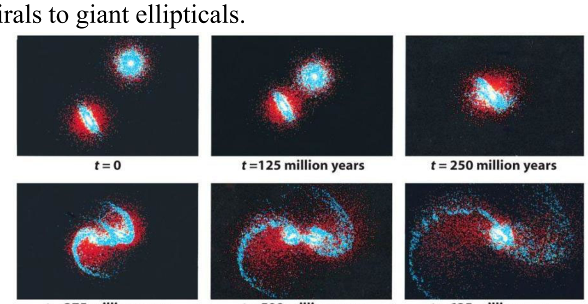
Because of the rotation of the galaxies, the tails and bridges can take on unusual shapes, especially when account is taken of the fact that the orbital motions of the galaxies can lie in a plane at any angle to our line of sight.

Interacting Galaxies

The **interstellar material** is much more affected by galaxy interactions than are the stars. Interstellar gas clouds are large and are likely to have direct impacts with other clouds. These violent collisions compress the gas in the clouds, and the increased density can lead to vigorous star formation.

Galactic Collisions

If galaxies collide with a slow relative speed, they may avoid tidal disruption. Some parts of slowly colliding galaxies can be ejected, while the main masses become binary (or multiple) systems with small orbits about each other. These binaries may coalesce into a single large galaxy. This is especially likely in the collisions of the most massive members of clusters, which tend to have the lowest relative speeds and to be concentrated toward the center. Mergers may convert spirals to giant ellipticals.



Galactic Mergers and Cannibalisms

The term **merger** is used to refer to the interaction of two galaxies of comparable size, whereas the swallowing of a small galaxy by a much larger one is described as **cannibalism**. Two mechanisms are relevant.

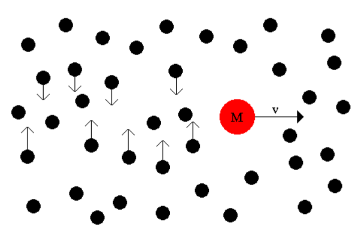
1) The first is **tidal stripping**. If a small galaxy approaches a large one too closely, then its self-gravity may be inadequate to retain the stars and gas in its outer regions. The tidal forces of the larger galaxy will dominate and will rip away stars from the galaxy of lower mass.

Galactic Mergers and Cannibalisms

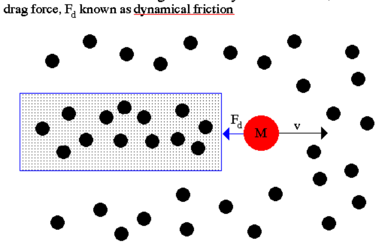
2) A large galaxy can swallow the dense core of a smaller galaxy through a second mechanism, called **dynamical friction**.

If the core of the smaller galaxy is moving rapidly through the envelope of stars of the larger one, it will lose energy and decelerate while the stars in the larger galaxy will be pulled behind into its "wake".

This process causes the smaller galaxy to slow down and to spiral into the massive one.

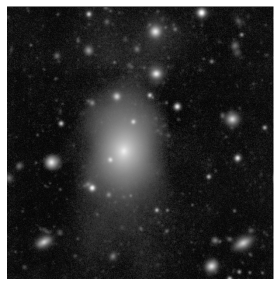


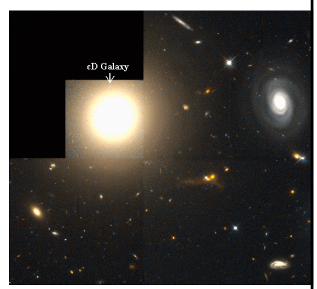
this results in an enhanced region of density behind the mass, with a drag force, F_d known as dynamical friction



Galactic Mergers and Cannibalisms

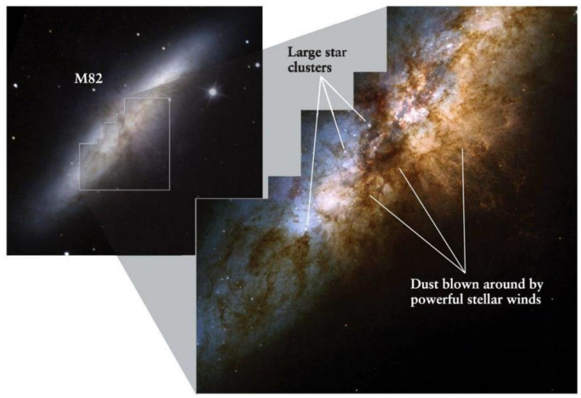
Rich clusters are often observed to have one or more supergiant galaxies, which are called **cD galaxies**, near their centers. It is likely that these galaxies formed by galactic cannibalism. In a cluster of galaxies, the most massive and most luminous galaxies are usually found near the center. These galaxies are often much more luminous than typical galaxies, and they frequently have more than one nucleus.





Star Formation in Galaxies

In spirals, star formation is a continuous process that is still occurring. In ellipticals, even the youngest stars are older than the Sun. Since they have very little dust or gas, star formation cannot take place in the present era.



Star Formation in Galaxies

In Elliptical galaxies, where did the gas and dust go?

Much of it must have been consumed very rapidly in the formation of the first generation of stars. But star formation alone would not be efficient enough to consume all of the gas and dust.

As stars evolve, they lose mass via stellar winds or explosions. In the process, they eject dust and gas into the space between the stars.

Star Formation in Galaxies

It must be that gas and dust are some how efficiently removed from elliptical galaxies. Maybe the gas is swept out. Ellipticals occur in clusters of galaxies, and in such, there is hot gas present.

As an elliptical galaxy orbits within a cluster, it moves rapidly (about 1000 km/s) through the gas that lies within the cluster but outside the galaxies. This intergalactic gas bombards whatever small amount of gas may lie within the elliptical and drives the gas from the galaxy.

Spiral galaxies are able to retain their gas and dust because they lie isolated in regions where the density of intergalactic gas is too low to sweep them clean.

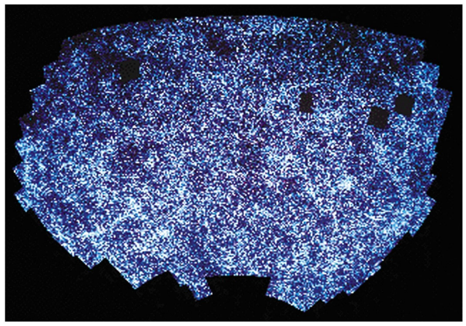
Neighboring Groups and Clusters

Clusters of galaxies are usually sources of X-rays. The X-rays from a cluster are thermal radiation from intra-cluster gas at a temperature of 10^7 to 10^8 K, with the most intense radiation generally coming from the center of the cluster. The mass of gas required is typically 10 to 20%.

This hot gas from the galaxies may explain the lack of spirals – the sweeping of interstellar material would stop star formation and the spiral arms would disappear, leaving the galaxies as S0 types.

The swept gas is hot because the galaxies collide with one another or pass through intra-cluster gas at speeds up to thousands of km per second.

Superclusters



Superclusters contain one or more clusters of galaxies. Between the super-clusters are great **voids**. The Universe is homogeneous and isotropic only on scale sizes large enough to include a number of superclusters and voids.

Superclusters

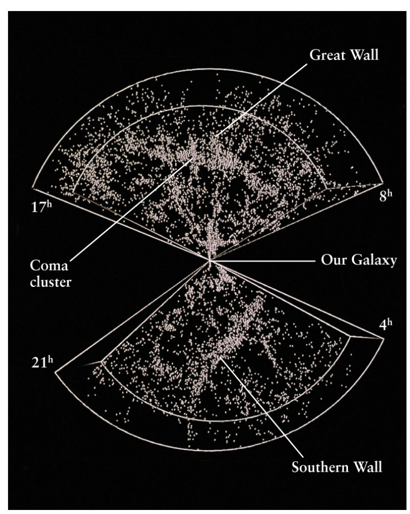
The best studied supercluster is the one that includes the Milky Way. The most prominent grouping of galaxies within the Local Supercluster is the Virgo Cluster. The Milky Way Galaxy lies in the outskirts of the Local Supercluster. Its diameter is at least 20 Mpc (70,000,000 ly), and its mass is about 10^{15} solar masses.

The vast majority of bright galaxies lie in a small number of clumps and most of these are **confined to a plane**. In fact, 60% of all the galaxies within the Local Supercluster are located within a disk-like region whose diameter is about six times its thickness. Both the Local Group and the Virgo Cluster itself lie in the plane of the disk.

The Great Wall

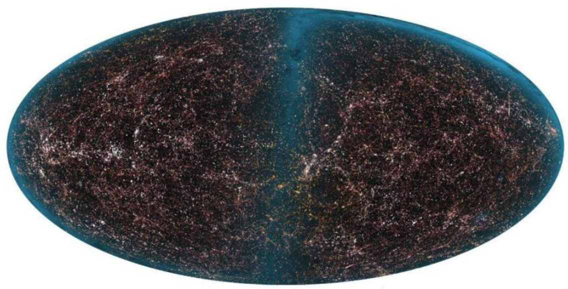
The Great Wall is a sheet of galaxies:
150 Mpc (500,000,000 ly) long,
60 Mpc (150,000,000 ly) high, and
5 Mpc (20,000,000 ly) thick.

It is ~ 80 Mpc (250,000,000 ly) away. Its mass is estimated to be 2×10^{16} solar masses, a factor of 10 greater than the mass of the Local Supercluster.



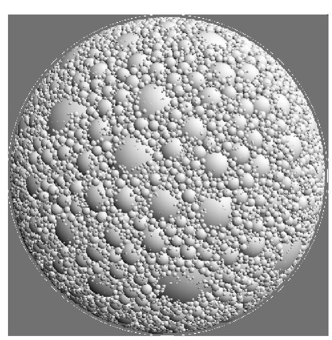
Empty Space

The most startling fact is that most of space is *empty*. Most of the galaxies are concentrated, and these clusters occupy only about 5% of the total volume of the Local Supercluster.



Meatballs or Swiss Cheese?

If the Universe is Swiss Cheese, then galaxies are distributed in large connecting structures that surround empty holes that are typically 25 to 50 million pc in diameter.



Meatballs or Swiss Cheese?

On the other hand, we may live in a Meatball Universe, in which the concentrations of matter – galaxies – are isolated from one another and are surrounded by connecting empty tunnels where no galaxies occur.

Meatballs or Swiss Cheese?

The third possibility is that the Universe is sponge-like, with long, interconnected filamentary chains of galaxies, and connecting filamentary voids as well.