Chapter 17. Galaxies

Discovery

With the development of the telescope, astronomers began to find vast numbers of small fuzzy patches of light, called "nebulae". Some of them were later resolved into clusters of stars, while some were found to have pure emission line spectra thus had to be gaseous, e.g., planetary nebulae and HII regions. However, some of the "nebulae" were neither resolvable nor gaseous.

The nature of these "nebulae" was settled by Edwin Hubble in 1923. Using the 100-inch telescope at Mount Wilson, he resolved M31 and M33 into stars. In the following year, he discovered Cepheid variables in M31; from the period-luminosity relation, he measured the distance of M31 at 300 kpc. Therefore, these "nebulae" are really *galaxies* at great distances.

Types of Galaxies

Edwin Hubble divided galaxies into three classes - elliptical, spiral, and irregular. The elliptical galaxies are subclassified into E0 to E7 in increasing elongation. The spiral galaxies are divided into *normal spirals* and *barred spirals*, which are further subclassified into S0-Sa-Sb-Sc and SB0-SBa-SBb-SBc sequences.

Along the spiral sequences of Sa-Sb-Sc and SBa-SBb-SBc, the spiral arms become more open, the bulge becomes smaller, the disk becomes thinner, and the star formation becomes more active (producing more prominent OB stars). Our Galaxy can be classified as a Sb galaxy.

Hubble's tuning fork diagram does NOT represent a sequence of galaxy evolution.

Distances

We need to know the distance to a galaxy before we can learn anything about its physical nature. Various *distance indicators* are used to determine distances. Cepheid variables and RR Lyrae variables are both good distance indicators, as their intrinsic luminosities can be determined from the measured periods and the known period-luminosity relation. This method is good up to 10 Mpc. The absolute magnitudes of globular clusters can be inferred from galactic studies, so globular clusters can be distance indicators up to 20 Mpc.

At still larger distances, the velocity spreads of the HI 21-cm emission line of spiral galaxies provide the distance indicator. Brent Tully and Richard Fisher found that the velocity spread of the HI 21-cm line is correlated with the luminosity of a spiral galaxy. This *Tully-Fisher relation* provides the only way to measure distances greater than 20 Mpc.

At distance greater than 20 Mpc, galaxies are used as distance indicators; however, any class of galaxy has a great range in size and absolute magnitude, so they are not very reliable distance indicators.

Clusters of Galaxies

Galaxies tend to gather together, forming gravitationally bound *clusters of galaxies*. Our Galaxy is in the *Local Group* cluster of galaxies. M31, M32, the Large Magellanic Cloud, and the Small Magellanic Cloud are all members of the Local Group.

Some clusters of galaxies have high concentration toward the center and are dominated by giant elliptical galaxies, while some clusters are not as centrally condensed and contain mostly spiral galaxies.

Dynamics and Masses

The rotation curve of spiral galaxies can be determined from observations of their emission lines, such as Hα. The rotational velocity at the outermost edge of a galaxy can be used to compute the total mass of the galaxy. Most galaxies have flat rotation curve, indicating the existence of dark matter.

Elliptical galaxies do not rotate as rapidly as spirals, and they do not contain much gas to emit spectral lines. However, stars move in the gravitational field of an elliptical galaxy would show a spread in stellar speeds, which can be measured in stellar absorption lines. With the aid of theory, it is then possible to derive the mass of an elliptical galaxy.

Some elliptical galaxies are enmeshed in large X-ray emitting halos of hot gas at temperatures of over 10^6 K. The existence of the hot gas implies a strong gravitational field, which requires a mass many times that of the luminous mass. Dark mass is needed.

The distribution of velocities of galaxies in a cluster reflects the gravitational field of the cluster. Again, dark matter is needed to explain the observed velocity distribution.

The Origin of Galactic Forms

One possible origin of the different galactic forms is the different amounts of angular momentum in the initial clouds. Elliptical galaxies would have a smaller initial angular momentum, which allowed easier star formation during the early stage. Spiral galaxies have a larger angular momentum, which slows down the star formation and spins the gas into a thin disk. However, it is not clear whether the formation of a bar is related to angular momentum.

Collisions and mergers may play an important role in the formation of galaxies. Many *peculiar* galaxies are actually interacting galaxies. Tidal interactions can deform spiral arms, trigger star formation, produce tails or antenna-type structures.

Some galaxies are observed to have two cores, indicating the merger of two galaxies. Mergers may be instrumental in making the giant ellipticals and the giant galaxies in the center of rich clusters.

Active Galactic Nuclei

The Galaxy and many otehr galaxies show evidence of massive black holes in the central nucleus. Stars orbiting at high rotational velocities close to the nucleus provides the most convincing evidence for the existence of a black hole (use Kepler's third law of motion). The mass of the black hole can be 10^6–10^7 $M_\odot$.

"A massive black hole with an accretion disk" in the center of a galaxy can explain many different types of active galaxies observed: Seyfert galaxies, active galactic nuclei (AGNs), radio galaxies, even quasars. Different viewing angles result in different observed characteristics.