# Chapter 16. The Galaxy

## Basic Structure

The Milky Way galaxy is often called *the Galaxy*. It consists of three parts: disk, halo, and bulge. The disk can be recognized as "the band of light" in the night sky.

The constituents of the Galaxy can be roughly divided into two populations, called *Population I* and *Population II*, with the following different characteristics:

| | Population I | Population II |
|---|---|---|
| Location | Galactic disk | Galactic halo |
| Members | O and B stars, the ISM, supergiants | red dwarfs and giants |
| Clusters | open clusters | globular clusters |
| Abundances | metal-rich | metal-deficient |
| Age | young stars, star formation | old stars |
| Supernovae | all types | only Type Ia from white dwarfs |

## The Size of the Galaxy

The location of the Galactic center can be determined from the distribution of globular clusters in the halo. The Sun is at ∼8.5 kpc from the Galactic center. The Galaxy has no clearly defined edge; the number of stars and the density of the ISM diminish gradually at large radii. About 90% of the light of the Galactic disk falls within a radius of 12.5 kpc, so this radius has been adopted as the size of the Galactic disk.

## Galactic Disk

The Galactic disk contains different types of objects that are distributed with different scale heights. Roughly, the interstellar medium and O, B stars are distributed in the disk within ±100 pc from the mid plane, the other stars ±350 pc, and some oldest stars ±1000 pc.

The Galactic disk rotates about the Galactic center under its own gravitational force. The halo stars do not partake in galactic rotation, so their average velocity reflects the the rotational velocity of the Sun. The Sun is found to have a rotational velocity of 240 km/s. This is faster than the rotational velocity of the average motion of the stars in the solar neighborhood, 220 km/s.

## Galactic Rotation Curve

The rotational velocities of different positions in the Galaxy can be determined using the HI 21-cm emission line observations. A cloud at the tangent point to its orbit would show the largest Doppler shift along that line of sight. We can subtract the solar motion from the observed radial velocity to obtain the rotational velocity of the cloud. The plot of rotational velocities against distances from the Galactic center is the *Galactic rotation curve*.

The outer galactic rotation curve is determined by measuring the radial velocities of HII regions and molecular clouds and the distances of their embedded O and B stars. The rotation curve of the outer part of the Galaxy has been determined out to 20 kpc from the center.

**Spiral Structure**

The distribution of HI gas and molecular clouds in the Galaxy shows spiral arms, similar to those seen in other galaxies. The spiral arms are not permanent collection of stars. They appear to be waves of density. Some disturbance causes a clumping of interstellar gas. The increased gravity causes the clumping to propagate outwards through the Galaxy in response to the rotation. The density wave theory can explain the propagation of the arms, but the origin of the initial disturbances is unknown.

**The Mass of the Galaxy and Dark Matter**

The mass of the Galaxy can be determined from the rotation curve using Kepler's third law of planetary motion. $M_{innerGalaxy} + M_\odot = a^3/P^2$, where $M_{innerGalaxy}$ is the mass within the solar orbit in solar masses, $a$ is the distance from the Sun to the Galactic center in AU, and $P$ is the period in years. The period can be determined from the orbital speed $v$, $P = 2\pi a/v$. The mass of the inner Galaxy is $9\times10^{10}$ $M_\odot$.

Assuming that mass follows light, the total mass of the whole Galaxy is $\sim 10^{11}$ $M_\odot$, since the Galactic disk outside the solar orbit contains only 20% of the galactic light. However, the orbital velocity does not decrease at larger distances as expected in Keplerian orbital motion. The flat rotation curve indicates that the total mass within an orbital radius grows with the radius. There is apparently more mass than the light indicates. *Dark matter* is required to explain the rotation curve. The exact nature of dark matter is still unknown.

**The Galactic Nucleus**

The nucleus of the Galaxy is behind 30 magnitude of dust absorption. The Galactic center can be observed in radio and infrared wavelengths. These observations show a gas-rich, active star forming region. Additionally, gamma ray observations of the Galactic center show the existence of a positron-electron annihilation source. This source has been called "the Great Annihilator". It probably contains a massive black hole. The mass of the black hole, 1-2 million solar masses, has been inferred from the rotational velocities of the surrounding stars (using their infrared spectra).

**The Origin and Evolution of the Galaxy**

The age of the Galaxy, 15 billion years, is adopted from the ages of the oldest globular clusters, 13–17 billion years. The age of a globular cluster can be determined by fitting isochrones to the distribution of its stars in the HR diagram.

The formation of the Galaxy started with the contraction of a large hydrogen and helium cloud under the force of its own gravity. The cloud fragmented and formed the first-generation stars, called *Population III.* The massive stars evolved rapidly, injecting heavy elements into the ISM. The contracting cloud then produced the ancient halo component of globular clusters. The conservation of angular momentum caused the ISM to spin into a disk. The next-generation globular clusters are then formed in a thick disk with slightly higher metal abundances. Further contraction of the ISM developed a thin disk of Population I objects. This picture is qualitatively consistent with the observed distribution and metal abundances of Population I and Population II objects; however, the details are still unsettled.