Astronomy 400B Lecture 4: The Milky Way

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Today's class will regard the Milky Way!

1 Solar Neighborhood

Stars in the local neighborhood provide a lot of our information about the Milky Way and, frankly, a lot of what we infer about any galaxy. Learning about the stars requires knowing something about their intrinsic luminosities and masses. This requirement results in the need to have robust distance estimates for a large number of stars.

1.1 Parallax

Trignometric parallax provides a direct distance estimate for very nearby stars. Trignometric parallax is the shift in the angular position on the sky of a star as viewed from different locations of the Earth's orbit around the Sun.

For an object at distance d, the parallax p is

$$\frac{1\ \mathrm{AU}}{d} = \tan p \approx p \tag{1}$$

The pc is the distance where the parallax of a star would be $p = 1$ arcsec. The closest star is Proxima Centuari, with $p = 0.8$ arcsec and a $d = 1.3$ pc.

1.2 Distance Modulus

For nearby (Galactic) objects, we can relate the difference between the apparent and absolute magnitude of an object with its distance or parallax through the *distance modulus* equation

$$m - M = 5 \log \left(\frac{d}{10\ \mathrm{pc}} \right) = 5 \log \left(\frac{0.1\ \mathrm{arcsec}}{p} \right). \tag{2}$$

1.3 Luminosity and Mass Functions

The luminosity and mass functions of stars enable us to learn about the star formation history of the Galaxy and about the star formation process itself.

See Figure 2.3 of Sparke and Gallagher

The luminosity and mass functions reflect combinations of the numbers of stars per unit mass and the mass to light ratio of stars as a function of mass.

The luminosity function is

$$\Phi(x) = \frac{\text{number of stars per unit magnitude}}{\text{detectable volume}} \tag{3}$$

1.3.1 Initial Luminosity Function

Stars have a finite lifetime, so the observed luminosity function defined above is a time-evolved distribution where some fraction of stars have left the main sequence after their MS lifetime $\tau_{\rm MS}$. If the star formation rate of the disk has been roughly constant, the initial luminosity function is related to the observed luminosity function as

$$\begin{aligned} \Psi(M_V) &= \Phi_{\rm MS}(M_V) \quad \text{for } \tau_{\rm MS}(M_V) \geq \tau_{\rm gal} \\ &= \Phi_{\rm MS}(M_V) \times \frac{\tau_{\rm gal}}{\tau_{\rm MS}(M_V)} \quad \text{when } \tau_{\rm MS}(M_V) < \tau_{\rm gal} \end{aligned} \tag{4}$$

where $\tau_{\rm gal} \approx 8 - 10$ Gyr is the star formation timescale of the disk.

1.3.2 Initial Mass Function

The stellar initial mass function, or IMF for short, is one of the most important distributions in astronomy and represents an interesting combination of physics in molecular gas, cooling, and gravity. The IMF represents the initial number of stars per unit mass that forms in a typical volume. We write

$$\xi(M)dM = \xi_0 (M/M_\odot)^{-2.35} \frac{dM}{M_\odot} \tag{5}$$

The power-law slope -2.35 is called the *Salpeter* slope.

See Figure 2.5 of Sparke and Gallagher

2 Stars in the Galaxy

Understanding the structure of the Galaxy is tightly connected to understanding the distances to stars at all distances.

2.1 Distances from Motions

The tangential and radial velocities of stars can inform us about their distances. The radial (line-of-sight) velocities can be measured via the Doppler shift we discussed previously. The tangential velocity is related to the apparent proper motion μ on the sky of an object and its distance d. If the relation between tangential and radial velocities is known, then by measuring the radial velocity and proper motion we can find an object's distance.

The tangential velocity is

$$v_t = \mu \text{ (radians/time)} \times d, \ \textit{or} \ \mu \text{ (0.001arcsec/yr)} = \frac{v_t \text{ (km s}^{-1})}{4.74 \times d \text{ (kpc)}} \tag{6}$$

We can identify stars that orbit the supermassive black hole at the center of the Galaxy. The orbits of these stars allow us to measure the mass of the Galactic SMBH, and since we can compute their physical tangential velocity their distances can be inferred. It turns out we are $d = 8.46 \pm 0.4$ kpc away from the Galactic center.