1.3: Our Galaxy - The Milky Way

Learning Objectives

- You will know the objects in our Galaxy: Stars; Star Clusters; Nebulae
- You will know the shape of our Galaxy and that its major components are the bulge, disk, and halo
- You will know where we fit within our Galaxy

WHAT DO YOU THINK: LOOKING AT GALAXIES

Members of the Stargazers Club are trying to find interesting objects in their telescopes during a star party.

> **Danielle**: I really want to find our Galaxy, but I'm not sure I am pointing the right direction.
> **Emma**: Well, you can't get our whole Galaxy in the scope at the same time, it is too big.
> **Danielle**: Then what am I seeing here?
> **Faith**: I think that's the Andromeda Galaxy. It is a different galaxy than ours.

If you look up into the sky on a summer night, you may be able to see a bright strip of stars and gas across the sky (Figure 1.3.1). This is part of the Milky Way, our Galaxy (denoted with a capital "G" to distinguish it from other galaxies). Our Galaxy, like other galaxies, is a massive collection of hundreds of billions of stars, gas, dust, and mysterious dark matter. Here we will describe the various constituents and components of the Galaxy.

Figure 1.3.1: Photograph of the Milky Way rising over the MacDonald Observatory in Texas. Credit: Shutterstock.

1.3.1: STARS AND STAR SYSTEMS

Of the hundreds of billions of stars in the Galaxy, you can only see about 2,000 of them at any given time, and only if you are in a place with very clear and very dark skies. But even if you have viewed the sky from a less pristine location, you might have noticed that not all stars look the same. Viewing them at night, you can see some stars appear slightly red or blue or yellow, though their colors are subtle. Some stars are brighter than others, and some are fainter. The colors of stars correspond to their surface temperatures, which range from about 3,500 K to more than 30,000 K. All are at least tens of millions of kelvin at their cores, with some being billions of kelvin. Stars can be anywhere from 10,000 times dimmer to in excess of 100,000 times brighter than the Sun.

During the main part of their lives, stars are in a state of what is called hydrostatic equilibrium. The inward pressure from gravity due to a star's own mass is balanced by the outward thermal pressure sustained by nuclear reactions in the star's core. As long as the star has enough nuclear fuel in its core - hydrogen during the first phase of its life - it will be able to generate the pressure needed to resist collapsing under its own weight.

Stars can be found alone or in groups. Many stars exist in pairs, called binary star systems. It was surprising for astronomers to find out that the Sun is uncommon among stars of its type, having no orbiting companion star.

Open clusters are groups of several hundred stars that all lie within about 30 light-years of each other. The stars in an open cluster are loosely gravitationally bound. Within the Milky Way, we see that open clusters often consist of young, recently formed stars. The Galaxy has thousands of open clusters. The Pleiades (in Japanese, Subaru) is one of the most recognizable in the night sky (Figure 1.3.1).

Globular clusters are larger (~50 – 500 ly radius) and spherically shaped. They contain far greater numbers of stars and are tightly gravitationally bound. The stars in globlular clusters are much older (Figure 1.3.1) than typical stars in the disk of the Milky Way. While open clusters contain anywhere between a hundred to a thousand stars, globular clusters have tens of thousands or hundreds of thousands, and there are a few known that contain over a million stars. Globular clusters are so densely packed that their central regions have an average of about 1,000 stars per cubic light-year! Compare that to the region around the Sun, where there are only 12 stars within 10 light-years.

Figure 1.3.2: The Pleiades star cluster, also known as the Seven Sisters, or in Japanese as Subaru, is 440 light-years from Earth. It is an example of an open cluster. Credit: NASA/ESA/AURA/Caltech. (right) The globular cluster 47 Tucanae is about 15,000 light-years from Earth, and 120 light-years across. Credit: South African Large Telescope.

Extremely exciting to many astronomers, as well as members of the public, has been the discovery of extra-solar planets. These are planets that orbit stars other than the Sun. The first extra-solar planets were discovered in 1992 orbiting a star called PSR B1257+12, which is 980 light-years away from Earth. By the year 2014, more than 1500 extra-solar planets have been confirmed, most within about 300 light-years of Earth. Some of the star systems have multiple planets orbiting the central star. Most of the planets detected thus far have been more massive than Jupiter; this is likely because current detection techniques make more massive planets easier to detect. No Earth-like planets have been found … yet (meaning both Earth-sized and the right temperature for liquid water; each of these criteria has been met separately as of 2012). Extra-solar planets are typically found indirectly, either by observing the effects of their gravitational interaction with their central star or by observing a tiny dip in brightness of the parent star as the planet passes in front of it. A few rare extra solar planets have been imaged directly. Figure 1.14 shows the location of most extra-solar planets found so far in the Galaxy, and Figure 1.3.3 is a diagram of one extra-solar planetary system.

For the latest information and an updated planet count, see JPL Planet Quest.

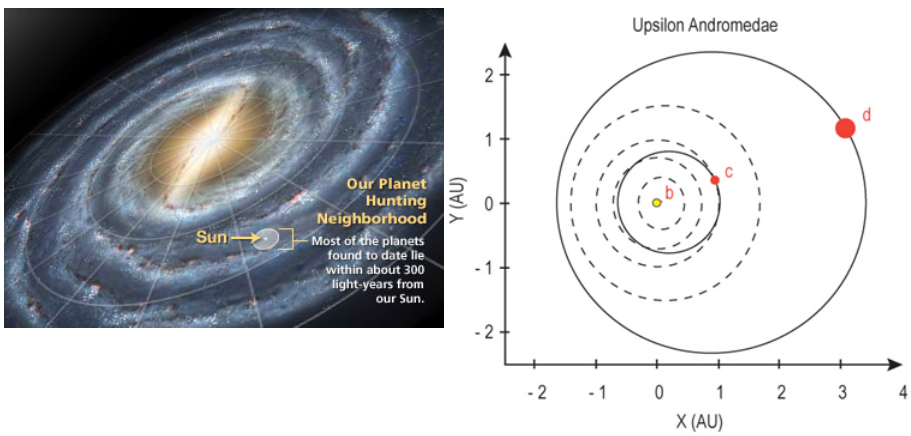

Figure 1.3.3: (left) Most of the extra-solar planets found so far are within a few hundred light-years of earth. Credit: NASA/JPL. (right) Scale drawing of the Upsilon Andromedae system, showing the orbits of the three planets at points b, c, and d. The masses of the planets are 0.72 $M^{Jupiter}$, 1.98 $M^{Jupiter}$, and 4.11 $M^{Jupiter}$, respectively. The yellow dot at (0,0) represents the parent star. The dashed lines represent the orbits of the four inner planets of our Solar System for comparison. Credit: NASA/SSU/Aurore Simonnet.

1.3.2: NEBULAE: GAS AND DUST BETWEEN THE STARS

In addition to the pinpoints of starlight, we also see many objects in the sky that are fuzzy—their light is spread out. Some of these extended objects are clouds of gas and dust, known as nebulae (singular: nebula). In the early days of Western astronomy, nearly anything that looked fuzzy (including star clusters and galaxies) was called a nebula, which is Latin for “cloud.” As telescopes became more powerful, more detailed observations of these objects were possible, allowing them to be sorted and given their modern names and designations. Today, a nebula refers only to a cloud of gas and dust. By gas, we mean atoms and small molecules, primarily hydrogen. By dust we mean a mixture of tiny particles or grains composed of silicates, graphite, iron, and other compounds.

There are dark interstellar clouds located primarily in the disk-shaped plane of the Galaxy. These provide the raw materials from which stars are made. On average, interstellar space is quite empty; there is about 1 particle per cm^3. It is also quite cold: below 100 K on average. Contrast that with Earth’s atmosphere, which has 10^{19} particles per cm^3 and temperatures around 300 K. The nebulae where stars form are relatively dense compared to rest of interstellar space; they have about $10^4 – 10^9$ particles per cm^3.

If a cloud becomes dense and cold enough it will begin to collapse in upon itself due to the self-gravitational attraction of one part of the cloud to another, triggering stars to form in that region. Star formation can also be triggered by anything that compresses an interstellar cloud. These triggers can be a collision with a different cloud, or an internal collision in a cloud with disorganized internal motions. Certain of the new stars that form can light up the clouds in which they were born, causing the clouds to heat up to temperatures around 10,000 K and glow brightly. These ionized gas clouds, known as emission nebulae, tend to look red in color. This is the result of strong emission by hydrogen. Figure 1.3.4 shows emission nebulae and dark nebulae in a star-forming region. The colors seen in images like this are not generally very realistic and are used to set off different regions of emission (by different types of atoms) from one another.

Figure 1.3.4: Pillars of gas and dust in a star-forming region as seen by the Hubble Space Telescope. Credit: NASA/STSCI/KPNO/T. Rector (University of Alaska)

Nebulae can also result when stars die. So-called planetary nebulae occur when a low-mass star expels its outer layers of gas after it runs out of fuel for nuclear fusion (Figure 1.3.4). This expelled gas is primarily composed of hydrogen and helium, but often contains heavier elements that were formed in the parent star during its lifetime. In contrast, a massive star produces a nebula called a supernova remnant. It is the outer regions of a massive star that catastrophically exploded when it ran out of nuclear fuel (Figure 1.3.4). A supernova is a much more violent event than formation of a planetary nebula: If a planetary nebula is like a dandelion losing its seeds in a light breeze, then a supernova remnant is like setting off a bomb in a sunflower. Some of the expanding material can reach speeds up to 10% the speed of light (~30,000 km/s), and it creates a shockwave that will plow through all of the dust and gas in its path, heating it up to million kelvin temperatures. Over millions of years, the expanding supernova remnant will have run into enough surrounding dust and gas to slow and cool down. The supernova shockwave itself can help spur the gases surrounding the exploding star into collapse, thus creating new stars. The new generation of stars will be enriched with heavier elements (than hydrogen and helium) that were created by the star that exploded. The new stars will also incorporate even heavier elements that were created in the supernova explosion itself.

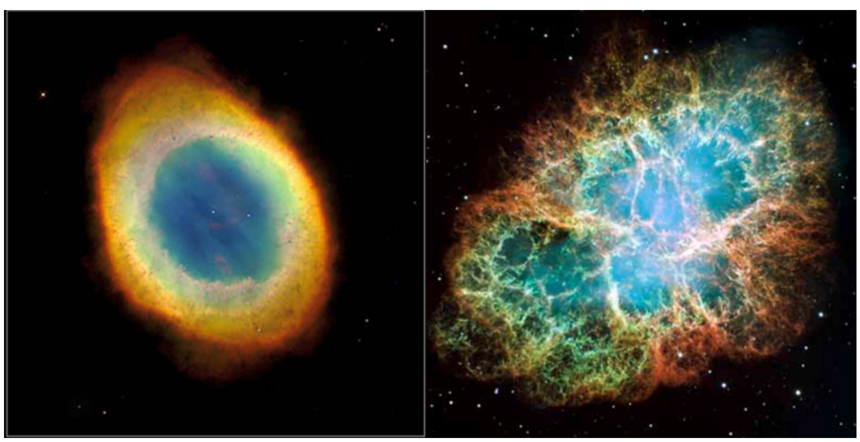

Figure 1.3.4: (left) The Ring Nebula. A planetary nebula is formed by the expulsion of the outer layers of a star similar to our Sun at the end of its life. Credit: NASA/STScI. (right) The Crab Nebula, the remnants of a massive star that exploded as a supernova in 1054 AD. Credit: NASA/STScI.

Sometimes, many of the stages of the lives of stars, including molecular clouds and the nebulae where stars form, clusters of stars, and dying stars and their nebulae, can be seen together in the same complex, as shown in Figure 1.3.5.

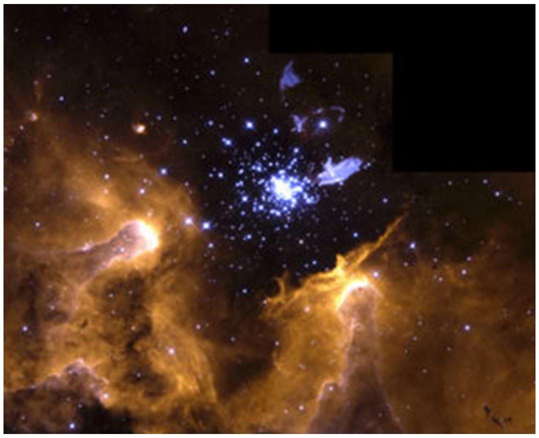

Figure 1.3.5: "Many stages of star birth, life, and death can be seen in the nebula NGC 3603. For more information, see the press release." Credit: NASA/STScI. .

1.3.3: THE SHAPE OF THE GALAXY

At first glance, the Milky Way (and similar galaxies) is shaped like a round, flat disk. Because we are inside the Galaxy, and because of its shape, we see it as a bright swath across the whole sky rather than a separate fuzzy region. We have an “edge-on” view. Furthermore, all of the stars that we are able to see as we look into the night sky are within our own Galaxy.

Because we cannot travel outside of our Galaxy and look down at it, we do not know exactly what it looks like. However, by making careful maps of the stars and gas within it, using observations at many different wavelengths of light, we can get a basic sense of its structure. Also, by observing other galaxies outside our own, we can get a sense for how normal or unique our Galaxy is in the Universe. From our observations of our own and other galaxies, we know that the Milky Way is comprised of several parts: the bulge, the disk, and the halo.

The bright, puffy region that we observe at the center of the Milky Way is a central bulge composed of many stars. At the very center of the Galaxy astronomers have determined that there is a supermassive black hole, about 4 million times the mass of the Sun. Yet this black hole is squeezed into an area smaller than the size of Mercury’s orbit around the Sun. One way astronomers have deduced this is by observing the orbits of stars at the center of the Galaxy, and by calculating the mass of the very central region of the nucleus based on the movements of those stars.

Outside of the bulge, astronomers have mapped several spiral arms. These lie within the flat plane comprising the disk of the Galaxy. Most of the gas and dust within the Galaxy lies within the disk, and most of the open clusters of young stars lie within the arms themselves. These stars, gas, and dust revolve around the flat central plane and bulge of the Galaxy. When the gas clouds enter a spiral arm, they can bump into each other and trigger the formation of new stars. The entire disk of the Galaxy is roughly 100,000 light-years across. The Sun is located within the disk, about 30,000 light-years from the galactic center.

While most of the stars and gas within the Milky Way lie in the Galaxy’s disk, there is actually a lot of matter that is distributed in a larger spherical region that is called the halo. The halo is very large, about 500,000 light-years in diameter. Most of the globular clusters in our Galaxy lie within the halo, as does a significant amount of dark matter. Dark matter is matter that does not emit light, so we can not see it with our telescopes, but we know it is there because of its gravitational effects. In fact, as we shall see in later chapters, the dark matter dominates the total mass of the galaxy, comprising by far the bulk of the entire mass of the galactic system.

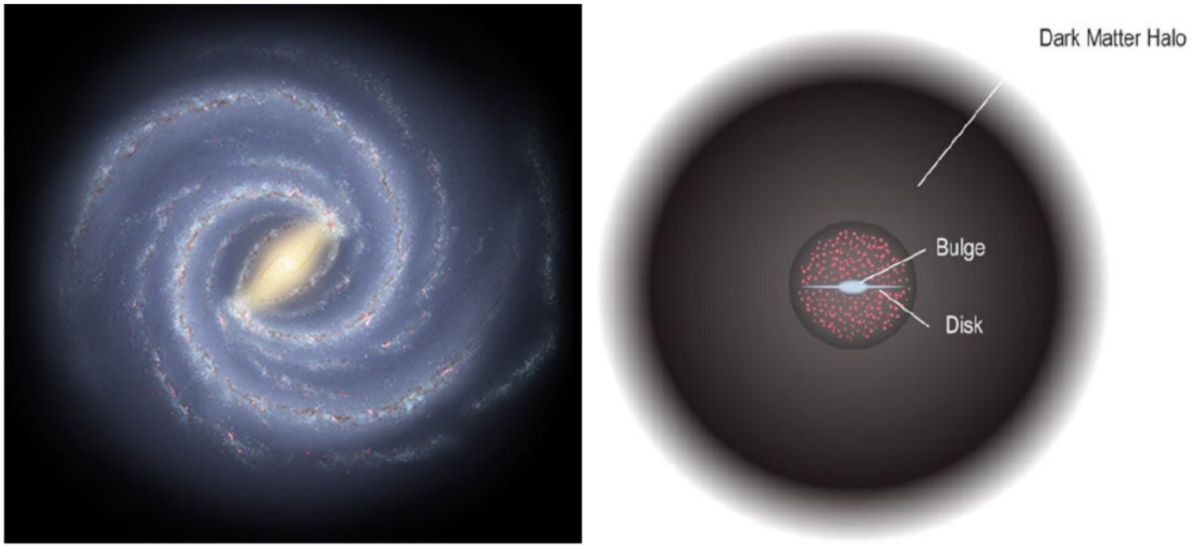

Figure 1.3.6: Drawing of the bulge and disk of our Milky Way Galaxy (face-on view). Credit: NASA/JPL-Caltech/R. Hurt. (right) Drawing of our Milky Way Galaxy including the dark matter halo (side view). Credit: NASA/SSU/Aurore Simonnet.

Exercise: SIZE AND SCALE OF OUR GALAXY

Adapted from Prather, Edward E.; Slater, Timothy F.; Adams, Jeffrey P.; Brissenden, Gina; and the CAPER Team, *Lecture Tutorials for Introductory Astronomy*, 2nd Edition, © 2008, pp. 123-126. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

Figure A.1.1 shows a picture of the spiral galaxy NGC 3184. This is much like what astronomers think the Milky Way Galaxy would look like if we could view it from outside, which, of course, we cannot do from our vantage point within the Galaxy. Nonetheless, we will assume that this is a picture of our own Galaxy and then use this model to try to understand the size scale of the Milky Way. Answer the following set of questions by referring to the picture, noting the size scales indicated by the arrows.

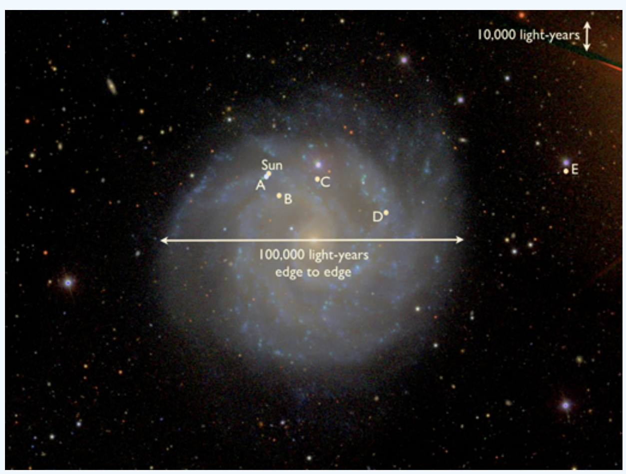

Figure A.1.1: An image of NGC 3184 – to be used as a model for our Milky Way Galaxy. Credit: Sloan Digital Sky Survey.