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

Exercise \(\PageIndex{1}\): 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.

Do you agree with any of these students and if so, whom?

- [ ] Danielle
- [ ] Emma
- [ ] Faith
- [ ] None
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). 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 our Galaxy.

**STARS AND STAR SYSTEMS**

Of the hundreds of billions of stars in our Galaxy, on a perfectly clear evening far away from city lights, you would only be able to see about 2,000 of those stars. You may have noticed that not all stars appear the same. Looking up at night, you can see some stars are slightly more red or blue or yellow than others; some are brighter, and some are fainter. The colors of stars correspond to their surface temperatures, which range from about 3,500 to 30,000 K. All are tens of millions of Kelvin at their cores. Stars can be anywhere from 10,000 times dimmer to 100,000 times brighter than our Sun. During the main part of their lifetimes, 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 with the outward pressure sustained by nuclear reactions in the star’s core. As long as the star has enough hydrogen to fuse into helium, then it will have enough pressure to resist collapsing from its own gravity.

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 our 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 30 light-years of each other. The stars in an open cluster
are loosely gravitationally bound. In our Galaxy, the Milky Way, we see that open clusters often consist of young, recently formed stars. Our Galaxy has thousands of open clusters, the Pleiades (in Japanese, Subaru) being one of the most recognizable in the night sky (Figure \(\PageIndex{1}\)).

Globular clusters are larger (~50 – 500 ly radius) and spherically shaped, contain far greater numbers of stars, are tightly gravitationally bound, and have stars that are mostly older (Figure \(\PageIndex{1}\)). 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 our Sun where there are only 12 stars within 10 light-years.

Figure \(\PageIndex{2}\): 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 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, because more massive planets are 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 where most extra-solar planets found so far are located in our galaxy and Figure \((\PageIndex{3})\) is a diagram of one extra-solar planetary system.

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

Figure \((\PageIndex{3})\): (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\(_{\text{Jupiter}}\), 1.98 M\(_{\text{Jupiter}}\), and 4.11 M\(_{\text{Jupiter}}\), 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.
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, these objects were sorted and given their modern names. 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 molecules, such as silicates, graphite, iron, and other compounds.

There are dark interstellar clouds throughout our Galaxy; these are 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: less than 100 K on average. Contrast that with Earth’s atmosphere, which has $10^{19}$ particles per cm$^3$. 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 too dense, it will begin to collapse in upon itself because of the mutual gravitational attraction of the particles to each other. Star formation can also be triggered by anything that compresses an interstellar cloud, such as the collision of clouds. Lit up by certain types of young stars, there are often glowing clouds of hot (100,000 K), ionized gas, known as emission nebulae, which tend to look red in color. Figure 4 shows emission nebulae and dark nebulae in a star-forming region.

![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)](image)

Nebulae can also result when stars die. Planetary nebulae occur when a low-mass star expels its outer layers of gas after it runs out of fuel for nuclear fusion (Figure 4). This gas is also primarily composed of hydrogen and helium, but often contains heavier elements that were formed in the parent star during its lifetime. A supernova remnant is the outer regions of a massive star that catastrophically exploded when it ran out of nuclear fuel (Figure 4). 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. The expanding material can reach speeds of around 1% of the speed of light (~3,000 km/s) and creates a shockwave that will plow through all of the dust and gas in its path, heating it up to a million kelvin. 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 to condense the gases into new stars, enriched with heavier elements created by the star during its life, as well as even heavier elements created in the supernova itself.

Figure \(\PageIndex{4}\): (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 \(\PageIndex{5}\).

![Figure \(\PageIndex{5}\): Many stages of star birth, life, and death can be seen in the nebula NGC 3603. For more information, see the press release.](Image)

**THE SHAPE OF THE GALAXY**

The Milky Way is shaped like a round, but flat, compact disc. 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, disk, and halo.

The bright, puffy region that we observe at the center of the Milky Way is a central bulge, which is composed of many stars. At the very center of the Galaxy, astronomers have determined that there is a supermassive black hole that is about 4 million times the mass of the Sun, yet it 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, we have mapped several spiral arms, which lie within the flat plane, or disk of the Galaxy. Most of the gas and dust within our Galaxy lies within these arms, as do most of the open clusters of young stars. These stars, gas, and dust rotate around the flat central plane of the Galaxy, and when the gas clouds enter a spiral arm, they may bump into each other and form new stars. The entire disk of our Galaxy is about 100,000 light-years across, and the Sun lies within the disk,
about 30,000 light-years from the center of the Galaxy.

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, which is 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.
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.

1. The Sun’s approximate position in the Milky Way is shown in the picture. What is the approximate distance to the center of the Milky Way? Use the scale arrows to determine your answer.

   \[ \text{value light-years} \]

2. The table below lists five bright stars in the night sky. Write the letter of the dot in the image that best represents the location of each star. You can use letters more than once, so just pick the one that you feel works best for the stars in the table.

<table>
<thead>
<tr>
<th>Star</th>
<th>Distance from Sun (ly)</th>
<th>Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sirius</td>
<td>9</td>
<td>value</td>
</tr>
<tr>
<td>Vega</td>
<td>26</td>
<td>value</td>
</tr>
</tbody>
</table>
3. We normally consider Deneb to be a bright but distant star at 1,400 light-years away. Compared to the size of our Galaxy, is Deneb truly distant? Explain your reasoning.

4. Are the stars from Question 2 inside or outside the Milky Way Galaxy? Explain your reasoning.

5. The table below lists three objects and their distances from the Sun. Write the letter of the dot from the picture in Figure A. 1. 1 that best represents the location of each object. You can use letters more than once, so pick the one that you feel works best for the objects in the table.

<table>
<thead>
<tr>
<th>Object</th>
<th>Distance from Sun (ly)</th>
<th>Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>M45 (Pleiades Star Cluster)</td>
<td>380</td>
<td>value</td>
</tr>
<tr>
<td>M1 (Crab Nebula)</td>
<td>6,300</td>
<td>value</td>
</tr>
<tr>
<td>M71 (Globular Cluster)</td>
<td>12,700</td>
<td>value</td>
</tr>
</tbody>
</table>
6. Are these objects part of the Milky Way? Explain your reasoning.

7. The Crab Nebula has a width of about 11 light-years. If you wanted to accurately draw the Crab Nebula on your diagram, would you use a small blob or a tiny dot at the location you intended? Explain your reasoning.

8. The Sun is much smaller than a nebula. We used a dot to represent the Sun’s location in the picture. Is this dot too small, too large, or just about the right size to represent the Sun to scale on the image? Explain your reasoning.

9. The Milky Way Galaxy is one of the largest galaxies in a group of nearby galaxies called the Local Group. The following list provides the distances of the centers of three Local Group galaxies. Where on the image should the center of each galaxy be located? Don’t worry about the direction; just try to describe the approximate distance (one of the lettered points, edge of the image, middle of the image, off of the image, etc). Do any of the galaxies fit in the image? Which one(s)?

   Object: Sagittarius Dwarf Elliptical Galaxy, closest galaxy to the Milky Way
   Distance from Sun (ly): 80,000

   Object: Large Magellanic Cloud (LMC)
   Distance from Sun (ly): 160,000

   Object: Andromeda Galaxy (M31)
   Distance from Sun (ly): 2,500,000

10. The objects in Question 9 are all visible in the night sky from Earth. Are these objects inside or outside the disk of
the Milky Way? Explain your reasoning.

11. The Sagittarius Dwarf galaxy is approximately 11,000 light-years across. Is this galaxy better represented on the image by a small blob or a tiny dot? Explain your reasoning.

12. Within the Local Group, the two largest galaxies are the Milky Way and Andromeda galaxies. We have seen that the Andromeda Galaxy is about 2.5 million light-years from us. On the picture, the spot representing Andromeda would be 25 Milky Way disk diameters away, not even on your computer screen. The nearest group of galaxies outside the Local Group is the Virgo Cluster, about 60 million light-years away. How many Milky Way disk diameters is this? About how far away would this be from your screen? For example, will it be in your room, down the street, the next city, etc.? Your answer will depend somewhat on the resolution of your screen.

13. How many disk diameters would the dark matter halo of the Milky Way be? Would this fit on the image? On your computer screen?