

CHAPTER 2**WELCOME TO THE MILKY WAY**

Fig. 2.1 The Sun is a small star located near the rim of one of the spiral arms of the Milky Way. It's located 30,000 ly from the center of our galaxy

Introduction

Observing the stars is a great pastime. The pleasure becomes even greater when we comprehend our vantage point and what the objects we are looking at represent in terms of parts of a greater structure, like the Milky Way. Most classic astronomy books project the universe onto a celestial sphere, a huge hemispheric dome, with the observer at the center of it. The concept of the celestial sphere is very useful to explain the motions of

the heavenly bodies such as the Sun, the stars and the planets. We deliberately did not follow this approach in this book because imagining all the celestial objects on a dome takes away the depth of field.

You will soon understand the celestial motions through your observations in the field. With the use of various figures, sketches and galaxy views in this book you should gain an extra sense of depth of field when you are out observing the stars. Observing is obviously done with your eyes, but even more it is done with your mind's eye. On our voyage through the universe, the various galaxy views explain the true location of the deep-sky objects in space. Once you understand the true depth of space, you will be able to see various structures within the universe and the Milky Way in real perspective. But first we need to know our place in space.

Let's start with our Sun. Not so long ago, the Sun was believed to be the center of the universe, but it is not. The Sun lies at 30,000 ly from the center of the Milky Way. Our day star is a modest star, one member of our home galaxy. Today astronomers catalog our Sun as a small G2V star with an absolute magnitude of 4.8 and an estimated fuel (hydrogen) reserve of 4–5 billion years. The Sun orbits the center of the Milky Way, just like Earth orbits the Sun. In fact all the stars are in orbit, otherwise the Milky Way would collapse under its own gravity. One orbit of the Sun around the center of the Milky Way, which we can call one galactic year, takes about 220 million years. Given its age of 4.5 billion years, it has made 20 or so revolutions (and Earth with it), which equals an age of 20 galactic years. The Sun will continue to do so for another 20 galactic years, before it runs out of fuel.

Until recently, our species was tied completely to Earth. We've only made it to the Moon and back. Other destinations seem inviting. Mars is a worthy candidate for our next stop in space. Nevertheless manned space exploration turns out to be a complicated endeavor. And yet, we can consider ourselves interstellar travelers. Our trusty spacecraft is called Earth, propelled through the universe along with our Sun. It's not a frivolous idea, really. Since the dawn of modern human culture, about 50,000 years ago, the Sun, and our kind with it, has traveled 42 light-years through space. It's an exhilarating leap in interstellar space covered by humankind in the safest possible spacecraft ever built. About 42 light-years is the distance to Capella, the brightest star in the constellation of Auriga. We may have had close encounters with other stars, considering that more than 300 stars are closer to us than Capella.

All the stars we see in the sky with the naked eye are distant suns, belonging to the Milky Way. Astronomers estimate the total number of stars in the Milky Way at over 300 billion. Sizes and numbers are overwhelming in space, but a galaxy like the Milky Way is still a very empty place. When two galaxies merge, there is so much clear space that their stars never collide.

We can describe the Milky Way as a huge rotating disk of smoothly distributed (mainly A, F and G) stars. The disk is about 3,000 ly thick and measures 100,000 ly in diameter. At the center of the disk, there is a small but dense central bulge, consisting of older, evolved (K and M) stars.

The center of our galaxy is relatively poor in gas and dust. The disk of our galaxy contains the spiral arms, which are very rich in gas and dust. These spiral arms are about 1,500 ly thick. They also contain the emission nebulae and the young and hot (O and B) giant and supergiant stars that light up the spiral structure (see Fig. 2.1). The Milky Way is surrounded by a halo of globular clusters. These globulars orbit the center of our galaxy on elliptical paths, whereas the disk stars have a more circular orbit within the disk. This implies that the globular clusters must pass through the disk to complete their orbits. The disk stars also have a different composition than the globular stars. Astronomers call disk stars, like our Sun, Population I stars. Globulars are generally made up of Population II stars. Population I stars are said to have a higher metallicity than Population II stars. In astronomy, all elements heavier than helium are called metals. The metallicity is a measure of the age of a star.

In the early evolution of the Milky Way, the interstellar medium was thought to be low on metals. Stars formed at that time would have a low metallicity. When the Milky Way grew older, the metallicity of the interstellar matter increased due to the heavier elements that enriched the interstellar medium by means of planetary nebulae and supernova explosions. The later a star forms, the higher its metallicity is.

Because of our vantage point from within this huge disk, we see the Milky Way like a glowing path of unresolved starlight, like the backbone of a huge creature that bends over our heads. The stars that make up the classical constellations are merely disk stars that are closer to us, whose light is bright enough for us to see them resolved against the background

glow of the sky. Unfortunately our view of our home galaxy is greatly obscured by huge clouds of dark interstellar matter of which the spiral arms are made up. To us, the Milky Way resembles the look of an edge-on galaxy, whose central bulge is also obscured by its spiral arms. Without this obscuring interstellar matter, the Milky Way would appear much brighter. If a supernova explosion would occur near the center of our Milky Way, we could not see it, because all of its light would be absorbed by the interstellar dust. Ironically we can in fact examine nearby galaxies much better than our home galaxy. However there exist several windows in the spiral arms, places where the interstellar clouds are much thinner, which we can and will use to look deeper into our own galaxy.

Our knowledge of the true structure of the Milky Way remained limited for a long time because the large interstellar dust clouds are opaque to visible light. With the development of radio telescopes and infrared telescopes in the 1950s, astronomers could see through the interstellar medium. The appearance of our galaxy, as in Fig. 2.1, is a calculated guess, based on the latest observations at various radio and infrared wavelengths.

The Galactic Coordinate System

We can locate the structures and the deep-sky objects within our Milky Way with the use of a coordinate system, just like the coordinate system we use on Earth. Astronomers make use of the Galactic Coordinate system ('galactic' refers to our Milky Way). We can imagine a galactic plane in the middle of the galactic disk. The center of the central bulge of our galaxy also lies on this galactic plane. The projection of this galactic plane in the sky then represents a line that we can call the galactic equator.

From our point of view, within this galactic plane, the galactic equator resembles a grand circle projected in the sky, with us in the center of it. The galactic equator traces the middle line of the Milky Way across the sky, as represented in Fig. 2.7. On the galactic equator we can measure the galactic longitude from 0° to 360° . We agree that 0° longitude points to the center of the Milky Way, in the constellation of Sagittarius. The anti-center, at 180° longitude, points to the edge of the Milky Way on the opposite side of where we see the center, in the constellation of Auriga. 90° longitude

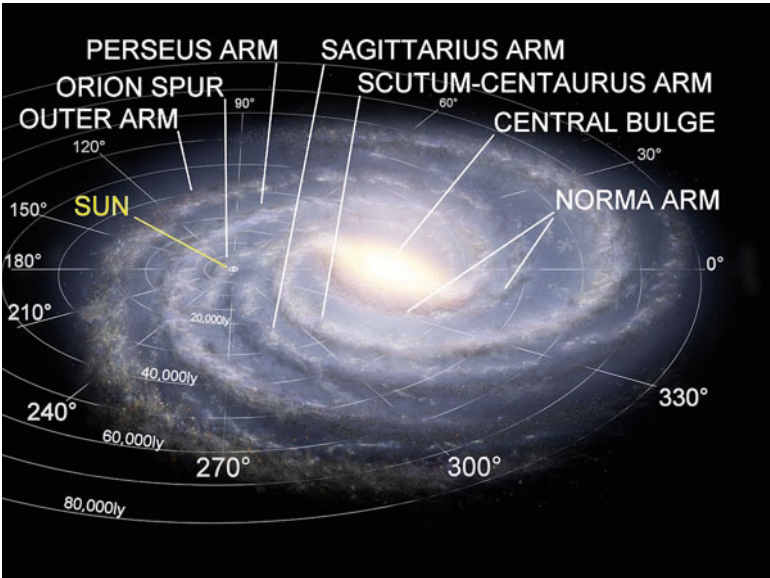


Fig. 2.2 The galactic plane, with its longitude directions and distance scale, lies in the middle of the galactic disk. The various spiral features bear the name of the constellation in which they are prominently visible

lies in the direction of the constellation of Cygnus. This is the direction at which the Sun is orbiting the hub of our galaxy. Opposite of 90° is 270° , the point in the constellation of Vela, where the Sun came from, on its orbit around the center of our galaxy. Figure 2.2 displays the galactic plane and the longitude measures astronomers use. All the galaxy views throughout the book have the same orientation as Fig. 2.2.

Galactic latitude indicates the angular ‘height’ of an object measured from the galactic equator. It ranges from -90° to 0° to 90° . There are two important directions: the galactic poles. The galactic North pole (at 90° latitude) lies in the direction of Coma Berenices. The galactic South pole lies in the direction of Sculptor. When we look in the direction of Coma Berenices, we look out of the galactic disk where our view is less obscured by the interstellar medium.

Our Orientation in the Milky Way

The galactic coordinate system is very straightforward. However, the orientation of Earth in space is by no means related to the galactic coordinate system. But what is then the orientation of Earth, with respect to the galactic plane? Figure 2.3 tries to illustrate the Earth-based view of the Milky Way.

The orientation of Earth is linked with the position of Polaris. Polaris is a disk star with the galactic coordinates 123° longitude, 27° latitude. For convenience let's suppose that the rotational axis of Earth is pointed towards Polaris. The 123° longitude is in the direction of Cassiopeia. You can check also the seasonal map for spring (Fig. 1.4) where Cassiopeia hovers above the northern horizon. During spring evenings we have Coma Berenices and thus the north galactic pole near the zenith. When we look in the direction of Cassiopeia, we look in the direction of the galactic plane around 123° longitude.

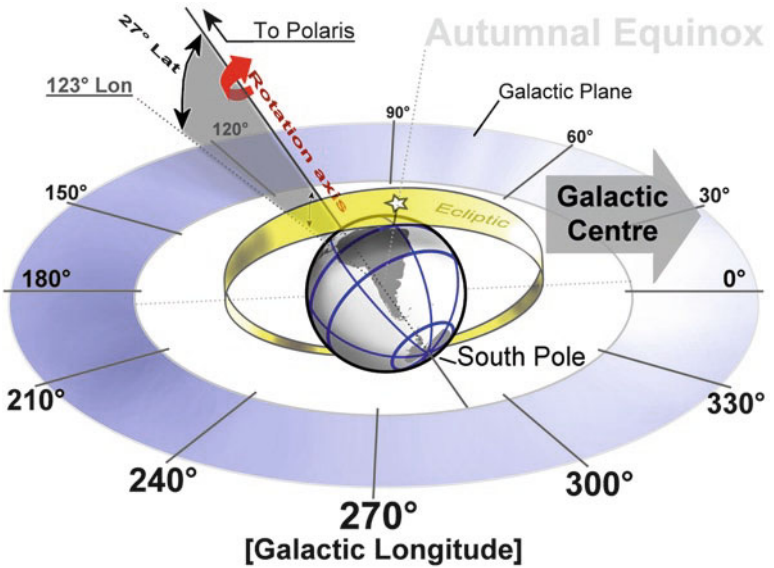


Fig. 2.3 The orientation of Earth with regards to the galactic plane. The *golden ring* around Earth represents the ecliptic, the apparent path of the Sun in the sky. Both the galactic equator and the ecliptic are *grand circles* in the sky

When we look at Coma Berenices, we look in the direction perpendicular to the galactic disk, thus at the north galactic pole. The golden ring is added to Fig. 2.3 to represent the path of the Sun among the stars – the ecliptic.

With the change of the seasons, the Sun's position and thus our nighttime window to the universe also changes. During winter, when the Sun is on the right side of the golden ring (near 0° longitude), it appears low in the south for a mid-northern observer. This indicates that the opposite site, near 180° longitude, is visible during the night. That's why we can see the part of the Milky Way in the direction of Auriga during winter (see also Figs. 1.9 and 1.10). In spring, the Sun is located in the part of the golden ring that is obscured by Earth (see Fig. 2.3), beneath the galactic plane. Therefore the nights of spring offer us a clear view at the north galactic pole, and less clear of the galactic plane. When summer comes, the Sun is near 180° longitude, at the left side of the golden ring. Then the galactic plane from 90° longitude to 0° longitude is visible at night (see Figs. 1.5 and 1.6). And finally, during autumn, the Sun is located near the star symbol on the golden ring. During that season, the Milky Way is visible at night from 30° longitude up to 160° longitude. Figure 2.3 also explains why mid-northern observers are oriented towards higher galactic longitudes than mid-southern observers. Therefore mid-northern observers have a better view on the anti-center of the Milky Way and mid-southern observers have a better view of the center of the Milky Way. An observer who wants to see the whole Milky Way will need to travel across Earth's equator.

The stars that make up the constellations are also a part of the Milky Way. From our Earth-based view, the constellations give the impression of being related to specific seasons. We are used to linking Orion and Auriga with winter, Leo with spring, Sagittarius with summer, and Pegasus with autumn. Figure 2.4 shows what constellations are linked to what part of the Milky Way. The constellation of Sagittarius shows us the center of the Milky Way. The constellation of Cygnus points towards the incurving spiral arm where we belong, etc. If we want to have a look at the Orion Spur, the part of the spiral arm the Sun passes through, we should turn our view away from the center of the Milky Way. From the constellations of Cygnus through Auriga to Puppis is where our spiral arm is located.

Remember that the whole Milky Way cannot be seen from a mid-northern latitude on Earth, nor can all the constellations. The reason is that our natural horizon blocks our view to the south. Figure 2.5 shows what the hidden sectors are for a mid-northern observer.

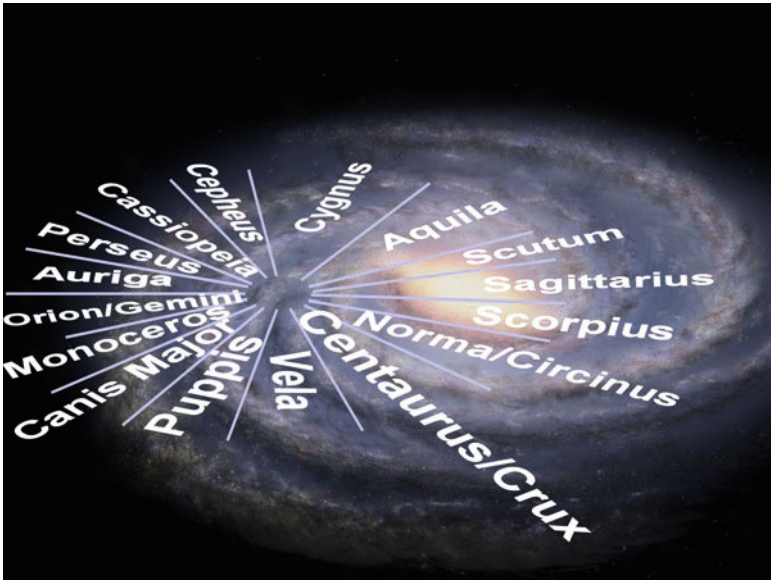


Fig. 2.4 From our viewpoint, the Milky Way surrounds us. Each of these constellations offer us a view on a particular section of the Milky Way



Fig. 2.5 These are the hidden sectors of the Milky Way. The northern observer's view of them is blocked by the natural horizon of the observer

The Changing Orientation of Earth

We share with our ancestors the stars and the constellations. The appearance of the most visible stars and the shapes of the constellations have not changed to a great extent during the last 6,000 years. But that's about it. The seasonal sky maps of this book would have been completely useless in the time of, let's say, the ancient Egyptians. How can that be?

The reason for this 'inconvenience' is called the precession of the equinoxes. Precession is a difficult word to explain, so let's start with the equinoxes. Literally, equinox means that day and night are both exactly 12 h long. Because the rotation axis of Earth is tilted at $23\frac{1}{2}^\circ$ in relation to its path around the Sun, we have the seasons. During our summer, the northern side of Earth is pointed towards the Sun. That's why we have longer days and shorter nights. During winter, the southern side of Earth is pointed towards the Sun (see also Fig. 1.2).

Our ancestors already noticed that the Sun follows a yearly path among the stars. This path is a great circle in the sky called the ecliptic. If the axis of rotation of Earth would have been perpendicular to its orbit around the Sun, the ecliptic would be equal to the celestial equator. But because of the tilt of Earth's rotational axis, the great circle of the ecliptic is tilted with regards to the great circle of the celestial equator.

There are four important moments in a year that indicate a particular position of the Sun on the ecliptic. The winter solstice indicates the moment when the Sun arrives at its most southerly point in the sky, in the constellation of Sagittarius. For observers north of the equator, this will be the longest night of the year. The winter solstice is followed by the vernal equinox, which indicates the moment when day and night are exactly 12 h long. At that moment, the Sun is positioned perpendicular to the Earth's equator, and thus exactly at the celestial equator. If we were to project the Sun's position among the stars onto the ecliptic, we would arrive in the constellation of Pisces. This point, where the ecliptic cuts the celestial equator in the constellation of Pisces, is called the vernal point. The summer solstice indicates the moment when the Sun arrives at its most northerly point on the ecliptic, in the constellation of Taurus. Observers north of the equator then experience the shortest night of the year.

The last important moment is the autumnal equinox, which indicates the moment that day and night are exactly 12 h long again. The Sun is then in the constellation of Virgo, where the ecliptic cuts the celestial equator again. Figure 2.3 illustrates the autumnal point in relation to the galactic plane.

These four important moments in a year announce the start of a new season. It has always been vital in the history of humankind to keep track of these key moments of the year. Our ancestors tried to grab hold of these 'dates' with the seasonal apparition of the constellations. There is the one great example of the first morning apparition of Sirius, which for the Egyptians more than 3,000 years ago announced the annual flood of the Nile. The Egyptians believed that Sirius was responsible for the flooding. Today we know that the rainy season causes the swelling of the Nile.

So, in short, the equinoxes indicate the cross sections of the ecliptic with the celestial equator. These are two distinct points that can be located in the sky. The precession of the equinoxes indicates a slow shift to the west of the ecliptic with regards to the stars. This was discovered by the great Greek astronomer Hipparchus. The reason for this shift is the changing orientation of the rotation axis of Earth, due to the mutual gravitational forces exercised by the Sun and the Moon. We are all familiar with this phenomenon. It's the same wobble a spinning top exhibits when it tries to keep its balance.

The rotation axis of Earth describes a circle as illustrated by Fig. 2.6. For a backyard astronomer, this motion is negligible. Historians and cartographers however are more concerned about the precession. Celestial cartographers have to deal with the so-called equatorial coordinate system. In this system, the longitude of celestial objects (which is then named 'Right Ascension') is measured from the vernal point, and the latitude (called 'Declination') is measured from the celestial equator.

Unfortunately, sky atlases are only relevant for a certain epoch because the equatorial coordinate grid slowly drifts. Today's atlases are based on the position of Earth's rotational axis in the year 2,000 A.D. Historians, too, should take into account that the north celestial pole and the vernal point changes with time. This implies that many years ago, the local horizons on Earth differed from today. Figure 2.7 shows what the consequences of precession are.

For a mid-northern observer, the center of the Milky way does not rise very high above the southern horizon, due to the orientation of Earth in space.

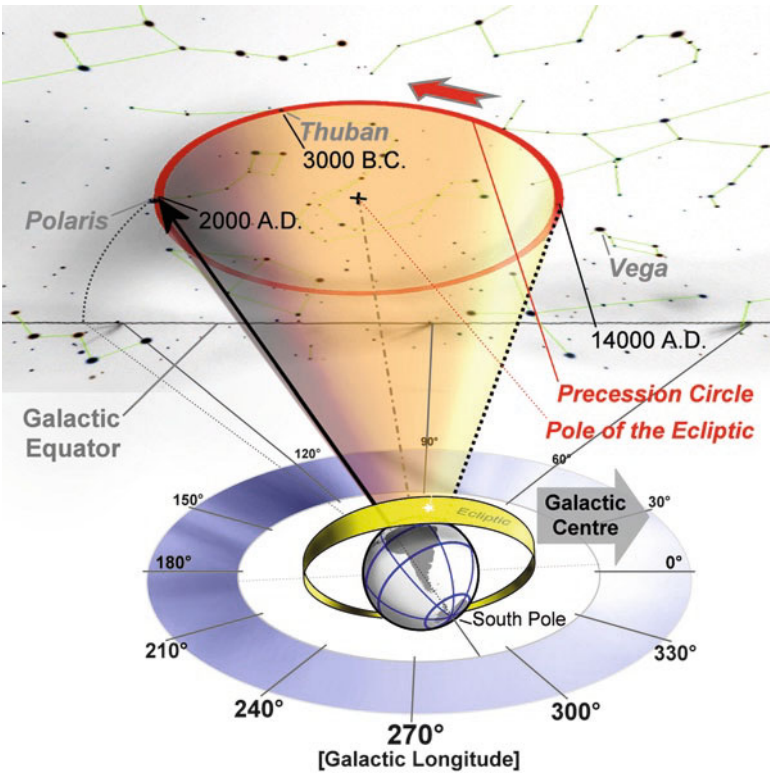


Fig. 2.6 The rotational axis of Earth traces a precession circle among the stars in about 26,000 years. About 3,000 years ago, the Pole Star was Thuban, in the constellation of Draco. In 14,000 A.D., Vega will become the new Pole Star

This is shown in the left panel of Fig. 2.7. The constellation of Scorpius hovers just above the horizon. The ecliptic also reaches its lowest point in the sky, indicating that these constellations and this region of the Milky Way are visible during the summer nights.

You might think that this is too obvious to be mentioned, but now take a look at the right panel. This panel shows the horizon from that same location in the year 14,000 A.D. Scorpius now rises much higher in the sky. Take note of the constellations that used to lie below the observer's horizon. The ecliptic now reaches its highest point in the sky. This implies that these

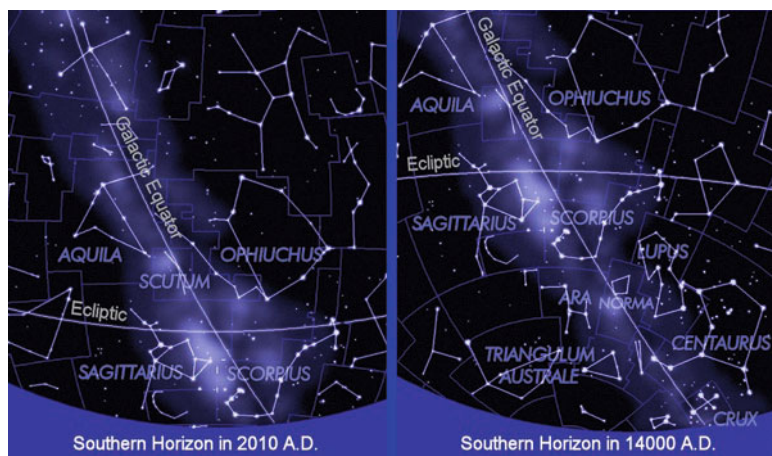


Fig. 2.7 The *left panel* shows today's southern horizon for a mid-northern observer. The *right panel* shows what happens when Earth's rotational axis is tilted in the other direction, like in the year 14,000 A.D. In this example we assume that there is no continental drift

constellations and this part of the Milky Way are visible during – winter! The slow wobble of Earth, which we call precession, determines our nighttime window to the universe as well as which constellations are visible during what season. Our seasons are dictated by the orientation of Earth. The seasonal appearance of the constellations is only a mere consequence of it.

The Structure of Our Summer Milky Way as Seen with the Naked Eye

In the previous chapter, we already discussed the benefits of binoculars for deep-sky observations. Now, it might come as a surprise to you, but on this first tour through the heavens, we will only use our bare eyes. Don't underestimate the power of your dark-adapted eyes. Many features of the Milky Way can be perfectly discerned with the naked eye from a dark location. The seasoned observer will even recognize several deep-sky objects without the use of any optical aid.

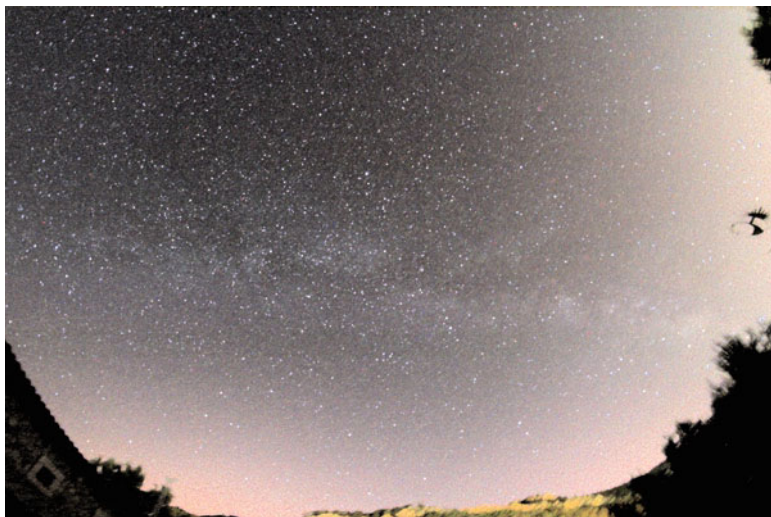


Fig. 2.8 The summer Milky Way is the brightest part of our home galaxy. The Milky Way is represented by the glowing band of light that arcs through the sky from *left to right*. South is at the *right* of the picture, where you can see the constellation of Sagittarius. The Cygnus star cloud shines brightly in the *middle* of the picture. Cassiopeia is at the *left side* of the frame

Our Sun is situated within the disk of our galaxy. It's not a favored position to tell the different structures of the Milky Way. But once we understand what we are looking at, our view on our galaxy looks totally different. The best visible part of the Milky Way is displayed during the summer nights, when Scorpius and Sagittarius rule the southern sky. Figure 2.8 is a picture of the summer Milky Way.

Figure 2.9 represents a sketch of the Milky Way, based on a very careful naked-eye observation. Just like with every deep-sky observation, the details don't pop into view at first glance. Only with patience and a mix of direct and averted vision can such an observation be made. Bear in mind that your view will depend on the local light pollution as well as on your latitude and of course on your experience.

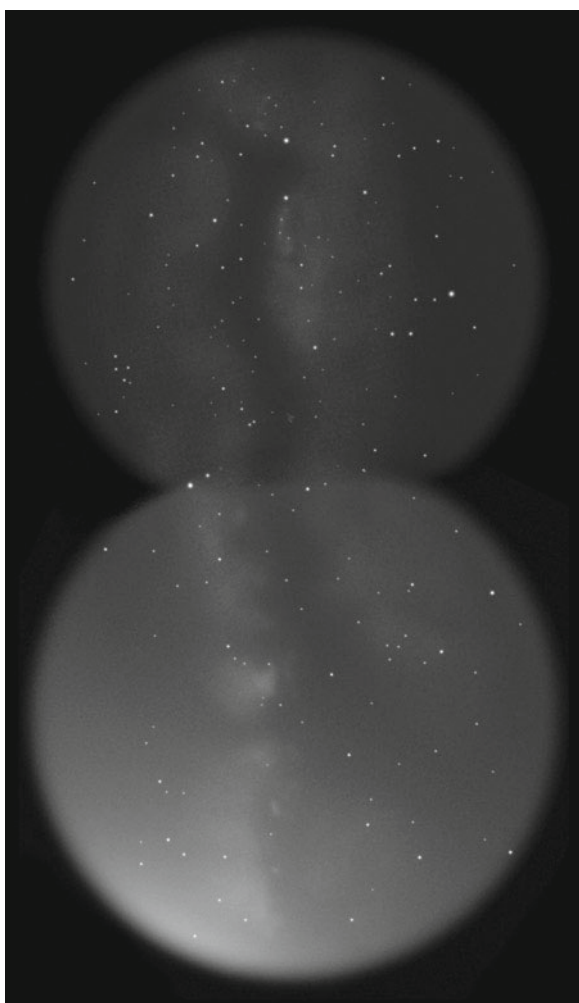


Fig. 2.9 A naked-eye sketch of the summer Milky Way from Sagittarius near the *bottom* to Cygnus at the *top* of the sketch. For this sketch, two observations were made with use of the sketching template shown in Fig. 1.26. One observation was centered upon the Scutum star cloud. The other observation was focused on the Cygnus star cloud. The sketch, which was made at a mid-northern latitude, offers a very wide view. It covers the galactic equator from longitude 0° to 90°

The glare in the lower left of the sketch, under the Sagittarius Teapot, is produced by a streetlight. You can recognize several constellations (see also Fig. 1.5). The upper circle of the sketch is filled with the cross of the Swan, Cygnus, with bright Vega at its lower left side. Under Cygnus, near the top of the lower circle, flies the Eagle, Aquila. Below the Eagle shines the Shield, Scutum, and at the bottom of the sketch boils the Teapot figure that represents the Archer, Sagittarius.

Since Fig. 2.9 is a fairly wide panorama of the summer Milky Way, a lot of details are squeezed into a tiny area. Novices, who are not used to the appearance of our galaxy, might find it very hard to initially get their bearings. For them, included are two extra, labeled views: Fig. 2.10 has the constellations and the Summer Triangle marked upon the glowing band of the Milky Way, and Fig. 2.11 has the most prominent galactic features indicated.

The Milky Way can be thought of as the hot vapor that comes out of the spout of the Sagittarius's Teapot. The cloud right above the spout of the Teapot is the large Sagittarius star cloud. It represents the central bulge of the Milky Way, at 30,000 ly from us! Here is where the central hub of our galaxy resides. Remember that this region is heavily obscured by the interstellar matter of several spiral arms. There is a small cloudlet, visible with the naked eye, at the right of the large Sagittarius star cloud. This is the Lagoon Nebula, called Messier 8 (M8). This deep-sky object lies in the next interior spiral arm, the Sagittarius Arm, at 5,000 ly from us. Above M8, there is another, bar-shaped cloud, the small Sagittarius star cloud, called Messier 24 (M24). Here is one of the windows in the interstellar matter that allows us to see deeper in the disk towards the interior of our galaxy. M24 is believed to be a part of the Norma Arm, at around 15,000 ly from us.

The stars that make up the teapot figure of the Archer are between 60 and 600 ly away. They are in fact residents of our own spiral arm, the Orion Spur, through which we look to see the far interior of our galaxy. Our Sun is located near the inner rim of the Orion Spur. Therefore, if we want to see the structure of our own spiral arm, we should turn our gaze away from Sagittarius and look at the constellations in the opposite direction.

Another tracer of an important Milky Way structure is the Scutum star cloud, centered in the lower circle of the sketch. The Scutum star cloud

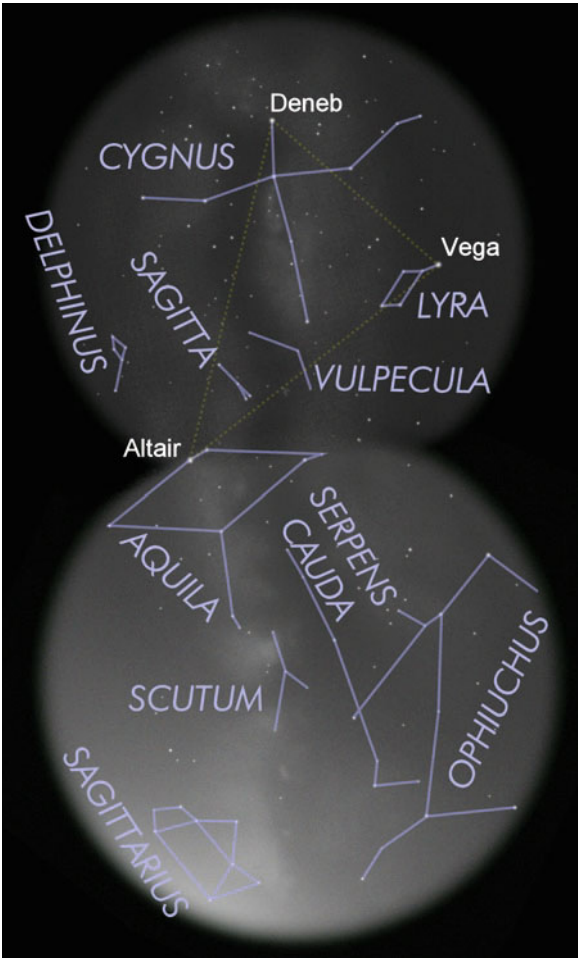


Fig. 2.10 The summer Milky Way with the constellations and the Summer Triangle formed by Deneb, Vega and Altair. The Summer Triangle shows the first stars that can be seen at dusk during summer

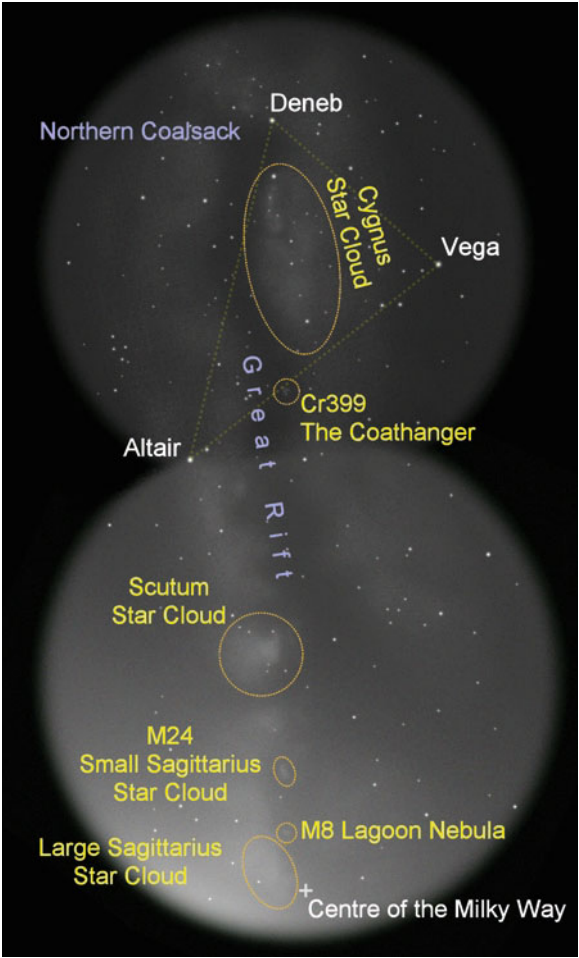


Fig. 2.11 These prominent galaxy features are visible with the naked eye under a dark sky

represents the incurving arc of the Scutum-Centaurus Arm, at a distance of 12,000 ly. This, too, is a window in the interstellar matter. The next bright Milky Way structure is located in the middle of the upper circle of the sketch: the Cygnus star cloud. The Cygnus star cloud is located at 90° longitude; thus its direction forms a straight angle with the direction of the large Sagittarius star cloud.



Fig. 2.12 A picture of the summer Milky Way from the tail of Scorpius near the horizon up to Aquila at the top of the picture. Don't expect to be able to see all these details with your naked eye. However, these glorious Milky Way features are well within reach of a pair of binoculars

Now we look deep into the cross-section of our own spiral arm, the Orion Spur. You can think of the Cygnus star cloud as the direction in which the Sun rotates around the center of our galaxy. The most spectacular and largest feature is without doubt the Great Rift. Don't seek a bright structure, though, as the Great Rift shines with – darkness! As shown in the sketch, the Milky Way is split into two parallel sections, by the obscuring masses of

the Great Rift. We can only see its presence by its silhouette in front of the gleaming galactic disk. The dark dust clouds of which the Great Rift is built up are relatively close to us. The Great Rift, which is estimated to be about 300 ly away, is thus a feature of our own spiral arm. It is in such dust clouds that stars can form. These clouds of molecular dust are gigantic. The total mass of the Great Rift is equal to about one million solar masses. Be aware that the silhouette of the Great Rift can only be seen when the sky is reasonably dark.

You see that with the help of your mind's eye, the Milky Way looks totally different. The next time that you observe the summer Milky Way, you will have a deeper impression of our galaxy. And for all this celestial beauty, you don't even need any optical aid!

Photographs of constellations typically show more detail than the naked eye can see (Fig. 2.12). These photographs become very representative when using a pair of binoculars. The view of our galaxy is simply stunning when you sweep along the celestial river with a pair of binoculars. Figure 2.11 gives you an impression of the glorious celestial treasures that are awaiting you with a pair of binoculars. It is an interesting exercise to compare Fig. 2.11 with Fig. 2.9. This comparison shows how different the dark-adapted eye functions, compared to a camera. A camera is capable of recording fainter stars. It also captures the brighter galaxy clouds with greater detail, hence the mottled appearance of the Milky Way. The naked eye sees fewer stars and shows less resolution. However, thanks to the greater sensitivity of averted vision, the human eye is capable of detecting the general contours of the Great Rift, which don't show up very well in the picture.

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