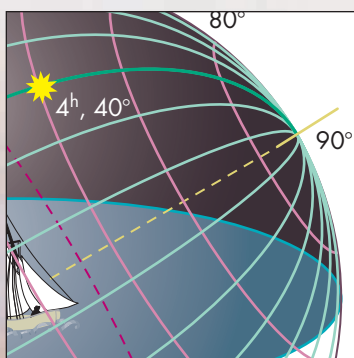


The Night Sky



Background Pathways: Units 1 and 2

One of nature's spectacles is the night sky seen from a clear, dark location with the stars scattered across the vault of the heavens. From ancient records we know that the pattern of stars has changed little over the last several thousand years. Thus, the night sky affords us a direct link with our remote ancestors as they tried to understand the nature of the heavens. When you look up at the stars, you might imagine a shepherd in ancient Egypt, a hunter-gatherer on the African plains, a trader sailing along the coast of Persia, or even an airplane navigator in the early twentieth century.

Astronomical observations are part of virtually every culture and include the obvious events that anyone who watches the sky can see without the need of any equipment, such as the setting of the Sun in the western sky and the moving pattern of stars seen in the night sky. Sadly, many of the astronomical phenomena well known to ancient people are not familiar to us today because the bright lights of cities make it hard to see the sky and its rhythms. Therefore, if we are to appreciate the context of astronomical ideas, we need to first understand what our distant ancestors knew and what we ourselves can learn by watching the sky throughout a night.

5.1 THE CELESTIAL SPHERE

From a dark location on a clear night, thousands of stars are visible to the naked eye. The stars appear to be sprinkled on the inside of a huge dome that arches overhead. At any moment as you look at the stars, another half of this dome lies below the **horizon**, hidden by the solid Earth beneath your feet. If we took a spaceship far enough away from the Earth, we would see the whole panorama of stars surrounding us.

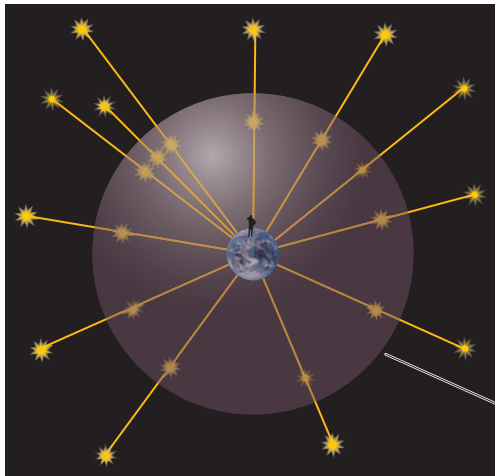
Although the stars look as if they form a dome over us, the stars are at vastly different distances from us. For example, the nearest star is about four light-years away, while others we can see are thousands of times more distant. And even the planets, the Sun, and the Moon, which is 100 million times closer than the nearest star, are still so distant that we are unable to get a direct sense of their true three-dimensional arrangement in space without precise measurements and careful deduction.

Nevertheless, for the purposes of studying the patterns of the night sky with our naked eyes, we can treat all stars as if they are at the same distance from us—a distant starscape on the interior of a giant **celestial sphere**, with the Earth at its center, as depicted in Figure 5.1. The celestial sphere is a model (Unit 4.1). It has no physical reality, but it serves as a useful way to visualize the arrangement and motions of celestial bodies.

5.2 CONSTELLATIONS

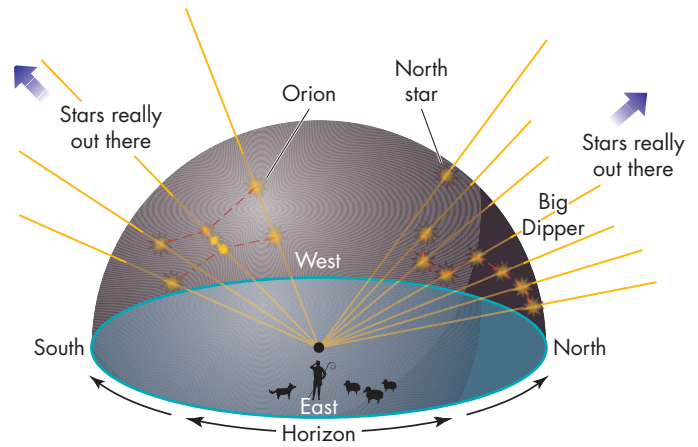
The patterns formed by brighter stars sometimes suggest the shapes of animals, personages, or objects of cultural relevance. For example, the pattern of stars shown in Figure 5.2A looks a little like a lion, although other cultures saw a dragon

Stars are scattered throughout space in different directions and at different distances.



Model

A



Our Experience of the Celestial Sphere.

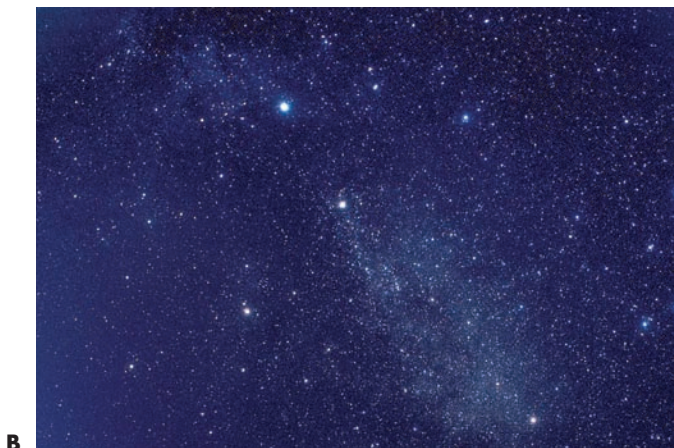
B

FIGURE 5.1

(A) Although the stars are scattered through space at very different distances, they appear to lie at the same distance from us on what we call the *celestial sphere*. Note: Sizes and distances are drastically exaggerated. For Earth at the size shown, the nearest star would really be 10,000 km (6000 miles) away and would be about 100 times larger than the Earth. (B) The celestial sphere meets the ground at the horizon.



A



B

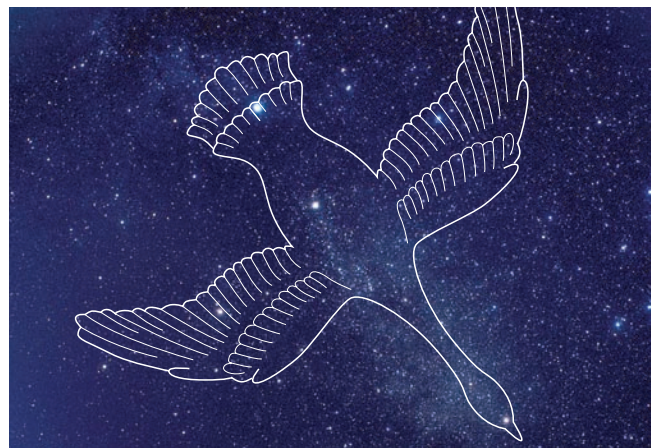


FIGURE 5.2

The two constellations Leo (A) and Cygnus (B) with figures sketched in to help you visualize the animals they resemble.



In Figure 5.1 and many others throughout the book, the sizes of astronomical bodies are exaggerated compared to the distances between them for clarity.

or a sphinx in this pattern of stars. Today we call this **constellation**—a recognized grouping of stars—Leo. This name has been carried down through the centuries from the Latin word for lion, and the connection with a lion dates back millennia earlier.

Today the International Astronomical Union recognizes 88 official constellations that cover the entire celestial sphere. About half of these have ancient roots, particularly the larger constellations. Some smaller constellations were named more recently by cartographers making maps of the skies and filling in areas of the sky between the better-known constellations. Some groupings of stars remain in common use even though they are not part of the 88 recognized constellations. These “unofficial” groupings of stars are called **asterisms**. For example, the pattern of stars that makes up the head of Leo is sometimes called the “Sickle.” Similarly, the “Big Dipper” is an asterism within the constellation Ursa Major (Latin for “large bear”).

Many constellations bear no obvious resemblance to their namesakes. It takes some imagination to see a swan in the constellation Cygnus (Figure 5.2B), which is one of the more recognizable constellations. In some cases, factors other than their shape may have played a role. The location of constellations like Ursa Major and Ursa Minor (the large and small bear), always in the northern part of the sky, may have made early sky watchers think of real or legendary bears in northern lands. In some cases the names are connected with legends regarding other constellations, like Canis Major and Canis Minor, the large and small dogs who were hunting companions of Orion—one of the more recognizable constellations. Some areas of the southern sky that are not visible from Europe were given names by early European navigators and explorers. This yielded names like Telescopium, Microscopium, and Antlia, named respectively for the telescope, microscope, and the air pump!



What point on the Earth is directly opposite where you live? Where is the zenith for someone there?

Although most of the constellation names come to us from the classical world of ancient Greece and Rome, many other astronomical terms show the influence of Islam and other Middle Eastern cultures. For example, the **zenith** (the point of the sky that is straight overhead) and the **nadir** (the point on the celestial sphere directly below you and opposite the zenith) come from Arabic words. So do the names of nearly all the bright stars—Aldebaran, Betelgeuse, and Zubeneshamali, to name a few. Many of these star names describe the parts of a constellation; for example, the second brightest star in Leo is called Denebola, from Arabic words meaning “the lion’s tail.”

Keep in mind that stars in a constellation generally have no physical relation to one another. They simply happen to be in more or less the same direction in the sky. Also, all stars move through space; but as seen from Earth, their positions change very slowly, usually taking tens of thousands of years to make any noticeable shift. Thus we see today virtually the same pattern of stars that was seen by ancient peoples.



5.3 DAILY MOTION

If you watch a star near the horizon, in as little as 10 minutes you will notice a shift in its position. If you locate a constellation near your zenith and then come back to look at it after few hours, you will find it has changed position dramatically. Almost everyone has noticed these phenomena for one star—the Sun. Our cycle of day and night and the motion of the Sun across the sky occur because, as the Earth spins, we face different parts of the celestial sphere.

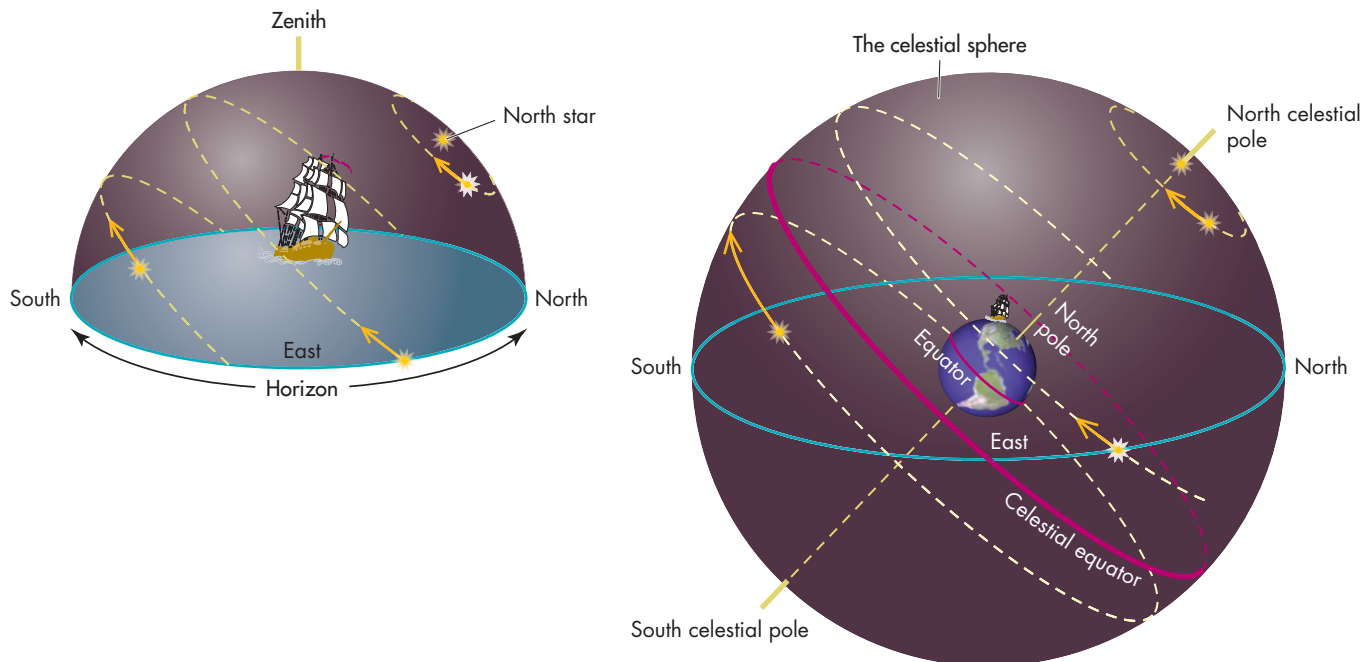


FIGURE 5.3

Stars appear to rise and set as the celestial sphere rotates overhead. Also shown are the celestial equator and poles and where they lie on the celestial sphere with respect to the Earth's equator and poles.

ANIMATIONS

Star rise and star set

From our perspective standing on Earth, it seems as if the celestial sphere rotates around a stationary Earth (Figure 5.3). Objects within the Solar System, including the nearest star to us, the Sun, move more perceptibly on the celestial sphere, generally over the course of days or weeks. These motions are gradual enough that in 24 hours the objects remain at nearly the same position on the celestial sphere.

As with the Sun, the stars, the planets, and the Moon all rise in the east, move across the sky, and set in the west. Ancient peoples had no compelling reasons to believe that the Earth spun, so they attributed all daily motion—that of the Sun, Moon, stars, and planets—to the turning of the vast celestial sphere overhead. Today, of course, we know that it is not the celestial sphere that spins but the Earth; however, we still speak of the Sun “setting.”

As the celestial sphere turns overhead, two points on it do not move, as you can see in Figure 5.3. These points are defined as the north and south **celestial poles**. The celestial poles lie exactly above the North and South Poles of the Earth, and just as our planet turns about a line running from its North to South Poles, so the celestial sphere rotates around the celestial poles from our perspective on Earth. The star **Polaris** in the constellation Ursa Minor is very close to the north celestial pole, making it an important navigation aid. Because the north celestial pole lies directly above the Earth's North Pole, it always marks the direction of true north, and it is frequently called the “North Star.” There is no comparably bright star anywhere near the south celestial pole, so finding true south from the stars usually requires some triangulation between brighter constellations fairly far from the pole.

Another useful sky marker frequently used by astronomers is the **celestial equator**. The celestial equator lies directly above the Earth's equator, just as the celestial poles lie above the Earth's poles, as Figure 5.3 shows. Stars on the celestial equator rise due east and set due west.



5.4 LATITUDE AND LONGITUDE

The part of the sky we can see depends on where we are located on the Earth. Some parts of the celestial sphere rotate into view during the night, but some parts may remain forever hidden unless we move to a different location on the Earth. Our location is determined by a **longitude**, defining our east–west position, and a **latitude**, defining our north–south position.

We can divide a map of the Earth into a grid by drawing lines of latitude, each at a fixed distance from the equator, and lines of longitude running from pole to pole. The positions of these lines are measured not in a linear unit like kilometers, but instead by an angle in degrees. Ninety degrees (90°) makes up a right angle, and 360° makes up a full circle. Latitudes are measured north and south relative to the equator; for example, Boston, Massachusetts, and Rome, Italy, are both about 42°N , while Buenos Aires, Argentina, and Sydney, Australia, are both about 34°S .

The position east or west has no such natural reference line as the equator. By international agreement, the line of constant longitude that runs through the Royal Observatory in Greenwich, England, is used to mark 0° longitude. Using our sample cities above, Boston is 71°W , Rome is 12°E , Buenos Aires is 58°W , and Sydney is 151°E of this line.

Any two locations at the same latitude will see the same parts of the celestial sphere during a night, so Boston's sky is the same as Rome's. The difference in longitude means they do not see it at the same time. For anyone observing the sky north of the equator, there will be some stars near the north celestial pole that

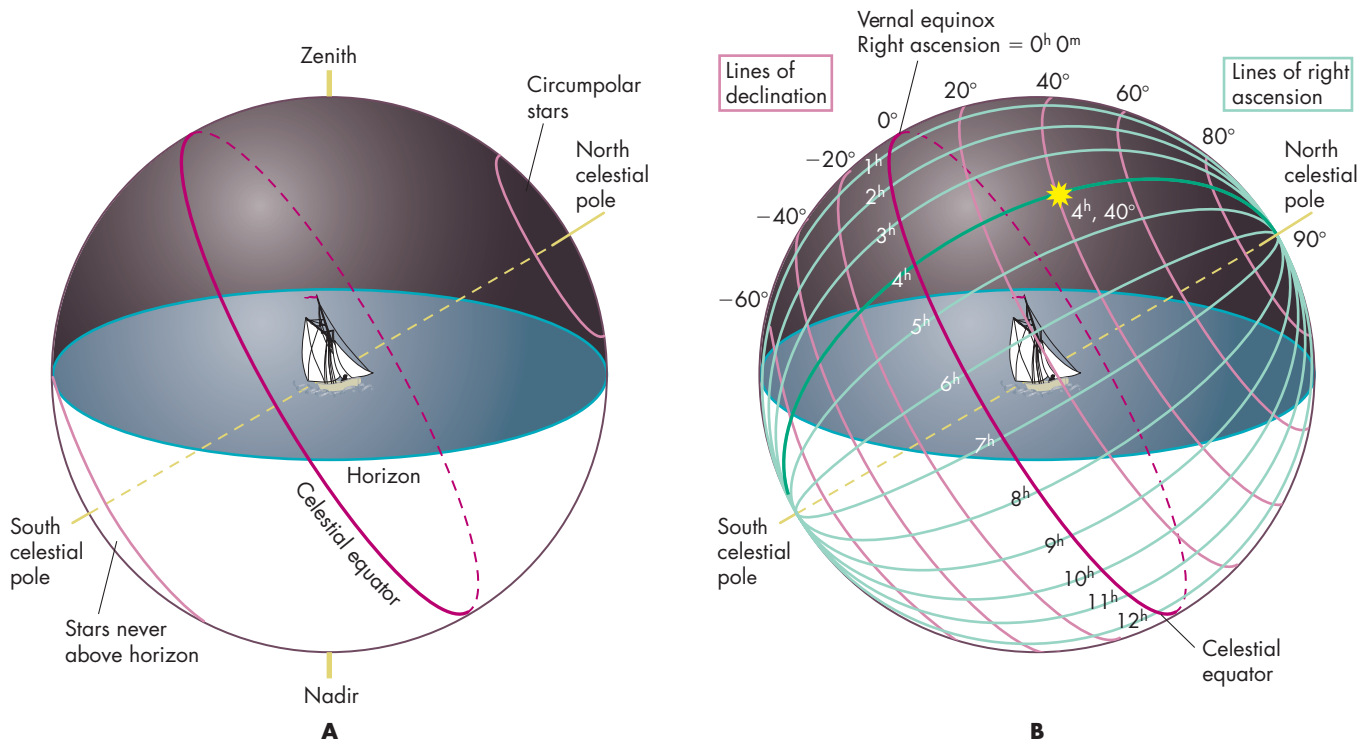


FIGURE 5.4

(A) Some stars rise and set, whereas circumpolar stars near the north celestial pole remain above the horizon continuously. Others near the south celestial pole never rise for a northern observer. (B) Locating a star according to right ascension and declination.



If you were standing on the Earth's equator, where would you look to see the north celestial pole? Could you see this pole from Australia?



Can you think of a way to build a simple device to measure the angle of a star above the horizon?

always remain above the horizon, said to be **circumpolar**, and some stars near the south celestial pole that always remain below the horizon (Figure 5.4A). The reverse is true south of the equator.

The most extreme case is at the poles. If you were standing at the North Pole, Polaris, the North Star, would remain always straight overhead. The Earth under your feet would permanently block the view of the southern half of the sky, while all the stars north of the celestial equator would be circumpolar, appearing to move around you parallel to the horizon. Again, the reverse would be true if you were at the South Pole, but there happens to be no stellar equivalent of a “South Star” located almost directly overhead.

The location of the celestial poles is particularly important for navigation by the stars because the celestial pole is at an angle above the horizon equal to your latitude. Observing from the Earth's North Pole, 90°N , the north celestial pole is 90° above the horizon. From the equator, the north celestial pole is just on the horizon—we could say 0° above it. Thus, if you can find the celestial pole, you can determine your latitude.



5.5 CELESTIAL COORDINATES

The coordinate grid used by astronomers is similar to the longitude and latitude system used to describe positions on Earth. A star's location in the sky is described by a **right ascension**, defining its east–west position, and a **declination**, defining its north–south position. Right ascension (or **RA** for short) plays the same role as longitude, while declination (or **dec**) plays the same role as latitude.

The celestial sphere can thus be divided into a grid consisting of east–west lines parallel to the celestial equator, and north–south lines connecting one celestial pole to the other (Figure 5.4B). Declination values run from $+90^\circ$ to -90° (at the north and south celestial poles), with 0° at the celestial equator. Right ascension values can likewise be recorded in degrees, but they are commonly listed in “hours.” Just as we can divide a circle into 360° , we can divide it into 24 “hours.” Each hour of RA equals 15° ; that is, $360^\circ \div 24 = 15^\circ$. The convenience of this system is that if a star at $\text{RA} = 2^{\text{h}}$ is overhead now, a star at $\text{RA} = 5^{\text{h}}$ will be overhead three hours from now. The right ascension of an object can be further refined to minutes (m) and seconds (s), just as we divide time intervals.

With a set of coordinate lines established, we can now locate astronomical objects in the sky the same way we can locate places on the Earth. Astronomers use star charts for this purpose, much as navigators use maps to find places on Earth. Part of a detailed star chart is shown in Figure 5.5. It shows the location of the constellations, the stars, and other objects. It also gives some indication of the relative brightness of the stars by marking their positions with larger or smaller dots. Many charts also have information about the season and time of night at which the stars are visible. The foldout star chart in the back of the book labels the dates when different stars will be overhead at 8 P.M. in the evening—a common time to be outside viewing the stars.

In Figure 5.5 an oval-shaped object is located at right ascension 0 hours 42.7 minutes ($0^{\text{h}} 42.7^{\text{m}}$), declination $+41^\circ$. This is a nearby galaxy called M31, located in the Local Group. Because its declination very nearly matches the latitude of Boston and Rome, M31 passes nearly through the zenith, the point directly overhead, as observed from both cities. This holds true anywhere: If a star's declination matches your latitude, it will pass through your zenith.



The location of the chart in Figure 5.5 can be found on the foldout chart at the back of the book. Compare these charts to the photograph of the sky in Looking Up #3: Perseus & M31.

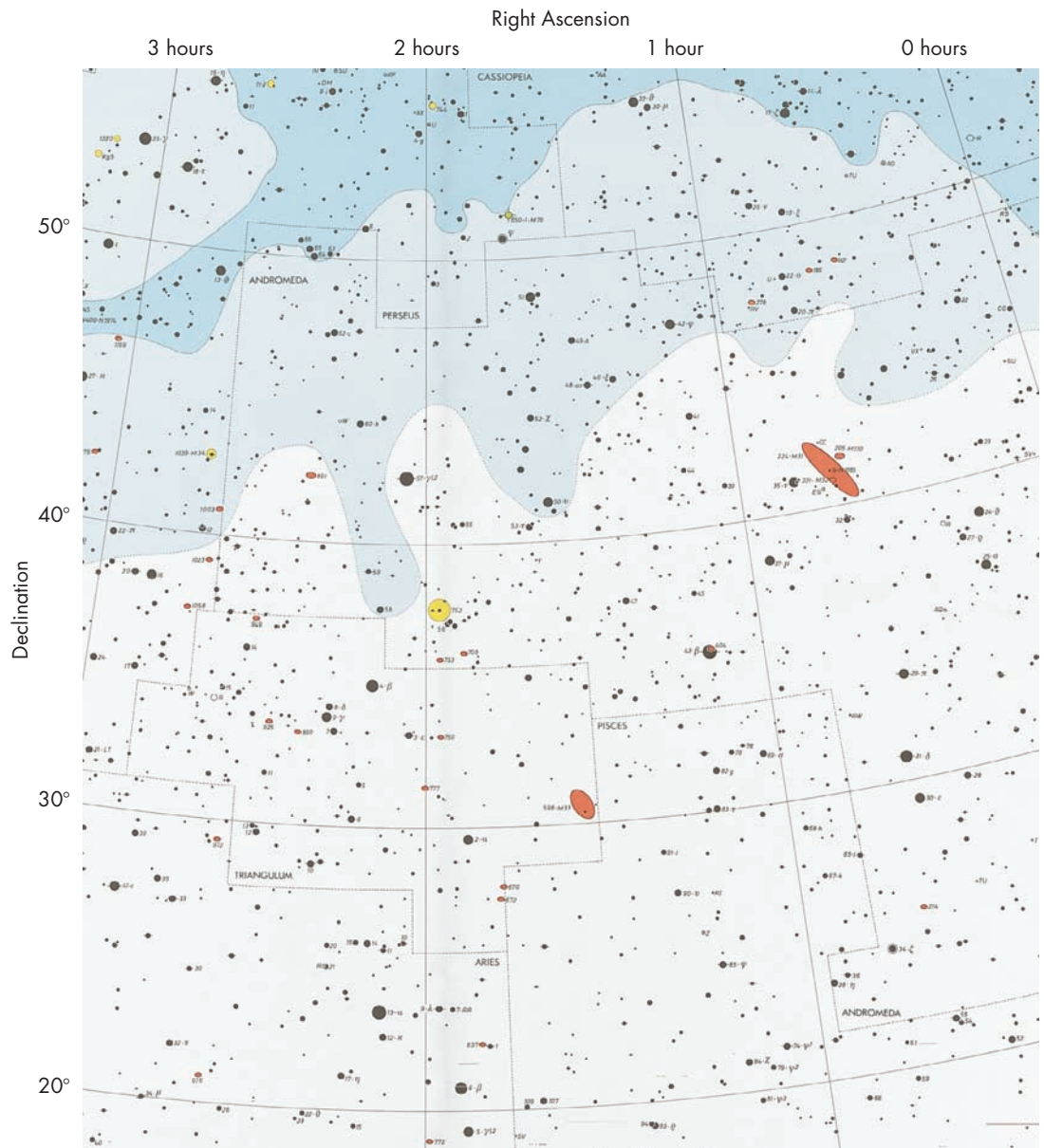


FIGURE 5.5

A modern star chart showing stars, galaxies, and coordinates. Black circles are stars. Their size indicates their brightness—larger circles are brighter stars. Red ellipses are galaxies. The shaded blue area is the Milky Way.

KEY TERMS

asterism, 41

celestial equator, 42

celestial pole, 42

celestial sphere, 39

circumpolar, 44

constellation, 41

declination (dec), 44

horizon, 39

latitude, 43

longitude, 43

nadir, 41

Polaris, 42

right ascension (RA), 44

zenith, 41

QUESTIONS FOR REVIEW

1. What is the celestial sphere?
2. What is a constellation?
3. What is right ascension?

PROBLEMS

1. What are your latitude and longitude? What are the latitude and longitude at the point on the Earth exactly opposite you (in the direction of your nadir)? What geographic features are located there?
2. From different locations on the Earth, stars will appear to rise at different angles with respect to the horizon. If you were located on the equator, what would be the angle to the horizon of stars rising in the east? What if you were at the North Pole? What about your own latitude?
3. Boston and Rome are at the same latitude, but Boston is at a longitude of 71°W, while Rome is at 12°E. If M31 passes through the zenith at a particular time in Rome, how many hours later will it pass through the zenith in Boston?
4. How far is the celestial equator from your zenith if your latitude is 42°N? 34°S?
5. Using a protractor, draw a diagram of the Earth. Mark the poles, the equator, and your own latitude. With a ruler, find the line that is “tangent” to your location—that is, the line should be parallel to the Earth’s surface and just touching this point. This tangent line represents your horizon. Draw a line extending from pole to pole to indicate the Earth’s axis, and extend both this line and your horizon line until they cross. Show that your latitude is the same as the angle of the celestial pole with respect to your horizon.

TEST YOURSELF

1. What makes the star Polaris special?
 - a. It is the brightest star in the sky.
 - b. The Earth’s axis points nearly at it.
 - c. It sits a few degrees above the northern horizon from any place on Earth.
 - d. It is part of one of the most easily recognized constellations in the sky.
 - e. All of the above
2. Where must you be located if a star with a declination of 10° passes through your zenith?
 - a. The North Pole
 - b. A longitude of 10°W
 - c. A latitude of 10°N
 - d. A longitude of 10°E
 - e. A latitude of 10°S

3. If you are standing at the Earth’s North Pole, which of the following will be at the zenith?
 - a. The celestial equator
 - b. The Moon
 - c. M31
 - d. The north celestial pole
 - e. The Sun

PLANETARIUM EXERCISES

All the planetarium exercises use the Starry Night planetarium software provided with your text. You should install the program and familiarize yourself with the various parameters and controls before trying these exercises. When the program asks you to enter a password, simply click “OK” to run Starry Night.

Set the location from which you are viewing to the nearest large city or your latitude and longitude. Accomplish this by clicking on the Location box on the toolbar. Verify that the local time is correct.

1. Set the field to 60 degrees on the left toolbar, the magnitude limits from -2.0 to 5.0 , by going under the heading Settings and finding Star Magnitudes. Next set the time step to 30 minutes with the Time option on the toolbar. Set the program so that it displays stars and illustrations for the constellations by using the heading Settings, then Constellations, Illustrations. Set your view to due East. Now step the program forward in 30-minute increments using the Time option in the toolbar. Try the same thing facing due west (Azimuth 270), due south (Azimuth 180), and due north (Azimuth 0). What does this star motion tell you about the rotation of the Earth on its axis? If stars rise in the east and set in the west just like the Sun, is the Earth moving west to east or east to west?
2. Pick a well-known constellation that is easily visible, such as Orion. Center on it using the heading Settings and then using the Find option. Set the time step to half-hour intervals and step ahead a few hours. Find that same constellation in your sky and follow its motion in half-hour intervals just as in the program. Does this motion follow what you envisioned after seeing it in the planetarium program? What seems different?
3. Set the field to 60 degrees on the left toolbar, the magnitude limits from -2.0 to 5.0 under the Settings heading, and the time step to 30 minutes. Look north and center on Polaris. Step the program ahead for six hours. Do the stars near Polaris appear to rise and set? In what direction do they rotate around Polaris during the evening? What does this suggest about the direction in which the Earth rotates on its axis as seen from above? What do you see near the south celestial pole?