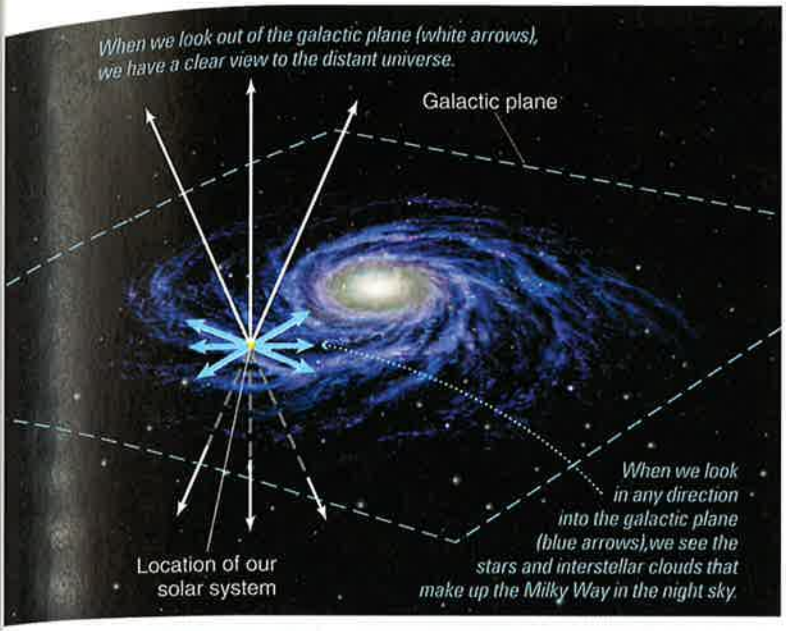


FIGURE 2.5 This painting shows how our galaxy's structure affects our view from Earth.

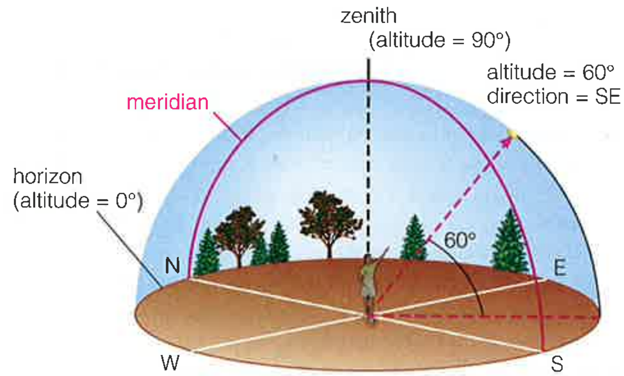


FIGURE 2.6 From any place on Earth, the local sky looks like a dome (hemisphere). This diagram shows key reference points in the local sky. It also shows how we can describe any position in the local sky by its altitude and direction.

decades ago, when new technologies allowed us to peer through the clouds by observing forms of light that are invisible to our eyes (such as radio waves and X rays [Section 5.2]).

THINK ABOUT IT

Consider a distant galaxy located in the same direction from Earth as the center of our own galaxy (but much farther away). Could we see it with our eyes? Explain.

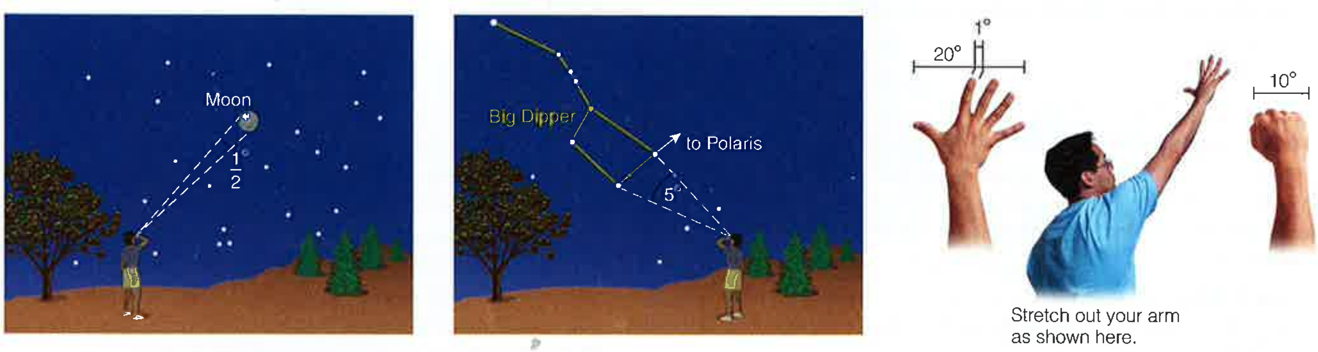
The Local Sky The celestial sphere provides a useful way of thinking about the appearance of the universe from Earth. But it is not what we actually see when we go outside. Picture yourself standing in a flat, open field. The sky appears to take the shape of a dome, making it easy to understand why people of many ancient cultures imagined that we lived on a flat Earth under a great dome encompassing the world. We see only half of the celestial sphere at any particular moment from any particular location, while the other half is blocked from view by the ground. The half of the celestial sphere that you see at any time represents what we call your **local sky**—the sky as seen from wherever you happen to be standing.

Figure 2.6 shows key reference features of the local sky. The boundary between Earth and sky defines the **horizon**. The point directly overhead is the **zenith**. The **meridian** is an imaginary half circle stretching from the horizon due south, through the zenith, to the horizon due north.

We can pinpoint the position of any object in the local sky by stating its **direction** along the horizon (sometimes stated as *azimuth*, which is degrees clockwise from due north) and its **altitude** above the horizon. For example, Figure 2.6 shows a person pointing to a star located in the direction of southeast at an altitude of 60°. Note that the zenith has altitude 90° but no direction, because it is straight overhead.

Angular Sizes and Distances Our lack of depth perception on the celestial sphere means we have no way to judge the true sizes or separations of the objects we see in the sky. However, we can describe the *angular* sizes or separations of objects even without knowing how far away they are.

The **angular size** of an object is the angle it appears to span in your field of view. For example, the angular sizes of the Sun and Moon are each about $\frac{1}{2}°$ (Figure 2.7a). Notice that angular size does not by itself tell us an object's true size, because angular size also depends on distance. The Sun



a The angular sizes of the Sun and the Moon are about 1/2°.

b The angular distance between the "pointer stars" of the Big Dipper is about 5°.

c You can estimate angular sizes or distances with your outstretched hand.

FIGURE 2.7 We measure *angular sizes* or *angular distances,* rather than actual sizes or distances, when we look at objects in the sky.

MATHEMATICAL INSIGHT 2.1

Angular Size, Physical Size, and Distance

If you hold a quarter in front of your eye, it can block your entire field of view. But as you move it farther away, it appears to get smaller and blocks less of your view. Figure 1a summarizes the idea by showing the quarter in cross section, so we can see how its angular diameter decreases with distance.

It's useful to have a formula telling us how an object's angular size depends on its physical size and distance, and we can find the formula with a little mathematical trick that works when the angular size is small. In Figure 1b, we've made the quarter from Figure 1a look like a tiny piece of a circle going all the way around your eye. The radius of the circle is the *distance* from your eye to the quarter, the angle from your eye is the quarter's *angular size*, and we've labeled the quarter's actual diameter as its *physical size*. Now, notice that as long as the angular size is relatively small (less than a few degrees), we can pretend that the quarter's physical size (diameter) is a small piece of the circle we've drawn. This is the trick we needed: The quarter's angular size is now the *same fraction* of the full 360° circle as its physical size is of the circle's physical circumference. Since the circumference of this circle is $2\pi \times (distance)$, we can write what we've found as

$$\frac{\text{angular size}}{360^\circ} = \frac{\text{physical size}}{2\pi \times \text{distance}}$$

Multiplying both sides by 360° and rearranging a bit, we have a formula that allows us to determine angular size when we know physical size and distance:

$$\text{angular size} = \text{physical size} \times \frac{360^\circ}{2\pi \times \text{distance}}$$

This formula is sometimes called the *small-angle formula*, since it is valid only when the angular size is small.

In astronomy, we generally measure an object's angular size and often have a way of determining its distance (we'll discuss distance measurement techniques in later chapters). We can therefore rearrange the formula to calculate physical size. You should confirm that a little algebra tells us that

$$\text{physical size} = \text{angular size} \times \frac{2\pi \times \text{distance}}{360^\circ}$$

The context of a problem will tell you which form of the formula to choose.

EXAMPLE 1: The angular diameter of the Moon is about 0.5° and the Moon is about 380,000 km away. Estimate the Moon's actual diameter.

SOLUTION:

Step 1 Understand: We are asked to find the Moon's actual diameter given its angular diameter and distance. The formula below tells us how to find physical *size* from angular size and distance; we can use this formula once we realize that, in this case, the "size" is a diameter.

Step 2 Solve: We now use the formula to calculate the Moon's physical size (diameter) from the given values of its angular size and distance:

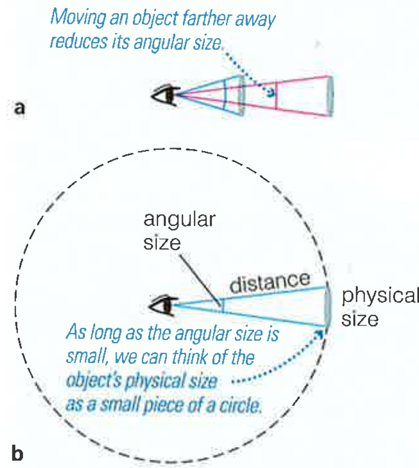


FIGURE 1 Angular size depends on physical size and distance.

$$\text{physical size} = \text{angular size} \times \frac{2\pi \times \text{distance}}{360^\circ}$$

$$= 0.5^\circ \times \frac{2\pi(380{,}000 \text{ km})}{360^\circ}$$

$$\approx 3300 \text{ km}$$

Step 3 Explain: We have found that the Moon's diameter is about 3300 kilometers. We can check that our answer makes sense by comparing it to the value for the Moon's diameter given in Appendix E. Our estimate of 3300 kilometers is fairly close to the Moon's actual diameter of 3476 kilometers, which we could find by using more precise values for the Moon's angular diameter and distance.

EXAMPLE 2: Suppose the two headlights on a car are separated by 1.5 meters and you are looking at the car from a distance of 500 meters. What is the angular separation of the headlights?

SOLUTION:

Step 1 Understand: In this case we are asked about "separation" between two lights rather than size, but the idea is the same. We simply replace size with separation in the formulas below and we have all the information we need to solve the problem.

Step 2 Solve: Because we know the physical separation and distance in this case, we use the formula in the first form that we found above.

$$\text{angular separation} = \text{physical separation} \times \frac{360^\circ}{2\pi \times \text{distance}}$$

$$= 1.5 \text{ m} \times \frac{360^\circ}{2\pi(500 \text{ m})} = 0.17^\circ$$

Step 3 Explain: We have found that the angular separation of the two headlights is 0.17°. However, remember that it is more common to express fractions of a degree in arcminutes or arcseconds. There are 60 arcminutes in 1°, so our answer of 0.17° is equivalent to $0.7^\circ \times 60 \text{ arcmin}/1^\circ = 10.2$ arcminutes. In other words, the angular separation of the headlights is about 10 arcminutes, which is about $\frac{1}{3}$ of the 30 arcminute (0.5°) angular diameter of the full moon.

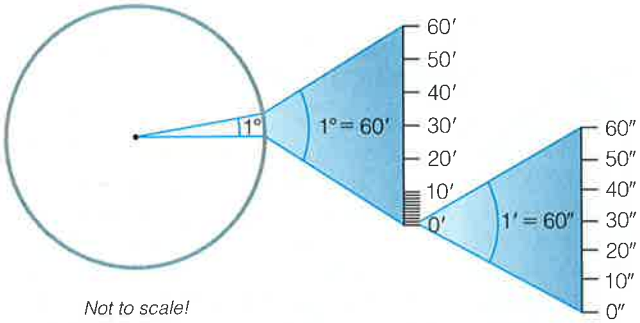


FIGURE 2.8 We subdivide each degree into 60 arcminutes and each arcminute into 60 arcseconds.

is about 400 times larger in diameter than the Moon, but it has the same angular size in our sky because it is also about 400 times farther away.

The **angular distance** between a pair of objects in the sky is the angle that appears to separate them. For example, the angular distance between the "pointer stars" at the end of the Big Dipper's bowl is about 5° (Figure 2.7b). You can use your outstretched hand to make rough estimates of angles in the sky (Figure 2.7c).

For more precise astronomical measurements, we subdivide each degree into 60 **arcminutes** and subdivide each arcminute into 60 **arcseconds** (Figure 2.8). We abbreviate arcminutes with the symbol ' and arcseconds with the symbol ". For example, we read 35°27'15" as "35 degrees, 27 arcminutes, 15 arcseconds."

THINK ABOUT IT

Children often try to describe the sizes of objects in the sky (such as the Moon or an airplane) in inches or miles, or by holding their fingers apart and saying "it was THIS big." Can we really describe objects in the sky in this way? Why or why not?

Why do stars rise and set?

If you spend a few hours out under a starry sky, you'll notice that the universe seems to be circling around us, with stars moving gradually across the sky from east to west. Many ancient people took this appearance of movement at face

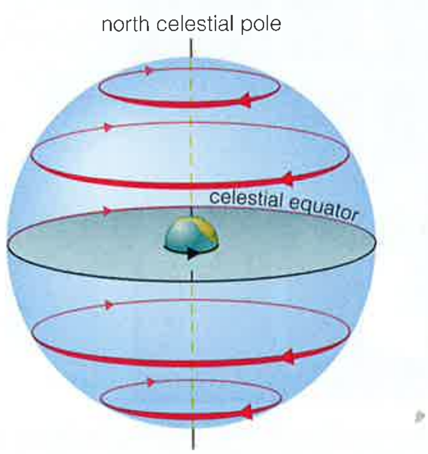


FIGURE 2.9 Earth rotates from west to east (black arrow), making the celestial sphere *appear* to rotate around us from east to west (red arrows).

COMMON MISCONCEPTIONS

The Moon Illusion

You've probably noticed that the full moon appears to be larger when it is near the horizon than when it is high in your sky. However, this apparent size change is an illusion. If you measure the angular size of the full moon on a particular night, you'll find that it is about the same whether the Moon is near the horizon or high in the sky. The Moon's angular size in the sky depends only on its true size and its distance from Earth. Although this distance varies over the course of the Moon's monthly orbit, it does not change enough to cause a noticeable effect on a single night. You can confirm that the Moon's angular size remains the same by measuring it. You may also be able to make the illusion go away by viewing the Moon upside down between your legs when it is on the horizon.

value, concluding that we lie at the center of a universe that rotates around us each day. Today we know that the ancients had it backward: It is Earth that rotates, not the rest of the universe, and that is why the Sun, Moon, planets, and stars all move across our sky each day.

We can picture the movement of the sky by imagining the celestial sphere rotating around Earth (Figure 2.9). From this perspective you can see how the universe seems to turn around us: Every object on the celestial sphere appears to make a simple daily circle around Earth. However, the motion can look a little more complex in the local sky, because the horizon cuts the celestial sphere in half. Figure 2.10 shows the idea for a location in the United States. If you study the figure carefully, you'll notice the following key facts about the paths of various stars (and other celestial objects) through the local sky:

- Stars relatively near the north celestial pole remain perpetually above the horizon. They never rise or set but instead make daily counterclockwise circles around the north celestial pole. We say that such stars are **circumpolar**.

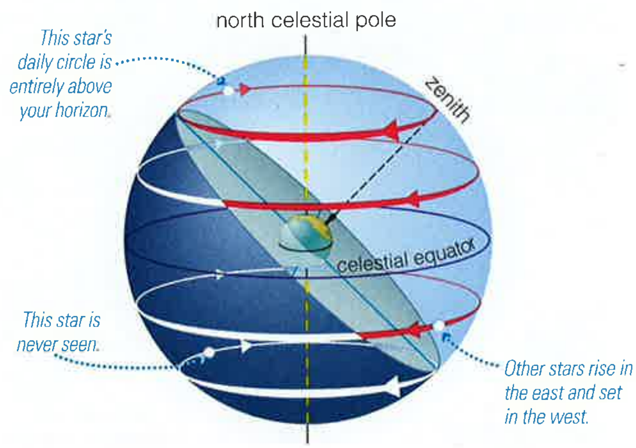


FIGURE 2.10 The local sky for a location in the United States (40°N). The horizon slices through the celestial sphere at an angle to the equator, causing the daily circles of stars to appear tilted in the local sky. Note: It may be easier to follow the star paths in the local sky if you rotate the page so that the zenith points up.