1.1

The Celestial Sphere

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 (fig. 1.1*). Many of the patterns and motions of the stars have been all but forgotten in our hectic modern world, so our first goal is to familiarize ourselves with some general aspects of the sky at night.

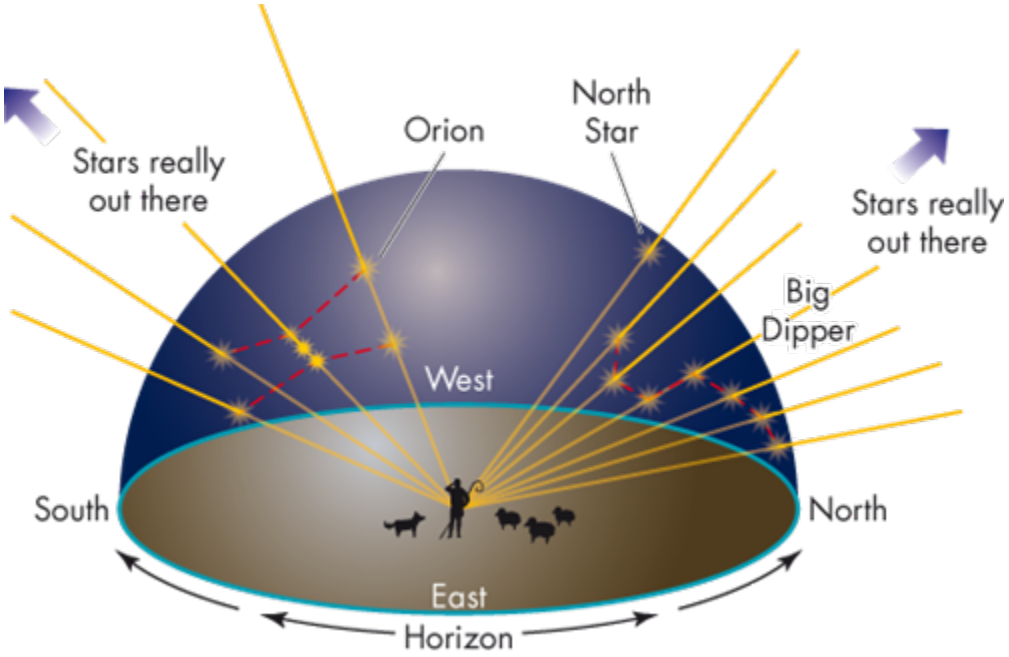

FIGURE 1.1
The stars appear to lie on a hemisphere over us that meets the ground at the horizon.

Stars are at such huge distances that we cannot get any sense of their true three-dimensional arrangement in space when we view them. For purposes of naked-eye observations, we can therefore treat all stars as if they are at the same distance from the Earth, and imagine that they lie on the inside of a gigantic dome that stretches overhead. This dome seems to stretch to where the sky meets the ground along a horizontal circle that we call the **horizon**.

Page 16

Astronomers picture the dome of the night sky as half of the **celestial sphere**, which surrounds the Earth as depicted in figure 1.2. When we stand on the Earth, the ground blocks our view of approximately half the celestial sphere. If you were suspended in space far from Earth, you would see the entire celestial sphere surrounding you.

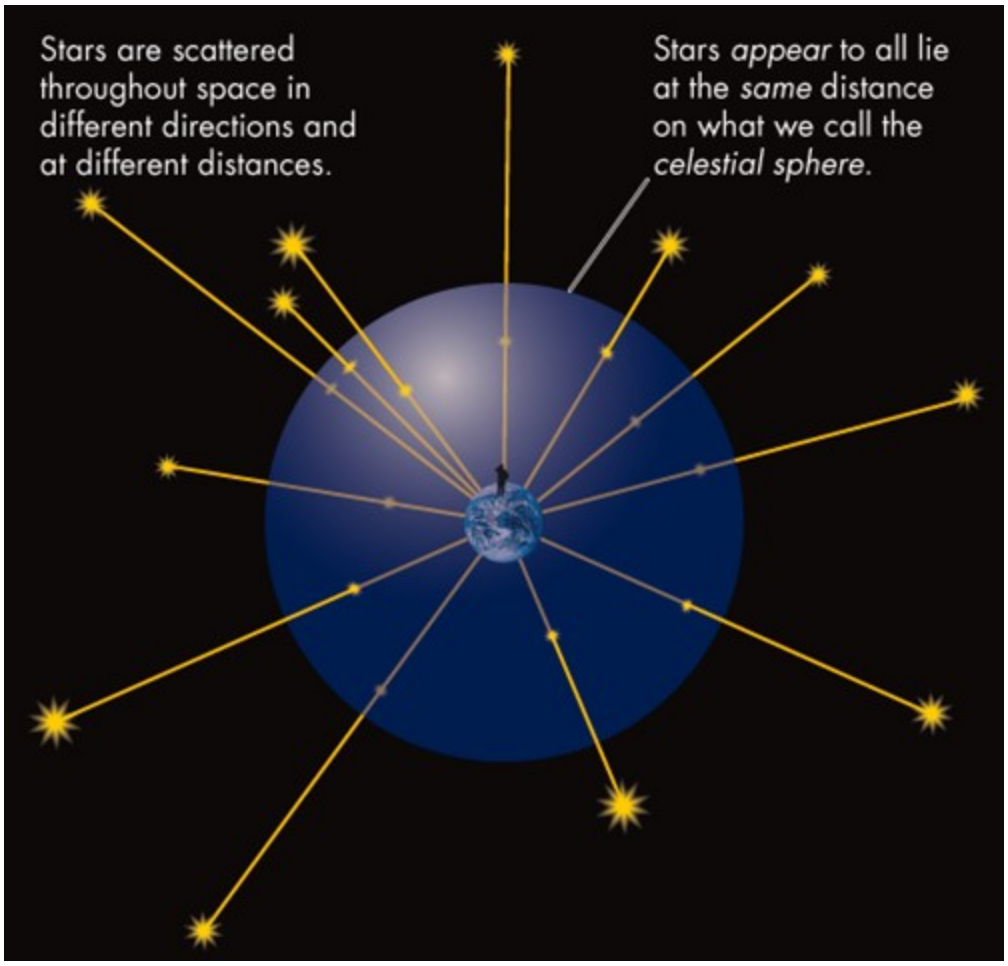

FIGURE 1.2
The stars are scattered through space at very different distances, but they *appear* to lie at the same distance from us on what we call the celestial sphere.

In reality, the thousands of stars visible on a clear night are at vastly different distances from us. The nearest is about 4 light-years away, so for the Earth at the size shown in figure 1.2, it would be about 6000 miles away. Other bright stars are thousands of times farther, millions of miles at the figure's scale!

Depicting the stars as though they lie on a celestial sphere is not physically realistic, but it serves as a useful **model** of the heavens—a way of simplifying the arrangement and motions of celestial bodies so they are easier to visualize. We use the term *model* to mean a representation of some aspect of the Universe. The celestial sphere represents a way of thinking about or picturing the location and motions of stars and planets for someone observing the sky from the Earth.

The celestial sphere is the first of many models we will encounter that humans have used to describe the Universe. In later chapters, we will use models to enhance our understanding whenever the size or other properties of what we study fall outside the range of everyday experience. We will speak of models of atoms, models of stars, and models of the Universe itself.

Constellations

Some of the interesting celestial objects in and around Cygnus can be found in Looking Up #4 at the front of the book.

As human beings, we seek order in what we see. When ancient people looked at the night sky, they noticed that the stars form fixed patterns on the celestial sphere, what we today call **constellations**. Some of these constellations resemble animals if we use a little imagination. For example, the pattern of stars in Leo looks a little like a lion, whereas that of Cygnus looks like a swan in flight, as depicted in figure 1.3. However, you will discover, as you learn to identify the constellations, that many have shapes that bear little resemblance to their namesakes.

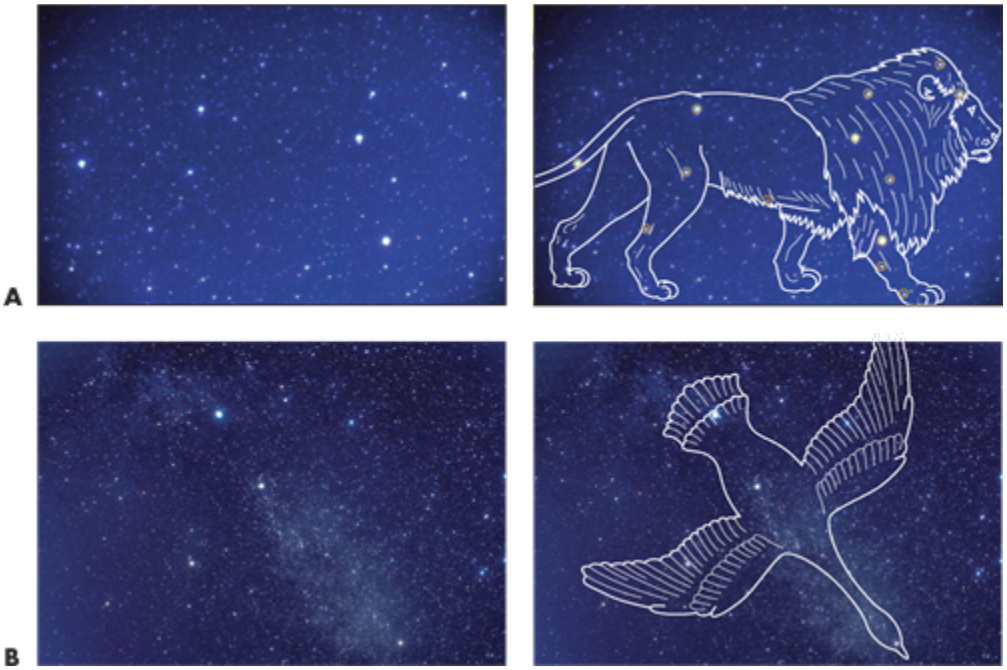

FIGURE 1.3
The two constellations Leo (A) and Cygnus (B) with figures sketched in to help you visualize the animals they represent.
Page 17

All stars move through space, but as seen from Earth, their positions change very slowly, 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. A shepherd who lived 5000 years ago in the Middle East would have no trouble recognizing the star patterns of the night sky we see and might even call them by the same names.

We do not know how all the constellation names were chosen. Most date back thousands of years to prehistoric times. It seems likely that some names served as mnemonic devices for keeping track of the seasons and for navigating. For example, the beginning of the stormy winter months, when sailing was dangerous and ships were often wrecked, was foretold by the Sun's appearance in the

constellations Pisces and Aquarius, the water constellations. Likewise, the harvest time was indicated by the Sun's appearance in Virgo, a constellation often depicted as the goddess Proserpine, holding a sheaf of grain.

Daily Motions of the Sun and Stars

Take a look at the night sky, and you will see stars rise along the eastern horizon, move across the sky, and set along the western horizon, just as the Sun does. You can verify this by watching the night sky for as little as 10 minutes. A star seen just above the eastern horizon will have risen noticeably higher, and stars near the western horizon will have sunk lower or disappeared (fig. 1.4A). Likewise, if you look at a constellation, you see its stars rise as a fixed pattern in the eastern sky, move across the sky, and set in the western sky.

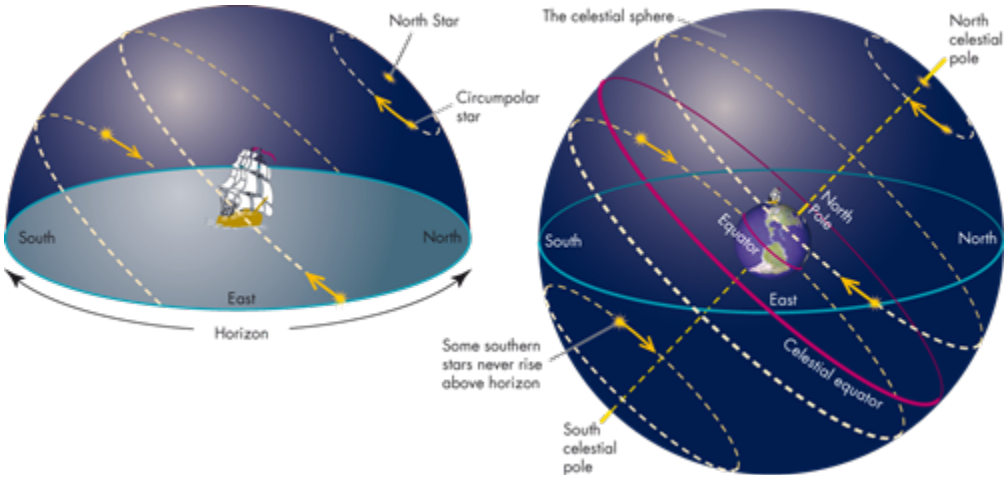

FIGURE 1.4
(A) Stars appear to rise and set during the course of a night, although some circumpolar stars always stay above the horizon. (B) The whole celestial sphere can be pictured as spinning around the celestial poles, which lie above the Earth's poles, with a celestial equator above Earth's equator.

Q: The stars appear to rotate counterclockwise around the north celestial pole. Which way does the Earth rotate as viewed from above the North Pole?

Answer

In terms of our model of the heavens based on the celestial sphere, we can visualize the rising and setting of stars as rotation of the celestial sphere around us (fig. 1.4B). Ancient peoples would have found it far easier to believe in that rotation than to believe that the Earth moved. Thus, they attributed all celestial motion—that of the Sun, Moon, stars, and planets—to a vast sphere slowly turning overhead. Today we still say the Sun *rises* and *sets*, but of course we know that it is the Earth's rotation that makes the Sun, Moon, and stars rise and move westward across the sky each day. It is not the celestial sphere that spins but the Earth.

The region of the north celestial pole is shown in Looking Up #1 at the front of the book. The region of the south celestial pole is shown in Looking Up #9.

If you look at the celestial sphere turning overhead, two points on it do not move. 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 appears to rotate around the celestial poles, as illustrated in figure 1.4B. Over the course of a night, stars appear to circle the north celestial pole in a counterclockwise direction for observers in the Earth's northern hemisphere.

Star rise and set caused by Earth's rotation

Page 18

Because it lies directly above the Earth's North Pole, the north celestial pole always marks the direction of true north. Near the position of the north celestial pole, there happens to be a moderately bright star, Polaris, which is therefore known as the North Star. This is an important and widely used guide for travelers on land and sea, but it has not always been the same star throughout history. The direction of the Earth's axis gradually shifts or precesses over thousands of years, so different stars have served as the North Star in ancient times. No similarly bright star has happened to lie close to the south celestial pole for many thousands of years, so there is no equivalent "South Star." We examine the precession of the Earth's axis further in chapter 6.

Another important 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 1.4B shows. Only stars on the celestial equator rise due east and set due west. Stars north of the celestial equator rise in the northeast and set in the northwest, while stars south of the equator rise in the southeast and set in the southwest. For a northern observer some *circumpolar* stars near the north celestial pole never cross below the horizon, while stars close enough to the south celestial pole never rise above the horizon.

Annual Motion of the Sun

At the same time that the Earth's spin causes the apparent daily motion of the Sun and stars across the sky, the Earth's orbital motion around the Sun also causes changes in the parts of the sky we see on different nights of the year. If you compare the sky at the same time each evening for a few months, you will discover that different constellations are visible.

For example, in early June the Sun appears to lie in the direction of the constellation Taurus, so this constellation's stars are lost in the Sun's glare. After sunset, however, we can see the neighboring constellation, Gemini, just above the western horizon as illustrated in figure 1.5. By July, Gemini has disappeared behind the Sun, and instead Cancer is visible just above the horizon. And by August, Cancer has disappeared to be replaced by Leo. Around the rest of the sky we see a steady change of constellations throughout the course of the year. A year later, though, the same constellations will again be visible as they were originally.

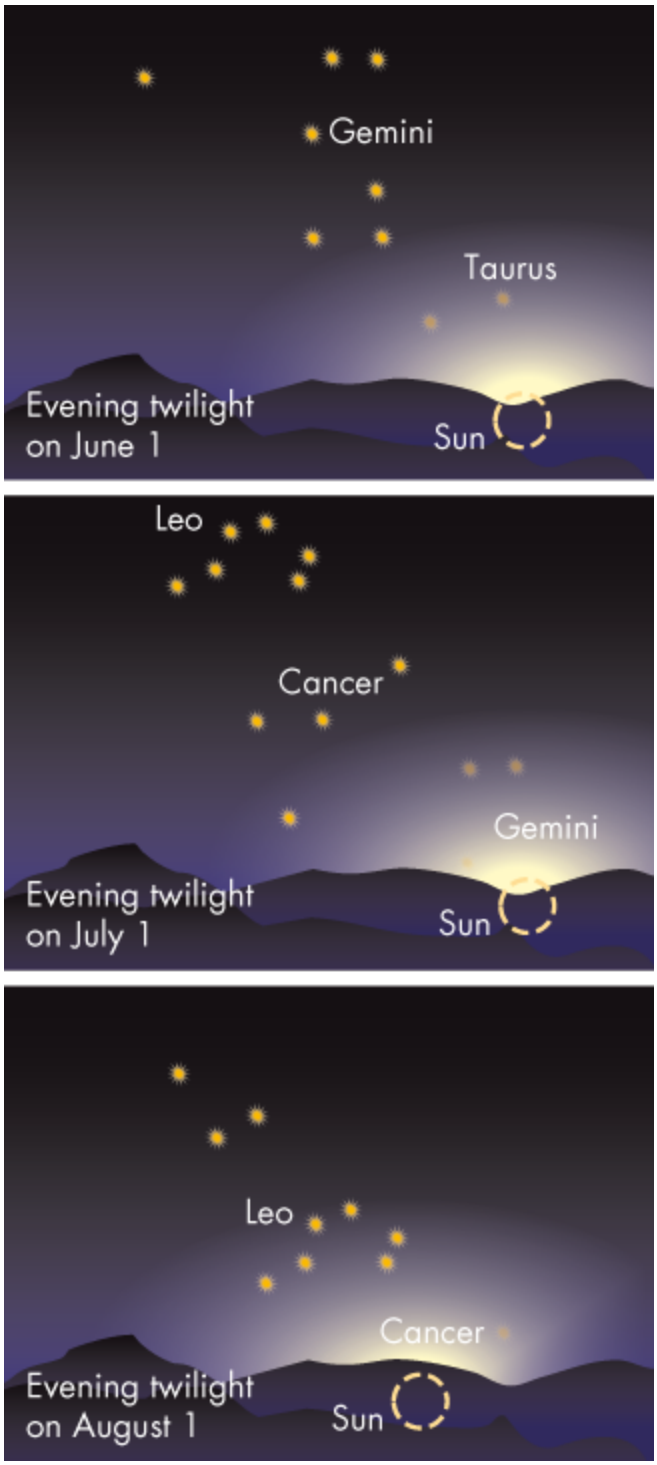

FIGURE 1.5
The Sun appears to lie in Taurus on June 1, in Gemini on July 1, in Cancer on August 1, and so forth, making the constellations we see after sunset change with the seasons.

The change of the constellations with the seasons is caused by the Earth's motion around the Sun. The Sun's glare blocks our view of the part of the celestial sphere that lies toward the Sun, making the stars that lie beyond the Sun invisible. If we picture the Earth orbiting the Sun within the celestial sphere, as illustrated in figure 1.6, month by month the Sun covers one constellation after another. It is like sitting around a campfire and not being able to see the faces of the people on the far side. But if we get up and walk around the fire, we can see faces that were previously hidden. Similarly the

Earth's motion allows us to see stars previously hidden in the Sun's glare. Because these movements repeat in a yearly cycle, they are called *annual motions.*

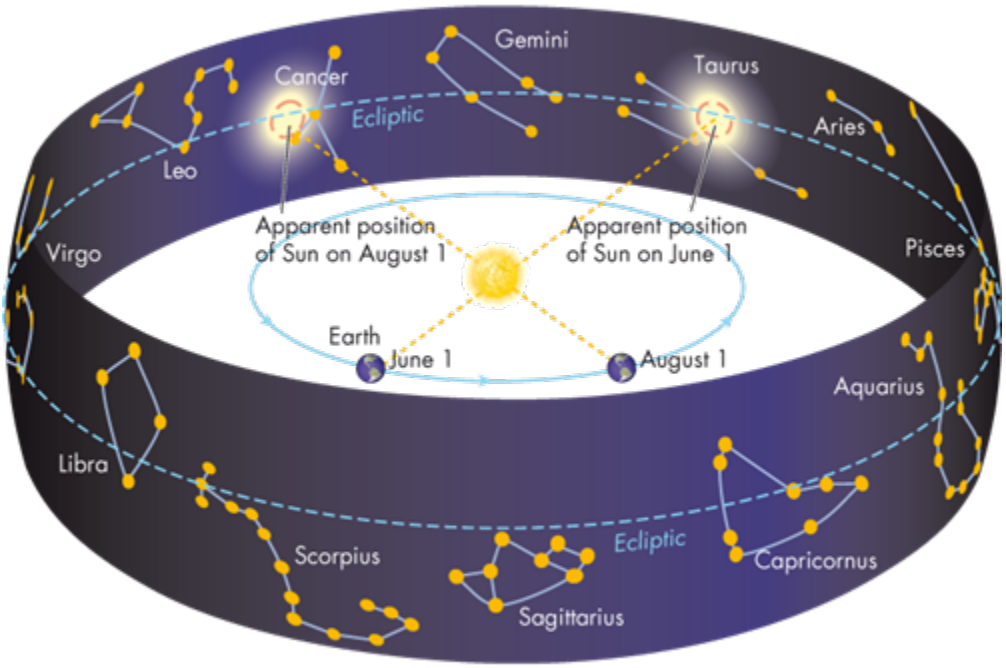

FIGURE 1.6
As the Earth orbits the Sun, the Sun appears to move around the celestial sphere through the background stars. The figure illustrates the portion of the celestial sphere on either side of the Sun's path, which is called the ecliptic. As the Earth orbits the Sun, the Sun appears to move through twelve constellations known as the zodiac that lie near the ecliptic. Note that the ecliptic is the extension of the Earth's orbital plane out to the celestial sphere.

ANIMATION

Constellations by seasons

Astronomers distinguish an object's spinning motion from its orbital motion with different terms. We say that the Earth rotates on its axis (spins) daily while it revolves around the Sun (moves along its orbit) annually. Because our planet orbits in the same direction as it spins, the Earth does not need to rotate quite as far each night to make a particular star visible as it does to face back toward the Sun. As a result, a star rises 3 minutes and 56 seconds earlier each night. That 3 minutes and 56 seconds, when added up each night over an entire year, amounts to 24 hours.

This motion is slow and difficult to observe, but many ancient peoples developed techniques to keep track of these motions. This was extremely important to early people because it provided a way to measure the passage of time other than by carefully counting days. Moreover, the stars demonstrated that many celestial events are predictable and that they may be used to order our lives on Earth. For example, ancient Egyptians looked for the star Sirius near the Sun just before dawn as a way of predicting when the annual rising of the Nile would occur. Knowing the exact season can be crucial for such things as planting crops. A brief warm spell might have tricked an ancient farmer into sowing seeds too early, but by studying the sky for many years, she might have discovered that when the constellation Taurus is visible just before dawn, it is time to plant.

The Ecliptic and the Zodiac

If we could mark on the celestial sphere the path traced by the Sun as it moves through the constellations, we would see a line that runs around the celestial sphere, as illustrated in figure 1.6. Astronomers call the line that the Sun traces across the celestial sphere the **ecliptic**. The name *ecliptic* arises because only when the new or full moon crosses this line can an eclipse occur, as discussed in section 1.4. Examining figure 1.6, you can see that the ecliptic is the extension of the Earth's orbit onto the celestial sphere, just as the celestial equator is the extension of the Earth's equator onto the celestial sphere.

The belt-shaped region of the sky surrounding the ecliptic passes primarily through twelve constellations and is called the **zodiac**. The word *zodiac* is from the Greek *zoidion*, "little animal," and *kyklos*, "circle." That is, zodiac refers to a circle of animals, which the majority of its constellations represent. The names of these constellations are Aries (ram), Taurus (bull), Gemini (twins), Cancer (crab), Leo (lion), Virgo (maiden), Libra (scales), Scorpius (scorpion), Sagittarius (archer), Capricornus (sea-goat), Aquarius (water-bearer), and Pisces (fish).

The names of the constellations of the zodiac may look familiar from horoscope "signs," part of an ancient belief system of *astrology* that stars determined human destinies, much as they predicted the rising of the Nile. Astrology is today regarded as a pseudoscience, although horoscopes remain a popular entertainment (see Extending Our Reach: "Are You an Ophiuchan?").

EXTENDING *our reach*
ARE YOU AN OPHIUCHAN?

The origin of horoscope signs dates back several thousand years. It is based on the notion that the location of the Sun along the zodiac at the time of people's birth (their "Sun sign") determines their basic personal traits. Astrologers often say things such as that a person born under the sign of Taurus is "strong and silent like a bull."

If you check where the Sun was actually located on the date of your birth, chances are that it was not in the constellation you would think based on your newspaper horoscope sign. This is because the dates of Sun signs were established thousands of years ago, but the precession of the Earth's axis (see chapter 6) has caused a shift in the dates of our calendar relative to the location of the Sun among the stars.

In fact, the Sun has shifted almost one full constellation, so if you think your sign is Aquarius, for example, the Sun was probably in Capricornus when you were born. In fact, the boundaries of the constellations are a little arbitrary, but the Sun actually moves through the constellation Ophiuchus, a snake charmer, during the first half of December. So many people who think they are Sagittarians are in fact “Ophiuchans”! Astronomers are not concerned about this, however, since there is no scientific evidence that astrology has any predictive power.