2.2

The Planets

Many ancient cultures noted that there are five bright “stars” visible in the night sky that do not stay fixed relative to the rest of the stars in the sky. The Greeks called them *planētai*, meaning “wanderers,” from which our word *planet* comes.

ANIMATION

Mercury and Venus as morning and evening stars

Because these wandering stars seemed to have a will of their own, many cultures named the planets after divine beings. The names we use for them today come from Greco-Roman mythology. Mercury, named for the fleet-footed messenger god, is seen always near the Sun, switching back and forth between the evening and morning skies half a dozen times each year. Venus, named for the goddess of love and beauty, spends about 9 months as the brightest star gracing the evening sky, then 9 months in the predawn sky, then back again. Mars is probably named for the god of war because of its blood-red color. Jupiter, named for the king of the gods, shines steadily as one of the brightest stars, moving at a stately pace among the stars. Saturn, usually the faintest and slowest-moving of the planets, was Jupiter’s father in mythology, cast into the deepest recesses when his son overthrew him.

Today we know that the planets move across the background stars because of a combination of the Earth’s and their own orbital motion around the Sun. One of the more striking features of this motion is that the planets always remain close to the ecliptic, within the constellations of the zodiac. The motion of the planets lies in the same narrow zone as the Sun because their orbits, like that of the Earth, all lie in nearly the same plane, as illustrated in figure 2.11. Thus, like the path of the Sun through the stars, the paths of the planets are tilted by about 23.5° to the celestial equator, moving into our northern and southern skies depending on their position in their orbits.

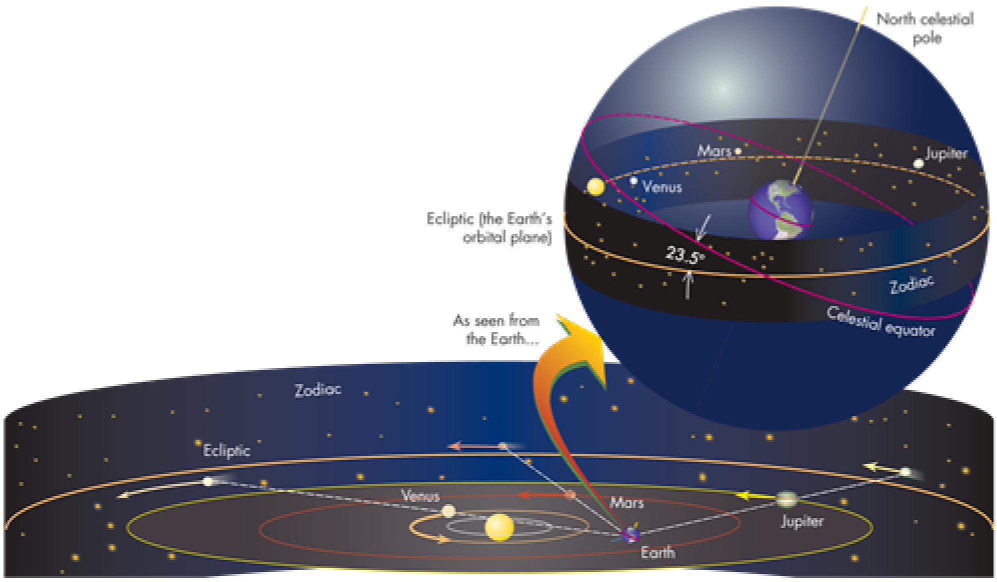

FIGURE 2.11
To the naked eye, the planets look like bright stars that “wander” through the sky. Although they move, they always remain near the ecliptic in the constellations of the zodiac, like the Sun and the Moon.

The motions of the planets relative to the stars are gradual, detectable only through observations over many nights. Therefore, like the Sun, the planets rise and set each day—reflecting, of course, the rotation of the Earth. The motion of a planet through the zodiac can be seen by marking off its position on the celestial sphere over a period of a week or more. Figure 2.12 illustrates such a plot and shows that planets normally move eastward through the stars as a result of their orbital motion around the Sun.

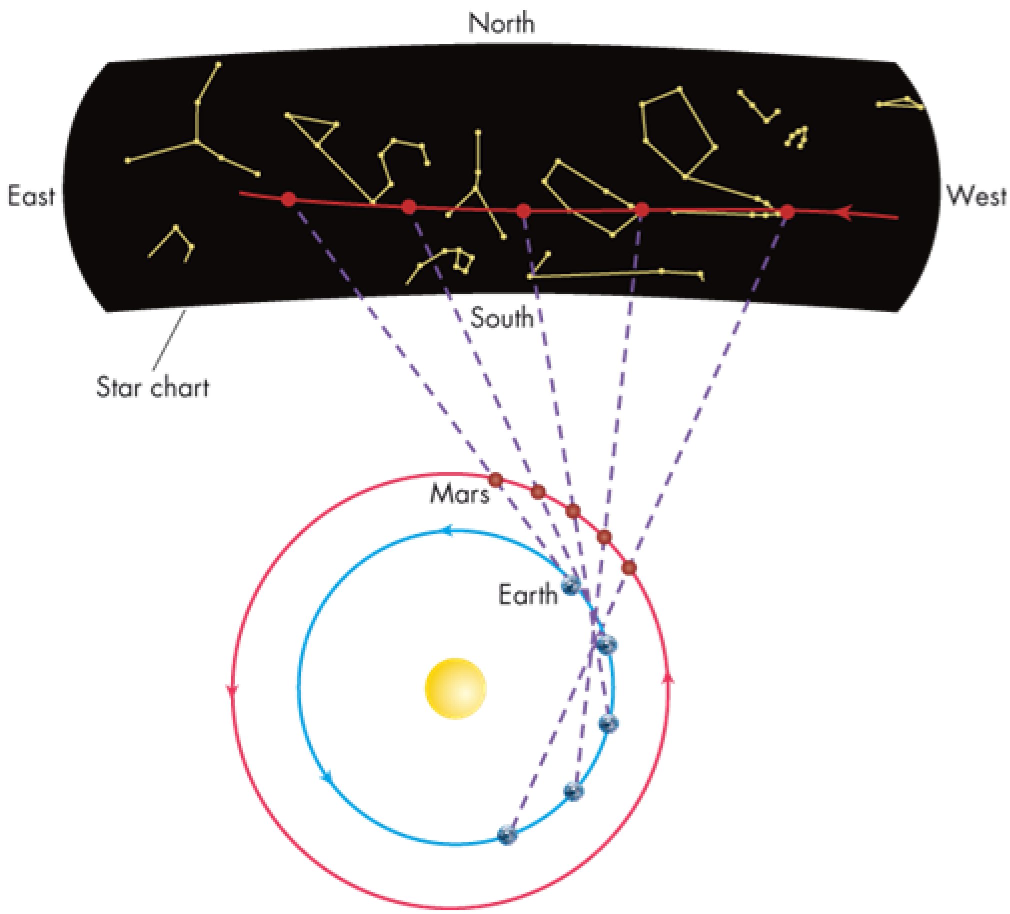

FIGURE 2.12
A planet's eastward drift against the background stars plotted on the celestial sphere. Note: Star maps usually have east on the left and west on the right, so that they depict the sky when looking south.
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Although planets usually move from west to east through the stars, this does *not* mean that they rise in the west and set in the east. As seen from Earth, planets *always* rise in the east and set in the west because they are carried across the sky—just as the stars are—by the Earth's rotation. However, the motion of the planets is usually slower than that of the stars because their orbital motion partly offsets the rotation of the Earth that causes this apparent motion of the stars. Generally, when we observe a star and a planet rising side by side, at some later time that evening the planet will not be as far above the horizon as the star. Therefore, *with respect to the stars*, the planet has moved to the east because of its orbital motion around the Sun.

INTERACTIVE

Retrograde motion

This simple pattern of movement is sometimes interrupted. Occasionally a planet will move west with respect to the stars, a condition known as **retrograde motion** and shown in figure 2.13. The word *retrograde* means "backward," and when a planet is in retrograde motion, its path through the stars bends backward, sometimes even forming a loop, for a few months. All planets undergo retrograde motion for a portion of their paths around the sky. This motion greatly complicates the otherwise straightforward idea that the celestial sphere and its bodies rotate around the Earth. In fact, the search for a simple, plausible explanation of retrograde motion was what led astronomers ultimately to reject models of the Solar System with the Earth at the center.

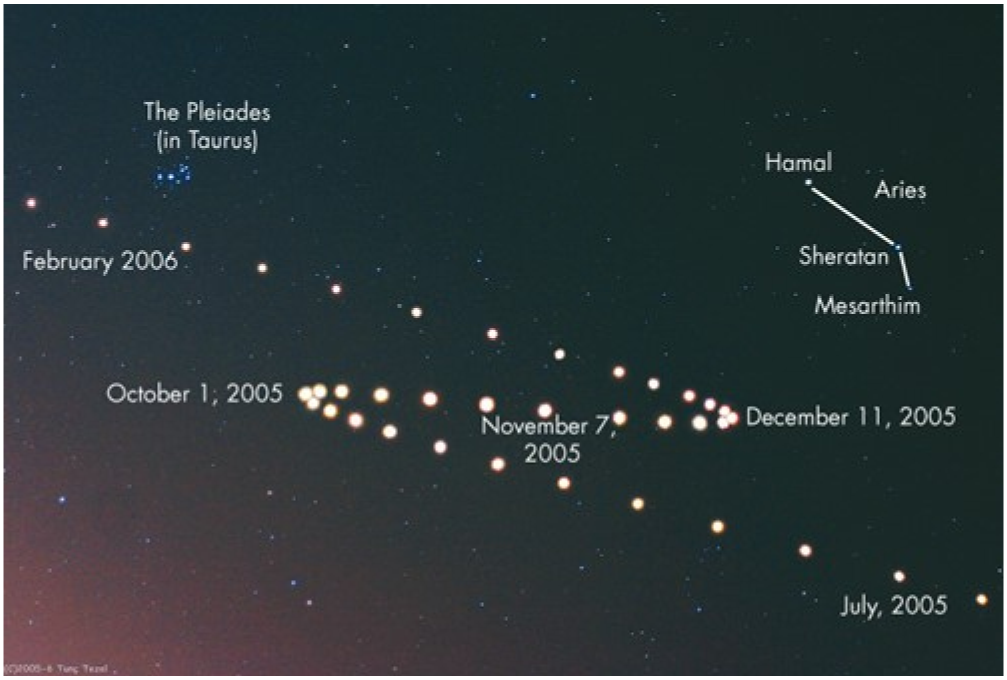

FIGURE 2.13
A sequence of images of Mars made in late 2005, showing its motion relative to the background stars. The pictures were taken roughly a week apart. Mars underwent retrograde motion in October and November of that year.

Q: Why does the brightness of Mars change in the image? (Hint: Draw a sketch of the positions of Mars and the Earth as Mars undergoes retrograde motion.)

Answer

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Explaining the Motion of the Planets

Following the basic discoveries about the size and distance of the Sun and Moon, the main thread of astronomical research for almost the next 2000 years centered on the motion of the planets. The Sun, Moon, stars, and planets appear to move around the Earth, rising in the east and setting in the west once a day with slight differences in timing. The earliest models placed the Earth at the center of the Universe with all other bodies revolving around it. Descriptions of the Universe of this type are called **geocentric** models.

Figure 2.14 shows an early geocentric model based on the work of the Greek astronomer Eudoxus, who lived about 400–347 B.C. In this model, the celestial bodies all lie on transparent spheres that revolve around the Earth. The bodies that move fastest across the sky are those that are nearest to the Earth. Thus, the Moon, whose path through the stars takes only about 27 days, is nearest to the Earth, whereas Saturn, whose path through the stars takes roughly 29 years, is located the farthest out of the planets known then. By assuming that each body was mounted on its own revolving sphere and by tipping the spheres slightly with respect to one another, Eudoxus was able to explain most of the motions of the heavenly bodies.

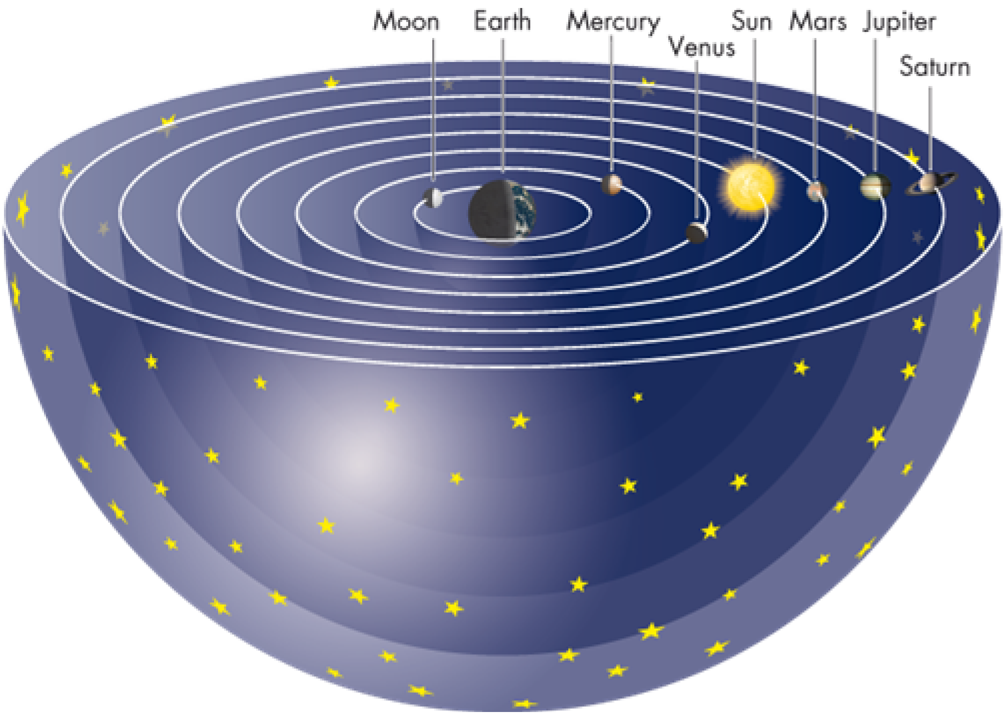

FIGURE 2.14
A cutaway view of the geocentric model of the Solar System according to Eudoxus.

Unfortunately, such a model does not explain retrograde motion, unless one believes that the giant spheres sometimes stop, reverse direction, stop again, and then resume their original motion. This idea is clumsy and unappealing. Eudoxus explained retrograde motion by requiring that each planet moved on *two* interconnected spheres, one inside the other. By adjusting their rotation rates and axes, he was able to get rough agreement with the observed positions of the planets as they shifted across the sky.

Ptolemy

ANIMATION

Ptolemy's model of motion of a planet

By about A.D. 150, the great astronomer of the Roman Empire, Claudius Ptolemy, developed a more elaborate model that could predict the planets’ motions with much better accuracy. Ptolemy lived in Alexandria, Egypt, which at that time was one of the intellectual centers of the world, in part because of its magnificent library. Ptolemy’s era was one of social and political instability for the Roman Empire, which accounts for our uncertainty about the year of his birth or death. We know of him mainly through his great book, the *Almagest*, a compendium of the astronomical knowledge of the ancient Greeks. The book includes tables of star positions and brightnesses and is the source of much of our knowledge of ancient Greek astronomy.

In the *Almagest* Ptolemy fashioned a model of planetary motions in which each planet moved on one small circle, which in turn moved on a larger one (fig. 2.15). The small circle, called an **epicycle**, was supposedly carried along on the large circle like a Frisbee spinning on the rim of a bicycle wheel. Ptolemy probably developed his model of epicycles based on the writings of Hipparchus, who lived about 150 B.C.*

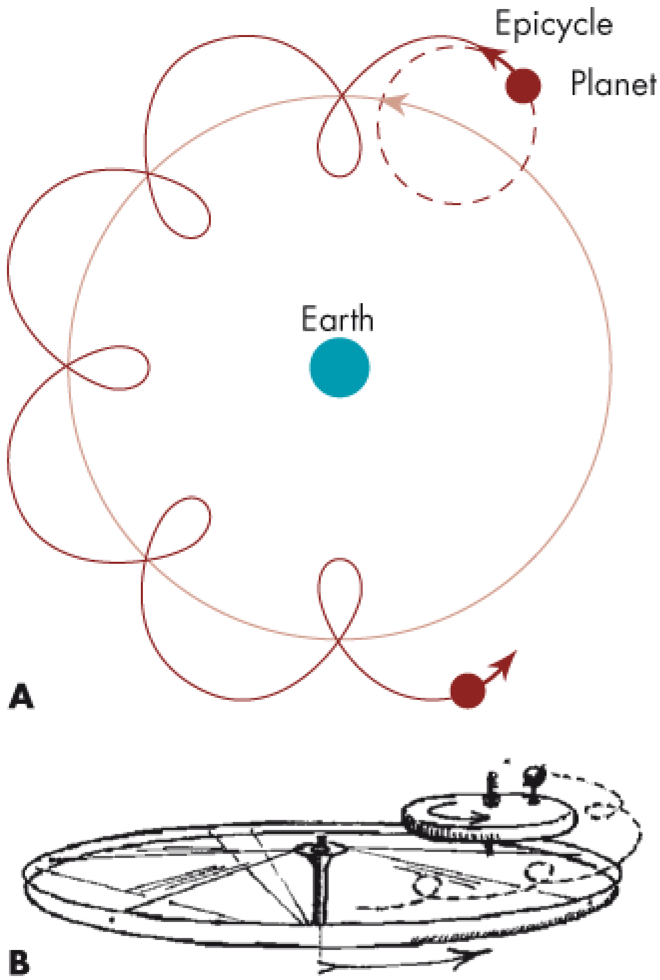

FIGURE 2.15
Epicycles are a bit like a bicycle wheel with a Frisbee bolted onto its rim.

According to Ptolemy's model, the motion of a planet from east to west across the night sky is caused by the rotation of the large circle (the bicycle wheel, in our analogy). Retrograde motion occurs when the epicycle carries the planet in a reverse direction (caused by the rotation of the Frisbee, in our model). By choosing epicycles of the right size and spin rate, Ptolemy's model was able to account for retrograde motion, and predict planetary positions with reasonable accuracy.

Unfortunately, discrepancies remained between the predicted and true positions of the planets. This led to further modifications of the model, each of which led to slightly better agreement but at the cost of adding greater complexity. Ptolemy's model remained dominant until the 1500s, when its inability to make precise predictions despite a steadily growing complexity led astronomers to look for better, simpler models. Simplicity is an important element of scientific theory. As the medieval British philosopher William of Ockham wrote in the 1300s, "Entities must not be unnecessarily multiplied," a principle known as "Ockham's razor."

Islamic Astronomy

A great deal of what we know of Ptolemy, and of Greek and Roman astronomy (and their civilizations more broadly), we owe to the Islamic civilization that flourished around the southern edge of the Mediterranean from about 700 to 1200. Islamic scholars preserved, studied, and expanded upon ancient texts while most of Europe struggled through the Middle Ages.

Islamic civilization, like so many others, relied on celestial phenomena to set its religious calendar, and Islamic astronomers made many detailed studies of the sky and the motions of Sun, Moon, and planets. Islam's influence is very evident in astronomy through Arabic words such as *zenith* and the names of nearly all the bright stars—Betelgeuse, Aldebaran, and so on. In addition, Islamic scholars revolutionized mathematical techniques through innovations such as algebra (another Arabic word) and Arabic numerals.

Asian Astronomy

The early people of Asia, like their contemporaries to the west, studied the heavens. They too devised constellations, but based on their own mythologies, and they too made maps of the sky. Although the ancient astronomers of East Asia did not devise elaborate geometric models of the heavens, their careful observations of celestial events nevertheless prove useful to astronomers even today. For example, Chinese, Japanese, and Korean astronomers kept detailed records of unusual celestial events, such as eclipses, comets, and exploding stars.

Based on their records, Chinese astronomers devised ways to predict eclipses. They even noted dark spots on the Sun (sunspots) that they could occasionally see with the naked eye when the Sun was low in the sky and its glare was dimmed by dust or haze. These records have allowed astronomers to discover ancient patterns of variation in the Sun's behavior. Their records of exploding stars also allow today's astronomers to determine the dates of many of these celestial outbursts.