UNIT 1

This cloud of dust and gas called the Orion Nebula sits 1,500 light-years from Earth. It's part of the constellation Orion and home to hundreds of infant stars, which appear as orange-yellow specks of light.

Courtesy of NASA/JPL-Caltech/T. Megeath, University of Toledo/M. Robberto, STScI

The Space Environment

Unit Chapters

CHAPTER 1

The constellation Orion includes Orion's belt, three stars hanging in the sky from left to right named Alnitak, Alnilam, and Mintaka. These blue stars are larger and hotter than the Sun. The Orion Nebula is the fuzzy bright cloud just "south" of the belt.

The History of Astronomy

> "Philosophy is written in this grand book—I mean the Universe—which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written."
>
> *Galileo*

LESSON 1 Prehistoric and Classical Astronomy

Quick Write

What does Eratosthenes' experience in measuring the Earth tell you about what's needed for scientific discoveries?

Learn About

- the celestial sphere
- the Greek Earth-centered model
- Ptolemy's model

You have perhaps never heard of Eratosthenes (Eh-ra-TAHS-thin-ees) of Cyrene (276–195 BC). But this Greek mathematician and astronomer was the first person to measure the Earth's approximate size. His work was important not only for its results but for its illustration of scientific method.

Eratosthenes was a surveyor working for the Pharaoh, or king of Egypt. He was in charge of the scrolls at the Library of Alexandria, at that time the largest in the world. He had in his collection a map of the Kingdom of Egypt, with distances paced off by his surveyors. By ancient standards, it was quite a collection of data. He was the best mapmaker of his time, and he had invented a system of latitude and longitude.

Scientists don't know much about his life. But his work surely kept him and his staff out and about all over Egypt, measuring, observing, making notes, and asking questions.

Somehow he became aware of an apparently insignificant fact: In the town of Syene (today's Aswan), far up the Nile and well south of Alexandria, there was a remarkable well. When the summer solstice occurred each year, the Sun would rise so high in the sky that at noon, people could see its reflection in the water at the bottom of that well. That meant the Sun was directly overhead.

Not so on Midsummer Day in Alexandria, however. Eratosthenes measured the Sun there and observed that at noon, it was seven degrees off the vertical. He understood that the world was round—a circle, to think in terms of the simplest math for a moment.

The Sun struck Syene and Alexandria differently because they were at different points on that circle. The arc—represented by the distance between the two cities as points on that circle—was seven degrees. (Think of the arc as the outer edge of a slice of pie.) A circle has 360 degrees. So the distance from Syene to Alexandria was a little less than one-fiftieth, or 2 percent, of the whole way around the globe.

Eratosthenes knew the distance between Syene and Alexandria because his surveyors had paced it off. Once he realized that path was nearly 2 percent of the way around the entire globe, all he had to do was multiply that distance by a number a little greater than 50, and—voilà!—he knew the size of the Earth. To give his figures in modern measurements, he calculated its circumference to be about 25,937.5 miles (41,500 km). He also figured its radius to be 4,125 miles (6,600 km). He came amazingly close to the correct value for the Earth's radius of 3,986.25 miles (6,378 km).

Eratosthenes had measured the Earth without even having to leave home. It was an early demonstration of science as we know it.

Vocabulary

- celestial sphere
- north celestial pole
- south celestial pole
- constellation
- ecliptic
- zodiac
- retrograde motion
- parallax
- epicycle

The Celestial Sphere

If you ever get a chance to watch the stars for a few hours at a time—around a campfire, for instance—at almost any middle latitude on Earth, you can see how some stars rise in the east and set in the west, just like the Sun. Stars above the poles move in concentric circles in the sky. The center of these circles is a spot in the sky above the Earth's north and south poles.

This time-exposure photo of the northern sky shows stars making arcs around a single point. Polaris, the North Star, is almost, but not quite, at that point. It appears as a short, bright streak at the top of the image.

Courtesy of NOAO/AURA/NSF

It's also easy to observe that the stars stay in the same patterns every night. It may take only a few minutes of observing one evening after another before you start to recognize the arrangements of stars in the sky.

The ancients observed this, too—and many of them had more time to see and watch than you do. They came up with the idea that the Earth was surrounded by a large sphere that rotated around it (Figure 1.1). The stars were somehow glued to this sphere and moved with it around the Earth.

Today people know that there is no actual sphere with stars glued to it rotating around the Earth. But astronomers still use the term celestial sphere to refer to *an imaginary sphere of heavenly objects that seems to center on the observer.* It's a useful concept for describing and predicting the motions of stars and other objects in the sky. Astronomers speak of the north celestial pole and the south celestial pole as well. These refer to *the points on the celestial sphere directly above Earth's poles*.

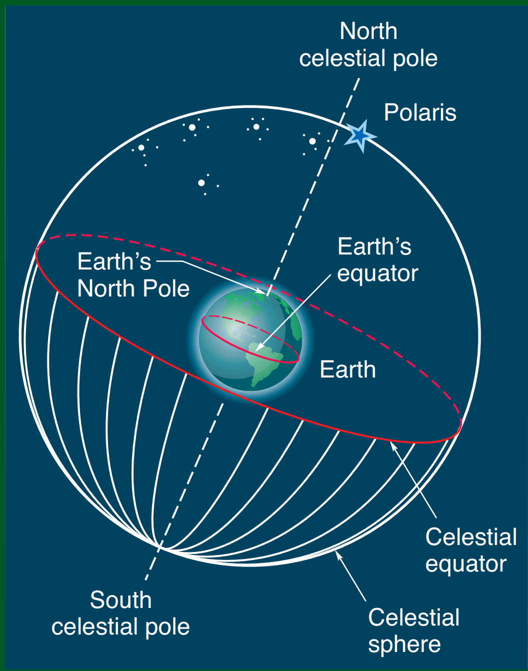

Figure 1.1 Because of their daily motion, heavenly objects appear to be in a sphere surrounding the Earth.

Constellations–Patterns of Stars

A constellation is *an area of the sky containing a group of stars in a pattern.* The search for patterns is very human, and it's very much a part of science, too. The ancients recognized shapes in the night sky and gave them names drawn from their myths.

As early as 2000 BC the Sumerians had identified several constellations, including a bull and a lion. But one of the best-known constellations is Ursa Major—Latin for "great bear" or "big bear." Ancient peoples across North America, Europe, Asia, and Egypt identified this shape as a bear. You may be more familiar with a part of it: the Big Dipper (Figure 1.2).

According to Greek legend, the bear had once been a nymph—a beautiful young goddess—who had attracted the attention of Zeus, father of the gods. His jealous wife changed her into a bear. And then, to protect the bear from hunters, Zeus grabbed her by her unusually long tail and flung her into the sky.

The Sun's Motion Across the Sky

Like the other stars, the Sun seems to revolve around the Earth. Except in the Arctic and Antarctic Circles—where it may not rise or set for several days in winter or summer—the Sun rises in the east and sets in the west. It is much closer than

Constellations become familiar patterns to anyone who watches the sky regularly. But their patterns aren't completely fixed. They're all in motion, with some stars moving toward Earth, others moving away. These pictures show how the Big Dipper continues to change shape over thousands of years.

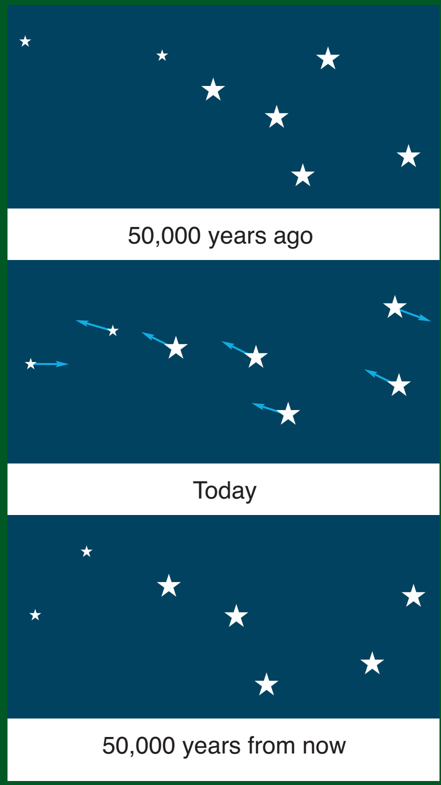

Figure 1.2 How the Big Dipper looked 50,000 years ago, how it looks today, and how it will look 50,000 years in the future: In the center image, the arrows show individual stars' direction of movement.

the other stars, though. And so whereas sunrise and sunset happen every day (even when it's cloudy!), the more distant stars have a much longer cycle (Figure 1.3).

The Sun takes about 365.25 days to revolve around the celestial sphere. This cycle matches the cycle of seasons on Earth and the length of the year. That extra quarter day is the reason for adding an extra day to the calendar in leap years.

The Sun's apparent rotation around the Earth does not follow the Earth's celestial equator. Rather, it swings above and below that imaginary line. The ecliptic is the name for *the Sun's apparent path among the stars around the Earth*. (An eclipse can occur only when the Moon is on or very near this line; more on that later [Figure 1.4].)

The zodiac is *the group of constellations the Sun passes through on its apparent path along the ecliptic*. Long before people had calendars, they learned to "read" the change of season in the stars. The constellations of the zodiac were the stars they looked for.

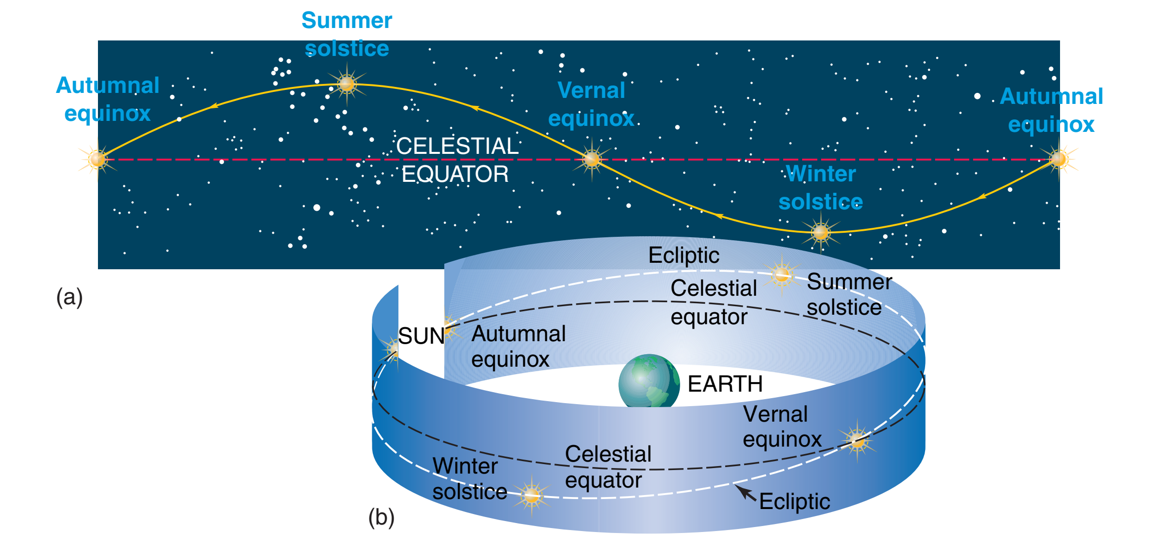

Figure 1.3 These two pictures show how the Sun cycles past the other, more distant stars as seen from Earth.

Solar Eclipses

The Sun rises every day on Earth. But sometimes something gets in the way: the Moon. When the Moon is in just the right position, it can block the view of the Sun from Earth—at least from parts of the Earth. If you are in just the right place, you may experience a total solar eclipse, in which the Sun is blacked out, with only its atmosphere visible. This is one of the world's most spectacular natural phenomena. The reason only some people can view a given total solar eclipse is that the Moon's shadow on Earth is relatively narrow. It may stretch in a thin band that is thousands of kilometers long across the Earth's surface, but it seldom exceeds 250 miles (about 400 km) in width.

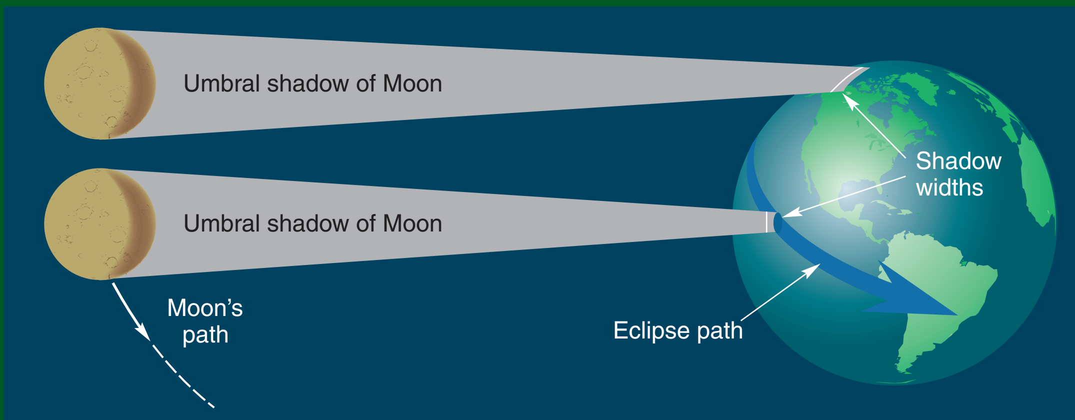

Figure 1.4 This figure shows how the width of the path of an eclipse varies according to the angle of the Earth as the Moon's shadow falls on it.

The Moon's Phases

Unlike the other heavenly objects you've read about so far, the Moon actually does orbit the Earth. Earth's gravity holds the Moon in such a firm grip that it always keeps the same face turned toward the Earth. That is the secret of the Moon's phases (Figure 1.5). The Sun lights the Moon. When the Moon is behind the Earth, it gets a full splash of sunshine and appears as a full moon. When it is between the Earth and the Sun, the Earth-facing part of the Moon gets no light, and so the palest sliver of moonlight is all that's visible on Earth.

The half moons appear when the Moon is at a right angle to the line between the Sun and the Earth. The phases when the Moon appears as a half are actually known as the first and third *quarters*, respectively.

Lunar Eclipses

Earlier in this lesson, you read about how occasionally the Moon blocks the Sun to create a solar eclipse. Sometimes the Earth comes between the Moon and the Sun to create a lunar eclipse.

Don't be tempted to believe an eclipse happens with every full moon. For one thing, the Earth and the Moon are both too small and too far apart for that to happen. The diagrams on page 11 are not all to scale. For an eclipse to happen, you'd need an alignment of Sun, Earth, and Moon that would be like aligning a grapefruit with a ping-pong ball 12 feet away, and then with a third object in the far distance.

The most important factor affecting lunar eclipses is that the Moon orbits the Earth at a tilt relative to the Earth's orbit around the Sun. When the Earth is in certain positions, its shadow cannot fall on the Moon. Lunar eclipses can only occur about twice a year.

Observing Planetary Motion

The planets are another major class of objects in the sky. Five are visible to the naked eye: Mercury, Venus, Mars, Jupiter, and Saturn. *Planet* comes from a Greek word meaning "wanderer." How did they get that name? They were observed in retrograde motion—*backward motion*, in other words. The planets moved eastward for a while, and then would start moving westward, or so it seemed.

Scientists today know that the planets all travel in continuous motion. This would appear counterclockwise if you were hovering over the Solar System from some point near the north celestial pole. Scientists also know that planets move in elliptical, not circular, orbits. And this is the key point: The planets revolve around the Sun, not the Earth. What appears as a loop-the-loop in the movements of Mars, for instance, is the result of the planet being on the same side of the Sun as Earth, and relatively close. Earth moves faster than Mars in its orbit and overtakes Mars, making it look as if Mars is going backward for a time (Figure 1.6).

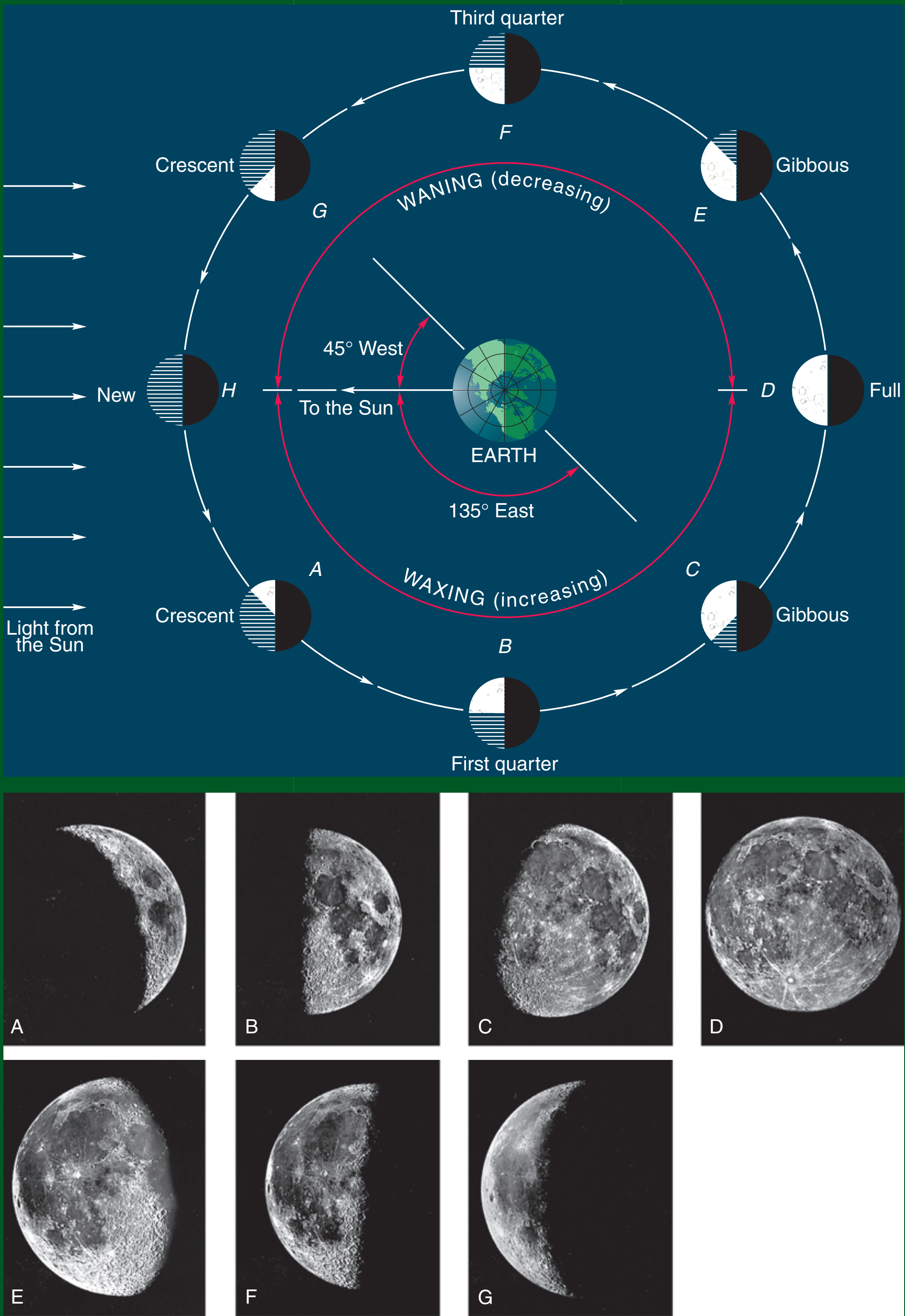

Figure 1.5 This diagram shows how the different positions of the Moon in orbit around the Earth create phases of the Moon. The photos show what the phases look like in the sky. Note the different terms for these phases.

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So it is with the planets farther than Earth from the Sun. They appear at some points to observers on Earth to be changing course. But in reality they are continuing in the same direction—around the Sun, not the Earth. This would be one of the most difficult lessons for astronomers to grasp.

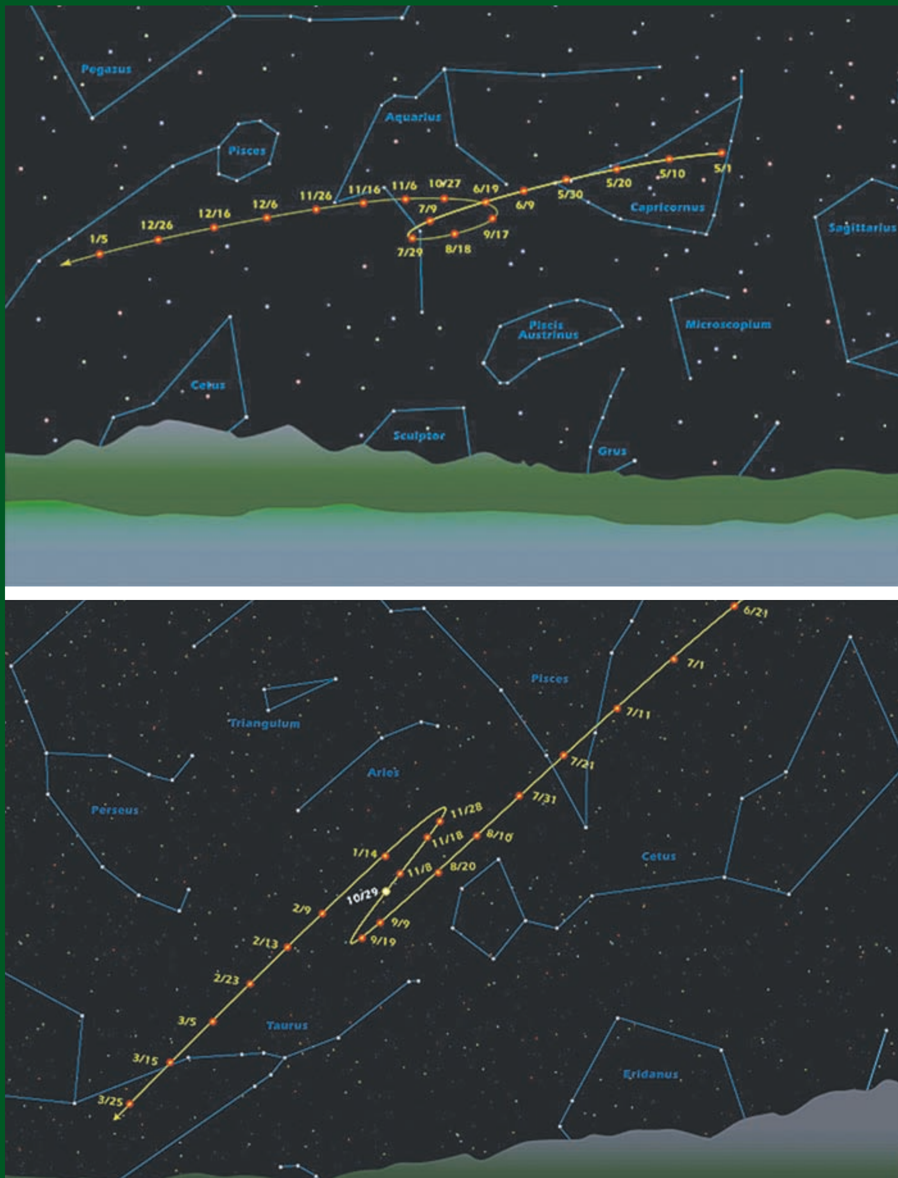

Figure 1.6 This diagram shows the loop Mars seems (to observers on Earth) to make as it orbits the Sun.

Courtesy of NASA/JPL, Caltech

The Greek Earth-Centered Model

As the ancients observed the sky over the centuries, they began to develop models for explaining the relationships among heavenly bodies. Some early scientists put the Sun at the center of the universe. But the Greek models that were most influential over time put the Earth at the center.

The Greek Search for Symmetry, Order, and Unity in the Universe

Many different ancient peoples looked to the heavens for different kinds of answers for their daily lives. The Babylonians looked up to the sky for the meaning behind current affairs on Earth. They read the heavens like a horoscope. The Egyptians thought they could make crop forecasts based on clues from the sky. The Chinese believed events in the sky controlled events on Earth.

But the ancient Greeks studied astronomy out of a pure desire to understand how the universe works. They believed in, and looked for, symmetry, order, and unity in the cosmos.

The Rational Approach to Astronomy: Thales of Miletus and the Pythagoreans' Central 'Fire'

Thales of Miletus, a Greek philosopher, lived about 600 BC. He believed that rational thought could lead to an understanding of the universe. More specifically, he reasoned that the Sun and other stars were not gods but balls of fire.

Around 530 BC, another Greek philosopher and mathematician named Pythagoras (Pith-AG-oh-ras) proposed that the Earth is spherical. Some 80 years later, his followers, known as the Pythagoreans, proposed a spherical universe controlled by a central "fire" whose force controlled all motion. Their idea accounted for the Earth, the Moon, the Sun, the five known planets, and the stars. This was 2,000 years before Nicolaus Copernicus published his revolutionary model of planets revolving around the Sun.

Aristotle's Earth-Centered View of the Solar System

Like the Pythagoreans, the Greek philosopher Aristotle believed that both the Earth and the Moon were spherical. But he rejected the Pythagoreans' ideas about a Sun-centered universe. He placed the Earth at the center of things.

This seems obviously wrong today. But the evidence available at the time supported his view. If the Earth were moving, he argued, people would see changes in the relative positions of the stars in the sky. He was noticing an effect that you have probably experienced while riding down a highway: As you move, you see changes in the relative positions of nearby and distant trees and other objects.

Star POINTS

Aristotle saw some important differences between earthly and heavenly objects. Objects on Earth have a natural tendency to fall down to the ground. Objects up in the heavens remain up in the heavens, he observed. He also noted that earthly objects tend to come to a stop. Heavenly objects keep moving. From Aristotle, the ancient Greeks developed the idea that the natural world had two sets of rules: one for things on Earth and one for celestial objects.

Parallax is *the apparent shifting of nearby objects with respect to distant ones as the position of the observer changes*. Astronomers now know that the parallax phenomenon occurs in the case of stars, too. It's just that the stars are so far from the Earth that the apparent shifts of position are quite tiny. Stellar parallax, as it is known, was not observed until 1838.

Ptolemy's Model

Aristotle was an enormously influential ancient Greek scientist. But the Greek model of the universe that won the widest acceptance was that of Claudius Ptolemy. He lived around AD 150, and for 1,300 years, his model was the conventional wisdom of the scientific world.

Ptolemy's Ideal of Circular Motion and Heavenly Perfection

Ptolemy understood that the celestial sphere was not an actual physical thing on which stars and planets hung. But, like Aristotle, he believed that heavenly bodies were heavenly, celestial, and indeed even perfect, in contrast to earthbound objects. In Ptolemy's view, the universe was based on perfect circles.

The Moon fit perfectly into Ptolemy's model: a single body orbiting another body in (he thought) a perfectly circular orbit. Yes, the Moon had some imperfections, craters, and other scars. But then again, it was at a midpoint between the obviously imperfect Earth and the perfection of the heavens. So followers of Ptolemy thought the Moon's imperfections supported his model.

The Theory of Epicycles

Once Ptolemy set his gaze beyond the Moon, though, his model got more complicated. He managed to explain the planets' motions in terms of circles, all right. But it took lots of them. Specifically, he relied on something called an epicycle.

An epicycle is a kind of small circle. Specifically, it's *the circular orbit of a planet, the center of which revolves around the Earth in another circle*. In Ptolemy's view, a planet revolved in a small orbit around a central point that was part of a perfect circle around the Earth. A planet would buzz around in its epicycle while orbiting the Earth in this larger perfect circle. Epicycles were Ptolemy's way of explaining the retrograde motion of planets (Figure 1.7). For Venus and Mercury, the two planets between the Sun and the Earth, he worked out an even more complicated theory. These two planets are never far from the Sun, and so Ptolemy suggested that the centers of their epicycles remained on a line between the Earth and the Sun (Figure 1.8).

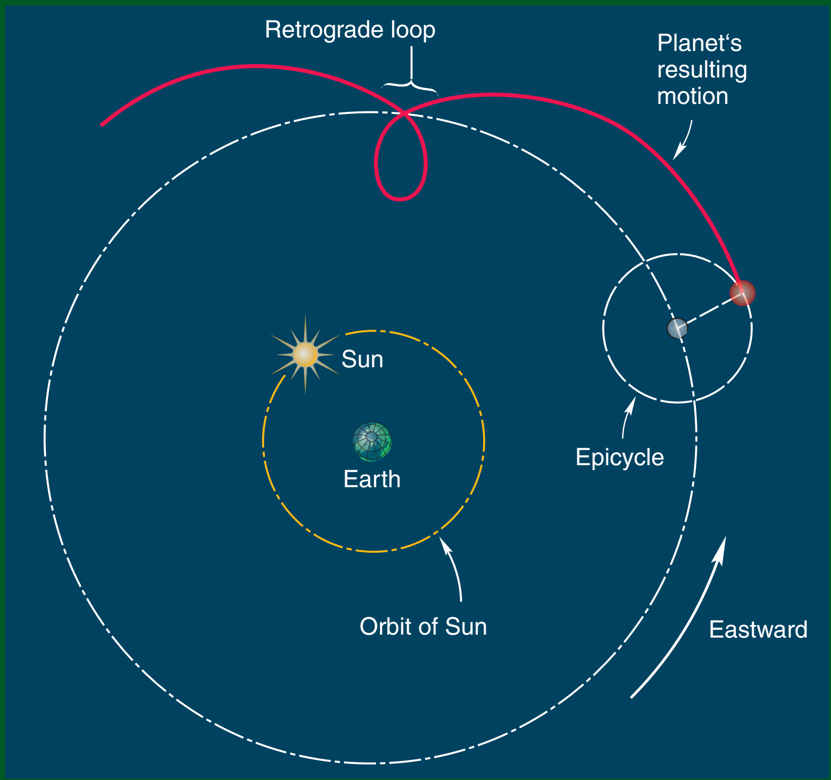

Figure 1.7 Ptolemy explained the retrograde motion of Mars with his idea of epicycles.

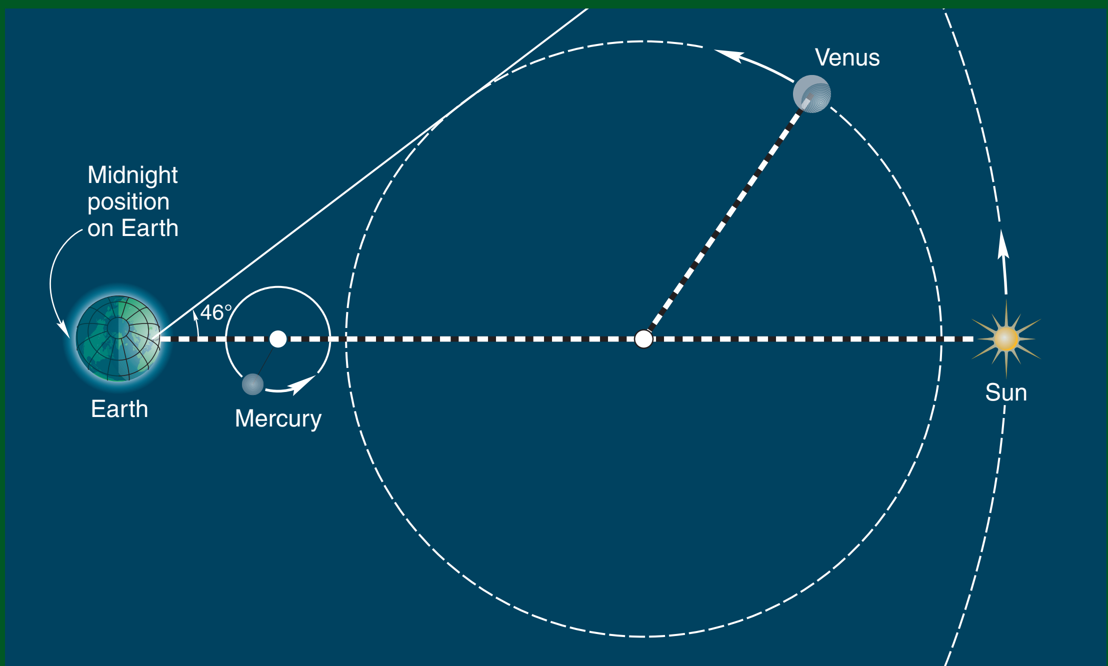

Figure 1.8 Ptolemy figured that the centers of the epicycles for Mercury and Venus were on a straight line between the Earth and the Sun.

Evaluating Ptolemy's Model

Before you leave Ptolemy, take a moment to consider how well his model holds up under modern standards of scientific method.

- Ptolemy's model fits the evidence available during his lifetime pretty well. He offered up a system of perfect circles and epicycles. The epicycles were complicated, but they convincingly explained planetary motion.
- The model includes testable predictions. It could be used to predict that Jupiter, for instance, would be at a particular place in the sky at a particular time on a given date.
- The model also assumed that the Earth was stationary. By stating his ideas this way, Ptolemy was leaving a door open to new facts or new data, in light of which he would be ready to change his idea.
- Science favors simplicity and symmetry. Ptolemy's model, with its reliance on circles and uniform motion from east to west around the Earth, largely embodies these values. But the theory of epicycles was a departure from them, especially once Ptolemy devised the special rule for Venus and Mercury. While Ptolemy's model did fit the data of his time, but in order for it to do so, it had to be continuously adjusted over hundreds of years.

In the next lesson you will read about Nicolaus Copernicus and how he arrived at his very different model of the universe.

CHECK POINTS

Lesson 1 Review

Using complete sentences, answer the following questions on a sheet of paper.

1. How did the human search for patterns lead to the naming of constellations?
2. How did the zodiac help early humans before they had calendars?
3. When do half moons appear?
4. What was it about the planets that made it hard for the ancients to make sense of them?
5. How did the ancient Greeks' interest in studying the skies differ from that of other ancient peoples?
6. What model of the universe did the Pythagoreans present?
7. What is parallax, and why did it take so long to confirm that this phenomenon occurs in the case of stars, too?
8. Why did the Moon fit so well into Ptolemy's model?
9. How did Ptolemy rely on epicycles in his model of the universe?
10. Ptolemy's model assumed the Earth was stationary. What was the significance of that?

APPLYING YOUR LEARNING

11. Why did the Greeks use circles and spheres to account for the motion of the Sun, Moon, planets, and stars?