UNIT FOUR

Exten

Space Shuttle *Discovery* lifts off.

Courtesy of NASA

ding FLIGHT

Unit Chapters

CHAPTER 7

The Andromeda galaxy

Courtesy of Comstock Images

Astronomy and Space

Chapter Outline

"The Congress declares that the general welfare and security of the United States require that adequate provision be made for aeronautical and space activities. The Congress further declares that such activities shall be the responsibility of, and shall be directed by, a civilian agency exercising control over aeronautical and space activities sponsored by the United States."

National Space Act creating NASA, 1958

LESSON 1

The Solar System and Some Early Astronomers

Quick Write

Why did Copernicus take so long to publish his important book?

Learn About...

- **the objects in the solar system**
- **the significant contributions of key early astronomers**

The Polish astronomer Nicolaus Copernicus (1473–1543) loved to study the night sky. He didn't have a fancy telescope. It hadn't been invented yet.

But when it got dark in Copernicus's city of Fromburk, Poland, it got very dark. It was a world before electric light. So he had a wonderful view of the sky. He studied it from the tower of the city's cathedral.

Copernicus went to the tower night after night. Based on what he'd seen, he came up with a theory that would revolutionize astronomy.

In Copernicus's day, people thought the sun and the planets revolved around Earth. They had a geocentric, or *Earth-centered*, view of the solar system. The solar system *is the sun and all the objects in space that circle around it*. According to this theory, the sun and the planets revolve around Earth in circular paths.

Astronomers had believed for centuries that the Earth was the center of the solar system. Their belief originated with astronomers such as Ptolemy, who worked in Egypt in the second century AD.

Belief in a geocentric solar system was even part of church doctrine. At this time there was only one church in Western Europe, the Roman Catholic Church. It had a great deal of political power. Most universities had a church connection, and so, therefore, did most scientists.

NICOLAUS COPERNICUS

Courtesy of Paul Almasv/Corbis

But some ancient astronomers saw a problem with the geocentric theory. As the planets moved across the sky, they generally seemed to move in one direction. But once in a while they seemed to reverse course and go backward.

These astronomers tried to explain the reversal by suggesting that, in addition to their main cycles around Earth, the planets moved in epicycles—*cycles within cycles*.

This explanation didn't totally challenge people's thinking. It left Earth at the center of things. But the idea of epicycles was complex. And it didn't fully explain the planets' movements.

Copernicus decided to defy tradition. He proposed a heliocentric—*sun-centered*—view of the solar system. Like good scientists of today, he then tried to confirm that hypothesis—*an unconfirmed explanation that can be tested for truthfulness*—based on his observations.

COPERNICUS OBSERVED THE SKIES FROM A WINDOW IN THE TOWER ON THE WALL OF THE CATHEDRAL OF FROMBURK (FRAUENBURG), POLAND.
Courtesy of Erich Lessing/Art Resource, NY

Vocabulary

- geocentric
- solar system
- epicycle
- heliocentric
- hypothesis
- revolve
- orbit
- rotate
- galaxy
- gravity
- elliptical
- geosynchronous
- asteroid
- comet
- light-year
- meteoroid
- meteorite
- meteor
- constellation
- observatory
- sunspot

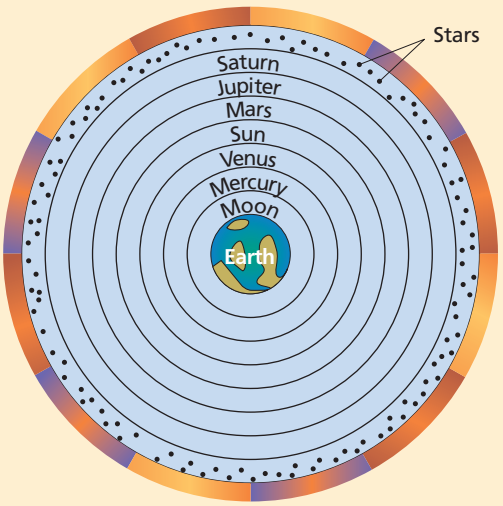


FIGURE 1.1

An early geocentric model

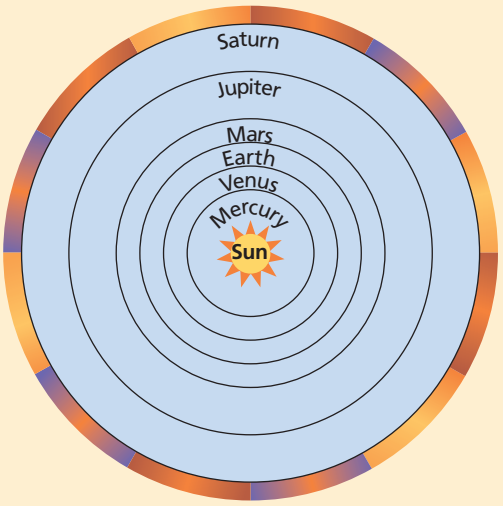


FIGURE 1.2

An early heliocentric model

Although he didn't have a telescope, Copernicus did have other instruments to study the sky. These instruments were better than those that earlier astronomers had. Once he assumed that the solar system was heliocentric, Copernicus found he could easily explain the planets' puzzling motions.

Copernicus had made a great discovery. But it took him a long time to put the word out. He spent years on his great work. He published it in 1593 in Latin, as was the custom of the day. Translated into English, the title is *On the Revolutions of the Celestial Spheres*. He died soon after the book came out.

Why did it take Copernicus so long? Some people say it was because he feared the reactions of church officials. Others say he was just being careful. He wanted to get everything right.

With his new theory, Copernicus set in motion a revolution. He didn't just change the way people thought about the solar system. He changed the way people thought—period.

Today, scientists still respect Copernicus's work. "The Copernican Revolution was a revolution in ideas, a transformation of man's perception of the universe and of his relation to it," wrote historian Thomas S. Kuhn.

The Objects in the Solar System

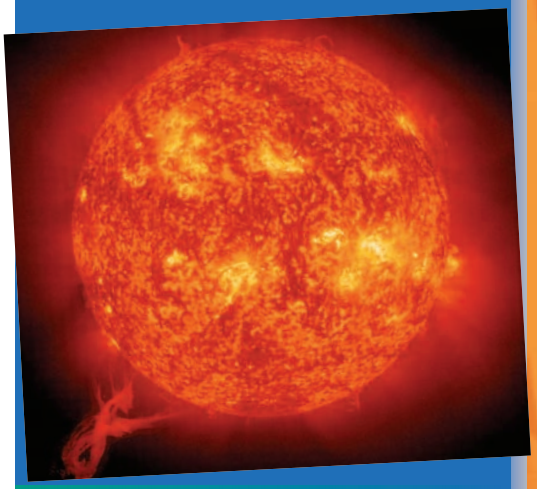
The solar system includes eight planets, their moons, and many other objects.

Each of the planets revolves, or *circles in an orbit*, around the sun. An orbit *is the path of a celestial body as it revolves around another body*. Mercury, the closest planet to the sun, makes a revolution in 88 days; Neptune, the farthest planet out, takes 165 years.

In addition, each planet rotates, or *spins on its axis*. These times vary, too. One Earth day, 24 hours, is the standard by which astronomers measure the other planets' rotation times.

The Sun

The sun is the largest object in the solar system. It contains more than 99.8 percent of the total mass—the "stuff"—of the solar system. It is one of 100 billion stars in the Milky Way Galaxy. A galaxy *is a huge mass of stars, gas, and dust clouds that exists in one area of space*. Based on mass, the sun is in the top 10 percent of all stars in the Milky Way. Our galaxy is one of billions in the universe.



The Sun

Courtesy of NASA

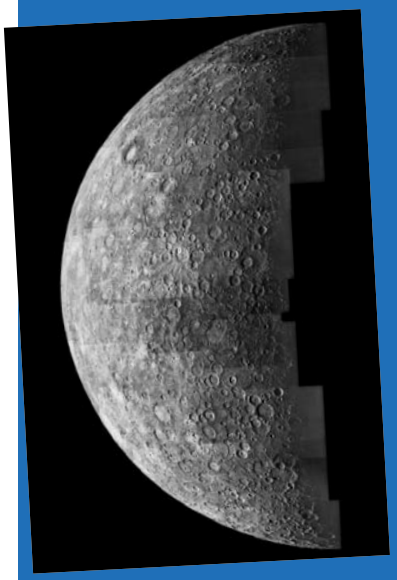
The Planets and Their Key Satellites

Galaxies and the solar system hold together because of gravity. Gravity *is an invisible force that pulls all objects toward one another*. The gravity of the sun holds the planets in place as they revolve around it. Likewise, the gravity of a planet holds its moons in place.

Mercury

Mercury is the smallest planet. It's also the one closest to the sun. It has a rocky, cratered surface. Mercury revolves around the sun every 88 Earth days. Mercury rotates very slowly. It takes 59 Earth days to make a rotation. Mercury has no atmosphere, except for small amounts of helium and hydrogen.

Temperatures on Mercury are extreme: 750 degrees Fahrenheit (F) during the day and 330 degrees F below zero at night. The Mariner 10 spacecraft made flybys in 1974 and 1975 and found pockets of polar ice in deep craters where solar heat cannot melt it.



Mercury

Courtesy of NASA

Venus

Courtesy of NASA

Earth

Courtesy of NASA/Science Source

Venus

At 67 million miles from the sun, Venus is the planet closest to Earth. It's also closest to Earth in terms of size. Its "year"—the time it takes to orbit around the sun—lasts 225 Earth days. Its "day"—the time it takes to make one rotation—is 243 Earth days. It is the only planet to rotate "backwards"—the opposite direction of all the other planets.

Venus is cloaked in a thick layer of clouds made up of water and sulfuric acid.

Scientists think that the sulfuric acid comes from volcanoes on the planet's surface. The volcanic activity, plus the cloud cover, makes Venus the hottest planet in the solar system. Its surface temperature is almost 900 degrees F.

Earth and Its Moon

Earth is the only planet to sustain life as far as we know. Its atmosphere is 78 percent nitrogen and 21 percent oxygen. The remaining 1 percent is argon, carbon dioxide, neon, helium, ozone, and hydrogen. The clouds of Earth's atmosphere help protect the planet from the sun's radiation. More than 70 percent of Earth's surface is covered with water.

Earth makes a complete rotation every 24 hours. It completes an orbit around the sun every 365 $^1/_4$ days.

Earth has one moon. The moon has no atmosphere to protect it. As a result, it has extreme temperatures and a rough surface.

The moon revolves around Earth in an elliptical orbit—*an orbit shaped like an oval, not a circle*. Because of this elliptical orbit, the moon's distance from Earth varies. At its closest, the moon is 221,000 miles from Earth. At its farthest, it is 252,000 miles.

The moon orbits Earth in a little less than 28 days. Both Earth and its moon rotate at about the same rate. That means the moon always has same "face" turned toward Earth. This kind of orbit is known as geosynchronous—*an orbit "in sync" with Earth that takes one day to complete*. From Earth, we can never see the moon's dark side.

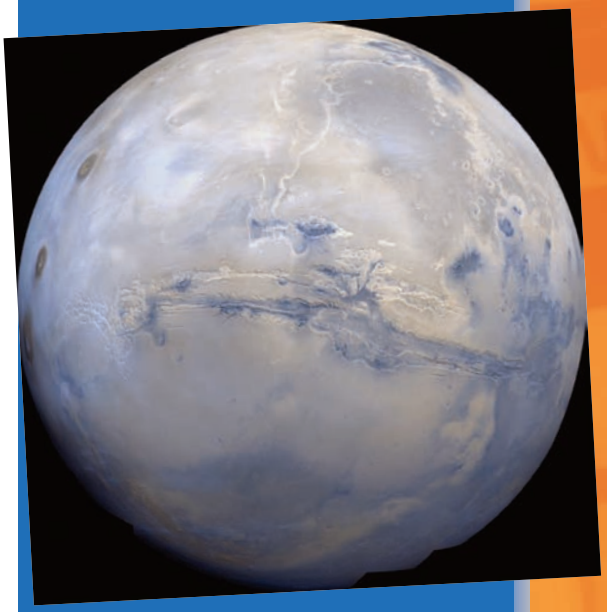
The pull of the moon's gravity creates tides on Earth.

Mars

Mars, the Red Planet, is visible to the naked eye as a reddish dot in the sky. The color comes from the iron that makes up much of the planet's core. The Martian atmosphere is very thin, mostly carbon dioxide. Mars is covered with deserts, mountains, craters, and volcanoes. One mountain on Mars is 17 miles high. That's the highest known mountain in our solar system.

A day on Mars is a little longer than an Earth day: 24 hours, 37 minutes. Mars takes 687 Earth days to orbit the sun.

Mars has two tiny moons, Demos and Phobos. These are Greek words meaning "terror" and "fear." These are fitting companions for this planet, which is named for the ancient god of war.



Mars

Courtesy of NASA

Jupiter

Jupiter is by far the largest planet. It rotates quickly—about once every 10 hours. This speed flattens it at the top and makes it bulge in the middle. Jupiter has windy, stormy weather.

Scientists call the four planets that are closest to the sun "rocky planets" because they are made up mostly of rock. Jupiter is different. It's made up mostly of gases and has no solid surface. For that reason, and because of its size, astronomers call Jupiter a "gas giant."

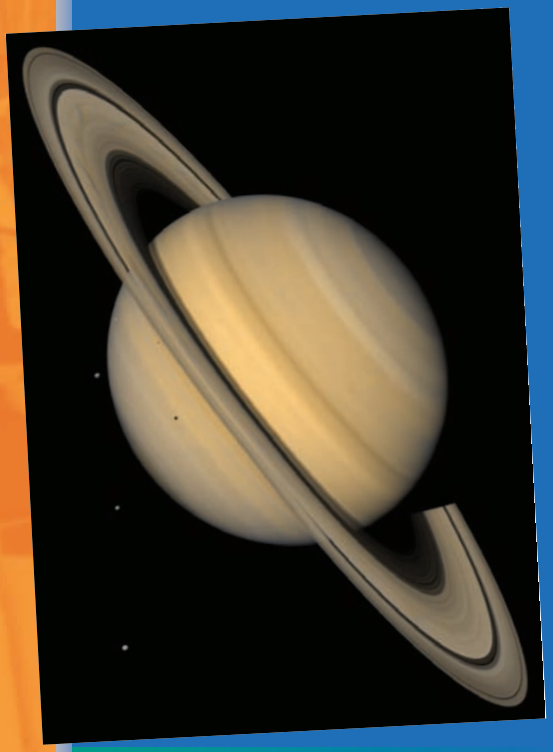
The liquids of Jupiter's outer core mix with the gases in its atmosphere to form swift-moving belts of colorful clouds. One colorful feature of Jupiter is the Great Red Spot. It is a kind of never-ending hurricane 30,000 miles long and 10,000 miles wide.

Jupiter has 16 known moons. The famous astronomer Galileo discovered the four largest—Io, Europa, Ganymede, and Callisto—in 1610.

Jupiter

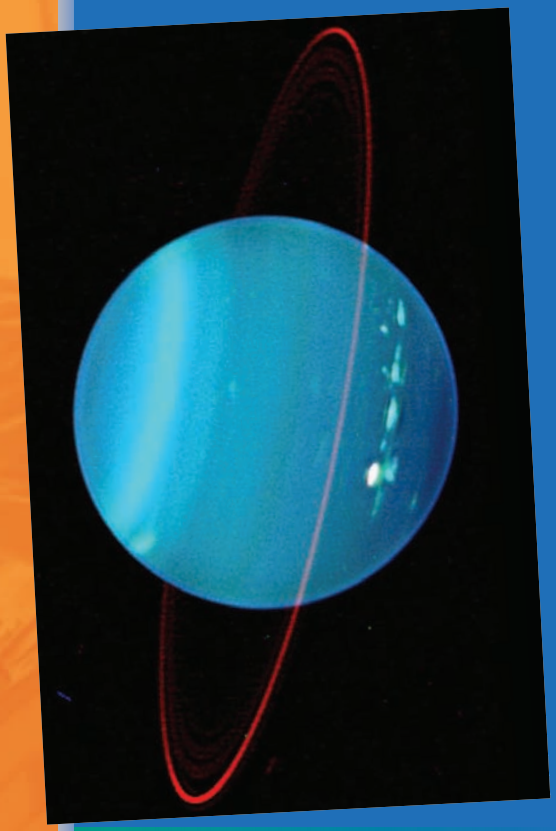
Jupiter, with the Great Red Spot in the lower left quarter

Courtesy of the US Geological Survey/ the US Department of the Interior



Saturn

Courtesy of NASA



Uranus

Courtesy of California Association for Research in Astronomy/Photo Researchers, Inc.

Saturn

The second-largest planet in the solar system, Saturn is called the "ringed planet." Its seven rings are made of icy chunks of rocks. The rings extend about 250,000 miles out from the planet.

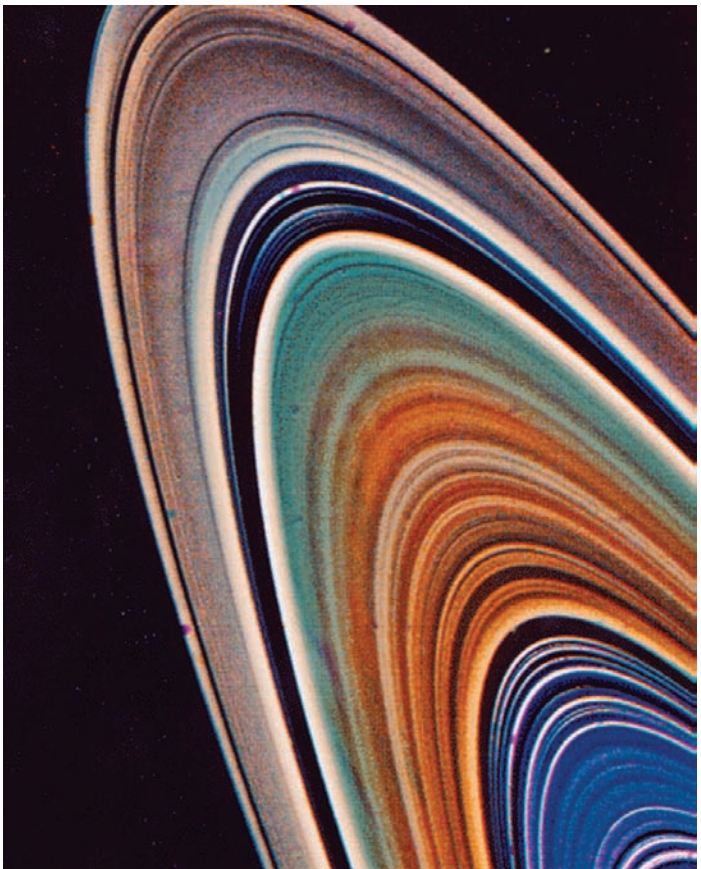
The rings have fascinated people for centuries. Galileo discovered five of them in 1610. The Pioneer spacecraft discovered the other two in the 1970s.

Like Jupiter, Saturn is a gas giant. It rotates quickly. It has stormy weather and 18 known moons. One of these, Titan, is the only moon in the solar system known to have its own atmosphere.

Uranus

Uranus, the third-largest planet, is another gas giant. Its main claim to fame is that it spins on its side. Scientists think that a long time ago, it may have collided with some other body that tilted it. Space probes of the 1970s discovered rings around Uranus. But they aren't as impressive as Saturn's. Uranus has 15 known moons.

The icy rings of Saturn



Courtesy of NASA

Neptune

Neptune is Uranus's smaller twin. Astronomers discovered it in 1846, after noticing that some body was exerting a gravitational tug on Uranus. Neptune is the windiest planet in the solar system. Its winds blow up to 1,500 miles an hour. Like Jupiter, it has several dark storms, the largest of which is the Great Dark Spot.

Neptune has eight moons. The largest is Triton. About three-fourths the size of Earth's moon, Triton zips around Neptune in just 5.9 days.

Pluto and the Dwarf Planets

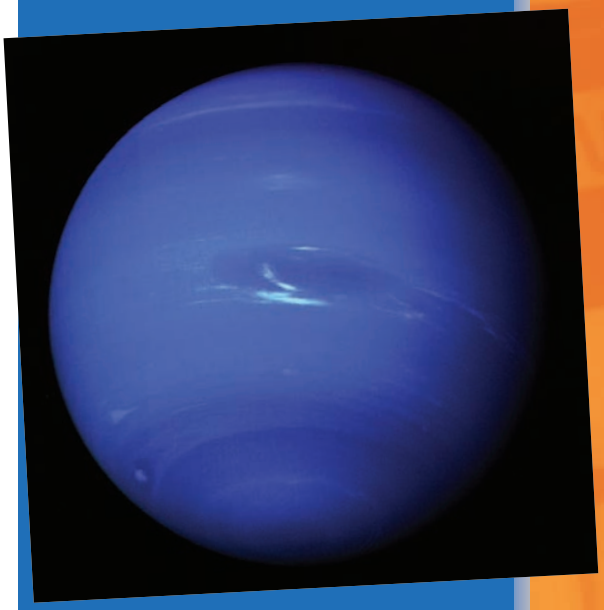
Pluto is unique for many reasons. It's very small and very far away. It's also unique because its career as a planet had a clearly marked beginning—and end.

Clyde W. Tombaugh discovered Pluto on 18 February 1930. He was a 24-year-old astronomer at the Lowell Observatory in Arizona. For seven months he searched for something he knew had to be there: a heavenly body that tugged on Neptune, just as Neptune tugged on Uranus.

Finally he found it. It was named Pluto and declared the ninth planet.

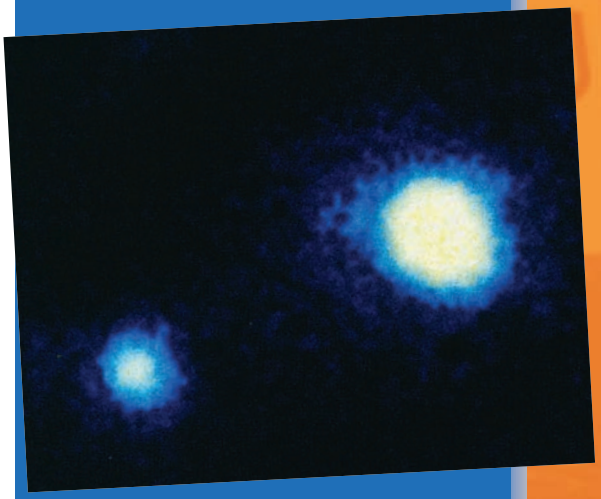
But on 24 August 2006 the International Astronomical Union voted to reclassify Pluto as a "dwarf planet." In making this decision, astronomers defined for the first time what it takes to qualify as a planet. Pluto didn't make the cut. It doesn't dominate its moon, Charon, as a planet should. Besides, Pluto's orbit is not fixed. Sometimes it loops inside Neptune's.

As a dwarf planet, Pluto has lots of company. Scientists have identified more than 40 dwarfs and they expect to find more. Beyond Pluto lies the Edgeworth-Kuiper Belt of "ice dwarfs" or minor planets.



Neptune

Courtesy of NASA



Pluto and Charon

Courtesy of NASA

The Asteroids

An asteroid *is a rocky and metallic object orbiting the sun*. Most asteroids are in a belt that lies between Mars and Jupiter. Astronomers have found and catalogued more than 15,000 asteroids.

Some asteroids are no bigger than pebbles. The largest asteroid is Ceres. It has a diameter of 623 miles.

Key Comets, the Edgeworth-Kuiper Belt, and the Oort Cloud

Comets

A comet *is a small, odd-shaped body with a center of ice, rock, and frozen gas*. Comets have elliptical orbits. They draw close to the sun and then fly far out into space.

A comet has a head made up of dust and gas wrapped around a nucleus, or center, of ice and rock. As a comet nears the sun, it forms a tail. Some of these tails are 100 million miles long.

Some people call comets "dirty snowballs," because they are made up largely of ice. After enough trips to the sun, the ice melts, and a comet becomes just another rocky object in space. By the standards of outer space, comets have short lives.

Halley's is one of the best-known comets. It makes a complete revolution of the sun every 76 years. It last swung by the inner solar system in 1986. Hale-Bopp, another well-known comet, was last visible from Earth in 1997. Swift-Tuttle and Hyakutake are two other well-known comets.

The Edgeworth-Kuiper Belt

The Edgeworth-Kuiper Belt is a vast region extending beyond Neptune. Scientists think there are millions of small, rocky or icy objects orbiting there. Pluto and Charon may be part of the belt. NASA hopes to visit this region around 2010 with its Pluto-Kuiper Express. The goal of this mission is to learn more about Pluto, Charon, and the outer reaches of our solar system.

The Oort Cloud

The Oort Cloud is an immense spherical cloud. It surrounds the solar system and reaches about three light-years from the sun. A light-year *is the distance light travels in a year*. Astronomers think this distance is the outer limit of the sun's gravitational influence.

About a trillion icy objects are in the outer region of the Oort Cloud. Another five trillion are thought to be in the core. The estimated mass of the cloud is 40 times that of Earth.

Meteoroids, Meteorites, and Meteors

A meteoroid *is a piece of rock or metal that travels in space*. Meteoroids are the smallest objects in the solar system. The smallest bits, dust particles, are called micrometeorites.

No one is sure where meteoroids come from. They may be chunks of rock melting away from comets as they approach the sun.

Some meteoroids orbit the sun, and some enter Earth's atmosphere. When they enter Earth's atmosphere, they usually burn up right away. But some land on Earth. A meteorite *is a meteoroid that lands on Earth's surface*. A meteor *is a meteoroid passing through Earth's atmosphere, leaving a visible trail*. Other terms for meteors are shooting stars or falling stars.

The Significant Contributions of Key Early Astronomers

The history of astronomy is the story of humanity's attempts to make sense of the heavens. All peoples have looked up to the skies and wondered about the movements of the sun, moon, and stars. People of many cultures have thought their gods live in the skies. For some, the skies were places where humans could never go.

But as time passed, people began to see the stars and planets as ordinary physical objects. People learned that heavenly bodies obey the same laws that objects on Earth do. This idea began in the Middle East and spread to other cultures.

The Contributions of Ptolemy

The names of many of the first astronomers are no longer known. These astronomers lived in Egypt, Mexico, and what is now Iraq.

The earliest widely known astronomer is Claudius Ptolemy, often known as Ptolemy of Alexandria. He was a Roman citizen of Greek background. Alexandria was a center of learning in Egypt. Ptolemy lived from around AD 85 until AD 165.

Ptolemy is known not for his own work but for the way he combined other astronomers' ideas. The system he came up with, called the Ptolemaic system, put Earth at the center of the universe. Copernicus, as you read earlier, would later show that system to be wrong. But it made sense to the best minds of Ptolemy's day.

Ptolemy was the first astronomer to make scientific maps of the heavens. He also developed a catalog listing 48 constellations. A constellation *is a group of stars people think of as forming a picture in the sky*. Scientists still use this catalog.

PTOLEMY OF ALEXANDRIA

Courtesy of Dr. Jeremy Burgess/ Photo Researchers, Inc.

Ulug Bek: Astronomer of the East

Ulug Bek (1393–1449) was born in what is now Iran. His grandfather was Timur, or Tamerlane, one of the great Mongol conquerors. Timur ruled a territory that included the modern countries of Iran, Iraq, and eastern Turkey. His warriors, riding on horseback and armed with bows and arrows, thundered across much of Asia.

Ulug Bek's father, Shah Rukh, was the youngest of Timur's four sons. He succeeded his father as emperor. His capital was Herat, in today's Afghanistan. Shah Rukh turned over the city of Samarkand, in Uzbekistan, to Ulug Bek when the boy was only 16.

Ulug Bek's greatest desire was to make Samarkand a center of culture and learning. He was an astronomer and a mathematician. He also wrote poetry and history. He studied the Koran, the book of sacred writings of people of the Muslim faith.

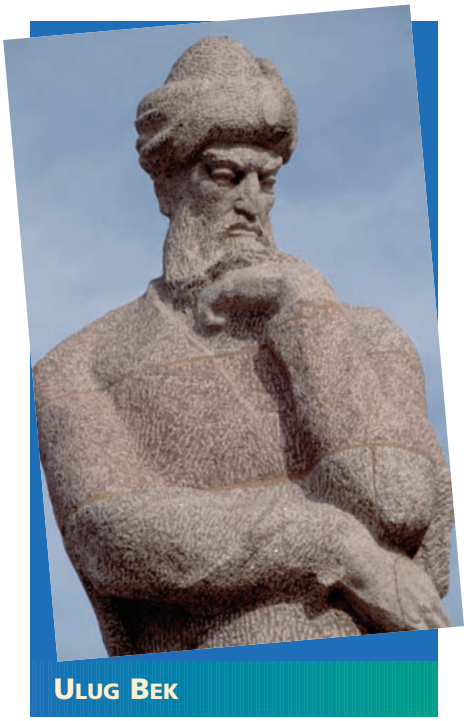
To promote the study of astronomy, Ulug Bek built a madrassah, a center for higher education. He recruited the best scientists he could find to teach there.

Ulug Bek was most famous for the observatory he built in Samarkand in 1428. There he could study the skies and observe the stars and planets.

His observatory was the best in the world at that time. It helped make Samarkand an influential scientific center.

Architect, artist, scholar, scientist, and astronomer, Ulug Bek was a man of many talents. Some Americans compare him to Thomas Jefferson.

The central square of Samarkand
Courtesy of Orban Thierry/Corbis Sygma



ULUG BEK

Courtesy of K.M. Westermann/Corbis

The Contributions of Ulug Bek

Ulug Bek was a mathematician and an astronomer. He had an observatory, or *a building designed to observe the stars*, in what is today Uzbekistan. He made detailed observations and calculations. He set a new standard for scientific work.

In 1437 Ulug Bek published a catalog of the stars (*Zij-i Sultani*). It gave the positions of 992 stars. It was the first major catalog of stars since Ptolemy's.

Ulug Bek also discovered several errors in Ptolemy's calculations. No one had ever before questioned Ptolemy's work. Using data he'd recorded in his observatory, Ulug Bek calculated the length of the year as 365 days, 5 hours, 49 minutes, and 15 seconds. He also produced data for the movements of the sun, the moon, and the planets.

These numbers were very accurate, even by today's standards. Some of his estimates were off by less than five seconds.

The Contributions of Copernicus

Copernicus wasn't the first astronomer to think Earth might revolve around the sun.

A Greek astronomer named Aristarchus (320–250 BC) gets that honor. He thought the sun was bigger than Earth, and that a smaller body would revolve around a larger one. He was right, but had no instruments to help him gather the data to prove it.

And although Copernicus didn't have a telescope, he did have access to records of the observations made over centuries, beginning with the ancient Greeks. He combined his study of those records with his own observations to come up with his own ideas.

Although he never explained what inspired him to propose a heliocentric solar system, one thing is sure: he wasn't trying to stir up a revolution.

But the Ptolemaic system, with its cycles and epicycles, was complicated. To a true scientist, it also seemed messy. The motions of each planet were independent. In his book Copernicus compared the Ptolemaic system to a monster made up of spare parts, with a head from here, feet from there, and the arms from somewhere else.

The Copernican system had fewer circles. It also had a unity and a logic that the Ptolemaic system lacked.

Nicolaus Copernicus: The Monk Who Reordered the Heavens

Nicolaus Copernicus (1473–1543) was born in Torun, Poland. He was a Renaissance man. That means he was interested in both science and art, and was able to do many things well.

His parents died when Nicolaus was young. But his mother's brother was a church official. Through this uncle, Nicolaus won a position in the church.

For many years he served at the cathedral in Fromburk, Poland. This city, also called Frauenburg, is on the Baltic Sea, not far from Russia.

But before coming to the cathedral, Copernicus traveled widely. He studied mathematics and optics in Krakow. He studied church law and medicine in Italy, where learned about astronomy.

He moved in privileged circles. But he always remained a student.

Johannes Kepler: Pioneer of the Scientific Method

Johannes Kepler (1571–1630) was born in southern Germany. He was a sickly child of a poor family. But he was also bright. He won a scholarship to the University of Tübingen. He was supposed to study for the ministry. Instead he learned about Copernicus's new theory of the solar system. It fascinated him. He became a champion of the new thinking.

It was a time of religious upheaval between the Protestants (Lutherans) and the Catholics. Kepler got caught up in the debate. He had to move from place to place because he was Lutheran. He finally moved to Czechoslovakia.

There, in the city of Prague, he worked with Tycho Brahe. Tycho was a well-known Danish astronomer who was mathematician to Emperor Rudolf II. When Tycho died in 1601, Kepler took over his job.

Using Tycho's data, Kepler discovered that Mars had an elliptical orbit. That led him to other discoveries about the planets. In 1609 he shared his findings in a book called *Astronomia Nova*, which means "New Astronomy" in Latin.

Kepler's discoveries were important on two levels. First, it was important to astronomy to understand how Mars orbits the sun. But Kepler was also one of the first to use the modern scientific method. He made observations, collected and analyzed data, and then drew accurate conclusions, so his work was also important to the overall advancement of science.

JOHANNES KEPLER

Courtesy of The Granger Collection, New York

The Contributions of Kepler

Copernicus put the sun at the center of the solar system. But he still thought that the planets' orbits were perfect circles. Even in the Renaissance, people had an idea of celestial, or heavenly, perfection.

Johannes Kepler studied the work of Copernicus in Germany late in the 16th century. As a young professor, he wrote the first outspoken defense of the Copernican system in 1596.

But Kepler also improved on the Copernican theory. He showed that orbits of the planets weren't perfect circles, but ellipses, or ovals. He also formulated three laws of planetary motion that astronomers still use today.

The Contributions of Galileo

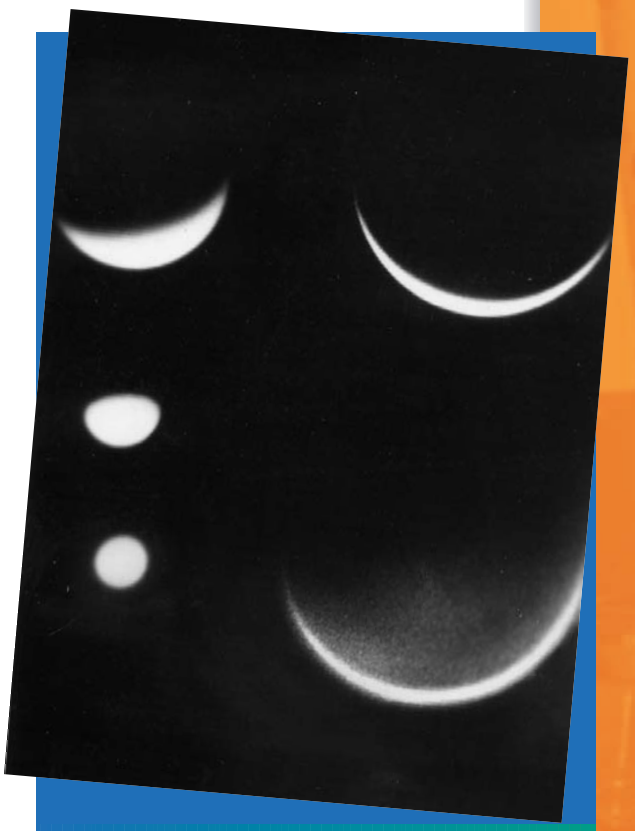
Galileo didn't invent the telescope. It was probably invented in the Netherlands in the early 1600s. But Galileo was among the first to appreciate the importance of this device. He read about the Dutch telescopes and soon started building his own.

Galileo was also the first to use the telescope to methodically observe the sky. He was the first to see the moon's craters. He risked blindness by looking straight into the sun to observe sunspots, or *the relatively cool dark spots that sometimes appear on the surface of the sun*.

Galileo also turned his telescope on Venus. He saw that it goes through phases, just as Earth's moon does. He spotted four "stars" near Jupiter and decided they were moons that circled that planet.

For Galileo, this was further confirmation that Copernicus's view of the solar system was correct. Galileo became an advocate of the Copernican view.

In a famous trial in 1633 the Catholic Church condemned Galileo for taking this position. In 1992, however, Pope John Paul II determined the church had acted "imprudently" in opposing Galileo.



VENUS'S PHASES

Through his telescope, Galileo saw that Venus has phases.

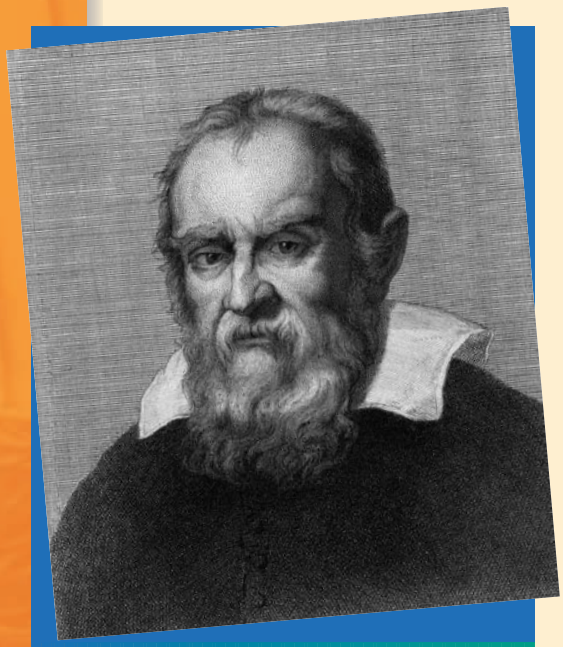
Courtesy of the Lowell Observatory

Galileo Galilei: The Father of Science Was Wrong About Tides

Galileo Galilei (1564–1642) made enormous contributions to mathematics, physics, and astronomy. People have called him the "father of the telescope," the "father of modern astronomy," and even the "father of modern science."

But he was wrong about what causes the tides in the ocean.

Galileo had a theory about tides that he pushed for years. During boat rides around Venice, he noticed that water inside the boat sloshed around as the boat changed direction. If the boat hit a sandbar and stopped, the water inside would slosh forward and then move back. Sometimes this happened several times before the water came to a stop. This action was the result of the water's momentum.



GALILEO GALILEI

Courtesy of Bettmann/Corbis

Galileo thought something similar happened to the water in the oceans as Earth rotated. He thought Earth's rotation created tides.

Now we know that the pull of the moon's gravity causes the tides. Kepler understood this. But until Sir Isaac Newton explained gravity in 1687, the moon theory of tides didn't win wide acceptance. That was years after Galileo's death.

Galileo's "big mistake" is instructive. It shows that even someone known as "the father of modern science" can make a mistake.

CHECKPOINTS

Lesson 1 Review

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

1. What part of planetary movement in the sky did Ptolemy's theory fail to explain well?
2. Where does the sun rank among stars in the Milky Way galaxy?
3. What causes Jupiter's colorful clouds?
4. Explain the start and finish of Pluto's career as a planet.
5. How did Ulug Bek improve on Ptolemy's work?
6. How is Kepler's work a good example of the scientific method?
7. How did Kepler improve on Copernicus's findings?
8. What did Galileo discover about Venus?
9. What did Galileo see about Jupiter that confirmed Copernicus's findings?

Applying Your Learning

10. How was Galileo wrong about tides, and what lessons can you draw from this?