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Mr. Kaddatz The Solar System

Bethel

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Chapter 1

The Solar System

1.1 Introduction to the Solar System

Lesson Objectives

- Describe historical views of the solar system.
- Name the planets, and describe their motion around the sun.
- Explain how the solar system formed.

Changing Views of the Solar System

People have not always known about all the objects in our solar system. The ancient Greeks were aware of five of the planets. They did not know what these objects were; they just noticed that they moved differently than the stars did. They seemed to wander around in the sky, changing their position against the background of stars. In fact, the word "planet" comes from a Greek word meaning "wanderer." They named these objects after gods from their mythology. The names we use now for the planets are the Roman equivalents of these Greek names: Mercury, Venus, Mars, Jupiter, and Saturn.

The Geocentric Universe

The ancient Greeks believed that Earth was at the center of the universe, as shown in **Figure** 1.1. This view is called the **geocentric model** of the universe. *Geocentric* means "Earth-centered." The geocentric model also described the sky, or *heavens,* as having a set of spheres layered on top of one another. Each object in the sky was attached to one of these spheres, and moved around Earth as that sphere rotated. From Earth outward, these spheres contained the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and an outer sphere which contained all the stars. The planets appear to move much faster than the stars and so the Greeks placed them closer to Earth.

Today, powerful telescopes can actually see the surfaces of planets in our solar system. Even though the closest stars have diameters that are hundreds of times larger than the Earth, the distant stars appear as tiny dots that cannot be resolved.

The geocentric model may seem strange to us now, but at the time, it worked quite well. It explained why all the stars appear to rotate around Earth once per day. It also explained why the planets move differently from the stars, and from each other. One problem with the geocentric model was resolved around 150 A.D.

Figure 1.1: Model of a geocentric universe. This diagram of the universe from the Middle Ages shows Earth at the center, with the Moon, the Sun, and the planets orbiting Earth.

by the astronomer Ptolemy. At times, some planets seemed to move backwards (in retrograde) instead of in their usual forward motion around the Earth. Ptolemy resolved this problem by using a system of circles to describe the motion of planets (**Figure** 1.2). In Ptolemy's system, a planet moved in a small circle, called an *epicycle.* This circle in turn moved around Earth in a larger circle, called a *deferent.* Ptolemy's version of the geocentric model worked so well that it remained the accepted model of the universe for more than a thousand years.

The Heliocentric Universe

Ptolemy's geocentric model worked pretty well, but it was complicated and occasionally made errors in predicting the movement of planets. At the beginning of the 16th century A.D., Nicolaus Copernicus proposed a different model in which Earth and all the other planets orbited the Sun. Because this model put the Sun at the center, it is called the **heliocentric model** of the universe. *Heliocentric* means "sun-centered." **Figure** 1.3 shows the heliocentric model compared to the geocentric model. Copernicus' model explained the motion of the planets about as well as Ptolemy's model, but it did not require complicated additions like epicycles and deferents.

Although Copernicus' model worked more simply than Ptolemy's, it still did not perfectly describe the motion of the planets. The problem was that, like Ptolemy, Copernicus still thought planets moved in perfect circles. Not long after Copernicus, Johannes Kepler refined the heliocentric model. He proposed that planets move around the Sun in ellipses (ovals), not circles. This model matched observations perfectly.

Because people were so used to thinking of Earth at the center of the universe, the heliocentric model was not widely accepted at first. However, when Galileo Galilei first turned a telescope to the heavens in 1610, he made several striking discoveries. He found that the planet Jupiter has moons orbiting around

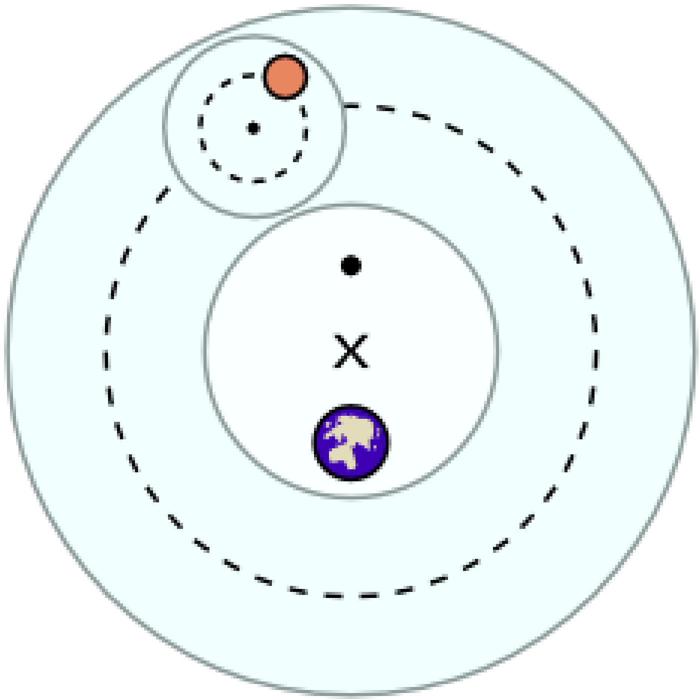

Figure 1.2: Diagram of an epicycle and deferent. According to Ptolemy, a planet moves on a small circle that in turn moves on a larger circle around Earth.

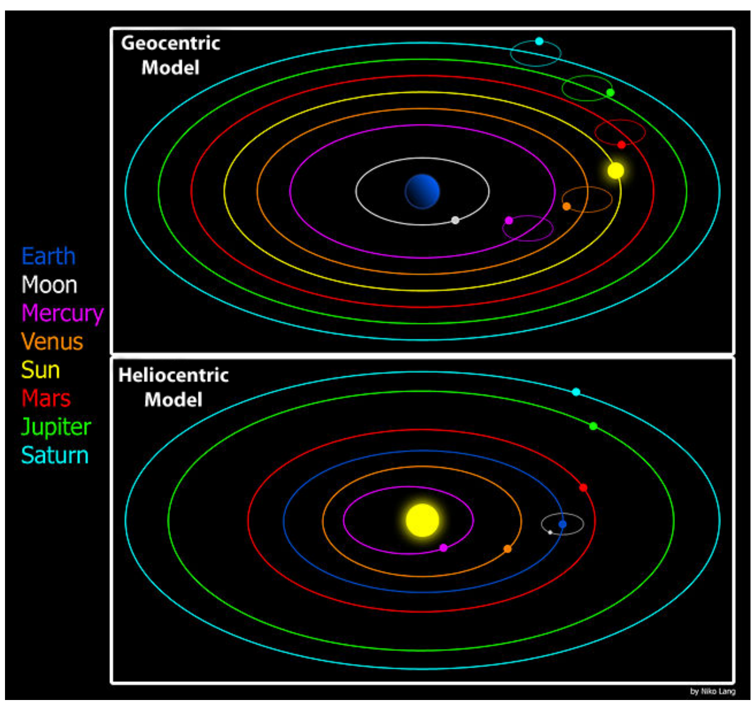

Figure 1.3: Unlike the geocentric model (top image), the heliocentric model (lower image), had the Sun at the center, and did not require epicycles.

it. This was the first evidence that objects could orbit something besides Earth. He also discovered that Venus has phases like our moon does. The phases of Venus provided direct evidence that Venus orbits the Sun. Galileo's discoveries caused many more people to accept the heliocentric model of the universe. The shift from an Earth-centered view to a Sun-centered view of the universe is referred to as the *Copernican Revolution.*

The Modern Solar System

Today, we know that our solar system is just one tiny part of the universe as a whole. Neither Earth nor the Sun are at the center of the universe —in fact, the universe has no true center. However, the heliocentric model does accurately describe our solar system. In our modern view of the solar system, the Sun is at the center, and planets move in elliptical orbits around the Sun. The planets do not emit their own light, but instead reflect light from the Sun.

Extrasolar Planets or Exoplanets

Since the early 1990s, astronomers have discovered other solar systems, with planets orbiting stars other than our own Sun (called "extrasolar planets" or simply "exoplanets"). Although a handful of exoplanets have now been directly imaged, the vast majority have been discovered by indirect methods. One technique involves detecting the very slight motion of a star periodically moving toward and away from us along our line-of-sight (also known as a star's "radial velocity"). This periodic motion can be attributed to the gravitational pull of a planet (or, sometimes, another star) orbiting the star. Another technique involves measuring a star's brightness over time. A temporary, periodic decrease in light emitted from a star can occur when a planet crosses in front of (or "transits") the star it is orbiting, momentarily blocking out some of the starlight. As of February 2010, over 420 exoplanets have been confirmed with more being discovered at an ever-increasing rate.

Planets and Their Motions

Since the time of Copernicus, Kepler, and Galileo, we have learned a lot more about our solar system. We have discovered two more planets (Uranus and Neptune), four dwarf planets (Ceres, Makemake, Pluto and Eris), over 150 moons, and many, many asteroids and other small objects.

Figure 4 shows the Sun and the major objects that orbit the Sun. There are eight planets. From the Sun outward, they are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The Sun is just an average star compared to other stars, but it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! **Table** 1.1 gives more exact data on the sizes of the sun and planets relative to Earth.

Table 1.1: **Sizes of Solar System Objects Relative to Earth**

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth masses	109.2 Earth diameters
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth mass	1.00 Earth diameter
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth masses	11.21 Earth diameters

Table 1.1: (continued)

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Saturn	95.2 Earth masses	9.41 Earth diameters
Uranus	14.6 Earth masses	3.98 Earth diameters
Neptune	17.2 Earth masses	3.81 Earth diameters

What Is (and Isn't) a Planet?

So what exactly is a planet? Simply put, a **planet** is a massive, round body orbiting a star. For our solar system, this star is the Sun. A **moon** is an object that orbits a planet.

"Isn't Pluto a planet?" you may wonder. When it was discovered in 1930, Pluto was considered a ninth planet. When we first saw Pluto, our telescopes actually saw Pluto and its moon, Charon as one much larger object. With better telescopes, we realized that Pluto had a moon and Pluto was much smaller than we thought! With the discovery of many objects like Pluto, and one of them, Eris, even larger than Pluto, in 2006, astronomers refined the definition of a planet. According to the new definition, a planet must:

- orbit a star
- be big enough that its own gravity causes it to be shaped like a sphere
- be small enough that it isn't a star itself
- have cleared the area of its orbit of smaller objects

Objects that meet the first three criteria but not the fourth are called **dwarf planets**. Most astronomers now consider Pluto to be a dwarf planet, along with the objects Ceres and Eris. Even before astronomers decided to change the definition of a planet, there were many aspects of Pluto that did not fit with the other planets in our solar system.

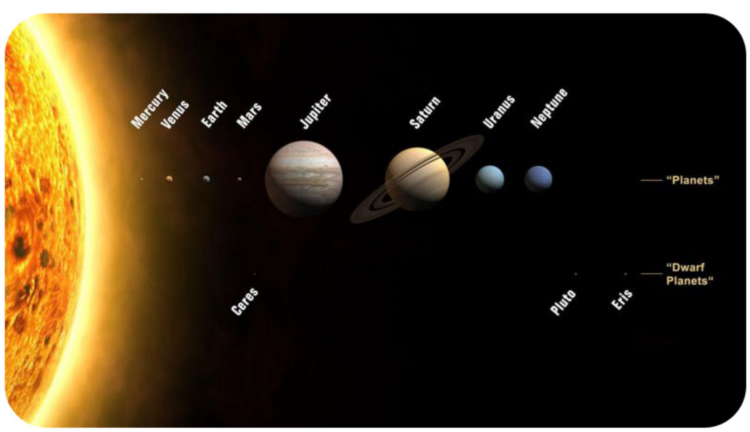

Figure 1.4: Relative sizes of the Sun, planets & dwarf planets. The largest objects in the solar system are the Sun, the eight planets, and the three known dwarf planets. In this figure, the relative sizes are correct but the relative distances are not correct.

The Size and Shape of Orbits

Figure 1.4 shows the Sun and planets in the correct relative sizes. However, the relative distances are not correct. **Figure** 1.5 shows the relative sizes of the orbits. The image in the upper left shows the orbits of the inner planets. The upper left image also shows the *asteroid belt*, a collection of many small objects between the orbits of Mars and Jupiter. The image in the upper right shows the orbits of the outer planets. This upper right image also shows the *Kuiper belt*, another group of objects beyond the orbit of Neptune. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next.

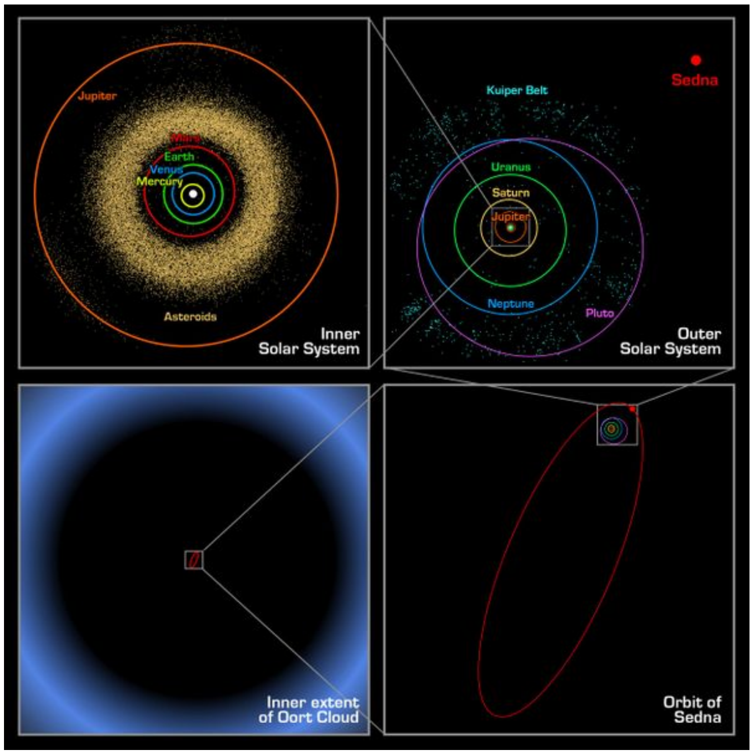

Figure 1.5: This figure shows the relative sizes of the orbits of planets in the solar system. The inner solar system is on the upper left. The upper right shows the outer planets of our solar system.

In **Figure 5**, you can see that the orbits of the planets are nearly circular. In fact, the orbits are not quite circular, but are slightly elliptical. The orbit of Pluto is a much longer ellipse. Some astronomers think Pluto was dragged into its current orbit by Neptune.

Something else Kepler discovered was a relationship between the time it takes a planet to make one complete orbit around the Sun (this is also called an "orbital period") and the distance from the Sun to the planet. So, if the orbital period of a planet is known, then it is possible to determine how far away from the Sun the planet orbits. This is how we can measure the distances to other planets within our own solar system.

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km, or 93 million miles. **Table** 1.2 shows the distances to the planets (the average radius of orbits) in AU. The table also shows how long it takes each planet to spin on its axis (the length of a day) and how long it takes each planet to complete an orbit (the length of a year); in particular, notice how slowly Venus rotates relative to Earth.

Table 1.2: **Distances to the Planets and Properties of Orbits Relative to Earth's Orbit**

Planet	Average Distance from Sun (AU)	Length of Day (In Earth Days)	Length of Year (In Earth Years)
Mercury	0.39 AU	56.84 days	0.24 years
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

(*Source:* http://en.wikipedia.org/wiki/Planets, *License:* GNU-FDL)

The Role of Gravity

Planets are held in their orbits by the force of gravity. Imagine swinging a ball on a string in a circular motion. If you were to let go of the string, the ball would go flying out in a straight line. But the force of the string pulling on the ball keeps the ball moving in a circle. The motion of a planet is very similar, except the force pulling the planet is the attractive force of gravity between the planet and the Sun.

Every object is attracted to every other object by gravity. The force of gravity between two objects depends on how much mass the objects have and on how far apart they are. When you are sitting next to a friend, there is a gravitational force between you and your friend, but it is far too weak for you to detect. In order for the force of gravity to be strong enough to detect, at least one of the objects has to have a lot of mass. You can feel the force of gravity between you and Earth because Earth has a lot of mass. This force of gravity is what keeps you from floating off the ground. The distances from the Sun to the planets are very large. But the force of gravity between the Sun and each planet is very large because the Sun and the planets are very large objects. The force of gravity also holds moons in orbit around planets.

The moon orbits the Earth, and the Earth-moon system orbits the Sun. But Earth and its moon are not the only things that orbit the Sun. There are also other planets and smaller objects, such as asteroids, meteoroids, and comets that also orbit the Sun. The **solar system** consists of the Sun and all the objects that revolve around the sun as a result of gravity.

Formation of the Solar System

There are two key features of the solar system we haven't mentioned yet. First, all the planets lie in nearly the same plane, or flat disk like region. Second, all the planets orbit in the same direction around the Sun. These two features are clues to how the solar system formed.

A Giant Nebula

The most widely accepted explanation of how the solar system formed is called the **nebular hypothesis**. According to this hypothesis, the solar system formed about 4.6 billion years ago from the collapse of a giant cloud of gas and dust, called a **nebula**. The nebula was made mostly of hydrogen and helium, but there were heavier elements as well.

The nebula was drawn together by gravity. As the nebula collapsed, it started to spin. As it collapsed further, the spinning got faster, much as an ice skater spins faster when he pulls his arms to his sides during a spin move. This effect, called "conservation of angular momentum," along with complex effects of gravity, pressure, and radiation, caused the nebula to form into a disk shape, as shown in **Figure** 1.6. This is why all the planets are found in the same plane.

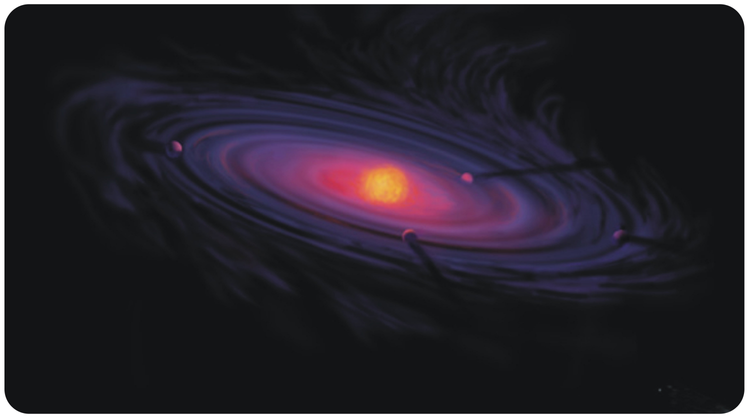

Figure 1.6: The nebular hypothesis describes how the solar system formed from a cloud of gas and dust into a disk with the Sun at the center. This painting was made by an artist; it's not an actual photograph of a protoplanetary disk.

Formation of the Sun and Planets

As gravity pulled matter into the center of the disk, the density and pressure increased at the center. When the pressure in the center was high enough that nuclear fusion reactions started in the center, a star was born—the Sun.

Meanwhile, the outer parts of the disk were cooling off. Small pieces of dust in the disk started clumping together. These clumps collided and combined with other clumps. Larger clumps, called *planetesimals*, attracted smaller clumps with their gravity. Eventually, the planetesimals formed the planets and moons that we find in our solar system today.

The outer planets—Jupiter, Saturn, Uranus and Neptune—condensed farther from the Sun from lighter materials such as hydrogen, helium, water, ammonia, and methane. Out by Jupiter and beyond, where it's very cold, these materials can form solid particles. But in closer to the Sun, these same materials are gases. As a result, the inner planets—Mercury, Venus, Earth, and Mars—formed from dense rock, which is solid even when close to the Sun.

Lesson Summary

- The **solar system** consists of the Sun and all the objects that are bound to the Sun by gravity.
- There are eight planets in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, and Neptune. Ceres, Makemake, Pluto and Eris are considered dwarf planets.
- The ancient Greeks believed in a geocentric model of the universe, with Earth at the center and everything else orbiting Earth.
- Copernicus, Kepler, and Galileo promoted a heliocentric model of the universe, with the sun at the center and Earth and the other planets orbiting the Sun.
- Planets are held by the force of gravity in elliptical orbits around the Sun.

- The nebular hypothesis describes how the solar system formed from a giant cloud of gas and dust about 4.6 billion years ago.
- The nebular hypothesis explains why the planets all lie in one plane and orbit in the same direction around the Sun.

Review Questions

1. What does *geocentric* mean?
2. Describe the geocentric model and heliocentric model of the universe.
3. How was Kepler's version of the heliocentric model different from Copernicus'?
4. Name the eight planets in order from the Sun outward.
5. What object used to be considered a planet, but is now considered a dwarf planet?
6. What keeps planets and moons in their orbits?
7. How old is the solar system?
8. Use the nebular hypothesis to explain why the planets all orbit the Sun in the same direction.

Further Reading / Supplemental Links

- http://www.youtube.com/watch?v=FHSWVLwbbNw&NR=1
- http://sse.jpl.nasa.gov/planets/index.cfm
- http://www.iau.org/iau0602.423.0.html
- http://starchild.gsfc.nasa.gov/docs/StarChild/solar_system_level2/solar_system.html; http://sse.jpl.nasa.gov/planets/index.cfm
- http://www.solarviews.com/eng/homepage.htm
- http://www.nineplanets.org/
- http://www.teachingideas.co.uk/science/orderingplanets.htm
- http://www.classzone.com/books/earth_science/terc/content/visualizations/es2701/es2701page01.cfm?chapter_no=27
- http://www.windows.ucar.edu/tour/link=/our_solar_system/formation.html
- http://www.solarviews.com/cap/misc/ssanim.htm
- http://en.wikipedia.org/

Vocabulary

geocentric model Model used by the ancient Greeks that puts the Earth at the center of the universe.

heliocentric model Model proposed by Copernicus that put the Sun at the center of the universe.

moon A celestial object that orbits a larger celestial object.

nebula An interstellar cloud of gas and dust.

nebular hypothesis The hypothesis that our solar system developed from a spinning cloud of gas and dust, or a nebula.

planet Around, celestial object that orbits a star and has cleared its orbit of smaller objects.

solar system The Sun and all the objects that revolve around the Sun as a result of gravity.

Points to Consider

- Would you expect all the planets in the solar system to be made of similar materials? Why or why not?
- The planets are often divided into two groups: the inner planets and the outer planets. Which planets do you think are in each of these two groups? What do members of each group have in common?

1.2 Inner Planets

Lesson Objectives

- Describe key features of each of the inner planets.
- Compare each of the inner planets to Earth and to one another.

The Inner Planets

The four planets closest to the sun - Mercury, Venus, Earth and Mars are the inner planets, also called the terrestrial planets because they are similar to Earth. **Figure** 1.7 shows the relative sizes of these four planets. All of the inner planets are small, relative to the outer planets. All of the inner planets are solid, dense, rocky planets. The inner planets either do not have moons or have just one (Earth) or two (Mars). None of the inner planets has rings. Compared to the outer planets, the inner planets have shorter orbits around the Sun, but all the inner planets spin more slowly. Venus spins the slowest of all the planets. At one time, all the inner planets have been geologically active. They are all made of cooled igneous rock with inner iron cores.

Mercury

Mercury, shown in **Figure** 1.7, is the planet closest to the Sun. Mercury is the smallest planet, and it has no moon. As **Figure** 1.7 shows, the surface of Mercury is covered with craters, like Earth's moon. The presence of impact craters that are so old means that Mercury hasn't changed much geologically for billions of years and, with only a trace of an atmosphere, has no weather to wear down the ancient craters.

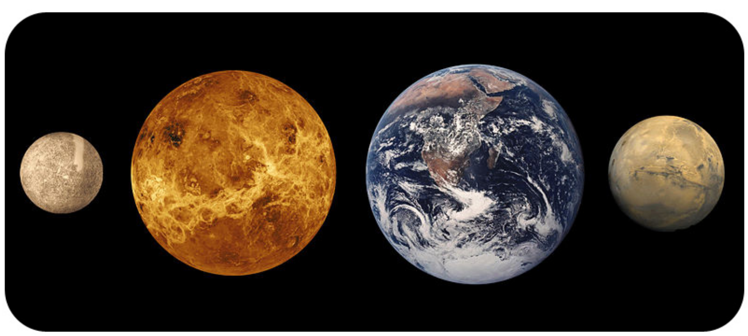

Figure 1.7: This composite shows the relative sizes of the four inner planets. From left to right, they are Mercury, Venus, Earth, and Mars.

Because Mercury is so close to the Sun, it is difficult to observe from Earth, even with a telescope. However, the Mariner 10 spacecraft, shown in **Figure** 1.8, visited Mercury in 1974–1975. In January 2008, the Messenger mission returned to Mercury and took much more detailed pictures. One of these images can be seen in **Figure** 1.9.

Figure 1.8: Mariner 10 made three flybys of Mercury in 1974 and 1975.

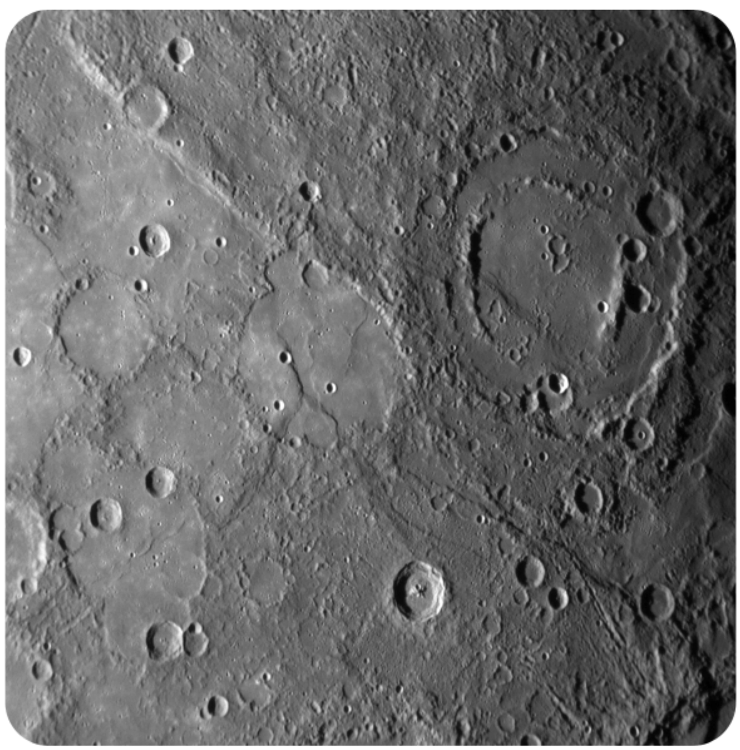

Figure 1.9: Mercury is covered with craters, like Earth's moon.

Short Year, Long Days

Mercury is named for the Roman messenger god, who could run extremely fast. Likewise, Mercury moves very fast in its orbit around the Sun. A **year** on Mercury—the length of time it takes to orbit the Sun—is just 88 Earth days.

Mercury has a very short year, but very long days. A **day** is defined as the time it takes a planet to turn on its axis. Mercury rotates slowly on its axis, turning exactly three times for every two times it orbits the Sun. Therefore, each day on Mercury is 58 Earth days long. In other words, on Mercury, a year is only a Mercury day and a half long!

Extreme Temperatures

Mercury is very close to the Sun, so it can get very hot. However, Mercury has virtually no atmosphere and it rotates very slowly. Because there is no atmosphere and no water to insulate the surface, temperatures on the surface of Mercury vary widely. In direct sunlight, the surface can be as hot as 427 °C (801 °F). On the dark side, or in the shadows inside craters, the surface can be as cold as –183 °C (–297 °F)! Although most of Mercury is extremely dry, scientists believe there may be a small amount of water in the form of ice at the poles of Mercury, in areas which never receive direct sunlight.

A Liquid Metal Core

Figure 1.10 shows a diagram of Mercury's interior. Mercury is one of the densest planets. Scientists believe the interior contains a relatively large, liquid core made mostly of melted iron. Mercury's core takes up about 42% of the planet's volume. Mercury's highly cratered surface is evidence that Mercury is not geologically active.

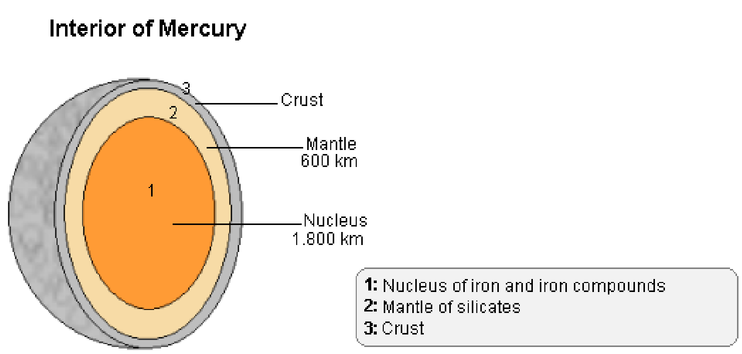

Figure 1.10: Mercury contains a thin crust, a mantle, and a large, liquid core that is rich in iron.

Venus

The second planet out from the Sun, Venus, is our nearest neighbor. Not only is it closer to Earth than any other planet, but it also is the most similar to Earth in size. Named after the Roman goddess of love, it is the only planet named after a female. Venus is sometimes called Earth's "sister planet." But just how similar is Venus to Earth?

A Harsh Environment

Viewed through a telescope, Venus looks smooth and featureless. That's because Venus is covered by a thick layer of clouds, as shown in pictures of Venus taken at ultraviolet wavelengths, such as **Figure** 1.11. Because of the thick, cloudy atmosphere, we cannot take ordinary photos of the surface of Venus, even from spacecraft orbiting the planet. However, we can make maps of the surface using radar. **Figure** 1.12 shows a topographical map of Venus produced by the Magellan probe using radar.

Unlike clouds on Earth, Venus's clouds are not made of water vapor. They are made of carbon dioxide and sulfur dioxide—and they also contain large amounts of corrosive sulfuric acid!

Figure 1.11: This ultraviolet image from the Pioneer Venus Orbiter shows thick layers of clouds in the atmosphere of Venus.

The atmosphere of Venus is so thick that the atmospheric pressure on the surface of Venus is 90 times greater than the atmospheric pressure on Earth's surface. The thick atmosphere also causes a strong greenhouse effect, which traps heat from the Sun. As a result, Venus is the hottest planet, even hotter than Mercury. Temperatures at the surface reach 465°C (860 °F). That's hot enough to melt lead!

Volcanoes

Venus has more volcanoes than any other planet. Planetary scientists have estimated that Venus has up to 100,000 or even a million volcanoes. Although these volcanoes contributed carbon dioxide in the past, most of the volcanoes are now dead. Venus doesn't seem to have tectonic plates like the Earth's. It's surface is covered with dead volcanoes and ancient craters.

Orbiting spacecraft have used radar to reveal mountains, valleys, and canyons on Venus. Most of the surface, however, has large areas of volcanoes surrounded by plains of lava. **Figure** 1.13 is an image made

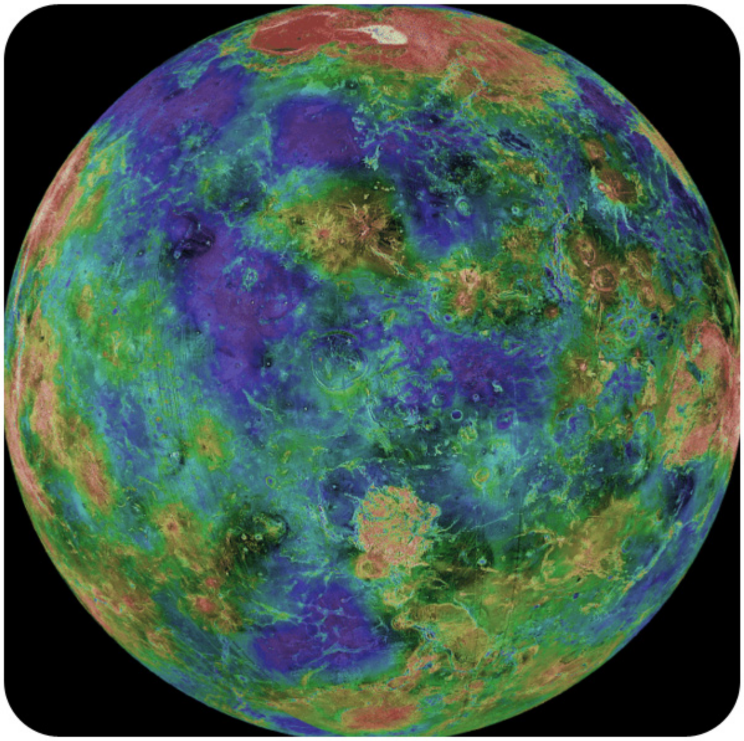

Figure 1.12: This topographic map of Venus was made from radar data collected by the Magellan probe between 1990 and 1994.

by a computer using radar data. It shows a volcano called Maat Mons, with lava beds in the foreground. The reddish-orange color is close to what scientists think the color of sunlight would look like on the surface of Venus.

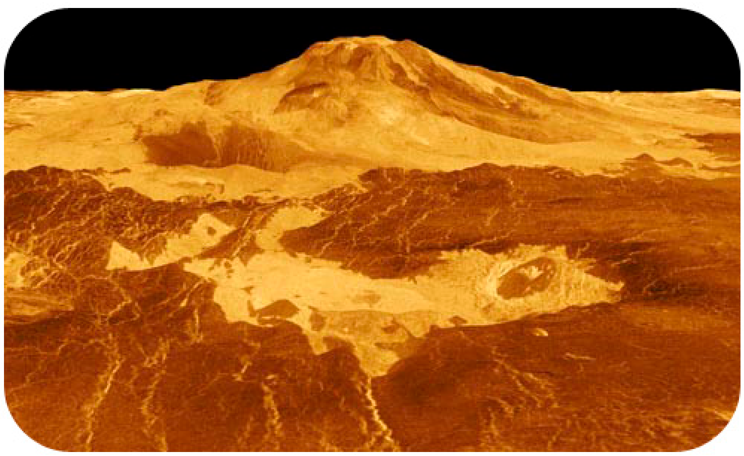

Figure 1.13: This image of Maat Mons was generated from radar data. The surface of Venus has many mountains, volcanoes, and plains of lava.

Motion and Appearance

Venus is the only planet that rotates clockwise as viewed from its North pole, in a direction opposite to the direction it orbits the Sun. It turns slowly in the reverse direction, making one turn every 243 days. This is longer than a year on Venus—it takes Venus only 224 days to orbit the Sun.

Because the orbit of Venus is inside Earth's orbit, Venus always appears close to the Sun. When Venus rises early in the morning, just before the Sun rises, it is sometimes called "the morning star." When it sets in the evening, just after the Sun sets, it may be called "the evening star." Venus' clouds reflect sunlight very well. As a result, Venus is very bright. When it is visible, Venus is the brightest object in the sky besides the sun and the Moon.

Like Mercury, Venus has no moon.

Earth

The third planet out from the Sun is shown in **Figure** 1.14. Does it look familiar? It's Earth! Because it is our home planet, we know a lot more about Earth than we do about any other planet. But what are key features of Earth when viewed as a member of our solar system?

Figure 1.14: This famous image of Earth was taken during the Apollo 17 mission to the moon.

Oceans and Atmosphere

As you can see in **Figure** 1.14, Earth has vast oceans of liquid water, large masses of land, ice covering the poles, and a dynamic atmosphere with clouds of water vapor. Earth's average surface temperature is 14°C (57°F). As you know, water is a liquid at this temperature. The oceans and the atmosphere help keep Earth's surface temperatures fairly steady.

Earth is the only planet known to have life. The conditions on Earth, especially the presence of liquid water, are ideal for life as we know it. The atmosphere filters out radiation that would be harmful to life, such as ultraviolet radiation and X rays. The presence of life has changed Earth's atmosphere, so it has much more oxygen than the atmospheres of other planets.

Plate Tectonics

The top layer of Earth's interior—the crust—contains numerous plates, known as tectonic plates. These plates move on the convecting mantle below, so they slowly move around on the surface. Movement of the plates causes other geological activity, such as earthquakes, volcanoes, and the formation of mountains. Earth is the only planet known to have plate tectonics.

Earth's Motions and Moon

Earth rotates on its axis once per day. In fact, the time of this rotation is how people have defined a day. Earth orbits the Sun once every 365.24 days, which is also how we have defined a year. Earth has one large moon, which orbits Earth once every 29.5 days, a period known as a month.

Earth's moon is the only large moon around a terrestrial planet in the solar system. The Moon is covered with craters, and also has large plains of lava. There is evidence that the Moon formed when a very large object—perhaps as large as the planet Mars—struck Earth in the distant past.

Mars

Mars, shown in **Figure** 1.15, is the fourth planet from the Sun, and the first planet beyond Earth's orbit. The Martian atmosphere is thin relative to Earth's and with much lower atmospheric pressure. Unlike Earth's neighbor on the side nearer the sun, Mars has only a weak greenhouse effect, which raises its temperature only slightly above what it would be if the planet did not have an atmosphere.

Although Mars is not the closest planet to Earth, it is the easiest to observe. Therefore, Mars has been studied more thoroughly than any other planet besides Earth. Humans have sent many space probes to Mars. Currently, there are three scientific satellites in orbit around Mars, and two functioning rovers on the surface. No humans have ever set foot on Mars. However, both NASA and the European Space Agency have set goals of sending people to Mars sometime between 2030 and 2040.

A Red Planet

Viewed from Earth, Mars is reddish in color. The ancient Greeks and Romans named the planet after the god of war. They may have associated the planet with war because its red color reminded them of blood. Mars appears red because the surface of the planet really is a reddish-orange rust color, due to large amounts of iron in the soil. Mars has only a very thin atmosphere, made up mostly of carbon dioxide.

Surface Features

Mars is home to the largest mountain in the solar system—Olympus Mons, shown in **Figure** 1.16. Olympus Mons is a shield volcano, similar to the volcanoes that make up the Hawaiian islands on Earth. Olympus Mons is about 27 km (16.7 miles/88,580 ft) above the normal Martian surface level. That makes it more

Figure 1.15: This image of Mars, taken by the Hubble Space Telescope in August, 2003, shows the planets reddish color and a prominent polar ice cap.

than three times taller than Mount Everest. At its base, Olympus Mons is about the size of the entire state of Arizona!

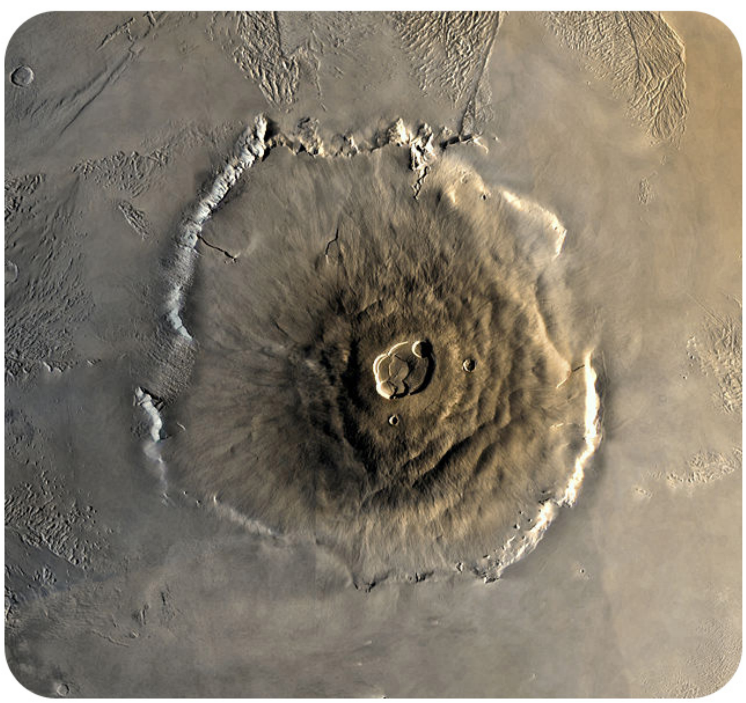

Figure 1.16: The Martian volcano Olympus Mons is the largest mountain in the solar system.

Mars also has the largest canyon in the solar system, Valles Marineris (**Figure** 1.17). This canyon is 4,000 km (2,500 miles) long, as long as Europe is wide, and one-fifth the circumference of Mars. The canyon is 7 km (4.3 miles) deep. By comparison, the Grand Canyon on Earth is only 446 km (277 miles) long and about 2 km (1.2 miles) deep.

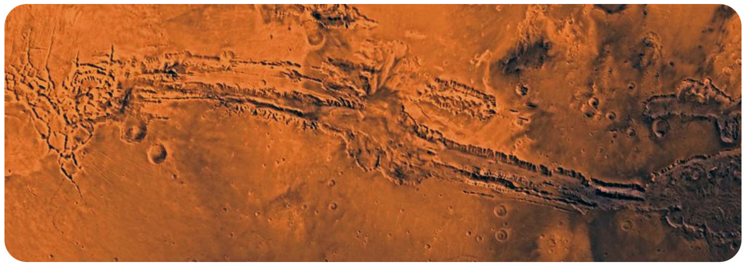

Figure 1.17: The Martian canyon Valles Marineris is the largest canyon in the solar system.

Although Mars has mountains, canyons, and other features similar to Earth, it doesn't have as much geological activity as Earth. There is no evidence of plate tectonics on Mars. There are also more craters on Mars than on Earth, though fewer than on the Moon.

Is There Water on Mars?

Water cannot stay in liquid form on Mars because the pressure of the atmosphere is too low. However, there is a lot of water in the form of ice. **Figure** 1.15 shows a prominent ice cap at the south pole of Mars. Scientists also believe there is also a lot of ice water present just under the Martian surface. This ice can melt when volcanoes erupt, and water can flow across the surface temporarily.

Scientists have reason to think that water once flowed over the surface of Mars because they can see surface features that look like water-eroded canyons, and the Mars rover collected round clumps of crystals that, on Earth, usually form in water. The presence of water on Mars, even though it is now frozen as ice, suggests that it might have been possible for life to exist on Mars in the past.

Two Martian Moons

Mars has two very small moons, Phobos and Deimos. As you can see in **Figure** 1.18, these moons are not spherical in shape, but instead just look like irregular rocks. Phobos and Deimos were discovered in 1877. They are named after characters in Greek mythology—the two sons of Ares, who followed their father into war. Ares is equivalent to the Roman god Mars.

Lesson Summary

- The four inner planets, or terrestrial planets, have solid, rocky surfaces.
- Mercury is the smallest planet and the closest to the Sun. It has an extremely thin atmosphere, with surface temperatures ranging from very hot to very cold. Like the Moon, it is covered with craters.
- Venus is the second planet from the Sun and the closest planet to Earth, in distance and in size. It has a very thick, corrosive atmosphere, and the surface temperature is extremely high.
- Radar maps of Venus show that it has mountainous areas, as well as volcanoes surrounded by plains of lava.
- Venus rotates slowly in a direction opposite to the direction of its orbit.

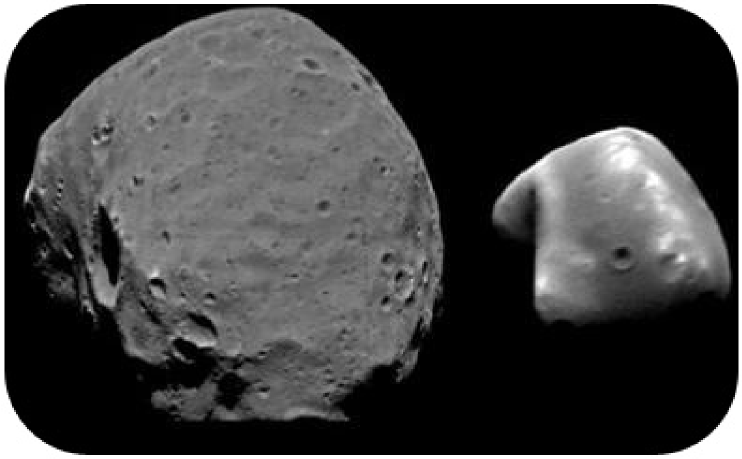

Figure 1.18: Mars has two small moons, Phobos (left) and Deimos (right).

- Earth is the third planet from the Sun. It is the only planet with large amounts of liquid water, and the only planet known to support life. Earth has a large moon, the only large moon around a terrestrial planet.
- Mars is the fourth planet from the Sun. It has two small moons. Mars is reddish in color because of oxidized iron (rust) in its soil. Mars has the largest mountain and the largest canyon in the solar system.
- There is a lot of water ice in the polar ice caps and under the surface of Mars.

Review Questions

1. Name the inner planets in order from the Sun outward. Then name them from smallest to largest.
2. Why do the temperatures on Mercury vary widely?
3. Venus is farther from the Sun than Mercury. Why does Venus have higher temperatures than Mercury?
4. How are maps of Venus made?
5. Name two major ways in which Earth is unlike any other planets.
6. Why does Mars appear to be red?
7. Suppose you are planning a mission to Mars. Identify two places where you might be able to get water on the planet.

Further Reading / Supplemental Links

- http://www.nasa.gov/worldbook/venus_worldbook.html
- http://solarsystem.nasa.gov/planetselector.cfm?Object=Mercury
- http://solarsystem.jpl.nasa.gov/planets/profile.cfm?Object=Mercury&Display=Kids
- http://mars.jpl.nasa.gov/extreme/
- http://www.google.com/mars/
- http://www.youtube.com/watch?v=U8-DTJpygyk
- http://www.youtube.com/watch?v=U8-DTJpygyk
- http://www.youtube.com/watch?v=HqFVxWfVtoo&feature=related
- http://www.youtube.com/watch?v=M-KfYEQUg2s

Vocabulary

day

The time it takes a planet to rotate once on its axis.

inner planets

The four planets inside the asteroid belt of our solar system; Mercury, Venus, Earth and Mars.

terrestrial planets

The solid, dense, rocky planets that are like Earth.

year

The time it takes for a planet to orbit the Sun.

Points to Consider

- We are planning to send humans to Mars sometime in the next few decades. What do you think it would be like to be on Mars? Why do you think we are going to Mars instead of Mercury or Venus?
- Why do you think the four inner planets are also called terrestrial planets? What might a planet be like if it weren't a terrestrial planet?

1.3 Outer Planets

Lesson Objectives

- Describe key features of the outer planets and their moons.
- Compare the outer planets to each other and to Earth.

Introduction

The four planets farthest from the sun—Jupiter, Saturn, Uranus, and Neptune—are called the **outer planets** of our solar system. **Figure** 1.19 shows the relative sizes of the outer planets and the Sun. Because they are much larger than Earth and the other inner planets, and because they are made primarily of gases and liquids rather than solid matter, the outer planets are also called **gas giants**.

The gas giants are made up primarily of hydrogen and helium, the same elements that make up most of the Sun. Astronomers believe that hydrogen and helium gases were found in large amounts throughout the solar system when it first formed. However, the inner planets didn't have enough mass to hold on to these very light gases. As a result, the hydrogen and helium initially on these inner planets floated away into space. Only the Sun and the massive outer planets had enough gravity to keep hydrogen and helium from drifting away.

All of the outer planets have numerous moons. All of the outer planets also have **planetary rings**, which are rings of dust and other small particles encircling a planet in a thin plane. Only the rings of Saturn can be easily seen from Earth.

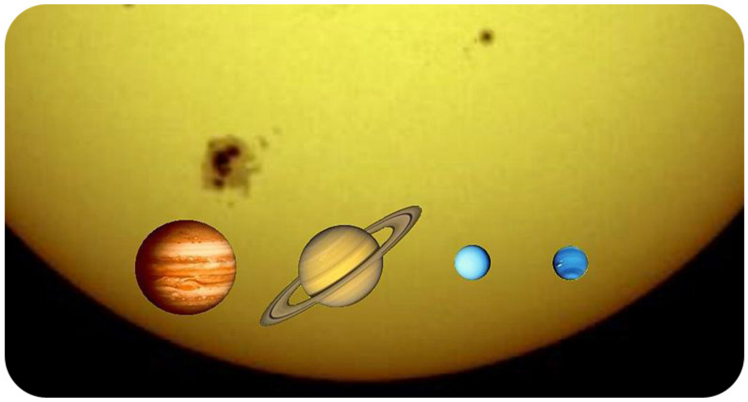

Figure 1.19: This image shows the four outer planets and the Sun, with sizes to scale. From left to right, the outer planets are Jupiter, Saturn, Uranus, and Neptune.

Jupiter

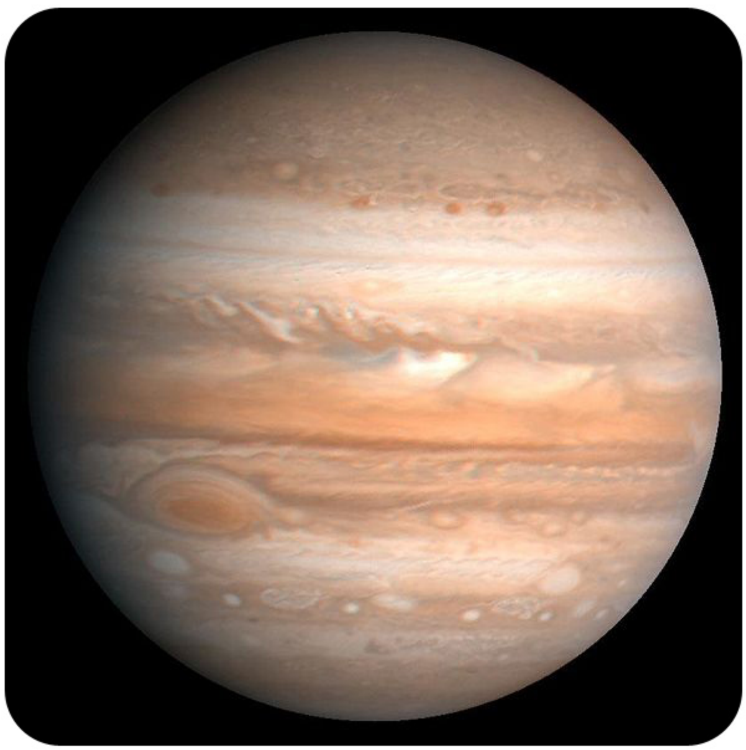

Figure 1.20: This image of Jupiter was taken by Voyager 2 in 1979. The colors were later enhanced to bring out more details.

Jupiter, shown in **Figure** 1.20, is the largest planet in our solar system, and the largest object in the solar system besides the Sun. Jupiter is named for the king of the gods in Roman mythology. Jupiter is truly a giant! It is much less dense than Earth—it has 318 times the mass of Earth, but over 1,300 times Earth's volume. Because Jupiter is so large, it reflects a lot of sunlight. When it is visible, it is the brightest object in the night sky besides the Moon and Venus. This brightness is all the more impressive, since Jupiter is quite far from the Earth — 5.20 AUs away. It takes Jupiter about 12 Earth years to orbit once around the Sun.

A Ball of Gas and Liquid

If a spaceship were to try to land on the surface of Jupiter, the astronauts would find that there is no solid surface at all! Jupiter is made mostly of hydrogen, with some helium, and small amounts of other elements. The outer layers of the planet are gas. Deeper within the planet, pressure compresses the gases into a liquid. Some evidence suggests that Jupiter may have a small rocky core at its center.

A Stormy Atmosphere

The upper layer of Jupiter's atmosphere contains clouds of ammonia (NH_3) in bands of different colors. These bands rotate around the planet, but also swirl around in turbulent storms. The **Great Red Spot,** shown in **Figure** 1.21, is an enormous, oval-shaped storm found south of Jupiter's equator. It is more than three times as wide as the entire Earth! Clouds in the storm rotate in a counterclockwise direction, making one complete turn every six days or so. The Great Red Spot has been on Jupiter for at least 300 years. It is possible, but not certain, that this storm is a permanent feature on Jupiter.

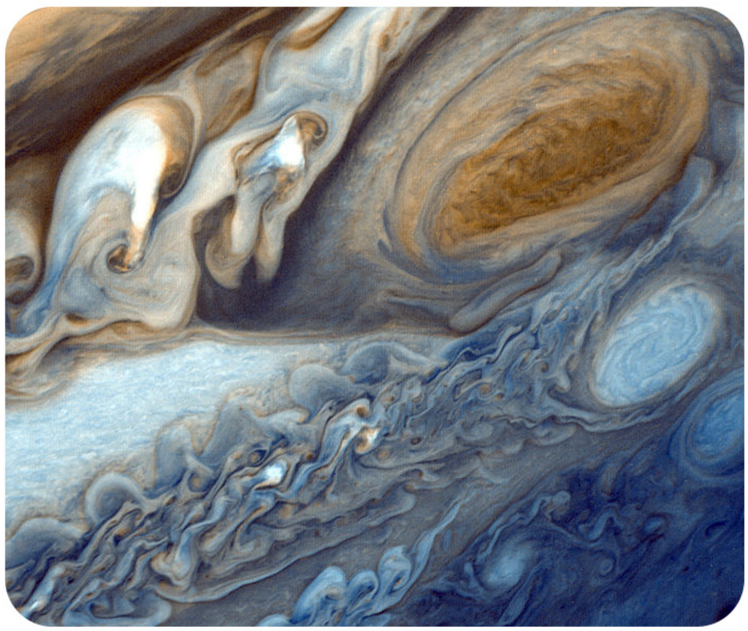

Figure 1.21: This image of Jupiter's Great Red Spot (upper right of image) was taken by the Voyager 1 spacecraft. The white storm just below the Great Red Spot is about the same diameter as Earth.

Jupiter's Moons and Rings

Jupiter has a very large number of moons. As of 2008, we have discovered over 60 natural satellites of Jupiter. Of these, four are big enough and bright enough to be seen from Earth, using no more than a pair of binoculars. These four moons—named Io, Europa, Ganymede, and Callisto—were first discovered by Galileo in 1610, so they are sometimes referred to as the **Galilean moons**.

Figure 1.22 shows the four Galilean moons and their sizes relative to the Great Red Spot. The Galilean moons are larger than the dwarf planets Pluto, Ceres, and Eris. In fact, Ganymede, which is the biggest moon in the solar system, is even larger than the planet Mercury!

Scientists are particularly interested in Europa, the smallest of the Galilean moons, because it may be a

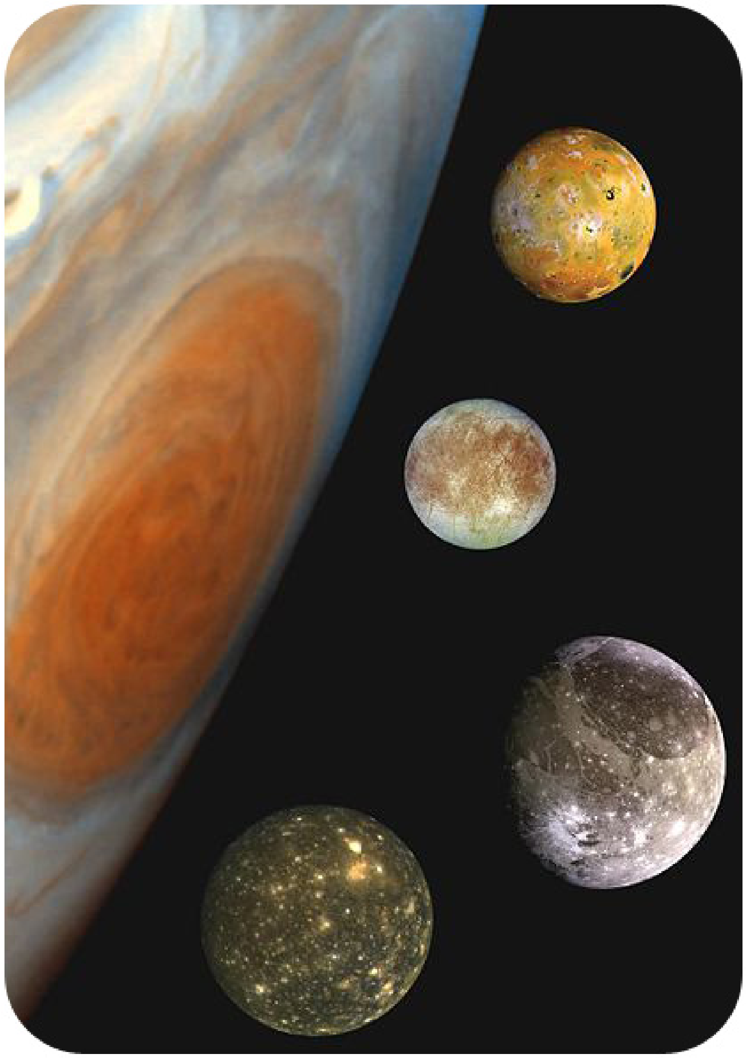

Figure 1.22: This composite image shows the the four Galilean moons and Jupiter. From top to bottom, the moons are Io, Europa, Ganymede and Callisto. Jupiter's Great Red Spot is in the background. Sizes are to scale.

likely place to find extraterrestrial life. The surface of Europa is a smooth layer of ice. Evidence suggests that there is an ocean of liquid water under the ice. Europa also has a continual source of energy—it is heated as it is stretched and squashed by tidal forces from Jupiter. Because it has liquid water and a continual heat source, astrobiologists surmise that life might have formed on Europa much as it did on Earth. Numerous missions have been planned to explore Europa, including plans to drill through the ice and send a probe into the ocean. However, no such mission has yet been attempted.

In 1979, two spacecrafts—Voyager 1 and Voyager 2—visited Jupiter and its moons. Photos from the Voyager missions showed that Jupiter has a ring system. This ring system is very faint, so it is very difficult to observe from Earth.

Saturn

Saturn, shown in **Figure** 1.23, is famous for its beautiful rings. Saturn's mass is about 95 times the mass of Earth, and its volume is 755 times Earth's volume, making it the second largest planet in the solar system. Despite its large size, Saturn is the least dense planet in our solar system. It is less dense than water, which means if there could be a bathtub big enough, Saturn would float. In Roman mythology, Saturn was the father of Jupiter. So, it is an appropriate name for the next planet beyond Jupiter. Saturn orbits the Sun once about every 30 Earth years.

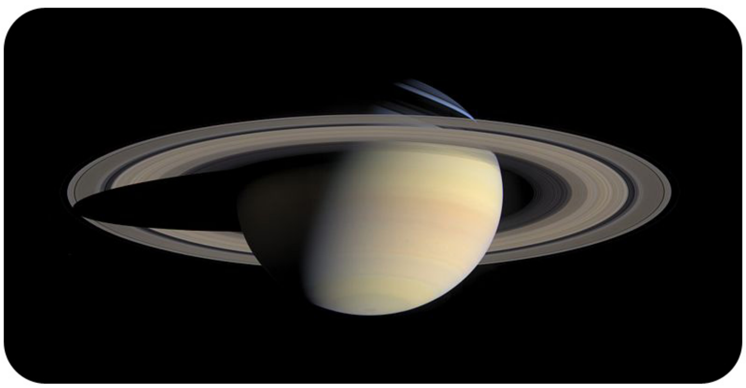

Figure 1.23: This image of Saturn and its rings is a composite of pictures taken by the Cassini orbiter in 2004.

Saturn's composition is similar to Jupiter. It is made mostly of hydrogen and helium, which are gases in the outer layers and liquids at deeper layers. It may also have a small solid core. The upper atmosphere has clouds in bands of different colors. These rotate rapidly around the planet, but there seems to be less turbulence and fewer storms on Saturn than on Jupiter. One interesting phenomena that has been observed in the storms on Saturn is the presence of thunder and lightning (see video, below).

Figure 1.24: (Watch Youtube Video)
http://omega.ck12.org/flexbook/embed/view/20

A Weird Hexagon

There is a strange feature at Saturn's north pole—the clouds form a hexagonal pattern, as shown in the infrared image in **Figure** 1.25. This hexagon was viewed by Voyager 1 in the 1980s, and again by the Cassini Orbiter in 2006, so it seems to be a long-lasting feature. Though astronomers have hypothesized and speculated about what causes these hexagonal cloud, no one has yet come up with a convincing explanation.

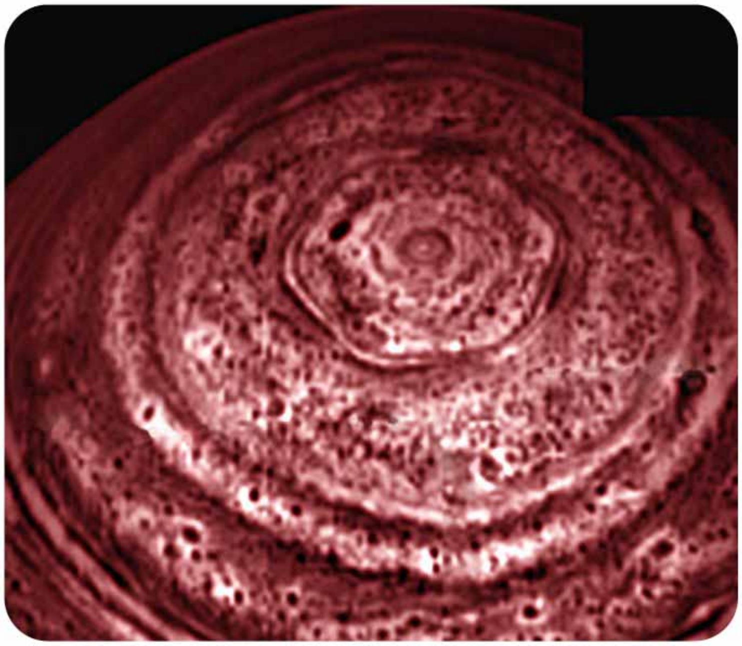

Figure 1.25: This infrared image taken of Saturn's north pole shows that the clouds are in a hexagon (six-sided) shape.

Saturn's Rings

The rings of Saturn were first observed by Galileo in 1610. However, he could not see them clearly enough to realize they were rings; he thought they might be two large moons, one on either side of Saturn. In 1659, the Dutch astronomer Christiaan Huygens was the first to realize that the rings were in fact rings. The rings circle Saturn's equator. They appear tilted because Saturn itself is tilted about 27 degrees to the side. The rings do not touch the planet.

The Voyager 1 spacecraft visited Saturn in 1980, followed by Voyager 2 in 1981. The Voyager probes sent back detailed pictures of Saturn, its rings, and some of its moons. From the Voyager data, we learned that Saturn's rings are made of particles of water and ice, with a little bit of dust as well. There are several gaps in the rings. Some of the gaps have been cleared out by moons that are within the rings. Scientists believe the moons' gravity caused ring dust and gas to fall towards the moon, leaving a gap in the rings. Other gaps in the rings are caused by the competing gravitational forces of Saturn and of moons outside the rings.

Saturn's Moons

As of 2008, over 60 moons have been identified around Saturn. Most of them are very small. Some are even found within the rings. In a sense, all the particles in the rings are like little moons, too, because they orbit around Saturn. Only seven of Saturn's moons are large enough for gravity to have made them spherical, and all but one are smaller than Earth's moon.

Saturn's largest moon, Titan, is about one and a half times the size of Earth's Moon and is also larger than the planet Mercury. **Figure** 1.26 compares the size of Titan to Earth. Scientists are very interested in Titan because it has an atmosphere that is similar to what Earth's atmosphere might have been like before life developed on Earth. Titan may have a layer of liquid water under a layer of ice on the surface. Scientists now believe there are also lakes on the surface of Titan, but these lakes contain liquid methane (CH_4) and ethane (C_2H_6) instead of water! Methane and ethane are compounds found in natural gas, a mixture of gases found naturally on Earth and often used as fuel.

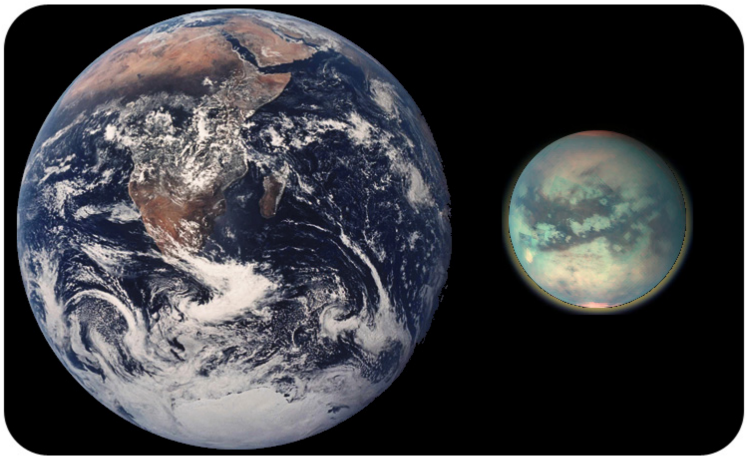

Figure 1.26: This composite image compares Saturn's largest moon, Titan (right) to Earth (left). Titan has an atmosphere similar to what Earth's might have been like before life formed on Earth.

Uranus

Figure 1.27: This image of Uranus was taken by Voyager 2 in 1986.

Uranus, shown in **Figure** 1.27, is named for the Greek god of the sky. In Greek mythology, Uranus was the father of Cronos, the Greek equivalent of the Roman god Saturn. By the way, astronomers pronounce the name "YOOR-uh-nuhs."

Uranus was not known to ancient observers. It was first discovered by the astronomer William Herschel in 1781. Uranus can be seen from Earth with the unaided eye, but it was overlooked for centuries because it is very faint. Uranus is faint because it is very far away, not because it is small. It is about 2.8 billion kilometers (1.8 billion miles) from the Sun. Light from the Sun takes about 2 hours and 40 minutes to reach Uranus. Uranus orbits the Sun once about every 84 Earth years.

An Icy Blue-Green Ball

Like Jupiter and Saturn, Uranus is composed mainly of hydrogen and helium. It has a thick layer of gas on the outside, then liquid further on the inside. However, Uranus has a higher percentage of icy materials, such as water, ammonia (NH_3), and methane (CH_4), than Jupiter and Saturn do. When sunlight reflects off Uranus, clouds of methane filter out red light, giving the planet a blue-green color. There are bands of clouds in the atmosphere of Uranus, but they are hard to see in normal light, so the planet looks like a plain blue ball.

Uranus is the lightest of the outer planets, with a mass about 14 times the mass of Earth. Even though it has much more mass than Earth, it is much less dense than Earth. At the "surface" of Uranus, the gravity is actually weaker than on Earth's surface. If you were at the top of the clouds on Uranus, you would weigh about 10% less than what you weigh on Earth.

The Sideways Planet

Most of the planets in the solar system rotate on their axes in the same direction that they move around the Sun. Uranus, though, is tilted on its side so its axis is almost parallel to its orbit. In other words, it rotates like a top that was turned so that it was spinning parallel to the floor. Scientists think that Uranus was probably knocked over by a collision with another planet-sized object billions of years ago.

Rings and Moons of Uranus

Uranus has a faint system of rings, as shown in **Figure** 1.28. The rings circle the planet's equator, but because Uranus is tilted on its side, the rings are almost perpendicular to the planet's orbit.

Uranus has 27 moons that we know of. All but a few of them are named for characters from the plays of William Shakespeare. The five biggest moons of Uranus—Miranda, Ariel, Umbriel, Titania and Oberon—are shown in **Figure** 1.29.

Neptune

Neptune, shown in **Figure** 1.30, is the eighth planet from the Sun. It is the only major planet that can't be seen from Earth without a telescope. Scientists predicted the existence of Neptune before it was actually discovered. They noticed that Uranus did not always appear exactly where it should appear. They knew there must be another planet beyond Uranus whose gravity was affecting Uranus' orbit. This planet was discovered in 1846, in the position that had been predicted, and it was named Neptune for the Roman god of the sea due to its blush color.

Neptune has slightly more mass than Uranus, but it is slightly smaller in size. In many respects, it is

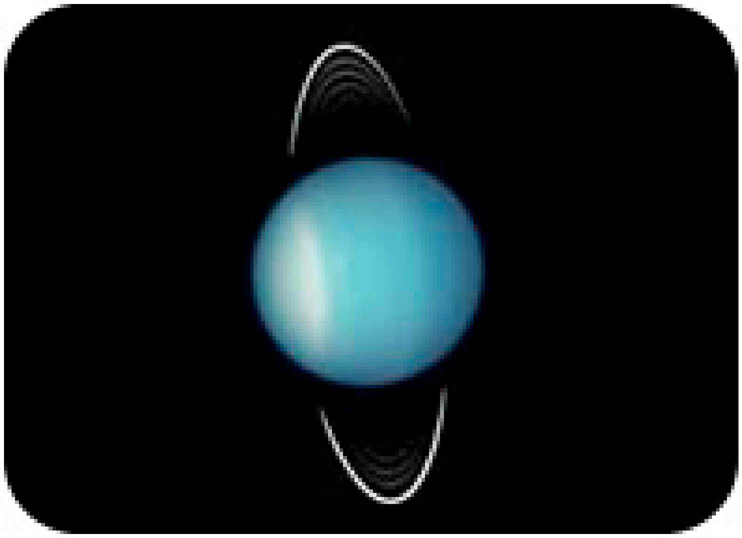

Figure 1.28: This image from the Hubble Space Telescope shows the faint rings of Uranus. The planet is tilted on its side, so the rings are nearly vertical.

Figure 1.29: These Voyager 2 photos have been resized to show the relative sizes of the five main moons of Uranus.

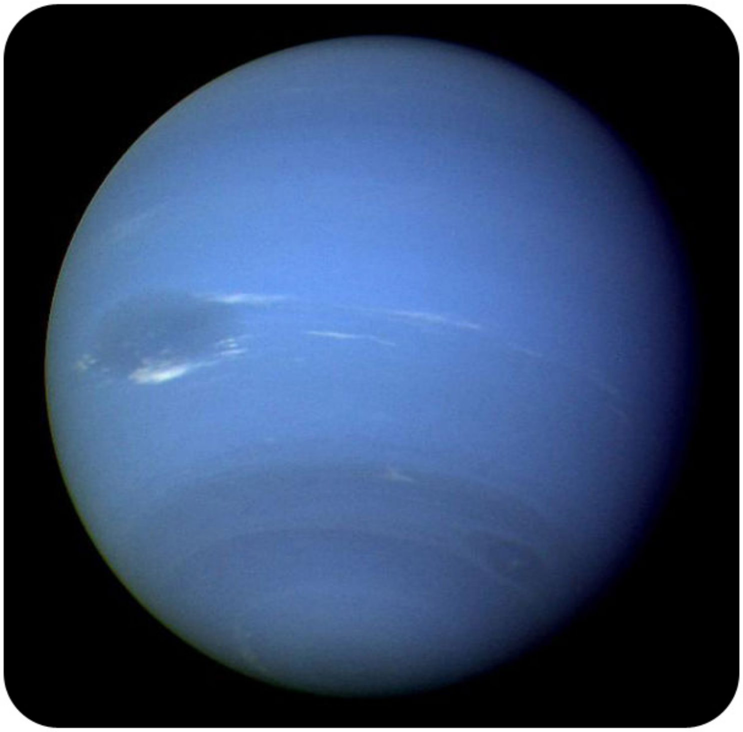

Figure 1.30: This image of Neptune was taken by Voyager 2 in 1989. The Great Dark Spot seen on the left center in the picture has since disappeared, but a similar dark spot has appeared on another part of the planet.

similar to Uranus. Uranus and Neptune are often considered "sister planets." Neptune, which is nearly 4.5 billion kilometers (2.8 billion miles) from the Sun, is much farther from the Sun than even distant Uranus. It moves very slowly in its orbit, taking 165 Earth years to complete one orbit around the Sun.

Extremes of Cold and Wind

Neptune is blue in color, with a few darker and lighter spots. The blue color is caused by atmospheric gases, including methane (CH_4). When Voyager 2 visited Neptune in 1986, there was a large dark-blue spot south of the equator. This spot was called the Great Dark Spot. However, when the Hubble Space Telescope took pictures of Neptune in 1994, the Great Dark Spot had disappeared. Instead, another dark spot had appeared north of the equator. Astronomers believe both of these spots represent gaps in the methane clouds on Neptune.

The changing appearance of Neptune is due to its turbulent atmosphere. The winds on Neptune are stronger than on any other planet in the solar system, reaching speeds of 1,100 km/h (700 mi/h), close to the speed of sound. This extreme weather surprised astronomers, since the planet receives little energy from the Sun to power weather systems. Neptune is also one of the coldest places in the solar system. Temperatures at the top of the clouds are about -218_oC (-360_oF).

Neptune's Rings and Moons

Like the other outer planets, Neptune has rings of ice and dust. These rings are much thinner and fainter than those of Saturn. Some evidence suggests that the rings of Neptune may be unstable, and may change or disappear in a relatively short time.

Neptune has 13 known moons. Triton, shown in **Figure** 1.31, is the only one of them that has enough mass to be spherical in shape. Triton orbits in the direction opposite to the orbit of Neptune. Scientists think Triton did not form around Neptune, but instead was captured by Neptune's gravity as it passed by.

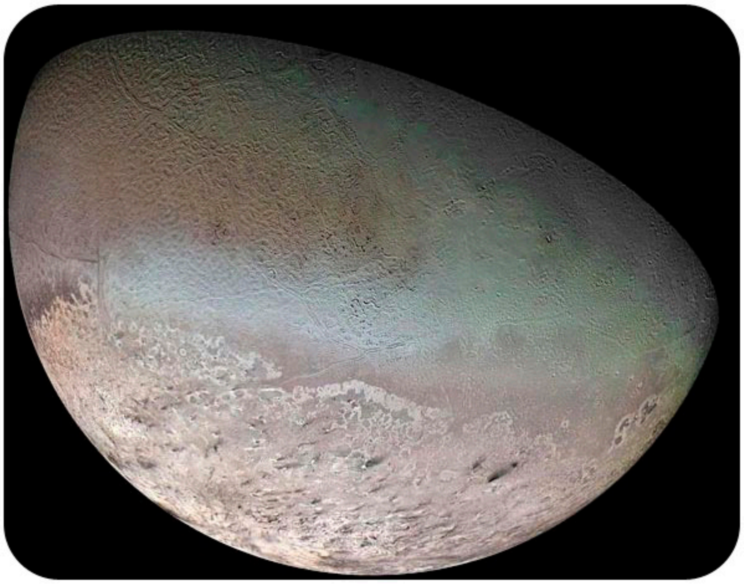

Figure 1.31: This image Triton, Neptune's largest moon, was taken by Voyager 2 in 1989.

Pluto

Pluto was once considered one of the outer planets, but when the definition of a planet was changed in 2006, Pluto became one of the leaders of the dwarf planets. It is one of the largest and brightest objects that make up this group. Look for Pluto in the next section in the discussion of dwarf planets.

Lesson Summary

- The four outer planets—Jupiter, Saturn, Uranus, and Neptune—are all gas giants made primarily of hydrogen and helium. They have thick gaseous outer layers and liquid interiors.
- All of the outer planets have numerous moons, as well as planetary rings made of dust and other particles.
- Jupiter is by far the largest planet in the solar system. It has bands of different colored clouds, and a long-lasting storm called the Great Red Spot.
- Jupiter has over 60 moons. The four biggest were discovered by Galileo, and are called the Galilean moons.
- One of the Galilean moons, Europa, may have an ocean of liquid water under a layer of ice. The conditions in this ocean might be right for life to have developed.
- Saturn is smaller than Jupiter, but similar in composition and structure.
- Saturn has a large system of beautiful rings. Saturn's largest moon, Titan, has an atmosphere similar to Earth's atmosphere before life formed.
- Uranus and Neptune were discovered in modern times. They are similar to each other in size and composition. They are both smaller than Jupiter and Saturn, and also have more icy materials.
- Uranus is tilted on its side, probably due to a collision with a large object in the past.

- Neptune is very cold and has very strong winds. It had a large dark spot that disappeared, then another dark spot appeared on another part of the planet. These dark spots are storms in Neptune's atmosphere.
- Pluto is no longer considered one of the outer planets. It is now considered a dwarf planet.

Review Questions

1. Name the outer planets a) in order from the Sun outward, b) from largest to smallest by mass, and c) from largest to smallest by size.
2. Why are the outer planets called gas giants?
3. How do the Great Red Spot and Great Dark Spot differ?
4. Name the Galilean moons, and explain why they are called that.
5. Why might Europa be a likely place to find extraterrestrial life?
6. What causes gaps in Saturn's rings?
7. Why are scientists interested in the atmosphere of Saturn's moon Titan?
8. What liquid is found on the surface of Titan?
9. Why is Uranus blue-green in color?
10. What is the name of Neptune's largest moon?

Further Reading / Supplemental Links

- http://www.nasa.gov/worldbook/jupiter_worldbook.html
- http://solarsystem.nasa.gov/planetselector.cfm?Object=Jupiter
- http://www.youtube.com/watch?v=5iVw72sX3Bg
- http://www.youtube.com/watch?v=iLXeUVCNoX8
- http://www.youtube.com/watch?v=29wfzotaBIg
- http://www.youtube.com/watch?v=FqX2YdnwtRc

Vocabulary

Galilean moons The four largest moons of Jupiter discovered by Galileo.

gas giants The four large outer planets composed of the gases hydrogen and helium.

Great Red Spot An enormous, oval shaped storm on Jupiter.

outer planets The four large planets beyond the asteroid belt in our solar system.

planetary rings Rings of dust and rock encircling a planet in a thin plane.

Points to Consider

- The inner planets are small and rocky, while the outer planets are large and gaseous. Why might the planets have formed into two groups like they are?
- We have discussed the Sun, the planets, and the moons of the planets. What other objects can you think of that can be found in our solar system?

1.4 Other Objects in the Solar System

Lesson Objectives

- Locate and describe the asteroid belt.
- Explain where comets come from and what causes their tails.
- Differentiate between meteors, meteoroids, and meteorites.

Introduction

When our solar system formed, most of the matter ended up in the Sun, the star at the center of the system. Material spinning in a disk around the Sun clumped together into larger and larger pieces, forming the eight planets and their moons. But some of the smaller pieces of matter in the solar system never joined one of these larger bodies. In this lesson, we will talk about some of these other objects in the solar system.

Asteroids

Asteroids are very small, rocky bodies that orbit the Sun. "Asteroid" means "star-like," and in a telescope, asteroids look like points of light, just like stars. Asteroids are also sometimes called *planetoids or minor planets,* because in some ways they are similar to miniature planets. Unlike planets, though, asteroids are irregularly shaped because they do not have enough gravity to become round like planets. They do not have atmospheres, and they are not geologically active. The only geological changes to an asteroid are due to collisions, which may break up the asteroid or create craters on the asteroid's surface. **Figure** 1.32 shows a typical asteroid.

Figure 1.32: Asteroid 951 Gaspra was the first asteroid photographed at close range. This picture was taken in 1991 by the Galileo probe on its way to Jupiter. 951 Gaspra is a medium-sized asteroid, measuring about 19 by 12 by 11 kilometers (12 by 7.5 by 7 miles).

The Asteroid Belt

Hundreds of thousands of asteroids have been discovered in our solar system. They are still being discovered at a rate of about 5,000 new asteroids per month! The majority of the asteroids are found in between the orbits of Mars and Jupiter, in a region called the **asteroid belt**, as shown in **Figure** 1.33. Although there are many thousands of asteroids in the asteroid belt, their total mass adds up to only about 4% of Earth's moon.

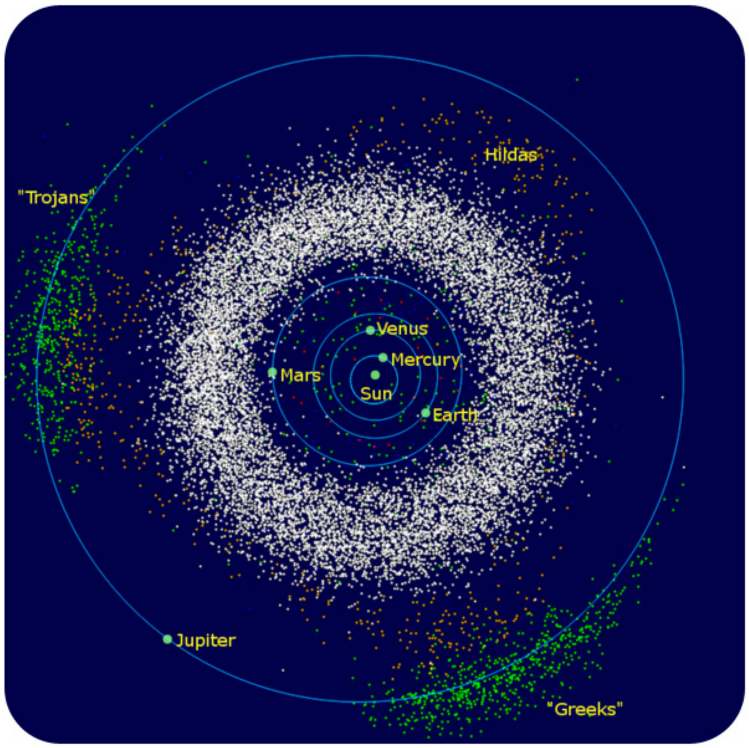

Figure 1.33: The asteroid belt is a ring of many asteroids between the orbits of Mars and Jupiter. The white dots in the figure are asteroids in the main asteroid belt. Other groups of asteroids closer to Jupiter are called the Hildas (orange), the Trojans (green), and the Greeks (also green).

Scientists believe that the bodies in the asteroid belt formed there during the formation of the solar system. However, they have never been able to form into a single planet because the gravity of Jupiter, which is very massive, continually disrupts the asteroids.

Near-Earth Asteroids

Near-Earth asteroids are asteroids whose orbits cross Earth's orbit. Any object whose orbit crosses Earth can collide with Earth. There are over 4,500 known near-Earth asteroids; between 500 and 1,000 of these are over 1 kilometer in diameter. Small asteroids do in fact collide with Earth on a regular basis—asteroids 5–10 m in diameter hit Earth on average about once per year. Evidence suggests that large asteroids hitting Earth in the past have caused many organisms to die and many species to go extinct. Astronomers are always on the lookout for new asteroids, and follow the known near-Earth asteroids closely, so they can predict a possible collision as early as possible.

Asteroid Missions

Scientists are interested in asteroids in part because knowing more about what they are made of can tell us about our solar system and how it might have formed. They may also eventually be mined for rare minerals or for construction projects in space. Some asteroids have been photographed as spacecraft have flown by on their way to the outer planets. A few missions have been sent out to study asteroids directly. In 1997, the NEAR Shoemaker probe went into orbit around an asteroid called 433 Eros, and finally landed on its surface in 2001. The Japanese Hayabusa probe is currently studying an asteroid and may return samples of its surface to Earth. In 2007, NASA launched the Dawn mission, which is scheduled to visit some of the largest asteroids in 2011-2015.

Meteors

If you have spent much time looking at the sky on a dark night, you have probably seen a 'shooting star', like in **Figure** 1.34. A shooting star is a streak of light across the sky. The proper scientific name for a shooting star is a **meteor**. Meteors are not stars at all. Rather, they are small pieces of matter burning up as they enter Earth's atmosphere from space.

Figure 1.34: This photo captures a meteor - also called a 'shooting star,' streaking across the sky to the right of the Milky Way.

Meteoroids

Before these small pieces of matter enter Earth's atmosphere, they are called **meteoroids**. Meteoroids are like asteroids, only smaller. Meteoroids range from the size of boulders down to the size of tiny sand grains. Objects larger than meteoroids are considered asteroids, and objects smaller than meteoroids are considered *interplanetary dust.* Meteoroids are sometimes found clustered together in long trails. These are remnants left behind by comets. When Earth passes through one of these clusters, there is a **meteor shower**, an increase in the number of bright meteors in a particular region of the sky for a period of time.

Meteorites

Suppose a small rocky object—a meteoroid—enters Earth's atmosphere. Friction in the atmosphere heats the object quickly so it starts to vaporize, leaving a trail of glowing gases. At this point, it has become a meteor. Most meteoroids vaporize completely before they ever reach Earth's surface, but larger meteoroids may have a small core of material that travels all the way through the atmosphere and hits the Earth's surface. The solid remains of a meteoroid found on Earth's surface is called a **meteorite**.

Meteorites provide clues about our solar system. Many meteorites come from meteoroids that formed when the solar system formed (**Figure** 1.35). Some are from the insides of asteroids that have split apart. A few meteorites are made of materials more like the rocks on Mars. Scientists believe the material in these meteorites was actually knocked off the surface of Mars by an asteroid impact, and then entered Earth's atmosphere as a meteor.

Figure 1.35: A lunar meteorite

Comets

Comets are small, icy objects that orbit the Sun in very elliptical orbits. Their orbits carry them from the outer solar system to the inner solar system, close to the Sun. When a comet gets close to the Sun, the outer layers of ice melt and evaporate. The gas and dust released in this way forms an atmosphere—called a *coma*—around the comet. Radiation and particles streaming from the Sun also push some of this gas and dust into a long *tail*, which always points away from the Sun no matter which way the comet is moving. **Figure** 1.36 shows Comet Hale-Bopp, which shone brightly for several months in 1997.

Gases in the coma and tail of a comet glow, and also reflect light from the Sun. Comets are very hard to see except when they have their comas and tails. For this reason, comets appear for only a short time when they are near the Sun, then seem to disappear again as they move back to the outer solar system. The time between one appearance of a comet and the next is called the comet's *period*. For example, the

Figure 1.36: Comet Hale-Bopp, also called the Great Comet of 1997, shone brightly for several months in 1997. The comet has two visible tails: a bright, curved dust tail and a fainter, straight tail of ions (charged atoms) pointing directly away from the Sun.

first comet whose period was known, Halley's comet, has a period of 75 years. It last traveled through the inner solar system in 1986, and will appear again in 2061.

Where Comets Come From

Comets that have periods of about 200 years or less are considered short period comets. Most short-period comets come from a region beyond the orbit of Neptune. This area, which contains not only comets but also asteroids and at least two dwarf planets, is called the *Kuiper belt.* (Kuiper is pronounced "KI-per," rhyming with "viper.")

Some comets have much longer periods, as long as thousands or even millions of years. Most long-period comets come from a very distant region of the solar system called the *Oort cloud*, which is about 50,000–100,000 AU from the Sun (50,000–100,000 times the distance from the Sun to Earth). Comets carry materials from the outer solar system to the inner solar system. Comets may have brought water and other substances to Earth during collisions early in Earth's history.

Dwarf Planets

The **dwarf planets** of our solar system are exciting proof of how much we are learning about our solar system. With the discovery of many new objects in our solar system, in 2006, astronomers refined the definition of a planet. According to the new definition, a planet must:

1. orbit a star
2. be big enough that its own gravity causes it to be shaped like a sphere
3. be small enough that it isn't a star itself
4. have cleared the area of its orbit of smaller objects

At the same time, astronomers defined a new type of object: dwarf planets. A dwarf planet is an object that meets numbers 1–3 above, but not number 4. There are four dwarf planets in our solar system: Ceres, Pluto, Makemake and Eris.

Figure 1.37 shows Ceres, a rocky, spherical body that is by far the largest object in the asteroid belt. Before 2006, Ceres was considered the largest of the asteroids. Ceres has enough mass that its gravity causes it to be shaped like a sphere. Still, Ceres only has about 1.3% of the mass of the Earth's Moon. Ceres orbits the Sun, is round and is not a star but the area of its orbit is full of other smaller bodies, so Ceres fails the fourth criterion for being a planet, and is now considered a dwarf planet.

Pluto

From the time it was discovered in 1930 until 2006, Pluto was considered the ninth planet of the solar system. However, it was always thought of as an oddball planet. Unlike the other outer planets in the solar system, which are all gas giants, it is small, icy and rocky. Its diameter is about 2400 kilometers. It is only about 1/5 the mass of Earth's Moon. Its orbit is tilted relative to the other planets and is shaped like a long, narrow ellipse, sometimes even passing inside the orbit of Neptune.

Starting in 1992, many objects have been discovered in the same area as Pluto's orbit, an area now known as the Kuiper belt. The Kuiper belt begins outside the orbit of Neptune and continues out at least 500 AU. We have discovered more than 200 million Kuiper belt objects. Pluto orbits within this region. When the definition of a planet was changed in 2006, Pluto failed the test of clearing out its orbit of other bodies, so it is now considered a dwarf planet.

Figure 1.37: This composite image compares the size of the dwarf planet Ceres to Earth and the Moon.

Pluto has 3 moons of its own. The largest, Charon, is big enough that the Pluto-Charon system is sometimes considered to be a double dwarf planet (**Figure** 1.38). Two smaller moons, Nix and Hydra, were discovered in 2005.

Makemake

Makemake is the third largest and second brightest dwarf planet we have discovered so far (**Figure** 1.38). It is about three quarters the size of Pluto. Its diameter is estimated to be between 1300 and 1900 kilometers. Makemake is named after the deity that created humanity in the mythology of the people of Easter Island. It orbits the Sun in 310 years at a distance between 38.5 to 53 AU. It is believed to be made of methane, ethane and nitrogen ices.

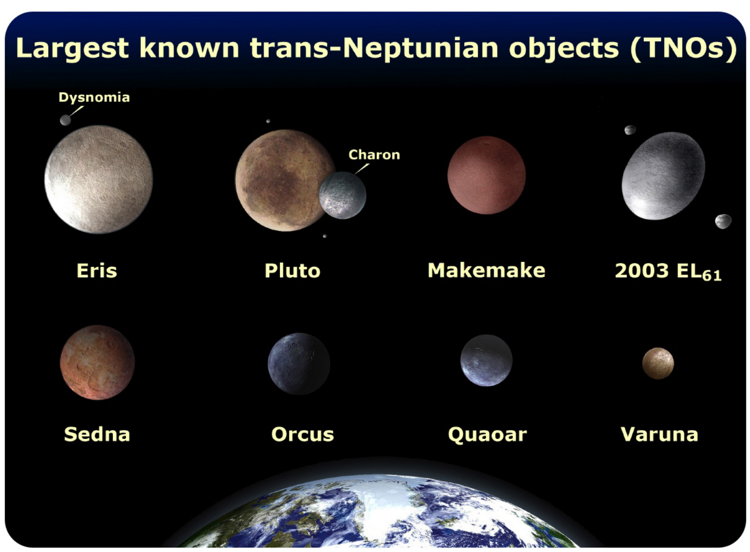

Figure 1.38: Largest Known Trans-Neptunian Objects.

Eris

Eris is the largest known dwarf planet in the solar system — about 27% more massive than Pluto (**Figure** 1.38). It was not discovered until 2003 because it is extremely far away from the Sun. Although Pluto, Makemake and Eris are in the Kuiper belt, Eris is about 3 times farther from the Sun than Pluto is, and almost 100 times farther from the Sun than Earth is. When it was first discovered, it was considered for a short time to be the "tenth planet" in the solar system. The discovery of Eris helped prompt the new definition of planets and dwarf planets in 2006. Eris also has a small moon, Dysnomia that orbits it once about every 16 days.

Astronomers already know there may be other dwarf planets in the outer reaches of the solar system. Look for Haumea, Quaoar, Varuna and Orcus to be possibly added to the list of dwarf planets in the future. We still have a lot to discover and explore!

Lesson Summary

- Asteroids are irregularly-shaped, rocky bodies that orbit the Sun. Most of them are found in the asteroid belt, between the orbits of Mars and Jupiter.
- Meteoroids are smaller than asteroids, ranging from the size of boulders to the size of sand grains. When meteoroids enter Earth's atmosphere, they vaporize, creating a trail of glowing gas called a meteor. If any of the meteoroid reaches Earth, the remaining object is called a meteorite.
- Comets are small, icy objects that orbit the Sun in very elliptical orbits. When they are close to the Sun, they form comas and tails, which glow and make the comet more visible.
- Short-period comets come from the Kuiper belt, beyond Neptune. Long-period comets come from the very distant Oort cloud.
- Dwarf planets are spherical bodies that orbit the Sun, but that have not cleared their orbit of smaller bodies. Ceres is a dwarf planet in the asteroid belt. Pluto, Makemake and Eris are dwarf planets in the Kuiper belt.

Review Questions

1. Arrange the following from smallest to largest: asteroid, star, meteoroid, planet, dwarf planet.
2. Where are most asteroids found?
3. What is the difference between a meteor, a meteoroid, and a meteorite?
4. What kind of objects would scientists study to learn about the composition of the Oort cloud?
5. Why is Pluto no longer considered a planet?
6. Name the four known dwarf planets in our solar system.

Further Reading / Supplemental Links

- http://www.nasa.gov/worldbook/asteroid_worldbook.html
- http://www.iau.org/iau0602.423.0.html
- http://en.wikipedia.org/

Vocabulary

asteroid

Rocky objects larger than a few hundred meters that orbit the Sun in the region known as the asteroid belt.

asteroid belt

Region between the orbits of Mars and Jupiter where many asteroids are found.

comet

Asmall, icy, dusty object in orbit around the Sun.

dwarf planet

Around celestial object orbiting the Sun that has not cleared its orbit of other objects.

Kuiper belt

Aregion of space around the Sun beyond the orbit of Neptune that contains millions of frozen objects.

meteor

Material from outer space that burns up as it enters Earth's atmosphere.

meteorite

The solid portion of a meteor that hits Earth's surface.

meteoroid

Asmall rock in interplanetary space that has not yet entered Earth's atmosphere.

meteor shower

An area of frequent meteors appearing to originate in a particular part of the sky.

Points to Consider

- In 2006, astronomers changed the definition of a planet and created a new category of dwarf planets. Do you think planets, dwarf planets, moons, asteroids, and meteoroids are clearly separate groups?
- What defines each of these groups, and what do objects in these different groups have in common? Could an object change from being in one group to another? How?
- We have learned about many different kinds of objects that are found within our solar system. What objects or systems of objects can you think of that are found outside our solar system?

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