CK-12

flexbook
next generation textbooks

8: Astronomy v2

8: Astronomy

Laura Enama
Colleen Haag
Julie Sandeen

To access a customizable version of this book, as well as other interactive content, visit www.ck12.org

CK-12 Foundation is a non-profit organization with a mission to reduce the cost of textbook materials for the K-12 market both in the U.S. and worldwide. Using an open-source, collaborative, and web-based compilation model, CK-12 pioneers and promotes the creation and distribution of high-quality, adaptive online textbooks that can be mixed, modified and printed (i.e., the FlexBook® textbooks).

Printed: October 14, 2015

flexbook
next generation textbooks

AUTHORS
Laura Enama
Colleen Haag
Julie Sandeen

CONTRIBUTORS
David Bethel
Mary Lusk

Contents

CHAPTER 1 Observing and Exploring Space

Chapter Outline

Since the 1970s, the National Aeronautics and Space Administration (NASA) has used space shuttles like the one pictured above to move astronauts to and from space stations orbiting the Earth. From landing on the Moon to building the International Space Station, these scientists have helped improve our understanding of space by observing and exploring it. But it's possible to study our solar system and beyond without ever leaving the ground! Thanks to telescopes, observatories, and satellites, we learn more about space every day.

Steve Jurvetson. www.flickr.com/photos/jurvetson/1055810551/. CC BY 2.0.

1.1 Telescopes

Lesson Objectives

- Explain how astronomers use light to study the universe beyond Earth.
- Describe some different types of telescopes.
- Discuss what we have learned by using telescopes.

Vocabulary

- constellation
- electromagnetic radiation
- electromagnetic spectrum
- frequency
- gamma rays
- infrared light
- light-year
- microwaves
- planet
- radio telescope
- radio waves
- reflecting telescope
- refracting telescope
- space telescope
- spectrometer
- ultraviolet
- wavelength
- visible light
- X rays

Introduction

Many scientists can touch the materials they study. Most can do experiments to test those materials. Biologists can collect cells, seeds, or sea urchins to study in the laboratory. Physicists can test the strength of metal or smash atoms into each other. Geologists can chip away at rocks and test their chemistry. But astronomers study the universe far beyond Earth. They have to observe their subjects at a very large distance! A meteorite that lands on Earth is one of the few actual objects that astronomers could study.

Electromagnetic Spectrum

Earth is just a tiny speck in the universe. Our planet is surrounded by lots of space. Light travels across empty space. Astronomers can study light from stars to learn about the universe. Light is the visible part of the **electromagnetic spectrum**. Astronomers use the light that comes to us to gather information about the universe.

The Speed of Light

In space, light travels at about 300,000,000 meters per second (670,000,000 miles per hour). How fast is that? A beam of light could travel from New York to Los Angeles and back again nearly 40 times in just one second. Even at that amazing rate, objects in space are so far away that it takes a lot of time for their light to reach us. Even light from the nearest star, our Sun, takes about 8 minutes to reach Earth.

Light-Years

We need a really big unit to measure distances out in space because distances between stars are so great. A **light-year**, 9.5 trillion kilometers (5.9 trillion miles), is the distance that light travels in one year. That's a long way! Out in space, it's actually a pretty short distance.

Proxima Centauri is the closest star to us after the Sun. This near neighbor is 4.22 light-years away. That means the light from Proxima Centauri takes 4.22 years to reach us. Our galaxy, the Milky Way Galaxy, is about 100,000 light-years across. So it takes light 100,000 years to travel from one side of the galaxy to the other! It turns out that even 100,000 light years is a short distance. The most distant galaxies we have detected are more than 13 billion light-years away. That's over a hundred-billion-trillion kilometers!

Looking Back in Time

When we look at stars and galaxies, we are seeing over great distances. More importantly, we are also seeing back in time. When we see a distant galaxy, we are actually seeing how the galaxy used to look. For example, the Andromeda Galaxy, shown in **Figure** 1.1, is about 2.5 million light-years from Earth. When you see an image of the galaxy what are you seeing? You are seeing the galaxy as it was 2.5 million years ago!

Since scientists can look back in time they can better understand the Universe's history. Check out http://science.nasa.gov/headlines/y2002/08feb_gravlens.htm to see how this is true.

Electromagnetic Waves

Light is one type of **electromagnetic radiation**. Light is energy that travels in the form of an electromagnetic wave. **Figure** 1.2 shows a diagram of an electromagnetic wave. An electromagnetic (EM) wave has two parts: an electric field and a magnetic field. The electric and magnetic fields vibrate up and down, which makes the wave.

The **wavelength** is the horizontal distance between two of the same points on the wave, like wave crest to wave crest. A wave's **frequency** measures the number of wavelengths that pass a given point every second. As wavelength increases, frequency decreases. This means that as wavelengths get shorter, more waves move past a particular spot in the same amount of time.

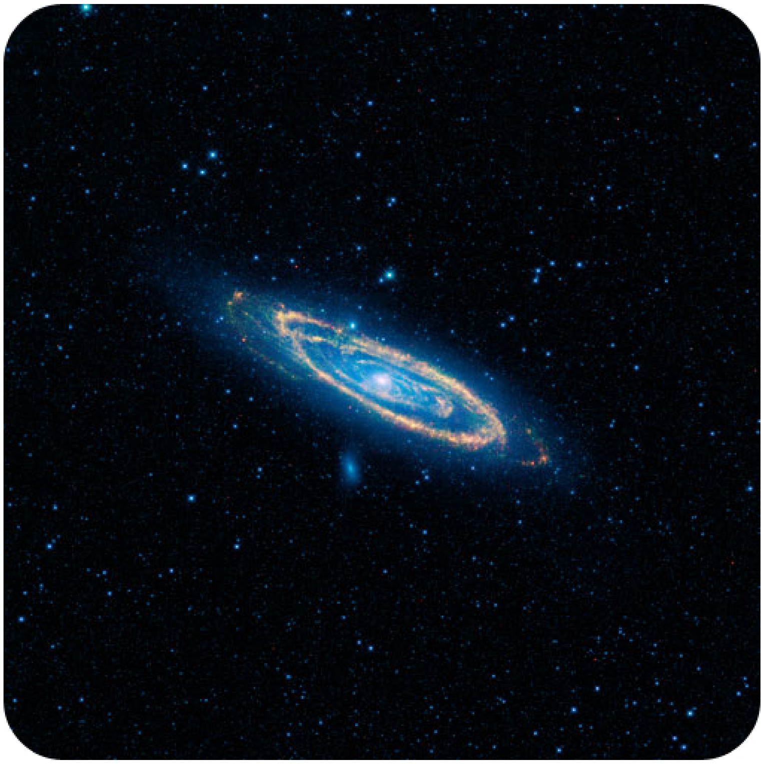


FIGURE 1.1
The Andromeda Galaxy as it appeared 2.5 million years ago. How would you find out how it looks right now?

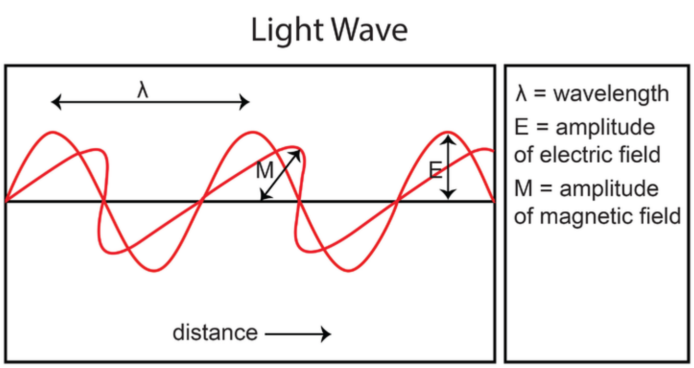


FIGURE 1.2
An electromagnetic wave has oscillating electric and magnetic fields.

The Electromagnetic Spectrum

Visible light is the part of the electromagnetic spectrum (**Figure** 1.3) that humans can see. Visible light includes all the colors of the rainbow. Each color is determined by its wavelength. Visible light ranges from violet wavelengths of 400 nanometers (nm) through red at 700 nm.

There are parts of the electromagnetic spectrum that humans cannot see. This radiation exists all around you. You just can't see it! Every star, including our Sun, emits radiation of many wavelengths. Astronomers can learn a lot from studying the details of the spectrum of radiation from a star.

Many extremely interesting objects can't be seen with the unaided eye. Astronomers use telescopes to see objects at wavelengths all across the electromagnetic spectrum. Some very hot stars emit light primarily at **ultraviolet**

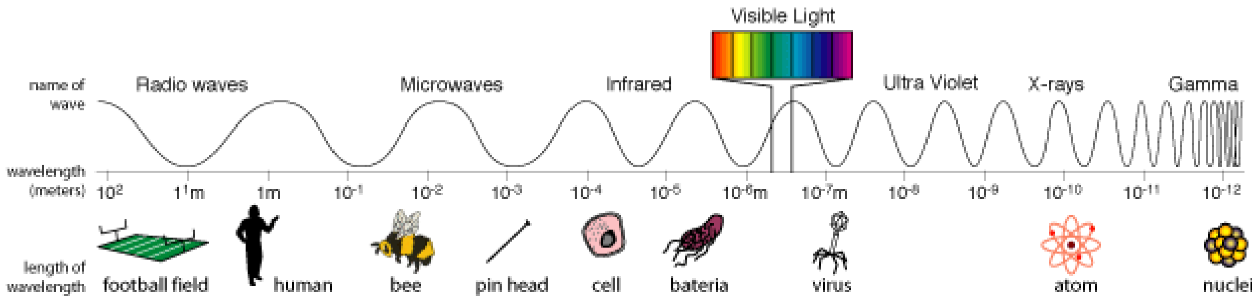


FIGURE 1.3

The electromagnetic spectrum from radio waves to gamma rays.

wavelengths. There are extremely hot objects that emit **X-rays** and even **gamma rays**. Some very cool stars shine mostly in the **infrared light** wavelengths. **Radio waves** come from the faintest, most distant objects.

To learn more about stars' spectra, visit http://www.colorado.edu/physics/PhysicsInitiative/Physics2000/quantumzone/ .

Types of Telescopes

Optical Telescopes

Humans have been making and using magnifying lenses for thousands of years. The first telescope was built by Galileo in 1608. His telescope used two lenses to make distant objects appear both nearer and larger.

Telescopes that use lenses to bend light are called **refracting telescopes**, or refractors (**Figure** 1.4). The earliest telescopes were all refractors. Many amateur astronomers still use refractors today. Refractors are good for viewing details within our solar system. Craters on the surface of Earth's Moon or the rings around Saturn are two such details.

Around 1670, Sir Isaac Newton built a different kind of telescope. Newton's telescope used curved mirrors instead of lenses to focus light. This type of telescope is called a **reflecting telescope**, or reflector (see **Figure** 1.5). The mirrors in a reflecting telescope are much lighter than the heavy glass lenses in a refractor. This is important because a refracting telescope must be much stronger to support the heavy glass.

It's much easier to precisely make mirrors than to precisely make glass lenses. For that reason, reflectors can be made larger than refractors. Larger telescopes can collect more light. This means that they can study dimmer or more distant objects. The largest optical telescopes in the world today are reflectors. Telescopes can also be made to use both lenses and mirrors.

For more on how telescopes were developed, visit http://galileo.rice.edu/sci/instruments/telescope.html .

Radio Telescopes

Radio telescopes collect radio waves. These telescopes are even larger telescopes than reflectors. Radio telescopes look a lot like satellite dishes. In fact, both are designed to collect and focus radio waves or microwaves from space.

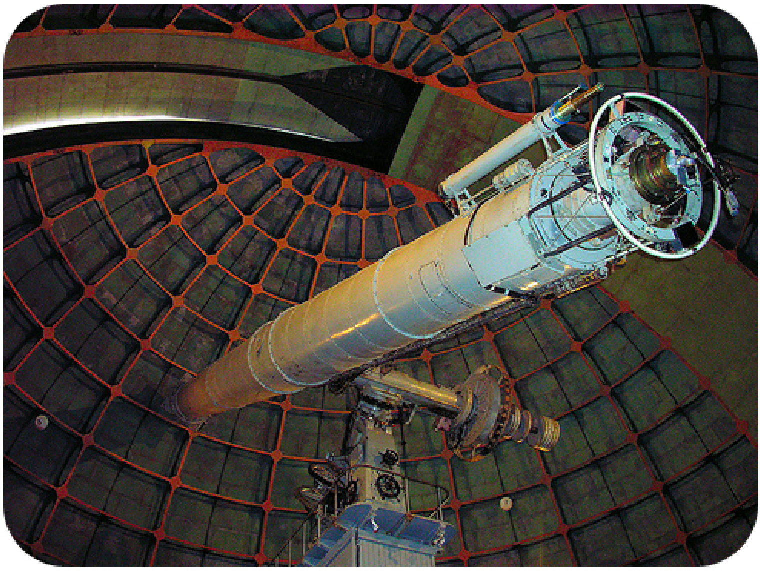


FIGURE 1.4
Refracting telescopes can be very large.

FIGURE 1.5
Newtonian reflector telescopes are fairly easy to make. These telescopes can be built by school students.

The largest single radio telescope in the world is at the Arecibo Observatory in Puerto Rico (see **Figure** 1.6). This telescope is located in a natural sinkhole. The sinkhole formed when water flowing underground dissolved the limestone. This telescope would collapse under its own weight if it were not supported by the ground. There is a big disadvantage to this design. The telescope can only observe the part of the sky that happens to be overhead at a given time.

A group of radio telescopes can be linked together with a computer. The telescopes observe the same object. The computer then combines the data from each telescope. This makes the group function like one single telescope. An example is shown in **Figure** 1.7.

To learn more about radio telescopes and radio astronomy in general, go to http://www.nrao.edu/whatisra/index.shtml .

FIGURE 1.6
The radio telescope at the Arecibo Observatory in Puerto Rico.

FIGURE 1.7
The Very Large Array in New Mexico consists of 27 radio telescopes.

Space Telescopes

Telescopes on Earth all have one big problem: Incoming light must pass through the atmosphere. This blocks some wavelengths of radiation. Also, motion in the atmosphere distorts light. You see this when you see stars twinkling in the night sky. Many observatories are built on high mountains. There is less air above the telescope, so there is less interference from the atmosphere. **Space telescopes** avoid such problems completely since they orbit outside the atmosphere.

The Hubble Space Telescope is the best known space telescope. Hubble is shown in **Figure** 1.8. Hubble began operations in 1994. Since then it has provided huge amounts of data. The telescope has helped astronomers answer many of the biggest questions in astronomy.

The National Aeronautics and Space Administration (NASA) has placed three other major space telescopes in orbit. Each uses a different part of the electromagnetic spectrum. The James Webb Space Telescope will launch in 2014.

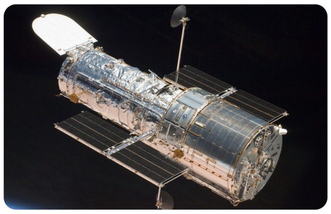


FIGURE 1.8
The Hubble Space Telescope has opened up the universe to human observation.

The telescope will replace the aging Hubble.

To learn more about NASA's great observatories, check out http://www.nasa.gov/audience/forstudents/postsecondary/features/F_NASA_Great_Observatories_PS.html .

FIGURE 1.9
Stars in the star cluster appear as points of light. Observations like these must be made with a space telescope.

Observations with Telescopes

Before Telescopes

Humans have been studying the night sky for thousands of years. Knowing the motions of stars helped people keep track of seasons. With this information they could know when to plant crops. Stars were so important that the patterns they made in the sky were named. These patterns are called **constellations**. Even now, constellations help astronomers know where they are looking in the night sky.

The ancient Greeks carefully observed the locations of stars in the sky. They noticed that some of the "stars" moved across the background of other stars. They called these bright spots in the sky **planets**. The word in Greek means "wanderers." Today we know that the planets are not stars. They are objects in the solar system that orbit the Sun. Ancient astronomers made all of their observations without the aid of a telescope.

Galileo's Observations

In 1610, Galileo looked at the night sky through the first telescope. This tool allowed him to make the following discoveries (among others):

- There are more stars in the night sky than the unaided eye can see.
- The band of light called the Milky Way consists of many stars.
- The Moon has craters (see **Figure** 1.10).
- Venus has phases like the Moon.

- Jupiter has moons orbiting around it.
- There are dark spots that move across the surface of the Sun.

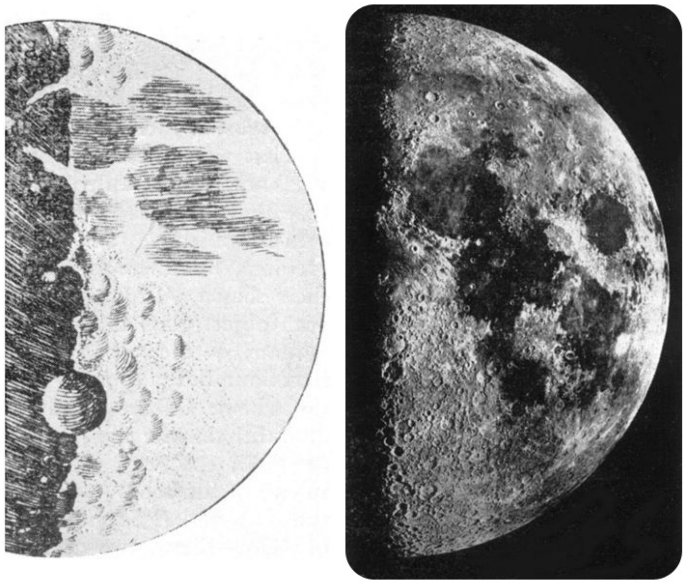


FIGURE 1.10
Galileo made the drawing on the left in 1610. On the right is a modern photograph of the Moon.

Galileo's observations made people think differently about the universe. They made them think about the solar system and Earth's place in it. Until that time, people believed that the Sun and planets revolved around Earth. One hundred years before Galileo, Copernicus had said that the Earth and the other planets revolved around the Sun. No one would believe him. But Galileo's observations through his telescope proved that Copernicus was right.

Observations with Modern Telescopes

Galileo's telescope got people to think about the solar system in the right way. Modern tools have also transformed our way of thinking about the universe. Imagine this: Today you can see all of the things Galileo saw using a good pair of binoculars. You can see sunspots if you have special filters on the lenses. (Never look directly at the Sun without using the proper filters!) With the most basic telescope, you can see polar caps on Mars, the rings of Saturn, and bands in the atmosphere of Jupiter.

You can see many times more stars with a telescope than without a telescope. Still, stars seen in a telescope look like single points of light. They are so far away. Only the red supergiant star Betelgeuse is large enough to appear as a disk. Except for our Sun, of course.

Today, astronomers attach special instruments to telescopes. This allows them to collect a wide variety of data. The data is fed into computers so that it can be studied. An astronomer may take weeks to analyze all of the data collected from just a single night!

Studying Starlight with Spectrometers

A **spectrometer** is a special tool that astronomers commonly use. Spectrometers allow them to study the light from a star or galaxy. A spectrometer produces a spectrum, like the one shown in **Figure** 1.11. A prism breaks light into all its colors. Gases from the outer atmosphere of a star absorb light. This forms dark lines in the spectrum. These dark lines reveal what elements the star contains.

Astronomers use the spectrum to learn even more about the star. One thing they learn is how hot the star is. They also learn the direction the star is going and how fast. By carefully studying light from many stars, astronomers

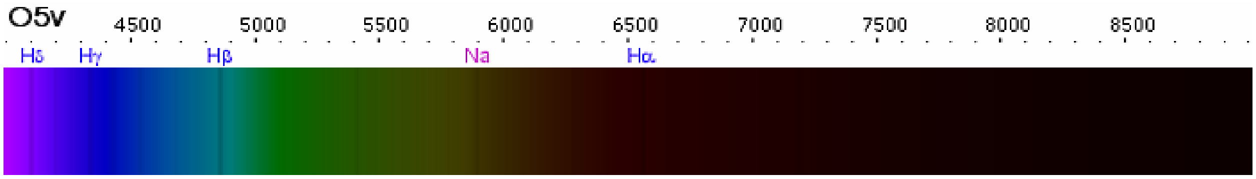


FIGURE 1.11
The dark lines indicate the elements that this star contains.

know how stars evolve. They have learned about the distribution and kinds of matter found throughout the universe. They even know something about how the universe might have formed.

To find out what you can expect to see when looking through a telescope, check out http://www.astronomics.com/main/category.asp/catalog_name/Astronomics/category_name/V1X41SU50GJB8NX88JQB360067/Page/1 .

Lesson Summary

- Astronomers study light from stars and galaxies.
- Light travels at 300,000,000 meters per second—faster than anything else in the universe.
- A light-year is a unit of distance equal to the distance light travels in one year, 9.5 trillion kilometers.
- When we see a star or galaxy, we see them as they were in the past, because their light has been traveling to us for many years.
- Light is energy that travels as a wave.
- Visible light is part of the electromagnetic spectrum.
- Telescopes make distant objects appear both nearer and larger. You can see many more stars through a telescope than with the unaided eye.
- Optical telescopes are designed to collect visible light. The two types of optical telescopes are reflecting telescopes and refracting telescopes.
- Radio telescopes collect and focus radio waves from distant objects.
- Space telescopes are telescopes orbiting Earth. They can collect wavelengths of light that are normally blocked by the atmosphere.
- Galileo was the first person known to use a telescope to study the sky. His discoveries helped change the way humans think about the universe.
- Modern telescopes collect data that can be stored on a computer.
- A spectrometer produces a spectrum from starlight. Astronomers can learn a lot about a star by studying its spectrum.

Lesson Review Questions

Recall

1. Define what is one “light year.” What is a light year in numbers? Don’t forget the units!

2. What is the speed of light? Why is this important to astronomers?

3. How do refracting telescopes work?

4. What are constellations? Why were they important to ancient people?

5. What did Galileo observe about Jupiter?

Apply Concepts

6. Picture the visible light spectrum. Where do ultraviolet wavelengths fall? Where do infrared wavelengths fall?

7. You look through a telescope at Rigel. Rigel is the brightest star in the Orion constellation. Rigel is around 800 light years from Earth. What are you looking at when you look through that telescope? What does Rigel look like today?

8. What can you learn from studying starlight through a spectrometer?

Think Critically

9. Why do astronomers need to look at more than just visible objects when studying space? What can they learn from objects in other wavelengths of radiation?

10. Identify four regions of the electromagnetic spectrum that astronomers use when observing objects in space.

11. How do reflecting telescopes work? What are the advantages and disadvantages of reflecting telescopes over refracting telescopes?

12. If you wanted to study the most distant galaxies what sort of tool would you design and why?

Points to Consider

- Radio waves are used for communicating with spacecraft. A round-trip communication from Earth to Mars takes anywhere from 6 to 42 minutes. What challenges might this present for sending unmanned spacecraft and probes to Mars?
- The Hubble Space Telescope is a very important source of data for astronomers. The fascinating and beautiful images from the Hubble also help to maintain public support for science. However, the Hubble is growing old. Missions to service and maintain the telescope are extremely expensive and put the lives of astronauts at risk. Do you think there should be another servicing mission to the Hubble?

1.2 Early Space Exploration

Lesson Objectives

- Describe different types of satellites.
- Outline major events in early space exploration, including the Space Race.

Vocabulary

- orbit
- satellite
- Space Race

Introduction

Telescopes made objects in space seem closer. But they didn't make it any easier to visit them. Human space flight required something entirely different: rockets.

Satellites

One of the first uses of rockets in space was to launch satellites. A **satellite** is an object that orbits a larger object. An **orbit** is a circular or elliptical path around an object. Natural objects in orbit are called natural satellites. The Moon is a natural satellite. Human-made objects in orbit are called artificial satellites. There are more and more artificial satellites orbiting Earth all the time. They all get into space using some sort of rocket.

How Satellites Stay in Orbit

Why do satellites stay in orbit? Why don't they crash into Earth due to the planet's gravity? Newton's law of universal gravitation describes what happens. Every object in the universe is attracted to every other object. Gravity makes an apple fall to the ground. Gravity also keeps you from floating away into the sky. Gravity holds the Moon in orbit around Earth. It keeps Earth in orbit around the Sun.

Newton used an example to explain how gravity makes orbiting possible. Imagine a cannonball launched from a high mountain, as shown in **Figure** 1.12. If the cannonball is launched at a slow speed, it will fall back to Earth. This is shown as paths (A) and (B). Something different happens if the cannonball is launched at a fast speed. The Earth below curves away at the same rate that the cannonball falls. The cannonball then goes into a circular orbit, as in path (C). If the cannonball is launched even faster, it could go into an elliptical orbit (D). It might even leave Earth's gravity and go into space (E).

Unfortunately, Newton's idea would not work in real life. A cannonball launched at a fast speed from Mt. Everest would not go into orbit. The cannonball would burn up in the atmosphere. However, a rocket can launch straight up, then steer into orbit. It won't burn up in the orbit. A rocket can carry a satellite above the atmosphere and then release the satellite into orbit.

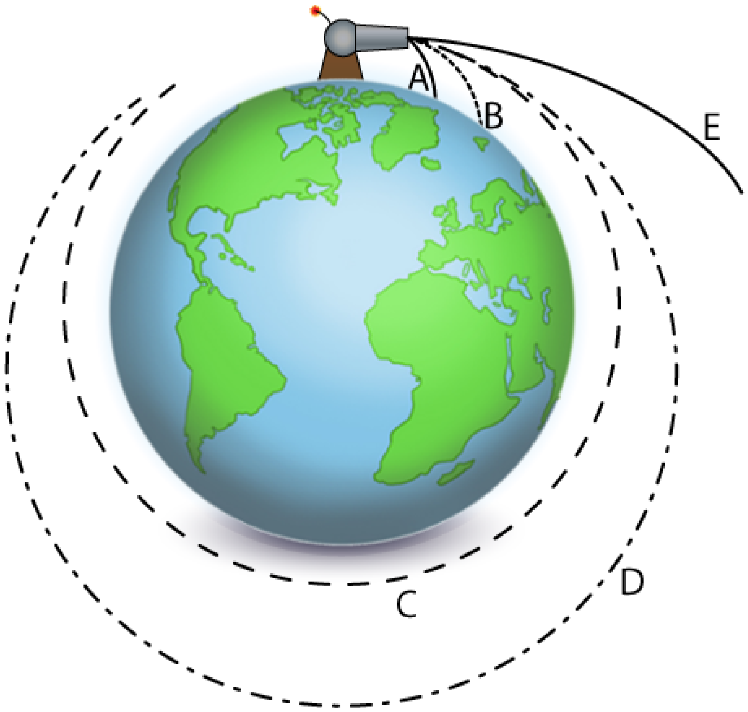


FIGURE 1.12
Isaac Newton explained how a cannonball fired from a high point with enough speed could orbit Earth.

Types of Satellites

The first artificial satellite was launched just over 50 years ago. Thousands are now in orbit around Earth. Satellites have orbited other objects in the solar system. These include the Moon, the Sun, Venus, Mars, Jupiter, and Saturn. Satellites have many different purposes.

- Imaging satellites take pictures Earth's surface. These images are used for military or scientific purposes.
- Astronomers use imaging satellites to study and make maps of the Moon and other planets.
- Communications satellites, such as the one in **Figure** 1.13, are now extremely common. These satellites receive and send signals for telephone, television, or other types of communications.
- Navigational satellites are used for navigation systems, such as the Global Positioning System (GPS).
- The largest artificial satellite is the International Space Station. The ISS is designed for humans to live in space while conducting scientific research.

Earth Science Satellites

Dozens of satellites collect data about the Earth. One example is NASA's Landsat satellites. These satellites make detailed images of Earth's continents and coastal areas. Other satellites study the oceans, atmosphere, polar ice sheets, and other Earth systems. This data helps us to monitor climate change. Other long-term changes in the planet are also best seen from space. Satellite images help scientists understand how Earth's systems affect one another. Different satellites monitor different wavelengths of energy, as in **Figure** 1.14.

Types of Orbits

Satellites have different views depending on their orbit. Satellites may be put in a low orbit. These satellites orbit from north to south over the poles. These satellites view a different part of Earth each time they circle. Imaging and

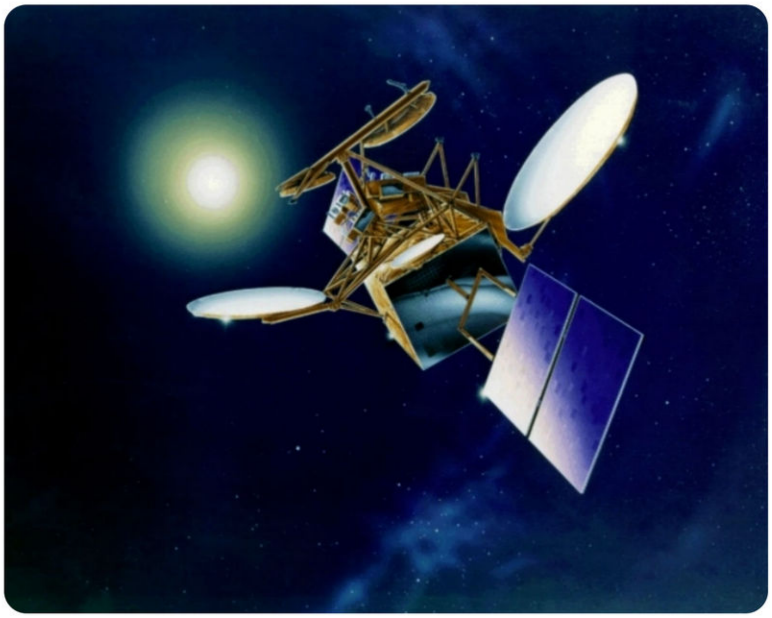


FIGURE 1.13
Communications satellites carry solar panels to provide energy for their missions.

weather satellites need this type of view.

Satellite may be placed so that they orbit at the same rate the Earth spins. The satellite then remains over the same location on the surface. Communications satellites are often placed in these orbits.

The Space Race

The Cold War was between the Soviet Union (USSR) and the United States. The war lasted from the end of World War II in 1945 to the breakup of the USSR in 1991. The hallmark of the Cold War was an arms race. The two nations spared no expense to create new and more powerful weapons. The development of better missiles fostered better rocket technologies.

Sputnik

The USSR launched Sputnik 1 on October 4, 1957. This was the first artificial satellite ever put into orbit. Sputnik 1, shown in **Figure** 1.15, sent out radio signals, which were detected by scientists and amateur radio operators around the world. The satellite stayed in orbit for about 3 months, until it burned up as a result of friction with Earth's atmosphere.

The launch of Sputnik 1 started the **Space Race** between the USSR and the USA. Americans were shocked that the Soviets had the technology to put the satellite into orbit. They worried that the Soviets might also be winning the arms race. On November 3, 1957, the Soviets launched Sputnik 2. This satellite carried the first living creature into orbit, a dog named Laika.

The Race Is On

In response to Sputnik program, the U.S. launched two satellites. Explorer I was launched on January 31, 1958 and Vanguard 1 on March 17, 1958. National Aeronautics and Space Administration (NASA) was established that same year.

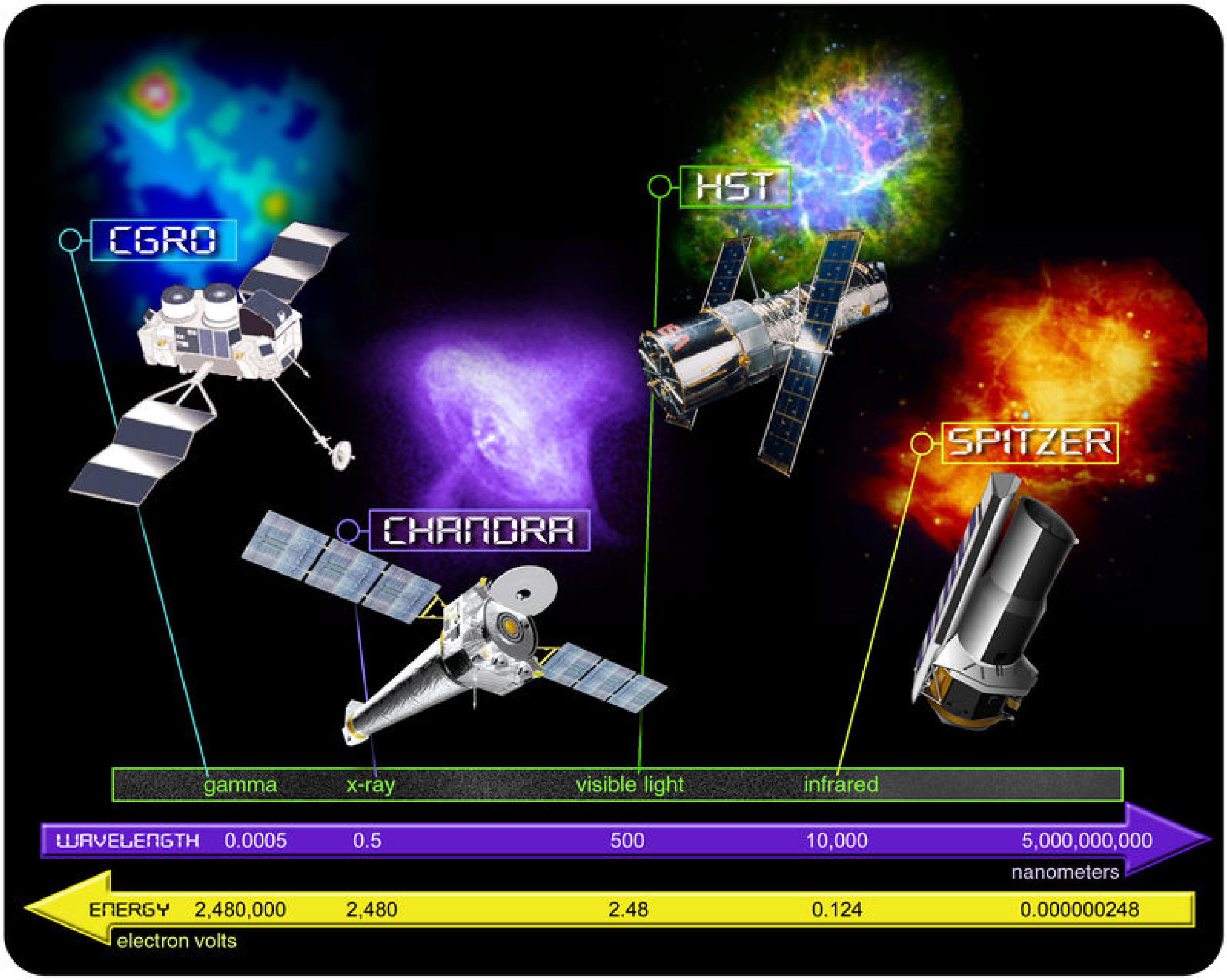


FIGURE 1.14

Satellites detect different wavelengths of energy. This means that they can find different types of objects.

The race was on! On April 12, 1961, a Soviet cosmonaut became the first human in space and in orbit. Less than one month later — May 5, 1961 — the U.S. sent its first astronaut into space: Alan Shepherd. The first American in orbit was John Glenn, in February 1962. And on it went.

Reaching the Moon

On May 25, 1961, President John F. Kennedy challenged the U.S. Congress:

"I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him back safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."

The Soviets were also trying to reach the Moon. Who would win? The answer came eight years after Kennedy's challenge, on July 20, 1969. NASA's Apollo 11 mission put astronauts Neil Armstrong and Buzz Aldrin on the

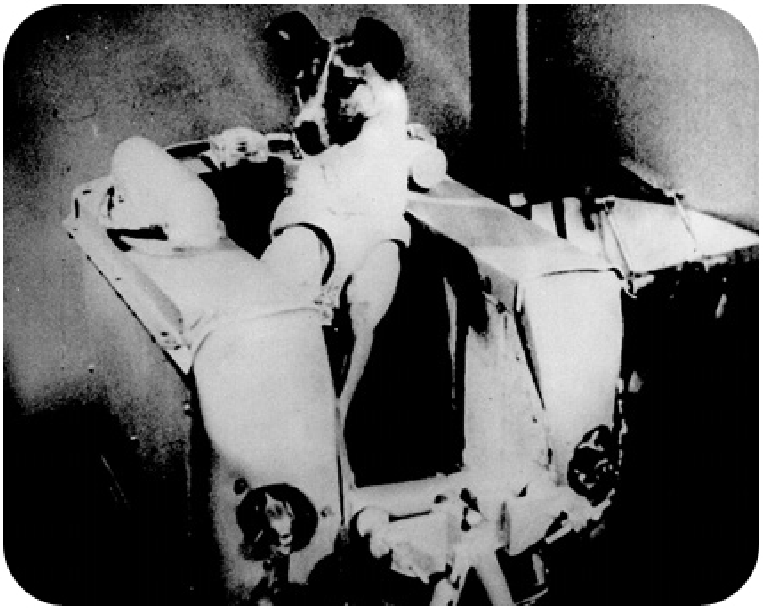


FIGURE 1.15
Laika went into orbit on the Soviet spacecraft, Sputnik 2.

Moon, as shown in **Figure** 1.16.

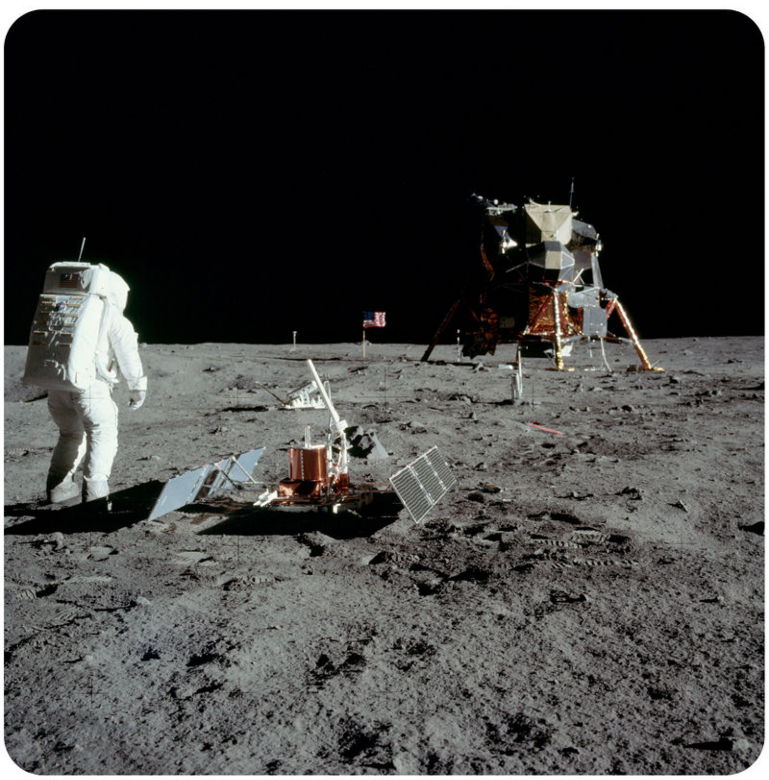


FIGURE 1.16
Apollo 11 astronaut Buzz Aldrin with the Lunar Module "Eagle" and the American flag in the background. The photo was taken by Commander Neil Armstrong.

A total of five American missions put astronauts on the Moon. The last was Apollo 17. This mission landed on December 11, 1972. No other country has yet put a person on the Moon. Today, most space missions are done by nations working together.

Exploring Other Planets

Both the United States and the Soviet Union sent space probes to other planets. A **space probe** is an unmanned spacecraft. The craft collects data by flying near or landing on an object in space. This could be a planet, moon, asteroid, or comet. The USSR sent several probes to Venus in the Venera missions. Some landed on the surface and sent back data. The U.S. sent probes to Mercury, Venus, and Mars in the Mariner missions. Two probes landed on Mars during the Viking missions.

The U.S. also sent probes to the outer solar system. These probes conducted fly-bys of Jupiter, Saturn, Uranus, and Neptune. The Pioneer and Voyager probes are now out beyond the edges of our solar system. We have lost contact with the two Pioneer probes. We hope to maintain contact with the two Voyager probes until at least 2020.

Lesson Summary

- A satellite orbits a larger object. Moons are natural satellites. Artificial satellites are made by humans.
- Newton's law of universal gravitation explains how the force of gravity works, both on Earth and across space. Gravity holds satellites in orbit.
- Artificial satellites are used to take pictures of Earth and other planets, for navigation, and for communication.
- The launch of the Sputnik 1 satellite started the Space Race between the United States and the Soviet Union.
- The United States' Apollo 11 mission put the first humans on the Moon.
- The U.S. and Soviet Union also sent several probes to other planets.

Lesson Review Questions

Apply Concepts

6. What is the value of satellites that can take images all around Earth within hours of each other?

7. What is the value of satellites that can remain in place over time?

Think Critically

9. It's common to hear someone say "if we can put a man on the Moon we can do xxx." What might xxx be? What are they saying when they make this statement?

Points to Consider

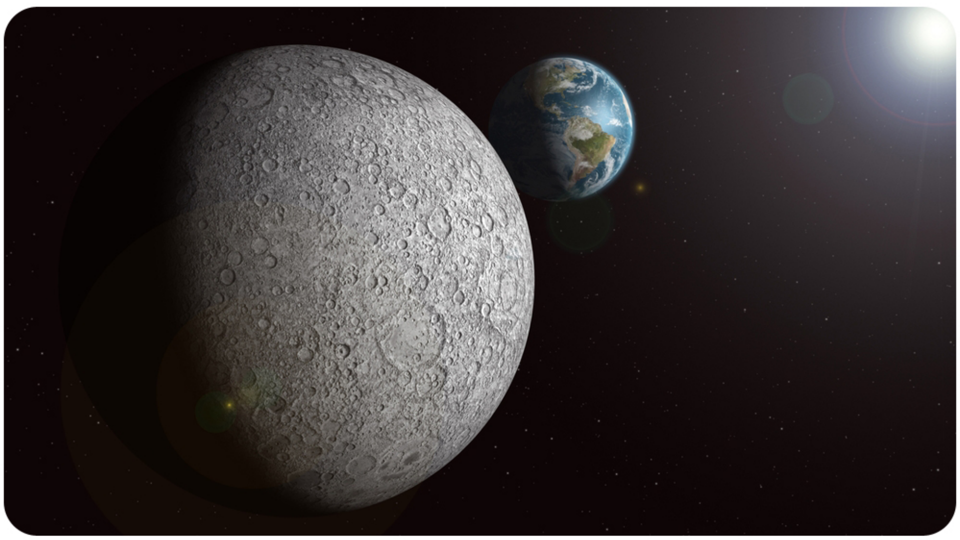
- The Space Race and the USA's desire to get to the Moon brought about many advances in science and technology. Can you think of any challenges we face today that are, could be, or should be a focus of science and technology?
- If you were in charge of NASA, what new goals would you set for space exploration?

1.3 References

1. Courtesy of NASA/JPL-Caltech/UCLA. http://www.nasa.gov/mission_pages/WISE/multimedia/pia12832-c.html . Public Domain
2. Rupali Raju. CK-12 Foundation . CC BY-NC 3.0
3. Courtesy of NASA. http://science.hq.nasa.gov/kids/imagers/ems/waves3.html . Public Domain
4. Flickr:the_tahoe_guy. http://www.flickr.com/photos/the_tahoe_guy/3130169128/ . CC BY 2.0
5. User:Gil-Estel/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:150mm_Texereau_telescope_-n1.jpg . CC BY 2.5
6. Courtesy of H. Schweiker/WIYN and NOAO/AURA/NSF. http://commons.wikimedia.org/wiki/File:Arecibo_-Observatory_Aerial_View.jpg . Public Domain
7. Flickr:mnchilemom. http://www.flickr.com/photos/50228879@N00/6335305177/ . CC BY 2.0
8. Courtesy of NASA. http://hubble.nasa.gov/multimedia/wallpaper.php . Public Domain
9. ESO. http://commons.wikimedia.org/wiki/File:ESO-RCW_38.jpg . CC BY 3.0
10. The Moon as drawn by Galileo Galilei and published in "Sidereus Nuncius" in 1610; composition made by ECeDee. http://commons.wikimedia.org/wiki/File:Galileos_Moon.jpg . Public Domain
11. User:Gypaete/Fr.Wikipedia. http://commons.wikimedia.org/wiki/File:O5v-spectre.png . Public Domain
12. Zachary Wilson and Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
13. Courtesy of NASA. http://www.nasa.gov/centers/glenn/multimedia/artgallery/art_feature_006_ACTS.html . Public Domain
14. Courtesy of NASA. http://www.nasa.gov/audience/forstudents/postsecondary/features/F_NASA_Great_Observatories_PS.html . Public Domain
15. Courtesy of NASA. http://history.nasa.gov/sputnik/gallerysput.html . Public Domain
16. Courtesy of Neil Armstrong/NASA. http://commons.wikimedia.org/wiki/File:Aldrin_with_experiment.jpg . Public Domain

CHAPTER 2 Earth, Moon, and Sun

Chapter Outline



From out in the solar system, Earth and Moon appear as one dot of light. The two bodies are linked tightly together by their mutual gravitational attraction. Yet they could hardly look more different. One reveals nothing but craters, geologically dead. The other is covered with blue oceans, swirling clouds, and lands that vary from brown to bright green. Despite their differences, the two bodies have a shared history. Moon was born from Earth's side! Both of these bodies share the same spot in space, a spot as the 3rd object out from the Sun. The Sun may be an ordinary star, but it reveals all sorts of wonders for the interested observer.

2.1 Planet Earth

Lesson Objectives

- Describe some of the characteristics of Earth.
- Describe how gravity affects Earth in the solar system.
- Explain Earth's magnetism, and its effects.
- Describe Earth's rotation on its axis.
- Describe Earth's revolution around the Sun.

Vocabulary

- axis
- gravity
- magnetic field
- revolution
- rotation

Introduction

This section is called *Planet Earth*. Isn't that what nearly this whole book has been about so far? Yes! In this section we will look at Earth as a planet. Some information will be review from other chapters. Some will be new information.

Earth's Gravity

Earth and Moon orbit each other. This Earth-Moon system orbits the Sun in a regular path (**Figure** 2.1). **Gravity** is the force of attraction between all objects. Gravity keeps the Earth and Moon in their orbits. Earth's gravity pulls the Moon toward Earth's center. Without gravity, the Moon would continue moving in a straight line off into space.

All objects in the universe have a gravitational attraction to each other (**Figure** 2.2). The strength of the force of gravity depends on two things. They are the mass of the objects and the distance between them. The greater the objects' mass, the greater the force of attraction. As the distance between the objects increases, the force of attraction decreases.

Earth's Magnetism

Earth has a **magnetic field** (**Figure** 2.3). The magnetic field has north and south poles. The field extends several thousand kilometers into space. Earth's magnetic field is created by the movements of molten metal in the outer core.

Earth's magnetic field shields us from harmful radiation from the Sun (**Figure** 2.4).

If you have a large bar magnet, you can hang it from a string. Then watch as it aligns itself in a north-south direction, in response to Earth's magnetic field. A compass needle also aligns with Earth's magnetic field. People can navigate by finding magnetic north (**Figure** 2.5).

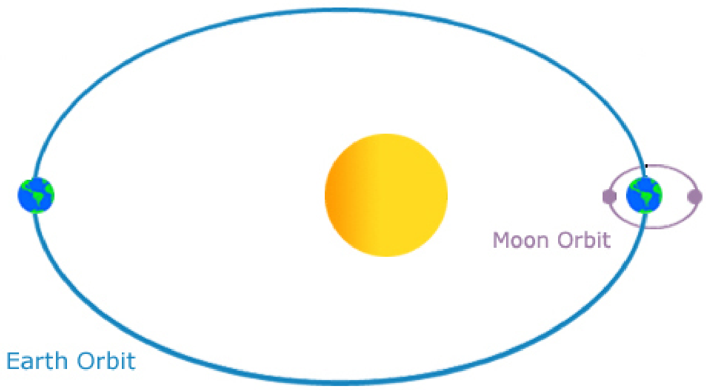


FIGURE 2.1
The Moon orbits the Earth, and the Earth-Moon system orbits the Sun.

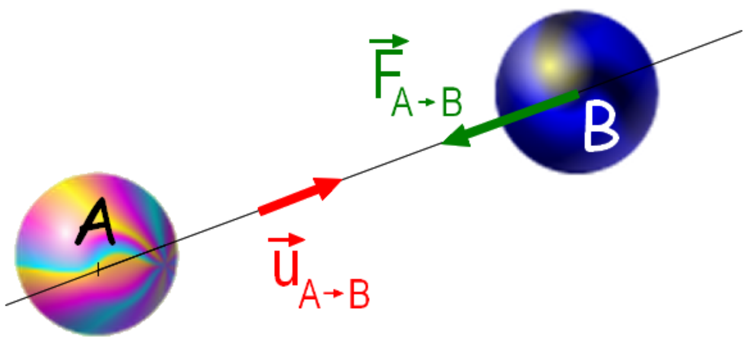


FIGURE 2.2
The strength of the force of gravity between objects A and B depends on the mass of the objects and the distance (*u*) between them.

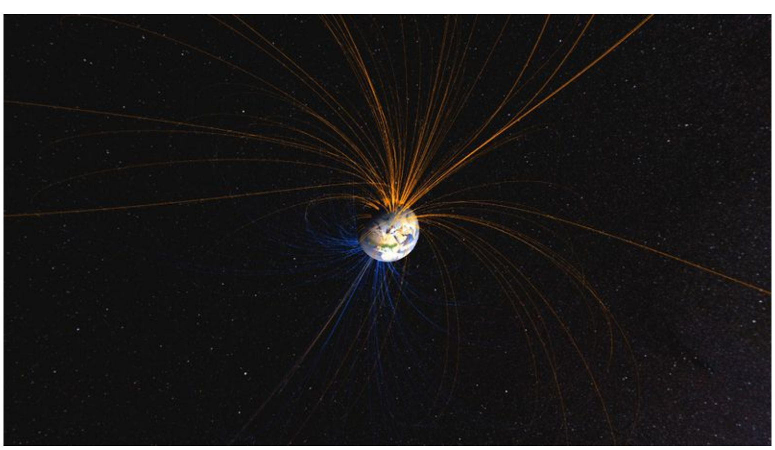


FIGURE 2.3
Earth's magnetic field extends into space.

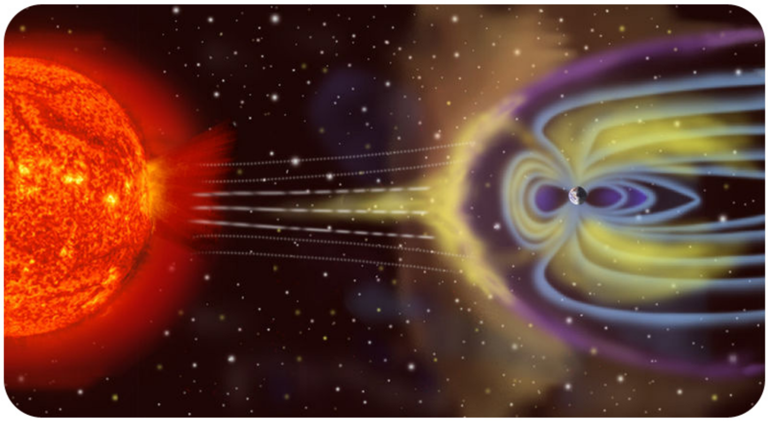


FIGURE 2.4
Earth's magnetic field protects the planet from harmful radiation.

FIGURE 2.5
The needle of a compass will align with Earth's magnetic field, making the compass a useful device for navigation.

Earth's Motions

Earth's **axis** is an imaginary line passing through the North and South Poles. Earth's **rotation** is its spins on its axis. Rotation is what a top does around its spindle. As Earth spins on its axis, it also orbits around the Sun. This is called Earth's **revolution**. These motions lead to the cycles we see. Day and night, seasons, and the tides are caused by Earth's motions.

Earth's Rotation

In 1851, Léon Foucault, a French scientist, hung a heavy iron weight from a long wire. He pulled the weight to one side and then released it. The weight swung back and forth in a straight line. If Earth did not rotate, the pendulum would not change direction as it was swinging. But it did, or at least it appeared to. The direction of the pendulum appeared to change because Earth rotated beneath it. **Figure** 2.6 shows how this might look.

FIGURE 2.6
Imagine a pendulum at the North Pole. The pendulum always swings in the same direction. But because of Earth's rotation, its direction appears to change to observers on Earth.

A Turn of the Earth

In this video, MIT students demonstrate how a Foucault Pendulum is used to prove that the Earth is rotating. See the video at https://www.youtube.com/watch?v=_pECtfYa2Us .

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/145419

Earth's Day and Night

How long does it take Earth to spin once on its axis? One rotation is 24 hours. That rotation is the length of a day! Whatever time it is, the side of Earth facing the Sun has daylight. The side facing away from the Sun is dark. If you look at Earth from the North Pole, the planet spins counterclockwise. As the Earth rotates, you see the Sun moving across the sky from east to west. We often say that the Sun is "rising" or "setting." The Sun rises in the east and sets in the west. Actually, it is the Earth's rotation that makes it appear that way. The Moon and the stars at night also seem to rise in the east and set in the west. Earth's rotation is also responsible for this too. As Earth turns, the Moon and stars change position in the sky.

Earth's Seasons

The Earth is tilted 23 $1/2^{\circ}$ on its axis (**Figure** 2.7). This means that as the Earth rotates, one hemisphere has longer days with shorter nights. At the same time the other hemisphere has shorter days and longer nights. For example, in the Northern hemisphere summer begins on June 21. On this date, the North Pole is pointed directly toward the Sun. This is the longest day and shortest night of the year in the Northern Hemisphere. The South Pole is pointed away from the Sun. This means that the Southern Hemisphere experiences its longest night and shortest day (**Figure** 2.8).

The hemisphere that is tilted away from the Sun is cooler because it receives less direct rays. As Earth orbits the Sun, the Northern Hemisphere goes from winter to spring, then summer and fall. The Southern Hemisphere does the opposite from summer to fall to winter to spring. When it is winter in the Northern hemisphere, it is summer in the Southern hemisphere, and vice versa.

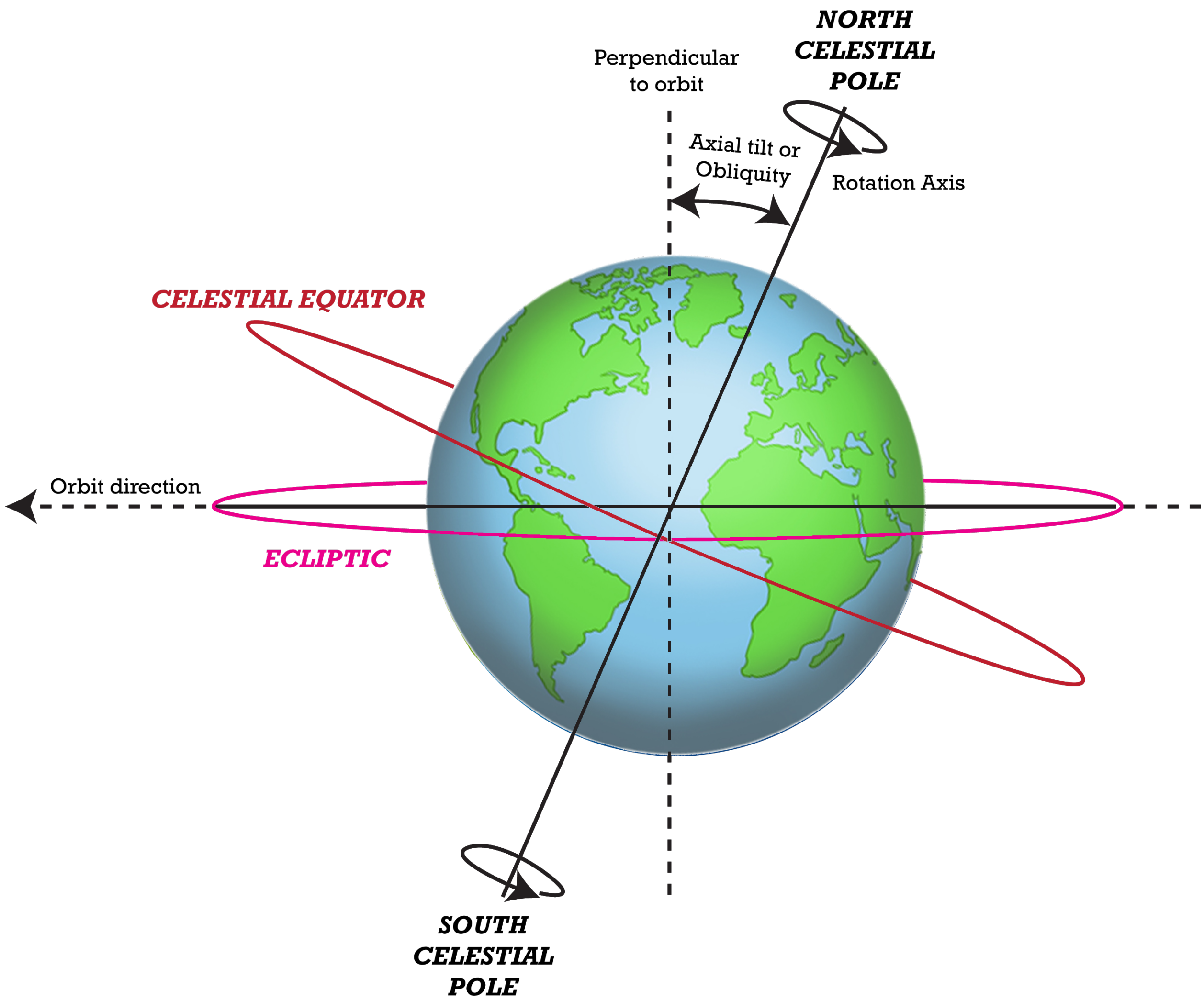


FIGURE 2.7
The Earth tilts on its axis.

Earth's Revolution

Earth's revolution around the Sun takes 365.24 days. That is equal to one year. The Earth stays in orbit around the Sun because of the Sun's gravity (**Figure** 2.9). Earth's orbit is not a circle. It is somewhat elliptical. So as we travel around the Sun, sometimes we are a little farther away from the Sun. Sometimes we are closer to the Sun.

Students sometimes think the slightly oval shape of our orbit causes Earth's seasons. That's not true! The seasons are due to the tilt of Earth's axis, as discussed above.

The distance between the Earth and the Sun is about 150 million kilometers. Earth revolves around the Sun at an average speed of about 27 kilometers (17 miles) per second. Mercury and Venus are closer to the Sun, so they take shorter times to make one orbit. Mercury takes only about 88 Earth days to make one trip around the Sun. All of the other planets take longer amounts of time. The exact amount depends on the planet's distance from the Sun. Saturn takes more than 29 Earth years to make one revolution around the Sun.

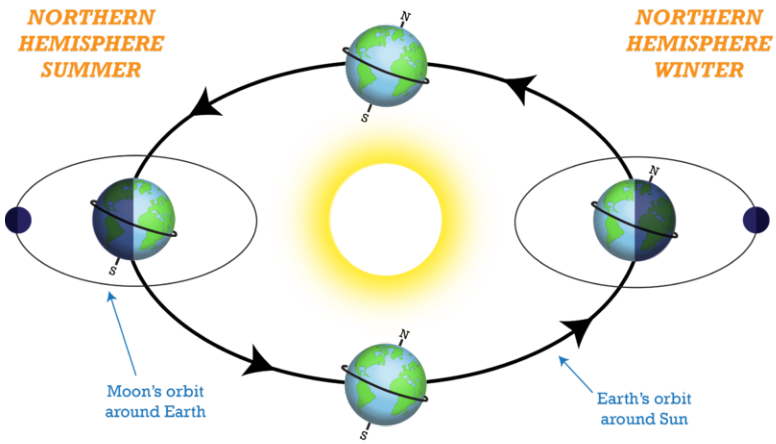


FIGURE 2.8
Earth's tilt changes the length of the days and nights during different seasons.

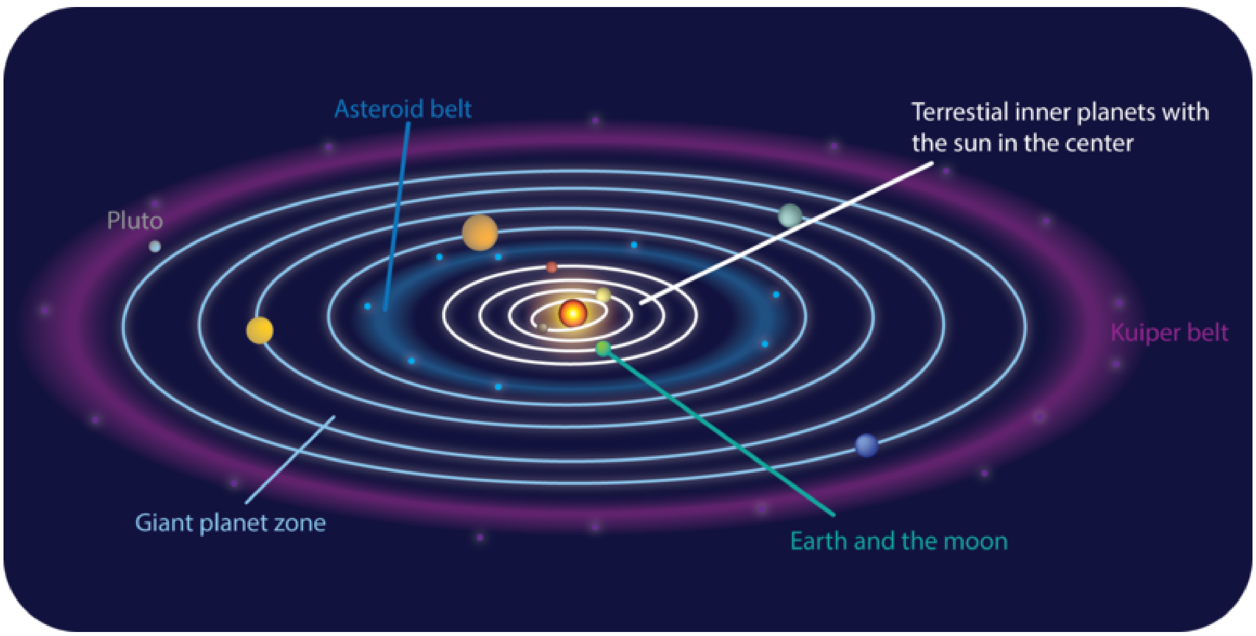


FIGURE 2.9
Earth and the other planets in the solar system make elliptical orbits around the Sun.

Lesson Summary

- The planets in our solar system all spin as they revolve around the Sun in fixed paths called orbits.
- The balance between gravity and our motion around the Sun, keep the planets in orbit at fixed distances from the Sun.
- Earth has a magnetic field, created by motion within Earth's outer, liquid iron core. The magnetic field shields us from harmful radiation.
- Earth rotates on its axis once each day and revolves around the Sun once every year.
- The tilt of Earth's axis produces seasons.

Lesson Review Questions

Recall

1. What was the evidence that Earth was round before there were photos from space?

2. What two substances does Earth have that allow it to support life?

3. What does a compass have that allows you to tell direction?

4. Describe Earth's rotation. Describe Earth's revolution.

Apply Concepts

5. Earth's "spheres" all interact. Given what you know about Earth science, can you give some examples?

6. What would happen to Earth-Moon if Earth suddenly shrunk to half its current size?

Think Critically

7. Why do the planets that are furthest from the Sun take longer to make one orbit around the Sun? Explain your answer.

8. Even though Earth is closest to the Sun in January, people in the Northern hemisphere experience winter weather. Why do you think people in the Northern Hemisphere have winter in January?

Points to Consider

- What would other planets need to have if they were able to support life?
- What type of experiment could you create to prove that the Earth is rotating on its axis?
- If you lived at the equator, would you experience any effects due to Earth's tilted axis?
- If Earth suddenly increased in mass, what might happen to its orbit around the Sun?

2.2 Earth's Moon

Lesson Objectives

- Find similarities and differences between Moon and Earth.
- Describe the features of the Moon.

Vocabulary

- crater
- landscape
- lunar
- meteorites

Introduction

Between 1969 and 1972, six spaceships landed on the lunar surface. (**Lunar** means "related to the moon.") The astronauts brought back soil and rock samples. Scientists have used modern methods to study these samples. Because of the Apollo missions, we have learned a great deal about the Moon. No astronauts have visited the Moon since 1972. There is talk of someday returning, but as of now there are no concrete plans.

Lunar Characteristics

The Moon is Earth's only natural satellite. The Moon is about one-fourth the size of Earth, 3,476 kilometers in diameter. Gravity on the Moon is only one-sixth as strong as it is on Earth. If you weigh 120 pounds on Earth, you would only weigh 20 pounds on the Moon. You can jump six times as high on the Moon as you can on Earth. The Moon makes no light of its own. Like every other body in the solar system, it only reflects light from the Sun.

The Moon rotates on its axis once for every orbit it makes around the Earth. What does this mean? This means that the same side of the Moon always faces Earth. The side of the Moon that always faces Earth is called the near side. The side of the Moon that always faces away from Earth is called the far side (**Figure** 2.10). All people for all time have only seen the Moon's near side. The far side has only been seen by spacecraft.

The Moon has no atmosphere. With no atmosphere, the Moon is not protected from extreme temperatures. The average surface temperature during the day is approximately 107°C (225°F). Daytime temperatures can reach as high as 123°C (253°F). At night, the average temperature drops to -153°C (-243°F). The lowest temperatures measured are as low as -233°C (-397°F).

Lesson Summary

- The evidence suggests that the Moon formed when a Mars sized planet collided with Earth.
- The Moon makes one rotation on its axis for each orbit around the Earth.
- The Moon is made of materials similar to Earth and has a crust, mantle and core, just like Earth.

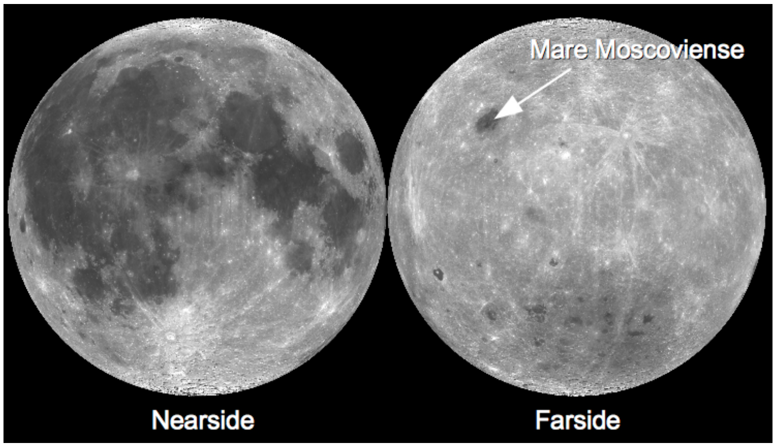


FIGURE 2.10
The Mare Moscoviense is one of the few maria, or dark, flat areas, on the far side.

Lesson Review Questions

Recall

1. What features does Earth have that the Moon does not?

2. How long will astronaut footprints remain on the Moon?

Apply Concepts

4. Why doesn't the Moon have an atmosphere?

5. Why is the crust thicker on the near side of the Moon than on the far side?

6. Why is the force of gravity weaker on the Moon than on Earth?

Think Critically

7. Why doesn't the Moon have much water?

9. How much do landscape features on the Moon change over time compared to landscape features on Earth? Explain your answer.

Points to Consider

- What things would be different on Earth if Earth did not have a Moon?
- If the Moon rotated on its axis twice as fast as it does now, would we see anything different than we do now?
- How do we know that the Moon has been geologically inactive for billions of years?

2.3 The Sun

Lesson Objectives

- Describe the layers of the Sun.
- Describe the surface features of the Sun.

Vocabulary

- chromosphere
- convection zone
- core
- corona
- photosphere
- plasma
- radiative zone
- solar flare
- solar wind
- sunspots

Introduction

Our Sun is a star. This star provides light and heat and supports almost all life on Earth. The Sun is the center of the solar system. It is by far the largest part of the solar system. Added together, all of the planets make up just 0.2 percent of the solar system's mass. The Sun makes up the remaining 99.8 percent of all the mass in the solar system (**Figure** 2.11)!

Layers of the Sun

The Sun is made almost entirely of the elements hydrogen and helium. The Sun has no solid material. Most atoms in the Sun exist as **plasma**. Plasma is superheated gas with an electrical charge. Because the Sun is made of gases, it does not have a defined outer boundary. Like Earth, the Sun has an internal structure. The inner three layers make up what we would actually call "the Sun."

The Core

The **core** is the Sun's innermost layer. The core is plasma. It has a temperature of around 15 million degrees Celsius (C). Nuclear fusion reactions create the immense temperature. In these reactions, hydrogen atoms fuse to form

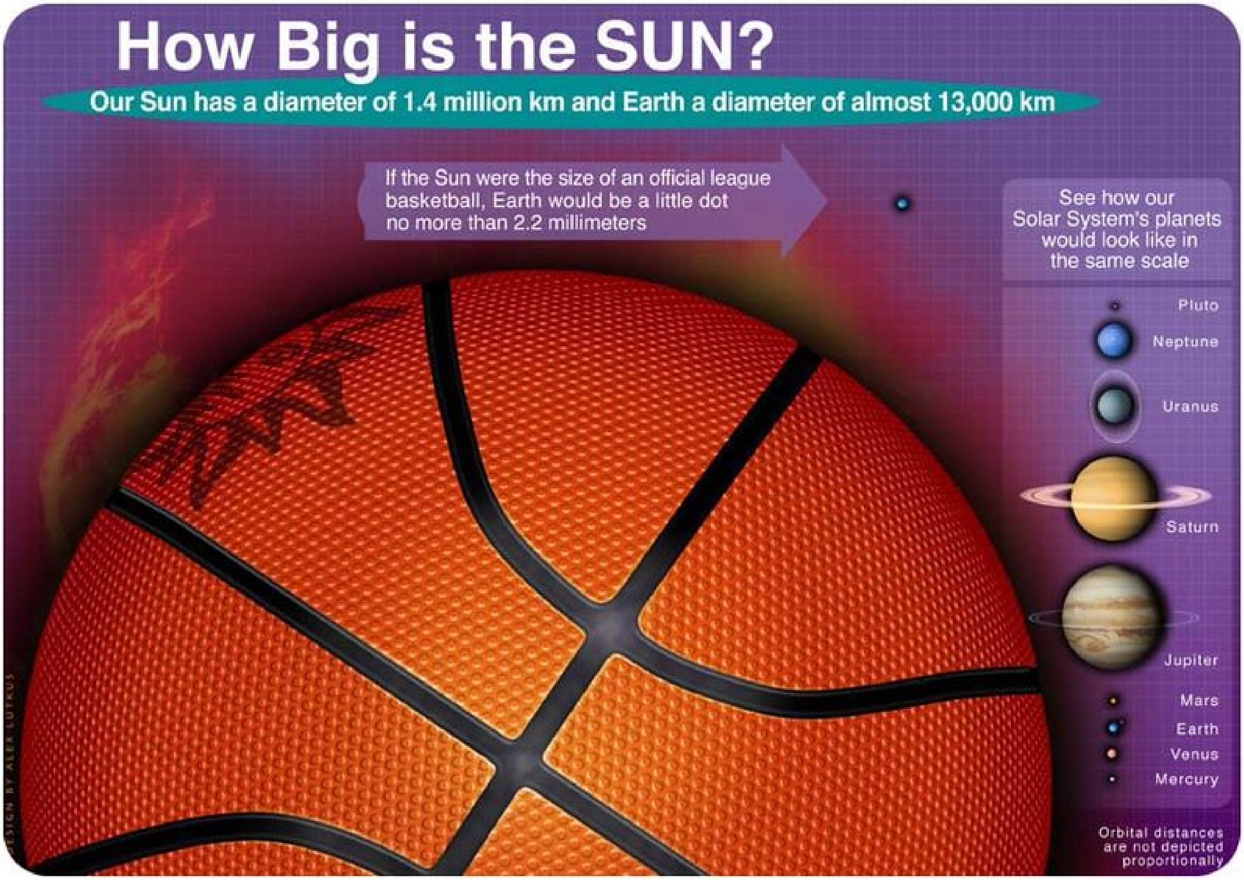


FIGURE 2.11

The sizes of the planets relative to the Sun, if the Sun was the size of a basketball.

helium. This releases vast amounts of energy. The energy moves towards the outer layers of the Sun. Energy from the Sun's core powers most of the solar system.

Radiative Zone

The **radiative zone** is the next layer out. It has a temperature of about 4 million degrees C. Energy from the core travels through the radiative zone. The rate the energy travels is extremely slow. Light particles, called photons, can only travel a few millimeters before they hit another particle. The particles are absorbed and then released again. It may take 50 million years for a photon to travel all the way through the radiative zone.

The Convection Zone

The **convection zone** surrounds the radiative zone. In the convection zone, hot material from near the Sun's center rises. This material cools at the surface, and then plunges back downward. The material then receives more heat from the radiative zone.

The Sun's Atmosphere

The three outer layers of the Sun are its atmosphere.

The Photosphere

The **photosphere** is the visible surface of the Sun (**Figure** 2.12). It's the part that we see shining. Surprisingly, the photosphere is also one of the coolest layers of the Sun. It is only about 6000 degrees C.

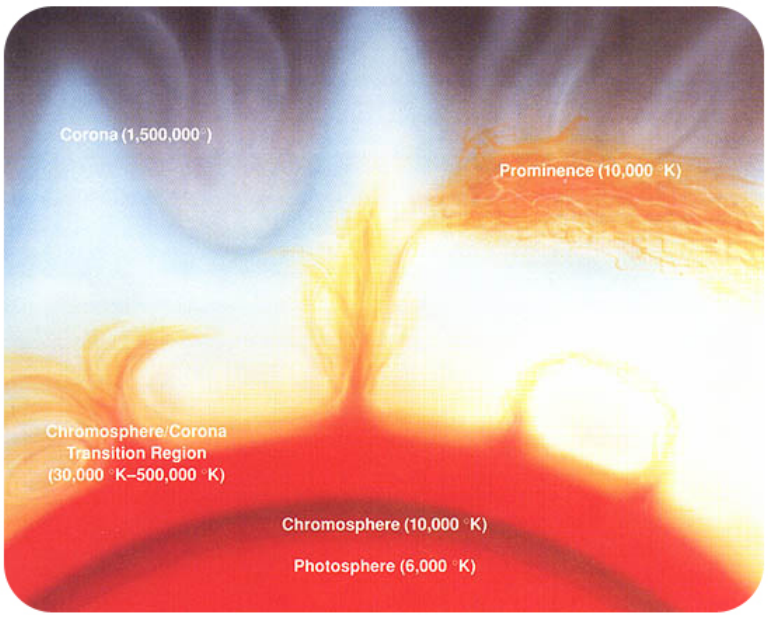


FIGURE 2.12
The Sun's atmosphere contains the photosphere, the chromosphere, and the corona. This image was taken by NASA's Spacelab 2 instruments.

The Chromosphere

The **chromosphere** lies above the photosphere. It is about 2,000 km thick. The thin chromosphere is heated by energy from the photosphere. Temperatures range from about 4000 degrees C to about 10,000 degrees C. The chromosphere is not as hot as other parts of the Sun, and it glows red. Jets of gas sometimes fly up through the chromosphere. With speeds up to 72,000 km per hour, the jets can fly as high as 10,000 kilometers.

The Corona

The **corona** is the outermost part of the Sun's atmosphere. It is the Sun's halo, or "crown." With a temperature of 1 to 3 million K, the corona is much hotter than the photosphere. The corona extends millions of kilometers into space. Sometime you should try to see a total solar eclipse. If you do you will see the Sun's corona shining out into space.

Surface Features of the Sun

The Sun has many incredible surface features. Don't try to look at them though! Looking directly at the Sun can cause blindness. Find the appropriate filters for a pair of binoculars or a telescope and enjoy!

Sunspots

The most noticeable magnetic activity of the Sun is the appearance of sunspots. **Sunspots** are cooler, darker areas on the Sun's surface (**Figure** 2.13). Sunspots occur in an 11 year cycle. The number of sunspots begins at a minimum. The number gradually increases to the maximum. Then the number returns to a minimum again.

Sunspots form because loops of the Sun's magnetic field break through the surface. Sunspots usually occur in pairs. The loop breaks through the surface where it comes out of the Sun. It breaks through again where it goes back into the Sun. Sunspots disrupt the transfer of heat from the Sun's lower layers.

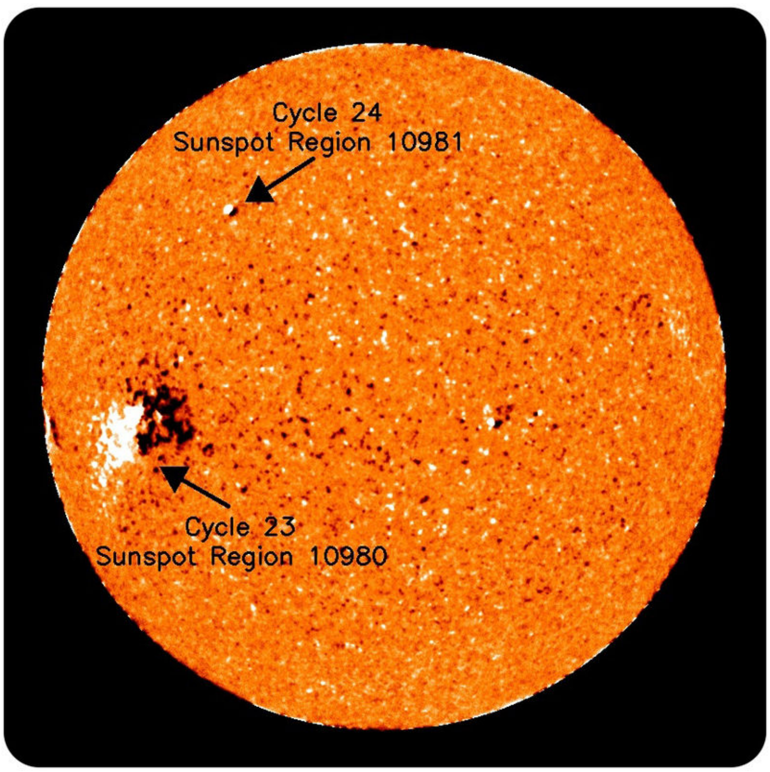


FIGURE 2.13
The darker regions in this image are sunspots.

Solar Flares

A loop of the Sun's magnetic field may break. This creates **solar flares**. Solar flares are violent explosions that release huge amounts of energy (**Figure** 2.14). The streams of high energy particles they emit make up the **solar wind**. Solar wind is dangerous to spacecraft and astronauts. Solar flares can even cause damage on Earth. They have knocked out entire power grids and can disturb radio, satellite, and cell phone communications.

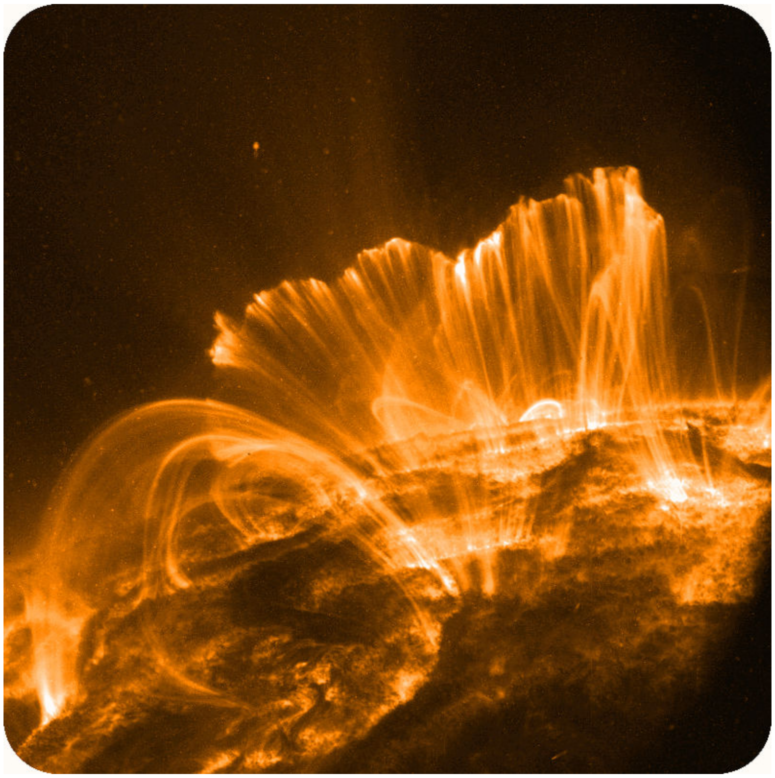


FIGURE 2.14
This image is actually made up of two successive images and shows how a solar flare develops.

Solar Prominences

Another amazing feature on the Sun is solar prominences. Plasma flows along the loop that connects sunspots. This plasma forms a glowing arch. The arch is a solar prominence. Solar prominences can reach thousands of kilometers into the Sun's atmosphere. Prominences can last for a day to several months. Prominences can be seen during a total solar eclipse.

NASA's Solar Dynamics Observatory (SDO) was launched on February 11, 2010. SDO is studying the Sun's magnetic field. This includes how the Sun affects Earth's atmosphere and climate. SDO provides extremely high resolution images. The craft gathers data faster than anything that ever studied the Sun.

To learn more about the SDO mission, visit: http://sdo.gsfc.nasa.gov

To find these videos for download, check out: http://www.nasa.gov/mission_pages/sdo/news/briefing-materials-20100421.html http://svs.gsfc.nasa.gov/Gallery/SDOFirstLight.html

There are other ways to connect with NASA. Subscribe to NASA's Goddard Shorts HD podcast (http://svs.gsfc.nasa.gov/vis/iTunes/f0004_index.html)

Lesson Summary

- The mass of the Sun is 99.8% of the mass of our solar system.
- The Sun is mostly hydrogen with smaller amounts of helium. The material is in the form of plasma.
- The main part of the Sun has three layers: the core, the radiative zone and the convection zone.
- The Sun's atmosphere also has three layers: the photosphere, the chromosphere and the corona.
- Nuclear fusion of hydrogen in the core of the Sun produces tremendous amounts of energy that radiate out

from the Sun.
- Some features of the Sun's surface include sunspots, solar flares, and prominences.

Lesson Review Questions

Recall

1. What is the Sun mostly made of?

2. Where does the Sun's energy come from?

Apply Concepts

3. What is nuclear fusion? Is it a form of energy that can be used by people?

4. How does the Sun's magnetic field affect its surface features?

Think Critically

5. Describe the energy of the Sun. Where is it generated? Where does it go? How does it move?

6. Solar wind can be dangerous to human life. Why is this fact important? What usually protects humans from harm from the solar wind?

Points to Consider

- If something were to suddenly cause nuclear fusion to stop in the Sun, how would we know?
- Are there any types of dangerous energy from the Sun? What might be affected by them?
- If the Sun is all made of gases like hydrogen and helium, how can it have layers?

2.4 Moon Phases and Eclipses

Lesson Objectives

- Explain solar and lunar eclipses.
- Describe the phases of the Moon and explain why they occur.

Vocabulary

- crescent
- gibbous
- lunar eclipse
- penumbra
- solar eclipse
- umbra

Introduction

The Earth, Moon and Sun are linked together in space. Monthly or daily cycles continually remind us of these links. Every month, you can see the Moon change. This is due to where it is relative to the Sun and Earth. In one phase, the Moon is brightly illuminated - a full moon. In the opposite phase it is completely dark - a new moon. In between, it is partially lit up. When the Moon is in just the right position, it causes an eclipse. The daily tides are another reminder of the Moon and Sun. They are caused by the pull of the Moon and the Sun on the Earth. Tides were discussed in the *Oceans* chapter.

Solar Eclipses

When a new moon passes directly between the Earth and the Sun, it causes a **solar eclipse** (**Figure** 2.15). The Moon casts a shadow on the Earth and blocks our view of the Sun. This happens only all three are lined up and in the same plane. This plane is called the ecliptic. The ecliptic is the plane of Earth's orbit around the Sun.

The Moon's shadow has two distinct parts. The **umbra** is the inner, cone-shaped part of the shadow. It is the part in which all of the light has been blocked. The **penumbra** is the outer part of Moon's shadow. It is where the light is only partially blocked.

When the Moon's shadow completely blocks the Sun, it is a total solar eclipse (**Figure** 2.16). If only part of the Sun is out of view, it is a partial solar eclipse. Solar eclipses are rare events. They usually only last a few minutes. That is because the Moon's shadow only covers a very small area on Earth and Earth is turning very rapidly.

Solar eclipses are amazing to experience. It appears like night only strange. Birds may sing as they do at dusk. Stars become visible in the sky and it gets colder outside. Unlike at night, the Sun is out. So during a solar eclipse, it's easy to see the Sun's corona and solar prominences. This NASA page will inform you on when solar eclipses are expected: http://eclipse.gsfc.nasa.gov/solar.html

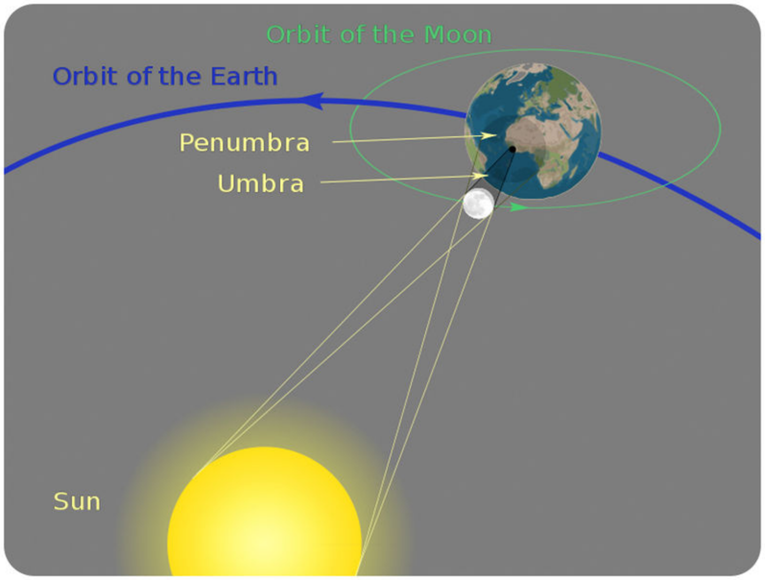


FIGURE 2.15
During a solar eclipse, the Moon casts a shadow on the Earth. The shadow is made up of two parts: the darker umbra and the lighter penumbra.

FIGURE 2.16
A photo of a total solar eclipse.

A Lunar Eclipse

Sometimes a full moon moves through Earth's shadow. This is a **lunar eclipse** (**Figure** 2.17). During a total lunar eclipse, the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. When the Moon passes through Earth's penumbra, it is a penumbral eclipse. Since Earth's shadow is large, a lunar eclipse lasts for hours. Anyone with a view of the Moon can see a lunar eclipse.

Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common. The Moon glows with a dull red coloring during a total lunar eclipse.

FIGURE 2.17
A lunar eclipse is shown in a series of pictures.

The Phases of the Moon

The Moon does not produce any light of its own. It only reflects light from the Sun. As the Moon moves around the Earth, we see different parts of the Moon lit up by the Sun. This causes the phases of the Moon. As the Moon revolves around Earth, it changes from fully lit to completely dark and back again.

A full moon occurs when the whole side facing Earth is lit. This happens when Earth is between the Moon and the Sun. About one week later, the Moon enters the quarter-moon phase. Only half of the Moon's lit surface is visible from Earth, so it appears as a half circle. When the Moon moves between Earth and the Sun, the side facing Earth is completely dark. This is called the new moon phase. Sometimes you can just barely make out the outline of the new moon in the sky. This is because some sunlight reflects off the Earth and hits the Moon. Before and after the quarter-moon phases are the gibbous and crescent phases. During the **crescent** moon phase, the Moon is less than half lit. It is seen as only a sliver or crescent shape. During the **gibbous** moon phase, the Moon is more than half lit. It is not full. The Moon undergoes a complete cycle of phases about every 29.5 days.

Lesson Summary

- When the new moon comes between the Earth and the Sun along the ecliptic, a solar eclipse is produced.
- When the Earth comes between the full moon and the Sun along the ecliptic, a lunar eclipse occurs.
- Observing the Moon from Earth, we see a sequence of phases as the side facing us goes from completely darkened to completely illuminated and back again once every 29.5 days.

Review Questions

Recall

1. What is happening with Earth and the Sun during Northern Hemisphere summer? What is happening in the Southern Hemisphere at that time?

2. Draw a picture of Earth, Moon, and Sun during a new moon. Draw picture during a full moon.

Apply Concepts

3. Why do lunar eclipses happen more often and last longer than solar eclipses?

4. The same side of the Moon always faces Earth. What would Earth be like if its same side always faced the Sun?

Think Critically

5. Why is it a different time in San Francisco and in Denver? Why is the time different in Denver and Chicago? What would things be like if the entire United States decided to have all places be the same time always?

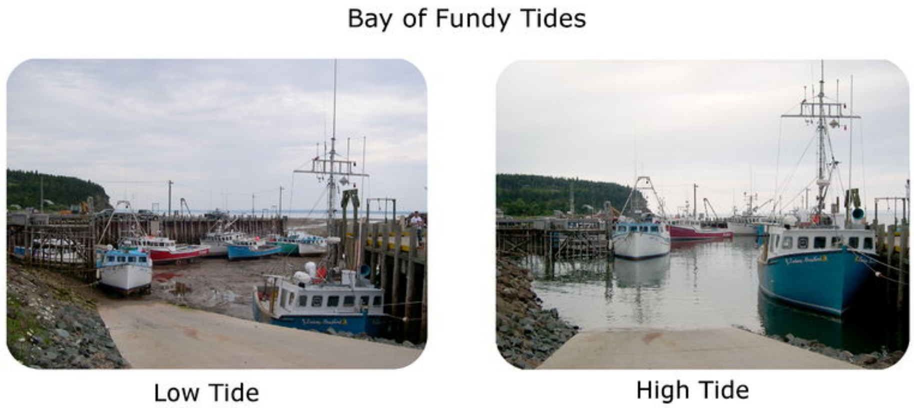
6. People think that Earth's season are caused by its elliptical orbit around the Sun. Explain why this is not so.

Points to Consider

- Why don't eclipses occur every single month at the full and new moons?
- The planet Mars has a tilt that is very similar to Earth's. What does this produce on Mars?
- Venus comes between the Earth and the Sun. Why don't we see an eclipse when this happens?

2.5 Tides

- Define tides.
- Describe types of tides.
- Explain why tides occur.



How could a tide be so extreme?

These two photos show high tide (left) and low tide (right) at Bay of Fundy on the Gulf of Maine. The Bay of Fundy has the greatest tidal ranges on Earth at 38.4 feet. Why is this tidal range so extreme? Why aren't all tidal ranges so great? Tidal range depends on many factors, including the slope of the continental margin.

The Tides

Tides are the daily rise and fall of sea level at any given place. The pull of the Moon's gravity on Earth is the primary cause of tides and the pull of the Sun's gravity on Earth is the secondary cause (**Figure** 2.18). The Moon has a greater effect because, although it is much smaller than the Sun, it is much closer. The Moon's pull is about twice that of the Sun's.

To understand the tides it is easiest to start with the effect of the Moon on Earth. As the Moon revolves around our planet, its gravity pulls Earth toward it. The lithosphere is unable to move much, but the water is pulled by the gravity and a bulge is created. This bulge is the high tide beneath the Moon. On the other side of the Earth, a high tide is produced where the Moon's pull is weakest. These two water bulges on opposite sides of the Earth aligned with the Moon are the **high tides**. The places directly in between the high tides are **low tides**. As the Earth rotates beneath the Moon, a single spot will experience two high tides and two low tides approximately every day.

High tides occur about every 12 hours and 25 minutes. The reason is that the Moon takes 24 hours and 50 minutes to rotate once around the Earth, so the Moon is over the same location every 24 hours and 50 minutes. Since high tides occur twice a day, one arrives each 12 hours and 25 minutes. What is the time between a high tide and the next low tide?

The gravity of the Sun also pulls Earth's water towards it and causes its own tides. Because the Sun is so far away, its pull is smaller than the Moon's.

Some coastal areas do not follow this pattern at all. These coastal areas may have one high and one low tide per day or a different amount of time between two high tides. These differences are often because of local conditions, such as the shape of the coastline that the tide is entering.

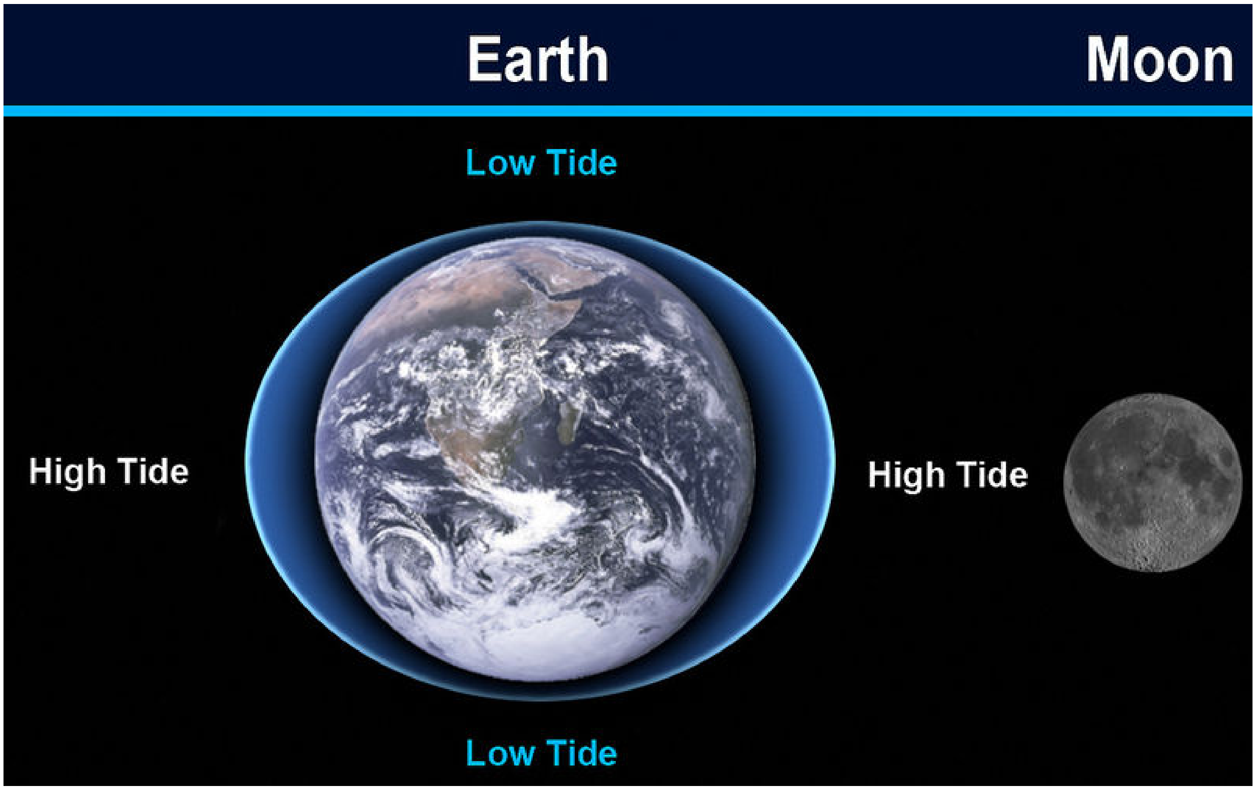


FIGURE 2.18
The gravitational attraction of the Moon to ocean water creates the high and low tides.

Tidal Range

The **tidal range** is the difference between the ocean level at high tide and the ocean level at low tide (**Figure** 2.19). The tidal range in a location depends on a number of factors, including the slope of the seafloor. Water appears to move a greater distance on a gentle slope than on a steep slope.

Monthly Tidal Patterns

If you look at the diagram of high and low tides on a circular Earth above, you'll see that tides are waves. So when the Sun and Moon are aligned, what do you expect the tides to look like?

Waves are additive, so when the gravitational pull of both bodies is in the same direction, the high tides are higher and the low tides lower than at other times through the month (**Figure** 2.20). These more extreme tides, with a greater tidal range, are called **spring tides**. Spring tides don't just occur in the spring; they occur whenever the Moon is in a new-moon or full-moon phase, about every 14 days.

Neap tides are tides that have the smallest tidal range, and they occur when the Earth, the Moon, and the Sun form a 90^o angle (**Figure** 2.21). They occur exactly halfway between the spring tides, when the Moon is at first or last quarter. How do the tides add up to create neap tides? The Moon's high tide occurs in the same place as the Sun's low tide and the Moon's low tide in the same place as the Sun's high tide. At neap tides, the tidal range is relatively small.

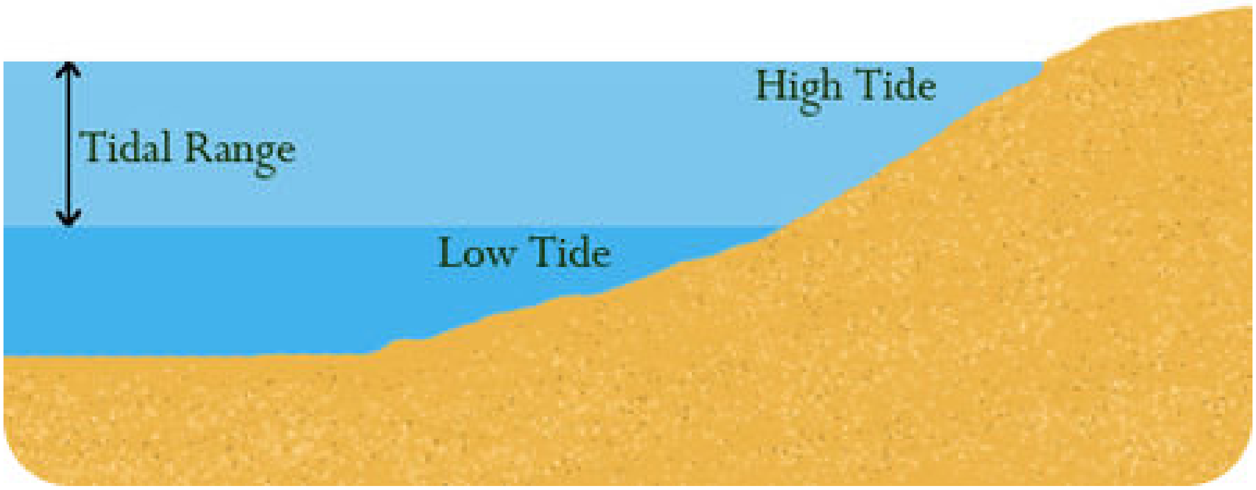


FIGURE 2.19
The tidal range is the difference between the ocean level at high tide and low tide.

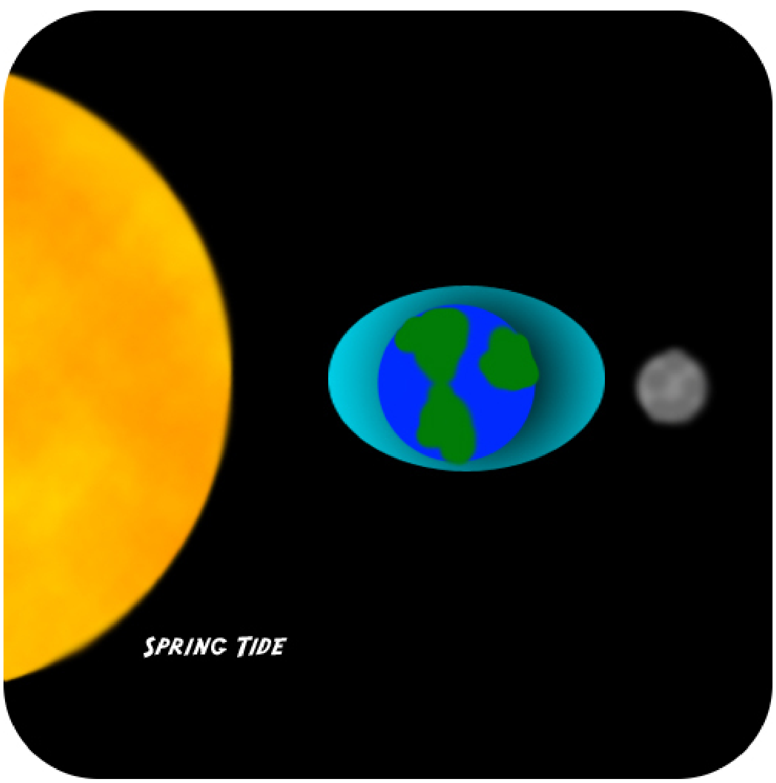


FIGURE 2.20
A spring tide occurs when the gravitational pull of both Moon and the Sun is in the same direction, making high tides higher and low tides lower and creating a large tidal range.

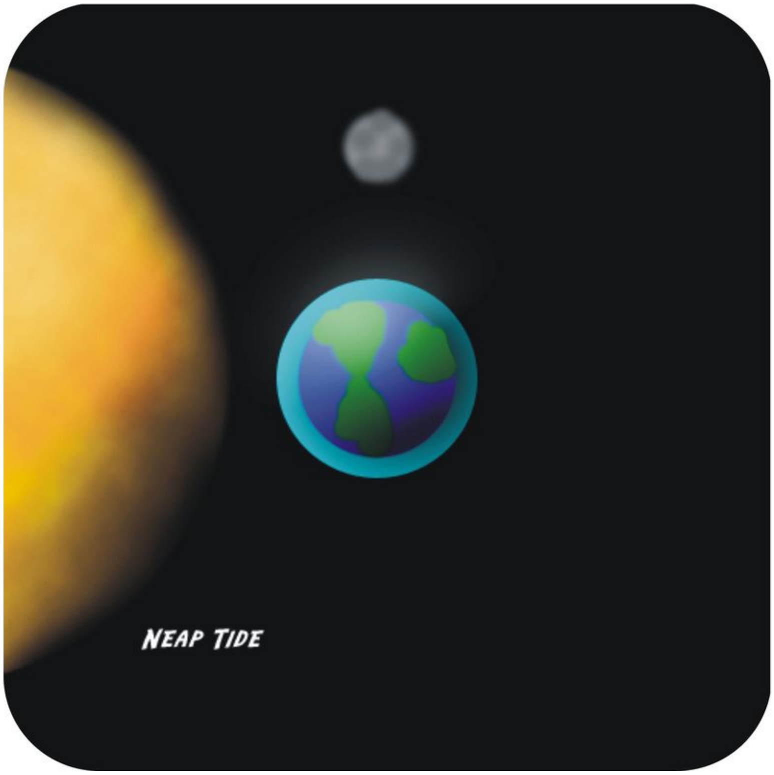


FIGURE 2.21
A neap tide occurs when the high tide of the Sun adds to the low tide of the Moon and vice versa, so the tidal range is relatively small.

This animation shows the effect of the Moon and Sun on the tides: http://www.onr.navy.mil/Focus/ocean/motion/tides1.htm .

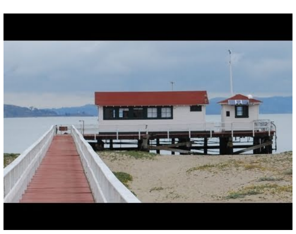
A detailed animation of lunar tides is shown here: http://www.pbs.org/wgbh/nova/venice/tides.html .

Here is a link to see these tides in motion: http://oceanservice.noaa.gov/education/kits/tides/media/tide06a_450.gif .

A simple animation of spring and neap tides is found here: http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html .

Studying ocean tides' rhythmic movements helps scientists understand the ocean and the Sun/Moon/Earth system. This QUEST video explains how tides work, and visits the oldest continually operating tidal gauge in the Western Hemisphere.

Watch it at http://www.kqed.org/quest/television/science-on-the-spot-watching-the-tides .



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/116518

Summary

- The primary cause of tides is the gravitational attraction of the Moon, which causes two high and two low tides a day.
- When the Sun's and Moon's tides match, there are spring tides; when they are opposed, there are neap tides.
- The difference between the daily high and the daily low is the tidal range.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=gftT3wHJGtg

1. If the moon only goes around Earth once per day why are there two high tides per day?
2. If you are standing on the shore and it is high tide, what are the two possible locations for the moon relative to where you are?
3. What is the secondary reason for the tides? Why are these tides weaker than the moon's tides?
4. Why is it good that the moon is not closer to the Earth?

Review

1. Using the terminology of waves, describe how the gravitational attraction of the Moon and Sun make a high tide and a low tide.
2. Describe the causes of spring and neap tides.
3. What are the possible reasons that the Bay of Fundy has such a large tidal range?

2.6 References

1. Image copyright Scott Norris Photography, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
2. Courtesy of NOAA. http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=6763 . Public Domain
3. User:Xzapro4/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Gravitation.png . Public Domain
4. NASA Goddard Photo and Video. http://www.flickr.com/photos/gsfc/7402439760/ . CC BY 2.0
5. Courtesy of NASA. http://commons.wikimedia.org/wiki/Image:Magnetosphere_rendition.jpg . Public Domain
6. Flickr:Calsidyrose. http://www.flickr.com/photos/calsidyrose/4925267732/ . CC BY 2.0
7. Christopher Auyeung and Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
8. Christopher Auyeung and Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
9. Christopher Auyeung and Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
10. Zachary Wilson. CK-12 Foundation . CC BY-NC 3.0
11. Courtesy of the U.S. Geological Survey/Arizona State University. http://www.nasa.gov/mission_pages/LRO/multimedia/lroimages/lroc-20100107-new-images.html . Public Domain
12. Courtesy of NASA. http://sohowww.nascom.nasa.gov/classroom/classroom.html . Public Domain
13. Courtesy of NASA. http://history.nasa.gov/NP-119/ch4.htm . Public Domain
14. Courtesy of NOAA. http://www.noaanews.noaa.gov/stories2008/20080104_sunspot.html . Public Domain
15. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Solar_flare_%28TRACE%29.gif . Public Domain
16. User:Sagredo/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Geometry_of_a_Total_Solar_Eclipse.svg . Public Domain
17. Courtesy of NASA/Cirtain. http://www.flickr.com/photos/24662369@N07/8188704492/ . CC BY 2.0
18. Courtesy of Mass Communication Specialist Seaman Joshua Valcarcel, U.S. Navy. http://commons.wikimedia.org/wiki/File:Lunar_eclipse_March_2007.jpg . Public Domain
19. Hana Zavadska, using Earth image courtesy of NASA, Moon image courtesy of NASA/GSFC/Arizona State University. Diagram of how the moon causes tides . CC BY-NC 3.0 (Earth and Moon: public domain)
20. User:Jared/Wikipedia. Diagram of the tidal range . Public Domain
21. User:BrianEd/Wikipedia. Diagram of a spring tide, when the Moon and Sun are aligned . Public Domain
22. User:BrianEd/Wikipedia. Diagram of a neap tide, when the Moon and Sun are opposed . Public Domain

CHAPTER 3 Stars, Galaxies, and the Universe

Chapter Outline

3.1 Stars

Lesson Objectives

- Define constellation.
- Classify stars based on their color and temperature.
- Outline the stages of a star.
- Use light-years as a unit of distance.

Vocabulary

- binary star system
- black hole
- main sequence star
- neutron star
- red giant
- supernova
- star

Introduction

When you look at the sky on a clear night, you can see hundreds of stars. A **star** is a giant ball of glowing gas that is very, very hot. Most of these stars are like our Sun, but some are smaller than our Sun, and some are larger. Except for our own Sun, all stars are so far away that they only look like single points, even through a telescope.

Constellations

The stars that make up a constellation appear close to each other from Earth. In reality, they may be very distant from one another. Constellations were important to people, like the Ancient Greeks. People who spent a lot of time outdoors at night, like shepherds, named them and told stories about them. **Figure** 3.1 shows one of the most easily recognized constellations. The ancient Greeks thought this group of stars looked like a hunter. They named it Orion, after a great hunter in Greek mythology.

The constellations stay the same night after night. The patterns of the stars never change. However, each night the constellations move across the sky. They move because Earth is spinning on its axis. The constellations also move with the seasons. This is because Earth revolves around the Sun. Different constellations are up in the winter than in the summer. For example, Orion is high up in the winter sky. In the summer, it's only up in the early morning.

Energy of Stars

Only a tiny bit of the Sun's light reaches Earth. But that light supplies most of the energy at the surface. The Sun is just an ordinary star, but it appears much bigger and brighter than any of the other stars. Of course, this is just because it is very close. Some other stars produce much more energy than the Sun. How do stars generate so much energy?

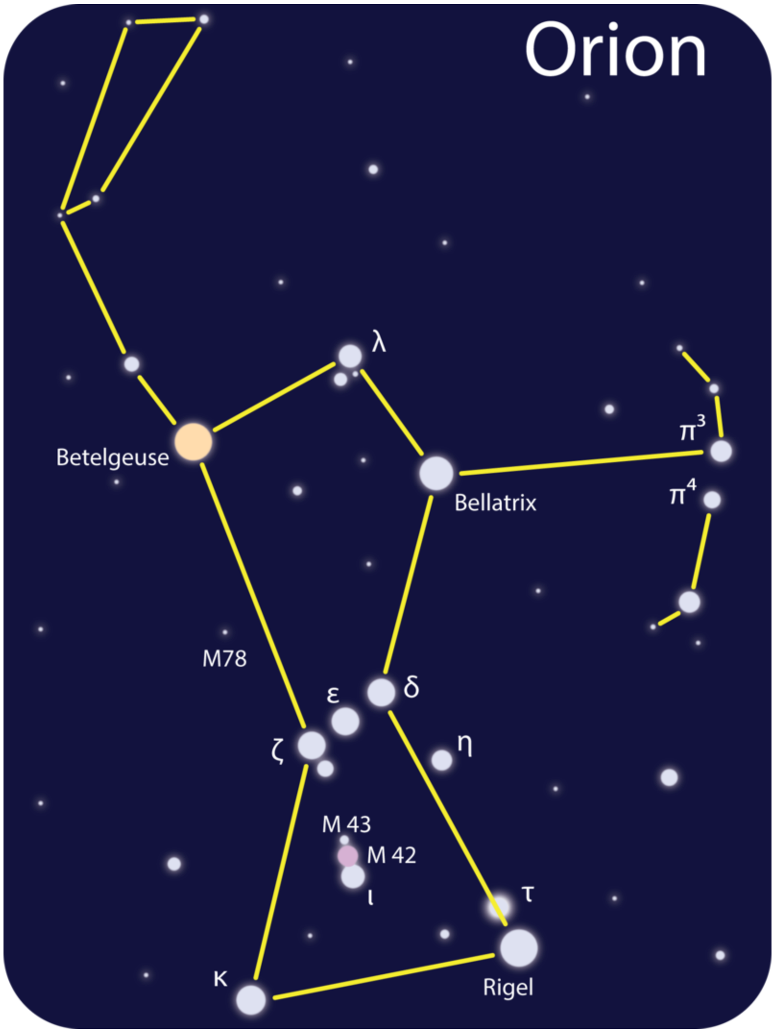


FIGURE 3.1
Orion has three stars that make up his belt. Orion's belt is fairly easy to see in the night sky.

Nuclear Fusion

Stars shine because of nuclear fusion. Fusion reactions in the Sun's core keep our nearest star burning. Stars are made mostly of hydrogen and helium. Both are very lightweight gases. A star contains so much hydrogen and helium that the weight of these gases is enormous. The pressure at the center of a star is great enough to heat the gases. This causes nuclear fusion reactions.

A nuclear fusion reaction is named that because the nuclei (center) of two atoms fuse (join) together. In stars like our Sun, two hydrogen atoms join together to create a helium atom. Nuclear fusion reactions need a lot of energy to get started. Once they begin, they produce even more energy.

Particle Accelerators

Scientists have built machines called particle accelerators. These amazing tools smash particles that are smaller than atoms into each other head-on. This creates new particles. Scientists use particle accelerators to learn about nuclear fusion in stars. They can also learn about how atoms came together in the early universe. Two well-known accelerators are SLAC, in California, and CERN, in Switzerland.

How Stars Are Classified

Stars shine in many different colors. The color relates to a star's temperature and often its size.

Color and Temperature

Think about the coil of an electric stove as it heats up. The coil changes in color as its temperature rises. When you first turn on the heat, the coil looks black. The air a few inches above the coil begins to feel warm. As the coil gets hotter, it starts to glow a dull red. As it gets even hotter, it becomes a brighter red. Next it turns orange. If it gets extremely hot, it might look yellow-white, or even blue-white. Like a coil on a stove, a star's color is determined by the temperature of the star's surface. Relatively cool stars are red. Warmer stars are orange or yellow. Extremely hot stars are blue or blue-white.

Classifying Stars by Color

The most common way of classifying stars is by color as shown, in **Table** 3.1. Each class of star is given a letter, a color, and a range of temperatures. The letters don't match the color names because stars were first grouped as A through O. It wasn't until later that their order was corrected to go by increasing temperature. When you try to remember the order, you can use this phrase: "Oh Be A Fine Good Kid, Man."

TABLE 3.1: Classification of Stars By Color and Temperature

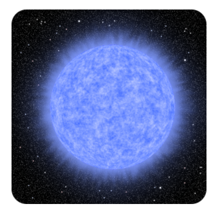
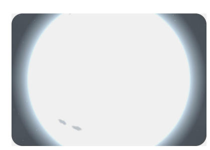
Class	Color	Temperature range	Sample Star
O	Blue	30,000 K or more	 An artist's depiction of the O class star Zeta Puppis.
B	Blue-white	10,000–30,000 K	 An artist's depiction of Rigel, a Class B star.

TABLE 3.1: (continued)

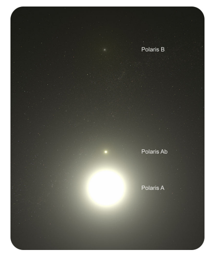
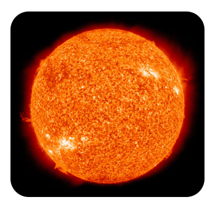
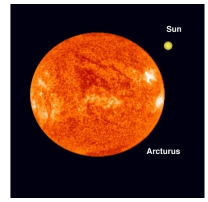
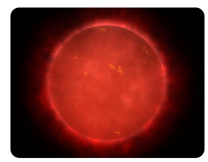
Class	Color	Temperature range	Sample Star
A	White	7,500–10,000 K	 Sirius A is the brightest star that we see in the night sky. The dot on the right, Sirius B, is a white dwarf.
F	Yellowish-white	6,000–7,500 K	 There are two F class stars in this image, the supergiant Polaris A and Polaris B. What we see in the night sky as the single star "Polaris," we also known as the North Star.
G	Yellow	5,500–6,000 K	 Our Sun: the most important G class star in the Universe, at least for humans.

TABLE 3.1: (continued)

Class	Color	Temperature range	Sample Star
K	Orange	3,500–5,000 K	 Arcturus is a Class K star that looks like the Sun but is much larger.
M	Red	2,000–3,500 K	There are two types of Class M stars: red dwarfs and red giants.  An artist's concept of a red dwarf star. Most stars are red dwarfs.
			 The red supergiant Betelgeuse is seen near Orion's belt. The blue star in the lower right is the Class B star Rigel.

The surface temperature of most stars is due to its size. Bigger stars produce more energy, so their surfaces are hotter. But some very small stars are very hot. Some very big stars are cool.

Lifetimes of Stars

We could say that stars are born, change over time, and eventually die. Most stars change in size, color, and class at least once during their lifetime.

Formation of Stars

Stars are born in clouds of gas and dust called nebulas. Our Sun and solar system formed out of a nebula. A nebula is shown in **Figure** 3.2. In **Figure** 3.1, the fuzzy area beneath the central three stars contains the Orion nebula.

FIGURE 3.2
Stars form in a nebula like this one in Orion's sword.

For a star to form, gravity pulls gas and dust into the center of the nebula. As the material becomes denser, the pressure and the temperature increase. When the temperature of the center becomes hot enough, nuclear fusion begins. The ball of gas has become a star!

Main Sequence Stars

For most of a star's life, hydrogen atoms fuse to form helium atoms. A star like this is a **main sequence star**. The hotter a main sequence star is, the brighter it is. A star remains on the main sequence as long as it is fusing hydrogen to form helium.

Our Sun has been a main sequence star for about 5 billion years. As a medium-sized star, it will continue to shine for about 5 billion more years. Large stars burn through their supply of hydrogen very quickly. These stars "live fast and die young!" A very large star may only be on the main sequence for 10 million years. A very small star may be on the main sequence for tens to hundreds of billions of years.

Red Giants and White Dwarfs

A star like our Sun will become a **red giant** in its next stage. When a star uses up its hydrogen, it begins to fuse helium atoms. Helium fuses into heavier atoms like carbon. At this time the star's core starts to collapse inward. The star's outer layers spread out and cool. The result is a larger star that is cooler on the surface, and red in color.

Eventually a red giant burns up all of the helium in its core. What happens next depends on the star's mass. A star like the Sun stops fusion and shrinks into a white dwarf star. A white dwarf is a hot, white, glowing object about the size of Earth. Eventually, a white dwarf cools down and its light fades out.

Supergiants and Supernovas

A more massive star ends its life in a more dramatic way. Very massive stars become red supergiants, like Betelgeuse.

In a red supergiant, fusion does not stop. Lighter atoms fuse into heavier atoms. Eventually iron atoms form. When there is nothing left to fuse, the star's iron core explodes violently. This is called a **supernova** explosion. The incredible energy released fuses heavy atoms together. Gold, silver, uranium and the other heavy elements can only form in a supernova explosion. A supernova can shine as brightly as an entire galaxy, but only for a short time, as shown in **Figure** 3.3.

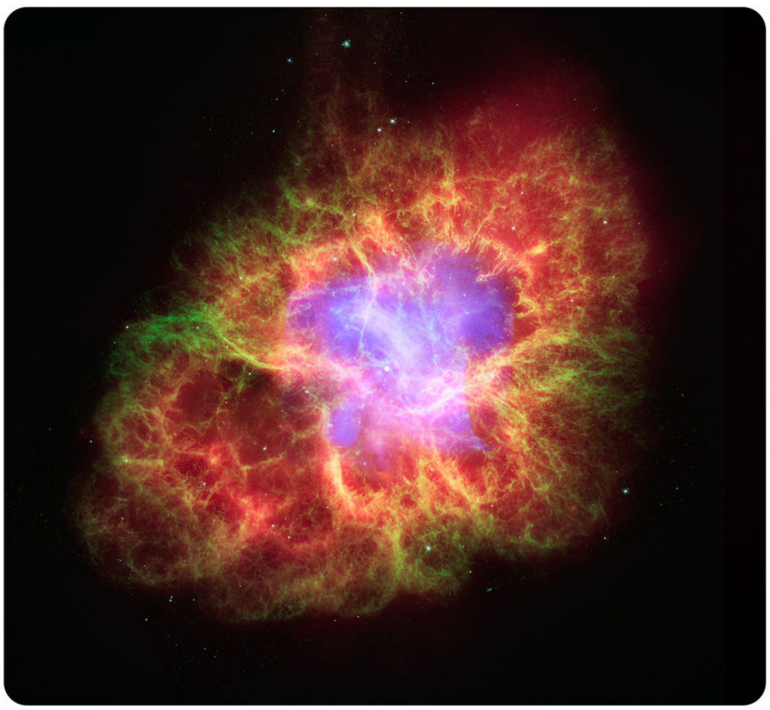


FIGURE 3.3
A supernova, as seen by the Hubble Space Telescope.

Neutron Stars and Black Holes

After a supernova explosion, the star's core is left over. This material is extremely dense. If the core is less than about four times the mass of the Sun, the star will become a neutron star. A **neutron star** is shown in **Figure** 3.4. This type of star is made almost entirely of neutrons. A neutron star has more mass than the Sun, yet it is only a few kilometers in diameter.

If the core remaining after a supernova is more than about 5 times the mass of the Sun, the core collapses to become a **black hole**. Black holes are so dense that not even light can escape their gravity. For that reason, we can't see black holes. How can we know something exists if radiation can't escape it? We know a black hole is there by the effect that it has on objects around it. Also, some radiation leaks out around its edges. A black hole isn't a hole at all. It is the tremendously dense core of a supermassive star.

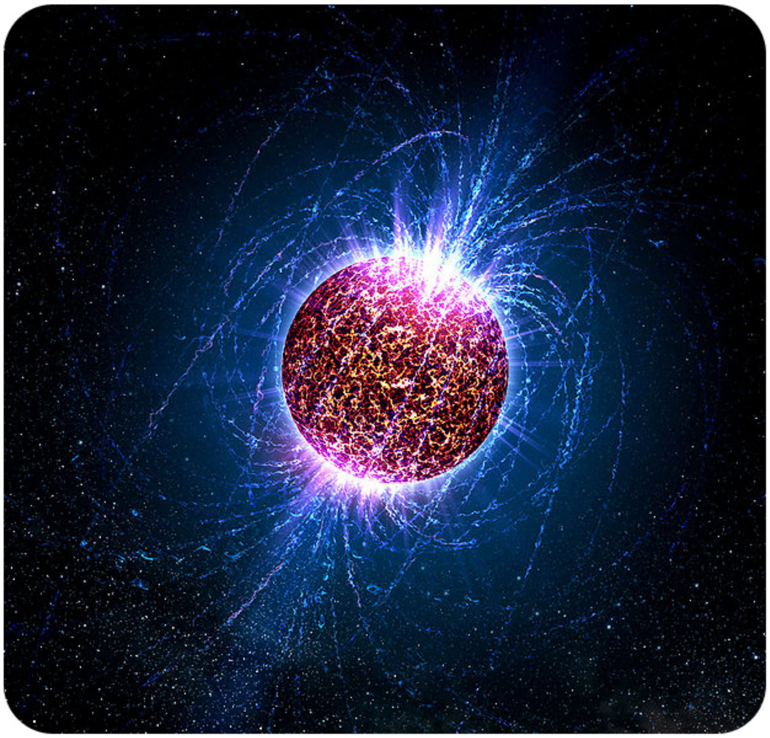


FIGURE 3.4
An artist's depiction of a neutron star.

Measuring Star Distances

Astronomers use light years as the unit to describe distances in space. Remember that a light year is the distance light travels in one year.

How do astronomers measure the distance to stars? For stars that are close to us, they measure shifts in their position over time. This is called parallax. For distant stars, they use the stars' brightness. For example, if a star is like the Sun, it should be about as bright as the Sun. They then figure out the star's distance from Earth by measuring how much less bright it is than expected.

Star Systems

Our solar system has only one star. But many stars are in systems of two or more stars. Two stars that orbit each other are called a **binary star system**. If more than two stars orbit each other, it is called a multiple star system. **Figure** 3.5 shows two binary star systems orbiting each other. This creates an unusual quadruple star system.

Lesson Summary

- A star generates energy by nuclear fusion reactions in its core.
- The color of a star is determined by its surface temperature.
- Stars are classified by color and temperature. The most common system uses the letters O (blue), B (blue-white), A (white), F (yellow-white), G (yellow), K (orange), and M (red), from hottest to coolest.
- Stars form from clouds of gas and dust called nebulas. Nebulas collapse until nuclear fusion starts.
- Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
- Sun-like stars expand into red giants, and then fade out as white dwarf stars.
- Very massive stars expand into red supergiants, explode in supernovas, then end up as neutron stars or black

FIGURE 3.5
This is an artist's concept of HD 98800. This is a quadruple star system made of two binary star systems. The distance separating the two pairs is about the same as the distance from our Sun to Pluto.

holes.
- Star distances can be measured in a number of creative ways.
- Many stars orbit another star to form a binary system. More than two stars may also orbit each other.

Lesson Review Questions

Recall

1. What is nuclear fusion?

2. What do the colors of stars mean?

3. What is a black hole? Why is it called that?

4. What is a binary star system?

Apply Concepts

5. Where are the stars in a constellation located relative to each other? Are they always near each other? Are they always far from each other?

6. What does a particle accelerator do? Why is it an important tool for astronomers?

Think Critically

7. Beginning with hydrogen how do the chemical elements form? You can think of them in groups.

8. Describe the Sun's life from its beginning to it eventual end.

9. How do astronomers know how stars form? What evidence do they have?

Points to Consider

- Although stars in constellations appear to be close together, they are usually not close together out in space. Can you think of any groups of astronomical objects that are relatively close together in space?
- Most nebulas contain more mass than a single star. If a large nebula collapsed into several different stars, what would the result be like?

3.2 Galaxies

Lesson Objectives

- Identify different types of galaxies.
- Describe our own galaxy, the Milky Way Galaxy.

Vocabulary

- elliptical galaxy
- galaxy
- globular cluster
- irregular galaxy
- Milky Way Galaxy
- open cluster
- spiral arm
- spiral galaxy
- star cluster

Introduction

Compared to Earth, the solar system is a big place. But galaxies are bigger - a lot bigger. A **galaxy** is a very large group of stars held together by gravity. How enormous a galaxy is and how many stars it contains are impossible for us to really understand. A galaxy contains up to a few billion stars! Our solar system is in the Milky Way Galaxy. It is so large that if our solar system were the size of your fist, the galaxy's disk would be wider than the entire United States! There are several different types of galaxies, and there are billions of galaxies in the universe.

Star Clusters

Star clusters are groups of stars smaller than a galaxy. There are two main types, open clusters and globular clusters. **Open clusters** are groups of up to a few thousand stars held together by gravity. The Jewel Box, shown in **Figure** 3.6, is an open cluster. Open clusters tend to be blue in color, and often contain glowing gas and dust. The stars in an open cluster are young stars that all formed from the same nebula.

Globular clusters are groups of tens to hundreds of thousands of stars held tightly together by gravity. Globular clusters have a definite, spherical shape. They contain mostly old, reddish stars. Near the center of a globular cluster, the stars are closer together. **Figure** 3.7 shows a globular cluster. The heart of the globular cluster M13 has hundreds of thousands of stars. M13 is 145 light years in diameter. The cluster contains red and blue giant stars.

FIGURE 3.6
These hot blue stars are in an open cluster known as the Jewel Box. The red star is a young red supergiant.

FIGURE 3.7
The globular cluster, M13, contains red and blue giant stars.

Types of Galaxies

The biggest groups of stars are called galaxies. A few million to many billions of stars may make up a galaxy. With the unaided eye, every star you can see is part of the Milky Way Galaxy. All the other galaxies are extremely far away. The closest spiral galaxy, the Andromeda Galaxy, shown in **Figure** 3.8, is 2,500,000 light years away and contains one trillion stars!

Spiral Galaxies

Galaxies are divided into three types, according to shape. There are spiral galaxies, elliptical galaxies, and irregular galaxies. **Spiral galaxies** are a rotating disk of stars and dust. In the center is a dense bulge of material. Several

FIGURE 3.8
The Andromeda Galaxy is the closest major galaxy to our own.

arms spiral out from the center. Spiral galaxies have lots of gas and dust and many young stars. **Figure** 3.9 shows a spiral galaxy from the side. You can see the disk and central bulge.

FIGURE 3.9
The Pinwheel Galaxy is a spiral galaxy displaying prominent arms.

Elliptical Galaxies

Figure 3.10 shows a typical elliptical galaxy. **Elliptical galaxies** are oval in shape. The smallest are called dwarf elliptical galaxies. Look back at the image of the Andromeda Galaxy. It has two dwarf elliptical galaxies as its companions. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

Giant elliptical galaxies contain over a trillion stars. Elliptical galaxies are red to yellow in color because they contain mostly old stars. Most contain very little gas and dust because the material has already formed into stars.

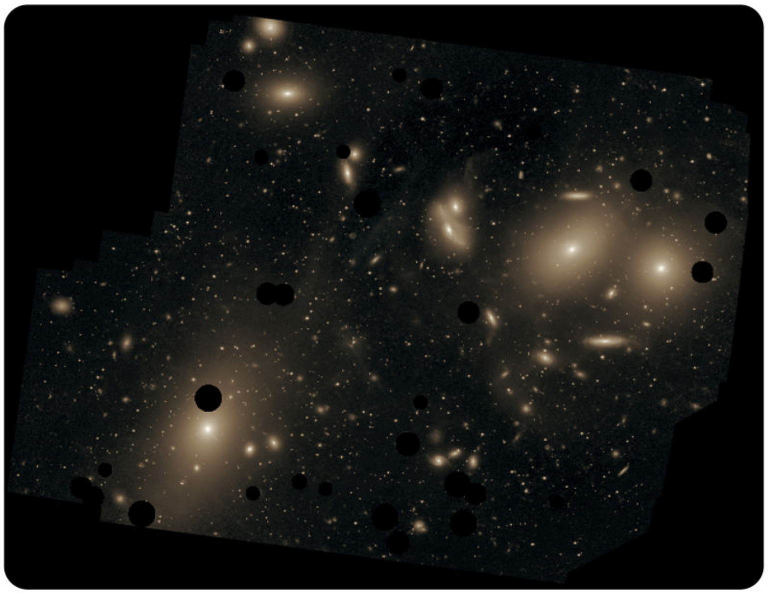


FIGURE 3.10
M87 is an elliptical galaxy in the lower left of this image. How many elliptical galaxies do you see? Are there other types of galaxies displayed?

Irregular Galaxies

Look at the galaxy in **Figure** 3.11. Do you think this is a spiral galaxy or an elliptical galaxy? It doesn't look like either! If a galaxy is not spiral or elliptical, it is an **irregular galaxy**. Most irregular galaxies have been deformed. This can occur either by the pull of a larger galaxy or by a collision with another galaxy.

The Milky Way Galaxy

If you get away from city lights and look up in the sky on a very clear night, you will see something spectacular. A band of milky light stretches across the sky, as in **Figure** 3.12. This band is the disk of the **Milky Way Galaxy**. This is the galaxy where we all live. The Milky Way Galaxy looks different to us than other galaxies because our view is from inside of it!

Shape and Size

The Milky Way Galaxy is a spiral galaxy that contains about 400 billion stars. Like other spiral galaxies, it has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across. It is about 3,000 light years thick. Most of the galaxy's gas, dust, young stars, and open clusters are in the disk. Some astronomers think that there is a gigantic black hole at the center of the galaxy. **Figure** 3.13 shows what the Milky Way probably looks like from the outside.

Our solar system is within one of the spiral arms. Most of the stars we see in the sky are relatively nearby stars that are also in this spiral arm. We are a little more than halfway out from the center of the Galaxy to the edge, as shown in **Figure** 3.13.

Our solar system orbits the center of the galaxy as the galaxy spins. One orbit of the solar system takes about 225 to 250 million years. The solar system has orbited 20 to 25 times since it formed 4.6 billion years ago.

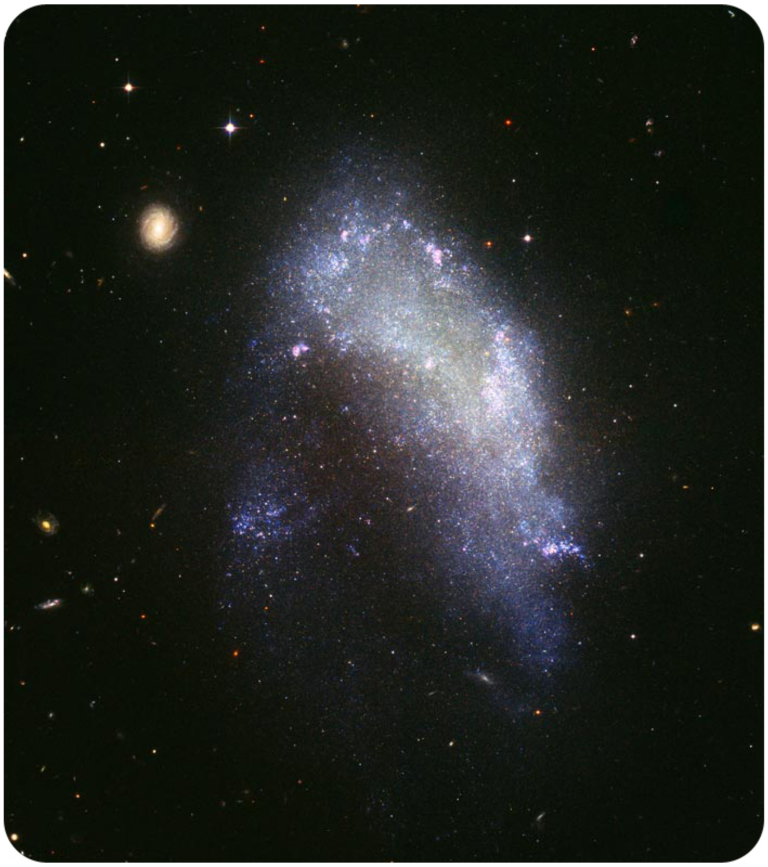


FIGURE 3.11
This irregular galaxy, NGC 55, is neither spiral nor elliptical.

FIGURE 3.12
The Milky Way Galaxy in the night sky above Death Valley.

Lesson Summary

- Open clusters are groups of young stars loosely held together by gravity.
- Globular clusters are spherical groups of old stars held tightly together by gravity.
- Galaxies are collections of millions to many billions of stars.
- Spiral galaxies have a rotating disk of stars and dust, a bulge in the middle, and several arms spiraling out from the center. The disk and arms contain many young, blue stars.
- Typical elliptical galaxies are oval shaped, red or yellow, and contain mostly old stars.
- A galaxy that is not elliptical or spiral is an irregular galaxy. These galaxies were deformed by other galaxies.
- The band of light called the Milky Way is the disk of our galaxy, the Milky Way Galaxy, which is a typical spiral galaxy.

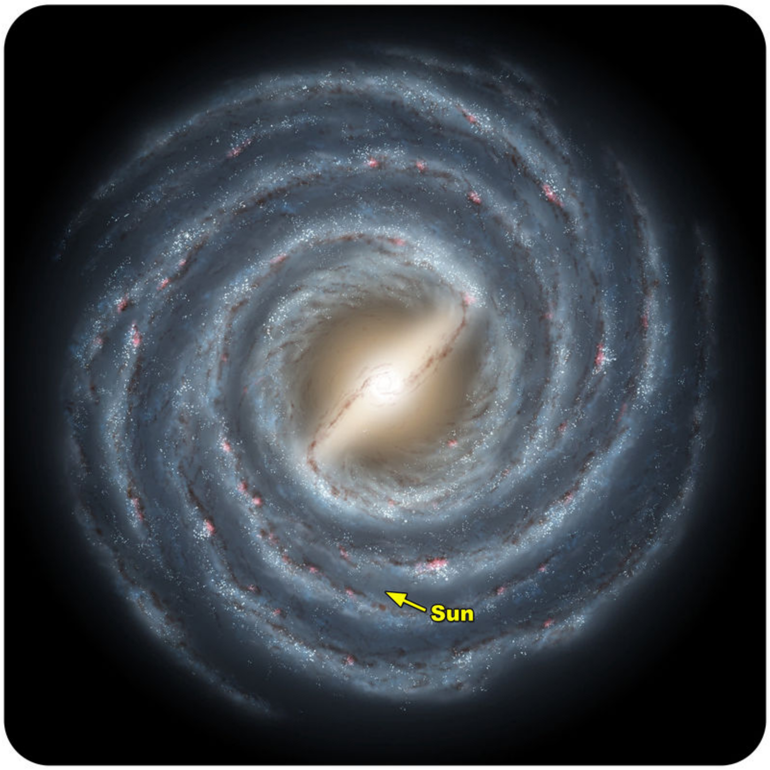


FIGURE 3.13
This is an artist's rendering of the Milky Way Galaxy seen from above. The Sun and solar system (and you!) are a little more than halfway out from the center.

- Our solar system is in a spiral arm of the Milky Way Galaxy, a little more than halfway from the center to the edge of the disk. Most of the stars we see are in our spiral arm.

Lesson Review Questions

Recall

1. What is the difference between a globular cluster and an open cluster?
2. What are the features of a spiral galaxy?
3. What are the features of an elliptical galaxy?

Apply Concepts

4. Where in the Milky Way galaxy is Earth?
5. How do irregular galaxies become irregular? Why do astronomers think that?

Think Critically

6. How do astronomers know that we live in a spiral galaxy if we're inside it?
7. How can astronomers tell the age of a galaxy?

Points to Consider

- Objects in the universe tend to be grouped together. What might cause them to form and stay in groups?
- Can you think of anything that is bigger than a galaxy?

3.3 The Universe

Lesson Objectives

- Explain the evidence for an expanding universe.
- Describe the formation of the universe according to the Big Bang Theory.
- Define dark matter and dark energy.

Vocabulary

- Big Bang Theory
- dark energy
- dark matter
- universe

Introduction

The **universe** contains all the matter and energy that exists and all of space and time. We are always learning more about the universe. In the early 20th century, Edwin Hubble used powerful telescopes to show that some distant specks of light seen through telescopes are actually other galaxies. (**Figure** 3.14) Hubble discovered that the Andromeda Nebula is over 2 million light years away. This is many times farther than the farthest distances we had measured before. He realized that galaxies were collections of millions or billions of stars. Hubble also measured the distances to hundreds of galaxies. Today, we know that the universe contains about a hundred billion galaxies.

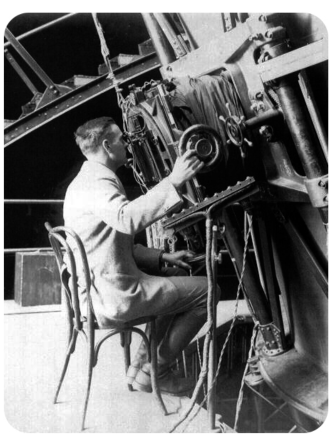


FIGURE 3.14
Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California.

The Expanding Universe

Hubble measured the distances to galaxies. He also studied the motions of galaxies. In doing these things, Hubble noticed a relationship. This is now called Hubble's Law: The farther away a galaxy is, the faster it is moving away from us. There was only one conclusion he could draw from this. The universe is expanding!

Figure 3.15 shows a simple diagram of the expanding universe. Imagine a balloon covered with tiny dots. When you blow up the balloon, the rubber stretches. The dots slowly move away from each other as the space between them increases. In an expanding universe, the space between galaxies is expanding. We see this as the other galaxies moving away from us. We also see that galaxies farther away from us move away faster than nearby galaxies.

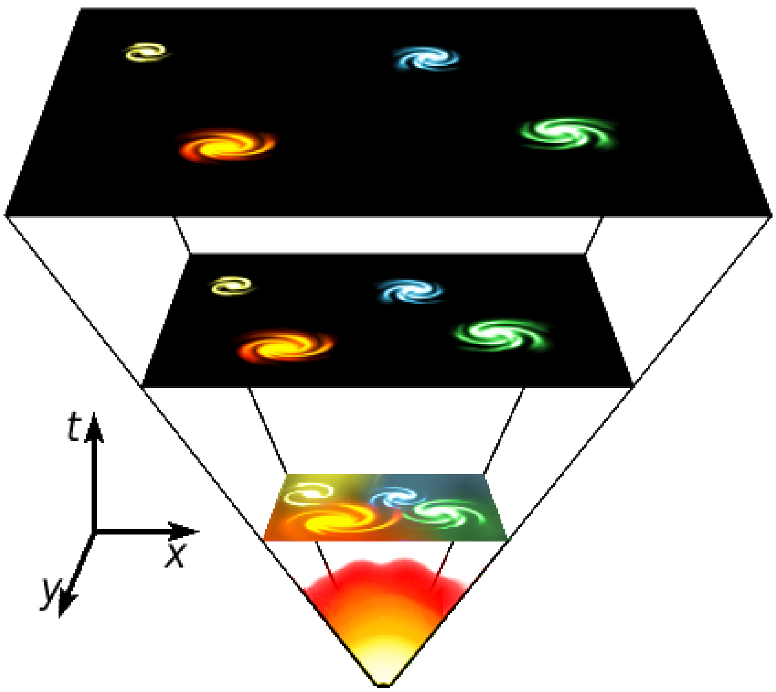


FIGURE 3.15

This is a simplified diagram of the expansion of the universe. The distance between galaxies gets bigger, but the size of each galaxy stays about the same.

The Big Bang Theory

About 13.7 billion years ago, the entire universe was packed together. Everything was squeezed into a tiny volume. Then there was an enormous explosion. After this "big bang," the universe expanded rapidly (**Figure** 3.16). All of the matter and energy in the universe has been expanding ever since. Scientists have evidence this is how the universe formed. One piece of evidence is that we see galaxies moving away from us. If they are moving apart, they must once have been together. Also, there is energy left over from this explosion throughout the universe. The theory for the origin of the universe is called the **Big Bang Theory**.

After the Big Bang

In the first few moments after the Big Bang, the universe was extremely hot and dense. As the universe expanded, it became less dense. It began to cool. First protons, neutrons, and electrons formed. From these particles came hydrogen. Nuclear fusion created helium atoms. Some parts of the universe had matter that was densely packed.

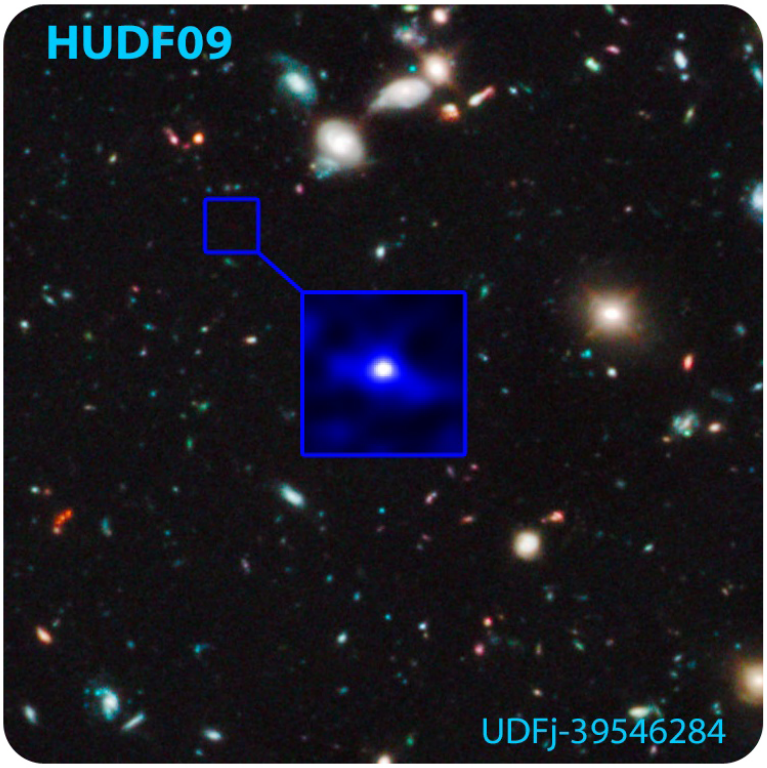


FIGURE 3.16
HUDF09 is 13.2 billion light years away from us. This is only 480 million years after the Big Bang. The smaller box shows where the galaxy is and the larger box contains a larger image of the galaxy. This is part of the Hubble Ultra Deep Field.

Enormous clumps of matter were held together by gravity. Eventually this material became the gas clouds, stars, galaxies, and other structures that we see in the universe today.

Dark Matter

We see many objects out in space that emit light. This matter is contained in stars, and the stars are contained in galaxies. Scientists think that stars and galaxies make up only a small part of the matter in the universe. The rest of the matter is called **dark matter**.

Dark matter doesn't emit light, so we can't see it. We know it is there because it affects the motion of objects around it. For example, astronomers measure how spiral galaxies rotate. The outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot more matter in the galaxy than we can see.

What is dark matter? Actually, we don't really know. Dark matter could just be ordinary matter, like what makes up Earth. The universe could contain lots of objects that don't have enough mass to glow on their own. There might just be a lot of black holes. Another possibility is that the universe contains a lot of matter that is different from anything we know. If it doesn't interact much with ordinary matter, it would be very difficult or impossible to detect directly.

Most scientists who study dark matter think it is a combination. Ordinary matter is part of it. That is mixed with some kind of matter that we haven't discovered yet. Most scientists think that ordinary matter is less than half of the total matter in the universe.

Dark Energy

We know that the universe is expanding. Astronomers have wondered if it is expanding fast enough to escape the pull of gravity. Would the universe just expand forever? If it could not escape the pull of gravity, would it someday start to contract? This means it would eventually get squeezed together in a big crunch. This is the opposite of the Big Bang.

Scientists may now have an answer. Recently, astronomers have discovered that the universe is expanding even faster than before. What is causing the expansion to accelerate? One hypothesis is that there is energy out in the universe that we can't see. Astronomers call this **dark energy**. We know even less about dark energy than we know about dark matter. Some scientists think that dark energy makes up more than half of the universe.

Lesson Summary

- The universe contains all matter and all energy as well as all of space and time.
- We can see that galaxies are moving away from us which tells us that the universe is expanding.
- In the past the universe was squeezed into a very small volume.
- The Big Bang theory proposes that the universe formed in an enormous explosion about 13.7 billion years ago.
- Recent evidence shows that there is a lot of matter in the universe that we cannot see. This matter is called dark matter.
- The rate of the expansion of the universe is increasing. The cause of this increase is unknown; one possible explanation involves a new form of energy called dark energy.

Lesson Review Questions

Recall

1. What is Hubble's law?
2. How old is the universe?
3. What is dark matter?
4. What is dark energy?

Apply Concepts

5. Describe the Big Bang theory.
6. Why do scientists think that dark matter exists?

Think Critically

7. How do you think scientists can calculate the age of the universe?
8. How is the Big Bang theory different from other explanations of how the universe came to be?

Points to Consider

- In what ways is an expanding balloon a good model of the universe, and in what ways is it incorrect? Can you think of a different way to model the expansion of the universe?

- The Big Bang theory is currently the most widely accepted scientific theory for how the universe formed. What is another explanation of how the universe could have formed? Is your explanation one that a scientist would accept?

For **Table** 3.1, from top to bottom,

- User:Kryptid/Wikipedia. http://commons.wikimedia.org/wiki/File:Zeta_Puppis.png . Public Domain.
- Will Fox. http://commons.wikimedia.org/wiki/File:Rigel_blue_supergiant.jpg . Public Domain.
- Courtesy of G. Bacon (STScI), NASA, ESA. http://commons.wikimedia.org/wiki/File:Sirius_A_and_B_artwork.jpg . Public Domain.
- Courtesy of NASA/ESA/HST, G. Bacon (STScI). http://en.wikipedia.org/wiki/File:Polaris_system.jpg . Public Domain.
- Courtesy of NASA/SDO (AIA). http://commons.wikimedia.org/wiki/File:The_Sun_by_the_Atmospheric_Imaging_Assembly_of_NASA%27s_Solar_Dynamics_Observatory_-_20100819.jpg . Public Domain.
- Windows to the Universe. http://www.windows2universe.org/the_universe/Arcturus.html&edu=high . The copyright holder of this file allows anyone to use it for any purpose, provided that Windows to the Universe be referenced and/or linked to.
- Courtesy of NASA/Walt Feimer. http://commons.wikimedia.org/wiki/File:RedDwarfNASA.jpg . Public Domain.
- Courtesy of Hubble European Space Agency/Akira Fujii, modified by Henrykus. http://commons.wikimedia.org/wiki/File:Betelgeuse_position_in_Orion.png . Public Domain.

3.4 References

1. Zachary Wilson. CK-12 Foundation . CC BY-NC 3.0
2. Courtesy of NASA, Hui Yang University of Illinois ODNursery of New Stars. http://commons.wikimedia.org/wiki/File:Nursery_of_New_Stars_-_GPN-2000-000972.jpg . Public domain
3. X-ray: NASA/CXC/J.Hester (ASU); Optical: NASA/ESA/J.Hester A.Loll (ASU); Infrared: NASA/JPL-Caltech/R.Gehrz (Univ. Minn.). http://commons.wikimedia.org/wiki/File:Sig06-028.jpg . Public Domain
4. Casey Reed/Penn State University. http://commons.wikimedia.org/wiki/File:Neutron_star_illustrated.jpg . Public Domain
5. Courtesy of NASA/JPL-Caltech/T. Pyle (SSC). http://commons.wikimedia.org/wiki/File:HD_98800.jpg . Public Domain
6. European Southern Observatory (ESO). http://commons.wikimedia.org/wiki/File:A_Snapshot_of_the_Jewel_-Box_cluster_with_the_ESO_VLT.jpg . CC BY 3.0
7. Courtesy of ESA/Hubble and NASA. http://commons.wikimedia.org/wiki/File:Heart_of_M13_Hercules_Globular_Cluster.jpg . Public Domain
8. Adam Evans. http://commons.wikimedia.org/wiki/File:Andromeda_Galaxy_(with_h-alpha).jpg . CC BY 2.0
9. Credit for Hubble Image: NASA and ESA, K.D. Kuntz (GSFC), F. Bresolin (University of Hawaii), J. Trauger (JPL), J. Mould (NOAO), and Y.-H. Chu (University of Illinois, Urbana); Credit for CFHT Image: Canada-France-Hawaii Telescope/ J.-C. Cuillandre/Coelum; Credit for NOAO Image: G. Jacoby, B. Bohannan, M. Hanna/ NOAO/AURA/NSF. http://hubblesite.org/newscenter/archive/releases/2006/10/image/a/ . Public Domain
10. Chris Mihos (Case Western Reserve University)/European Southern Observatory (ESO). http://commons.wikimedia.org/wiki/File:ESO-M87.jpg . CC BY 3.0
11. Courtesy of NASA, ESA, and The Hubble Heritage Team (STScI/AURA). http://hubblesite.org/newscenter/archive/releases/2005/09/image/a/ . Public Domain
12. Courtesy of Dan Duriscoe, for the US National Park Service. http://commons.wikimedia.org/wiki/File:Deathvalleysky_nps_big.jpg . Public Domain
13. Courtesy of NASA/JPL-Caltech/R. Hurt (SSC). http://sscws1.ipac.caltech.edu/Imagegallery/image.php?image_name=sig05-010 . Public domain
14. Courtesy of JPL-Caltech. http://planck.caltech.edu/epo/epo-cmbDiscovery1.html . Public Domain
15. User:Gnixon/Wikipedia. http://commons.wikimedia.org/wiki/File:Universe_expansion2.png . Public Domain
16. NASA, ESA, Garth Illingworth (University of California, Santa Cruz) and Rychard Bouwens (University of California, Santa Cruz and Leiden University) and the HUDF09 Team. http://commons.wikimedia.org/wiki/File:Hudf09z10nl.png . Public Domain

CHAPTER 4 The Solar System

Chapter Outline

4.1 Introduction to the Solar System

Lesson Objectives

- Describe some early ideas about our solar system.
- Name the planets, and describe their motion around the Sun.
- Explain how the solar system formed.

Vocabulary

- astronomical unit
- dwarf planet
- nebula
- nuclear fusion
- planet
- solar system

Introduction

We can learn a lot about the universe and about Earth history by studying our nearest neighbors. The solar system has planets, asteroids, comets, and even a star for us to see and understand. It's a fascinating place to live!

Changing Views of the Solar System

The Sun and all the objects that are held by the Sun's gravity are known as the **solar system**. These objects all revolve around the Sun. The ancient Greeks recognized five planets. These lights in the night sky changed their position against the background of stars. They appeared to wander. In fact, the word "planet" comes from a Greek word meaning "wanderer." These objects were thought to be important, so they named them after gods from their mythology. The names for the planets Mercury, Venus, Mars, Jupiter, and Saturn came from the names of gods and a goddess.

Earth at the Center of the Universe

The ancient Greeks thought that Earth was at the center of the universe, as shown in **Figure** 4.1. The sky had a set of spheres layered on top of one another. Each object in the sky was attached to one of these spheres. The object moved around Earth as that sphere rotated. These spheres contained the Moon, the Sun, and the five planets they recognized: Mercury, Venus, Mars, Jupiter, and Saturn. An outer sphere contained all the stars. The planets appear to move much faster than the stars, so the Greeks placed them closer to Earth. Ptolemy published this model of the solar system around 150 AD.

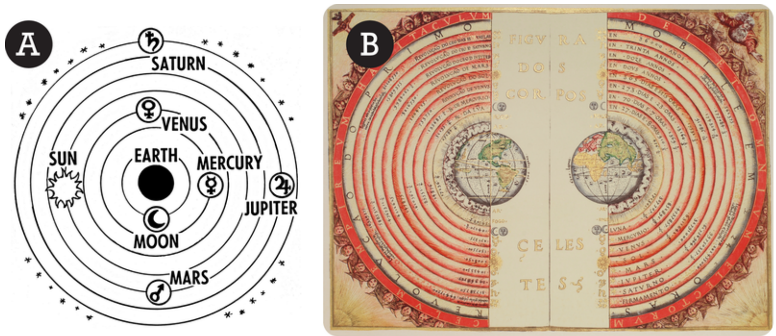


FIGURE 4.1
On left is a line art drawing of the Ptolemaic system with Earth at the center. On the right is a drawing of the Ptolemaic system from 1568 by a Portuguese astronomer.

The Sun at the Center of the Universe

About 1,500 years after Ptolemy, Copernicus proposed a startling idea. He suggested that the Sun is at the center of the universe. Copernicus developed his model because it better explained the motions of the planets. **Figure** 4.2 shows both the Earth-centered and Sun-centered models.

FIGURE 4.2
Copernicus proposed a different idea that had the Sun at the center of the universe

Copernicus did not publish his new model until his death. He knew that it was heresy to say that Earth was not the center of the universe. It wasn't until Galileo developed his telescope that people would take the Copernican model more seriously. Through his telescope, Galileo saw moons orbiting Jupiter. He proposed that this was like the planets orbiting the Sun.

Planets and Their Motions

Today we know that we have eight planets, five dwarf planets, over 165 moons, and many, many asteroids and other small objects in our solar system. We also know that the Sun is not the center of the universe. But it is the center of the solar system.

FIGURE 4.3
This artistic composition shows the eight planets, a comet, and an asteroid.

Figure 4.3 shows our solar system. The planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. **Table** 4.1 gives some data on the mass and diameter of the Sun and planets relative to Earth.

TABLE 4.1: Sizes of Solar System Objects Relative to Earth

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth's mass	109.2 Earth's diameter
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's mass	1.00 Earth's diameter
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth's mass	11.21 Earth's diameter
Saturn	95.2 Earth's mass	9.41 Earth's diameter
Uranus	14.6 Earth's mass	3.98 Earth's diameter

TABLE 4.1: (continued)

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Neptune	17.2 Earth's mass	3.81 Earth's diameter

What Is (and Is Not) a Planet?

You've probably heard about Pluto. When it was discovered in 1930, Pluto was called the ninth planet. Astronomers later found out that Pluto was not like other planets. For one thing, what they were calling Pluto was not a single object. They were actually seeing Pluto and its moon, Charon. In older telescopes, they looked like one object. This one object looked big enough to be a planet. Alone, Pluto was not very big. Astronomers also discovered many objects like Pluto. They were rocky and icy and there were a whole lot of them.

Astronomers were faced with a problem. They needed to call these other objects planets. Or they needed to decide that Pluto was something else. In 2006, these scientists decided what a planet is. According to the new definition, a **planet** must:

- Orbit a star.
- Be big enough that its own gravity causes it to be round.
- Be small enough that it isn't a star itself.
- Have cleared the area of its orbit of smaller objects.

If the first three are true but not the fourth, then that object is a **dwarf planet**. We now call Pluto a dwarf planet. There are other dwarf planets in the solar system. They are Eris, Ceres, Makemake and Haumea. There are many other reasons why Pluto does not fit with the other planets in our solar system.

The Size and Shape of Orbits

FIGURE 4.4
The Sun and planets with the correct sizes. The distances between them are not correct.

Figure 4.4 shows the Sun and planets with the correct sizes. The distances between them are way too small. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next.

Figure 4.5 shows those distances correctly. In the upper left are the orbits of the inner planets and the asteroid belt. The asteroid belt is a collection of many small objects between the orbits of Mars and Jupiter. In the upper right are the orbits of the outer planets and the Kuiper belt. The Kuiper belt is a group of objects beyond the orbit of Neptune.

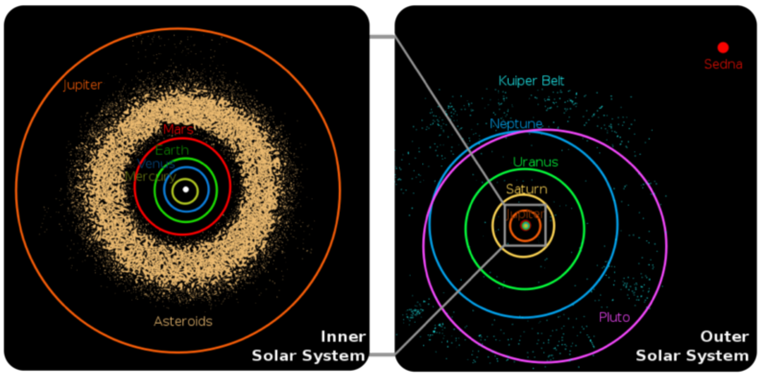


FIGURE 4.5
In this image, distances are shown to scale.

In **Figure** 4.5, you can see that the orbits of the planets are nearly circular. Pluto's orbit is a much longer ellipse. Some astronomers think Pluto was dragged into its orbit by Neptune.

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 (93 million miles). **Table** 4.2 shows the distance from the Sun to each planet in AU. The table shows how long it takes each planet to spin on its axis. It also shows how long it takes each planet to complete an orbit. Notice how slowly Venus rotates! A day on Venus is actually longer than a year on Venus!

TABLE 4.2: 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

The Role of Gravity

Planets are held in their orbits by the force of gravity. What would happen without gravity? Imagine that you are swinging a ball on a string in a circular motion. Now let go of the string. The ball will fly away from you in a straight line. It was the string pulling on the ball that kept the ball moving in a circle. The motion of a planet is very similar to the ball on a string. The force pulling the planet is the pull 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 the mass of the objects. It also depends on how far apart the objects are. When you are sitting next to your dog, there is a gravitational force between the two of you. That force is far too weak for you to notice. You can feel the force of gravity between you and Earth because Earth has a lot of mass. The force of gravity between the Sun and planets is also very large. This is because the Sun and the planets are very large objects. Gravity is great enough to hold the planets to the Sun even though the distances between them are enormous. Gravity also holds moons in orbit around planets.

Extrasolar Planets

Since the early 1990s, astronomers have discovered other solar systems. A solar system has one or more planets orbiting one or more stars. We call these planets "extrasolar planets," or "exoplanets". They are called exoplanets because they orbit a star other than the Sun. As of June 2013, 891 exoplanets have been found. More exoplanets are found all the time. You can check out how many we have found at http://planetquest.jpl.nasa.gov/.

We have been able to take pictures of only a few exoplanets. Most are discovered because of some tell-tale signs. One sign is a very slight motion of a star that must be caused by the pull of a planet. Another sign is the partial dimming of a star's light as the planet passes in front of it.

Formation of the Solar System

To figure out how the solar system formed, we need to put together what we have learned. There are two other important features to consider. First, all the planets orbit in nearly the same 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

Scientists think the solar system formed from a big cloud of gas and dust, called a **nebula**. This is the solar nebula hypothesis. The nebula was made mostly of hydrogen and helium. There were heavier elements too. Gravity caused the nebula to contract (**Figure** 4.6).

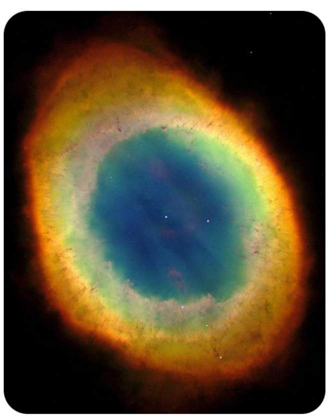


FIGURE 4.6

The nebula was drawn together by gravity.

As the nebula contracted, it started to spin. As it got smaller and smaller, it spun faster and faster. This is what happens when an ice skater pulls her arms to her sides during a spin move. She spins faster. The spinning caused the nebula to form into a disk shape.

This model explains why all the planets are found in the flat, disk-shaped region. It also explains why all the planets revolve in the same direction. The solar system formed from the nebula about 4.6 billion years ago

Formation of the Sun and Planets

The Sun was the first object to form in the solar system. Gravity pulled matter together to the center of the disk. Density and pressure increased tremendously. **Nuclear fusion** reactions begin. In these reactions, the nuclei of atoms come together to form new, heavier chemical elements. Fusion reactions release huge amounts of nuclear energy. From these reactions a star was born, the Sun.

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

The outer planets —Jupiter, Saturn, Uranus, and Neptune —condensed from lighter materials. Hydrogen, helium, water, ammonia, and methane were among them. It's so cold by Jupiter and beyond that these materials can form solid particles. Closer to the Sun, they are gases. Since the gases can escape, the inner planets —Mercury, Venus, Earth, and Mars —formed from denser elements. These elements are solid even when close to the Sun.

Lesson Summary

- The Sun and all the objects held by its gravity make up the solar system.
- There are eight planets in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, and Neptune. Pluto, Eris, Ceres, Makemake and Haumea are dwarf planets.
- The ancient Greeks believed Earth was at the center of the universe and everything else orbited Earth.
- Copernicus proposed that the Sun at the center of the universe and the planets and stars orbit the Sun.
- Planets are held by the force of gravity in elliptical orbits around the Sun.
- The solar system formed from a giant cloud of gas and dust about 4.6 billion years ago.
- This model explains why the planets all lie in one plane and orbit in the same direction around the Sun.

Lesson Review Questions

Recall

1. What are the names of the planets from the Sun outward? What are the names of the dwarf planets?

2. How old is the Sun? How old are the planets?

Apply Concepts

3. Describe the role of gravity in how the solar system functions. Why don't the planets fly off into space? Why don't the planets ram into the Sun?

4. Why does the nebular hypothesis explain how the solar system originated?

Think Critically

5. Why do you think so many people for so many centuries thought that Earth was the center of the universe?

6. People were pretty upset when Pluto was made a dwarf planet. Why do you think they were upset? How do you feel about it?

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?

4.2 Inner Planets

Lesson Objectives

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

Vocabulary

- inner planets
- year

Introduction

The four planets closest to the Sun - Mercury, Venus, Earth, and Mars - are the **inner planets**. They are similar to Earth. All are solid, dense, and rocky. None of the inner planets has rings. Compared to the outer planets, the inner planets are small. They have shorter orbits around the Sun and they spin more slowly. Venus spins backwards and spins the slowest of all the planets.

All of the inner planets were geologically active at one time. They are all made of cooled igneous rock with inner iron cores. Earth has one big, round moon, while Mars has two very small, irregular moons. Mercury and Venus do not have moons.

Mercury

Mercury is the smallest planet. It has no moon. The planet is also closest to the Sun and appears in **Figure** 4.7.

As **Figure** 4.8 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. With only a trace of an atmosphere, it has no weather to wear down the ancient craters.

Because Mercury is so close to the Sun, it is difficult to observe from Earth, even with a telescope. The Mariner 10 spacecraft did a flyby of Mercury in 1974–1975, which was the best data from the planet for decades. In 2004, the MESSENGER mission left Earth. On its way to Mercury it did one flyby of Earth, two of Venus and three of Mercury. In March 2011, MESSENGER became the first spacecraft to enter an orbit around Mercury. During its year-long mission, the craft will map the planet's surface and conduct other studies. One of these images can be seen in **Figure** 4.9.

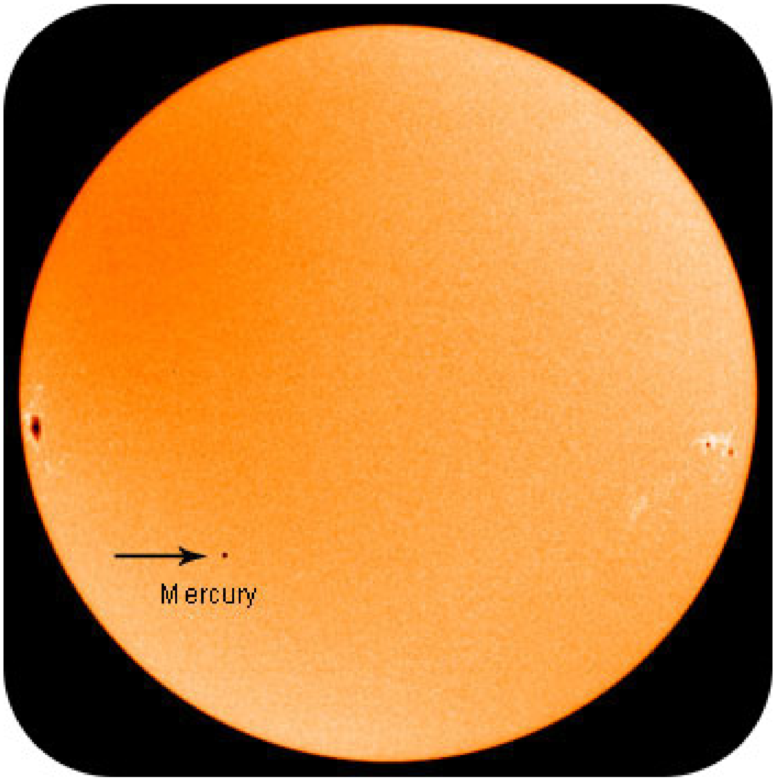


FIGURE 4.7
Tiny Mercury is the small black dot in the lower center of this picture of the Sun. The larger dark area near the left edge is a sunspot.

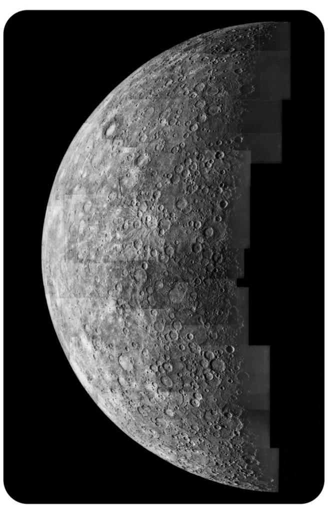


FIGURE 4.8
The surface of Mercury is covered with craters, like Earth's Moon.

Short Year, Long Days

Mercury is named for the Roman messenger god. Mercury was a messenger because he could run extremely fast. The Greeks gave the planet this name because Mercury moves very quickly in its orbit around the Sun. Mercury orbits the Sun in just 88 Earth days. Mercury has a very short year, but it also has very long days. 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.

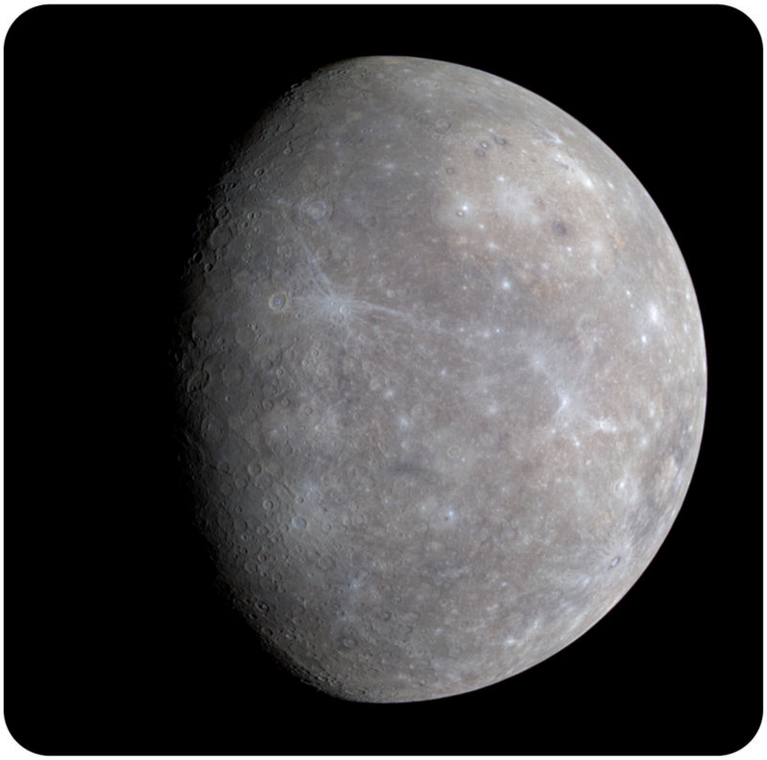


FIGURE 4.9

Extreme Temperatures

Mercury is very close to the Sun, so it can get very hot. Mercury also has virtually no atmosphere. As the planet rotates very slowly, the temperature varies tremendously. In direct sunlight, the surface can be as hot as 427°C (801°F). On the dark side, the surface can be as cold as –183°C (–297°F)! The coldest temperatures may be on the insides of craters. Most of Mercury is extremely dry. Scientists think that there may be a small amount of water, in the form of ice, at the planet's poles. The poles never receive direct sunlight.

A Liquid Metal Core

Figure 4.10 shows a diagram of Mercury's interior. Mercury is one of the densest planets. Scientists think that the interior contains a large 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.

Venus

Named after the Roman goddess of love, Venus is the only planet named after a female. Venus is sometimes called Earth's "sister planet." But just how similar is Venus to Earth? Venus is our nearest neighbor. Venus is most like Earth in size.

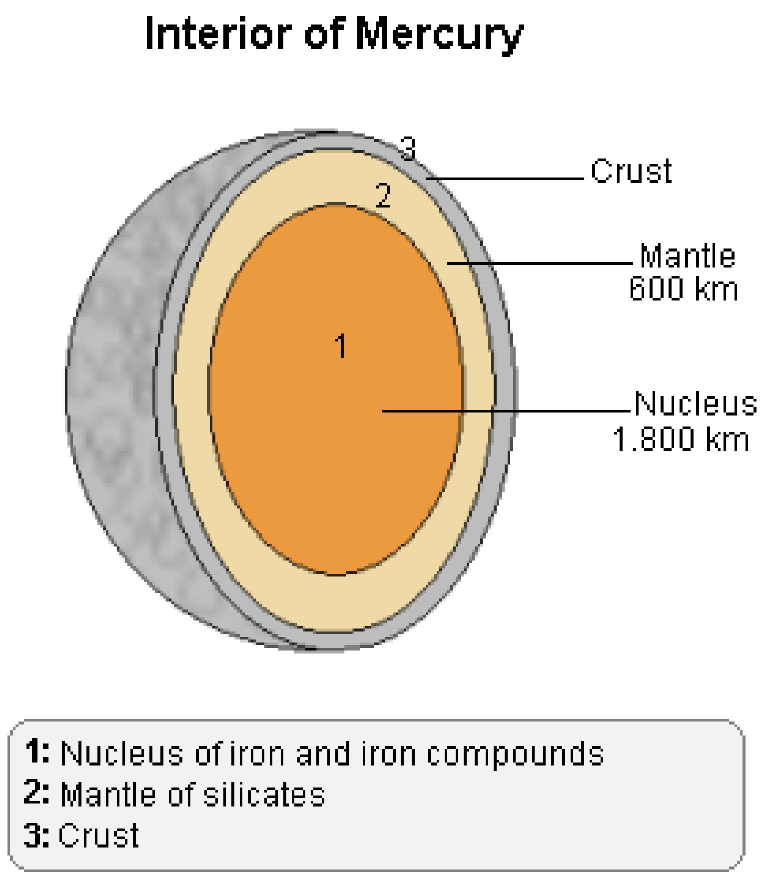


FIGURE 4.10
Mercury is one of the most dense planets, with a very large core.

A Harsh Environment

Viewed through a telescope, Venus looks smooth and featureless. The planet is covered by a thick layer of clouds. You can see the clouds in pictures of Venus, such as **Figure** 4.11. We make maps of the surface using radar, because the thick clouds won't allow us to take photographs of the surface of Venus.

Figure 4.12 shows the topographical features of Venus. The image was produced by the Magellan probe on a flyby. Radar waves sent by the spacecraft reveal mountains, valleys, vast lava plains, and canyons. Like Mercury, Venus does not have a moon.

Clouds on Earth are made of water vapor. Venus's clouds are a lot less pleasant. They are made of carbon dioxide, sulfur dioxide and large amounts of corrosive sulfuric acid! The atmosphere of Venus is so thick that the pressure on the surface of Venus is very high. In fact, it is 90 times greater than the pressure at Earth's surface! The thick atmosphere causes a strong greenhouse effect. As a result, Venus is the hottest planet. Even though it is farther from the Sun, Venus is much hotter even 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. There are between 100,000 and one million volcanoes on Venus! Most of the volcanoes are now inactive. There are also a large number of craters. This means that Venus doesn't have tectonic plates. Plate tectonics on Earth erases features over time. **Figure** 4.13 is an image made using radar data. The volcano is Maat Mons. Lava beds are in the foreground. Scientists think the color of sunlight on Venus is

FIGURE 4.11
Venus in real color. The planet is covered by a thick layer of clouds.

FIGURE 4.12
A topographical image of Venus produced by the Magellan probe using radar. Color differences enhance small scale structure.

reddish-brown.

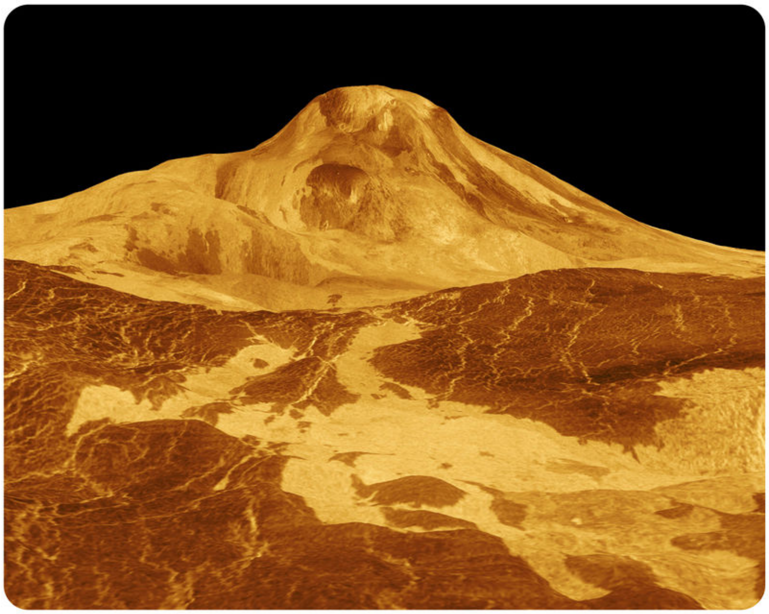


FIGURE 4.13
Maat Mons volcano on Venus, with lava beds in the foreground.

Motion and Appearance

Venus is the only planet that rotates clockwise as viewed from its North Pole. All of the other planets rotate counterclockwise. Venus turns slowly, making only one turn every 243 days. This is longer than a year on Venus! It takes Venus only 225 days to orbit the Sun.

Because the orbit of Venus is inside Earth's orbit, Venus always appears close to the Sun. You can see Venus rising early in the morning, just before the Sun rises. For this reason, Venus is sometimes called "the morning star." When it sets in the evening, just after the Sun sets, it may be called "the evening star." Since planets only reflect the Sun's light, Venus should not be called a star at all! Venus is very bright because its clouds reflect sunlight very well. Venus is the brightest object in the sky besides the Sun and the Moon.

Earth

Earth is the third planet out from the Sun, shown in **Figure** 4.14. Because it is our planet, we know a lot more about Earth than we do about any other planet. What are main features of Earth?

Oceans and Atmosphere

Earth is a very diverse planet, seen in **Figure** 4.14. Water appears as vast oceans of liquid. Water is also seen as ice at the poles or as clouds of vapor. Earth also has large masses of land. Earth's average surface temperature is 14°C (57°F). At this temperature, water is a liquid. The oceans and the atmosphere help keep Earth's surface temperatures fairly steady.

Earth is the only planet known to have life. Conditions on Earth are ideal for life! The atmosphere filters out harmful radiation. Water is abundant. Carbon dioxide was available for early life forms. The evolution of plants introduced

FIGURE 4.14
Earth from space.

more oxygen for animals.

Plate Tectonics

The Earth is divided into many plates. These plates move around on the surface. The plates collide or slide past each other. One may even plunge beneath another. Plate motions cause most geological activity. This activity includes earthquakes, volcanoes, and the buildup of mountains. The reason for plate movement is convection in the mantle. Earth is the only planet that we know has plate tectonics.

Earth's Motions and Moon

Earth rotates on its axis once every 24 hours. This is the length of an Earth day. Earth orbits the Sun once every 365.24 days. This is the length of an Earth **year**. Earth has one large moon. This satellite orbits Earth once every 29.5 days. This moon is covered with craters, and also has large plains of lava. The Moon came into being from material that flew into space after Earth and a giant asteroid collided. This moon is not a captured asteroid like other moons in the solar system.

Mars

Mars, shown in **Figure** 4.15, is the fourth planet from the Sun. The Red Planet is the first planet beyond Earth's orbit. Mars' atmosphere is thin compared to Earth's. This means that there is much lower pressure at the surface. Mars also has a weak greenhouse effect, so temperatures are only slightly higher than they would be if the planet did not have an atmosphere.

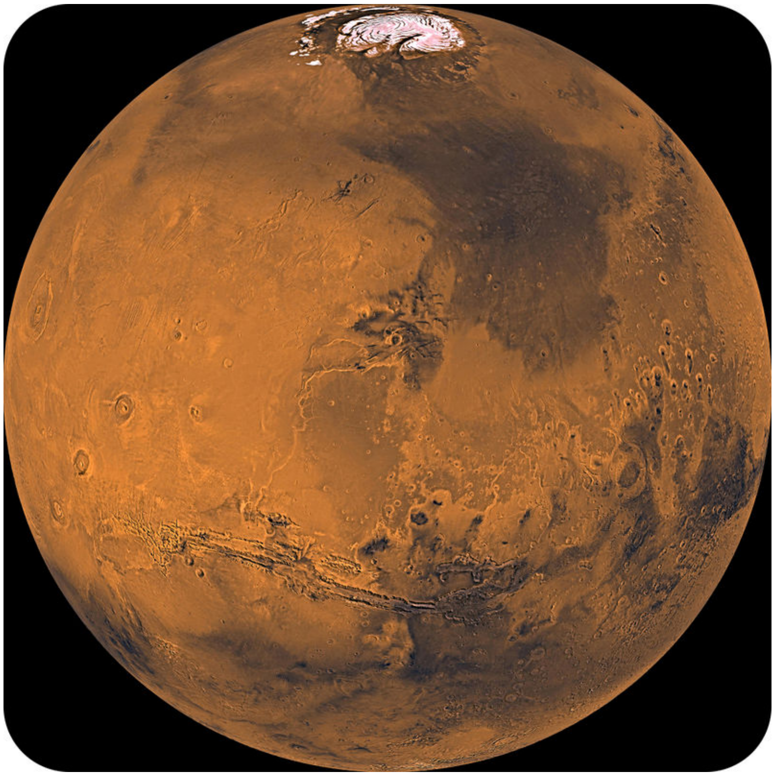


FIGURE 4.15
Mars is Earth's second nearest neighbor planet.

Mars is the easiest planet to observe. As a result, it has been studied more than any other planet besides Earth. People can stand on Earth and observe the planet through a telescope. We have also sent many space probes to Mars. In April 2011, there were three scientific satellites in orbit around Mars. The rover, Opportunity, was still moving around on the surface. No humans have ever set foot on Mars. NASA and the European Space Agency have plans to send people to Mars. The goal is to do it sometime between 2030 and 2040. The expense and danger of these missions are phenomenal.

A Red Planet

Viewed from Earth, Mars is red. This is due to large amounts of iron in the soil. The ancient Greeks and Romans named the planet Mars after the god of war. The planet's red color reminded them of blood. Mars has only a very thin atmosphere, made up mostly of carbon dioxide.

Surface Features

Mars is home to the largest volcano in the solar system. Olympus Mons is shown in **Figure** 4.16. Olympus Mons is a shield volcano. The volcano is similar to the volcanoes of the Hawaiian Islands. But Olympus Mons is a giant, about 27 km (16.7 miles/88,580 ft) tall. That's three times taller than Mount Everest! At its base, Olympus Mons is about the size of the entire state of Arizona.

Mars also has the largest canyon in the solar system, Valles Marineris (**Figure** 4.17). This canyon is 4,000 km (2,500 miles) long. That's as long as Europe is wide! One-fifth of the circumference of Mars is covered by the canyon. Valles Marineris is 7 km (4.3 miles) deep. How about Earth's Grand Canyon? Earth's most famous canyon is only 446 km (277 miles) long and about 2 km (1.2 miles) deep.

Mars has mountains, canyons, and other features similar to Earth. But it doesn't have as much geological activity

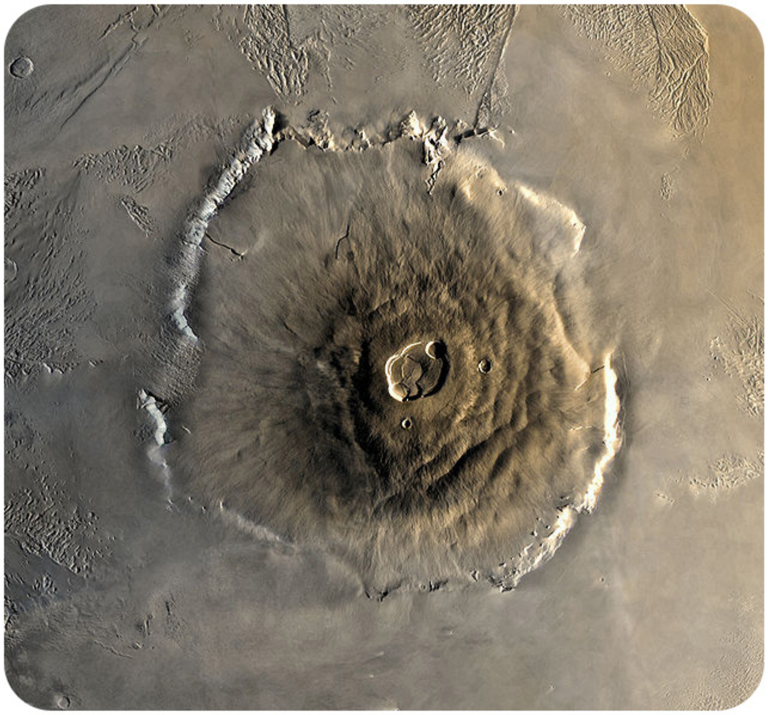


FIGURE 4.16
The largest volcano in the solar system, Olympus Mons.

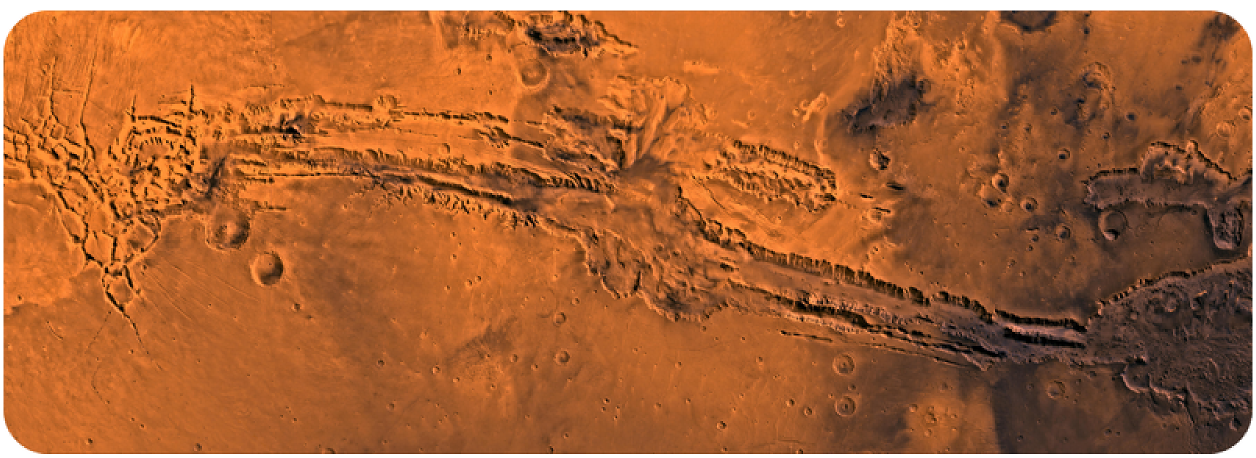


FIGURE 4.17
The largest canyon in the solar system, Valles Marineris.

as Earth. There is no evidence of plate tectonics on Mars. There are also more craters on Mars than on Earth. Buy there are fewer craters than on the Moon. What does this suggest to you regarding Mars' plate tectonic history?

Is There Water on Mars?

Water on Mars can't be a liquid. This is because the pressure of the atmosphere is too low. The planet does have a lot of water; it is in the form of ice. The south pole of Mars has a very visible ice cap. Scientists also have evidence that there is also a lot of ice just under the Martian surface. The ice melts when volcanoes erupt. At this times liquid water flows across the surface.

Scientists think that there was once liquid water on the planet. There are many surface features that look like water-eroded canyons. The Mars rover collected round clumps of crystals that, on Earth, usually form in water. If there was liquid water on Mars, life might have existed there in the past.

Two Martian Moons

Mars has two very small, irregular moons, Phobos (seen in **Figure** 4.18) and Deimos. These moons were discovered in 1877. They are named after the two sons of Ares, who followed their father into war. The moons were probably asteroids that were captured by Martian gravity.

FIGURE 4.18
Phobos is Mars' larger moon. It has a 6.9 mile (11.1 km) radius.

Lesson Summary

- The four inner planets are small, dense, solid, rocky planets.
- Mercury is the smallest planet and the closest to the Sun. It has an extremely thin atmosphere so surface temperatures range 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. Venus has a very thick, corrosive atmosphere, and the surface temperature is extremely high.

- Radar maps of Venus show that it has mountains, canyons and volcanoes surrounded by plains of lava.
- Venus rotates slowly in a direction opposite to the direction of its orbit.
- 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 is the only inner planet that has a large round moon.
- Mars is the fourth planet from the Sun. It has two small, irregular moons. Mars is red because of 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.

Lesson Review Questions

Recall

1. Name the four inner planets from nearest to the Sun to farthest out from the Sun.

2. Which planet is most like Earth? Why?

3. How do scientists get maps of Venus' surface? What do you see if you look at Venus from Earth through a telescope?

Apply Concepts

4. Which planet do you think has the smallest temperature range? Why?

5. If you were told to go to one of the three inner planets besides Earth to look for life where would you go? Why?

6. Mercury is small, rocky and covered with craters. Why?

Think Critically

7. Venus is said to have runaway greenhouse effect? Why does it have such a large amount of greenhouse effect? Why do you think is meant by runaway greenhouse effect?

8. Why are there no Martians? In other words, why didn't life evolve on Mars?

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 live on Mars? Why do you think we are going to Mars instead of Mercury or Venus?
- In what ways are the four inner planets like Earth? What might a planet be like if it weren't like Earth?

4.3 Outer Planets

Lesson Objectives

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

Vocabulary

- Galilean moons
- gas giants
- Great Red Spot
- outer planets
- planetary rings

Introduction

Jupiter, Saturn, Uranus, and Neptune are the **outer planets** of our solar system. These are the four planets farthest from the Sun. The outer planets are much larger than the inner planets. Since they are mostly made of gases, they are also called **gas giants**.

The gas giants are mostly made of hydrogen and helium. These are the same elements that make up most of the Sun. Astronomers think that most of the nebula was hydrogen and helium. The inner planets lost these very light gases. Their gravity was too low to keep them and they floated away into space. The Sun and the outer planets had enough gravity to keep the hydrogen and helium.

All of the outer planets have numerous moons. They also have **planetary rings** made of dust and other small particles. Only the rings of Saturn can be easily seen from Earth.

Jupiter

Jupiter, shown in **Figure** 4.19, is the largest planet in our solar system. Jupiter is named for the king of the gods in Roman mythology.

Jupiter is truly a giant! The planet has 318 times the mass of Earth, and over 1,300 times Earth's volume. So Jupiter is much less dense than Earth. 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. Jupiter is quite far from the Earth. The planet is more than five times as far from Earth as the Sun. It takes Jupiter about 12 Earth years to orbit once around the Sun.

FIGURE 4.19
Jupiter is the largest planet in our solar system.

A Ball of Gas and Liquid

Since Jupiter is a gas giant, could a spacecraft land on its surface? The answer is no. 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, the intense pressure condenses the gases into a liquid. Jupiter may have a small rocky core at its center.

A Stormy Atmosphere

Jupiter's atmosphere is unlike any other in the solar system! The upper layer contains clouds of ammonia. The ammonia is different colored bands. These bands rotate around the planet. The ammonia also swirls around in tremendous storms. The **Great Red Spot**, shown in **Figure** 4.20, is Jupiter's most noticeable feature. The spot is an enormous, oval-shaped storm. It is more than three times as wide as the entire Earth! Clouds in the storm rotate counterclockwise. They make one complete turn every six days or so. The Great Red Spot has been on Jupiter for at least 300 years. It may have been observed as early as 1664. It is possible that this storm is a permanent feature on Jupiter. No one knows for sure.

Jupiter's Moons and Rings

Jupiter has lots of moons. As of 2011, we have discovered over 60 natural satellites of Jupiter. Four are big enough and bright enough to be seen from Earth using a pair of binoculars. These four moons were first discovered by Galileo in 1610. They are called the **Galilean moons**. **Figure** 4.21 shows the four Galilean moons and their sizes relative to Jupiter's Great Red Spot. These moons are named Io, Europa, Ganymede, and Callisto. The Galilean moons are larger than even the biggest dwarf planets, Pluto and Eris. Ganymede is the biggest moon in the solar system. It is even larger than the planet Mercury!

FIGURE 4.20
The Great Red Spot has been on Jupiter since we've had telescopes powerful enough to see it.

FIGURE 4.21
The Galilean moons are as large as small planets.

Scientists think that Europa is a good place to look for extraterrestrial life. Europa is the smallest of the Galilean moons. The moon's surface is a smooth layer of ice. Scientists think that the ice may sit on top of an ocean of liquid water. How could Europa have liquid water when it is so far from the Sun? Europa is heated by Jupiter. Jupiter's tidal forces are so great that they stretch and squash its moon. This could produce enough heat for there to be liquid water. 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** 4.22, is famous for its beautiful rings. Saturn is the second largest planet in the solar system. Saturn's mass is about 95 times Earth's mass. The gas giant is 755 times Earth's volume. Despite its large size, Saturn is the least dense planet in our solar system. Saturn is actually less dense than water. This means that if there were a bathtub big enough, Saturn would float! In Roman mythology, Saturn was the father of Jupiter. Saturn orbits the Sun once about every 30 Earth years.

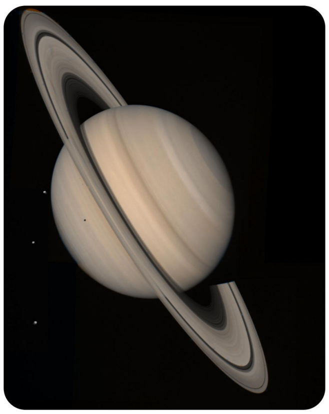


FIGURE 4.22
Saturn is the least dense planet in our solar system.

Saturn's composition is similar to Jupiter's. The planet is made mostly of hydrogen and helium. These elements are gases in the outer layers and liquids in the deeper layers. Saturn may also have a small solid core. Saturn's upper atmosphere has clouds in bands of different colors. These clouds rotate rapidly around the planet. But Saturn has fewer storms than Jupiter. Thunder and lightning have been seen in the storms on Saturn (**Figure** 4.23).

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** 4.24. This hexagon was viewed by Voyager 1 in the 1980s. It was still there when the Cassini Orbiter visited in 2006. No one is sure why the clouds form this pattern.

Saturn's Rings

Saturn's rings were first observed by Galileo in 1610. He didn't know they were rings and thought that they were two large moons. One moon was on either side of the planet. In 1659, the Dutch astronomer Christiaan Huygens realized that they were rings circling Saturn's equator. The rings appear tilted. This is because Saturn is tilted about 27 degrees to its side.

The Voyager 1 spacecraft visited Saturn in 1980. Voyager 2 followed in 1981. These 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. There are several gaps in the rings. These gaps were cleared out by moons within the rings. Ring dust and gas are attracted to the moon by its gravity. This leaves a gap in the rings. Other gaps in the rings are caused by the competing forces of Saturn and its moons outside the rings.

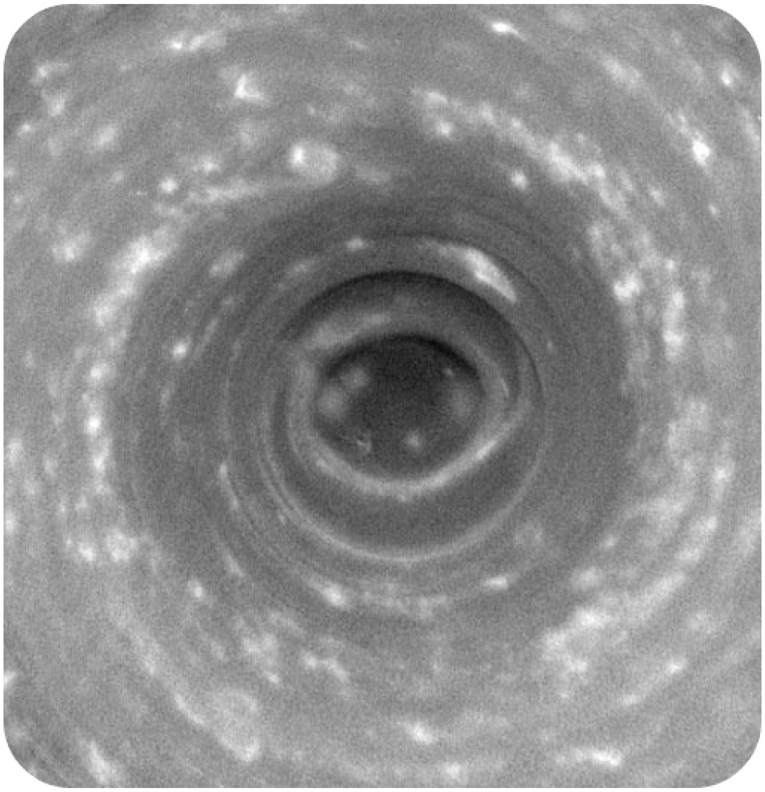


FIGURE 4.23
Cassini scientists waited years for the right conditions to produce the first movie that shows lightning on another planet - Saturn.

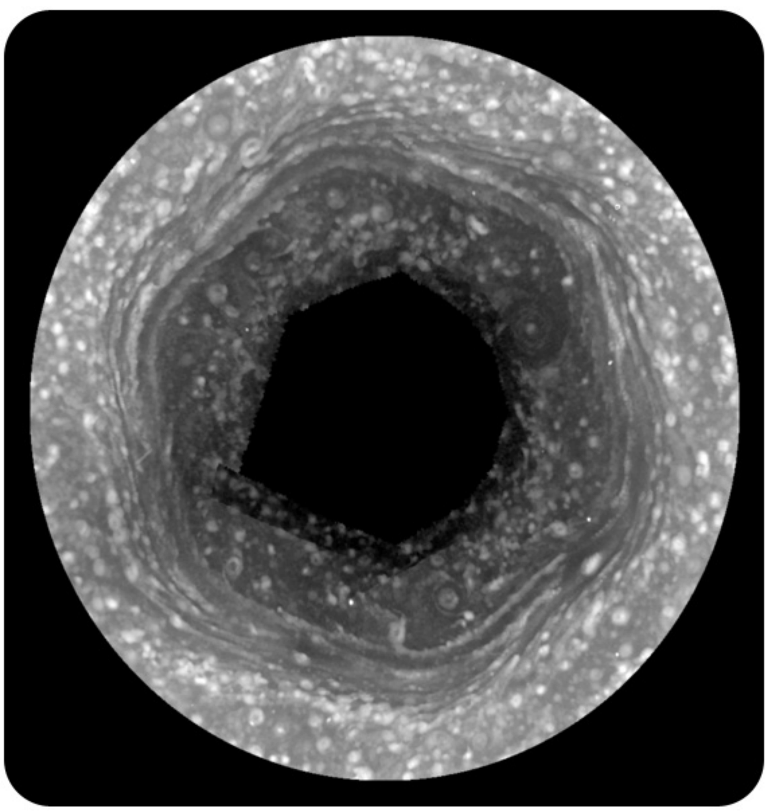


FIGURE 4.24
This hexagon has been visible for nearly 30 years.

Saturn's Moons

As of 2011, over 60 moons have been identified around Saturn. Only seven of Saturn's moons are round. All but one is smaller than Earth's Moon. Some of the very small moons are found within the rings. All the particles in the rings are like little moons, because they orbit around Saturn. Someone must decide which ones are large enough to call moons.

Saturn's largest moon, Titan, is about one and a half times the size of Earth's Moon. Titan is even larger than the planet Mercury. **Figure** 4.25 compares the size of Titan to Earth. Scientists are very interested in Titan. The moon has an atmosphere that is thought to be like Earth's first atmosphere. This atmosphere was around before life developed on Earth. Like Jupiter's moon, Europa, Titan may have a layer of liquid water under a layer of ice. Scientists now think that there are lakes on Titan's surface. Don't take a dip, though. These lakes contain liquid methane and ethane instead of water! Methane and ethane are compounds found in natural gas.

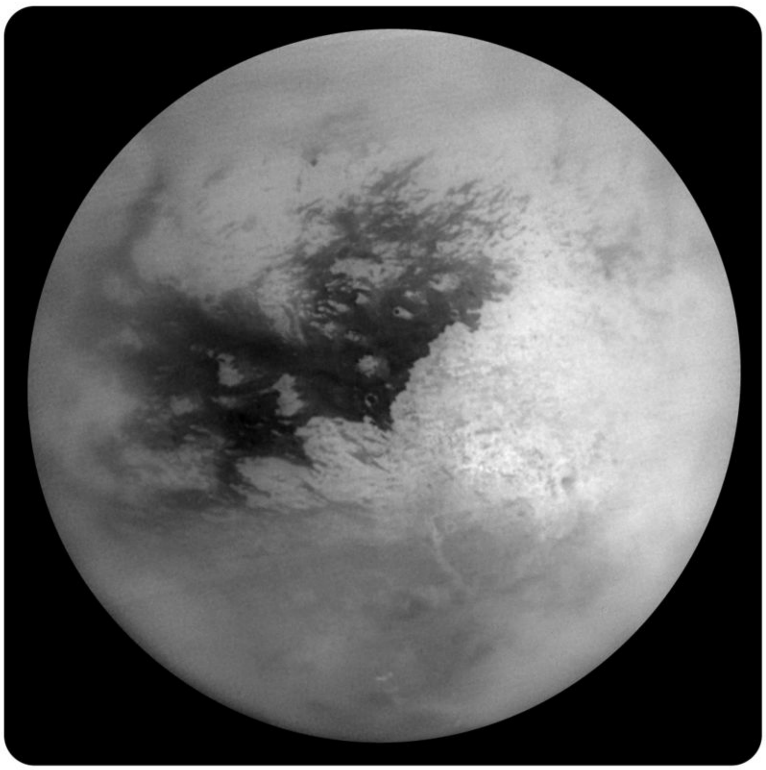


FIGURE 4.25
Titan has an atmosphere like Earth's first atmosphere.

Uranus

Uranus, shown in **Figure** 4.26, is named for the Greek god of the sky, the father of Saturn. Astronomers pronounce the name "YOOR-uh-nuhs." Uranus was not known to ancient observers. The planet was first discovered with a telescope by the astronomer William Herschel in 1781.

Uranus is faint because it is very far away. Its distance from the Sun is 2.8 billion kilometers (1.8 billion miles). A photon from the Sun takes about 2 hours and 40 minutes to reach Uranus. Uranus orbits the Sun once about every 84 Earth years.

FIGURE 4.26
Uranus is the 7th planet out from the Sun.

An Icy Blue-Green Ball

Uranus is a lot like Jupiter and Saturn. The planet is composed mainly of hydrogen and helium. There is a thick layer of gas on the outside. Further on the inside is liquid. But Uranus has a higher percentage of icy materials than Jupiter and Saturn. These materials include water, ammonia, and methane. Uranus is also different because of its blue-green color. Clouds of methane filter out red light. This leaves a blue-green color. The atmosphere of Uranus has bands of clouds. These clouds are hard to see in normal light. The result is that the planet looks like a plain blue ball.

Uranus is the least massive outer planet. Its mass is only about 14 times the mass of Earth. Like all of the outer planets, Uranus is much less dense than Earth. 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 percent less than what you weigh on Earth.

The Sideways Planet

All of the planets rotate on their axes in the same direction that they move around the Sun. Except for Uranus. Uranus is tilted on its side. Its axis is almost parallel to its orbit. So Uranus rolls along like a bowling ball as it revolves around the Sun. How did Uranus get this way? Scientists think that the planet was struck and knocked over by another planet-sized object. This collision probably took place billions of years ago.

Rings and Moons of Uranus

Uranus has a faint system of rings, as shown in **Figure** 4.27. The rings circle the planet's equator. However, Uranus is tilted on its side. So the rings are almost perpendicular to the planet's orbit.

We have discovered 27 moons around Uranus. All but a few are named for characters from the plays of William

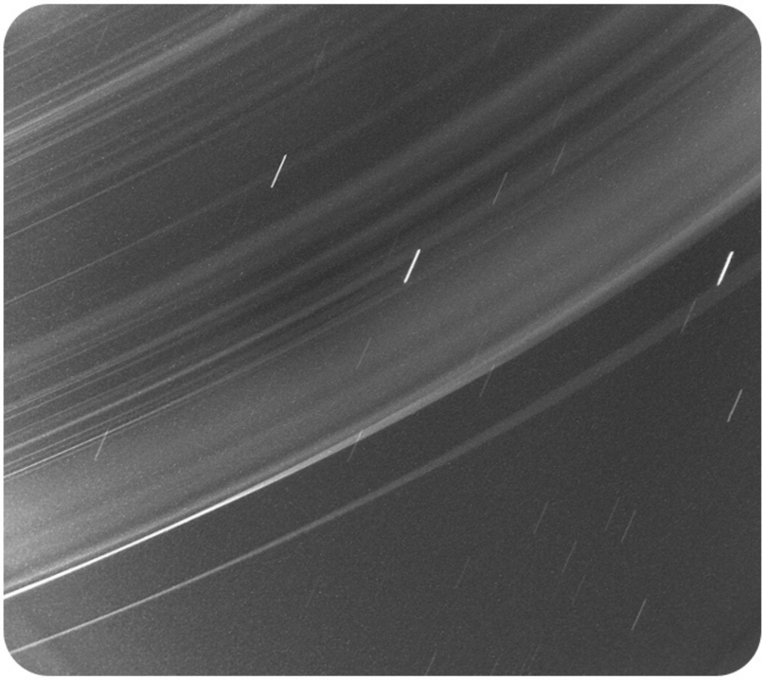


FIGURE 4.27
Uranus' rings are almost perpendicular to the planet's orbit.

Shakespeare. The five biggest moons of Uranus, Miranda, Ariel, Umbriel, Titania, and Oberon, are shown in **Figure** 4.28.

FIGURE 4.28
The five biggest moons of Uranus: Miranda, Ariel, Umbriel, Titania, and Oberon.

Neptune

Neptune is shown in **Figure** 4.29. It is the eighth planet from the Sun. Neptune is so far away you need a telescope to see it from Earth. Neptune is the most distant planet in our solar system. It is nearly 4.5 billion kilometers (2.8

billion miles) from the Sun. One orbit around the Sun takes Neptune 165 Earth years.

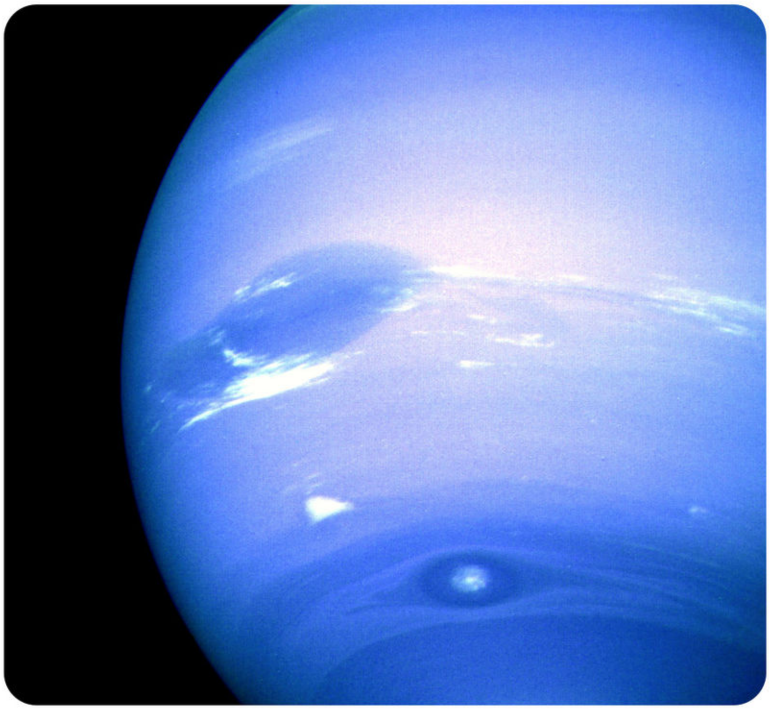


FIGURE 4.29
Neptune has a great dark spot at the center left and a small dark spot at the bottom center.

Scientists guessed Neptune's existence before it was discovered. Uranus did not always appear exactly where it should. They said this was because a planet beyond Uranus was pulling on it. This gravitational pull was affecting its orbit. Neptune was discovered in 1846. It was just where scientists predicted it would be! Due to its blue color, the planet was named Neptune for the Roman god of the sea.

Uranus and Neptune are often considered "sister planets." They are very similar to each other. Neptune has slightly more mass than Uranus, but it is slightly smaller in size.

Extremes of Cold and Wind

Like Uranus, Neptune is blue. The blue color is caused by gases in its atmosphere, including methane. Neptune is not a smooth looking ball like Uranus. The planet has a few darker and lighter spots. 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. When the Hubble Space Telescope photographed Neptune in 1994, the Great Dark Spot had disappeared. Another dark spot had appeared north of the equator. Astronomers believe that both of these spots represent gaps in the methane clouds on Neptune.

Neptune's appearance changes due to its turbulent atmosphere. Winds are stronger than on any other planet in the solar system. Wind speeds can reach 1,100 km/h (700 mph). This is close to the speed of sound! The rapid winds surprised astronomers. This is because Neptune receives little energy from the Sun to power weather systems. It is not surprising that Neptune is one of the coldest places in the solar system. Temperatures at the top of the clouds are about –218°C (–360°F).

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 Saturn's. Neptune's rings may be unstable. They may change or disappear in a relatively short time.

Neptune has 13 known moons. Only Triton, shown in **Figure** 4.30, has enough mass to be round. Triton orbits in the direction opposite to Neptune's orbit. Scientists think Triton did not form around Neptune. The satellite was captured by Neptune's gravity as it passed by.

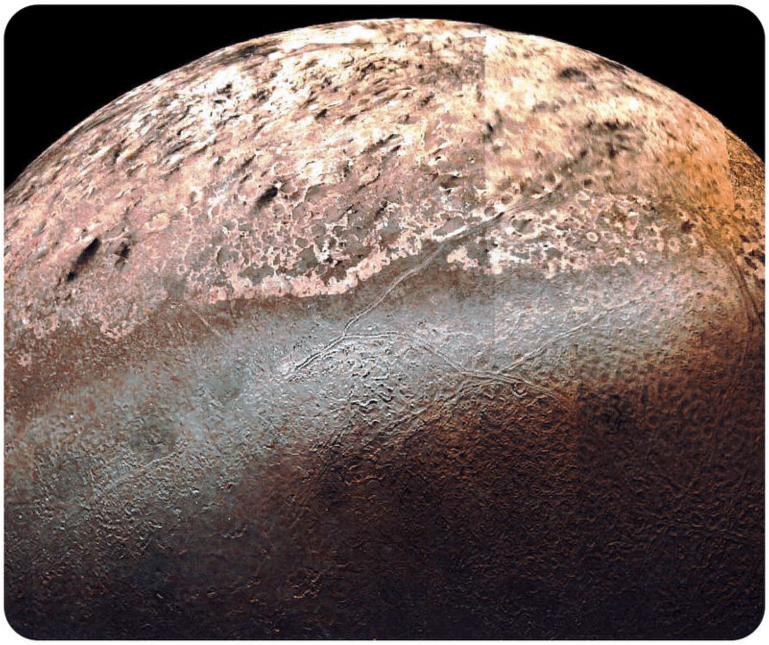


FIGURE 4.30
Neptune's moon Triton.

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 dwarf planets. It is one of the largest and brightest objects that make up this group. Look for Pluto in the next lesson, in the discussion of dwarf planets.

Lesson Summary

- The four outer planets —Jupiter, Saturn, Uranus, and Neptune —are all gas giants made mostly of hydrogen and helium. Their thick outer layers are gases and have liquid interiors.
- All of the outer planets have lots of moons, as well as planetary rings made of dust and other particles.
- Jupiter is 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 very similar to Jupiter. 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 using a telescope. 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 distant past.
- Neptune is very cold and has very strong winds. It had a large dark spot that disappeared. Another dark spot appeared on another part of the planet. These dark spots are storms in Neptune's atmosphere.

Lesson Review Questions

Recall

1. Why were the Galilean moons given that name? What are they?

2. Why are Neptune and Uranus blue?

Apply Concepts

3. How are the outer planets different from the inner planets?

4. Describe Saturn's rings? What are they and what has made them that way?

5. How can liquid be found so far out in the solar system where temperatures are so cold?

Think Critically

6. Why did Jupiter's Great Red Spot last for 300 years and Neptune's Great Dark Spot disappear in a couple of decades?

7. If you were given the task of finding life in the solar system somewhere besides Earth where would you look?

8. The atmosphere of Saturn's moon Titan because it resembles the early Earth's atmosphere. Why is this interesting to scientists?

Points to Consider

- The inner planets are small and rocky, while the outer planets are large and made of gases. Why might the planets have formed into these two groups?
- 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?

4.4 Other Objects in the Solar System.

Lesson Objectives

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

Vocabulary

- asteroid
- asteroid belt
- comet
- Kuiper belt
- meteor
- meteoroid
- meteor shower

Introduction

Debris. Space junk. After the Sun and planets formed, there was some material left over. These small chunks didn't get close enough to a large body to be pulled in by its gravity. They now inhabit the solar system as asteroids and comets.

Asteroids

Asteroids are very small, irregularly shaped, rocky bodies. Asteroids orbit the Sun, but they are more like giant rocks than planets. Since they are small, they do not have enough gravity to become round. They are too small to have an atmosphere. With no internal heat, they are not geologically active. An asteroid can only change due to a collision. A collision may cause the asteroid to break up. It may create craters on the asteroid's surface. An asteroid may strike a planet if it comes near enough to be pulled in by its gravity. **Figure** 4.31 shows a typical asteroid.

The Asteroid Belt

Hundreds of thousands of asteroids have been found in our solar system. They are still being discovered at a rate of about 5,000 new asteroids per month! The majority are located in between the orbits of Mars and Jupiter. This region is called the **asteroid belt**, as shown in **Figure** 4.32. There are many thousands of asteroids in the asteroid belt. Still, their total mass adds up to only about 4 percent of Earth's Moon.

Asteroids formed at the same time as the rest of the solar system. Although there are many in the asteroid belt, they were never were able to form into a planet. Jupiter's gravity kept them apart.

FIGURE 4.31
Asteroid Ida with its tiny moon Dactyl. The asteroid's mean radius is 15.7 km.

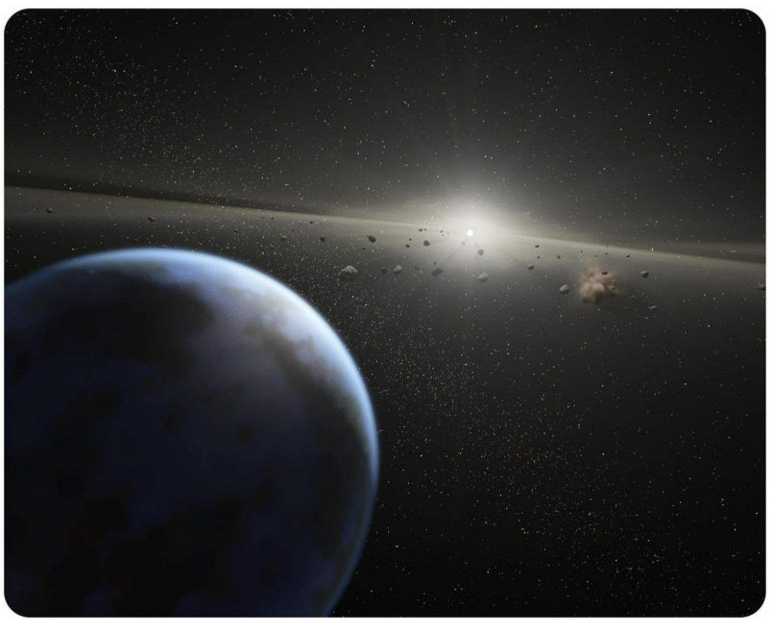


FIGURE 4.32
The asteroid belt is between Mars and Jupiter.

Near-Earth Asteroids

Near-Earth asteroids have orbits that cross Earth's orbit. This means that they can collide with Earth. There are over 4,500 known near-Earth asteroids. Small asteroids do sometimes collide with Earth. An asteroid about 5–10 m in diameter hits about once per year. Five hundred to a thousand of the known near-Earth asteroids are much bigger. They are over 1 kilometer in diameter. When large asteroids hit Earth in the past, many organisms died. At times, many species became extinct. Astronomers keep looking for near-Earth asteroids. They hope to predict a possible collision early so they can to try to stop it.

Asteroid Missions

Scientists are very interested in asteroids. Most are composed of material that has not changed since early in the solar system. Scientists can learn a lot from them about how the solar system formed. Asteroids may be important for space travel. They could be mined for rare minerals or for construction projects in space.

Scientists have sent spacecraft to study asteroids. In 1997, the NEAR Shoemaker probe orbited the asteroid 433 Eros. The craft finally landed on its surface in 2001. The Japanese Hayabusa probe returned to Earth with samples of a small near-earth asteroid in 2010. The U.S. Dawn mission will visit Vesta in 2011 and Ceres in 2015.

Meteors

If you look at the sky on a dark night, you may see a **meteor**, like in **Figure** 4.33. A meteor forms a streak of light across the sky. People call them shooting stars because that's what they look like. But meteors are not stars at all. The light you see comes from a small piece of matter burning up as it flies through Earth's atmosphere.

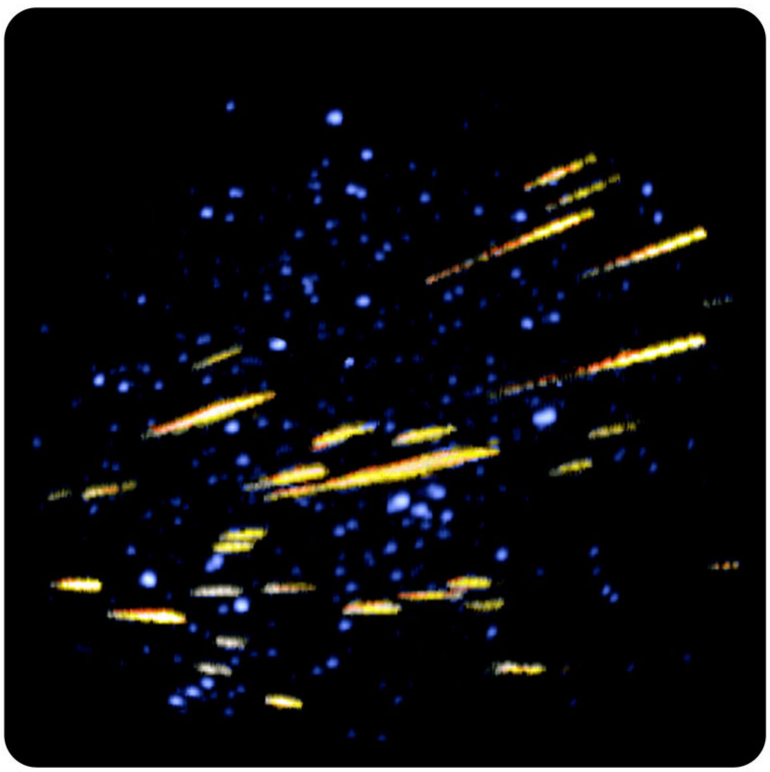


FIGURE 4.33
Meteors burning up as they fall through Earth's atmosphere.

Meteoroids

Before these small pieces of matter enter Earth's atmosphere, they are called **meteoroids**. Meteoroids are as large as boulders or as small as tiny sand grains. Larger objects are called asteroids; smaller objects are interplanetary dust. Meteoroids sometimes cluster together in long trails. They are the debris left behind by comets. When Earth passes through a comet trail, there is a **meteor shower**. During a meteor shower, there are many more meteors than normal for a night or two.

Meteorites

A meteoroid is dragged towards Earth by gravity and enters the atmosphere. Friction with the atmosphere heats the object quickly, so it starts to vaporize. As it flies through the atmosphere, it leaves a trail of glowing gases. The object is now a meteor. Most meteors vaporize in the atmosphere. They never reach Earth's surface. Large meteoroids may not burn up entirely in the atmosphere. A small core may remain and hit the Earth's surface. This is called a **meteorite**.

Meteorites provide clues about our solar system. Many were formed in the early solar system (**Figure** 4.34). Some are from asteroids that have split apart. A few are rocks from nearby bodies like Mars. For this to happen, an asteroid smashed into Mars and sent up debris. A bit of the debris entered Earth's atmosphere as a meteor.

FIGURE 4.34

The Mars Rover, Opportunity, found a metal meteorite on the Red Planet.

Comets

Comets are small, icy objects that orbit the Sun. Comets have highly elliptical orbits. Their orbits carry them from close to the Sun to the solar system's outer edges. When a comet gets close to the Sun, its outer layers of ice melt and evaporate. The vaporized gas and dust forms an atmosphere around the comet. This atmosphere is called a coma. Radiation and particles streaming from the Sun push some of this gas and dust into a long tail. A comet's tail always points away from the Sun, no matter which way the comet is moving. Why do you think that is? **Figure** 4.35 shows Comet Hale-Bopp, which shone brightly for several months in 1997.

Gases in the coma and tail of a comet reflect light from the Sun. Comets are very hard to see except when they have comas and tails. That is why they appear only when they are near the Sun. They disappear again as they move back to the outer solar system.

The time between one visit from a comet and the next is called the comet's period. The first comet whose period was known was Halley's Comet. Its period is 75 years. Halley's Comet last traveled through the inner solar system in 1986. The comet will appear again in 2061. Who will look up at it?

FIGURE 4.35
Comet Hale-Bopp lit up the night sky in 1997.

Where Comets Come From

Some comets have periods of 200 years or less. They are called short-period comets. Short-period comets are from a region beyond the orbit of Neptune called the **Kuiper Belt**. Kuiper is pronounced "KI-per," rhyming with "viper." The Kuiper Belt is home to comets, asteroids, and at least two dwarf planets.

Some comets have periods of thousands or even millions of years. Most long-period comets come from a very distant region of the solar system. This region is called the Oort cloud. The Oort cloud is about 50,000–100,000 times the distance from the Sun to Earth.

Comets carry materials in from the outer solar system. Comets may have brought water into the early Earth. Other substances could also have come from comets.

Dwarf Planets

For several decades, Pluto was a planet. But new solar system objects were discovered that were just as planet-like as Pluto. Astronomers figured out that they were like planets except for one thing. These objects had not cleared their orbits of smaller objects. They didn't have enough gravity to do so. Astronomers made a category called dwarf planets. There are five dwarf planets in our solar system: Ceres, Pluto, Makemake, Haumea and Eris.

Figure 4.36 shows Ceres. Ceres is a rocky body that orbits the Sun and is not a star. It could be an asteroid or a planet. Before 2006, Ceres was thought to be the largest asteroid. Is it an asteroid? Ceres is in the asteroid belt. But it is by far the largest object in the belt. Ceres has such high gravity that it is spherical. Is it a planet? Ceres only has about 1.3% of the mass of the Earth's Moon. Its orbit is full of other smaller bodies. Its gravity was not high enough to clear its orbit. Ceres fails the fourth criterion for being a planet. Ceres is now considered a dwarf planet along with Pluto.

Pluto

For decades Pluto was a planet. But even then, scientists knew it was an unusual planet. The other outer planets are all gas giants. Pluto is small, icy and rocky. With a diameter of about 2400 kilometers, it has only about 1/5 the mass of Earth's Moon. The other planets orbit in a plane. Pluto's orbit is tilted. The shape of the orbit is like a long, narrow ellipse. Pluto's orbit is so elliptical that sometimes it is inside the orbit of Neptune.

Pluto's orbit is in the Kuiper belt. We have discovered more than 200 million Kuiper belt objects. Pluto has 3 moons of its own. The largest, Charon, is big. Some scientists think that Pluto-Charon system is a double dwarf planet (**Figure** 4.37). Two smaller moons, Nix and Hydra, were discovered in 2005.

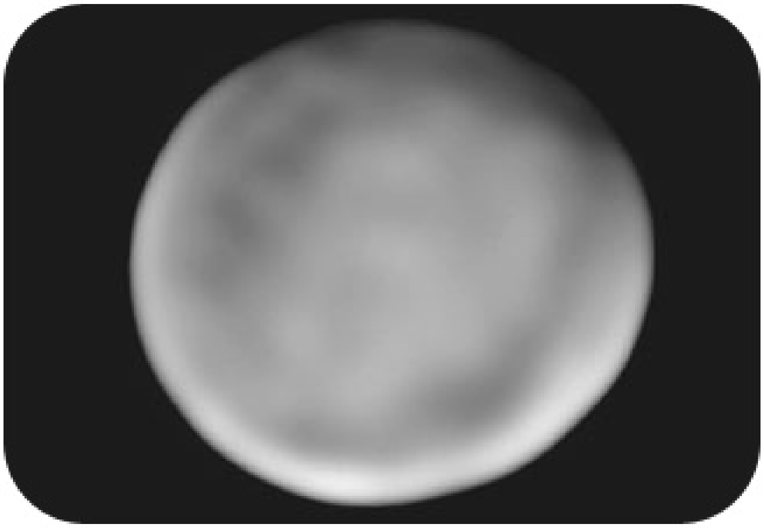


FIGURE 4.36
Ceres is a large spherical object in the asteroid belt.

FIGURE 4.37
Pluto with its moons: Charon, Nix and Hydra.

Haumea

Haumea was named a dwarf planet in 2008. It is an unusual dwarf planet. The body is shaped like an oval! Haumea's longest axis is about the same as Pluto's diameter, and its shortest axis is about half as long. The body's orbit is tilted 28°. Haumea is so far from the Sun that it takes 283 years to make one orbit (**Figure** 4.38).

Haumea is the third-brightest Kuiper Belt object. It was named for the Hawaiian goddess of childbirth. Haumea has two moons, Hi'iaka and Namaka, the names of the goddess Haumea's daughters. Haumea's odd oval shape is probably caused by its extremely rapid rotation. It rotates in just less than 4 hours! Like other Kuiper belt objects, Haumea is covered by ice. Its density is similar to Earth's Moon, at 2.6 – 3.3 g/cm^3. This means that most of Haumea is rocky.

Haumea is part of a collisional family. This is a group of astronomical objects that formed from an impact. This family has Haumea, its two moons, and five more objects. All of these objects are thought to have formed from a collision very early in the formation of the solar system.

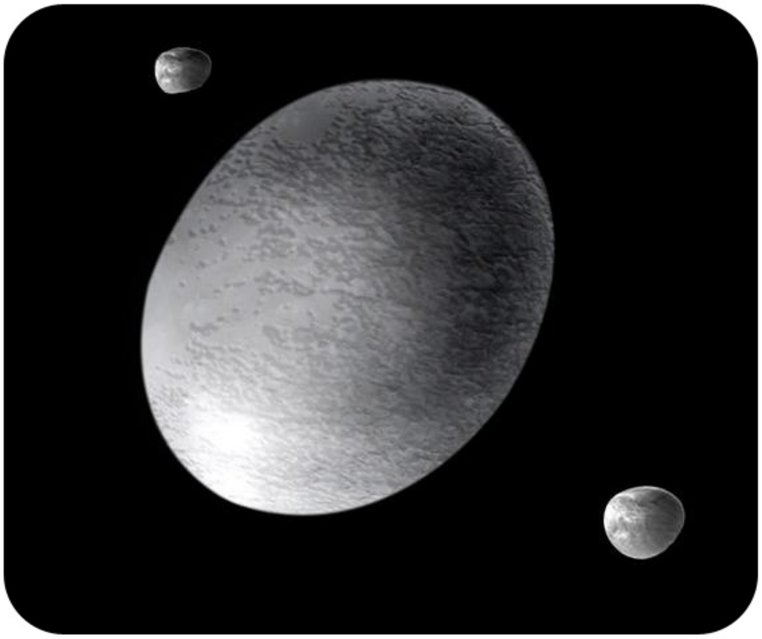


FIGURE 4.38
An artist's drawing of what Haumea and its moons might look like. The moons are drawn closer to Haumea than their actual orbits.

Makemake

Makemake is the third-largest and second-brightest dwarf planet we have discovered so far (**Figure** 4.39). Makemake is only 75 percent the size of Pluto. Its diameter is between 1300 and 1900 kilometers. The name comes from the mythology of the Eastern Islanders. Makemake was the god that created humanity. At a distance between 38.5 to 53 AU, this dwarf planet orbits the Sun in 310 years. Makemake is made of methane, ethane, and nitrogen ices.

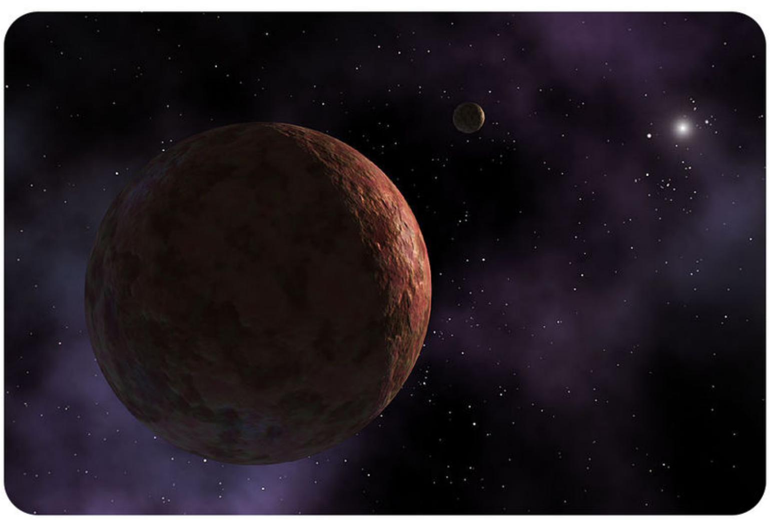


FIGURE 4.39
Makemake is a dwarf planet.

Eris

Eris is the largest known dwarf planet in the solar system. It is 27 percent larger than Pluto (**Figure** 4.40). Like Pluto and Makemake, Eris is in the Kuiper belt. But Eris is about 3 times farther from the Sun than Pluto. Because

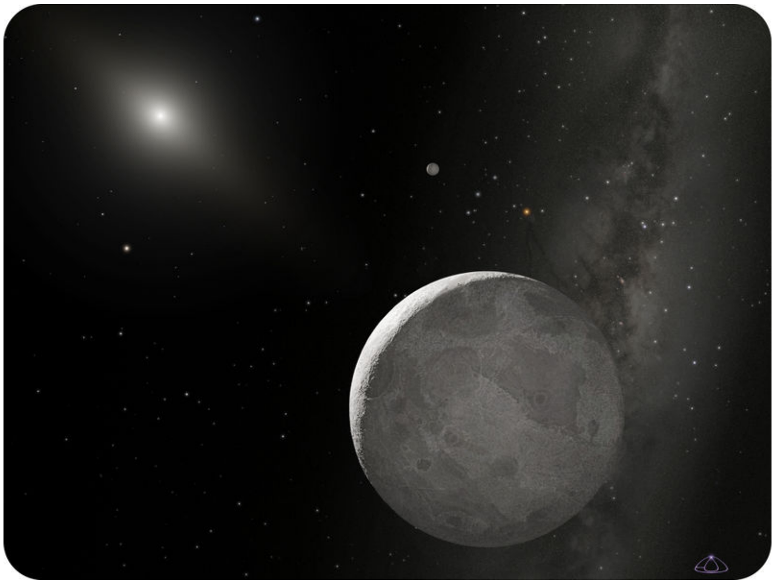


FIGURE 4.40
Eris is the largest known dwarf planet, but it's so far from the Sun that it wasn't discovered until 2005.

of its distance, Eris was not discovered until 2005. Early on, it was thought that Eris might be the tenth planet. Its discovery helped astronomers realize that they needed a new definition of "planet." Eris has a small moon, Dysnomia. Its moon orbits Eris once about every 16 days.

Astronomers know there may be other dwarf planets far out in the solar system. Look for 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. Eris, Pluto, Makemake and Haumea are dwarf planets in the Kuiper belt.

Lesson Review Questions

Recall

1. Define each of the following: asteroid, meteoroid, meteorite, meteor, planet, dwarf planet.

2. Which type of asteroids are most likely to hit Earth?

3. What comes from the Oort Cloud? What about the Kuiper Belt?

Apply Concepts

4. What is the asteroid belt? Why are there so many asteroids orbiting in this location?

5. What damage can an asteroid do when it hits Earth?

Think Critically

6. How well defined are the categories planet, dwarf planet and asteroid? If astronomers find a new object is it always clear which category to put it in?

7. Which type of object do you think NASA should make the subject of its next mission?

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?

4.5 References

1. Left: Pearson Scott Foresman; Right: Bartolomeu Velho. Left: http://commons.wikimedia.org/wiki/File:Ptolemaic_system_2_%28PSF%29.png; Right: http://commons.wikimedia.org/wiki/File:Bartolomeu_Velho_1568.jpg . Public Domain
2. Edward Grant. http://commons.wikimedia.org/wiki/File:Ptolemaicsystem-small.png . Public Domain
3. Courtesy of NASA/JPL. http://photojournal.jpl.nasa.gov/catalog/PIA10969 . Public Domain
4. Courtesy of NASA/JPL. http://photojournal.jpl.nasa.gov/catalog/PIA10231 . Public domain
5. Courtesy of NASA/JPL-Caltech/R. Hurt. http://commons.wikimedia.org/wiki/File:Oort_cloud_Sedna_orbit.svg . Public Domain
6. The Hubble Heritage Team (AURA/STScI/NASA). http://commons.wikimedia.org/wiki/File:Ring_Nebula.jpg . Public Domain
7. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Transit_of_Mercury,_2006-11-08.jpg . Public Domain
8. Courtesy of NASA/JPL. http://commons.wikimedia.org/wiki/File:Mercury.jpg . Public Domain
9. Courtesy of NASA/JPL. http://commons.wikimedia.org/wiki/File:Mercury_in_color_-_Prockter07_centered.jpg . Public Domain
10. User:Lmb/Es.Wikipedia. http://commons.wikimedia.org/wiki/File:Mercury_inside_Lmb.png . Public Domain
11. Image processing by Ricardo Nunes (http://www.astrosurf.com/nunes). http://commons.wikimedia.org/wiki/File:Venus-real_color.jpg . The copyright holder of this file allows anyone to use it for any purpose, provided that the creator is credited and a link is provided
12. Courtesy of NASA/JPL. http://photojournal.jpl.nasa.gov/catalog/PIA00104 . Public Domain
13. Courtesy of NASA/JPL. http://photojournal.jpl.nasa.gov/catalog/pia00254 . Public Domain
14. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:As08-16-2593.jpg . Public Domain
15. Courtesy of NASA/JPL. http://commons.wikimedia.org/wiki/File:MARS-Viking.jpg . Public domain
16. Courtesy of NASA, modifications by User:Seddon/Wikipedia. http://commons.wikimedia.org/wiki/File:Olympus_Mons_alt.jpg . Public Domain
17. Courtesy NASA/JPL-Caltech/USGS. http://commons.wikimedia.org/wiki/File:VallesMarinerisHuge.jpg . Public Domain
18. Courtesy of NASA/JPL-Caltech/University of Arizona. http://commons.wikimedia.org/wiki/File:Phobos_colour_2008.jpg . Public Domain
19. Courtesy of NASA/JPL. http://commons.wikimedia.org/wiki/File:Júpiter_com_Mancha.jpg . Public Domain
20. Courtesy of NASA/JPL. http://commons.wikimedia.org/wiki/File:Great_Red_Spot_From_Voyager_1.jpg . Public Domain
21. Courtesy of NASA/JPL/DLR. http://photojournal.jpl.nasa.gov/catalog/PIA01400 . Public Domain
22. Courtesy of NASA/JPL. http://commons.wikimedia.org/wiki/File:Saturn_(planet)_large.jpg . Public Domain
23. Courtesy of NASA/JPL/Space Science Institute. http://commons.wikimedia.org/wiki/File:Looking_saturn_in_the_eye.jpg . Public Domain
24. Courtesy of NASA/JPL/Space Science Institute. http://commons.wikimedia.org/wiki/File:Spring_Unveils_Saturn%27s_Hexagon.gif . Public Domain
25. Courtesy of NASA/JPL/Space Science Institute, additional editing by User:Kaldari/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Titan2005.jpg . Public Domain
26. Courtesy of NASA/JPL. http://commons.wikimedia.org/wiki/File:Uranus.jpg . Public Domain
27. Courtesy of NASA/JPL/University of Arizona/Texas AM University. http://commons.wikimedia.org/wiki/File:FDS_26852.19_Rings_of_Uranus.png . Public Domain
28. Original pictures courtesy of NASA, montage created by User:Vzb83/Wikimedia Commons. http://commo

ns.wikimedia.org/wiki/File:Uranus_moons.jpg . Public Domain
29. Courtesy of NASA/Voyager 2 Team. http://apod.nasa.gov/apod/ap010821.html . Public Domain
30. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Triton_%28moon%29.jpg . Public Domain
31. Courtesy of NASA/JPL, modified by User:Chzz/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:243_ida_crop.jpg . Public Domain
32. Courtesy of NASA/JPL-Caltech. http://commons.wikimedia.org/wiki/File:Asteroid_Belt_Around_Sun_Sized_Star.jpg . Public Domain
33. Courtesy of S. Molau and P. Jenniskens, NASA Ames Research Center. http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=843 . Public Domain
34. Courtesy of NASA/JPL/Cornell. http://photojournal.jpl.nasa.gov/catalog/PIA07269 . Public Domain
35. Flickr:sungod17. http://www.flickr.com/photos/43437384@N07/8675567467/ . CC BY 2.0
36. Courtesy of NASA/JPL. http://www.nasa.gov/mission_pages/dawn/ceresvesta/index.html . Public Domain
37. European Southern Observatory. http://commons.wikimedia.org/wiki/File:ESO_-_Pluto-Charon_system_%28by%29.jpg . CC BY 3.0
38. Courtesy of NASA. http://apod.nasa.gov/apod/ap080923.html . Public Domain
39. Courtesy of R. Hurt (SSC-Caltech), JPL-Caltech, and NASA. http://apod.nasa.gov/apod/ap080716.html . Public Domain
40. Courtesy of A. Schaller (STScI), NASA. http://commons.wikimedia.org/wiki/File:2006-16-a-full-1-.jpg . Public Domain