LESSON 2

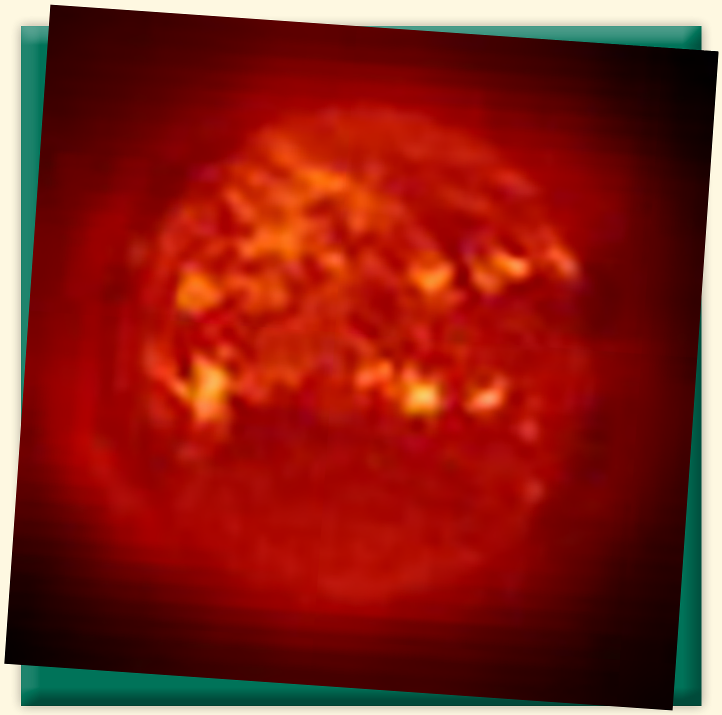
The Sun and Its Domain

Quick Write

After reading the following vignette, consider all the possible uses of solar energy in everyday life. Describe at least one way that you could use solar energy.

Learn About

- the Sun's energy
- the Sun's core, atmosphere, and sunspots
- the solar system's structure



Energy from the Sun has powered life on Earth for millions of years.

Courtesy of NASA Space Place/NASA.gov

Throughout history, we have considered the Sun to be the "giver of life." Without the Sun, our land, water, and air would be frozen solid, and life as we know it would end. Lucky for us, the Sun is our partner and the center of our solar system. We use the Sun for light and heat, and since time began, we have been on a pursuit to harness its energy. The ancient Greeks, for example, built their homes to get the most sunlight during the cold winter months.

Today, solar energy is becoming a more common and sustainable electricity option for homeowners, business owners, and communities. Solar energy is *the solar radiation that reaches Earth*. We can collect this energy for heat and convert it into electricity.

One of the first attempts at using solar energy was in the 1830s. British astronomer John Herschel used a solar thermal collector box to cook food during an expedition to Africa. This device absorbs sunlight to collect heat. Some people use solar ovens today, to make backyard s'mores and homemade pizzas! Many homeowners use solar energy for heating water and generating electrical energy.

Solar thermal power plants also use solar energy to heat fluids to high temperatures. Some power plants have large solar photovoltaic (PV) arrays to convert sunlight into electricity for the areas they serve. *Photovoltaic refers to the production of energy from light*.

The pursuit of solar energy is sure to continue. Not only does it reduce electricity costs, it is renewable, abundant, sustainable, and cleaner for the environment. There are limitations on using solar energy, however. In winter (and at night), much less sunlight arrives at the Earth's surface. Similarly, cloudy days can pose a challenge to maintaining a constant energy supply from the Sun.

Photovoltaic panels.
wzlv/Shutterstock

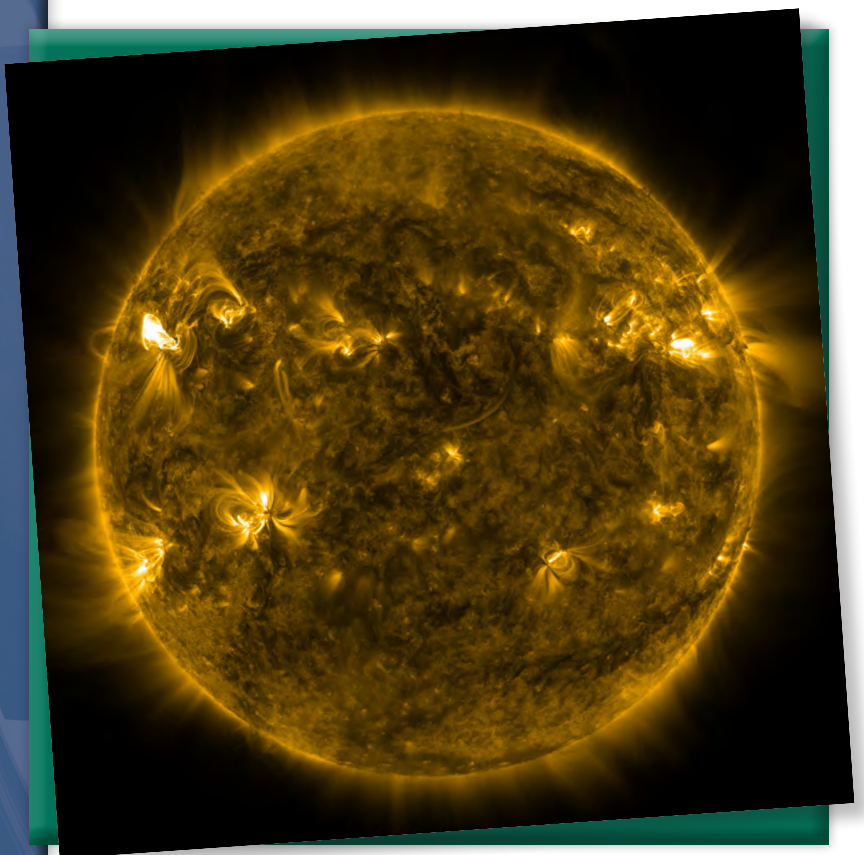
Vocabulary

- solar energy
- photovoltaic (PV)
- nuclear fusion
- gravitational contraction
- luminosity
- hydrostatic equilibrium
- conduction
- convection
- radiation
- photosphere
- chromosphere
- corona
- solar wind
- sunspots
- prominence
- solar flare
- theory
- asteroids
- meteoroids
- comets
- terrestrial planets
- Jovian planets
- dwarf planet

The Sun's Energy

The Sun is our main source of light, heat and energy. It powers weather, climate, and life on Earth. Without it, we would cease to exist. Because it is so close to Earth, scientists study the Sun's physical and chemical properties to better understand most other stars in the sky.

Although our Sun is a star, it is not star shaped. Instead, it is a big, yellow ball of gas. This gas can be found in layers of mainly hydrogen and helium. In the Sun's core, *hydrogen atoms compress and fuse into helium*, a process called nuclear fusion. Every minute, the Sun converts enormous amounts of mass into energy. The Earth's surface receives that energy in just eight minutes!



An image of active regions on the Sun from NASA's Solar Dynamics Observatory. The glowing hot gas traces out the twists and loops of the Sun's magnetic field lines.
Courtesy of NASA/SDO/AIA

The Source of the Sun's Energy

How does the Sun shine, year after year? How old is the Sun? Finding answers to these questions has challenged scientists and scholars for hundreds of years. Beginning in the mid-nineteenth century, a researcher and physics professor, Hermann von Helmholtz, suggested that the source of the Sun's energy was gravitational contraction, *or the shrinking and compression of gases, caused by gravity*. Another great scientist of the time, William Thomson (also known as 1st Baron Kelvin of Largs), also believed the main source of the Sun's energy was from gravitational contraction. With this belief, Lord Kelvin estimated the age of the Sun to be only 30 million years old.

Other scientists of the time, such as Charles Darwin, thought the Sun must be at least hundreds of millions of years old. For Darwin, only a Sun that old could explain the evolution of living things on Earth that depend on energy from the Sun.

Early in the twentieth century, scientific discoveries related to natural radioactivity suggested a new possibility: nuclear energy might be the source of the Sun's energy. Without evidence that the Sun contains many radioactive materials, scientists would continue to look further for answers.

About this time in history, Albert Einstein introduced his famous formula, E=mc2. Einstein's equation showed how mass and energy are interchangeable. Einstein proposed that a small amount of mass could, in theory, be converted into an enormous amount of energy. Einstein's formula would provide the direction needed to help scientists better understand the source of the Sun's energy.

Did You Know?

Scientists use spectroscopy to study the heat and chemicals of the stars by using a spectrum. A spectrograph breaks up light into a rainbow. Thin dark lines in the Sun's spectrum indicate different elements. Through spectroscopy, scientists know the Sun is made up of about 70% hydrogen gas.

A spectroscope breaks down white light into a spectrum of colors. Each color on the spectrum represents a temperature, with red being the hottest and violet the coldest.
Fouad Asaad/Shutterstock

Nuclear Fusion

By 1920, scientists began to consider the high temperature inside the star as a source of the Sun's energy. With Einstein's formula at work, they measured the masses of many different atoms. These included hydrogen and helium. Astrophysicist Sir Arthur Eddington made a proposition in 1920. He proposed that the measurement of the mass difference between hydrogen and helium was significant. It meant that the Sun gives off heat and light by converting hydrogen atoms to helium. Earlier in the lesson, we defined this process as nuclear fusion.

To be exact, it takes four hydrogen atoms fusing together to form one helium atom. Each atom has a nucleus, which makes up most of an atom's mass. When the nuclei (plural of the word nucleus) combine, the result is a new nucleus with less total mass than the two that fused together. What happens to the lost mass? It is converted to energy. As shown in Einstein's formula (E=mc2), energy is equal to mass times the speed of light squared.

Applying this formula to nuclear fusion, the conversion of hydrogen to helium releases about 0.7% of the mass equivalent of the energy.

Did You Know?

Every minute, the Sun converts 240 million tons of mass into energy.

The Sun's Core, Atmosphere, and Sunspots

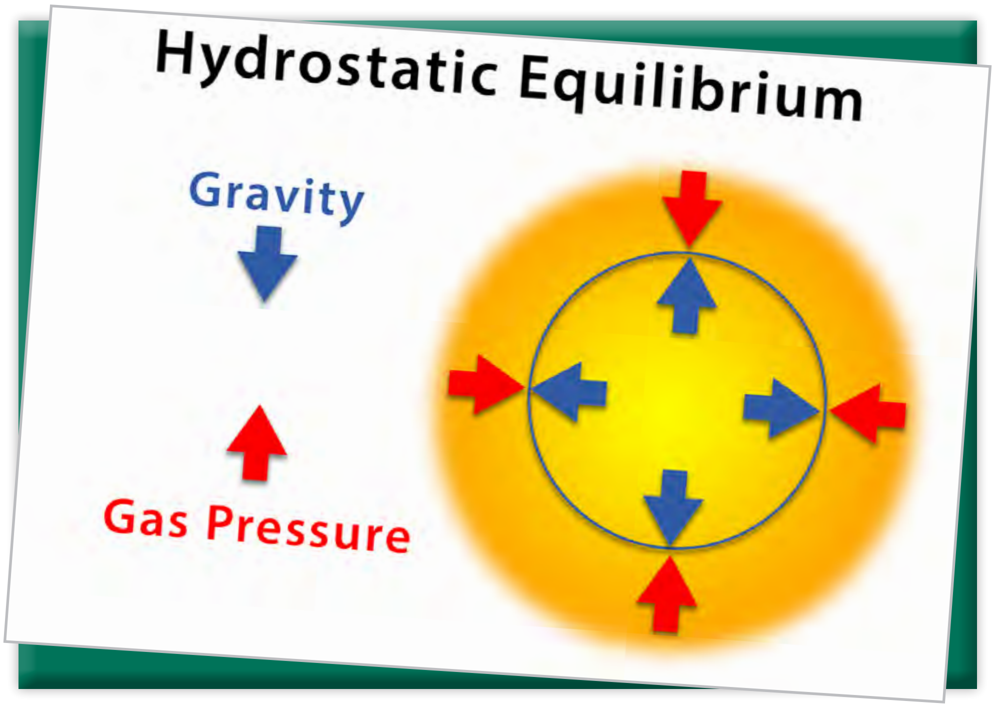
The Sun's Core

We know that the Sun's core is the source of its energy, but how do we know this? No direct observations can be made at the center of the Sun! Instead, scientists must use mathematical models based on the Sun's mass, radius, temperature, and luminosity. Luminosity *is the amount of energy produced per unit of time by a star*. These mathematical models assume that gases make up the Sun and that gas pressure is greater in the core of the Sun than on the surface.

With all of the Sun's internal gas pressure, what prevents the Sun from collapsing or exploding? If the Sun were to collapse under pressure, it would crunch down into a black hole. This has not happened, thanks to nature's balancing act, known as hydrostatic equilibrium. Hydrostatic equilibrium *occurs when compression due to gravity is balanced by outward pressure from the Sun's core*. In other words, a balance occurs as gravity pulls inward and the heat created inside, pushes outward.

Did You Know?

The outer pressure of the Sun is 340 billion times greater than the air pressure on Earth.



A star is somewhat like a balloon. The gas inside the balloon pushes outward and the rubber material supplies just enough inward compression to balance the internal gas pressure.

Modes of Solar Energy Transfer

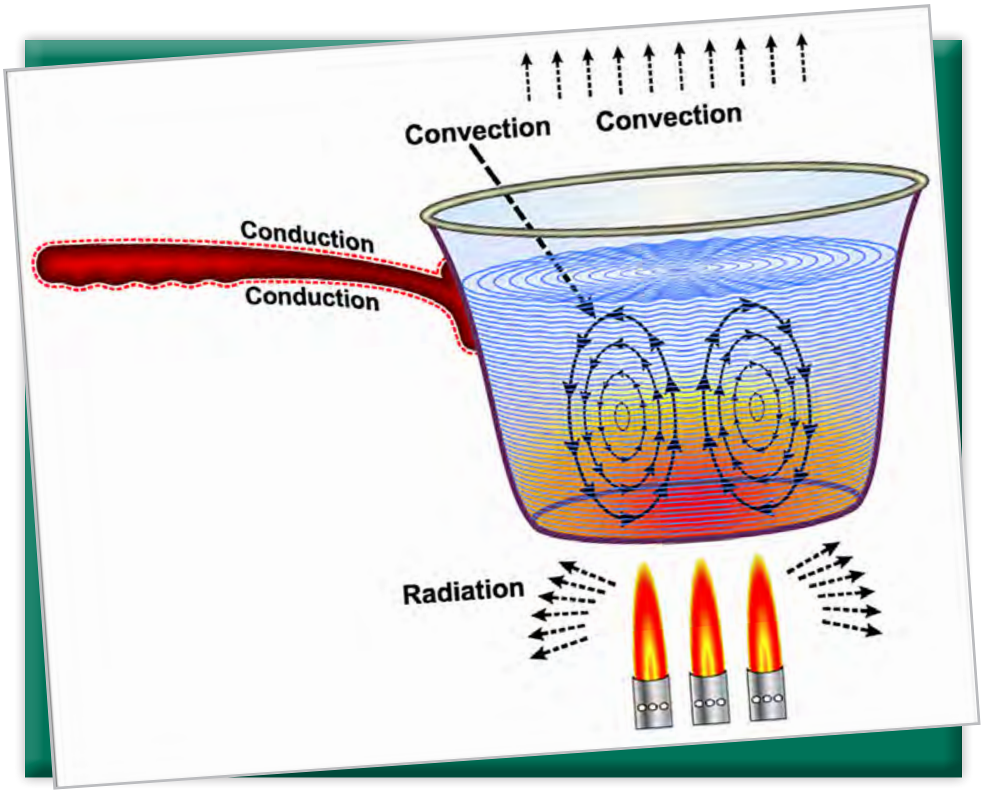
The three basic methods of transferring energy on Earth, and also on the Sun, are conduction, convection, and radiation. Conduction *occurs in solids as energy transfers from atom to atom or molecule to molecule*. This energy transfer causes particles to vibrate faster without the particles moving out of their positions in the solid structure.

Different materials have different abilities to conduct energy, but conduction is usually high in metals. That is why we make most cooking utensils, such as pots and pans, out of metals but with nonmetallic handles. Conduction is not a major energy transfer method in the Sun, because the particles are too far apart.

Convection *occurs in liquids or gases when atoms move from one location to another*. Liquids and gases are made of atoms or molecules that are free to move about, instead of vibrating faster. They can move from one location to another to transfer their energy to another particle.

In a room with a heater, air molecules gain energy from the heat source. The molecules increase in speed, causing them to expand and rise until they encounter a barrier like the ceiling. Then, they transfer some of that energy to other molecules. As they lose energy, they slow down and contract, become denser, and move downward. This usually results in a circular pattern of movement that we can find in the Sun and here on Earth. Large birds we see flying effortlessly are using the updrafts of these convection currents to stay in the air.

The main method of energy transfer in the Sun is by radiation which is *the movement of energy as waves through great distances without having the particles closely packed together*. This also allows the energy to move at the speed of light which is 186,000 miles per second. The energy we can feel as sunlight shining through a window is a good example of radiation. Different materials absorb radiation at different rates. Dark materials, like black leather car seats, become hotter than lighter ones when exposed to sunlight. This is why we make solar panels with a dark background, so they absorb more radiation.



This diagram demonstrates the three methods of energy transfer, conduction, convection, and radiation.

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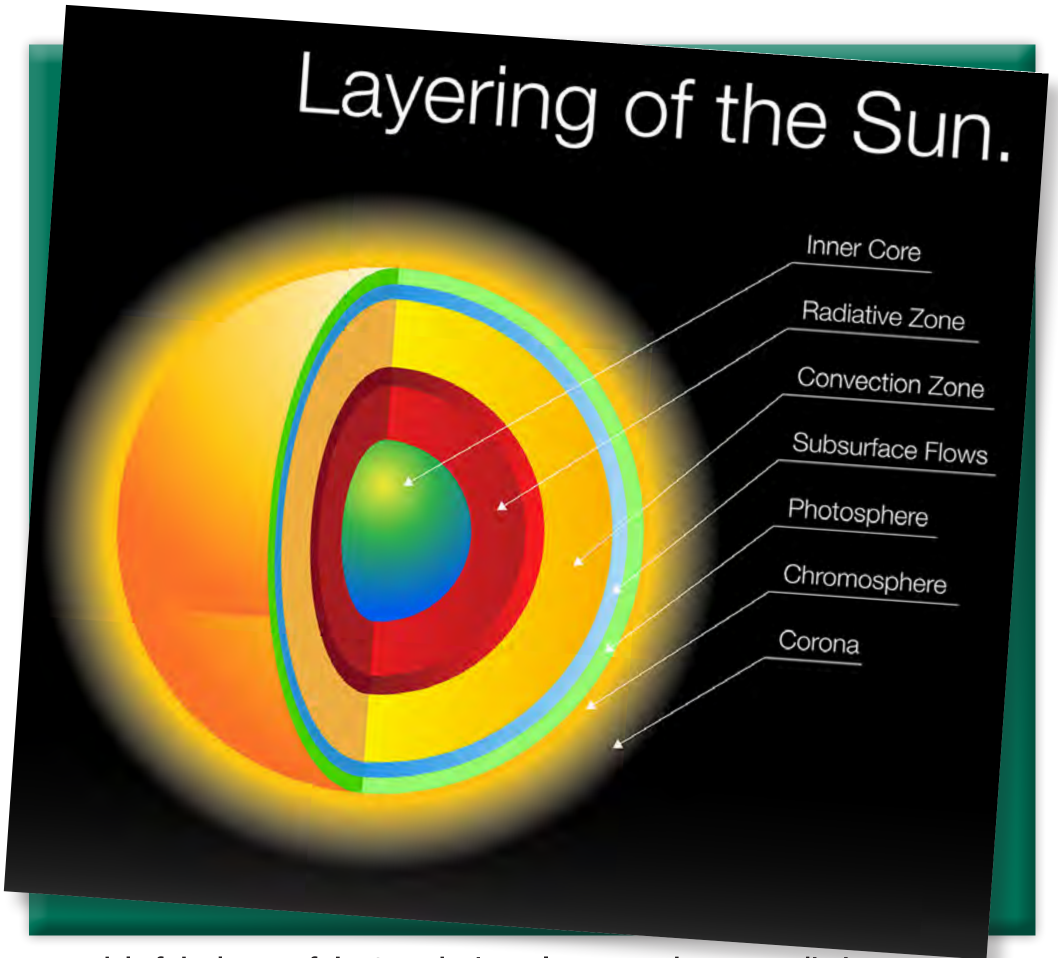
The Layers of the Sun's Atmosphere

What comes to mind when you hear the word "atmosphere"? The mood of your favorite hangout? The air around you? The Earth's atmosphere? Like the Earth, the Sun has an atmosphere. Just as the Sun itself has layers, so does its atmosphere. The Sun's atmosphere has three layers. They are the photosphere, the chromosphere, and the corona. It is important to note that these layers do not have distinct boundaries as they appear in a diagram but gradually change from one layer to the next.



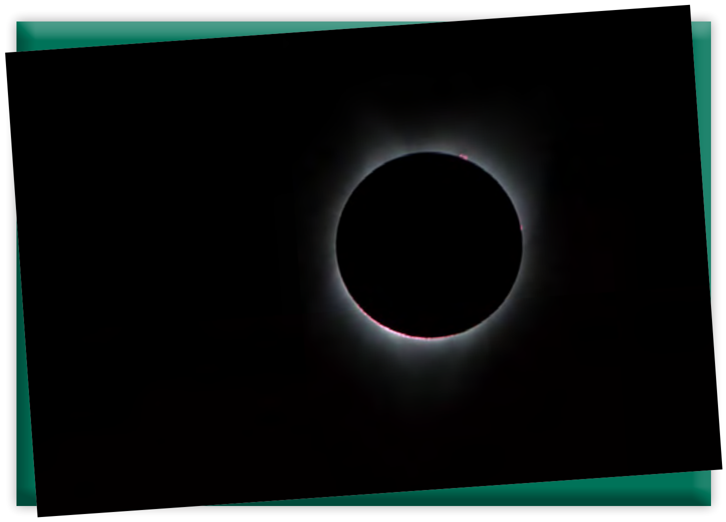
A model of the layers of the Sun. The inner layers are the core, radiative zone and convection zone. The outer layers are the photosphere, the chromosphere, and the corona.

John T Takai/Shutterstock

The deepest layer of the Sun's atmosphere is the photosphere. This is the layer we can see from Earth. It is about 300 miles thick. This layer is where the Sun's energy releases as the yellow-white light that we see. The brightness of the light varies as temperatures vary. Images of the photosphere show light and dark areas. These represent hotter and cooler regions as convection currents rise and fall. The average temperature in the photosphere is 10,000°F.

The layer just above the photosphere, and below the corona, is the *Sun's* chromosphere. This layer is between 250 miles and 1,300 miles above the photosphere. The temperature in the chromosphere also varies from 6,700°F to 20,000°F. The temperature rises as you move higher toward the top of the chromosphere. The light in this layer appears bright red during a solar eclipse.

The highest part of the Sun's atmosphere is the **corona**, or crown. This is the layer that extends out into space and is much hotter than the photosphere. It is about 1,300 miles from the photosphere. This layer has an average temperature of 3,500,000°F. Like the chromosphere, the corona is only visible during a solar eclipse and appears as white plumes of gas.



The Sun's visible-light corona, the inner part of which is only visible during a total solar eclipse, is seen here as a pearly crown. The reddish light around the edge of the limb of the Moon is from the Sun's chromosphere.

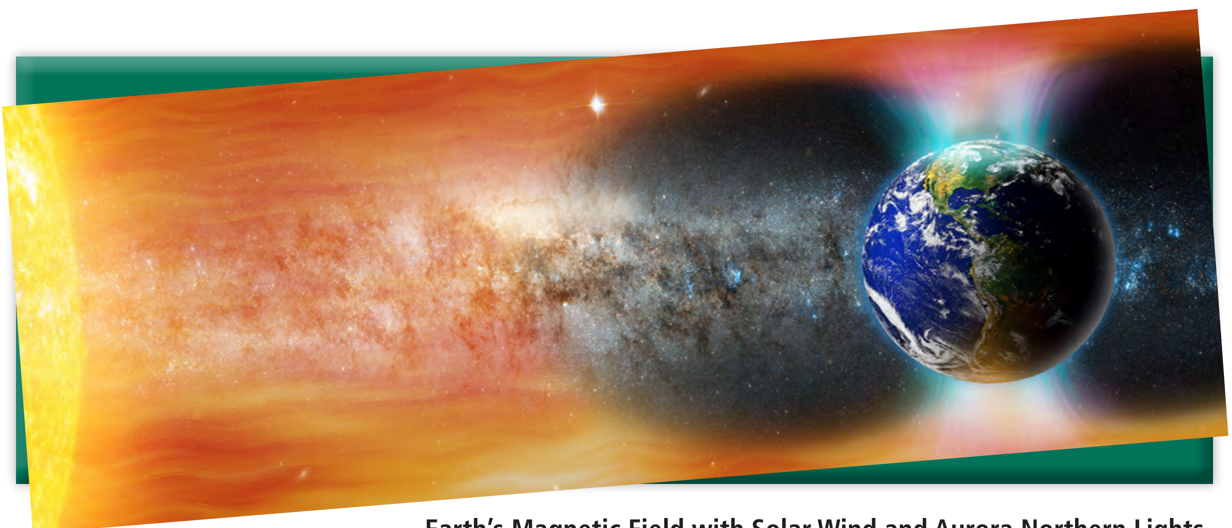
Courtesy of NASA.gov.

The Solar Wind

The outer part of the Sun's atmosphere creates a **solar wind**, which is *the emission of high-speed protons and electrons*. We call this a wind because it has the same effect on objects in its path as a strong wind blowing against a tree. It causes comets in space to form a "tail" that always points away from the Sun. These winds can also cause weather changes. They can affect radio signals and create the glowing lights called auroras around the North and South poles on Earth.

Did You Know?

The solar wind takes about four days to reach Earth.



Earth's Magnetic Field with Solar Wind and Aurora Northern Lights. Elements of this image are furnished by NASA.

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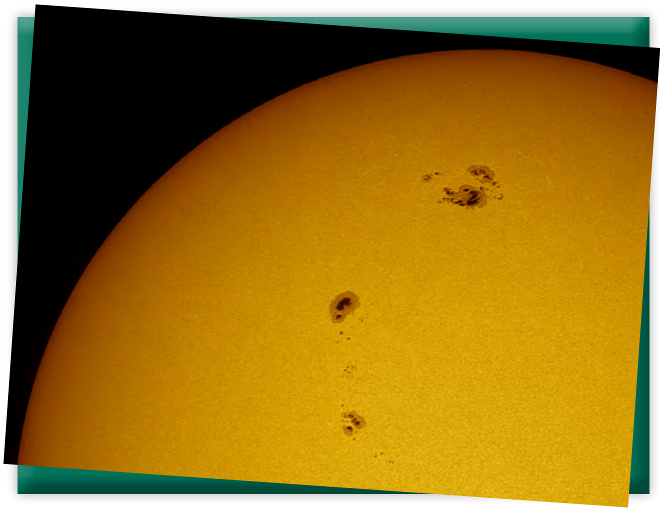
The Impact of Sunspots and Solar Flares on Earth's Climate

Pictures of the Sun's photosphere show areas on the surface called sunspots. These *are dark regions that appear when hot gases cool during the convection process*. We have been able to see them for hundreds of years, but did not understand them until about 200 years ago. We now estimate sunspots to be about 2,000^{0} F cooler than the brighter areas of the photosphere. Although they are cooler, the magnetic fields in sunspots may be 1,000 times stronger than the bright, hot areas. These magnetic spots often appear in pairs with one being an N-pole and the other an S-pole, like a simple magnet here on Earth.

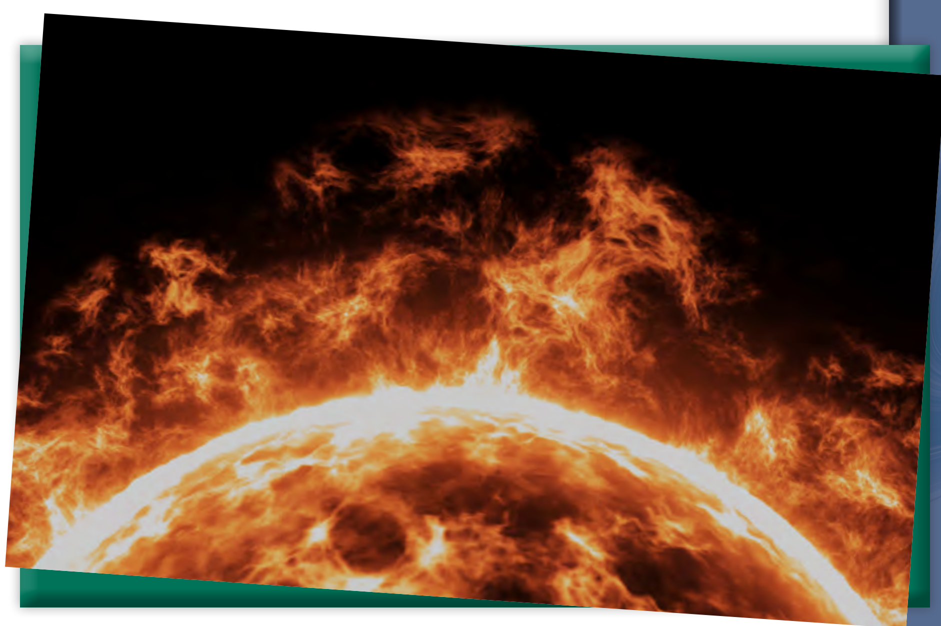


Sunspots on the Sun's photosphere
DeepSkyTX/Shutterstock

Sunspot activity occurs in cycles of about 11 years and ranges in number from almost none to hundreds. The life of a sunspot also varies from only minutes to a few months.

How are sunspots important to us on Earth? Studies between astronomy and geology seem to indicate that we have had ice ages on Earth at the same time as periods of low sunspot activity. Even during shorter periods, sunspots affect our climate.

The Sun's magnetic field can also create violent eruptions in the photosphere. Massive numbers of particles spew into the corona. Scientists view these areas of eruption as active regions of the Sun. One type of activity is a prominence, or *loop or arc of glowing gas extending from the photosphere into the corona*. We do not fully understand the cause of prominences. They usually last about a day and can be up to several hundred thousand miles long.



Sun's surface with solar flares, and splashes of solar prominences..
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Another powerful explosive activity on the photosphere is the solar flare. A solar flare is *an eruption on the Sun's surface*. As seen from Earth, a solar flare appears like a giant flame extending outward from the Sun. The solar flare gives off massive amounts of energy and radiation. Unlike the trapped gases that make up a prominence, the energy produced by a flare blasts out into space by the force of the explosion. Very large flares reach Earth in minutes and create the auroras in our polar regions. They may also affect radio signals on our planet.

The Right Stuff

The Parker Solar Probe

On August 12, 2018, NASA launched the Parker Solar Probe on a seven-year mission to "touch" the Sun. The spacecraft will fly directly through the Sun's atmosphere, as close as 3.8 million miles from its surface. The Parker Solar Probe will move around the Sun at speeds of up to 430,000 miles per hour. With the help of thermal technology that can protect the probe on its dangerous journey, the spacecraft's four instrument suites will study magnetic fields, plasma and energetic particles, and the solar wind.

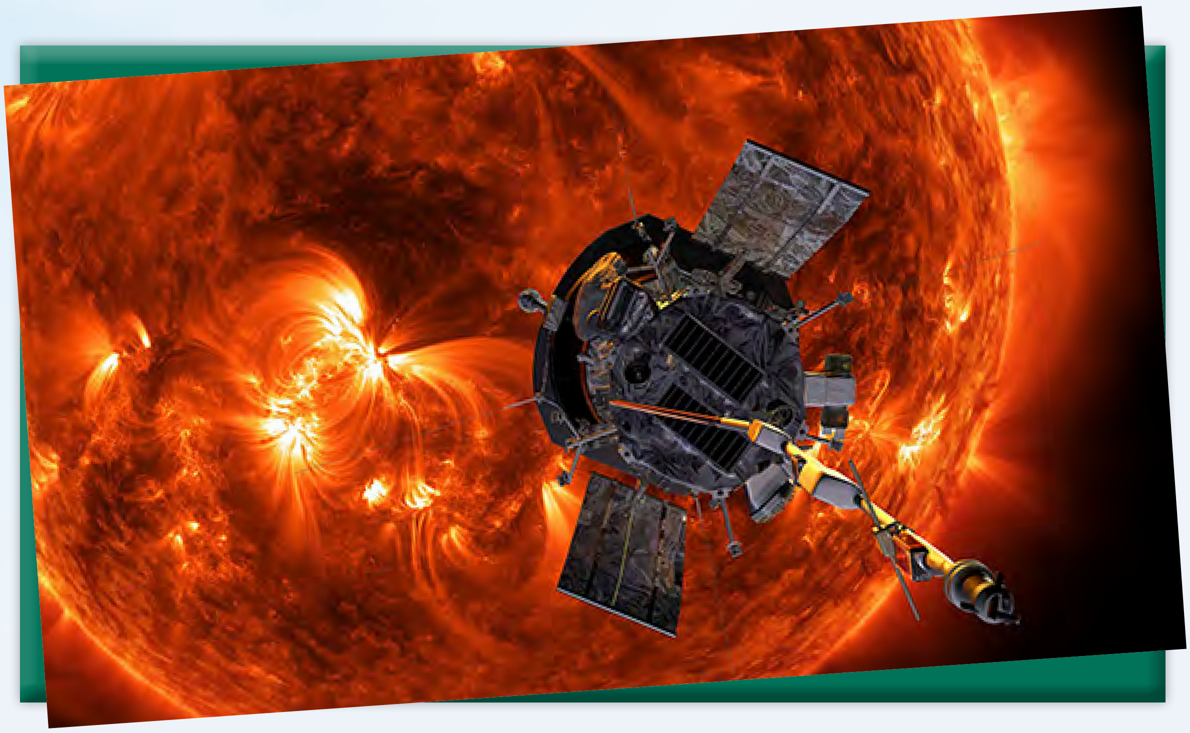


Illustration of NASA's Parker Solar Probe approaching the Sun.

Courtesy of NASA/Johns Hopkins APL/Steve Gribben

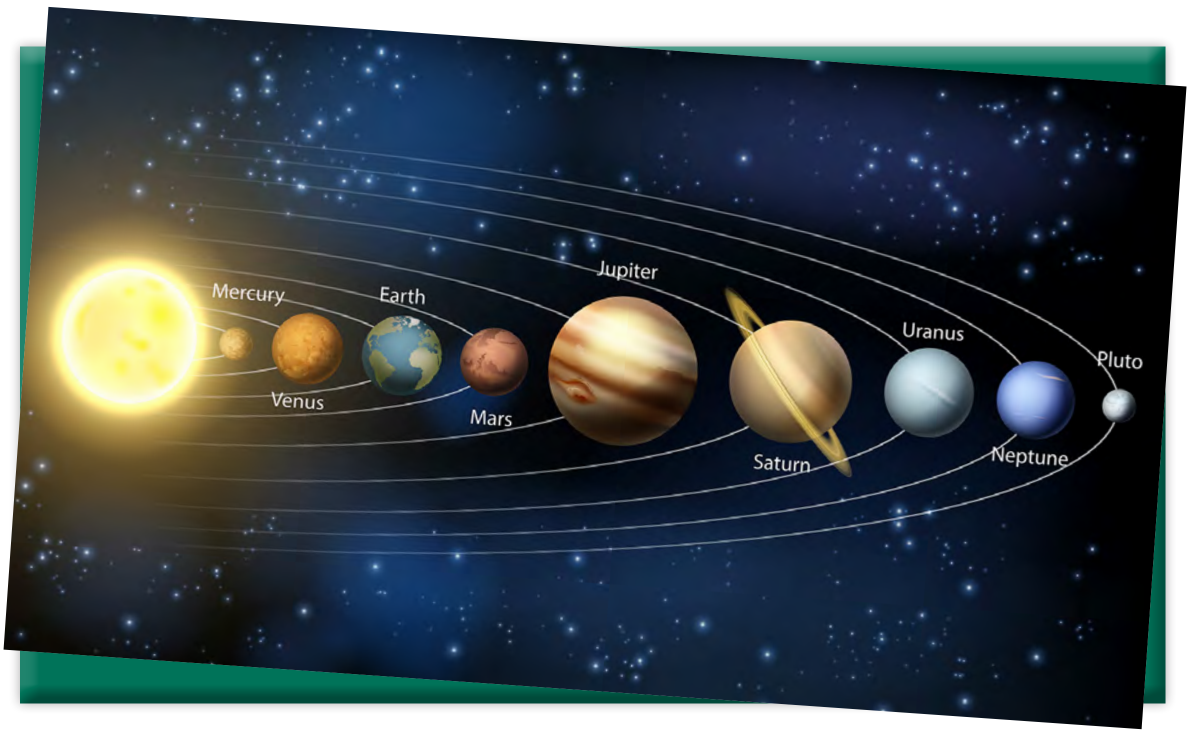
The Solar System's Structure

"My Very Educated Mother Just Served Us Noodles." What does this phrase have to do with our solar system? For many, it is an easy way to remember the order of planets orbiting the Sun. Using the first letter of each word as a reminder of the first letter of each planet, in order, we have Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

We once considered Pluto to be a planet. However, based on the 2006 International Astronomical Union definition, Pluto no longer qualifies. According to the definition, a planet must orbit a star, be big enough to have enough gravity to force it into a spherical shape, and be big enough that its gravity cleared away any other objects of a similar size near its orbit around the Sun.

Did You Know?

The Sun is nearly 1,000 times bigger than the rest of the planets put together. It has a diameter of almost 865,000 miles.



An illustration of the planets of our solar system.
Christos Georghiou/Shutterstock

We know the planets and their order of orbit around the Sun. This provides a solid start to visualizing our solar system. Of course, we have much more to learn about the planets. For example, why are the rocky inner planets so much smaller than the giant, gassy outer planets?

Jupiter, for example, is hundreds of times more massive than Earth. It is about five times the distance of Earth from the Sun. In comparison, Mercury is a little more than one-third the size of Earth. If Earth were the size of a tennis ball, Mercury would be about the size of a large marble.

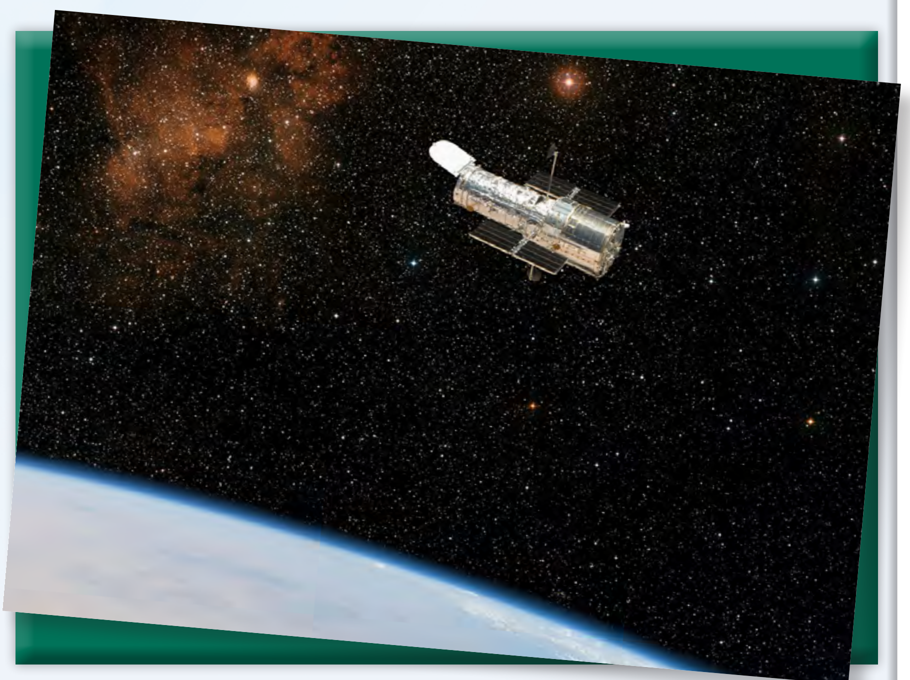
What are the distances between the planets, using our tennis ball analogy? If you hold the tennis ball, Earth, you need to stand seven football fields away to be the same distance from the Sun. For the marble, Mercury, you would need to be 304 miles away to be the same distance from the Sun.

The Right Stuff

The Hubble Space Telescope

How do we know so much about the planets? Many stars and planets release or reflect light that we can see either with the naked eye or with telescopes. Just by looking at the light, scientists can determine the locations of stars and planets. The Hubble Space Telescope is the largest, most sensitive light-receiving telescope ever put into orbit. Hubble probes the universe with about 10x finer resolution and about 30x greater sensitivity to light than devices on Earth.

Other objects are either too far away to be seen or are behind something that blocks the light. We can detect their radio waves using radio telescopes. For other objects that do not emit radio waves, scientists rely on models and logic to detect planets around other stars.



The Hubble Space Telescope in orbit above the Earth. As light enters the main tube (at right), it strikes the main mirror (light blue disk at center), from which it can be directed to any of several instruments (behind the mirror). Elements of this image furnished by NASA.

Marcel Clemens/Shutterstock

How the Solar System Formed

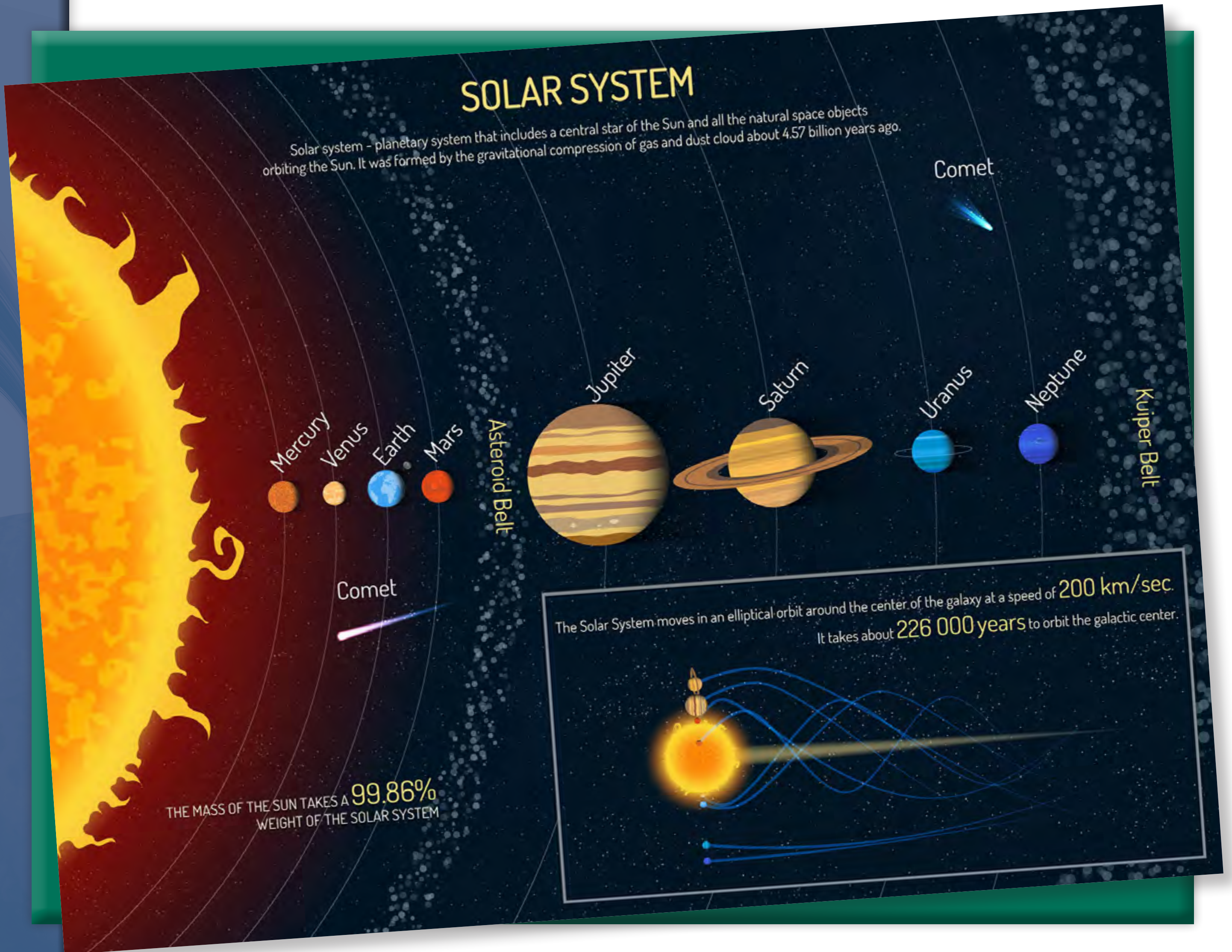
Scientists believe that the solar system formed about five billion (5,000,000,000) years ago from gas and dust in space. To explain the origin and development of the solar system, we depend upon one or more theories. A theory is *an educated explanation of something but without real proof*. Although we cannot prove our solar system formation theories, they at least help to explain these facts:

1. The Sun is in the center of the solar system.
2. All of the planets revolve around the Sun, most in the same direction, and in nearly circular orbits.
3. The orbits of the planets are nearly parallel.
4. They all rotate in the same direction except for Venus and Uranus.
5. Most of the moons circle "their" planet in the same direction that the planet rotates and revolves in its orbit.
6. The orbits of the planets form a definite pattern from the Sun outward.
7. The denser planets are closer to the Sun.
8. The planets with solid surfaces, such as Earth, all have craters like those on our Moon.
9. The outer Jovian planets (such as Jupiter) have rings around them.
10. Within the orbits of the planets, there are asteroids (*small rocky objects orbiting the Sun mostly between Mars and Jupiter, although some have passed close to Earth*), meteoroids (*similar to asteroids but smaller*), and comets (*objects made of ice and dust and having a "tail" that points away from the Sun*) with their own motion patterns.
11. Other stars, besides the Sun, also have systems of planets.

Scientists divide theories about the development of the solar system into two categories. Evolution theories explain the creation of the solar system as evolving or forming from something else. René Descartes (1596-1650) was a famous philosopher, scientist, and mathematician. Descartes was responsible for developing the most popular theory of planetary motion in the seventeenth century. The famous scientist and philosopher stated that about 350 years ago the solar system may have formed from a spinning mass of material in the universe, like a tornado, which threw out pieces, such as the Sun and Earth. The problem with this theory is that it does not agree with scientific laws developed since Descartes' time.

Did You Know?

Descartes is mostly remembered for the saying, "I think, therefore I am.'



Any theory of the origin and evolution must explain the observed patterns in the solar system.

SkyPics Studio/Shutterstock

A second category of theories is catastrophe theories. Surprisingly, catastrophe theories do not mean something destructive like tornadoes took place. Instead, these theories suggest that the solar system was created during some "unusual" events. An early theory, about 250 years ago, suggested that a comet may have come close to the Sun and pulled material out to form the planets, like a car blowing leaves off a tree as it passes by at a high speed. This theory was later rejected as not being a real possibility, but it led to other theories that came later.

One such theory stated that the Sun may have been one of three stars that revolved around each other. (Astronomers have observed such formations in the universe in modern times.) Perhaps, the theory stated, this three-star system was not stable, and one star was thrown away from the other two, causing the formation of the Sun and its planets. There are two major problems with this theory. The material from the developing Sun would have been so hot that it would have scattered instead of coming together to

This image of Comet C/2001 Q4 (NEAT) was taken at the WIYN 0.9-meter telescope at Kitt Peak National Observatory.

Courtesy of T. A. Rector (University of Alaska Anchorage), Z. Levay and L.Frattare (Space Telescope Science Institute) and WIYN/NOAO/AURA/NSF

form the planets. Also, this catastrophe theory suggests that a star with planets around it would have been extremely rare, which has not turned out to be the case. Thousands of other systems with such an arrangement have been discovered to date.

Classifying Objects in the Solar System

We usually divide the planets into two groups. The terrestrial planets *are small and dense, with rocky surfaces and a great deal of metals in their core*. These include Mercury, Venus, Earth, and Mars. They are closer to the Sun, they have few (if any) moons, and they have no rings.

The outer planets, or Jovian planets, *are much larger and made up of gases*. These include Jupiter, Saturn, Uranus, and Neptune. They are lower in average density, and they all have ring systems and many moons. We often refer to them as the gas giants; they are made up mostly of hydrogen and helium.

Recall that Pluto was once considered to be a planet until scientists reclassified it. Today, Pluto is known as a dwarf planet. A dwarf planet *orbits the Sun, is large enough to be a spherical shape, but not large enough to have cleared away other objects of a similar size near its orbit*. Ceres, Haumea, Makemake, and Eris are four other dwarf planets.

The planets share many similarities and also significant differences. In the upcoming lessons we will explore more of the unique differences in their position, composition, and other features.

Did You Know?

Dwarf planet Ceres is the largest object in the asteroid belt between Mars and Jupiter and the only dwarf planet located in the inner solar system.

✔ CHECKPOINTS

Lesson 2 Review

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

1. What is the main source of the Sun's energy?
2. What is hydrostatic equilibrium?
3. What is the main mode of solar energy transfer?
4. Compare and contrast the Sun's three atmospheric layers.
5. Why have studies shown that sunspots are important to Earth?
6. Describe one catastrophe theory of the solar system's formation.
7. What is Pluto's classification as a planet?

APPLYING YOUR LEARNING

8. Using the theory of planetary formation and the world we live in, describe how the Earth came to exist and how it relates to the rest of the solar system.