Activity 1 The History and Scale of the Solar System

Goals

In this activity you will:

- Produce a scale model of the solar system.
- Identify some strengths and limitations of scale models.
- Calculate distances to objects in the solar system in astronomical units (AU), light-years, and parsecs.
- Explain, in your own words, the nebular theory of the formation of the solar system.
- Explain the formation of the universe.

Think about It

Earth is part of a large number of objects that orbit around a star called the Sun.

- **What objects make up the solar system? Where are they located in relation to Earth?**

What do you think? Record your ideas in the form of a diagram of the solar system in your *EarthComm* notebook. Without looking ahead in this book, draw the Sun and the planets, and the distances from the Sun to the planets, as nearly to scale as you can. Be prepared to discuss your diagram with your small group and the class.

Investigate

1. Use the data in *Table 1* to make a scale model of the solar system. Try using the scale 1 m = 150,000,000 km.

   a) Divide all the distances in the first column by 150,000,000 (one hundred and fifty million). Write your scaled-down distances in your notebook, in meters.

   b) Divide all the diameters in the second column by 150,000,000. Write your scaled-down diameters in your notebook, in meters.

   c) Looking at your numbers, what major drawback is there to using the scale 1 m = 150,000,000 km?

Table 1 Diameters of the Sun and Planets, and Distances from the Sun

Object	Distance from Sun (km)	Diameter (km)
Sun	0	1,391,400
Mercury	57,900,000	4878
Venus	108,209,000	12,104
Earth	149,598,770	12,756
Mars	227,900,000	6794
Jupiter	778,200,000	142,984
Saturn	1,429,200,000	120,536
Uranus	2,875,000,000	51,118
Neptune	4,504,400,000	49,528
Pluto	5,915,800,000	2302

2. Now try another scale: 1 m = 3,000,000 km (three million kilometers).

   a) Divide all the distances in the first column by 3,000,000. Write your scaled-down distances in your notebook in meters.

   b) Divide all the diameters in the second column by 3,000,000. Write your scaled-down diameters in your notebook in meters.

   c) Looking at your numbers, what major drawback is there to using the scale 1 m = 3,000,000 km?

3. Using what you have learned about scaling distances and diameters in the solar system, make models of the Sun and the planets. Each of the planets can be drawn on a different sheet of paper using a ruler to lay out the correct sizes for the different planets and the Sun.

4. To represent the distances from the Sun to the planets you will need to use a tape measure. You may want to measure the size of your stride and use this as a simple measuring tool.

To do this, stand behind a line and take five steps in as normal a way as possible and note where your last step ended. Now measure the distance from where you started to the end. Divide by five to determine how far you walk with each step. Knowing the length of your stride is an easy way to determine distances.

a) Explain the scale(s) you decided to use and your reasons for your choices.

b) Is it possible to make a model of the solar system on your school campus in which both the distances between bodies and the diameters of the bodies are to the same scale? Why or why not?

Reflecting on the Activity and the Challenge

In this activity you used ratios to make a scale model of the solar system. You found out that scale models help you appreciate the vastness of distances in the solar system. You also found out that there are some drawbacks to the use of scale models. Think about how you might use the model you made as part of your **Chapter Challenge.**

Digging Deeper

OUR PLACE IN THE UNIVERSE

Distances in the Universe

Astronomers often study objects far from Earth. It is cumbersome to use units like kilometers (or even a million kilometers) to describe the distances to the stars and planets. For example, the star nearest to the Sun is called Proxima Centauri. It is 39,826,600,000,000 km away. (How would you say this distance?)

Astronomers get around the problem by using larger units to measure distances. When discussing distances inside the solar system, they often use the **astronomical unit** (abbreviated as AU). One AU is the average distance of the Earth from the Sun. It is equal to 149,598,770 km (about 93 million miles).

Stars are so far away that using astronomical units quickly becomes difficult, too! For example, Proxima Centauri is 266,221 AU away. This number is easier to use than kilometers, but it is still too cumbersome for most purposes. For distances to stars and galaxies, astronomers use a unit called a **light-year**. A light-year sounds as though it is a unit of time, because a year is a unit of time, but it is really the distance that light travels in a year. Because light travels

Geo Words

astronomical unit: a unit of measurement equal to the average distance between the Sun and Earth, i.e., about 149,600,000 (1.496×10^8) km.

light-year: a unit of measurement equal to the distance light travels in one year, i.e., 9.46×10^{12} km.

extremely fast, a light-year is a very large distance. For example, the Sun is only 8 light *minutes* away from Earth, and the nearest stars are several light-years away. Light travels at a speed of 300,000 km/s. This makes a light-year 9.46×10^{12} (9,460,000,000,000) km. Light from Proxima Centauri takes 4.21 years to reach Earth, so this star is 4.21 light-years from Earth.

Astronomers also use a unit called the **parsec** (symbol pc) to describe large distances. One parsec equals 3.26 light-years. Thus, Proxima Centauri is 1.29 pc away. The kiloparsec (1000 pc) and megaparsec (1,000,000 pc) are used for objects that are extremely far away. The nearest spiral galaxy to the Milky Way galaxy is the Andromeda galaxy. It is about 2.5 million light-years, or about 767 kpc (kiloparsecs), away.

The Nebular Theory

As you created a scale model of the solar system, you probably noticed how large the Sun is in comparison to most of the planets. In fact, the Sun contains over 99% of all of the mass of the solar system. Where did all this mass come from? According to current thinking, the birthplace of our solar system was a **nebula**. A nebula is a cloud of gas and dust probably cast off from other stars that used to live in this region of our galaxy. More than 4.5 billion years ago this nebula started down the long road to the formation of a star and planets. The idea that the solar system evolved from such a swirling cloud of dust is called the nebular theory.

You can see one such nebula in the winter **constellation** Orion (see *Figure 1*), just below the three stars that make up the Belt of Orion. Through a pair of binoculars or a small, backyard-type telescope, the Orion Nebula looks like a faint green, hazy patch of light. If you were able to view this starbirth region through a much higher-power telescope, you would be able to see amazing details in the gas and dust clouds. The Orion Nebula is very much like the one that formed our star, the Sun. There are many star nurseries like this one scattered around our galaxy. On a dark night, with binoculars or a small telescope, you can see many gas clouds that are forming stars.

Figure 1 Orion is a prominent constellation in the night sky.

Geo Words

parsec: a unit used in astronomy to describe large distances. One parsec equals 3.26 light-years.

nebula: general term used for any "fuzzy" patch on the sky, either light or dark; a cloud of interstellar gas and dust.

constellation: a grouping of stars in the night sky into a recognizable pattern. Most of the constellations get their name from the Latin translation of one of the ancient Greek star patterns that lies within it. In more recent times, more modern astronomers introduced a number of additional groups, and there are now 88 standard configurations recognized.

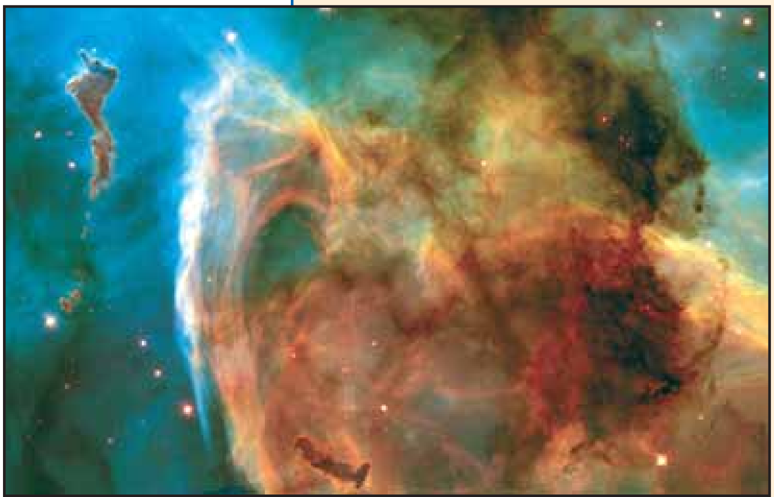

Figure 2 The Keyhole Nebula. Imaged by the Hubble Space Telescope.

In the nebula that gave birth to our solar system, gravity caused the gases and dust to be drawn together into a denser cloud. At the same time, the rate of rotation (swirling) of the entire nebula gradually increased. The effect is the same as when a rotating ice skater draws his or her arms in, causing the rate of rotation to speed up. As the nebular cloud began to collapse and spin faster, it flattened out to resemble a disk, with most of the mass collapsing into the center. Matter in the rest of the disk clumped together into small masses called **planetesimals**, which then gradually collided together to form larger bodies called **protoplanetary bodies**.

At the center of the developing solar system, material kept collapsing under gravitational force. As the moving gases became more concentrated, the temperature and pressure of the center of the cloud started to rise. The same kind of thing happens when you pump up a bicycle tire with a tire pump: the pump gets warmer as the air is compressed. When you let the air out of a tire, the opposite occurs and the air gets colder as it expands rapidly. When the temperature in the center of the gas cloud reached about 15 million degrees Celsius, hydrogen atoms in the gas combined or fused to create helium atoms. This process, called **nuclear fusion**, is the source of the energy from the Sun. A star—the Sun—was born!

Fusion reactions inside the Sun create very high pressure, and like a bomb, threaten to blow the Sun apart. The Sun doesn't fly apart under all this outward pressure, however. The Sun is in a state of equilibrium. The gravity of the Sun is pulling on each part of it and keeps the Sun together as it radiates energy out in all directions, providing solar energy to the Earth community.

The Birth of the Planets

The rest of the solar system formed in the swirling disk of material surrounding the newborn Sun. Nine planets, 67 satellites (with new ones still being discovered!), and a large number of comets and asteroids formed. The larger objects were formed mostly in the flat disk surrounding where the Sun was forming.

Geo Words

planetesimal: one of the small bodies (usually micrometers to kilometers in diameter) that formed from the solar nebula and eventually grew into protoplanets.

protoplanetary body: a clump of material, formed in the early stages of solar system formation, which was the forerunner of the planets we see today.

nuclear fusion: a nuclear process that releases energy when lightweight nuclei combine to form heavier nuclei.

Four of these planets, shown in *Figure 3*—Mercury, Venus, Earth, and Mars—are called the **terrestrial** ("Earth-like") **planets**. They formed in the inner part of our solar system, where temperatures in the original nebula were high. They are relatively small, rocky bodies. Some have molten centers, with a layer of rock called a mantle outside their centers, and a surface called a crust. The Earth's crust is its outer layer. Even the deepest oil wells do not penetrate the crust.

The larger planets shown in *Figure 3*—Jupiter, Saturn, Uranus, and Neptune—consist mostly of dense fluids like liquid hydrogen. These **gas giants** formed in the colder, outer parts of the early solar nebula. They have solid rocky cores about the size of Earth, covered with layers of hydrogen in both gas and liquid form. They lie far from the Sun and their surfaces are extremely cold.

Pluto is the most distant planet from the Sun. Some astronomers do not even classify it as a planet, and there is controversy about whether Pluto should be included among the "official" planets. Pluto is very different from the terrestrial or the gaseous planets. Some scientists think that it may not have been part of the original solar system but instead was captured later by the Sun's gravity. Others think that it was once a moon of an outer planet because it resembles the icy moons of the gas giants.

Figure 3 Composite image of the planets in the solar system, plus the Moon.

All life, as we know it on Earth, is based on carbon and water. Although there is evidence that water may once have been plentiful on Mars, liquid water has not been found on any of the planets in the solar system. Without water, these planets cannot support life as we know it. There is evidence, however, that Jupiter's moon Europa may be covered with ice, and that an ocean may lie beneath the ice. Scientists have found that life on Earth can thrive in even some of the most extreme environments. Powerful telescopes have discovered organic molecules in interstellar gas and have discovered planets around many nearby stars. Although life may not exist on the other planets in the solar system, the possibility of life on Europa and in other places in the universe exists!

Geo Words

terrestrial planets: any of the planets Mercury, Venus, Earth, or Mars, or a planet similar in size, composition, and density to the Earth. A planet that consists mainly of rocky material.

gas giant planets: the outer solar system planets: Jupiter, Saturn, Uranus, and Neptune, composed mostly of hydrogen, helium, and methane, and having a density of less than 2 gm/cm^2.

Geo Words

comet: a chunk of frozen gases, ice, and rocky debris that orbits the Sun.

asteroid: a small planetary body in orbit around the Sun, larger than a meteoroid (a particle in space less than a few meters in diameter) but smaller than a planet. Many asteroids can be found in a belt between the orbits of Mars and Jupiter.

There are trillions of **comets** and **asteroids** scattered throughout the solar system. Earth and other solar-system bodies are scarred by impact craters formed when comets and asteroids collided with them. On Earth, erosion has removed obvious signs of many of these craters. Astronomers see these comets and asteroids as the leftovers from the formation of the solar system. Asteroids are dark, rocky bodies that orbit the Sun at different distances. Many are found between the orbits of Mars and Jupiter, making up what is called the asteroid belt. Many others have orbits outside of the asteroid belt. Comets are mixtures of ice and dust grains. They exist mainly in the outer solar system, but when their looping orbits bring them close to the Sun, their ices begin to melt. That is when you can see tails streaming out from them in the direction away from the Sun. Some comets come unexpectedly into the inner solar system. Others have orbits that bring them close to the Sun at regular intervals. For example, the orbit of Halley's comet brings it into the inner solar system every 76 years.

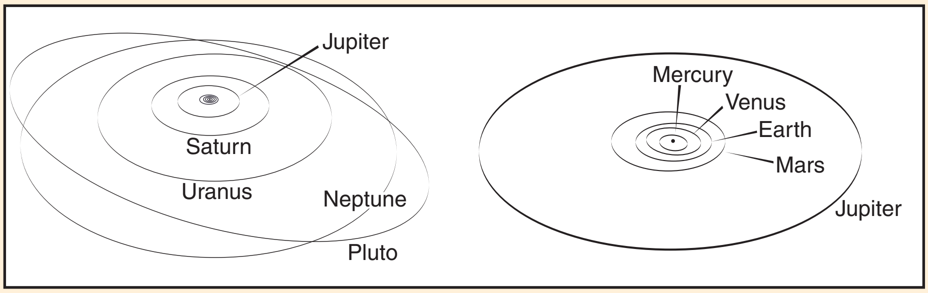

Figure 4 Two diagrams are required to show the orbits of the planets to scale.

Where is the Solar System in Our Galaxy?

Have you ever seen the Milky Way? It is a swath of light, formed by the glow of billions of stars, which stretches across the dark night sky. From Earth, this band of celestial light is best seen from dark-sky viewing sites. Binoculars and backyard-type telescopes magnify the view and reveal individual stars and nebulae. Unfortunately, for those who like to view the night sky, light pollution in densely populated areas makes it impossible to see the Milky Way even on nights when the atmosphere is clear and cloudless.

Galaxies are classified according to their shape: elliptical, spiral, or irregular. Our home galaxy is a flat spiral, a pinwheel-shaped collection of stars held together by their mutual gravitational attraction. Our galaxy shown in *Figure 5* is called the Milky Way Galaxy, or just the galaxy. Our solar system is located in one of the spiral arms about two-thirds of the way out from the center of the galaxy. What is called the Milky Way is the view along the flat part of our galaxy. When you look at the Milky Way, you are looking out through the galaxy parallel to the

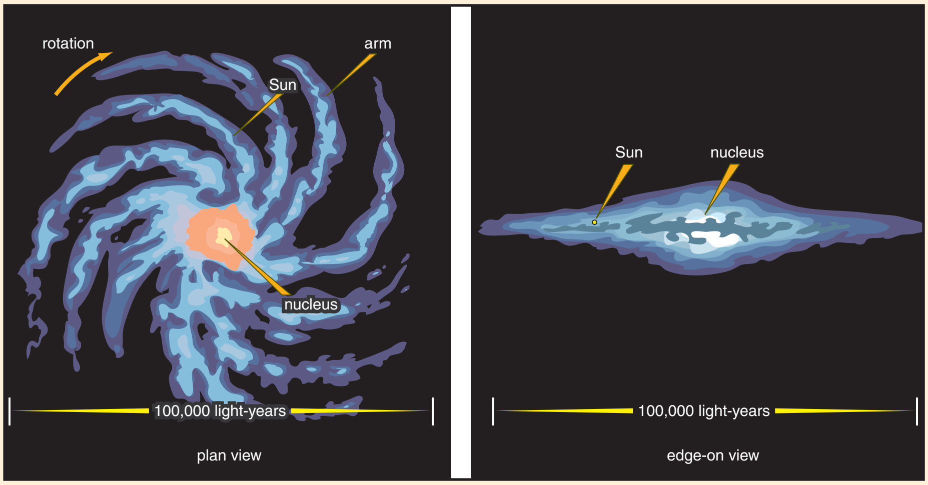

Figure 5 The Milky Way Galaxy. Our solar system is located in a spiral band about two-thirds of the way from the nucleus of the galaxy.

plane of its disk. The individual stars you see dotting the night sky are just the ones nearest to Earth in the galaxy. When you view the Milky Way, you are "looking through" those nearest stars to see the more distant parts of the galaxy. In a sense, you are looking at our galaxy from the inside. In other directions, you look through the nearest stars to see out into intergalactic space!

Our Milky Way Galaxy formed about 10 billion years ago and is one of billions of galaxies in the universe. The universe itself formed somewhere between 12 to 14 billion years ago in an event called the Big Bang. This sounds like the universe began in an explosion, but it did not. In the beginning, at what a scientist would call "time zero," the universe consisted almost entirely of energy, concentrated into a volume smaller than a grain of sand. The temperatures were unimaginably high. Then the universe expanded, extremely rapidly, and as it expanded the temperature dropped and matter was formed from some of the original energy. **Cosmologists** (scientists who study the origin and dynamics of the universe) think that most of the matter in the universe was formed within minutes of time zero! The expansion and cooling that started with the Big Bang continues to this day.

The galaxies and stars are the visible evidence of the Big Bang, but there is other, unseen evidence that it happened. It's called the cosmic background radiation, which is radiation that is left over from the initial moments of the Big Bang. Astronomers using special instruments sensitive to low-energy radio waves have detected it coming in from all directions from the universe. The existence of the cosmic background radiation is generally considered to be solid evidence of how the Big Bang happened.

Geo Words

cosmologist: a scientist who studies the origin and dynamics of the universe.

Check Your Understanding

1. What are the distances represented by a light-year, an astronomical unit, and a parsec?
2. Which of the units in Question 1 would you use to describe each of the following? Justify your choice.
   a) Distances to various stars (but not our Sun)?
   b) Distances to various planets within our solar system?
   c) Widths of galaxies?
3. In your own words, explain the nebular theory for the beginning of our solar system.
4. Briefly describe the origin of the universe.

Understanding and Applying What You Have Learned

1. Using the second scale (1 m = 3,000,000 km) you used for distance in your model of the solar system:
   a) How far away would Proxima Centauri be from Earth?
   b) How far away would the Andromeda galaxy be on your scale, given that Andromeda is 767 kiloparsecs or 2.5 million light-years away?
2. The Moon is 384,000 km from Earth and has a diameter of 3476 km. Calculate the diameter of the Moon and its distance from the Earth using the scale of the model you developed in the **Investigate** section.
3. Refer again to *Table 1*. If the Space Shuttle could travel at 100,000 km/hr, how long would it take to go from Earth to each of the following objects? Assume that each object is as close to the Earth as it can be in its orbit.
   a) The Moon?
   b) Mars?
   c) Pluto?
4. What is the largest distance possible between any two planets in the solar system?
5. Use your understanding of a light-year and the distances from the Sun shown in *Table 1*. Calculate how many minutes it takes for sunlight to reach each of the nine planets in the solar system. Then use the unit "light-minutes" (how far light travels in one minute) to describe the *distances* to each object.
6. Write down your school address in the following ways:
   a) As you would normally address an envelope.
   b) To receive a letter from another country.
   c) To receive a letter from a friend who lives at the center of our galaxy.
   d) To receive a letter from a friend who lives in a distant galaxy.

Preparing for the Chapter Challenge

Begin to develop your brochure for the **Chapter Challenge**. In your own words, explain your community's position relative to the Earth, Sun, the other planets in our solar system, and the entire universe. Include a few paragraphs explaining what your scale model represents and how you chose the scale or scales you used.

Inquiring Further

1. **Solar-system walk**

   Create a "solar-system walk" on your school grounds or your neighborhood. Draw the Sun and the planets to scale on the sidewalk in chalk. Pace off the distances between the Sun and the nine planets at a scale that is appropriate for the site.

2. **Scaling the nearest stars**

   Look up the distances to the five stars nearest to the Sun. Where would they be in your scale model? To show their location, would you need a map of your state? Country? Continent? The world?

3. **Nuclear fusion**

   Find out more about the process of nuclear fusion. Explain how and why energy is released in the process by which hydrogen atoms are converted into helium atoms within the Sun. Be sure to include Albert Einstein's famous equation, $E = mc^2$, in your explanation, and explain what it means.

4. **Star formation**

   Write a newspaper story about star formation. Visit the *EarthComm* web site to find information available on the web sites of the Hubble Space Telescope and the European Southern Observatory to find examples of star-forming nebulae in the galaxy. How are they similar? How are they different? What instruments do astronomers use to study these nebulae?