7.1 OVERVIEW OF OUR PLANETARY SYSTEM

Learning Objectives

By the end of this section, you will be able to:

- Describe how the objects in our solar system are identified, explored, and characterized
- Describe the types of small bodies in our solar system, their locations, and how they formed
- Model the solar system with distances from everyday life to better comprehend distances in space

The solar system[1] consists of the Sun and many smaller objects: the planets, their moons and rings, and such "debris" as asteroids, comets, and dust. Decades of observation and spacecraft exploration have revealed that most of these objects formed together with the Sun about 4.5 billion years ago. They represent clumps of material that condensed from an enormous cloud of gas and dust. The central part of this cloud became the Sun, and a small fraction of the material in the outer parts eventually formed the other objects.

During the past 50 years, we have learned more about the solar system than anyone imagined before the space age. In addition to gathering information with powerful new telescopes, we have sent spacecraft directly to many members of the planetary system. (Planetary astronomy is the only branch of our science in which we can, at least vicariously, travel to the objects we want to study.) With evocative names such as Voyager, Pioneer, *Curiosity*, and Pathfinder, our robot explorers have flown past, orbited, or landed on every planet, returning images and data that have dazzled both astronomers and the public. In the process, we have also investigated two dwarf planets, hundreds of fascinating moons, four ring systems, a dozen asteroids, and several comets (smaller members of our solar system that we will discuss later).

Our probes have penetrated the atmosphere of Jupiter and landed on the surfaces of Venus, Mars, our Moon, Saturn's moon Titan, the asteroids Eros and Itokawa, and the Comet Churyumov-Gerasimenko (usually referred to as 67P). Humans have set foot on the Moon and returned samples of its surface soil for laboratory analysis (**Figure 7.2**). We have even discovered other places in our solar system that might be able to support some kind of life.

1 The generic term for a group of planets and other bodies circling a star is *planetary system*. Ours is called the *solar system* because our Sun is sometimes called *Sol*. Strictly speaking, then, there is only one solar system; planets orbiting other stars are in planetary systems.

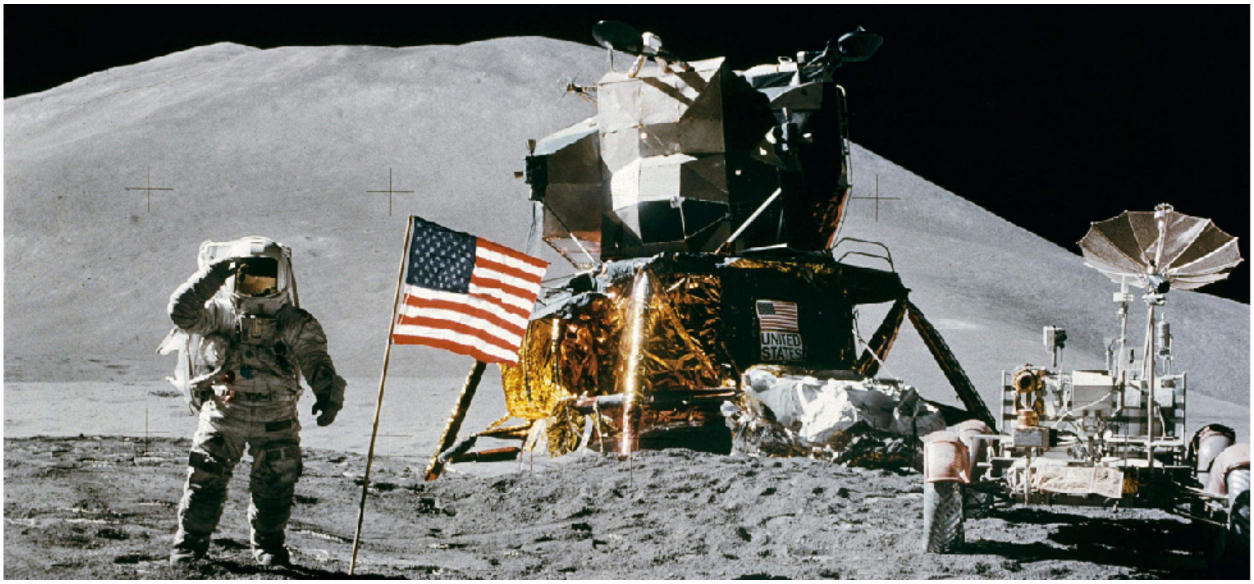

Figure 7.2 Astronauts on the Moon. The lunar lander and surface rover from the Apollo 15 mission are seen in this view of the one place beyond Earth that has been explored directly by humans. (credit: modification of work by David R. Scott, NASA)

LINK TO LEARNING

View this gallery of NASA images (https://openstaxcollege.org/l/30projapolloarc) that trace the history of the Apollo mission.

An Inventory

The Sun, a star that is brighter than about 80% of the stars in the Galaxy, is by far the most massive member of the solar system, as shown in Table 7.1. It is an enormous ball about 1.4 million kilometers in diameter, with surface layers of incandescent gas and an interior temperature of millions of degrees. The Sun will be discussed in later chapters as our first, and best-studied, example of a star.

Mass of Members of the Solar System

Object	Percentage of Total Mass of Solar System
Sun	99.80
Jupiter	0.10
Comets	0.0005–0.03 (estimate)
All other planets and dwarf planets	0.04
Moons and rings	0.00005

Table 7.1

Mass of Members of the Solar System

Object	Percentage of Total Mass of Solar System
Asteroids	0.000002 (estimate)
Cosmic dust	0.0000001 (estimate)

Table 7.1

Table 7.1 also shows that most of the material of the planets is actually concentrated in the largest one, Jupiter, which is more massive than all the rest of the planets combined. Astronomers were able to determine the masses of the planets centuries ago using Kepler's laws of planetary motion and Newton's law of gravity to measure the planets' gravitational effects on one another or on moons that orbit them (see **Orbits and Gravity**). Today, we make even more precise measurements of their masses by tracking their gravitational effects on the motion of spacecraft that pass near them.

Beside Earth, five other planets were known to the ancients—Mercury, Venus, Mars, Jupiter, and Saturn—and two were discovered after the invention of the telescope: Uranus and Neptune. The eight planets all revolve in the same direction around the Sun. They orbit in approximately the same plane, like cars traveling on concentric tracks on a giant, flat racecourse. Each planet stays in its own "traffic lane," following a nearly circular orbit about the Sun and obeying the "traffic" laws discovered by Galileo, Kepler, and Newton. Besides these planets, we have also been discovering smaller worlds beyond Neptune that are called trans-Neptunian objects or TNOs (see **Figure 7.3**). The first to be found, in 1930, was Pluto, but others have been discovered during the twenty-first century. One of them, Eris, is about the same size as Pluto and has at least one moon (Pluto has five known moons.) The largest TNOs are also classed as *dwarf planets,* as is the largest asteroid, Ceres. (Dwarf planets will be discussed further in the chapter on **Rings, Moons, and Pluto**). To date, more than 1750 of these TNOs have been discovered.

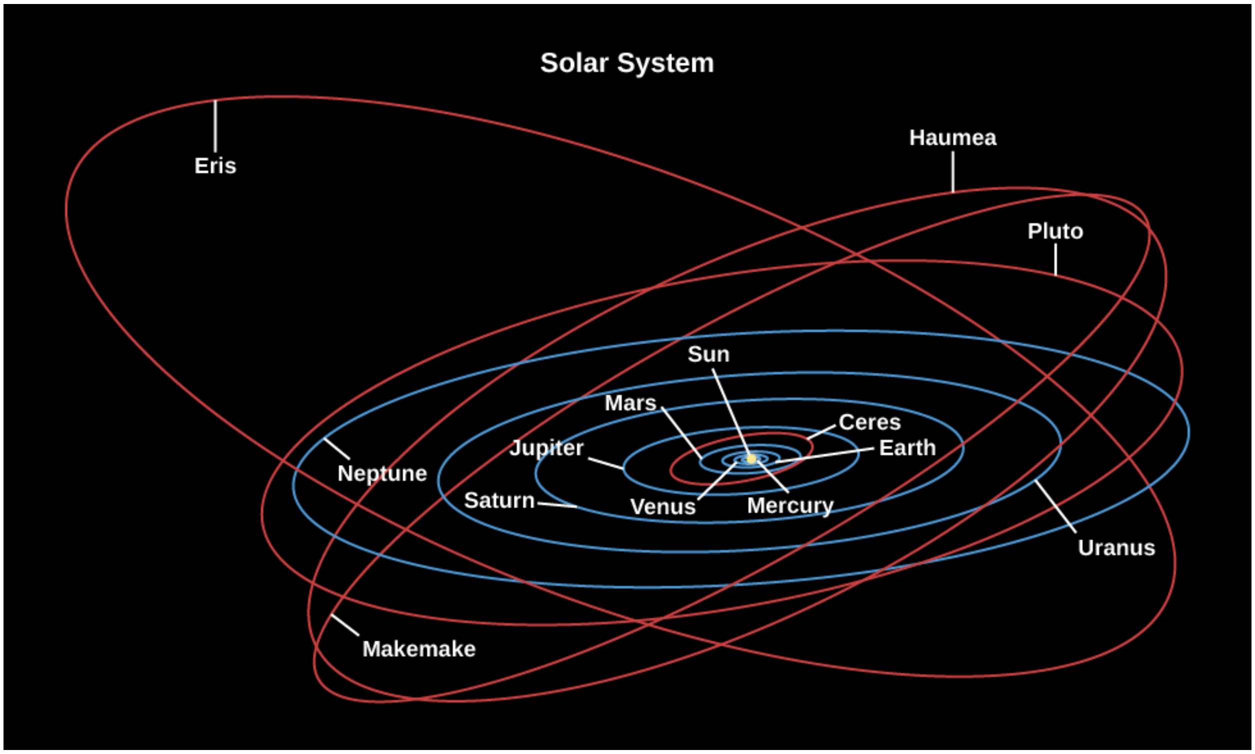

Figure 7.3 Orbits of the Planets. All eight major planets orbit the Sun in roughly the same plane. The five currently known dwarf planets are also shown: Eris, Haumea, Pluto, Ceres, and Makemake. Note that Pluto's orbit is not in the plane of the planets.

Each of the planets and dwarf planets also rotates (spins) about an axis running through it, and in most cases the direction of rotation is the same as the direction of revolution about the Sun. The exceptions are Venus, which rotates backward very slowly (that is, in a retrograde direction), and Uranus and Pluto, which also have strange rotations, each spinning about an axis tipped nearly on its side. We do not yet know the spin orientations of Eris, Haumea, and Makemake.

The four planets closest to the Sun (Mercury through Mars) are called the inner or **terrestrial planets**. Often, the Moon is also discussed as a part of this group, bringing the total of terrestrial objects to five. (We generally call Earth's satellite "the Moon," with a capital M, and the other satellites "moons," with lowercase m's.) The terrestrial planets are relatively small worlds, composed primarily of rock and metal. All of them have solid surfaces that bear the records of their geological history in the forms of craters, mountains, and volcanoes (Figure 7.4).

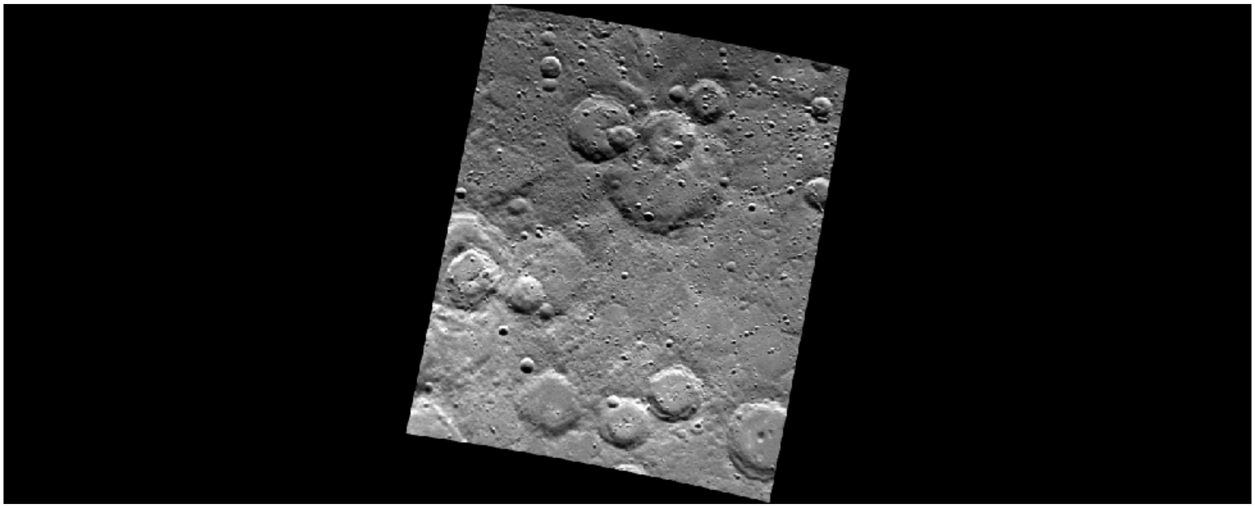

Figure 7.4 Surface of Mercury. The pockmarked face of the terrestrial world of Mercury is more typical of the inner planets than the watery surface of Earth. This black-and-white image, taken with the Mariner 10 spacecraft, shows a region more than 400 kilometers wide. (credit: modification of work by NASA/John Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington)

The next four planets (Jupiter through Neptune) are much larger and are composed primarily of lighter ices, liquids, and gases. We call these four the jovian planets (after "Jove," another name for Jupiter in mythology) or **giant planets**—a name they richly deserve (**Figure 7.5**). More than 1400 Earths could fit inside Jupiter, for example. These planets do not have solid surfaces on which future explorers might land. They are more like vast, spherical oceans with much smaller, dense cores.

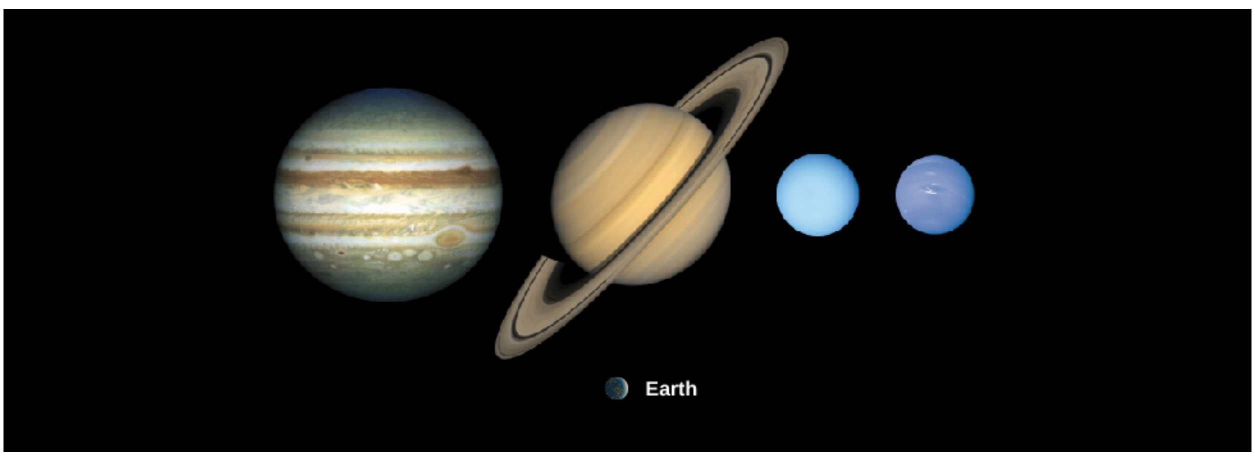

Figure 7.5 The Four Giant Planets. This montage shows the four giant planets: Jupiter, Saturn, Uranus, and Neptune. Below them, Earth is shown to scale. (credit: modification of work by NASA, Solar System Exploration)

Near the outer edge of the system lies Pluto, which was the first of the distant icy worlds to be discovered beyond Neptune (Pluto was visited by a spacecraft, the NASA New Horizons mission, in 2015 [see **Figure 7.6**]). **Table 7.2** summarizes some of the main facts about the planets.

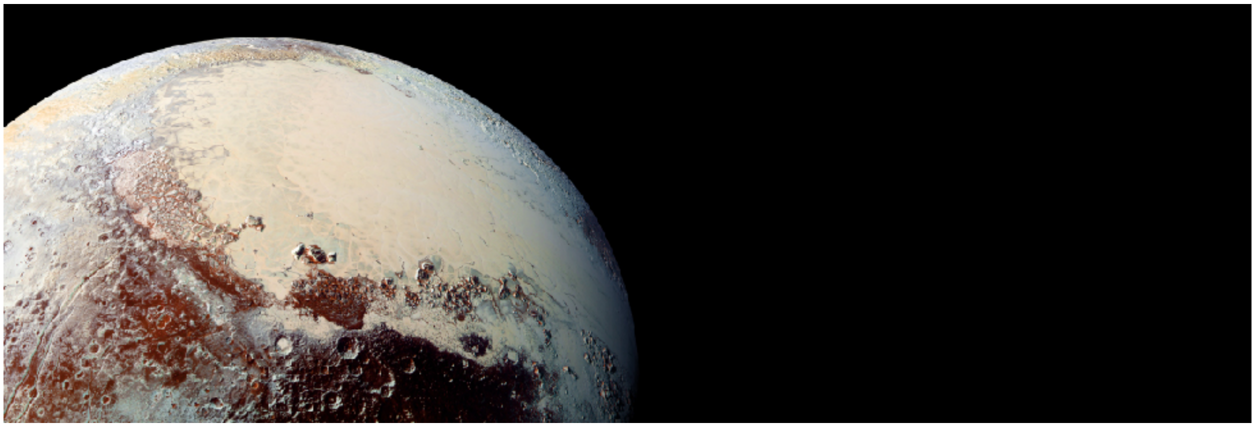

Figure 7.6 Pluto Close-up. This intriguing image from the New Horizons spacecraft, taken when it flew by the dwarf planet in July 2015, shows some of its complex surface features. The rounded white area is temporarily being called the Sputnik Plain, after humanity's first spacecraft. (credit: modification of work by NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute)

The Planets

Name	Distance from Sun (AU)[2]	Revolution Period (y)	Diameter (km)	Mass (10^{23} kg)	Density (g/cm^3)[3]
Mercury	0.39	0.24	4,878	3.3	5.4
Venus	0.72	0.62	12,120	48.7	5.2
Earth	1.00	1.00	12,756	59.8	5.5
Mars	1.52	1.88	6,787	6.4	3.9
Jupiter	5.20	11.86	142,984	18,991	1.3
Saturn	9.54	29.46	120,536	5686	0.7
Uranus	19.18	84.07	51,118	866	1.3
Neptune	30.06	164.82	49,660	1030	1.6

Table 7.2

EXAMPLE 7.1

Comparing Densities

Let's compare the densities of several members of the solar system. The density of an object equals its mass divided by its volume. The volume (*V*) of a sphere (like a planet) is calculated using the equation

2 An AU (or astronomical unit) is the distance from Earth to the Sun.
3 We give densities in units where the density of water is 1 g/cm^3. To get densities in units of kg/m^3, multiply the given value by 1000.

$$V = \frac{4}{3}\pi R^3$$

where π (the Greek letter pi) has a value of approximately 3.14. Although planets are not perfect spheres, this equation works well enough. The masses and diameters of the planets are given in **Table 7.2**. For data on selected moons, see **Appendix G**. Let's use Saturn's moon Mimas as our example, with a mass of 4×10^{19} kg and a diameter of approximately 400 km (radius, 200 km = 2×10^5 m).

Solution

The volume of Mimas is

$$\frac{4}{3} \times 3.14 \times \left(2 \times 10^5 \text{ m}\right)^3 = 3.3 \times 10^{16} \text{ m}^3.$$

Density is mass divided by volume:

$$\frac{4 \times 10^{19} \text{ kg}}{3.3 \times 10^{16} \text{ m}^3} = 1.2 \times 10^3 \text{ kg/m}^3.$$

Note that the density of water in these units is 1000 kg/m^3, so Mimas must be made mainly of ice, not rock. (Note that the density of Mimas given in **Appendix G** is 1.2, but the units used there are different. In that table, we give density in units of
g/cm^3, for which the density of water equals 1. Can you show, by converting units, that 1 g/cm^3 is the same as 1000 kg/m^3?)

Check Your Learning

Calculate the average density of our own planet, Earth. Show your work. How does it compare to the density of an ice moon like Mimas? See **Table 7.2** for data.

Answer:

For a sphere,

$$\text{density} = \frac{\text{mass}}{\left(\frac{4}{3}\pi R^3\right)} \text{ kg/m}^3.$$

For Earth, then,

$$\text{density} = \frac{6 \times 10^{24} \text{ kg}}{4.2 \times 2.6 \times 10^{20} \text{ m}^3} = 5.5 \times 10^3 \text{ kg/m}^3.$$

This density is four to five times greater than Mimas'. In fact, Earth is the densest of the planets.

LINK TO LEARNING

Learn more about NASA's **mission to Pluto (https://openstaxcollege.org/l/30NASAmisspluto)** and see high-resolution images of Pluto's moon Charon.

Smaller Members of the Solar System

Most of the planets are accompanied by one or more moons; only Mercury and Venus move through space alone. There are more than 180 known moons orbiting planets and dwarf planets (see **Appendix G** for a listing