The night sky seen from Mauna Kea in Hawaii. The feature extending across the sky is the Milky Way, consisting of hundreds of billions of stars. The Milky Way is the galaxy in which we reside. (John Hook/Flickr/Getty Images) R I V U X G

CHAPTER 1

Astronomy and the Universe

LEARNING GOALS

By reading the sections of this chapter, you will learn

1-1 What distinguishes the methods of science from other human activities

1-2 How exploring other planets provides insight into the origins of the solar system and the nature of our Earth

1-3 Stars have a life cycle—they form, evolve over millions or billions of years, and die

1-4 Stars are grouped into galaxies, which are found throughout the universe

1-5 How astronomers measure position and size of a celestial object

1-6 How to express very large or very small numbers in convenient notation

1-7 Why astronomers use different units to measure distances in space

1-8 What astronomy can tell us about our place in the universe

Imagine yourself looking skyward on a clear, dark, moonless night, far from the glare of city lights. As you gaze upward, you see a panorama that no poet's words can truly describe and that no artist's brush could truly capture. Literally thousands of stars are scattered from horizon to horizon, many of them grouped into a luminous band called the Milky Way (which extends up and down across the middle of this photograph). As you watch, the entire spectacle swings slowly overhead from east to west as the night progresses.

For thousands of years people have looked up at the heavens and contemplated the universe. Like our ancestors, we find our thoughts turning to profound questions as we gaze at the stars. How was the universe created? Where did Earth, the Moon, and the Sun come from? What are the planets and stars made of? And how do we fit in? What is our place in the cosmic scope of space and time?

Wondering about the universe is a key part of what makes us human. Our curiosity, our desire to explore and discover, and, most important, our ability to reason about what we have discovered are qualities that distinguish us from other animals. The study of the stars transcends all boundaries of culture, geography, and politics. In a literal sense, astronomy is a universal subject—its subject is the entire universe.

1-1 To understand the universe, astronomers use the laws of physics to construct testable theories and models

Astronomy has a rich heritage that dates back to the myths and legends of antiquity. Centuries ago, the heavens were thought to be populated with demons and heroes, gods and goddesses. Astronomical phenomena were explained as the result of supernatural forces and divine intervention.

The course of civilization was greatly affected by a profound realization: *The universe is comprehensible*. For example, ancient Greek astronomers discovered that by observing the heavens and carefully reasoning about what they saw, they could learn something about how the universe operates. As we shall see in Chapter 3, ancient Greek astronomers measured the size of Earth and were able to understand and predict eclipses without appealing to supernatural forces. Modern science is a direct descendant of astronomy, which had many contributors from the Middle East, Africa, Asia, Central America, and, eventually, Greece.

The Scientific Method

TUTORIAL 1.1 Like art, music, or any other human creative activity, science makes use of intuition and experience. But the approach used by scientists to explore physical reality differs from other forms of intellectual endeavor in that it is based fundamentally on *observation, logic,* and *skepticism*. This approach, called the **scientific method,** requires that our ideas about the world around us be consistent with what we actually observe.

The scientific method goes something like this: A scientist trying to understand some observed phenomenon proposes a **hypothesis,** which is a collection of ideas that seems to explain what is observed. It is in developing hypotheses that scientists are at their most creative, imaginative, and intuitive. But their hypotheses must always agree with existing observations and experiments, because a discrepancy with what is observed implies that the hypothesis is wrong. (The exception is if the scientist thinks that the existing results are wrong and can give compelling evidence to show that they are wrong.) The scientist then uses logic to work out the implications of the hypothesis and to make predictions that can be tested. A hypothesis is on firm ground only after it has accurately forecast the results of new experiments or observations. (In practice, scientists typically go through these steps in a less linear fashion than we have described.)

> Hypotheses, models, theories, and laws are essential parts of the scientific way of knowing

Scientists describe reality in terms of **models,** which are hypotheses that have withstood observational or experimental tests. A model tells us about the properties and behavior of some object or phenomenon. A familiar example is a model of the atom, which scientists picture as electrons orbiting a central nucleus. Another example, which we will encounter in Chapter 18, is a model that tells us about physical conditions (for example, temperature, pressure, and density) in the interior of the Sun (Figure 1-1). A well-developed model uses mathematics—one of the most powerful tools for logical thinking—to make detailed predictions. For example, a successful model of the Sun's interior should describe what the values of temperature, pressure, and density are at each

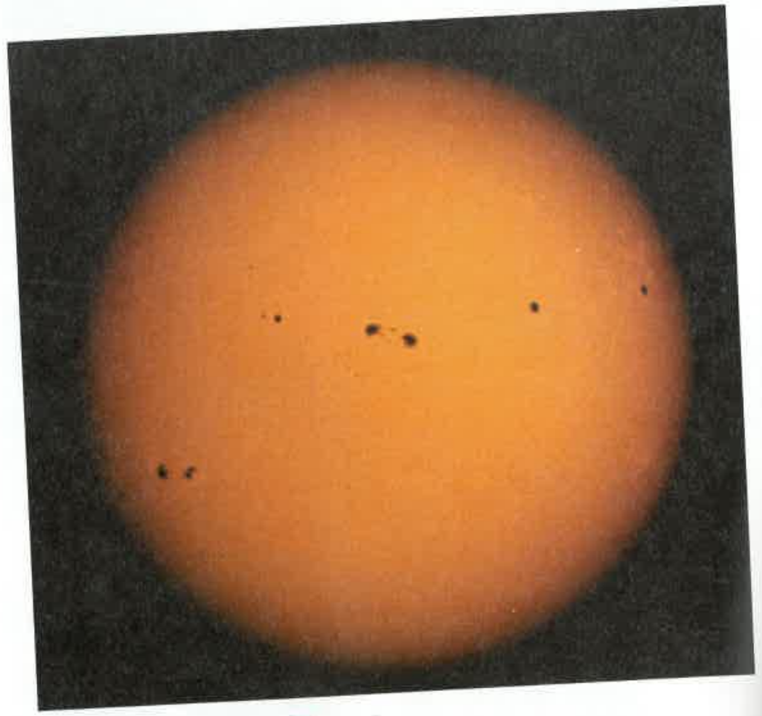


FIGURE 1-1 R I V U X G
Our Star, the Sun The Sun is a typical star. Its diameter is about 1.39 million kilometers (roughly a million miles), and its surface temperature is about 5500°C (10,000°F). A detailed scientific model of the Sun tells us that it draws its energy from nuclear reactions occurring at its center, where the temperature is about 15 million degrees Celsius. (NSO/AURA/NSF)

depth within the Sun, as well as the relations between these quantities. For this reason, mathematics is one of the most important tools used by scientists.

A body of related hypotheses can be pieced together into a self-consistent description of nature called a **theory.** An example from Chapter 4 is the theory that the planets are held in their orbits around the Sun by the Sun's gravitational force (Figure 1-2). Without models and theories there is no understanding and no science, only collections of facts.

> **CAUTION!** In everyday language the word "theory" is often used to mean an idea that looks good on paper, but has little to do with reality. In science, however, a good theory is one that explains reality very well and that can be applied to explain new observations. An excellent example is the theory of gravitation (Chapter 4), which was devised by the English scientist Isaac Newton in the late 1600s to explain the orbits of the six planets known at that time. When astronomers of later centuries discovered the planets Uranus and Neptune and the dwarf planet Pluto, they found that these planets also moved in accordance with Newton's theory. The same theory describes the motions of satellites around Earth as well as the orbits of planets around other stars.

An important part of a scientific theory is its ability to make predictions that can be tested by other scientists. If the predictions are verified by observation that lends support to the theory and

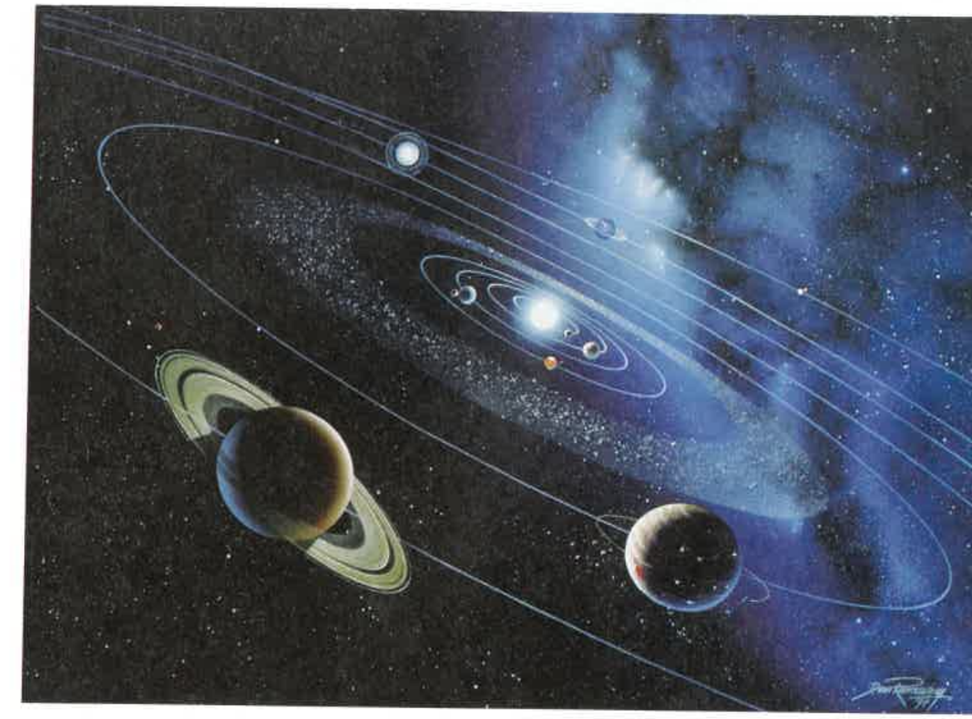


FIGURE 1-2
Planets Orbiting the Sun An example of a scientific theory is the idea that Earth and planets orbit the Sun due to the Sun's gravitational attraction. This theory is universally accepted because it makes predictions that have been tested and confirmed by observation. (The Sun and planets are actually much smaller than this illustration would suggest.) (Detlev Van Ravenswaay/Science Photo Library)

suggests that it might be correct. If the predictions are *not* verified, the theory needs to be modified or completely replaced. For example, an old theory held that the Sun and planets orbit around a stationary Earth. This theory led to certain predictions that could be checked by observation, as we will see in Chapter 4. In the early 1600s the Italian scientist Galileo Galilei used one of the first telescopes to show that these predictions were incorrect. As a result, the theory of a stationary Earth was rejected, eventually to be replaced by the modern model shown in Figure 1-2 in which Earth and other planets orbit the Sun.

An idea that *cannot* be tested by observation or experiment does not qualify as a scientific theory. An example is the idea that there is a little man living in your refrigerator who turns the inside light on or off when you open and close the door. The little man is invisible, weightless, and makes no sound, so you cannot detect his presence. While this is an amusing idea, it cannot be tested and so cannot be considered science.

Skepticism is an essential part of the scientific method. New hypotheses must be able to withstand the close scrutiny of other scientists. The more radical the hypothesis, the more skepticism and critical evaluation it will receive from the scientific community, because the general rule in science is that **extraordinary claims require extraordinary evidence.** That is why scientists as a rule do not accept claims that people have been abducted by aliens and taken aboard UFOs. The evidence presented for these claims is flimsy, secondhand, and unverifiable.

At the same time, scientists must be open-minded. They must be willing to discard long-held ideas if these ideas fail to agree with new observations and experiments, provided the new data have survived critical review. (If an alien spacecraft really did land on Earth, scientists would be the first to accept that aliens existed—provided they could take a careful look at the spacecraft and its occupants.) That is why the validity of scientific knowledge can be temporary. With new evidence, some ideas only need modification, while occasionally, some ideas may need to be entirely replaced. As you go through this book, you will encounter many instances where new observations have transformed our understanding of Earth, the planets, the Sun and stars, and indeed the very structure of the universe.

Theories that accurately describe the workings of physical reality have a significant effect on civilization. For example, basing his conclusions in part on observations of how the planets orbit the Sun, Isaac Newton deduced a set of fundamental principles that describe how *all* objects move. These theoretical principles, which we will encounter in Chapter 4, work equally well on Earth as they do in the most distant corner of the universe. They represent our first complete, coherent description of how objects move in the physical universe. **Newtonian mechanics** had an immediate practical application in the construction of machines, buildings, and bridges. It is no coincidence that the Industrial Revolution followed hard on the heels of these theoretical and mathematical advances inspired by astronomy.

Newtonian mechanics and other physical theories have stood the test of time and been shown to have great and general validity. Proven theories of this kind are collectively referred to as the **laws of physics.** Thus, the most reliable theories with the

lest applicability can eventually be considered laws of phys-
astronomers use these laws to interpret and understand their
rvations of the universe. The laws governing light and its
ionship to matter are of particular importance, because the
information we can gather about distant stars and galaxies
the light that we receive from them. Using the physical laws
describe how objects absorb and emit light, astronomers have
asured the temperature of the Sun and even learned what the
is made of. By analyzing starlight in the same way, they have
covered that our own Sun is a rather ordinary star and that the
servable universe may contain 10 billion trillion stars just like
e Sun.

echnology in Science

n important part of science is the development of new tools for
esearch and new techniques of observation. As an example, until
airly recently everything we knew about the distant universe was
based on visible light. Astronomers would peer through telescopes
to observe and analyze visible starlight. By the end of the nine-
teenth century, however, scientists had begun to discover forms of
light invisible to the human eye: X-rays, gamma rays, radio waves,
microwaves, and ultraviolet and infrared radiation.

As we will see in Chapter 6, in recent years astronomers have constructed telescopes that can detect such nonvisible forms of light (Figure 1-3). These instruments give us views of the universe vastly different from anything our eyes can see. These new views have allowed us to see through the atmospheres of distant planets, to study the thin but incredibly violent gas that surrounds our Sun, and even to observe new solar systems being formed around distant stars. Aided by high-technology telescopes, today's astronomers carry on the program of careful observation and logical analysis begun thousands of years ago by their ancient Greek predecessors.

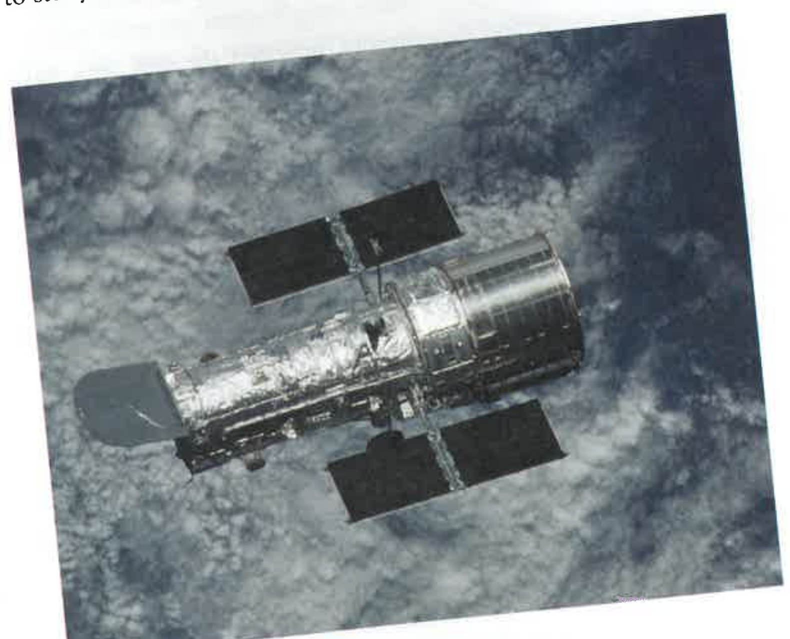


FIGURE 1-3 R I V U X G
A Telescope in Space Because it orbits outside Earth's atmosphere in the near-vacuum of space, the Hubble Space Telescope (HST) can detect not only visible light but also ultraviolet and near-infrared light coming from distant stars and galaxies. These forms of nonvisible light are absorbed by our atmosphere and hence are difficult or impossible to detect with a telescope on Earth's surface. This photo of HST was taken by the crew of the space shuttle *Columbia* ...ing mission in 2002. (Courtesy of Scientific American/NASA/AAT)

CONCEPTCHECK 1-1
Which is held in higher regard by professional astronomers: a hypothesis or a theory? Explain your answer.
Answer appears at the end of the chapter.

1-2 By exploring the planets, astronomers uncover clues about the formation of the solar system

> Studying planetary science gives us a better perspective on our own unique Earth

The science of astronomy allows our intellects to voyage across the cosmos. We can think of three stages in this voyage: from Earth to other parts of the solar system, from the solar system to the stars, and from stars to galaxies and the grand scheme of the universe.

The star we call the Sun and all the celestial bodies that orbit the Sun—including Earth, the other planets, all their various moons, and smaller bodies such as asteroids and comets—make up the **solar system.** Since the 1960s a series of unmanned spacecraft has been sent to explore each of the planets (Figure 1-4). Using the remote "eyes" of such spacecraft, we have flown over Mercury's cratered surface, peered beneath Venus's poisonous cloud cover, and discovered enormous canyons and extinct volcanoes on Mars. We have found active volcanoes on a moon of Jupiter, probed the atmosphere of Saturn's moon Titan, seen the rings of Uranus up close, and looked down on the active atmosphere of Neptune.

Along with rocks brought back by the *Apollo* astronauts from the Moon (the only world beyond Earth visited by humans), new information from spacecraft has revolutionized our understanding of the origin and evolution of the solar system. We have come to realize that many of the planets and their satellites were shaped by collisions with other objects. Craters on the Moon and on many other worlds are the relics of innumerable impacts by bits of interplanetary rock. The Moon may itself be the result of a catastrophic collision between Earth and a planet-sized object shortly after the solar system was formed. Such a collision could have torn sufficient material from the primordial Earth to create the Moon.

The oldest objects found on Earth are **meteorites,** chemically distinct bits of interplanetary debris that sometimes fall to our planet's surface. By using radioactive age-dating techniques, scientists have found that the oldest meteorites are 4.56 billion years old—older than any other rocks found on Earth or the Moon. The conclusion is that our entire solar system, including the Sun and planets, formed 4.56 billion years ago. The few thousand years of recorded human history is no more than the twinkling of an eye compared to the long history of our solar system.

The discoveries that we have made in our journeys across the solar system are directly relevant to the quality of human life on our own planet. Until recently, our understanding of geology, weather, and climate was based solely on data from Earth. Since the advent of space exploration, however, we have been able to compare and contrast other worlds with our own. This new knowledge gives us valuable insight into our origins, the nature of our planetary home, and the limits of our natural resources.

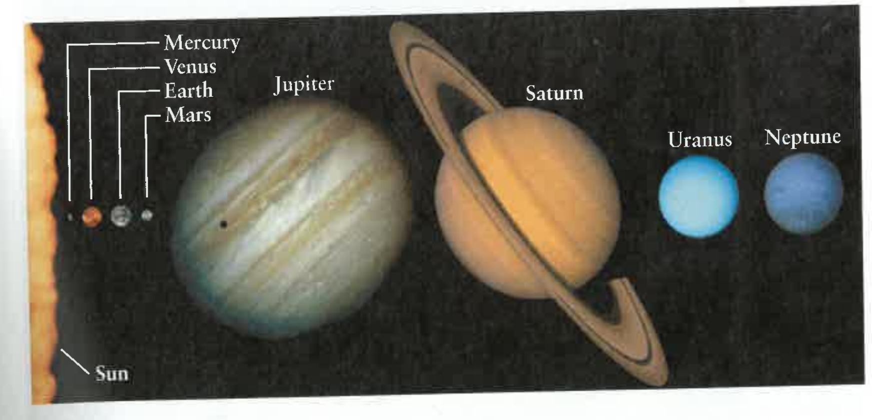


FIGURE 1-4
The Sun and Planets to Scale This montage of images from various spacecraft and ground-based telescopes shows the relative sizes of the planets and the Sun. The Sun is so large compared to the planets that only a portion of it fits into this illustration. The distances from the Sun to each planet are not shown to scale; the actual distance from the Sun to Earth, for instance, is 12,000 times greater than Earth's diameter. (Calvin J. Hamilton and NASA/JPL)

1-3 By studying stars and nebulae, astronomers discover how stars are born, grow old, and die

The nearest of all stars to Earth is the Sun. Although humans have used the Sun's warmth since the dawn of our species, it was only in the 1920s and 1930s that physicists figured out how the Sun shines. At the center of the Sun, thermonuclear reactions—so called because they require extremely high temperatures—convert hydrogen (the Sun's primary constituent) into helium. This violent process releases a vast amount of energy, which eventually makes its way to the Sun's surface and escapes as light (see Figure 1-1). Thus, through nuclear reactions, hydrogen acts as a "fuel" for stars. All the stars you can see in the nighttime sky also shine by nuclear reactions (Figure 1-5). By 1950 physicists could reproduce such nuclear reactions here on Earth in the form of a hydrogen bomb (Figure 1-6). In the future, converting hydrogen into helium might someday offer a cleaner method for the production of nuclear energy.

Because nuclear reactions consume the original material of which stars are made, the way an engine consumes its fuel, stars cannot last forever. Rather, they must form, evolve, and eventually die.

FIGURE 1-5 R I V U X G
Stars like Grains of Sand This Hubble Space Telescope image shows thousands of stars in the constellation Sagittarius. Each star shines because of thermonuclear reactions that release energy in its interior. Different colors indicate stars with different surface temperatures: stars with the hottest surfaces appear blue, while those with the coolest surfaces appear red. (The Hubble Heritage Team, AURA/STScI/NASA)

FIGURE 1-6 R I V U X G
A Thermonuclear Explosion A hydrogen bomb uses the same physical principle as the thermonuclear reactions at the Sun's center: the conversion of matter into energy by nuclear reactions. This thermonuclear detonation on October 31, 1952, had an energy output equivalent to 10.4 million tons of TNT (almost 1000 times greater than the nuclear bomb detonated over Hiroshima in World War II). This is a mere ten-billionth of the amount of energy released by the Sun in one second. (Defense Nuclear Agency)

CAUTION! Astronomers often use biological terms such as "birth" and "death" to describe stages in the evolution of inanimate objects like stars. Keep in mind that such terms are used only as *analogies*, which help us visualize these stages. They are not to be taken literally!

The Life Stories of Stars

The rate at which stars emit energy in the form of light tells us how rapidly they are consuming their nuclear "fuel" (hydrogen), and hence how long they can continue to shine before reaching the end of their life spans. More massive stars have more hydrogen, and thus, more nuclear "fuel," but consume it at such a prodigious rate that they live out their lives in just a few million years. Less massive stars have less material to consume, but their nuclear reactions proceed so slowly that their life spans are measured in billions of years. (Our own star, the Sun, is in early middle age: It is 4.56 billion years old, with a lifetime of 12.5 billion years.)

While no astronomer can watch a single star go through all of its life stages, we have been able to piece together the life stories of stars by observing many different stars at different points in their life cycles. Important pieces of the puzzle have been discovered by studying huge clouds of interstellar gas, called **nebulae** (singular **nebula**), which are found scattered across the sky. Within some nebulae, such as the Orion Nebula shown in Figure 1-7, stars are born from the material of the nebula itself. Other nebulae reveal what happens when nuclear reactions stop and a star dies. Some stars that are far more massive than the Sun end their lives with a spectacular detonation called a **supernova** (plural **supernovae**) that blows the star apart. The Crab Nebula (Figure 1-8) is a striking example of a remnant left behind by a supernova.

Studying the life cycles of stars is crucial for understanding our own origins

Dying stars can produce some of the strangest objects in the sky. Some dead stars become **pulsars**, which spin rapidly at rates of tens or hundreds of rotations per second. And some stars end their lives as almost inconceivably dense objects called **black holes**, whose gravity is so powerful that nothing—not even light—can escape. Even though a black hole itself emits essentially no radiation, a number of black holes have been discovered beyond our solar system by Earth-orbiting telescopes. This is done by detecting the X-rays emitted by gas falling toward a black hole.

During their death throes, stars return the gas of which they are made to interstellar space. (Figure 1-8 shows these expelled gases expanding away from the site of a supernova explosion.) This gas contains heavy elements—that is, elements heavier than hydrogen and helium—that were created during the star's lifetime by nuclear reactions in its interior. Interstellar space thus becomes enriched with newly manufactured atoms and molecules. The Sun and its planets were formed from interstellar material that was enriched in this way. This means that the atoms of iron and nickel that make up Earth, as well as the carbon in our bodies and the oxygen we breathe, were created deep inside ancient stars. By studying stars and their evolution, we are really studying our own origins.

FIGURE 1-7 R I V U X G
The Orion Nebula—Birthplace of Stars This beautiful nebula is a stellar "nursery" where stars are formed out of the nebula's gas. Intense ultraviolet light from newborn stars excites the surrounding gas and causes it to glow. Many of the stars embedded in this nebula are less than a million years old, a brief interval in the lifetime of a typical star. The Orion Nebula is some 1500 light-years from Earth and is about 30 light-years across. (NASA, ESA, M. Robberto/STScI/ESA, and the Hubble Space Telescope Orion Treasury Project Team)

FIGURE 1-8 R I V U X G
The Crab Nebula—Wreckage of an Exploded Star When a dying star exploded in a supernova, it left behind this elegant funeral shroud of glowing gases blasted violently into space. A thousand years after the explosion these gases are still moving outward at about 1800 kilometers per second (roughly 4 million miles per hour). The Crab Nebula is 6500 light-years from Earth and about 13 light-years across. (NASA, ESA, J. Hester and A. Loll/Arizona State University)

FIGURE 1-9 R I V U X G
A Galaxy This spectacular galaxy, called M63, contains about a hundred billion stars. M63 has a diameter of about 60,000 light-years and is located about 35 million light-years from Earth. Along this galaxy's spiral arms you can see a number of glowing clumps. Like the Orion Nebula in our own Milky Way Galaxy (see Figure 1-7), these are sites of active star formation. (2004–2013 R. Jay GaBany, Cosmotography.com)

CONCEPTCHECK 1-2

If a star were twice as massive as our Sun, would it shine for a longer or shorter span of time? Why?

Answer appears at the end of the chapter.

1-4 By observing galaxies, astronomers learn about the origin and fate of the universe

Stars are not spread uniformly across the universe but are grouped together in huge assemblages called **galaxies**. Galaxies come in a wide range of shapes and sizes. Our Sun is just one star in a galaxy we call the Milky Way (see the figure that opens this chapter). A typical galaxy, like our Milky Way, contains several hundred billion stars. Some galaxies are much smaller, containing only a few million stars. Others are monstrosities that devour neighboring galaxies in a process called "galactic cannibalism."

Our Milky Way Galaxy has arching spiral arms like those of the galaxy shown in Figure 1-9. These arms are particularly active sites of star formation. In recent years, astronomers have discovered a mysterious object at the center of the Milky Way with a mass millions of times greater than that of our Sun. It now seems certain that this curious object is an enormous black hole.

Some of the most intriguing galaxies appear to be in the throes of violent convulsions and are rapidly expelling matter. The centers of these strange galaxies, which may harbor even more massive black holes, are often powerful sources of X-rays and radio waves.

Even more awesome sources of energy are found still deeper in space. Often located at distances so great that their light takes billions of years to reach Earth, we find the mysterious **quasars**. Although in some ways quasars look like nearby stars (Figure 1-10), they are among the most distant and most luminous objects in the sky. A typical quasar shines with the brilliance of a hundred galaxies. Detailed observations of quasars imply that they draw their energy from material falling into enormous black holes.

Galaxies and the Expanding Universe

The motions of distant galaxies reveal that they are moving away from us and from each other. In other words, the universe is *expanding*. Extrapolating into the past, we learn that the universe must have been born from an incredibly dense state some 13.7 billion years ago. A variety of evidence indicates that at that moment—the beginning of time—the universe began with a cosmic explosion, known as the **Big Bang**, which occurred throughout all space.

The motions of distant galaxies motivate the ideas of the expanding universe and the Big Bang

Thanks to the combined efforts of astronomers and physicists, we are making steady advances in understanding the nature and history of the universe. This understanding may reveal the origin of some of the most basic properties of physical reality. Studying the most remote galaxies is also helping to answer questions about the

FIGURE 1-10 R I V U X G
A Quasar The two bright starlike objects in this image look almost identical, but they are dramatically different. The object on the left is indeed a star that lies a few hundred light-years from Earth. But the "star" on the right is actually a quasar about 9 billion light-years away. To appear so bright even though they are so distant, quasars like this one must be some of the most luminous objects in the universe. The other objects in this image are galaxies like that in Figure 1-9. (Charles Steidel, California Institute of Technology; and NASA)

ultimate fate of the universe. Such studies suggest that the expansion of the universe will continue forever, and it is actually gaining speed.

LOOKING DEEPER 1.1 The work of unraveling the deepest mysteries of the universe requires specialized tools, including telescopes, spacecraft, and computers. But for many purposes, the most useful device for studying the universe is the human brain itself. Our goal in this book is to help you use *your* brain to share in the excitement of scientific discovery.

In the remainder of this chapter we introduce some of the key concepts and mathematics that we will use in subsequent chapters. Study these carefully, for you will use them over and over again throughout your own study of astronomy.

1-5 Astronomers use angles to denote the positions and apparent sizes of objects in the sky

Whether they study planets, stars, galaxies, or the very origins of the universe, astronomers must know where to point their telescopes. For this reason, an important part of astronomy is keeping track of the positions of objects in the sky. A system for measuring angles is an essential part of this aspect of astronomy (Figure 1-11).

An **angle** measures the opening between two lines that meet at a point. A basic unit to express angles is the **degree,** designated by the symbol °. A full circle is divided into 360°, and a right angle measures 90° (Figure 1-11a). As Figure 1-11b shows, if you draw lines from your eye to each of the two "pointer stars" in the Big Dipper, the angle between these lines—that is, the **angular distance** between these two stars—is about 5°. (In Chapter 2 we will see that these two stars "point" to Polaris, the North Star.) The angular distance between the stars that make up the top and bottom of the Southern Cross, which is visible from south of the equator, is about 6° (Figure 1-11c).

Angles are a tool that we will use throughout our study of astronomy

Astronomers also use angles to describe the apparent size of a celestial object—that is, how wide the object appears in the sky. For example, the angle covered by the diameter of the full moon is about ½° (Figure 1-11a). We therefore say that the **angular diameter** (or **angular size**) of the Moon is ½°. Alternatively, astronomers say that the Moon **subtends,** or extends over, an angle of ½°. Ten full moons could fit side by side between the two pointer stars in the Big Dipper.

The average adult human hand held at arm's length provides a means of estimating angles, as Figure 1-12 shows. For example, a fist covers an angle of about 10°, whereas a fingertip is about 1° wide. You can use various segments of your index finger extended to arm's length to estimate angles a few degrees across.

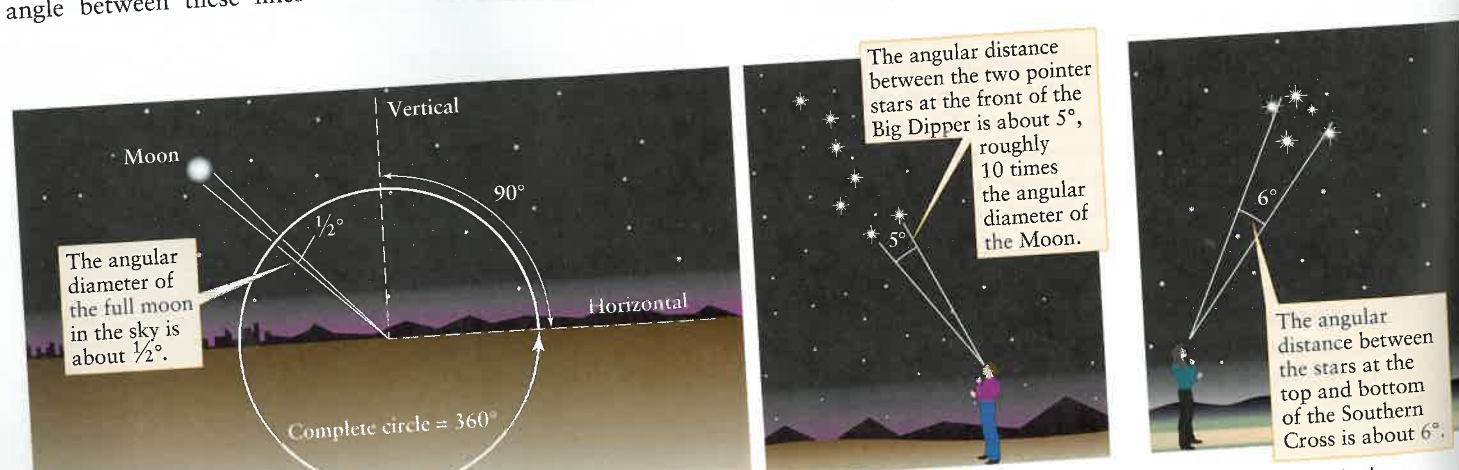
To talk about smaller angles, we subdivide the degree into 60 **arcminutes** (also called minutes of arc), which is commonly abbreviated as 60 arcmin or 60′. An arcminute is further subdivided into 60 **arcseconds** (or seconds of arc), usually written as 60 arcsec or 60″. Thus,

$$1° = 60 \text{ arcmin} = 60'$$

$$1' = 60 \text{ arcsec} = 60''$$

For example, on January 1, 2007, the planet Saturn had an angular diameter of 19.6 arcsec as viewed from Earth. That is a convenient, precise statement of how big the planet appeared in Earth's sky on that date. (Because this angular diameter is so small, to the naked eye Saturn appears simply as a point of light. To see any detail on Saturn, such as the planet's rings, requires a telescope.)

If we know the angular size of an object as well as the distance to that object, we can determine the actual linear size of the object (measured in kilometers or miles, for example). Box 1-1 describes how this is done.



(a) Measuring angles in the sky

(b) Angular distances in the northern hemisphere

(c) Angular distances in the southern hemisphere

FIGURE 1-11

Measuring Angles **(a)** Angles are measured in degrees (°). There are 360° in a complete circle and 90° in a right angle. For example, the angle between the vertical direction (directly above you) and the horizontal direction (toward the horizon) is 90°. The angular diameter of the full moon in the sky is about ½°. **(b)** The seven bright stars that make up the Big Dipper can be seen from anywhere in the northern hemisphere. The angular distance between the two "pointer stars" at the front of the Big Dipper is about 5°. **(c)** The four bright stars that make up the Southern Cross can be seen from anywhere in the southern hemisphere. The angular distance between the stars at the top and bottom of the cross is about 6°.

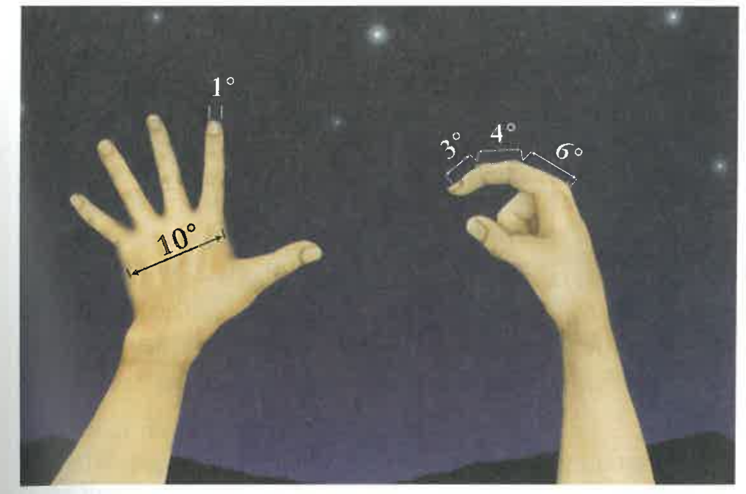


FIGURE 1-12

Estimating Angles with Your Hand The adult human hand extended to arm's length can be used to estimate angular distances and angular sizes in the sky.

CONCEPTCHECK 1-3

Is it possible for a basketball to look bigger than the Moon? Smaller?

Answer appears at the end of the chapter.

1-6 Powers-of-ten notation is a useful shorthand system for writing numbers

Learning powers-of-ten notation will help you deal with very large and very small numbers

Astronomy is a subject of extremes. Astronomers investigate the largest structures in the universe, including galaxies and clusters of galaxies. But they must also study atoms and atomic nuclei, among the smallest objects in the universe, in order to explain how and why stars shine. They also study conditions

BOX 1-1 TOOLS OF THE ASTRONOMER'S TRADE

The Small-Angle Formula

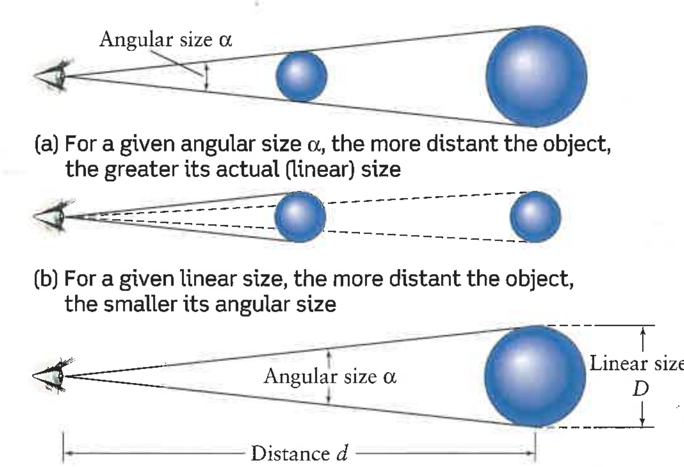
You can estimate the angular sizes of objects in the sky with your hand and fingers (see Figure 1-12). Using rather more sophisticated equipment, astronomers can measure angular sizes to a fraction of an arcsecond. Keep in mind, however, that *angular* size is not the same as *actual* size. As an example, if you extend your arm while looking at a full moon, you can completely cover the Moon with your thumb. That's because from your perspective, your thumb has a larger angular size (that is, it subtends a larger angle) than the Moon. But the actual size of your thumb (about 2 centimeters) is much less than the actual diameter of the Moon (more than 3000 kilometers).

The accompanying figure shows how the angular size of an object is related to its linear size. Part **(a)** of the figure shows that for a given angular size, the more distant the object, the larger its actual size. For example, your fingertip held at arm's length covers the full moon, but the Moon is much farther away and is far larger in linear size. Part **(b)** shows that for a given linear size, the angular size decreases the farther away the object. This is why a car looks smaller and smaller as it drives away from you.

We can put these relationships together into a single mathematical expression called the **small-angle formula.** Suppose that an object subtends an angle α (the Greek letter alpha) and is at a distance *d* from the observer, as in part (c) of the figure. If the angle α is small, as is almost always the case for objects in the sky, the width or linear size (*D*) of the object is given by the following expression:

The small-angle formula

$$D = \frac{\alpha d}{206{,}265}$$



(a) Two objects that have the same angular size may have different linear sizes if they are at different distances from the observer. **(b)** For an object of a given linear size, the angular size is smaller the farther the object is from the observer. **(c)** The small-angle formula relates the linear size *D* of an object to its angular size α and its distance *d* from the observer.

D = width or linear size of an object

α = angular size of the object, in arcsec

d = distance to the object

The number 206,265 is required in the formula so that the units of α are in arcseconds. (206,265 is the number of

(continued on the next page)

BOX 1-1 *(continued)*

arcseconds in a complete 360° circle divided by the number 2π.) As long as the same units are used for D and d, any units for linear distance can be used (km, light-years, etc.).

The following examples show two different ways to use the small-angle formula. In both examples we follow a four-step process: Evaluate the *situation* given in the example, decide which *tools* are needed to solve the problem, use those tools to find the *answer* to the problem, and *review* the result to see what it tells you. Throughout this book, we'll use these same four steps in *all* examples that require the use of formulas. We encourage you to follow this four-step process when solving problems for homework or exams. You can remember these steps by their acronym: *S.T.A.R.*

EXAMPLE: On December 11, 2006, Jupiter was 944 million kilometers from Earth and had an angular diameter of 31.2 arcsec. From this information, calculate the actual diameter of Jupiter in kilometers.

Situation: The astronomical object in this example is Jupiter, and we are given its distance d and its angular size π (the same as angular diameter). Our goal is to find Jupiter's diameter D.

Tools: The equation to use is the small-angle formula, which relates the quantities d, α, and D. Note that when using this formula, the angular size α must be expressed in arcseconds.

Answer: The small-angle formula as given is an equation for D. Plugging in the given values $\alpha = 31.2$ arcsec and $d = 944$ million kilometers,

$$D = \frac{31.2 \times 944{,}000{,}000 \text{ km}}{206{,}265} = 143{,}000 \text{ km}$$

Because the distance d to Jupiter is given in kilometers, the diameter D is also in kilometers.

Review: Does our answer make sense? From Appendix 2 at the back of this book, the equatorial diameter of Jupiter measured by spacecraft flybys is 142,984 kilometers, so our calculated answer is very close.

EXAMPLE: Under excellent conditions, a telescope on Earth can see details with an angular size as small as 1 arcsec. What is the greatest distance at which you could see details as small as 1.7 meters (the height of a typical person) under these conditions?

Situation: Now the object in question is a person, whose linear size D we are given. Our goal is to find the distance d at which the person has an angular size α equal to 1 arcsec.

Tools: Again we use the small-angle formula to relate d, α, and D.

Answer: We first rewrite the formula to solve for the distance d, then plug in the given values $D = 1.7$ m and $\alpha = 1$ arcsec:

$$d = \frac{206{,}265 D}{\alpha} = \frac{206{,}265 \times 1.7 \text{ m}}{1} = 350{,}000 \text{ m} = 350 \text{ km}$$

Review: This value is much less than the distance to the Moon, which is 384,000 kilometers. Thus, even the best telescope on Earth could not be used to see an astronaut walking on the surface of the Moon.

ranging from the incredibly hot and dense centers of stars to the frigid near-vacuum of interstellar space. To describe such a wide range of phenomena, we need an equally wide range of both large and small numbers.

Powers-of-Ten Notation: Large Numbers

Astronomers avoid such confusing terms as "a million billion billion" by using a standard shorthand system called **powers-of-ten notation.** All the cumbersome zeros that accompany a large number are consolidated into one term consisting of 10 followed by an **exponent,** which is written as a superscript. The exponent indicates how many zeros you would need to write out the long form of the number. Thus,

$10^0 = 1$ (one)

$10^1 = 10$ (ten)

$10^2 = 100$ (one hundred)

$10^3 = 1000$ (one thousand)

$10^4 = 10{,}000$ (ten thousand)

$10^6 = 1{,}000{,}000$ (one million)

$10^9 = 1{,}000{,}000{,}000$ (one billion)

$10^{12} = 1{,}000{,}000{,}000{,}000$ (one trillion)

and so forth. The exponent also tells you how many tens must be multiplied together to give the desired number, which is why the exponent is also called the **power of ten.** For example, ten thousand can be written as 10^4 ("ten to the fourth" or "ten to the fourth power") because $10^4 = 10 \times 10 \times 10 \times 10 = 10{,}000$.

In powers-of-ten notation, numbers are written as a figure between 1 and 10 multiplied by the appropriate power of ten. The approximate distance between Earth and the Sun, for example, can be written as 1.5×10^8 kilometers (or 1.5×10^8 km, for short). Once you get used to it, this is more convenient than writing "150,000,000 kilometers" or "one hundred and fifty million kilometers." (The same number could also be written as 15×10^7 or 0.15×10^9, but the preferred form is *always* to have the first figure be between 1 and 10.)

Calculators and Powers-of-Ten Notation

Most electronic calculators use a shorthand for powers-of-ten notation. To enter the number 1.5×10^8, you first enter 1.5, then

press a key labeled "EXP" or "EE," then enter the exponent 8. (The EXP or EE key takes care of the "× 10" part of the expression.) The number will then appear on your calculator's display as "1.5 E 8," "1.5 8," or some variation of this; typically the "× 10" is not displayed as such. There are some variations from one kind of calculator to another, so you should spend a few minutes reading over your calculator's instruction manual to make sure you know the correct procedure for working with numbers in powers-of-ten notation. You will be using this notation continually in your study of astronomy, so this is time well spent.

CAUTION! Confusion can result from the way that calculators display powers-of-ten notation. Since 1.5×10^8 is displayed as "1.5 8" or "1.5 E 8," it is not uncommon to think that 1.5×10^8 is the same as 1.5^8. That is not correct, however; 1.5^8 is equal to 1.5 multiplied by itself 8 times, or 25.63, which is not even close to $150{,}000{,}000 = 1.5 \times 10^8$. Another, not uncommon, mistake is to write 1.5×10^8 as 15^8. If you are inclined to do this, perhaps you are thinking that you can multiply 1.5 by 10, then tack on the exponent later. Another process that does not work: 15^8 is equal to 15 multiplied by itself 8 times, or 2,562,890,625, which again is nowhere near 1.5×10^8. Reading over the manual for your calculator will help you to avoid these common errors.

Powers-of-Ten Notation: Small Numbers

You can use powers-of-ten notation for numbers that are less than one by using a minus sign in front of the exponent. A negative exponent tells you to *divide* by the appropriate number of tens. For example, 10^{-2} ("ten to the minus two") means to divide by 10 twice, so $10^{-2} = 1/10 \times 1/10 = 1/100 = 0.01$. This same idea tells us how to interpret other negative powers of ten:

$10^0 = 1$ (one)

$10^{-1} = 1/10 = 0.1$ (one tenth)

$10^{-2} = 1/10 \times 1/10 = 1/10^2 = 0.01$ (one hundredth)

$10^{-3} = 1/10 \times 1/10 \times 1/10 = 1/10^3 = 0.001$ (one thousandth)

$10^{-4} = 1/10 \times 1/10 \times 1/10 \times 1/10 = 1/10^4 = 0.0001$ (one ten-thousandth)

$10^{-6} = 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 = 1/10^6 = 0.000001$ (one millionth)

$10^{-12} = 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 \times 1/10 = 1/10^{12} = 0.000000000001$ (one trillionth)

and so forth.

As these examples show, negative exponents tell you how many tenths must be multiplied together to give the desired number. For example, one ten-thousandth, or 0.0001, can be written as 10^{-4} ("ten to the minus four") because $10^{-4} = 1/10 \times 1/10 \times 1/10 \times 1/10 = 0.0001$.

A useful shortcut in converting a decimal to powers-of-ten notation is to notice where the decimal point is. For example, the decimal point in 0.0001 is four places to the left of the "1," so the exponent is −4, that is, $0.0001 = 10^{-4}$.

You can also use powers-of-ten notation to express a number like 0.00245, which is not a multiple of 1/10. For example, $0.00245 = 2.45 \times 0.001 = 2.45 \times 10^{-4}$. (Again, the standard for powers-of-ten notation is that the first figure is a number between 1 and 10.) This notation is particularly useful when dealing with very small numbers. A good example is the diameter of a hydrogen atom, which is much more convenient to state in powers-of-ten notation (1.1×10^{-10} meter, or 1.1×10^{-10} m) than as a decimal (0.00000000011 m) or a fraction (110 trillionths of a meter.)

Because it bypasses all the awkward zeros, powers-of-ten notation is ideal for describing the size of objects as small as atoms or as big as galaxies (Figure 1-13). Box 1-2 explains how powers-of-ten notation also makes it easy to multiply and divide numbers that are very large or very small.

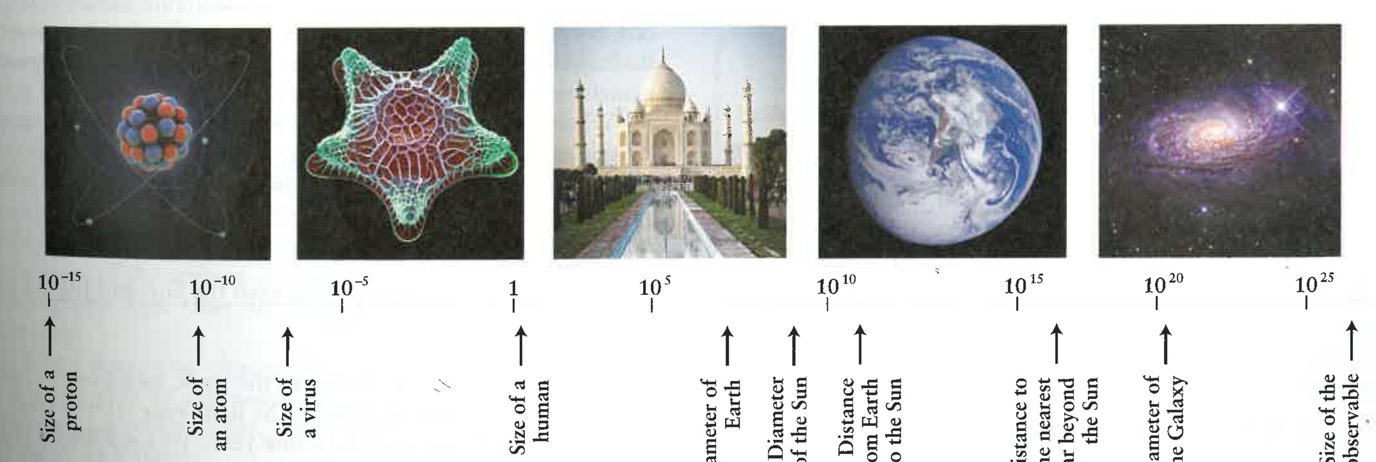


FIGURE 1-13 **Examples of Powers-of-Ten Notation** This scale gives the sizes of objects in meters, ranging from subatomic particles at the left to the entire observable universe at the right. The protons and neutrons in the illustration on the left form the nucleus of an atom; the electrons orbit around a hundred thousand times farther out. Second from left is the cell wall of a single-celled aquatic organism called a diatom, 10^{-4} meter (0.1 millimeter) in size. At the center is the Taj Mahal, about 60 meters tall and within reach of our unaided senses. On the right is the planet Earth, about 10^7 meters in diameter. At the far right is a galaxy, 10^{21} meters (100,000 light-years) in diameter. (Andrzej Wojcicki/Science Photo Library/Getty Images; Steve Gschmeissner/Science Photo Library/Getty; iStockphoto/Thinkstock; NASA/JPL; 2004–2013 R. Jay GaBany, Cosmotography.com)

BOX 1-2 TOOLS OF THE ASTRONOMER'S TRADE

Arithmetic with Powers-of-Ten Notation

Using powers-of-ten notation makes it easy to multiply numbers. For example, suppose you want to multiply 100 by 1000. If you use ordinary notation, you have to write a lot of zeros:

$$100 \times 1000 = 100{,}000 \text{ (one hundred thousand)}$$

By converting these numbers to powers-of-ten notation, we can write this same multiplication more compactly as

$$10^2 \times 10^3 = 10^5$$

Because $2 + 3 = 5$, we are led to the following general rule for *multiplying* numbers expressed in terms of powers of ten: Simply *add* the exponents.

EXAMPLE: $10^4 \times 10^3 = 10^{4+3} = 10^7$.

To *divide* numbers expressed in terms of powers of ten, remember that $10^{-1} = 1/10$, $10^{-2} = 1/100$, and so on. The general rule for any exponent n is

$$10^{-n} = \frac{1}{10^n}$$

In other words, dividing by 10^n is the same as multiplying by 10^{-n}. To carry out a division, you first transform it into multiplication by changing the sign of the exponent, and then carry out the multiplication by adding the exponents.

EXAMPLE: $\frac{10^4}{10^6} = 10^4 \times 10^{-6} = 10^{4+(-6)} = 10^{4-6} = 10^{-2}$

Usually a computation involves numbers like 3.0×10^{10}, that is, an ordinary number multiplied by a factor of 10 with an exponent. In such cases, to perform multiplication or division, you can treat the numbers separately from the factors of 10^n.

EXAMPLE: We can redo the first numerical example from Box 1-1 in a straightforward manner by using exponents:

$$D = \frac{31.2 \times 944{,}000{,}000 \text{ km}}{206{,}265}$$

$$= \frac{3.12 \times 10 \times 9.44 \times 10^8}{2.06265 \times 10^5} \text{ km}$$

$$= \frac{3.12 \times 9.44 \times 10^{1+8-5}}{2.06265} \text{ km} = 14.3 \times 10^4 \text{ km}$$

$$= 1.43 \times 10 \times 10^4 \text{ km} = 1.43 \times 10^5 \text{ km}$$

1-7 Astronomical distances are often measured in astronomical units, light-years, or parsecs

> Specialized units make it easier to comprehend immense cosmic distances

Astronomers use many of the same units of measurement as do other scientists. They often measure lengths in meters (abbreviated m), masses in kilograms (kg), and time in seconds (s). (You can read more about these units of measurement, as well as techniques for converting between different sets of units, in Box 1-3.)

Like other scientists, astronomers often find it useful to combine these units with powers of ten and create new units using prefixes. As an example, the number 1000 ($= 10^3$) is represented by the prefix "kilo," and so a distance of 1000 meters is the same as 1 kilometer (1 km). Here are some of the most common prefixes, with examples of how they are used:

one-billionth meter	$= 10^{-9}$ m	= 1 nanometer
one-millionth second	$= 10^{-6}$ s	= 1 microsecond
one-thousandth arcsecond	$= 10^{-3}$ arcsec	= 1 milliarcsecond
one-hundredth meter	$= 10^{-2}$ m	= 1 centimeter
one thousand meters	$= 10^3$ m	= 1 kilometer
one million tons	$= 10^6$ tons	= 1 megaton

In principle, we could express all sizes and distances in astronomy using units based on the meter. Indeed, we will use kilometers to give the diameters of Earth and the Moon, as well as the Earth-Moon distance. But, while a kilometer (roughly equal to three-fifths of a mile) is an easy distance for humans to visualize, a megameter (10^6 m) is not. For this reason, astronomers have devised units of measurement that are more appropriate for the tremendous distances between the planets and the far greater distances between the stars.

When discussing distances across the solar system, astronomers use a unit of length called the **astronomical unit** (abbreviated AU). This is the average distance between Earth and the Sun:

$$1 \text{ AU} = 1.496 \times 10^8 \text{ km} = 92.96 \text{ million miles}$$

Thus, the average distance between the Sun and Jupiter can be conveniently stated as 5.2 AU.

ANIMATION 1.4 To talk about distances to the stars, astronomers use two different units of length. The **light-year** (abbreviated ly) is the distance that light travels in one year. This is a useful concept because the speed of light in empty space always has the same value, 3.00×10^5 km/s (kilometers per second) or 1.86×10^5 mi/s (miles per second). In terms of kilometers or astronomical units, one light-year is given by

$$1 \text{ ly} = 9.46 \times 10^{12} \text{ km} = 63{,}240 \text{ AU}$$

This distance is roughly equal to 6 trillion miles.

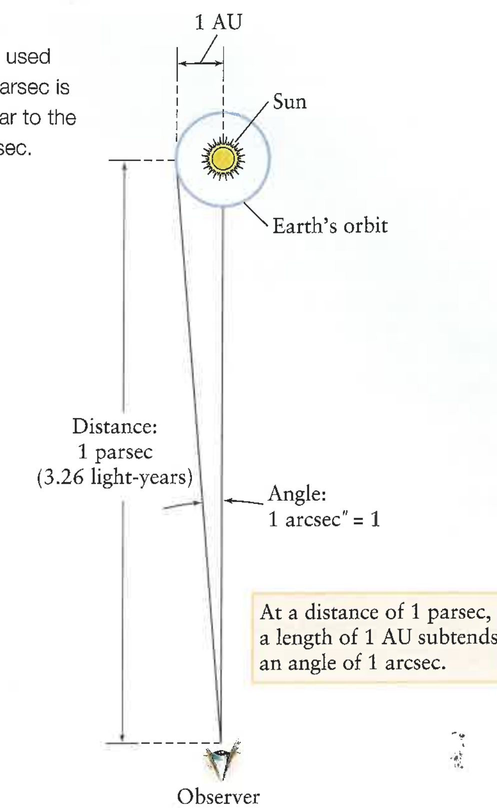


FIGURE 1-14
A Parsec The parsec, a unit of length commonly used by astronomers, is equal to 3.26 light-years. The parsec is defined as the distance at which 1 AU perpendicular to the observer's line of sight subtends an angle of 1 arcsec.

CAUTION! Keep in mind that despite its name, the light-year is a unit of distance and *not* a unit of time. As an example, Proxima Centauri, the nearest star other than the Sun, is a distance of 4.2 light-years from Earth. This means that light takes 4.2 years to travel to us from Proxima Centauri.

Physicists often measure interstellar distances in light-years because the speed of light is one of nature's most important numbers. But many astronomers prefer to use another unit of length, the *parsec,* because its definition is closely related to a method of measuring distances to the stars.

Imagine taking a journey far into space, beyond the orbits of the outer planets. As you look back toward the Sun, Earth's orbit subtends, or extends over, a smaller angle in the sky the farther you are from the Sun. As Figure 1-14 shows, the distance at which 1 AU subtends an angle of 1 arcsec is defined as 1 **parsec** (abbreviated **pc**):

$$1 \text{ pc} = 3.09 \times 10^{13} \text{ km} = 3.26 \text{ ly}$$

BOX 1-3 TOOLS OF THE ASTRONOMER'S TRADE

Units of Length, Time, and Mass

To understand and appreciate the universe, we need to describe phenomena not only on the large scales of galaxies but also on the submicroscopic scale of the atom. Astronomers generally use units that are best suited to the topic at hand. For example, interstellar distances are conveniently expressed in either light-years or parsecs, whereas the diameters of the planets are more comfortably presented in kilometers.

Most scientists prefer to use a version of the metric system called the International System of Units, abbreviated SI (after the French name Système International). In **SI units**, length is measured in meters (m), time is measured in seconds (s), and mass (a measure of the amount of material in an object) is measured in kilograms (kg). How are these basic units related to other measures?

When discussing objects on a human scale, sizes and distances can also be expressed in millimeters (mm), centimeters (cm), and kilometers (km). These units of length are related to the meter as follows:

$$1 \text{ millimeter} = 0.001 \text{ m} = 10^{-3} \text{ m}$$
$$1 \text{ centimeter} = 0.01 \text{ m} = 10^{-2} \text{ m}$$
$$1 \text{ kilometer} = 1000 \text{ m} = 10^3 \text{ m}$$

A useful set of conversions for the English system is

$$1 \text{ in} = 2.54 \text{ cm}$$
$$1 \text{ ft} = 0.3048 \text{ m}$$
$$1 \text{ mi} = 1.609 \text{ km}$$

Each of these equalities can also be written as a fraction equal to 1. For example, you can write

$$\frac{0.3048 \text{ m}}{1 \text{ ft}} = 1 \quad \text{or} \quad \frac{1 \text{ ft}}{0.3048 \text{ m}} = 1$$

Fractions like this are useful for converting a quantity from one set of units to another. For example, the *Saturn V* rocket used to send astronauts to the Moon stands about 363 ft tall. How can we convert this height to meters? The trick is to remember that a quantity does not change if you multiply it by 1. Expressing the number 1 by the fraction (0.3048 m)/(1 ft), we can write the height of the rocket as

$$363 \text{ ft} \times 1 = 363 \text{ ft} \times \frac{0.3048 \text{ m}}{1 \text{ ft}} = 111 \frac{\text{ft} \times \text{m}}{\text{ft}} = 111 \text{ m}$$

(continued on the next page)

BOX 1-3 *(continued)*

EXAMPLE: The diameter of Mars is 6794 km. Let's try expressing this in miles.

CAUTION! You can get into trouble if you are careless in applying the trick of taking the number whose units are to be converted and multiplying it by 1. For example, if we multiply the diameter by 1 expressed as (1.609 km)/(1 mi), we get

$$6794 \text{ km} \times 1 = 6794 \text{ km} \times \frac{1.609 \text{ km}}{1 \text{ mi}} = 10{,}930 \ \frac{\text{km}^2}{\text{mi}}$$

The unwanted units of km did not cancel, so this answer cannot be right. Furthermore, a mile is larger than a kilometer, so the diameter expressed in miles should be a smaller number than when expressed in kilometers.

The correct approach is to write the number 1 so that the unwanted units *will* cancel. The number we are starting with is in kilometers, so we must write the number 1 with kilometers in the denominator ("downstairs" in the fraction). Thus, we express 1 as (1 mi)/(1.609 km):

$$6794 \text{ km} \times 1 = 6794 \text{ km} \times \frac{1 \text{ mi}}{1.609 \text{ km}}$$

$$= 4222 \text{ km} \times \frac{\text{mi}}{\text{km}} = 4222 \text{ mi}$$

Now the units of km cancel as they should, and the distance in miles is a smaller number than in kilometers (as it must be).

When discussing very small distances such as the size of an atom, astronomers often use the micrometer (μm) or the nanometer (nm). These are related to the meter as follows:

$$1 \text{ micrometer} = 1\ \mu\text{m} = 10^{-6} \text{ m}$$

$$1 \text{ nanometer} = 1 \text{ nm} = 10^{-9} \text{ m}$$

Thus, $1\ \mu\text{m} = 10^3$ nm. (Note that the micrometer is often called the micron.)

The basic unit of time is the second (s). It is related to other units of time as follows:

$$1 \text{ minute (min)} = 60 \text{ s}$$

$$1 \text{ hour (h)} = 3600 \text{ s}$$

$$1 \text{ day (d)} = 86{,}400 \text{ s}$$

$$1 \text{ year (y)} = 3.156 \times 10^7 \text{ s}$$

In the SI system, speed is properly measured in meters per second (m/s). Quite commonly, however, speed is also expressed in km/s and mi/h:

$$1 \text{ km/s} = 10^3 \text{ m/s}$$

$$1 \text{ km/s} = 2237 \text{ mi/h}$$

$$1 \text{ mi/h} = 0.447 \text{ m/s}$$

$$1 \text{ mi/h} = 1.47 \text{ ft/s}$$

In addition to using kilograms, astronomers sometimes express mass in grams (g) and in solar masses ($M_\odot$), where the subscript ⊙ is the symbol denoting the Sun. It is especially convenient to use solar masses when discussing the masses of stars and galaxies. These units are related to each other as follows:

$$1 \text{ kg} = 1000 \text{ g}$$

$$1\ M_\odot = 1.99 \times 10^{30} \text{ kg}$$

CAUTION! You may be wondering why we have not given a conversion between kilograms and pounds (lb). The reason is that these units do not refer to the same physical quantity! A kilogram is a unit of *mass*, which is a measure of the amount of material in an object. By contrast, a pound is a unit of *weight*, which tells you how strongly gravity pulls on that object's material. Consider a person who weighs 110 pounds on Earth, corresponding to a mass of 50 kg. Gravity is only about one-sixth as strong on the Moon as it is on Earth, so on the Moon this person would weigh only one-sixth of 110 pounds, or about 18 pounds. But that person's mass of 50 kg is the same on the Moon; wherever you go in the universe, you take all of your material along with you. We will explore the relationship between mass and weight in Chapter 4.

The distance from Earth to Proxima Centauri can be stated as 1.3 pc or as 4.2 ly. Whether you choose to use parsecs or light-years is a matter of personal taste.

For even greater distances, astronomers commonly use **kiloparsecs** and **megaparsecs** (abbreviated **kpc** and **Mpc**). As we saw before, these prefixes simply mean "thousand" and "million," respectively:

$$1 \text{ kiloparsec} = 1 \text{ kpc} = 1000 \text{ pc} = 10^3 \text{ pc}$$

$$1 \text{ megaparsec} = 1 \text{ Mpc} = 1{,}000{,}000 \text{ pc} = 10^6 \text{ pc}$$

For example, the distance from Earth to the center of our Milky Way Galaxy is about 8 kpc, and the galaxy shown in Figure 1-9 is about 11 Mpc away.

Some astronomers prefer to talk about thousands or millions of light-years rather than kiloparsecs and megaparsecs. Once again, the choice is a matter of personal taste. As a general rule, astronomers use whatever measuring sticks seem best suited for the issue at hand and do not restrict themselves to one system of measurement. For example, an astronomer might say that the

supergiant star Antares has a diameter of 860 million kilometers and is located at a distance of 185 parsecs from Earth. The *Cosmic Connections* figure on the following page shows where these different systems are useful.

1-8 Astronomy is an adventure of the human mind

An underlying theme of this book is that the behavior of the universe is governed by underlying laws of nature. It is not a hodgepodge of unrelated things behaving in unpredictable ways. Rather, we find strong evidence that fundamental laws of physics govern the nature of the universe and the behavior of everything in it. These unifying concepts enable us to explore realms far removed from our earthly experience. Thus, a scientist can do experiments in a laboratory to determine the properties of light or the behavior of atoms and then use this knowledge to investigate the structure of the universe. Through careful testing, the laws of physics discovered on Earth have been found to apply throughout the universe at the most distant locations and in the distant past. Indeed, Albert Einstein expressed the view that **"the eternal mystery of the world is its comprehensibility."**

Studying the universe benefits our lives on Earth

The discovery of fundamental laws of nature has had a profound influence on humanity. These laws have led to an immense number of practical applications that have fundamentally transformed commerce, medicine, entertainment, transportation, and other aspects of our lives. In particular, space technology has given us instant contact with any point on the globe through communication satellites, precise navigation to any point on Earth using signals from the satellites of the Global Positioning System (GPS), and accurate weather forecasts from meteorological satellites (Figure 1-15).

As important as the applications of science are, the pursuit of scientific knowledge for its own sake is no less important. We are fortunate to live in an age in which this pursuit is in full flower. Just as explorers such as Columbus and Magellan discovered the true size of our planet in the fifteenth and sixteenth centuries, astronomers of the twenty-first century are exploring the universe to an extent that is unparalleled in human history. Indeed, even the voyages into space imagined by such great science fiction writers as Jules Verne and H. G. Wells pale in comparison to today's reality. Over a few short decades, humans have walked on the Moon, sent robot spacecraft to dig into the Martian soil and explore the satellites of Saturn, and used the most powerful telescopes ever built to probe the limits of the observable universe. Never before has so much been revealed in so short a time.

As you proceed through this book, you will learn about the tools that scientists use to explore the natural world, as well as what they observe with these tools. But, most important, you will see how astronomers build from their observations an understanding of the universe in which we live. It is this search for understanding that makes science more than merely a collection of data and elevates it to one of the great adventures of the human mind.

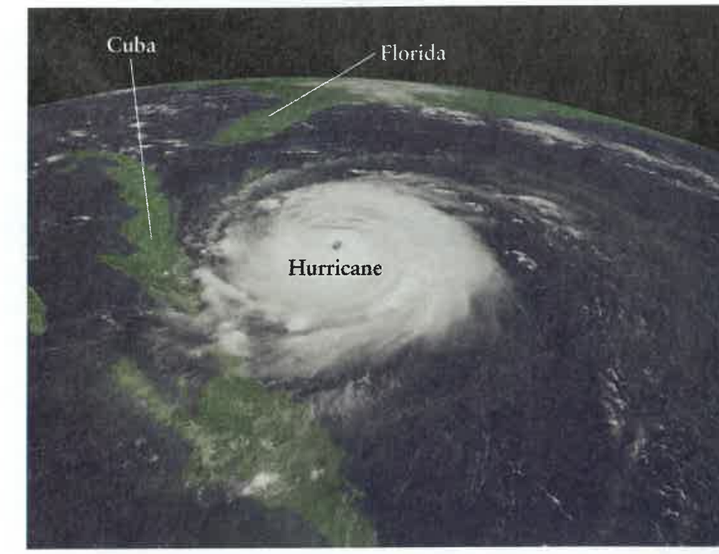


FIGURE 1-15 R I V U X G

A Hurricane Seen from Space This image of Hurricane Frances was made on September 2, 2004, by GOES-12 (*Geostationary Operational Environmental Satellite 12*). A geostationary satellite like GOES-12 orbits around Earth's equator every 24 hours, the same length of time it takes the planet to make a complete rotation. Hence, this satellite remains over the same spot on Earth, from which it can monitor the weather continuously. By tracking hurricanes from orbit, GOES-12 makes it much easier for meteorologists to give early warning of these immense storms. The resulting savings in lives and property more than pay for the cost of the satellite. (NASA, NOAA)

It is an adventure that will continue as long as there are mysteries in the universe—an adventure we hope you will come to appreciate and share.

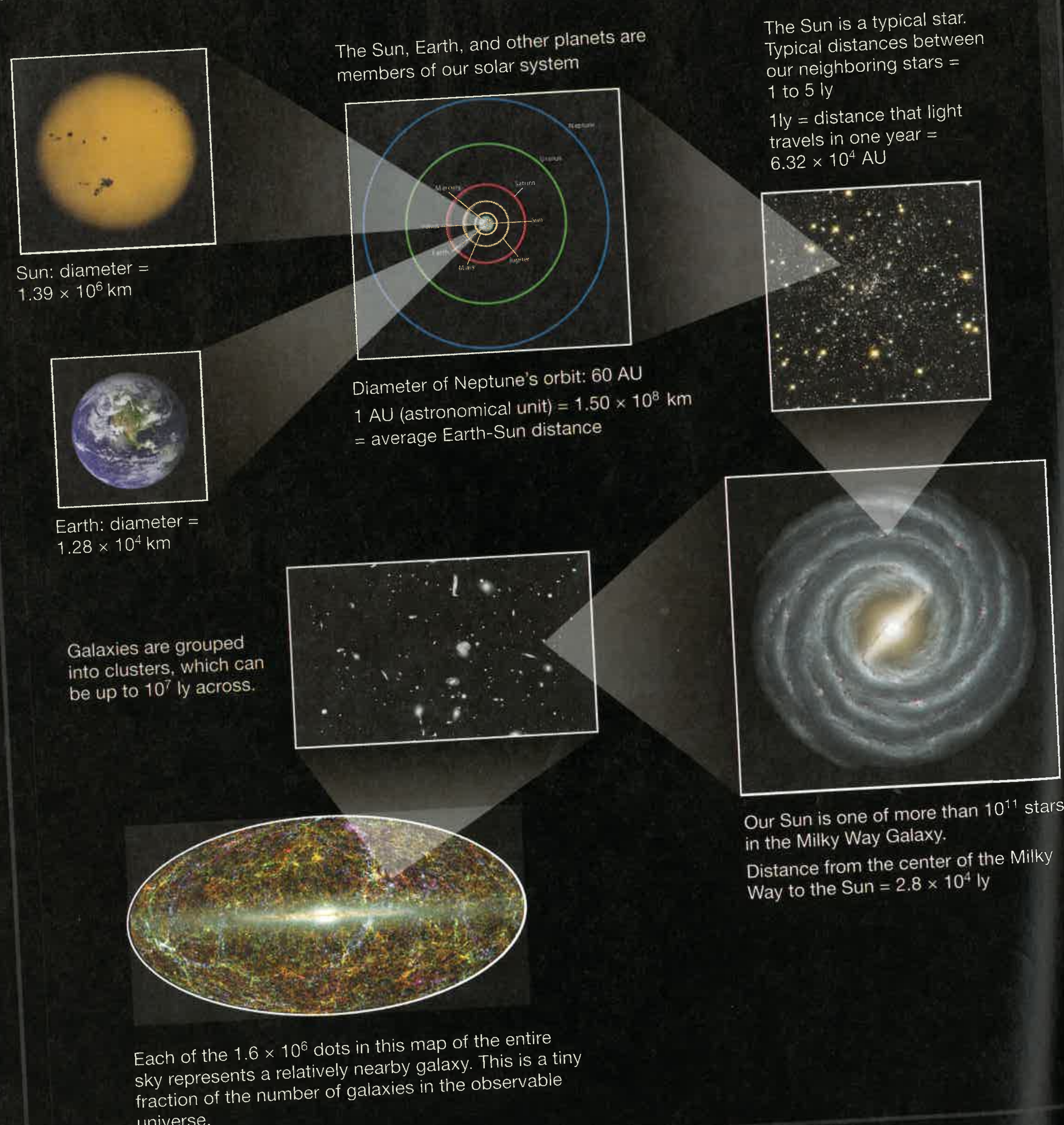
KEY WORDS

Terms preceded by an asterisk (*) are discussed in the Boxes.

COSMIC CONNECTIONS

Sizes in the Universe

Powers-of-ten notation provides a a convenient way to express the sizes of astronomical objects and distances in space. This illustration suggests the immense distances within our solar system, the far greater distances between the stars within our Milky Way Galaxy, and the truly cosmic distances between galaxies.



KEY IDEAS

Astronomy, Science, and the Nature of the Universe: The universe is comprehensible. The scientific method is a procedure for formulating hypotheses about the universe. Hypotheses are tested by observation or experimentation in order to build consistent models or theories that accurately describe phenomena in nature.

Observations of the heavens have helped scientists discover some of the fundamental laws of physics. The laws of physics are in turn used by astronomers to interpret their observations.

The Solar System: Exploration of the planets provides information about the origin and evolution of the solar system, as well as about the history and resources of Earth.

Stars and Nebulae: Studying the stars and nebulae helps us learn about the origin and history of the Sun and the solar system.

Galaxies: Observations of galaxies tell us about the origin and history of the universe.

Angles: Astronomers use angles to denote the positions and sizes of objects in the sky. The size of an angle is measured in degrees, arcminutes, and arcseconds.

Powers-of-Ten Notation is a convenient shorthand system for writing numbers. It allows very large and very small numbers to be expressed in a compact form.

Units of Distance: Astronomers use a variety of distance units. These include the astronomical unit (the average distance from Earth to the Sun), the light-year (the distance that light travels in one year), and the parsec.

QUESTIONS

Review Questions

1. (TUTORIAL 1.1) What is the difference between a hypothesis and a theory?
2. What is the difference between a theory and a law of physics?
3. How are scientific theories tested?
4. Describe the role that skepticism plays in science.
5. Describe one reason why it is useful to have telescopes in space.
6. What caused the craters on the Moon?
7. What are meteorites? Why are they important for understanding the history of the solar system?
8. What makes the Sun and stars shine?
9. What role do nebulae like the Orion Nebula play in the life stories of stars?
10. What is the difference between a solar system and a galaxy?
11. What are degrees, arcminutes, and arcseconds used for? What are the relationships among these units of measure?
12. How many arcseconds equal 1°?
13. With the aid of a diagram, explain what it means to say that the Moon subtends an angle of ½°.
14. What is an exponent? How are exponents used in powers-of-ten notation?
15. What are the advantages of using powers-of-ten notation?
16. Write the following numbers using powers-of-ten notation: (a) ten million, (b) sixty thousand, (c) four one-thousandths, (d) thirty-eight billion, (e) your age in months.
17. How is an astronomical unit (AU) defined? Give an example of a situation in which this unit of measure would be convenient to use.
18. What is the advantage to the astronomer of using the light-year as a unit of distance?
19. What is a parsec? How is it related to a kiloparsec and to a megaparsec?
20. Give the word or phrase that corresponds to the following standard abbreviations: (a) km, (b) cm, (c) s, (d) km/s, (e) mi/h, (f) m, (g) m/s, (h) h, (i) y, (j) g, (k) kg. Which of these are units of speed? (*Hint:* You may have to refer to a dictionary. All of these abbreviations should be part of your working vocabulary.)
21. In the original (1977) *Star Wars* movie, Han Solo praises the speed of his spaceship by saying, "It's the ship that made the Kessel run in less than 12 parsecs!" Explain why this statement is obvious misinformation.
22. A reporter once described a light-year as "the time it takes light to reach us traveling at the speed of light." How would you correct this statement?

Advanced Questions

Questions preceded by an asterisk (*) are discussed in the Boxes.

> **Problem-solving tips and tools**
>
> The small-angle formula, given in Box 1-1, relates the size of an astronomical object to the angle it subtends. Box 1-3 illustrates how to convert from one unit of measure to another. An object traveling at speed v for a time t covers a distance d given by $d = vt$; for example, a car traveling at 90 km/h (v) for 3 h (t) covers a distance d = (90 km/h)(3 h) = 270 km. Similarly, the time t required to cover a given distance d at speed v is $t = d/v$; for example, if d = 270 km and v = 90 km/h, then t = (270 km)/(90 km/h) = 3 h.

23. What is the meaning of the letters **R I V U X G** that appear with some of the figures in this chapter? Why in each case is one of the letters highlighted? (*Hint:* See the Preface that precedes Chapter 1.)
24. The diameter of the Sun is 1.4×10^{11} cm, and the distance to the nearest star, Proxima Centauri, is 4.2 ly. Suppose you want to build an exact scale model of the Sun and Proxima Centauri, and you are using a ball 30 cm in diameter to represent the Sun. In your scale model, how far away would Proxima Centauri be from the Sun? Give your answer in kilometers, using powers-of-ten notation.

25. How many Suns would it take, laid side by side, to reach the nearest star? Use powers-of-ten notation. (*Hint:* See the preceding question.)

26. A hydrogen atom has a radius of about 5×10^{-9} cm. The radius of the observable universe is about 14 billion light-years. How many times larger than a hydrogen atom is the observable universe? Use powers-of-ten notation.

27. The Sun's mass is 1.99×10^{30} kg, three-quarters of which is hydrogen. The mass of a hydrogen atom is 1.67×10^{-27} kg. How many hydrogen atoms does the Sun contain? Use powers-of-ten notation.

28. The average distance from Earth to the Sun is 1.496×10^{8} km. Express this distance (a) in light-years and (b) in parsecs. Use powers-of-ten notation. (c) Are light-years or parsecs useful units for describing distances of this size? Explain.

29. The speed of light is 3.00×10^{8} m/s. How long does it take light to travel from the Sun to Earth? Give your answer in seconds, using powers-of-ten notation. (*Hint:* See the preceding question.)

30. When the *Voyager 2* spacecraft sent back pictures of Neptune during its flyby of that planet in 1989, the spacecraft's radio signals traveled for 4 hours at the speed of light to reach Earth. How far away was the spacecraft? Give your answer in kilometers, using powers-of-ten notation. (*Hint:* See the preceding question.)

31. The star Altair is 5.15 pc from Earth. (a) What is the distance to Altair in kilometers? Use powers-of-ten notation. (b) How long does it take for light emanating from Altair to reach Earth? Give your answer in years. (*Hint:* You do not need to know the value of the speed of light.)

32. The age of the universe is about 13.7 billion years. What is this age in seconds? Use powers-of-ten notation.

*33. Explain where the number 206,265 in the small-angle formula comes from.

*34. At what distance would a person have to hold a European 2-euro coin (which has a diameter of about 2.6 cm) in order for the coin to subtend an angle of (a) 1°? (b) 1 arcmin? (c) 1 arcsec? Give your answers in meters.

*35. A person with good vision can see details that subtend an angle of as small as 1 arcminute. If two dark lines on an eye chart are 2 millimeters apart, how far can such a person be from the chart and still be able to tell that there are two distinct lines? Give your answer in meters.

*36. The average distance to the Moon is 384,000 km, and the Moon subtends an angle of ½°. Use this information to calculate the diameter of the Moon in kilometers.

*37. Suppose your telescope can give you a clear view of objects and features that subtend angles of at least 2 arcsec. What is the diameter in kilometers of the smallest crater you can see on the Moon? (*Hint:* See the preceding question.)

*38. On April 18, 2006, the planet Venus was a distance of 0.869 AU from Earth. The diameter of Venus is 12,104 km. What was the angular size of Venus as seen from Earth on April 18, 2006? Give your answer in arcminutes.

*39. (a) Use the information given in the caption to Figure 1-7 to determine the angular size of the Orion Nebula. Give your answer in degrees. (b) How does the angular diameter of the Orion Nebula compare to the angular diameter of the Moon?

Discussion Questions

40. Scientists assume that "reality is rational." Discuss what this means and the thinking behind it.

41. All scientific knowledge is inherently provisional. Discuss whether this is a weakness or a strength of the scientific method.

42. How do astronomical observations differ from those of other sciences?

Web/eBook Questions

43. Use the links given in the *Universe* Web site or eBook, Chapter 1, to learn about the Orion Nebula (Figure 1-7). Can the nebula be seen with the naked eye? Does the nebula stand alone, or is it part of a larger cloud of interstellar material? What has been learned by examining the Orion Nebula with telescopes sensitive to infrared light?

44. Use the links given in the *Universe* Web site or eBook, Chapter 1, to learn more about the Crab Nebula (Figure 1-8). When did observers on Earth see the supernova that created this nebula? Does the nebula emit any radiation other than visible light? What kind of object is at the center of the nebula?

ACTIVITIES

Observing Projects

45. On a dark, clear, moonless night, can you see the Milky Way from where you live? If so, briefly describe its appearance. If not, what seems to be interfering with your ability to see the Milky Way?

46. Look up at the sky on a clear, cloud-free night. Is the Moon in the sky? If so, does it interfere with your ability to see the fainter stars? Why do you suppose astronomers prefer to schedule their observations on nights when the Moon is not in the sky?

47. Look up at the sky on a clear, cloud-free night and note the positions of a few prominent stars relative to such reference markers as rooftops, telephone poles, and treetops. Also note the location from where you make your observations. A few hours later, return to that location and again note the positions of the same bright stars that you observed earlier. How have their positions changed? From these changes, can you deduce the general direction in which the stars appear to be moving?

48. If you have access to the *Starry Night*™ planetarium software, install it on your computer. There are several guides to the use of this software. As an initial introduction, you can run through the step-by-step basics of the program by clicking the **Sky Guide** tab to the left of the main screen and then clicking the **Starry Night basics** hyperlink at the bottom of the **Sky Guide** pane. A more comprehensive guide is available by choosing the **Student Exercises** hyperlink and then the **Tutorial** hyperlink. A User's Guide to this software is available under the **Help** menu. As a start, you can use this program to determine when the Moon is visible today from your location. If the viewing location in the *Starry Night*™ control panel is not set to your location, select **Set Home Location ...** in the **File** menu (on a Macintosh, this command is found under the **Starry Night** menu). Click the **List** tab in the **Home Location** dialog box; then select the name of your city or town and click the **Save As Home Location** button. Next, use the hand tool to explore the sky and search for the Moon by moving your viewpoint around the sky. (Click and drag the mouse to achieve this motion.) If the Moon is not easily seen in your sky at this time, click the **Find** tab at the top left of the main view. The **Find** pane that opens should contain a list of solar system objects. Ensure that there is no text in the edit box at the top of the **Find** pane. If the message "Search all Databases" is not displayed below this edit box, then click the magnifying glass icon in the edit box and select **Search All** from the drop-down menu that appears. Click the + symbol to the left of the listing for **Earth** to display **The Moon** and double-click on this entry in the list in order to center the view upon the Moon. (If a message is displayed indicating that "the Moon is not currently visible from your location," click on the **Best Time** button to advance to a more suitable time). You will see that the Moon can be seen in the daytime as well as at night. Note that the **Time Flow Rate** is set to **1x**, indicating that time is running forward at the normal rate. Note also the phase of the Moon. (a) Estimate how long it will take before the Moon reaches its full phase. Set the **Time Flow Rate** to **1 minutes.** (b) Find the time of moonset at your location. (c) Determine which, if any, of the following planets are visible tonight: Mercury, Venus, Mars, Jupiter, and Saturn. (*Hint:* Use the **Find** pane and click on each planet in turn to explore the positions of these objects.) Feel free to experiment with the many features of *Starry Night*™.

49. Use the *Starry Night*™ program to measure angular spacing between stars in the sky. Open **Favourites > Explorations > N Pole** to display the northern sky from Calgary, Canada, at a latitude of 51°. This view shows several asterisms, or groups of stars, outlined and labeled with their common names. The stars in the Big Dipper asterism outline the shape of a "dipper," used for scooping water from a barrel. The two stars in the Big Dipper on the opposite side of the scoop from the handle, Merak and Dubhe, can be seen to point to the brightest star in the Little Dipper, the Pole Star. The Pole Star is close to the North Celestial Pole, the point in the sky directly above the north pole of Earth. It is thus a handy aid to navigation for northern hemisphere observers because it indicates the approximate direction of true north. Measure the spacing between the two "pointer stars" in the Big Dipper and then the spacing between the Pole Star and the closest of the pointer stars, Dubhe. (*Hint:* These measurements are best made by activating the angular separation tool from the cursor selection control on the left side of the toolbar.) (a) What is the angular distance between the pointer stars Merak and Dubhe? (b) What is the angular spacing, or separation, between Dubhe (the pointer star at the end of the Big Dipper) and the Pole Star? (c) Approximately how many pointer-star spacings are there between Dubhe and the Pole Star?

Click the **Play** button in the toolbar. Notice that the Pole Star will appear to remain fixed in the sky as time progresses because it lies very close to the North Celestial Pole. Select **Edit > Undo Time Flow** or **File > Revert** from the menu to return to the initial view. Select **View > Celestial Guides > Celestial Poles** from the menu to indicate the position of the North Celestial Pole on the screen. Right-click on the Pole Star (Ctrl-click on a Macintosh) and select **Centre** from the drop down menu to center the view on the Pole Star. Zoom in and use the angular separation tool to measure the angular spacing between the Pole Star and the North Celestial Pole. (d) What is the angular separation between the Pole Star and the North Celestial Pole? (e) Select **File > Revert** from the menu and use the angular separation tool to measure the angle between the Pole Star and the horizon at Calgary. What is the relationship between this angle and the latitude of Calgary (51°)?

Collaborative Exercises

50. A scientific theory is fundamentally different than the everyday use of the word "theory." List and describe any three scientific theories of your choice and creatively imagine an additional three hypothetical theories that are not scientific. Briefly describe what is scientific and what is nonscientific about each of these theories.

51. Angles describe how far apart two objects appear to an observer. From where you are currently sitting, estimate the angular distance between the floor and the ceiling at the front of the room you are sitting in, the angular distance between the two people sitting closest to you, and the angular size of a clock or an exit sign on the wall. Draw sketches to illustrate each answer and describe how each of your answers would change if you were standing in the very center of the room.

52. Astronomers use powers of ten to describe the distances to objects. List an object or place that is located at very roughly each of the following distances from you: 10^{-2} m, 10^{0} m, 10^{1} m, 10^{3} m, 10^{7} m, 10^{10} m, and 10^{20} m.

ANSWERS

ConceptChecks

ConceptCheck 1-1: While a hypothesis is a testable idea that seems to explain an observation about nature, a scientific theory represents a set of well-tested and internally consistent hypotheses that are able to successfully and repeatedly predict the outcome of experiments and observations.

ConceptCheck 1-2: Shorter lifetime. The larger star has twice as much mass as the Sun. However, it consumes its nuclear fuel much more than twice as fast, so that its lifetime is shorter than the Sun.

ConceptCheck 1-3: Yes. The apparent size of an object is given by how wide it appears (in other words, the angle that it subtends). By moving a basketball near and far, it can appear very large or very small.