1

A MODERN VIEW OF THE UNIVERSE

LEARNING GOALS

1.1 THE SCALE OF THE UNIVERSE

- What is our place in the universe?
- How big is the universe?

1.2 THE HISTORY OF THE UNIVERSE

- How did we come to be?
- How do our lifetimes compare to the age of the universe?

1.3 SPACESHIP EARTH

- How is Earth moving through space?
- How do galaxies move within the universe?

1.4 THE HUMAN ADVENTURE OF ASTRONOMY

- How has the study of astronomy affected human history?

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.
—*T. S. Eliot*

Far from city lights on a clear night, you can gaze upward at a sky filled with stars. Lie back and watch for a few hours, and you will observe the stars marching steadily across the sky. Confronted by the seemingly infinite heavens, you might wonder how Earth and the universe came to be. If you do, you will be sharing an experience common to humans around the world and in thousands of generations past.

Modern science offers answers to many of our fundamental questions about the universe and our place within it. We now know the basic content and scale of the universe. We know the age of Earth and the approximate age of the universe. And, although much remains to be discovered, we are rapidly learning how the simple ingredients of the early universe developed into the incredible diversity of life on Earth.

In this first chapter, we will survey the scale, history, and motion of the universe. This "big picture" perspective on our universe will provide a base on which you'll be able to build a deeper understanding in the rest of the book.

1.1 THE SCALE OF THE UNIVERSE

For most of human history, our ancestors imagined Earth to be stationary and located at the center of a relatively small universe. These ideas made sense at a time when understanding was built upon everyday experience. After all, we cannot feel the constant motion of Earth as it rotates on its axis and orbits the Sun, and if you observe the sky you'll see that the Sun, Moon, planets, and stars all appear to revolve around us each day. Nevertheless, we now know that Earth is a planet orbiting a rather average star in a vast universe.

The historical path to this knowledge was long and complex. In later chapters, we'll see that the ancient belief in an Earth-centered (or *geocentric*) universe changed only when people were confronted by strong evidence to the contrary, and we'll explore how the method of learning that we call *science* enabled us to acquire this evidence. First, however, it's useful to have a general picture of the universe as we know it today.

What is our place in the universe?

Take a look at the remarkable photo that opens this chapter (on page 1). This photo, taken by the Hubble Space Telescope, shows a piece of the sky so small that you could block your view of it with a grain of sand held at arm's length. Yet it encompasses an almost unimaginable expanse of both space and time: Nearly every object within it is a *galaxy* filled with billions of stars, and some of the smaller smudges are galaxies so far away that their light has taken billions of years to reach us. Let's begin our study of astronomy by exploring what a photo like this one tells us about our own place in the universe.

Our Cosmic Address The galaxies that we see in the Hubble Space Telescope photo are just one of several levels of structure in our universe. A good way to build context on these levels is to consider what we might call our "cosmic address," illustrated in FIGURE 1.1.

Earth is a planet in our **solar system**, which consists of the Sun, the planets and their moons, and countless smaller objects that include rocky *asteroids* and icy *comets*. Keep in mind that our Sun is a *star*, just like the stars we see in our night sky.

Our solar system belongs to the huge, disk-shaped collection of stars called the **Milky Way Galaxy**. A **galaxy** is a great island of stars in space, containing between a few hundred million and a trillion or more stars. The Milky Way is a relatively large galaxy, containing more than 100 billion stars. Our solar system is located a little over halfway from the galactic center to the edge of the galactic disk.

Billions of other galaxies are scattered throughout space. Some galaxies are fairly isolated, but many others are found in groups. Our Milky Way, for example, is one of the two largest among about 40 galaxies in the **Local Group.** Groups of galaxies with more than a few dozen members are often called **galaxy clusters.**

On a very large scale, galaxies and galaxy clusters appear to be arranged in giant chains and sheets with huge voids between them; the background of Figure 1.1 shows this large-scale structure. The regions in which galaxies and galaxy clusters are most tightly packed are called **superclusters,** which are essentially clusters of galaxy clusters. Our Local Group is located in the outskirts of the Local Supercluster.

Together, all these structures make up our **universe.** In other words, the universe is the sum total of all matter and energy, encompassing the superclusters and voids and everything within them.

THINK ABOUT IT

Some people think that our tiny physical size in the vast universe makes us insignificant. Others think that our ability to learn about the wonders of the universe gives us significance despite our small size. What do *you* think?

Astronomical Distance Measurements Notice that Figure 1.1 is labeled with an approximate size for each structure in kilometers. In astronomy, many of the distances are so large that kilometers are not the most convenient unit. Instead, we often use two other units:

- One **astronomical unit (AU)** is Earth's average distance from the Sun, which is about 150 million kilometers (93 million miles). We commonly describe distances within our solar system in astronomical units.
- One **light-year (ly)** is the distance that light can travel in 1 year, which is about 10 trillion kilometers (6 trillion miles). We generally use light-years to describe the distances of stars and galaxies.

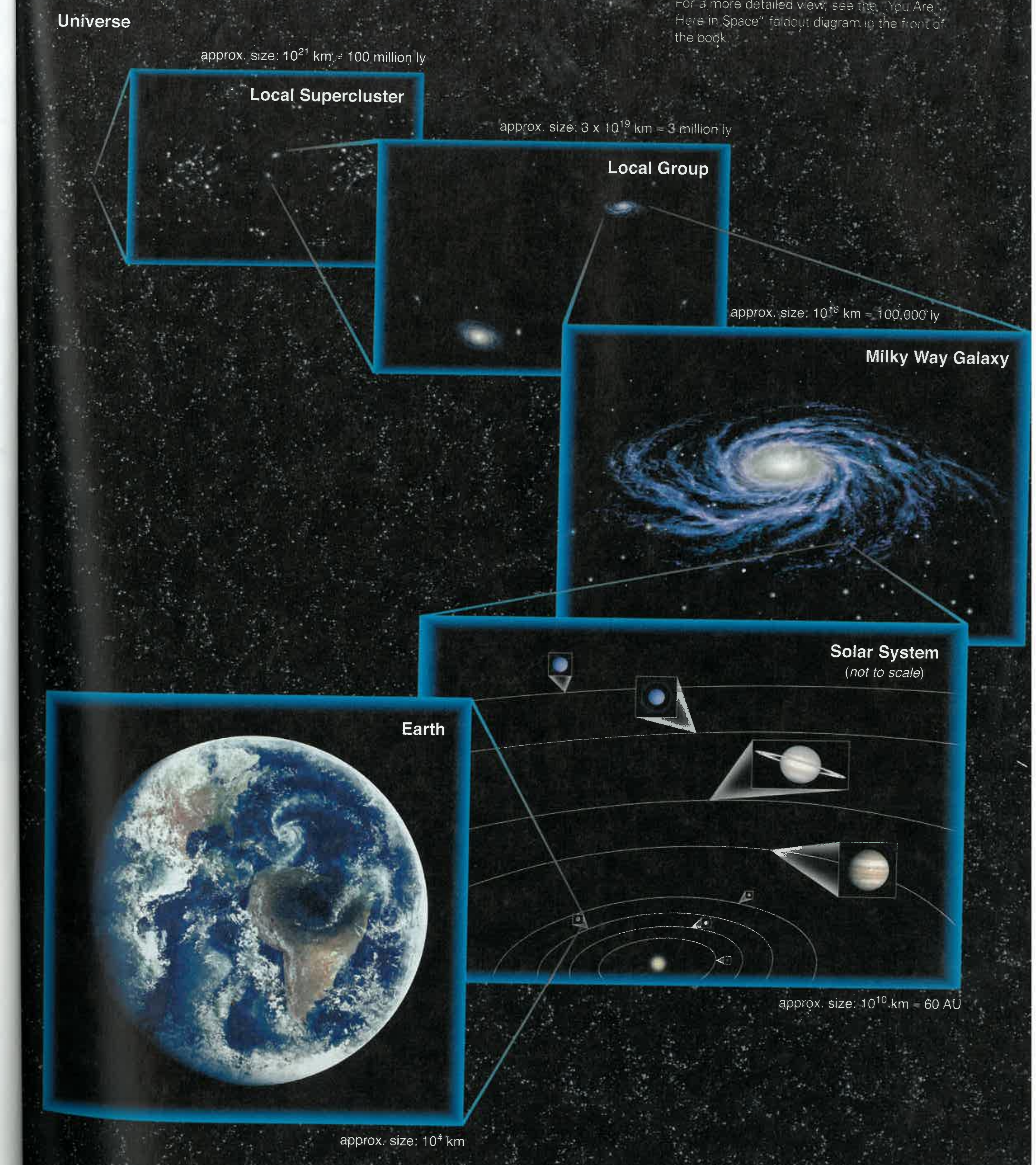

FIGURE 1.1 Our cosmic address. These diagrams show key levels of structure in our universe. For a more detailed view, see the "You Are Here in Space" foldout diagram in the front of the book.

Be sure to note that a light-year is a unit of *distance*, not of time. Light travels at the speed of light, which is 300,000 kilometers per second. We therefore say that one *light-second* is about 300,000 kilometers, because that is the distance light travels in one second. Similarly, one light-minute is the distance that light travels in one minute, one light-hour is the distance that light travels in one hour, and so on. Mathematical Insight 1.1 shows that light travels about 10 trillion kilometers in one year, so that distance represents a light-year.

Looking Back in Time The speed of light is extremely fast by earthly standards. It is so fast that if you could make light go in circles, it could circle Earth nearly eight times in a single second. Nevertheless, even light takes time to travel the vast distances in space. Light takes a little more than 1 second to reach Earth from the Moon, and about 8 minutes to reach Earth from the Sun. Stars are so far away that their light takes years to reach us, which is why we measure their distances in light-years.

Consider Sirius, the brightest star in the night sky, which is located about 8 light-years away. Because it takes light 8 years to travel this distance, we see Sirius not as it is today, but rather as it was 8 years ago. The effect is more dramatic at greater distances. The Orion Nebula (FIGURE 1.2) is a giant cloud in which stars and planets are forming. It is located about 1500 light-years from Earth, which means we see it as it looked about 1500 years ago—about the time of the fall of the Roman Empire. If any major events have occurred in the Orion Nebula since that time, we cannot yet know about them because the light from these events has not yet reached us.

The general idea that light takes time to travel through space leads to a remarkable fact:

> *The farther away we look in distance, the further back we look in time.*

The Andromeda Galaxy (FIGURE 1.3) is about 2.5 million light-years away, which means we see it as it looked about 2.5 million years ago. We see more distant galaxies as they were even further in the past. Some of the galaxies in the Hubble Space Telescope photo that opens the chapter are billions of light-years away, meaning we see them as they were billions of years ago.

SEE IT FOR YOURSELF

The glow from the central region of the Andromeda Galaxy is faintly visible to the naked eye and easy to see with binoculars. Use a star chart to find it in the night sky. Contemplate the fact that you are seeing light that spent 2.5 million years in space before reaching your eyes. If students on a planet in the Andromeda Galaxy were looking at the Milky Way, what would they see? Could they know that we exist here on Earth?

Basic Astronomical Definitions

ASTRONOMICAL OBJECTS

star A large, glowing ball of gas that generates heat and light through nuclear fusion in its core. Our Sun is a star.

planet A moderately large object that orbits a star and shines primarily by reflecting light from its star. According to a definition adopted in 2006, an object can be considered a planet only if it (1) orbits a star, (2) is large enough for its own gravity to make it round, and (3) has cleared most other objects from its orbital path. An object that meets the first two criteria but has not cleared its orbital path, like Pluto, is designated a **dwarf planet.**

moon (or **satellite**) An object that orbits a planet. The term *satellite* is also used more generally to refer to any object orbiting another object.

asteroid A relatively small and rocky object that orbits a star.

comet A relatively small and ice-rich object that orbits a star.

small solar system body An asteroid, comet, or other object that orbits a star but is too small to qualify as a planet or dwarf planet.

COLLECTIONS OF ASTRONOMICAL OBJECTS

solar system The Sun and all the material that orbits it, including planets, dwarf planets, and small solar system bodies. Although the term *solar system* technically refers only to our own star system (*solar* means "of the Sun"), it is often applied to other star systems as well.

star system A star (sometimes more than one star) and any planets and other materials that orbit it.

galaxy A great island of stars in space, containing from a few hundred million to a trillion or more stars, all held together by gravity and orbiting a common center.

cluster (or **group**) **of galaxies** A collection of galaxies bound together by gravity. Small collections (up to a few dozen galaxies) are generally called *groups*, while larger collections are called *clusters*.

supercluster A gigantic region of space in which many groups and clusters of galaxies are packed more closely together than elsewhere in the universe.

universe (or **cosmos**) The sum total of all matter and energy—that is, all galaxies and everything between them.

observable universe The portion of the entire universe that can be seen from Earth, at least in principle. The observable universe is probably only a tiny portion of the entire universe.

ASTRONOMICAL DISTANCE UNITS

astronomical unit (AU) The average distance between Earth and the Sun, which is about 150 million kilometers. More technically, 1 AU is the length of the semimajor axis of Earth's orbit.

light-year The distance that light can travel in 1 year, which is about 9.46 trillion kilometers.

TERMS RELATING TO MOTION

rotation The spinning of an object around its axis. For example, Earth rotates once each day around its axis, which is an imaginary line connecting the North and South Poles.

orbit (revolution) The orbital motion of one object around another due to gravity. For example, Earth orbits the Sun once each year.

expansion (of the universe) The increase in the average distance between galaxies as time progresses.

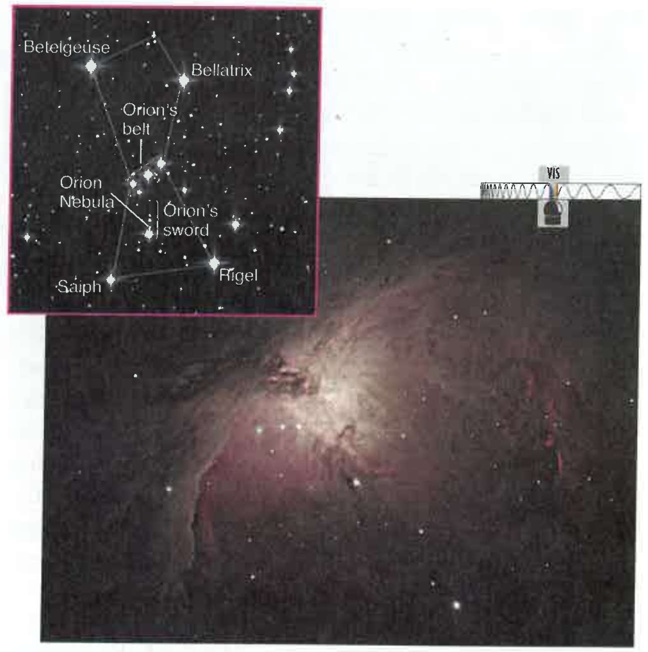

FIGURE 1.2 The Orion Nebula, located about 1500 light-years away. The inset shows its location in the constellation Orion.

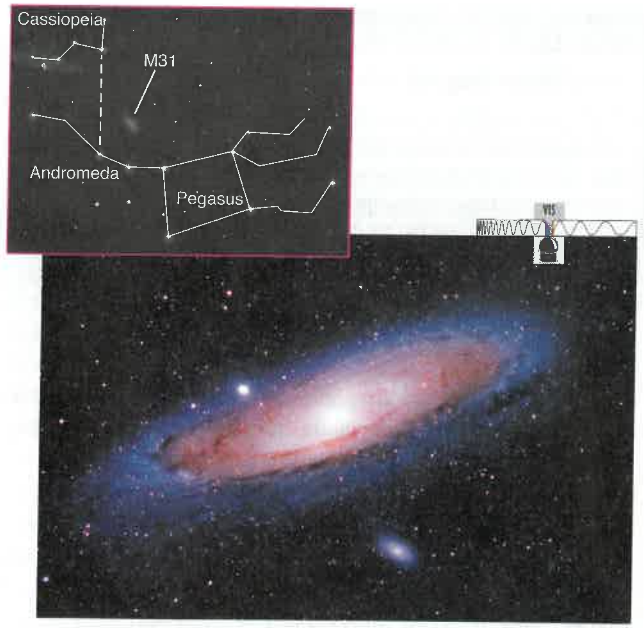

FIGURE 1.3 The Andromeda Galaxy (M31). When we look at this galaxy, we see light that has been traveling through space for 2.5 million years.

It's also amazing to realize that any "snapshot" of a distant galaxy is a picture of both space and time. For example, because the Andromeda Galaxy is about 100,000 light-years in diameter, the light we currently see from the far side of the galaxy must have left on its journey to us some 100,000 years before the light we see from the near side. Figure 1.3 therefore shows different parts of the galaxy spread over a time period of 100,000 years. When we study the universe, it is impossible to separate space and time.

The Observable Universe As we'll discuss in Section 1.2, astronomers estimate that the universe is about 14 billion years old. This fact, combined with the fact that looking deep into space means looking far back in time, places a limit on the portion of the universe that we can see, even in principle. FIGURE 1.4 shows the idea. If we look at a galaxy that is 7 billion light-years away, we see it as it looked 7 billion years ago*—which means we see it as it was when the universe was half its current age. If we look at a galaxy that is 12 billion light-years away (like the most distant ones in the Hubble Space Telescope photo), we see it as it was 12 billion years ago, when the universe was only 2 billion years old. And if we tried to look beyond 14 billion light-years, we'd be looking to a time more than 14 billion years ago—which is before the universe existed and therefore means that there is nothing to see. This distance of 14 billion light-years therefore marks the boundary (or *horizon*) of our **observable universe**—the portion of the entire universe that we can potentially observe. Note that this fact does not put any limit on the size of the

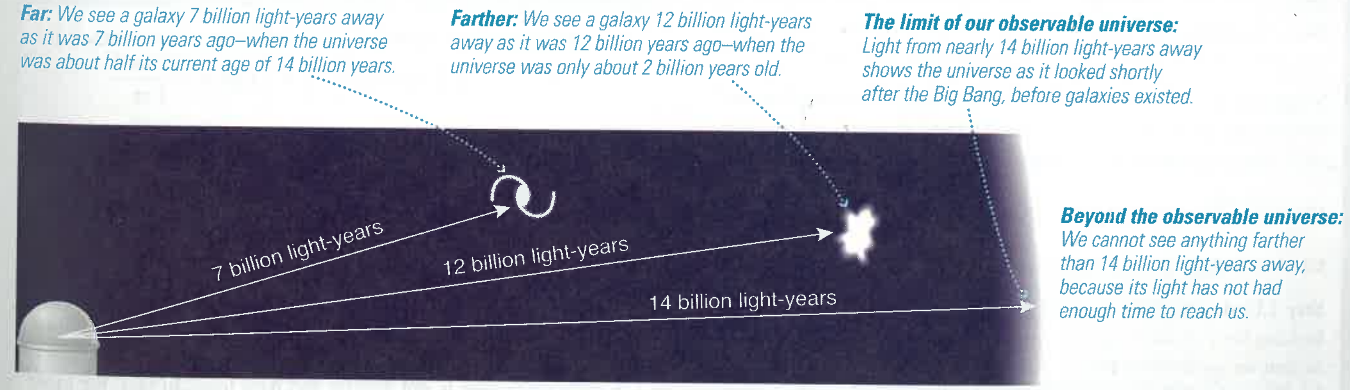

FIGURE 1.4 **interactive figure** The farther away we look in space, the further back we look in time. The age of the universe therefore puts a limit on the size of the *observable* universe—the portion of the entire universe that we can observe, at least in principle.

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*As we'll see in Chapter 20, distances to faraway galaxies must be defined carefully in an expanding universe; distances like those given here are based on the time it has taken a galaxy's light to reach us (called the *lookback time*).

COMMON MISCONCEPTIONS

The Meaning of a Light-Year

You've probably heard people say things like "It will take me light-years to finish this homework!" But a statement like this one doesn't make sense, because light-years are a unit of *distance*, not time. If you are unsure whether the term *light-year* is being used correctly, try testing the statement by using the fact that 1 light-year is about 10 trillion kilometers, or 6 trillion miles. The statement then reads "It will take me 6 trillion miles to finish this homework," which clearly does not make sense.

entire universe, which may be far larger than our observable universe. We simply have no hope of seeing or studying anything beyond the bounds of our observable universe.

MA Scale of the Universe Tutorial, Lessons 1–3

How big is the universe?

Figure 1.1 put numbers on the sizes of different structures in the universe, but these numbers have little meaning for most people—after all, they are literally astronomical. Therefore, to help you develop a greater appreciation of our modern view of the universe, we'll discuss a few ways of putting these numbers into perspective.

The Scale of the Solar System One of the best ways to develop perspective on cosmic sizes and distances is to imagine our solar system shrunk down to a scale that would allow you to walk through it. The Voyage scale model solar system in Washington, D.C., makes such a walk possible (FIGURE 1.5). The Voyage model shows the Sun and the planets, and the distances between them, at *one ten-billionth* of their actual sizes and distances.

FIGURE 1.6a shows the Sun and planets at their correct sizes (but not distances) on the Voyage scale. The model Sun is about the size of a large grapefruit, Jupiter is about the size of a marble, and Earth is about the size of the ball point in a pen. You can immediately see some key facts about our solar system. For example, the Sun is far larger than any of the planets; in mass, the Sun outweighs all the planets combined by a factor of nearly 1000. The planets also vary considerably in size: The storm on Jupiter known as the Great Red Spot (visible near Jupiter's lower left in the painting) could swallow up the entire Earth.

The scale of the solar system is even more remarkable when you combine the sizes shown in Figure 1.6a with the distances illustrated by the map of the Voyage model in FIGURE 1.6b. For example, the ball-point-size Earth is located about 15 meters (16.5 yards) from the grapefruit-size Sun, which means you can picture Earth's orbit as a circle of radius 15 meters around a grapefruit.

MATHEMATICAL INSIGHT 1.1

How Far Is a Light-Year? An Introduction to Astronomical Problem Solving

MA Math Review Video: Problem Solving Part 1

We can develop greater insight into astronomical ideas by applying mathematics. The key to using mathematics is to approach problems in a clear and organized way. One simple approach uses the following three steps:

Step 1 Understand the problem: Ask yourself what the solution will look like (for example, what units will it have? will it be big or small?) and what information you need to solve the problem. Draw a diagram or think of a simpler analogous problem to help you decide how to solve it.

Step 2 Solve the problem: Carry out the necessary calculations.

Step 3 Explain your result: Be sure that your answer makes sense, and consider what you've learned by solving the problem.

You can remember this process as "Understand, Solve, and Explain," or USE for short. You may not always need to write out the three steps explicitly, but they may help if you are stuck.

EXAMPLE: How far is a light-year?

SOLUTION: Let's use the three-step process.

Step 1 Understand the problem: The question asks how *far*, so we are looking for a *distance*. In this case, the definition of a light-year tells us that we are looking for the *distance that light can travel in 1 year*. We know that light travels at the speed of light, so we are looking for an equation that gives us distance from speed. If you don't remember this equation, just think of a simpler but analogous problem, such as "If you drive at 50 kilometers per hour, how far will you travel in 2 hours?" You'll realize that you simply multiply the speed by the time: distance = speed × time. In this case, the speed is the speed of light, or 300,000 km/s, and the time is 1 year.

Step 2 Solve the problem: From Step 1, our equation is that 1 light-year is the speed of light times one year. To make the units consistent, we convert 1 year to seconds by remembering that there are 60 seconds in 1 minute, 60 minutes in 1 hour, 24 hours in 1 day, and 365 days in 1 year. (See Appendix C.3 to review unit conversions.) We now carry out the calculations:

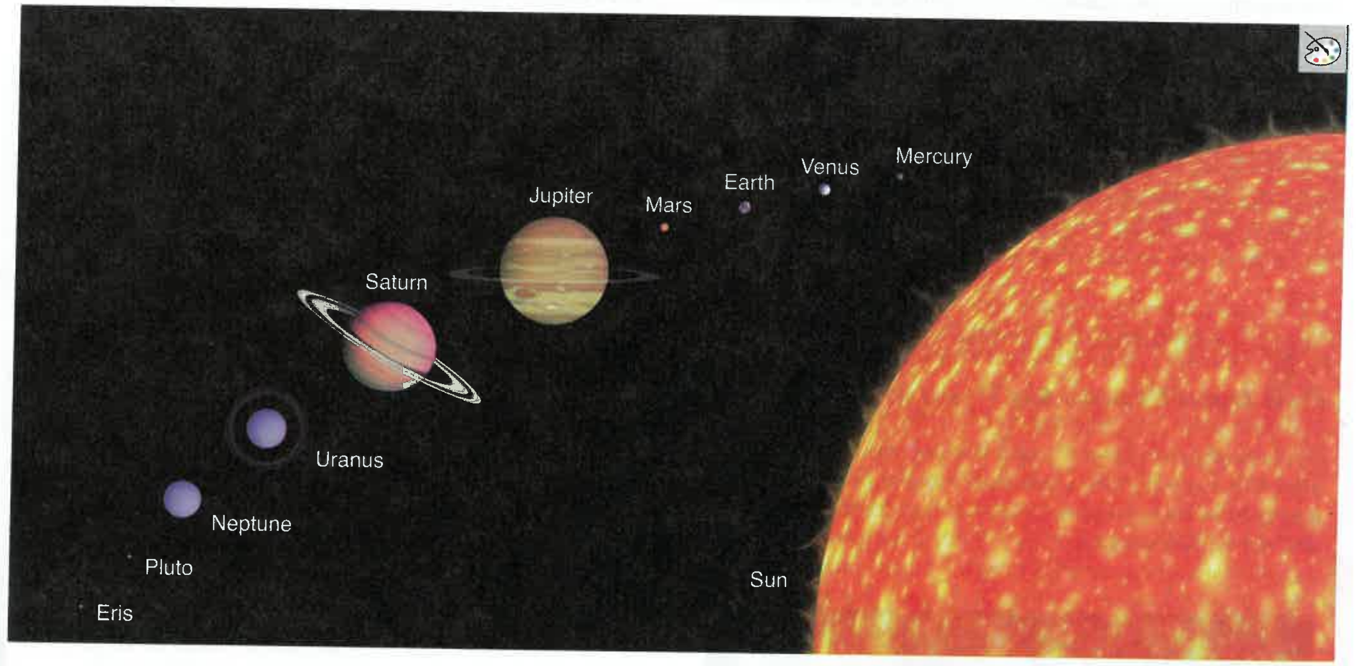
$$\begin{aligned}1 \text{ light-year} &= (\text{speed of light}) \times (1 \text{ yr})\\ &= \left(300{,}000 \frac{\text{km}}{\cancel{\text{s}}}\right) \times \left(1 \cancel{\text{yr}} \times \frac{365 \cancel{\text{days}}}{1 \cancel{\text{yr}}}\right.\\ &\qquad \left.\times \frac{24 \cancel{\text{hr}}}{1 \cancel{\text{day}}} \times \frac{60 \cancel{\text{min}}}{1 \cancel{\text{hr}}} \times \frac{60 \cancel{\text{s}}}{1 \cancel{\text{min}}}\right)\\ &= 9{,}460{,}000{,}000{,}000 \text{ km } (9.46 \text{ trillion km})\end{aligned}$$

Step 3 Explain your result: In sentence form, our answer is "One light-year is about 9.46 trillion kilometers." This answer makes sense: It has the expected units of distance (kilometers) and it is a long way, which we expect for the distance that light can travel in a year. We say "about" in the answer because we know it is not exact. For example, a year is not exactly 365 days long. In fact, for most purposes, we can approximate the answer further as "One light-year is about 10 trillion kilometers."

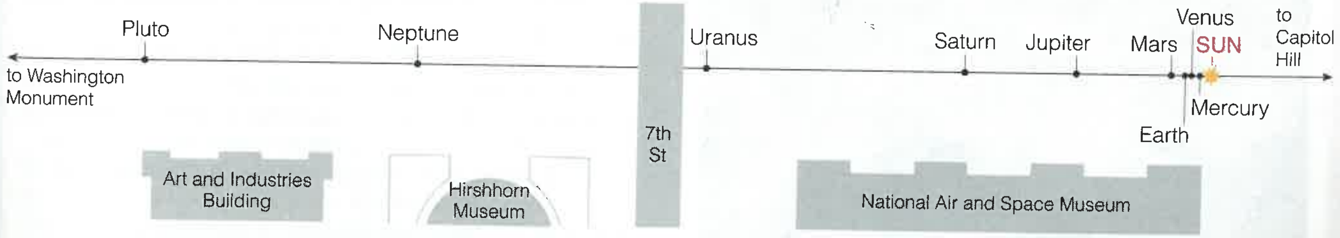
FIGURE 1.5 This photo shows the pedestals housing the Sun (the gold sphere on the nearest pedestal) and the inner planets in the Voyage scale model solar system (Washington, D.C.). The model planets are encased in the sidewalk-facing disks visible at about eye level on the planet pedestals. The building at the left is the National Air and Space Museum.

Perhaps the most striking feature of our solar system when we view it to scale is its emptiness. The Voyage model shows the planets along a straight path, so we'd need to draw each planet's orbit around the model Sun to show the full extent of our planetary system. Fitting all these orbits would require an area measuring more than a kilometer on a side—an area equivalent to more than 300 football fields arranged in a grid. Spread over this large area, only the grapefruit-size Sun, the planets, and a few moons would be big enough to see. The rest of it would look virtually empty (that's why we call it *space!*).

Seeing our solar system to scale also helps put space exploration into perspective. The Moon, the only other world on which humans have ever stepped (FIGURE 1.7), lies only about 4 centimeters ($1\frac{1}{2}$ inches) from Earth in the Voyage model. On this scale, the palm of your hand can cover the entire region of the universe in which humans have so far traveled. The trip to Mars is more than 150 times as far as the trip to the Moon, even when Mars is on the same side of its orbit as Earth. And while you can walk from the Sun to Pluto in a few minutes on the Voyage scale, the *New Horizons* spacecraft that is making the real journey will have been in space nearly a decade when it flies past Pluto in July 2015.



a The scaled sizes (but not distances) of the Sun, planets, and two largest known dwarf planets.



b Locations of the Sun and planets in the Voyage model, Washington, D.C.; the distance from the Sun to Pluto is about 600 meters (1/3 mile). Planets are lined up in the model, but in reality each planet orbits the Sun independently and a perfect alignment never occurs.

FIGURE 1.6 **interactive figure** The Voyage scale model represents the solar system at *one ten-billionth* of its actual size. Pluto is included in the Voyage model, which was built before the International Astronomical Union reclassified Pluto as a dwarf planet.

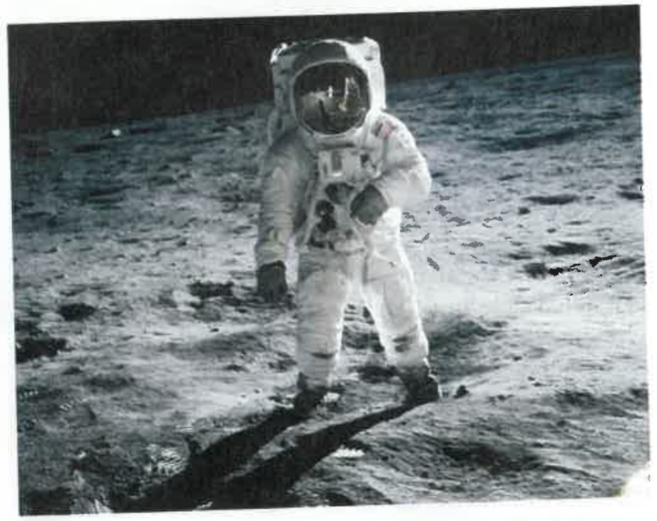


FIGURE 1.7 This famous photograph from the first Moon landing (*Apollo 11* in July 1969) shows astronaut Buzz Aldrin, with Neil Armstrong reflected in his visor. Armstrong was the first to step onto the Moon's surface, saying, "That's one small step for a man, one giant leap for mankind."

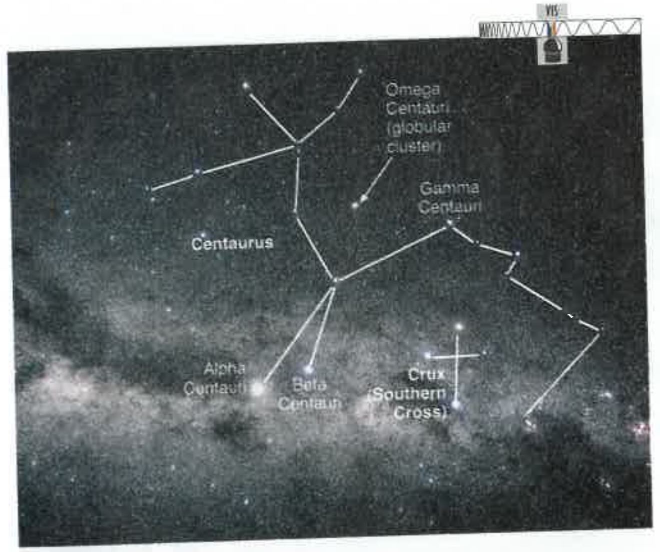


FIGURE 1.8 This photograph and diagram show the constellation Centaurus, which is visible from tropical and southern latitudes. Alpha Centauri's real distance of 4.4 light-years is 4400 kilometers on the 1-to-10-billion Voyage scale.

Distances to the Stars If you visit the Voyage model in Washington, D.C., you can walk the roughly 600-meter distance from the Sun to Pluto in just a few minutes. How much farther would you have to walk to reach the next star on this scale?

Amazingly, you would need to walk to California. If this answer seems hard to believe, you can check it for yourself. A light-year is about 10 trillion kilometers, which becomes 1000 kilometers on the 1-to-10-billion scale (because 10 trillion ÷ 10 billion = 1000). The nearest star system to our own, a three-star system called Alpha Centauri (**FIGURE 1.8**), is about 4.4 light-years away. That distance is about 4400 kilometers (2700 miles) on the 1-to-10-billion scale, or roughly equivalent to the distance across the United States.

The tremendous distances to the stars give us some perspective on the technological challenge of astronomy. For example, because the largest star of the Alpha Centauri system is roughly the same size and brightness as our Sun, viewing it in the night sky is somewhat like being in Washington, D.C., and seeing a very bright grapefruit in San Francisco (neglecting the problems introduced by the curvature of Earth). It may seem remarkable that we can see the star at all, but the blackness of the night sky allows the naked eye to see it as a faint dot of light. It looks much brighter through powerful telescopes, but we still cannot see features of the star's surface.

Now, consider the difficulty of detecting *planets* orbiting nearby stars, which is equivalent to looking from Washington, D.C., and trying to find ball points or marbles orbiting grapefruits in California or beyond. When you consider this challenge, it is all the more remarkable to realize that we now have technology capable of finding such planets [**Section 13.1**].

The vast distances to the stars also offer a sobering lesson about interstellar travel. Although science fiction shows like *Star Trek* and *Star Wars* make such travel look easy, the reality is far different. Consider the *Voyager 2* spacecraft. Launched in 1977, *Voyager 2* flew by Jupiter in 1979, Saturn in 1981, Uranus in 1986, and Neptune in 1989. It is now bound for the stars at a speed of close to 50,000 kilometers per hour—about 100 times as fast as a speeding bullet. But even at this speed, *Voyager 2* would take about 100,000 years to reach Alpha Centauri if it were headed in that direction (which it's not). Convenient interstellar travel remains well beyond our present technology.

The Size of the Milky Way Galaxy The vast separation between our solar system and Alpha Centauri is typical of the separations among star systems in our region of the Milky Way Galaxy. We therefore cannot use the 1-to-10-billion scale for thinking about distances beyond the nearest stars, because more distant stars would not fit on Earth with this scale. To visualize the galaxy, let's reduce our scale by another factor of 1 billion (making it a scale of 1 to 10^{19}).

On this new scale, each light-year becomes 1 millimeter, and the 100,000-light-year diameter of the Milky Way Galaxy becomes 100 meters, or about the length of a football field. Visualize a football field with a scale model of our galaxy centered over midfield. Our entire solar system is a microscopic dot located around the

SPECIAL TOPIC

How Many Planets Are There in Our Solar System?

Until recently, children were taught that our solar system had nine planets. However, in 2006 astronomers voted to demote Pluto to a *dwarf planet*, leaving our solar system with only eight official planets (**FIGURE 1**). Why the change?

FIGURE 1 Notes left at the Voyage scale model solar system Pluto plaque upon Pluto's demotion to dwarf planet.

When Pluto was discovered in 1930, it was assumed to be similar to other planets. But as we'll discuss in Chapter 12, we now know that Pluto is much smaller than any of the first eight planets and that it shares the outer solar system with thousands of other icy objects. Still, as long as Pluto was the largest known of these objects, most astronomers were content to leave the planetary status quo. Change was forced by the 2005 discovery of an object called Eris. Because Eris is slightly larger than Pluto, astronomers could no longer avoid the question of what objects should count as planets.

Official decisions on astronomical names and definitions rest with the International Astronomical Union (IAU), an organization made up of professional astronomers from around the world. The question of Pluto's status was voted upon during the IAU's 2006 meeting. The result was the new definition of "planet" that you see in the Basic Astronomical Definitions box on page 4, and the addition of the "dwarf planet" category to accommodate objects like Pluto and Eris.

Not all astronomers are happy with the new definitions, but for now they seem likely to hold. Of course, some people are likely to keep thinking of Pluto as a planet regardless of what professional astronomers say, much as many people still talk of Europe and Asia as separate continents even though both belong to the same land mass (Eurasia). So if you're a Pluto fan, don't despair: It's good to know the official classifications, but it's better to understand the science behind them.

COMMON MISCONCEPTIONS

Confusing Very Different Things

Most people are familiar with the terms *solar system* and *galaxy*, but few realize how incredibly different they are. Our solar system is a single star system, while our galaxy is a collection of more than 100 billion star systems—so many that it would take thousands of years just to count them. Moreover, if you look at the sizes in Figure 1.1, you'll see that our galaxy is about 100 million times larger in diameter than our solar system. So be careful; numerically speaking, mixing up *solar system* and *galaxy* is a gigantic mistake!

MATHEMATICAL INSIGHT 1.2

The Scale of Space and Time

MA Math Review Video: Scientific Notation, Parts 1 to 3

Making a scale model usually requires nothing more than division. For example, in a 1-to-20 architectural scale model, a building that is actually 6 meters tall will be only 6 ÷ 20 = 0.3 meter tall. The idea is the same for astronomical scaling, except that we usually divide by such large numbers that it's easier to work in *scientific notation*—that is, with the aid of powers of 10. (See Appendixes C.1 and C.2 to review these concepts.)

EXAMPLE 1: How big is the Sun on a 1-to-10-billion scale?

SOLUTION:

Step 1 Understand: We are looking for the scaled *size* of the Sun, so we simply need to divide its actual radius by 10 billion, or 10^{10}. Appendix E.1 gives the Sun's radius as 695,000 km, or 6.95×10^5 km in scientific notation.

Step 2 Solve: We carry out the division:

$$\begin{aligned}\text{scaled radius} &= \frac{\text{actual radius}}{10^{10}}\\ &= \frac{6.95 \times 10^5\,\text{km}}{10^{10}}\\ &= 6.95 \times 10^{(5-10)}\,\text{km} = 6.95 \times 10^{-5}\,\text{km}\end{aligned}$$

Notice that we used the rule that dividing powers of 10 means subtracting their exponents [**Appendix C.1**].

Step 3 Explain: We have found an answer, but because most of us don't have a good sense of what 10^{-5} kilometer looks like, the answer will be more meaningful if we convert it to units that will be easier to interpret. In this case, because there are 1000 (10^3) meters in a kilometer and 100 (10^2) centimeters in a meter, we convert to centimeters:

$$6.95 \times 10^{-5}\,\cancel{\text{km}} \times \frac{10^3\,\cancel{\text{m}}}{1\,\cancel{\text{km}}} \times \frac{10^2\,\text{cm}}{1\,\cancel{\text{m}}} = 6.95\ \text{cm}$$

We've found that on the 1-to-10-billion scale the Sun's radius is about 7 centimeters, which is a diameter of about 14 centimeters—about the size of a large grapefruit.

EXAMPLE 2: What scale allows the 100,000-light-year diameter of the Milky Way Galaxy to fit on a 100-meter-long football field?

SOLUTION:

Step 1 Understand: We want to know *how many times larger* the actual diameter of the galaxy is than 100 meters, so we'll divide the actual diameter by 100 meters. To carry out the division, we'll need both numbers in the same units. We can put the galaxy's diameter in meters by using the fact that a light-year is about 10^{13} kilometers (see Mathematical Insight 1.1) and a kilometer is 10^3 meters; because we are working with powers of 10, we'll write the galaxy's 100,000-light-year diameter as 10^5 ly.

Step 2 Solve: We now convert the units and carry out the division:

$$\begin{aligned}\frac{\text{galaxy diameter}}{\text{football field diameter}} &= \frac{10^5\,\cancel{\text{ly}} \times \dfrac{10^{13}\,\cancel{\text{km}}}{1\,\cancel{\text{ly}}} \times \dfrac{10^3\,\cancel{\text{m}}}{1\,\cancel{\text{km}}}}{10^2\,\cancel{\text{m}}}\\ &= 10^{(5+13+3-2)} = 10^{19}\end{aligned}$$

Note that the answer has no units, because it simply tells us how many times larger one thing is than the other.

Step 3 Explain: We've found that we need a scale of 1 to 10^{19} to make the galaxy fit on a football field.

20-yard line. The 4.4-light-year separation between our solar system and Alpha Centauri becomes just 4.4 millimeters on this scale—smaller than the width of your little finger. If you stood at the position of our solar system in this model, millions of star systems would lie within reach of your arms.

Another way to put the galaxy into perspective is to consider its number of stars—more than 100 billion. Imagine that tonight you are having difficulty falling asleep (perhaps because you are contemplating the scale of the universe). Instead of counting sheep, you decide to count stars. If you are able to count about one star each second, how long would it take you to count 100 billion stars in the Milky Way? Clearly, the answer is 100 billion (10^{11}) seconds, but how long is that? Amazingly, 100 billion seconds is more than 3000 years. (You can confirm this by dividing 100 billion by the number of seconds in 1 year.) You would need thousands of years just to *count* the stars in the Milky Way Galaxy, and this assumes you never take a break—no sleeping, no eating, and absolutely no dying!

The Observable Universe As incredible as the scale of our galaxy may seem, the Milky Way is only one of roughly 100 billion galaxies in the observable universe. Just as it would take thousands of years to count the stars in the Milky Way, it would take thousands of years to count all the galaxies.

Think for a moment about the total number of stars in all these galaxies. If we assume 100 billion stars per galaxy, the total number of stars in the observable universe is roughly 100 billion × 100 billion, or 10,000,000,000,000,000,000,000 (10^{22}). How big is this number? Visit a beach. Run your hands through the fine-grained sand. Imagine counting each tiny grain of sand as it slips through your fingers. Then imagine counting every grain of sand on the beach and continuing to count *every* grain of dry sand on *every* beach on Earth (see Mathematical Insight 1.3). If you could actually complete this task, you would find that the number of grains of sand is comparable to the number of stars in the observable universe (FIGURE 1.9).

THINK ABOUT IT

Contemplate the fact that it would take more than 3000 years just to count out loud the stars in our galaxy, and that each star is a potential sun for a system of planets. How does this perspective affect your thoughts about the possibilities for finding life—or intelligent life—beyond Earth? Explain.

THINK ABOUT IT

Study the foldout in the front of this book, which illustrates the ideas covered in this section in greater detail. Overall, how does visualizing Earth to scale affect your perspective on our planet and on human existence? Explain.

MATHEMATICAL INSIGHT 1.3

Order of Magnitude Estimation

In astronomy, numbers are often so large that an estimate can be useful even if it's good only to about the nearest power of 10. For example, when we multiplied 100 billion stars per galaxy by 100 billion galaxies to estimate that there are about 10^{22} stars in the observable universe, we knew that the "ballpark" nature of these numbers means the actual number of stars could easily be anywhere from about 10^{21} to 10^{23}. Estimates good to about the nearest power of 10 are called **order of magnitude estimates**.

EXAMPLE: Verify the claim that the number of grains of (dry) sand on all the beaches on Earth is comparable to the number of stars in the observable universe.

SOLUTION:

Step 1 Understand: To verify the claim, we need to estimate the number of grains of sand and see if it is close to our estimate of 10^{22} stars. We can estimate the total number of sand grains by dividing the *total volume* of sand on Earth's beaches by the *average volume* of an individual sand grain. Volume is equal to length times width times depth, so the total volume is the total length of sandy beach on Earth multiplied by the typical width and depth of dry sand. That is,

$$\text{total sand grains} = \frac{\text{total volume of beach sand}}{\text{average volume of 1 sand grain}} = \frac{\text{beach length} \times \text{beach width} \times \text{beach depth}}{\text{average volume of 1 sand grain}}$$

We now need numbers to put into the equation. We can estimate the average volume of an individual sand grain by measuring out a small volume of sand, counting the number of grains in this volume, and then dividing the volume by the number of grains. If you do this, you'll find that a reasonable order of magnitude estimate is one-tenth of a cubic millimeter, or 10^{-10} m^3, per sand grain. We can estimate beach width and depth from experience or photos of beaches. Typical widths are about 20 to 50 meters and typical sand depth is about 2 to 5 meters, so we can make the numbers easy by assuming that the product of beach width times depth is about 100 square meters, or 10^2 m^2. The total length of sandy beach on Earth is more difficult to estimate, but you can look online and find that it is less than about 1 million kilometers, or 10^9 m.

Step 2 Solve: We already have our equation and all the numbers we need, so we just put them in; note that we group beach width and depth together, since we estimated them together in Step 1:

$$\begin{aligned}\text{total sand grains} &= \frac{\text{beach length} \times (\text{beach width} \times \text{beach depth})}{\text{average volume of 1 sand grain}}\\ &= \frac{10^9\,\cancel{\text{m}} \times 10^2\,\cancel{\text{m}^2}}{10^{-10}\,\cancel{\text{m}^3}}\\ &= 10^{[9+2-(-10)]} = 10^{21}\end{aligned}$$

Step 3 Explain: Our order of magnitude estimate for the total number of grains of dry sand on all the beaches on Earth is 10^{21}, which is within a factor of 10 of the estimated 10^{22} stars in the observable universe. Because both numbers could easily be off by a factor of 10 or more, we cannot say with certainty that one is larger than the other, but the numbers are clearly comparable.

FIGURE 1.9 The number of stars in the observable universe is comparable to the number of grains of dry sand on all the beaches on Earth.

1.2 THE HISTORY OF THE UNIVERSE

Our universe is vast not only in space, but also in time. In this section, we will briefly discuss the history of the universe as we understand it today.

Before we begin, you may wonder how we can claim to know anything about what the universe was like in the distant past. We'll devote much of the rest of this textbook to understanding how science enables us to do this, but you already know part of the answer: Because looking farther into space means looking further back in time, we can actually *see* parts of the universe as they were long ago, simply by looking far enough away. In other words, our telescopes act somewhat like time machines, enabling us to observe the history of the universe. At great distances, we see the universe as it was long ago, when it was much younger than it is today.

How did we come to be?

FIGURE 1.10 (pages 12–13) summarizes the history of the universe according to modern science. Let's start at the upper left of the figure, and discuss the key events and what they mean.

The Big Bang, Expansion, and the Age of the Universe Telescopic observations of distant galaxies show that the entire universe is *expanding*, meaning that average distances between galaxies are increasing with time. This fact implies that galaxies must have been closer together in the past, and if we go back far enough, we must reach the point at which the expansion began. We call this beginning the **Big Bang**, and scientists use the observed rate of expansion to calculate that it occurred about 14 billion years ago. The three cubes in the upper left portion of Figure 1.10 represent the expansion of a small piece of the universe through time.

The universe as a whole has continued to expand ever since the Big Bang, but on smaller size scales the force of gravity has drawn matter together. Structures such as galaxies and galaxy clusters occupy regions where gravity has won out against the overall expansion. That is, while the universe as a whole continues to expand, individual galaxies and galaxy clusters (and objects within them such as stars and planets) do *not* expand. This idea is also illustrated by the three cubes in Figure 1.10. Notice that as the cube as a whole grew larger, the matter within it clumped into galaxies and galaxy clusters. Most galaxies, including our own Milky Way, formed within a few billion years after the Big Bang.

Stellar Lives and Galactic Recycling Within galaxies like the Milky Way, gravity drives the collapse of clouds of gas and dust to form stars and planets. Stars are not living organisms, but they nonetheless go through "life cycles." A star is born when gravity compresses the material in a cloud to the point at which the center becomes dense enough and hot enough to generate energy by **nuclear fusion**, the process in which lightweight atomic nuclei smash together and stick (or fuse) to make heavier nuclei. The star "lives" as long as it can shine with energy from fusion, and "dies" when it exhausts its usable fuel.

In its final death throes, a star blows much of its content back out into space. The most massive stars die in titanic explosions called *supernovae*. The returned matter mixes with other matter floating between the stars in the galaxy, eventually becoming part of new clouds of gas and dust from which new generations of stars can be born. Galaxies therefore function as cosmic recycling plants, recycling material expelled from dying stars into new generations of stars and planets. This cycle is illustrated in the lower right of Figure 1.10. Our own solar system is a product of many generations of such recycling.

Star Stuff The recycling of stellar material is connected to our existence in an even deeper way. By studying stars of different ages, we have learned that the early universe contained only the simplest chemical elements: hydrogen and helium (and a trace of lithium). We and Earth are made primarily of other elements, such as carbon, nitrogen, oxygen, and iron. Where did these other elements come from? Evidence shows that they were manufactured by stars, some through the nuclear fusion that makes stars shine, and others through nuclear reactions accompanying the explosions that end stellar lives.

By the time our solar system formed, about $4\frac{1}{2}$ billion years ago, earlier generations of stars had already converted about 2% of our galaxy's original hydrogen and helium into heavier elements. Therefore, the cloud that gave birth to our solar system was made of about 98% hydrogen and helium and 2% other elements. This 2% may sound small, but it was more than enough to make the small rocky planets of our solar system, including Earth. On Earth, some of these elements became the raw ingredients of life, which ultimately blossomed into the great diversity of life on Earth today.

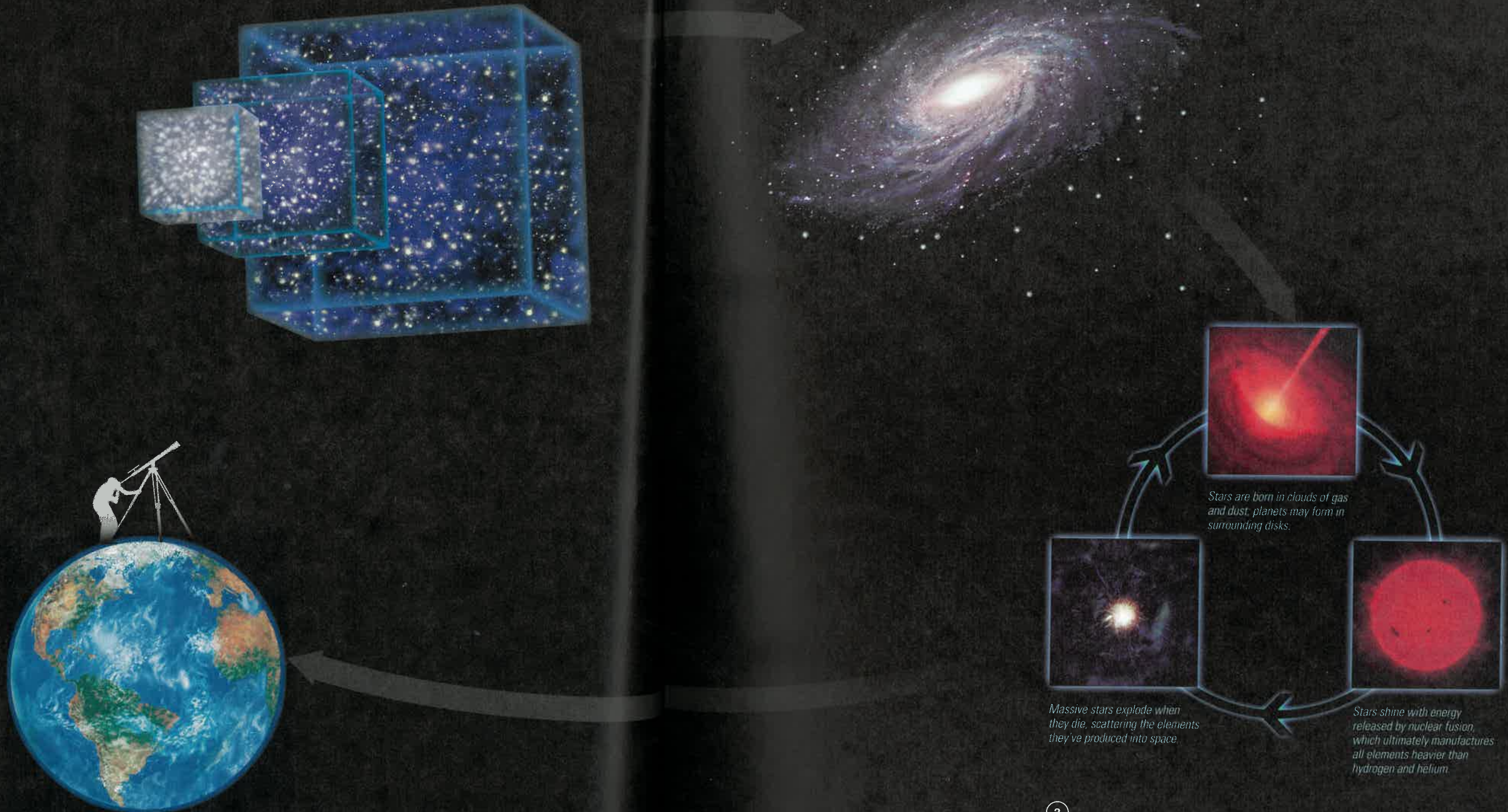
In summary, most of the material from which we and our planet are made was created inside stars that lived and died before the birth of our Sun. As astronomer Carl Sagan (1934–1996) said, we are "star stuff."

COSMIC CONTEXT FIGURE 1.10 Our Cosmic Origins

Throughout this book we will see that human life is intimately connected with the development of the universe as a whole. This illustration presents an overview of our cosmic origins, showing some of the crucial steps that made our existence possible.

① **Birth of the Universe:** The expansion of the universe began with the hot and dense Big Bang. The cubes show how one region of the universe has expanded with time. The universe continues to expand, but on smaller scales gravity has pulled matter together to make galaxies.

② **Galaxies as Cosmic Recycling Plants:** The early universe contained only two chemical elements: hydrogen and helium. All other elements were made by stars and recycled from one stellar generation to the next within galaxies like our Milky Way.



Stars are born in clouds of gas and dust; planets may form in surrounding disks.

Stars shine with energy released by nuclear fusion, which ultimately manufactures all elements heavier than hydrogen and helium.

Massive stars explode when they die, scattering the elements they've produced into space.

③ **Life Cycles of Stars:** Many generations of stars have lived and died in the Milky Way.

④ **Earth and Life:** By the time our solar system was born, 4½ billion years ago, about 2% of the original hydrogen and helium had been converted into heavier elements. We are therefore "star stuff," because we and our planet are made from elements manufactured in stars that lived and died long ago.

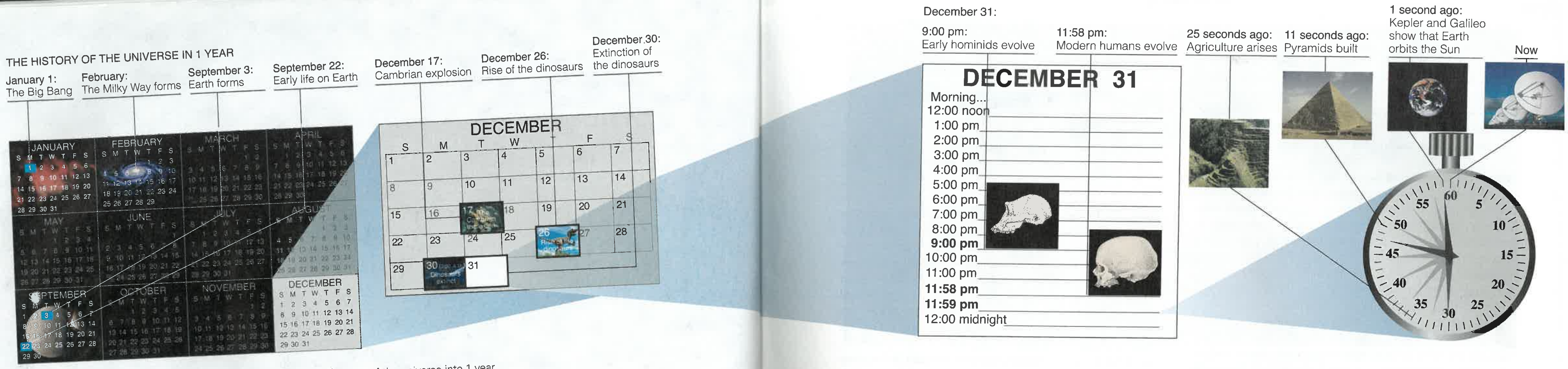


FIGURE 1.11 The cosmic calendar compresses the 14-billion-year history of the universe into 1 year, so each month represents a little more than 1 billion years. This cosmic calendar is adapted from a version created by Carl Sagan. (For a more detailed version, see the "You Are Here in Time" foldout diagram in the front of the book.)

How do our lifetimes compare to the age of the universe?

We can put the 14-billion-year age of the universe into perspective by imagining this time compressed into a single year, so each month represents a little more than 1 billion years. On this *cosmic calendar*, the Big Bang occurred at the first instant of January 1 and the present is the stroke of midnight on December 31 (FIGURE 1.11).

On this time scale, the Milky Way Galaxy probably formed in February. Many generations of stars lived and died in the subsequent cosmic months, enriching the galaxy with the "star stuff" from which we and our planet are made.

Our solar system and our planet did not form until early September on this scale ($4\frac{1}{2}$ billion years ago in real time). By late September, life on Earth was flourishing. However, for most of Earth's history, living organisms remained relatively primitive and microscopic. On the scale of the cosmic calendar, recognizable animals became prominent only in mid-December. Early dinosaurs appeared on the day after Christmas. Then, in a cosmic instant, the dinosaurs disappeared forever—probably because of the impact of an asteroid or a comet **[Section 12.4]**. In real time the death of the dinosaurs occurred some 65 million years ago, but on the cosmic calendar it was only yesterday. With the dinosaurs gone, small furry mammals inherited Earth. Some 60 million years later, or around 9 p.m. on December 31 of the cosmic calendar, early hominids (human ancestors) began to walk upright.

Perhaps the most astonishing fact about the cosmic calendar is that the entire history of human civilization falls into just the last half-minute. The ancient Egyptians built the pyramids only about 11 seconds ago on this scale. About 1 second ago, Kepler and Galileo proved that Earth orbits the Sun rather than vice versa. The average college student was born about 0.05 second ago, around 11:59:59.95 p.m. on the cosmic calendar. On the scale of cosmic time, the human species is the youngest of infants, and a human lifetime is a mere blink of an eye.

THINK ABOUT IT

Study the backside of the foldout in the front of this book, which shows a more detailed version of the cosmic calendar. How does an understanding of the scale of time affect your view of human civilization? Explain.

1.3 SPACESHIP EARTH

Wherever you are as you read this book, you probably have the feeling that you're "just sitting here." Nothing could be further from the truth. As we'll discuss in this section, all of us are moving through space in so many ways that noted inventor and philosopher R. Buckminster Fuller (1895–1983) described us as travelers on *spaceship Earth.*

How is Earth moving through space?

As you "sit" on spaceship Earth, you are in fact being spun in circles as Earth rotates, you are racing around the Sun in Earth's orbit, you are circling the galactic center with our Sun, and you are careening through the cosmos in the Milky Way Galaxy. Let's explore each of these motions in a little more detail.

Rotation and Orbit The most basic motions of Earth are its daily **rotation** (spin) and its yearly **orbit** (or *revolution*) around the Sun.

Earth rotates once each day around its axis, which is the imaginary line connecting the North Pole to the South Pole. Earth rotates from west to east—counterclockwise as viewed from above the North Pole—which is why the Sun and stars appear to rise in the east and set in the west each day. Although the physical effects of rotation are so subtle that our ancestors assumed the heavens revolved around us, the rotation speed is substantial (FIGURE 1.12): Unless you live quite far north or south, you are whirling around Earth's axis at a speed of more than 1000 kilometers per hour (600 miles per hour)—faster than most airplanes travel.

At the same time as it is rotating, Earth also orbits the Sun, completing one orbit each year (FIGURE 1.13). Earth's orbital distance varies slightly over the course of each year, but as we discussed earlier, the average distance is one astronomical unit (AU), which is about 150 million kilometers. Again, even though we don't feel this motion, the speed is impressive: We are racing around the Sun at a speed in excess of 100,000 kilometers per hour (60,000 miles per hour), which is faster than any spacecraft yet launched.

As you study Figure 1.13, notice that Earth's orbital path defines a flat plane that we call the **ecliptic plane**. Earth's axis is tilted by $23\frac{1}{2}°$ from a line *perpendicular* to the ecliptic plane. This **axis tilt** happens to be oriented so that the axis points almost directly at a star called *Polaris,* or the *North Star*. Keep in mind that the idea of axis tilt makes sense only in relation to the ecliptic plane. That is, the idea of "tilt" by itself has no meaning in space, where there is no absolute up or down. In space, "up" and "down" mean only "away from the center of Earth" (or another planet) and "toward the center of Earth," respectively.

THINK ABOUT IT

If there is no up or down in space, why do you think that most globes and maps have the North Pole on top? Would it be equally correct to have the South Pole on top or to turn a globe sideways? Explain.

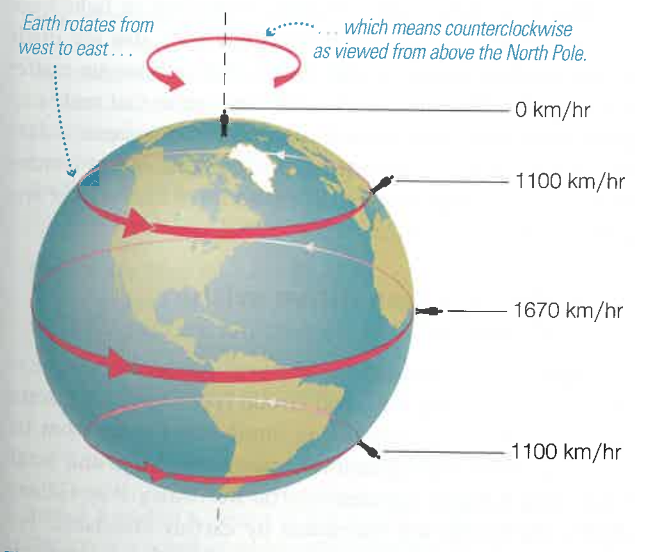


FIGURE 1.12 As Earth rotates, your speed around Earth's axis depends on your location: The closer you are to the equator, the faster you travel with rotation.

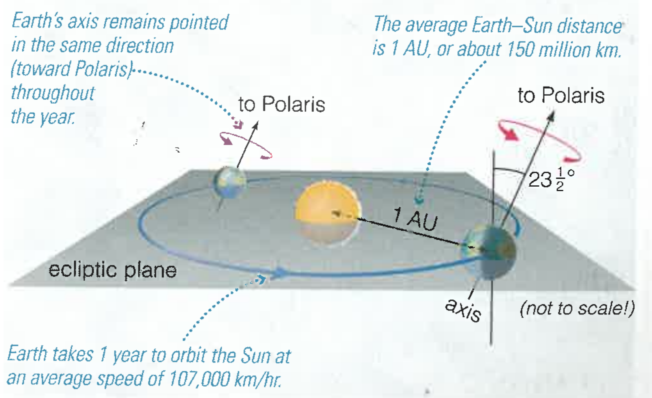


FIGURE 1.13 Earth orbits the Sun at a surprisingly high speed. Notice that Earth both rotates and orbits counterclockwise as viewed from above the North Pole.

Notice also that Earth orbits the Sun in the same direction that it rotates on its axis: counterclockwise as viewed from above the North Pole. This is not a coincidence but a consequence of the way our planet was born. As we'll discuss in Chapter 8, strong evidence indicates that Earth and the other planets were born in a spinning disk of gas that surrounded our Sun when it was young, and Earth rotates and orbits in the same direction that the disk was spinning.

Motion Within the Local Solar Neighborhood Rotation and orbit are only a small part of the travels of spaceship Earth. Our entire solar system is on a great journey within the Milky Way Galaxy. There are two major components to this motion, both shown in FIGURE 1.14. Let's begin with our motion relative to other stars in our *local solar neighborhood,* by which we mean the region of the Sun and nearby stars.

To get a sense of the size of our local solar neighborhood relative to the galaxy, imagine drawing a tiny dot on the painting of the galaxy. Because the galaxy contains at least 100 billion stars, even a dot that is 10,000 times smaller than the whole painting will cover a region representing more than 10 million stars (because 100 billion ÷ 10,000 = 10 million). We usually think of our local solar neighborhood as a region containing just a few thousand to a few million of the nearest stars.

The arrows in the box in Figure 1.14 indicate that stars in our local solar neighborhood move essentially at random relative to one another. The speeds are quite fast: On average, our Sun is moving relative to nearby stars at a speed of about 70,000 kilometers per hour (40,000 miles per hour), almost three times as fast as the Space Station orbits Earth.

Given these high speeds, you might wonder why we don't see stars racing around our sky. The answer lies in their vast distances from us. You've probably noticed that a distant airplane appears to move through your sky more slowly than one flying close overhead. Stars are so far away that even at speeds of 70,000 kilometers per hour, their motions would be noticeable to the naked eye only if we watched them for thousands of years. That is why the patterns in the constellations seem to remain fixed. Nevertheless, in 10,000 years the constellations will be noticeably different from those we see today. In 500,000 years they will be unrecognizable. If you could watch a time-lapse movie made over millions of years, you *would* see stars racing across our sky.

FIGURE 1.14 This painting illustrates the motion of the Sun both within the local solar neighborhood and around the center of the galaxy.

THINK ABOUT IT

Despite the chaos of motion in the local solar neighborhood over millions and billions of years, collisions between star systems are extremely rare. Explain why. (*Hint:* Consider the sizes of star systems, such as the solar system, relative to the distances between them.)

Galactic Rotation If you look closely at leaves floating in a stream, their motions relative to one another might appear random, just like the motions of stars in the local solar neighborhood. As you widen your view, you see that all the leaves are being carried in the same general direction by the downstream current. In the same way, as we widen our view beyond the local solar neighborhood, the seemingly random motions of its stars give way to a simpler and even faster motion: rotation of the Milky Way Galaxy. Our solar system, located about 27,000 light-years from the galactic center, completes one orbit of the galaxy in about 230 million years. Even if you could watch from outside our galaxy, this motion would be unnoticeable to your naked eye. However, if you calculate the speed of our solar system as we orbit the center of the galaxy, you will find that it is close to 800,000 kilometers (500,000 miles) per hour.

Careful study of the galaxy's rotation reveals one of the greatest mysteries in science. Stars at different distances from the galactic center orbit at different speeds, and we can learn how mass is distributed in the galaxy by measuring these speeds. Such studies indicate that the stars in the disk of the galaxy represent only the "tip of the iceberg" compared to the mass of the entire galaxy (FIGURE 1.15). Most of the mass of the galaxy seems to be located outside the visible disk (occupying the galactic *halo* that surrounds and encompasses the disk), but the matter that makes up this mass is completely invisible to our telescopes. We therefore know very little about the nature of this matter, which we refer to as *dark matter* (because of the lack of light from it). Studies of other galaxies suggest that they also are made mostly of dark matter, which means this mysterious matter must significantly outweigh the ordinary matter that makes up planets and stars. We know even less about the mysterious *dark energy* that seems to make up much of the total energy content of the universe. We'll discuss the mysteries of dark matter and dark energy in Chapter 23.

How do galaxies move within the universe?

The billions of galaxies in the universe also move relative to one another. Within the Local Group (see Figure 1.1), some of the galaxies move toward us, some move away from us, and at least two small galaxies (known as the Large and Small Magellanic Clouds) apparently orbit our Milky Way Galaxy. Again, the speeds are enormous by earthly standards. For example, the Milky Way is moving toward the Andromeda Galaxy at about 300,000 kilometers per hour (180,000 miles per hour). Despite this high speed, we needn't worry about a

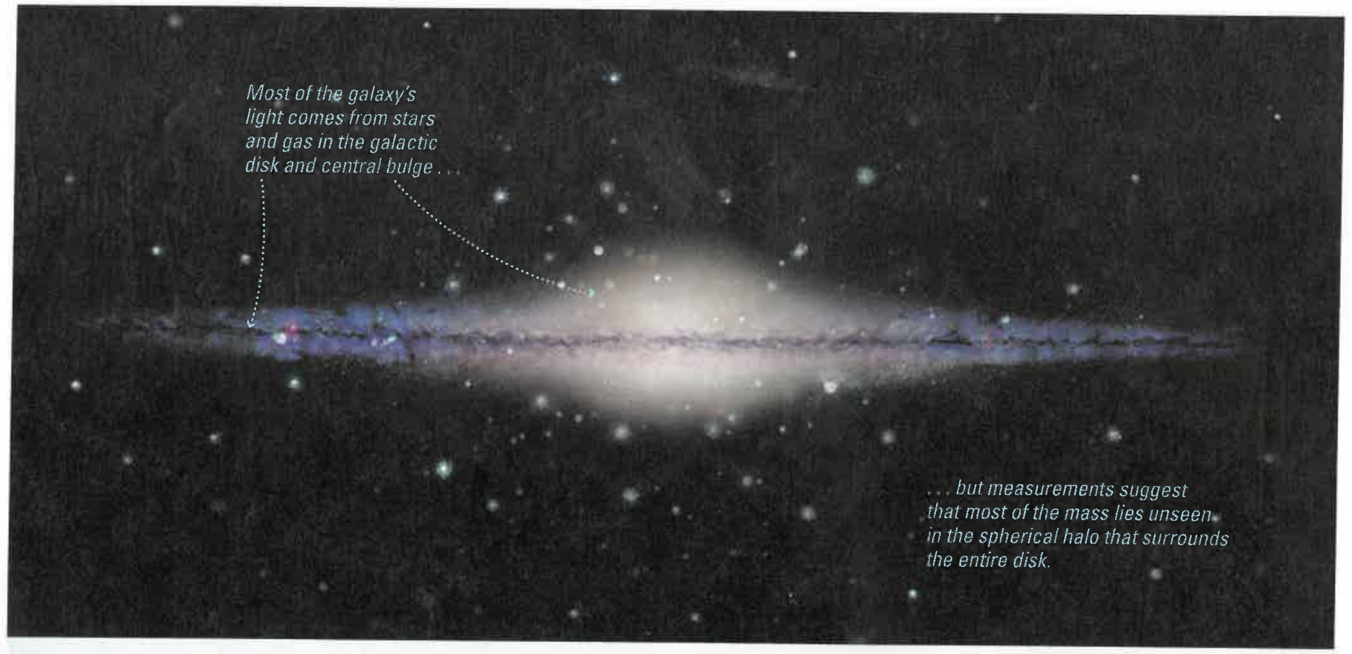


FIGURE 1.15 This painting shows an edge-on view of the Milky Way Galaxy. Study of galactic rotation shows that although most visible stars lie in the central bulge or thin disk, most of the mass lies in the halo that surrounds and encompasses the disk. Because this mass emits no light that we have detected, we call it *dark matter.*

MATHEMATICAL INSIGHT 1.4

Speeds of Rotation and Orbit

MA Math Review Video: Problem Solving, Part 3

Building upon prior Mathematical Insights, we will now see how simple formulas—such as the formula for the circumference of a circle—expand the range of astronomical problems we can solve.

EXAMPLE 1: How fast is a person on Earth's equator moving with Earth's rotation?

SOLUTION:

Step 1 Understand: The question *how fast* tells us we are looking for a *speed.* If you remember that highway speeds are posted in miles (or kilometers) per hour, you'll realize that speed is a distance (such as miles) divided by a time (such as hours). In this case, the distance is Earth's equatorial circumference, because that is how far a person at the equator travels with each rotation (see Figure 1.12); we'll therefore use the formula for the circumference of a circle, $C = 2 \times \pi \times \text{radius}$. The time is 24 hours, because that is how long each rotation takes.

Step 2 Solve: From Appendix E.1, Earth's equatorial radius is 6378 km, so its circumference is $2 \times \pi \times 6378\text{ km} = 40{,}074\text{ km}$. We divide this distance by the time of 24 hours:

$$\begin{aligned}\text{rotation speed at equator} &= \frac{\text{equatorial circumference}}{\text{length of day}}\\ &= \frac{40{,}074\text{ km}}{24\text{ hr}} = 1670\,\frac{\text{km}}{\text{hr}}\end{aligned}$$

Step 3 Explain: A person at the equator is moving with Earth's rotation at a speed of about 1670 kilometers per hour, which is a little over 1000 miles per hour, or about twice the flying speed of a commercial jet.

EXAMPLE 2: How fast is Earth orbiting the Sun?

SOLUTION:

Step 1 Understand: We are again asked *how fast* and therefore need to divide a distance by a time. In this case, the distance is the circumference of Earth's orbit, and the time is the 1 year that Earth takes to complete each orbit.

Step 2 Solve: Earth's average distance from the Sun is 1 AU, or about 150 million (1.5×10^8) km, so the orbit circumference is about $2 \times \pi \times 1.5 \times 10^8\text{ km} \approx 9.40 \times 10^8\text{ km}$. The orbital speed is this distance divided by the time of 1 year, which we convert to hours so that we end up with units of km/hr:

$$\begin{aligned}\text{orbital speed} &= \frac{\text{orbital circumference}}{1\text{ yr}}\\ &= \frac{9.40 \times 10^8\text{ km}}{1\,\cancel{\text{yr}} \times \frac{365\,\cancel{\text{day}}}{\cancel{\text{yr}}} \times \frac{24\text{ hr}}{\cancel{\text{day}}}} \approx 107{,}000\,\frac{\text{km}}{\text{hr}}\end{aligned}$$

Step 3 Explain: Earth orbits the Sun at an average speed of about 107,000 km/hr (66,000 mi/hr). Most "speeding bullets" travel between about 500 and 1000 km/hr, so Earth's orbital speed is more than 100 times as fast as a speeding bullet.

collision anytime soon. Even if the Milky Way and Andromeda Galaxies are approaching each other head-on, it will be billions of years before any collision begins.

When we look outside the Local Group, however, we find two astonishing facts recognized in the 1920s by Edwin Hubble, for whom the Hubble Space Telescope was named:

1. Virtually every galaxy outside the Local Group is moving *away* from us.
2. The more distant the galaxy, the faster it appears to be racing away.

These facts might make it sound as if we suffered from a cosmic case of chicken pox, but there is a much more natural explanation: *The entire universe is expanding.* We'll save the details for later in the book, but you can understand the basic idea by thinking about a raisin cake baking in an oven.

The Raisin Cake Analogy Imagine that you make a raisin cake in which the distance between adjacent raisins is 1 centimeter. You place the cake into the oven, where it expands as it bakes. After 1 hour, you remove the cake, which has expanded so that the distance between adjacent raisins has increased to 3 centimeters (FIGURE 1.16). The expansion of the cake seems fairly obvious. But what would you see if you lived *in* the cake, as we live in the universe?

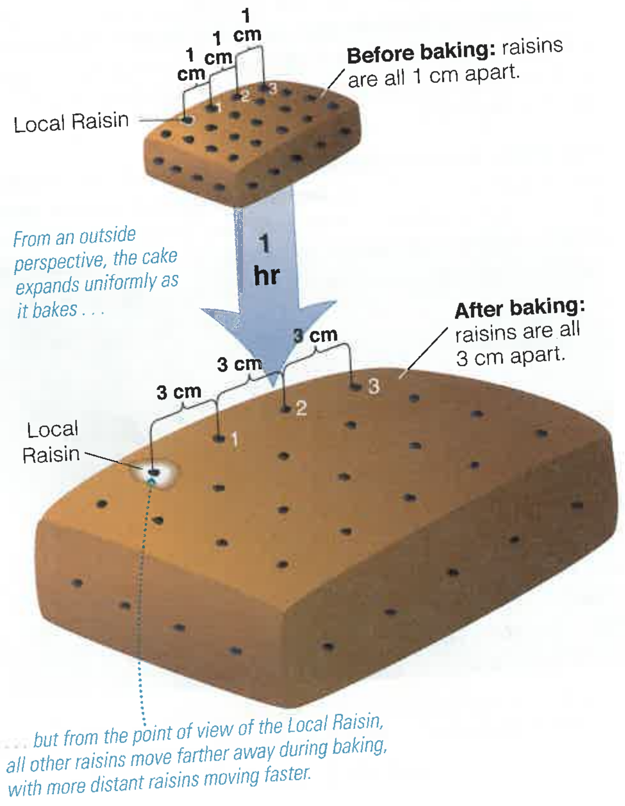
Pick any raisin (it doesn't matter which one) and call it the Local Raisin. Figure 1.16 shows one possible choice, with three nearby raisins also labeled. The accompanying table summarizes what you would see if you lived within the Local Raisin. Notice, for example, that Raisin 1 starts out at a distance of 1 centimeter before baking and ends up at a distance of 3 centimeters after baking, which means it moves a distance of 2 centimeters away from the Local Raisin during the hour of baking. Hence, its speed as seen from the Local Raisin is 2 centimeters per hour. Raisin 2 moves from a distance of 2 centimeters before baking to a distance of 6 centimeters after baking, which means it moves a distance of 4 centimeters away from the Local Raisin during the hour. Hence, its speed is 4 centimeters per hour, or twice the speed of Raisin 1. Generalizing, the fact that the cake is expanding means that all the raisins are moving away from the Local Raisin, with more distant raisins moving away faster.

THINK ABOUT IT

Suppose a raisin started out 10 centimeters from the Local Raisin. How far away would it be after one hour, and how fast would it be moving away from the Local Raisin?

Hubble's discovery that galaxies are moving in much the same way as the raisins in the cake, with most moving away from us and more distant ones moving away faster, implies that the universe is expanding much like the raisin cake. If you now imagine the Local Raisin as representing our Local Group of galaxies and the other raisins as representing more distant galaxies or clusters of galaxies, you have a basic picture of the expansion of the universe. Like the expanding dough between the raisins in the cake, *space* itself is growing between galaxies. More distant galaxies move away from us faster because they are carried along with this expansion like the raisins in the expanding cake. Many billions of light-years away, we see galaxies moving away from us at speeds approaching the speed of light.

The Real Universe There's at least one important distinction between the raisin cake and the universe: A cake has a center and edges, but we do not think the same is true of the entire universe. Anyone living in any galaxy in an expanding universe sees just what we see—other galaxies moving away, with more distant ones moving away faster. Because the view from each point in the universe is about the same, no place can claim to be more "central" than any other place.



Distances and Speeds as Seen from the Local Raisin

Raisin Number	Distance Before Baking	Distance After Baking (1 hour later)	Speed
1	1 cm	3 cm	2 cm/hr
2	2 cm	6 cm	4 cm/hr
3	3 cm	9 cm	6 cm/hr
⋮	⋮	⋮	⋮

FIGURE 1.16 **interactive figure** An expanding raisin cake offers an analogy to the expanding universe. Someone living in one of the raisins inside the cake could figure out that the cake is expanding by noticing that all other raisins are moving away, with more distant raisins moving away faster. In the same way, we know that we live in an expanding universe because all galaxies outside our Local Group are moving away from us, with more distant ones moving faster.

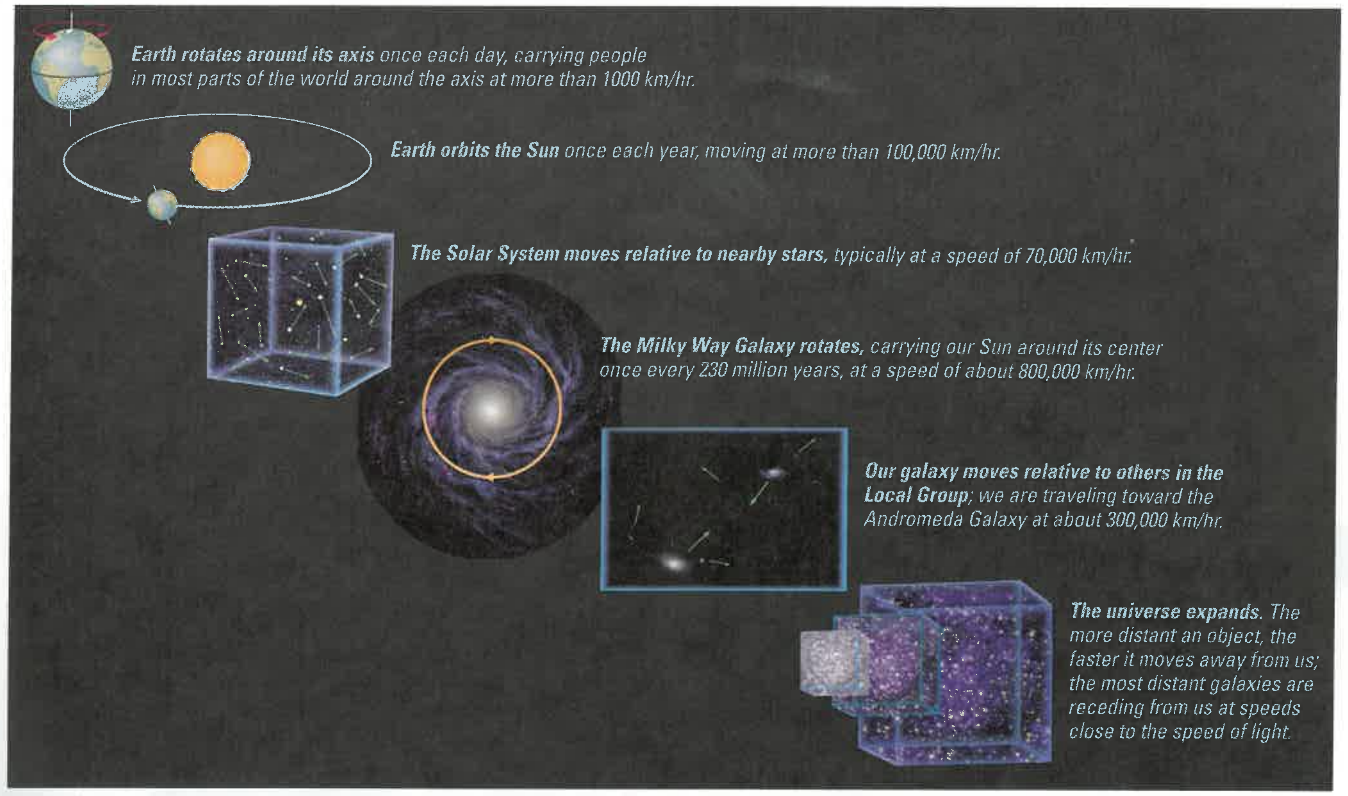


FIGURE 1.17 This figure summarizes the basic motions of Earth in the universe, along with their associated speeds.

It's also important to realize that, unlike the case with a raisin cake, we can't actually *see* galaxies moving apart with time—the distances are too vast for any motion to be noticeable on the time scale of a human life. Instead, we measure the speeds of galaxies by spreading their light into spectra and observing what we call *Doppler shifts* [**Section 5.4**]. This illustrates how modern astronomy depends both on careful observations and on using current understanding of the laws of nature to explain what we see.

Motion Summary FIGURE 1.17 summarizes the motions we have discussed. As we have seen, we are never truly sitting still. We spin around Earth's axis at more than 1000 kilometers per hour, while our planet orbits the Sun at more than 100,000 kilometers per hour. Our solar system moves among the stars of the local solar neighborhood at typical speeds of 70,000 kilometers per hour, while also orbiting the center of the Milky Way Galaxy at a speed of about 800,000 kilometers per hour. Our galaxy moves among the other galaxies of the Local Group, while all other galaxies move away from us at speeds that grow greater with distance in our expanding universe. Spaceship Earth is carrying us on a remarkable journey.

1.4 THE HUMAN ADVENTURE OF ASTRONOMY

In relatively few pages, we've laid out a fairly complete overview of modern scientific ideas about the universe. But our goal in this book is not simply for you to be able to recite these ideas. Rather, it is to help you understand the evidence that supports them and the extraordinary story of how they developed.

How has the study of astronomy affected human history?

Astronomy is a human adventure in the sense that it affects everyone—even those who have never looked at the sky—because the history of astronomy has been so deeply intertwined with the development of civilization. Revolutions in astronomy have gone hand in hand with the revolutions in science and technology that have shaped modern life.

Witness the repercussions of the *Copernican revolution*, which showed us that Earth is not the center of the universe but rather just one planet orbiting the Sun. This revolution, which we will discuss further in Chapter 3, began when Copernicus published his idea of a Sun-centered solar system in 1543. Three later figures—Tycho Brahe, Johannes Kepler, and Galileo—provided the key evidence that eventually led to wide acceptance of the Copernican idea. The revolution culminated with Isaac Newton's uncovering of the laws of motion and gravity. Newton's work, in turn, became the foundation of physics that helped fuel the industrial revolution.

More recently, the development of space travel and the computer revolution have helped fuel tremendous progress in astronomy. We've sent probes to all the planets in our solar system, and many of our most powerful observatories, including the Hubble Space Telescope, reside in space. On the ground, computer design and control have led to tremendous growth in the size and power of telescopes.

Many of these efforts, and the achievements they spawned, led to profound social change. The most famous example is the fate of Galileo, whom the Vatican put under house arrest in 1633 for his claims that Earth orbits the Sun. Although the Church soon recognized that Galileo was right, he was formally vindicated only in 1992 with a statement by Pope John Paul II. In the meantime, his case spurred great debate in religious circles and profoundly influenced both theological and scientific thinking.

As you progress through this book and learn about astronomical discovery, try to keep in mind the context of the human adventure. You will then be learning not just about a science, but also about one of the great forces that has shaped our modern world.

These forces will continue to play a role in our future. What will it mean to us when we learn the nature of dark matter and dark energy? How will our view of Earth change when we learn whether life is common or rare in the universe? Only time may answer these questions, but the chapters ahead will give you the foundation you need to understand how we changed from a primitive people looking at patterns in the night sky to a civilization capable of asking deep questions about our existence.

The Big Picture

Putting Chapter 1 into Context

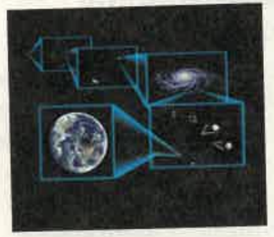
In this first chapter, we developed a broad overview of our place in the universe. As we consider the universe in more depth in the rest of the book, remember the following "big picture" ideas:

- Earth is not the center of the universe but instead is a planet orbiting a rather ordinary star in the Milky Way Galaxy. The Milky Way Galaxy, in turn, is one of billions of galaxies in our observable universe.
- Cosmic distances are literally astronomical, but we can put them in perspective with the aid of scale models and other scaling techniques. When you think about these enormous scales, don't forget that every star is a sun and every planet is a unique world.
- We are "star stuff." The atoms from which we are made began as hydrogen and helium in the Big Bang and were later fused into heavier elements by massive stars. Stellar deaths released these atoms into space, where our galaxy recycled them into new stars and planets. Our solar system formed from such recycled matter some $4\frac{1}{2}$ billion years ago.
- We are latecomers on the scale of cosmic time. The universe was already more than half its current age when our solar system formed, and it took billions of years more before humans arrived on the scene.
- All of us are being carried through the cosmos on spaceship Earth. Although we cannot feel this motion in our everyday lives, the associated speeds are surprisingly high. Learning about the motions of spaceship Earth gives us a new perspective on the cosmos and helps us understand its nature and history.

SUMMARY OF KEY CONCEPTS

1.1 THE SCALE OF THE UNIVERSE

- **What is our place in the universe?** Earth is a planet orbiting the Sun. Our Sun is one of more than 100 billion stars in the **Milky Way Galaxy.** Our galaxy is one of about 40 galaxies in the **Local Group.** The Local Group is one small part of the **Local Supercluster,** which is one small part of the **universe.**

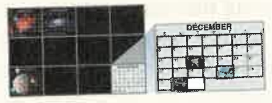


- **How big is the universe?** If we imagine our Sun as a large grapefruit, Earth is a ball point that orbits 15 meters away; the nearest stars are thousands of kilometers away on the same scale. Our galaxy contains more than 100 billion stars—so many that it would take thousands of years just to count them out loud. The observable universe contains roughly 100 billion galaxies, and the total number of stars is comparable to the number of grains of dry sand on all the beaches on Earth.

1.2 THE HISTORY OF THE UNIVERSE

- **How did we come to be?** The universe began in the **Big Bang** and has been expanding ever since, except in localized regions where gravity has caused matter to collapse into galaxies and stars. The Big Bang essentially produced only two chemical elements: hydrogen and helium. The rest have been produced by stars and recycled within galaxies from one generation of stars to the next, which is why we are "star stuff."

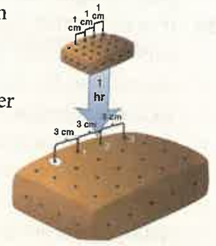
- **How do our lifetimes compare to the age of the universe?** On a cosmic calendar that compresses the history of the universe into 1 year, human civilization is just a few seconds old, and a human lifetime lasts only a fraction of a second.



1.3 SPACESHIP EARTH

- **How is Earth moving through space?** Earth **rotates** on its axis once each day and **orbits** the Sun once each year. At the same time, we move with our Sun in random directions relative to other stars in our local solar neighborhood, while the galaxy's rotation carries us around the center of the galaxy every 230 million years.

- **How do galaxies move within the universe?** Galaxies move essentially at random within the Local Group, but all galaxies beyond the Local Group are moving away from us. More distant galaxies are moving faster, which tells us that we live in an expanding universe.



1.4 THE HUMAN ADVENTURE OF ASTRONOMY

- **How has the study of astronomy affected human history?** Throughout history, astronomy has developed hand in hand with social and technological development. Astronomy thereby touches all of us and is a human adventure that all can enjoy.

VISUAL SKILLS CHECK

Use the following questions to check your understanding of some of the many types of visual information used in astronomy. Answers are provided in Appendix J. For additional practice, try the Chapter 1 Visual Quiz at MasteringAstronomy®.

Useful Data:

Earth-Sun distance = 150,000,000 km

Diameter of Sun = 1,400,000 km

Earth-Moon distance = 384,000 km

Diameter of Earth = 12,800 km

The figure above shows the sizes of Earth and the Moon to scale; the scale used is 1 cm = 4000 km. Using what you've learned about astronomical scale in this chapter, answer the following questions. Hint: If you are unsure of the answers, you can calculate them using the data given above.

1. If you wanted to show the *distance* between Earth and the Moon on the same scale, about how far apart would you need to place the two photos?
   a. 10 centimeters (about the width of your hand)
   b. 1 meter (about the length of your arm)
   c. 100 meters (about the length of a football field)
   d. 1 kilometer (a little more than a half mile)
2. Suppose you wanted to show the Sun on the same scale. About how big would it need to be?
   a. 3.5 centimeters in diameter (the size of a golf ball)
   b. 35 centimeters in diameter (a little bigger than a basketball)
   c. 3.5 meters in diameter (about 11-1/2 feet across)
   d. 3.5 kilometers in diameter (the size of a small town)
3. About how far away from Earth would the Sun be located on this scale?
   a. 3.75 meters (about 12 feet)
   b. 37.5 meters (about the height of a 12-story building)
   c. 375 meters (about the length of four football fields)
   d. 37.5 kilometers (the size of a large city)
4. Could you use the same scale to represent the distances to nearby stars? Why or why not?

EXERCISES AND PROBLEMS

For instructor-assigned homework go to MasteringAstronomy®.

MasteringAstronomy®

REVIEW QUESTIONS

Short-Answer Questions Based on the Reading

1. Briefly describe the major levels of structure (such as planet, star, galaxy) in the universe.
2. Define *astronomical unit* and *light-year*.
3. Explain the statement *The farther away we look in distance, the further back we look in time.*
4. What do we mean by the *observable universe*? Is it the same thing as the entire universe?
5. Using techniques described in the chapter, put the following into perspective: the size of our solar system; the distance to nearby stars; the size and number of stars in the Milky Way Galaxy; the number of stars in the observable universe.
6. What do we mean when we say that the universe is *expanding*, and how does expansion lead to the idea of the *Big Bang* and our current estimate of the age of the universe?
7. In what sense are we "star stuff"?

8. Use the cosmic calendar to describe how the human race fits into the scale of time.
9. Briefly explain Earth's daily rotation and annual orbit, defining the terms *ecliptic plane* and *axis tilt*.
10. Briefly describe our solar system's location and motion within the Milky Way Galaxy.
11. Where does *dark matter* seem to reside in our galaxy? What makes dark matter and *dark energy* so mysterious?
12. What key observations lead us to conclude that the universe is expanding? Use the raisin cake model to explain how these observations imply expansion.

TEST YOUR UNDERSTANDING

Does It Make Sense?

Decide whether the statement makes sense (or is clearly true) or does not make sense (or is clearly false). Explain clearly; not all of these have definitive answers, so your explanation is more important than your chosen answer.

Example: I walked east from our base camp at the North Pole.

Solution: The statement does not make sense because east has no meaning at the North Pole—all directions are south from the North Pole.

13. Our solar system is bigger than some galaxies.
14. The universe is billions of light-years in age.
15. It will take me light-years to complete this homework assignment!
16. Someday we may build spaceships capable of traveling a light-year in only a decade.
17. Astronomers recently discovered a moon that does not orbit a planet.
18. NASA plans soon to launch a spaceship that will photograph our Milky Way Galaxy from beyond its halo.
19. The observable universe is the same size today as it was a few billion years ago.
20. Photographs of distant galaxies show them as they were when they were much younger than they are today.
21. At a nearby park, I built a scale model of our solar system in which I used a basketball to represent Earth.
22. Because nearly all galaxies are moving away from us, we must be located at the center of the universe.

Quick Quiz

Choose the best answer to each of the following. Explain your reasoning with one or more complete sentences.

23. Which of the following correctly lists our "cosmic address" from small to large? (a) Earth, solar system, Milky Way Galaxy, Local Group, Local Supercluster, universe (b) Earth, solar system, Local Group, Local Supercluster, Milky Way Galaxy, universe (c) Earth, Milky Way Galaxy, solar system, Local Group, Local Supercluster, universe.
24. An astronomical unit is (a) any planet's average distance from the Sun. (b) Earth's average distance from the Sun. (c) any large astronomical distance.
25. The star Betelgeuse is about 600 light-years away. If it explodes tonight, (a) we'll know because it will be brighter than the full Moon in the sky. (b) we'll know because debris from the explosion will rain down on us from space. (c) we won't know about it until about 600 years from now.
26. If we represent the solar system on a scale that allows us to walk from the Sun to Pluto in a few minutes, then (a) the planets are the size of basketballs and the nearest stars are a few miles away. (b) the planets are marble-size or smaller and the nearest stars are thousands of miles away. (c) the planets are microscopic and the stars are light-years away.
27. The total number of stars in the observable universe is roughly equivalent to (a) the number of grains of sand on all the beaches on Earth. (b) the number of grains of sand on Miami Beach. (c) infinity.
28. When we say the universe is *expanding*, we mean that (a) everything in the universe is growing in size. (b) the average distance between galaxies is growing with time. (c) the universe is getting older.
29. If stars existed but galaxies did not, (a) we would probably still exist anyway. (b) we would not exist because life on Earth depends on the light of galaxies. (c) we would not exist because we are made of material that was recycled in galaxies.
30. Could we see a galaxy that is 50 billion light-years away? (a) Yes, if we had a big enough telescope. (b) No, because it would be beyond the bounds of our observable universe. (c) No, because a galaxy could not possibly be that far away.
31. The age of our solar system is about (a) one-third of the age of the universe. (b) three-fourths of the age of the universe. (c) two billion years less than the age of the universe.
32. The fact that nearly all galaxies are moving away from us, with more distant ones moving faster, helped us to conclude that (a) the universe is expanding. (b) galaxies repel each other like magnets. (c) our galaxy lies near the center of the universe.

PROCESS OF SCIENCE

Examining How Science Works

33. *Earth as a Planet.* For most of human history, scholars assumed Earth was the center of the universe. Today, we know that our Sun is just one star in a vast universe. How did science make it possible for us to learn these facts about Earth?
34. *Thinking About Scale.* One key to success in science is finding simple ways to evaluate new ideas, and making a simple scale model is often helpful. Suppose someone tells you that the reason it is warmer during the day than at night is that the day side of Earth is closer to the Sun than the night side. Evaluate this idea by thinking about the size of Earth and its distance from the Sun in a scale model of the solar system.
35. *Looking for Evidence.* In this first chapter, we have discussed the scientific story of the universe but have not yet discussed most of the evidence that backs it up. Choose one idea presented in this chapter—such as the idea that there are billions of galaxies in the universe, or that the universe was born in the Big Bang, or that the galaxy contains more dark matter than ordinary matter—and briefly discuss the type of evidence you would want to see before accepting the idea. (*Hint:* It's okay to look ahead in the book to see the evidence presented in later chapters.)

GROUP WORK EXERCISE

36. *Counting the Milky Way's Stars.* In this exercise, you will first make an estimate of the number of stars in the Milky Way and then apply some scientific thinking to your estimation method. Before you begin, assign the following roles to the people in your group: *Scribe* (takes notes on the group's activities), *Proposer* (proposes explanations to the group), *Skeptic* (points out weaknesses in proposed explanations), and *Moderator* (leads group discussion and makes sure everyone contributes).

    a. Estimate the number of stars in the Milky Way as follows. First, count the number of stars within 12 light-years of the Sun, which are listed in Appendix F. Assuming that the Milky Way's disk is 100,000 light-years across and 1000 light-years thick, its volume is about 1 billion times the volume of the region of your star count. You should therefore multiply your count by 1 billion to get an estimate of the total number of stars in the Milky Way. **b.** Your estimate from part a is based on the number of stars near the Sun. Compare it to the value given in this chapter and determine whether your estimate is an underestimate or an overestimate of the total number of stars in the Milky Way. Write down a list of possible reasons why your technique gave you an under/overestimate.

INVESTIGATE FURTHER

In-Depth Questions to Increase Your Understanding

Short-Answer/Essay Questions

37. *Alien Technology.* Some people believe that Earth is regularly visited by aliens who travel here from other star systems. For this to be true, how much more advanced than our own technology would the alien space travel technology have to be? Write one to two paragraphs to give a sense of the technological difference. (*Hint:* Use the scale model from this chapter to contrast the distance the aliens would have to travel easily with the distances we currently are capable of traveling.)
38. *Raisin Cake Universe.* Suppose that all the raisins in a cake are 1 centimeter apart before baking and 4 centimeters apart after baking.

    a. Draw diagrams to represent the cake before and after baking.
    b. Identify one raisin as the Local Raisin on your diagrams. Construct a table showing the distances and speeds of other raisins as seen from the Local Raisin. **c.** Briefly explain how your expanding cake is similar to the expansion of the universe.
39. *Scaling the Local Group of Galaxies.* Both the Milky Way Galaxy and the Andromeda Galaxy (M31) have a diameter of about 100,000 light-years. The distance between the two galaxies is about 2.5 million light-years.

    a. Using a scale on which 1 centimeter represents 100,000 light-years, draw a sketch showing both galaxies and the distance between them to scale. **b.** How does the separation between galaxies compare to the separation between stars? Based on your answer, discuss the likelihood of galactic collisions in comparison to the likelihood of stellar collisions.
40. *The Cosmic Perspective.* Write a short essay describing how the ideas presented in this chapter affect your perspectives on your own life and on human civilization.

Quantitative Problems

Be sure to show all calculations clearly and state your final answers in complete sentences.

41. *Distances by Light.* Just as a light-year is the distance that light can travel in 1 year, we define a light-second as the distance that light can travel in 1 second, a light-minute as the distance that light can travel in 1 minute, and so on. Calculate the distance in both kilometers and miles represented by each of the following:

    a. 1 light-second. **b.** 1 light-minute. **c.** 1 light-hour. **d.** 1 light-day.
42. *Spacecraft Communication.* We use radio waves, which travel at the speed of light, to communicate with robotic spacecraft. How long does it take a message to travel from Earth to a spacecraft at

    a. Mars at its closest to Earth (about 56 million km)? **b.** Mars at its farthest from Earth (about 400 million km)? **c.** Pluto at its average distance from Earth (about 5.9 billion km)?
43. *Saturn vs. the Milky Way.* Photos of Saturn and photos of galaxies can look so similar that children often think the photos show similar objects. In reality, a galaxy is far larger than any planet. About how many times larger is the diameter of the Milky Way Galaxy than the diameter of Saturn's rings? (Data: Saturn's rings are about 270,000 km in diameter; the Milky Way is 100,000 light-years in diameter.)
44. *Galaxy Scale.* Consider the 1-to-10^{19} scale on which the disk of the Milky Way Galaxy fits on a football field. On this scale, how far is it from the Sun to Alpha Centauri (real distance: 4.4 light-years)? How big is the Sun itself on this scale? Compare the Sun's size on this scale to the actual size of a typical atom (about 10^{-10} m in diameter).
45. *Universal Scale.* Suppose we wanted to make a scale model of the Local Group of galaxies, in which the Milky Way Galaxy was the size of a marble (about 1 cm in diameter).

    a. How far from the Milky Way Galaxy would the Andromeda Galaxy be on this scale? **b.** How far would the Sun be from Alpha Centauri on this scale? **c.** How far would it be from the Milky Way Galaxy to the most distant galaxies in the observable universe on this scale?
46. *Driving Trips.* Imagine that you could drive your car at a constant speed of 100 km/hr (62 mi/hr), even across oceans and in space. (In reality, the law of gravity would make driving through space at a constant speed all but impossible.) How long would it take to drive

    a. around Earth's equator? **b.** from the Sun to Earth? **c.** from the Sun to Pluto? **d.** to Alpha Centauri?
47. *Faster Trip.* Suppose you wanted to reach Alpha Centauri in 100 years.

    a. How fast would you have to go, in km/hr? **b.** How many times faster is the speed you found in part a than the speeds of our fastest current spacecraft (around 50,000 km/hr)?
48. *Galactic Rotation Speed.* We are located about 27,000 light-years from the galactic center and we orbit the center about once every 230 million years. How fast are we traveling around the galaxy, in km/hr?
49. *Earth Rotation Speed.* Mathematical Insight 1.3 shows how to find Earth's equatorial rotation speed. To find the rotation speed at any other latitude, you need the following fact: The radial distance from Earth's axis at any latitude is equal to the equatorial radius times the *cosine* of the latitude. Use this fact to find the rotation speed at the following latitudes. (*Hint:* When using the cosine (cos) function, be sure your calculator is set to recognize angles in degree mode, not in radian or gradient mode.)

    a. 30°N **b.** 60°N **c.** your latitude.

Discussion Questions

50. *Eliot Quote.* Think carefully about the chapter-opening quotation from T. S. Eliot. What do you think he means? Explain clearly.
51. *Infant Species.* In the last few tenths of a second before midnight on December 31 of the cosmic calendar, we have developed an incredible civilization and learned a great deal about the universe, but we also have developed technology with which we could destroy ourselves. The midnight bell is striking, and the choice for the future is ours. How far into the next cosmic year do you think our civilization will survive? Defend your opinion.
52. *A Human Adventure.* Astronomical discoveries clearly are important to science, but are they also important to our personal lives? Defend your opinion.

Web Projects

53. *Astronomy on the Web.* The Web contains a vast amount of astronomical information. Spend at least an hour exploring astronomy on the Web. Write two or three paragraphs summarizing what you learned from your research. What was your favorite astronomical website, and why?
54. *NASA Missions.* Visit the NASA website to learn about upcoming astronomy missions. Write a one-page summary of the mission you believe is most likely to give us new astronomical information before the end of your astronomy course.
55. *The Hubble Ultra Deep Field.* The photo that opens this chapter is called the Hubble Ultra Deep Field. Find this photo on the Hubble Space Telescope website. Learn how it was taken, what it shows, and what we've learned from it. Write a short summary of your findings.