Michael Seeds
Dana Backman

HORIZONS

EXPLORING THE UNIVERSE

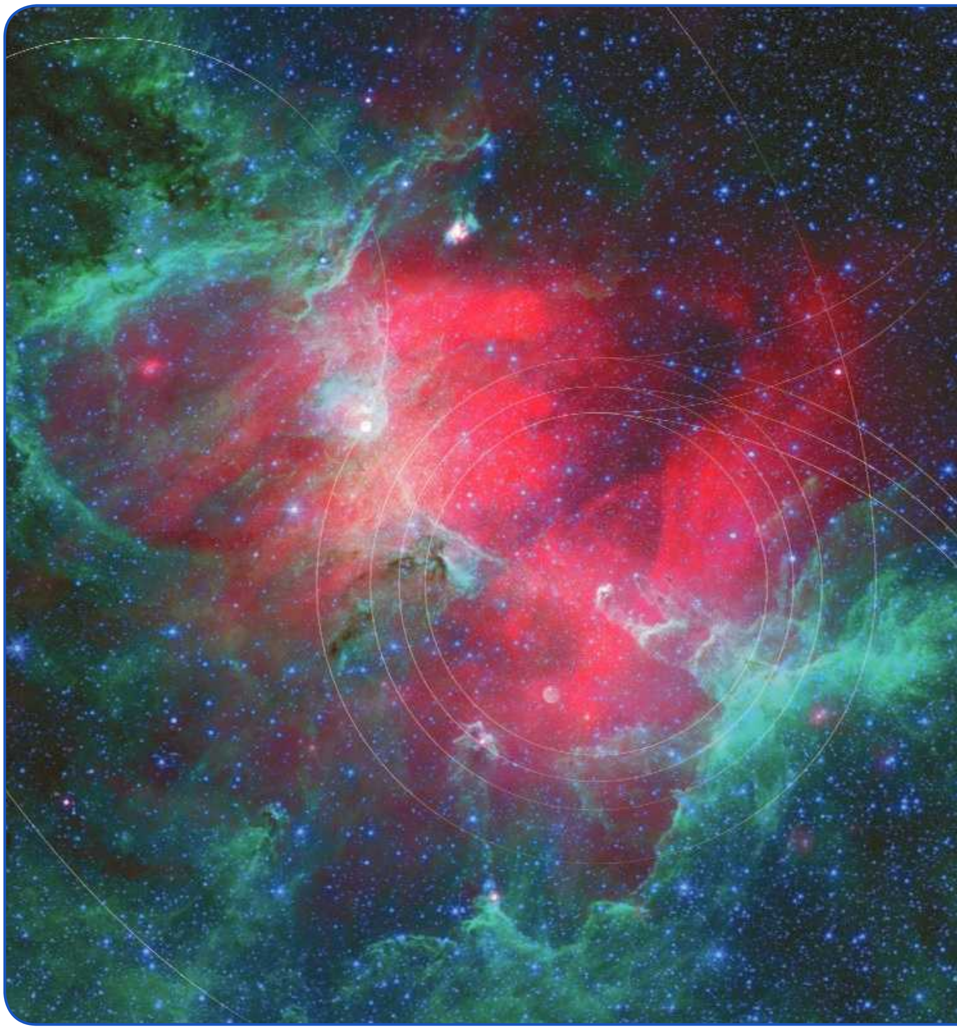
14th Edition

Horizons

14 FOURTEENTH EDITION

Horizons

Exploring the Universe



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With MindTap media contributions and additional problems from Michele Montgomery, University of Central Florida.

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Dedication

For our families

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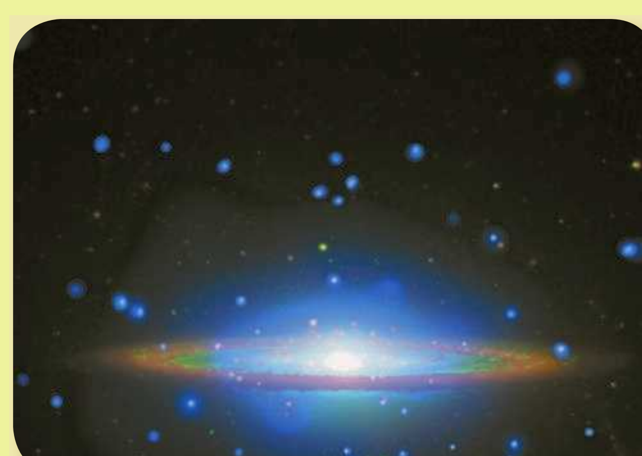

X-ray: NASA/CXC/SAO/Univ. of Massachusetts/Q. D. Wang et al.; Visual: NASA/ESA/STScI/AURA/NSF/The Hubble Heritage Team; Infrared: NASA/JPL-Caltech/Univ. of Arizona/R. Kennicutt, SINGS Team

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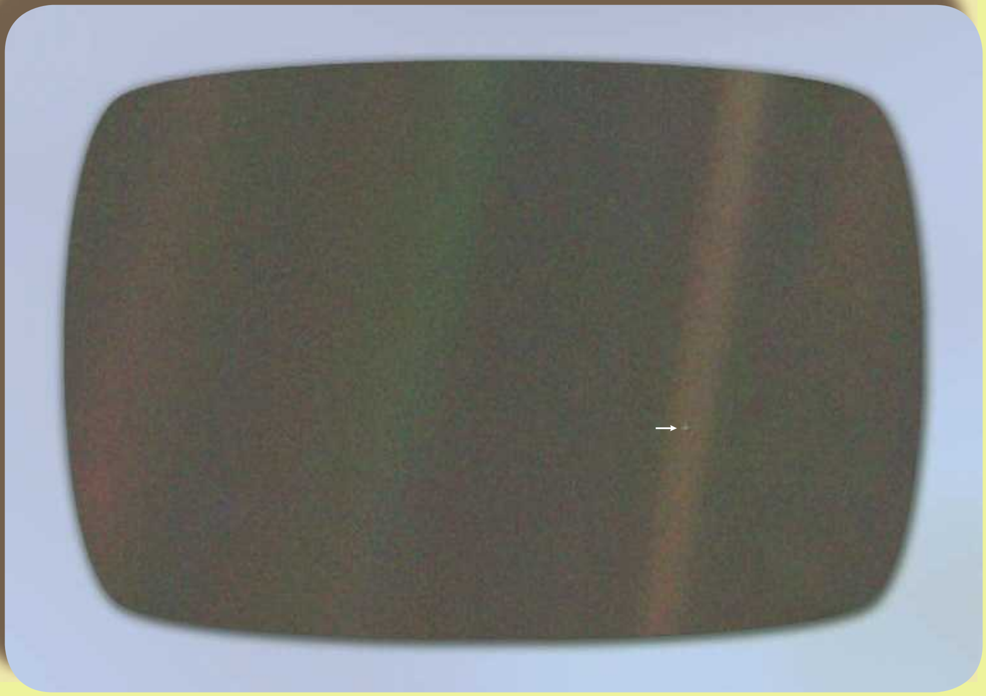

NASA

A Note to Students

From Dana and Mike

We are excited that you are taking an astronomy course and using our MindTap and textbook. You are going to see some amazing things, from the icy rings of Saturn to monster black holes. We are proud to be your guides as you explore.

We have developed this book to help you expand your knowledge of astronomy, from the Moon and a few stars in the evening sky to a deeper understanding of the extent, power, and diversity of the Universe. You will meet worlds where it rains methane, stars so dense atoms cannot exist there, colliding galaxies that are ripping each other apart, and a Universe that is expanding faster and faster.

Two Goals

This book is designed to help you answer two important questions:

- **What are we?**
- **How do we know?**

By the question "What are we?" we mean, "How do we fit into the Universe and its history?" The atoms you are made of had their first birthday in the big bang when the Universe began, but those atoms were cooked and remade inside stars, and now they are inside you. Where will they be in a billion years? Astronomy is the only course on campus that can tell you that story, and it is a story that everyone should know.

By the question "How do we know?" we mean, "How does science work?" What is the evidence, and how do you know it is true? For instance, how can anyone know there was a big bang? In today's world, you need to think carefully about the things so-called experts say. You should demand explanations. Scientists have a special way of knowing based on evidence that makes scientific knowledge much more powerful than just opinion, policy, marketing, or public relations. It is the human race's best understanding of nature. To understand the world around you, you need to understand how science works. Throughout this book, you will find boxes called ***How Do We Know?*** and ***Practicing Science.*** They will help you understand how scientists use the methods of science to know what the Universe is like.

Expect to Be Astonished

One reason astronomy is exciting is that astronomers discover new things every day. Astronomers expect to be astonished. You can share in the excitement because we have worked hard to include the newest images, the newest discoveries, and the newest insights that will take you, in an introductory course, to the frontier of human knowledge. Telescopes in space and on remote mountaintops provide a daily dose of excitement that goes far beyond sensationalism. These new discoveries in astronomy are exciting because they are about us. They tell us more and more about what we are.

As you read this book, notice that it is not organized as lists of facts for you to memorize. That could make even astronomy boring. Rather, this book is organized to show you how scientists use evidence and theory to create logical arguments that show how nature works. Look at the list of special features that follows this note. Those features were carefully designed to help you understand astronomy as evidence and theory. Once you see science as logical arguments, you hold the key to the Universe.

Don't Be Humble

As teachers, our quest is simple. We want you to understand your place in the Universe—not just your location in space but your location in the unfolding history of the physical Universe. Not only do we want you to know where you are and what you are in the Universe, but we want you to understand how scientists know. By the end of this book, we want you to know that the Universe is very big but that it is described by a small set of rules and that we humans have found a way to figure out the rules—through a method called science.

To appreciate your role in this beautiful Universe, you need to learn more than just the facts of astronomy. You can strive for an understanding of what we are and how we know. Every page of this book reflects that ideal.

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Key Content and Pedagogical Changes to the Fourteenth Edition

- Every chapter has been reviewed and updated with new discoveries and images.
- The lunar and solar eclipse tables in Chapter 3 have been updated to include eclipses through the year 2024.
- The Mars retrograde loop figure in Chapter 4 ("The Origin of Modern Astronomy," Concept Art 4A, "An Ancient Model of the Universe"), is updated to 2018.
- New and planned observatory facilities, including the Thirty Meter Telescope, are featured in Chapter 5 ("Light and Telescopes").
- Solar cycle plots in Chapter 7 ("The Sun") have been updated to 2016, and implications of the late start and weak maximum of the most recent solar activity cycle are discussed.
- Chapter 11 ("Neutron Stars and Black Holes") includes a description of the discovery of gravity waves from distant black hole mergers by the LIGO interferometer.
- Chapter 12 ("The Milky Way Galaxy") includes a new image of the galaxy's circumnuclear ring orbiting a central supermassive black hole, obtained by an infrared camera onboard NASA's *Stratospheric Observatory for Infrared Astronomy (SOFIA)*.
- Chapter 14 ("Modern Cosmology") contains a discussion of the claimed detection of cosmological gravity waves in 2014 and subsequent careful reanalysis of the data by several research teams, as an object lesson in the care that professional scientists take to check their results and avoid wishful thinking.
- Chapter 15 ("Origin of the Solar System and Extrasolar Planets") has been updated with new information regarding the wide and wonderful variety of extrasolar planets discovered and studied by the *Kepler* and *Spitzer* space telescopes plus ground-based research programs.
- Chapter 17 ("Mercury, Venus, and Mars"), Chapter 18 ("The Outer Solar System"), and Chapter 19 ("Meteorites, Asteroids, and Comets") are updated with new findings and images regarding Mercury, Mars, Ceres, Comet Churyumov-Gerasimenko, and Pluto from the *MESSENGER, Curiosity, Dawn, Rosetta-Philae*, and *New Horizons* space missions, respectively.

Special Features

- ***What Are We?*** essays are placed at the end of each chapter to help you understand your own role in the cosmos.
- ***How Do We Know?*** commentaries appear in every chapter and will help you see how science works. They point out where scientists use statistical evidence, why they think with analogies, and how they build confidence in hypotheses.
- ***Practicing Science*** boxes at the end of many text sections are carefully designed to help you review and synthesize concepts from the section and practice thinking like a scientist.
- ***Special two-page Concept Art spreads*** provide an opportunity for you to create your own understanding and share in the satisfaction that scientists feel as they uncover the secrets of nature.
- ***Celestial Profiles*** of objects in our Solar System directly compare and contrast planets with each other. This is the way planetary scientists understand the planets, not as isolated, unrelated bodies but as siblings with noticeable differences and yet many characteristics and a family history in common.
- ***Guided discovery figures*** illustrate important ideas visually and guide you to understand relationships and contrasts interactively.
- ***Guideposts*** on the opening page of each chapter help you see the organization of the book by focusing on a small number of questions to be answered as you read the chapter.
- ***End-of-Chapter Review Questions*** are designed to help you review and test your understanding of the material.
- ***End-of-Chapter Discussion Questions*** go beyond the text and invite you to think critically and creatively about scientific questions. You can ponder these questions yourself or discuss them in class. Many of the Discussion Questions have been replaced or rewritten in this edition to better support active-learning classroom scenarios.

MindTap for Astronomy

- **Sense of Proportion** questions extend the journey of discovery through every chapter while grounding the concepts in mathematical meaning.
- **Show Me Astronomy** videos guide you through chapter topics selected and presented by co-author Michele Montgomery, UCF

MindTap is a digital learning solution that helps instructors engage and transform today's students into critical thinkers. Through paths of dynamic assignments and applications that you can personalize, real-time course analytics, and an accessible reader, MindTap helps you turn cookie cutter into cutting edge, apathy into engagement, and memorizers into higher-level thinkers.

MindTap for Astronomy has a carefully curated learning path that includes tutorial simulations, readings, and assessments. Research has proven that students perform better when activities encourage an active experience; with this research in mind, author Mike Seeds has developed tutorial simulations that are integrated right into the MindTap reader to help students better visualize the concepts. Animation tutorials will build student reasoning so they will ultimately be able to draw stronger conclusions.

The end of chapter homework questions in MindTap provide a tighter integration with the textbook content and emphasize conceptual understanding. In addition, instructors can customize the learning path with the Assessment app, which includes thousands of questions pulled from decades of legacy content. Instructor supplements include Class Engagement Lecture Slides, Images from the book, and Cengage Learning Testing, powered by Cognero®.

Acknowledgments

Over the years we have had the guidance of a great many people who care about astronomy and teaching. We would like to thank all of the students and teachers who have contributed their insights and suggestions. Their comments have been very helpful in shaping this book.

We would especially like to thank Susan English, whose careful reading and thoughtful suggestions have been invaluable in completing this new edition, and Michael Jacobs for his help with new Discussion Questions.

Many observatories, research institutes, laboratories, and individual astronomers have supplied figures and diagrams for this edition. They are listed in the individual item credits, and we would like to thank them here specifically for their generosity.

We are happy to acknowledge the use of images and data from a number of important programs. In updating materials for this book, especially the data tables in Chapters 9 and 10 and Appendix A, we made extensive use of the SIMBAD database operated at CDS, Strasbourg, France. We also used images and image mosaics obtained as part of the Two Micron All Sky Survey (2MASS), a joint project of the University of Massachusetts and Caltech, funded by NASA and the NSF.

It is always a pleasure to work with the Cengage Learning team. Special thanks go to all of the people who have contributed directly to this project, including Product Assistants Margaret O'Neil and Caitlin Ghegan and Content Developer Michael Jacobs. We always enjoy working with Margaret Pinette, and continue to appreciate her understanding and goodwill. We would especially like to thank Product Manager Rebecca Berardy Schwartz for her help and guidance throughout this project.

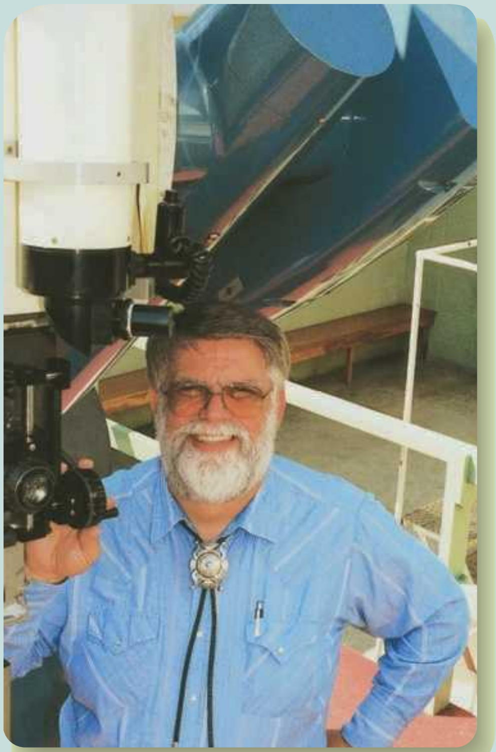
Most of all, we would like to thank our families for putting up with "the books." They know all too well that textbooks are made of time.

Dana Backman
Mike Seeds

Seth Shostak / SETI Institute

About the Authors

Dana Backman taught in the physics and astronomy department at Franklin and Marshall College in Lancaster, Pennsylvania, from 1991 until 2003. He invented and taught a course titled "Life in the Universe" in F&M's interdisciplinary Foundations program. Dana now teaches some introductory astronomy classes at Santa Clara University. His research interests focus on infrared observations of planet formation, models of debris disks around nearby stars, and evolution of the Solar System's Kuiper Belt. Dana is employed by the SETI Institute in Mountain View, California, as director of education and public outreach for SOFIA (the Stratospheric Observatory for Infrared Astronomy) at NASA's Ames Research Center. Dana is coauthor with Mike Seeds of *Horizons: Exploring the Universe,* 12th edition (2012); *Universe: Solar Systems, Stars, and Galaxies,* 7th edition (2012); *Stars and Galaxies,* 8th edition (2013); *The Solar System,* 8th edition (2013); and *ASTRO*, 2nd edition (2013), all published by Cengage.



Courtesy of Kris Koenig

Mike Seeds was a professor of physics and astronomy at Franklin and Marshall College in Lancaster, Pennsylvania, from 1970 until his retirement in 2001. In 1989 he received F&M College's Lindback Award for Distinguished Teaching. Mike's love for the history of astronomy led him to create upper-level courses on archaeoastronomy and on the Copernican Revolution ("Changing Concepts of the Universe"). His research interests focus on variable stars and automation of astronomical telescopes. Mike is coauthor with Dana Backman of *Horizons: Exploring the Universe,* 12th edition (2012); *Universe: Solar Systems, Stars, and Galaxies,* 7th edition (2012); *Stars and Galaxies,* 8th edition (2013); *The Solar System,* 8th edition (2013); and *ASTRO*, 2nd edition (2013), all published by Cengage. He was senior consultant for creation of the 20-episode telecourse accompanying his book *Horizons: Exploring the Universe.*

Here and Now

1

Guidepost As you study astronomy, you also learn about yourself. You are a planet-walker, and this chapter offers you a preview of what that means. The planet you live on whirls around a star that moves through a space filled with other stars and galaxies (see the photo in CO1). You owe it to yourself to know where you are located in the Universe and when you are living its history because those are important steps to knowing what you are.

In this chapter, you will consider three important questions:

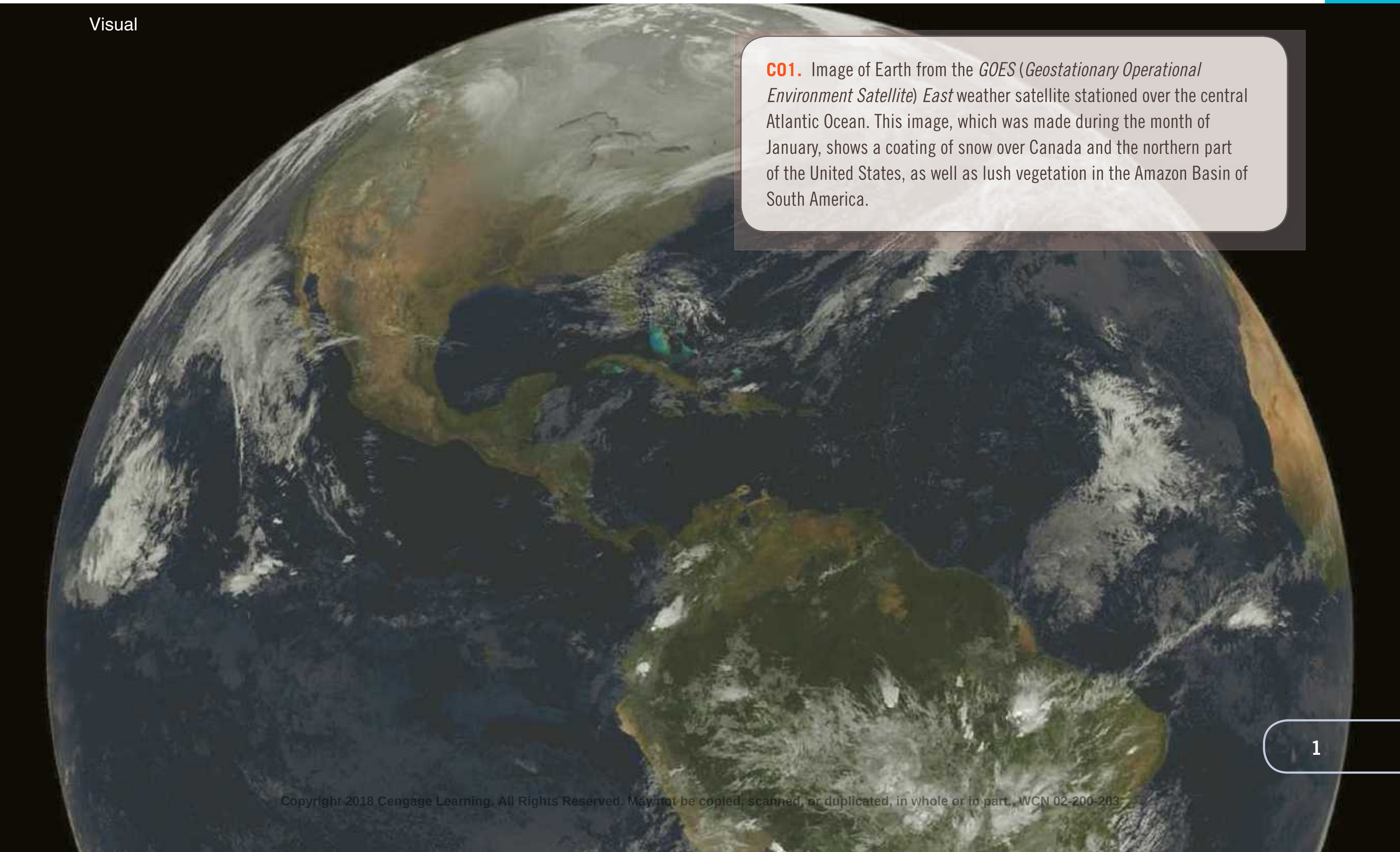
- **Where is Earth in the Universe?**
- **How does human history fit into the history of the Universe?**
- **Why study astronomy?**

This chapter is a jumping-off point for your exploration of deep space and deep time. The next chapter continues your journey by looking at the night sky as seen from Earth. As you study astronomy, you will see how science gives you a way to know how nature works. Later chapters will provide more specific insights into how scientists study and understand nature.

The longest journey begins with a single step.

—LAOZI

NOAA/NASA GOES Project



CO1. Image of Earth from the *GOES* (*Geostationary Operational Environment Satellite*) *East* weather satellite stationed over the central Atlantic Ocean. This image, which was made during the month of January, shows a coating of snow over Canada and the northern part of the United States, as well as lush vegetation in the Amazon Basin of South America.

1-1 Where Are We?

To find your place among the stars, you can take a cosmic zoom, a ride out through the Universe to preview the kinds of objects you are about to study.

You can begin with something familiar. **Figure 1-1** shows a region about 50 feet across occupied by a human being, a sidewalk, and a few trees—all objects with sizes you can understand. Each successive picture in this cosmic zoom will show you a region of the Universe that is 100 times wider than the preceding picture. That is, each step will widen your **field of view**, the region you can see in the image, by a factor of 100.

Widening your field of view by a factor of 100 allows you to see an area 1 mile in diameter (**Figure 1-2**). People, trees, and sidewalks have become too small to see, but now you see a college campus and surrounding streets and houses. The dimensions of houses and streets are familiar. This is still the world you know.

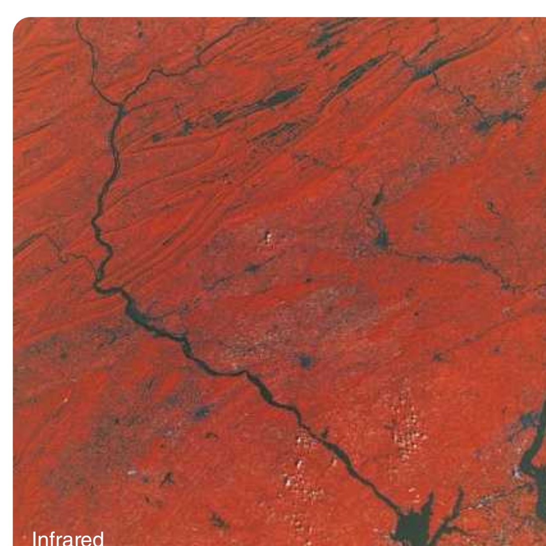
Before leaving this familiar territory, you should make a change in the units you use to measure sizes. All scientists, including astronomers, use the metric system of units because it is well understood worldwide and, more importantly, because it simplifies calculations. If you are not already familiar with the metric system, or if you need a review, study Appendix A before reading on.

In metric units, the image in Figure 1-1 is about 16 meters across, and the 1-mile diameter of Figure 1-2 equals about 1.6 kilometers. You can see that a kilometer (abbreviated km) is a bit under two-thirds of a mile—a short walk across a neighborhood. But when you expand your field of view by a factor of 100, the neighborhood you saw in the previous photo vanishes (**Figure 1-3**). Now your field of view is 160 km wide, and you see cities and towns as patches of gray. Wilmington, Delaware, is visible at the lower right. At this scale, you can see some of the natural features of Earth's surface. The Allegheny Mountains of southern Pennsylvania cross the image in the upper left, and the Susquehanna River flows southeast into Chesapeake Bay. What look like white bumps are a few puffs of clouds.

Figure 1-3 is an infrared photograph in which healthy green leaves and crops show up as red. Human eyes are sensitive to only a narrow range of colors called "visual." As you explore the Universe in the following chapters, you will learn to use a wide range of other "colors," from X-rays to radio waves, to reveal

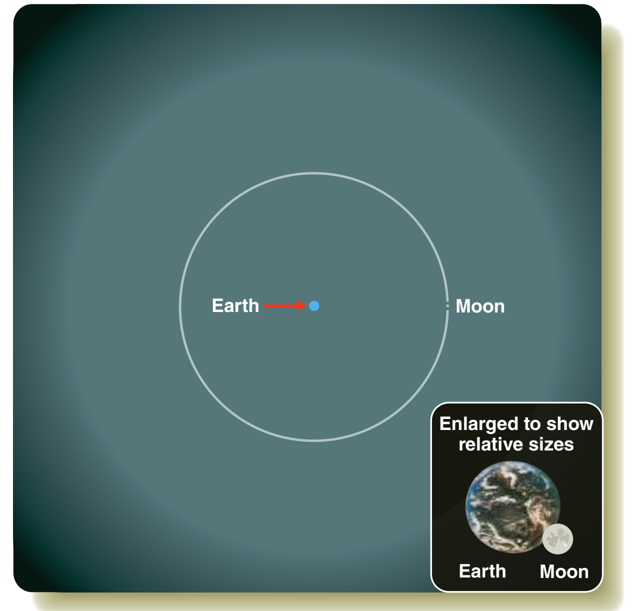
▲ **Figure 1-2** This box ■ represents the relative size of the previous frame.

▲ **Figure 1-1**



▲ **Figure 1-3** This box ■ represents the relative size of the previous frame.

▲ Figure 1-4 This box ■ represents the relative size of the previous frame.



▲ Figure 1-5 This box ■ represents the relative size of the previous frame.

sights invisible to unaided human eyes. Photographs in this book generally will have labels noting which color or type of light was used to make the image.

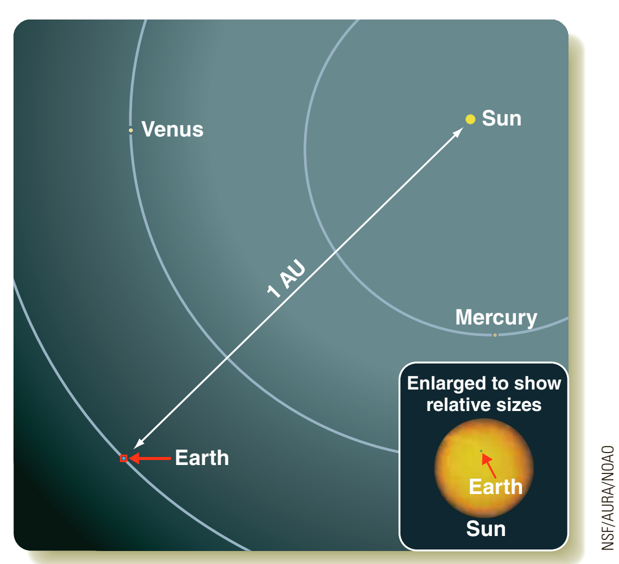
At the next step in your journey, you can see your entire planet, which is nearly 13,000 km in diameter (Figure 1-4). At any particular moment, half of Earth's surface is exposed to sunlight, and half is in darkness. As Earth rotates on its axis, it carries you through sunlight and then through darkness, producing the cycle of day and night. The blurriness you see at the extreme right of the photo is the boundary between day and night—the sunset line. This is a good example of how a photo can give you visual clues to understanding a concept. Special questions called "Learning to Look" at the end of each chapter give you a chance to find connections between images and information regarding astronomical objects.

Enlarge your field of view by another factor of 100, and you see a region 1,600,000 km wide (Figure 1-5). Earth is the small blue dot in the center, and the Moon, whose diameter is only one-fourth that of Earth, is an even smaller dot along its orbit 380,000 km away. The relative sizes of Earth and Moon are shown in the inset at the bottom right of Figure 1-5.

These numbers are so large that it is inconvenient to write them out. Astronomy is sometimes known as the science of big numbers, and soon you will be using numbers much larger than these to discuss the Universe. Rather than writing out these numbers as in the previous paragraph, it is more convenient to write them in **scientific notation.** This is nothing more than a simple way to write very big or very small numbers without using lots of zeros. In scientific notation, 380,000 becomes 3.8×10^5. If you are not familiar with scientific notation, read the section on powers of 10 notation in Appendix A. The Universe is too big to discuss without using scientific notation.

When you once again enlarge your field of view by a factor of 100, Earth, the Moon, and the Moon's orbit all lie in the small red box at lower left of Figure 1-6. Now you can see the Sun and two other planets that are part of our Solar System. Our **Solar System** consists of the Sun, its family of planets, and some smaller bodies, such as moons and comets.

Earth, Venus, and Mercury are **planets**, small, spherical, nonluminous bodies that orbit a star and shine by reflected light. Venus is about the size of Earth, and Mercury has just over a third of Earth's diameter. On this diagram, they are both too small to be seen as anything but tiny dots. The Sun is a **star**, a self-luminous ball of hot gas that generates its own energy. Even



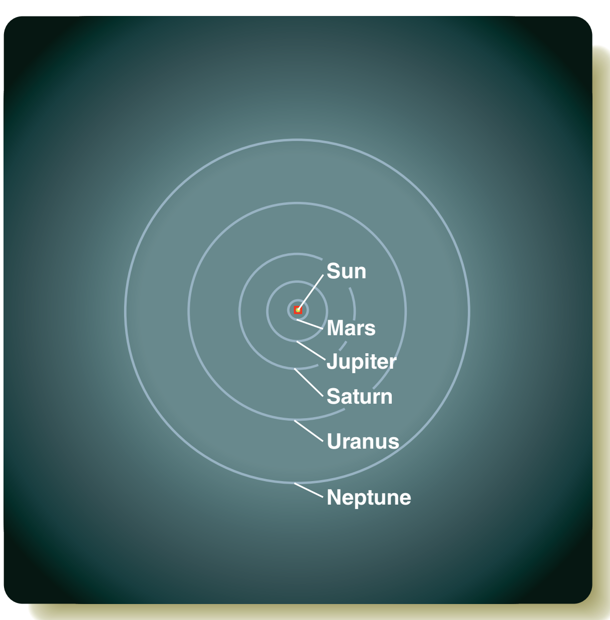
▲ Figure 1-6 The small red box around Earth at lower left contains the entire field of view of Figure 1-5 .

though the Sun is about 100 times larger in diameter than Earth (inset), it too is nothing more than a dot in the figure.

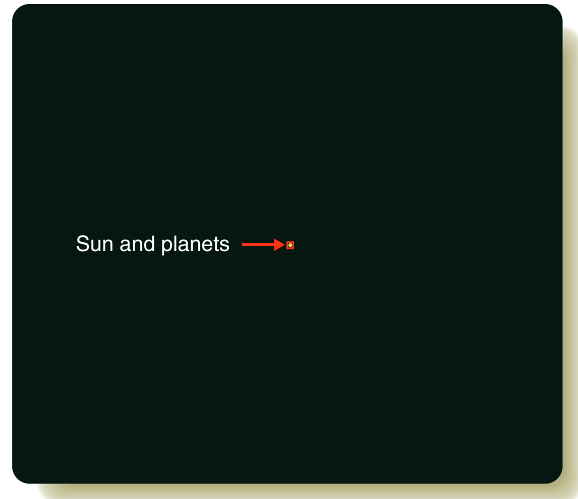
This diagram represents an area with a diameter of 1.6×10^8 km. Another way astronomers simplify descriptions and calculations using large numbers is to define larger units of measurement. For example, the average distance from Earth to the Sun is a unit of distance called the **astronomical unit (AU)**, which is equal to 1.5×10^8 km. You can express the average distance from Venus to the Sun as about 0.72 AU and the average distance from Mercury to the Sun as about 0.39 AU.

These distances are averages because the orbits of the planets are not perfect circles. This is particularly apparent in the case of Mercury. Its orbit carries it as close to the Sun as 0.31 AU and as far away as 0.47 AU. You can see the variation in the distance from Mercury to the Sun in Figure 1-6. Earth's orbit is more circular, and its distance from the Sun varies by only a few percent.

Enlarge your field of view again by a factor of 100, and you can see the entire Solar System (**Figure 1-7**). The Sun, Mercury, Venus, and Earth lie so close together that you cannot see them separately at this scale, and they are lost in the red square at the center of the diagram that shows the size of the previous figure. You can see only the brighter, more widely separated objects such as Mars, the next planet outward. Mars lies only 1.5 AU from the Sun, but Jupiter, Saturn, Uranus, and Neptune are farther from the Sun and so are easier to place in this diagram. They are cold worlds far from the Sun's warmth. Light from the Sun reaches Earth in only 8 minutes, but it takes more than 4 hours to reach Neptune.



▲ **Figure 1-7** The small red box around the Sun at center contains the entire field of view of Figure 1-6.



▲ **Figure 1-8** The small red box at the center contains the entire field of view of Figure 1-7.

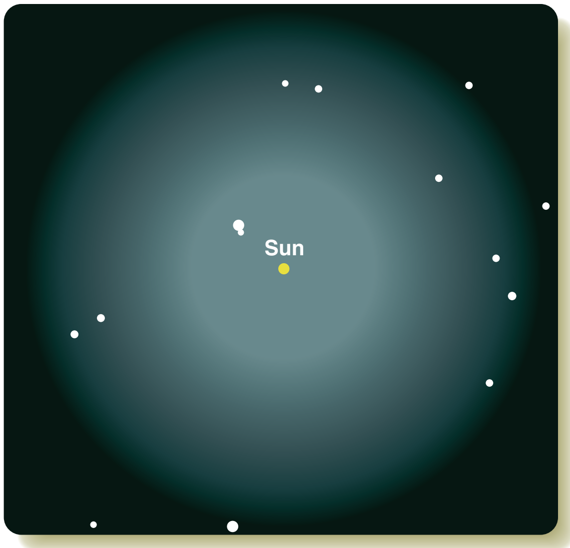
You can remember the order of the plants from the Sun outward by remembering a simple sentence: *My Very Educated Mother Just Served Us Noodles* (perhaps you can come up with a better one). The first letter of each word is the same as the first letter of a planet's name: Mercury, Venus Earth, Mars Jupiter, Saturn, Uranus, Neptune.

When you again enlarge your field of view by a factor of 100, the Solar System vanishes (**Figure 1-8**). The Sun is only a point of light, and all the planets and their orbits are now crowded into the small red square at the center. The planets are too small and too faint to be visible so near the brilliance of the Sun.

Notice that no stars are visible in Figure 1-8 except for the Sun. The Sun is a fairly typical star, and it seems to be located in a fairly average neighborhood in the Universe. Although there are many billions of stars like the Sun, none are close enough to be visible in this diagram, which shows a region only 11,000 AU in diameter. Stars are typically separated by distances about 30 times larger than that.

In **Figure 1-9**, your field of view has expanded to a diameter of a bit over 1.1 million AU. The Sun is at the center, and at this scale you can see a few of the nearest stars. These stars are so distant that it is not convenient to give their distances in astronomical units. To express distances so large, astronomers define a new unit of distance, the light-year. One **light-year (ly)** is the distance that light travels in one year, roughly 10^{13} km or 63,000 AU. It is a **Common Misconception** that a light-year is a unit of time, and you can sometimes hear the term misused in science fiction movies and TV shows. The diameter of your field of view in Figure 1-9 is 17 ly.

Another **Common Misconception** is that stars look like disks when seen through a telescope. Although stars are typically



▲ **Figure 1-9** This box ■ represents the relative size of the previous frame.

NSF/AURA/NOAO/Bill Schoening

▲ **Figure 1-10** This box ■ represents the relative size of the previous frame.

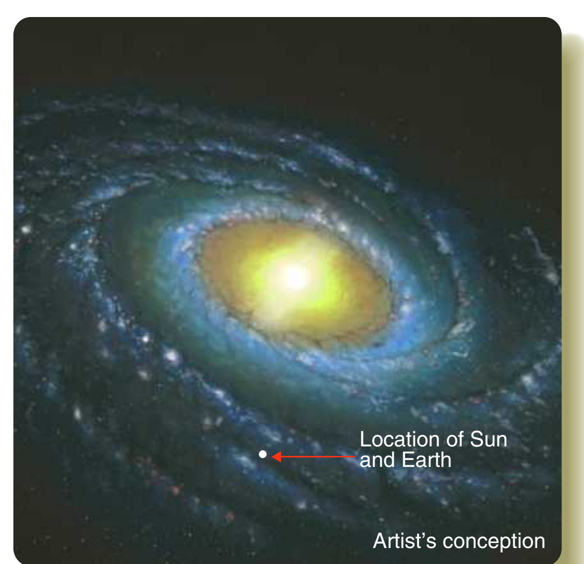
about the same size as the Sun, they are so far away that astronomers cannot see them as anything but points of light. Even the closest star to the Sun—Proxima Centauri, only 4.2 ly away—looks like a point of light through the biggest telescopes on Earth. Furthermore, planets that circle other stars are much too small, too faint, and too close to the glare of their star to be easily visible. Astronomers have used indirect methods to detect thousands of planets orbiting other stars, but only a few have been photographed directly, and even those show up as nothing more than faint points of light.

Figure 1-9 follows the astronomical custom of making the sizes of the dots represent not the sizes of the stars but their brightnesses. This is how star images are recorded on photographs. Bright stars make larger spots on a photograph than faint stars, so the size of a star image in a photograph tells you only how bright the star is, not how big it is.

In **Figure 1-10**, you expand your field of view by another factor of 100, and the Sun and its neighboring stars vanish into the background of thousands of other stars. The field of view is now 1700 ly in diameter. Of course, no one has ever journeyed thousands of light-years from Earth to look back and photograph the solar neighborhood, so this is a representative photograph of the sky. The Sun is a relatively faint star that would not be easily located in a photo at this scale.

If you again expand your field of view by a factor of 100, you see our galaxy, with a visible disk of stars about 80,000 ly in diameter (**Figure 1-11**). A **galaxy** is a great cloud of stars, gas, and dust held together by the combined gravity of all of its matter. Galaxies range from 1500 to over 300,000 ly in diameter, and the largest contain more than 1 trillion stars. In the night sky, you can see our galaxy as a great, cloudy ring of stars surrounding us. of stars surrounding us and ringing the sky. This band of stars is known as the **Milky Way**, and our galaxy is called the **Milky Way Galaxy**.

How does anyone know what the disk of the Milky Way Galaxy would look like from a vantage point tens of thousands of light years away? Astronomers use evidence to guide their explanations as they envision what our galaxy looks like. Artists can then use those scientific descriptions to create a painting. Many images in this book are artists' renderings of objects and events that are too big or too dim to see clearly, emit energy your eyes



Mark A. Garlick/space-art.co.uk

▲ **Figure 1-11** This box ■ represents the relative size of the previous frame.

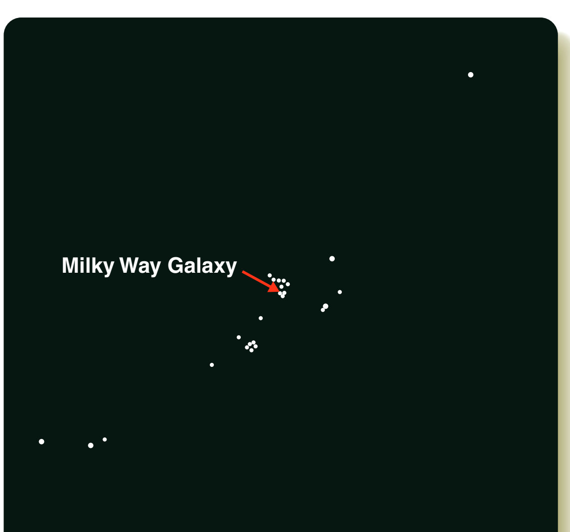
cannot detect, or happen too slowly or too rapidly for humans to sense. These images are much better than mere guesses; they are scientifically based illustrations guided by the best information astronomers can gather. As you continue to explore, notice how astronomers use the methods of science to imagine, understand, and depict cosmic events.

The artist's conception of the Milky Way reproduced in Figure 1-11 shows that our galaxy, like many others, has graceful **spiral arms** winding outward through its disk. In a later chapter, you will learn that the spiral arms are places where stars are formed from clouds of gas and dust. Our Sun was born in one of these spiral arms; if you could see it in this picture, it would be in the disk of the galaxy about two-thirds of the way out from the center, at about the location of the marker dot indicated in the figure.

Ours is a fairly large galaxy. Only a century ago astronomers thought it was the entire Universe—an island cloud of stars in an otherwise empty vastness. Now they know that our galaxy is not unique; it is only one of many billions of galaxies scattered throughout the Universe.

You can see a few of these other galaxies when you expand your field of view by another factor of 100 (**Figure 1-12**). Our galaxy appears as a tiny luminous speck surrounded by other specks in a region 17 million ly in diameter. Each speck represents a galaxy. Notice that our galaxy is part of a cluster of a few dozen galaxies. Galaxies are commonly grouped together in such clusters. Some galaxies have beautiful spiral patterns like our own galaxy, but others do not. Some are strangely distorted. In a later chapter, you will learn what produces these differences among the galaxies.

Now is a chance for you to spot another **Common Misconception**. People often say *Galaxy* when they mean *Solar System*, and they sometimes confuse both terms with *Universe*. Your cosmic zoom has shown you the difference. The Solar System is your local neighborhood, that is, the Sun and its planets, one planetary system. The Milky Way Galaxy contains our Solar System plus billions of other stars and whatever planets orbit around them—in other words, billions of planetary systems. The Universe includes everything: all of the galaxies, stars, and planets, including the Milky Way Galaxy and, a very small part of that, our Solar System.



▲ **Figure 1-12** This box ■ represents the relative size of the previous frame.

▲ **Figure 1-13** This box ■ represents the relative size of the previous frame.

If you expand your field of view one more time, you can see that clusters of galaxies are connected in a vast network (**Figure 1-13**). Clusters are grouped into superclusters—clusters of clusters—and the superclusters are linked to form long filaments and walls outlining nearly empty voids. These filaments and walls appear to be the largest structures in the Universe. Were you to expand your field of view another time, you would probably see a uniform fog of filaments and walls. When you puzzle over the origin of these structures, you are at the frontier of human knowledge.

1-2 When Is Now?

Now that you have an idea where you are in space, you might also like to know where you are in time. Stars shone for billions of years before the first human looked up and wondered what they were.

To get a sense of your place in time, all you need is a long ribbon. Imagine stretching that ribbon down the center of a U.S. football field from goal line to goal line, a distance of 100 yards (about 91 meters), as shown on the inside front cover of this book. Further, imagine that one end of the ribbon represents *today* and the other end represents the beginning of the Universe—the moment of beginning that astronomers call the *big bang.* In a later chapter, "Modern Cosmology," you will learn about the big bang, and you will see evidence that the Universe is approximately 14 billion years old. Your ribbon represents 14 billion years, the entire history of the Universe.

Imagine beginning at the goal line labeled BIG BANG and replaying the entire history of the Universe as you walk along the ribbon toward the goal line labeled TODAY. Astronomers have evidence that the big bang filled the entire Universe with hot, glowing gas, but as the gas cooled and dimmed the Universe went dark. All that happened along the first half inch of the ribbon. There was no light for the next 400 million years, until gravity was able to pull some of the gas together to form the first stars. That seems like a lot of years, but if you stick a little flag beside the ribbon to mark the birth of the first stars, it would be not quite 3 yards from the goal line where the Universe began.

You have to walk only about 4 or 5 yards along the ribbon before galaxies formed in large numbers. Our home galaxy would be one of those taking shape. By the time you cross the 50-yard line, the Universe is full of galaxies, but the Sun and Earth have not formed yet. You need to walk past the 50-yard line all the way to the other 33-yard line before you can finally stick a flag beside the ribbon to mark the formation of the Sun and planets—our Solar System— 4.6 billion years ago and about 9 billion years after the big bang.

You can carry your flags a few yards further to about the 25-yard line, 3.4 billion years ago, to mark the earliest firm evidence for life on Earth—microscopic creatures in the oceans—and you have to walk all the way to the 3-yard line before you can mark the emergence of life on land only 0.4 billion (400 million) years ago. Your dinosaur flag goes inside the 2-yard line. Dinosaurs go extinct as you pass the one-half-yard line, 65 million years ago.

What about people? You can put a little flag for the first humanlike creatures, 4 million years ago, only about 1 inch (2.5 cm) from the goal line labeled TODAY. Civilization, the building of cities, began about 10,000 years ago, so you have to try to fit that flag in only 0.0026 inches (0.066 millimeter) from the goal line. That's less than the thickness of the page you are reading right now. Compare the history of human civilization with the history of the Universe. Every war you have ever heard of, the life of every person whose name is recorded, and the construction of every structure ever made from Stonehenge to the building you are in right now fits into that final 0.0026 inches of the time ribbon.

Humanity is very new to the Universe. Our civilization on Earth has existed for only a flicker of an eyeblink in the history of the Universe. As you will discover in the chapters that follow, only in the last hundred years or so have astronomers begun to understand where we are in space and in time.

1-3 Why Study Astronomy?

Your exploration of the Universe will help you answer two fundamental questions:

What are we?
How do we know?

The question "What are we?" is the first organizing theme of this book. Astronomy is important to you because it will tell you what you are. Notice that the question is not "*Who* are we?" If you want to know who we are, you may want to talk to a psychologist, sociologist, theologian, paleontologist, artist, or poet. "*What* are we?" is a fundamentally different question.

As you study astronomy, you will learn how you fit into the history of the Universe. You will learn that the atoms in your body had their first birthday in the big bang when the Universe began. Those atoms have been cooked and remade inside generations of stars, and now, after billions of years, they are inside you. Where will they be in another 10 billion years? This is a story everyone should know, and astronomy is the only course on campus that can tell you that story.

Every chapter in this book ends with a short segment titled "What Are We?" This summary shows how the astronomy in the chapter relates to your role in the story of the Universe.

The question "How do we know?" is the second organizing theme of this book. It is a question you should ask yourself whenever you encounter statements made by so-called experts in any field. Should you swallow a diet supplement recommended by a TV star? Should you vote for a candidate who warns of a climate crisis? To understand the world around you and to make wise decisions for yourself, for your family, and for your nation, you need to understand how science works.

You can use astronomy as a case study in science. Throughout this book, you will find short essays titled "How Do We Know?" and "Practicing Science." These essays are designed to help you think not about only *what* is known, but *how* it is known. To do that, they will explain a variety of scientific thought processes and procedures to help you understand how scientists know about the natural world.

Over the last four centuries, scientists have developed a way to understand nature by comparing hypotheses with evidence, a process that has been called the **scientific method** (**How Do We Know? 1-1**). As you read about exploding stars, colliding galaxies, and alien planets in the following chapters, you will see astronomers using the scientific method over and over. The Universe is very big, but it is described by a small set of rules, and we humans have found a way to figure out the rules by using a method called *science.* See **What Are We? 1.**

How Do We Know? 1-1

The Scientific Method

How do scientists learn about nature? You have probably heard several times during your education about the scientific method as the process by which scientists form hypotheses and test them against evidence gathered by experiments and observations. That is an oversimplification of the subtle and complex ways that scientists actually work. Scientists use the scientific method all the time, and it is critically important, but they rarely think of it while they are doing it, any more than you think about the details of what you are doing while you are riding a bicycle. It is such an ingrained way of thinking about and understanding nature that it is almost transparent to the people who use it most.

Scientists try to form hypotheses that explain how nature works. If a hypothesis is contradicted by evidence from experiments or observations, it must be revised or discarded. If a hypothesis is confirmed, it still must be tested further. In that very general way, the scientific method is a way of testing and refining ideas to better describe how nature works.

For example, Gregor Mendel (1822–1884) was an Austrian abbot who liked plants. He formed a hypothesis that offspring usually inherit traits from their parents not as a smooth blend, as most scientists of the time believed, but in discrete units according to strict mathematical rules. Mendel cultivated and tested more than 28,000 pea plants, noting which produced smooth peas and which produced wrinkled peas and how that trait was inherited by successive generations (See Figure UN 1-1). His study of pea plants confirmed his hypothesis and allowed the development of a series of laws of inheritance. Although the importance of his work was not recognized in his lifetime, Mendel is now called the "father of modern genetics."

The scientific method is not a simple, mechanical way of grinding facts into understanding; a scientist needs insight and ingenuity both to form and to test good hypotheses. Scientists use the scientific method almost automatically, sometimes forming, testing, revising, and discarding hypotheses minute by minute as they discuss a new idea, other times spending years studying a single promising hypothesis.

The scientific method is, in fact, a combination of many ways of analyzing information, finding relationships, and creating new ideas, in order to know and understand nature. The "How Do We Know?" essays in the chapters that follow will introduce you to some of those techniques.

Inspirestock/Jupiterimages/Getty Images

▲ **Figure UN 1-1** *Whether peas are wrinkled or smooth is an inherited trait.*

What Are We? 1 Participants

Astronomy will give you perspective on what it means to be here on Earth. This chapter has helped you locate yourself in space and time. Once you realize how vast our Universe is, Earth seems quite small. People on the other side of the world seem like neighbors. And, in the entire history of the Universe, the human story is only the blink of an eye. This may seem humbling at first, but you can be proud of how much we humans have understood in such a short time.

Not only does astronomy locate you in space and time, it places you in the physical processes that govern the Universe. Gravity and atoms work together to make stars, light the Universe, generate energy, and create the chemical elements in your body. The chapters that follow will show how you fit into those cosmic processes.

Although you are very small and your kind have existed in the Universe for only a short time, you are an important part of something very large and very beautiful.

Study and Review

Summary

- You surveyed the Universe by taking a cosmic zoom in which each **field of view** was 100 times wider than the previous field of view.
- Astronomers use the metric system because it simplifies calculations and use **scientific notation** for very large or very small numbers.
- You live on a **planet,** Earth, which orbits our **star,** the Sun, once a year. As Earth rotates once a day, you see the Sun rise and set.
- The Moon is only one-fourth the diameter of Earth, but the Sun is about 100 times larger in diameter than Earth—a typical size for a star.
- The **Solar System** includes the Sun at the center, all of the planets that orbit around it—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune—plus the moons of the planets and all other objects bound to the Sun by its gravity.
- The **astronomical unit (AU)** is the average distance from Earth to the Sun. Mars, for example, orbits 1.5 AU from the Sun. The **light-year (ly)** is the distance light can travel in one year. The nearest star is 4.2 ly from the Sun.
- Many stars seem to have planets, but such small, distant worlds are difficult to detect. Nevertheless, thousands have been found after almost 30 years of searching by astronomers. So far only a few of those planets have been determined to be Earth-like in terms of size and temperature.
- The **Milky Way,** the hazy band of light that encircles the sky, is the **Milky Way Galaxy** seen from inside. The Sun is just one out of the billions of stars that fill the Milky Way Galaxy.
- **Galaxies** contain many billions of stars. Our galaxy is about 80,000 ly in diameter and contains over 100 billion stars.
- Some galaxies, including our own, have graceful **spiral arms** bright with stars, but some galaxies are plain clouds of stars.
- The Solar System consists of the Sun plus eight planets, including Earth. Our galaxy contains our Solar System plus billions of other stars and whatever planets orbit around them. The **Universe** includes everything that there is: billions of galaxies, each containing billions of stars and, presumably, billions of planetary systems.
- Our galaxy is just one of billions of galaxies that fill the Universe in great clusters, clouds, filaments, and walls—the largest structures in the Universe.
- The Universe began about 14 billion years ago in an event called the big bang, which filled the Universe with hot gas.
- The hot gas cooled, the first galaxies began to form, and stars began to shine only about 400 million years after the big bang.
- The Sun and planets of our Solar System formed about 4.6 billion years ago.
- Life began in Earth's oceans soon after Earth formed but did not emerge onto land until only 400 million years ago. Dinosaurs evolved not long ago and went extinct only 65 million years ago.
- Humanlike creatures developed on Earth only about 4 million years ago, and human civilizations developed only about 10,000 years ago.
- Although astronomy seems to be about stars and planets, it describes the Universe in which you live, so it is really about you. Astronomy helps you answer the question "What are we?"
- As you study astronomy, you should ask "How do we know?" and that will help you understand how science gives us a way to understand nature.
- In its simplest outline, science follows the **scientific method,** by which scientists test hypotheses against evidence from experiments and observations. This method is a powerful way to learn about nature.

Review Questions

1. What is the largest dimension of which you have personal knowledge? Have you run a mile? Hiked 10 miles? Run a marathon?
2. What is the difference between our Solar System, our galaxy, and the Universe?
3. Why are light-years more convenient than miles, kilometers, or astronomical units for measuring certain distances?
4. Why is it difficult to detect planets orbiting other stars?
5. What does the size of the star image in a photograph tell you?
6. What is the difference between the Milky Way and the Milky Way Galaxy?
7. What are the largest known structures in the Universe?
8. How does astronomy help answer the question "What are we?"
9. **How Do We Know?** How does the scientific method give scientists a way to know about nature?

Discussion Questions

1. You and three of your friends have won an all-expenses paid one-time-only round-trip first-class vacation to anywhere in the Universe, so long as the choice of destination is unanimous. Where do you want to go, and how do you convince your friends to agree?
2. Think back to the last time you got a new phone and had to figure out how it worked. In what way did you employ the scientific method, maybe without even realizing that you did?

Problems

1. The diameter of Earth across the equator is 7928 miles. If a mile equals 1.609 km, what is Earth's diameter in kilometers? In centimeters?
2. The diameter of the Moon across its equator is 3476 kilometers. If a kilometer equals 0.6214 miles, what is the Moon's diameter in miles?
3. One astronomical unit is about 1.50×10^8 km. Explain why this is the same as 150×10^6 km.
4. Venus orbits 0.72 AU from the Sun. What is that distance in kilometers? (*Hint:* See Problem 3.)
5. Light from the Sun takes 8 minutes to reach Earth. How long does it take to reach Mars?
6. The Sun is almost 400 times farther from Earth than is the Moon. How long does light from the Moon take to reach Earth?