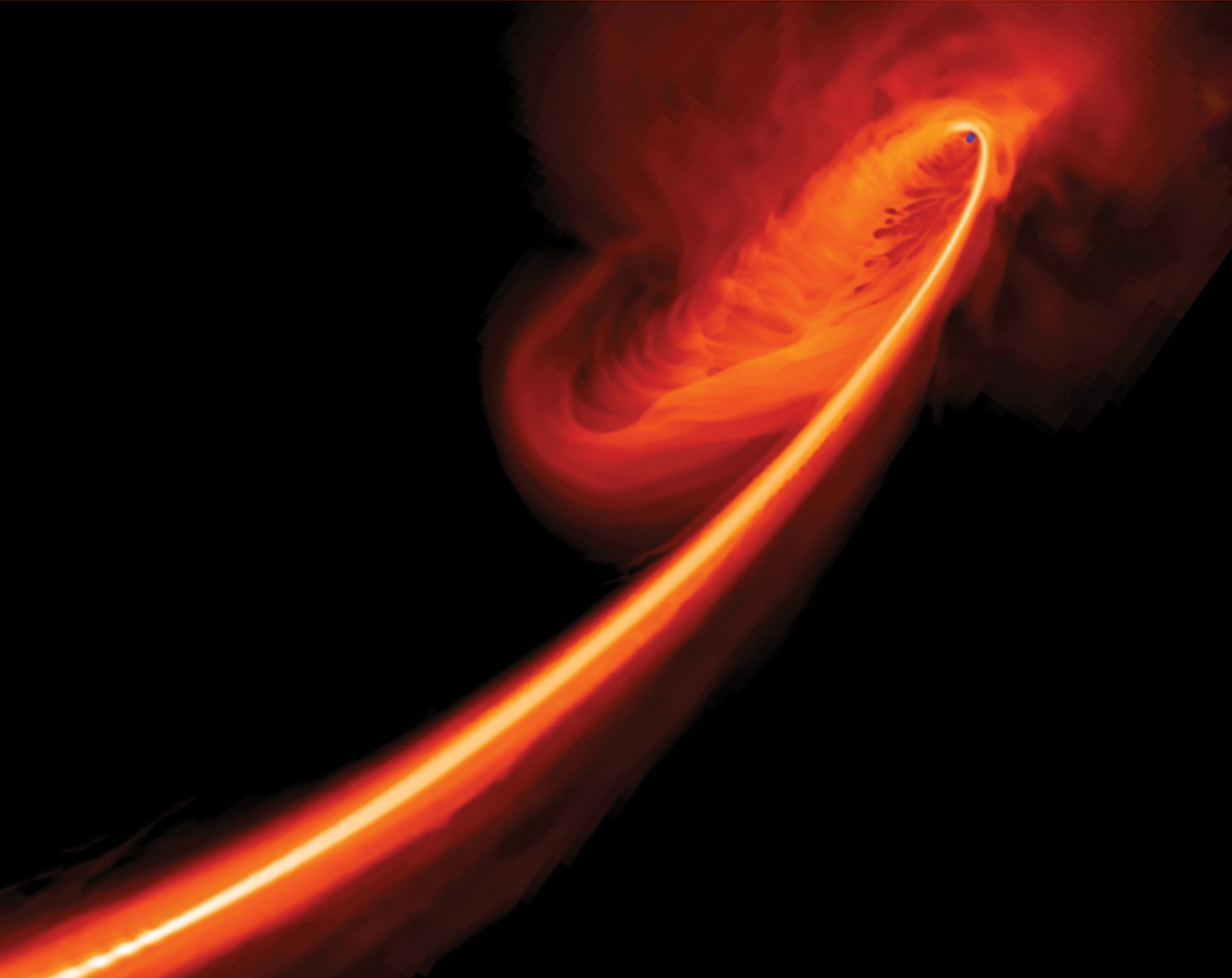
UNIVERSE

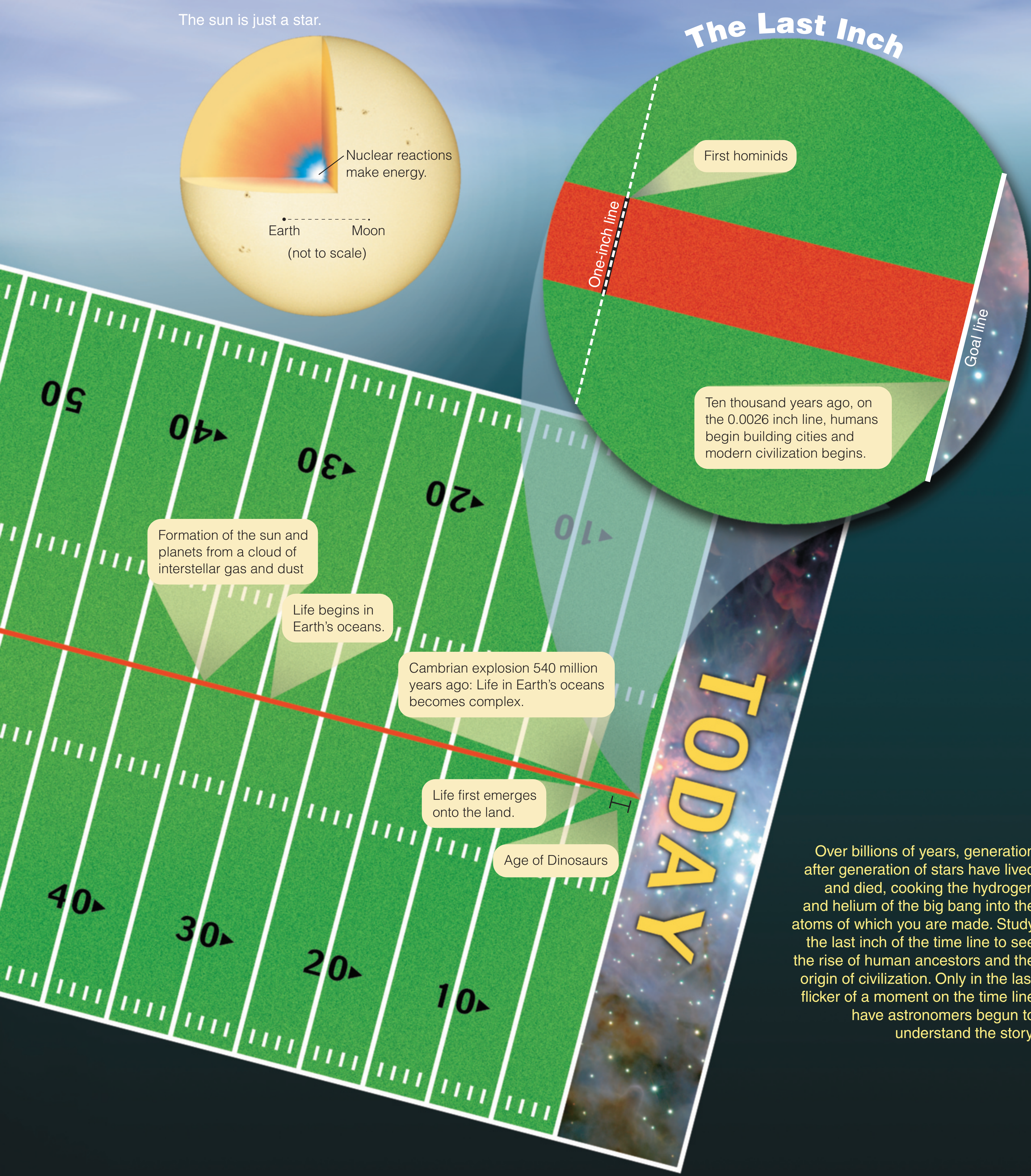
8TH EDITION

SOLAR SYSTEMS, STARS AND GALAXIES



MICHAEL SEEDS AND DANA BACKMAN

A typical galaxy contains 100 billion stars.



Over billions of years, generation after generation of stars have lived and died, cooking the hydrogen and helium of the big bang into the atoms of which you are made. Study the last inch of the time line to see the rise of human ancestors and the origin of civilization. Only in the last flicker of a moment on the time line have astronomers begun to understand the story.

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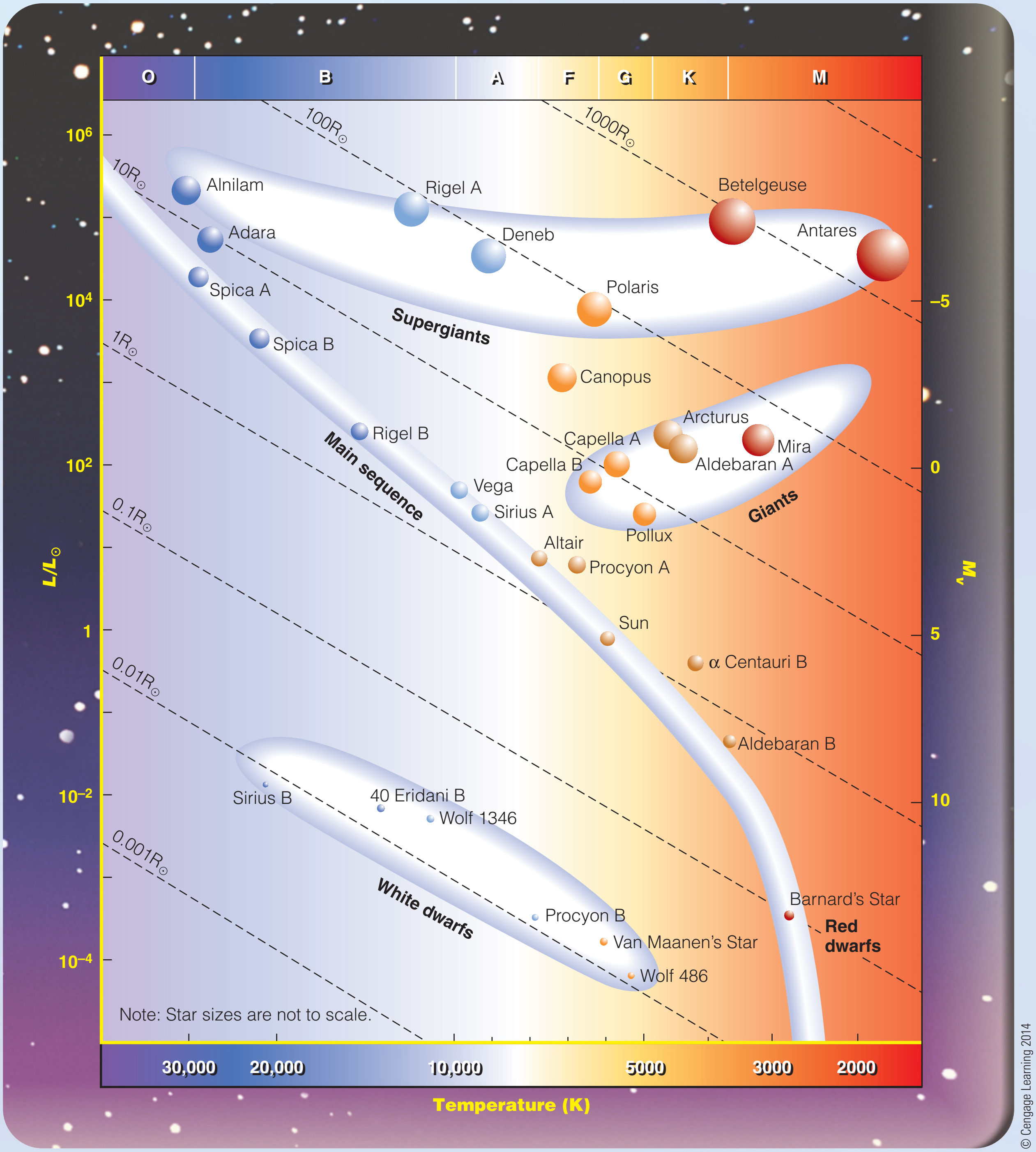
Flash Reference: H–R Diagram



The H–R diagram is the key to understanding stars, their birth, their long lives, and their eventual deaths. Luminosity ($L/L_\odot$) refers to the total amount of energy that a star emits in terms of the sun's luminosity, and the temperature refers to the temperature of its surface. Together, the temperature and luminosity of a star locate it on the H–R diagram and tell astronomers its radius, its family relationships with other stars, and a great deal about its history and fate.

Flash Reference: Comparative Planetology

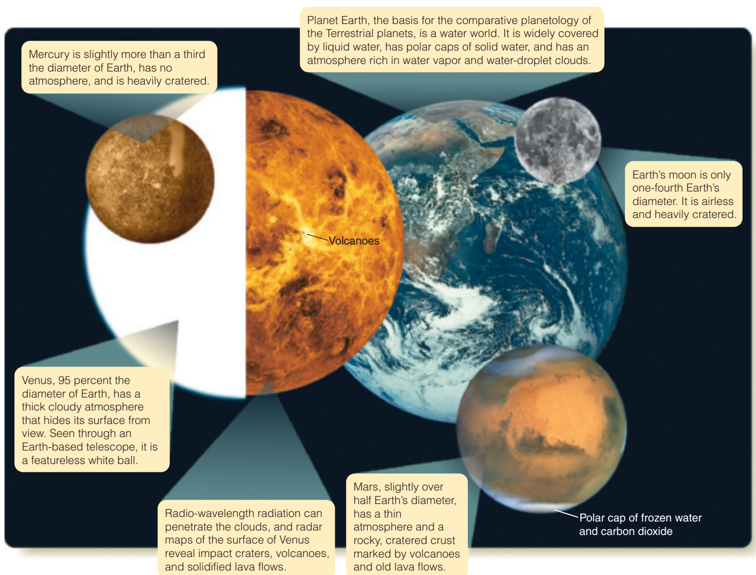
The terrestrial or Earthlike planets lie very close to the sun, and their orbits are hardly visible in a diagram that includes the outer planets.

Mercury, Venus, Earth and its moon, and Mars are small worlds made of rock and metal with little or no atmospheric gases.

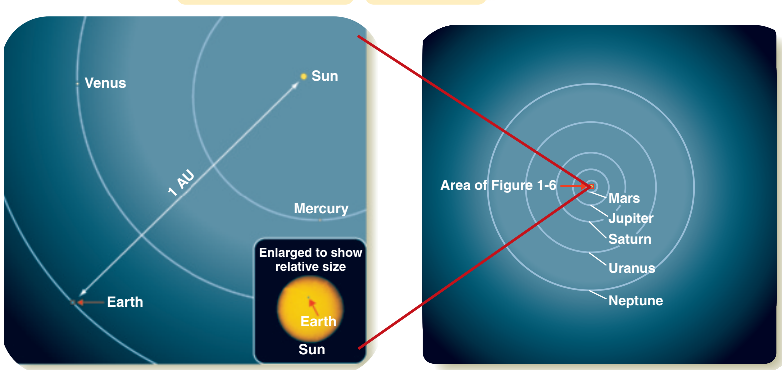
The outer worlds of our solar system orbit far from the sun. Jupiter, Saturn, Uranus, and Neptune are Jovian or Jupiter-like planets much bigger than Earth. They contain large amounts of low-density gases.

Pluto is one of a number of small, icy worlds orbiting beyond Neptune. Astronomers have concluded that Pluto is not really a planet and now refer to it as a dwarf planet.

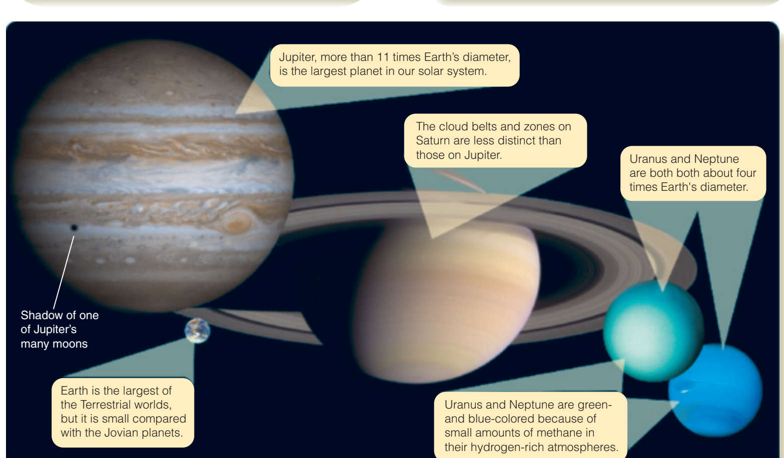
The Terrestrial Worlds



Planetary Orbits



The Outer Worlds

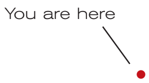


• *Horizons* readers: see page 341 for the terrestrial planets. See pages 3 and 4 for the two orbital diagrams. See page 404 for the outer worlds. *Universe* readers: See page 167 for the terrestrial planets. See pages 3 and 4 for the two orbital diagrams. See page 210 for the outer worlds.

Flash Reference: Arrows

This book is designed to use arrows to alert you to important concepts in diagrams and graphs. Some arrows point things out, but others represent motion, force, or even the flow of light. Look at arrows in the book carefully and use this Flash Reference card to catch all of the arrow clues.

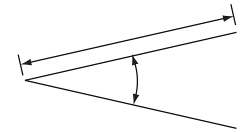
Point at things:



Force:

Process flow:

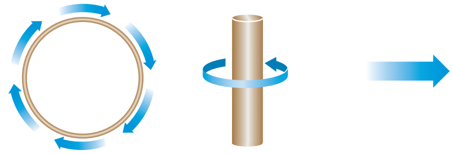
Measurement:



Direction:

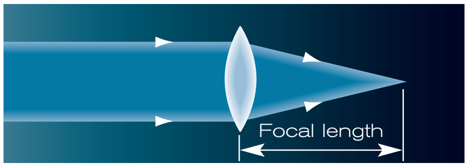
Radio waves, infrared, photons:

Motion:



Light flow:

Updated arrow style

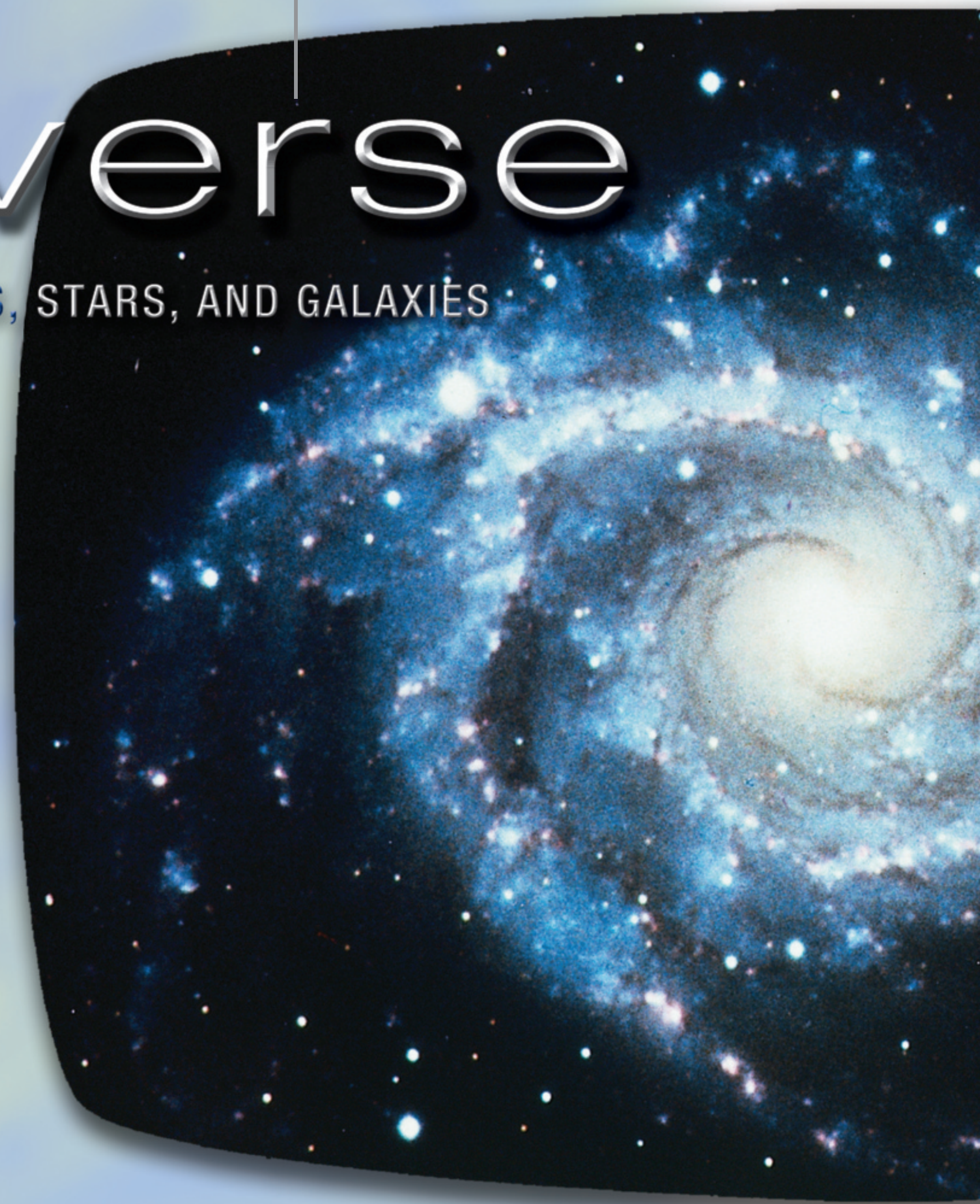


8

EIGHTH EDITION

Universe

SOLAR SYSTEMS, STARS, AND GALAXIES



About the Authors

Mike Seeds has been a Professor of Physics and Astronomy at Franklin and Marshall College in Lancaster, Pennsylvania, since 1970. 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 changing concepts of the universe. His research interests focus on variable stars and the automation of astronomical telescopes. Mike is coauthor with Dana Backman of *Foundations of Astronomy,* Twelfth Edition (2013); *Stars and Galaxies,* Eighth Edition (2013); *The Solar System,* Eighth Edition (2013); and *ASTRO* (2010), all published by Cengage Learning. He was Senior Consultant for creation of the 20-episode telecourse accompanying the book *Horizons: Exploring the Universe.*

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 introductory astronomy at Santa Clara University, a course on global climate change, and a course on cosmology in Stanford University's Continuing Studies Program. Dana is employed by the SETI Institute in Mountain View, California, as the manager of Outreach (education, public outreach, and media relations) for NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) at NASA's Ames Research Center. Dana is coauthor with Mike Seeds of *Foundations of Astronomy,* Twelfth Edition (2013); *Stars and Galaxies,* Eighth Edition (2013); *The Solar System,* Eighth Edition (2013); and *ASTRO* (2010), all published by Cengage Learning.

8 | EIGHTH EDITION

Universe

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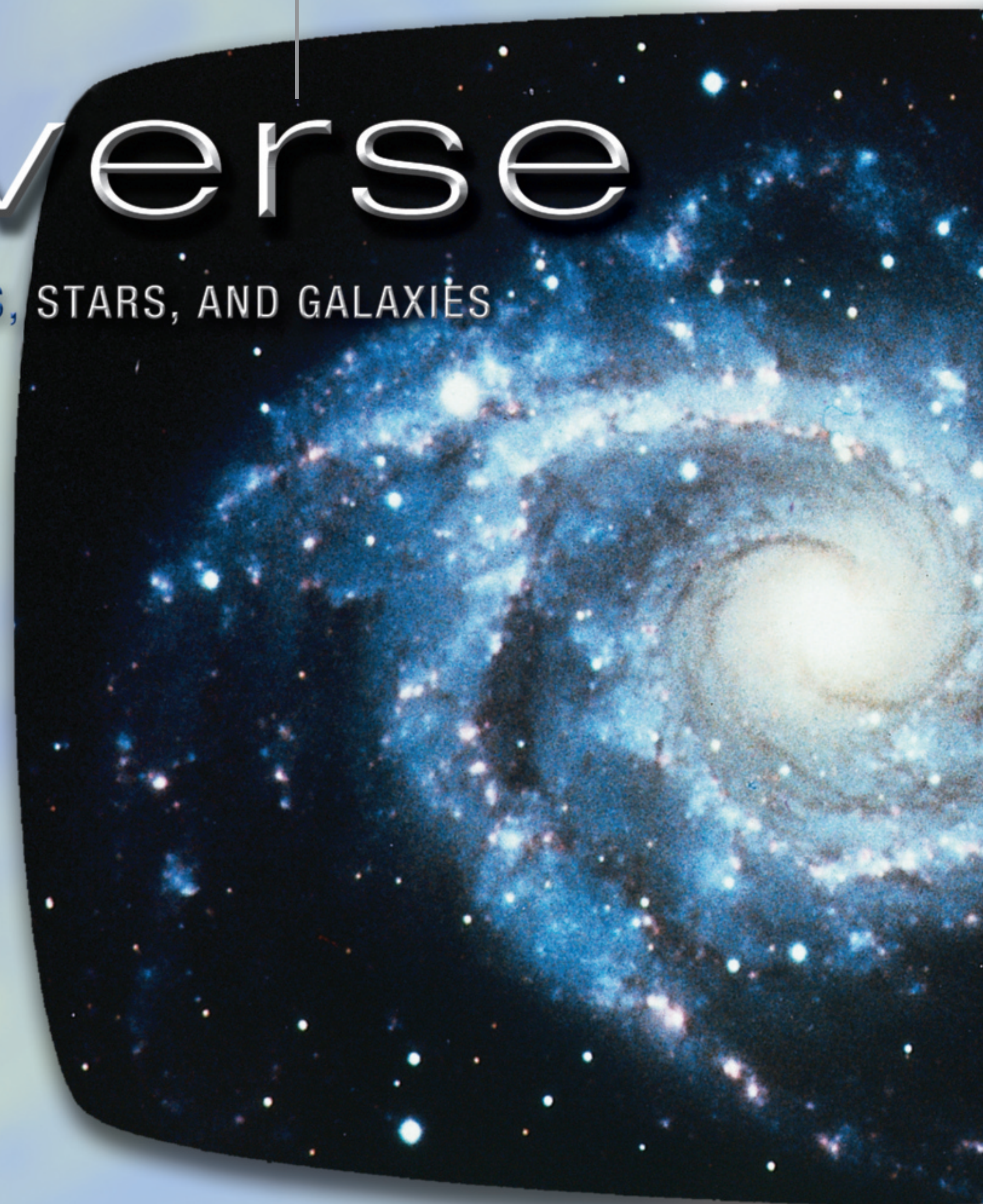

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Dedication

For our families

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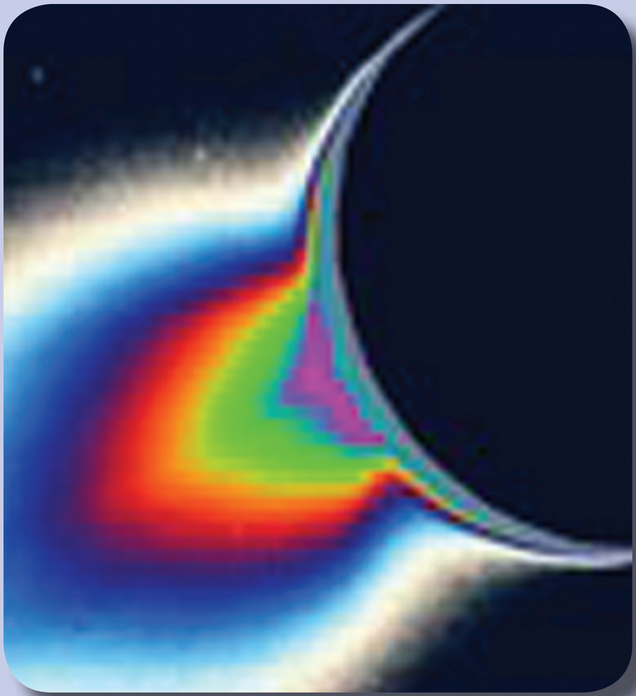

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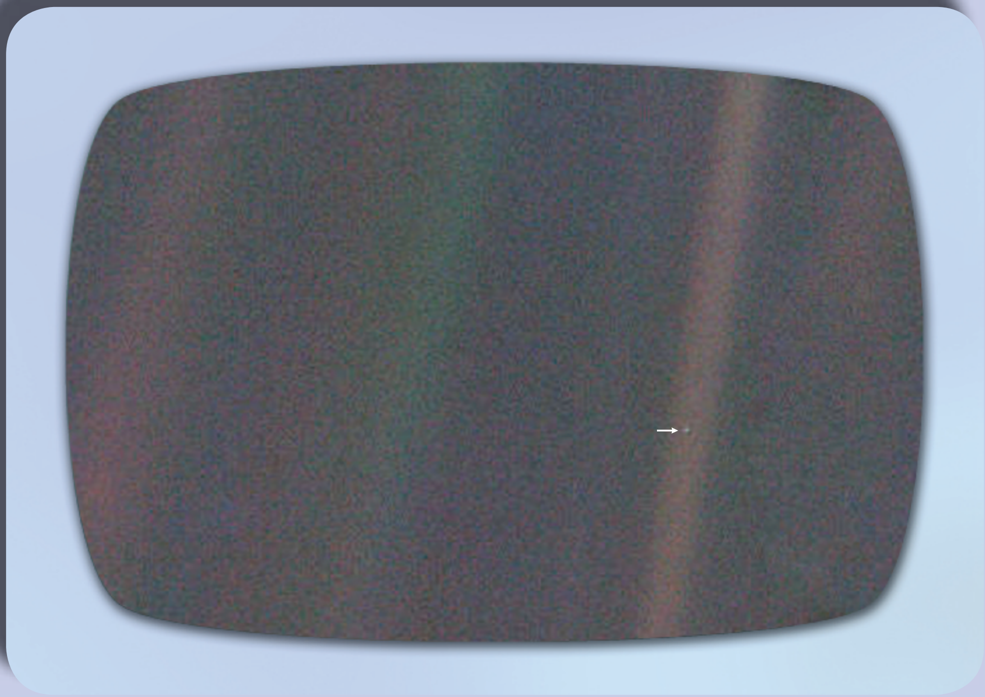

A Note to the Student

From Mike and Dana

We are excited that you are taking an astronomy course and using our book. 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, 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?*** 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. Huge 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.

Do Not 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 must learn more than just the facts of astronomy. You must understand 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 Eighth Edition

- Every chapter has been reviewed and updated with the latest discoveries and images such as photos of colliding galaxies and planets orbiting distant stars. You will read about methane lakes on Saturn's moon Titan and the newest understanding of bursts of gamma rays detected coming from the most distant galaxies. Every chapter has been reviewed and updated with the latest discoveries and images. You will read about particles from distant supernovae flying through Earth, the coevolution of galaxies with supermassive black holes, the discovery of Earth-size and Earth-temperature extrasolar planets, and findings from the first robot probes to orbit Mercury and the asteroid Vesta.
- Normal galaxies and active galaxies have been unified in a single new Chapter 18 to better show how active galactic nuclei are a natural stage in the evolution of normal galaxies. Chapter 15 ("The Deaths of Stars") has been updated with new photos and a new graph regarding the 1987A neutrino burst. Three new subsections, *Classifying Supernovae, A History of Supernovae*, and *Supernova Remnants* update and reorganize the discussion of supernovae.
- The discussion of Cyg-X-1 in Chapter 16 ("Neutron Stars and Black Holes") has been reorganized and updated to emphasize its place in the history of the subject.
- Chapter 10 uses comparative planetology to analyze the structure and history of Mercury, Venus, and Mars. Chapter 18 ("Galaxies: Normal and Active") has been updated with new images, and a new section *The Coevolution of Galaxies and Black Holes* has been added to include the newest understanding.
- The discussion of stellar spectra and their classification has been moved to Chapter 13 to better illustrate how astronomers know what stars are like. Chapter 8 ("The Origin of the Solar System") has been updated with the newest information regarding the wide and wonderful variety of extrasolar planets discovered by the *Kepler* and *Corot* space telescopes and ground-based research programs.
- Chapter 10 ("Mercury, Venus, and Mars") and Chapter 12 ("Meteorites, Asteroids, and Comets") have been updated with new findings and images from the *MESSENGER* and *Dawn* 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 astronomy you have just learned.
- ***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 theories.
- ***Special two-page 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.
- ***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.
- ***Scientific Arguments*** at the end of many text sections are carefully designed questions to help you review and synthesize concepts from the section. A short answer follows to show how scientists construct scientific arguments from observations, evidence, theories, and natural laws that lead to a conclusion. A further question then gives you a chance to construct your own scientific argument on a related issue.
- ***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 think about these questions yourself or discuss them in class.
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  New to *Universe* are **animation tutorials** written exclusively for *Universe* by text author Mike Seeds. These tutorials build on the interactive animations from the Cengage YouBook and are assignable in WebAssign. These tutorials will help students review important concepts and explore topics from the textbook in more detail. Each tutorial requires a student to consider, and sometimes manipulate an animation, and to then answer a series of questions. Hints are offered with each step, which encourage students to think through each question. Animation tutorials will build student reasoning so they will ultimately be able to draw conclusions.

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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.

Mike Seeds
Dana Backman

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1

Here and Now

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 universe filled with other stars and galaxies. 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 about astronomy:

- **Where are you and Earth in the universe?**
- **How does the time span of human civilization compare with the age of the universe?**
- **Why study astronomy?**

This chapter is a summary of your upcoming exploration of deep space and deep time. The following chapter continues your journey by looking at the night sky as seen from Earth. Later chapters will provide many examples of how science gives you a way to know and understand nature.

A cloud of gas and dust in space named Messier 78, so far away its light takes 1600 years to reach Earth. This image was created by a private citizen, Igor Chekalin of Russia, in response to a worldwide contest sponsored by the European Southern Observatory (ESO) in 2010. Mr. Chekalin's prize was an all-expense-paid trip to Chile to work with the astronomers using one of ESO's giant telescopes.

The longest journey begins with a single step.

—LAO-TZU

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 whose size 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.

■ **Figure 1-2**

This box ■ represents the relative size of the previous frame.

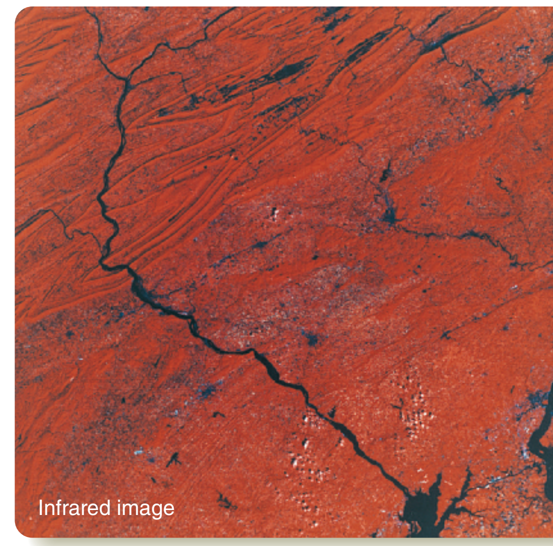
© USGS

■ **Figure 1-1**

Michael A. Seeds

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.

■ **Figure 1-3**



NASA

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.

The photo in Figure 1-2 is 1 mile across, which equals 1.609 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. 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 sights invisible to unaided human eyes.

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 use your own imagination to connect images with explanations about astronomical objects.

■ **Figure 1-4**

NASA

Enlarge your field of view by a 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.

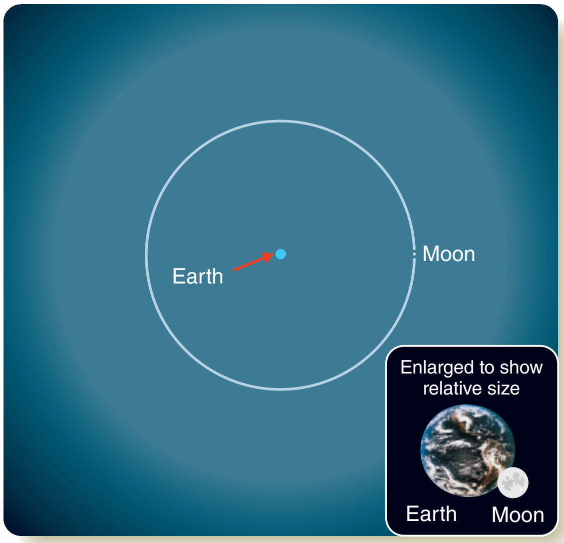
These numbers are so large that it is inconvenient to write them out. Astronomy is sometimes known as the science of big numbers, and soon you will be using numbers much larger than these to discuss the universe. Rather than writing out these numbers as in the previous paragraph, it is more convenient 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 the Appendix. 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 is 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 though the sun is 109 times larger in diameter than Earth (inset), it too is nothing more than a dot in this diagram.

This diagram represents an area with a diameter of 1.6×10^8 km. One way astronomers simplify 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. Now you can express the average distance from Venus to the

■ **Figure 1-5**



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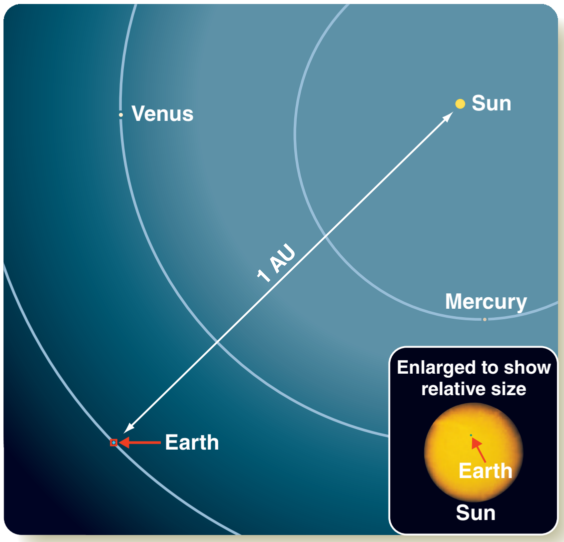
■ **Figure 1-6**

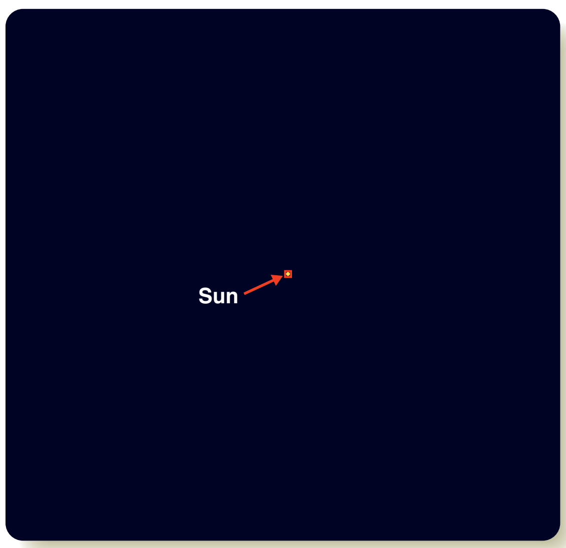


© Cengage Learning 2014; Images: NOAO/AURA/NSF sun as about 0.72 AU and the average distance from Mercury to the sun as about 0.39 AU.

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 0.307 AU and as far away as 0.467 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, 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 this diagram. 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 over 4 hours to reach Neptune.

■ **Figure 1-8**



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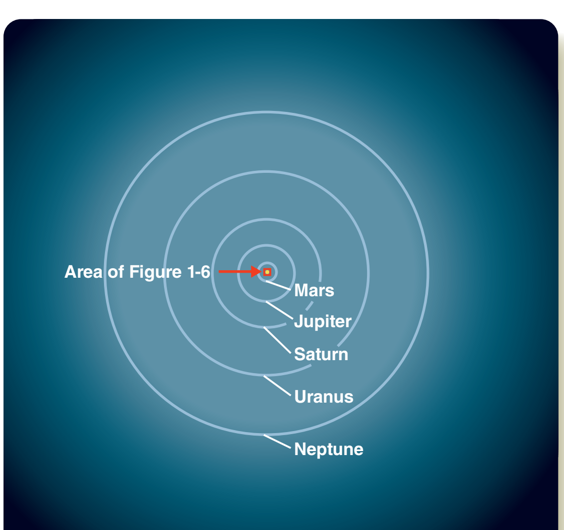
■ **Figure 1-7**



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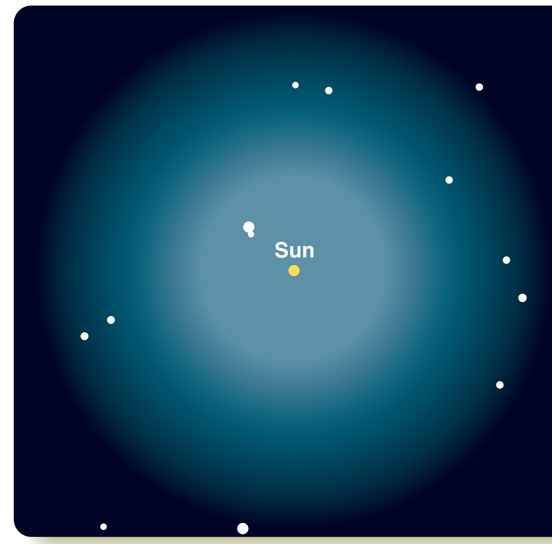
You can remember the order of the plants from the sun outward by remembering a simple sentence: *My Very Educated Mother Just Served Us Noodles.* The first letter of each word reminds you of a planet: Mercury, Venus Earth, Mars Jupiter, Saturn, Uranus, Neptune.

■ **Figure 1-9**



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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.

Nor are any stars visible 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 10 times larger than that.

In ■ Figure 1-9, your field of view has expanded to a diameter of a bit over 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 next time you hear someone say, "It will take me light-years to finish my history paper," you can tell that person that a light-year is a distance, not a time. 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 roughly 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 from Earth—looks like a point of light through even 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 over 800 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 1-10

NOAO/AURA/NSF

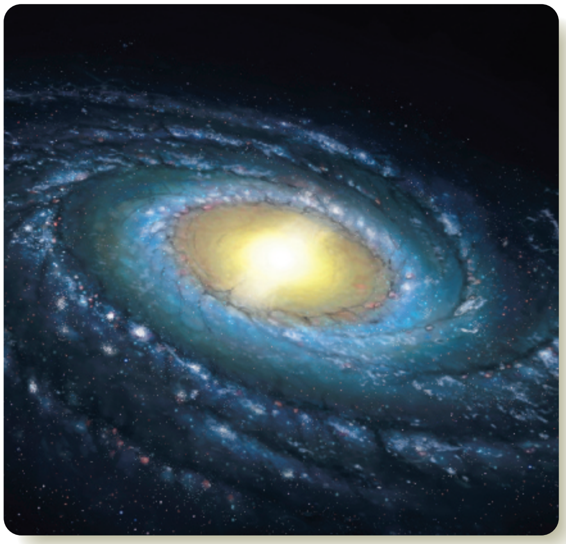
Figure 1-9 follows the astronomical custom of making the sizes of the dots represent not the sizes of the stars but their brightnesses. This is how star images are recorded on photographs. Bright stars make larger spots on a photograph than faint stars, so the size of a star image in a photograph tells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

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, a 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 some contain over 100 billion stars. In the night sky, you can see our galaxy as a great, cloudy wheel 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 our galaxy looks like if no one can leave it and look back? Astronomers use evidence to guide their theories as they imagine what the Milky Way 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 cannot detect, or hap-pen too slowly or too rapidly for humans to sense. These images are not just guesses; they are scientifically based illustrations guided by the best information astronomers can gather.

Figure 1-11



© Mark Garlick/Space-art.com

Figure 1-12

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As you explore, notice how astronomers use science to imagine, understand, and depict cosmic events.

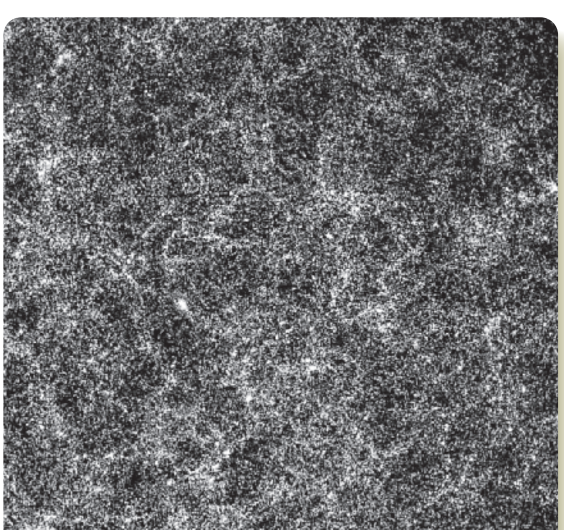
The artist's conception of the Milky Way reproduced in Figure 1-11 shows that our galaxy, like many others, has graceful **spiral arms** winding outward through its disk. In a later chapter, you will learn that the spiral arms are places where stars are formed from clouds of gas and dust. Our own sun 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.

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 light-years 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 correct 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 the sun and its planets, including Earth. Our **galaxy** contains our solar system plus billions of other stars and whatever planets orbit around them. The **universe** includes everything: billions of galaxies, each containing billions of stars and, presumably, billions of planetary systems.

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.



Based on data from M. Seldner, B. L. Siebers, E. J. Groth, and P. J. E. Peebles, *Astronomical Journal 82* [1977].

■ **Figure 1-13**

1-2 When Is Now?

Now that you have an idea where you are in space, you need to know where you are in time. The stars have 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 red ribbon.

Imagine stretching that ribbon down the center of an American 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 long red 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 your ribbon toward the goal line labeled *today.* Observations tell astronomers 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 must walk only about 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 must walk past the 50-yard line down to the 35-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, about 9 billion years after the big bang.

You must carry your flags a few yards further to the 29-yard line to mark the appearance of the first 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. Your dinosaur flag goes just inside the 2-yard line. Dinosaurs go extinct as you pass the one-half-yard line.

What about people? The first humanlike creatures appeared on Earth about 4 million years ago, so you can put a little flag for the first humans only about an inch 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 inch from the goal line. That's half the thickness of a sheet of paper. Compare the history of human civilization with the history of the universe. Every war you have ever heard of, every person whose name is recorded, every structure ever built from Stonehenge to the building you are in right now fits into that 0.0026 inch.

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 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 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. In every chapter of this book, you will find short essays titled "How Do We Know?" They are designed to help you think not about *what* is known but about *how* it is known. To do that, they will explain different aspects of scientific reasoning and in that way 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—a method called *science.*