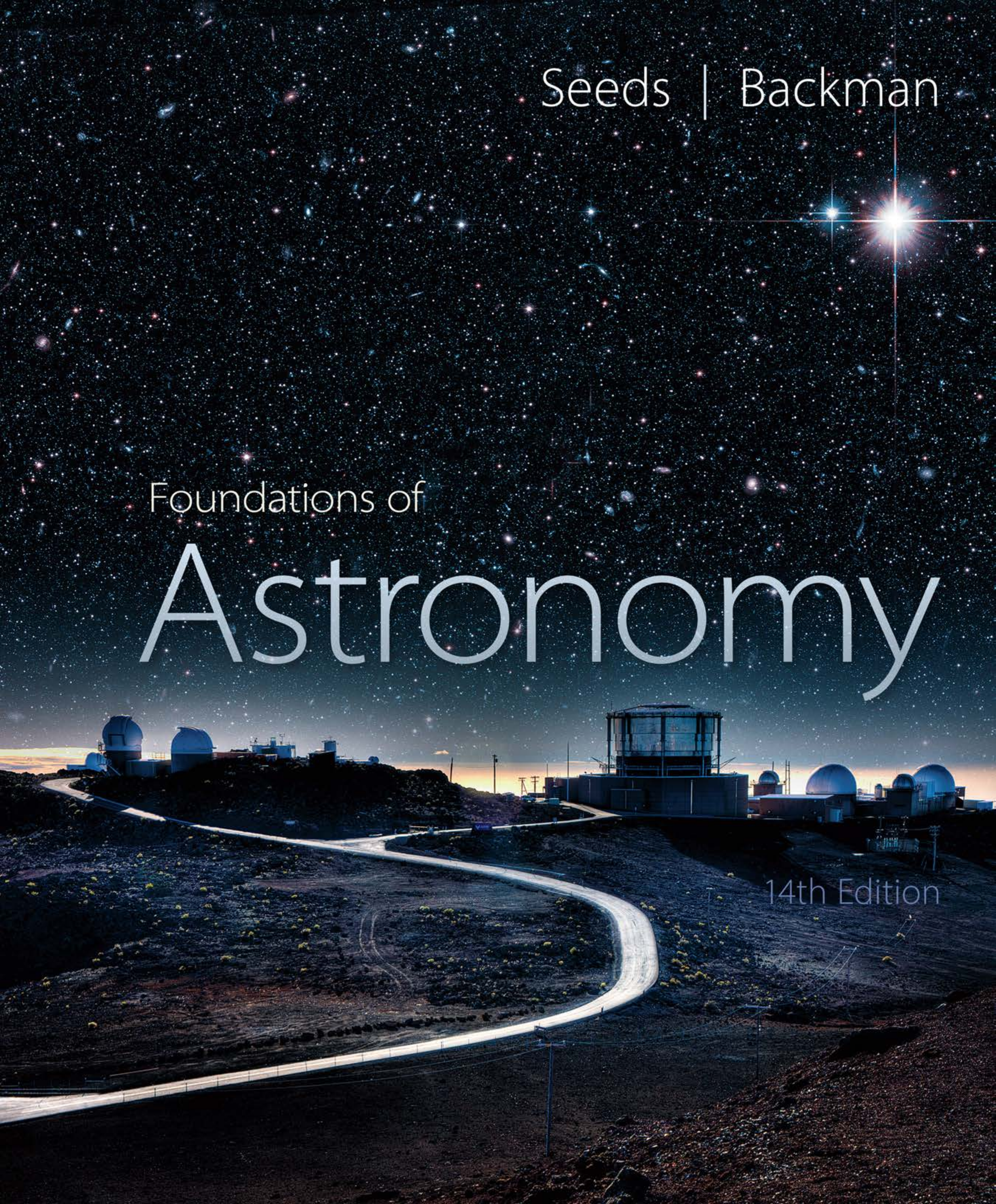
Seeds | Backman

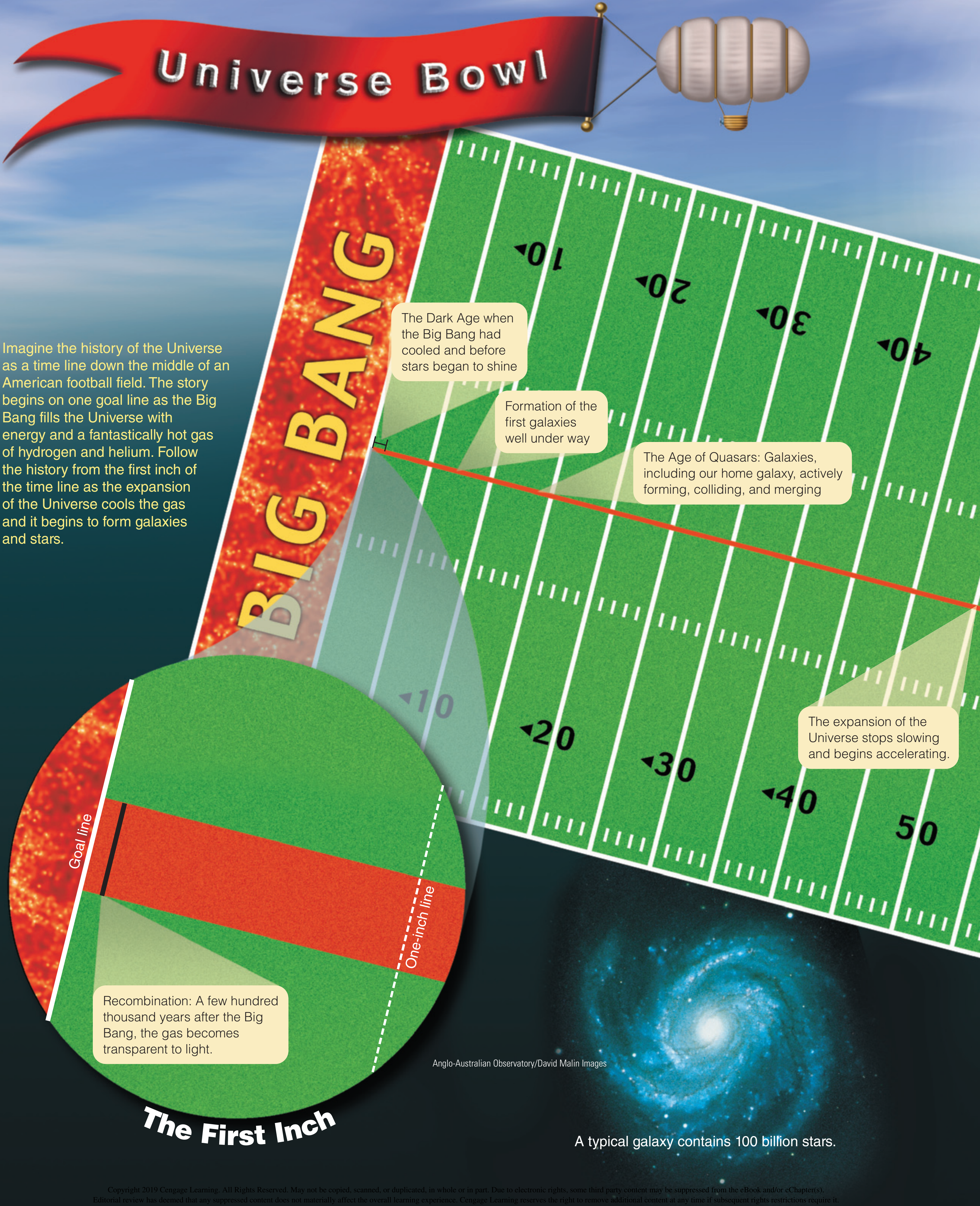
Foundations of Astronomy

14th Edition



Universe Bowl

Imagine the history of the Universe as a time line down the middle of an American football field. The story begins on one goal line as the Big Bang fills the Universe with energy and a fantastically hot gas of hydrogen and helium. Follow the history from the first inch of the time line as the expansion of the Universe cools the gas and it begins to form galaxies and stars.



The Dark Age when the Big Bang had cooled and before stars began to shine

Formation of the first galaxies well under way

The Age of Quasars: Galaxies, including our home galaxy, actively forming, colliding, and merging

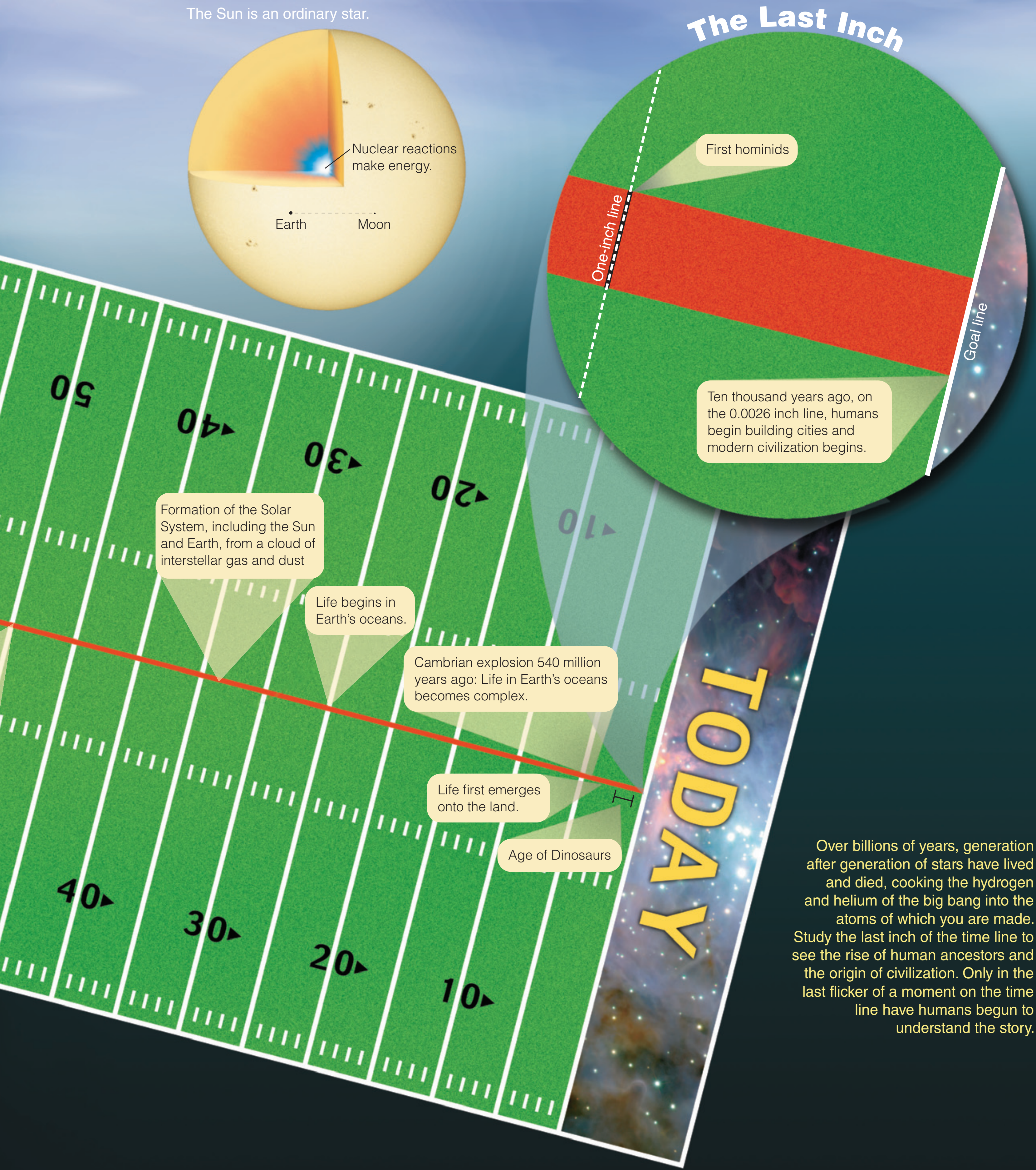
The expansion of the Universe stops slowing and begins accelerating.

Recombination: A few hundred thousand years after the Big Bang, the gas becomes transparent to light.

Anglo-Australian Observatory/David Malin Images

A typical galaxy contains 100 billion stars.

The Last Inch



The Sun is an ordinary star.

Nuclear reactions make energy.

Earth

Moon

First hominids

One-inch line

Goal line

Ten thousand years ago, on the 0.0026 inch line, humans begin building cities and modern civilization begins.

Formation of the Solar System, including the Sun and Earth, from a cloud of interstellar gas and dust

Life begins in Earth's oceans.

Cambrian explosion 540 million years ago: Life in Earth's oceans becomes complex.

Life first emerges onto the land.

Age of Dinosaurs

TODAY

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 humans begun to understand the story.

Foundations of Astronomy

FOURTEENTH EDITION

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Joseph R. Grundy Observatory
Franklin and Marshall College

Dana E. Backman

SETI Institute & NASA Airborne
Astronomy Ambassadors
SOFIA (Stratospheric Observatory
for Infrared Astronomy)

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***Foundations of Astronomy,* Fourteenth Edition**
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Dedication

In memory of Edward & Antonette Backman and Emery & Helen Seeds

CONTENTS

PART 1: EXPLORING THE SKY

HOW DO WE KNOW?

CONCEPT ART

PART 2: THE STARS

HOW DO WE KNOW?

CONCEPT ART

PART 3: THE UNIVERSE

PART 4: THE SOLAR SYSTEM

HOW DO WE KNOW?

CONCEPT ART

Celestial Profile

PART 5: LIFE

HOW DO WE KNOW?

CONCEPT ART

A NOTE TO STUDENTS

From Dana and Mike

We are excited that you are taking an astronomy course and using our book and related online resources. You are going to see and learn about 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 recognizing 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 their atoms are crushed, 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 were born 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 we use it? For instance, how can anyone know there was a Big Bang? In today's world, you need think carefully about the quality of the information with which we are flooded. You should demand evidence, not just 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 comprehend 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 new images, new discoveries, and new insights that will take you, in an introductory course, to the frontier of human knowledge. Telescopes on remote mountaintops and in space provide a daily dose of excitement that goes far beyond entertainment. 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. Rather, this book is organized to show you how scientists use evidence and theory to create logical arguments that explain 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—your location not just in space but in the unfolding history of the physical Universe. We want you not only to know where you are and what you are in the Universe but also 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 and governed by a small set of rules and that we humans have found a way to figure out the rules—a method called science.

To appreciate your role in this beautiful Universe, you need to learn more than just the facts of astronomy. You have to 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 for the Fourteenth Edition

- Every chapter has been revised and updated with new text and images regarding observatories, scientific missions, and new discoveries.
- Material on normal galaxies, active galaxies, and black holes (Chapters 16 and 17 in the previous edition), have been combined and streamlined into a single chapter (Chapter 16). The following chapters have been renumbered as a result.
- Some sections have been reorganized and updated to give clearer and more current presentations, especially Section 11-3, Young Stellar Objects and Protostellar Disks; Section 13-4, Supernovae Explosions; Section 18-4, Planets Orbiting Other Stars; Section 23-3b, Pluto as a World; and Section 24-3b, Comet Nuclei.
- Other chapters and sections with less substantial but still significant revisions are Section 6-3a, Modern Optical Telescopes; Section 6-6b, Gravity Wave Astronomy; Section 8-1d Composition of the Sun; Section 9-1c, Parallax and Distance; Section 19-4a, Origin of the Atmosphere; Section 20-2b, Mercury's Surface; and Section 20-2c, Mercury's Interior.
- A *How Do We Know?* essay has been added to the cosmology chapter regarding what we can learn from a mistaken claim about discovering gravity waves,
- All art has been carefully reviewed and revised in the interest of accuracy, clarity, and consistency.
- *Key Equations* now have numbers and titles, as well as examples to demonstrate their use. This feature highlights and reinforces the equations that will be needed to solve problems in later chapters.
- New *Sense of Proportion* questions have been added to help students ground their understanding of relative sizes of celestial objects, distances, and so on. As a complement to this, discussion of proportionality has been expanded where relevant throughout the text.
- The *Focus on Fundamentals* boxed feature has been eliminated and relevant material was moved back into the text.
- The end-of-chapter *Summary* sections have been significantly revised in all chapters with the goal of helping students focus and better navigate key concepts for review.
- Discussion Questions have been replaced with *Active Inquiry Questions*, designed to engage students in deeper critical thinking.
- All numerical values in the text and tables were checked and in some cases updated.
- The features known as *Doing Science* in earlier editions were renamed *Practicing Science*.

Special Features

- The opening page of each chapter helps students see the organization of the book by connecting the chapter with the preceding and following chapters. The short list of important questions highlights the learning objectives of the chapter.
- *How Do We Know?* boxes help students understand how science works. Topics include the difference between a hypothesis and a theory, the use of statistical evidence, the construction of scientific models, and more.
- *Concept Art* features appear at least once in every chapter and cover topics that are strongly visual. Color and numerical keys in the introduction to the Concept Art guide you to the main concepts.
- *Common Misconceptions* highlight and correct popularly held misconceptions about astronomy.
- *Practicing Science* boxes at the end of most chapter sections begin with questions designed to put students into the role of scientists considering how best to proceed as they investigate the cosmos. These questions serve a second purpose as a further review of how we know what we know. Many of the *Practicing Science* boxes end with a second question that points the student-as-scientist in a direction for further investigation.
- *Celestial Profiles* 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; they have noticeable differences but many characteristics and a family history in common.
- *What Are We?* features at the end of each chapter show how the chapter content helps explain our place in the cosmos.
- Chapter *Summaries* review the key concepts of the chapter, highlighting key terms and equations, to aid student study.
- End-of-chapter *Review Questions* are designed to help students review and test their understanding of the material.
- End-of-chapter *Active Inquiry Questions* go beyond the text and invite students to think critically and creatively about scientific questions.
- End-of-chapter *Problems* promote quantitative understanding of the chapter contents.

- *Sense of Proportion* questions gauge student understanding of relative sizes and quantities in the Universe.
- *Learning to Look* questions prompt students to answer questions based on observations of visual evidence shown in diagrams or photographs.

MindTap for Astronomy

MindTap Astronomy for *Foundations of Astronomy*, 14th Edition, is the digital learning solution that powers students from memorization to mastery. It gives you complete control of your course—to provide engaging content, to challenge every individual and to build their confidence. Empower students to accelerate their progress with MindTap. MindTap: Powered by You.

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.

Virtual Astronomy Labs 3.0 used real astronomical data combined with robust simulations in auto-graded modular segments to provide a true online laboratory experience. Through the use of simulations and exercises, students are introduced to fundamental and complex theories. The labs focus on 20 of the most important concepts in astronomy, such as astronomical measurements, dark matter, black holes, binary stars, and extrasolar planets.

Waypoints bring the Concept Art from the printed page alive in short (4- to 6-minute) animated lessons narrated by author Mike Seeds. Waypoints serve to clarify important concepts and present dynamic interactions in full multimedia presentations on topics ranging from the Celestial Sphere and the Ancient Universe to Emission Nebulae, Galaxy Classification, and Stellar Evolution.

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 to this book. They helped shape the book through their comments and suggestions.

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

We are happy to acknowledge the use of images and data from a number of important programs. In preparing materials for this book we used several atlas images and mosaics produced by the Two Micron All Sky Survey (2MASS), a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/JPL-Caltech, funded by NASA and the NSF. A number of solar images are used courtesy of the *SOHO* consortium, a project of international cooperation between ESA and NASA. The NASA Sky View facility located at Goddard Space Flight Center and the SIMBAD database operated by the CDS in Strasbourg, France, were also used in preparation of this text.

It has been a great pleasure to work with our Cengage production team, Content Developer Rebecca Heider, Product Assistant Caitlin Ghegan, Art Director Cate Barr, and Product Manager Rebecca Berardy-Schwartz, plus Edward Dionne of MPS Limited.

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

ABOUT THE AUTHORS

Seth Shostak / SETI Institute

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 also has taught introductory astronomy and astronomy for physics majors at Santa Clara University as well as introductory astronomy, astrobiology, and cosmology courses in Stanford University's Continuing Studies program. His research interests focused 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, managing NASA's Airborne Astronomy Ambassadors and outreach programs for SOFIA, the Stratospheric Observatory for Infrared Astronomy. Along with this book, Dana is coauthor with Mike Seeds of *Horizons: Exploring the Universe; Stars and Galaxies; The Solar System;* and *ASTRO*, 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 focused on variable stars and automation of astronomical telescopes. In addition to this book, Mike is coauthor with Dana Backman of *Horizons: Exploring the Universe; Stars and Galaxies; The Solar System;* and *ASTRO*, 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

Courtesy of NASA

▲ Composite image of Earth's western hemisphere at night assembled from data acquired by the *Suomi National Polar-orbiting Partnership* satellite. The bright crescent at right is the location of dawn.

As you study astronomy, you will learn about yourself. You are a planet-walker, and this chapter will give 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 which are all results of billions of years of history and evolution. You owe it to yourself to know where you are in the Universe, and when you are in its history, because those are important steps toward knowing what you are.

In this chapter, you will consider three important questions about astronomy:

- ▶ 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

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.

Begin with something familiar. **Figure 1-1** shows an area 52 feet across on a college campus including a person, a sidewalk, and a few trees, which are all objects with sizes you can understand. Each successive picture in this "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**, which is 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 in the next image (**Figure 1-2**). People, trees, and sidewalks have become too small to discern, but now you can view an entire college campus plus 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 need to change 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 important, 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 less than two-thirds of a mile—a short walk across a neighborhood. When you expand your field of view by another factor of 100, the neighborhood you saw in Figure 1-2 vanishes. Now your field of view is 160 km wide, and you see cities and towns as patches of gray (**Figure 1-3**). 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 at the upper left, and the Susquehanna River flows southeast into Chesapeake Bay. What look like white bumps are a few puffs of cloud.

Figure 1-3 is an infrared photograph in which healthy green leaves and crops are shown as red. Human eyes are sensitive to only a narrow range of colors. As you explore the Universe, 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. You will learn more about infrared, X-ray, and radio energy in later chapters.

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 the other 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 at the right edge of the Earth image 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.

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, the diameter of which is only one-fourth of Earth's, is an even smaller dot along its orbit

Michael A. Seeds

▲ **Figure 1-1** This familiar scene is an area about 52 feet (16 meters) wide.

Imagery ©2016 DigitalGlove, PA Department of Conservation and Natural Resources-PAMP /USGS, U.S. Geological Survey, USDA 500 ft Farm Service Agency, Map data ©2016 Google

▲ **Figure 1-2** The field of view is 1 mile (1.6 km) wide. This box ■ represents the relative size of Figure 1-1.

NASA/*Landsat*

▲**Figure 1-3** The field of view is 160 km wide. This box ■ represents the relative size of Figure 1-2.

NASA

▲**Figure 1-4** The field of view is 16,000 km wide. This box ■ represents the relative size of Figure 1-3.

380,000 km away. (The relative sizes of Earth and Moon are shown in the inset at the bottom right of Figure 1-5.)

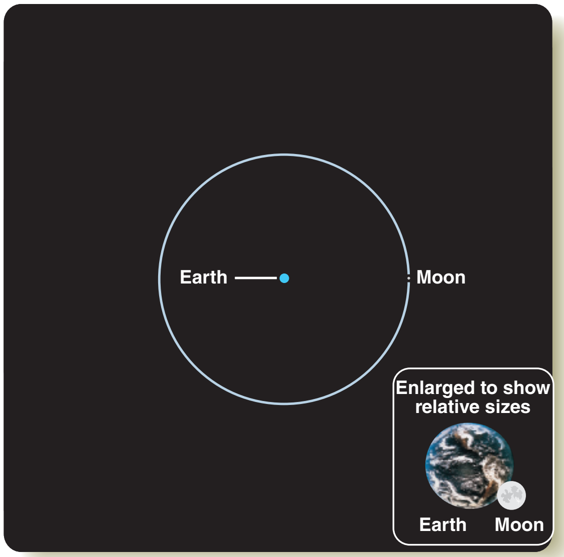
The numbers in the preceding paragraph are so large that it is inconvenient to write them out. Soon you will be using numbers even larger than these to describe the Universe; rather than writing such astronomical numbers as they are in the previous paragraph, it is more convenient to write them in **scientific notation**. This is nothing more than a simple way to write very big or very small numbers without using lots of zeros. For example, 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 describe without using scientific notation.

When you once again enlarge your field of view by a factor of 100 (**Figure 1-6**), Earth, the Moon, and the Moon's orbit that filled the previous figure are indistinguishable in the blue dot at lower left of the new figure. 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, asteroids, and comets.

Earth, Venus, and Mercury are **planets**, which are spherical, nonluminous bodies that orbit a star and shine by reflected light. Venus is about the size of Earth, and Mercury has slightly more than one-third of Earth's diameter. On this diagram, they are both too small to be portrayed as anything but tiny dots. The Sun is a **star**, a self-luminous ball of hot gas. Even though the Sun is about 100 times larger in diameter than Earth (inset at bottom right of Figure 1-6), it, too, is no more than a dot in this diagram. Figure 1-6 represents an area with a diameter of 1.6×10^8 km.

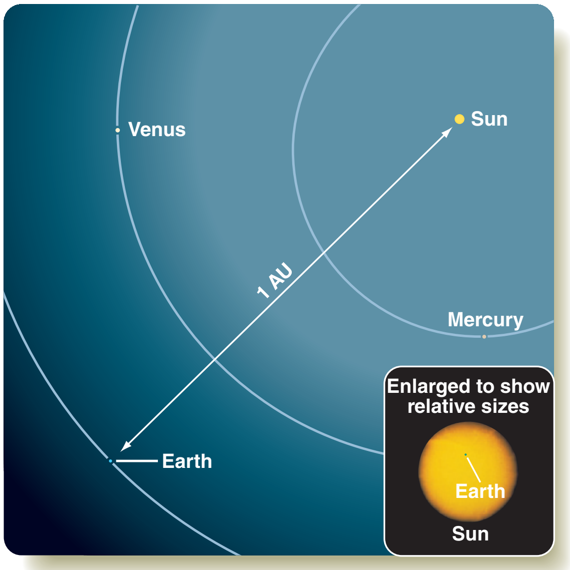
Another way astronomers simplify descriptions and calculations that require large numbers is to define larger units of measurement. For example, the average distance from Earth to the Sun is a unit of distance called the **astronomical unit (AU)**; an AU is equal to 1.5×10^8 km. Using that term, you can express the average distance from Mercury to the Sun as about 0.39 AU and the average distance from Venus to the Sun as about 0.72 AU.

These distances are averages because the orbits of the planets are not perfect circles. This is especially 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 than Mercury's; its distance from the Sun varies by only a few percent.



NASA

▲**Figure 1-5** The field of view is 1.6 million km wide. This box ■ represents the relative size of Figure 1-4.



▲**Figure 1-6** The field of view is 160 million km wide. This box ■ represents the relative size of Figure 1-5.

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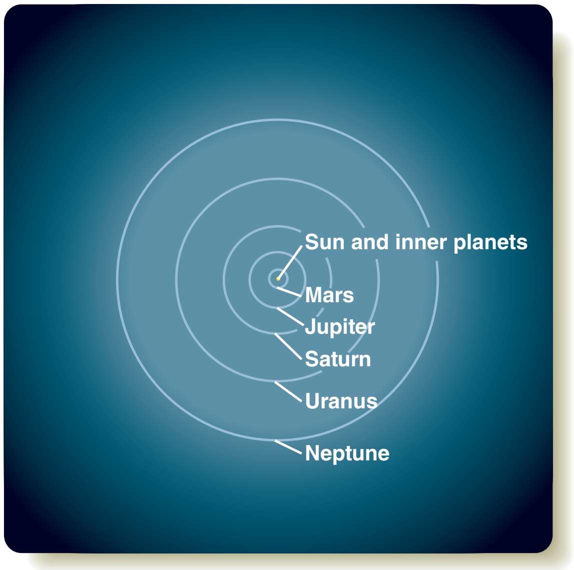


▲**Figure 1-7** The field of view is 16 billion km (about 110 AU) wide. The orbits of the three innermost planets—Mercury, Venus, and Earth—are too small to show at this scale. This box ■ represents the relative size of Figure 1-6.

Enlarge your field of view again by a factor of 100, and you can see the entire planetary region of our Solar System (**Figure 1-7**). The Sun, Mercury, Venus, and Earth lie so close together that you cannot see them separately at this scale. You can see only the brighter, more widely separated objects such as Mars, the next planet outward. Mars is only 1.5 AU from the Sun, but Jupiter, Saturn, Uranus, and Neptune are farther from the Sun, so they are easier to locate in this diagram. They are cold worlds that are 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.

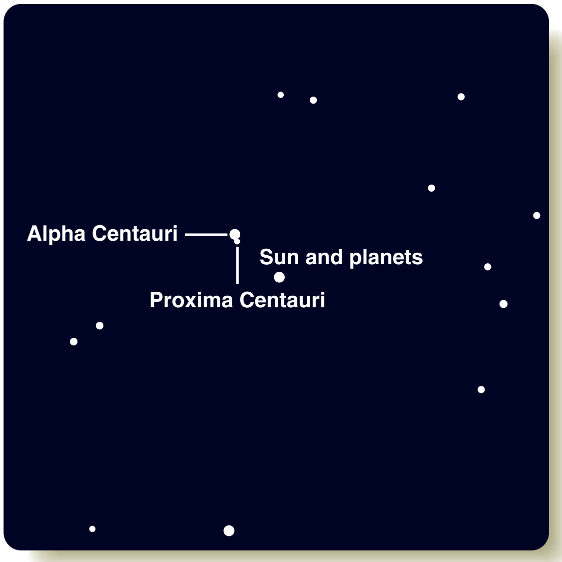
You can remember the order of the planets from the Sun outward by remembering a simple sentence such as: *My Very Educated Mother Just Served Us Noodles* (perhaps you can come up with a better one). The first letter of each word is the same as the first letter of a planet's name: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The list of planets once included Pluto, but in 2006, astronomers attending an international scientific congress made the decision that Pluto should be redefined as a **dwarf planet**. Pluto meets some of the criteria to be considered a planet, but not others. Pluto is now known to be just one of a group of small objects that have been discovered circling the Sun beyond 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 yellow dot 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 is close enough to be visible in this diagram, which shows a region only 11,000 AU in diameter. Stars in the Sun's neighborhood are typically separated by distances about 30 times larger than that.

In **Figure 1-9**, your field of view has expanded again by a factor of 100 to a diameter of 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 AU. To express distances so large, astronomers defined a new unit of distance, the light-year. One **light-year (ly)** is the distance that light travels in one year, approximately 9.5 × 10^{12} km or 63,000 AU. It is a **Common Misconception** that a light-year is a unit of time,

▲**Figure 1-8** The field of view is 11,000 AU wide. This box ■ represents the relative size of Figure 1-7.



▲**Figure 1-9** The field of view is 17 ly wide. The sizes of the dots representing each star are not to scale. This box ■ represents the relative size of Figure 1-8.

NSF/AURA/NOAO/Bill Schoening

▲**Figure 1-10** The field of view is 1700 ly wide. This box ■ represents the relative size of Figure 1-9.

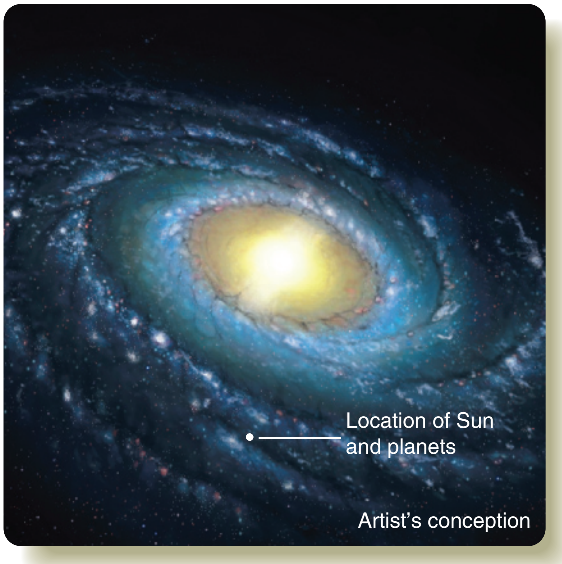
and you can sometimes hear the term misused in science fiction movies and TV shows. The next time you hear someone say, "It will take me light-years to finish my history paper," you could tell the person that a light-year is a distance, not a time (although perhaps that comment wouldn't be appreciated). 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 most stars are approximately 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, which is only 4.2 ly from Earth—looks like a point of light through the biggest telescopes on Earth. Figure 1-9 follows the common astronomical practice of making the sizes of the dots represent not the sizes of the stars but their brightness. 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 photo tells you not how big the star is but rather how bright it is.

You might wonder whether other stars have families of planets orbiting around them as the Sun does. Such objects, termed *extrasolar planets,* are very difficult to see because they are generally small, faint, and too close to the glare of their respective parent stars. Nevertheless, astronomers have used indirect methods to find thousands of such objects, although only a handful have been photographed directly.

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 our 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 1000 ly to more than 300,000 ly in diameter, and the biggest ones contain more than a trillion (10^{12}) stars. In the night sky, you can see our Galaxy as a great, cloudy wheel of stars ringing the sky. This band of stars is known as the *Milky Way,* and our home galaxy is called the **Milky Way Galaxy**.



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

▲ **Figure 1-11** The field of view is 170,000 ly wide. This box ■ represents the relative size of Figure 1-10.

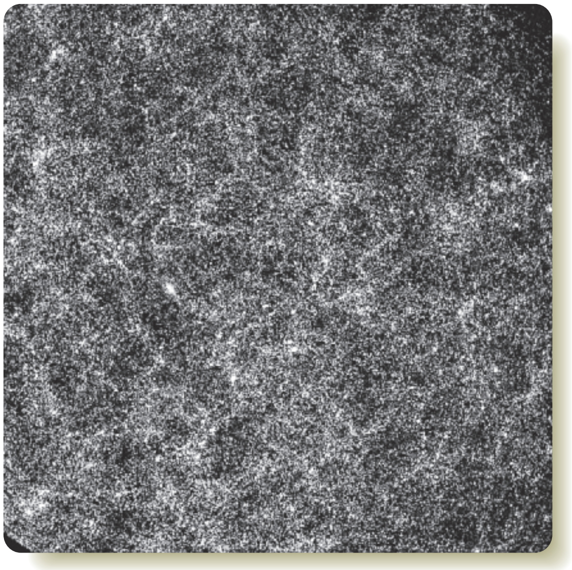
How does anyone know what the disk of the Milky Way Galaxy would look like from a vantage point tens of thousands of light years away? Astronomers use evidence to guide their explanations as they envision what our Galaxy looks like. Artists can then use those scientific descriptions to create a painting. Many images in this book are artists' conceptions of objects and events that are too big or too dim to see clearly, emit energy your eyes cannot detect, or happen too slowly or too rapidly for humans to sense. These images are much better than guesses; they are illustrations guided by the best scientific information astronomers can gather. As you continue to explore, notice how astronomers use the methods of science to understand and depict cosmic events.

The artist's conception of the Milky Way Galaxy 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, and, if you could see the Sun 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 the Milky Way 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 group of a few dozen galaxies. Galaxies are commonly grouped together in such clusters. Some galaxies have beautiful spiral patterns like our home, the Milky Way Galaxy, some are globes of stars without spirals, and some seem strangely distorted. In a later chapter, you will learn what produces these differences among the galaxies.

▲ **Figure 1-12** The field of view is 17 million ly wide. This box ■ represents the relative size of Figure 1-11.



Based on data from M. Seldner et al. 1977, Astronomical Journal 82, 249.

▲ **Figure 1-13** The field of view is 1.7 billion ly wide. This box ■ represents the relative size of Figure 1-12.

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 our Galaxy and, a very small part of that, our Solar System. Distinguishing among the Solar System, the Galaxy, and the Universe requires having an accurate sense of proportion.

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. The 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 from goal line to goal line down the center of a U.S. football field, a distance of 100 yards (about 91 meters), as shown on the inside front cover of the printed book. Imagine that one end of the ribbon represents *today*, and the other end represents the beginning of the Universe—the moment that astronomers call the *Big Bang*. In Chapter 17, Modern Cosmology, you will learn about the Big Bang and 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 your ribbon toward the goal line labeled *TODAY*. Astronomers have evidence that the Big Bang initially filled the entire Universe with hot, glowing gas, but, as the gas cooled and dimmed, the Universe went dark. That all 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's history 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 inch 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 0.0026 inch 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 sociologist, theologian, 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 birth in the Big Bang when the Universe began. Those atoms have been cooked and remade inside generations of stars, and now, after more than 10 billion 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 feature titled "What Are We?" This summary shows how the astronomy in the chapter relates to your part 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 denies that we face 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, these essays will explain different aspects of scientific thought processes and procedures to help you understand how scientists learn about the natural world.

Over the last four centuries, a way to understand nature has been developed that is called the **scientific method** (**How Do We Know? 1-1**). You will see this process applied over and over as you read about exploding stars, colliding galaxies, and alien planets. 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.

HOW DO WE KNOW? 1-1

The Scientific Method

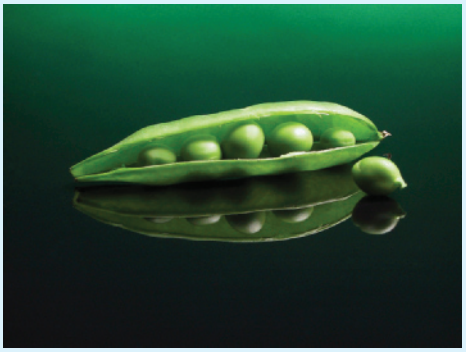
How do scientists learn about nature?

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. 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."



Inspirestock/Jupiter Images

Using the scientific method, Gregor Mendel discovered that whether peas are smooth or wrinkled is an inherited trait.

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.

WHAT ARE WE?

Participants

Astronomy gives 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 story of humanity 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 within the physical processes that govern the Universe. Gravity and atoms work together to make stars, generate energy, light the Universe, and create the chemical elements in your body. The chapters that follow will show how you fit into that cosmic process.

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

Study and Review

SUMMARY

1-1 Where Are We?

- 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 they use **scientific notation** for very large or very small numbers.
- You live on a **planet**, Earth, which orbits our **star**, the Sun, once per year. As Earth rotates once per day, you see the Sun rise and set.
- The **Solar System** includes the Sun at the center, all of the major planets that orbit around it—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune—plus the moons of the planets and other objects such as asteroids, comets, and **dwarf planets** like Pluto, bound to the Sun by its gravity.
- The **astronomical unit (AU)** is the average distance from Earth to the Sun. The **light-year (ly)** is the distance light can travel in one year.

- Astronomers have found thousands of planets orbiting stars other than our Sun, even though such distant and small bodies are very difficult to detect.
- The Milky Way, the hazy band of light that encircles the sky, is our **Milky Way Galaxy** seen from inside. **Galaxies** contain many billions of stars. The Milky Way Galaxy is about 80,000 ly in diameter and contains more than 100 billion stars including our Sun.
- 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.

1-2 When Is Now?

- Astronomers have evidence that the Universe began about 14 billion years ago in an event called the Big Bang that filled the Universe with hot gas.
- The hot gas cooled, the first galaxies began to form, and stars began to shine 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 400 million years ago, less than 1/30 of the age of the Universe. Dinosaurs evolved relatively soon after that and went extinct just 65 million years ago.
- Humanlike creatures developed on Earth only about 4 million years ago, less than 1/3000 of the age of the Universe, and human civilizations developed just 10,000 years ago.

1-3 Why Study Astronomy?

- 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 provides a way to understand nature.
- In its simplest outline, science follows the **scientific method**, in which scientists test hypotheses against evidence from experiments and observations. This method is a powerful way to learn about nature.

REVIEW QUESTIONS

1. The field of view in Figure 1-2 is a factor of 100 larger than the field of view in Figure 1-1. What aspects of Figure 1-2 increased by a factor of 100 relative to Figure 1-1? Did the height increase by that amount? The diameter? The area?
2. What is the largest dimension of which you have personal sensory experience? Have you ever hiked 10 miles? Run a marathon? Driven across a continent? Flown to the opposite side of Earth?
3. What is the difference between the Solar System, the Galaxy, and the Universe?
4. What is the difference between the Moon and a moon?
5. Why do astronomers now label Pluto a "dwarf planet"?
6. Why are light-years more convenient than miles, kilometers, or AU for measuring the distances to stars and galaxies?
7. Why is it difficult to detect planets orbiting other stars?
8. What does the size of the star image in a photograph tell you?
9. What is the difference between the Milky Way and the Milky Way Galaxy?
10. What are the Milky Way Galaxy's spiral arms?
11. What are the largest known structures in the Universe?
12. Where are you in the Universe? If you had to give directions to your location in the Universe, what directions would you give?
13. Approximately what fraction of the age of the Solar System is your life span? Of the age of the Universe?
14. Why should you study astronomy? Do you anticipate needing to know astronomy 5 or 10 years from now? If so, where?
15. How does astronomy help answer the question, "What are we?"
16. **How do we know?** How does the scientific method give scientists a way to know about nature?

ACTIVE INQUIRY 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

(Give your answers in scientific notation when appropriate.)

1. The equatorial diameter of Earth is 7928 miles. If a mile equals 1.609 km, what is Earth's diameter in kilometers? In centimeters?
2. The equatorial diameter of the Moon is 3476 kilometers. If a kilometer equals 0.6214 miles, what is the Moon's diameter in miles?
3. One astronomical unit (AU) is about 1.5×10^8 km. Explain why this is the same as 150×10^6 km.
4. A typical galaxy is shown on the first page of the Universe Bowl on the inside cover of the printed book. Express the number of stars in this typical galaxy in scientific notation.
5. The time of the Cambrian explosion is listed on the second page of the Universe Bowl on the inside cover of the printed book. Express that time in scientific notation.
6. Venus orbits 0.72 AU from the Sun. What is that distance in kilometers? (*Hint*: See Problem 3.)
7. Light from the Sun takes 8 minutes to reach Earth. How long does it take to reach Mars, 1.5 AU from the Sun?
8. The Sun is almost 400 times farther from Earth than is the Moon. How long does light from the Moon take to reach Earth?
9. If the speed of light is 3.0×10^5 km/s, how many kilometers are in a light-year? How many meters? (*Hint*: First look up or calculate how many seconds are in a year.)
10. Light from the star Betelgeuse takes 640 years to reach Earth. How far away is Betelgeuse in units of light-years? Name any historical event that was occurring on Earth at about the time the light left Betelgeuse. Is the distance to Betelgeuse unusual compared with other stars?
11. How long does it take light to cross the diameter of the Milky Way Galaxy?
12. The nearest galaxy to our home galaxy is about 2.5 million light-years away. How many meters is that?
13. How many galaxies like our own would it take if they were placed edge-to-edge to reach the nearest galaxy? (*Hint*: See Problems 11 and 12.)