

UNIVERSE



8TH EDITION

SOLAR SYSTEMS, STARS AND GALAXIES

MICHAEL SEEDS AND DANA BACKMAN

Universe Bowl



Imagine the history of the universe as a time line down the middle of a 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.

BIG BANG

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

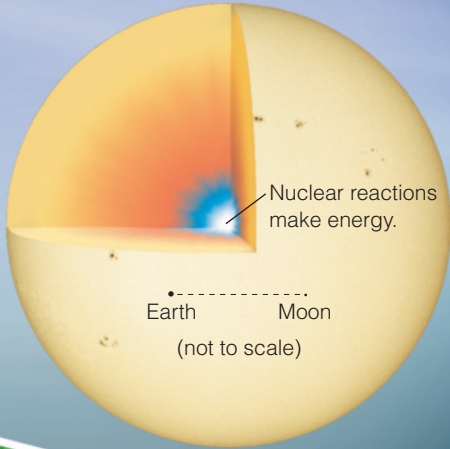
The expansion of the universe stops slowing and begins accelerating.

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

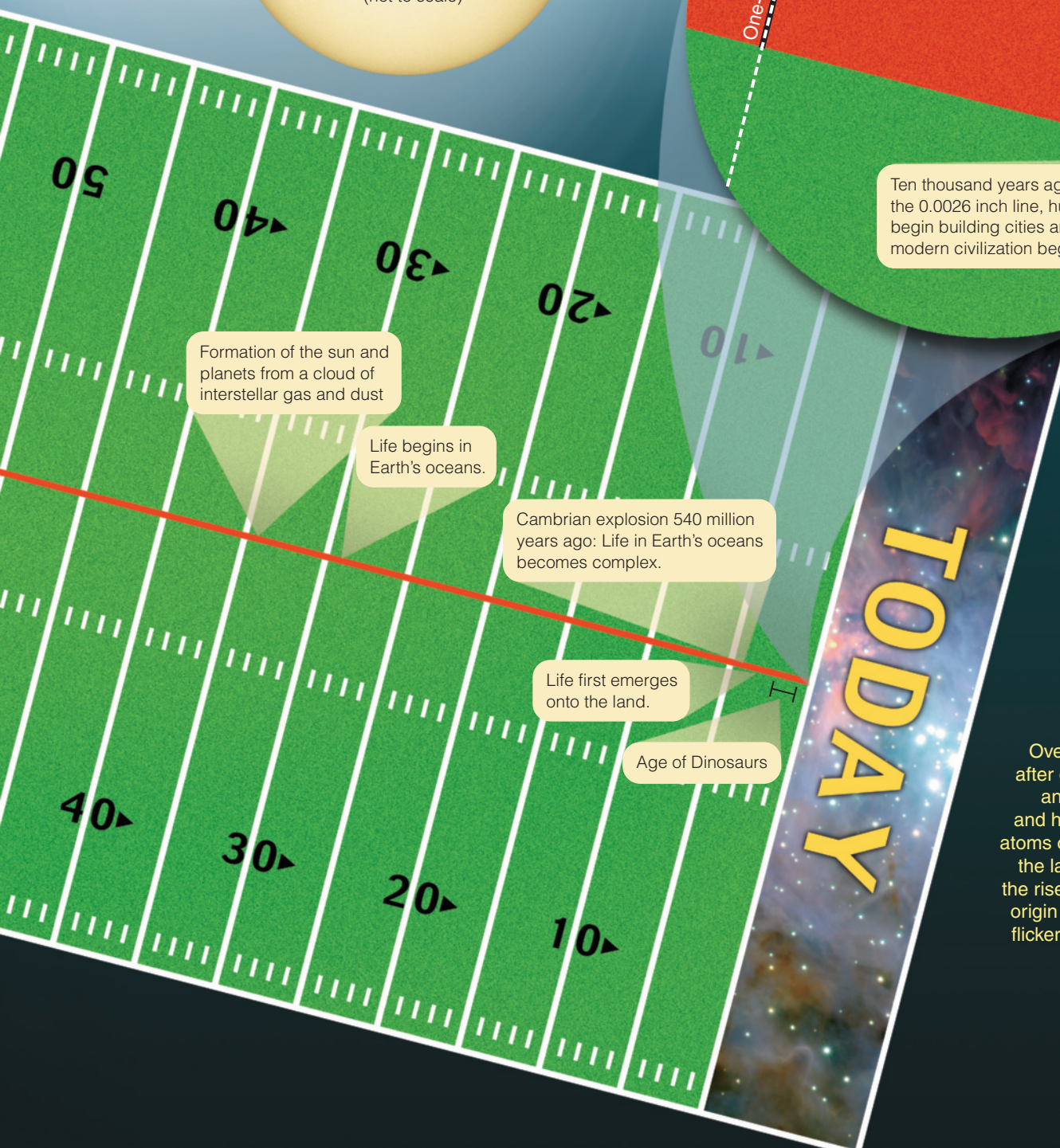
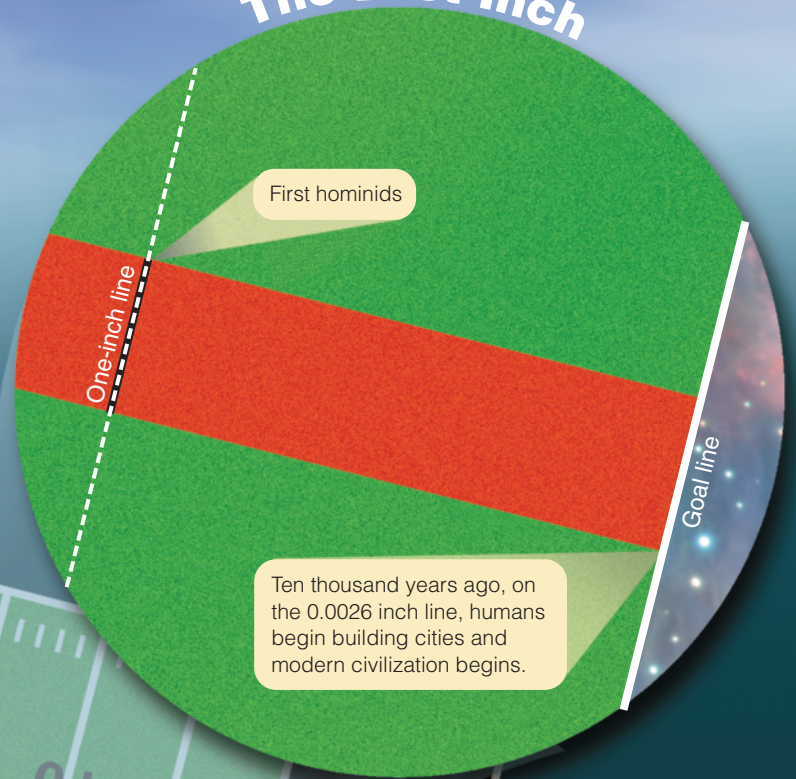
The First Inch

A typical galaxy contains 100 billion stars.

The sun is just a star.



The Last Inch



Formation of the sun and planets 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

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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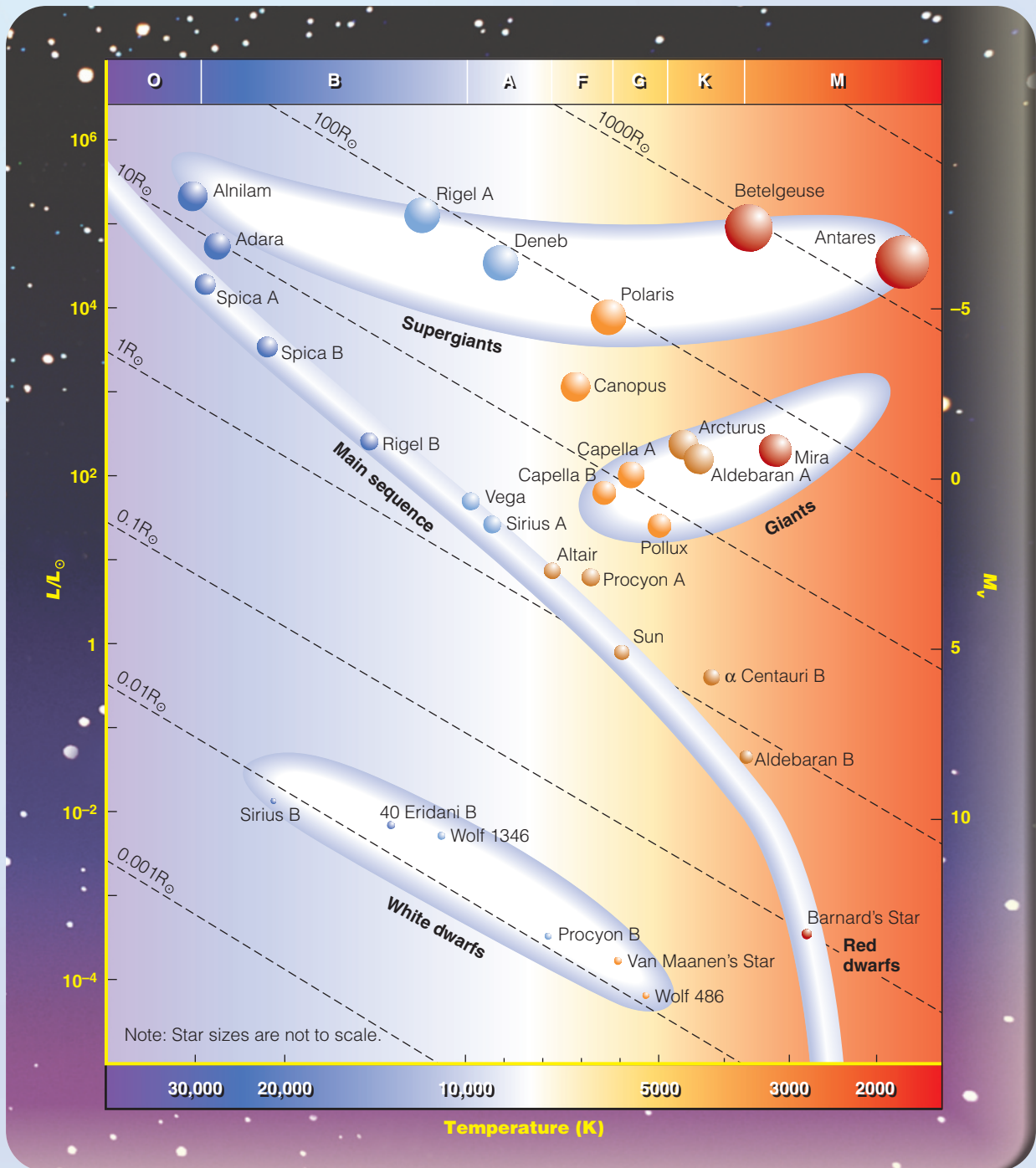
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Flash Reference: H-R Diagram



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

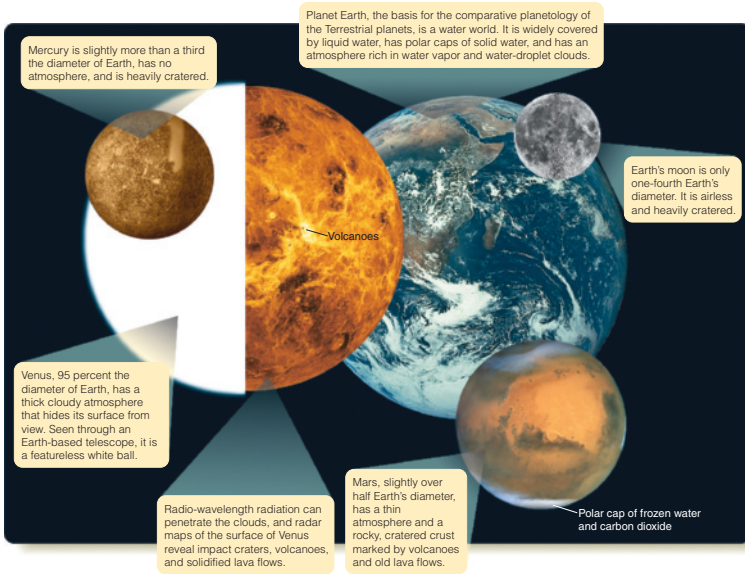
The terrestrial or Earthlike planets lie very close to the sun, and their orbits are hardly visible in a diagram that includes the outer planets.

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

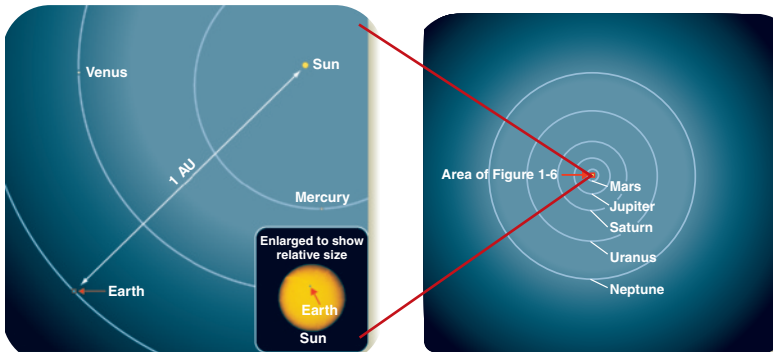
The outer worlds of our solar system orbit far from the sun. Jupiter, Saturn, Uranus, and Neptune are Jovian or Jupiter-like planets much bigger than Earth. They contain large amounts of low-density gases.

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.

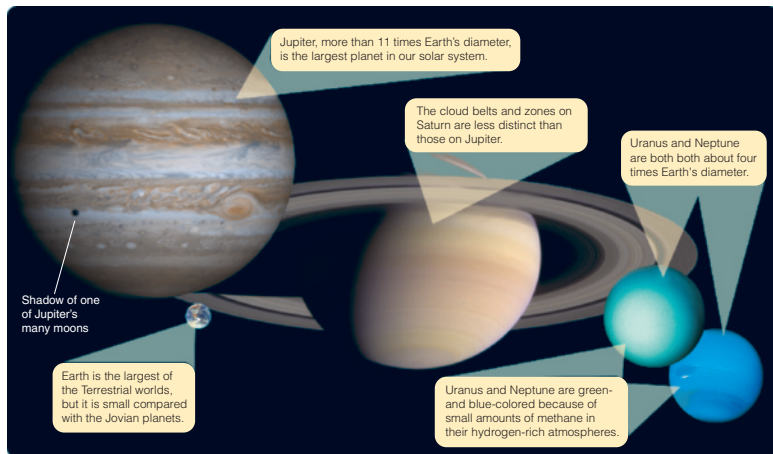
The Terrestrial Worlds



Planetary Orbits



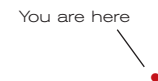
The Outer Worlds



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.

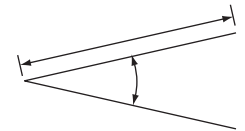
Point at things:



Force:



Process flow: **Measurement:**



Direction:



Radio waves, infrared, photons:

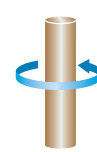


Motion:

Rotation 2-D



Rotation 3-D

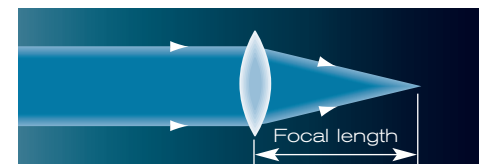


Linear



Light flow:

Updated arrow style

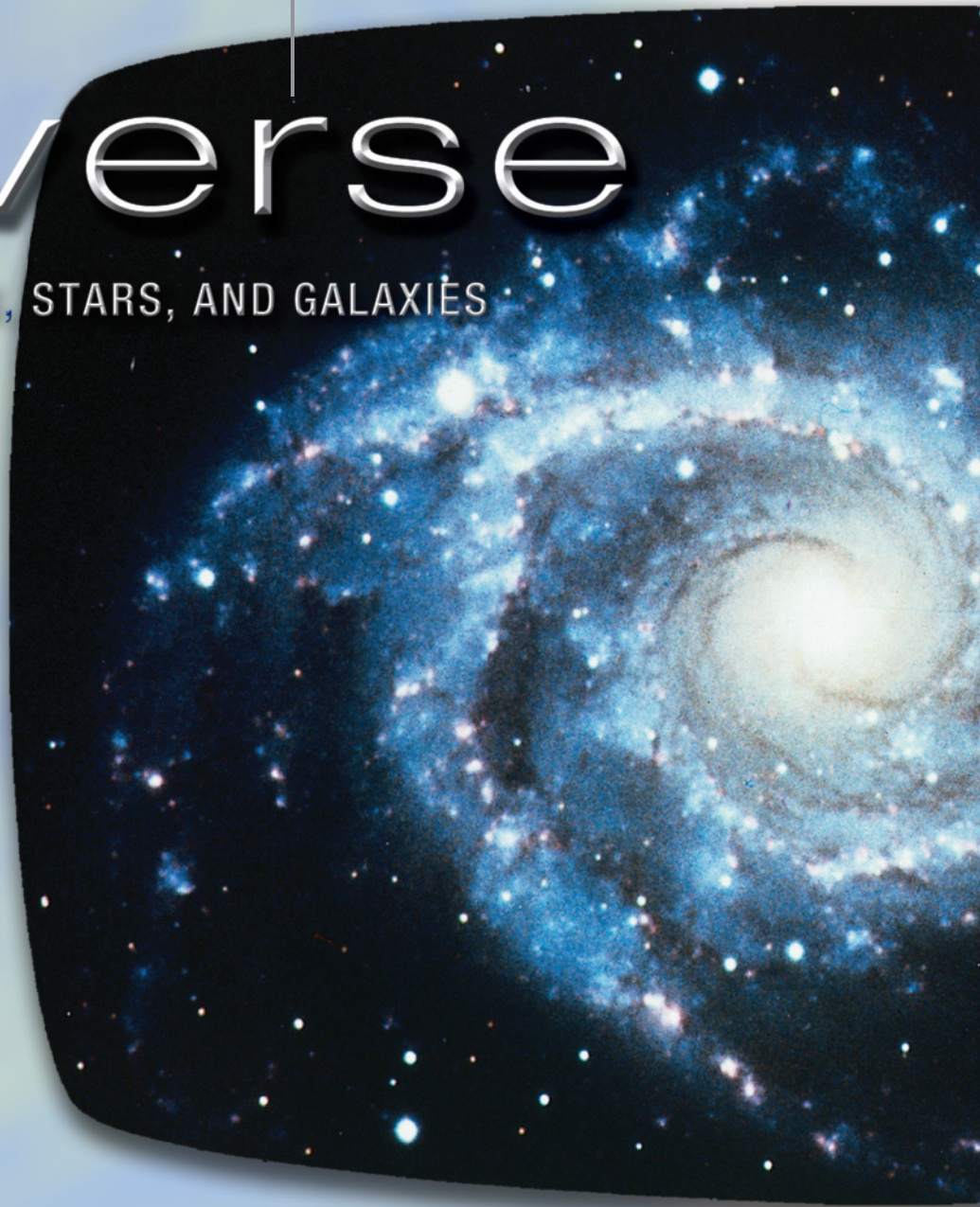


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EIGHTH EDITION

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.

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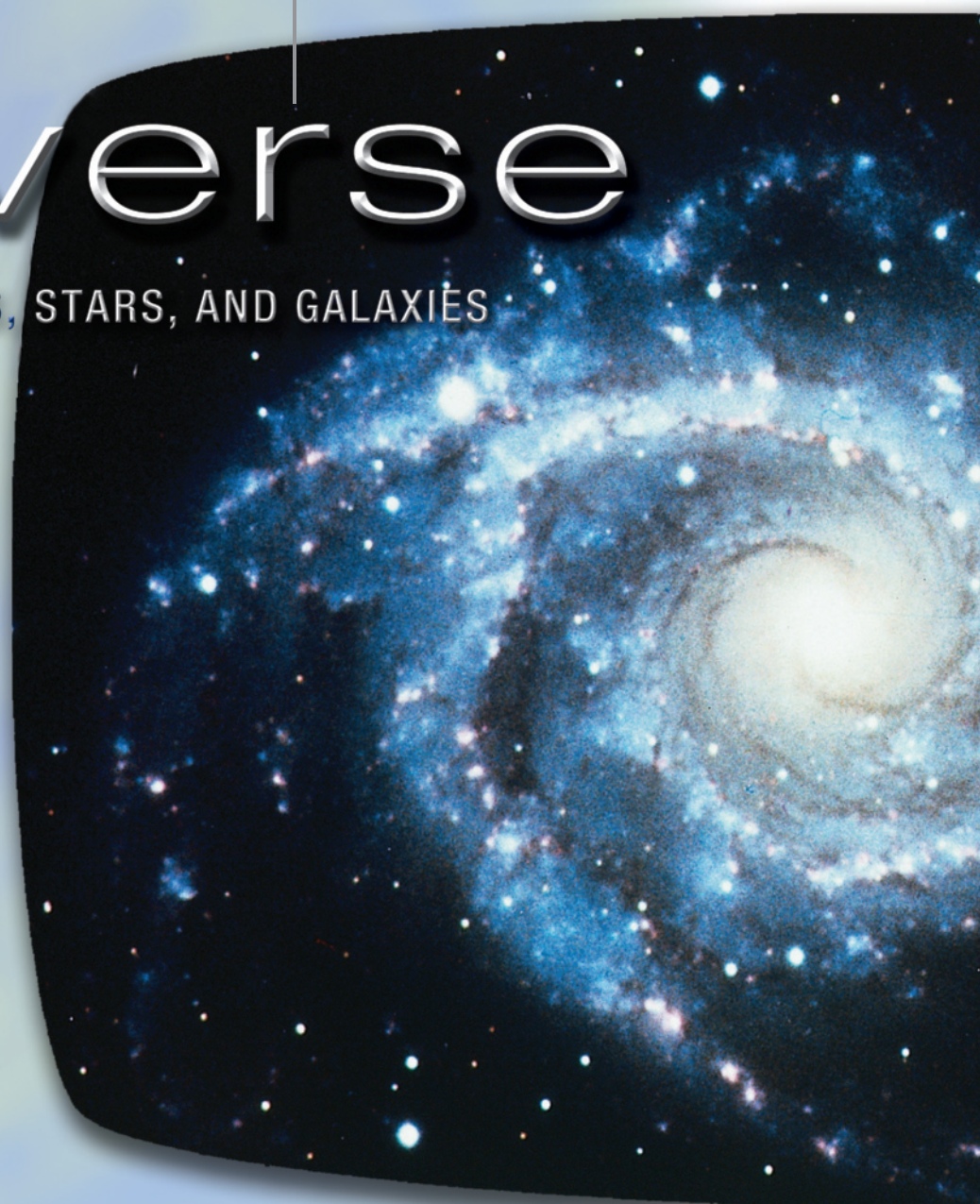
SOLAR SYSTEMS, STARS, AND GALAXIES

Michael Seeds

Joseph R. Grundy Observatory
Franklin and Marshall College

Dana Backman

SOFIA (Stratospheric Observatory
for Infrared Astronomy)
SETI Institute & NASA Ames
Research Center



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Associate Development Editor: Brandi Kirksey

Editorial Assistant: Brendan Killion

Media Editor: Stephanie Van Camp

Content Project Manager: Cathy Brooks

Art Director: Cate Barr

Manufacturing Planner: Sandee Milewski

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Dedication

For our families

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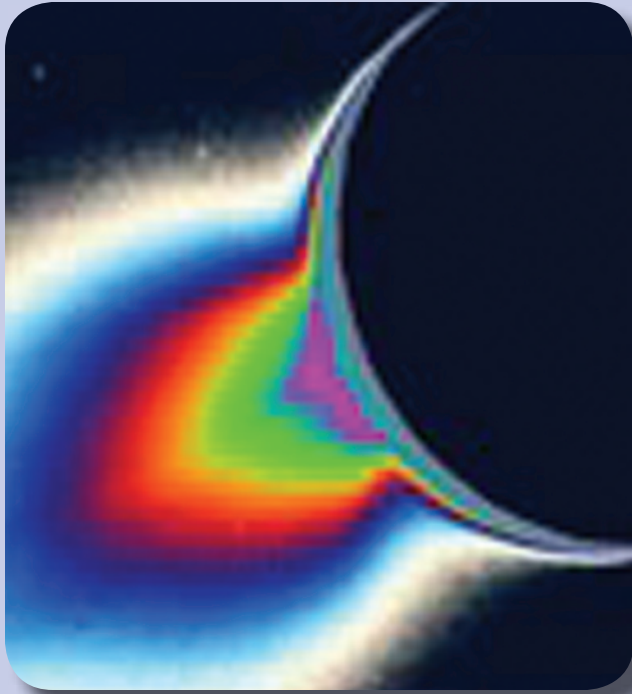
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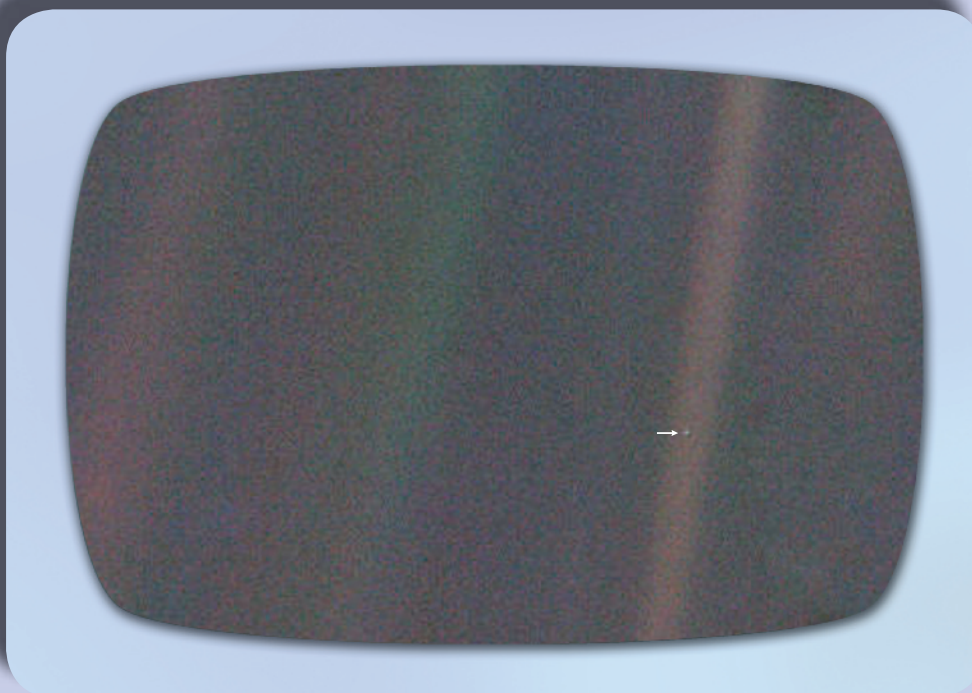
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A Note to the Student

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.

Mike Seeds
mseeds@fandm.edu

Dana Backman
dbackman@sofia.usra.edu

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

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.

Here and Now



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.

Igor Chekalin

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 1-1



Michael A. Seelick

■ Figure 1-2

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



© USGS

■ 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

■ **Figure 1-4**



NASA

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.

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.

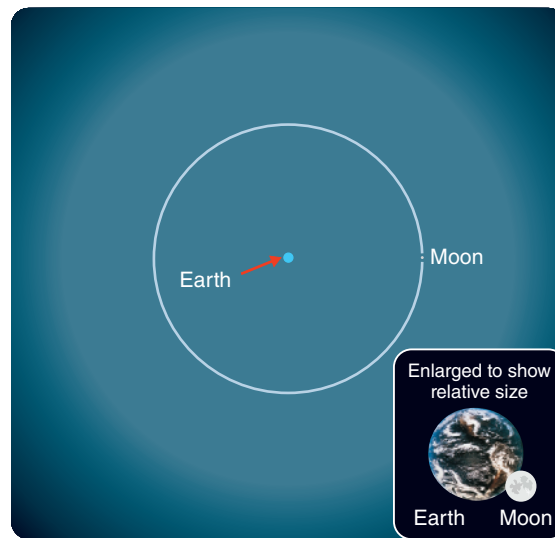
When you once again enlarge your field of view by a factor of 100, Earth, the moon, and the moon's orbit all lie in the small

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, non-luminous 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.

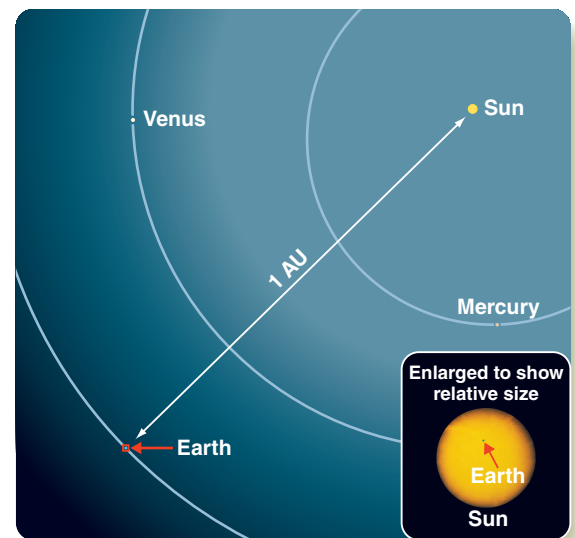
This diagram represents an area with a diameter of 1.6×10^8 km. One way astronomers simplify calculations using large numbers is to define larger units of measurement. For example, the average distance from Earth to the sun is a unit of distance called the **astronomical unit (AU)**, which is equal to 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**



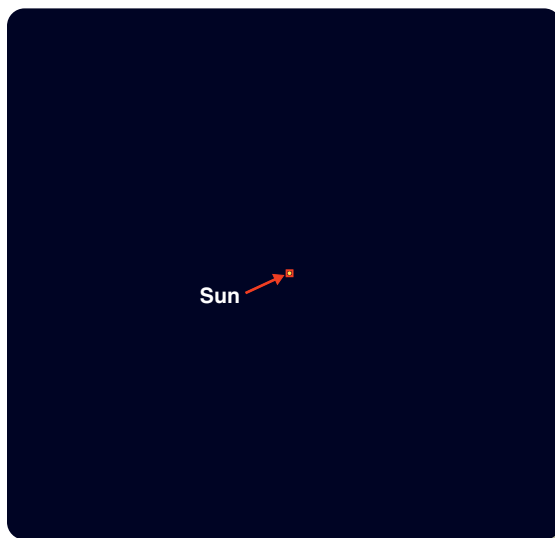
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sun as about 0.72 AU and the average distance from Mercury to the sun as about 0.39 AU.

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.

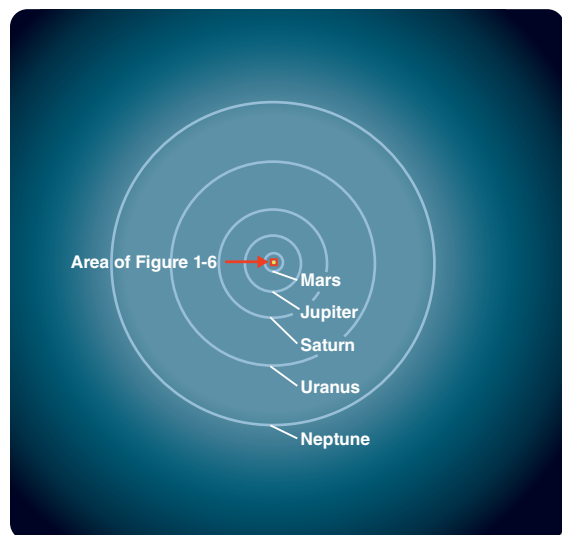
Enlarge your field of view again, and you can see the entire solar system (■ Figure 1-7). The sun, Mercury, Venus, and Earth lie so close together that you cannot see them separately at this scale, and they are lost in the red square at the center of this diagram. You can see only the brighter, more 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

■ Figure 1-8



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■ Figure 1-7

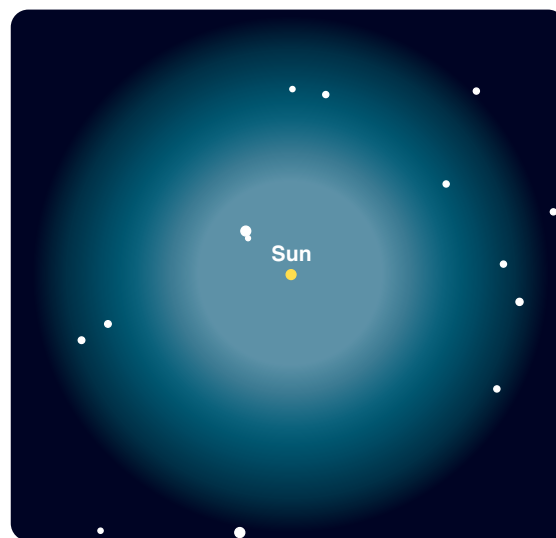


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the sun reaches Earth in only 8 minutes, but it takes over 4 hours to reach Neptune.

You can remember the order of the planets from the sun outward by remembering a simple sentence: *My Very Educated*

■ Figure 1-9



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Mother Just Served Us Noodles. The first letter of each word reminds you of a planet: Mercury, Venus Earth, Mars Jupiter, Saturn, Uranus, Neptune.

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

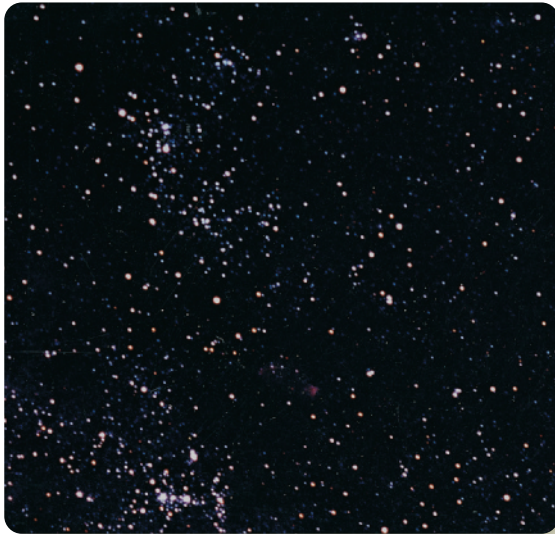
Nor are any stars visible except for the sun. The sun is a fairly typical star, and it seems to be located in a fairly average neighborhood in the universe. Although there are many billions of stars like the sun, none are close enough to be visible in this diagram, which shows a region only 11,000 AU 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

■ **Figure 1-10**



NOAO/AURA/NSF

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 1-9 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 happen 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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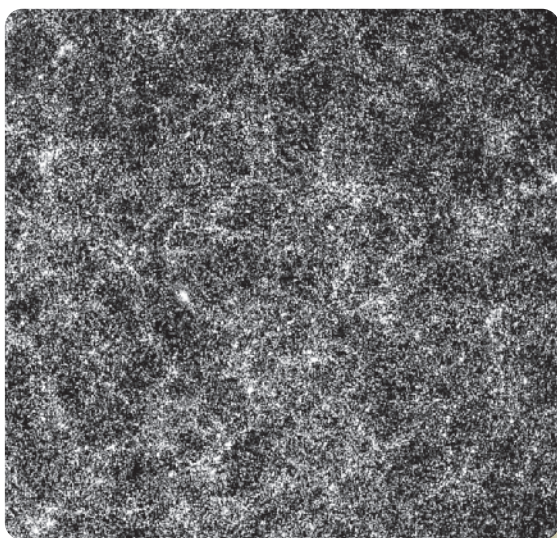
As you explore, notice how astronomers use science to imagine, understand, and depict cosmic events.

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



Based on data from M. Seldner, B. L. Siebers, E. J. Groth, and P. J. E. Peebles, *Astronomical Journal* 82 (1971).

■ **Figure 1-13**

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.

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 flag 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*.

The So-Called Scientific Method

How do scientists learn about nature? You have probably heard of the **scientific method** as the process by which scientists form hypotheses and test them against evidence gathered by experiment or observation. Scientists use the scientific method all the time, and it is critically important, but they rarely think of it at all, and they certainly don't think of it as a numbered list of steps. It is such an ingrained way of thinking and understanding nature that it is almost invisible 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 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 according to strict mathematical rules. Mendel cultivated and tested over 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.”

The scientific method is not a simple, mechanical way of grinding facts into understanding. It is, in fact, a combination of many ways of analyzing information, finding relationships, and creating new ideas. A scientist needs insight and ingenuity to form and test a good hypothesis. Scientists use the scientific method almost automatically, forming, testing, revising, and discarding hypotheses almost minute by minute as they discuss a

new idea. Sometimes, however, a scientist will spend years studying a single promising hypothesis. The so-called scientific method is a way of thinking and a way of knowing about nature. The “How Do We Know?” essays in the chapters that follow will introduce you to some of those methods.



Whether peas are wrinkled or smooth is an inherited trait.

iStockphoto.com/Jupiterimages

What Are We? Part of the Story

Astronomy will give you perspective on what it means to be here on Earth. This chapter has helped you locate yourself in space and time. Once you realize how vast our universe is, Earth seems quite small. People on the other side of the world seem like neighbors. And, in the entire history of the universe, the human story is only the

blink of an eye. This may seem humbling at first, but you can be proud of how much we humans have understood in such a short time.

Not only does astronomy locate you in space and time, it places you in the physical processes that govern the universe. Gravity and atoms work together to make stars,

light the universe, generate energy, and create the chemical elements in your body. The chapters that follow will show how you fit into 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 part of something very large and very beautiful.

Study and Review

Summary

- ▶ You surveyed the universe by taking a cosmic zoom in which each **field of view (p. 2)** was 100 times wider than the previous field of view.
- ▶ Astronomers use the metric system because it simplifies calculations and use **scientific notation (p. 3)** for very large or very small numbers.
- ▶ You live on a **planet (p. 3)**, Earth, which orbits our **star (p. 3)**, the sun, once a year. As Earth rotates once a day, you see the sun rise and set.
- ▶ The moon is only one-fourth the diameter of Earth, but the sun is 109 times larger in diameter than Earth—a typical size for a star.
- ▶ The **solar system (p. 3)** includes the sun at the center, all of the planets that orbit around it—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune—plus the moons of the planets and all other objects bound to the sun by its gravity.
- ▶ The **astronomical unit (AU) (p. 3)** is the average distance from Earth to the sun. Mars, for example, orbits 1.5 AU from the sun. The **light-year (ly) (p. 4)** is the distance light can travel in one year. The nearest star is 4.2 ly from the sun.
- ▶ Many stars seem to have planets, but such small, distant worlds are difficult to detect. Nevertheless, over 400 have been found after almost 20 years of searching by astronomers. So far only a few of those planets have been determined to be Earth-like in terms of size and temperature.
- ▶ The **Milky Way (p. 5)**, the hazy band of light that encircles the sky, is the **Milky Way Galaxy (p. 5)** seen from inside. The sun is just one out of the billions of stars that fill the Milky Way Galaxy.
- ▶ **Galaxies (p. 5)** contain many billions of stars. Our galaxy is about 80,000 ly in diameter and contains over 100 billion stars.
- ▶ Some galaxies, including our own, have graceful **spiral arms (p. 6)** bright with stars, but some galaxies are plain clouds of stars.
- ▶ The **solar system (p. 6)** consists of the sun plus eight planets, including Earth. Our **galaxy (p. 6)** contains our solar system plus billions of other stars and whatever planets orbit around them. The **universe (p. 6)** includes everything that there is: billions of galaxies, each containing billions of stars and, presumably, billions of planetary systems.
- ▶ Our galaxy is just one of billions of galaxies that fill the universe in great clusters, clouds, filaments, and walls—the largest structures in the universe.
- ▶ The universe began about 14 billion years ago in an event called the big bang, which filled the universe with hot gas.
- ▶ The hot gas cooled, the first galaxies began to form, and stars began to shine only about 400 million years after the big bang.
- ▶ The sun and planets of our solar system formed about 4.6 billion years ago.
- ▶ Life began in Earth's oceans soon after Earth formed but did not emerge onto land until only 400 million years ago. Dinosaurs evolved not long ago and went extinct only 65 million years ago.
- ▶ Humanlike creatures developed on Earth only about 4 million years ago, and human civilizations developed only about 10,000 years ago.
- ▶ Although astronomy seems to be about stars and planets, it describes the universe in which you live, so it is really about you. Astronomy helps you answer the question, "What are we?"

- ▶ As you study astronomy, you should ask "How do we know?" and that will help you understand how science gives us a way to understand nature.
- ▶ In its simplest outline, science follows the **scientific method (p. 7)**, by which scientists test hypotheses against evidence from experiments and observations. This method is a powerful way to learn about nature.

Review Questions

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

Discussion Questions

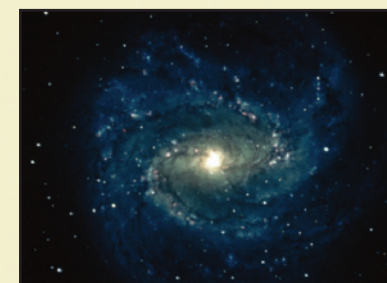
1. Do you think you have a duty to know the astronomy described in this chapter? Can you think of ways this knowledge helps you enjoy a richer life and be a better citizen?
2. How is a statement in a political campaign speech different from a statement in a scientific discussion? Find examples in newspapers, magazines, and this book.

Problems

1. The diameter of Earth across the equator is 7928 miles. If a mile equals 1.609 km, what is Earth's diameter in kilometers? In centimeters?
2. The diameter of the moon across its equator is 3476 kilometers. If a kilometer equals 0.6214 miles, what is the moon's diameter in miles?
3. One astronomical unit is about 1.50×10^8 km. Explain why this is the same as 150×10^6 km.
4. Venus orbits 0.72 AU from the sun. What is that distance in kilometers?
5. Light from the sun takes 8 minutes to reach Earth. How long does it take to reach Mars?
6. The sun is almost 400 times farther from Earth than is the moon. How long does light from the moon take to reach Earth?
7. If the speed of light is 3.00×10^5 km/s, how many kilometers is 1 light-year? How many meters? (*Note:* One year contains 3.16×10^7 s.)
8. How long does it take light to cross the diameter of our Milky Way Galaxy?
9. The nearest large galaxy to our own is about 2.5 million light-years away. How many meters is that?
10. How many galaxies like our own would it take laid edge-to-edge to reach the nearest galaxy? (*Hint:* See Problem 9.)

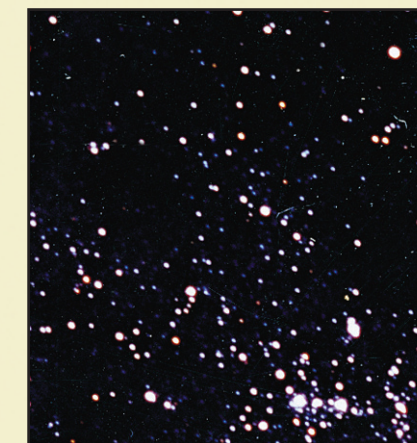
Learning to Look

1. In Figure 1-4, the division between daylight and darkness is at the right on the globe of Earth. How do you know this is the sunset line and not the sunrise line?
2. Look at Figure 1-6. How can you tell that Mercury does not follow a circular orbit?
3. Of the objects listed here, which would be contained inside the object shown in the photograph at the right? Which would contain the object in the photo?
stars
planets
galaxy clusters
filaments
spiral arms



Bill Schoening/NOAO/AURA/NSF

4. In the photograph shown here, which stars are brightest, and which are faintest? How can you tell? Why can't you tell which stars in this photograph are biggest or which have planets?



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