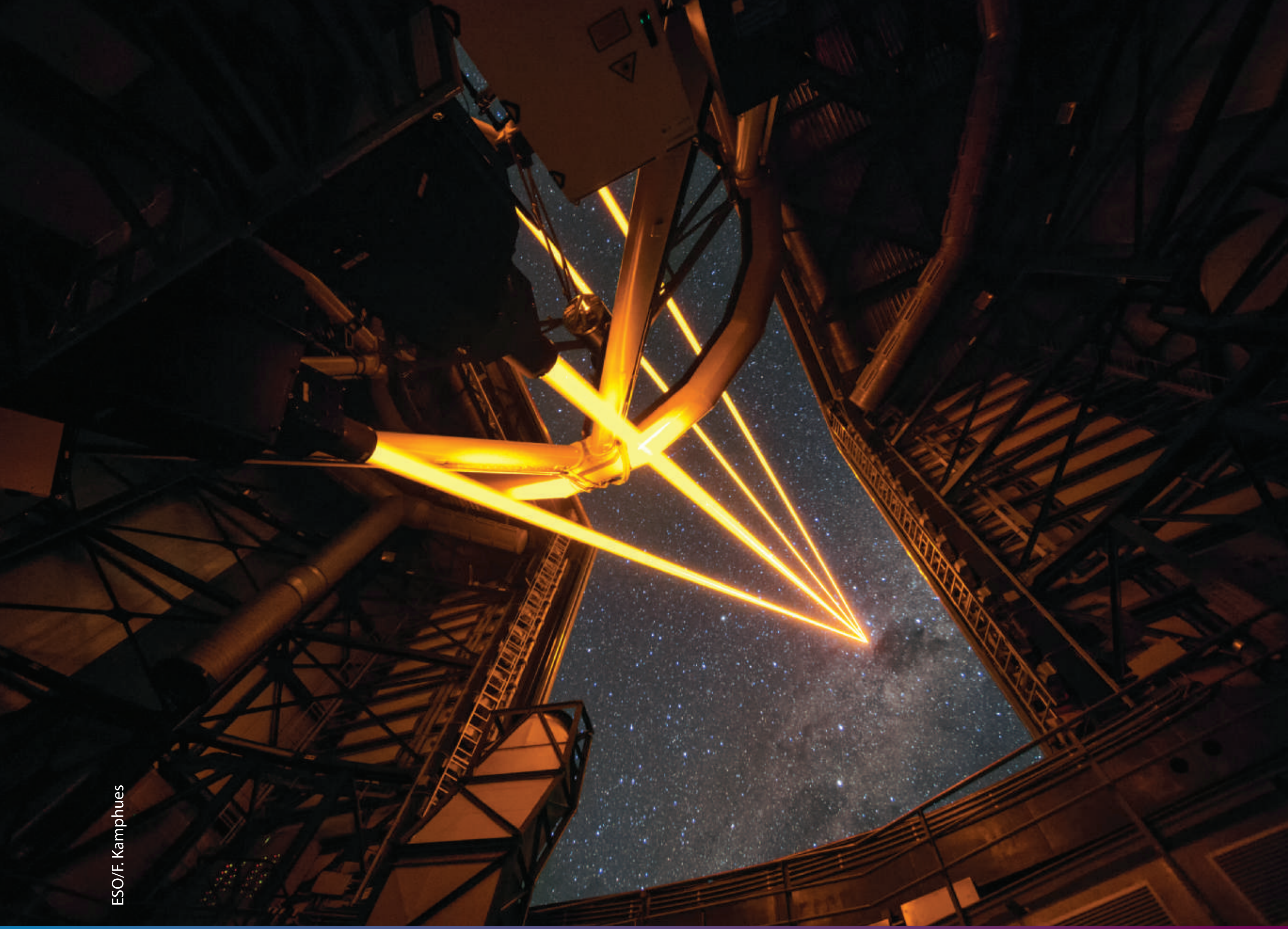
11TH EDITION

DISCOVERING THE UNIVERSE

Neil F. Comins



DISCOVERING THE UNIVERSE

Eleventh Edition

Neil F. Comins *University of Maine*

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Dedicated to my wife, Suzanne Comins, and to the many students I have had the privilege to teach.

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CONTENTS

PREFACE

OPEN THE DOOR TO DISCOVERY

To confine our attention to terrestrial matters would be to limit the human spirit.

–Stephen Hawking

Learning is a complex process of acquiring new information, comparing it to what we think we know, learning how to unlearn incorrect information, finding places for new facts in our memories, and finding ways of recalling them, among other things. Based on decades of teaching and of studying how people learn, *Discovering the Universe* incorporates a wide variety of insights in many places that help students both learn (currently accepted information) and unlearn (misconceptions about the cosmos). Indeed, *Discovering the Universe* has all the elements needed to learn quickly and efficiently, and all at a student-friendly level.

The eleventh edition of *Discovering the Universe* includes: many brand-new images, including some of Pluto, Ceres, and Jupiter; updates on the search for life on other worlds; and exciting results of gravitational wave and neutrino observations, among many other things. The book also provides coverage of many recent astronomical discoveries, all presented at a level accessible and insightful to students. This edition includes new pedagogical features to engage and challenge students, along with additional examples of the familiar features from previous editions.

NEW! **Exoplanets Chapter** expands the coverage of our rapidly developing knowledge and understanding of exoplanets (planets orbiting stars other than the Sun).

NEW! **Meet the Discoverers** interviews working astronomers across the field to provide insight into the process of doing science, as well as the inspiration that drives the people who do that work. This material will help students understand astronomy as an active, relevant, and vibrant discipline.

MEET THE DISCOVERERS

Dr. John Johnson is a Professor of Astronomy at Harvard University, where he leads the ExoLab, specializing in the detection and characterization of exoplanets.

(Michael Wong)

What Do You Think? questions at the beginning of each chapter invite students to examine and challenge their current understanding of astronomical phenomena. Tags within the text sections indicate where students can look to find the relevant information. **What Did You Think?** answers at the end of each chapter ask students to revisit their initial answers and reconcile them with what they have learned over the course of the chapter.

WHAT DO YOU THINK?

1. What is light?
2. Which type of electromagnetic radiation is most dangerous to life?
3. What is the main purpose of a telescope?
4. Why do research telescopes that collect electromagnetic radiation use mirrors, rather than lenses, to collect light?
5. Why do stars twinkle?
6. What are cosmic rays? Where do they come from?

Answers to these questions appear in the text beside the corresponding numbers in the margins and at the end of the chapter.

3-3 Einstein showed that light sometimes behaves as particles that carry energy

1 By 1905, scientists were comfortable with the wave nature of light. However, in that year, Albert Einstein (1879–1955) threw a monkey wrench into that theory when he proposed that light is composed of particles that have wave properties, creating what is now called the *wave-particle duality*. He used this idea to explain the *photoelectric effect*. Physicists knew that electrons are bound onto a metal's surface by electric forces and that it takes energy to overcome those forces. Shorter wavelengths of light can knock some electrons off the surfaces of metals, while longer wavelengths of light cannot, no matter how intense the beam of long-wavelength light. Because some colors (or, equivalently, wavelengths) can remove the electrons and others cannot, the electrons must receive different amounts of

What If... questions inspire student curiosity and invite them to think critically about the way our universe works.

WHAT IF...

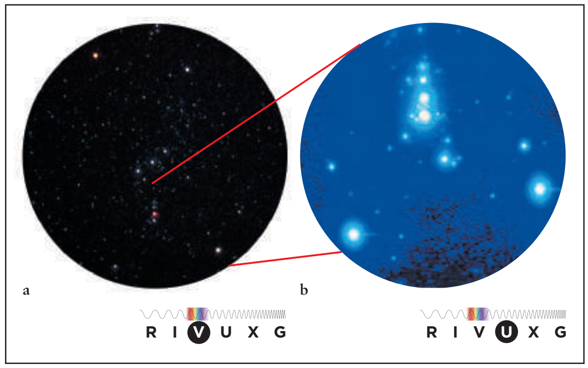
Stars actually twinkled?
Stars appear to significantly change their brightness (twinkle) in fractions of a second. If they actually did vary in brightness as much as we see them vary, they would do so by changing size—bigger is brighter. If such expansion and contraction occurred, the rapid motion of their gases would cause stars to blow apart in a matter of seconds.

Guided Discovery goes in-depth on challenging astronomical concepts to help students gain a conceptual understanding through thoughtful analogies and useful perspectives from the history of science.

An Astronomer's Almanac, a dynamic timeline that relates discoveries in astronomy to other historical events, opens each of the four Parts of the text. These almanacs provide strong context for the information presented.

An Astronomer's Toolbox introduces some of the algebraic equations used in astronomy. Most of the material in the book is descriptive, so essential equations are set off in numbered boxes to maintain the flow of the material and to allow students and instructors to focus on the right level of quantitative material for their course. The toolboxes also contain worked examples, additional explanations, and practice doing calculations; answers are given at the end of the book. All the equations are summarized in Appendix C.

Wavelength Indicators included with photographic images show whether an image was made with radio waves (R), infrared radiation (I), visible light (V), ultraviolet light (U), X-rays (X), or gamma rays (G).



(a: peresanz/iStock/Getty Images; b: NASA/MSX/Johns Hopkins University Applied Physics Laboratory)

Margin Questions give students the opportunity to reinforce a variety of important concepts they have read in just the previous page or two. This can help solidify concepts that are challenging, easy to confuse, or that are associated with common misconceptions.

Margin Question 3-3
Which has more energy, an infrared photon or an ultraviolet photon?

In This Chapter items provide the most important learning goals of each chapter. It helps orient students to the upcoming topics and provides a checklist for their reading of the chapter.

Insight Into Science boxes provide insights into how science works, why it works, what scientists do, and how science protects itself from pseudoscientific claims. These boxes provide important information that applies to all realms of science and, as such, takes students beyond just the factual information about astronomy.

Insight Into Science

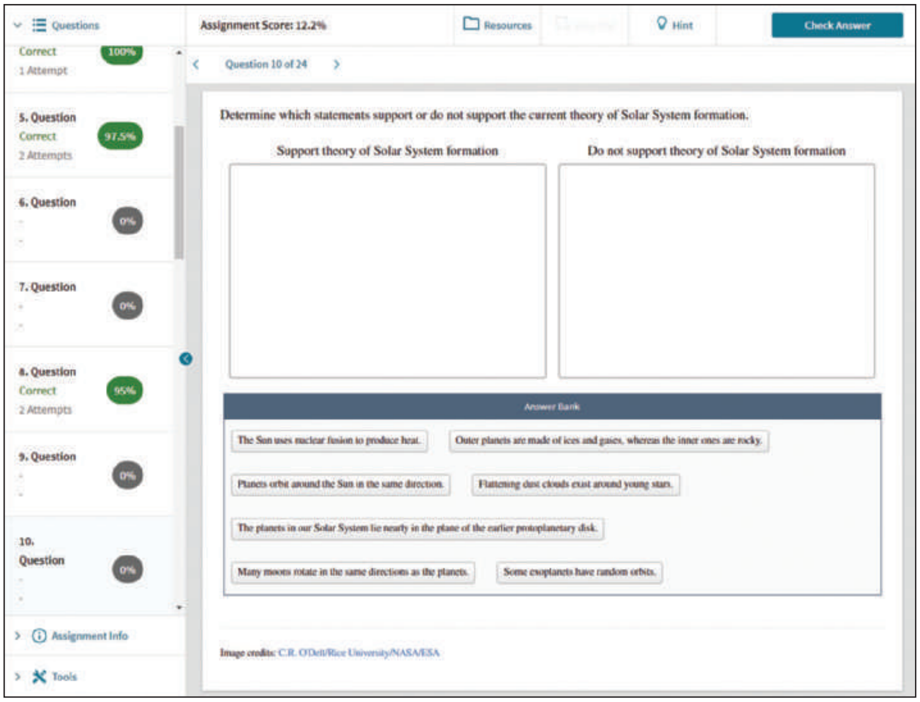
Research Requires Patience Seeing conditions—indeed, most observing situations in science—are rarely ideal. Besides such natural phenomena, which are beyond their control, scientists must also contend with equipment failures, late deliveries of parts, and design flaws. Furthermore, because travel time is so long, some missions (like the robotic spacecraft roving on Mars or the New Horizons voyage to Pluto and the Kuiper belt) take years or even decades to complete.

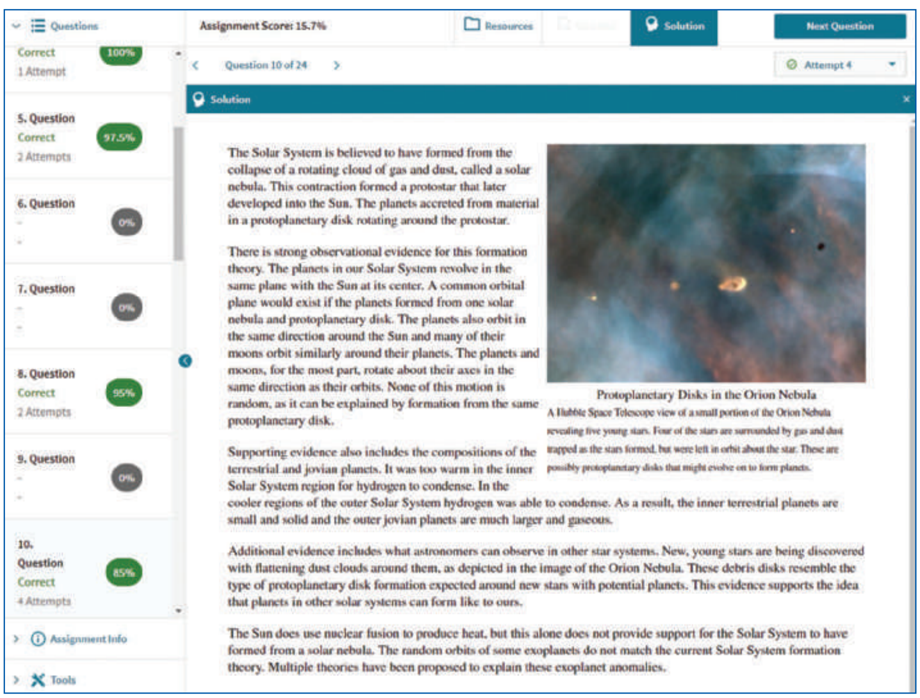
***Starry Night*™ Explorations** in the end-of-chapter questions ask students to be astronomers themselves by providing activities to complete within the robust, interactive *Starry Night*™ observational software.

ONLINE HOMEWORK AND MEDIA

SaplingPlus

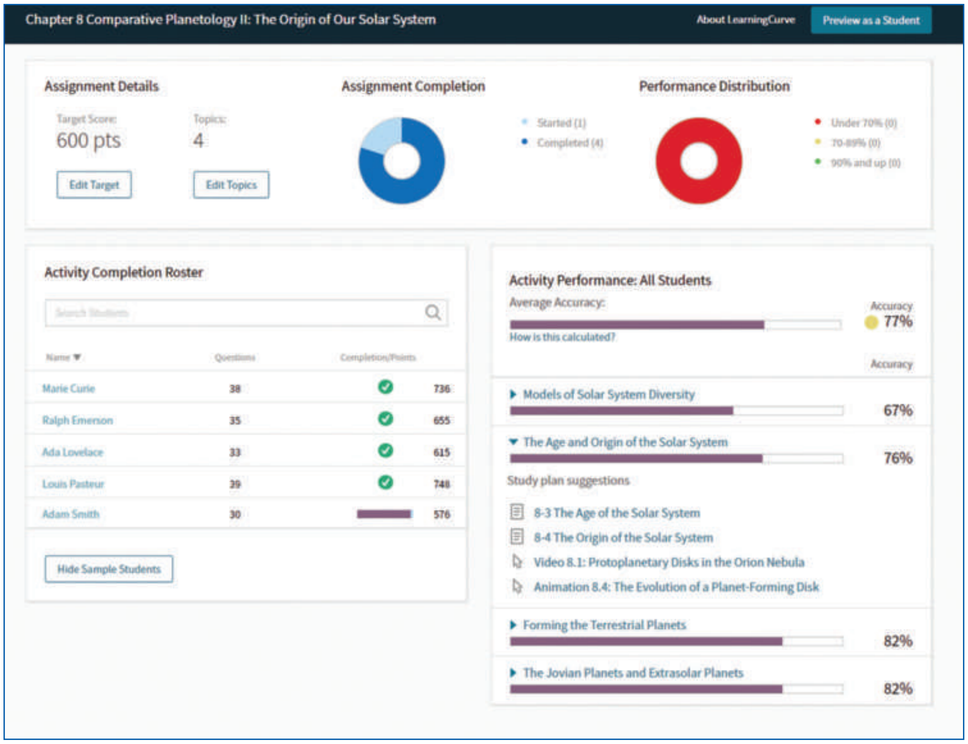
Sapling Plus for *Discovering the Universe* combines the rigor of Sapling homework with the formative power of LearningCurve adaptive quizzing. In the Sapling homework, every question includes hints, targeted, answer-specific feedback, and fully worked-out solutions to guide students through their progress toward understanding.





(NASA/MSX/Johns Hopkins University Applied Physics Laboratory)

LearningCurve adaptive quizzing provides material at different difficulty levels and topics based on student performance. Students work to achieve a target score, allowing highly prepared students to complete the activity promptly, and providing students unfamiliar with the material the necessary time to practice. The student and instructor dashboards provide the accuracy of student responses for each topic, giving insight into important topics to review in class or study.



The mobile-accessible e-book included with every course contains embedded animations to augment the striking visuals found in the text, as well as many tools for studying, such as shareable highlighting, note-taking, and flashcards.

Achieve
READ & PRACTICE

Achieve Read & Practice marries Macmillan Learning's mobile-accessible e-book with the acclaimed Learning-Curve adaptive quizzing. It is an easy-to-use yet exceptionally powerful teaching and learning option that streamlines the process of increasing student engagement and understanding. Instructors can assign reading simply, students can complete assignments on any device, and the cost is significantly less than that of a printed book.

With Achieve Read & Practice:

• Instructors can arrange and assign chapters and sections from the e-book in any sequence they prefer.

• Assignments come with LearningCurve quizzes offering individualized question sets, feedback, and e-book references that adapt to correct and incorrect answers. If students struggle with a particular topic, they are encouraged to reread the material and answer a few short additional questions.

• The Read & Practice gradebook tracks student performance individually and for the whole class, helping instructors shape their lectures and address underperforming topics.

STARRY NIGHT™

Starry Night™ is a brilliantly realistic planetarium software package. It is designed for easy use by anyone with an interest in the night sky. See the sky from anywhere on Earth or lift off and visit any solar system body or any location up to 20,000 light-years away. A download code for ***Starry Night***™ is available with the text upon request.

INSTRUCTORS RESOURCES

The instructor's resources for *Discovering the Universe* are all available for download from SaplingPlus, as well as from the Macmillan Learning catalog site.

The **Test Bank** offers more than 3,500 multiple-choice questions that are section-referenced, available in editable Microsoft Word documents or Diploma files for quick exam creation.

The **Instructor's Manual** accompanying the text provides instructors with a summary and table of contents of each chapter, pedagogical advice on how to teach the chapter, additional questions for in-class discussion, and the answers to book problems, all in one place.

Lecture Slides and Images in PowerPoint allow instructors to tailor their lectures to suit their own needs using images and notes from the textbook, preorganized into slides.

Clicker Questions can be used as lecture launchers with or without a classroom response system such as iClicker. Each chapter includes questions relating to figures from the text and common misconceptions, as well as writing questions for instructors who would like to add a writing or class discussion element to their lectures.

ACKNOWLEDGMENTS

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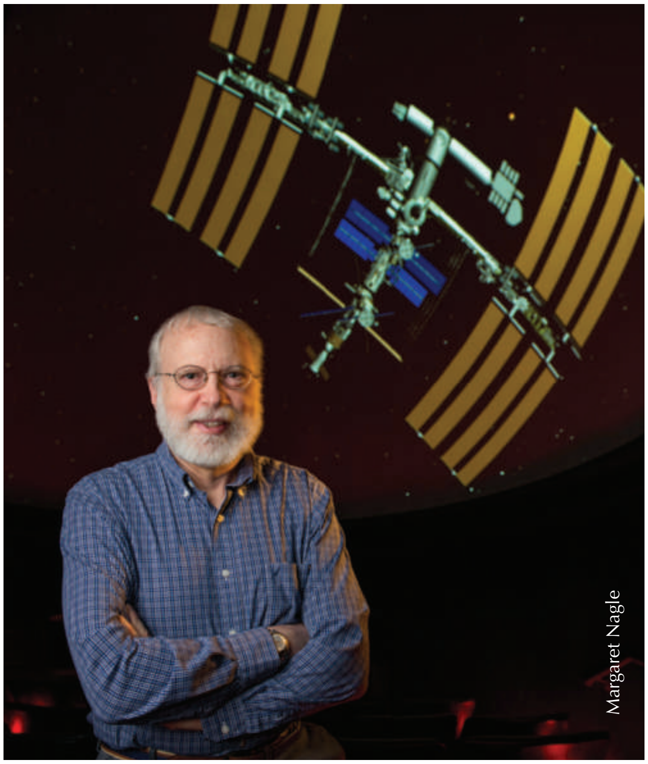
Margaret Nagle

Professor Neil F. Comins is on the faculty of the University of Maine. Born in 1951 in New York City, he grew up in New York and New England. He earned a bachelor's degree in engineering physics at Cornell University, a master's degree in physics at the University of Maryland, and a Ph.D. in astrophysics from University College, Cardiff, Wales, under the guidance of Bernard F. Schutz. Dr. Comins's work for his doctorate, on general relativity, was cited in Subramanyan Chandrasekhar's Nobel laureate speech. He has done theoretical and experimental research in general relativity, optical and radio observational astronomy, computer simulations of galaxy evolution, and science education. The fourth edition of *Discovering the Universe* was the first book in this series that Dr. Comins wrote, having taken over following the death of William Kaufmann in 1994. He is also the author of five trade books, *What If the Moon Didn't Exist?*, *Heavenly Errors*, *The Hazards of Space Travel*, *What If the Earth Had Two Moons?*, and *The Traveler's Guide to Space*. Worlds envisioned in *What If the Moon Didn't Exist?* have been made into planetarium shows, been excerpted for television and radio, and made into Minecraft worlds. The title chapter was also the theme for the Mitsubishi Pavilion at the World Expo 2005 in Aichi, Japan, and is presently a show at the Japanese resort, Huis Ten Bosch. *Heavenly Errors* explores misconceptions people have about astronomy, why such misconceptions are so common, and how to correct them. Dr. Comins has appeared on numerous television and radio shows and gives many public talks. Although he has jumped out of airplanes while in the military, today his activities are a little more sedate: He is a licensed pilot and avid sailor, having once competed against Prince Philip, Duke of Edinburgh.

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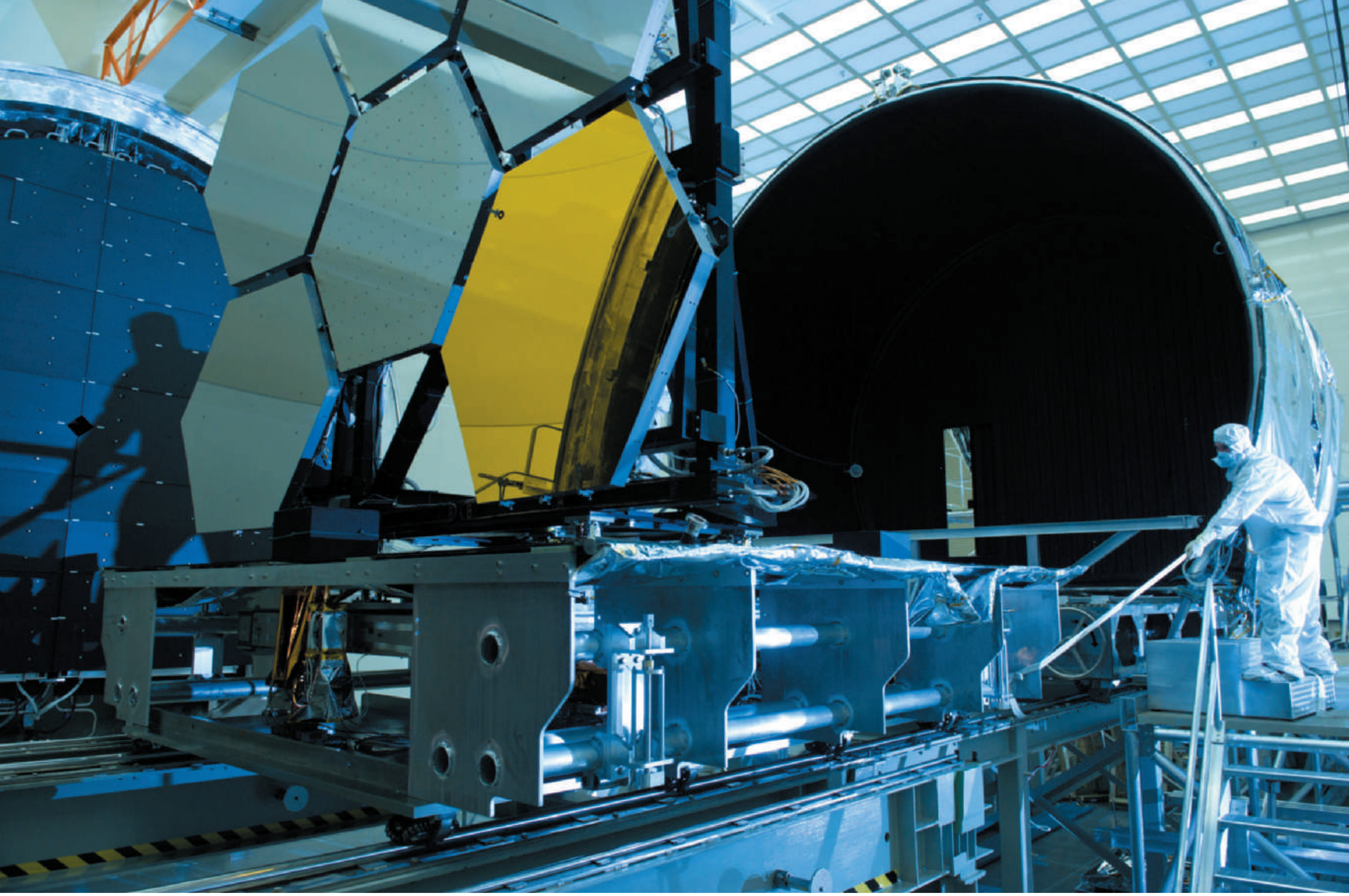


Telescopes enhance our views of the cosmos. (NASA/MSFC/Emmett Given)

PART I | UNDERSTANDING THE SCIENCE OF ASTRONOMY

AN ASTRONOMER'S ALMANAC

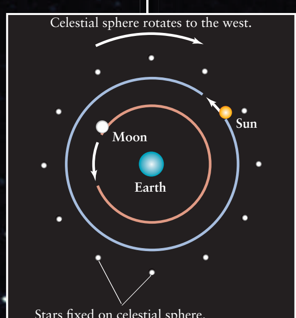
Greek Golden Age

2136 B.C.E. Chinese astronomers record solar eclipse. (Dr. Mario Motta)

586 B.C.E. Thales of Miletus predicts solar eclipse.

350 B.C.E. Aristotle proposes spherical Earth, geocentric cosmology.

ca. 270 B.C.E. Aristarchus of Samos proposes heliocentric cosmology.



ca. A.D. 125 Claudius Ptolemy refines and details geocentric cosmology in his *Almagest*.

European Renaissance

1512-1543 Nicolas Copernicus proposes heliocentric cosmology in his *Commentariolus* and *De revolutionibus orbium coelestium*.

1576-1601 Tycho Brahe makes precise observations of stars and planets.

1589-1609 Galileo Galilei proposes that all objects fall with the same acceleration, independent of their masses; builds his first telescope, a refractor.

1609-1610 Johannes Kepler publishes his three laws of planetary motion.

1665-1704 Isaac Newton deduces gravitational force from the orbit of the Moon; builds first reflecting telescope; proves that the planets obey Kepler's laws because they move under the influence of the gravitational force; and publishes compendium on light, *Opticks*. (Photo12/Ann Ronan Picture Library/Alamy)

1715 Edmond Halley calculates shadow path of a solar eclipse over Earth's surface. (NASA/SSPL/Getty Images)

1766 Henry Cavendish discovers hydrogen.

1800-1803 William Herschel discovers infrared radiation from the Sun. Thomas Young demonstrates wave nature of light. John Dalton proposes that matter is composed of atoms of different masses.

DISCOVERING ASTRONOMY

Industrial Revolution

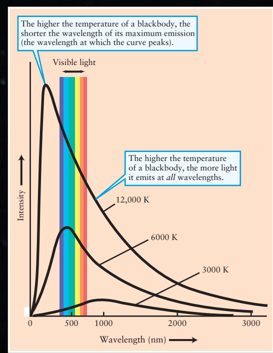
1840-1849 J. W. Draper invents astronomical photography; takes first photographs of the Moon. Christian Doppler proposes that wavelength is affected by motion. Lord Rosse completes 60-in. reflecting telescope at Birr Castle in Ireland. Armand Fizeau and Jean-Bernard Foucault measure speed of light accurately. (ClawsAndPaws/iStock/Getty Images)

1847 Maria Mitchell observed a comet, now called "Miss Mitchell's Comet," through a telescope.

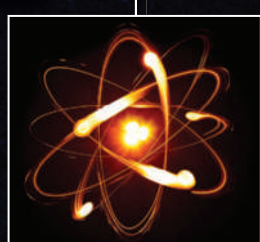
1871-1873 Dimitri Mendeleyev develops periodic table of the elements. Henry Draper develops spectroscopy. James Clerk Maxwell asserts that light is an electromagnetic phenomenon.

1885-1888 Johann Balmer expresses spectral lines of hydrogen mathematically. Heinrich Hertz detects radio waves.

1895-1897 Wilhelm Roentgen discovers X-rays. Joseph Thomson detects the electron. Yerkes 40-in. optical refracting telescope completed. (ALAN SOLOMON/Tribune News Service/LAKE GENEVA/WI/USA/Newscom)

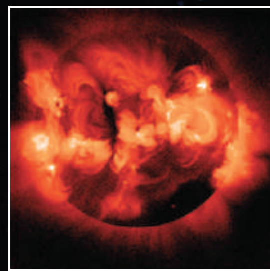


1900 Max Planck explains blackbody radiation. Paul Villard discovers gamma rays.



1913 Niels Bohr proposes quantum theory of the atom. (Roman Sigaev/Shutterstock)

1930-1934 Karl Jansky builds first radio telescope. James Chadwick discovers the neutron. Bernhard Schmidt builds his Schmidt optical reflecting telescope.



1942-1949 J. S. Hey detects radio waves from the Sun. First astronomical telescope launched into space. Herbert Friedman detects X-rays from the Sun. 200-in. optical reflecting telescope begins operation on Mt. Palomar, California. (Lockheed-Martin Solar & Astrophysics Laboratory, the National Astronomical Observatory of Japan, the University of Tokyo, NASA & ISAS)

Information Age

1963-1967 Largest single-dish radio telescope, 300 m across, begins operation at Arecibo, Puerto Rico. First Very Long Baseline Interferometer (VLBI) images.

1975 First charge-coupled device (CCD) astronomical observations.

1980 Very Large Array (VLA) radio observatory completed, Socorro, New Mexico.

1990-1996 Hubble Space Telescope launched. Keck 10-m optical/infrared telescopes begin operation at Mauna Kea, Hawaii. SOHO solar observatory launched. (Chris Butler/Science Source)

1999 Chandra X-ray Telescope launched.

2004-present Two rovers travel on Mars, detectors search for gravitational radiation.

2013 *Voyager I* is first spacecraft to leave the solar system.

Background image courtesy of Imageman/Shutterstock

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The night sky is stunning when viewed in dark, pollution-free environments. (Westend61/Getty Images)

R I V U X G

CHAPTER 1

Discovering the Night Sky

WHAT DO YOU THINK?

1. Is the North Star—Polaris—the brightest star in the night sky?
2. What do astronomers define as constellations?
3. What causes the seasons?
4. When is Earth closest to the Sun?
5. How many zodiac constellations are there?
6. Does the Moon have a dark side that we never see from Earth?
7. Is the Moon ever visible during the daytime?
8. What causes lunar and solar eclipses?

Answers to these questions appear in the text beside the corresponding numbers in the margins and at the end of the chapter.

You are studying astronomy at an extraordinary time, as our understanding of the cosmos (or the *universe*) and how it evolves grows as never before. That is due, in large measure, to the immense light-gathering power and sensitivity of modern telescopes, as well as the recent development of telescopes that can detect gravitational radiation (miniscule vibrations of space-time). Both types of telescopes enable us to test mathematical theories that describe many aspects of the cosmos, as well as to discover totally unexpected phenomena, such as the fact that the universe is expanding faster every day.

Current telescope technology makes it possible for astronomers to observe objects and events that were completely invisible to us just a few years ago. For example, we can now see so far away—and therefore so far into the past—that we see the first stars and the first galaxies as they just began forming more than 13½ billion years ago. We could not see these objects even two decades ago, and likewise, it took just 21 years for astronomers to discover 1000 planets orbiting nearby stars, a feat that would have been impossible 30 years ago. After 25 years of searching, we have cataloged over 3700 of these worlds.

Telescopes are not the only means by which we are deepening our understanding of what lies beyond Earth's atmosphere. We have also begun the process of physically exploring our neighborhood in space. In just the past half century, humans have walked on the Moon; space probes have roamed over parts of Mars, dug into its rocks and soil, and blasted its surface with laser beams. Other probes have crashed into one comet; brought back debris from another one; landed on an asteroid and on Saturn's murky moon Titan; traveled through the shimmering rings of Saturn; discovered active volcanoes and barren ice fields on the moons of Jupiter; and, some have even departed from the realm of the planets in our solar system, to mention just a few accomplishments. (The solar system is comprised of the Sun and every object that orbits it.) We are also witnessing the dawn of space tourism, with people buying trips to the International Space Station.

In the best locations, the night sky is truly breathtaking (**Figure 1-1a**). Even if you cannot see the thousands of stars visible in clear locations (see Figure 1-1b), software such as ***Starry Night™*** can show them to you. The night sky can draw you out of yourself, inviting you to understand what is happening beyond Earth and inspiring you to think about our place in the universe.

Until the past few centuries, the explanations people found for what they saw in the sky were based on beliefs that had to be accepted on faith—there was no way to test ideas of what stars are, or whether the Moon really has liquid water oceans (as was believed back then but is not true), or how the planets move, or why the Sun shines. Times have changed. We are fortunate to be living in an era when science has answers to many of the questions inspired by the universe.

FIGURE 1-1 The Night Sky Without and With Light Pollution (a) The daytime sky, made by scattering blue sunlight, is a curtain that hides virtually everything behind it. (Can you name two exceptions?) As the Sun sets, places with little smog or light pollution treat viewers to beautiful panoramas of stars that inspire the artist or scientist in many of us. This photograph shows the night sky in Goodwood, Ontario, Canada, during a power outage. (b) This photograph shows the same sky with normal city lighting. (Todd Carlson/SkyNews Magazine)

Beautiful, intriguing, and practical, astronomy and its ongoing process of discovery have something for everyone. This course and this book will help you better understand the universe by sharing what we have learned and are still learning about many of these questions. They will also demonstrate the awesome power of the human mind to reach out, to observe, to explore, and to comprehend. One of the great lessons of modern astronomy is that by gaining, sharing, and passing on knowledge, we transcend the limitations of our bodies and the brevity of human life.

IN THIS CHAPTER YOU WILL DISCOVER

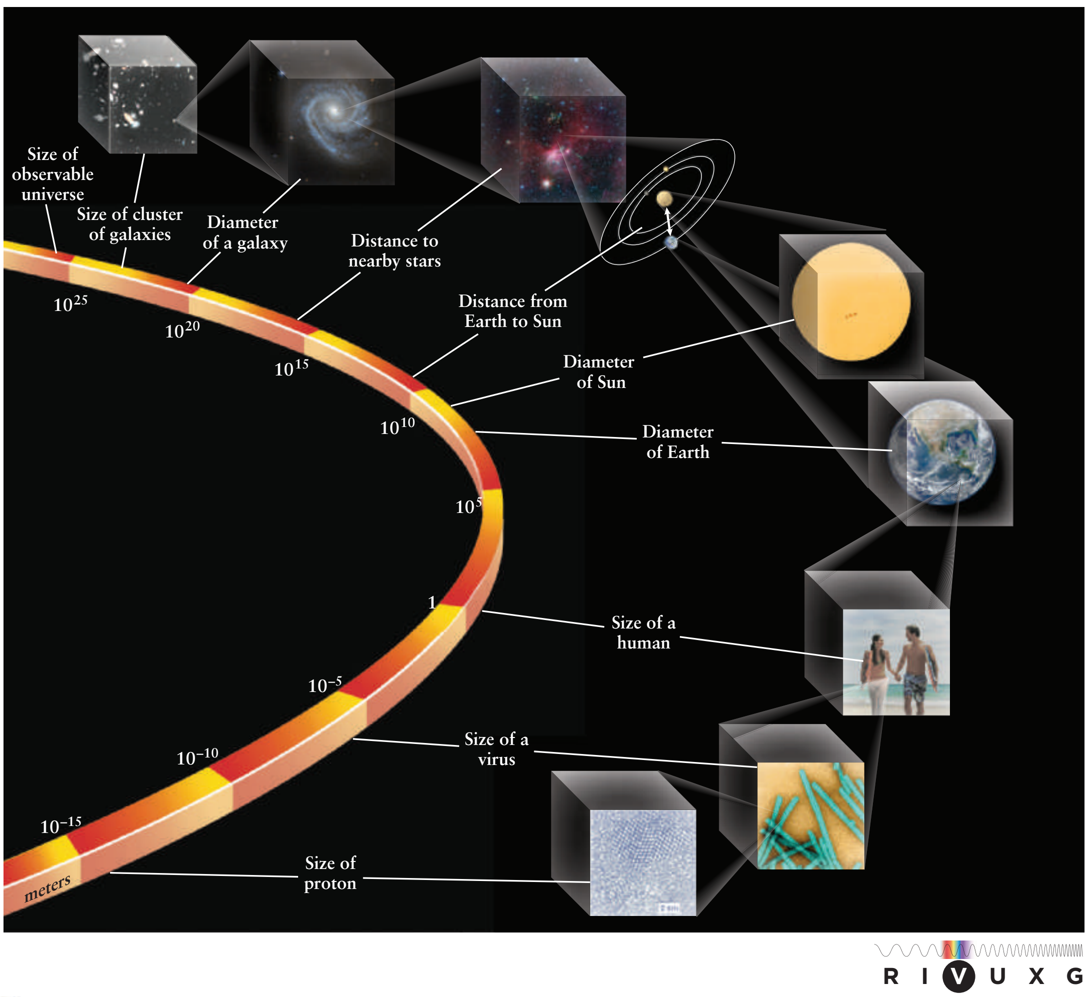
- how astronomers map the night sky to help them locate objects in it
- that Earth's spin on its axis causes day and night
- how Earth's orbit around the Sun combined with the tilt of Earth's axis of rotation relative to its orbit create the seasons
- that the Moon's orbit as seen from Earth creates the phases of the Moon, as well as lunar and solar eclipses
- how the year is defined and how the calendar was developed

SCALES OF THE UNIVERSE

In learning a new field it is often useful to see the "big picture" before exploring the details. For this reason, we begin by surveying the major types of objects in the universe, along with their ranges of size and the scale of distances between them (Figure 1-2).

1-1 Astronomical distances are, well, astronomical

One of the thrills and challenges of studying astronomy is becoming familiar and comfortable with the vast range of sizes that occur in it. In our everyday lives we typically deal with distances ranging from millimeters to thousands of kilometers. (The metric or International System [SI] of units is standard in science and will be used throughout this book; however, we will often provide the equivalent in U.S. customary units.



ANIMATION 1.1 **FIGURE 1-2 The Scales of the Universe** This curve gives the sizes of objects in meters, ranging from subatomic particles at the bottom to the entire observable universe at the top. Every 0.5 cm up along the arc represents a factor of 10 larger. (Top to bottom: R. Williams and the Hubble Deep Field Team [STScI] and NASA; ESA/Hubble & NASA; NASA/JPL-Caltech/University of Wisconsin; NASA/SDO/HMI; NASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring; Jose Luis Pelaez/Getty Images; Lee D. Simon/Science Source; Courtesy of Florian Banhart/University of Mainz)

Appendix E-10 lists conversion factors between these two sets of units.)

A hundredth of a meter or a thousand kilometers are numbers that are easy to visualize and write. In astronomy, we deal with particles as small as a millionth of a billionth of a meter and systems of stars as large as a thousand billion billion kilometers across. Similarly, the speeds of some things, like light, are so high as to be cumbersome if you have to write them out in words each time. **Scientific notation** (Appendix A) makes comparisons easy, telling us how many factors of 10 in size, mass, brightness, distance, and other parameters one object is compared to another.

The size of the universe that we can observe and the range of sizes of the objects in it are truly staggering. Figure 1-2 summarizes the array of sizes from atomic particles up to the diameter of the entire universe visible to us. Unlike linear intervals measured on a ruler, the sizes of objects increase by powers of 10 in equal intervals in this figure; moving up 0.5×10^{-2} m (0.5 cm) along the arc of this figure brings you to objects 10 times larger. Because of this, going from the size of a proton (roughly 10^{-15} m) up to the size of an atom (roughly 10^{-10} m) takes about the same space along the arc as going from the distance between Earth and the Sun to the distance between Earth and the nearby stars.

This wide range of sizes underscores the fact that astronomy *synthesizes* or brings together information from many other fields of science. While we cannot go to the ends of the universe to examine all its components, the light from the universe coming to us, combined with our ever-growing understanding of the laws of nature, provides invaluable insights into how the various components of the cosmos work and how they interact with each other. We will discuss some of the underlying principles of science as we need them.

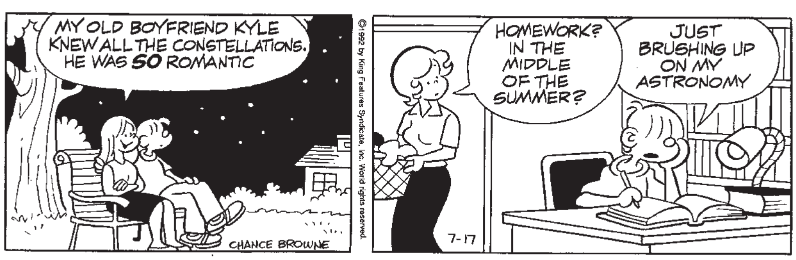
What, then, have astronomers seen of the universe? **Figure 1-3** presents examples of the types of objects we will explore in this text. An increasing number of planets like Jupiter, rich in hydrogen and helium (Figure 1-3a), as well as rocky planets similar to Earth, are being discovered orbiting other stars. Much smaller pieces of space debris—some of rock and metal called **asteroids** or **meteoroids** (Figure 1-3b), and others of rock and ice called **comets** (Figure 1-3c)—orbit the Sun (Figure 1-3d) and other stars. Vast stores of interstellar gas and dust are found in many galaxies; these "clouds" are often the incubators of new generations of stars (Figure 1-3e). Stars by the millions, billions, or even trillions, often accompanied by interstellar gas and dust, are held together in galaxies by the force of their mutual gravitational attraction (i.e., gravity; Figure 1-3f). Most galaxies also contain **black holes**, objects with such strong gravitational attraction that nothing can escape from them in the usual sense of how light leaves from the Sun or rockets leave Earth (Figure 1-3g). Groups of galaxies, called clusters, are held together by gravity (Figure 1-3h), and clusters of galaxies are grouped together in superclusters. Huge quantities of intergalactic gas are often found between galaxies (Figure 1-3i).

Every object in astronomy is constantly changing—each has an origin, an active period you might consider as its "life," and each will have an end. In addition to examining the objects that fill the universe, we will also study the processes that cause them to change. After all is said and done, you will discover that all the matter and energy that astronomers have detected are but the tip of the cosmic iceberg—there is much more in the universe, but astronomers do not yet know its nature!

PATTERNS OF STARS

When you gaze at the sky on a clear night where the air is free of pollution and there is not too much light from cities or other sources, there seem to be millions of stars twinkling overhead. In reality, the unaided human eye can detect only about 6000 stars over the entire sky. At any one time, you can see roughly 3000 stars in dark skies, because only half of the stars are above the *horizon*—the boundary between Earth and the sky. In very smoggy or light-polluted cities, you may see only a tenth of that number or less (see Figure 1-1).

In any event, you probably have noticed patterns of bright stars, each technically called an **asterism**, and you are familiar with some common names for some of them, such as the ladle-shaped Big Dipper and broad-shouldered Orion. These recognizable patterns of stars (**Figure 1-4a**) are informally called *constellations* in everyday conversation. Technically, however, constellations are entire regions of the sky and everything in them (**Figure 1-4b**). In what follows, we will often use the word "constellation" to mean either the asterisms or the regions of the sky. Be careful to consider which version of the word is in use.



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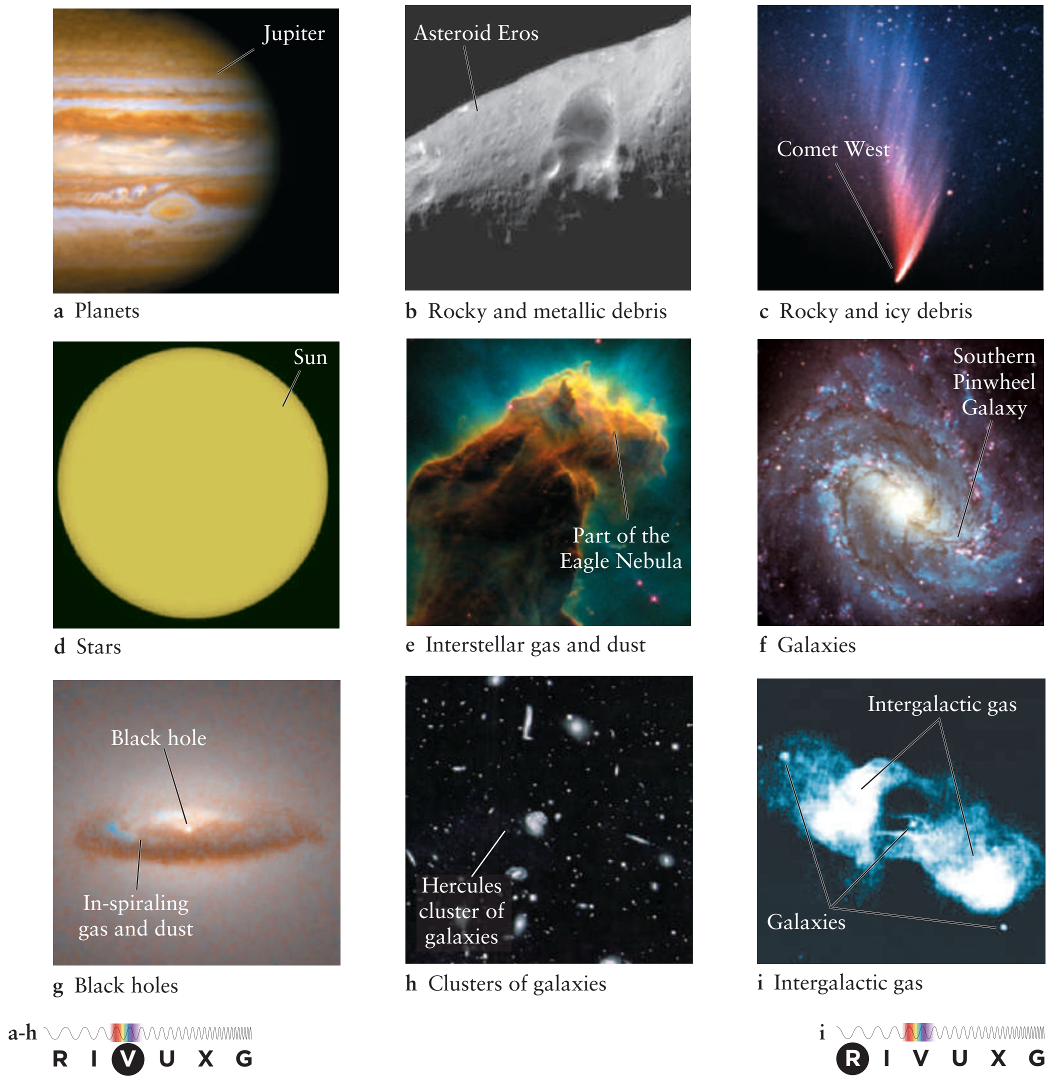

FIGURE 1-3 Inventory of the Universe Pictured here are examples of the major categories of objects that have been found throughout the universe. The black hole is in the center of the bright dot in (g). You will discover more about each type of object in the chapters that follow. (a: NASA/Hubblesite; b: NASA; c: Peter Stattmayer/ESO; d: Big Bear Solar Observatory/New Jersey Institute of Technology; e: NASA/Jeff Hester & Paul Scowen; f: Australian Astronomical Observatory/David Malin Images; g: NASA; h: NOAO/AURA/NSF; i: Image courtesy of NRAO/AUI/NSF)

1-2 Well-known constellations make locating more obscure stars and constellations easy

1 People have known for millennia how to find the direction north in locations where the Big Dipper is visible. To do this, locate the Big Dipper (the asterism in the constellation Ursa Major) and imagine that its bowl is resting on a table (Figure 1-5). If you see the dipper upside down in the sky, as you frequently will, imagine the dipper resting on an upside-down table above it. Locate the two stars of the bowl farthest from the Big Dipper's handle. These are called the *pointer stars.* Draw a mental line through these stars in the direction away from the table, as shown in Figure 1-5. The first *moderately bright* star you then encounter is Polaris, also called the *North Star* because it is located almost directly over Earth's North Pole. So, while Polaris is not even among the 20 brightest stars (see Appendix E-6), it is easy to locate. Whenever you face Polaris, you are facing north. East is then on your right, south is behind you, and west is on your left. (There is no equivalent star over the South Pole.)

The Big Dipper also illustrates the fact that being familiar with just a few constellations makes it easy to locate less distinctive stars and other constellations. The most effective way to do this is to use vivid visual connections, especially those of your own devising. For example, imagine gripping the handle of the Big Dipper and slamming its bowl straight down onto the head of Leo (the Lion). Leo comprises the first group of bright stars your bowl encounters. As shown in Figure 1-5, the brightest