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Discovering the UNIVERSE

Tenth Edition

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Tenth Edition

W.H. Freeman and Company
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NASA/Handout/Getty Images

Dedicated to my aunt Zelda Fields and to the memory of my uncle David S. Fields.

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PREFACE

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

–Stephen Hawking

Our knowledge about the universe is expanding at a phenomenal rate. New discoveries are being made in many astronomical realms: astronomers are probing the extent of water on the Moon, developing new theories of how the solar system formed, finding planets orbiting numerous stars, and discovering stars and stellar remnants with unexpected properties, among myriad other things.

Many of these scientific updates are included in this edition. I am also pleased to include a wide variety of modern learning techniques and new features in the tenth edition of *Discovering the Universe* while still providing the wide range of factual topics that are a hallmark of this text.

In the realm of astronomy education, educators continue to develop methods to help students understand how to think like scientists and grasp the core concepts, even when scientific theories are at odds with students' prior beliefs and misconceptions. In-class interactivities, such as students responding to questions with "clickers," enrich the classroom experience. Online materials provide tutorials and practice questions that turn students from passive into active learners.

The tenth edition of *Discovering the Universe* continues to present concepts clearly and accurately to students, while strengthening the pedagogical tools to make the learning process even more worthwhile. The pedagogy includes:

- presenting the observations and underlying physical *concepts* needed to connect astronomical observations to theories that explain them coherently and meaningfully;
- using both textual and graphical information to present concepts for students who learn in different ways;
- addressing student misconceptions in a respectful but rigorous manner, helping readers to understand why modern scientific views are correct;
- using analogies from everyday life to make cosmic phenomena more concrete;
- providing visually rich timelines that connect astronomical discoveries with other events throughout history;
- providing the dates of the lives of all the people introduced in the text to help students relate discoveries to the historical times in which they occurred;
- expanding student perspectives and confronting misconceptions by exploring plausible alternative situations (asking "What if…?" questions);
- pointing students toward cutting-edge research in "Frontiers yet to be discovered" sections;
- linking material presented in the book with enhanced material offered electronically.

MANY FEATURES BRING THE UNIVERSE INTO CLEARER FOCUS

What If…? margin questions about important concepts stretch students' thinking using hypothetical situations. These questions help to correct misconceptions by explaining to students what strange effects and consequences would result if their initial misconceptions were true.

> WHAT IF…
>
> **Earth's changing distance from the Sun caused the seasons (and how do we know it doesn't)?**
> Earth's orbit around the Sun is elliptical (we will discuss this oval shape in detail in Chapter 2). If the seasons *were* caused by the changing distance between Earth and the Sun, all parts of Earth should have the same seasons at the same time. In fact, the northern and southern hemispheres have seasons at exactly opposite times, so they must be caused by something else.

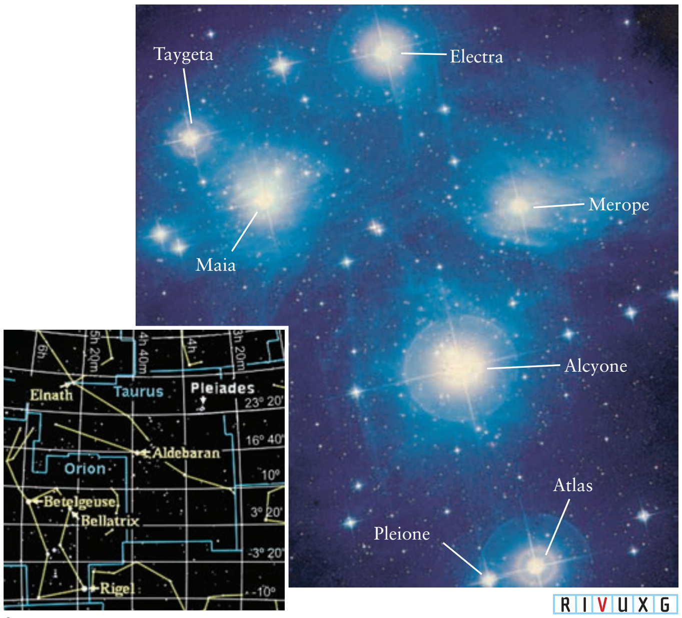
New theory of planet formation Chapter 5 now presents the Nice (pronounced niece) theory of solar system formation, walking students through a fully up-to-date picture of how the interactions between the Sun and planets evolved. Its effects are discussed in Chapters 6–9.

Margin questions about important concepts are presented in most sections of the book. These questions encourage students to frequently test themselves and correct their beliefs before errors accumulate. For example, after learning about inertia, students are asked how, while driving in a car, they can show that their bodies have inertia. (They could put on the brakes and feel themselves being restrained by the seatbelts.) Answers to approximately one-third of the margin questions appear at the end of this text.

> **Margin Question 6-8**
> Why haven't the ocean tides on Earth put our planet into synchronous rotation with respect to the Moon?

Margin photos provide a connection between the concepts being presented and their applications in everyday life.

Margin charts show the location in the sky of important astronomical objects cited in the text. Sufficient detail in the margin charts allows students to locate the objects with either the unaided eye or a small telescope, as appropriate. In this example, an image of the Pleiades star cluster is shown with a star chart of the constellation Aldebaran, in which it lies, among other constellations.



Australian Astronomical Observatory/David Malin Images

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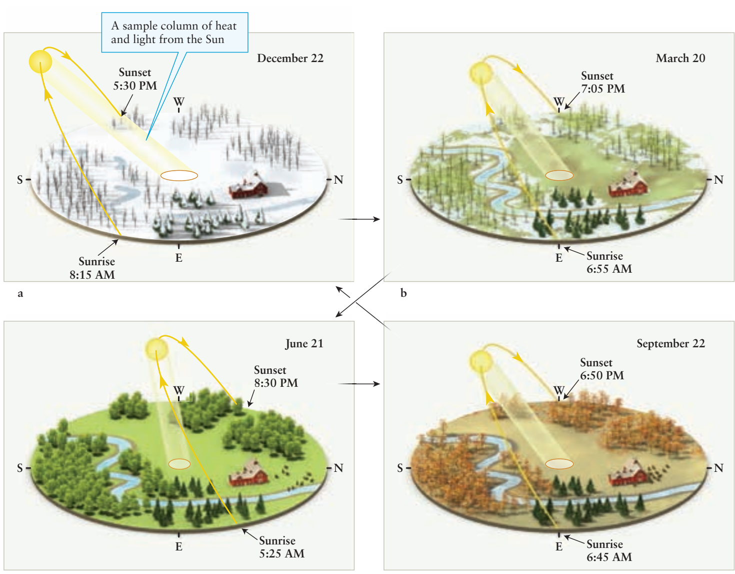


FIGURE 1-17 The Sun's Daily Path and the Energy It Deposits Here **Northern Hemisphere:** (a) On the winter solstice—the first day of winter—the Sun rises farthest south of east, is lowest in the noontime sky, stays up the shortest time, and its light and heat are least intense (most spread out) of any day of the year in the northern hemisphere. (b) On the vernal equinox—the first day of spring—the Sun rises precisely in the east and sets precisely in the west. Its light and heat have been growing more intense, as shown by the brighter oval of light than in (a). (c) On the summer solstice—the first day of summer—the Sun rises farthest north of east of any day in the year, is highest in the noontime sky, stays up the longest time, and its light and heat are most intense of any day in the northern hemisphere. (d) On the autumnal equinox, the same astronomical conditions exist as on the vernal equinox. **Southern Hemisphere**: If you are reading this in the southern hemisphere, make the following changes: (a) Change December 22 to June 21 and visualize the Sun's path starting and ending the same distance *north* of east and north of west as it is south of east and south of west as shown here; (b) change March 20 to September 23; (c) change June 21 to December 21 and visualize the Sun's path starting and ending the same distance *south* of east and south of west as shown north of east and north of west here; (d) change September 22 to March 20.

Dynamic art Summary figures appear throughout the book to show either the interactions between important concepts or the evolution of important objects. For example, the location of the Sun in the sky, which varies over the seasons, as does the corresponding intensity of the light and the appropriate ground cover, is shown in a sequence of drawings combined into one figure.

Revised coverage of planet classification The categories of *planets*, *dwarf planets*, and *small solar system objects* are explained and reconciled with the existing classes of objects, including planets, moons, asteroids, meteoroids, and comets. Also explained is how Pluto fits more comfortably with the dwarf planets than with the eight planets.

Deeper focus on fundamental student understanding *Discovering the Universe* is well known for the clarity of its exposition, but that doesn't mean we can't do better. In this edition, a variety of concepts have been fine-tuned to help students better understand them. Some of these are misconception-rich subjects, while others are topics that require exquisite attention to words with multiple meanings.

PROVEN FEATURES SUPPORT LEARNING

What Do You Think? and What Did You Think? questions in each chapter ask students to consider their present beliefs and actively compare them with the correct science presented in the book. Numbered icons mark the places in the text where each concept is discussed. Encouraging students to think about what they believe is true and then work through the correct science step-by-step has proved to be an effective teaching technique, especially when time constraints prevent instructors from working with students individually or in small groups as they try to reconcile incorrect beliefs with proper science.

WHAT DO YOU THINK?

1. What percentage of the solar system's mass is in the Sun?
2. Does the Sun have a solid and liquid interior like Earth?
3. What is the surface of the Sun like?

WHAT DID YOU THINK?

1. ***What percentage of the solar system's mass is in the Sun?*** The Sun contains about 99.85% of the solar system's mass.

2. ***Does the Sun have a solid and liquid interior like Earth?*** No. The entire Sun is composed of hot gases.

3. ***What is the surface of the Sun like?*** The Sun has no solid surface. Indeed, it has no solids or liquids anywhere. The level we see, the photosphere, is composed of hot, churning gases.

Chapter opening narratives introduce and launch the chapter's topics and provide students with a context for understanding the material.

Learning objectives underscore the key chapter concepts.

Section headings are brief sentences that summarize section content and serve as a quick study guide to the chapter when reread.

Icons link the text to Web material

- *Starry Night*™ icons link the text to a specific interactivity in the *Starry Night*™ observing programs.
- Video icons link the text to relevant video clips available on the textbook's Web site.
- Animation icons link the text to animated figures available on the textbook's Web site.

Guided Discovery boxes offer hands-on experience with astronomy. Several use the *Starry Night*™ software.

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. 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.

GUIDED DISCOVERY

Extrasolar Planets and Brown Dwarfs

The lowest mass that an object can have and still maintain the fusion of normal hydrogen into helium, as occurs in the Sun (see An Astronomer's Toolbox 10-1: Thermonuclear Fusion), is 0.08 $M_\odot$, or about 75 times the mass of Jupiter. Astronomers have discovered hundreds of objects in our Galaxy with less than this mass. Like Jupiter, they are primarily composed of hydrogen and helium, with traces of other elements. Many of them are found in orbit around stars, while some are found as free-floating masses that apparently formed without ever orbiting a star. An intriguing question has arisen: *What should these various objects be called?*

Although normal hydrogen fusion does not occur in them, bodies with between 13 and 75 times Jupiter's mass do fuse deuterium (a rare form of hydrogen) into helium and those with between 60 and 75 times Jupiter's mass also fuse lithium (the element with three protons) into helium. Both of these types of fusion occur very briefly (in cosmic terms) be
of deuterium and lithium i

cade later, an extrasolar planet, 2M1207b, was observed orbiting brown dwarf 2M1207 (Figure 5-15). Hundreds more brown dwarfs have been found, along with more than a dozen sub-brown dwarfs. Many of these are found in active star-forming regions, such as the Orion Nebula (see Figure 12-17) and the Rho Ophiuchi cloud (see the accompanying figure below). Astronomers have also found more than 925 extrasolar planets. In 2002, astronomers observed clouds and storms on a brown dwarf similar to, but probably much larger than, the storms observed on the giant planets in our solar system.

Brown dwarfs of larger mass have the interesting feature that when they fuse deuterium or lithium, the helium they create moves upward, out of the core where it is formed. This helium is replaced with fresh deuterium or lithium fuel to fuse. The upward motion of the helium and downward motion of deuterium and lithium-rich hydrogen are due to convection, and, as a

AN ASTRONOMER'S TOOLBOX 11-2

Details of the Magnitude Scales

The magnitude scales were created before accurate measurements of the relative brightnesses of stars could be made, and they have since been refined. Specifically, careful measurements reveal that the original first-magnitude stars were about 100 times brighter than the original sixth-magnitude stars. Therefore, in 1856 astronomer Sir Norman Pogson (1829–1891) set the brightness factor of exactly 100 to *define* the range of brightness between modern first- and sixth-magnitude stars. In other words, it takes 100 stars of apparent magnitude $m = +6$ to provide as much light as we receive from a single star of apparent magnitude $m = +1$.

To find out how much brighter each magnitude is from the next dimmer one, we note that there are five integer magnitudes between first and sixth magnitude. Going from $m = +6$ to $m = +5$ increases (multiplies) the brightness we see by the same factor as going from $m = +5$ to $m = +4$, and so on. Going from $m = +6$ to $m = +1$ requires multiplying the same brightness factor from one magnitude to the next 5 times. The number we must multiply 5 times to get the range of brightness of 100 is $100^{1/5} \approx 2.512$, or, put another way, $2.512 \times 2.512 \times 2.512 \times 2.512 \times 2.512 \approx 100$. This mathematical statement means that *each successively brighter magnitude is approximately 2.512 times brighter than the preceding magnitude*.

Example: An $m = +3$ star is approximately 2.512 times brighter than an $m = +4$ star. Equivalently, it takes 2.512 fourth-magnitude stars to provide as much light as we receive from a single third-magnitude star.

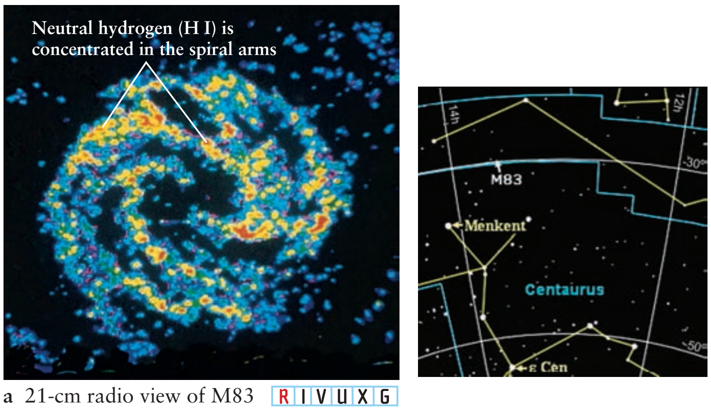
Try these questions after reading Section 11-2: How much brighter is an $m = 0$ star than an $m = +4$ star? How much brighter is an $m = -2$ star than an $m = +5$ star? If one star is 7.93 times brighter than another and the brighter star has an absolute magnitude of $m = +3$, what is the absolute magnitude of the dimmer star? (*Hint for last question:* Recall that magnitudes need not be integers.)

(Answers appear at the end of the book.)

Insight Into Science boxes are brief asides that relate topics to the nature of scientific inquiry and encourage critical thinking.

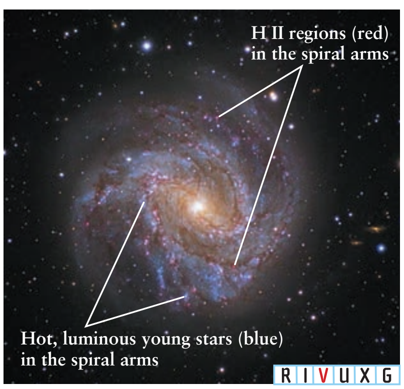
> **Insight Into Science**
>
> **A Little Knowledge** Incomplete information often leads to incorrect interpretation of data and, therefore, to incorrect conclusions. Herschel's lack of knowledge about the matter in interstellar space prevented him from correctly interpreting the distribution of stars that surround Earth and, thus, led to his inaccurate conclusion about the position of the Sun within the Galaxy.

Wavelength tabs 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).



Atlas Image courtesy of 2MASS/UMass/IPAC-Caltech/NASA/NSF

a 21-cm radio view of M83



Robert Gendler and Stephane Guisard

b Visible-light view of M83

Review and practice material

- **Summary of Key Ideas** is a bulleted list of key concepts.
- **What Did You Think?** questions at the end of each chapter answer the What Do You Think? questions posed at the beginning of the chapter.
- **Key Words, Review Questions,** and **Advanced Questions** help students understand the chapter material.
- **Discussion Questions** offer interesting topics to spark lively, insightful debate.
- **Web Questions** take students to the Web for further study.
- **NEW: Got It? Questions** ask students about either big picture concepts related to the chapter or questions associated with common misconceptions about that material (or both!).
- **Observing Projects,** featuring ***Starry Night™*** activities, ask students to be astronomers themselves.

What If… Selected chapters conclude with a "What If…" essay that encourages critical thinking by speculating on how changes in the universe could have profound effects on Earth.

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.

MULTIMEDIA

FOR STUDENTS

Electronic Versions

Discovering the Universe is offered in two electronic versions. One is an **Interactive e-Book**, available as part of LaunchPad, described below. The other is a PDF-based **e-Book from CourseSmart**, available through www.coursesmart.com. These options are provided to offer students and instructors flexibility in their use of course materials.

CourseSmart e-Book

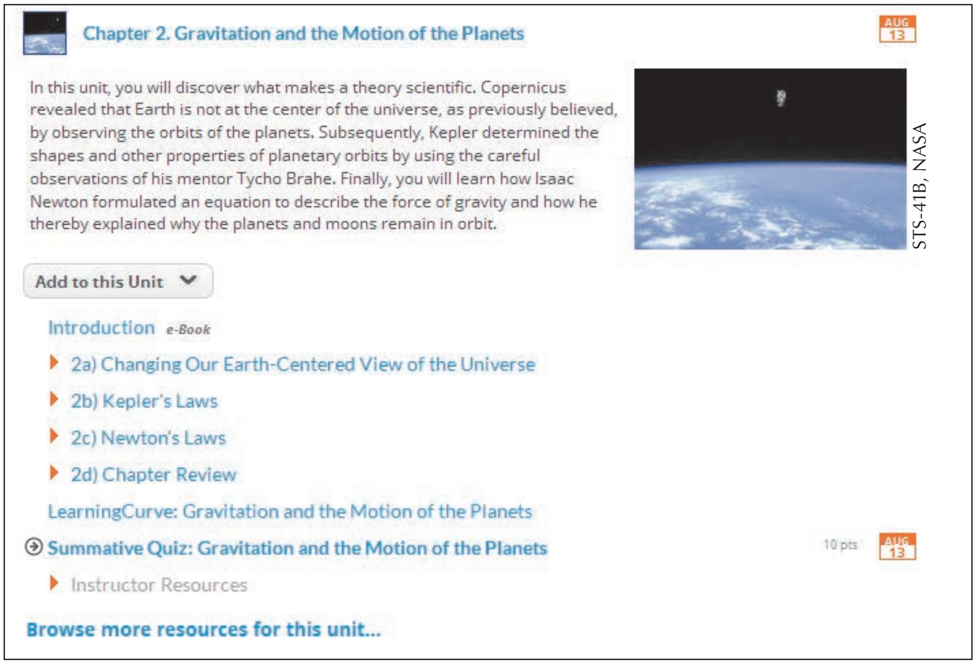
Discovering the Universe **CourseSmart e-Book** offers the complete text in an easy-to-use, flexible format. Students can choose to view the CourseSmart e-Book online or to download it to their computer or a mobile device, such as iPad, iPhone, or Android device. To help students study and mirror the experience of a printed textbook, CourseSmart e-Books feature notetaking, highlighting, and bookmark features.

ONLINE LEARNING OPTIONS

Discovering the Universe supports instructors with a variety of online learning preferences. Its rich array of resources and platforms provides solutions according to each instructor's teaching method. Students can also access resources through the **Companion Web Site**.

LaunchPad: Because Technology Should Never Get in the Way

At W. H. Freeman, we are committed to providing online instructional materials that meet the needs of instructors and students in powerful, yet simple ways—powerful enough to dramatically enhance teaching and learning, yet simple enough to use right away.



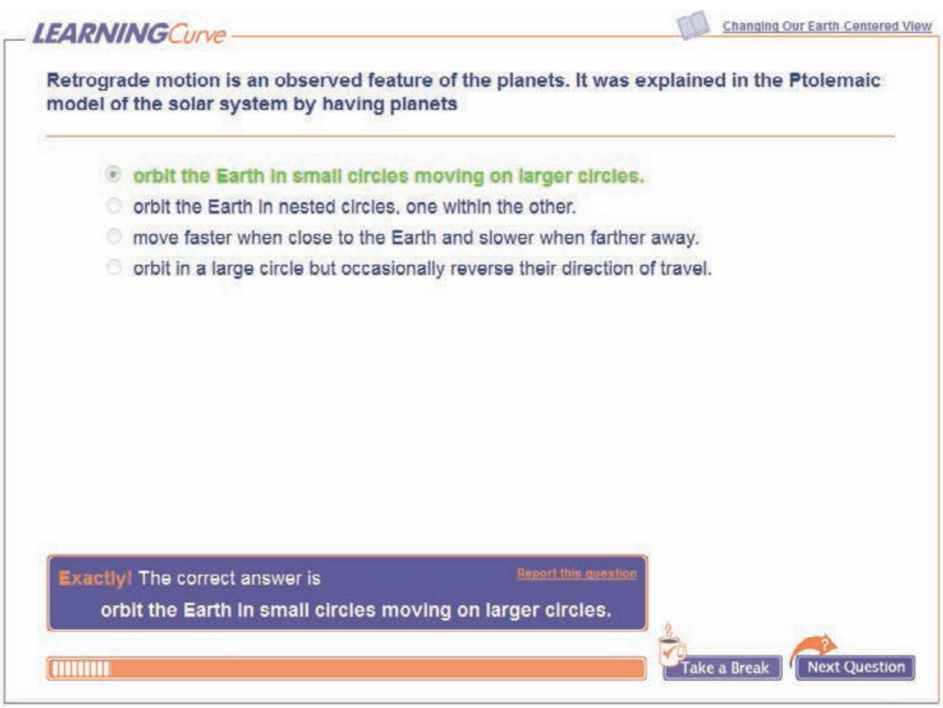
We have taken what we've learned from thousands of instructors and hundreds of thousands of students to create a new generation of technology: **LaunchPad.** LaunchPad offers our acclaimed content curated and organized for easy assignment in a breakthrough user interface in which power and simplicity go hand in hand.

Curated LaunchPad units make class prep a whole lot easier

Combining a curated collection of video, tutorials, animations, projects, multimedia activities and exercises, and e-Book content, LaunchPad's interactive units give instructors building blocks to use as is or as a starting point for their own learning units. An entire unit's worth of work can be assigned in seconds, drastically saving the amount of time it takes to have the course up and running.

LearningCurve

• Powerful adaptive quizzing, a gamelike format, direct links to the e-Book, instant feedback, and the promise of better grades make using **LearningCurve** a no-brainer.



• Customized quizzing tailored to the text adapts to students' responses and provides material at different difficulty levels and topics based on student performance. Students love the simple yet powerful system, and instructors can access class reports to help refine lecture content.

Interactive e-Book

The **Interactive e-Book** is a complete online version of the textbook with easy access to rich multimedia resources. All text, graphics, tables, boxes, and end-of-chapter resources are included in the e-Book, and the e-Book provides instructors and students with powerful functionality to tailor their course resources to fit their needs.

• Quick, intuitive navigation to any section or subsection

• Full-text search, including the Glossary and Index

• Sticky-note feature allows users to place notes anywhere on the screen, and choose the note color for easy categorization.

• "Top-note" feature allows users to place a prominent note at the top of the page to provide a more significant alert or reminder.

• Text highlighting in a variety of colors

Astronomy Tutorials

These self-guided, concept-driven experiential walk-throughs engage students in the process of scientific discovery as they make observations, draw conclusions, and apply their knowledge. Astronomy tutorials combine multimedia resources, activities, and quizzes.

Image Map Activities

These activities use figures and photographs from the text to assess key ideas, helping students to develop their visual literacy. Students must click the appropriate section(s) of the image and answer corresponding questions.

Animations, Videos, Interactive Exercises, Flashcards

Other LaunchPad resources highlight key concepts in introductory astronomy.

Assignments for Online Quizzing, Homework, and Self-Study

Instructors can create and assign automatically graded homework and quizzes from the complete test bank, which is preloaded in LaunchPad. All quiz results feed directly into the instructor's gradebook.

Scientific American Newsfeed

To demonstrate the continued process of science and the exciting new developments in astronomy, the *Scientific American* Newsfeed delivers regularly updated material from the well-known magazine. Articles, podcasts, news briefs, and videos on subjects related to astronomy are selected for inclusion by *Scientific American*'s editors. The Newsfeed provides several updates per week, and instructors can archive or assign the content they find most valuable.

Gradebook

The included **gradebook** quickly and easily allows instructors to look up performance **metrics** for a whole class, for individual students and for individual assignments. Having ready access to this information can help both in lecture prep and in making office hours more productive and efficient.

Sapling Learning

www.saplinglearning.com

Developed by educators with both online expertise and extensive classroom experience, Sapling Learning provides highly effective interactive homework and instruction that improve student learning outcomes for the problem-solving disciplines. Sapling Learning offers enjoyable teaching and effective learning experiences that are distinctive in three important ways:

• **Ease of use:** Sapling Learning's easy-to-use interface keeps students engaged in problem-solving, not struggling with the software.

• **Targeted instructional content:** Sapling Learning increases student engagement and comprehension by delivering immediate feedback and targeted instructional content.

• **Unsurpassed service and support:** Sapling Learning makes teaching more enjoyable by providing a dedicated Masters and Ph.D. level colleague to service instructors' unique needs throughout the course, including content customization.

We offer bundled packages with all versions of our texts that include Sapling Learning Online Homework.

STUDENT COMPANION WEB SITE

The Companion Web site at www.whfreeman.com/dtu10e features a variety of study and review resources designed to help students understand the concepts. The open-access Web site includes the following:

• **Online quizzing** offers questions and answers with instant feedback to help students study, review, and prepare for exams. Instructors can access results through an online database or they can have results e-mailed directly to their accounts.

• **Animations and videos** both original and NASA-created, are keyed to specific chapters.

• **Flashcards** offer help with vocabulary and definitions.

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. View 2,500,000 stars along with more than 170 deep-space objects such as galaxies, star clusters, and nebulae. Travel 15,000 years in time, check out the view from the International Space Station, and see planets up close from any one of their moons. Included are stunning OpenGL graphics. Handy star charts can be printed to explore outdoors. A download code for ***Starry Night***™ is available with the text upon request.

OBSERVING PROJECTS USING *STARRY NIGHT*™

by T. Alan Clark and William J. F. Wilson, University of Calgary, and Marcel Bergman

ISBN 1-4641-2502-3

Available for packaging with the text and compatible with both PC and Mac, this workbook contains a variety of comprehensive lab activities for use with ***Starry Night***™. The Observing Projects workbook can also be packaged with th ***Starry Night***™ software.

FOR INSTRUCTORS

TEST BANK CD-ROM

Windows and Mac versions on one disc,

ISBN 1-4641-6878-4

More than 3,500 multiple-choice questions are section-referenced. The easy-to-use CD-ROM allows instructors to add, edit, resequence, and print questions to suit their needs.

ONLINE COURSE MATERIALS (BLACKBOARD, MOODLE, SAKAI, CANVAS)

As a service for adopters, we will provide content files in the appropriate online course format, including the instructor and student resources for the textbook. The files can be used as is or can be customized to fit specific needs. Prebuilt quizzes, animations, and activities, among other materials, are included.

CLASSROOM PRESENTATION AND INTERACTIVITY

A set of online lecture presentations created in PowerPoint allows instructors to tailor their lectures to suit their own needs using images and notes from the textbook. These presentations are available on the instructor portion of the companion Web site.

CLICKER QUESTIONS

Written by Neil Comins, these 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.

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P. L. Matheson, *Salt Lake Community College*
Steve May, *Walla Walla Community College*
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J. Scott Miller, *University of Louisville*
Scott Miller, *Pennsylvania State University*
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ABOUT THE AUTHORS

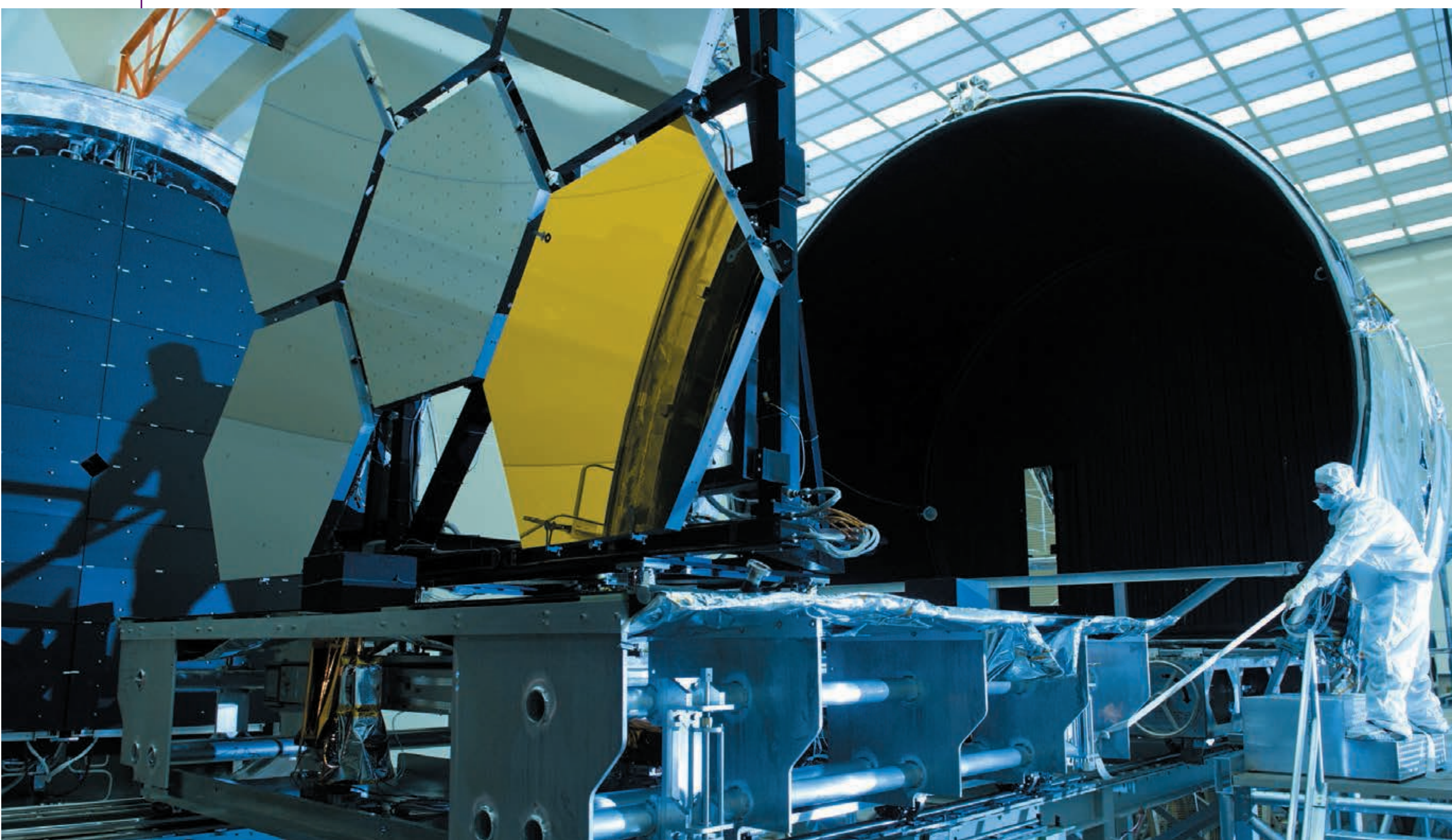
Thomas Morelli Photography

***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 Bill Kaufmann in 1994. He is also the author of four trade books, *What If the Moon Didn't Exist?*, *Heavenly Errors, The Hazards of Space Travel,* and *What If the Earth Had Two Moons? What If the Moon Didn't Exist?* has been made into planetarium shows, been excerpted for television and radio, translated into several languages, and was the theme for the Mitsubishi Pavilion at the World Expo 2005 in Aichi, Japan. *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.

William J. Kaufmann III was the author of the first three editions of *Discovering the Universe*. Born in New York City on December 27, 1942, he often visited the magnificent Hayden Planetarium as he was growing up. Dr. Kaufmann earned his bachelor's degree magna cum laude in physics from Adelphi University in 1963, a master's degree in physics from Rutgers in 1965, and a Ph.D. in astrophysics from Indiana University in 1968. At 27 he became the youngest director of any major observatory in the United States when he took the helm of the Griffith Observatory in Los Angeles. During his career he also held positions at San Diego State University, UCLA, Caltech, and the University of Illinois. Throughout his professional life as a scientist and educator, Dr. Kaufmann worked to bridge the gap between the scientific community and the general public to help the public share in the advances of astronomy. A prolific author, his many books include *Black Holes and Warped Spacetime, Relativity and Cosmology, The Cosmic Frontiers of General Relativity, Exploration of the Solar System, Planets and Moons, Stars and Nebulas, Galaxies and Quasars,* and *Supercomputing and the Transformation of Science*. Dr. Kaufmann died in 1994.

PART I

Understanding Astronomy



R I V U X G Telescopes enhance our views of the cosmos. (NASA/MSFC/Emmett Given)

AN ASTRONOMER'S ALMANAC

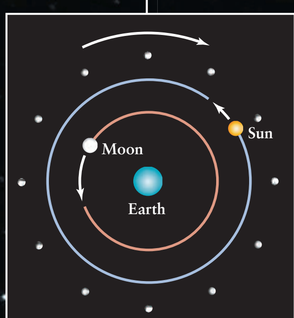
2136 B.C.E. Chinese astronomers record solar eclipse. (Atlas Photo Bank/Science Source)

Greek Golden Age

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

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

350 B.C.E. Aristotle proposes spherical Earth, geocentric 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*. (Science and Society/SuperStock)

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

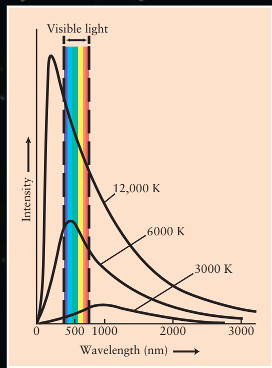
1840-1849 J. W. Draper invents astronomical photography; takes first photographs of the Moon. Christian Doppler proposes that wavelength is affected by motion. Lord Rosse completes 60-in. reflecting telescope at Birr Castle in Ireland. Armand Fizeau and Jean-Bernard Foucault measure speed of light accurately.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

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

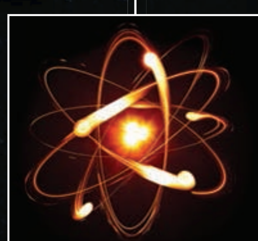
1871-1873 Dimitri Mendeleyev develops periodic table of the elements. Henry Draper develops spectroscopy. James Clerk Maxwell asserts that light is an electromagnetic phenomenon.

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. (Yerkes Observatory/National Geographic Society/Corbis)

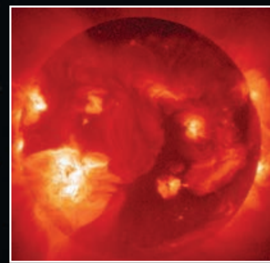


1900 Max Planck explains blackbody radiation. Paul Villard discovers gamma rays.



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. (Reuters/Corbis)

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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R I V U X G Stars appear to rotate around Polaris, the North Star (top), in this time exposure, taken January 26, 2006. Below Polaris is the 4-m telescope dome at Kitt Peak National Observatory near Tucson, Arizona. The image is composed of 114 thirty-second exposures of the night sky combined to make the equivalent of a nearly 1-hour exposure in which Earth's rotation causes the stars to appear to move across the night sky. The orange glow on the horizon is from the city of Phoenix, 160 km (100 mi) away. (STAN HONDA/AFP/Getty Images)

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 exciting time as astronomers draw open the curtains of the cosmos. Our understanding of the cosmos (or the *universe*) and how it evolves is growing as never before. That is due, in large measure, to the immense light-gathering power and sensitivity of modern telescopes. Current telescope technology makes it possible for astronomers to observe objects 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 a decade 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.

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; and other probes have crashed into one comet and brought back debris from another one, landed on an asteroid and on murky Titan, discovered active volcanoes and barren ice fields on the moons of Jupiter, traveled through the shimmering rings of Saturn, and departed from the realm of the planets in our solar system, to mention just a few accomplishments. 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 (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.

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.

a

b

FIGURE 1-1 The Night Sky Without and With Light Pollution (a) Sunlight is a curtain that hides virtually everything behind it. As the Sun sets, places with little smog or light pollution treat viewers to beautiful panoramas of stars that can 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)

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 and lunar and solar eclipses
- how the year is defined and how the calendar was developed

SCALES OF THE UNIVERSE

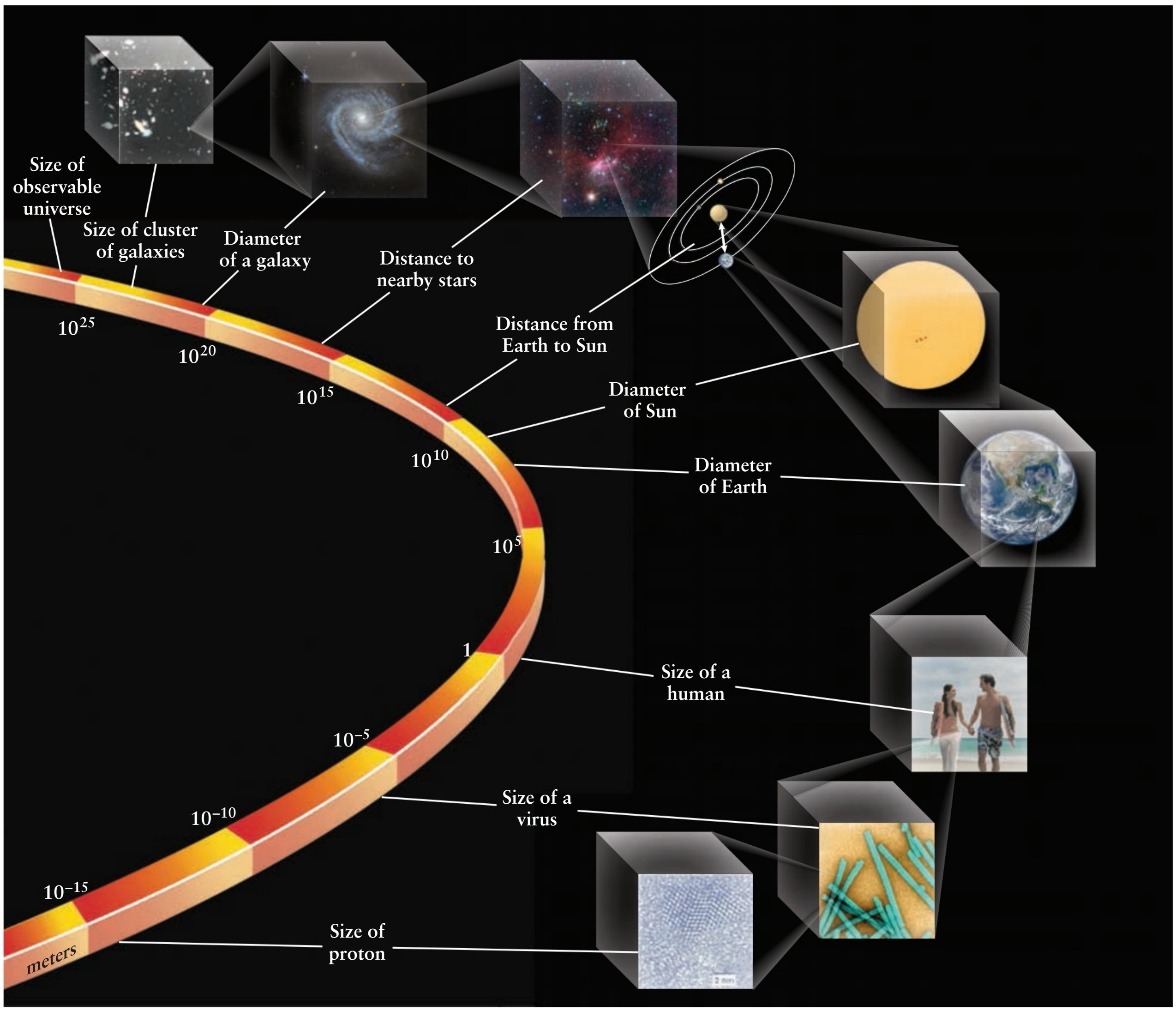
In learning a new field it is often useful to see the "big picture" before exploring the details. For this reason, we begin by surveying the major types of objects in the universe, along with their ranges of size and the scale of distances between them.

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. 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 large 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



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)

particles up to the diameter of the entire universe visible to us. Unlike linear intervals measured on a ruler, 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.

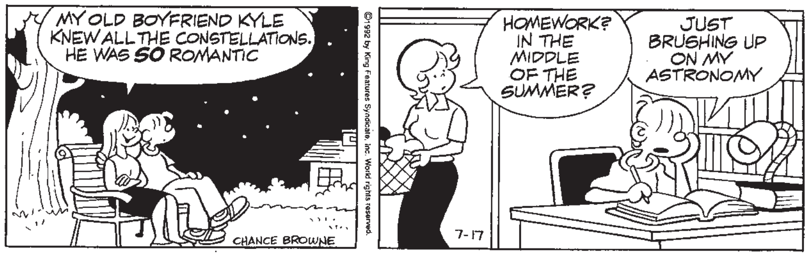
This wide range of sizes underscores the fact that astronomy *synthesizes* or brings together information from many other fields of science. While we cannot go to the ends of the universe to examine all its components, the light from the universe coming to us, combined with our understanding of the laws 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 are held together in galaxies by the force of gravity (Figure 1-3f). Most galaxies contain **black holes**, objects with such strong gravitational attraction that nothing can escape from them (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

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

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.

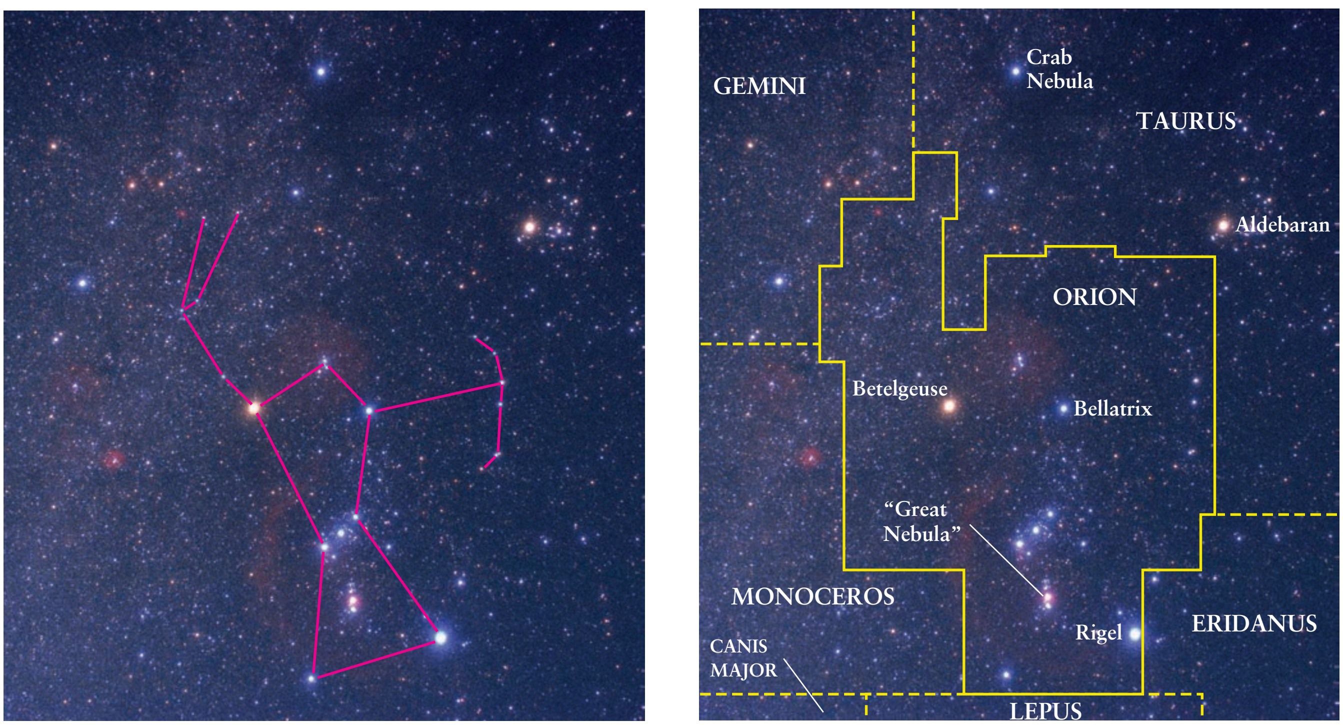


(Hi and Lois © 1992 King Features Syndicate)

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. 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.



a

b

FIGURE 1-4 The Constellation Orion (a) The pattern of stars (asterism) called Orion is prominent in the winter sky. From the northern hemisphere, it is easily seen high above the southern horizon from December through March. You can see in this photograph that the various stars have different colors—something to watch for when you observe the night sky. (b) Technically, constellations are entire regions of the sky. The constellation called Orion and parts of other nearby constellations are depicted in this photograph. All the stars and other celestial objects, like galaxies, inside the boundary of Orion are members of that constellation. The entire sky is covered by a quilt-like pattern of 88 constellations of differing sizes and shapes. (© 2004 Jerry Lodriguss/Astropix.com)