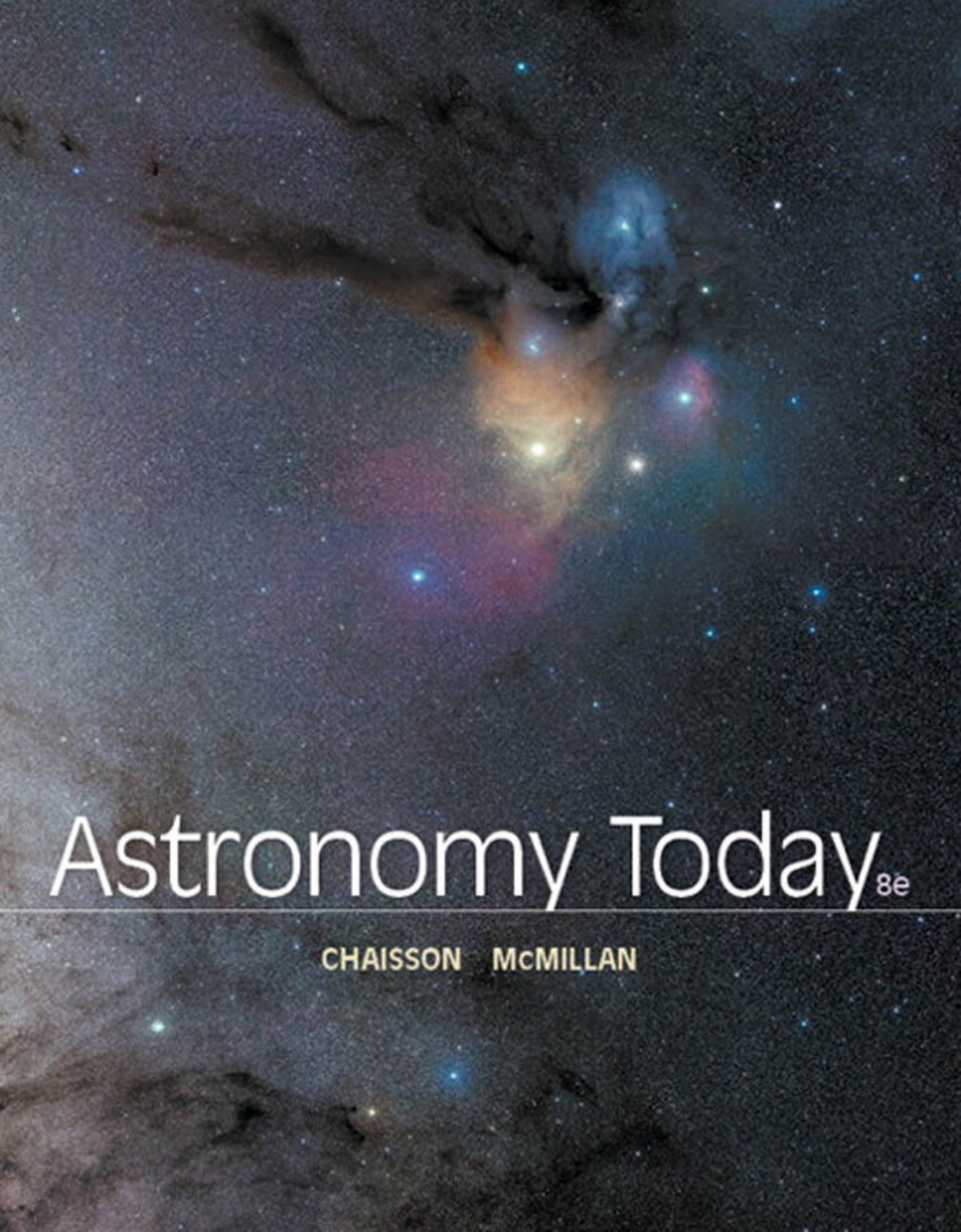
Astronomy Today 8e
CHAISSON McMILLAN

# Astronomy Today 8e

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# Astronomy Today 8e

Eric Chaisson
*Harvard University*

Steve McMillan
*Drexel University*

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# Online Contents

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# About the Authors

## Eric Chaisson

Eric holds a doctorate in astrophysics from Harvard University, where he spent 10 years on the faculty of Arts and Sciences. For more than two decades thereafter, he served on the senior science staff at the Space Telescope Science Institute and held various professorships at Johns Hopkins and Tufts universities. He is now back at Harvard, where he teaches and conducts research at the Harvard-Smithsonian Center for Astrophysics. Eric has written 12 books on astronomy and has published nearly 200 scientific papers in professional journals.

## Steve McMillan

Steve holds a bachelor's and master's degree in mathematics from Cambridge University and a doctorate in astronomy from Harvard University. He held postdoctoral positions at the University of Illinois and Northwestern University, where he continued his research in theoretical astrophysics, star clusters, and high-performance computing. Steve is currently Distinguished Professor of Physics at Drexel University and a frequent visiting researcher at Princeton's Institute for Advanced Study and Leiden University. He has published more than 100 articles and scientific papers in professional journals.

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# Preface

Astronomy is a science that thrives on new discoveries. Fueled by new technologies and novel theoretical insights, the study of the cosmos continues to change our understanding of the universe. We are pleased to have the opportunity to present in this book a representative sample of the known facts, evolving ideas, and frontier discoveries in astronomy today.

*Astronomy Today* has been written for students who have taken no previous college science courses and who will likely not major in physics or astronomy. It is intended for use in a one- or two-semester, nontechnical astronomy course. We present a broad view of astronomy, straightforwardly descriptive and without complex mathematics. The absence of sophisticated mathematics, however, in no way prevents discussion of important concepts. Rather, we rely on qualitative reasoning as well as analogies with objects and phenomena familiar to the student to explain the complexities of the subject without oversimplification. We have tried to communicate the excitement we feel about astronomy and to awaken students to the marvelous universe around us.

We are very gratified that the first seven editions of this text have been so well received by many in the astronomy education community. In using those earlier texts, many teachers and students have given us helpful feedback and constructive criticisms. From these, we have learned to communicate better both the fundamentals and the excitement of astronomy. Many improvements inspired by these comments have been incorporated into this new edition.

## Focus of the Eighth Edition

From the first edition, we have tried to meet the challenge of writing a book that is both accurate and approachable. To the student, astronomy sometimes seems like a long list of unfamiliar terms to be memorized and repeated. Many new terms and concepts will be introduced in this course, but we hope students will also learn and remember how science is done, how the universe works, and how things are connected. In the eighth edition, we have taken particular care to show how astronomers know what they know, and to highlight both the scientific principles underlying their work and the process used in discovery.

## New and Revised Material

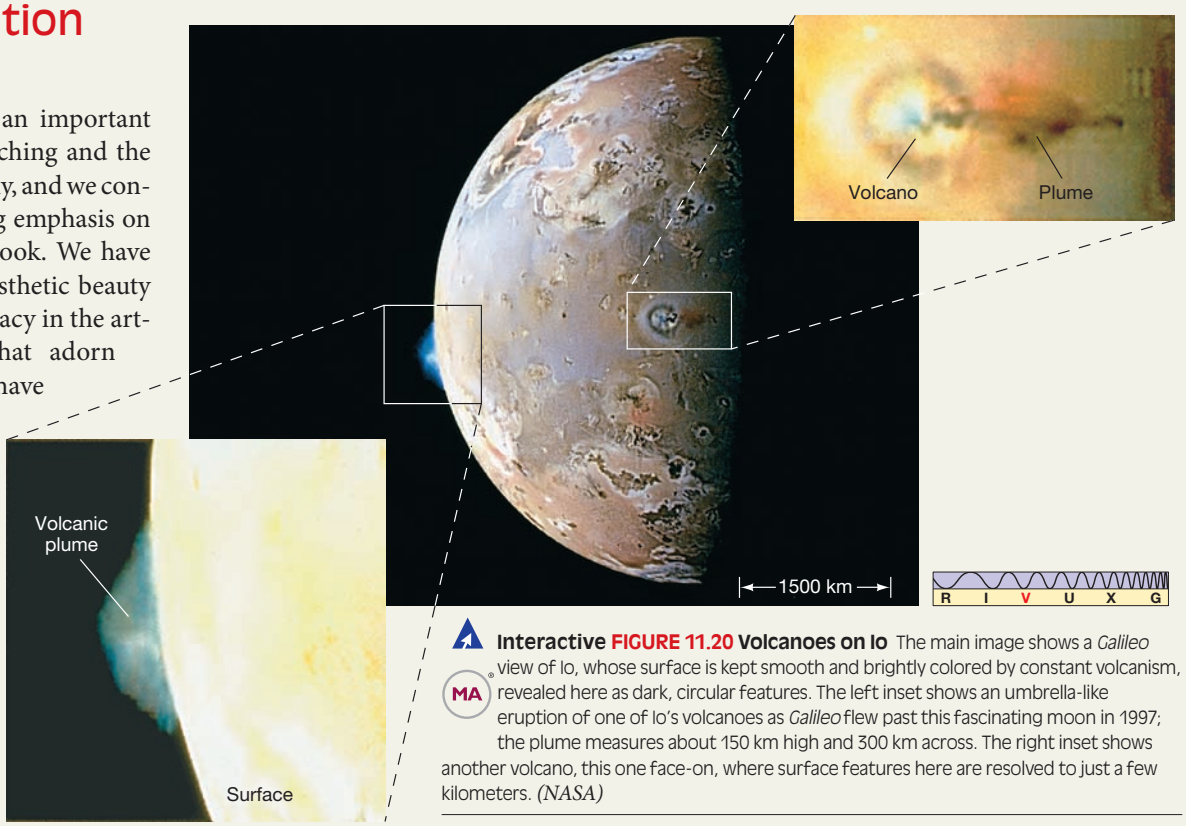
Astronomy is a rapidly evolving field and, in the three years since the publication of the seventh edition of *Astronomy Today,* has seen many new discoveries covering the entire spectrum of astronomical research. Almost every chapter in the eighth edition has been substantially updated with new information. Several chapters have also seen significant reorganization in order to streamline the overall presentation, strengthen our focus on the process of science, and reflect new understanding and emphases in contemporary astronomy.

In addition to updates throughout the text on the numbers and properties of the many astronomical objects, the many substantive changes include the following:

- A new *Discovery* box in Chapter 5 on the *ALMA* interferometric array.
- Significant revision in Chapter 5 of the discussion of infrared telescopes, including new coverage of *Herschel* and introduction of the *James Webb Space Telescope*.
- A new two-page box in Chapter 6 on planetary exploration.
- Incorporation and reorganization of the entire "standard" theory of solar system formation into Chapter 6, laying the groundwork for interpreting the planetary data presented in Part 2 and allowing Chapter 15 to focus on solar system details, irregularities, and exoplanets.
- Updated discussion in *Discovery 8-1* of *Chang'e*, *GRAIL*, and other recent lunar missions; new discussion of the *Prospector*, *LRO*, *and LCROSS* missions, with updated coverage of the search for lunar ice.
- Updated coverage in Chapter 8 of the lunar core and interior based on the latest *GRAIL* results.
- Updated discussion in Chapter 8 of surface features on Mercury, following the *Messenger* mission.
- Updated discussion in Chapter 8 of Mercury's inner and outer core and magnetic field and formation, in light of new *Messenger* data.
- Updated discussion in Chapter 9 of *Venus Express* findings and status.
- Updated discussion in Chapter 10 of the collision hypothesis as the origin of the northern Martian lowlands.
- Reorganized and updated discussion in Chapter 10 of liquid water on the Martian surface.
- Updated discussion in Chapter 10 on the *Spirit, Opportunity*, and *Phoenix* landers; new material on the *Curiosity* lander and its findings.
- Revised discussion in Chapter 10 of the origin of the Martian moons.
- Updated coverage of cometary impacts in *Discovery 11-1*, indicating that such impacts are commonplace in the solar system.

## The Illustration Program

Visualization plays an important role in both the teaching and the practice of astronomy, and we continue to place strong emphasis on this aspect of our book. We have tried to combine aesthetic beauty with scientific accuracy in the artist's conceptions that adorn the text, and we have sought to present the best and latest imagery of a wide range of cosmic objects. Each illustration has been carefully crafted to enhance student learning; each is pedagogically sound and tied tightly to the nearby discussion of important scientific facts and ideas. This edition contains more than 100 revised figures that show the latest imagery and the results learned from them.

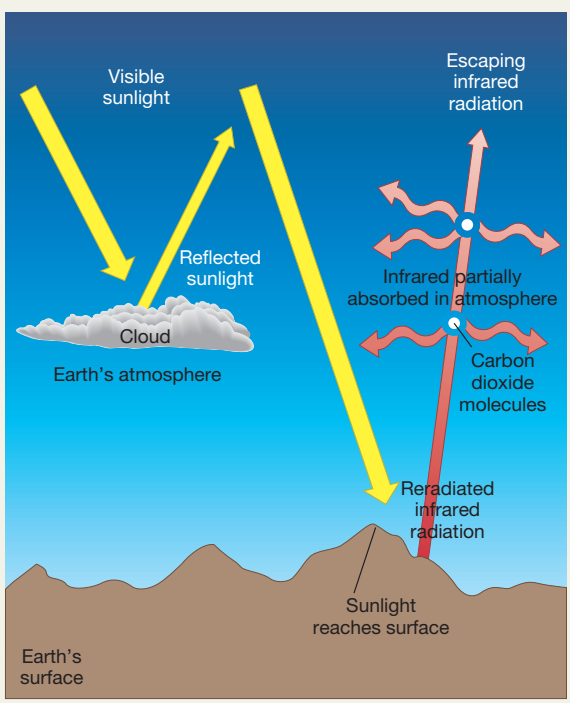



**Interactive FIGURE 11.20 Volcanoes on Io** The main image shows a *Galileo* view of Io, whose surface is kept smooth and brightly colored by constant volcanism, revealed here as dark, circular features. The left inset shows an umbrella-like eruption of one of Io's volcanoes as *Galileo* flew past this fascinating moon in 1997; the plume measures about 150 km high and 300 km across. The right inset shows another volcano, this one face-on, where surface features here are resolved to just a few kilometers. *(NASA)*

**Compound Art** It is rare that a single image, be it a photograph or an artist's conception, can capture all aspects of a complex subject. Wherever possible, multiple-part figures are used in an attempt to convey the greatest amount of information in the most vivid way:

- Visible images are often presented along with their counterparts captured at other wavelengths.
- Interpretive line drawings are often superimposed on or juxtaposed with real astronomical photographs, helping students to really "see" what the photographs reveal.
- Breakouts—often multiple ones—are used to zoom in from wide-field shots to close-ups so that detailed images can be understood in their larger context.

**Interactive Figures and Photos** Icons throughout the text direct students to dynamic, interactive versions of art and photos on MasteringAstronomy®. Using online applets, students can manipulate factors such as time, wavelength, scale, and perspective to increase their understanding of these figures.

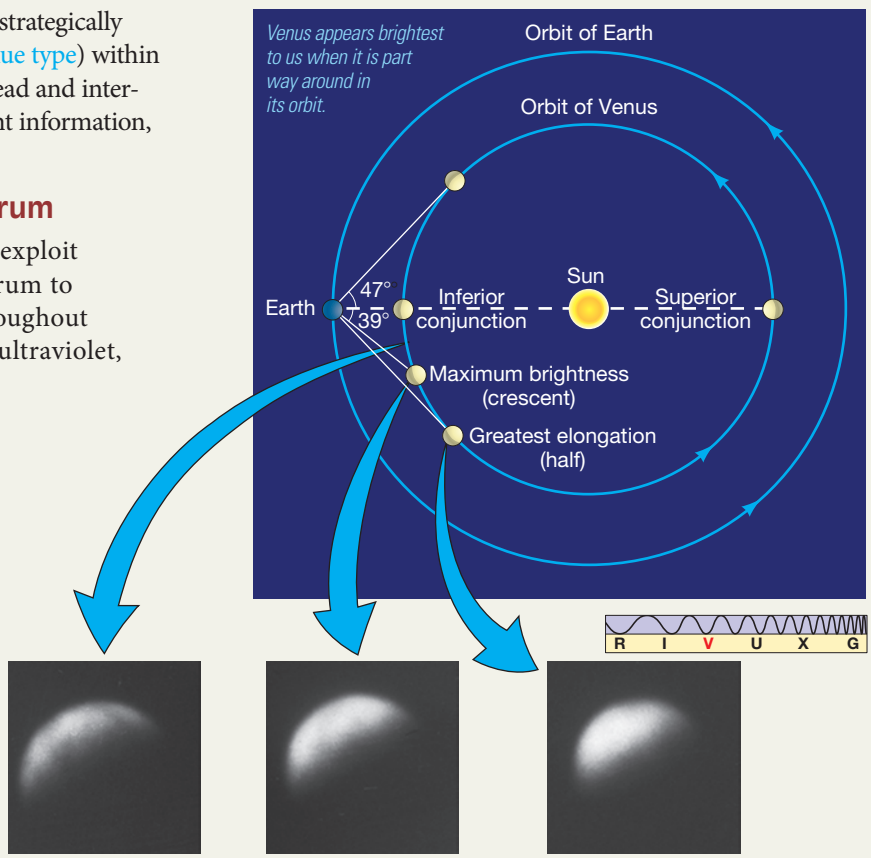



**Interactive FIGURE 7.5 Greenhouse Effect** Sunlight that is not reflected by clouds reaches Earth's surface, warming it up. Infrared radiation reradiated from the surface is partially absorbed by carbon dioxide (and also water vapor, not shown here) in the atmosphere, causing the overall surface temperature to rise.

**Narrated Figures (NEW)** Narrated Figures are brief videos that step students through complex figures from the text, expanding students' understanding of fundamental concepts in a presentation that includes narration, enhanced visuals, and one to two embedded questions, followed by short, one- to two-question Mastering activities that are graded. They mirror how an instructor might present a topic in class and can be assigned as homework, self-study, or as part of a pre-lecture program.

**Figure Annotations (REVISED)** The eighth edition incorporates the research-proven technique of strategically placing annotations (which always appear in blue type) within key pieces of art, fostering students' ability to read and interpret complex figures, focus on the most relevant information, and integrate written and visual knowledge.

**Full Spectrum Coverage and Spectrum Icons** R I V U X G Astronomers exploit the full range of the electromagnetic spectrum to gather information about the cosmos. Throughout this book, images taken at radio, infrared, ultraviolet, X-ray, or gamma-ray wavelengths are used to supplement visible-light images. As it is sometimes difficult (even for a professional) to tell at a glance which images are visible-light photographs and which are false-color images created with other wavelengths, each photo in the text is accompanied by an icon that identifies the wavelength of electromagnetic radiation used to capture the image.




**Narrated FIGURE 9.2 Venus's Brightness** Venus appears full when it is at its greatest distance from Earth, on the opposite side of the Sun from us (superior conjunction). As its distance decreases, less and less of its sunlit side becomes visible. When closest to Earth, it lies between us and the Sun (inferior conjunction), so we cannot see the sunlit side of the planet at all. Venus appears brightest when it is about 39° from the Sun. (Compare Figure 2.12.) *(Insets: UC/Lick Observatory)*

- Revised discussion in Chapter 12 of storms on Saturn and new moons and features in Saturn's rings.
- Expanded coverage in Chapter 12 of *Cassini Solstice* observations of Titan and Enceladus.
- Updated discussion in Chapter 13 of Uranus's tilted spin axis and new imagery of weather patterns on Uranus and Neptune.
- New coverage in Chapter 14 of the *Dawn* mission to Vesta and Ceres.
- Updated coverage in Chapter 14 of Earth-crossing asteroids and asteroid near misses.
- Updated coverage in Chapter 14 of Pluto's moons and trans-Neptunian objects
- New *Discovery* box in Chapter 15 on the Alpha Centauri planetary system.
- Expanded coverage in Chapter 15 of exoplanet discoveries and properties and the *Kepler* candidates list.
- New discussion in Chapter 15 of Earths and super-Earths in the habitable zones of their parent stars.

- New coverage in Chapter 16 of the *Solar Dynamics Observatory* and its findings.
- Updated discussion in Chapter 19 of star cluster observations and formation.
- Revised discussion in Chapter 22 of gamma-ray bursts and hypernovae.
- Updated coverage in Chapter 23 of activity near the center of the Milky Way Galaxy.
- Significantly updated coverage in Chapter 25 of galaxies, including new discussion of inflow of gas from intergalactic space.
- Expanded discussion of tidal streams in the Milky Way halo.
- Significantly expanded coverage in Chapter 27 of baryon acoustic oscillations in the early universe and their connection to fluctuations in the microwave background.
- Updated discussion in Chapter 28 of the frequency of planetary systems and the numbers of habitable planets per system.
- Added 18 new Narrated Figure notations.
- Added helpful annotations so that now about half of the figures in the text employ this pedagogically useful tool.
- Added distance scales to many figures, helping students gain an understanding of the vastness of the universe.
- Replaced a number of older images for currency and clarity.
- Updated the art throughout the text.
- Added new table of contents for online material (Online Contents), which lists by chapter all the online assets the book delivers: Narrated Figures, Interactive Figures, Animation/Videos, and Self-Guided Tutorials.

## Other Pedagogical Features

As with many other parts of our text, instructors have helped guide us toward what is most helpful for effective student learning. With their assistance, we have revised both our in-chapter and end-of-chapter pedagogical apparatus to increase its utility to students.

**Learning Outcomes (NEW)** Studies indicate that beginning students have trouble prioritizing textual material. For this reason, a few (typically five or six) well-defined Learning Outcomes are provided at the start of each chapter. These help students structure their reading of the chapter and then test their mastery of key concepts. The Learning Outcomes are numbered and keyed to the items in the Chapter Summary, which in turn refer back to passages in the text. This highlighting of the most important aspects of the chapter helps students prioritize information and also aids in their review. The Learning Outcomes are organized and phrased in such a way as to make them objectively testable, affording students a means of gauging their own progress.

**Learning Outcomes**

*Studying this chapter will enable you to*

1. Summarize the composition and physical properties of the interstellar medium.
2. Describe the characteristics of emission nebulae, and explain their significance in the life cycle of stars.
3. List the basic properties of dark interstellar clouds.
4. Specify the radio techniques used to probe the nature of interstellar matter.
5. Explain the nature and significance of interstellar molecules.

**The Big Picture (REVISED)** The Big Picture feature on every chapter opening spread encapsulates the overarching message that each chapter imparts, helping students see how chapter content is connected to a broad understanding of the universe.

**The Big Picture** Stars are everywhere in the nighttime sky. The naked eye can spot about 6000 of them, spread across 88 constellations. Millions more are visible even with binoculars or a small telescope. The total number of stars is impossible to count, and relatively few have been studied in detail. Yet, it is stars that tell us more about the fundamentals of astronomy than any other objects in the universe.

**The Big Question (NEW)** Each chapter now ends with a broad, open-ended query that is intended to ignite students' curiosity about the still-unanswered questions at the forefront of astronomical research. The Big Question builds on the material presented in the chapter and invites students to speculate on the larger scope of what they have just learned.

**The Big Question** Our Sun will expand as it ages, and it is destined to balloon rapidly into a red giant as it begins running out of fuel in about 5 billion years. A burning question, often asked and then quickly dismissed as being too remote in time is, will the red-giant Sun expand enough to engulf Earth? No one is certain. We do know that the Sun is losing lots of matter, thereby lessening its gravitational pull. Perhaps that will allow Earth to recede eventually to a relatively safe orbit.

**Concept Checks** We incorporate into each chapter a number of "Concept Checks"—key questions that require the reader to reconsider some of the material just presented or attempt to place it into a broader context. Answers to these in-chapter questions are provided at the back of the book.

**CONCEPT Check**

✔ Why do astronomers draw such a clear distinction between the inner and the outer planets?

**Process of Science Checks** Each chapter now also includes one or two "Process of Science Checks," similar to the Concept Checks but aimed specifically at clarifying the questions of how science is done and how scientists reach the conclusions they do. Answers to these in-chapter questions are also provided at the back of the book.

**PROCESS OF SCIENCE Check**

✔ In what sense are the comets we see *un*representative of comets in general?

**Concept Links** In astronomy, as in many scientific disciplines, almost every topic seems to have some bearing on almost every other. In particular, the connection between the astronomical material and the physical principles set forth early in the text is crucial. Practically everything in Chapters 6–28 of this text rests on the foundation laid in the first five chapters. For example, it is important that students, when they encounter the discussion of high-redshift objects in Chapter 25, recall not only what they just learned about Hubble's law in Chapter 24 but also refresh their memories, if necessary, about the inverse-square law (Chapter 17), stellar spectra (Chapter 4), and the Doppler shift (Chapter 3). Similarly, the discussions of the mass of binary-star components (Chapter 17) and of galactic rotation (Chapter 23) both depend on the discussion of Kepler's and Newton's laws in Chapter 2. Throughout, discussions of new astronomical objects and concepts rely heavily on comparison with topics introduced earlier in the text.

It is important to remind students of these links so that they recall the principles on which later discussions rest and, if necessary, review them. To this end, we have inserted "concept links" throughout the text—symbols that mark key intellectual bridges between material in different chapters. The links, denoted by the symbol ∞ together with a section reference, signal that the topic under discussion is related in some significant way to ideas developed earlier and provide direction to material to review before proceeding.

**Key Terms** Like all subjects, astronomy has its own specialized vocabulary. To aid student learning, the most important astronomical terms are boldfaced at their first appearance in the text. Boldfaced Key Terms in the Chapter Summary are linked with the page number where the term was defined. In addition, an expanded alphabetical glossary, defining each Key Term and locating its first use in the text, appears at the end of the book.

**H–R Diagrams and Acetate Overlays** All of the book's H–R diagrams are drawn in a uniform format, using real data. In addition, a unique set of transparent acetate overlays dramatically demonstrates to students how the H–R diagram helps us to organize our information about the stars and track their evolutionary histories.

**More Precisely Boxes** These boxes provide more quantitative treatments of subjects discussed qualitatively in the text. Removing these more challenging topics from the main flow of the narrative and placing them within a separate modular element of the chapter design (so that they can be covered in class, assigned as supplementary material, or simply left as optional reading for those students who find them of interest) will allow instructors greater flexibility in setting the level of their coverage.

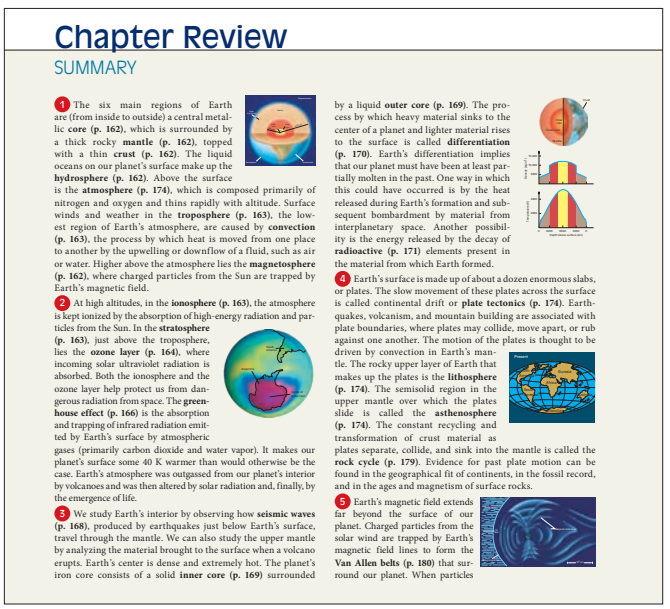
**Discovery Boxes** Exploring a wide variety of interesting supplementary topics, Discovery boxes provide the reader with insight into how scientific knowledge evolves and emphasizes the process of science.

**End-of-Chapter Questions, Problems, and Activities (NEW)** Many elements of the end-of-chapter material have seen substantial reorganization:

- Each chapter incorporates **Review and Discussion Questions,** which may be used for in-class review or for assignment. As with the Self-Test Questions, the material needed to answer Review Questions may be found within the chapter. The Discussion Questions explore particular topics more deeply, often asking for opinions, not just facts. As with all discussions, these questions usually have no single "correct" answer. Questions identified with a POS icon encourage students to explore the Process of Science, and each Learning Outcome is reflected in one of the Review and Discussion questions, marked by LO.
- Each chapter also contains **Conceptual Self-Test Questions** in a multiple-choice format, including select questions that are tied directly to a specific figure or diagram in the text, allowing students to assess their understanding of the chapter material. These questions are identified with a VIS icon. Answers to all these questions appear at the end of the book.
- The end-of-chapter material includes **Problems,** based on the chapter contents and requiring some numerical calculation. In many cases the problems are tied directly to quantitative statements made (but not worked out in detail) in the text. The solutions to the problems are not contained verbatim within the chapter, but the information necessary to solve them has been presented in the text. Answers to odd-numbered Problems appear at the end of the book.

- Also new to this edition, the end-of-chapter material now ends with collaborative and individual **Activities** relevant to the material presented in the text. These range from basic naked-eye and telescopic observing projects to opinion polls, surveys, group discussions, and astronomical research on the Web.

**Chapter Review Summaries** The Chapter Review Summaries, a primary review tool, are linked to the Learning Outcomes at the beginning of each chapter. Key Terms introduced in each chapter are listed again, in context and in boldface, along with key figures and page references to the text discussion.



Chapter Review

SUMMARY

1 The six main regions of Earth are (from inside to outside) a central metallic **core (p. 162)**, which is surrounded by a thick rocky **mantle (p. 162)**, topped with a thin **crust (p. 162)**. The liquid oceans on our planet's surface make up the **hydrosphere (p. 162)**. Above the surface is the **atmosphere (p. 174)**, which is composed primarily of nitrogen and oxygen and thins rapidly with altitude. Surface winds and weather in the **troposphere (p. 163)**, the lowest region of Earth's atmosphere, are caused by **convection (p. 163)**, the process by which heat is moved from one place to another by the upwelling or downflow of a fluid, such as air or water. Higher above the atmosphere lies the **magnetosphere (p. 162)**, where charged particles from the Sun are trapped by Earth's magnetic field.

2 At high altitudes, in the **ionosphere (p. 163)**, the atmosphere is kept ionized by the absorption of high-energy radiation and particles from the Sun. In the **stratosphere (p. 163)**, just above the troposphere, lies the **ozone layer (p. 164)**, where incoming solar ultraviolet radiation is absorbed. Both the ionosphere and the ozone layer help protect us from dangerous radiation from space. The **greenhouse effect (p. 166)** is the absorption and trapping of infrared radiation emitted by Earth's surface by atmospheric gases (primarily carbon dioxide and water vapor). It makes our planet's surface some 40 K warmer than would otherwise be the case. Earth's atmosphere was outgassed from our planet's interior by volcanoes and was then altered by solar radiation and, finally, by the emergence of life.

3 We study Earth's interior by observing how **seismic waves (p. 168)**, produced by earthquakes just below Earth's surface, travel through the mantle. We can also study the upper mantle by analyzing the material brought to the surface when a volcano erupts. Earth's center is dense and extremely hot. The planet's iron core consists of a solid **inner core (p. 169)** surrounded by a liquid **outer core (p. 169)**. The process by which heavy material sinks to the center of a planet and lighter material rises to the surface is called **differentiation (p. 170)**. Earth's differentiation implies that our planet must have been at least partially molten in the past. One way in which this could have occurred is by the heat released during Earth's formation and subsequent bombardment by material from interplanetary space. Another possibility is the energy released by the decay of **radioactive (p. 171)** elements present in the material from which Earth formed.

4 Earth's surface is made up of about a dozen enormous slabs, or plates. The slow movement of these plates across the surface is called continental drift or **plate tectonics (p. 174)**. Earthquakes, volcanism, and mountain building are associated with plate boundaries, where plates may collide, move apart, or rub against one another. The motion of the plates is thought to be driven by convection in Earth's mantle. The rocky upper layer of Earth that makes up the plates is the **lithosphere (p. 174)**. The semisolid region in the upper mantle over which the plates slide is called the **asthenosphere (p. 174)**. The constant recycling and transformation of crust material as plates separate, collide, and sink into the mantle is called the **rock cycle (p. 179)**. Evidence for past plate motion can be found in the geographical fit of continents, in the fossil record, and in the ages and magnetism of surface rocks.

5 Earth's magnetic field extends far beyond the surface of our planet. Charged particles from the solar wind are trapped by Earth's magnetic field lines to form the **Van Allen belts (p. 180)** that surround our planet. When particles

# Instructor Resources

MasteringAstronomy®
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MasteringAstronomy is the most widely used and most advanced astronomy tutorial and assessment system in the world. By capturing the step-by-step work of students nationally, MasteringAstronomy has established an unparalleled database of learning challenges and patterns. Using this student data, a team of renowned astronomy education researchers has refined every activity and problem. The result is a library of activities of unique educational effectiveness and assessment accuracy. MasteringAstronomy provides students with two learning systems in one: a dynamic self-study area and the ability to participate in online assignments.

MasteringAstronomy provides instructors with a fast and effective way to assign uncompromising, wide-ranging online homework assignments of just the right difficulty and duration. The tutorials coach 90 percent of students to the correct answer with specific wrong-answer feedback. Powerful post-diagnostics allow instructors to assess the progress of their class as a whole or to quickly identify an individual student's areas of difficulty. Tutorials built around text content and all the end-of-chapter problems from the text are available in MasteringAstronomy. A media-rich self-study area is included that students can use whether the instructor assigns homework or not.

**Instructor Guide** Revised by James Heath (Austin Community College), this online guide provides: sample syllabi and course schedules; an overview of each chapter; pedagogical tips; useful analogies; suggestions for classroom demonstrations; writing questions, selected readings, and answers/solutions to the end-of-chapter Review and Discussion Questions and Problems; and additional references and resources.
ISBN 0-321-91021-4

**Test Bank** An extensive file of approximately 2800 test questions, newly compiled and revised for the eighth edition. The questions are organized and referenced by chapter section and by question type. The eighth edition Test Bank has been thoroughly revised and includes many new Multiple Choice and Essay questions for added conceptual emphasis. This Test Bank is available in both Microsoft® Word and TestGen® formats (see description of Instructor Resource DVD).
ISBN 0-321-91008-7

## Instructor Resource Area in Mastering Astronomy

This instructor resource area resides in MasteringAstronomy and provides every electronic asset professors will need in and out of the classroom. The area not only contains an Instructor's Resource Manual, but also all text figures in jpeg and PowerPoint formats, including additional images, star charts, as well as the animations and videos from the MasteringAstronomy® Study Area. The area also contains TestGen®, an easy-to-use, fully networkable program for creating tests ranging from short quizzes to long exams. Questions from the Test Bank are supplied, and professors can use the Question Editor to modify existing questions or create new questions. It also contains chapter-by-chapter lecture outlines in PowerPoint and conceptual "clicker" questions in PowerPoint. It is available in both PC and Mac formats.

**Instructor Resource Center** The Pearson Instructor Resource Center contains everything found on the Instructor Resource Area in MasteringAstronomy and the Instructor DVD, above, with the exception of the text figures in jpeg and PowerPoint formats, which are too large to download.

**Instructor Resource DVD** This DVD contains every resource found in the Instructor Resource Area in MasteringAstronomy, and it provides virtually every electronic asset professors will need in and out of the classroom. The disc contain all text figures in jpeg and PowerPoint formats, as well as the animations and videos from the Mastering Astronomy® Study Area. The IR-DVD also contains TestGen®, an easy-to-use, fully networkable program for creating tests ranging

from short quizzes to long exams. Questions from the Test Bank are supplied, and professors can use the Question Editor to modify existing questions or create new questions. This disc set also contains chapter-by-chapter lecture outlines in PowerPoint and conceptual "clicker" questions in PowerPoint.
ISBN 0-321-90974-7

***Learner-Centered Astronomy Teaching: Strategies for ASTRO 101***
Timothy F. Slater, *University of Wyoming*
Jeffrey P. Adams, *Millersville University*

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***Peer Instruction for Astronomy***
Paul J. Green, *Harvard-Smithsonian Center for Astrophysics*

Peer instruction is a simple yet effective method for teaching science. Techniques of peer instruction for introductory physics were developed primarily at Harvard and have aroused interest and excitement in the physics education community. This approach involves students in the teaching process, making science more accessible to them. This book is an important vehicle for providing a large number of thought-provoking, conceptual short-answer questions aimed at a variety of class levels. While significant numbers of such questions have been published for use in physics, *Peer Instruction for Astronomy* provides the first such compilation for astronomy.
ISBN 0-13-026310-9

## Student Resources

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**Eric Chaisson**
**Steve McMillan**

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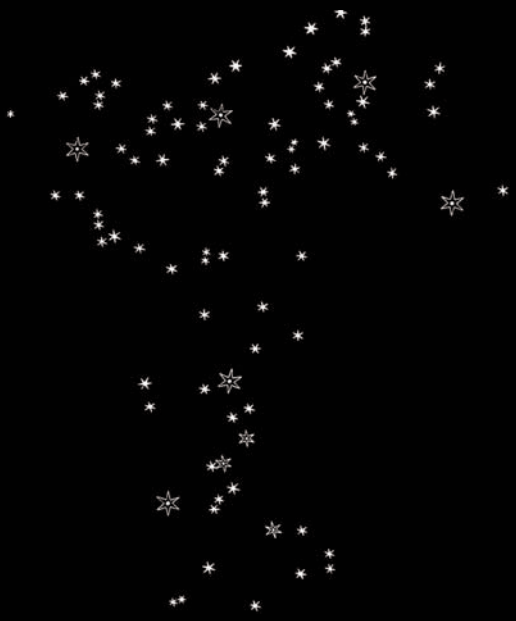
# Astronomy Today 8e

Galileo's sketch of Saturn

PART ONE

# Astronomy and the Universe



Galileo's sketch of Orion

**It is often said** that we live in a golden age of astronomy. Yet the dawn of the 21st century is actually the second such period of rich discovery and rapid exploration. The first era of stunning scientific growth began in the late Renaissance. Foremost among the early architects of modern astronomy was the Italian scientist Galileo Galilei (1564–1642). By turning his telescope to the heavens, he changed radically and forever our view of the universe in which we live.

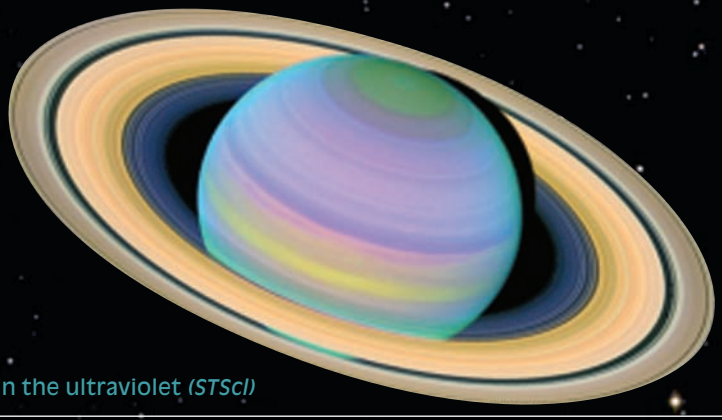
Although he did not invent the telescope, in 1610 Galileo was the first to record what he saw when he aimed a small (5-cm-diameter) lens at the sky. His findings created nothing less than a revolution in astronomy. Viewing for the first time dark blemishes on the Sun, rugged mountains on the Moon, and whole new worlds orbiting Jupiter, he demolished the Aristotelian notion that the heavens were perfect and unchanging. It was with the philosophers of the day, as much as with the theologians, that Galileo had trouble. In championing the scientific method, he used a tool to test his ideas, and what he found disagreed greatly with the leading thoughts and beliefs of the time.

Galileo's advance was simple yet profound: He used a telescope to focus, magnify, and study radiation reaching Earth from the heavens—in particular, light from the Sun, the Moon, and the planets. Light is the most familiar kind of radiation to humans on Earth, since it enables us to get around on the surface of our planet. But light also enables telescopes to see objects deep in space, allowing us to probe farther than the eye can alone. With his simple optical telescope, Galileo changed completely the way that the oldest science—astronomy—is pursued.

Among other "wondrous things" he found were star clusters along the Milky Way, moons and rings around the outer planets, and colorful nebulae unlike anything seen before. Some of Galileo's sketches are reproduced here (left side) and are compared with modern views at right.

Galileo Galilei

Galileo's sketch of the Pleiades



Saturn in the ultraviolet *(STScI)*

**Today**, we are again in the midst of another period of unsurpassed scientific achievement—a revolution in which modern astronomers are revealing the invisible universe as Galileo once spied the visible universe. We have learned how to detect, measure, and analyze invisible radiation streaming to us from dark objects in space. And once again our perceptions are changing.

Astronomy no longer evokes visions of plodding intellectuals peering through long telescope tubes. Nor does the cosmos any longer refer to that seemingly inactive, immutable domain seen visually when we gaze at the nighttime sky. Modern astronomers now decipher a more vibrant, changing universe—one in which stars emerge and perish much like living things, galaxies spew forth vast quantities of energy, and life itself is thought to be a natural consequence of the evolution of matter.

New discoveries are rapidly advancing our understanding of the universe, but they also raise new questions. Astronomers will encounter many problems in the decades ahead, but this should neither dismay nor frustrate us, for it is precisely how science operates. Each discovery adds to our storehouse of information, generating a host of questions that lead in turn to more discoveries, and so on, causing an acceleration of basic knowledge.

Most notably, we are beginning to perceive the universe in all its multivaried ways. A single generation—not the generation of our parents and not that of our children, but our generation—has opened up the whole electromagnetic spectrum beyond visible light. And what we, too, have found are "wondrous things."

Orion in the infrared *(Caltech)*

Emerging largely from studies of the invisible universe, our view of the cosmos in its full splendor is one of many new scientific insights that we have recently been privileged to attain. Historians of the future may well regard our generation as the one that took a great leap forward, providing a whole new glimpse of our richly endowed universe. In all of history, there have been only two periods in which our perception of the universe has been so revolutionized within a single human lifetime. The first occurred four centuries ago at the time of Galileo; the second is now under way.

Pleiades in the optical *(AURA)*

# 1 Charting the Heavens

## THE FOUNDATIONS OF ASTRONOMY

Nature offers no greater splendor than the starry sky on a clear, dark night. Silent and jeweled with the constellations of ancient myth and legend, the night sky has inspired wonder throughout the ages—a wonder that leads our imaginations far from the confines of Earth and the pace of the present day and out into the distant reaches of space and cosmic time itself.

Astronomy, born in response to that wonder, is built on two of the most basic traits of human nature: the *need to explore* and the *need to understand*. Through the interplay of curiosity, discovery, and analysis—the keys to exploration and understanding—people have sought answers to questions about the universe since the earliest times. Astronomy is the oldest of all the sciences, yet never has it been more exciting than it is today.

**The Big Picture** Our subject is science, and that means rich details and specific ideas. Even so, we also need to keep in mind a larger, general perspective. And when it comes to astronomy, there is perhaps no grander feature of the cosmos than stars—they're everywhere in the nighttime sky, like those seen in the photo opposite. Roughly as many stars reside in the observable universe as there are grains of sand in all the beaches of the world—about a hundred sextillion, or $10^{23}$.

**LEFT:** High overhead on a clear, dark night, we can see a rich band of stars known as the Milky Way—so-called for its resemblance to a milky band of countless stars. All these stars (and more) are part of a much larger system called the Milky Way Galaxy, of which our star, the Sun, is one member. This image shows the awesome splendor of the Milky Way shining above some of the big telescopes of the European Southern Observatory, a major astronomy facility high in the Chilean Andes. ***(ESO/Y. Beletsky)***

### Learning Outcomes

*Studying this chapter will enable you to*

1. Arrange the basic levels of structure in the universe in order of increasing size.
2. Distinguish among scientific theories, hypotheses, and observations, and describe how scientists combine observation, theory, and testing in their study of the universe.
3. Describe the celestial sphere, and tell how astronomers use constellations and angular measurement to locate objects in the sky.
4. Describe how and why the Sun and the stars appear to change their positions from night to night and from month to month.
5. Explain how Earth's axial tilt causes the seasons, and why the seasons change over time.
6. Account for the changing appearance of the Moon, and explain how the relative motions of Earth, the Sun, and the Moon lead to eclipses.
7. Give an example of how simple geometric reasoning can be used to measure the distances and sizes of otherwise inaccessible objects.

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