ASTRONOMY TODAY 9e

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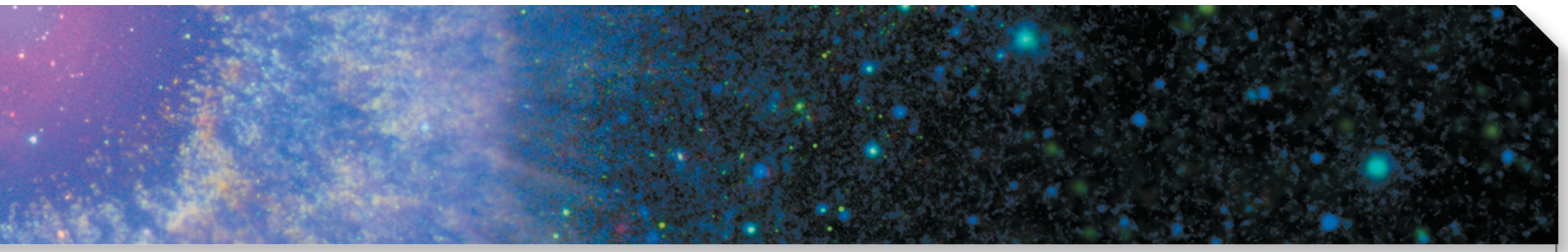

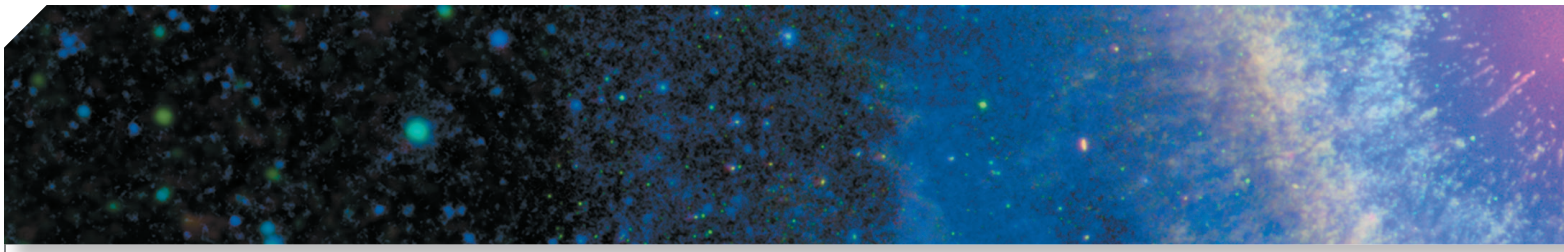

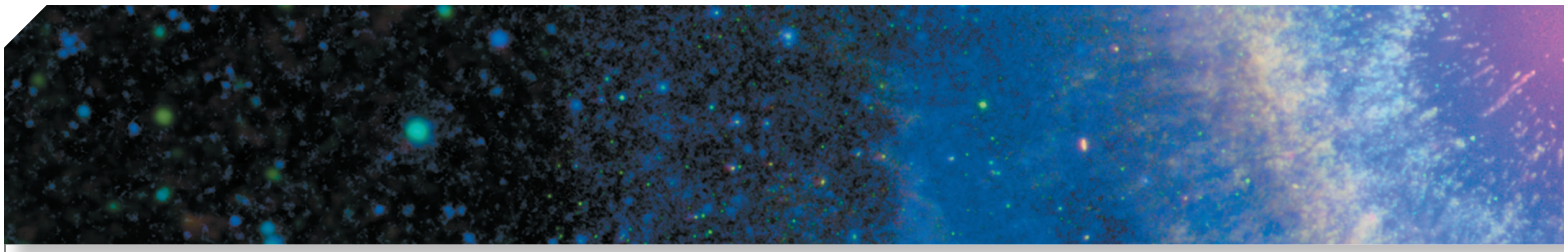

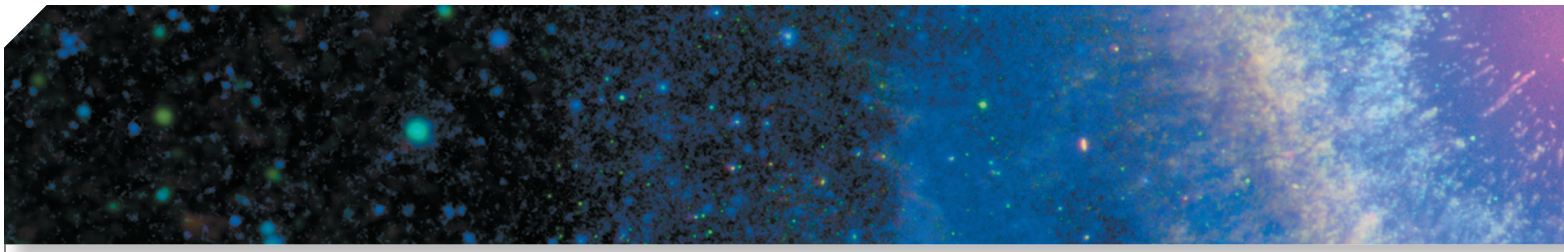

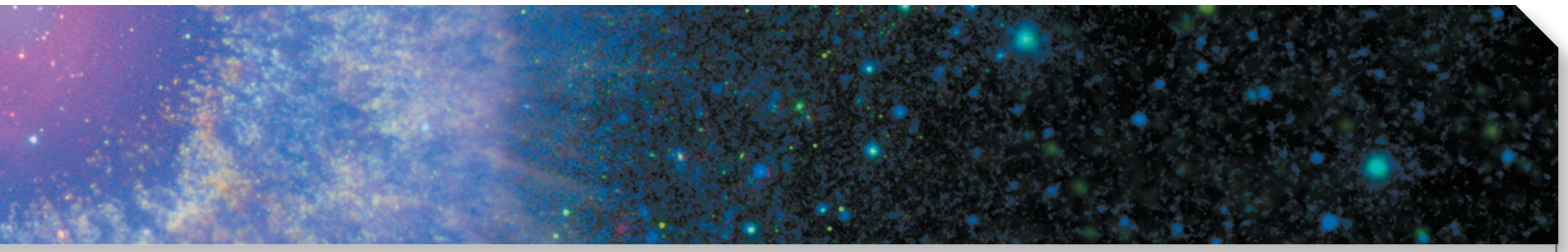

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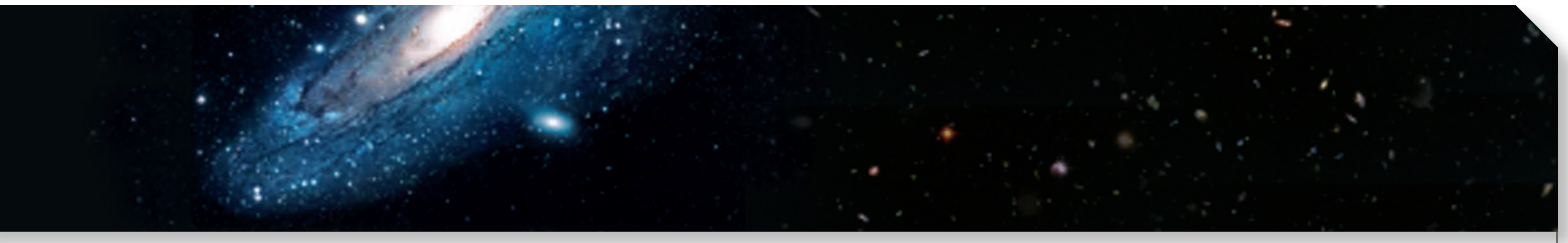

ABOUT THE AUTHORS

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 Department Head and Distinguished Professor of Physics at Drexel University and a frequent visiting researcher at Leiden University and Princeton's Institute for Advanced Study. 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 eight 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 Ninth 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 are 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 ninth 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 eighth edition of *Astronomy Today,* has seen many new discoveries covering the entire spectrum of astronomical research. Almost every chapter in the ninth 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:

- New discussion in Chapter 5 of next-generation telescopes and high-resolution astronomy.
- Updated information and imagery in *Discovery 5-1* on the ALMA array.
- New discussion in Chapter 8 of ice on the Moon.
- Additional coverage in Chapter 8 of Mercury's surface and interior based on *Messenger* data.
- New discussion in Chapter 10 of the depletion of the Martian atmosphere.
- Expanded coverage in Chapter 10 of the *Curiosity* rover on Mars and its findings so far.
- Update in Chapter 11 on the changing appearance of Jupiter's Great Red Spot.
- New material in Chapter 11 on the 2016 *Juno* mission.
- Updated discussion in Chapter 11 of the internal structure of Ganymede.
- New discussion in Chapter 12 of storms on Saturn.
- Expanded coverage in Chapter 12 of lakes and other features on the surface of Saturn's moon Titan.
- Additional material in Chapter 12 on Saturn's moon Enceladus.
- Update in Chapter 13 on the return of Neptune's Dark Spot.
- New coverage in Chapter 14 of the *Dawn* mission to Ceres.
- Extensive discussion in Chapter 14 of the *Rosetta* mission to comet 67 P/Churyumov–Gerasimenko.
- Completely revised presentation of Pluto in Chapter 14 based on data from the *New Horizons* mission.
- Updated and rewritten presentation in Chapter 15 of exoplanet searches and properties.
- New material in Chapter 15 on direct imaging as an exoplanet detection technique.
- Expanded discussion in Chapter 15 of exoplanet composition.
- Presentation in new *Discovery 15-1* of gravitational microlensing as an important exoplanet detection technique.
- Updated discussion in Chapter 15 of habitable zones and planetary systems in star clusters.

- Additional material in *Discovery 16-1* on *the Solar Dynamics Observatory*.
- Substantially improved discussion and imagery in Chapter 16 of the sunspot cycle.
- New coverage in Chapter 17 on the *GAIA* astrometric mission.
- Additional material in *Discovery 19-1* on brown dwarfs, clarifying the distinction between brown dwarfs and planets.
- Improved text and imagery in Chapter 19 on the observational evidence for various stages of star formation: ALMA imagery of protostellar collapse; *HST* observations of protoplanetary disks.
- Improved simulations of star cluster formation in Chapter 19.
- Expanded discussion in *Discovery 20-2* of mass loss from giant stars.
- Emphasis in Chapter 22 of the connection between hypernovae and black holes.
- Expanded treatment in *Discovery 22-1* of relativity and time dilation.
- Rewritten discussion of gravitational radiation in *Discovery 22-1*, including extensive coverage of the 2015 LIGO detections.
- Reconsideration in Chapter 22 of the existence of black holes, in the light of the new LIGO findings.
- New coverage in Chapter 23 of the "X" in the Milky Way bulge and its implication for our Galaxy's history.
- Expanded material in Chapter 23 on the "S stars" in the Galactic center and energetic outflows from the Galactic center into the halo.
- Updated discussion of extremophilic life in Chapter 28.
- Consistent distance scales in all figures, helping students gain an understanding of the vastness of the universe.
- Numerous replacement images for currency and clarity, and updated art throughout the text.

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.

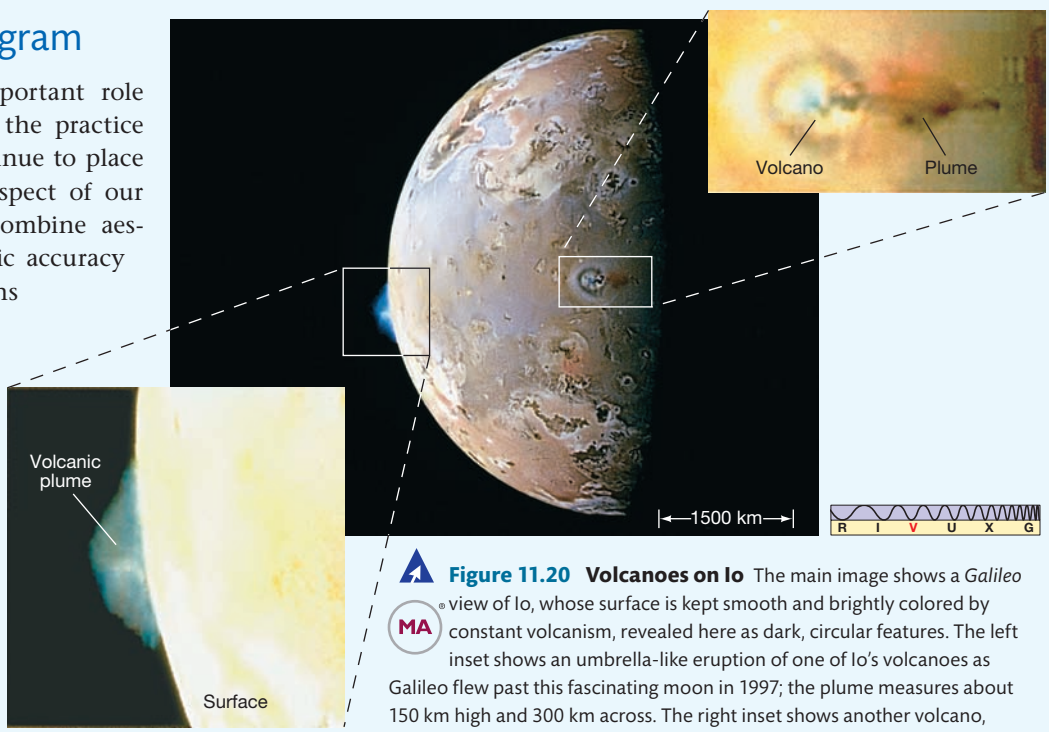


Figure 11.20 Volcanoes on Io The main image shows a *Galileo* view of Io, whose surface is kept smooth and brightly colored by constant volcanism, revealed here as dark, circular features. The left inset shows an umbrella-like eruption of one of Io's volcanoes as Galileo flew past this fascinating moon 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.

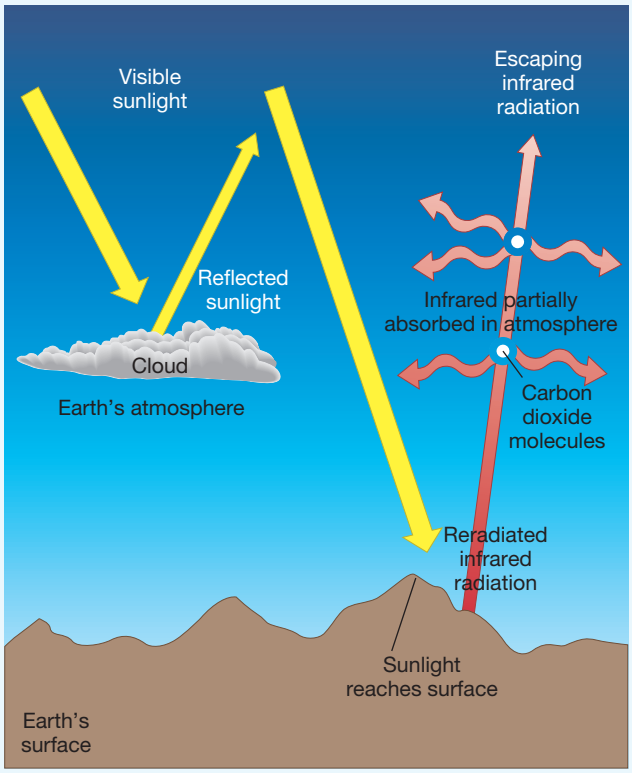


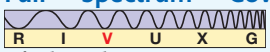
Figure 7.5 Greenhouse Effect Sunlight that is not reflected by clouds reaches Earth's surface, warming it up. Infrared radiation reradiated from the surface is partially absorbed by carbon dioxide (and also water vapor, not shown here) in the atmosphere, causing the overall surface temperature to rise.

- 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.

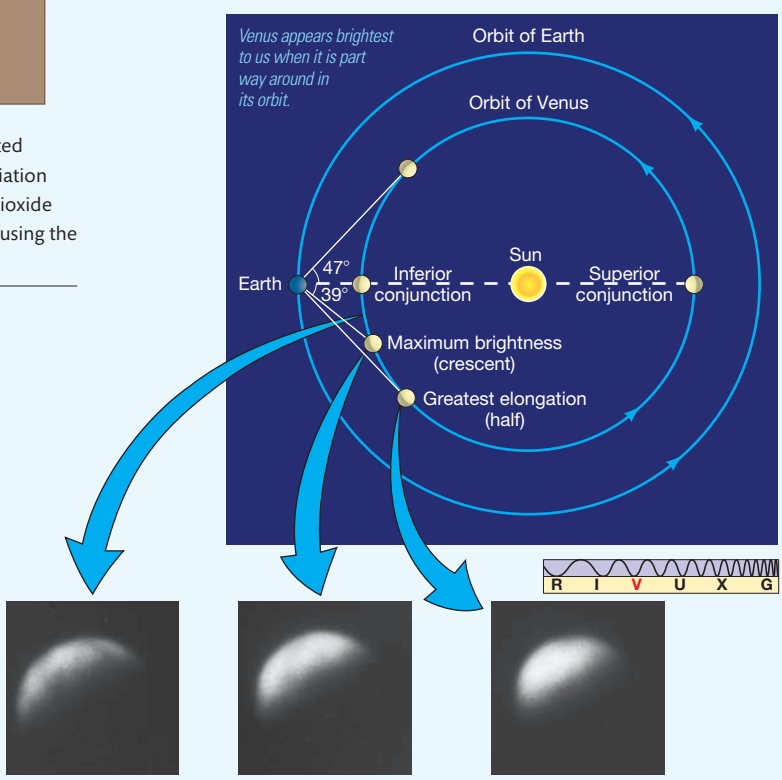
Figures and Photos Icons throughout the text direct students to dynamic, interactive versions of art and photos on MasteringAstronomy®. Using online applets, students can manipulate factors such as time, wavelength, scale, and perspective to increase their understanding of these figures.

NARRATED Figures 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 The ninth 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 

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 Regents/Lick Observatory)*

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 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 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 night sky. The naked eye can distinguish about 6000 of them, spread across 88 constellations. With binoculars or even a small telescope, millions more become visible. The total number of stars, even in our local cosmic neighborhood, is virtually beyond our ability to count. By analyzing the light from millions of distant stars, astronomers have learned a great deal about stellar properties—their masses and radii, their luminosities, even their ages and destinies. Stars tell us more about the fundamentals of astronomy than any other class of objects in the universe.

The Big Question 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

We will see in the next few chapters that, once you specify the mass and composition of a star, its structure and future evolution are largely set. But are the masses of newly formed stars pretty much the same everywhere, or do they vary systematically from place to place in our Galaxy and beyond? Astronomers generally assume the former, since that's the only practical way we can do astronomy, but is it true? At the cutting edge of research, astronomers are now testing this fundamental assumption against state-of-the-art observations.

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?

Data Points (NEW) Data Points sidebars in each chapter, based on data captured from thousands of students, alert students to the statistically most common mistakes made when working problems on related topics in MasteringAstronomy®.

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 (Extensively Revised)

- 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**. **BP (NEW)** questions relate to the Big Picture item at the start of the chapter.
- 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.
- Heavily revised in this edition, the end-of-chapter material now ends with collaborative and individual **Activities**

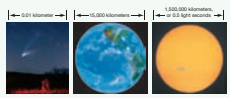
relevant to the material presented in the text. These range from basic naked-eye and telescopic observing projects to opinion polls, surveys, group discussions, and astronomical research on the Web.

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

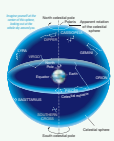
SUMMARY

1 The **universe (p. 7)** is the totality of all space, time, matter, and energy. **Astronomy (p. 7)** is the study of the universe. In order of increasing size, the basic constituents of the cosmos are planets, stars, galaxies, galaxy clusters, and the universe itself. They differ enormously in scale—a factor of a billion billion from planet Earth to the entire observable universe.



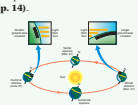
2 The **scientific method (p. 8)** is methodical approach employed by scientists to explore the universe around us in an objective manner. A **theory (p. 8)** is a framework of ideas and assumptions used to explain some set of observations and construct **theoretical models (p. 8)** that make predictions about the real world. These predictions in turn are amenable to further observational testing. In this way, the theory expands and science advances.

3 Early observers grouped the thousands of stars visible to the naked eye into patterns called **constellations (p. 10)**, which they imagined were attached to a vast **celestial sphere (p. 11)** centered on Earth. Constellations have no physical significance, but are still used to label regions of the sky. The points where Earth's axis of rotation intersects the celestial sphere are called the north and south **celestial poles (p. 12)**. The line where Earth's equatorial plane cuts the celestial sphere is the **celestial equator (p. 12)**.

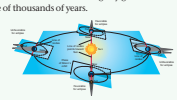


4 The nightly motion of the stars across the sky is the result of Earth's **rotation (p. 12)** on its axis. The time from one noon to the next is called a **solar day (p. 13)**. The time between successive risings of any given star is 1 **sidereal day (p. 13)**. Because of Earth's **revolution (p. 14)** around the Sun, we see different stars at night at different times of the year, and the Sun appears to move relative to the stars. The Sun's apparent yearly path around the celestial sphere (or the plane of Earth's orbit around the Sun) is called the **ecliptic (p. 14)**.

5 We experience **seasons (p. 16)** because Earth's rotation axis is inclined to the ecliptic plane. At the **summer solstice (p. 15)**, the Sun is highest in the sky and the length of the day is greatest. At the **winter solstice (p. 16)**, the Sun is lowest and the day is shortest. At the **vernal (p. 17)** and **autumnal equinoxes (p. 17)**, Earth's axis of rotation is perpendicular to the line joining Earth to the Sun, so day and night are of equal length. Because of **precession (p. 17)**, the slow "wobble" of Earth's axis due to the influence of the Moon, the orientation of Earth's axis changes slowly over time. As a result, the particular constellations visible during any given season change over the course of thousands of years.



6 The Moon emits no light of its own, but instead shines by reflected sunlight. As the Moon orbits Earth, we see lunar **phases (p. 18)** as the amount of the Moon's sunlit face visible to us varies. A **lunar eclipse (p. 20)** occurs when the Moon enters Earth's shadow.



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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. (Available for download from the Instructor Resource Center.)

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