ASTRONOMY

THE UNIVERSE AT A GLANCE

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THE UNIVERSE AT A GLANCE

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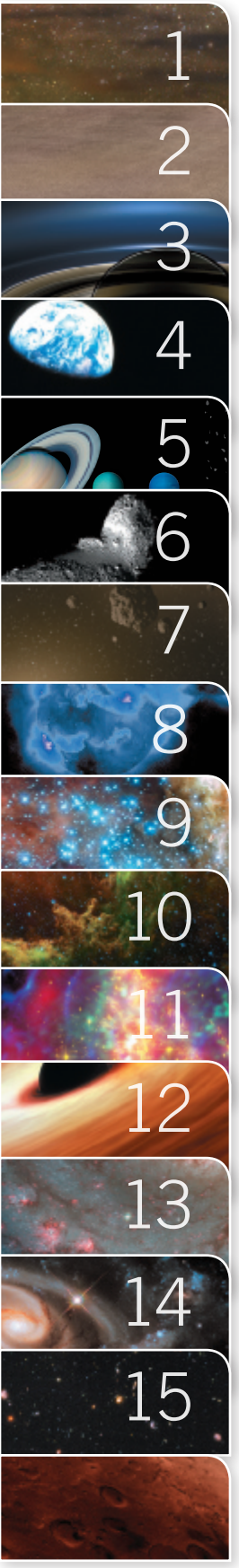
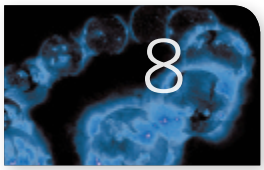
BRIEF CONTENTS

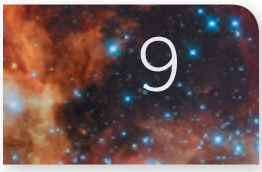


CONTENTS

7 FORMATION OF PLANETARY SYSTEMS



8 THE SUN



9 MEASURING THE STARS

10 STAR FORMATION AND EVOLUTION

11 STELLAR EXPLOSIONS

12 BLACK HOLES

13 THE MILKY WAY GALAXY

14 GALAXIES

15 COSMOLOGY AND THE UNIVERSE

APPENDICES

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.

PREFACE

Astronomy is enjoying a golden age of exploration and discovery. Fueled by new technologies and novel theoretical insights, the study of the cosmos has never been more exciting than it is right now. We are pleased to have the opportunity to present in this book a carefully chosen selection of the known facts, evolving ideas, and frontier discoveries in astronomy today.

In *Astronomy: The Universe at a Glance,* we have tried to combine a narrative that is both accurate and approachable with a visually compelling presentation that fosters learning. To that end, we have created a short (275-page) book in which we have taken the novel step of subdividing the material so that each new discussion topic fits precisely into a single two-page spread. This modular approach integrates art and text into a magazine-style format that is visually stunning, succinct, and scientifically correct. Although we have had to pare back or omit some topics, we think the final result captures the essence of 21st-century astronomy in a beautiful—and highly teachable—way. We have taken particular care to show how science is done, how the universe works, and how astronomers know what they know. In the process, we highlight both the scientific principles underlying scientific inquiry and the process of discovery.

Our organization follows the popular and effective "Earth out" progression. We have found that most students, especially those with little scientific background, are much more comfortable studying the relatively familiar solar system before tackling stars and galaxies. With Earth and the Moon as our initial planetary models, we move through the solar system, discussing both its content and its formation. This line leads directly to a study of the Sun. With the Sun as our model star, we broaden the discussion to include stars in general—their properties, their evolutionary histories, their varied fates. The journey then leads us to study the Milky Way Galaxy, which in turn serves as an introduction to other galaxies. Finally, we reach cosmology and the large-scale structure and dynamics of the universe as a whole. Throughout, we strive to emphasize the dynamic nature of the cosmos—virtually every major topic, from planets to quasars, includes a discussion of how those objects formed and how they evolve.

We place much of the needed physics in the early chapters—an approach derived from years of experience teaching thousands of students. Additional physical principles are developed as needed later in the book, both in the text and in the *Snapshot* boxes (described on p. xv). We have made the treatment of physics, as well as the more quantitative discussions, as modular as possible so that these topics can be omitted or assigned separately, as desired.

This book 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-semester, nontechnical astronomy course. We present a broad view of astronomy, straightforwardly and without complex mathematics. We rely on qualitative reasoning, as well as analogies to objects and phenomena familiar to students, to explain the complexities of the subject without oversimplification. We have tried to both communicate the excitement we feel about astronomy and awaken students to the magnificent universe around us.

In teaching astronomy to nonscientists, as in writing this book, we are not seeking to convert students to careers in astronomy or even science in general. Instead, we strive to reach the wider audience of students who are majoring in many other worthwhile fields. We want to encourage those students to become scientifically literate members of modern society, to appreciate new developments in the world of science, and to understand what scientists do for a living to enable them to make informed judgments regarding national initiatives in science and to vote intelligently in our democratic, increasingly technological world.

Acknowledgments

The publishing team at Pearson has assisted us at every step along the way in creating this innovative text. We owe huge debts of gratitude to Development Editor Barbara Price, who with great enthusiasm and passion almost single-handedly brought to life the design and layout of this book, and to Project Manager Tema Goodwin, who managed with unflappable aplomb and unerring judgment the many variables that go into a multifaceted publication such as this. Production Managers Angela Urquhart and Andrea Archer of Thistle Hill Publishing Services, Designer Tamara Newnam, LuAnn Murphy of Rolin Graphics, and Photo Researcher Cordes McMahan Hoffman of QBS Learning have excelled in tying together the threads of this complex project, made all the more so by the necessity of combining text, art, photos, and electronic media into a coherent whole. Special thanks are also in order to Design Director Mark Ong for making this first edition so spectacular and to Acquisitions Editor Nancy Whilton for supporting this grand experiment.

We would also like to express our gratitude to Kate Brayton and Ziki Dekel for creating and maintaining the media resources in the MasteringAstronomy® Study Area.

Throughout the development and production of this book, we have relied on the critical analysis of many colleagues and reviewers. Their suggestions have ranged from the macroscopic issue of the book's overall organization to the minutiae of the technical accuracy of each and every sentence. To all, we offer our sincerest thanks.

Eric Chaisson

Steve McMillan

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LEARNING AT A GLANCE

A Modular Approach to Teaching Astronomy

Visually Driven Modular Learning

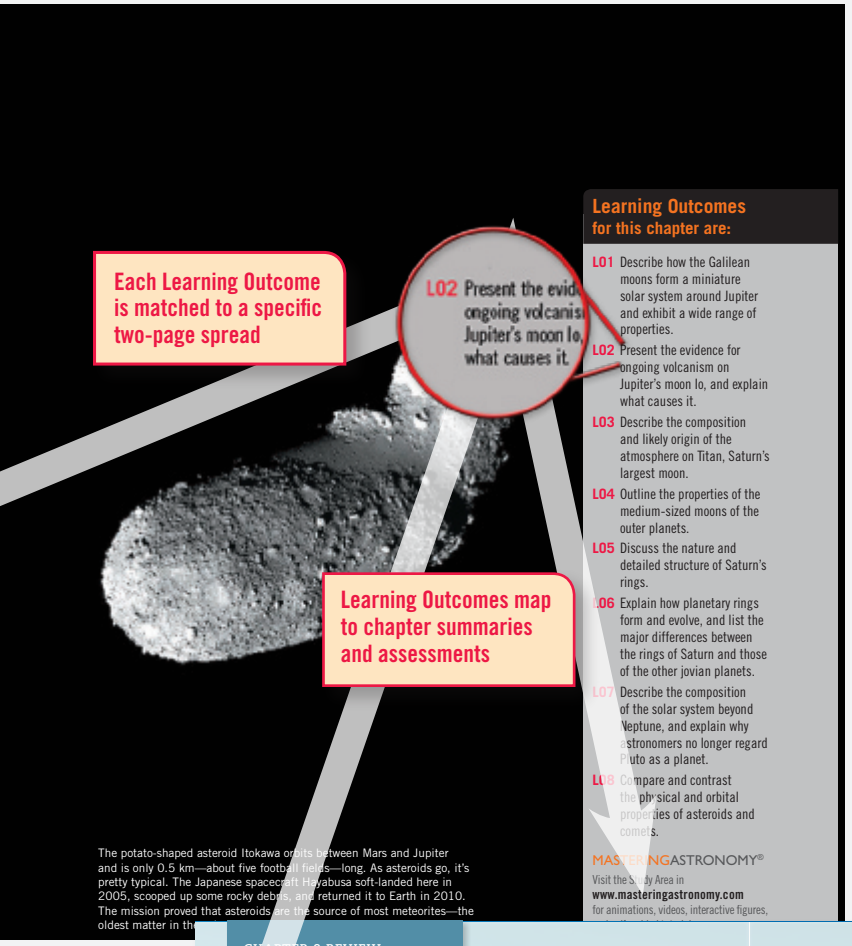
Th s new book by trusted authors Eric Chaisson and Steve McMillan reimagines their classic texts in a modularly organized, visual approach to learning. Here, the essential ideas, concepts, and discoveries of contemporary astronomy are presented in 15 chapters, each chapter composed of richly illustrated, two-page spreads designed to visually engage and instruct students.

Learning Outcomes: Navigation Tools for Student Success

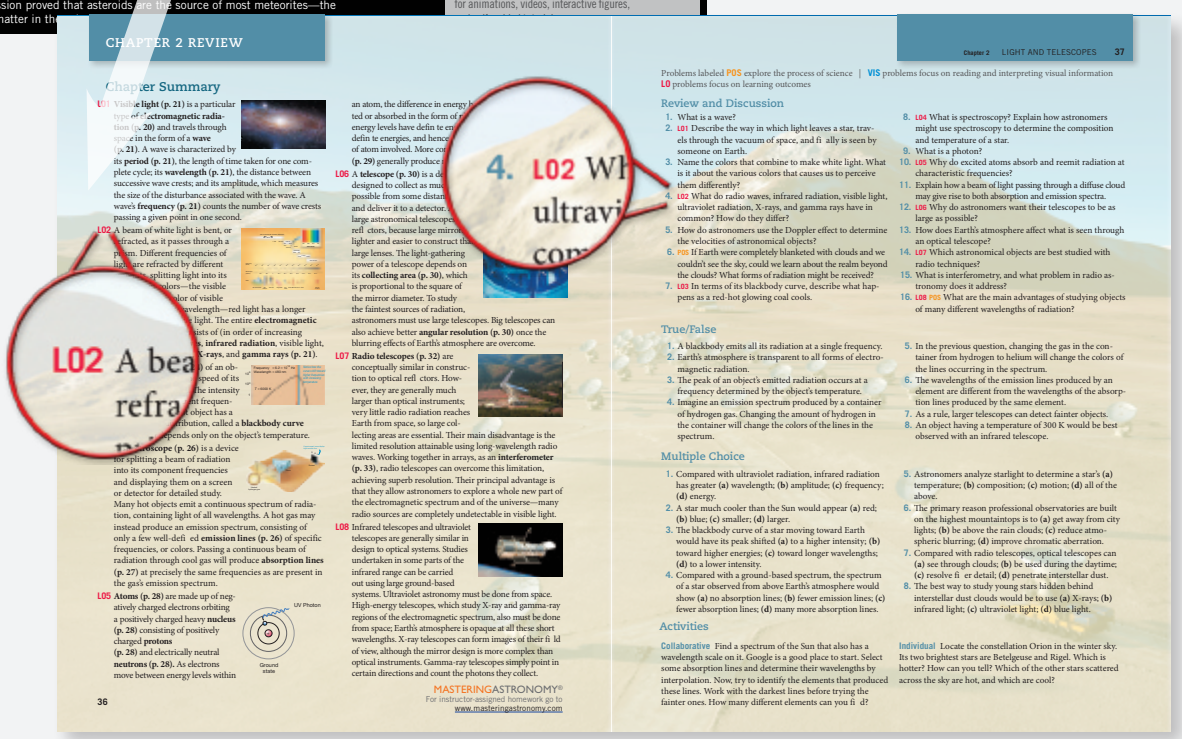
Studies indicate that beginning students have trouble prioritizing textual material. For this reason, six to eight well-defi ed, numbered Learning Outcomes are provided at the start of each chapter. Since each Learning Outcome is keyed to a specific, numbered section in the chapter, students can see at a glance the roadmap to discovery.

Th s unique modular structure helps students organize their reading and test their mastery of key concepts. The Learning Outcomes are also keyed to items in the Chapter Review Summary and to assessments at the end of each chapter. Th s highlighting of the most important aspects of the chapter helps students prioritize and review information.

The book's modular structure is also helpful to instructors. Because each Learning Outcome is keyed to a unique two-page spread, instructors can easily select topics, or rearrange the order of topics, with a quick review of the Learning Outcomes listed at the beginning of each chapter. In this way, instructors can adapt this book for courses taught over a semester, a quarter, or a summer.



The potato-shaped asteroid Itokawa orbits between Mars and Jupiter and is only 0.5 km—about five football fields—long. As asteroids go, it's pretty typical. The Japanese spacecraft Hayabusa soft-landed here in 2005, scooped up some rocky debris, and returned it to Earth in 2010. The mission proved that asteroids are the source of most meteorites—the oldest matter in the



End-of-Chapter Assessment

- Each chapter incorporates Review and Discussion Questions, which may be assigned or used for in-class review. As with the True/False and Multiple Choice Questions, the material needed to answer Review Questions can be found within the chapter. Questions identifi d with a **POS** icon encourage students to explore the Process of Science, and those flagged with a **VIS** icon are tied directly to a specific figu e or diagram in the text.
- Each Learning Outcome is matched to an assessment at the end of each chapter and is identifi d by number and the icon **LO**.
- The end-of-chapter material ends with collaborative and individual Activities relevant to the material presented in the text. These range from basic naked-eye and telescopic observation projects to surveys, group discussions, and astronomical research on the Web.

Chapter Review Summaries

The Chapter Review Summary, a primary review tool, is 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 figu es and page references to the text discussion.

A Visually Driven Textbook for Today's Students

Today's students are highly visual, effici t learners. Th s textbook, with its magnifice t art program and attractive, magazine-style design, appeals to students who want information that is concise and visually engaging. With that as their goal, the authors have also constructed a beautifully written narrative, distilling the essentials of each topic in a text that is both authoritative and accessible to non-science majors.

The Latest Content

From climate change on Earth, to on-going space missions inside the solar system, to the search for life on distant planets, astronomy is often in the headlines. In the process of writing this book, the authors relied on the most recent astronomical discoveries and data to bring students the latest information about the universe and our place in it.

The Illustration Program

Visualization plays an important role in both the teaching and the practice of astronomy. In this new, visually driven presentation of the essential topics of astronomy, each illustration has been carefully crafted to enhance student learning. Each piece of art is tied tightly to the nearby discussion of important scientific facts and ideas. We've also incorporated the research-proven technique of strategically placing annotations within key pieces of art, fostering students' ability to interpret complex figu es, focus on the most relevant information, and integrate written and visual knowledge.

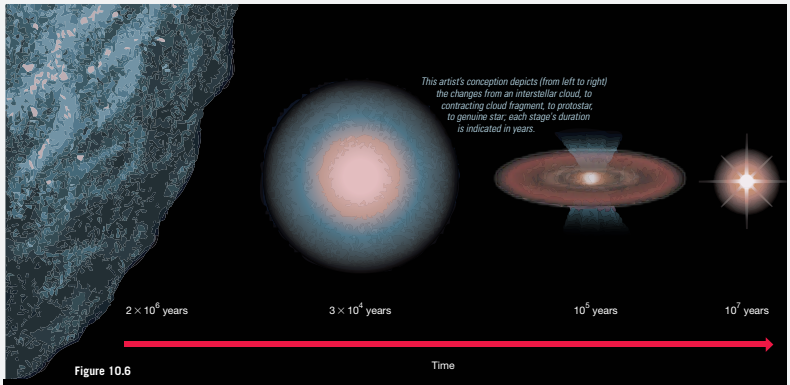


Figure 10.6

Protostars

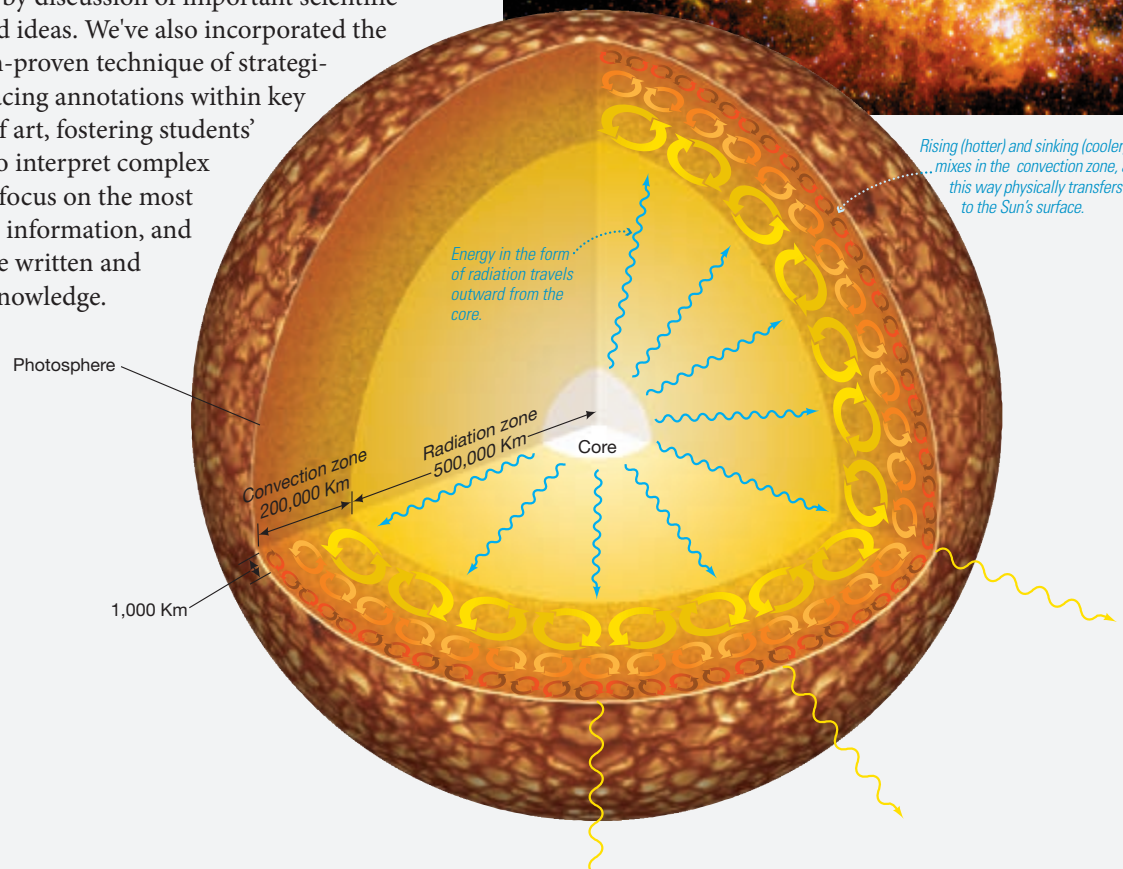
Now, for the fi st time, one or more of the fragments begin to resemble a star. A dense, opaque region at the center of each fragment is called a **protostar**—an embryonic object perched at the dawn of star birth; yet its mass continues increasing as more and more matter rains down on it from the outside. Its radius also continues shrinking because its internal heat is not yet enough for its gas pressure to compete with the relentless pull of gravity. Figure 10.6 artistically depicts the emergence of one such protostar from its parent interstellar cloud.

About 100,000 years after the fragment fi st formed, its central temperature has soared to a seething 1,000,000 K. Electrons and protons ripped from its atoms whiz around at great speeds, but even this temperature is short of the 10^7 K needed to ignite the proton–proton nuclear reactions that fuse hydrogen into helium. Still much larger than our Sun, this gassy heap is now about the size of Mercury's orbit.

A protostar is not well balanced—its contraction slows but does not stop completely. All the while, it often exhibits violent surface activity, resulting in protostellar winds a little like our Sun's solar wind today, but much stronger and denser. The interaction between the energetic winds and the nebular disk out of which the protostar (and possibly planets) has formed often results in a bipolar fl w—expelling two "jets" of matter perpendicular to the disk. Th s is illustrated toward the right of Figure 10.6.

Some 10 million years after it fi st began forming, the protostar fi ally becomes a true star. Protons begin fusing into helium nuclei in the core, and a star is born. Over the next 30 million years, it will contract a little more, adjusting its properties slightly and bringing its core to 15,000,000 K and its surface to 6000 K, much as for the Sun today.

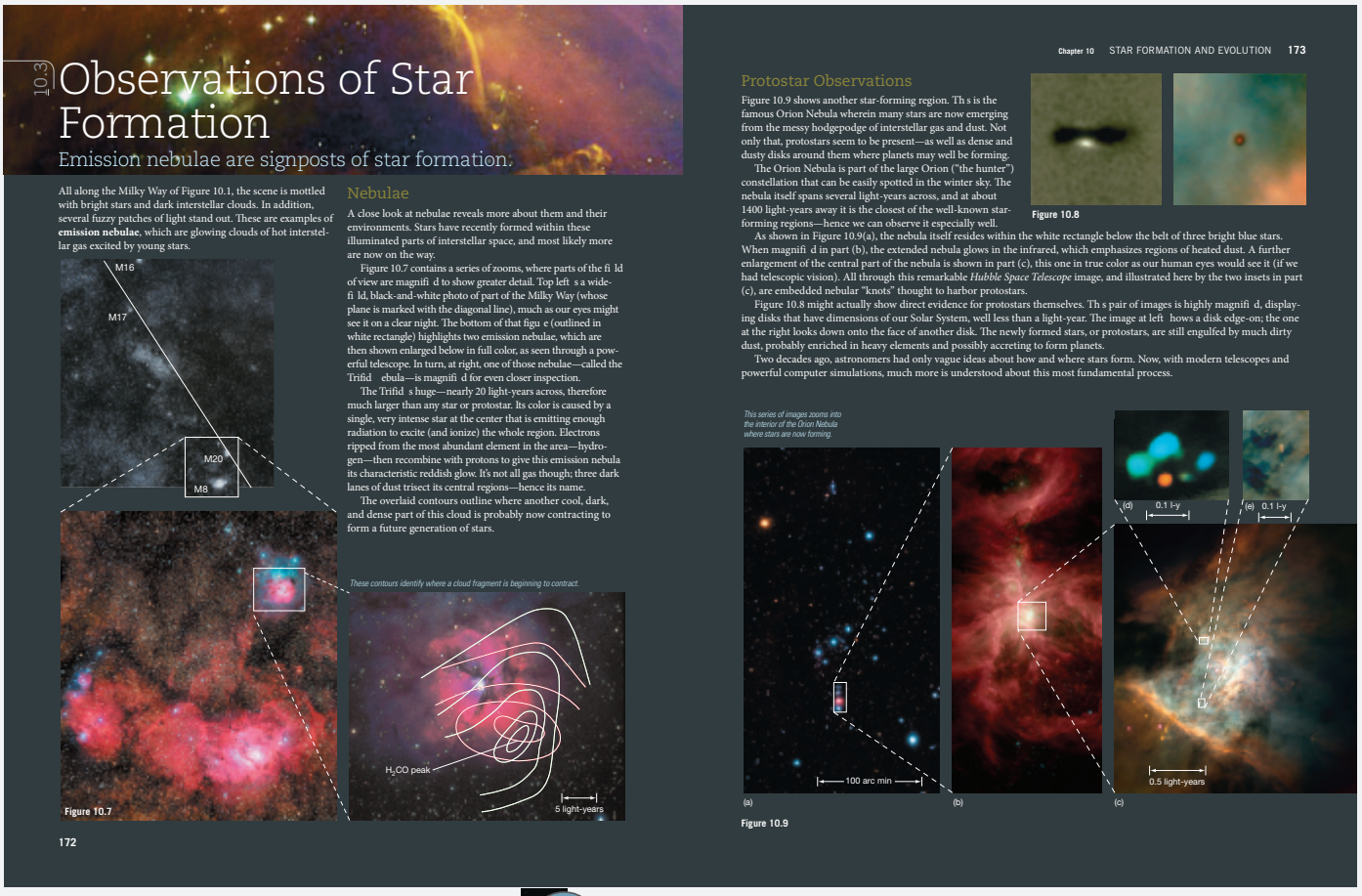
The journey from interstellar cloud to genuine star occurs over the course of 40–50 million years. Although this is a long time by human standards, it is still less than 1 percent of the Sun's lifetime as a star. Once such an object begins fusing hydrogen and establishes a "gravity-in/pressure-out" equilibrium, it burns steadily for a very long time. It will remain almost unchanged for the next 10 billion years.



Compound Art

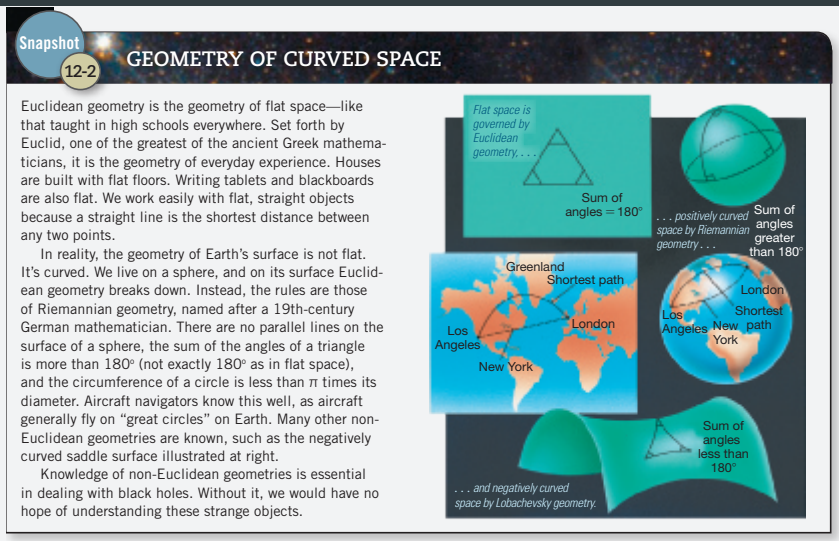
It is rare that a single image, be it a photograph or an artist's conception, can capture all aspects of a complex subject. Wherever possible, multiple-part figu es are used in an attempt to convey the greatest amount of information in the most vivid way:

- Breakouts—often multiple ones—are used to zoom in from wide-fi ld shots to close-ups so that detailed images can be understood in their larger context.
- Stepped art and timelines summarize processes and events.
- Interpretive line drawings are often superimposed on or juxtaposed with real astronomical photographs, helping students to really "see" what the photographs reveal.



Snapshot Boxes

Consistent with the modular construction of this book, the Snapshot Boxes encapsulate topics that are related to, but are not part of, the main narrative in each section. These asides might expand upon a particular discovery, showcase the process of science, describe an event in the history of science, or provide supplementary material on topics of current interest.



H–R Diagrams

All of the book's H–R diagrams are drawn in a uniform format, using real data.

Instructor Resources

MasteringAstronomy®

www.masteringastronomy.com

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, every activity and problem has been refined. 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 level and duration. The tutorials coach 90 percent of students to the correct answer with specific wrong-answer feedback. Powerful post-diagnostics enable instructors to assess the progress of their class as a whole and to quickly identify an individual student's areas of difficulty. Tutorials built around text content are available in MasteringAstronomy. A media-rich self-study area is included that students can use whether or not the instructor assigns homework.

Test Bank An extensive file of approximately 1500 test questions, newly compiled and updated for *At a Glance*. The questions are organized and referenced by chapter section and by question type. This Test Bank is available in both Microsoft® Word and TestGen® formats.
ISBN 0-321-99772-7

Instructor Resource Area in Mastering Astronomy

This instructor resource area resides in MasteringAstronomy and includes jpegs of all the figures from the text and the Test Bank in both Word and TestGen® formats. TestGen is 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.

Instructor Resource Center The Pearson Instructor Resource Center contains everything found on the Instructor Resource Area in MasteringAstronomy, with the exception of the text figures in jpeg format, which are too large to download.

Learner-Centered Astronomy Teaching: Strategies for ASTRO 101

Timothy F. Slater, *University of Wyoming*
Jeffrey P. Adams, *Millersville University*

Strategies for ASTRO 101 is a guide for instructors of the introductory astronomy course for nonscience majors. Written by two leaders in astronomy education research, this book details various techniques instructors can use to increase students' understanding and retention of astronomy topics, with an emphasis on making the lecture a forum for active student participation. Drawing from the large body of recent research to discover how students learn, this guide describes the application of multiple classroom-tested techniques to the task of teaching astronomy to predominantly nonscience students.
ISBN 0-13-046630-1

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

MasteringAstronomy®

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This homework, tutorial, and assessment system is uniquely able to tutor each student individually by providing students with instantaneous feedback specific to their wrong answers, simpler subproblems upon request when they get stuck, and partial credit for their method(s) used. Students also have access to a self-study area that contains self-guided tutorials, narrated and interactive figures, animations, videos, and more.

Pearson eText is available through MasteringAstronomy, either automatically when MasteringAstronomy is packaged with new books, or available as a purchased upgrade online. Allowing the students to access the text wherever they have access to the Internet, Pearson eText comprises the full text, including figures that can be enlarged for better viewing. Within Pearson eText students are also able to pop up definitions and terms to help with vocabulary and the reading of the material. Students also can take notes in Pearson eText using the annotation feature.

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Available as part of bundle with new books; free if requested. (Also available on CD-ROM. ISBN 0-321-89843-5)

Sky and Telescope Based on the most popular amateur astronomy magazine, this special student supplement contains nine articles by Evan Skillman, each with a general overview and four question sets focused on the issues professors most want to address in this course: General Review, Process of Science, Scale of the Universe, and Our Place in the Universe.
ISBN 0-321-70620-X

Lecture-Tutorials for Introductory Astronomy, 3rd Edition
Edward E. Prather, *University of Arizona*
Timothy F. Slater, *University of Wyoming*
Jeffrey P. Adams, *Millersville University*
Gina Brissenden, *University of Arizona*

Funded by the National Science Foundation, *Lecture-Tutorials for Introductory Astronomy* is designed to help make large-lecture-format courses more interactive. The third edition features six new tutorials on the Greenhouse Effect; Dark Matter; Making Sense of the Universe and Expansion; Hubble's Law; Expansion, Lookback Times, and Distances; and The Big Bang. Each of the 44 Lecture-Tutorials is presented in a classroom-ready format that asks students to work in groups of two to three for between 10 and 15 minutes and requires no equipment. These lecture-tutorials challenge students with a series of carefully designed questions that spark classroom discussion and engage students in critical reasoning.
ISBN 0-321-82046-0

Observation Exercises in Astronomy This workbook by Lauren Jones contains a series of astronomy exercises that integrate technology from planetarium software such as Stellarium, Starry Night College, WorldWide Telescope, and SkyGazer. Using these online products adds an interactive dimension to student learning.
ISBN: 0-321-63812-3

ASTRONOMY

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