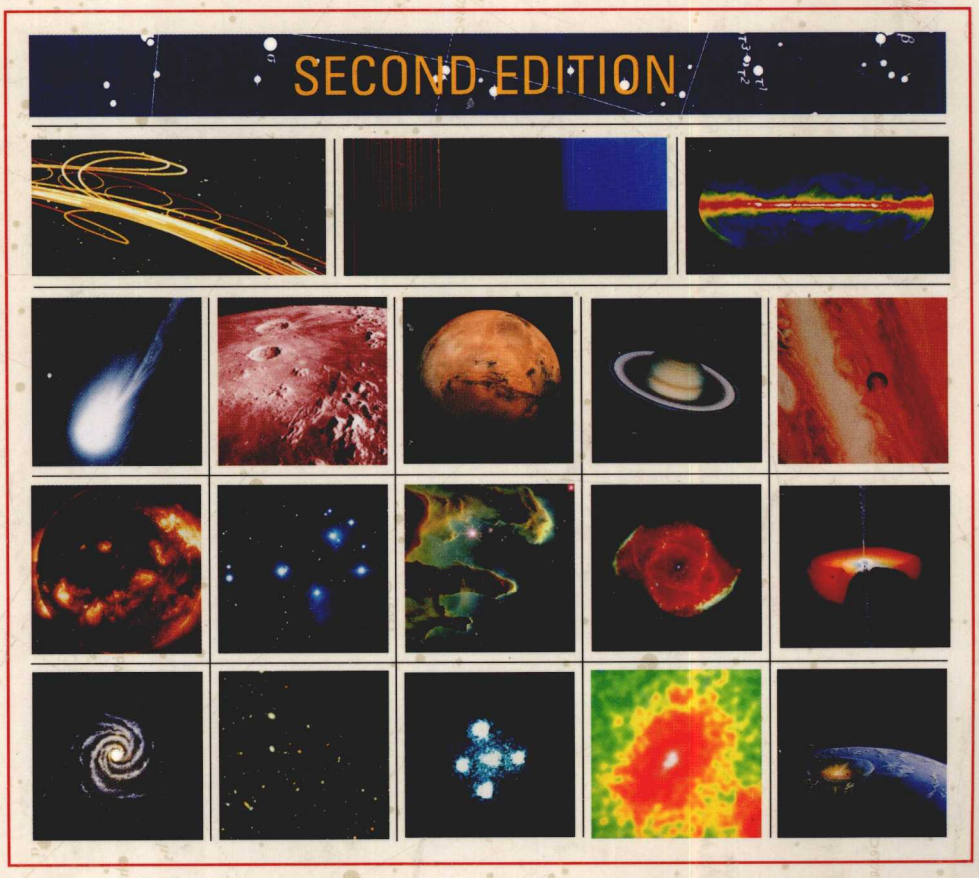
FREE CD-ROM INSIDE

Astronomy

A BEGINNER'S GUIDE TO THE UNIVERSE



CHAISSON McMILLAN

Astronomy

A Beginner's Guide to the Universe

Second Edition

Eric Chaisson
Tufts University

Steve McMillan
Drexel University

Prentice Hall
Upper Saddle River, New Jersey 07458

Chaisson, Eric.
Astronomy : a beginner's guide to the universe / Eric Chaisson, Steve McMillan. — 2nd ed.
p. cm.
Includes index.
ISBN 0-13-733916-X
1. Astronomy. I. McMillan, S. (Stephen). II. Title
QB43.2.C43 1998
520—dc21
97-38104
CIP

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Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-733916-X

Prentice Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
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Simon & Schuster Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

Preface

Astronomy continues to enjoy 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. 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: A Beginner's Guide to the Universe 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 primarily for use in a one-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 impart the enthusiasm that we feel about astronomy, and to awaken students to the marvelous universe around us.

We are very gratified that the first edition of this text has been received so well by many in the astronomy education community. In using that earlier text, many of you—teachers and students alike—have sent us your 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 your comments, as well as numerous innovations and popular new features from our companion hardback text *Astronomy Today, Media Edition*, have been incorporated into this new edition.

Organization and Approach

As in the first edition, 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. Thus, Earth is the first object we discuss in detail. With Earth and Moon as our initial planetary models, we move through the solar system. Integral to our coverage of the solar system is a discussion of its formation. This line of investigation leads directly into a study of our Sun. With the Sun as our model star, we broaden the scope of our discussion to include stars in general—their properties, their evolutionary histories, and their varied fates. This journey naturally leads us to coverage of the Milky Way Galaxy, which in turn serves as an introduction to our treatment of other galaxies, both normal and active. Finally, we reach the subject of 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 (we think) they evolve.

The second edition of *Astronomy: A Beginner's Guide to the Universe* contains two fewer chapters, and is almost 20 percent shorter (in terms of total text), than its predecessor. All chapters have been updated in content and several have seen significant internal reorganization. Specifically, the first two chapters have been restructured to create a brief Prologue, which presents some basic introductory material—the essentials of the celestial sphere and angular measure, and some elementary geometry—and a new Chapter 1, which discusses the motions of the Sun, the Moon, and the planets in a single chapter, resulting in a more concise and effective presentation. The solar system section has been reduced from 6 chapters to 5 by merging the overview of our planetary system with the discussion of its formation. Instructors presenting this material in a 1-quarter course, who wish to (or have time to) cover only the essentials of the solar system before proceeding on to the study of stars and the rest of the universe, may want to teach only Chapter 4, and then move directly to Chapter 9 (the Sun). Finally, our discussion of stellar evolution, which was spread over two chapters in the first edition, has been reworked into a more succinct single-chapter format.

We continue to 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, both in the text narrative and in the boxed *More Precisely* features (described below). We feel strongly that this is the most economical and efficient means of presentation. However, we acknowledge that not all instructors feel the same way. Accordingly, we have made the treatment of physics,

as well as the more quantitative discussions, as modular as possible, so that these topics can be deferred to later stages of an astronomy course if desired.

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 tightly tied to nearby discussion of important scientific facts and ideas.

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 closeups, so that detailed images can be understood in their larger context.

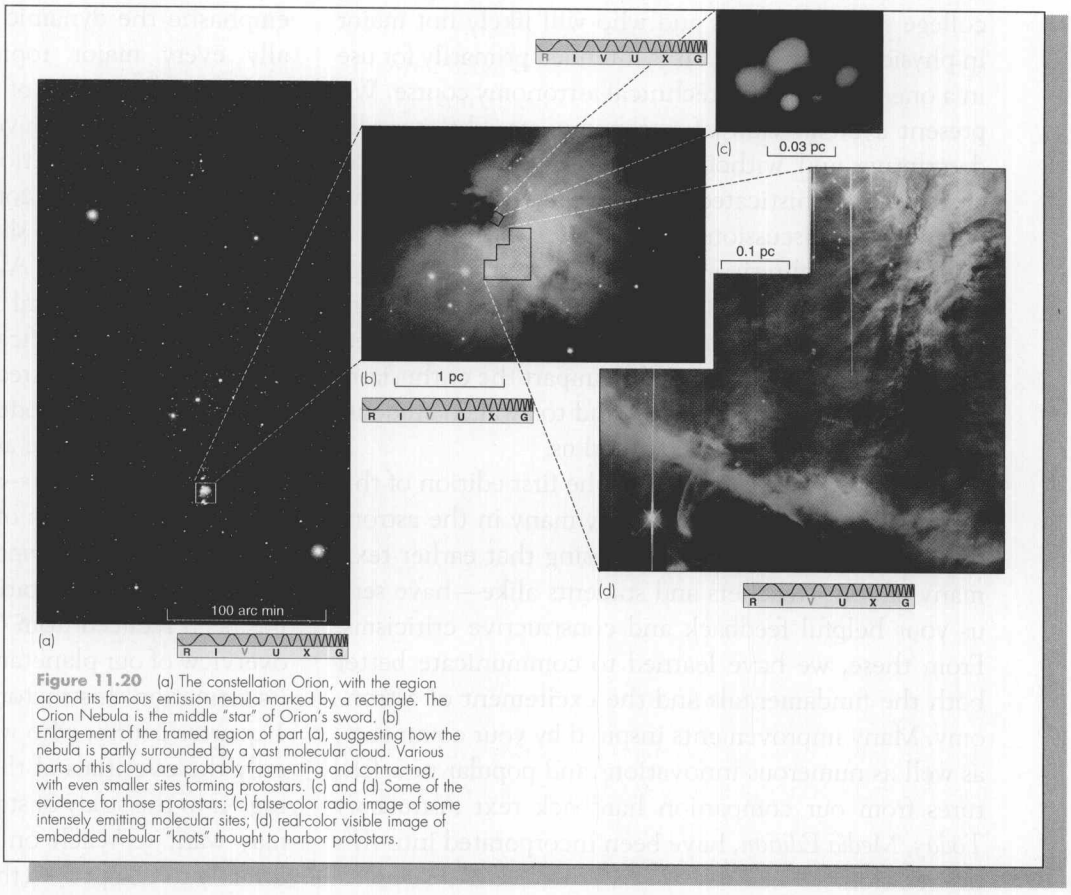
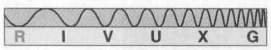


Figure 11.20 (a) The constellation Orion, with the region around its famous emission nebula marked by a rectangle. The Orion Nebula is the middle "star" of Orion's sword. (b) Enlargement of the framed region of part (a), suggesting how the nebula is partly surrounded by a vast molecular cloud. Various parts of this cloud are probably fragmenting and contracting, with even smaller sites forming protostars. (c) and (d) Some of the evidence for those protostars: (c) false-color radio image of some intensely emitting molecular sites; (d) real-color visible image of embedded nebular "knots" thought to harbor protostars.

▲

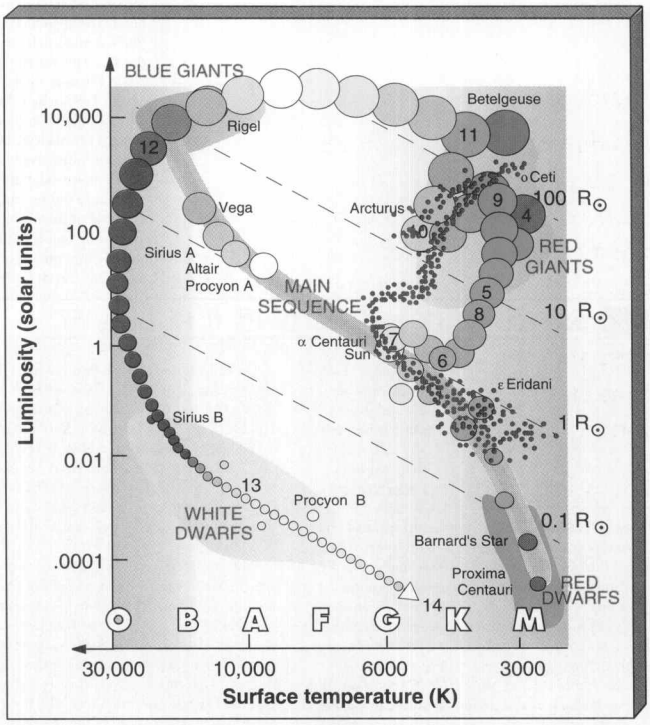
Explanatory Captions. Students often review a chapter by "looking at the pictures." For this reason, the captions in this book are often a bit longer and more detailed than those in other texts.

Full-Spectrum Coverage and Spectrum Icons. 

Increasingly, astronomers are exploiting 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 provided with an icon that identifies the wavelength of electromagnetic radiation used to capture the image.

H–R Diagrams and Acetate Overlays. ▶

All of the book's H-R diagrams have been redrawn in a uniform format, using real data. In addition, a unique set of transparent acetate overlays dramatically demonstrate to students how the H-R diagram helps us to organize our information about the stars and track their evolutionary histories.



Pedagogy

As with many other parts of our text, adopting 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 Goals. Studies indicate that beginning students often have trouble prioritizing textual material. For this reason, a few (typically 5 or 6) well-defined Learning Goals are provided at the start of each chapter. These help students to structure their reading of the chapter and then test their mastery of key facts and concepts. The Goals are numbered, and cross-referenced to key sections in the body of each chapter. This in-text highlighting of the most important aspects of the chapter also helps students to review. The Goals have also been reorganized and rephrased to make them more objectively testable, affording students better means of gauging their own progress.

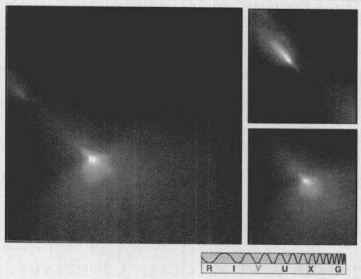
Key Terms. Like all subjects, astronomy has its own specialized vocabulary. To aid student learning, the most important astronomical terms are boldfaced at their first appearance in the text. Each boldfaced Key Term is also incorporated in the appropriate chapter summary, together with the page number where it was defined. In addition, a full alphabetical glossary, defining each Key Term and locating its first use in the text, appears at the end of the book.

Interludes. These explore a variety of interesting supplementary topics. ▶

4-1 INTERLUDE

COMETS HYAKUTAKE AND HALE-BOPP

One of the most spectacular comets in recent years was Comet Hyakutake 1996. Named after a Japanese amateur astronomer who noticed it as "something odd and out of place" while scanning the skies with a pair of binoculars, Hyakutake grew from a small smudge while still far from the Sun into a splendid display comprising a huge coma nearly the apparent size of the Moon and a tail that eventually stretched a third of the way across the sky. The accompanying figure shows a *Hubble Space Telescope* image of Hyakutake taken in March 1996, when the comet passed closest to Earth—only 15 million km (0.1 A.U.) away. The comet's icy nucleus, the brightest point in the image, is unresolved here (the field of view is about 1000 km across), but radar pulses sent toward Hyakutake did return an echo, indicating that the diameter of the nucleus was 1 to 3 km. In the image, the Sun is out of the frame at bottom right, and the innermost part of the comet's tail is at upper left (on the side opposite the Sun, as explained in the text).



Other images showed sporadic jets pointing mostly sunward. These jets are gases gushing from the side of the comet closest to the Sun before wrapping around to become part of the graceful tail. The comet was examined at every conceivable wavelength, but perhaps the most surprising result was the intense X rays emitted from its head. Even the sunward side of the comet was far too cool to emit X rays, which are usually associated with very-high-temperature phenomena. Astronomers speculate that the X rays were produced by shock waves created as the solar wind hit the leading edge of the comet's coma.

16-1 MORE PRECISELY

RELATIVISTIC REDSHIFTS AND LOOK-BACK TIME

When discussing very distant objects, astronomers usually talk about their redshifts rather than their distances. Indeed, it is very common for researchers to speak of an event occurring "at" a certain redshift—meaning that the light received today from that event is redshifted by the specified amount. Of course, because of Hubble's law, redshift and distance are equivalent to one another. However, redshift is the preferred quantity because it is a directly observable property of an object, whereas distance is derived from redshift using Hubble's constant, whose value is not accurately known. (In the next chapter, we will see another reason astronomers favor the use of redshift in studies of the cosmos.)

The redshift of a beam of light is, by definition, the *fractional* increase in its wavelength resulting from the recessional motion of the source. ∞ (*More Precisely 2-2*) Thus, a redshift of 1 corresponds to a *doubling* of the wavelength. Using the formula for the Doppler shift presented in *More Precisely 2-2*, the redshift of radiation received from a source moving away from us with speed v is given

Let's illustrate this with two examples, rounding the speed of light, c, to 300,000 km/s. A galaxy at a distance of 100 Mpc has a recessional speed (by Hubble's law) of 75 km/s/Mpc × 100 Mpc = 7,500 km/s. Its redshift therefore is 7,500 km/s ÷ 300,000 km/s = 0.025. Conversely, an object that has a redshift of 0.05 has a recessional velocity of 0.05 × 300,000 km/s = 15,000 km/s and hence a distance of 15,000 km/s ÷ 75 km/s/Mpc = 200 Mpc.

Unfortunately, while it is quite correct for low speeds, the foregoing equation does not take into account the effects of relativity. As we saw in Chapter 13, the rules of everyday physics have to be modified when speeds begin to approach the speed of light, and the formula for the Doppler shift is no exception. ∞ (*More Precisely 13-1*). In particular, while our formula is valid for speeds much less than the speed of light, when $v = c$, the redshift is not 1, as the equation suggests, but is in fact *infinite*. In other words, radiation received from an object moving away from us at nearly the speed of light would be redshifted to almost infinite wavelength.

Thus do not be alarmed to find that many quasars have redshifts greater than 1. This does not mean that they are receding at speeds faster than that of light! It simply means that their recessional

◀ **More Precisely** boxes. New to the second edition these 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.

∞ **Cross-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 specifically astronomical material and the physical principles set forth early in the text is crucial. It is important that students, when they encounter, say, Hubble's Law in Chapter 16, recall what they learned about spectral lines and the Doppler shift in Chapter 2. Similarly, the discussions of the masses of binary star components (Chapter 10) and of galactic rotation (Chapter 14) both depend on the discussion of Kepler's and Newton's laws in ▶

Mercury

5 Mercury's magnetic field, discovered by *Mariner 10*, is about 100 times weaker than Earth's field. The discovery that Mercury has a magnetic field came as a surprise to planetary scientists, who, having detected no magnetic field in the Moon, expected Mercury to have none either. In Chapter 5, we saw how a combination of liquid metal core *and* rapid rotation is necessary for the production of a planetary magnetic field. ∞ (Sec. 5.6) Mercury certainly does not rotate rapidly, and it may also lack a liquid

Chapter 1. To remind students of these links, so that the reader can recall the principles on which later discussions rest, and if necessary, review them, we have inserted "cross-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 to students that the topic under discussion is related in some significant way to ideas developed earlier, and direct them to material that they might need to review before proceeding.

Chapter Summaries. The Chapter Summaries, a primary review tool for the student, have been expanded and improved for the second edition. All Key Terms introduced in each chapter are listed again, in context and in boldface, in these Summaries, along with page references to the text discussion.

Questions, Problems, and Projects. Many elements of the end-of-chapter material have seen substantial reorganization:

- Each chapter now incorporates some 20–30 Self-Test Questions, roughly equally divided between "true/false" and "fill-in-the-blank" formats, designed to allow students to assess their understanding of the chapter material. Answers to all these questions appear at the end of the book.
- Each chapter has about 15 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.
- Several Problems in each chapter entail some numerical calculation; their answers are not contained verbatim within the chapter, but the information necessary to solve them has been presented in the text.
- Each chapter ends with a few Projects meant to get the student out of the classroom and looking at the sky, although some entail research in libraries or other extracurricular activities.

CD-ROM. Following the enthusiastic response to the *Astronomy Today, 2E* 1997 *Media Edition*, this second edition of the *Beginner's Guide* comes complete with a fully integrated CD-ROM. *Astronomy: A Beginner's Guide 2/e* includes a free CD in the back of the text which includes a fully hyperlinked electronic version of the text to help the reader quickly find related information and assist in review, integrated animations and videos to bring text figures to life, links to our companion website, which is organized by text chapter and updated monthly, and a separate executable multimedia study guide program.

A special feature of the CD for this text is a series of "Extensions"—1–2 page sections that expand on discussions in the printed text. In this way, we present essential material in the print-based text, but still provide additional material for those students who want to delve deeper into some topics, without making the text itself too long, detailed, or overwhelming. We are excited about the innovative use of media to complement the text and look forward to your response to it.

The CD-ROM material can be used on Macintosh and PC computers using any standard browser (such as Netscape Navigator or Microsoft Explorer). For those students who do not already have a browser, Microsoft's Internet Explorer is included on the CD. A UNIX script for using the CD or a UNIX system is available at

ftp://ftp.prenhall.com/pub/esm/physics.s-085/chaissonbg/

Content Updates in the Second Edition

This second edition of the Beginner's Guide has been updated throughout, both in the text itself and in the CD-ROM extensions, with new and late-breaking information, including

- the latest developments in telescope technology, covering both ground-based adaptive optics and interferometry, and the present status of the Hubble Space Telescope and other orbiting instruments (Chapter 3)
- coverage of the recent widely viewed Comets Hyakutake and Hale-Bopp (Chapter 4)
- the continuing story of the search for, and the apparent discovery of, planets orbiting stars other than our Sun (Chapter 4)
- the search for life on Mars, including the possibility that fossilized bacteria may have been detected in a meteorite believed to have originated on the Martian surface (Chapter 6)

- the Mars *Pathfinder* mission and plans for future visits to the red planet (Chapter 6)
- the *Galileo* mission to Jupiter, and its main findings so far (Chapters 7 and 8)
- revision of all distance scales throughout the text in light of the recent findings by the *Hipparcos* satellite. The *Hipparcos* mission is described in Extension 10.1
- Hubble Space Telescope observations of the Eagle Nebula, the Orion Nebula, and other star-forming regions (Chapter 11)
- the ongoing mystery of the cosmic gamma-ray bursts, and the recent strong evidence that at least one lies at cosmological distances (Chapter 13)
- the Hubble Deep Field, and its significance to studies of galaxy formation and cosmic evolution (Chapter 15)
- observations of quasar host galaxies, and how they relate to current theories of active galaxy evolution (Chapter 16)
- a review of how the *Hipparcos* data impact the long-standing debate on the age of the universe (Chapter 17)

Supplementary Material

This edition is accompanied by an outstanding set of instructional aids.

World Wide Web Site. For both teachers and students we have a companion website specifically for *Astronomy: A Beginner's Guide 2/e* at

http://www.prenhall.com/chaisson/bg

This powerful resource organizes material from a variety of sources on the web on a chapter-by-chapter basis, is updated monthly, and provides interactive on-line exercises for each chapter.

Each chapter of the website for *Astronomy: A Beginner's Guide 2/e* has the following three categories of materials:

- Online Archives—annotated images, videos, animations and free downloadable software
- Online Destinations—annotated links to relevant websites
- Online Exercises—interactive questions for students to answer on-line; scoring and feedback are provided immediately.

Comets. This is an annual update kit for Astronomy containing videos, slides, and *New York Times* articles. The VHS tape in the Fall 1997 Comets kit includes 27 custom animations prepared by the Wright Center for Science Visualization to accompany *Astronomy: A Beginner's Guide to the Universe 2/e* and *Astronomy Today, 2/e 1997 Media Edition* as well as three videos from the Space Telescope Science Institute, six from the Jet Propulsion Laboratories, a simulation on Galaxy Formation by Edward Bertschinger and a simulation from Roeland Van Der Marel called "A Black Hole in Galaxy M32." The slides, videos and animations can be shown in class; the collection of *New York Times* articles, called *Themes of the Times*, is published twice yearly and available free in quantity for your students using either text. A newsletter in the *Comets* kit provides descriptions of everything on the VHS tape and the slides and cross-references them, as well as the *Times* articles, with appropriate chapters of the Chaisson/McMillan texts. (ISBN: 0-13-754169-4)

Instructor's Manual, by Leo Connolly (California State University at San Bernardino). This manual provides an overview of each chapter; pedagogical tips, useful analogies, and suggestions for classroom demonstrations; answers to the end-of-chapter review and discussion questions and problems; and a list of selected readings. (ISBN: 0-13-754177-5)

Presentation Manager CD for Astronomy: A Beginner's Guide 2E. This flexible, easy-to-use tool contains a wealth of photographs, line art, animations, and videos to use in class lectures. With the *Presentation Manager* system, instructors can easily search, access, and organize the materials according to their lecture outlines and add their own visuals and lecture notes. The CD contains all the art and tables from *Astronomy: A Beginner's Guide 2E* as well as all the animations and videos that are on the CD in the back of the student text. In addition, the *Presentation Manager* incorporates over 80 slides from the past four editions of *Comets*. [(Mac) ISBN: 0-13-080420-7; (Win) ISBN: 0-13-754151-1]

Acetates and Slides. An extensive set of color acetates and a comprehensive 35-mm slide set are available free to qualified adopters. [(Slide set) ISBN: 0-13-754144-9; (Transparency pack) ISBN: 0-13-754136-8]

Test Item File. An extensive file of test questions, newly compiled for the second edition is offered free

upon adoption. Available in both printed and electronic form (Macintosh or IBM-compatible formats). (ISBN: 0-13-754094-9)

Prentice Hall Custom Test. *Prentice Hall Custom Test* is based on the powerful testing technology developed by Engineering Software Associates, Inc. (ESA). Available for Windows, Macintosh, and DOS, *Prentice Hall Custom Test* allows educators to create and tailor the exam to their own needs. With the Online Testing option, exams can also be administered online and data can then be automatically transferred for evaluation. A comprehensive desk reference guide is included, along with on-line assistance. [(Mac) ISBN: 0-13-754128-7; (Win) ISBN: 0-13-754110-4]

Student Observation Guide with Laboratory Exercises, by Michael Seeds and Joseph Holzinger (Franklin and Marshall College). The second edition of this useful supplement contains 42 classic labs and observational activities, along with cardboard cutout instruments that students can build and use for observations. Available for sale to students. (ISBN: 0-13-644196-3)

Basic Astronomy Labs, by Jay Huebner and Terry Smith (University of North Florida, Jacksonville), and Michael Reynolds (Chabot Observatory and Science Center). A collection of 40 laboratory exercises, including a wide range of both traditional and innovative topics (such as the nature of human vision, radioactivity and time, and astronomy on the Internet). Detailed introductions provide a fully-developed context for each exercise. Available for sale to students. (ISBN: 0-13-376336-6)

Astronomy on the Internet, by Andrew Stull and Alan Sill (Texas Tech University). A guide to general astronomy resources on the Internet. Everything you need to know to get yourself online and browsing the World Wide Web! (ISBN: 0-13-89011-2)

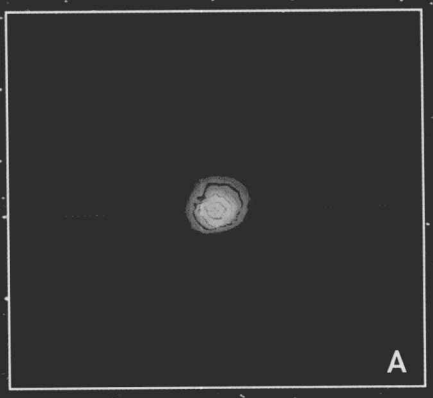
Acknowledgments

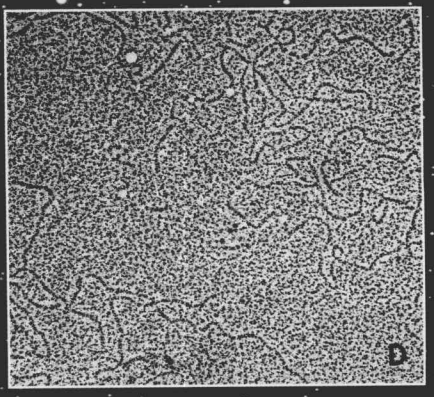
Throughout the many drafts that have led to this book, we have relied on the critical analysis of many colleagues. Their suggestions ranged from the macroscopic issue of the book's overall organization to the minutiae of the technical accuracy of each and every sentence. We have also benefited from much good advice and feedback from users of the first edition of the text and our longer book, *Astronomy Today, Media Edition*. To these many helpful colleagues, we offer our sincerest thanks.

Stephen G. Alexander, *Miami University*
Martin Goodson, *Delta College*
David J. Griffiths, *Oregon State University*
Andrew R. Lazarewicz, *Boston College*
Richard Nolthenius, *Cabrillo College*
Robert S. Patterson, *Southwest Missouri State University*
John C. Schneider, *Catonsville Community College*
Don Sparks, *Los Angeles Pierce College*
Jack W. Sulentic, *University of Alabama*

We would also like to acknowledge our gratitude to Leo Connolly for preparing the end-of-chapter questions and problems; to Ray Villard of the Space Telescope Science Institute for compiling the *Comets* supplement; and to Alan Sill of Texas Tech University for creating and maintaining our World Wide Web site.

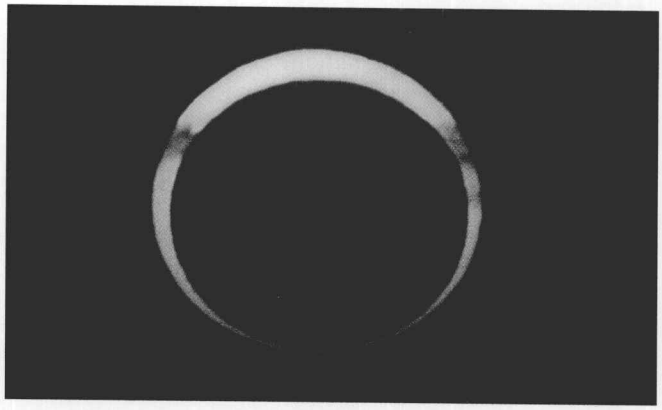
The publishing team at Prentice Hall has assisted us at every step along the way in creating this text. Much of the credit for getting the project completed on time goes to our Executive Editor, Alison Reeves, who has successfully navigated us through the twists, turns, and "absolute final deadlines" of the publishing world, all the while managing the many variables that go into a multifaceted publication such as this. Irene Nunes, our Development Editor, has skillfully helped us revise the manuscript and has been a constant source of insight and strength in making some very difficult content decisions. Production Editor Alison Aquino has done a remarkable job of tying together the threads of this very complex project, made all the more complex by the necessity of combining text, art, and electronic media into a coherent whole. Cindy Dunn has shown much technical leadership in this book's accompanying CD-ROM project. Finally, we would like to express our gratitude to renowned space artist Dana Berry for allowing us to use many of his beautiful renditions of astronomical scenes, and to Lola Judith Chaisson for assembling and drawing all the H–R diagrams (including the acetate overlays) for this edition.





Brief Contents

Contents



Animations, Videos, and Extensions on the CD

The enclosed CD contains a free, hyperlinked version of the text with integrated links to animations, videos, and extensions, as well as links to the text's WWW site, which provides on-line archives, on-line destinations, and on-line exercises for each chapter.

Following is a list of animations, videos, and extensions for each chapter.

Prologue

Charting the Heavens

1 The Copernican Revolution

The Birth of Modern Science

2 Light and Matter

The Inner Workings of the Cosmos

Video: Classical Hydrogen Atom I
Video: Classical Hydrogen Atom II

3 Telescopes

The Tools of Astronomy

Video: Taking the Deepest View of the Heavens
Extension: Pushing the Envelope Toward Better Optics
Extension: Acts of Violence Caught by a Satellite

4 The Solar System

Interplanetary Matter and the Birth of Planets

Animation: Astronomical Ruler
Animation: Terrestrial Planet Part I
Animation: Anatomy of a Comet Part I
Animation: Anatomy of a Comet Part II
Animation: Asteroid-Comet Breakup
Video: Comet Hyakutake
Video: Path of Comet Hyakutake Across Sky
Video: Close-up Images of Comet Hyakutake
Video: The Disk Around Beta Pictoris
Video: Formation of Warp in Beta Pictoris Disk
Extension: The Kuiper Belt and the Search for a Tenth Planet
Extension: Lunar and Martian Meteorites on Earth
Extension: New Insights for Beta Pic

5 Earth and Its Moon

Our Cosmic Backyard

Extension: Lunar Laser Ranging
Extension: Radioactive Dating
Extension: Lunar Exploration
Extension: A Remarkable Robot Named *Clementine*
Animation: Rotating Comet Hale-Bopp Nucleus

6 The Terrestrial Planets

A Study in Contrasts

Animation: Terrestrial Planets Part II
Video: Rotation of Mars
Video: Mars Rotation and North Pole
Video: Mars Global Surveyor
Extension: Spacecraft Exploration of the Inner Planets
Extension: Canals on Mars?
Extension: An Armada of Spacecraft Bound for Mars

7 The Jovian Planets

Giants of the Solar System

Animation: *Galileo* Mission to Jupiter Part I, Probe Separation
Animation: *Galileo* Mission to Jupiter Part II, Bus Arrival
Animation: *Galileo* Mission to Jupiter Part III, Probe on Final Approach
Animation: *Galileo* Mission to Jupiter Part IV, Atmospheric Re-entry
Animation: *Galileo* Mission to Jupiter Part V, Parachute Deployment
Animation: Jovian Planet Part I
Animation: Jovian Planet Part II
Video: Jupiter Rotation
Video: Saturn Storm
Extension: Spacecraft Exploration of the Jovian Planets
Extension: *Galileo* Arrives at Jupiter
Extension: *Galileo* at Jupiter, The Main Findings
Extension: Detailed Imaging of Uranus' Atmosphere
Extension: Almost a Star

8 Moons, Rings, and Pluto

Small Worlds Among Giants

Animation: Io Cutaway
Animation: *Galileo* Flyby of Io