ASTRONOMY

A Beginner's Guide to the Universe

FOURTH EDITION

CHAISSON • McMILLAN

eBook included

ASTRONOMY

A Beginner's Guide to the Universe

FOURTH EDITION

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ABOUT THE COVER:
Aside from its intrinsic yet subtle beauty, the cover image of distant galaxy NGC4526 was chosen to highlight several themes of this book: the evolution, size, and scale of the universe. Galactic systems, such as this one and our own Milky Way, are the universe's building blocks. The stars within those galaxies, such as the bright one (at lower left) caught in the act of exploding as a supernova, help astronomers both learn more about the evolutionary behavior of stars and chart the size and scale of the cosmos.

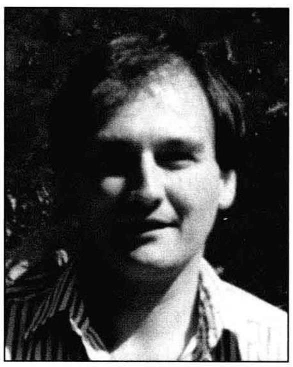
ASTRONOMY

ABOUT THE AUTHORS

ERIC CHAISSON

Eric holds a doctorate in Astrophysics from Harvard University, where he spent ten years on the faculty of Arts and Sciences. For five years, Eric was a Senior Scientist and Director of Educational Programs at the Space Telescope Science Institute and Adjunct Professor of Physics at Johns Hopkins University. He recently joined Tufts University, where he is now Professor of Physics, Professor of Education, and Director of the Wright Center for Innovative Science Education. He has written nine books on astronomy, which have received such literary awards as the Phi Beta Kappa Prize, two American Institute of Physics Awards, and Harvard's Smith Prize for Literary Merit. He has published more than 100 scientific papers in professional journals, and has also received Harvard's Book Prize for original contributions to astrophysics.

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 post-doctoral positions at the University of Illinois and Northwestern University, where he continued his research in theoretical astrophysics, star clusters, and numerical modeling. Steve is currently Distinguished Professor of Physics at Drexel University and a frequent visiting researcher at Princeton's Institute for Advanced Study and the University of Tokyo. He has published more than 50 scientific papers in professional journals.

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, non-technical 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 that we feel about astronomy and to awaken students to the marvelous universe around us.

We are very gratified that the first three editions of this text have been so well received by many in the astronomy education community. In using those earlier texts, many of you—teachers and students alike—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 your comments have been incorporated into this new edition.

ORGANIZATION AND APPROACH

As in previous editions, 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 the 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 they evolve.

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 *Discovery* and *More Precisely* features (described on p. xxii). 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. 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).

NEW AND REVISED MATERIAL

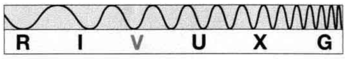
Astronomy is a rapidly evolving field, and the three years since the publication of the third edition of *Astronomy: A Beginner's Guide to the Universe* have seen many new discoveries covering the entire spectrum of astronomical research. Almost every chapter in the fourth edition has been substantially updated with new and late-breaking information. Several chapters have also seen significant internal 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. Among the many changes are:

- Expanded coverage throughout of the scientific method and how astronomers "know what they know."
- Updated material in Chapter 3 on adaptive optics, Subaru, Gemini, the VLT, and infrared and optical interferometry; new material on the *Chandra* mission; updates (and a conclusion) to the *CGRO* story.
- Updates in Chapter 4 on asteroid numbers and the properties of near-Earth objects; coverage of the *NEAR* mission and its exploration of Eros.
- Substantially updated coverage of solar system formation in Chapter 4, including disk instabilities, planetary migration, and their implications for extrasolar planetary systems.
- New section in Chapter 4 on extrasolar planets, with updated material on the latest observations.
- Expanded coverage of Pluto and new Kuiper belt objects in Chapters 4 and 8.
- New material in Chapter 5 on the Ozone Hole and Global Warming.
- Expanded material in Chapter 5 on *Clementine* and *Lunar Prospector*, with updates on their important findings, including the possibility of ice at the lunar poles.
- Greatly expanded coverage in Chapter 6 of *Mars Global Surveyor* and the many scientific results that have come from it; the possibility of (past or present) liquid water on Mars; an update on the Martian Meteorite controversy.

- Updates in Chapters 7 and 8 on the *Galileo/GEM* mission, including the latest results on the possible existence of a liquid water ocean below Europa's icy surface; discussion of the magnetic fields of the Galilean moons.
- Incorporation of results from the *Yohkoh*, *SOHO*, and *TRACE* missions into Chapter 9.
- The latest experimental results in the search for the missing solar neutrinos (Chapter 9).
- Use of *Hipparcos* data in Chapter 10 and throughout the text; a new H–R diagram based on *Hipparcos* measurements; discussion of future astrometry missions and their implications.
- Updated information in Chapter 10 on the numbers and mass distribution of stars in our Galaxy.
- Revision of the material on stellar mass determination in Chapter 10.
- Discussion in Chapter 11 of the Local Bubble.
- Updated information in Chapter 11 on brown dwarfs; new material on jets and outflows in star formation.
- New coverage in Chapter 12 of the end-states of stellar and binary evolution; discussion of blue stragglers; more examples of familiar stars in specific evolutionary stages.
- New section and latest results on gamma-ray bursts in Chapter 13; discussion of intermediate-mass and supermassive black holes.
- Latest results in Chapter 14 on Sgr A* and the Galaxy's central black hole.
- Reorganization of Chapter 15, combining normal and active galaxies as a single topic and expanding the discussion of black holes in galactic nuclei.
- Reorganization of Chapter 16 to focus on large-scale structure; new material on quasar absorption lines and the Lyman-alpha forest; expanded discussion of gravitational lensing, including the construction of dark-matter maps from lensing of background galaxies.
- Expanded and substantially revised coverage in Chapter 16 of galaxy collisions, hierarchical merging, and galaxy evolution; updated discussion of the measurement of *Hubble's* constant; revised discussion of active galaxy evolution.
- Consistent distances and times in Chapters 16 and 17, assuming a flat universe with dark matter and dark energy as determined by the WMAP satellite.
- Extensive rewriting of Chapter 17 to include recent observations of cosmic acceleration and discussion of "dark energy"; revised discussions of the cosmological constant and the age of the universe; results from the CBI and WMAP experiments suggesting a flat universe.
- Updated coverage of Europa, Mars, interstellar organic molecules, extrasolar planets, and SETI in Chapter 18.

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.



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.

Explanatory Captions

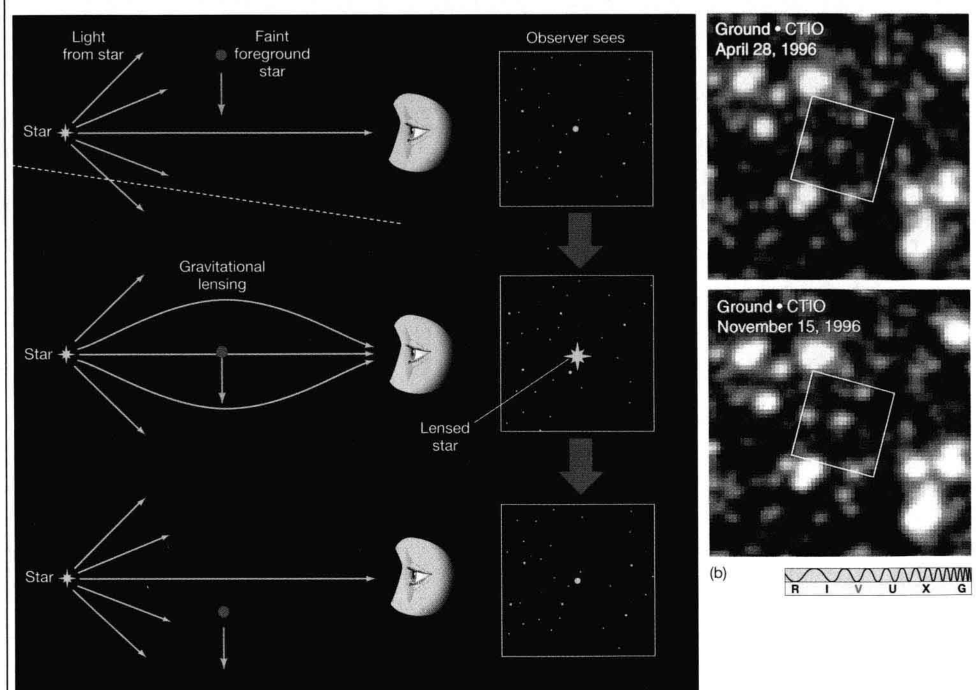
Students often review a chapter by "looking at the pictures." For this reason, the captions in this book are often a bit longer and more detailed than those in other texts.

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:

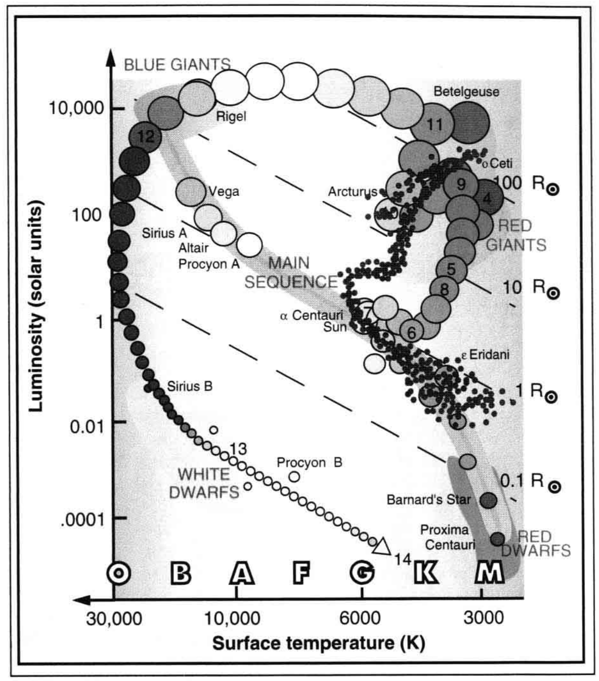
- Visible images are often presented along with their counterparts captured at other wavelengths.
- Interpretive line drawings are often superimposed on or juxtaposed with real astronomical photographs, helping students to really "see" what the photographs reveal.
- Breakouts—often multiple ones—are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

▼ **Figure 14.19 Gravitational Lensing** (a) Gravitational lensing by a faint foreground object (such as a brown dwarf) can temporarily cause a background star to brighten significantly, providing a means of detecting otherwise invisible stellar dark matter. (b) The brightening of a star during a lensing event, this one implying that a massive, but unseen, object passed in front of the unnamed star at the center of the two boxes imaged six months apart. (AURA)



(a)

(b)



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.

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.

> ### 17.4 The Geometry of Space
>
> **5** The idea of the entire universe expanding from a point—with *nothing*, not even space and time, outside—takes a lot of getting used to. Nevertheless, it lies at the heart of modern cosmology, and few modern astronomers seriously doubt it. But this description of the universe itself (not just its contents) as a dynamic, evolving object is far beyond the capabilities of Newtonian mechanics, which we have used almost everywhere in this book. ∞ (Sec. 1.5) Instead, the more powerful techniques of Einstein's theory of general relativity, with its built-in notions of warped space and dynamical spacetime, are needed. ∞ (Sec. 13.5)
>
> The theory of general relativity states that mass (or, equivalently, energy) curves, or "warps" space in its vicinity. The greater the *total* density of the cosmos—including not just matter (luminous and dark), but also radiation and dark energy—the greater the curvature. ∞ (Sec. 9.5) In the universe, the curvature must be the same everywhere (assuming homogeneity), so there are really only three possibilities for the large-scale geometry of space. For more information on the different types of geometry involved, see *More Precisely 17-1*.

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 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 review. The Goals are organized and phrased in such a way as to make them objectively testable, affording students a means of gauging their own progress.

∞ **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. 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 Chapter 1. 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 can 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 (and a hyperlink on the accompanying eBook), signal students that the topic under discussion is related in some significant way to ideas developed earlier, and direct them to material that they might wish to review before proceeding.

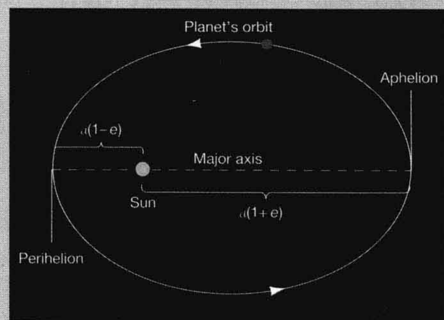
Key Terms Like all subjects, astronomy has its own specialized vocabulary. To aid student learning, the most important astronomical terms are boldfaced at their first appearance in the text. Each boldfaced Key Term is also incorporated in the appropriate chapter summary, together with the page number 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.

More Precisely 1-1 Some Properties of Planetary Orbits

Two numbers—semi-major axis and eccentricity—are all that are needed to describe the size and shape of a planet's orbital path. From them we can derive many other useful quantities. Two of the most important are the planet's *perihelion* (its point of closest approach to the Sun) and its *aphelion* (greatest distance from the Sun). From the definitions presented in the text, it follows that if the planet's orbit has semi-major axis a and eccentricity e, its perihelion is at a distance $a(1 - e)$ from the Sun, while its aphelion is at $a(1 + e)$. These points and distances are illustrated in the accompanying figure.

Note that while the Sun resides at one focus, the other focus is empty and has no particular significance. Thus, for example, a hypothetical planet with a semi-major axis of 400 million km and an eccentricity of 0.5 (the eccentricity of the ellipse shown in the diagram) would range between $400 \times (1 - 0.5) = 200$ million km and $400 \times (1 + 0.5) = 600$ million km from the Sun over the course of one complete orbit. With $e = 0.9$, the range would be 40–760 million km, and so on.

No planet has an orbital eccentricity as large as 0.5—the planet with the most eccentric orbit is Pluto, with $e = 0.248$ (see Table 1.1). However, many meteoroids and all comets (see Chapter 4) have eccentricities considerably greater than this. In fact, most comets visible from Earth have eccentricities very close to one. Their highly elongated orbits approach within a few A.U. of the Sun at perihelion, yet these tiny frozen worlds spend most of their time far beyond the orbit of Pluto.



More Precisely Boxes
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.

Discovery Boxes
Exploring a wide variety of interesting supplementary topics, these features have been expanded and renamed from the "Interludes" of previous editions to better reflect their goal of providing the reader with insight into how scientific knowledge evolves, and emphasizing our theme of the process of science.

Discovery 5-1 Earth's Growing Ozone Hole

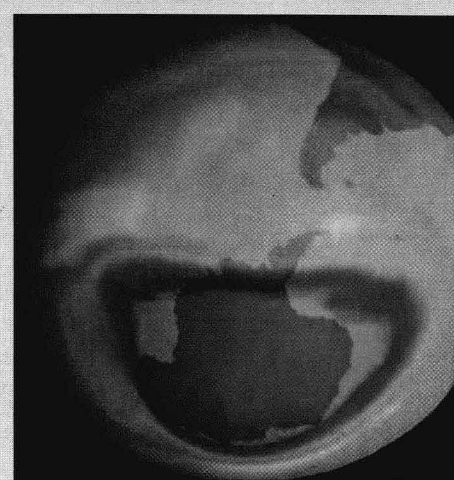
During the last two centuries, human technology has begun to produce measurable—and possibly permanent—changes in our planet. You can probably think of many instances, mostly negative, of such changes, from the threat of nuclear war to the reality of air and water pollution worldwide. One example very much in the news and relevant to the discussion in this chapter is the depletion of Earth's ozone layer. (See *Discovery 5-2* for an unrelated, but even more serious, threat to our environment.)

A particularly undesirable by-product of human technology is a group of chemicals known as chlorofluorocarbons (CFCs), relatively simple compounds once widely used for a variety of purposes—propellant in aerosol cans, dry-cleaning products, and in air conditioners and refrigerators. In the 1970s it was discovered that instead of quickly breaking down after use as had previously been thought, CFCs accumulate in the atmosphere and are carried high into the stratosphere by convection. There they are broken down by sunlight, releasing chlorine, which quickly reacts with ozone (O_3; see Section 5.3), turning it into oxygen (O_2). In chemical terms the chlorine is said to act as a *catalyst*—it is not consumed in the reaction, and so it survives to react with many more ozone molecules. A single chlorine atom can destroy up to 100,000 ozone molecules before being removed by other, less frequent chemical reactions. In this way, even a small quantity of CFCs turns out to be extraordinarily efficient at destroying atmospheric ozone.

As we saw in the text, ozone is part of the protective "blanket" of gases in our atmosphere that protect us from the harsh realities of outer space—in this case, solar ultraviolet radiation. Thus, the result of CFC emission is a substantial increase in ultraviolet radiation levels at Earth's surface, with detrimental effects to most living organisms. The accompanying figure shows the development of an ozone "hole" over the Antarctic—a region where atmospheric circulation and low temperatures conspire each Antarctic spring to create a vast circumpolar cloud of ice crystals, which act to promote the ozone-destroying reactions, resulting in ozone levels about 50 percent below normal for the region.

Since the hole was discovered in the 1980s, its depth and area have grown each year. Its peak size is now larger than North America. Ozone depletion is not confined to the Antarctic, although the effect is greatest there. Smaller holes have been observed in the Arctic, and occasional ozone depletions of up to 20 percent have been reported at lower northern latitudes.

In the late 1980s, when the effect of CFCs on the atmosphere was realized, the world moved remarkably rapidly to curtail their production and use, with the goal of phasing them out entirely by 2030. Substantial cuts have already been made. Still, scientists think that even if all remaining CFC emissions were to stop today, it would still take several decades for CFCs to leave the atmosphere completely.



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.

Chapter Summaries The Chapter Summaries, a primary review tool for the student, have been expanded and improved for the fourth 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.

End of Chapter Questions and Problems Many elements of the end-of-chapter material have seen substantial reorganization:

- Each chapter now incorporates 15 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 also has 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.
- The end of chapter material includes 10 Problems, based on the chapter contents and entailing 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 appear at the end of the book.

eBOOK CD-ROM

The *Astronomy: A Beginner's Guide to the Universe, Fourth Edition* eBook CD-ROM is included free with each new copy of the text. This easy-to-navigate eBook contains a fully hyperlinked electronic version of the text to help the reader quickly find related information and assist in review. The eBook, which has been redesigned for easier and clearer navigation, features:

- **New!** Interactive Tutorials: Written by Phillip Langill (University of Calgary). These animated, interactive Flash™ files, denoted by an icon in the text, allow students to explore the ideas and concepts from the text in depth. Students are engaged in the thought process as they answer questions and change parameters in these exploratory activities.
- **New!** Physlet® Illustrations for Astronomy: Written by Chuck Niederriter and Steve Mellema (Gustavus Adolphus College); Physlets by Wolfgang Christian (Davidson College). Through animation, these brief Java applets, denoted with an icon in the text, further illustrate concepts from the text. Each illustration is followed by a series of questions that encourages students to think critically about the concept at hand.
- Over 3,000 internal links that connect chapter Learning Goals, end-of-chapter material, and key concepts to the corresponding text discussion.

- 61 narrated videos and animations imbedded within the text, at point of use. These help to bring text figures and concepts to life.
- Direct access to the Companion Website, which provides updated images, videos, animations, multiple-choice quizzes, and algorithmic versions of the end of chapter problems.

COMPANION WEBSITE (astro.prenhall.com/chaisson)

The text-specific Companion Website for *Astronomy: A Beginner's Guide, Fourth Edition* organizes material from a variety of sources on the web on a chapter-by-chapter basis, is updated regularly, and provides interactive exercises for each chapter. This powerful resource provides students with a variety of interactive materials to discover more about topics that interest them, test their conceptual understanding of the course material, and practice their problem-solving skills. It includes:

- Annotated images, videos, and animations that are regularly updated to reflect the most recent astronomical discoveries.
- Interactive multiple-choice quizzes with hints and instant feedback.
- Algorithmically generated versions of the end-of-chapter problems from the text.
- Links to associated websites that are regularly updated for currency and relevancy.

SUPPLEMENTARY MATERIAL

For the Instructor

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

Course and Homework Management Tools

WebCT and **Blackboard** are comprehensive and flexible Web-based educational platforms. With a local installation of either system, Prentice Hall provides content designed especially for *Astronomy: A Beginner's Guide to the Universe, Fourth Edition* to create a complete course suite, tightly integrated with the system's course management tools.

Powered by Blackboard and with the highest level of service, support, and training available today, **CourseCompass** offers a nationally hosted solution for course management. It is designed to address the individual needs of instructors, who will be able to create an online course without any special technical skills or training.

Along with all the material from the Companion Website, our course management cartridges for WebCT, Blackboard and CourseCompass include additional material designed to match individual instructor teaching styles and support novel educational initiatives. These additional materials are only available through our course management packages. These include:

- Gradable follow-up questions to the Physlet® Illustrations for Astronomy and Interactive Tutorials
- Gradable multiple-choice and True/False self study quizzes

- Gradable Labeling exercises
- Test bank questions, converted from our TestGen test item file (see description below)

Online Homework

WebAssign (www.webassign.net) Create assignments from WebAssign's database of problems and questions from *Astronomy: A Beginner's Guide to the Universe, Fourth Edition*, or write and customize your own. The instructor has complete control over homework, including due date, content, feedback, and question formats.

Comets Published annually at the beginning of each academic year and available free to qualified adopters, *Comets* is a unique kit that includes a collection of slides, videos, and *New York Times* articles on events and discoveries that have occurred since the publication of the prior year's *Comets* kit. The slide kit contains 28 new slides from NASA, JPL, STScI, GSFC, *HST* Comet LINEAR Investigation Team, APL, JPL, ESA, *Hubble* Heritage Team, IPAC, European Southern Observatory, SDSS/Astrophysical Research Consortium, and the U.S. Department of Defense. Custom animations prepared by the Wright Center for Science Visualization and many other videos of new discoveries and animations from various sources, including NASA, STScI, APL/NRL, ESA, Stanford Lockheed Institute for Space Research, and JPL are provided in both CD and DVD formats. The collection of *New York Times* articles, called "Themes of the Times," is published twice yearly and is available free in quantity for your students using any Chaisson/McMillan text. A newsletter provides a cross reference between all the materials in the *Comets* kit and corresponding chapters of both Chaisson/McMillan texts, as well as annotations describing the subject and source of each slide and video in the kit.

Test Item File An extensive file of over 2200 test questions, newly compiled and revised for the fourth edition by J. Wayne Wooten (Pensacola Junior College), is offered free to qualified adopters. This is available in both printed and electronic formats (see desciption of IRCD). The fourth edition *Test Item File* has been thoroughly revised and includes many new Multiple Choice and Essay questions for added conceptual emphasis. Overall, approximately 600 new questions have been added. ISBN 0-13-100729-7

Instructor's Resource Manual By Judy Beck (University of North Carolina-Asheville) and Leo Connolly (California State University at San Bernardino). This manual provides an overview of each chapter, pedagogical tips, useful analogies, suggestions for classroom demonstrations, writing questions and answers to the end-of-chapter Review and Discussion questions and Problems. New features include an expanded introduction with an overview of how to use the IRM, a discussion of common student misconceptions, and a list of selected readings for each chapter. ISBN 0-13-100776-9

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