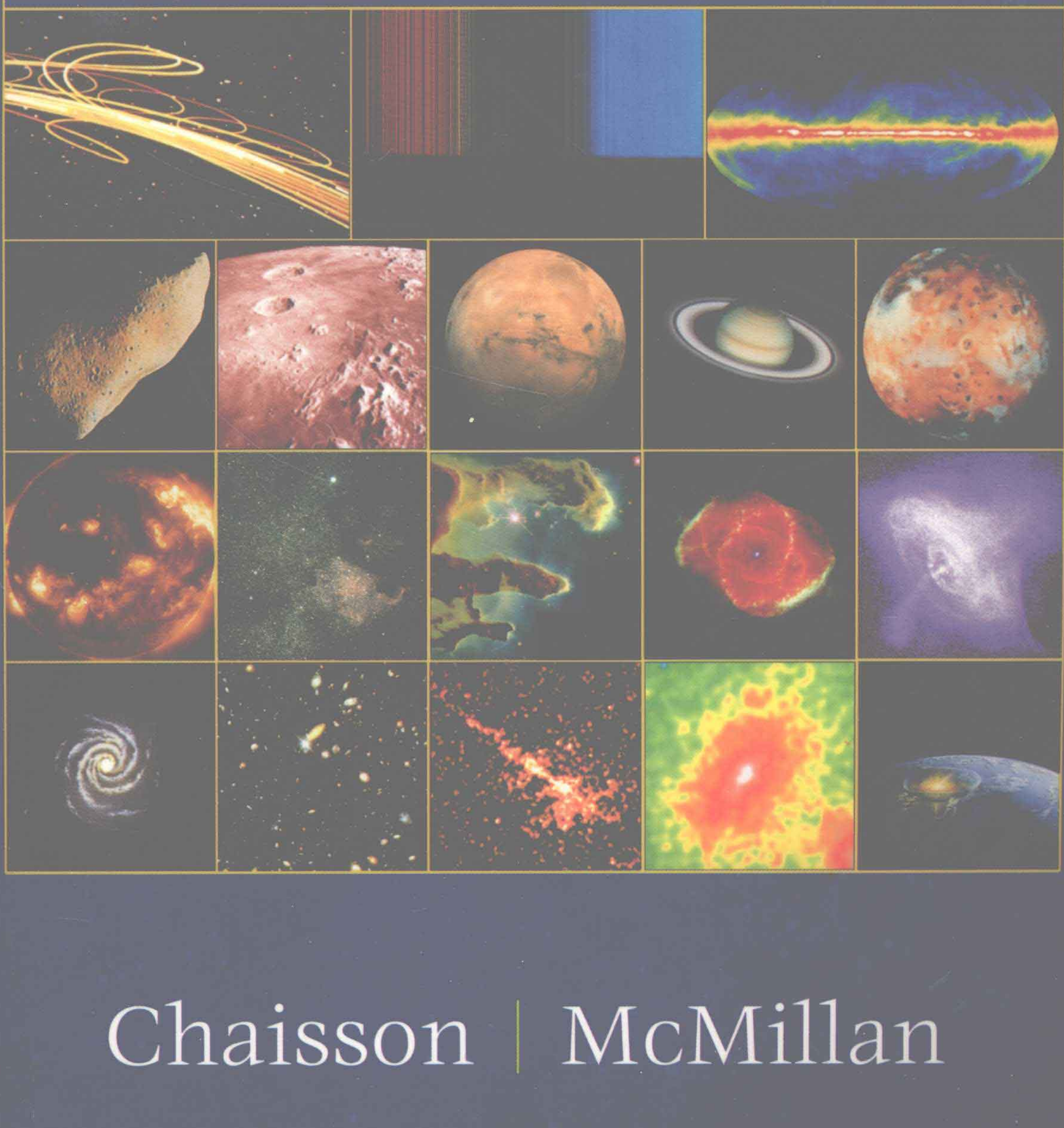
CD-ROM INCLUDED

ASTRONOMY

A Beginner's Guide to the Universe

THIRD EDITION



Chaisson | McMillan

ASTRONOMY

A Beginner's Guide to the Universe

THIRD EDITION

Eric Chaisson
Tufts University

Steve McMillan
Drexel University

Prentice Hall

PRENTICE HALL
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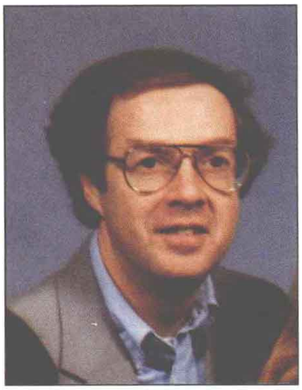
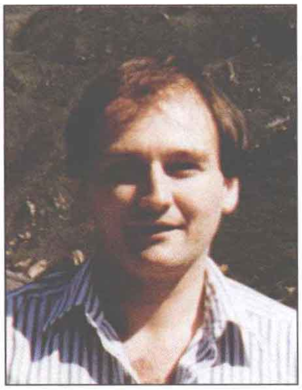
ASTRONOMY

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 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 Bok 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 over 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 two 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, as well as numerous innovations and popular new features from our companion hardback text *Astronomy Today*, have been incorporated into this new edition.

Organization and Approach

As in the first two 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 *More Precisely* features (described on p. xiv). 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 second 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 third 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. Among the many changes are:

- Addition of more quantitative material and worked examples to both the text and *More Precisely* boxes throughout the book.

- Updates to material on ground-based adaptive optics and interferometry, the present status of the *Hubble Space Telescope* and the *Compton Gamma-Ray Observatory*, and new coverage of the *Chandra Advanced X-ray Astrophysics Facility* (Chapter 3).
- Discussion of the *NEAR* mission to asteroid Eros (Chapter 4).
- Expanded discussion of the Kuiper belt and Oort cloud (Chapters 4 and 8).
- Further updates on the search for extrasolar planets (Chapter 4).
- Expanded discussion of tidal forces (Chapter 5).
- Updates on lunar exploration by *Clementine* and *Lunar Prospector* (Chapter 5).
- Updated discussion of recent spacecraft missions to Mars—*Pathfinder*, *Sojourner*, *Polar Lander*, and *Global Surveyor* (Chapter 6).
- Continuing coverage of the *Galileo* mission to Jupiter and its main findings regarding that planet's Galilean satellites (Chapters 7 and 8).
- The reported detection of neutrino oscillations, and its relevance to the solar neutrino problem (Chapter 9).
- New H–R diagram based on *Hipparcos* data on nearby stars (Chapter 10).
- Expanded material on the search for brown dwarfs (Chapter 11).
- New composite H–R diagram for the oldest globular clusters (Chapter 12).
- Greatly expanded discussion of cosmic gamma-ray bursts (Chapter 13).
- Update on the *LIGO* project (Chapter 13).
- Expanded coverage of conditions near the Galactic center (Chapter 14).
- Updated Hubble's constant of 65 km/s/Mpc used consistently throughout the text (Chapter 15).
- New imagery and discussion of galaxy collisions (Chapter 15).
- Updated observations of quasar host galaxies (Chapter 16).
- Incorporation of larger-scale (Las Campanas) redshift surveys into the text discussion of the cosmological principle (Chapter 17).
- Extensive discussion of the "accelerating universe," the cosmological constant, and their possible ramifications for the structure and large-scale geometry of the cosmos (Chapter 17).

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.

Other Pedagogical Features

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

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.

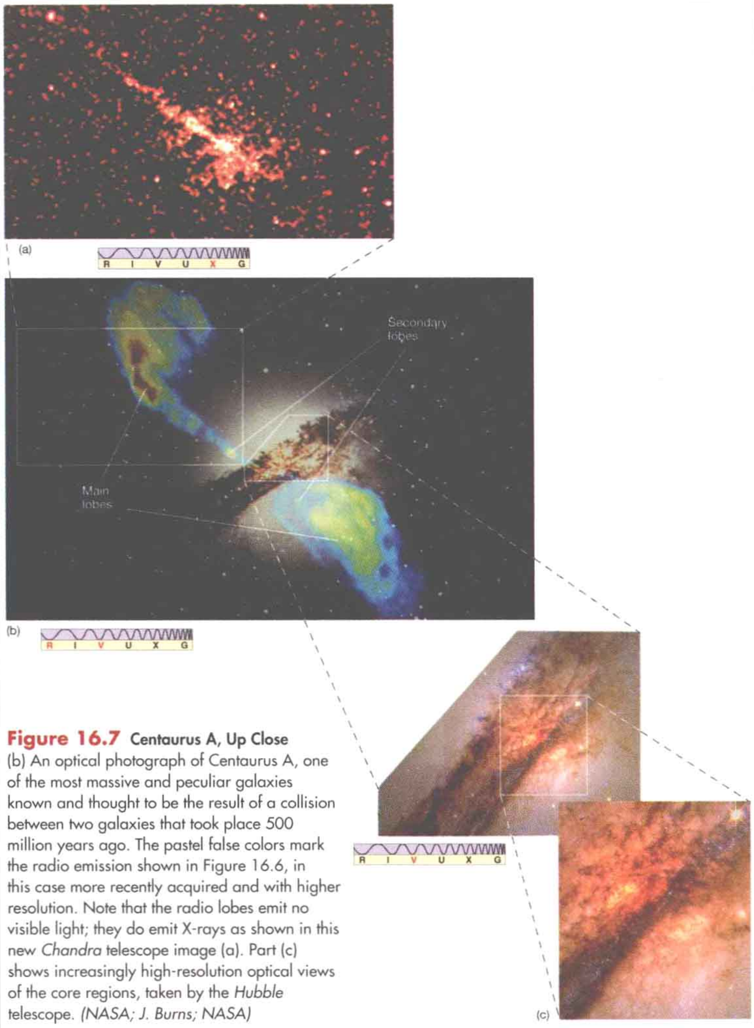
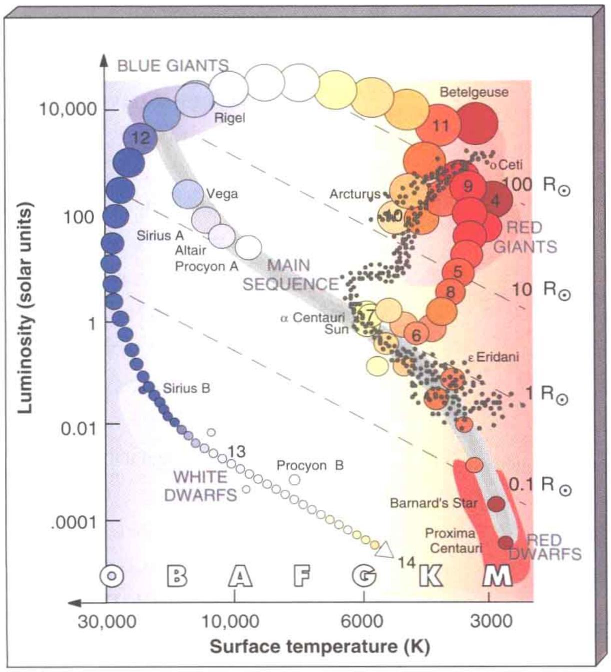


Figure 16.7 Centaurus A, Up Close
(b) An optical photograph of Centaurus A, one of the most massive and peculiar galaxies known and thought to be the result of a collision between two galaxies that took place 500 million years ago. The pastel false colors mark the radio emission shown in Figure 16.6, in this case more recently acquired and with higher resolution. Note that the radio lobes emit no visible light; they do emit X-rays as shown in this new *Chandra* telescope image (a). Part (c) shows increasingly high-resolution optical views of the core regions, taken by the *Hubble* telescope. *(NASA; J. Burns; NASA)*

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.



◀ 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 demonstrate to students how the H–R diagram helps us to organize our information about the stars and track their evolutionary histories.

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 explore a variety of interesting supplementary topics, such as *The Hubble Space Telescope*, *Life on Mars?*, *A Cometary Impact*, *Supernova 1987A*, *Colliding Galaxies*, *The Cosmological Constant*, and *What Killed the Dinosaurs?*

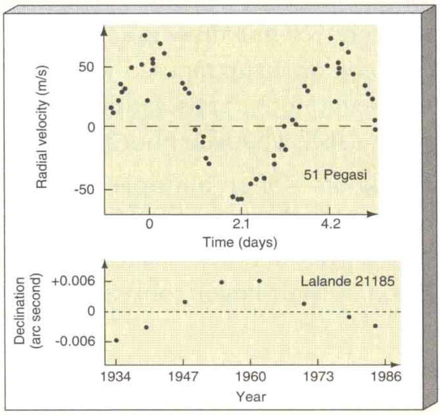
INTERLUDE 4-1

Planets Beyond the Solar System

The past few years have seen enormous strides in the search for extrasolar planets. These advances have come not through any dramatic scientific or technical breakthrough, but rather through steady improvements in both telescope and detector technology and computerized data analysis. The count of potential extrasolar planets currently stands at 28. However, it is not yet possible to image any of these newly discovered worlds. The techniques used to find them are indirect, based on analysis of light from the parent star, not from the unseen planet.

The accompanying figure shows two sets of data that betray the presence of planets. As a planet orbits a star, gravitationally pulling one way and then the other, the star wobbles slightly. The more massive the planet or the closer its orbit to the star, the greater its gravitational pull and hence the star's movement.

If the wobble happens to occur along our line of sight to the star (as illustrated in the upper graph, which shows the line-of-sight velocity of the star 51 Pegasi, a near-twin of our Sun lying some 40 light-years away), then we see small fluctuations in the star's radial velocity, which can be measured using the Doppler effect. ∞ (*More Precisely* 2-3) These data were acquired in 1994 by Swiss astronomers using the 1.9-m telescope at Haute-Provence Observatory in France, and imply that a planet at least half the mass of Jupiter orbits 51 Peg with a period of just 4.2 days. Alternatively, if the wobble is predominantly perpendicular to our line of sight (as indicated in the lower graph, which plots the declination of the star Lalande 21185 over the last half century), then the star's position in the sky changes slightly from night to night. ∞ (Sec. P.2) The 30-year-



More Precisely 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.

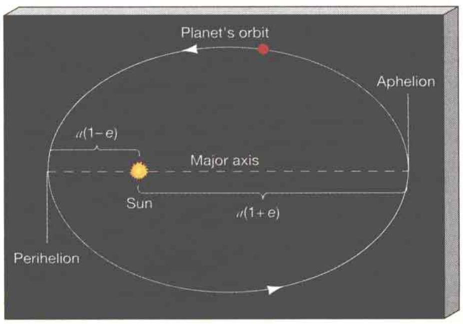
MORE PRECISELY 1-1

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.



> **Concept Check**
> - How do Newton's and Einstein's theories differ in their descriptions of gravity?

◀ **Concept Checks.** New to this edition, we have incorporated 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.

∞ **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 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 "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 (and a hyperlink on the accompanying CD-ROM), 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 wish to review before proceeding.

> ## 17.4 The Geometry of Space
>
> **4** 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. 1.4) 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, but also radiation and dark energy (if any), suitably converted to mass units using the relation $E = mc^2$—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*.

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 30 Self-Test Questions, 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 a number of Problems, based on the chapter contents and entailing some numerical calculation. In this edition we have increased the number of problems to 10, have significantly broadened their range of difficulty, and in many cases have tied their contents 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.
- Each chapter ends with a few (2–4) 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

The free CD for *Astronomy: A Beginner's Guide 3/e* is included at the end of the text and contains a fully hyperlinked electronic version of the text to help the reader quickly find related information and assist in review. It also contains integrated animations and videos to bring text figures to life, and links to our companion website, which is organized by text chapter and updated monthly. The CD for this edition has been redesigned for easier and clearer navigation, and to include larger, higher-resolution videos with voiceovers. 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 both 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, Netscape Navigator 4.08 is included on the CD. A script to facilitate use of the CD under UNIX is available at

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

Web Site

For both teachers and students, we have created a companion website specifically for *Astronomy: A Beginner's Guide 3/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 online exercises for each chapter.

Each chapter of the website for *Astronomy: A Beginner's Guide 3/e* has the following four categories of materials:

- *Online Exercises*—interactive questions for students to answer on-line; scoring and feedback are provided immediately. The new edition features a significantly increased number of true/false and multiple choice questions.
- *Online Archives*—annotated images, videos, animations, and free downloadable software
- *Online Destinations*—annotated links to relevant websites that are regularly updated for currency and functionality
- *Multimedia Study Guide*—twenty-five questions per chapter that focus on both quantitative and conceptual understanding; many chapters also include graphical labeling exercises

Supplementary Material

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

Comets. This is an annual update kit for *Astronomy: A Beginner's Guide, 3/e* containing videos, slides, and *New York Times* articles. The VHS tape in the Fall 2000 Comets kit includes 27 custom animations prepared by the Wright Center for Science Visualization to accompany *Astronomy: A Beginner's Guide to the Universe 3/e* and *Astronomy Today, 3/e 2000 Media Edition*. It also contains many other videos of new discoveries and animations from various sources: seven videos from the Space Telescope Science Institute including an imaginary look at a Saturn-like extrasolar planet; seven from the Jet Propulsion Laboratories, including a computer simulated fly-over of the Martian north pole; and four from the Applied Physics Laboratory including an image sequence of one rotation of the asteroid Eros. 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 is available free in quantity for your students using either text. A newsletter in the Comets kit provides descriptions of each video and slide. In addition, all slides, videos, and *Times* articles are cross-referenced to the appropriate chapters in both Chaisson/McMillan texts. (ISBN: 0-13-089233-5)

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: 0-13-089212-2)

Presentation Manager CD. 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 Presentation Manager CD contains all of the art and tables from *Astronomy: A Beginner's Guide 3/e*, as well as all animations and videos from the CD that ships with the student text. In addition, the *Presentation Manager* incorporates over 80 slides from the past four editions of Comets. [Available on one dual-platform CD (Macintosh/Windows) ISBN: 0-13-089216-5]

Acetates and Slides. A set of nearly 150 images from the text are available as a package of color acetates or 35-mm slides and are available free to qualified adopters. [(Slide set) ISBN: 0-13-089211-4; (Transparency pack) ISBN: 0-13-089200-9]

Test Item File. An extensive file of test questions, newly compiled for the third edition is offered free upon adoption. Available in both printed and electronic formats (Macintosh or IBM-compatible formats). (ISBN: 0-13-089213-0)

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: 0-13-089214-9; (Win) ISBN: 0-13-089215-7]

Science on the Internet: A Student's Guide, by Andrew Stull and Harry Nickla. A guide to general science resources on the Internet. Everything you need to know to get yourself online and browsing the World Wide Web! (ISBN: 0-13-028253-7)

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.

Reviewers of the Third Edition

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Susan Hartley, *University of Minnesota–Duluth*
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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 Wesley Phillips, also of Texas Tech, for maintaining our 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. Don Gecewicz, our Development Editor, has skillfully helped us update and trim the manuscript. Production Editor Joanne Hakim 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. Mike Banino has again displayed his technical skill in managing 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.

MEDIA RESOURCES

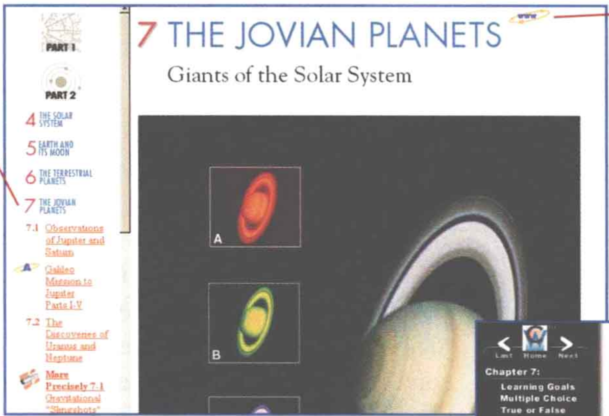
While almost all books in astronomy now have web sites, CD-ROMs, videos, and animations, our mission is to integrate all of these together in a more meaningful way for the student.

The videos and other material are intended to be viewed by the student in the context of text discussions. Web resources are therefore organized by chapter, both to expand students' knowledge of a given topic and to save time in locating relevant material. The text is fully hyperlinked, to encourage students to follow their natural curiosity about astronomy and to help them explore this fascinating subject.

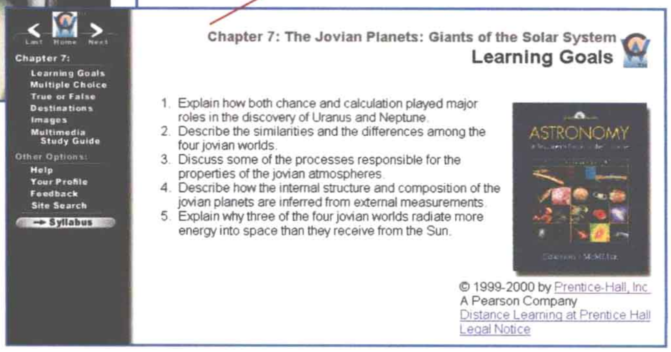
The following is a brief tour of how the Media Edition CD-ROM in the back of the text pulls together text, web, videos, and animations to help students take full advantage of these resources.

The navigation window on the left provides an icon for each part of the text. Clicking on one of the icons brings up a list of the chapters in the right-hand frame.

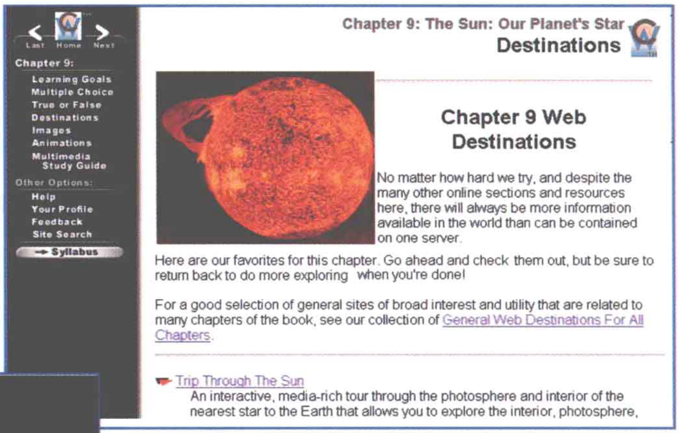
When you click on a given chapter, the complete chapter text loads in the right window and the section-level table of contents for the chapter expands in the left column. The part icons and chapters for other parts of the book remain resident in the left-hand frame so you can navigate easily within the chapter and/or throughout the book.



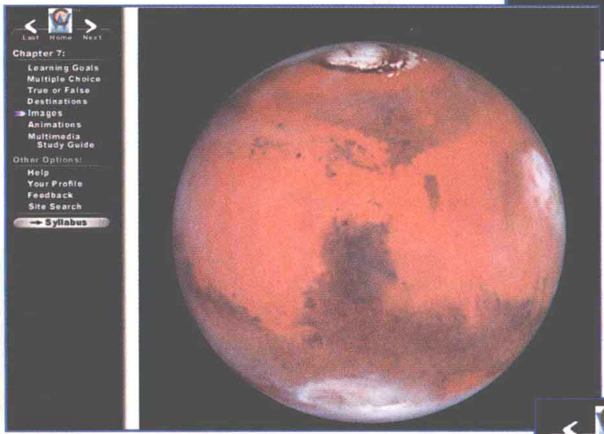
The World Wide Web icon appears at the top of the chapter-opening page. Clicking on this will take you to the corresponding chapter of the text's companion web site.



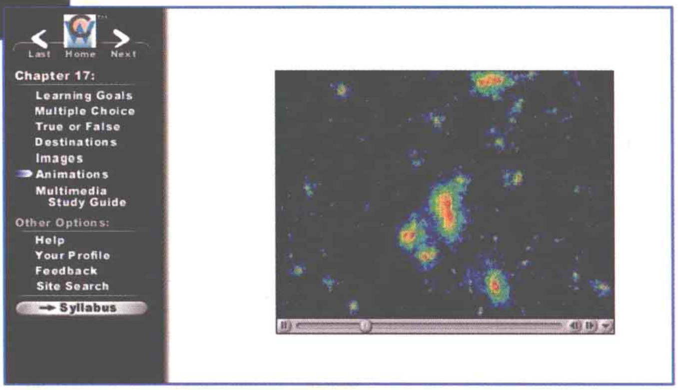
For each text chapter, the web site has self-scoring multiple choice and true/false questions; links to associated web sites (Destinations); annotated images and animations; and a multimedia study guide. The Destinations, Images, and Animations modules are updated on a monthly basis both to repair broken links and to add material on new events and discoveries.



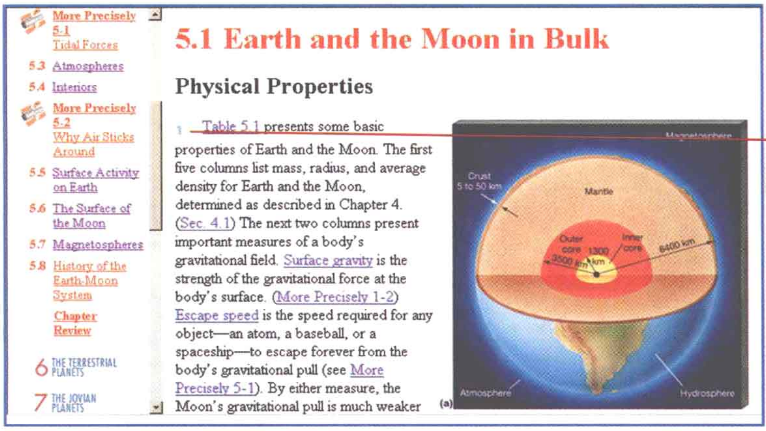
Destinations



Images



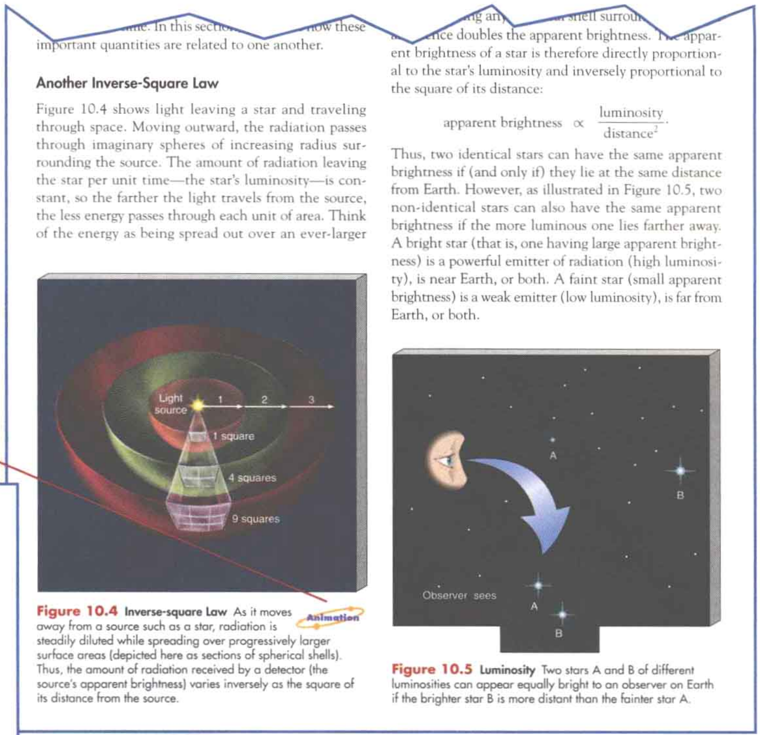
Animations



Each text chapter begins with learning objectives. In the printed text, discussions related to that objective are indicated by the corresponding learning objective number in blue type. In the CD-ROM version of the text, the chapter-opening learning objectives are hyperlinked so that you can go directly from one to the other.

Video icons in the printed text indicate the availability of a video or animation to help explain text discussions and illustrations.

In the CD-ROM version of the text, these videos are listed in the contents for each chapter. Clicking on the video name will bring you to the corresponding place in the text where you can look at the text figure and watch the animation at the same time. All videos and animations now have audio narration.


...important quantities are related to one another.

Another Inverse-Square Law

Figure 10.4 shows light leaving a star and traveling through space. Moving outward, the radiation passes through imaginary spheres of increasing radius surrounding the source. The amount of radiation leaving the star per unit time—the star's luminosity—is constant, so the farther the light travels from the source, the less energy passes through each unit of area. Think of the energy as being spread out over an ever-larger ...

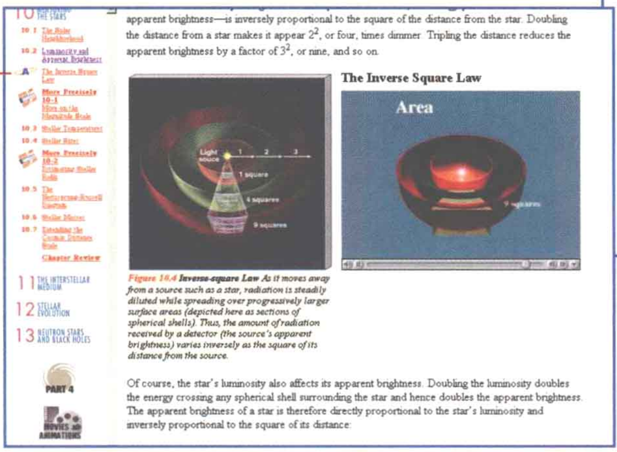
...ence doubles the apparent brightness. The apparent brightness of a star is therefore directly proportional to the star's luminosity and inversely proportional to the square of its distance:

$$\text{apparent brightness} \propto \frac{\text{luminosity}}{\text{distance}^2}.$$

Thus, two identical stars can have the same apparent brightness if (and only if) they lie at the same distance from Earth. However, as illustrated in Figure 10.5, two non-identical stars can also have the same apparent brightness if the more luminous one lies farther away. A bright star (that is, one having large apparent brightness) is a powerful emitter of radiation (high luminosity), is near Earth, or both. A faint star (small apparent brightness) is a weak emitter (low luminosity), is far from Earth, or both.

Figure 10.4 Inverse-square Law As it moves away from a source such as a star, radiation is steadily diluted while spreading over progressively larger surface areas (depicted here as sections of spherical shells). Thus, the amount of radiation received by a detector (the source's apparent brightness) varies inversely as the square of its distance from the source.

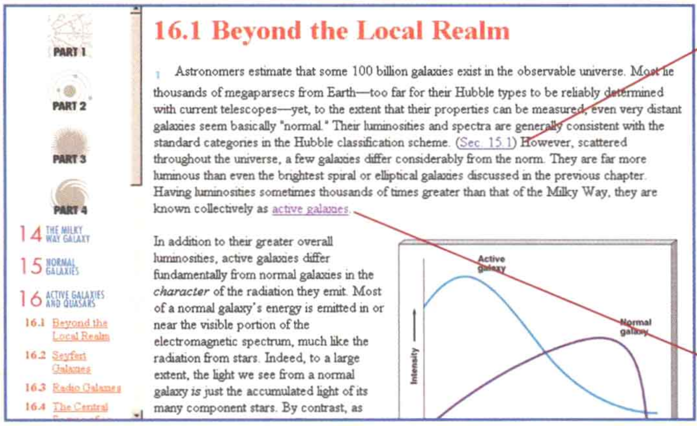
Figure 10.5 Luminosity Two stars A and B of different luminosities can appear equally bright to an observer on Earth if the brighter star B is more distant than the fainter star A.


apparent brightness—is inversely proportional to the square of the distance from the star. Doubling the distance from a star makes it appear 2^2, or four, times dimmer. Tripling the distance reduces the apparent brightness by a factor of 3^2, or nine, and so on.

The Inverse Square Law

Figure 10.4 Inverse-square Law As it moves away from a source such as a star, radiation is steadily diluted while spreading over progressively larger surface areas (depicted here as sections of spherical shells). Thus, the amount of radiation received by a detector (the source's apparent brightness) varies inversely as the square of its distance from the source.

Of course, the star's luminosity also affects its apparent brightness. Doubling the luminosity doubles the energy crossing any spherical shell surrounding the star and hence doubles the apparent brightness. The apparent brightness of a star is therefore directly proportional to the star's luminosity and inversely proportional to the square of its distance:

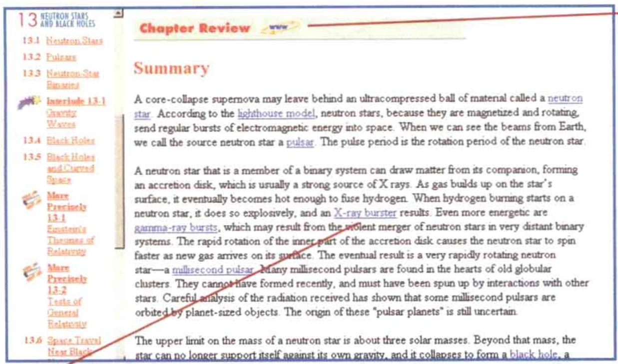

16.1 Beyond the Local Realm

Astronomers estimate that some 100 billion galaxies exist in the observable universe. Most lie thousands of megaparsecs from Earth—too far for their Hubble types to be reliably determined with current telescopes—yet, to the extent that their properties can be measured, even very distant galaxies seem basically "normal." Their luminosities and spectra are generally consistent with the standard categories in the Hubble classification scheme. (Sec. 15.1) However, scattered throughout the universe, a few galaxies differ considerably from the norm. They are far more luminous than even the brightest spiral or elliptical galaxies discussed in the previous chapter. Having luminosities sometimes thousands of times greater than that of the Milky Way, they are known collectively as active galaxies.

In addition to their greater overall luminosities, active galaxies differ fundamentally from normal galaxies in the *character* of the radiation they emit. Most of a normal galaxy's energy is emitted in or near the visible portion of the electromagnetic spectrum, much like the radiation from stars. Indeed, to a large extent, the light we see from a normal galaxy *is* just the accumulated light of its many component stars. By contrast, as

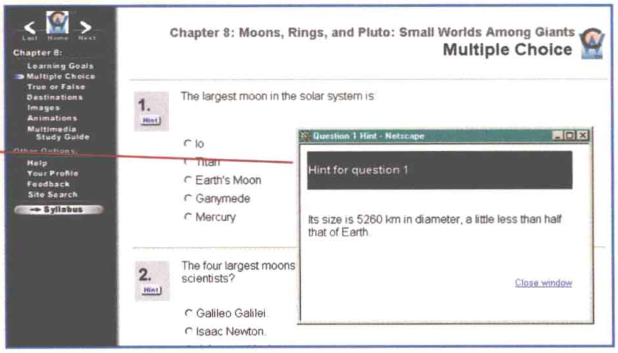
Cross-link icons tell you that a related text discussion is located in another part of the text. Often these link materials in later chapters to the underlying physics principles discussed earlier in the text. In the CD-ROM version of the text, the cross-links are hyperlinked so that you can go directly to the relevant discussion.

All glossary terms in the chapter narrative are linked to the end-of-book glossary definition.

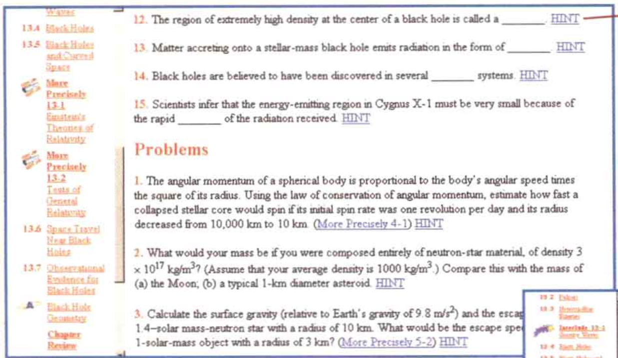


At each end-of-chapter review, clicking on the WWW icon again brings you to the corresponding web chapter. At this point, students may want to take advantage of the self-scoring multiple-choice and true/false quizzes. There are approximately 15 multiple choice and 15 true/false questions for each chapter.

Clicking on the glossary term in the chapter summary will take you to the place in the text where they are discussed.



Hints are provided for each question, but if you still get the answer wrong, the *wrong answer feedback* in the *scored results reporter* will tell you what section in the text you need to review. In addition, each chapter has a Multimedia Study Guide that includes 25 detailed multiple-choice questions, and, in many chapters, labeling exercises that help you visually test your knowledge.



Finally, all end-of-chapter questions and problems have hint buttons which take you to the place in the text where the topic for that question is discussed.