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ASTRONOMY TODAY

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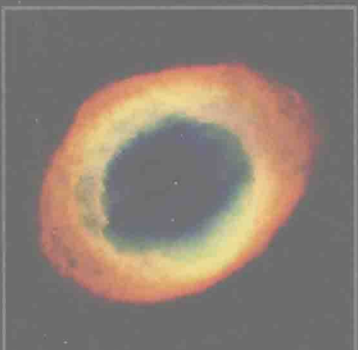


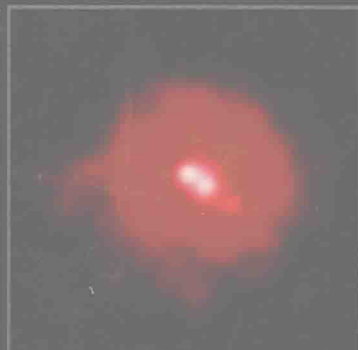

CHAISSON • MCMILLAN

ASTRONOMY TODAY

Fourth Edition

Eric Chaisson
TUFTS UNIVERSITY

Steve McMillan
DREXEL UNIVERSITY

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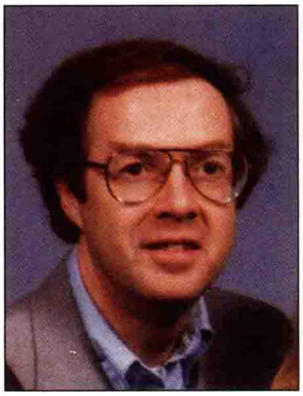

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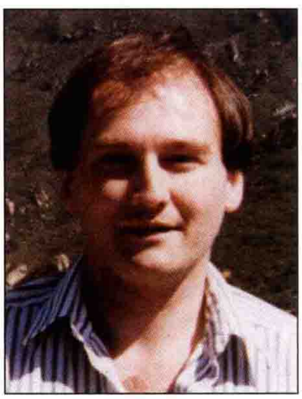
Eric holds a doctorate in Astrophysics from Harvard University, where he spent ten years on the faculty of Arts and Sciences. For five years, Eric was a Senior Scientist and Director of Educational Programs at the Space Telescope Science Institute and Adjunct Professor of Physics at Johns Hopkins University. He then 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-Weld 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 40 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 a representative sample of the known facts, evolving ideas, and frontier discoveries in astronomy today.

This book is written for students who have taken no previous college science courses and who will likely not major in physics or astronomy. The text is suitable for both one-semester and two-semester courses. 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.

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

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 sent us helpful feedback and constructive criticisms. From these, we have learned to better communicate both the fundamentals and the excitement of astronomy. Many improvements inspired by your comments have been incorporated into this new edition.

Organization and Approach

Our overall 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 the Moon as our initial planetary models, we move through the solar system, drawing on comparative planetology to provide an understanding of the many varied worlds we encounter. We conclude our coverage of the solar system with a discussion of its formation, a line of investigation that leads directly into a study of our Sun.

With the Sun as our model star, we then 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. 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 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. In addition, we have included as much modern astronomy as possible in the introductory chapters. These chapters are likely to engage students only if they are made to realize how simple physical principles provide the keys to our understanding of a vast and otherwise incomprehensible universe.

New and Revised Material

The text has been extensively updated in content since the third edition. Most chapters have been significantly changed, and several have seen major reorganization. Among the many changes are:

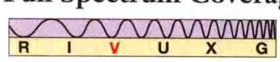
- New boxes in Chapter 1 on astronomical timekeeping and distance measurement.
- Expanded discussion in Chapter 2 of Newton's discovery of the law of gravity.
- Updated material in Chapter 5 on adaptive optics, Subaru, Gemini, the VLT, and infrared and optical interferometry; new material on the *Chandra* mission; updates (and a conclusion) to the *CGRO* story.

- New material in Chapter 6 on measuring planetary properties; updates on the *Galileo*, *Cassini*, and *Mars Global Surveyor* missions.
- Expanded material in Chapter 6 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 10 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 Chapter 11 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.
- Coverage of the many new moons of Jupiter, Saturn, and Uranus.
- Expanded coverage of Pluto and the Kuiper belt in Chapters 13–15.
- Updates in Chapter 14 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 15, including disk instabilities, planetary migration, and their implications for extrasolar planetary systems.
- New section in Chapter 15 on extrasolar planets, with updated material on the latest observations.
- Incorporation of results from the *Yohkoh*, *SOHO*, and *TRACE* missions into Chapter 16.
- The latest experimental results in the search for the missing solar neutrinos (Chapter 16).
- Use of *Hipparcos* data in Chapter 17 and throughout the text; new H–R diagram based on *Hipparcos* measurements; discussion of future astrometry missions and their implications.
- Updated information in Chapter 17 on the numbers and mass distribution of stars in our Galaxy.
- Extensive revision of the material on stellar mass determination in Chapter 17.
- Expanded discussion in Chapter 18 of the Local Bubble.
- Updated information in Chapter 19 on brown dwarfs; new material on jets and outflows in star formation.
- New coverage in Chapter 20 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 22; discussion of intermediate-mass and supermassive black holes.
- Latest results in Chapter 23 on Sgr A^* and the Galaxy's central black hole.
- Expanded and substantially revised coverage in Chapter 24 of galaxy collisions, hierarchical merging, and galaxy evolution; updated discussion of the measurement of *Hubble's* constant.
- Streamlined discussion in Chapter 25 of active galaxies and quasars; revised discussion of active galaxy evolution.
- New material in Chapter 25 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.
- Extensive rewriting of Chapter 26 to include recent observations of cosmic acceleration and discussion of "dark energy;" revised discussions of the cosmological constant and the "age controversy."
- New material in Chapter 26 on *HDF-S* and the *Chandra Deep Field.*
- Consistent distances and times in Chapters 25–27, assuming a flat universe with dark matter and dark energy.
- Expanded discussion in Chapter 27 of inflation, dark energy, and structure formation; results from the Boomerang experiment suggesting a flat universe.
- Updated coverage of Europa, Mars, interstellar organic molecules, and extrasolar planets in Chapter 28.

The Illustration Program

Visualization plays an important role in both the teaching and the practice of astronomy, and we continue to place strong emphasis on this aspect of our book. We have tried to combine aesthetic beauty with scientific accuracy in the artist's conceptions that adorn the text, and we have sought to present the best and latest imagery of a wide range of cosmic objects. Each illustration has been carefully crafted to enhance student learning; each is pedagogically sound and tied tightly to the nearby discussion of important scientific facts and ideas. For this edition, the illustration program has been extensively revised and updated, resulting in more than 100 figures that show the latest imagery and the results learned from them.

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 and reinforces the connection between wavelength and radiation properties.

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.

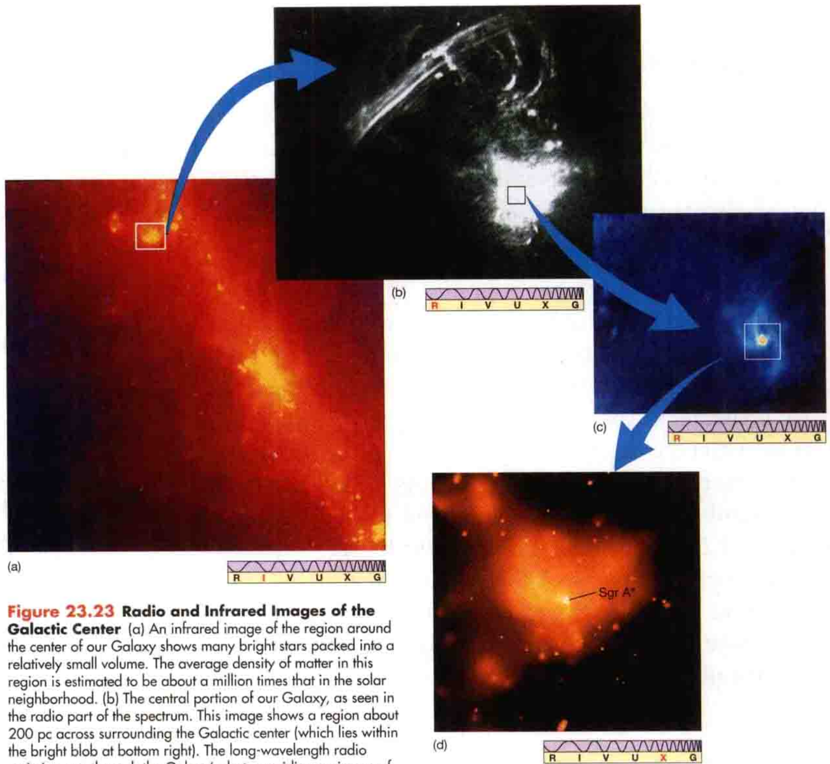
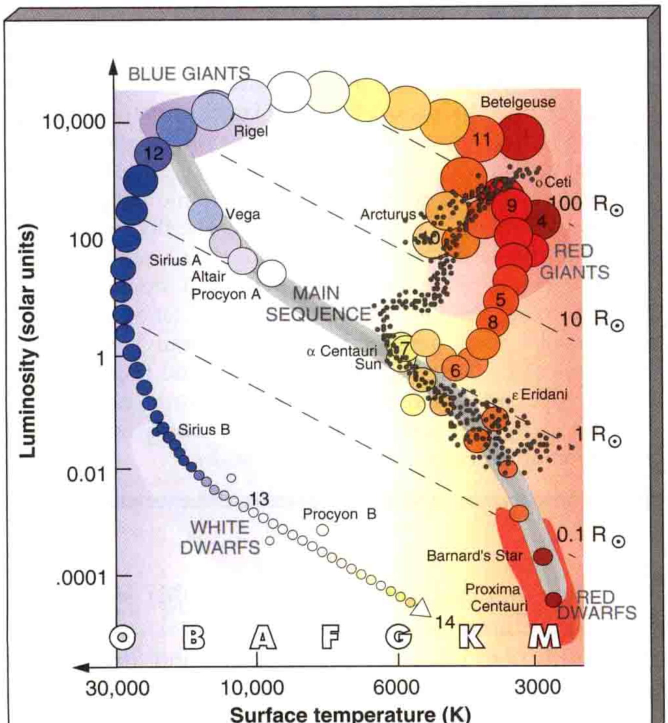


Figure 23.23 Radio and Infrared Images of the Galactic Center (a) An infrared image of the region around the center of our Galaxy shows many bright stars packed into a relatively small volume. The average density of matter in this region is estimated to be about a million times that in the solar neighborhood. (b) The central portion of our Galaxy, as seen in the radio part of the spectrum. This image shows a region about 200 pc across surrounding the Galactic center (which lies within the bright blob at bottom right). The long-wavelength radio emission cuts through the Galaxy's dust, providing an image of matter in the immediate vicinity of the Galaxy's center. (c) The spiral pattern of radio emission arising from Sagittarius A, the center of the Galaxy. The data suggest a rotating ring of matter only 5 pc across. (d) A recent *Chandra* image showing the relation of a hot supernova remnant (red) and Sgr A*, the suspected black hole at the very center. *(UMass/Caltech; NRAO; 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 the Cosmic Distance Ladder
All of the H–R diagrams, assembled and drawn by Lola Judith Chaisson, are presented in a uniform format, using real data wherever possible. The goal is to make it easy for students to compare theoretical and observational results presented across several different chapters. The cosmic distance ladder is a theme that spans the text, and we use an evolving set of standard figures to illustrate how distance measurement techniques fit into and ultimately drive our understanding of the cosmos.

Acetate Overlays
Two unique sets of transparent acetate overlays dramatically illustrate two key pedagogical elements of the book. The H–R diagram overlays demonstrate to students how astronomers organize information about the stars and track their evolutionary histories. The cosmic distance scale overlays summarize, in simplified form, the main methods used by astronomers to chart their way among increasing scales in the universe.

Other Pedagogical Features

As with many other parts of our textbook, 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 five or six) 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 Learning 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. They are organized and phrased in such a way as to make them objectively testable, affording students a means of gauging their own progress.

Key Terms. Like all subjects, astronomy has its own special 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.

Planetary Data Boxes. Providing concise summaries of planetary properties within the body of each chapter, the data are repeated in the Appendix for easy reference. Similar data boxes are provided for both the Moon and the Sun. All planetary data are drawn from the database maintained by the Solar System Dynamics Group at the Jet Propulsion Laboratory.

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. Answers to the Concept Check questions are provided at the end of the book.

Concept Check

- Explain, in terms of Newton's laws of motion and gravity, why planets orbit the Sun.

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. Practically everything in Chapters 6–28 of this text rests on the foundation laid in the first five chapters. For example, it is important that students, when they encounter the discussion of high-redshift objects in Chapter 25, recall not only what they just learned about Hubble's law in Chapter 24 but also refresh their memories, if necessary, about the inverse-square law (Chapter 17), stellar spectra (Chapter 4), and the Doppler shift (Chapter 3). Similarly, the discussions of the mass of binary-star components (Chapter 17) and of galactic rotation (Chapter 23) both depend on the discussion of Kepler's and Newton's laws in Chapter 2. Throughout, the discussion of new astronomical objects relies heavily on comparison with topics introduced earlier.

It is essential to remind students of these links so they can recall the principles on which later discussions rest and, if necessary, review them. To reinforce these connections, "cross links" have been inserted throughout the text—symbols that mark key intellectual bridges between material in different chapters. The links are denoted by the symbol ∞ and, together with a section reference (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.

27.5 The Formation of Structure in the Universe

6 Just as stars form from inhomogeneities in interstellar clouds, galaxies, galaxy clusters, and larger structures are believed to have grown from small density fluctuations in the matter of the expanding universe. ∞ (Sec. 19.1) Given the conditions in the universe during the atomic and galactic epochs (Table 27.1), cosmologists calculate that regions of higher-than-average density that contained more than about a million times the mass of the Sun would have begun to contract. There was thus a natural tendency for million-solar-mass "pregalactic" objects to form. In Chapter 24 we saw a little of how these pregalactic fragments might have interacted and merged to form galaxies. ∞ (Sec. 24.4) Here, we concern ourselves mostly with the formation of structure on much larger scales.

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.

DISCOVERY 5-2

The *Chandra* X-Ray Observatory

Animation

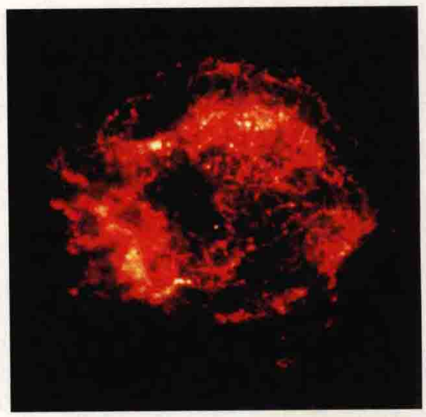
In the summer of 1999, the Space Shuttle *Columbia* carried into space the largest and most sophisticated X ray telescope ever built. Known simply as *Chandra* after the late Indian-American astrophysicist Subramanyan Chandrasekhar, the *Chandra X-ray Observatory* (*CXO*) is the third of NASA's "Great Observatories" to be deployed in space (the other two being *Hubble* and *Compton*). But unlike the others that hug Earth in low orbits only hundreds of kilometers in altitude, *Chandra* was boosted by onboard rockets to a much higher, elliptical orbit; its farthest point from Earth, 140,000 km, reaches almost one-third of the way to the Moon. The telescope's orbital period is 64 hours. Such an orbit takes *Chandra* well above most of the interfering van Allen belts girdling Earth and allows more efficient observations of the cosmos.

The first figure below, at left, shows the *Chandra* spacecraft in its final stages of construction in 1998. The technicians give perspective to this bus-sized craft which contains computers, antennae, and recorders to transmit and receive information between *Chandra* and ground stations, as well as finely polished, barrel-shaped mirrors to guide the X rays to a precise focus (see Figure 5.32). The front end of the telescope is at the bottom of the photograph and the scientific instruments at the top. Those instruments include a high-resolution camera to take images of X rays and a spectrometer to record the energy of those X rays. Data collected by *Chandra*'s instruments are relayed from orbit to scientists at the mission control center in Cambridge, Massachusetts.

The second figure below shows an example of *Chandra*'s scientific capabilities; many more will be found throughout this textbook. The object shown is a supernova remnant—a debris field of scattered, glowing gases that were once part of a massive star. This "object," known as Cas A, is all that remains of a star in the constellation Cassiopeia. Its explosion was observed about 320 years ago. For scale, the debris is spread across some 10 light-years; Cas A itself is roughly 10,000 light-years from Earth.

The image shows what *Chandra* saw when it targeted Cas A for its first image taken in X rays. The region, barely visible in the optical part of the spectrum, is awash in brilliantly glowing X rays—large amounts of energy emitted at wavelengths to which the human eye is insensitive. (The X rays detected by *Chandra* in orbit are converted to radio waves that are then sent to ground stations, after which they are converted into visible images by astronomers for display and analysis.) This X-ray image shows that the gas in the wisps of ejected stellar material has temperatures of nearly 50 million kelvins, and the bright white point at the very center of the debris might well be a black hole—all of which will be studied in more detail in Chapters 21 and 22.

(NASA)



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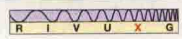


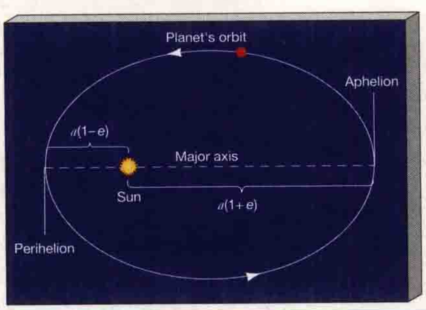
MORE PRECISELY 2-1

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.

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 400×3 $(1 + 0.5) = 600$ 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 $e = 0.249$ (see Table 2.1). However, many meteoroids, and all comets (see Chapter 14) have eccentricities considerably greater than this. In fact, most comets visible from Earth have eccentricities very close to $e = 1$. Their highly elongated orbits approach within a few astronomical units 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 quantitative treatments of subjects discussed qualitatively in the text, or explore the physics of astronomical processes in greater detail. 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) affords instructors greater flexibility in setting the level of their coverage.

Chapter Summaries. The chapter summaries, a primary review tool for the student, have been revised and streamlined for the fourth edition. All key terms introduced in each chapter are listed again, in context and in boldface, along with page references to the text discussion.

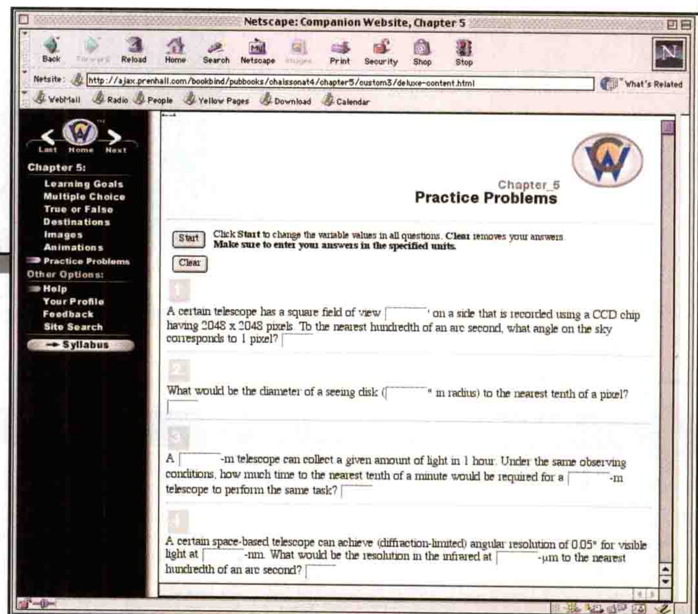
Questions, Problems, and Projects.
Other elements of the end-of-chapter material have also seen substantial reorganization and expansion:

- Each chapter 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* questions appear at the end of the book.
- Each chapter also has 20 Review and Discussion questions (increased from 15 in the previous edition), which may be used for in-class review or for assignments. 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 **Problems** have been expanded to contain 15 questions, spanning a somewhat broader range of difficulty than those in the previous edition. The level of difficulty is indicated on each problem. Answers to the Problems, particularly for the more sophisticated ones, are not necessarily contained verbatim within the chapter, but all the information required to solve the problems is in the text. Solutions for the odd-numbered problems are given at the end of the book. New for this edition, we have put algorithmic versions of the problems in a Practice Problems module of the text's Companion Website: The values in each problem change each time the student uses a chapter's problem set, thereby giving students unlimited practice in solving numeric problems.
- Each chapter includes 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.

PROBLEMS WWW *Algorithmic versions of these questions are available in the Practice Problems module of the Companion Website.*

The number of squares preceding each problem indicates its approximate level of difficulty.

1. ■ A certain telescope has a 10′ × 10′ field of view that is recorded using a CCD chip having 2048 × 2048 pixels. What angle on the sky corresponds to 1 pixel? What would be the diameter of a typical seeing disk (1″ radius), in pixels?
2. ■ Estimate the fraction of incoming starlight blocked by the observer and observing cage at the prime focus of the Hale 5-m telescope (see Figure 5.8).



New to this edition are **Collaborative Exercises** ▶ provided by Tim Slater at Montana State University. These interactive collaborative learning group activities are designed to encourage students to work together on reasoning tasks. They are designed specifically for use in the classroom, allow for multiple correct solution pathways, and give students some degree of choice in how to approach solving a complex, multifaceted problem. Most tasks require 7–12 minutes to complete.

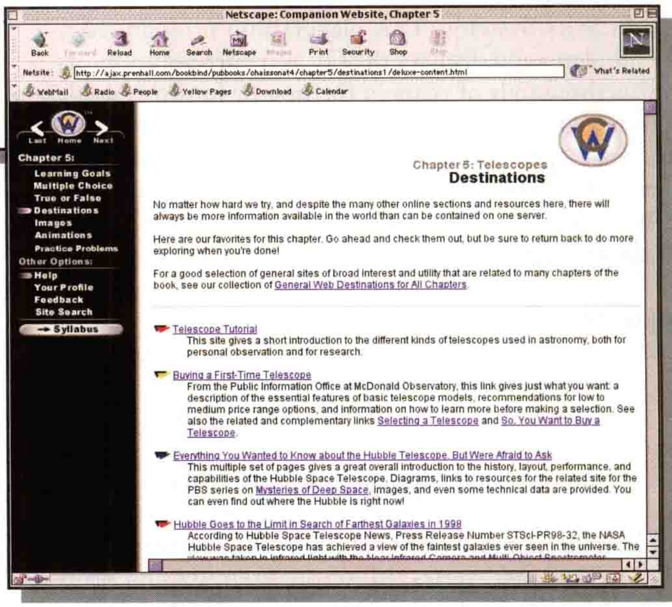
COLLABORATIVE EXERCISES

1. **Radio Interferometer.** Determine the maximum size interferometer your group could build if you placed 2 m radio telescopes where each group member lives.
2. **Observing New Stars in the Orion Region.** Your group has been assigned to observe the region of the sky around Orion to look for bright new stars hidden in molecular

RESEARCHING ON THE WEB

To complete the following exercises, go to the online Destinations module for Chapter 5 on the Companion Website for Astronomy Today 4/e.

1. Access the "Buying a First-Time Telescope" page and determine which telescopes can be purchased for about $1000.
2. Access the "Introduction to Light Pollution" page and determine the five most common contributors to light pollution.



▲ Also new to this edition and provided by Tim Slater are "**Researching on the Web**" exercises. Using stable and maintained Internet resources hyperlinked from the Destinations module on the text's Companion Website, students are assigned analysis tasks using current and real-time Internet data sources. Quite different from the single correct answer tasks often used, many of these engaging tasks yield different but correct results for students accessing data resources on different days.

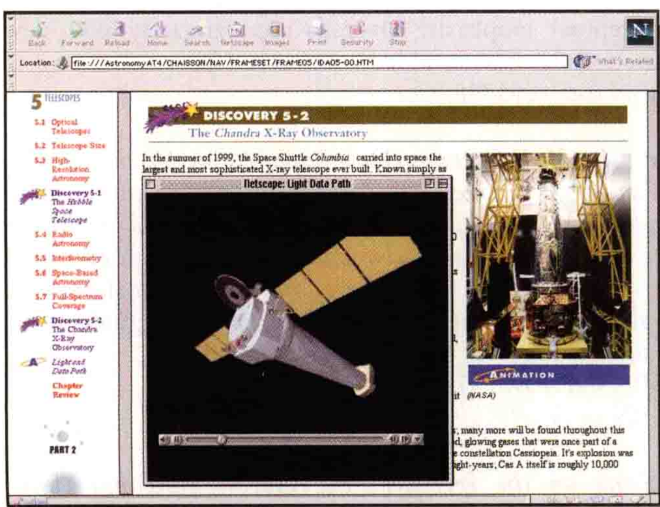
SKYCHART III PROJECTS

The SkyChart III Student Version planetarium program on which these exercises are based is included as a separately executable program on the CD in the back of this text.

1. ■ Change your view to a place in the Southern Hemisphere. Identify the brightest stars and most prominent constellations in the southern sky. Can you identify a southern pole star, the equivalent to the North Star, Polaris?
2. ■ Change your viewing location to Buenos Aires on January 1, 2001 at 12:00 a.m. Print a chart in which your view is

scope and adjust the parameters for field width to match those of your telescope. If you wish to drive a telescope with the software, it will be necessary first to deselect *Emulate real telescope connection* and to align the telescope according to normal procedures for that telescope. Either with a real telescope or with emulation, locate an object of interest on

▲ Finally, each chapter now concludes with **SkyChart III Projects** by Erik Bodegom and Sean Goe of Portland State University and Duane Ingram of Rock Valley College. These exercises are based on the SkyChart III Student Version planetarium software, which is included as a separately executable program on the e-book CD in the back of the text. Square bullets preceding each exercise indicate its approximate level of difficulty. Appendix 4 provides general instructions for the software, and specific menu commands are included with each exercise. Instructor's notes for all the exercises are included in a password-protected part of the text's Companion Website.



e-Book CD and Companion Website

◄ **e-Book CD.** Each copy of the text comes with a free e-book CD. This is a browser-based version of the text with extensive hyperlinks (over 3000 throughout the text), 61 videos integrated with relevant text discussions, and links to our Companion Website, which is organized by text chapter and updated monthly. We have added 12 new, exclusive animations from the Wright Center at Tufts University and redigitized all the videos and animations for larger size and higher resolution, and now they all have narrations. A script to facilitate use of the e-Book CD under Unix is available at:

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

SkyChart III Student Version. Also included on the e-Book CD as a separately executable program is a student version of the SkyChart III planetarium software by Southern Stars Systems. This planetarium program accurately simulates and displays the sky as it currently appears, as well as thousands of years in the past or future. The sky can be viewed from any place on Earth, or from any object in the solar system or beyond. The program includes a database of 300,000 fully customizable objects based on NASA's SKY2000 Master Star Catalog, showing all stars up to about magnitude 10.

Companion Website. Our Companion Website at http://www.prenhall.com/chaisson organizes Destinations (links to related websites), additional Images and Animations, Multiple Choice, True/False, and Labeling exercises, and algorithmic versions of the text's end-of-chapter Problems on a chapter-by-chapter basis. The Destinations, Images, and Animations modules are updated monthly to keep links current and provide information on significant new discoveries. All of the exercises and problems are interactive, meaning that the student answers the questions on-line and then receives immediate scoring and feedback, including text section references for any areas the student needs to study further if they answered a given question incorrectly.

Additional Supplementary Material

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

Comets Published annually at the beginning of each academic year and available free to 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 either 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.
ISBN 0-13-093801-7

Instructor's Resource Manual By 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, answers to the end-of-chapter Review and Discussion questions and Problems. New features include an expanded introduction with an overview of how to utilize the IRM, an index of demonstrations, applications of the writing questions, sample assignments, discussion of common student misconceptions, teaching notes for the collaborative exercises, and a list of selected readings for each chapter.
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Media Portfolio CD-ROM By Suzanne Willis (Northern Illinois University). This flexible, easy-to-use tool contains a wealth of photographs, line art, animations, and videos to use in class lectures. Instructors can easily search, access, and organize the materials according to their lecture outlines and add their own visuals and lecture notes. The hybrid CD contains all of the line art and photographs from *Astronomy Today 4e*, as well as the animations and videos that are on the e-Book CD in the back of the student text. In addition, the Image Viewer incorporates slides from the current and past editions of *Comets*.
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net. Everything you need to know to get yourself on-line and browsing the World Wide Web!
ISBN 0-13-028253-7

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BRIEF CONTENTS

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