ASTRONOMY

JOURNEY TO THE COSMIC FRONTIER

JOHN D. FIX

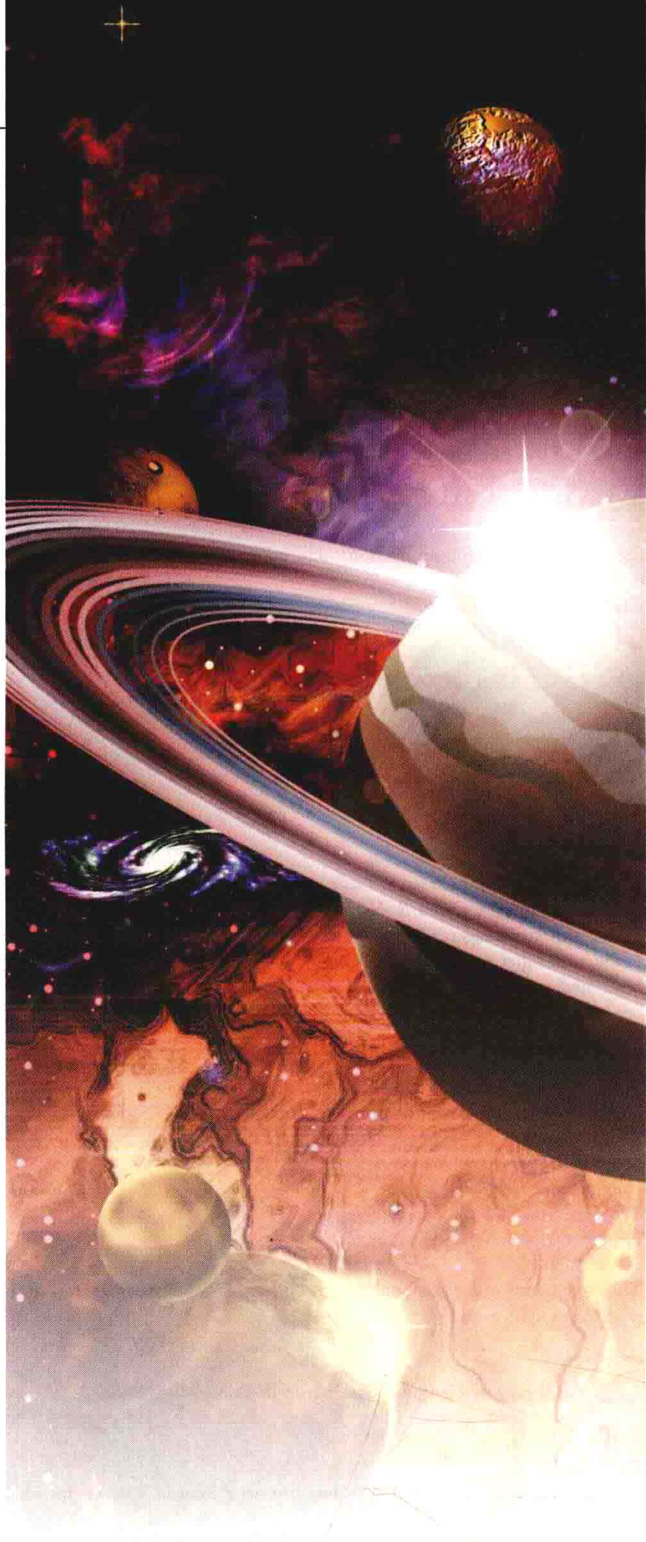
THIRD EDITION

Astronomy

Journey to the Cosmic Frontier

Third Edition

John D. Fix
University of Alabama in Huntsville



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ASTRONOMY: JOURNEY TO THE COSMIC FRONTIER
THIRD EDITION

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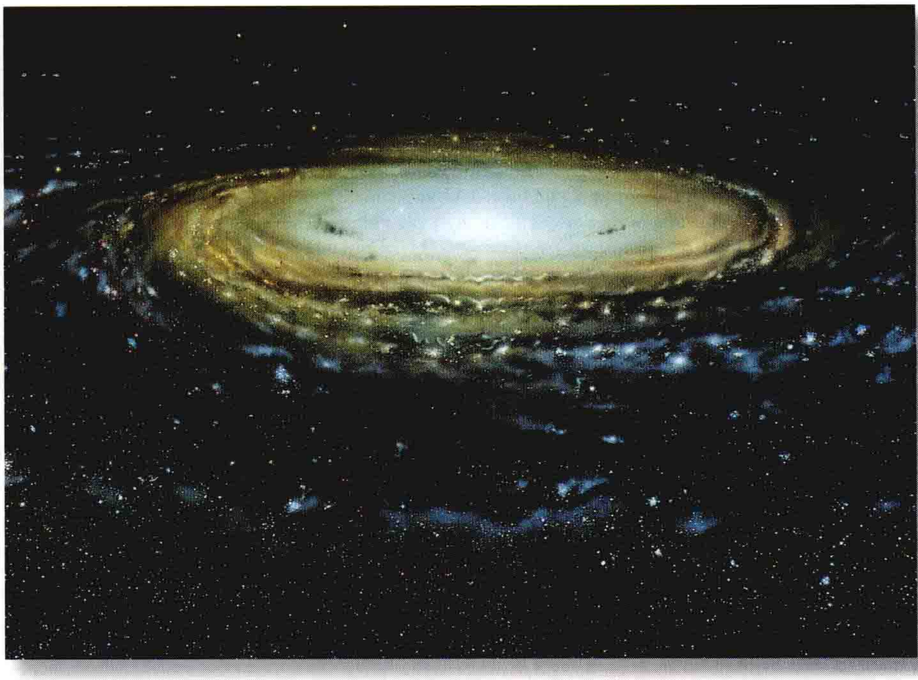
For Cynthia



Artist Jon Lomberg was assisted by astronomers Jeff Goldstein and Leo Blitz in creating this realistic depiction of the Milky Way from the perspective of 58,680 light years from the center of the galaxy and over 10,000 light years above the plane of the galaxy. This perspective view is oriented from a point in the constellation Auriga, nearly 32,000 light years from Earth. (Copyright © 1992 by Jon Lomberg and the National Air and Space Museum.)

Foreword

A layman challenges astronomers with the assertion: "If every object in the universe except the Earth, the Sun, and the Moon were eliminated, most people wouldn't know the difference." There is, undeniably, a measure of truth to this assertion. It resembles the assertion that humans are interested only in food, shelter, and procreation. But the full truth is much richer and more complex. Even the most primitive peoples marvel at the dazzling beauty of the night sky, identify stable patterns in the arrangement of easily identified stars, and note the movement of a few bright points of light, the planets, on the star field. They also derive spiritual inspiration from this scene. More advanced civilizations have shared this inspiration and gone beyond it to seek a scientific understanding of the grand scheme of the universe.

Even the most sophisticated modern astronomers are motivated by a primal awe of their subject. These astronomers then attempt rational explanations of its infinite detail, piece by piece, and they carry along with them the whole or nearly the whole of humanity. For example, what could be more esoteric or more remote from everyday experience than a supernova, a galaxy, the Big Bang, or a black hole? But these astronomical concepts have become a part of popular culture and language.

Astronomy takes its place with art, music, literature, drama, and religion as an inspiring subject in the minds and hearts of sensitive and thoughtful individuals. It contributes to lifting the human spirit above the break-even level of bare survival. We would be much the poorer without it. Is astronomy of practical importance? In a restricted sense, yes; it plays a key role in navigation, timekeeping, and the manifestation of physical principles at work in complex systems. But the grandeur and enormous physical scale of the universe and the realization of our tiny part in it are the aspects of astronomy that enrich our lives and permeate our culture.

Join Professor Fix and his professional colleagues in this great intellectual adventure of exploration and discovery.

James A. Van Allen

Preface

As James Van Allen writes in his foreword to this book, astronomy permeates our culture. Of all the sciences, astronomy is the one that generates the most public interest. There are hundreds of thousands of amateur astronomers, two monthly astronomy magazines with healthy circulations, and television specials about important astronomical discoveries. The *Pathfinder* landing on Mars in July 1997 got headline coverage in newspapers and was featured on newscasts. The *Pathfinder* website received 40 million hits in a single day. Part of the public interest in astronomy is due to the dramatic scope of the science. Part, I am sure, is because non-professionals cannot only understand astronomical discoveries, but also make some of those discoveries. Amateur astronomers regularly carry out important astronomical observations, often with telescopes they have made themselves.

THE GOALS OF ASTRONOMY: JOURNEY TO THE COSMIC FRONTIER

I wrote this book as a text for an introductory course in astronomy for college students. I have taught such courses for many years at the University of Iowa and the University of Alabama in Huntsville. One of my main goals in those courses, and one of my main goals in this book, is to provide my students with a broad enough, deep enough background in astronomy that they will be able to follow current developments years after they finish my course. This book is current with regard to recent developments, such as the discoveries made with the Hubble Space Telescope and the results from *Mars Global Surveyor* and *Galileo.* But I want my students to continue to learn about astronomy long after these developments have been followed by newer, even more exciting, ones. I hope that years from now my students, and the readers of this book, will be able to read and watch stories about astronomy, in any of the print or visual media available to them, with confidence that they know what is going on. I can guarantee that future astronomical discoveries will occur at least as often as they do today, and I want my students to be prepared to enjoy future discoveries.

NEW TO THIS EDITION

Here are a few examples of how this text has stayed current:

- Electronic Media Integration
- Planetarium Exercises at the end of most chapters
- Group Exercises at the end of all chapters
- Temperature Conversion Chart (Appendix 3)
- Periodic Table of the Elements (Appendix 4)
- Digital Content Manager CD-ROM for Instructors
- Essential Study Partner CD-ROM for students
- Constellation Quiz on the Essential Study Partner CD-ROM and Online Learning Center
- Six Interactives on the Essential Study Partner CD-ROM and Online Learning Center
- Links to *The New York Times* astronomy articles via the Online Learning Center
- Updated information on new, large telescopes (Chapter 6)
- New Mars images from *Mars Global Surveyor* and their implications for water on Mars (Chapter 11)
- New images of Jupiter (Chapter 12) and its satellites (Chapter 14)
- New data on the Kuiper belt and *NEAR-Shoemaker* landing on Eros (Chapter 17)
- Revised discussion of distant supernovae and the acceleration of expansion (Chapter 26)
- More than 75 images have been replaced with current and up-to-date images.

I hope that all the explanations and descriptions in the book will not obscure the awe and sense of wonder that all astronomers feel when they pause in their work and think about the beauty of the universe. People have felt that awe since prehistory and our wonderment has increased as we understand more about the order and underlying structure of the universe. If this book helps its readers to value both the sheer beauty of planets, stars, and galaxies and the equally beautiful principles that organize the universe, it will be a success.

I would be grateful for any suggestions and advice for improving this book. If you have any ideas to offer, please contact me at the Department of Physics, University of Alabama in Huntsville, Huntsville, Alabama, 35899, or by e-mail at fixj@uah.edu.

PEDAGOGICAL FEATURES

New Electronic Media Integration These NEW Interactives offer students a fresh and dynamic approach to learn the astronomy basics. Available on the Online Learning Center and Essential Study Partner CD-ROM, these Interactives are referenced in the text by this icon near the corresponding figures and sections.

INTERACTIVE

To help better understand key concepts, this animation icon has been placed near figures and sections where students can explore additional information on the Online Learning Center and Essential Study Partner CD-ROM.

Chapter Introduction Every chapter begins with an introduction designed to give the historical and scientific setting for the chapter material. The overview previews the chapter's contents and what you can expect to learn from reading the chapter. After reading the introduction, browse through the chapter, paying particular attention to the topic headings and illustrations so that you get a feel for the kinds of ideas included within the chapter. Also included in the chapter introduction are questions to explore while reading the text.

Historical Emphasis Throughout the book I have emphasized the historical development of astronomy to show that astronomy, like other sciences, advances through the efforts of many scientists and to show how our present ideas developed. In the main body of the text there are many comparisons of what was once known about a particular phenomenon to what we now know about it. These historical comparisons are used to illustrate the cycle of observation, hypothesis, and further observation, which is the essence of the scientific method of discovery.

Worked Examples Boxes This book, like my course, presumes that most of its readers are not science majors and that they probably have not had a college-level science or mathematics course. The book provides a complete description of current astronomical knowledge, neither at an extremely technical level nor at a level that fails to communicate the quantitative nature of physical science. I have used equations where they are relevant, but follow the equations with boxes containing one or more worked examples. The examples in the boxes show how and when to use each equation and tell why the equation is important.

End of Chapter Material

Chapter Summary: The summary highlights the key elements of the chapter.

Key Terms: Terms are defined in context and found in the glossary.

Conceptual Questions: The Conceptual Questions require qualitative verbal answers.

Problems: The reader's mastery of the equations can be tested by the Problems at the end of each chapter. The problems require numerical calculations.

Figure-Based Questions: The Figure-Based Questions require the reader to extract the answer from a particular graph or figure in the chapter.

New! Planetarium Exercises: The planetarium exercises require the reader to investigate key ideas of the chapter using the planetarium software on the CD that accompanies the book.

New! Group Exercises: The group exercises require readers to work in groups to discuss different viewpoints on issues in the chapter or to carry out small group projects.

End-of-Text Material At the back of the text you will find appendices that will give you additional background details, charts, and extensive tables. There is also a glossary of all key terms, an index organized alphabetically by subject matter, and a look at the constellations printed on the inside covers for reference use.

SUPPLEMENTS

NEW! Interactives McGraw-Hill is proud to bring you an assortment of outstanding interactives. These interactives offer a fresh and dynamic approach to learning astronomy basics. Each interactive allows students to manipulate parameters and gain a better understanding of topics such as blackbody radiation, the Bohr model, a solar system builder, retrograde motion, cosmology, and the H-R diagram by watching the effect of these manipulations. Each interactive includes an analysis tool (interactive model), a tutorial describing its function, content describing its principle themes, related exercises, and solutions to the exercises. Plus, users can jump between these exercises and the analysis tools with just the click of the mouse.

PowerWeb PowerWeb is a part of the Online Learning Center for Fix, *Astronomy.* This online resource provides high-quality, peer-reviewed content including up-to-date articles from leading periodicals and journals, current news, weekly updates with assessment, interactive exercises, Web research guide, study tips, and more.

NEW! Links to *The New York Times* Astronomy articles are available via PowerWeb on The Online Learning Center.

NetTutor NetTutor, an invaluable aid for all students, offers *live, personalized tutoring* via the Internet. Using NetTutor's powerful WWWhiteboard software, students and tutors are able to use proper mathematical notation as well as other highlighting features—making this a unique learning experience. Students may also post questions to an expert in the Q&A Center and receive a reply within 24 hours. The Archive Center provides a browseable list of questions and answers maintained by the subject tutor.

NEW Design! Online Learning Center www.mhhe.com/fix McGraw-Hill offers a wealth of online features and study aids that greatly enhance the astronomy teaching and learning experience. The new design will make it easier for students to take full advantage of the following tools:

- **Interactive student technology:** Includes NEW! "Interactive" Astronomy applets, NEW! Links to *The New York Times* astronomy articles, PowerWeb, NetTutor, Animations, and Constellation Quizzes.

- **Text-specific features:** Includes Learning Objectives, Chapter Overview, Chapter Summary, Practice Quizzes, Conceptual Questions, Problems, Key Term Flashcards, Glossary, and Crossword Puzzles.
- **General astronomy features:** Includes Planetarium Activities, Group Activities, Astronomy Timeline, Universally Speaking, Astronomy Links Library, Astronomy Picture of the Day, Further Readings, Ask the Author, and an Author Astronomy Update Page.
- **Additional instructor resources:** Includes Instructor's Manual, PowerPoint Presentation, and PageOut.

NEW! Essential Study Partner CD-ROM The ESP is the new student CD-ROM that accompanies the Fix, *Astronomy* text. The ESP offers study aids organized by topic. Each topic includes animations, tutorials that model key concepts, practice quizzes, math help for difficult concepts, as well as flashcards and crossword puzzles using key terms and glossary definitions. Also included are guest essays written by professors that expose students to a different viewpoint on a topic or a new research project. For your convenience, the six new Interactive applets also are available on the ESP. Finally, rounding out this complete study tool, *The Earth-Centered Universe* planetarium software is provided. The ESP is packaged free with each new textbook.

Instructor's Testing and Resource CD Available on CD-ROM in both Mac and Windows platforms, this test bank utilizes Brownstone Diploma software to quickly create customized exams. This user-friendly program allows instructors to search for questions by topic, format, or difficulty level; edit existing questions or add new ones; and scramble questions and answer keys for multiple versions of the same test. For your convenience, the Instructor's Manual and set of Test Bank questions will be available in Word and pdf formats.

Instructor's Manual The Instructor's Manual is found at the Fix Online Learning Center and on the Instructor's Testing and Resource CD, and can be accessed only by instructors.

NEW! Digital Content Manager This multimedia collection of visual resources allows instructors to utilize artwork from the text in multiple formats to create customized classroom presentations, visually-based tests and quizzes, dynamic course website content, or attractive printed support materials. The digital assets on this cross-platform CD-ROM are grouped by chapter within easy-to-use folders.

Transparencies This collection contains 80 overhead transparencies of conceptually-based artwork from *Astronomy: Journey to the Cosmic Frontier, Third Edition.*

ACKNOWLEDGMENTS

I am grateful to many people who helped in the development and production of this book. Perhaps the most important contributors to the book are the more than ten thousand University of Iowa and University of Alabama-Huntsville students who took my beginning astronomy classes. They taught me how to teach introductory astronomy and showed me the ingredients a good textbook must have. I owe a large debt to my fellow astronomers: Andrea Cox, Larry Molnar, Bob Mutel, John Neff, Stan Shawhan, Steve Spangler, and James Van Allen. Their help ranged from years' worth of lunchtime discussions about astronomy teaching to expert advice on difficult sections of this book. I am also grateful to Carissa Holler, who gave me great help in locating references and figures, Matt Neely, who took some of the beautiful astronomical photographs in the book, and Cynthia and Stephen Fix, who were the first reviewers of the first draft of the book.

Many students and teachers have pointed out errors in earlier editions of the book and offered suggestions for improving it. I found the comments of John Broderick, Anne Cowley, Bill Keel, Kathy Rajnak, Jeremy Tatum, and Virginia Trimble especially helpful. My colleague Larry Molnar compiled a lengthy, detailed list of comments and suggestions that improved both the book and my understanding of a number of topics. I owe Larry a special expression of thanks.

I also want to thank the dozens of people at McGraw-Hill who have worked on this and previous editions of the book, including Brian Loehr, Gloria Schiesl, Debra Hash, Sherry Kane, Rick Noel, Jodi Banowetz, Brenda Ernzen, Jeffry Schmitt, Lisa Gottschalk, Donna Nemmers, Stuart Paterson, Sandy Ludovissy, and Lori Hancock, who were key members of the book teams. Jim Smith, John Murdzek, Lloyd Black, Donata Dettbarn, Colleen Fitzpatrick, Mary Sheehan, Lori Sheil, Daryl Bruflodt, Brian Loehr, and J. P. Lenney have been my editors. Jim began the project and the others saw it to completion. Their advice and comments have nearly always been right on target. I am especially grateful to John Murdzek, who not only gave me his own advice but also digested and distilled reviewers' comments so that I could benefit as much as possible from the advice of the many reviewers of the various drafts of the first edition.

REVIEWERS OF PREVIOUS EDITIONS

The following astronomers and physicists reviewed previous editions of the book. Their comments and advice greatly improved the readability, accuracy, and currency of the book.

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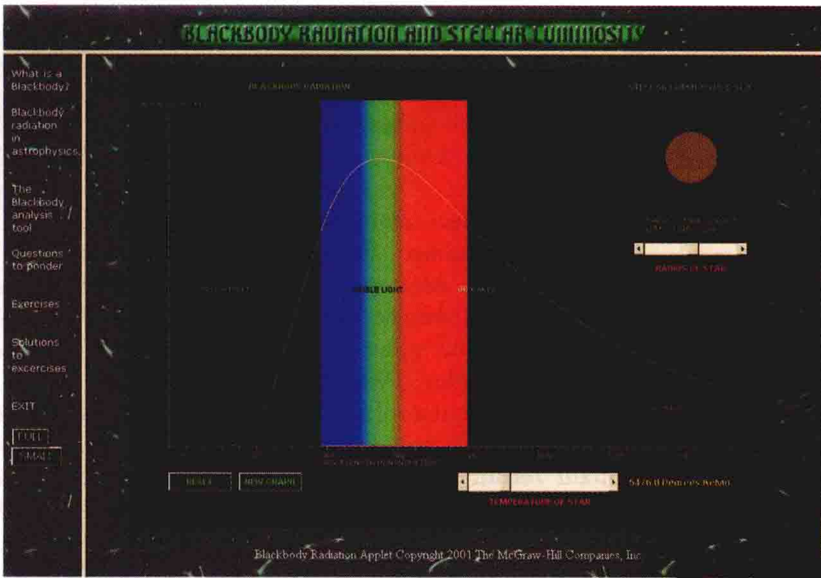
Guided Tour

INTERACTIVES LIKE NO OTHER

McGraw-Hill is proud to bring you an assortment of outstanding Interactives like no other. Available for students on the Online Learning Center and the Essential Study Partner CD-ROM, and for instructors on the Digital Content Manager, these Interactives offer a fresh and dynamic method to teach and learn the astronomy basics.

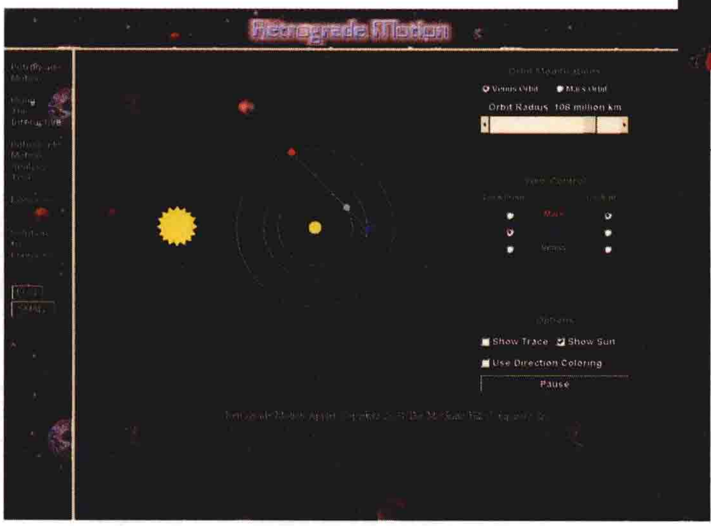


Blackbody Radiation and Stellar Luminosity

In the Blackbody Radiation Interactive, students can manipulate the scroll bar in the upper-right corner and see how temperature influences the luminosity of stars. In the scroll bar at the bottom portion of the interactive, users can see how the temperature of a star affects the wavelength at which the star is brightest.

Atomic Emission and Absorption

This interactive, based on the Bohr Atom, illustrates the concept of emission and absorption spectra as well as Kirchhoff's laws by having students "build an atom." Students can construct an atom with energy levels corresponding to different colors of light. By heating a gas of these atoms or shining a continuum light through them, students will construct different spectra.



Retrograde Motion

This interactive illustrates how the different planetary orbits lead to retrograde motion in the night sky. The interactive shows the view from the Earth as well as from a "bird's-eye" perspective in space. Users will be able to manipulate the sizes of planetary orbits, plus be able to view the retrograde motion from different perspectives, and see, for example, what the retrograde motion of Earth looks like from Mars.

Solar System Builder

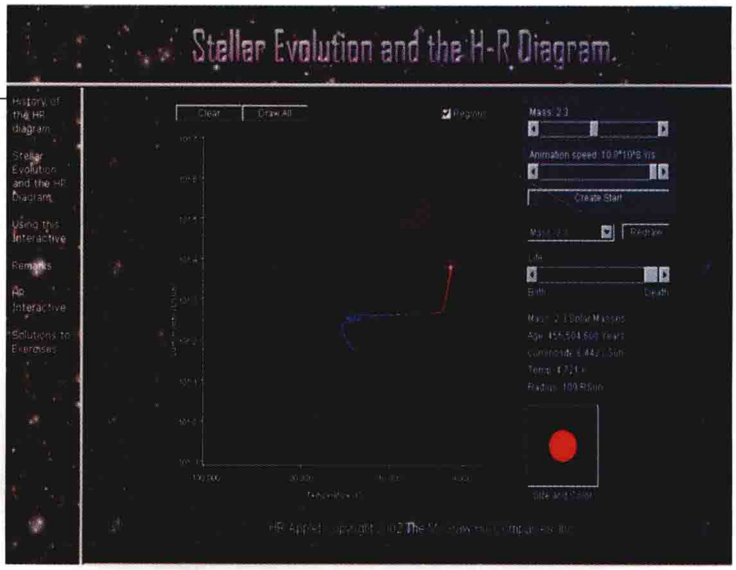
This interactive allows students to build their own solar systems by placing planets of different masses at different locations and watching these systems evolve. Choose from a Sun and Earth system; our solar system up to Saturn; or 2000 randomly selected systems. Watch how a hot Jupiter interacts with a Mercury-sized planet, or how Saturn interacts with a Mars-sized planet. What will happen? Check out the interactive and see for yourself.

Cosmology and the Cosmos' Fate

The Cosmology Interactive allows users to play with the equations for the evolution of the universe. Students will see how the universe might evolve for various values of parameters, such as Hubble's constant and the density parameter Omega. Students will see a representation of the universe's evolution in terms of the expansion or collapse of a uniform distribution of galaxies in a window viewer in the upper right. Users can see how the colors of the galaxies change from red when they are receding from each other (redshifting) to blue (blueshifting) when they approach one another in Omega > 1 universes.

Stellar Evolution and the H-R Diagram

Students can manipulate the properties of a star on the main sequence (temperature and luminosity), and see how the star evolves along its evolutionary path at a rate determined by its nuclear burning timescale. As the star evolves, its color and size will change.



NEW PLANETARIUM AND GROUP ACTIVITIES

New to this edition are planetarium and group activities. Use the Earth-Centered Universe Planetarium software to find out what constellation the Sun was in on the date of your birth. Or, use the Internet to study the motions of sunspots.

Planetarium Activity

Set chart mode to star atlas, the status line to on, and the field to 45°. Set the date to April 1, 2003. Center on Mars and lock the display to Mars. Set the animation trails to on and turn off all the trail labels. Set the time step to 2 days and start the animation. When Mars undergoes a retrograde loop, record the month during which retrograde motion occurs and the constellation in which it occurs. Sketch the shape of the retrograde loop. Repeat these steps for the next three retrograde loops. Use your data to estimate the synodic period of Mars. When do you think the retrograde motion of Mars will appear in the constellation of Aquarius again? Do you see a pattern to the changes from one retrograde loop to the next?

Group Activities

1. Divide your group into two subgroups. After a few minutes of preparation, have one subgroup present the evidence used in Percival Lowell's time to demonstrate the likelihood of life on Mars. Let the other subgroup huddle for a minute and then try to refute the evidence of the first subgroup based on more recent information.
2. With your group, prepare a plan for what you would need to take along in order to survive 6 months on the Martian surface. If possible, make a brief presentation of your plan in class. Invite the class to discuss whether recent discoveries of ice on Mars would have any impact on your plan.

The scientists who preceded Isaac Newton had developed the concept of inertial motion—that an object will move at a constant speed in a straight line unless an unbalanced force acts on it. They had also learned that the force responsible for planetary motion was a central force directed toward the Sun.

HISTORICAL EMPHASIS

Located throughout the book, these boxes emphasize the historical development of astronomy to show that astronomy, like other sciences, advances through the efforts of many scientists and to show how our present ideas developed.

PLANETARY DATA BOXES

We've added summaries of planetary data and made them even easier to access.

Table 11.1 Planetary Data

Mars

Orbital period	1.88 years
Mass	$0.11\ M_{Earth} = 6.42 \times 10^{23}$ kg
Radius	$0.53\ R_{Earth} = 3397$ km
Density (relative to water)	3.94
Escape velocity	5.0 km/s
Surface gravity	0.38 g
Global temperature	210 K
Main atmospheric gases	CO_2, N_2, Ar
Rotation period	24.6 hours
Axial tilt	25°
Known satellites	2
Distinguishing features	Most "Earthlike" environment, evidence of ancient oceans

WORKED EXAMPLE BOXES

We've made it even easier for students to understand math by highlighting the numbered mathematical equations in the text and the corresponding boxes that contain worked examples. An important feature of these boxes is to show how and when to use each equation and tell why the equation is important.

564 Chapter 23 Galaxies

FIGURE 23.27
Hubble's Law
The modern determination of Hubble's law extends to a distance of over 100 Mpc. In this graph, Hubble's constant is taken to be 70 km/s per Mpc. The scatter of points about the line is mostly due to uncertain distances.

where v is recession velocity, d is distance, and H ... **constant.**

Hubble's constant is the slope of the strai... describes the relationship between recession ... distance. Hubble calculated that H has ... 500 km/s per Mpc. This means that the speed with which the galaxies are receding increases by 500 km/s for each additional megaparsec of distance from the Sun. It turns out, however, that Hubble had systematically underestimated the distances to galaxies by a factor of 5 or 10. The Virgo cluster of galaxies, for example, which Hubble placed at a distance of 2 Mpc, is actually 20 Mpc away. Underestimating the distances of the galaxies is equivalent to overestimating the value of H. Thus, today's estimates of the value of Hubble's constant range between 50 and 85 km/s per Mpc. The best estimate, based on Hubble Space Telescope measurements of distances to galaxies, is 70 km/s per Mpc with an uncertainty of about 8 km/s per Mpc.

... distant galaxies and other objects, astronomers often assume that Hubble's law can be extrapolated beyond the greatest distance for which distances can actually be measured. By reorganizing the equation for Hubble's law, distance (d) is related to recession velocity (v) and Hubble's constant (H) by

$$d = v/H \qquad (23.2)$$

The Expanding Universe At first, it may seem incredible that virtually all of the galaxies are moving away from the Earth, the Sun, and the Milky Way. After all, as astronomical thinking matured, it became clear first that the Earth isn't in the center of the solar system and then

Equation 23.2 Hubble's Law

Equation 23.2 can be used to find the distance of a galaxy if its recession velocity can be measured. Suppose Hubble's constant has a value of 70 km/s per Mpc. Equation 23.2 then gives the distance of a galaxy with a recession velocity of 15,000 km/s as

$$d = v/H = \frac{15{,}000\ \text{km/s}}{70\ \text{km/s per Mpc}} = 210\ \text{Mpc}$$

Notice that the distance for a given recession velocity decreases as the value of Hubble's constant increases. If H is assumed to be 100 km/s per Mpc, for example, then the distance of a galaxy with a recession velocity of 15,000 km/s is

$$d = v/H = \frac{15{,}000\ \text{km/s}}{100\ \text{km/s per Mpc}} = 150\ \text{Mpc}$$

That is, for large values of Hubble's constant, the galaxies are nearer and the universe is smaller than for small values of Hubble's constant.

NEW MARS IMAGES

New *Mars Global Surveyor* images have been added, including this one of young Martian channels. Also several recent Hubble images also have been added, including this one showing a dust storm that covered the entire planet in September 2001.

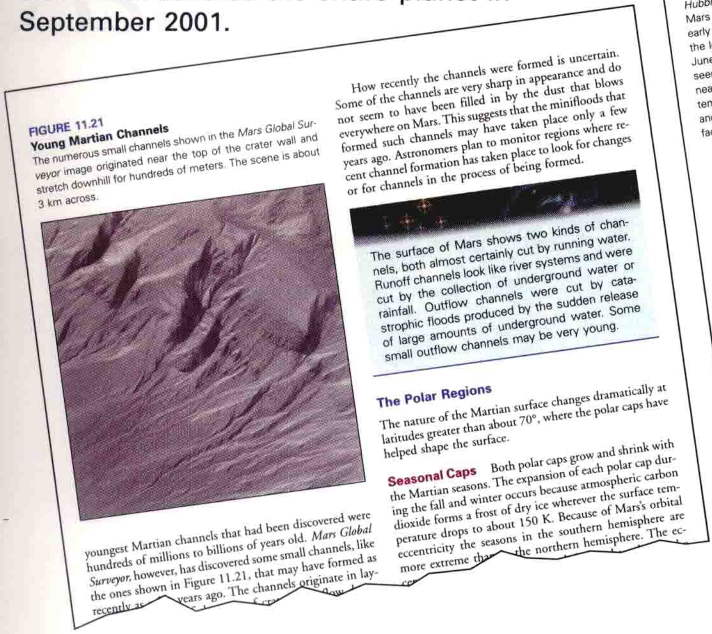


FIGURE 11.21
Young Martian Channels
The numerous small channels shown in the *Mars Global Surveyor* image originated near the top of the crater wall and stretch downhill for hundreds of meters. The scene is about 3 km across.

youngest Martian channels that had been discovered were hundreds of millions to billions of years old. *Mars Global Surveyor,* however, has discovered some small channels, like the ones shown in Figure 11.21, that may have formed as recently as … years ago. The channels originate in lay-

How recently the channels were formed is uncertain. Some of the channels are very sharp in appearance and do not seem to have been filled in by the dust that blows everywhere on Mars. This suggests that the minifloods that formed such channels may have taken place only a few years ago. Astronomers plan to monitor regions where recent channel formation has taken place to look for changes or for channels in the process of being formed.

The surface of Mars shows two kinds of channels, both almost certainly cut by running water. Runoff channels look like river systems and were cut by the collection of underground water or rainfall. Outflow channels were cut by catastrophic floods produced by the sudden release of large amounts of underground water. Some small outflow channels may be very young.

The Polar Regions
The nature of the Martian surface changes dramatically at latitudes greater than about 70°, where the polar caps have helped shape the surface.

Seasonal Caps Both polar caps grow and shrink with the Martian seasons. The expansion of each polar cap during the fall and winter occurs because atmospheric carbon dioxide forms a frost of dry ice wherever the surface temperature drops to about 150 K. Because of Mars's orbital eccentricity the seasons in the southern hemisphere are more extreme than … the northern hemisphere. The ec-

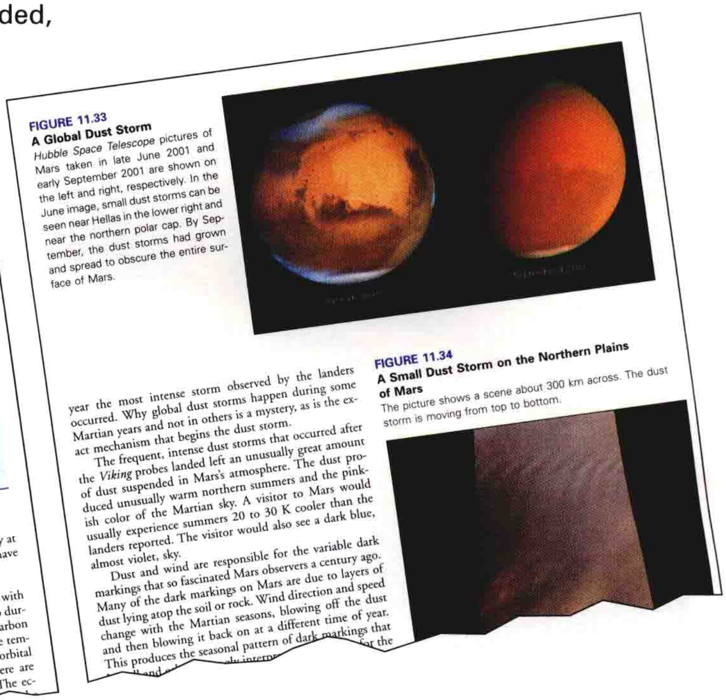


FIGURE 11.33
A Global Dust Storm
Hubble Space Telescope pictures of Mars taken in late June 2001 and early September 2001 are shown on the left and right, respectively. In the June image, small dust storms can be seen near Hellas in the lower right and near the northern polar cap. By September, the dust storms had grown and spread to obscure the entire surface of Mars.

year the most intense storm observed by the landers occurred. Why global dust storms happen during some Martian years and not in others is a mystery, as is the exact mechanism that begins the dust storm.

The frequent, intense dust storms that occurred after the *Viking* probes landed left an unusually great amount of dust suspended in Mars's atmosphere. The dust produced unusually warm northern summers and the pinkish color of the Martian sky. A visitor to Mars would usually experience summers 20 to 30 K cooler than the landers reported. The visitor would also see a dark blue, almost violet, sky.

Dust and wind are responsible for the variable dark markings that so fascinated Mars observers a century ago. Many of the dark markings on Mars are due to layers of dust lying atop the soil or rock. Wind direction and speed change with the Martian seasons, blowing off the dust and then blowing it back on at a different time of year. This produces the seasonal pattern of dark markings that …

FIGURE 11.34
A Small Dust Storm on the Northern Plains of Mars
The picture shows a scene about 300 km across. The dust storm is moving from top to bottom.

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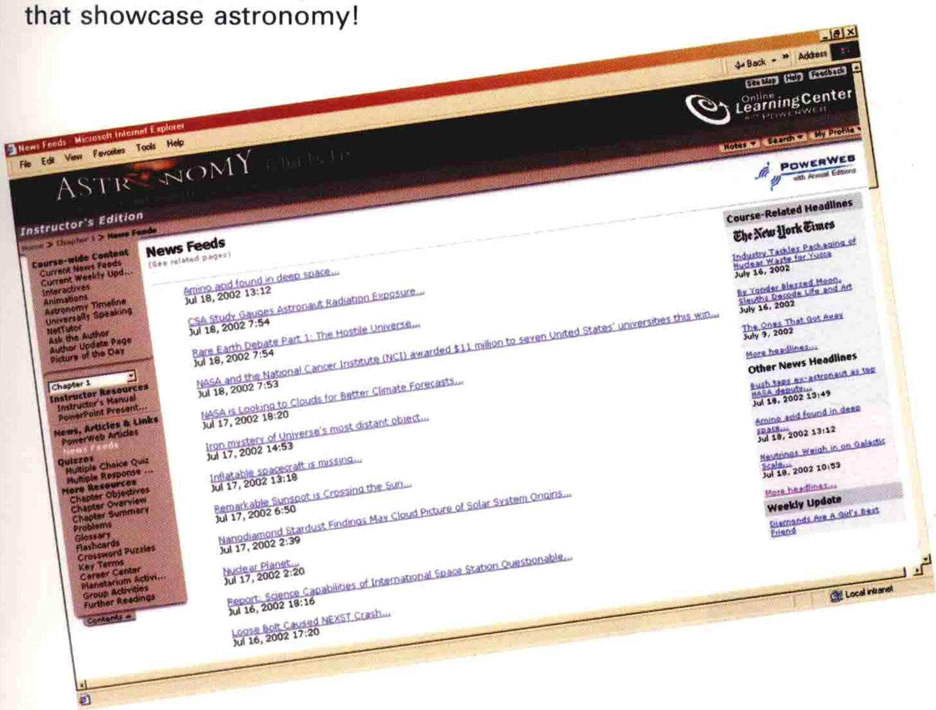

Contents in Brief

Contents