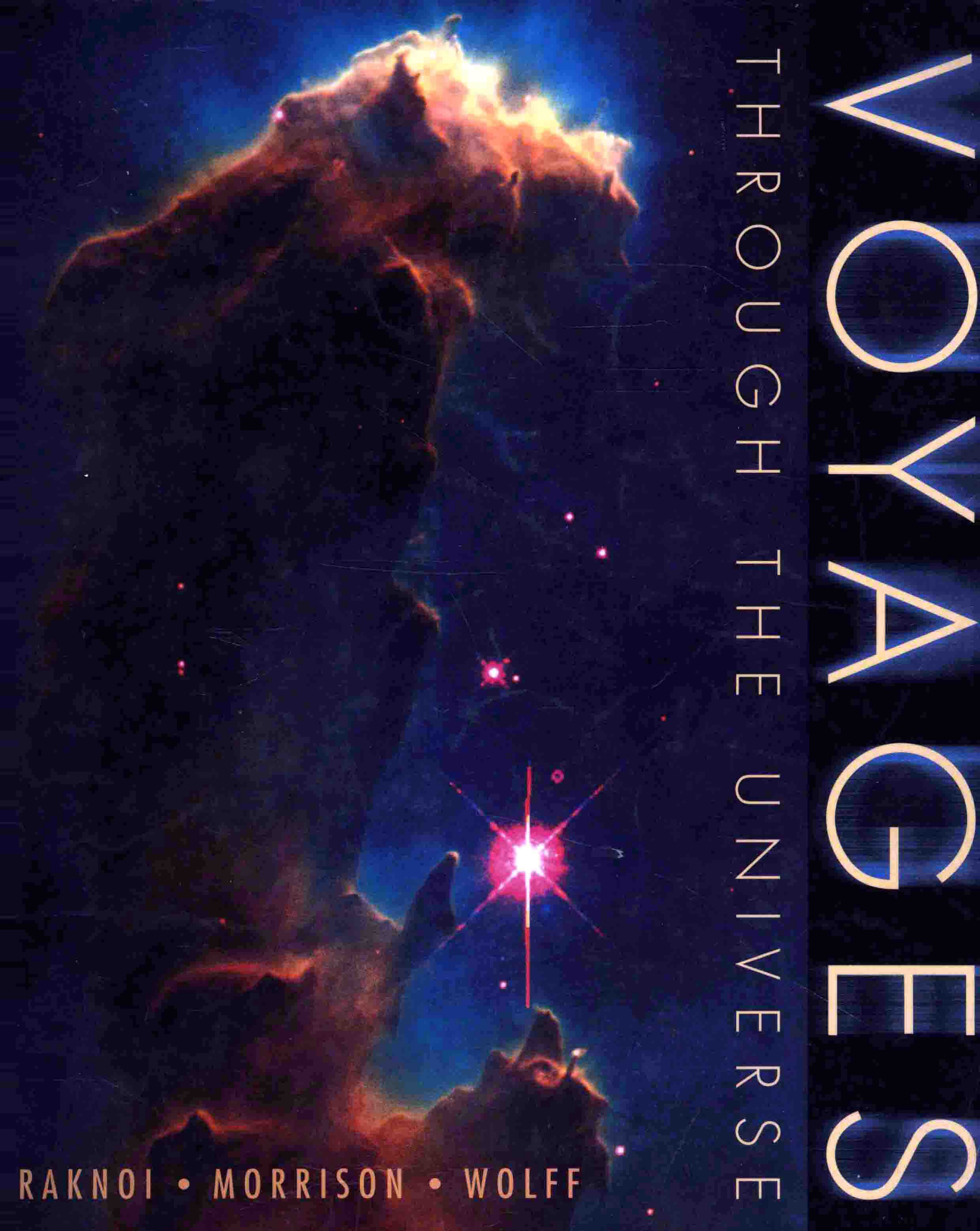

VOYAGES

THROUGH THE UNIVERSE

RAKNOI • MORRISON • WOLFF

VOYAGES
THROUGH THE UNIVERSE

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SAUNDERS COLLEGE PUBLISHING
Harcourt Brace College Publishers

FORT WORTH PHILADELPHIA SAN DIEGO NEW YORK ORLANDO AUSTIN
SAN ANTONIO TORONTO MONTREAL LONDON SYDNEY TOKYO

Text Typeface: New Caledonia
Composition: Progressive Information Technologies
Publisher: John Vondeling
Acquisitions Editor: Jennifer Bortel
Developmental Editor: Jennifer Bortel
Picture Development Editor: George Semple
Managing Editor: Carol Field
Senior Project Editor: Anne Gibby
Copy Editor: Judy Patton
Proofreader: Michele Gitlin
Manager of Art and Design: Carol Bleistine
Art Director: Carol Bleistine
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Text and Cover Designer: Ruth A. Hoover
Text Artwork: George V. Kelvin/Science Graphics
Rolin Graphics
Director of EDP: Tim Frelick
Production Manager: Alicia Jackson
Marketing Manager: Marjorie Waldron
Editorial Assistant: Tara Pauliny
Marketing Coordinator: Karen Milstein

Cover Credit: Hubble Space Telescope image. Gas pillars in M16, *Eagle Nebula*, a nearby star-forming region 7,000 light years away, in the constellation Serpens. (Jeff Hester and Paul Scowen, Arizona State University, and NASA)
Frontispiece: *Helix Nebula.* (© 1979 Anglo-Australian Telescope Board/David Malin)

Printed in The United States of America

Voyages Through the Universe

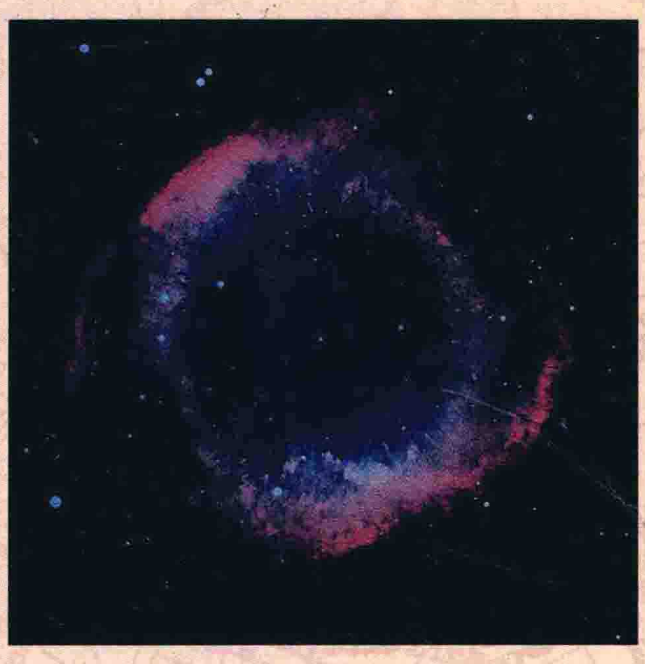
ISBN: 0-03-020053-9

Library of Congress Catalog Card Number: 96-68673

6 7 8 9 0 1 2 3 4 5 032 10 9 8 7 6 5 4 3 2 1

VOYAGES

THROUGH THE UNIVERSE



This recent image from the Hubble Space Telescope shows "cometary knots" in the Helix Nebula, a shell of glowing gas expelled by a dying star about 450 light years away in the constellation of Aquarius. A wind of hot gas from the star collides with the shell of denser gas the star emitted about 10,000 years earlier. The collision fragments the inner part of the shell into denser, finger-like droplets that superficially resemble comets we see in our solar system. However, the heads of the "comets" in the Helix Nebula are typically twice the size of our entire planetary system (twice the diameter of the orbit of Pluto). Each tail stretches away from the star for about 100 billion miles. (R. O'Dell, K. Handron & NASA) *(Inset)* A view of the full Helix Nebula taken with the Anglo-Australian telescope.

About the Authors

Andrew Fraknoi is the Chair of the Astronomy Department at Foothill College near San Francisco and an Educational Consultant for the Astronomical Society of the Pacific (where he directs Project ASTRO, a program to bring astronomers into elementary and junior high school classrooms). From 1978 to 1992 he was Executive Director of the Society, as well as Editor of *Mercury* Magazine and the *Universe in the Classroom* Newsletter. He has taught astronomy and physics at San Francisco State University, Cañada College, and the University of California Extension Division. He is author of *The Universe in the Classroom,* co-author of *Effective Astronomy Teaching and Student Reasoning Ability,* and scientific editor of *The Planets and The Universe,* two collections of science and science-fiction literature. In the past 22 years he has presented over 400 public lectures on astronomical topics. For five years he was the lead author of a nationally syndicated newspaper column on astronomy, and he appears regularly on radio and television explaining astronomical developments. He has received the Annenberg Foundation Prize of the American Astronomical Society and the Klumpke-Roberts Prize of the Astronomical Society of the Pacific for his contributions to the public understanding of astronomy. Asteroid 4859 was named Asteroid Fraknoi in 1992 in recognition of his work in astronomy education.

David Morrison received his Ph.D. from Harvard University. He was at the University of Hawaii from 1969 to 1988, where his positions included Professor of Astronomy, Chair of the Astronomy Graduate Program, Director of the Infrared Telescope Facility at Mauna Kea Observatory, and University Vice-Chancellor for Research and Graduate Education. Dr. Morrison currently heads the space science program at the NASA Ames Research Center. His primary research interests are in planetary science. Dr. Morrison is the author of more than 120 professional articles and of several books, including *The Planetary System, Cosmic Catastrophes, Exploring Planetary Worlds,* and three other astronomy texts from Saunders. He has served as President of the Astronomical Society of the Pacific, Chair of the Astronomy Section of the American Association for the Advancement of Science, and President of the Planetary Commission of the International Astronomical Union. Dr. Morrison has received the Klumpke-Roberts Prize of the Astronomical Society of the Pacific for contributions to public understanding of science, and two medals for Outstanding Leadership from NASA for his contributions to the Galileo mission and to protecting the Earth from asteroid impacts. A celestial object, Asteroid 2410 Morrison, is named for him.

Sidney C. Wolff received her Ph.D. from the University of California at Berkeley, and then joined the Institute for Astronomy at the University of Hawaii. During the seventeen years Dr. Wolff spent in Hawaii, the Institute for Astronomy developed Mauna Kea into the world's premier international observatory. Dr. Wolff became Associate Director of the Institute for Astronomy in 1976 and Acting Director in 1983. She earned international recognition for her research, particularly on stellar atmospheres—the evolution, formation, and composition of stars. In 1984, she was named Director of the Kitt Peak National Observatory, and in 1987 became Director of the National Optical Astronomy Observatories. She is the first woman to head a major observatory in the United States. As Director of NOAO, Dr. Wolff and her staff of 460 oversee facilities used annually by nearly 1000 visiting scientists. Recently, Dr. Wolff has also been acting as Director of the Gemini Project, which is an international program to build two state-of-the-art 8-m telescopes. Dr. Wolff has served as President of the Astronomical Society of the Pacific and is the second woman to be elected President of the American Astronomical Society. She is also a member of the Board of Trustees of Carleton College, a liberal arts school that excels in science education. Dr. Wolff is the author of more than 70 professional articles and a book, *The A-Type Stars: Problems and Perspectives.*

Preface for the Student

In college textbooks, there is a long tradition that the preface of the book is read by the instructor and the rest of the book by the student. Still, many students begin reading the preface (it does come first) and then wonder why it doesn't say much to them.

So, we begin our book with a preface for student readers. It's not a preface about the subject matter of astronomy, which is introduced in the Prologue, but a preface that tells you a little about the book and gives you some hints for the effective study of astronomy. (Your professor will probably have other, more specific suggestions for doing well in your class.)

Astronomy, the study of the universe beyond the confines of our planet, is one of the most exciting and rapidly changing branches of science. Even scientists from other fields often confess to having had a lifelong interest in astronomy, though they may now be doing something more practical, such as biology, chemistry, or engineering. There are fewer than 10,000 *professional* astronomers in the world; but astronomy has a large group of *amateur astronomers* who spend many an evening with a telescope under the stars observing the sky, and who occasionally make a discovery, such as a new comet or exploding star.

Many people are fascinated just to read about bizarre objects that astronomers are uncovering, such as black holes and quasars. Others are intrigued by the scientific search for planets or life in other star systems. And many people like to follow the challenges of space exploration, such as the repair of the Hubble Space Telescope by the Shuttle astronauts, or the Galileo mission to probe the giant planet Jupiter. Hearing about an astronomical event in the news media may be what first sparked your interest in taking an astronomy course.

But some of the things that make astronomy so interesting also make it a challenge for the beginning student. The universe is a big place full of objects and processes that do not necessarily have familiar counterparts here on Earth. Like a visitor to a new country, it will take you a while to feel familiar with the territory or the local customs. Astronomy, like other sciences, has its own special vocabulary, and keeping up with the pace of discovery in astronomy is a monumental challenge.

To assist students taking their first college-level course in astronomy, we have built a number of special features into this book, and we invite you to make use of them:

- All technical terms are printed in **boldface** type the first time they are used and clearly defined in the text; their definitions are listed alphabetically in Appendix 3 (the glossary), so you can refer to them at any time. The summaries at the end of each chapter also include these boldface terms as a review.
- The book begins with a historical summary of astronomy and then surveys the universe, starting at home and finishing with the properties of the entire cosmos. But don't worry if your instructor doesn't assign all the chapters or doesn't assign the chapters in order. Throughout the book "directional signs" lead you to earlier material you need to know before tackling the current section.
- We use tables to bring together numerical data for your convenience. For example, some tables summarize the important properties of each planet in the solar system (including the Earth). Students who want to see more of the data that astronomers use can investigate the appendices at the back of the book, which give the latest information on many aspects of astronomy.
- Figure captions clearly describe what phenomena or objects students are looking at. In many textbooks, captions are afterthoughts, with only a few words of description, but in this book, we have scrutinized each figure and asked what would help clarify the diagram or image.
- Each chapter ends with a summary of the essential points in the chapter, plus review questions, thought questions, and problems to help you "process" what you have learned.
- Suggestions for further reading are included for students who want or need to learn more about a particular topic. These books and articles are written at the same introductory level as this text.

- Appendix 1 is a guide to some of the more interesting astronomy sites on the World Wide Web.

Here are a few suggestions for studying astronomy that come from good teachers and good students from around the country:

- First, the best advice we can give you is to be sure to leave enough time in your schedule to study the material in this class *regularly*. It sounds obvious, but it is not very easy to catch up with a subject like astronomy by trying to do everything just before an exam. Try to put aside some part of each day, or every other day, when you can have uninterrupted time for reading and studying astronomy.
- Try to read each assignment in the book twice, once before it is discussed in class, and once afterwards. Take notes or use a highlighter to outline ideas that you may want to review later. Also, take some time to coordinate the notes from your reading with the notes you take in class. Many students start college without good note-taking habits. If you are not a good note-taker, get some help. Many colleges and universities have student learning centers that offer short courses, workbooks, or videos on developing good study habits. Take a little time and find out what your school has to offer.
- Form a small astronomy study group with people in your class; get together as often as you can and discuss the topics that may be giving group members trouble. Make up sample exam questions and make sure everyone in the group can answer them confidently. If you have always studied alone, you may at first resist this idea, but don't be too hasty to say no. Study groups are very effective ways of discussing new information, or learning a foreign language, or studying law or astronomy.
- Before each exam, do a concise outline of the main ideas discussed in class and presented in your text. Compare your outline with those of other students as a check on your own study habits.
- If you find a topic in the text or in class especially difficult or interesting, don't hesitate to make use of the resources in your library for additional study.
- *Don't be too hard on yourself!* If astronomy is new to you, many of the ideas and terms in this book will be unfamiliar. And astronomy is like any new language; it may take a while to become a good conversationalist. Practice as much as you can, but also realize that it is natural to be overwhelmed by the vastness of the universe and the variety of things that are going on in it.

We hope you enjoy reading this text as much as we enjoyed writing it. We are always glad to hear from students who have used the text and invite you to send us your reactions to the book and suggestions for how we can improve future editions. We promise you we will read and consider every serious letter we receive. You can send your comments to Andrew Fraknoi, Astronomy Department, Foothill College, 12345 El Monte Rd., Los Altos Hills, CA 94022, USA. (Please note that we will not send you the answers to the chapter problems or do your homework for you, but all other thoughts are welcome.)

Andrew Fraknoi, David Morrison, and Sidney Wolff
July 1996

Preface for the Instructor

Voyages Through the Universe is a new astronomy text produced with today's students in mind—it is designed for non-science majors who may even be a little intimidated by science, and who approach astronomy with more interest than experience. With features that make it appropriate for everyone from university business majors to first-time community college students, **Voyages** is written to draw in and engage all readers, while preserving the accuracy and timeliness that our colleagues expect of us.

This new text is based in part on **Realm of the Universe,** by the late George Abell, David Morrison, and Sidney Wolff, but has been completely rethought and rewritten to make it an even more useful tool for teaching and learning astronomy. We have made the language friendly and inviting and have used examples drawn from everyday experience. Vignettes from the lives of astronomers and occasional touches of humor make this a book that students will actually *enjoy* reading.

Organization and Special Features

The book is not too long for a one-semester course, yet not so brief that important topics have been omitted. It does not overwhelm the student with detail, but instead focuses on the major threads and overarching ideas that illuminate the relationships among the various branches of astronomy. We probably have a bit less jargon than most textbooks, but we have not sacrificed any of the key concepts that you would want to see students learn in a basic course.

We have worked hard to include many of the latest ideas and discoveries in astronomy, not merely for their novelty, but for their value in advancing the quest for a coherent understanding of the universe. In each case, we have tried to fit the latest research results into a wider context and to explain clearly what they mean. Among the recent topics included in the text are the discovery of planets around other stars, the results from both the Galileo probe and Comet Shoemaker-Levy 9 impacts on Jupiter, the discovery of a number of the icy members of the Kuiper belt, new candidates for black holes in our galaxy, recent measurements of the age of the universe from several different observing groups, clearer evidence for supermassive black holes at the centers of galaxies, and much more.

We portray astronomy as a human endeavor and have tried to include descriptions and images of some of the key men and women who have created our science over the years. Illustrations also include many of the latest images from the Hubble Space Telescope and other space instruments, as well as an up-to-date collection of color images from ground-based observatories around the world. Many of the planetary images are second- or third-generation corrected views, not merely the first releases rushed out for the news media. Full-color diagrams are used as teaching tools, not as cosmetic devices. Figure captions contain full explanations of what the student should be seeing and understanding.

- The book is written as a coherent story. However, because the authors know that many instructors follow an order of topics that is different from theirs, the sections are modular.

- We do not expect students to remember every concept introduced in previous chapters. Unobtrusive verbal "sign posts" are inserted throughout to help students find where a concept was defined or explained in detail or to briefly review a key idea that may have been introduced many chapters ago. We want every student to use the book as an easy navigational tool through the world of astronomy. A complete glossary is supplied in Appendix 3.

- A carefully written Prologue introduces the basic ideas and vocabulary of astronomy and makes sure all students start their study of the universe at the same point. The Epilogue summarizes key ideas about cosmic evolution and then applies them to the quest for life elsewhere.

- Appendix 1, written with David Bruning, lists a wide range of useful World Wide Web sites in astronomy that are accessible to students.

Special Sections and Boxes

The chapters in **Voyages Through the Universe** feature a number of highlighted sections designed to help non-science students appreciate the breadth of astronomy without distracting them from the main narrative.

- *Making Connections.* These special boxes show how astronomy connects to students' experiences with other fields of human endeavor and thought, from poetry to engineering, from popular culture to natural disasters.
- *Thinking Ahead.* Each chapter begins with a stimulating question about the material that follows.
- *Voyagers in Astronomy.* These profiles of noted astronomers focus not only on their work, but on their lives and human dimensions.
- *Astronomy Basics.* Fundamental science ideas and terms that other texts just assume students know are explained carefully.
- *Seeing for Yourself.* Students get familiar with the sky and everyday astronomical phenomena through observations using simple equipment.
- *Chapter Summary.* A concise overview that enumerates all important ideas and lists important new terms in boldface.
- *Review Questions, Thought Questions,* and numerical *Problems.* Questions that allow you a wide latitude for testing student understanding. Many can be used directly for discussion sections or essay exams.

RedShift CD-ROM

The award-winning *RedShift* software (Version 1, 2), published by Maris Multimedia, expands **Voyages Through the Universe** from a static presentation to a dynamic simulation of many aspects of astronomy. The dual-platform CD-ROM allows students to

- view realistic models of the planets and main satellites in the solar system
- identify over 300,000 stars, nebulae, and galaxies
- simulate astronomical events over the course of 15,000 years
- view more than 700 full-screen photographs (including a number by David Malin)
- access the *Penguin Dictionary of Astronomy* (with over 2,000 entries)
- navigate through surface maps of Earth, Moon, and Mars.

We have included some end-of-chapter exercises using *RedShift* (written by David Bruning of *Astronomy* magazine.)

RedShift is a valuable learning tool while your course is in progress. It is also an enjoyable piece of recreational software which students can use to explore the universe long after their academic experience is completed. The CD-ROM may be packaged with the text for a very low price.

Ancillaries

In addition to *RedShift,* qualified adopters of **Voyages Through the Universe** can receive

- *The Cosmos in the Classroom: A Resource Guide for Teaching Astronomy* by Andrew Fraknoi. This manual is a rich compilation of teaching ideas and resources for both novice and veteran instructors. It includes annotated listings of the best non-technical books and articles in astronomy organized by subject; listings of outstanding slides, videos, and software for each chapter, with addresses and phone numbers of suppliers; topics for discussion and for writing papers; resource guides for exploring the lives of astronomers; ideas for historical and interdisciplinary topics and on-site observation; and helpful appendices to make a teacher's job smoother.
- *The Saunders Internet Guide for Astronomy* by David Bruning, Randy Reddick, and Elliot King. This wonderful new handbook for both instructors and students is a thorough, up-to-date introduction to the internet and the World Wide Web. The first part reviews the history and current state of the internet and explains everything from simple e-mail to Multi-User Dungeons, with special attention to those applications useful in higher education. The second part features a thorough annotated listing of World Wide Web sites related to astronomy and astronomy education.
- *The Voyages Instructor's Manual/Test Bank.* The instructor's manual test bank contains answers to thought questions and problems in the textbook, as well as a host of multiple-choice test questions for use in a variety of classroom settings.
- *ExaMaster Computerized Test Bank* for Windows and Macintosh. ExaMaster features all the questions from the printed test bank in a format that allows instructors to edit them, add questions, and print assorted versions of the same test.
- The *Saunders Astronomy Transparency Collection.* This collection contains 205 overhead transparencies of conceptually based artwork. The enlarged reproductions contain figures from Saunders' astronomy textbooks, as well as supplemental illustrations that complement the text figures. A detailed guide arranged by

topic accompanies the collection. These images are also available as slides.

- The *Saunders Astronomy Collection Supplement, 1994,* features 25 additional images from the Hubble Space Telescope and major observatories.
- *Voyages Through the Universe Transparency Collection.* This collection includes 25 of the most current Hubble and ground-based telescope photographs as well as striking and informative illustrations from the textbook.
- *Saunders MediaActive CD-ROM to accompany Voyages Through the Universe.* This exclusive CD-ROM contains all the diagrams and tables from the textbook and is a superb presentation tool to be used with such software packages as Powerpoint™, Persuasion™, and Saunders' LectureActive™.
- *Saunders Astronomy Videodisc: The Solar System.* This two-sided CAV disc contains 1000 still images and 45 minutes of video showing some of the best spacecraft images of the solar system. A bar code manual and LectureActive™ presentation software accompany every disc.

The Registered Adopters Program

Instructors who fill out a brief survey can become **Registered Voyagers Adopters.** There is no cost involved, and registered adopters will receive

- invitations to special events at astronomy meetings (where they can talk with the authors and other adopters)
- first access to new ancillary materials
- updates on new developments in astronomy, as well as new teaching techniques and tools
- an opportunity to have direct input into the planning of future editions

To become a registered adopter, talk with your Saunders representative, call us toll-free at 1-800-939-7377 (ask for Karen Milstein), e-mail us at voyages@saunderscollege.com, or write to: Karen Milstein, Marketing Coordinator, Saunders College Publishing, Public Ledger Building, Suite 1250, 150 S. Independence Mall West, Philadelphia, PA 19106.

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Let Us Hear from You

Unlike stars and planets, textbooks in astronomy do not exist in a vacuum. All three authors have benefited tremendously over the years from the advice of colleagues and students who teach astronomy. We want to be sure that we continue to make changes and updates in Saunders' astronomy texts that will be the most useful to you.

Therefore, we welcome comments and suggestions about the text and the ancillaries and ideas for how future materials can be made more effective. Address your cards and letters to: Andrew Fraknoi, Astronomy Dept., Foothill College, 12345 El Monte Rd., Los Altos Hills, CA 94022 or e-mail: FRAKNOI@ADMIN.FHDA.EDU.

Acknowledgments

We would like to thank the many colleagues and friends who have provided information, images, and encouragement, including: Charles Avis, Charles Bailyn, Bruce Balick, Judy Barrett, Roger Bell, Michael Bennett, Roy Bishop, Chip Clark, Richard Dreiser, George Djorgovski, Alex Filippenko, Lola Fraknoi, Michael Friedlander, Alan Friedman, Ian Gatley, Paul Geissler, Margaret Geller, Cheryl Gundy, Heidi Hammel, Bob Havlen, Todd Henry, Scott Hildreth, George Jacoby, William Keel, Geoff Marcy, Jeff McClintock, Edward McNevin III, Michael Merrill, Jacqueline Mitton, Janet Morrison, Donald Osterbrock, Michael Perryman, Carle Pieters, Edward Purcell, Axel Quetz, Jessica Richter, Dennis Schatz, Rudy Schild, Maarten Schmidt, Joe Tenn, Ray Villard, Althea Washington, Adrienne Wasserman, and Richard Wolff.

David Bruning played an essential role in the development of the text, by writing the "Using RedShift" sections, as well as the first draft of Appendix 1. George Kelvin rendered some of the fine color diagrams that grace the book. We are grateful to Bill Hartmann, John Spencer, Don Davis, and Don Dixon for permission to reproduce their astronomical paintings, and to David Malin for his assistance and his superb astronomical photographs.

We benefited very much from the suggestions of the following reviewers of preliminary drafts of the text:

Grady Blount
Texas A&M University, Corpus Christi

Michael Briley
University of Wisconsin, Oshkosh

David Buckley
East Stroudsburg University

John Burns
Mt. San Antonio College

Paul Campbell
Western Kentucky University

Eugene R. Capriotti
Michigan State University

George L. Cassiday
University of Utah

John Cunningham
Miami-Dade Community College

Grace Deming
University of Maryland

Miriam Dittman
DeKalb College

Gary J. Ferland
University of Kentucky

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Community College of Philadelphia

Adrian Herzog
California State University, Northridge

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David Weintraub
Vanderbilt University

Mary Lou West
Montclair State University

Dan Wilkins
University of Nebraska, Omaha

J. Wayne Wooten
Pensacola Junior College

No book project of this complexity could succeed without the diligent efforts of many people at the publisher's. We very much appreciate the assistance of John Vondeling, Vice-President and Publisher; Jennifer Bortel, Acquisitions Editor; Anne Gibby, Senior Project Editor; Carol Bleistine, Manager of Art and Design; Alicia Jackson, Production Manager; George Semple, Picture Development Editor; Margie Waldron, Director of Marketing; Tara Pauliny, Editorial Assistant; Karen Milstein, Marketing Coordinator; and other members of the staff at Saunders College Publishing, for graciously accommodating the needs of three authors with busy schedules and strong opinions.

We dedicate this book to Alex Fraknoi, who came into the universe during the same period this book was planned and born. May a future edition of the text still be helping students with their exploration of the universe by the time he gets to college.

Andrew Fraknoi, David Morrison, and Sidney Wolff
July 1996

Galileo Orbiter Mission

In June 1996, the Galileo Orbiter began its two-year mission to survey the four large satellites of Jupiter. Although problems with the spacecraft antenna will limit the quantity of data radioed back to Earth, it is apparent that the quality of the images and spectra is superb, promising spectacular advances beyond the photos returned by the two Voyager spacecraft during their flybys 17 years earlier. Reproduced on these pages are examples of the first Galileo images of the moons Ganymede, Europa, and Io.

See Chapter 11 for more on these intriguing worlds.

Figure 1
A very high resolution view of the older, heavily cratered terrain on Ganymede, showing a region only a few miles across. The complex, hilly terrain and indications of the presence of both light- and dark-colored materials on the surface were among the new information revealed as the spacecraft passed much closer to Ganymede than had been possible with Voyager. (NASA/JPL)

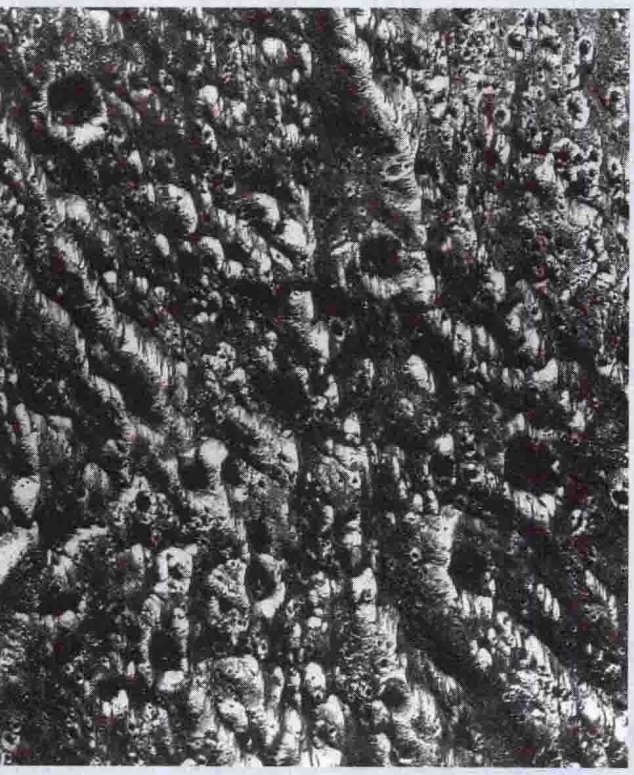


Figure 2
Two of the new better-detail Galileo photos of Ganymede are superposed on the image of the same area transmitted by Voyager in 1979. The mountainous areas of the satellite are now seen to be much more rugged than had been suggested previously, indicating a more violent geological history for this moon and suggesting the action of plate tectonics of Ganymede at some time in the distant past. (NASA/JPL)

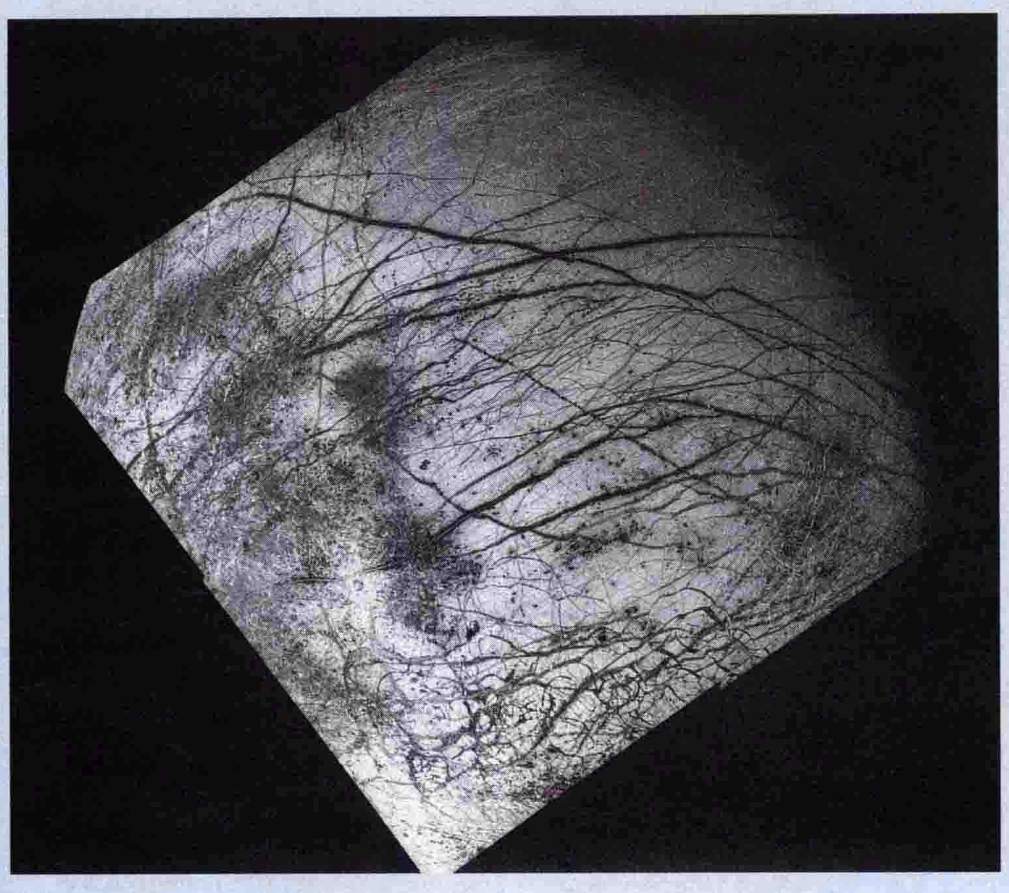
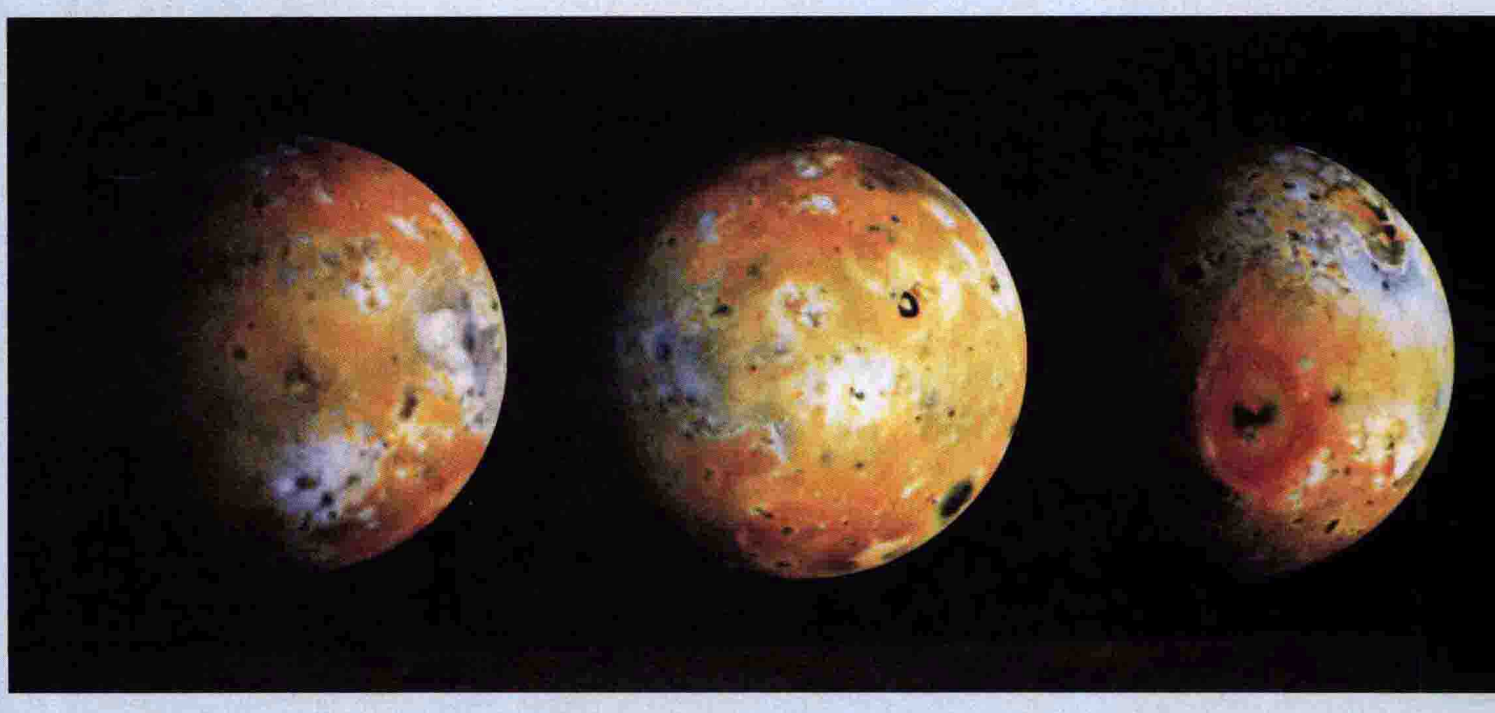


Figure 3
The first Galileo views of ice-covered Europa were better than the Voyager images but still far inferior to the two photos of Ganymede shown above. Still, the complex cracks on the surface hint of the possibility of a global ocean beneath the icy crust. If Europa really has large bodies of liquid water today, it is the only other location in the solar system beside our own planet Earth that possesses liquid water. (NASA/JPL)

Figure 4
Three early views of Io, imaged by the Galileo spacecraft from a great distance, show the multihued surface of this volcanically active satellite and demonstrate that its color has indeed changed in the 17 years since Voyager. These changes are the result of several large-scale volcanic eruptions that have taken place since the moon was last mapped. (NASA/JPL)



A mosaic of images of distant galaxies of stars, taken with four cameras aboard the repaired Hubble Space Telescope in March 1994. The area of the sky shown in this image is extremely small—about the size of President Roosevelt's eye on a dime held at arm's length. The brilliant galaxy that fills the small image (bottom right) lies on the outskirts of the Coma Cluster, a rich group of galaxies so far away that light from it takes 300 million years to reach us. Everything on this image that is *not* a round dot is a galaxy of billions of stars (the round dots are stars in our own Milky Way Galaxy). Except for the spiral-shaped galaxy at left, all the other galaxies in this view are significantly further away than the Coma Cluster, and are shown with great clarity from the Hubble's position above the Earth's atmosphere. They present a marvelous array of shapes and colors, challenging astronomers to understand their birth and evolution. (Courtesy of William Baum and NASA)

Contents Overview

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