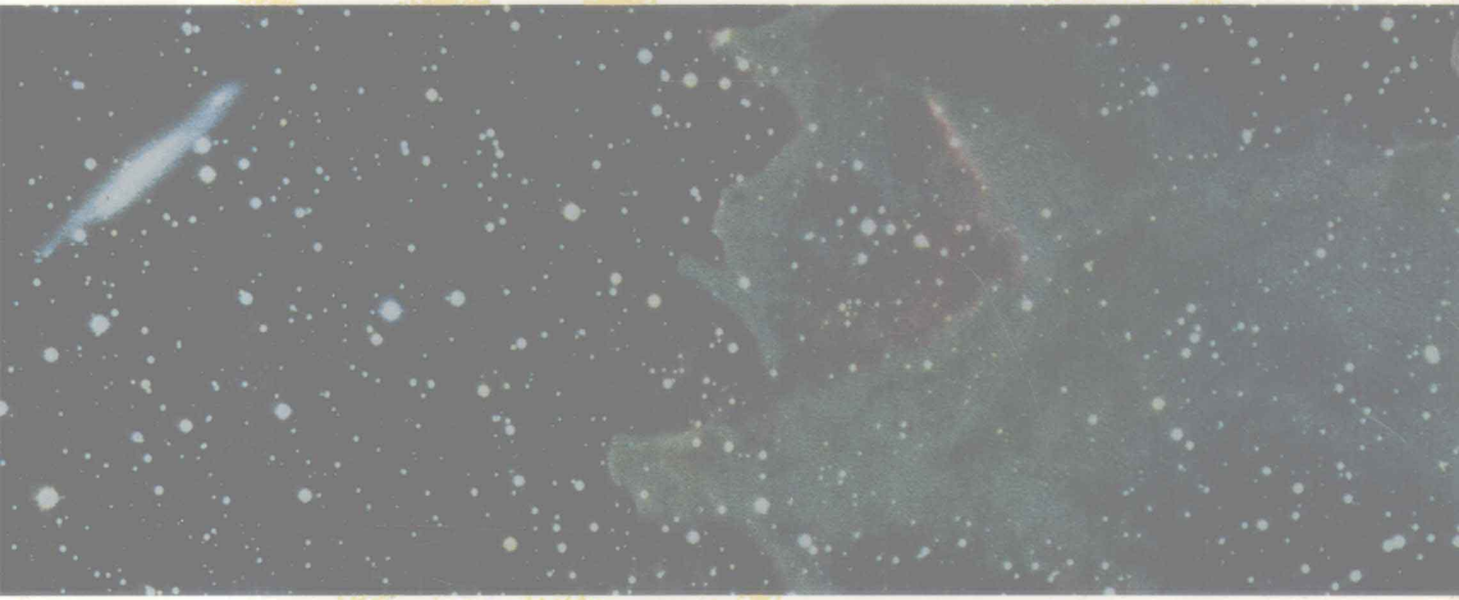
ASTRONOMY

THE COSMIC JOURNEY



5TH EDITION

WILLIAM K. HARTMANN

Astronomy: The Cosmic Journey

FIFTH EDITION

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Wadsworth Publishing Company
Belmont, California
A Division of Wadsworth, Inc.

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Compositor: Thompson Type
Printer: Arcata/Hawkins

Front Cover Photo: The cometary globule CG4 as photographed by David F. Malin, Anglo-Australian Observatory. Cometary globules are dense molecular clouds within the Milky Way that reflect the light of nearby stars. CG4 is 1300 light years distant and 8 light years across. The subtle colors are caused by emission from hot gas, and scattering and reddening of starlight. The edge-on galaxy, which CG4 appears to be about to devour, is actually millions of light years away, far beyond the Milky Way.

Back Cover Photo: Galileo image of Earth-Moon system made during Galileo's close pass by Earth on Dec. 16, 1992 (NASA, courtesy Galileo Imaging Team leader Michael Belton). See page 127 for an earlier photo.

Frontispiece: Asteroids are rocky and metallic bodies floating between the planets. The best close-up view of an asteroid is this remarkable photo of asteroid 243 Ida taken by the Galileo spacecraft in 1993 as it flew past Ida at a distance of 2400 km (1500 mi). This asteroid is believed to be a fragment of a larger parent body. It is about 52 km (32 mi) long and would just fit inside Rhode Island. Circular craters all over its surface mark billions of years of high-speed impacts by still smaller asteroidal fragments. (NASA photo courtesy of Michael Belton and Beatrice Müller, Galileo Team.)

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Printed in the United States of America
1 2 3 4 5 6 7 8 9 10—98 97 96 95 94

Library of Congress Cataloging-in-Publication Data

Hartmann, William K.
Astronomy : the cosmic journey / William K. Hartmann, Chris Impey.
— 5th ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-534-21192-5 (acid-free paper)
1. Astronomy. I. Impey, Chris. II. Title.
QB45.H32 1994
520—dc20 93-37926
CIP

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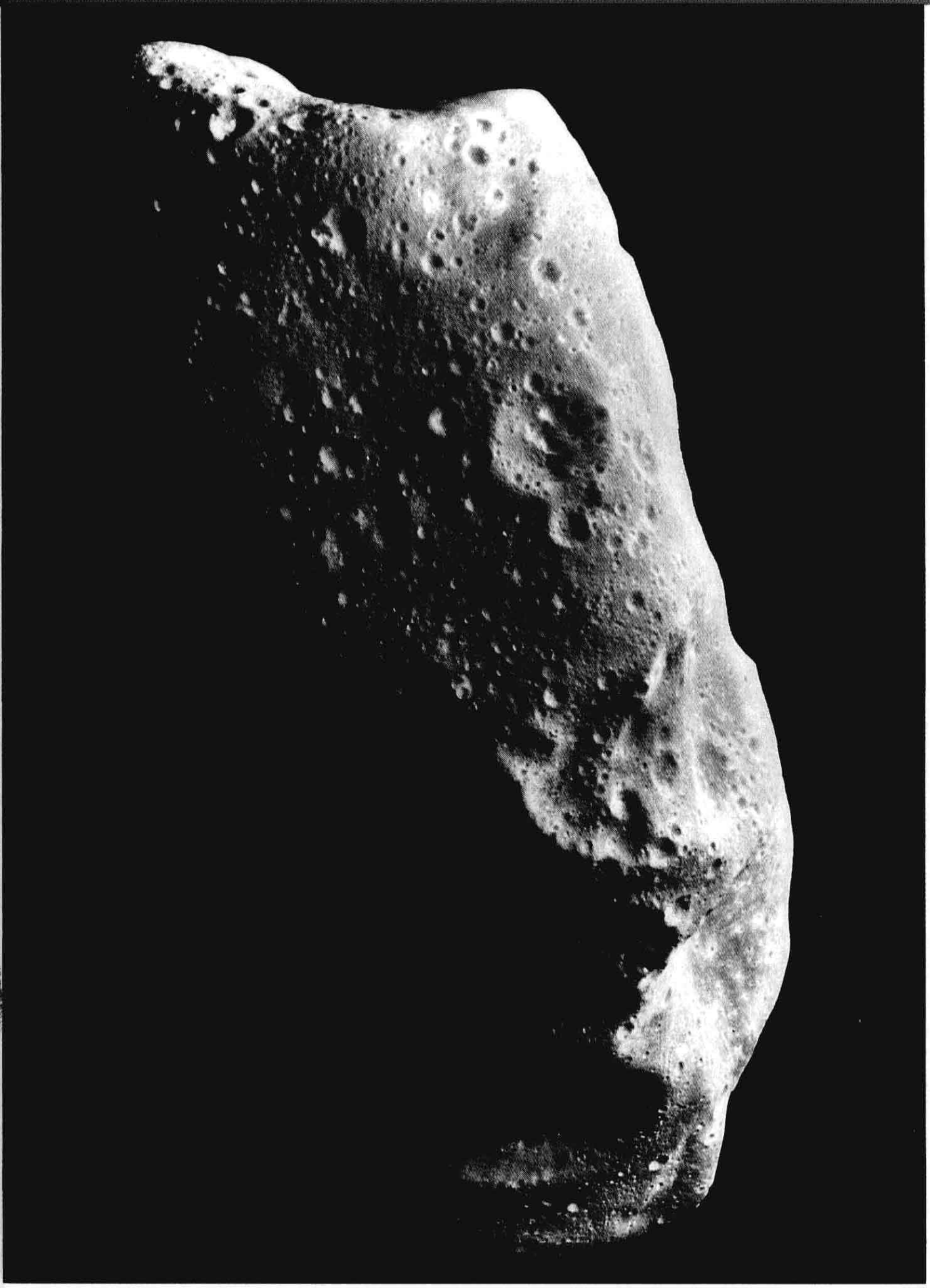

ABOUT THE AUTHORS

William K. Hartmann is a senior scientist at the Planetary Science Institute, in Tucson. He is known for research on the formation and evolution of planetary systems, discovering the giant multiring lunar impact basins, coauthoring the most widely accepted theory of lunar origin, and codiscovering "asteroid" Chiron's cometary outburst in 1988. He has participated in NASA's Mariner 9 and Mars Observer missions to Mars and the Russian Mars-94 mission, and has served on advisory committees for NASA and the National Academy of Science. His paintings of planetary landscapes and other astronomical subjects have been published and collected internationally. His paintings have been commissioned by the NASA Fine Arts Program, and he has collaborated on space art projects in Russia. In addition to *Astronomy: The Cosmic Journey*, he is the author of *The Cosmic Voyage* (Wadsworth) and *Moons and Planets* (Wadsworth). Hartmann has collaborated on five popular, illustrated books on astronomy: *The Grand Tour, Out of the Cradle, Cycles of Fire, The History of Earth*, and a Soviet-American astronomical art collection, *In the Stream of Stars.* He has also published a book of his text and photos on the Sonoran Desert, *Desert Heart.* Asteroid 3341 was named after him in 1987.

Chris Impey is an Associate Professor and Associate Astronomer at Steward Observatory of the University of Arizona. He is an experienced teacher of undergraduate and graduate astronomy courses, and has won five teaching awards in the past five years. He has active research programs on quasars and ultrafaint galaxies, which have been supported by numerous grants from the National Science Foundation and NASA. He has published more than 50 research articles in the astronomical literature. Impey has used most of the world's largest telescopes in Hawaii, California, Arizona, Russia, Chile, and Australia. His research has also involved satellite observations from X-ray to far infrared wavelengths. He has had four projects approved and funded with the Hubble Space Telescope. Impey is Associate Director of the NASA Arizona Space Grant Consortium, which supports a variety of educational and outreach programs. He has also codirected a successful Masters program for high school science teachers at the University of Arizona.

Preface

With human footprints on the Moon, radio telescopes listening for messages from alien creatures (who may or may not exist), technicians looking for celestial and planetary sources of energy to support our civilization, orbiting telescopes' data hinting at planetary systems around other stars, and a suddenly revised world order of nations struggling to repair damage to our planet, an astronomy book published today enters a world different from the one that greeted books a generation ago. Astronomy has broadened to involve our basic circumstances and our enigmatic future in the universe. With eclipses and space missions broadcast live, with Russia occupying a permanent space station, and with American and Russian leaders discussing cooperative missions to Mars, astronomy offers adventure for all people — an outward exploratory thrust that may one day be seen as an alternative to mindless consumerism, ideological bickering, and wars to control dwindling resources on a closed, finite Earth.

Today's astronomy students not only seek an up-to-date summary of astronomical facts; they ask, as people have asked for ages, about our basic relationships to the rest of the universe. They may study astronomy partly to seek points of contact between science and other human endeavors: philosophy, history, politics, environmental action, even the arts and religion.

Science fiction writers and the special effects artists on recent films help today's students realize that the unseen worlds of space are real places — not abstract concepts. Today's students are citizens of a more real, more vast cosmos than that conceptualized by students of a decade ago.

In designing this book, we have worked with the Wadsworth editors to respond to these developments. Rather than jumping at the start into the murky waters of cosmology, we have begun with the viewpoint of ancient people on Earth and worked outward across the universe. This method of organization automatically (if loosely) reflects the order of humanity's discoveries about astronomy and provides a unifying theme of increasing distance and scale.

This arrangement aims to give an unfolding, ever-expanding panorama of our cosmic environment. We hope it unfolds like a story in which each chapter provides not only a new facet but also a growing understanding of the relationships among the elements of the whole.

The subtitle refers to three separate cosmic journeys that we undertake simultaneously. First, we travel through historical time, where we see how humans slowly and sometimes painfully evolved our present picture of the universe. Second, we journey through space, where we see how our expanding frontiers have revealed the geography of the universe. Beginning with an Earth-centered view, we study the Earth-Moon system, the surrounding system of planets, the more distant surrounding stars, our own vast galaxy, and the encompassing universe of other galaxies. Finally, we travel back through cosmic time. Familiar features of the Earth are typically only a few hundred million years old. The solar system is about 4.6 billion years old. Our galaxy is roughly 12 to 15 billion years old. The universe itself began (or began to reach its present form) an estimated 15 billion years ago.

Because astronomy touches many areas of life and philosophy, we have allowed the text to encompass a wide range of relevant topics, including space exploration, financing of science, cosmic sources of energy, the checkout-counter's barrage of astrology and other pseudoscience, and the possibility of life on other worlds, as well as the conventional "hard science" of astronomy. This variety of topics shows how basic scientific research touches all areas of life — hopefully in a way that lets readers ponder the relation between science and priorities in our society.

Using This Book

The arrangement of text material into eight parts and 27 chapters, plus an optional enrichment essay, should give instructors some flexibility in tailoring a course according to their interest. For example, those who are not much interested in historical development could use Part A only as assigned outside reading. It would also be possible to omit the interesting but challenging material on the early universe contained in Chapter 27.

Each part gives some historical background, describes recent discoveries and theories, and then discusses advances that might occur if society continues to support research. This more or less chronological approach has several purposes. Since there is often a certain logic to the order in which discoveries were made, historical emphasis may help readers remember the facts. Second, historical discussion allows us to introduce basic concepts in a more interesting way than by reciting definitions. It makes life richer to realize that some seemingly modern concepts descend from knowledge of ancient millennia and have thousand-year-old names. Third, there is a widespread fallacy that the only progress worth mentioning is that of the last few decades. Astronomy, of all subjects, shows clearly that, to paraphrase Newton, we see as far as we do because we stand on the shoulders of past generations. Exploration of the universe is a continuing human enterprise. As we try to maintain and improve our civilization, that is an important lesson for a science course to teach.

Another principle we have followed is to treat astronomical objects in an *evolutionary* way, to show the sequence of development of matter in the universe. Stars, pulsars, black holes, and other celestial bodies are linked in evolutionary discussion, rather than listed as different types of objects detected by different observational techniques. We have also not hesitated to mention nonscientific approaches to cosmology and evolution, such as "creationist" concepts encouraged in two states' school systems by their state legislatures but later thrown out after courtroom battles.

The New Edition

This Fifth Edition is a major rewrite of the 1991 Edition with a co-author added for the first time, bringing a professional career focus on problems of galaxies and cosmology, leading to rewrites of the later chapters.

The first three chapters give an unbroken chronology of the events leading to our current view of the solar system. Following the teaching style of many instructors, we concentrate the basic physical principles in two early chapters, on gravity (4) and light (5). Scientific exploration of the Earth-Moon system (6 and 7) leads directly into our examination of the solar system, and the outer planets beyond Jupiter get their own chapter (12) to accommodate the recent explosion of data about them. The discussion of stellar evolution (18 and 19) has been further clarified, including current thought on black holes, neutron stars, and evolution in multiple star systems (21). The galaxies section has been entirely refocused, discussing the Milky Way in Chapter 23, the local galaxies in Chapter 24, and large-scale structure and quasars in Chapter 25. Cosmology is covered in two expanded chapters (26 and 27). The book has been completely updated throughout.

In the main part of the text, mathematics is almost nonexistent. The book can thus be used for a descriptive course. Ten basic equations are distributed through the book in optional boxes. The general content of each box is included qualitatively in the text, but the boxes introduce a higher level of physics and math, allowing a more quantitative course to be taught. Sample calculations using these equations now appear in every box, and the *Advanced Problems* at the ends of chapters use the optional equations. The 10 basic equations are described in more detail below.

Because color imagery plays an increasingly important role in astronomy, we use color figures throughout the book. Emphasis is on true-color imagery to give students the best conception of astronomical objects' appearance, though false-color image enhancement techniques are also described. Many new images represent information beyond the visible spectrum, at radio, infrared, and X-ray wavelengths. Astronomers' grasp now extends across the entire electromagnetic spectrum.

Interviews

This edition introduces a new feature, interviews with scientists, under the heading "Talking About . . ." These boxed interviews are not the career profiles of rather inaccessible famous scientists, found in a number of texts. Rather, we have created a small number of personal interviews with scientific workers from graduate students to well-known professionals, both women and men, representing several different countries and scientific specialties. One objective is to show how science fits into these peoples' lives; another is that the student reader should feel a certain satisfaction, as a result of reading the main text, at being able to understand the scientist speaking in his or her own words about problems on the frontier of research.

Illustrations and Text

1. In addition to the classic large telescope photos and recent NASA photos, we have included three other categories of illustrations:

a. Photos from recently published research papers, kindly provided by various authors and institutions.

b. Photos by amateurs with small and intermediate instruments, often used to show sky locations of well-known objects in the large-telescope photos. These can help readers to visualize and locate these objects in the sky, a difficult task if based on classic large-telescope photos alone. Photographic data provided with many of these pictures may be used in setting up student projects in sky photography.

c. Scientifically realistic paintings that show how various objects might look firsthand to observers in space. Discussion of features shown in the paintings illustrates a synthesis of scientific data from various sources.

2. Key concepts are shown in **boldface** type. These are repeated in *Concepts* lists at the ends of chapters and defined in a *Glossary* at the end of the book.

3. The 10 optional basic equations are introduced in the text as needed. Teachers offering a more quantitative course can integrate them into the course work; teachers offering more descriptive courses may skip over them. They are set off in boxes for optional use. The 10 boxes discuss:

I. *The Small-Angle Equation*, useful for calculating apparent sizes of objects at known distances.

II. *Newton's Universal Law of Gravitation*, illustrating the simplicity of gravitational attraction between bodies throughout the universe.

III. *Calculating Circular and Escape Velocities*, useful for deriving speeds or masses in coorbiting systems (planetary, binary star, galactic).

IV. *Measuring Temperatures of Astronomical Bodies: Wien's Law*, which shows how radiation measurements can reveal the temperatures of distant objects.

V. *The Definition of Mean Density*, a simple concept for gaining information about the nature of material inside planets and stars.

VI. *Typical Velocities of Atoms and Molecules in a Gas*, by which we characterize temperature, as well as collision energies when the atoms or molecules smash into each other. These energies, in turn, control the types of chemical or nuclear reactions that can occur.

VII. *The Doppler Effect: Approach and Recession Velocities*, which shows how spectral measures can reveal radial velocities of distant objects.

VIII. *The Stefan-Boltzmann Law: Rate of Energy Radiation*, which shows how temperature and luminosity measurements can reveal sizes of radiating sources.

IX. *The Hubble Law and the Age of the Universe*, which shows how the relationship between the distance and recession velocity of galaxies can lead to an estimate of the age of the universe.

X. *The Relativistic Redshift*, a modification of equation VII, to explain phenomena that occur at high velocities close to the velocity of light.

4. Limited numbers of references to technical and nontechnical sources appear in the text. They are there partly to help students and teachers find more material for projects and partly to help instructors emphasize that statements should be verifiable. Nontechnical sources are included in the *References* section; others are in the Instructor's Manual.

End-of-Chapter Materials

1. *Chapter Summaries* review basic ideas of the chapter and sometimes synthesize material from several preceding chapters.

2. *Concepts* lists include the important concepts appearing in **boldface** in the text. Reviewing the *Concepts* is a good way for the student to review the content of each chapter.

3. *Problems* are aimed at students with nonmathematical backgrounds.

4. *Advanced Problems* usually involve simple arithmetic or algebra and are often applications of the 10 basic equations. These can be omitted in nonmathematical courses.

5. *Projects* are intended for class use where modest observatory or planetarium facilities are available. The intent is to get students to do astronomical observing or experimenting.

Supplementary Material

1. An Enrichment Essay on *Astronomical Coordinates* and *Timekeeping Systems* can be used or not as instructors wish. An essay on *Pseudoscience and Nonscience* can be found in the Instructor's Manual.

2. *Appendixes* included are on *Powers of 10* and *Units of Measurement. Supplemental Aids in Studying Astronomy* are listed in the Instructor's Manual.

3. The *Glossary* defines all terms included in the *Concepts* lists, as well as other key terms.

4. The *References* section includes nontechnical references useful for student papers; widely available journals and magazines are emphasized in this group, including most astronomy articles appearing in *Scientific American* in recent years. Technical references are listed in the Instructor's Manual.

5. The *Index* includes names and terms.

6. *Star Maps* for the seasons are found after the index. Since more detailed, larger maps are usually available in classrooms or laboratories, these star maps have been simplified, emphasizing the plane of the solar system and the plane of the galaxy and indicating major constellations mentioned or illustrated in the text.

Acknowledgments

Our thanks go to many people who helped produce this book. We have tried to incorporate as many of their suggested corrections and improvements as possible; final responsibility for weaknesses remains ours.

We appreciate the help and advice of those reviewers who criticized parts of various editions for research comprehensiveness and teaching potential. For the 4th Edition they were Dale P. Cruikshank, NASA-Ames Research Center; Robert J. Dukes, Jr., College of Charleston; Thomas G. Harrison, University of North Texas; Leonard Muldawer, Temple University; Charles J. Peterson, University of Missouri; John L. Safko, University of South Carolina; and Robert F. Sears, Jr., Austin Peay State University.

For the 1991 Edition they were Edward Budd, Holyoke Community College; Michael Castelaz, East Tennessee State University; Ronald Kollgard, Penn State University; Emil Michal, El Paso Community College; James LoPresto, Edinboro University of Pennsylvania; Donald J. Taylor, University of Nebraska, Lincoln; Robert Mutel, University of Iowa; Jean-Pierre Caillault, University of Georgia; and Harold McAlister, Georgia State University.

For this Fifth Edition they were, from the University of Arizona, John Bieging, John Black, Adam Burrows, Rob Kennikutt, Jim Liebert, Don McCarthy, Ed Olszewski, Marica Rieke, Gary Schmidt, and Ray White; Catherine O'Sullivan, Tucson, AZ; Virginia Trimble, University of Maryland; Gary Mechler, Pima Community College; and Arthur W. Wiggins, Oakland Community College. We would particularly like to thank Mike Shull, University of Colorado, for an incisive review of the second half of this book. We also thank a wide circle of colleagues, especially in Tucson and at the University of Hawaii, for helpful discussions.

Thanks also to the staffs of Steward Observatory (University of Arizona) and the Planetary Science Institute (Science Applications International Corporation) for making our work easier. We also acknowledge the help and inspiration of our students at the University of Arizona and the University of Hawaii.

In locating and providing photographs, Dale Cruikshank, Walter Feibelman, Steven Larson, Alfred McEwen, Alan Stockton, Don Strittmatter, Alar Toomre, and Dave Webb were helpful. Don Bane and Jurrie Van der Woude (Jet Propulsion Laboratory), David Moore and Nigel Sharp (National Optical Astronomy Observatory), Margaret Weems and Pat Smiley (National Radio Astronomy Observatory), and David Malin (Anglo-Australian Observatory) gave kind assistance with their institutional files. We especially thank Chesley Bonestell, Dennis Davidson, Don Dixon, David Egge, James Hervat, Paul Hudson, Pamela Lee, Ron Miller, Jim Nichols, Mark Paternostro, Kim Poor, Adolf Schaller, Andrei Sokolov, Richard Sternbach, and Brian Sullivan for stimulating discussion about paintings of astronomical objects. Floyd Herbert and Mike Morrow helped in making several wide-angle sky photos with clock-driven mounts.

The staff at Wadsworth Publishing Company has worked hard to create a useful and beautiful product, and made the job a pleasure at the same time. We thank Mary Arbogast, Gary Mcdonald, Carolyn Deacy, Donna Kalal, Julie Butler, and Jennifer Burger for their friendship and professional help in shepherding the Fifth Edition through various editorial stages. Thanks to all of them as well for exceptional work on production and design, cheerful dispositions, hospitality, and care for the subject, not to mention care for the harried authors.

William K. Hartmann and Chris Impey
Tucson

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