1987 EDITION

ASTRONOMY THE COSMIC JOURNEY

William K. Hartmann

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

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Cover Painting: William K. Hartmann

Printed in the United States of America 48

1 2 3 4 5 6 7 8 9 10---91 90 89 88 87

Library of Congress Cataloging-in-Publication Data

Hartmann, William K.
Astronomy, the cosmic journey.

Bibliography: p.
Includes index.
1. Astronomy. I. Title.
QB45.H32 1987 520 86-28131
ISBN 0-534-07938-5

FOR TEACHERS AND STUDENTS

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 political groups trying to figure out how to save humanity from nuclear warfare that would damage life and climate on a planet-wide scale, 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, and with NASA, Europe, and the USSR planning and building permanent space stations, 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 conceptualized by students of a decade ago.

In designing this edition, the Wadsworth editors and I have tried to respond to these developments. Rather than jumping at the start into the murky waters of cosmology, I 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.

The arrangement of this book, then, 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 may be 10 to 13 billion years old. The universe itself began (or began to reach its present form) perhaps 10 to 18 billion years ago.

Because astronomy touches many areas of life and philosophy, I 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 pseudo-science, 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—I hope in a way that lets readers ponder the relation between science and priorities in our society.

The arrangement of text material into eight parts and twenty-six chapters 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.

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 millenia, 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 philosophy 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. I have also not hesitated to mention nonscientific approaches to cosmology and evolution, such as "creationist" concepts recently encouraged in two states' school systems by their state legislatures, but later thrown out after courtroom battles.

As a result of Wadsworth's extensive market surveys during preparation of this edition, we have adopted several noteworthy design concepts. The level of physics presentation is upgraded from the second edition, and the number of optional basic equations expanded from five to nine. (A shorter, nonmathematical, descriptive edition of this book is also in preparation.) Mathematics is reduced to a minimum in the text and discussed primarily as applications of the nine optional basic equations. These are described *qualitatively* in the main text, so that the book can be used in an entirely nonmathematical way. The basic equations are also described more *quantitatively* in optional boxes. Applications are illustrated there. For a more mathematical approach, instructors can emphasize these (and discuss the *Advanced Problems* at ends of chapters, which are mostly applications of the basic equations). At the request of numerous users, introductory material on light, atoms, and spectra has been integrated into the text as a new Chapter 7 (including Essay A in the previous editions). Thus, the student gets an overview of spectroscopy and atomic structure just before encountering spectroscopy in the study of planets. Then, in Chapters 13 and 14, as the sun and stars are introduced, this basic physics primer is expanded to cover topics more applicable to stars. Thus, the student gets a stepwise, perhaps gentle, introduction to some of the basic physics underlying astronomy. We have also included supplemental *Enrichment Essays* that can be used or omitted at will. We have cross-referenced the color plates thoroughly in the text. To reduce costs, we have limited our color photographs primarily to examples that illustrate the role of color in understanding astronomical phenomena.

More specifically, teaching aids incorporated in the book include the following.

TEXT

1. In addition to the classic large telescope photos and recent NASA photos, I 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 show how various objects might look first-hand 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 as aids to review. Definitions of key concepts are included in an expanded *Glossary* at the end of the book.

3. The nine optional basic equations are introduced in the text as needed, but are set off in boxes by a light gray screen for optional use. The nine 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. *Circular and Escape Velocities,* useful for deriving speeds or masses in co-orbiting systems (planetary, binary star, galactic).

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

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

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 Shift: 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 Relativistic Doppler Shift,* a modification of item VII, to explain phenomena that occur at high speeds, approaching the speed 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. These sources are included in an expanded *References* section.

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 usually applications of the nine 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. *Enrichment Essays* can be used or not as instructors wish. These include essays on:

- **A.** *Pseudoscience and Nonscience*
- **B.** *Astronomical Coordinates and Timekeeping Systems*

2. Appendixes are included on:

1. *Powers of Ten*
2. *Units of Measurement*
3. *Supplemental Aids in Studying Astronomy*

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

4. The *References* section includes all sources mentioned in the text and others used in compiling the text. Nontechnical references useful for student papers are starred (*); widely available journals and magazines are emphasized in this group, including most astronomy articles appearing in *Scientific American* in recent years.

5. Two indexes are included, an *Index of Names* and an *Index of Terms.*

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

ACKNOWLEDGMENTS

My thanks go to many people who helped produce this book. I have tried to incorporate as many of their suggested corrections and improvements as possible, although final responsibility for weaknesses remains mine.

Included among two groups of reviewers who criticized parts of the text for research comprehensiveness and teaching potential were: Helmut A. Abt, Bill T. Adams, Jr., Richard A. Bartels, Henry E. Bass, Bart J. Bok, Lee Bonneau, David R. Brown, Warren Campbell, Robert J. Chambers, Clark R. Chapman, Kwan-Yu Chen, Clark G. Christensen, Dale P. Cruikshank, Donald R. Davis, Robert J. Doyle, John Fix, Benjamin C. Friedrich, F. Trevor Gamble, Owen Gingerich, Edward Ginsberg, Jeff Goldstein, Richard Greenberg, Hubert E. Harber, Alan Harris, George H. Herbig, Ulrich O. Herrmann, J. R. Houck, William W. Hunt, Nathan Krumm, Gerald H. Newsom, Charles Peterson, Terry P. Roark, John M. Samaras, John Schopp, Richard Schwartz, Myron A. Smith, Richard C. Smith, Ronald Smith, Michael L. Stewart, Kjersti Swanson, Donald Taylor, James E. Thomas, Scott D. Tremaine, Peter D. Usher, Stuart J. Weidenschilling, Walter G. Wesley, Ray J. Weymann, Richard M. Williamon, R. E. Williams, and Warren Young.

I also thank Linda Dietrich, Gayle Hartmann, Floyd Herbert, and Roger Howlett for discussions and criticisms that affected the presentation of material; and finally, a wide circle of colleagues, especially in Tucson and at the University of Hawaii, for helpful discussions.

In locating and providing photographs, Dale Cruikshank, Walter Feibelman, Steven Larson, Alfred McEwen, Alan Stockton, Don Strittmatter, and Dave Webb were helpful. Don Bane and Jurrie Van der Woude (Jet Propulsion Laboratory), David Moore (Kitt Peak National Observatory), and Holly Chaffee (Arizona State Museum) gave kind assistance with their institutional files. I especially thank Chesley Bonestell, Don Dixon, David Egge, James Hervat, Paul Hudson, Pamela Lee, Ron Miller, Jim Nichols, Kim Poor, Adolf Schaller, Andrei Sokolov, Richard Sternbach, and Brian Sullivan for stimulating discussion about paintings of astronomical subjects. Floyd Herbert and Mike Morrow helped me in making several wide-angle sky photos with clock-driven mounts.

I thank Karla Hankey and Paula McBride for assistance in coordinating this and other research projects during preparation of the final manuscript of the third edition.

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. I thank Tom Nerney, Steve Rutter, Gary Mcdonald, MaryEllen Podgorski, and MaryLee Mackichan for their friendship and professional help in shepherding the third 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 the harried author.

William K. Hartmann
Tucson, January 1985

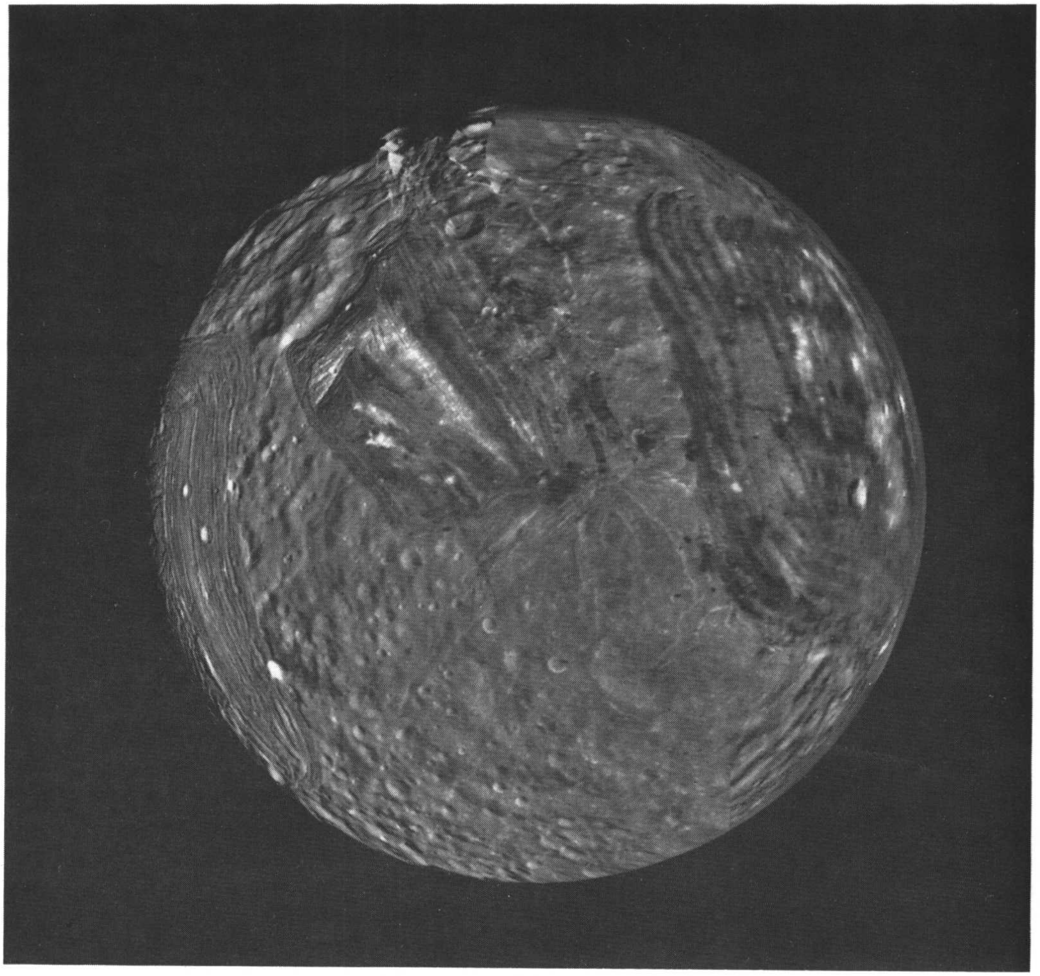
A NOTE FROM THE PUBLISHER

Since 1984, when the third edition of *Astronomy: The Cosmic Journey* was written, astronomers have increasingly come to accept black holes as the power sources at the center of active galactic nuclei, they are analyzing exciting new information about the structure of Uranus' rings, and they've photographed the nucleus of a comet. New telescopes, detectors, and computer processing techniques are allowing them to map the largest known structures of the universe in ever more revealing detail.

The rapid pace of such discoveries makes it difficult for people to keep up with the most recent advances. It's particularly challenging for textbooks to remain current because of the time needed to plan and publish them. This 1987 Edition of *Cosmic Journey* is our contribution toward providing instructors and students with the most accurate and up-to-date information available in this continually changing field. Incorporating the latest astronomical discoveries and research, William Hartmann has solidly updated sections of the text and included many new photographs and illustrations. He has also updated the bibliography, to direct students to the latest review articles. Yet the compelling writing, stunning visuals, and scientific accuracy of the content remain the same.

Among the recent events chronicled in *Astronomy: The Cosmic Journey,* 1987 Edition are new data and photographs from the various space probes sent to investigate Comet Halley (Chapter 11), new information and pictures from the Voyager encounter with Uranus (Chapter 10), and new data from Soviet radar mapping and balloon probes of Venus (Chapter 8). Some proposed missions are described, and the impact of the Challenger disaster is assessed (Chapter 4). New results on star formation and circumstellar material from IRAS and from the Epsilon Aurigae eclipse are discussed (Chapter 16). Hartmann also updates theoretical work on the moon's origin (Chapter 5), supernovae models (Chapter 17), our understanding of the galactic center (Chapter 21), models of the evolution of different galaxy shapes and galactic cannibalism (Chapter 22), the latest Hubble constant measurements (Chapter 23), the missing mass problem, and the filamentary arrangement of galaxies and galaxy clusters (Chapter 24).

We view this revision primarily as a necessary update, rather than as a major change in the text itself (which could require substantial revision of an instructor's course notes). Therefore, we have been careful to keep the original section-by-section sequence, chapter length, and book length intact, and have integrated the new material smoothly into the book's original structure. We sincerely believe these changes will assist instructors in their efforts to teach a current, accurate, and effective course in astronomy. And we hope that students will continue to be fascinated by the *Cosmic Journey* of learning about the scientific wonders of the universe.



On January 24, 1986, Voyager 2 flew by the strange moon Miranda of the planet Uranus. The spacecraft was more than 18 astronomical units (1.7 billion miles) from Earth, and only about 35 000 mi from Miranda, which is about 480 km (300 mi) across. Smallest details visible on this print are about 800 m (½ mi) across. Miranda's surface is composed of ice and dark dust. Ancient regions (bottom center) have been cratered by meteorite impacts for several billion years, but other regions (left, top, right) have been resurfaced by fractures, grooves, and canyons marked by dark stripes. The cause of these fractures and stripes is not well understood. See Chapter 10 for more detail on this and other icy moons of the outer solar system. (NASA photo, processed by U.S. Geological Survey; courtesy Jet Propulsion Laboratory of Caltech.)

DETAILED CONTENTS