Astronomy

JOURNEY TO THE COSMIC FRONTIER

1997 VERSION

JOHN D. FIX

Astronomy

Journey to the Cosmic Frontier

John D. Fix
University of Iowa

with 754 illustrations

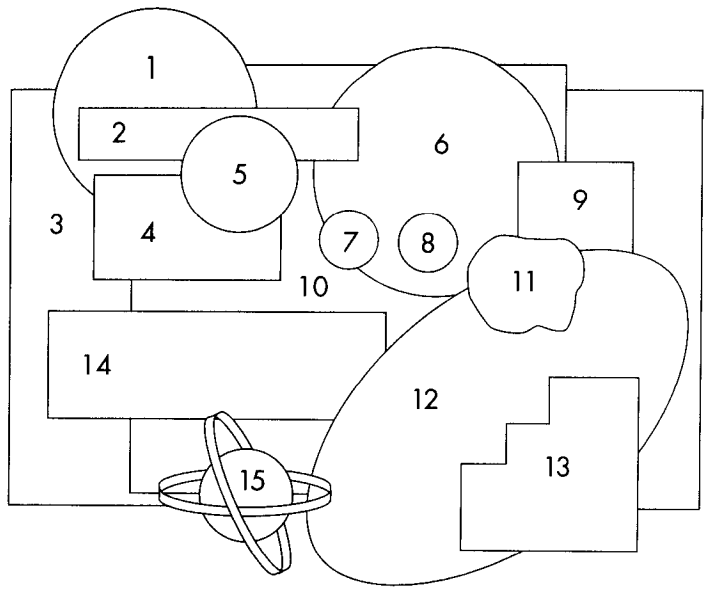
WCB McGraw-Hill

Boston, Massachusetts Burr Ridge, Illinois Dubuque, Iowa
Madison, Wisconsin New York, New York San Francisco, California St. Louis, Missouri

WCB/McGraw-Hill

A Division of The McGraw-Hill Companies

Publisher: James M. Smith
Executive Editor: Lloyd W. Black
Developmental Editors: John S. Murdzek/Donata Dettbarn
Art Developer: John S. Murdzek
Illustrations: ArtScribe, Inc.
Photo Researcher: Donata Dettbarn
Project Managers: Mark Spann/Christopher Baumle
Production Editors: Jennifer Doll/David Orzechowski
Composition Specialists: Joan Herron/Pamela Merritt
Designer: Paul Uhl
Design Manager: David Zielinski
Manufacturing Supervisor: Theresa Fuchs/John Babrick



Key to Cover Images

***1,** From Galileo's drawings of the Moon. **2,** Lava flows on Io. **3,** Hubble Deep Field. **4,** From Galileo's observations of the Sun. **5,** Interior structure of Europa. **6,** The winding dilemma in spiral galaxies. **7,** Venus imaged by Magellan. **8,** Saturn. **9,** Jet of gas from a young star. **10,** Celestial map. **11,** Meteorite believed to come from Mars. **12,** Radio telescope. **13,** Gaseous pillars in M16 (Eagle Nebula). **14,** Butterfly diagram. **15,** Earth and zodiac from antique map. Spine image: Planetary Nebula NGC 7027 from Hubble Telescope/STSci.*

FIRST EDITION

1997 Version

Printed in the U.S.

Color separation by Color Dot Graphics and Color Associates
Printing/binding by Von Hoffman Press, Inc.

Library of Congress Cataloging in Publication Data

Fix, John D.

Astronomy : journey to the cosmic frontier / John D. Fix. -- 1st ed.

p. cm.

Includes bibliographical references and index.

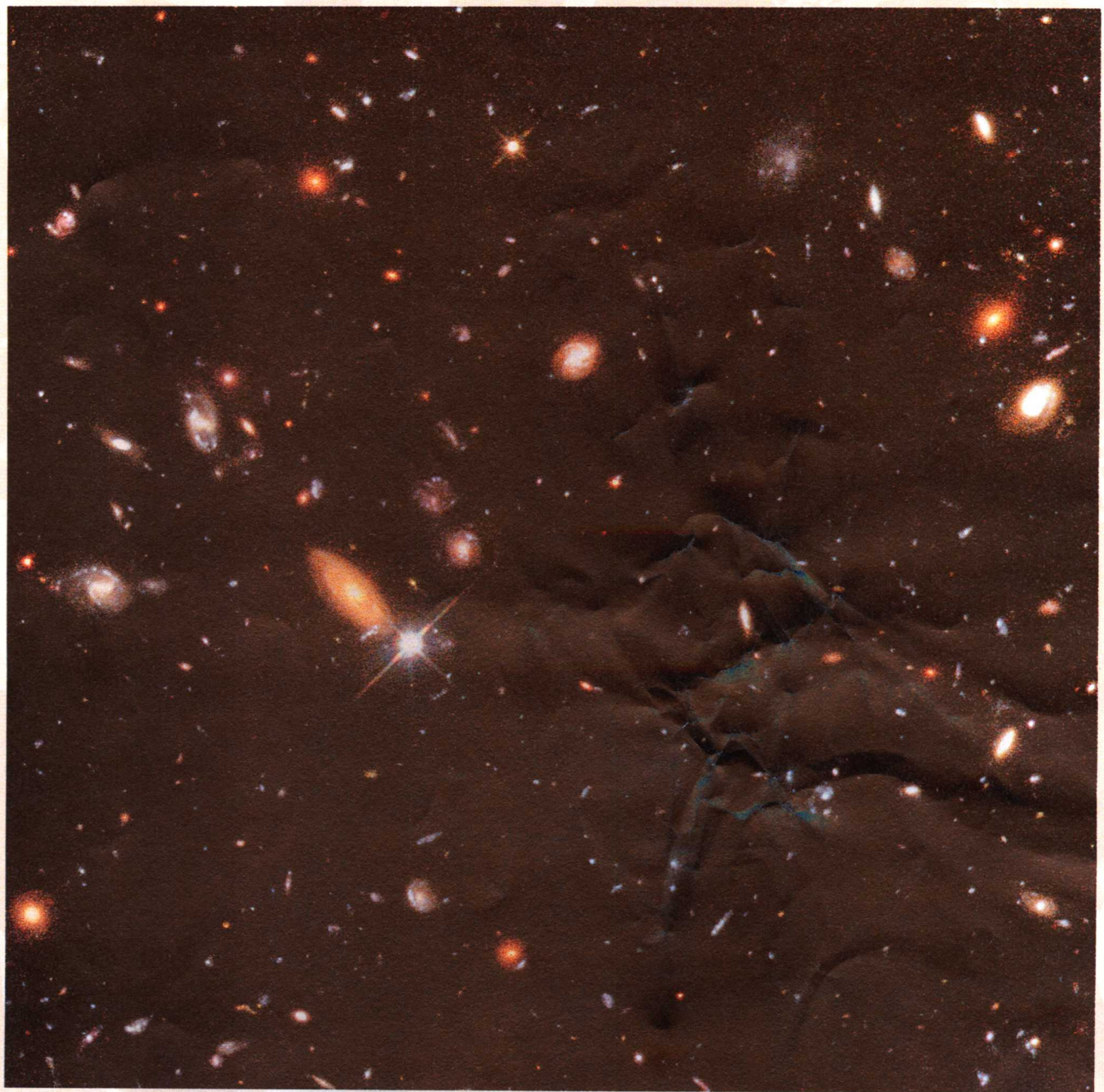
ISBN 0-8016-7449-2

1. Astronomy. I. Title.

QB43.2.F59 1995

520--dc20

97 98 99 00 01 / 9 8 7 6 5 4 3



A Hubble Space Telescope image of a small region of the sky. This image looks farther into space and reveals fainter galaxies than any previous view of the sky. For more information about galaxies, please see Chapter 23.

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, time-keeping, 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

A Hubble Space Telescope image of columns of cool interstellar gas and dust in which stars are forming in the constellation Serpens. For more about star formation and interstellar gas and dust, please read Chapters 18 and 20.

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 first observations by the repaired Hubble Space Telescope and the impacts of Comet Shoemaker-Levy 9 on Jupiter both received headline coverage in newspapers and were featured on newscasts. Part of the public interest in astronomy is due to the dramatic scope of the science. Part, I am sure, is because non-professionals can not 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. A recent example was David Levy's co-discovery of Comet Shoemaker-Levy 9.

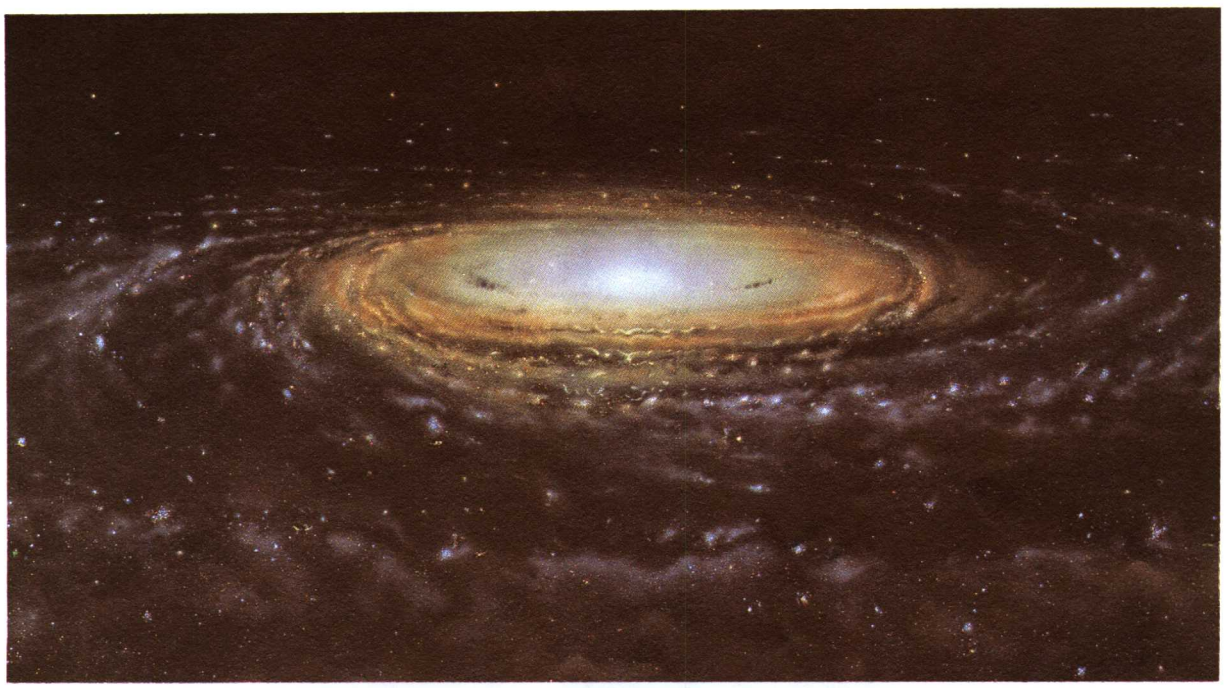
I wrote this book as a text for an introductory course in astronomy for college students. I have taught such courses for 25 years at the University of Iowa. One of my main goals in those courses, and one of my main goals in this book, is to provide my students with a broad enough, deep enough background 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 since its repair, the impacts of Comet Shoemaker-Levy 9 on Jupiter, and the discovery of the nearest galaxy to the Milky Way. 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 understand astronomy articles in *Scientific American* and watch television specials 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.

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 quantitive 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. The reader's mastery of the equations can be tested by the Problems at the end of each chapter. The Problems require numerical calculations, whereas the Conceptual Questions require qualitative verbal answers, and the Figure-Based Questions require the reader to extract the answer from a particular graph or figure in the chapter. About two dozen of the figures in this book are stereoscopic drawings that can be viewed using the special glasses included with the book. The illusion of depth in the stereoscopic drawings lets the reader see fully three-dimensional representations of the shapes and locations of astronomical bodies. Each stereoscopic drawing is paired with a one-dimensional drawing on which labels and details are given.

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. Every chapter begins with an introduction designed to give the historical and scientific setting for the chapter material. 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.

I hope that all the explanations and descriptions in the book won't 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 and Astronomy, University of Iowa, Iowa City, IA 52242 or by e-mail at jdf@ptolemy.physics.uiowa.edu.



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.

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 10,000 University of Iowa students who have taken 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 at the University of Iowa: 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 the first version of the book and offered suggestions for improving it. I found the comments of John Broderick, Bill Keel, Kathy Rajnak, and Jeremy Tatum 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 Mosby who have worked on the book, including Mark Spann, Jennifer Doll, Joan Herron, Dave Zielinski, Theresa Fuchs, David Orzechowski, and Pamela Merritt, who were key members of the production team. Jim Smith, John Murdzek, and Lloyd Black have been my editors. Jim began the project and John and Lloyd have seen 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 book. John also worked with Carolyn Duffy and Greg Holt of ArtScribe to produce the remarkable color figures in the book. In most cases, these figures are vastly better than the original sketches I sent to John. Donata Dettbarn worked miracles in locating and obtaining permission to use many of the images in the book and oversaw the many changes in this 1997 version of the book.

A mosaic of Hubble Space Telescope images of the Orion Nebula, a region in which stars are forming. For more information about star formation, please see Chapter 18.

Reviewers

The following astronomers and physicists reviewed one or more of the drafts of the book. Their comments and advice greatly improved the readability, accuracy, and currency of the book.

Robert H. Allen
University of Wisconsin
La Crosse, Wisconsin

Leonard B. Auerbach
Temple University

Thomas J. Balonek
Colgate University

James M. Borgwald

Elizabeth Bozyan
University of Rhode Island

Steve Cederbloom
Mt. Union College

Larry Corrado
University of Wisconsin Center
(Manitowoc)

George W. Crawford
Southern Methodist University

Bruce Daniel
Pittsburg State University

Barbara A. Gage
Prince George's
Community College

David Griffith
Oregon State University

Richard Herr
University of Delaware

Ken Janes
Boston University

Terry Jones
University of Minnesota

Eric Kincannon
Gonzaga University

Harold P. Klein
SETI Institute

David J. Kriegler
Creighton University

Claud H. Lacy
University of Arkansas

Neil Lark
University of the Pacific

Paul D. Lee
Louisiana State University

Wayne Lewis
Texas Tech University

David Loebbaka
University of Tennessee at Martin

Edwin Loh
Michigan State University

Loris Magnani
University of Georgia

William Millar
Grand Rapids Community College

David Roberts
Bowdoin College

Barbara Ryden
Ohio State University

Alberto Sadun
Agnes Scott College

Charles Schweighauser
Sangamon State University

Richard Sears
University of Michigan

Michael Sitko
University of Cincinnati

Alexander G. Smith
University of Florida

Michael Stewart
San Antonio College

Timothy D. Swindle
University of Arizona

F. D. Talbert
San Diego State University

Donald Terndrup
Ohio State University

Yervant Terzian
Cornell University

Charles R. Tolbert
University of Virginia

Peter Usher
Pennsylvania State University

Walter Wesley
Moorhead State University

J. Wayne Wooten
Pensacola Junior College

All of the reviewers were very helpful, but I especially want to thank James Borgwald, Steve Cederbloom, Paul D. Lee, William Millar, David Roberts, Alexander G. Smith, and Timothy D. Swindle for their unusually valuable and thoughtful comments.

A Hubble Space Telescope image of the planet Mars. For more about Mars, please read Chapter 13.

Instructional Supplements

A complete package of ancillary materials has been prepared to assist you and your instructor in making your learning experience as complete as possible:

FOR STUDENTS

View-Study™ Image Disc for Astronomy. This unique, inexpensive new CD-ROM software includes a database of artwork and photographs with accompanying captions from the textbook. Cross-referenced by topic, concept, and figure number, the figures and captions can be printed out in notecard or full-size format for convenient review.

FOR INSTRUCTORS

Instructor's Manual by John Fix. This manual, also available on disk for IBM and Macintosh, contains for each chapter an outline, goals and strategies, suggested transparency acetates, Key Terms, and answers to all end-of-chapter questions and problems. Also included are some sample syllabi for one- and two-semester courses and recommendations for video lecture demonstrations and student outside reading.

Test Bank by John Fix. This test bank contains 750 multiple-choice questions organized by chapter.

ESATEST III Computerized Testing System by Engineering Software Associates. This state-of-the-art test generation software is available for IBM (DOS and Windows) and Macintosh. ESATEST III offers an impressive array of features, including a two-track design (Easytest for the novice and Fulltest for the expert); full editing capabilities; ability to import text and graphics from conventional word processors and graphics programs; test generation by review, question number, criteria, or formula; support for special symbols and characters; support for over 700 printers; and full mouse support.

Transparency Acetates. This transparency art consists of full-color reproductions of box figures from the text.

Videodisc. This videodisc includes all line art from the textbook, many photographs, video clips, and animations. An accompanying Print Directory lists all still images, frame references, and movie narration. A second manual contains barcodes for programs and images for easy access to the disc.

View-Study™ Image Disc for Astronomy. Available free to adopters, this innovative new tool allows instructors to arrange and show images as well as create transparency acetates and illustrated exam materials.

Videotape Selection. Two videotapes are available to qualified adopters. The first is from the *Astronomers* six-part video series, which examines topics such as dark matter, quasars, black holes, and the search for planets outside our solar system. A second tape, *Star Recognition,* identifies the key constellations in our sky, as viewed from the middle latitues of the northern hemisphere.

For Cynthia.

Contents in Brief

Contents