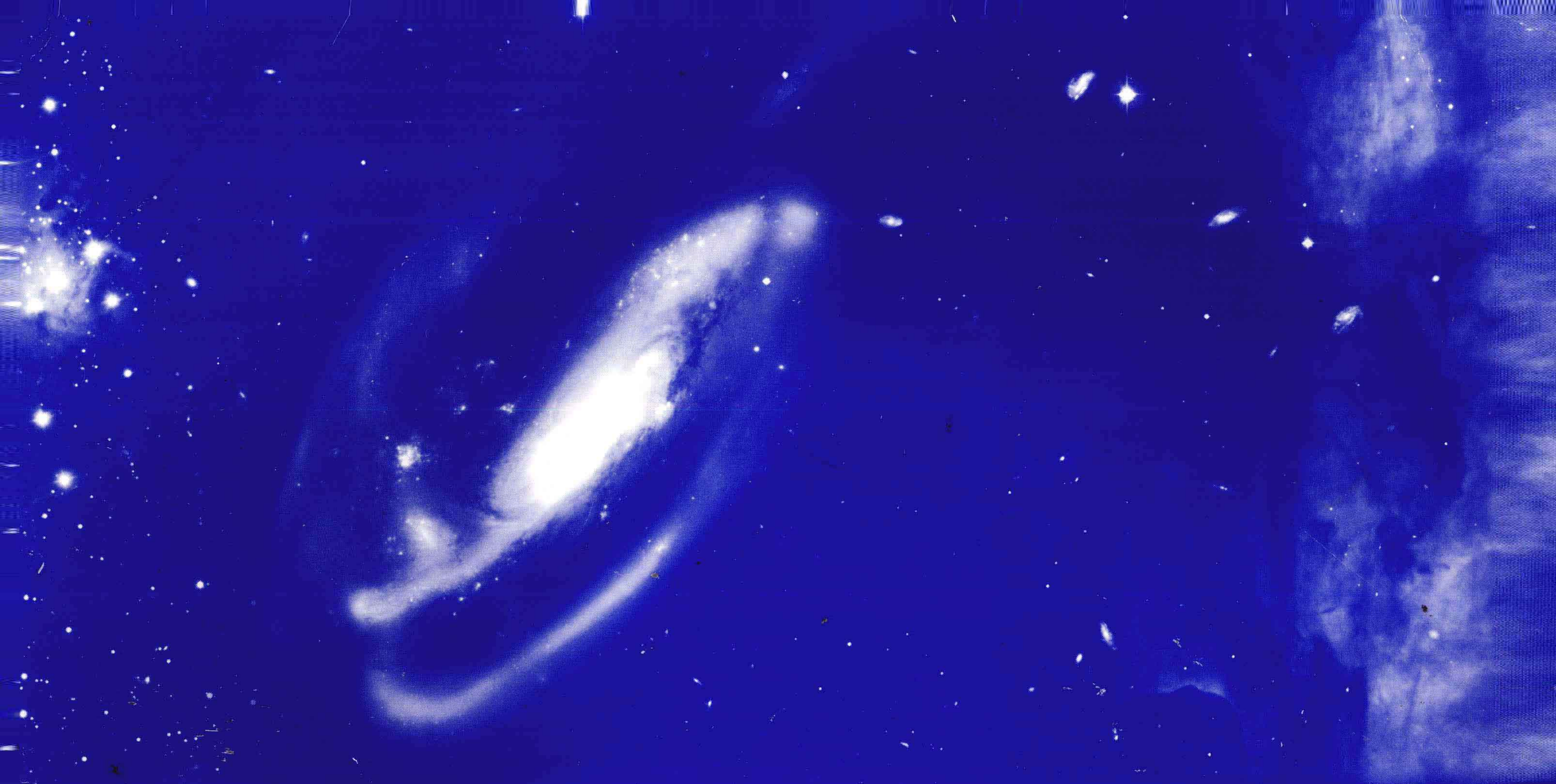

THOMAS T. ARNY

THIRD EDITION, UPDATED

EXPLORATIONS

VOLUME I

SOLAR SYSTEM

EXPLORATIONS

VOLUME I
SOLAR SYSTEMS

THIRD EDITION UPDATED

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Preface

When I began writing *Explorations: An Introduction to Astronomy,* many people asked me why I was writing an astronomy book. Much of my motivation comes from wanting to share my own sense of wonderment about the Universe. I hope that in an astronomy course, students can get some sense of where they fit in the astronomical Universe—a sense of location in the cosmic landscape. I also hope that students will come away from such a course with a sense of the richness of the Universe. When we look around us on our own planet, we see incredible biodiversity. So, too, when we look at the heavens, we see incredible astrodiversity. Stars, moons, and planets are as strange, colorful, and wonderful as tropical butterflies. Finally, I hope that students will gain some appreciation of the methods by which such tiny beings as we are have learned so much about the Universe. Those methods are not just laboratory techniques. Far more important is the process of learning: the steps by which we go from observation to hypothesis and then on to what we hope is understanding.

But why write your own astronomy book when so many already exist? Most of the current books have so much material that they are impossible to get through in a single semester, and much material is omitted. I therefore decided that my first goal was to make a book that was short. However, as I worked at it, I kept finding things that I didn't want to leave out, material such as calendars and the history of astronomy. But how could I write a short book and still include such topics? The solution was to organize the book so that instructors and students could omit the unwanted sections without interrupting the flow of ideas. Thus, I placed a number of topics such as time keeping and exo-biology into Essays that may be easily skipped. I also tried to make the book short by limiting its scope. Rather than covering everything, I have tried to focus on only what at the time seemed to me the most important ideas.

Another goal I set myself was to give simple explanations of why things happen. Such explanations generally involve physical principles that are unfamiliar to nonscience students. However, many even very complicated physical ideas can be appreciated, if not fully understood, by appeal to analogy or to similarities with everyday phenomena. For example, diffraction effects can be seen by looking at a bright light through a lock of your hair pulled over your eyes or through glasses that you have fogged with your breath. By tying physical principles to everyday observations, many of the more abstract and remote ideas become more familiar. Thus, I have used analogies heavily throughout the book, and I have designed the illustrations to make those analogies more concrete.

An additional aim throughout this text is to explain *how* astronomers know the many curious things they have learned about our Universe. Such explanations often require mathematics, and so I have included it wherever it is crucial to understanding a method of measurement, as in the use of the modified form of Kepler's third law to determine a star's mass or in Wien's law to measure its temperature. However, because math is so intimidating to so many students, I have tried to begin these discussions by introducing the essence of the calculations in everyday language. Thus, if the student or instructor chooses to omit the math, it will not prevent an understanding of the basic idea involved. For example, Wien's law relates the temperature of a hot object to its color by a mathematical law. However, the consequences of the law can be seen in everyday life when we estimate how hot an electric stove burner is by the color it glows.

Similarly, I have tried to work through the math problems step by step, explaining that terms must be cross-multiplied, and so forth.

As a final goal, I have set many of the modern discoveries in their historical context. I want to demonstrate that science is a dynamic process and that it is subject to controversy. Ideas are often not immediately accepted, and to appreciate those that scientists finally settle on, it helps to understand the arguments for and against them, as well as the train of reasoning that leads to the "accepted" answer. On this point, I must digress and reveal my own amazement (and naiveté) at how many widely accepted ideas have such flimsy underpinnings and how many widely quoted values for astronomical quantities are very imperfectly known.

NEW TO THIS UPDATE

NEW! Interactives McGraw-Hill is proud to bring you an assortment of outstanding Interactives like no other. These Interactives offer a fresh and dynamic way to teach the astronomy basics. Each Interactive will allow students to manipulate parameters and gain a better understanding of such topics as blackbody radiation, the Bohr model, a solar system builder, retrograde motion, cosmology, and the H-R diagram by watching the effect of these manipulations. Each Interactive will include an analysis tool (interactive model), a tutorial describing its function, content describing its principle themes, related exercises, and solutions to the exercises. Plus, you'll be able to jump between these exercises and the analysis tools with just the click of the mouse.

This 2004 update also includes some new images, revised figures, and updated material in several areas. I have expanded several topics, for example, the material on extra-solar planets, where I have added discussion of the transiting planet and some images of preplanetary disks. In that discussion, I have also emphasized that much of the motivation for studying extra-solar planets is to better understand planet formation. (I have *not,* however, tried to keep the number of such planets current, a hopeless task.)

Another area that I have updated is the discussion of what causes one forming galaxy to become a spiral, while another becomes an elliptical. Likewise, I have revised the section on whether the Universe will expand forever or recollapse, eliminating the distinction of "open" and "closed" universes. This was necessary because if the cosmological constant is not zero, the previously relatively simple relation between curvature and whether or not the Universe expands forever no longer holds.

As an experiment, I have also revised a number of the Re-Modeling boxes. These boxes were originally designed to show how new evidence leads astronomers to modify their ideas. The revisions to the Re-Modeling boxes are meant to show how scientific ideas are subjected to testing. Hence, these revised boxes have been renamed "Science at Work." I hope this will help students better see how the scientific method operates.

The above updates were built upon the changes to the Third Edition, which include:

- Migration of the giant planets within the Solar Nebula
- The shape of planetary nebulas
- Evidence from the cosmic microwave background that our Universe is flat
- Evidence for "recent" water flows on Mars
- Hypotheses for why Earth and Venus have such different surfaces
- The discovery of numerous brown dwarfs and low-temperature stars

I have made two shifts in the organization of the material. The discussion of seasons is now in chapter 1, and the chapter on telescopes now follows directly the chapter on light. Both these changes were urged by many reviewers, and, to be honest, I myself have generally discussed seasons with the material on aspects of the sky. Most of the

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other changes in this edition are minor or are corrections of typos or other points raised by reviewers. Foot and margin notes add a few topics that are of more specialized interest but that I wanted my own students to know of.

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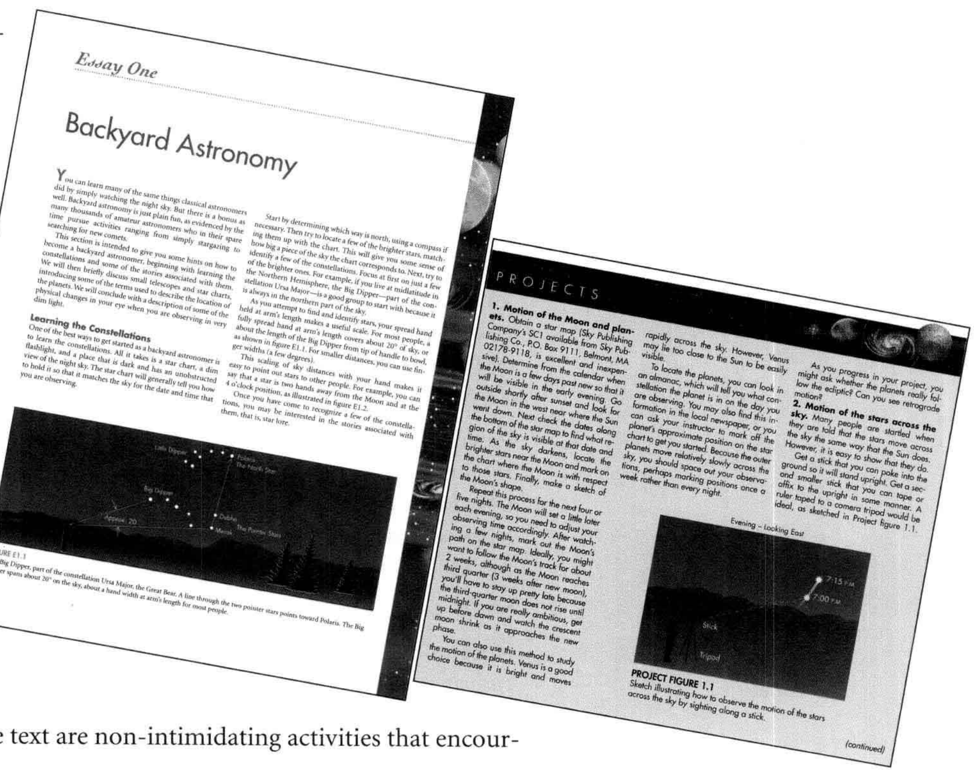

- *New Illustrations*—Stunning, full-color images emphasize text content and reflect current information and astronomical developments.
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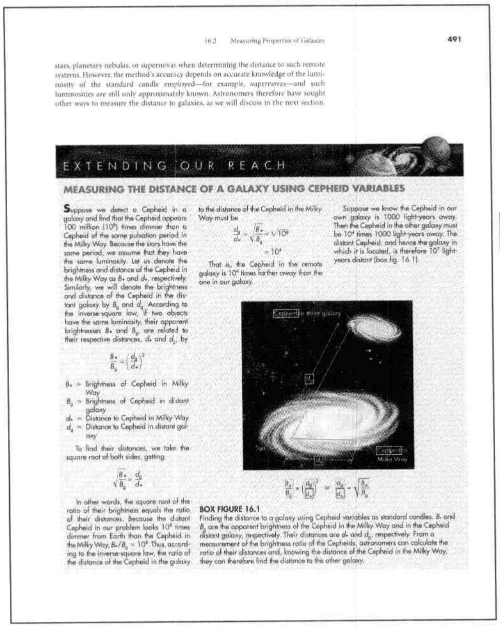
- *New! Science at Work Boxes*—are meant to show how scientific ideas are subjected to testing.



16.2 Measuring Properties of Galaxies 491

stars, planetary nebulas, or supernovas when determining the distance to such remote systems. However, the method's accuracy depends on accurate knowledge of the luminosity of the standard candle employed—for example, supernovas—and such luminosities are still only approximately known. Astronomers therefore have sought other ways to measure the distance to galaxies, as we will discuss in the next section.

EXTENDING OUR REACH

MEASURING THE DISTANCE OF A GALAXY USING CEPHEID VARIABLES

Suppose we detect a Cepheid in a galaxy and find that the Cepheid appears 100 million (10^8) times dimmer than a Cepheid of the same pulsation period in the Milky Way. Because the stars have the same period, we assume that they have the same luminosity. Let us denote the brightness and distance of the Cepheid in the Milky Way as B_* and d_*, respectively. Similarly, we will denote the brightness and distance of the Cepheid in the distant galaxy by B_g and d_g. According to the inverse-square law, if two objects have the same luminosity, their apparent brightnesses B_* and B_g are related to their respective distances, d_* and d_g, by

$$\frac{B_*}{B_g} = \left(\frac{d_g}{d_*}\right)^2$$

B_* = Brightness of Cepheid in Milky Way
B_g = Brightness of Cepheid in distant galaxy
d_* = Distance to Cepheid in Milky Way
d_g = Distance to Cepheid in distant galaxy

To find their distances, we take the square root of both sides, getting

$$\sqrt{\frac{B_*}{B_g}} = \frac{d_g}{d_*}$$

In other words, the square root of the ratio of their brightness equals the ratio of their distances. Because the distant Cepheid in our problem looks 10^8 times dimmer from Earth than the Cepheid in the Milky Way, $B_*/B_g = 10^8$. Thus, according to the inverse-square law, the ratio of the distance of the Cepheid in the galaxy to the distance of the Cepheid in the Milky Way must be

$$\frac{d_g}{d_*} = \sqrt{\frac{B_*}{B_g}} = \sqrt{10^8} = 10^4$$

That is, the Cepheid in the remote galaxy is 10^4 times farther away than the one in our galaxy.

Suppose we know the Cepheid in our own galaxy is 1000 light-years away. Then the Cepheid in the other galaxy must be 10^4 times 1000 light-years away. The distant Cepheid, and hence the galaxy in which it is located, is therefore 10^7 light-years distant (box fig. 16.1).

BOX FIGURE 16.1
Finding the distance to a galaxy using Cepheid variables as standard candles. B_* and B_g are the apparent brightness of the Cepheid in the Milky Way and in the Cepheid distant galaxy, respectively. Their distances are d_* and d_g, respectively. From a measurement of the brightness ratio of the Cepheids, astronomers can calculate the ratio of their distances and, knowing the distance of the Cepheid in the Milky Way, they can therefore find the distance to the other galaxy.

- *Analogy Sketches*—These sketches provide visual clarification of important textual analogies.
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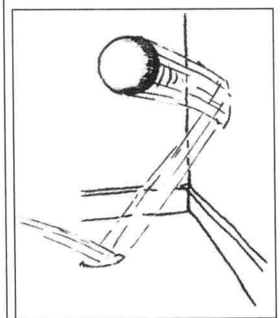

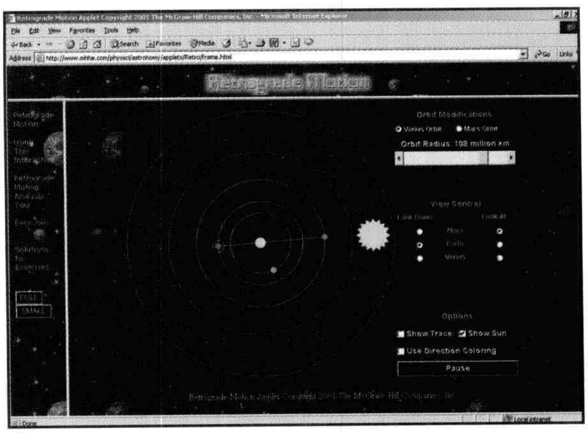

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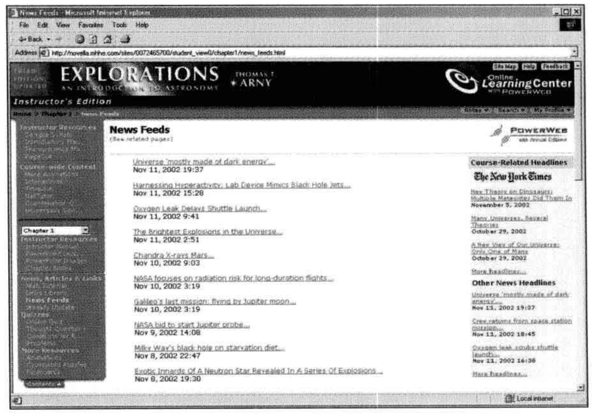

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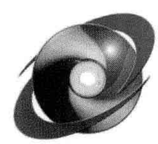
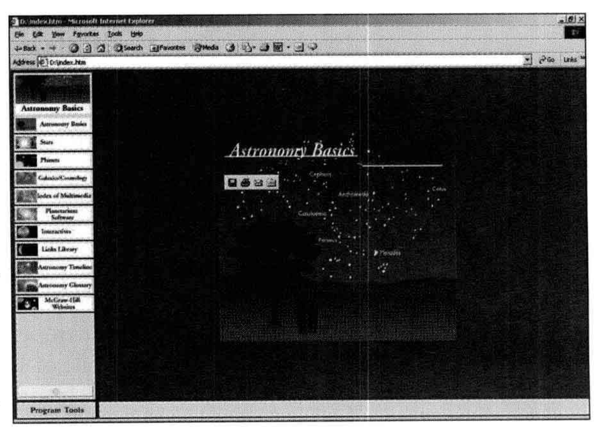
Animation icon A feature of this edition is an animation icon placed next to topic headings and images that have related animations on the Essential Study Partner CD-ROM and the Online Learning Center. In addition, a description of the animation is next to the icon. There are approximately 80 animations that will help bring each concept to life as each shows its special simulated physical phenomena.



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



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HOW TO STUDY WITH THIS BOOK

Learning anything requires a certain amount of work. You certainly don't expect to be able to pick up a guitar and play it without practice, nor do you expect to be able to jog 5 miles without working out regularly. Learning astronomy also requires some work. These steps will help you learn the material better and more easily.

In reading any assignment, begin by looking at the pictures. Turn the pages of the chapter and familiarize yourself with what the objects you will be reading about look like. Then read the introduction. Next, jump to the summary. Finally, start again and read the assigned material through. As you read, make notes of things you don't understand and ask your instructor or teaching assistant for clarification. For example, if you are puzzled about why eclipses don't happen every month, make a note. I would urge you *not* to highlight as you read. Making a few short notes is much more effective than highlighting whole paragraphs.

Look carefully at the pictures and diagrams. If the figure caption has a question in it, try to answer it. Make your own sketch of diagrams to be sure you understand what they represent.

In a first reading of a chapter, I'd suggest that if you are troubled by math, you should simply skip it for the time being. Be sure, however, to read the material leading into the math so you at least understand what is being dealt with. When you encounter a mathematical expression of a physical law, put in words what the law relates. For example, the law of gravity relates the force of gravity to the mass of the objects and their distance from each other.

If you encounter words or terms as you read that you don't know, look them up in the glossary or index. You are just wasting your time if you read a description of some object and you don't know what it is.

When you finish the assignment, try to answer the review questions. They are short and are designed to show you whether you have assimilated the basic factual material of the assignment. Try to do this without looking back into the chapter, but if you can't remember, look it up rather than skip over the question. You might find it helpful to get a pile of scratch paper and actually write out short answers to the questions.

Having read the material once, go back and try to work through the math parts. Then try a practice problem to see if you can work through the material on your own.

If you get stuck at any point, see your teaching assistant or professor for help. Don't be shy about asking questions. I wish someone had beaten this into my head earlier. Learning is a thousand times easier if you ask questions when you get stuck.

Throughout the book, I have also tried to convey some of my own enthusiasm for astronomy. Many astronomical objects are strikingly beautiful. Others conjure up a sense of amazement. To me, it is the ultimate wonder that within the Universe, life has formed that can contemplate the Universe and ask what it is about. Seeing a clear night sky spangled with stars is for me a nearly religious experience. And yet the beauty that I see and my sense of wonder are enriched even more by an appreciation of the complex processes that make the Universe work. I hope this book will similarly increase your appreciation of our Universe's wonders.

If while using this book you find mistakes or if you have suggestions about how to make it better, *please* let me know. Write me at the Astronomy Program, University of Massachusetts, Amherst, MA 01003-4525, USA. If you have access to e-mail, please let me know that way. My address is arny@nova.astro.umass.edu. I really want your feedback.

ACKNOWLEDGMENTS

I owe thanks to many people for their help in this book. Among these are all of my colleagues (past and present) in the Five College Astronomy Department and many of them in the Department of Physics and Astronomy. Neal Katz, Eric Linder, James Lowenthal, Mike Skrutskie, Daniel Wang, and Martin Weinberg, as neighbors down the hall, bore a disproportionate share of questions, and I owe them special thanks. I profited from many conversations with Ted Harrison, the late Ed Phinney (of the Classics Department), Peter Schloerb, the late David Van Blerkom, and Gene Golowich. Bill Bates and Rick Newton helped with setting up several photos and Linda Ray Arny helped me locate many references. I also want to thank Amy Lovell for her careful proofreading of the first edition.

Many readers (professors and students) have been kind enough to take the time to send me suggestions or point out errors. They include John Beach, James D. Edmonds, Jr., Bill Dent, Bill Irvine, Daniel Jaffe, Susan Kleinmann, Lauren Likkel, Mesgun Sebahu, Ron Snell, Mark Stuckey, Gene Tademaru, and Steve Schneider. I particularly want to thank the following people for very detailed critiques of several sections: James F. Andrus, Eric Feigelson, Wei Lee, Jeff Lewis, Rainer Mauersberger, James O'Connell, Cynthia W. Peterson, David Voigts, Joel Weisberg, Richard White, and Ben Zellner.

I also wish to thank William R. Luebke, who revised the test bank that he had done for the second printing of the first edition and improved it dramatically.

Many people at McGraw-Hill have helped immensely. I am very grateful to Jim Smith, who began the project and read the entire manuscript in its first draft; Judy Hauck, who was the developmental editor for the first edition and turned it into such an attractive book; Donata Dettbarn, who took over as the developmental editor for the second edition; and Lori Sheil, the developmental editor for a later update. For the present update and 3rd edition I want to thank the editors Daryl Bruflodt and Brian Loehr, as well as Jenni Lang. I also am grateful to the McGraw-Hill production people, especially Susan Brusch, the project manager. Others who helped greatly were Lori Hancock, Wayne Harms, Sherry Kane, Brenda Ernzen, Sandy Schnee, Deb Hash, Carrie Burger and Mary Reeg and Marilynn Taylor, the copy editor. Lisa Gottshalk in the sales office also deserves special thanks. The lovely line art work was done by Carolyn Duffy and Greg Holt of ArtScribe. Jay Hoagland did the margin sketches. Finally, I want to thank the many McGraw-Hill sales representatives who sent me comments from adopters and potential users.

The many reviewers whose direct input has shaped the changes in this third edition and update are listed separately, and I am very grateful for their suggestions and careful thought. I am also grateful to the many scientists who have obtained such lovely images. Although innumerable people have read the manuscript, any errors that remain are my responsibility. If you find mistakes, please let me know. I want to make *Explorations* as error-free as possible.

As a final comment, let me add that a number of professors have commented on the duplicate coverage of some topics. That repetition is deliberate and is designed to refresh the material in students' minds and allow the instructor to skip sections without the students missing discussion of important ideas.

REVIEWERS

The following people have reviewed this book at various stages of its development. I very much appreciate their help, suggestions, and corrections. Any errors that remain are not their fault, but mine.

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