The Cosmic Perspective
Fundamentals
Second Edition

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Dedication

TO ALL WHO HAVE EVER WONDERED about the mysteries of the universe. We hope this book will answer some of your questions—and that it will also raise new questions in your mind that will keep you curious and interested in the ongoing human adventure of astronomy.

And, especially, to Michaela, Emily, Sebastian, Grant, Nathan, Brooke, and Angela. The study of the universe begins at birth, and we hope that you will grow up in a world with far less poverty, hatred, and war so that all people will have the opportunity to contemplate the mysteries of the universe into which they are born. ✴
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Preface

We humans have gazed into the sky for countless generations. We have wondered how our lives are connected to the Sun, Moon, planets, and stars that adorn the heavens. Today, through the science of astronomy, we know that these connections go far deeper than our ancestors ever imagined. This book focuses on the story of modern astronomy and the new perspective—the cosmic perspective—that astronomy gives us on ourselves and our planet.

Who Is This Book For?
The Cosmic Perspective Fundamentals is designed as a textbook for one-term college courses in introductory astronomy. Our other textbooks, The Cosmic Perspective and The Essential Cosmic Perspective, are fairly complete and authoritative references, from which instructors can pick and choose the material that they will emphasize in their individual courses. In recent years, however, some instructors have adopted a new approach to teaching in which they rely more heavily on Web-based materials and active or collaborative learning techniques and less on textbook-based lectures. This new approach inspired us to create a much shorter book that would retain the pedagogy and flexibility of our longer texts but focus only on the most essential concepts of modern astronomy. The Cosmic Perspective Fundamentals is the result.

New to This Edition
Many new discoveries have been made in astronomy during the five years since publication of the first edition of The Cosmic Perspective Fundamentals, leading to many changes in this second edition. The most significant of these changes include the following: (1) In material dealing with the night sky, we have generalized discussions of the sky so that they now work well for readers in the Southern Hemisphere. (2) We have revised our discussion of several key issues about the nature of science in Chapter 3 and have added the new Table 3.1 on scientific terminology. (3) Content relating to Mars has been updated to include recent results from Curiosity and other missions. (4) We have fully updated Section 5.3 on global warming to reflect the latest data and understanding. (5) We have incorporated the latest Cassini results in our discussion of Saturn, Titan, and Enceladus, along with early results from Rosetta. (6) We have reorganized and rewritten Chapter 7 on extrasolar planets in light of the thousands of recently discovered planets. (7) We have restructured Section 11.3 to focus on current understanding of supermassive black holes rather than just on quasars. (8) Recent advances in understanding galaxy evolution led us to make significant scientific changes in Section 11.2, including the addition of the “galaxy H-R diagram” as a new Figure 11.17. (9) We have updated our discussion of the early universe to include the latest data from the Planck observatory. Please note that, in addition to the changes listed here, you’ll notice many other small improvements throughout the book.

Topical Selection
A dramatically shorter textbook must necessarily cover fewer topics. We have carefully selected those topics using the following four criteria:

- **Importance.** We surveyed a large number of professors to identify the topics considered of greatest importance in a college-level astronomy course, in order to ensure that the most fundamental concepts are covered in this text.

- **Engagement.** Most students in a college astronomy course are there to satisfy a general education requirement, but the subject is sufficiently interesting that it should be possible to choose topics that students will find highly engaging—and that they will therefore be willing to work hard to learn.

- **Process of science.** We believe that the primary purpose of a general education requirement in science is to ensure that students learn about science itself. Throughout the book, we have chosen topics that illustrate important aspects of the process of science, and each chapter concludes with a section called The Process of Science in Action, which presents a case study of how the process of science has helped (or is currently helping) to provide greater insight into key topics in astronomy.

- **Active learning.** Educational research has shown that students learn scientific concepts best by actively solving conceptual problems, both individually and in collaboration with other students. We have emphasized topics that are well suited to active learning, and each chapter includes Think About It critical thinking questions for in-class discussion and See It for Yourself hands-on activities to further promote active learning. These in-text features are reinforced by a variety of active learning resources on the MasteringAstronomy® website.

We recognize that most astronomy courses follow a similar structure, beginning with topics such as the scale of the universe, seasons, and phases of the Moon and then progressing to study of the planets, stars, galaxies, and cosmology. Our selected topics have been organized in a similar fashion. The fifteen chapters are designed so that they can be covered in a typical semester at a rate of approximately one chapter per week.
Book Structure

To facilitate student learning, we have created a simple pedagogical structure used in each of the book’s fifteen chapters:

- Each chapter begins with an opening page that includes a brief overview of the chapter content and a clear set of Learning Goals associated with the chapter; each Learning Goal is phrased as a question to engage students as they read.
- Each chapter consists of three sections. The first two sections focus on the key topics of the chapter; the third section builds on the ideas from the first two sections, but focuses on The Process of Science in Action.
- Each section is written to address the Learning Goal questions from the chapter-opening page.
- Each chapter concludes with a visual summary that provides a concise review of the answers to the Learning Goal questions.
- The summary is followed by a 12-question Quick Quiz and a set of short-answer, essay, and quantitative questions.

Additional features of the book include the following:

- Tools of Science boxes, which present a brief overview of key tools that astronomers use, including theories, equations, observational techniques, and technology. Each chapter includes one Tools of Science box related to the chapter content.
- Common Misconceptions boxes, which address popularly held but incorrect ideas about topics in the text.
- Annotated Figures and Photos, which act like the voice of an instructor, walking students through the key ideas presented in complex figures, photos, and graphs.
- Cosmic Context Figures, which combine text and illustrations into accessible and coherent two-page visual summaries that will help improve student understanding of essential topics.

MasteringAstronomy® — A New Paradigm in Astronomy Teaching

What is the single most important factor in student success in astronomy? Both research and common sense reveal the same answer: study time. No matter how good the teacher or how good the textbook, students learn only when they spend adequate time studying. Unfortunately, limitations on resources for grading have prevented most instructors from assigning much homework despite its obvious benefits to student learning. And limitations on help and office hours have made it difficult for students to make sure they use self-study time effectively. That, in a nutshell, is why we have created MasteringAstronomy®. For students, it provides adaptive learning designed to coach them individually—responding to their errors with specific, targeted feedback and providing optional hints for those who need additional guidance. For professors, MasteringAstronomy® provides the unprecedented ability to automatically monitor and record students’ step-by-step work and evaluate the effectiveness of assignments and exams. As a result, we believe that MasteringAstronomy® can change the way astronomy courses are taught: It is now possible, even in large classes, to ensure that each student spends his or her study time on optimal learning activities outside of class.

MasteringAstronomy® provides students with a wealth of self-study resources, including interactive tutorials targeting the most difficult concepts of the course, interactive versions of key figures and photos, and quizzes and other activities for self-assessment covering every chapter and every week. For professors, MasteringAstronomy® provides a library of tutoring activities that is periodically updated based on the performance of students nationwide. You can create assignments tailored to your specific class goals from among hundreds of activities and problems, including pre- and post-lecture diagnostic quizzes, tutoring activities, end-of-chapter problems from this textbook, and test bank questions. Visit MasteringAstronomy® to learn more.

Finally, in a world where everyone claims to have the best website, we’d like to point out four reasons why you’ll discover that MasteringAstronomy® really does stand out from the crowd:

- MasteringAstronomy® has been built specifically to support the structure and pedagogy of The Cosmic Perspective Fundamentals. You’ll find the same concepts emphasized in the book and on the website, using the same terminology and the same pedagogical approaches. This type of consistency ensures that students focus on the concepts, without the risk of becoming confused by different presentations.
- Nearly all MasteringAstronomy® content has been developed either directly by The Cosmic Perspective Fundamentals author team or in close collaboration with outstanding educators, including Jim Dowe, Jim Cooney, Jonathan Williams, Richard Gelderman, Ed Prather, Tim Slater, Daniel Lorenz, and Lauren Jones. The direct involvement of book authors ensures consistency from our website to the textbook, resulting in an effective high-quality learning program.
- The MasteringAstronomy® platform uses the same unique student-driven engine as the highly successful MasteringPhysics® product (the most widely adopted physics tutorial and assessment system), developed by a group led by MIT physicist David Pritchard. This robust platform gives instructors unprecedented power not only to tailor content to their own courses but also to evaluate the effectiveness of assignments and exams.

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Mark Voit is a professor in the Department of Physics and Astronomy and Associate Dean for Undergraduate Studies in the College of Natural Science at Michigan State University. He earned his A.B. in astrophysical sciences at Princeton University and his Ph.D. in astrophysics at the University of Colorado in 1990. He continued his studies at the California Institute of Technology, where he was a research fellow in theoretical astrophysics, and then moved on to Johns Hopkins University as a Hubble Fellow. Before going to Michigan State, Mark worked in the Office of Public Outreach at the Space Telescope, where he developed museum exhibitions about the Hubble Space Telescope and helped design NASA’s award-winning HubbleSite. His research interests range from interstellar processes in our own galaxy to the clustering of galaxies in the early universe, and he is a Fellow of the American Association for the Advancement of Science. He is married to coauthor Megan Donahue, and cooks terrific meals for her and their three children. Mark likes getting outdoors whenever possible and particularly enjoys running, mountain biking, canoeing, orienteering, and adventure racing. He is also author of the popular book Hubble Space Telescope: New Views of the Universe.
How to Succeed in Your Astronomy Course

The Key to Success: Study Time
The single most important key to success in any college course is to spend enough time studying. A general rule of thumb for college classes is that you should expect to study about 2 to 3 hours per week outside of class for each unit of credit. For example, based on this rule of thumb, a student taking 15 credit hours should expect to spend 30 to 45 hours each week studying outside of class. Combined with time in class, this works out to a total of 45 to 60 hours spent on academic work—not much more than the time a typical job requires, and you get to choose your own hours. Of course, if you are working while you attend school, you will need to budget your time carefully.

As a rough guideline, your studying time in astronomy might be divided as shown in the table above. If you find that you are spending fewer hours than these guidelines suggest, you can probably improve your grade by studying longer. If you are spending more hours than these guidelines suggest, you may be studying inefficiently; in that case, you should talk to your instructor about how to study more effectively.

Using This Book
Each chapter in this book is designed to make it easy for you to study effectively and efficiently. To get the most out of each chapter, you might wish to use the following study plan.

- A textbook is not a novel, and you’ll learn best by reading the elements of this text in the following order:
  1. Start by reading the Learning Goals and the introductory paragraphs at the beginning of the chapter so that you’ll know what you are trying to learn.
  2. Get an overview of key concepts by studying the illustrations and reading their captions and annotations. The illustrations highlight almost all of the major concepts, so this “illustrations first” strategy gives you an opportunity to survey the concepts before you read about them in depth. You will find the two-page Cosmic Context figures especially useful.
  3. Read the chapter narrative, trying the Think About It questions and the See It for Yourself activities as you go along, but save the boxed features (Common Misconceptions, Tools of Science) to read later. As you read, make notes on the pages to remind yourself of ideas you’ll want to review later. Take notes as you read, but avoid using a highlight pen (or a highlighting tool if you are using an e-book), which makes it too easy to highlight mindlessly.
  4. After reading the chapter once, go back through and read the Common Misconceptions and Tools of Science.
  5. Finally, turn your attention to the Chapter Summary. The best way to use the summary is to try to answer the Learning Goal questions for yourself before reading the short answers given in the summary.

- After completing the reading as outlined above, test your understanding with the end-of-chapter exercises. A good way to begin is to make sure you can answer all of the Quick Quiz Questions; if you don’t know an answer, look back through the chapter until you figure it out.

- Visit the MasteringAstronomy® site and make use of resources that will help you further build your understanding. These resources have been developed specifically to help you learn the most important ideas in your astronomy course, and they have been extensively tested to make sure they are effective. They really do work, and the only way you’ll gain their benefits is by going to the website and using them.

General Strategies for Studying

- Budget your time effectively. Studying 1 or 2 hours each day is more effective, and far less painful, than studying all night before homework is due or before exams.
- Engage your brain. Learning is an active process, not a passive experience. Whether you are reading, listening to a lecture, or working on assignments, always make sure that your mind is
Preparing for Exams

- Study the Review Questions, and rework problems and other assignments; try additional questions to be sure you understand the concepts. Study your performance on assignments, quizzes, or exams from earlier in the term.
- Work through the relevant online tutorials and chapter quizzes available at the MasteringAstronomy® site.
- Study your notes from lectures and discussions. Pay attention to what your instructor expects you to know for an exam.
- Reread the relevant sections in the textbook, paying special attention to notes you have made on the pages.
- Study individually before joining a study group with friends. Study groups are effective only if every individual comes prepared to contribute.
- Don’t stay up too late before an exam. Don’t eat a big meal within an hour of the exam (thinking is more difficult when blood is being diverted to the digestive system).
- Try to relax before and during the exam. If you have studied effectively, you are capable of doing well. Staying relaxed will help you think clearly.

Don’t miss class. Listening to lectures and participating in discussions is much more effective than reading someone else’s notes. Active participation will help you retain what you are learning. Also, be sure to complete any assigned reading before the class in which it will be discussed. This is crucial, since class lectures and discussions are designed to help reinforce key ideas from the reading.

- Take advantage of resources offered by your professor, whether it be email, office hours, review sessions, online chats, or other opportunities to talk to and get to know your professor. Most professors will go out of their way to help you learn in any way that they can.
- Start your homework early. The more time you allow yourself, the easier it is to get help if you need it. If a concept gives you trouble, do additional reading or studying beyond what has been assigned. And if you still have trouble, ask for help: You surely can find friends, peers, or teachers who will be glad to help you learn.
- Working together with friends can be valuable in helping you understand difficult concepts, but be sure that you learn with your friends and do not become dependent on them.
- Don’t try to multitask. A large body of research shows that human beings simply are not good at multitasking. When we attempt it, we do more poorly at all of the individual tasks. And in case you think you are an exception, the same research found that those people who believed they were best at multitasking were actually the worst! So when it is time to study, turn off your electronic devices, find a quiet spot, and give your work a focused effort at concentration.

Preferating Homework and Writing Assignments

All work that you turn in should be of collegiate quality: neat and easy to read, well organized, and demonstrating mastery of the subject matter. Future employers and teachers will expect this quality of work. Moreover, although submitting homework of collegiate quality requires “extra” effort, it serves two important purposes directly related to learning:

1. The effort you expend in clearly explaining your work solidifies your learning. In particular, research has shown that writing and speaking trigger different areas of your brain. Writing something down—even when you think you already understand it—reinforces your learning by involving other areas of your brain.
2. If you make your work clear and self-contained (that is, make it a document that you can read without referring to the questions in the text), you will have a much more useful study guide when you review for a quiz or exam.

The following guidelines will help ensure that your assignments meet the standards of collegiate quality:

- Always use proper grammar, proper sentence and paragraph structure, and proper spelling. Do not use texting shorthand.
- Make all answers and other writing fully self-contained. A good test is to imagine that a friend will be reading your work and to ask yourself whether the friend will understand exactly what you are trying to say. It is also helpful to read your work out loud to yourself, making sure that it sounds clear and coherent.
- In problems that require calculation:
  1. Be sure to show your work clearly so that both you and your instructor can follow the process you used to obtain an answer. Also, use standard mathematical symbols, rather than “calculator-ese.” For example, show multiplication with the symbol (not with an asterisk), and write, not $10^5$ or 10E5.
  2. Check that word problems have word answers. That is, after you have completed any necessary calculations, make sure that any problem stated in words is answered with one or more complete sentences that describe the point of the problem and the meaning of your solution.
  3. Express your word answers in a way that would be meaningful to most people. For example, most people would find it more meaningful if you expressed a result of 720 hours as 1 month. Similarly, if a precise calculation yields an answer of 9,745,600 years, it may be more meaningfully expressed in words as “nearly 10 million years.”
- Include illustrations whenever they help explain your answer, and make sure your illustrations are neat and clear. For example, if you graph by hand, use a ruler to make straight lines. If you use software to make illustrations, be careful not to make them overly cluttered with unnecessary features.
- If you study with friends, be sure that you turn in your own work stated in your own words—you should avoid anything that might give even the appearance of possible academic dishonesty.