Explore Modern Astronomy and Its Connections to Our Lives

*The Cosmic Perspective Fundamentals* provides a brief, engaging, and up-to-date introduction to astronomy for anyone who is curious about the universe. As respected teachers and active researchers, the authors present astronomy using a coherent narrative and a thematic approach that engages students immediately and guides them through connecting ideas. The Third Edition has been fully updated with the latest scientific discoveries, including detection of gravitational waves, results from recent planetary missions, and new insights into extrasolar planets. *Mastering Astronomy* includes a wealth of author-created resources for students to use before, during, and after class.

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 section is written to address the Learning Goal questions from the chapter-opening page.

For more than four centuries after the Copernican revolution taught us that Earth is just one member of our Sun’s planetary system, the study of planetary systems remained limited to our own. Then, less than three decades ago, a new scientific revolution began with the first discoveries of planets around other stars. The image above, from the Large Binocular Telescope, shows infrared light from four planets (marked b, c, d, e) orbiting the star HR 8799; light from the star itself (center) was mostly blocked out during the exposure, as indicated by the solid red circle. The discovery that planetary systems are common around other stars has profound implications, making it seem more likely that we might someday find life elsewhere, perhaps even intelligent life. It also allows us to learn more about the general nature of planets and how they form, giving us deeper insights into our cosmic origins. In this chapter, we’ll explore the exciting new science of other planetary systems.

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.

**LEARNING GOALS**

7.1 Detecting Planets Around Other Stars
- How do we detect planets around other stars?
- What properties of extrasolar planets can we measure?

7.2 Characteristics of Extrasolar Planets
- How do extrasolar planets compare with planets in our solar system?
- Are Earth-like planets common?

7.3 Extrasolar Planets and the Nebular Theory
- Do we need to modify our theory of solar system formation?
. . . with Emphasis on
the Process of Science

The final section of each chapter focuses on a topic that illustrates the **Process of Science in Action**.

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**Tools of Science** boxes introduce key tools when they are first needed with the subject matter.

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**10.3 Gravitational Waves**

Einstein’s general theory of relativity makes many predictions that have been tested and verified, including the effects of gravity on time discussed in the previous section. Another important prediction is the existence of what we call **gravitational waves**. Einstein himself doubted that we would ever detect such waves, but we have, and how we detect them is this chapter’s case study in the process of science in action. As you will see, gravitational-wave detectors have given astronomers an entirely new way to observe the universe.
Mastering Astronomy’s Study Area Helps Students Come Prepared to Class . . .

The Study Area features a Quick Quiz for each chapter, many videos and interactive figures, a set of self-guided tutorials covering key concepts, a media workbook, World Wide Telescope tours, and much more — PLUS access to a full etext of *The Cosmic Perspective Fundamentals*.

NEW! Dozens of new videos about key concepts and figures in the text, all written and most narrated by the authors to ensure consistency of terminology and pedagogy. Most videos include embedded pause-and-predict questions that allow students to check their understanding as they watch. Students can use these videos to help prepare for lectures, while instructors will find the same videos with assignable tutorials in the instructor-accessible Item Library.
While Instructors Can Access a Large Library of Homework and Test Questions

Many of the assignable tutorials use ranking or sorting tasks, which research shows to be particularly effective in building conceptual understanding. The Item Library also includes all end-of-chapter exercises from the book and a large test bank.

The Item Library consists of more than 250 assignable tutorials—all written or co-written by the textbook authors—including new tutorials based on all of the videos and interactive figures as well as updated tutorials on key concepts, process of science, vocabulary, and much more.
Reach Every Student with Pearson eText

Pearson eText, optimized for mobile, seamlessly integrates videos and other rich media with the text and gives students access to their textbook anytime, anywhere.
With Learning Catalytics, you’ll hear from every student when it matters most. You pose a variety of questions that help students recall ideas, apply concepts, and develop critical-thinking skills. Your students respond using their own smartphones, tablets, or laptops. You can monitor responses with real-time analytics and find out what your students do—and don’t—understand. Then you can adjust your teaching accordingly, and even facilitate peer-to-peer learning, helping students stay motivated and engaged.

NEW! Dynamic Study Modules in Mastering Astronomy help students study effectively—and at their own pace—by keeping them motivated and engaged. The assignable modules rely on the latest research in cognitive science, using methods—such as adaptivity, gamification, and intermittent rewards—to stimulate learning and improve retention.
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 to support one-term college courses in introductory astronomy—particularly those in which instructors couple the text with Mastering™ Astronomy to create an active or collaborative learning environment. No prior background in astronomy or physics is assumed, making The Cosmic Perspective Fundamentals suitable for both high school courses and college courses for nonscience majors. The Cosmic Perspective Fundamentals differs from our more comprehensive texts (The Cosmic Perspective and The Essential Cosmic Perspective) in covering a smaller set of topics and therefore being much shorter in length, but it is built upon the same “big picture” approach to astronomy and uses the same pedagogical principles.

New to This Edition

Many new discoveries have been made in astronomy during the four years since publication of the second edition of The Cosmic Perspective Fundamentals, leading to many changes in this third edition. Indeed, the changes are too many to list here, but those who used the second edition will notice significant updates to almost every chapter in the book, primarily as a result of the many new astronomical discoveries that have occurred in recent years, including results from missions such as New Horizons, Rosetta, Dawn, Curiosity, MAVEN, Cassini, Juno, and more; the first direct detections of gravitational waves; and major advances in our understanding of extrasolar planets.

Topical Selection

A briefer, focused text 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. Most astronomy courses begin with topics such as the scale of the universe, seasons, and phases of the Moon and then progress 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.

- 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 Mastering Astronomy website.

- 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.

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.
Mastering Astronomy—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 created Mastering Astronomy. For students, it provides personalized 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, Mastering Astronomy provides the unprecedented ability to automatically monitor and record students’ step-by-step work and evaluate the effectiveness of assignments and exams.

All students registered for Mastering Astronomy receive full access to the Study Area. Key resources available in the Study Area include the following:

- A large set of prelecture videos, narrated figures, and interactive figures that will help students understand key concepts from the textbook
- A set of self-study tools, including a Quick Quiz for each chapter and interactive self-guided tutorials that go into depth on topics that some students find particularly challenging
- A downloadable set of group activities
- Additional videos covering basic math skills, as well as selected videos of the authors speaking to the public
- And much more, including a media workbook, Starry Night activities, World Wide Telescope tours, and even access to a full etext of The Cosmic Perspective Fundamentals

Instructors have access to many additional resources, including a large Item Library featuring more than 250 assignable tutorials, organized by chapter, that include guidance for understanding key concepts, assessments based on the large set of prelecture videos, ranking tasks, sorting tasks, and more. There is also a set of Math Review tutorials to help students who need work on topics including scientific notation, working with units, metric units, and problem-solving skills.

Finally, please note that nearly all the content available at the Mastering Astronomy site for The Cosmic Perspective Fundamentals has been written or co-written by the textbook authors. This means that you can count on consistency between the textbook and web resources, with both emphasizing the same concepts and using the same terminology and the same pedagogical approaches. This type of consistency ensures that students will be able to study in the most efficient way possible.

Acknowledgments

A textbook may carry author names, but it is the result of hard work by a long list of committed individuals, as well as many reviewers. We could not possibly list everyone who has helped, but we would especially like to thank our editorial team at Pearson, our production team at Lifland et al., and the more than 100 professors who have reviewed our texts in depth, providing valuable feedback; a list of these professors can be found in The Cosmic Perspective, ninth edition.

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Megan Donahue
Nick Schneider
Mark Voit
When she joined the MSU faculty. She is also actively involved in ad-

and later as an STScI Institute Fellow at Space Telescope. Megan was

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tents of the universe and how galaxies form and evolve. She grew

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axies and clusters of galaxies: their contents—dark matter, hot gas,

ben, and particularly enjoys running, mountain biking, canoeing, orien-

Voit, and they collaborate on many projects, including this textbook,

over 70 peer-reviewed astrophysics papers, and the nurturing of their

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worked in the Office of Public Outreach at the 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, orien-
teering, 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 or have family obligations while you attend school, you will need to budget your time carefully.

The table above gives rough guidelines for how you might divide your study time. 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 paragraph 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 their captions and annotations. The illustrations highlight most 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 boxed features.
  5. Review the Summary of Key Concepts, ideally by trying to answer the Learning Goal questions for yourself before reading the given answers.
- 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.
- Further build your understanding by making use of the videos, quizzes, and other resources available at Mastering Astronomy. These resources have been developed specifically to help you learn the most important ideas in your 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. Note: Research shows that it can be helpful to create a “personal contract” for your study time (or for any other personal commitment), in which you specify rewards you’ll give yourself for success and penalties you’ll assess for failings.
- 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 actively engaged. If you find your mind drifting or find yourself falling asleep, make a conscious effort to revive yourself, or take a break if necessary.
- Don’t miss class, and come prepared. Listening to lectures and participating in class activities and discussions is much more effective than reading someone else’s notes or watching a video later. 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 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. However, be sure that you learn with your friends and do not become dependent on them.
• Don’t try to multitask. 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, research has also shown that those people who believe they are best at multitasking are often the worst! So when it is time to study, turn off your electronic devices, find a quiet spot, and concentrate on your work. (If you must use a device to study, as with an e-book or online homework, turn off email, text, and other alerts so that they will not interrupt your concentration; some apps will do this for you.)

Preparing for Exams
• Rework problems and other assignments; try additional questions, including the online quizzes available at Mastering Astronomy, to be sure you understand the concepts. Study your performance on assignments, quizzes, or exams from earlier in the term.
• Study your notes from classes, and reread relevant sections in your textbook. Pay attention to what your instructor expects you to know for an exam.
• 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.

Presenting 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. Writing (or typing) triggers different areas of your brain than reading, listening, or speaking. As a result, writing something down will reinforce your learning of a concept, even when you think you already understand it.

2. By making your work clear and self-contained (that is, making 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, and don’t become over-reliant on spell checkers, which may miss “too two three mistakes, to.”
• All answers and other writing should be fully self-contained. A good test is to imagine that a friend is reading your work and to ask yourself whether the friend would 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 $\times$ symbol (not with an asterisk), and write $10^5$, not $10^5$ or $10E5$.

2. Word problems should 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. Units are crucial. If your answer has units, be sure they are stated clearly. For example, if you are asked to calculate a distance, be sure you state whether your answer is in miles, kilometers, or some other distance unit.

4. 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.