



**THE**  
**ESSENTIAL** **Cosmic**  
**Perspective**



Astronauts get a unique opportunity to experience a cosmic perspective. Here, astronaut John Grunsfeld has a CD of *The Cosmic Perspective* floating in front of him while orbiting Earth during the Space Shuttle's final servicing mission to the Hubble Space Telescope (May 2009).

# THE ESSENTIAL Cosmic Perspective

SEVENTH 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

**W**e 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 tells the story of modern astronomy and the new perspective, *The Essential Cosmic Perspective*, that astronomy gives us on ourselves and our planet.

This book grew out of our experience teaching astronomy to both college students and the general public over the past 30 years. During this time, a flood of new discoveries fueled a revolution in our understanding of the cosmos but had little impact on the basic organization and approach of most astronomy textbooks. We felt the time had come to rethink how to organize and teach the major concepts in astronomy to reflect this revolution in scientific understanding. This book is the result.

## Who Is This Book For?

*The Essential Cosmic Perspective* is designed as a textbook for college courses in introductory astronomy, but is suitable for anyone who is curious about the universe. We assume no prior knowledge of astronomy or physics, and the book is especially written for students who do not intend to major in mathematics or science.

We have tailored *The Essential Cosmic Perspective* to one-semester survey courses in astronomy by carefully selecting the most important topics and presenting them with only as much depth as can be realistically learned in one semester. This book may also be used for two-semester astronomy sequences, though instructors of such courses may wish to consider our more comprehensive book, *The Cosmic Perspective*. We also offer a shorter version tailored more to one-quarter courses, called *The Cosmic Perspective Fundamentals*.

## New to This Edition

The underlying philosophy, goals, and structure of *The Essential Cosmic Perspective* remain the same as in past editions, but we have thoroughly updated the text and made a number of other improvements. Here, briefly, is a list of the significant changes you'll find in this seventh edition:

- **Major Chapter-Level Changes:** We have made numerous significant changes both to update the science and to improve the pedagogical flow in this edition. The full list is too long to put here, but major changes include the following:
  - **Chapter 1** has been reorganized so that Section 1.1 now focuses on our cosmic address and the scale of space, while Section 1.2 focuses on our cosmic origins and the scale of time. We believe these changes will make it easier for students to learn key ideas that they'll need for the rest of their course in astronomy.
  - In **Chapter 2**, we have made a number of small pedagogical changes to clarify the concepts and to make sure that the discussion works for students in the Southern Hemisphere as well as the Northern Hemisphere.
  - In **Chapter 3**, we have significantly reorganized and rewritten Sections 3.1 and 3.2, with the goal of making it easier for students to focus on the key take-away ideas in each of these sections. We have also added the new Table 3.2 on scientific terminology.
  - In **Chapter 5**, we have reorganized Section 5.3 with just two learning goals to make it easier for students to understand the key ideas about telescopes.
  - **Chapter 6** has been significantly reorganized and rewritten so that the four major features of the solar system are now all explained in a single section, making it much easier for students to draw connections between the features and how they are natural consequences of the nebular theory.
  - The **new Chapter 10** focuses entirely on the study of extrasolar planets and planetary systems. This new chapter replaces and expands on material formerly at the end of Chapter 6.
  - Portions of **Chapters 15 and 16** (formerly Chapters 14 and 15) have been significantly rewritten to reflect recent advances in the science of galaxies and galaxy formation.
  - **Chapters 17 and 18** (formerly Chapters 16 and 17) have been thoroughly reorganized so that we now cover the Big Bang theory before we cover dark matter, dark energy, and the fate of the universe. This change was motivated by the spectacular progress in cosmic microwave background observations during the past

decade and allows light-element abundances and microwave background observations to be presented as primary evidence that dark matter consists of exotic particles.

- The first three sections in **Chapter 19** (formerly Chapter 18) have been significantly rewritten to focus more clearly on what life on Earth tells us about possibilities for life elsewhere and on the factors that could make a world habitable.
- **Cosmic Calculations** boxes have been substantially reworked throughout the book. Although we have kept the same basic mathematical content and level, we have revised them to make the explanations shorter and simpler, and therefore more accessible to students.
- **Fully Updated Science:** Astronomy is a fast-moving field, and numerous new developments have occurred since the prior edition was published. In addition to the major chapter-level changes above, other scientific updates in this edition include
  - New results and images from spacecraft exploring our solar system, including the *Mars Reconnaissance Orbiter* and the *Curiosity* rover on Mars; *Venus Express* at Venus; *Cassini* at Saturn; *MESSENGER* at Mercury; *Stardust* and *Dawn* at Vesta; and *SOHO* and *TRACE* at the Sun
  - Recent results from major space observatories, including Hubble, Kepler, Spitzer, Chandra, and Fermi
  - Updated data and models on topics including global warming, cycling of gas in the Milky Way, and galaxy formation and evolution
  - New research on the timing and possible origin of life on Earth
- **New Content in MasteringAstronomy®:** We have reached the point where *The Essential Cosmic Perspective* is no longer just a textbook; rather, it is a “learning package” that combines a printed book with deeply integrated, interactive media developed to support every chapter of our book. For students, the MasteringAstronomy® Study Area provides a wealth of tutorials and activities to build understanding, while quizzes and exercises allow them to test what they’ve learned. For instructors, the MasteringAstronomy® Item Library provides the unprecedented ability to quickly build, post, and automatically grade pre- and post-lecture diagnostic tests, weekly homework assignments, and exams of appropriate difficulty, duration, and content coverage. It also provides the ability to record detailed information on the step-by-step work of every student directly into a powerful and easy-to-use gradebook, and to evaluate results with a sophisticated suite of diagnostics. Among the changes you’ll find to the MasteringAstronomy® site for this edition are numerous new interactive figures, including many narrated video tours; numerous new tutorials in the Item Library; and a fully updated set of reading, concept, and visual quizzes in both the Study Area and the Item Library.

## Themes of *The Essential Cosmic Perspective*

*The Essential Cosmic Perspective* offers a broad survey of our modern understanding of the cosmos and of how we have built that understanding. Such a survey can be presented in a number of different ways. We have chosen to interweave a few key themes throughout the book, each selected to help make the subject more appealing to students who may never have taken any formal science courses and who may begin the course with little understanding of how science works. Our book is built around the following five key themes:

- **Theme 1:** *We are a part of the universe and thus can learn about our origins by studying the universe.* This is the overarching theme of *The Essential Cosmic Perspective*, as we continually emphasize that learning about the universe helps us understand ourselves. Studying the intimate connections between human life and the cosmos gives students a reason to care about astronomy and also deepens their appreciation of the unique and fragile nature of our planet.
- **Theme 2:** *The universe is comprehensible through scientific principles that anyone can understand.* We can understand the universe because the same physical laws appear to be at work in every aspect, on every scale, and in every age of the universe. Moreover, while professional scientists generally have discovered the laws, anyone can understand their fundamental features. Students can learn enough in one or two terms of astronomy to comprehend the basic reasons for many phenomena that they see around them—ranging from seasonal changes and phases of the Moon to the most esoteric astronomical images that appear in the news.
- **Theme 3:** *Science is not a body of facts but rather a process through which we seek to understand the world around us.* Many students assume that science is just a laundry list of facts. The long history of astronomy shows that science is a process through which we learn about our universe—a process that is not always a straight line to the truth. That is why our ideas about the cosmos sometimes change as we learn more, as they did dramatically when we first recognized that Earth is a planet going around the Sun rather than the center of the universe. In this book, we continually emphasize the nature of science so that students can understand how and why modern theories have gained acceptance and why these theories may change in the future.
- **Theme 4:** *A course in astronomy is the beginning of a lifelong learning experience.* Building on the prior themes, we emphasize that what students learn in their astronomy course is not an end but a beginning. By remembering a few key physical principles and understanding the nature of science, students can follow astronomical developments for the rest of their lives. We therefore seek to motivate students to continue to participate in the ongoing human adventure of astronomical discovery.
- **Theme 5:** *Astronomy affects each of us personally with the new perspectives it offers.* We all conduct the daily business

of our lives with reference to some “world view”—a set of personal beliefs about our place and purpose in the universe that we have developed through a combination of schooling, religious training, and personal thought. This world view shapes our beliefs and many of our actions. Although astronomy does not mandate a particular set of beliefs, it does provide perspectives on the architecture of the universe that can influence how we view ourselves and our world, which can potentially affect our behavior. In many respects, the role of astronomy in shaping world views may represent the deepest connection between the universe and the everyday lives of humans.

## Pedagogical Principles of *The Essential Cosmic Perspective*

No matter how an astronomy course is taught, it is very important to present material according to a clear set of pedagogical principles. The following list briefly summarizes the major pedagogical principles that we apply throughout this book. (The Instructor Guide describes these principles in more detail.)

- **Stay focused on the big picture.** Astronomy is filled with interesting facts and details, but they are meaningless unless they fit into a big picture view of the universe. We therefore take care to stay focused on the big picture (essentially the themes discussed above) at all times. A major benefit of this approach is that although students may forget individual facts and details after the course is over, the big picture framework should stay with them for life.
  - **Always provide context first.** We all learn new material more easily when we understand why we are learning it. We therefore begin the book (in Chapter 1) with a broad overview of modern understanding of the cosmos so that students know what they will be studying in the rest of the book. We maintain this “context first” approach throughout the book by always telling students what they will be learning, and why, before diving into the details.
  - **Make the material relevant.** It’s human nature to be more interested in subjects that seem relevant to our lives. Fortunately, astronomy is filled with ideas that touch each of us personally. By emphasizing our personal connections to the cosmos, we make the material more meaningful, inspiring students to put in the effort necessary to learn it.
  - **Emphasize conceptual understanding over the “stamp collecting” of facts.** If we are not careful, astronomy can appear to be an overwhelming collection of facts that are easily forgotten when the course ends. We therefore emphasize a few key concepts that we use over and over again. For example, the laws of conservation of energy and conservation of angular momentum (introduced in Section 4.3) reappear throughout the book, and we find that the wide variety of features found on the terrestrial planets can be understood through just a few basic geological processes. Research shows that, long after the
- course is over, students are far more likely to retain such conceptual ideas than individual facts or details.
  - **Proceed from the more familiar and concrete to the less familiar and abstract.** It’s well known that children learn best by starting with concrete ideas and then generalizing to abstractions. The same is true for many adults. We therefore always try to “build bridges to the familiar”—that is, to begin with concrete or familiar ideas and then gradually develop more general principles from them.
  - **Use plain language.** Surveys have found that the number of new terms in many introductory astronomy books is larger than the number of words taught in many first-year foreign language courses. This means that most books are teaching astronomy in what looks to students like a foreign language! It is much easier for students to understand key astronomical concepts if they are explained in plain English without resorting to unnecessary jargon. We have gone to great lengths to eliminate jargon as much as possible or, at minimum, to replace standard jargon with terms that are easier to remember in the context of the subject matter.
  - **Recognize and address student misconceptions.** Students do not arrive as blank slates. Most students enter our courses not only lacking the knowledge we hope to teach but often holding misconceptions about astronomical ideas. Therefore, to teach correct ideas, we must also help students recognize the paradoxes in their prior misconceptions. We address this issue in a number of ways, most overtly with Common Misconceptions boxes. These summarize commonly held misconceptions and explain why they cannot be correct.

## The Topical (Part) Structure of *The Essential Cosmic Perspective*

*The Essential Cosmic Perspective* is organized into six broad topical areas (the six parts in the table of contents), each approached in a distinctive way designed to help maintain the focus on the themes discussed earlier. Here, we summarize the guiding philosophy through which we have approached each topic. Every part concludes with a two-page Cosmic Context figure, which ties together into a coherent whole the diverse ideas covered in the individual chapters.

### PART I: Developing Perspective (Chapters 1–3)

**Guiding Philosophy** Introduce the big picture, the process of science, and the historical context of astronomy.

The basic goal of these chapters is to give students a big picture overview and context for the rest of the book and to help them develop an appreciation for the process of science and how science has developed through history. Chapter 1 outlines our modern understanding of the cosmos, so that students gain perspective

on the entire universe before diving into its details. Chapter 2 introduces basic sky phenomena, including seasons and phases of the Moon, and provides perspective on how phenomena we experience every day are tied to the broader cosmos. Chapter 3 discusses the nature of science, offering a historical perspective on the development of science and giving students perspective on how science works and how it differs from nonscience.

*The Cosmic Context for Part I appears on pp. 80–81.*

## PART II: Key Concepts for Astronomy (Chapters 4–5)

**Guiding Philosophy** Connect the physics of the cosmos to everyday experiences.

These chapters lay the groundwork for understanding astronomy through what is sometimes called the “universality of physics”—the idea that a few key principles governing matter, energy, light, and motion explain both the phenomena of our daily lives and the mysteries of the cosmos. Chapter 4 covers the laws of motion, the crucial conservation laws of angular momentum and energy, and the universal law of gravitation. Chapter 5 covers the nature of light and matter, spectra, and telescopes.

*The Cosmic Context for Part II appears on pp. 134–135.*

## PART III: Learning from Other Worlds (Chapters 6–10)

**Guiding Philosophy** Learn about Earth by studying other planets in our solar system and beyond.

This set of chapters begins in Chapter 6 with a broad overview of the solar system and its formation, including a 10-page tour that highlights some of the most important and interesting features of the Sun and each of the planets. Chapters 7 to 9 focus, respectively, on the terrestrial planets, the jovian planets, and the small bodies of the solar system. Finally, Chapter 10 turns to the exciting topic of other planetary systems that have been discovered in recent years. Note that Part III is essentially independent of Parts IV and V, and thus can be covered either before or after them.

*The Cosmic Context for Part III appears on pp. 282–283.*

## PART IV: Stars (Chapters 11–14)

**Guiding Philosophy** We are intimately connected to the stars.

These are our chapters on stars and stellar life cycles. Chapter 11 covers the Sun in depth, so that it can serve as a concrete model for building an understanding of other stars. Chapter 12 describes the general properties of stars, how we measure these properties, and how we classify stars using the H-R diagram. Chapter 13 covers stellar evolution, tracing the birth-to-death lives of both low- and high-mass stars. Chapter 14 covers the end points of stellar evolution: white dwarfs, neutron stars, and black holes.

*The Cosmic Context for Part IV appears on pp. 378–379.*

## PART V: Galaxies and Beyond (Chapters 15–18)

**Guiding Philosophy** Present galaxy evolution and cosmology together as intimately related topics.

These chapters cover galaxies and cosmology. Chapter 15 presents the Milky Way as a paradigm for galaxies in much the same way that Chapter 11 uses the Sun as a paradigm for stars. Chapter 16 presents the variety of galaxies, how we determine key parameters such as galactic distances and age, and current understanding of galaxy evolution. Chapter 17 then presents the Big Bang theory and the evidence supporting it, setting the stage for Chapter 18, which explores dark matter and its role in galaxy formation, as well as dark energy and its implications for the fate of the universe.

*The Cosmic Context for Part V appears on pp. 488–489.*

## PART VI: Life on Earth and Beyond (Chapter 19)

**Guiding Philosophy** The study of life on Earth helps us understand the search for life in the universe.

This part consists of a single chapter. It may be considered optional, to be used as time allows. Those who wish to teach a more detailed course on astrobiology may consider the text *Life in the Universe*, by Jeffrey Bennett and Seth Shostak.

*The Cosmic Context for Part VI appears on pp. 526–527.*

## Pedagogical Features of *The Essential Cosmic Perspective*

Alongside the main narrative, *The Essential Cosmic Perspective* includes a number of pedagogical devices designed to enhance student learning:

- **Learning Goals:** Presented as key questions, motivational learning goals begin every chapter, and every section of every chapter is carefully written to address the specific learning goal in the title. This helps students stay focused on the big picture and stay motivated by the understanding they will gain.
- **Chapter Summary:** The end-of-chapter summary offers a concise review of the learning goal questions, helping reinforce student understanding of key concepts from the chapter. Thumbnail figures are included to remind students of key illustrations and photos in the chapter.
- **Highlighted “Essential Points”:** The list at the beginning of each chapter calls attention to key points and helps students find the relevant discussion in the text.
- **Annotated Figures:** Key figures in each chapter now include the research-proven technique of “annotation”—carefully crafted text placed on the figure (in blue) to guide students through interpreting graphs, following process figures, and translating between different representations.

- **Cosmic Context Two-Page Visual Summaries:** These two-page figures pull together related ideas in spectacular visual summaries.
- **Wavelength/Observatory Icons:** For astronomical photographs (or astronomy art that may be confused with photographs), simple icons (listed in Appendix J) identify the wavelength band; whether the image is a photo, artist's impression, or computer simulation; and whether the image came from ground-based or space-based observations.
- **MasteringAstronomy<sup>®</sup> Self-Guided Tutorials:** Lessons from within the highly acclaimed self-guided tutorials are referenced above specific section titles to direct students to targeted, self-paced help.
- **Think About It:** This feature, which appears throughout the book as short questions integrated into the narrative, gives students the opportunity to reflect on important new concepts. It also serves as an excellent starting point for classroom discussions.
- **See It for Yourself:** This feature, which appears throughout the book as short questions integrated into the narrative, gives students the opportunity to conduct simple observations or experiments that will help them understand key concepts.
- **Common Misconceptions:** These boxes address popularly held but incorrect ideas related to the chapter material.
- **Special Topic Boxes:** These boxes contain supplementary discussion topics related to the chapter material but not prerequisite to the continuing discussion.
- **Cosmic Calculations Boxes:** These boxes contain optional mathematics, set in the margin of the text.
- **The Big Picture:** Every chapter narrative ends with this feature. It helps students put what they've learned in the chapter into the context of the overall goal of gaining a broader perspective on ourselves and our planet.
- **Visual Skills Check:** This set of questions is designed to help students build their skills at interpreting the many types of visual information used in astronomy.
- **End-of-Chapter Exercises:** Each chapter includes an extensive set of exercises that can be used for study, discussion, or assignment. All of the end-of-chapter exercises are organized into the following subsets:
  - **Review Questions:** Questions that students should be able to answer from the reading alone.
  - **Does It Make Sense? (or similar title):** A set of short statements, each of which may or may not make sense. Students are expected to say whether the statement makes sense, and to explain why or why not. These exercises are generally easy once students understand a particular concept, but very difficult otherwise; thus, they are an excellent probe of comprehension.
  - **Quick Quiz:** A short multiple-choice quiz that allows students to check their progress.
  - **Process of Science Questions:** Essay and discussion questions that ask students to reflect on how science is done and how astronomers have learned about the universe over time.
  - **Group Work Exercises:** Questions designed for collaborative learning in class.
  - **Short-Answer/Essay Questions:** Questions that go beyond the Review Questions in asking for conceptual interpretation.
  - **Quantitative Problems:** Problems that require some mathematics, usually based on topics covered in the Cosmic Calculations boxes.
  - **Discussion Questions:** Open-ended questions for class discussions.
  - **Web Projects:** Online research projects designed for independent study.

Nearly all end-of-chapter questions are available at MasteringAstronomy<sup>®</sup> for online homework assignment and automatic grading and diagnostics.

- **Cross-References:** When a concept is covered in greater detail elsewhere in the book, we include a cross-reference in brackets to the relevant section (e.g., [Section 5.2](#)).
- **Glossary:** A detailed glossary makes it easy for students to look up important terms.
- **Appendixes:** The appendixes include a number of useful references and tables, including key constants (Appendix A), key formulas (Appendix B), key mathematical skills (Appendix C), and numerous data tables and star charts (Appendixes D–I).

## MasteringAstronomy<sup>®</sup>—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<sup>®</sup>. 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<sup>®</sup> 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<sup>®</sup> 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<sup>®</sup> 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<sup>®</sup> 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<sup>®</sup> to learn more.

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

- MasteringAstronomy<sup>®</sup> has been built specifically to support the structure and pedagogy of *The Essential Cosmic Perspective*. 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<sup>®</sup> content has been developed either directly by *The Essential Cosmic Perspective* author team or in close collaboration with outstanding educators including Jim Dove, 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<sup>®</sup> platform uses the same unique student-driven engine as the highly successful MasteringPhysics<sup>®</sup> 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.

## Additional Supplements for *The Essential Cosmic Perspective*

*The Essential Cosmic Perspective* is much more than just a textbook. It is a complete package of teaching, learning, and assessment resources designed to help both teachers and students. In addition to MasteringAstronomy<sup>®</sup>, the following supplements are available with this book:

- **SkyGazer v5.0:** Based on *Voyager V*, SkyGazer, one of the world's most popular planetarium programs now available for download, makes it easy for students to learn

constellations and explore the wonders of the sky through interactive exercises and demonstrations. Accompanying activities are available in LoPresto's Astronomy Media Workbook, Seventh Edition, available both on the MasteringAstronomy<sup>®</sup> study area and on the SkyGazer site. Ask your Pearson sales representative for details.

- **Starry Night™ College** (ISBN 0-321-71295-1): Now available as an additional option with *The Essential Cosmic Perspective*, Starry Night has been acclaimed as the world's most realistic desktop planetarium software. This special version has an easy-to-use point-and-click interface and is available as an additional bundle. The Starry Night Activity Workbook, consisting of thirty-five worksheets for homework or lab, based on Starry Night planetarium software, is available for download in the MasteringAstronomy<sup>®</sup> study area or with a Starry Night College access code. Ask your Pearson sales representative for details.
- **Astronomy Active Learning In-Class Tutorials** (ISBN 0-8053-8296-8) by Marvin L. De Jong: This workbook provides fifty 20-minute in-class tutorial activities for instructors to choose from. Designed for use in large lecture classes, these activities are also suitable for labs. The short, structured activities may be completed by students on their own or in peer-learning groups. Each activity targets specific learning objectives, such as understanding Newton's laws, understanding Mars's retrograde motion, tracking stars on the H-R diagram, or comparing the properties of planets.
- **Lecture Tutorials for Introductory Astronomy** (ISBN 0-321-82046-0) by Edward E. Prather, Timothy F. Slater, Jeffrey P. Adams, and Gina Brissenden: The forty-four lecture tutorials included are designed to engage students in critical reasoning and spark classroom discussion.
- **Sky and Telescope: Special Student Supplement** (ISBN 0-321-70620-X): The nine articles, each with an assessment following, provide a general review as well as covering such topics as the process of science, the scale of the universe, and our place in the universe. The supplement is available for bundling; ask your Pearson sales representative for details.
- **Observation Exercises in Astronomy** (ISBN 0-321-63812-3): This manual includes fifteen observation activities that can be used with a number of different planetarium software packages.

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- **Clickers in the Astronomy Classroom** (ISBN 0-8053-9616-0): This 100-page handbook by Douglas Duncan provides everything you need to know to successfully introduce or enhance your use of CRS (clicker) quizzing in your astronomy class—the research-proven benefits, common pitfalls to avoid, and a wealth of thought-provoking astronomy questions for every week of your course.
- **Instructor Guide** (ISBN 0-321-92853-9): This guide contains a detailed overview of the text, sample syllabi for courses of different emphasis and duration, suggestions for teaching strategies, answers or discussion points for all Think About It and See It for Yourself questions in the text, solutions to end-of-chapter problems, and a detailed reference guide summarizing media resources available for every chapter and section in the book. Word files can be downloaded from the instructor resource section of MasteringAstronomy®.
- **Carl Sagan’s Cosmos DVD Box Set** (ISBN 0-8053-8572-X): The complete, revised, enhanced, and updated Cosmos series is available free to qualified adopters of *The Essential Cosmic Perspective*. A week-by-week guide of segments to include in your course is provided in the Instructor Guide.
- **Test Bank** (ISBN 0-321-92845-8): The Test Bank includes hundreds of multiple-choice, true/false, and short-answer questions, plus a new set of Process of Science questions for each chapter. TestGen® and Word files can be downloaded from the instructor resource section of the study area in MasteringAstronomy®.

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## Megan Donahue



**MEGAN DONAHUE** is a professor in the Department of Physics and Astronomy at Michigan State University and a Fellow of the American Association for the Advancement of Science. Her current research is mainly about using X-ray, UV, infrared, and visible light to study clusters of galaxies: their contents—dark matter, hot gas, gal-

axies, active galactic nuclei—and what they reveal about the contents of the universe and how galaxies form and evolve. She grew up on a farm in Nebraska and received an S.B. in physics from MIT, where she began her research career as an X-ray astronomer. She has a Ph.D. in astrophysics from the University of Colorado. Her Ph.D. thesis on theory and optical observations of intergalactic and intracluster gas won the 1993 Trumpler Award from the Astronomical Society for the Pacific for an outstanding astrophysics doctoral dissertation in North America. She continued postdoctoral research as a Carnegie Fellow at Carnegie Observatories in Pasadena, California, and later as an STSci Fellow at Space Telescope. Megan was a staff astronomer at the Space Telescope Science Institute until 2003, when she joined the MSU faculty. Megan is married to Mark Voit, and they collaborate on many projects, including this textbook and the raising of their children, Michaela, Sebastian, and Angela. Between the births of Sebastian and Angela, Megan qualified for and ran the Boston Marathon. These days, Megan runs trails, orienteers, and plays piano and bass guitar whenever her children allow it.

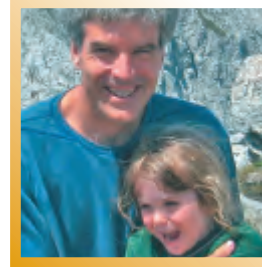
## Nicholas Schneider



**NICHOLAS SCHNEIDER** is an associate professor in the Department of Astrophysical and Planetary Sciences at the University of Colorado and a researcher in the Laboratory for Atmospheric and Space Physics. He received his B.A. in physics and astronomy from Dartmouth College in 1979 and his Ph.D. in planetary science from

the University of Arizona in 1988. In 1991, he received the National Science Foundation's Presidential Young Investigator Award. His research interests include planetary atmospheres and planetary astronomy. One research focus is the odd case of Jupiter's moon Io. Another is the mystery of Mars's lost atmosphere, which he hopes to answer by serving as science lead on the Imaging UV Spectrograph on NASA's *MAVEN* mission. Nick enjoys teaching at all levels and is active in efforts to improve undergraduate astronomy education. In 2010, he received the Boulder Faculty Assembly's Teaching Excellence Award. Off the job, Nick enjoys exploring the outdoors with his family and figuring out how things work.

## Mark Voit



**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

If Your Course Is	Times for Reading the Assigned Text (per week)	Times for Homework Assignments (per week)	Times for Review and Test Preparation (average per week)	Total Study Time (per week)
3 credits	2 to 4 hours	2 to 3 hours	2 hours	6 to 9 hours
4 credits	3 to 5 hours	2 to 4 hours	3 hours	8 to 12 hours
5 credits	3 to 5 hours	3 to 6 hours	4 hours	10 to 15 hours

## 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. Also watch for the Interactive Figure icons—when you see one, go to the MasteringAstronomy® website to try the interactive version.

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, Special Topics, Cosmic Calculations) to read later. As you read, make notes on the pages to remind yourself of ideas you'll want to review later. Avoid using a highlight pen (or a highlighting tool if you are using an e-book), which makes it too easy to highlight mindlessly. For a printed book, underlining with pen or pencil is far more effective, because it forces you to take greater care and therefore helps keep you alert as you study; be careful to underline selectively—it won't help you later if you've underlined everything. For an e-book, write notes to remind yourself why you marked a block of text as particularly important.
  4. After reading the chapter once, go back through and read the boxed material. You should read all of the Common Misconceptions and Special Topics boxes; whether you choose to read the Cosmic Calculations is up to you and your instructor. Also watch for the MasteringAstronomy® tutorial icons throughout the chapter; if a concept is giving you trouble, go to the MasteringAstronomy® site to try the relevant tutorial.
  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

Review Questions; if you don't know an answer, look back through the chapter until you figure it out. Then try the Does It Make Sense? and Quick Quiz questions.

- You can further check your understanding and get feedback on difficulties by trying the online quizzes in the Study Area at the MasteringAstronomy® site. Each chapter has three quizzes: a Reading Quiz, a Concept Quiz, and a Visual Quiz. Try the Reading Quiz first. Once you clear up any difficulties you have with it, try the Concept and Visual quizzes.
- If your course has a quantitative emphasis, work through all of the examples in the Cosmic Calculations before trying the quantitative problems for yourself. Remember that you should always try to answer questions qualitatively before you begin plugging numbers into a calculator. For example, make an order-of-magnitude estimate of what your answer should be so that you'll know your calculation is on the right track, and be sure that your answer makes sense and has the appropriate units.
- If you have done all the above, you will have already made use of numerous resources on the MasteringAstronomy® site. Don't stop there; visit the site again and make use of other 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 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. 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 e-mail, 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. 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.

## 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.

## 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. 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:

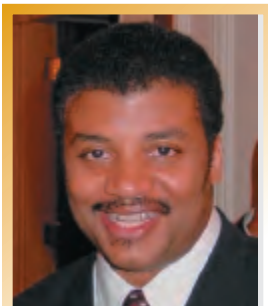
- Always use proper grammar, proper sentence and paragraph structure, and proper spelling. Do not use texting shorthand.
- Make all answers and other writing fully self-contained. A good test is to imagine that a friend will be reading your work and to ask yourself whether the friend will understand 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:
  - 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  $10^{\wedge}5$  or  $10E5$ .

- *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.
- 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.

# Foreword

## The Meaning of *The Cosmic Perspective*



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by Neil deGrasse Tyson

*Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of New York City's Hayden Planetarium at the American Museum of Natural History. He has written numerous books and articles, hosts the PBS series NOVA scienceNOW, and was named one of the "Time 100"—Time magazine's list of the 100 most influential people in the world. He contributed this essay about the meaning of "The Cosmic Perspective," abridged from his 100th essay written for Natural History magazine.*

Of all the sciences cultivated by mankind, Astronomy is acknowledged to be, and undoubtedly is, the most sublime, the most interesting, and the most useful. For, by knowledge derived from this science, not only the bulk of the Earth is discovered . . . ; but our very faculties are enlarged with the grandeur of the ideas it conveys, our minds exalted above [their] low contracted prejudices.

James Ferguson, *Astronomy Explained Upon Sir Isaac Newton's Principles, and Made Easy To Those Who Have Not Studied Mathematics* (1757)

LONG BEFORE ANYONE knew that the universe had a beginning, before we knew that the nearest large galaxy lies two and a half million light-years from Earth, before we knew how stars work or whether atoms exist, James Ferguson's enthusiastic introduction to his favorite science rang true.

But who gets to think that way? Who gets to celebrate this cosmic view of life? Not the migrant farm worker. Not the sweatshop worker. Certainly not the homeless person rummaging through the trash for food. You need the luxury of time not spent on mere survival. You need to live in a nation whose government values the search to understand humanity's place in the universe. You need a society in which intellectual pursuit can take you to the frontiers of discovery, and in which news of your discoveries can be routinely disseminated.

When I pause and reflect on our expanding universe, with its galaxies hurtling away from one another, embedded with the ever-stretching, four-dimensional fabric of space and time, sometimes I forget that uncounted people walk this Earth without food or shelter, and that children are disproportionately represented among them.

When I pore over the data that establish the mysterious presence of dark matter and dark energy throughout the universe, sometimes I forget that every day—every twenty-four-hour rotation of Earth—people are killing and being killed. In the name of someone's ideology.

When I track the orbits of asteroids, comets, and planets, each one a pirouetting dancer in a cosmic ballet choreographed by the forces of gravity, sometimes I forget that too many people act in wanton disregard for the delicate interplay of Earth's atmosphere, oceans, and land, with consequences that our children and our children's children will witness and pay for with their health and well-being.

And sometimes I forget that powerful people rarely do all they can to help those who cannot help themselves.

I occasionally forget those things because, however big the world is—in our hearts, our minds, and our outsize atlases—the universe is even bigger. A depressing thought to some, but a liberating thought to me.

Consider an adult who tends to the traumas of a child: a broken toy, a scraped knee, a schoolyard bully. Adults know that kids have no clue what constitutes a genuine problem, because inexperience greatly limits their childhood perspective.

As grown-ups, dare we admit to ourselves that we, too, have a collective immaturity of view? Dare we admit that our thoughts and behaviors spring from a belief that the world revolves around us? Part the curtains of society's racial, ethnic, religious, national, and cultural conflicts, and you find the human ego turning the knobs and pulling the levers.

Now imagine a world in which everyone, but especially people with power and influence, holds an expanded view of our place in the cosmos. With that perspective, our problems would shrink—or never arise at all—and we could celebrate our earthly differences while shunning the behavior of our predecessors who slaughtered each other because of them.

\* \* \*

Back in February 2000, the newly rebuilt Hayden Planetarium featured a space show called "Passport to the Universe," which took visitors on a virtual zoom from New York City to the edge of the cosmos. En route the audience saw Earth, then the solar system, then the 100 billion stars of the Milky Way galaxy shrink to barely visible dots on the planetarium dome.

I soon received a letter from an Ivy League professor of psychology who wanted to administer a questionnaire to visitors, assessing the depth of their depression after viewing the show. Our show, he wrote, elicited the most dramatic feelings of smallness he had ever experienced.

How could that be? Every time I see the show, I feel alive and spirited and connected. I also feel large, knowing that the goings-on within the three-pound human brain are what enabled us to figure out our place in the universe.

Allow me to suggest that it's the professor, not I, who has misread nature. His ego was too big to begin with, inflated by delusions of significance and fed by cultural assumptions that

human beings are more important than everything else in the universe.

In all fairness to the fellow, powerful forces in society leave most of us susceptible. As was I . . . until the day I learned in biology class that more bacteria live and work in one centimeter of my colon than the number of people who have ever existed in the world. That kind of information makes you think twice about who—or what—is actually in charge.

From that day on, I began to think of people not as the masters of space and time but as participants in a great cosmic chain of being, with a direct genetic link across species both living and extinct, extending back nearly 4 billion years to the earliest single-celled organisms on Earth.

\* \* \*

Need more ego softeners? Simple comparisons of quantity, size, and scale do the job well.

Take water. It's simple, common, and vital. There are more molecules of water in an eight-ounce cup of the stuff than there are cups of water in all the world's oceans. Every cup that passes through a single person and eventually rejoins the world's water supply holds enough molecules to mix 1,500 of them into every other cup of water in the world. No way around it: some of the water you just drank passed through the kidneys of Socrates, Genghis Khan, and Joan of Arc.

How about air? Also vital. A single breathful draws in more air molecules than there are breathfuls of air in Earth's entire atmosphere. That means some of the air you just breathed passed through the lungs of Napoleon, Beethoven, Lincoln, and Billy the Kid.

Time to get cosmic. There are more stars in the universe than grains of sand on any beach, more stars than seconds have passed since Earth formed, more stars than words and sounds ever uttered by all the humans who ever lived.

Want a sweeping view of the past? Our unfolding cosmic perspective takes you there. Light takes time to reach Earth's observatories from the depths of space, and so you see objects and phenomena not as they are but as they once were. That means the universe acts like a giant time machine: The farther away you look, the further back in time you see—back almost to the beginning of time itself. Within that horizon of reckoning, cosmic evolution unfolds continuously, in full view.

Want to know what we're made of? Again, the cosmic perspective offers a bigger answer than you might expect. The chemical elements of the universe are forged in the fires of high-mass stars that end their lives in stupendous explosions, enriching their host galaxies with the chemical arsenal of life as we know it. We are not simply in the universe. The universe is in us. Yes, we are stardust.

\* \* \*

Again and again across the centuries, cosmic discoveries have demoted our self-image. Earth was once assumed to be astronomically unique, until astronomers learned that Earth is just another planet orbiting the Sun. Then we presumed the Sun was unique, until we learned that the countless stars of the night sky are suns themselves. Then we presumed our galaxy, the Milky Way, was the entire known universe, until we established that the countless fuzzy things in the sky are other galaxies, dotting the landscape of our known universe.

The cosmic perspective flows from fundamental knowledge. But it's more than just what you know. It's also about having the

wisdom and insight to apply that knowledge to assessing our place in the universe. And its attributes are clear:

- The cosmic perspective comes from the frontiers of science, yet is not solely the provenance of the scientist. It belongs to everyone.
- The cosmic perspective is humble.
- The cosmic perspective is spiritual—even redemptive—but is not religious.
- The cosmic perspective enables us to grasp, in the same thought, the large and the small.
- The cosmic perspective opens our minds to extraordinary ideas but does not leave them so open that our brains spill out, making us susceptible to believing anything we're told.
- The cosmic perspective opens our eyes to the universe, not as a benevolent cradle designed to nurture life but as a cold, lonely, hazardous place.
- The cosmic perspective shows Earth to be a mote, but a precious mote and, for the moment, the only home we have.
- The cosmic perspective finds beauty in the images of planets, moons, stars, and nebulae but also celebrates the laws of physics that shape them.
- The cosmic perspective enables us to see beyond our circumstances, allowing us to transcend the primal search for food, shelter, and sex.
- The cosmic perspective reminds us that in space, where there is no air, a flag will not wave—an indication that perhaps flag waving and space exploration do not mix.
- The cosmic perspective not only embraces our genetic kinship with all life on Earth but also values our chemical kinship with any yet-to-be discovered life in the universe, as well as our atomic kinship with the universe itself.

\* \* \*

At least once a week, if not once a day, we might each ponder what cosmic truths lie undiscovered before us, perhaps awaiting the arrival of a clever thinker, an ingenious experiment, or an innovative space mission to reveal them. We might further ponder how those discoveries may one day transform life on Earth.

Absent such curiosity, we are no different from the provincial farmer who expresses no need to venture beyond the county line, because his forty acres meet all his needs. Yet if all our predecessors had felt that way, the farmer would instead be a cave dweller, chasing down his dinner with a stick and a rock.

During our brief stay on planet Earth, we owe ourselves and our descendants the opportunity to explore—in part because it's fun to do. But there's a far nobler reason. The day our knowledge of the cosmos ceases to expand, we risk regressing to the childish view that the universe figuratively and literally revolves around us. In that bleak world, arms-bearing, resource-hungry people and nations would be prone to act on their "low contracted prejudices." And that would be the last gasp of human enlightenment—until the rise of a visionary new culture that could once again embrace the cosmic perspective.

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