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Tenth Edition

the **COSMIC**
PERSPECTIVE

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the **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 he orbits Earth during the Space Shuttle's final servicing mission to the Hubble Space Telescope (May 2009).

Tenth Edition

the **COSMIC** PERSPECTIVE

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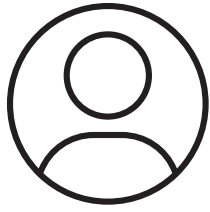
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About the Cover

The front cover is based on a remarkable image, one of the first images taken with the James Webb Space Telescope (JWST) after it began operations in 2022. At the time, it was humanity's deepest look into universe. Although the cover shows the image filling the sky, in reality it represents a point in the sky no larger in appearance than a grain of sand held at arm's length.

A few of the objects in the image are foreground stars within our own Milky Way galaxy. These stand out because their images have six prominent spikes, which result from how incoming light interacts with the hexagonal arrangement of JWST's mirrors. Nearly all of the other colorful objects in the image are entire galaxies, each consisting of billions of stars. Some of those galaxies belong to a single galaxy cluster at a distance of 4.6 billion light-years—which means we are seeing these galaxies as they looked around

the time that Earth and our solar system first formed. Many are even more distant, with some so far away that we see them as they were just a few hundred million years after the Big Bang. The objects shaped like small arcs are distant galaxies whose light has been bent as it passed by the cluster, representing a phenomenon known as “gravitational lensing.”

In the foreground, the image shows us—the human species—the only species yet known to have developed a “cosmic perspective” on our place in this amazing universe. As you read through this book, you will learn what modern science has to say about the universe and our place within it, and perhaps more important, you will have the opportunity to contemplate how this science affects our understanding of our planet and ourselves.

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 live to see 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 tells 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 provides a comprehensive survey of modern astronomy suitable for anyone who is curious about the universe, regardless of prior background in astronomy or physics. However, it is designed primarily to serve as a textbook for college courses in introductory astronomy. *The Cosmic Perspective* contains enough material for a full-year introductory astronomy sequence but can be flexibly used for shorter courses as well. Those teaching one-term general survey courses may alternatively wish to consider *The Essential Cosmic Perspective*, which covers a smaller set of topics and is tailored to meet the needs of comprehensive one-term survey courses in astronomy, or *The Cosmic Perspective Fundamentals*, which is even shorter and covers only the most fundamental topics in astronomy.

New to This Edition

The underlying philosophy, goals, and structure of *The Cosmic Perspective* remain the same as in past editions, but we have thoroughly updated the text with the latest science and made a number of other changes in our ongoing effort to provide the best possible pedagogical flow. Here, briefly, is a list of the major changes we have made for this tenth edition:

- **Major Chapter-Level Changes:** The full list is too long to put here, but major changes include the following:
 - **Chapter 6** has numerous updates on topics including the next generation of large ground-based telescopes, the James Webb Space Telescope, the impact of small satellite constellations on astronomy, the Event Horizon Telescope, and a new subsection and learning goal on multi-messenger astronomy, such as the gravitational-wave observatory LIGO.
 - **Chapters 7 through 12** have numerous scientific updates based on recent planetary missions, including the most recent missions to Mars; the *Juno* mission to Jupiter; updated discussions of asteroids and comets based on missions including *Hayabusa2* and *Osiris-REx*; the *New Horizons* encounter with

Arrokoth, and more. Of particular importance, we have almost completely rewritten our discussion of the critical topic of global warming, found in Section 10.6.

- **Chapter 13** covers the fast-evolving topic of exoplanets and hence has numerous scientific updates.
- **Chapter 19** includes updated discussion of the center of the Milky Way Galaxy, including the recent Event Horizon Telescope image of the central black hole.
- **Chapter 21** has been updated in light of the most recent research on supermassive black holes and how they interact with galaxies, and includes the Event Horizon Telescope image of the black hole in M87.
- **Chapter 24** has significant updates concerning evidence for early life on Earth, recent developments in the search for life on Mars and other worlds in our solar system, and the claimed detection of phosphine in Venus's atmosphere.
- **Revamped Exercise Sets:** We have reorganized the end-of-chapter exercise sets to make them easier for both students and instructors to use.
- **Note on JWST Images:** The James Webb Space Telescope (JWST) began science operations shortly before this book went to press, which allowed us to include several early release images, including the image that appears on the cover of this book. Of course, many other spectacular images will be available by the time you are using this textbook, so we encourage all instructors to show students how the JWST images improve upon the images that were available previously.

The Pedagogical Approach of *The Cosmic Perspective*

The Cosmic Perspective offers a broad survey of 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 build *The Cosmic Perspective* around a set of key themes designed to engage student interest and a set of pedagogical principles designed to ensure that all material comes across as clearly as possible to students.

Themes

Most students enrolled in introductory astronomy courses have little connection to astronomy when their course begins, and many have little understanding of how science actually works. The success of these students therefore depends on getting them engaged in the subject matter. To help achieve this, we have chosen to focus on the following five themes, which are interwoven throughout the book.

Theme 1: We are a part of the universe and can therefore learn about our origins by studying the universe. This is the overarching theme of *The 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 and its life.

Theme 2: The universe is comprehensible through scientific principles that anyone can understand. The universe is comprehensible 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—phenomena 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 can show them 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 what uncertainties and unknowns remain for the future.

Theme 4: Astronomy belongs to everyone. Astronomy has played a significant role throughout history in virtually every culture, and the modern science of astronomy owes a debt to these early and largely unsung astronomers. We therefore strive throughout the book to make sure that students understand that astronomical knowledge belongs to everyone, that people of all backgrounds have made and continue to make contributions to astronomical understanding, and that everyone should have the opportunity to study astronomy. Moreover, we seek to motivate students enough to ensure that they will remain engaged in the ongoing human adventure of astronomical discovery throughout their lives, no matter whether they choose to do that only by following the news media or by entering careers relating to astronomy.

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, which we have developed through a combination of schooling, religious training, family and cultural background, 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, and these perspectives can potentially affect our behavior. For example, someone who believes Earth to be at the center of the universe might treat our planet quite differently from someone who views it as a tiny and fragile world in the vast cosmos. 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

No matter how an astronomy course is taught, it is very important to present material according to well-established pedagogical principles. The following list briefly summarizes the major pedagogical principles that we apply throughout this book.*

- *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. In essence, this is simply the idea that it is easier to get somewhere when you know where you are going. We therefore begin the book (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. For example, the study of our solar system helps us better understand and appreciate our planet Earth, and the study of stars and galaxies helps us learn how we have come to exist. 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 “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 conceptual ideas, which we use

*More detail on these pedagogical principles can be found in the Instructor Guide and in the book *On Teaching Science* by Jeffrey Bennett (Big Kid Science, 2014).

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 the wide variety of features found on the terrestrial planets are described in terms of just a few basic geological processes. Research shows that, long after the course is over, students are far more likely to retain such conceptual learning 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 later. The same is true for adults. We therefore always try to “build bridges to the familiar”—that is, to begin with concrete or familiar ideas and then gradually draw 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 courses on a foreign language. In essence, this means the books are teaching astronomy in what looks to students like a foreign language! Clearly, 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 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 also holding misconceptions about astronomical ideas. Therefore, to teach correct ideas, we must help students recognize the paradoxes in their prior misconceptions. We address this issue in a number of ways, the most obvious being the presence of many Common Misconceptions boxes. These summarize commonly held misconceptions and explain why they cannot be correct.

The Organizational Structure of The Cosmic Perspective

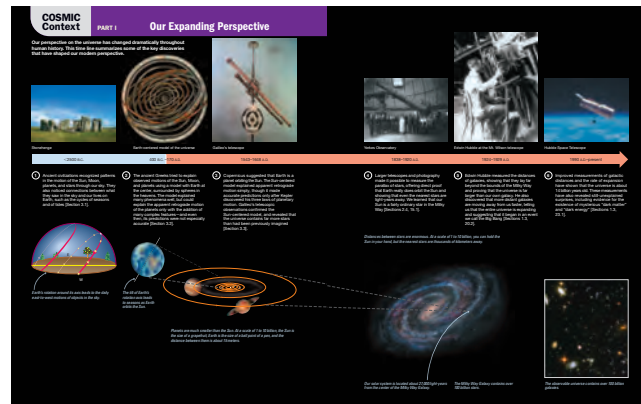
The Cosmic Perspective is organized into seven broad topical areas (the seven parts in the table of contents), each corresponding to a set of chapters along with related content in *Mastering Astronomy*. Note that the above themes and pedagogical principles are woven into this structure at every level.

Part Structure

The seven parts of *The Cosmic Perspective* each approach their set of chapters in a distinctive way designed to help maintain the focus on the five themes discussed earlier. Here, we summarize the philosophy and content of each part. Note that each part concludes with a two-page Cosmic Context spread designed to tie the part content together into a coherent whole.

Part I: Developing Perspective (Chapters 1–3, S1)

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

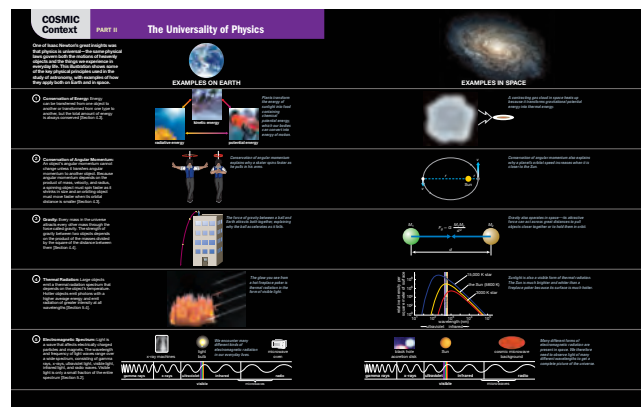


The Cosmic Context figure for Part I appears on pp. 108–109.

The basic goal of these chapters is to give students a big-picture overview and context for the rest of the book, as well as 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, including the scale of space and time, so that students gain perspective on the entire universe before diving into its details. Chapter 2 introduces basic sky phenomena, including seasons, phases of the Moon, and eclipses, and provides perspective on how phenomena we experience in our daily lives 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 supplementary (optional) Chapter S1 goes into more detail about the sky, including celestial timekeeping and navigation.

Part II: Key Concepts for Astronomy (Chapters 4–6)

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



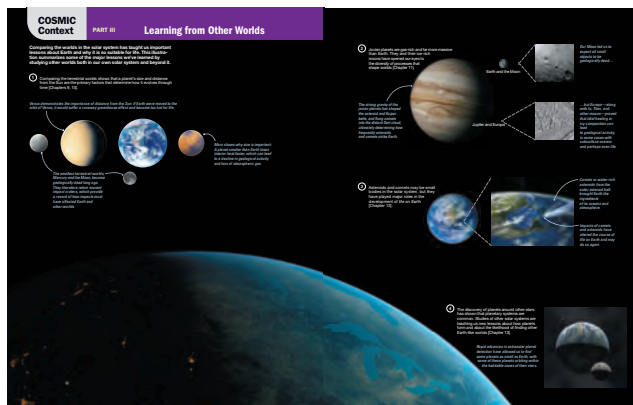
The Cosmic Context figure for Part II appears on pp. 190–191.

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. Each chapter begins with a section on science in everyday life in which we remind students how much they already know about scientific phenomena from their everyday experiences. We then build on this everyday knowledge to help students learn the formal principles of physics needed for the rest of their study of astronomy. Chapter 4 covers the laws of motion, the crucial conservation laws of angular momentum and energy, and the universal law of gravitation. Chapter 5 deals with the nature of light and matter, the formation of spectra, and the Doppler effect. Chapter 6 covers telescopes and astronomical observing techniques.

Part III: Learning from Other Worlds (Chapters 7–13)

Guiding Philosophy: We learn about our own world and existence by studying about other planets in our solar system and beyond.

Note: Part III is essentially independent of Parts IV through VII and can be covered either before or after them.



The Cosmic Context figure for Part III appears on pp. 408–409.

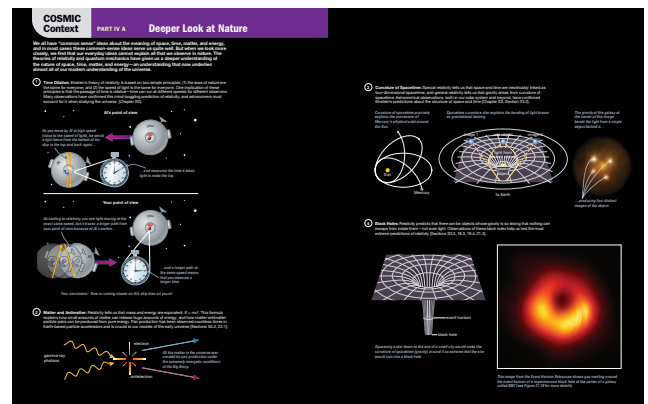
This set of chapters begins in Chapter 7 with a broad overview of the solar system, including a 10-page tour that highlights some of the most important and interesting features of the Sun and the planets in our solar system. In the remaining chapters of this part, we seek to explain these features through a true *comparative planetology* approach, in which the discussion emphasizes the *processes* that shape the planets rather than the “stamp collecting” of facts about them. Chapter 8 uses the concrete features of the solar system presented in Chapter 7 to build student understanding of the current theory of solar system formation. Chapters 9 and 10 focus on the terrestrial planets, covering key ideas of geology and atmospheres, respectively. In both chapters, we start with examples from our own planet Earth to help students understand the types of features that are found throughout the terrestrial worlds

and the fundamental processes that explain how these features came to be. We then complete each of these chapters by summarizing how the various processes have played out on each individual world. Chapter 11 covers the jovian planets and their moons and rings. Chapter 12 discusses small bodies in the solar system, including asteroids, comets, and dwarf planets. It also covers cosmic collisions, including the impact linked to the extinction of the dinosaurs and views on how seriously we should take the ongoing impact threat. Finally, Chapter 13 turns to the exciting topic of exoplanets and what they mean for prospects of finding “other Earths.”

Part IV: A Deeper Look at Nature (Chapters S2–S4)

Guiding Philosophy: Ideas of relativity and quantum mechanics are accessible to anyone.

Note: These chapters are labeled “supplementary” because coverage of them is optional. Covering them will give your students a deeper understanding of the topics that follow on stars, galaxies, and cosmology, but the later chapters are self-contained so that they may be studied without having read Part IV at all.

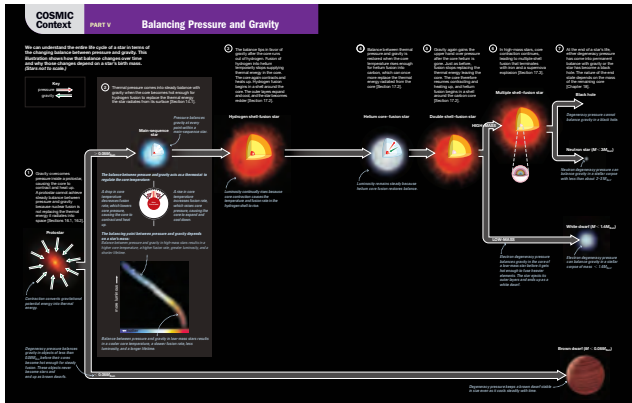


The Cosmic Context figure for Part IV appears on pp. 474–475.

Nearly all students have at least heard of things like the prohibition on faster-than-light travel, curvature of space-time, and the uncertainty principle. But few (if any) students enter an introductory astronomy course with any idea of what these things mean, and they are naturally curious about them. Moreover, a basic understanding of the ideas of relativity and quantum mechanics makes it possible to gain a much deeper appreciation of many of the most important and interesting topics in modern astronomy, including black holes, gravitational lensing, and the overall geometry of the universe. The three chapters of Part IV cover special relativity (Chapter S2), general relativity (Chapter S3), and key astronomical ideas of quantum mechanics (Chapter S4). The main thrust throughout is to demystify relativity and quantum mechanics by convincing students that they are capable of understanding the key ideas despite the reputation of these subjects for being hard or counterintuitive.

Part V: Stars (Chapters 14–18)

Guiding Philosophy: We are intimately connected to the stars.

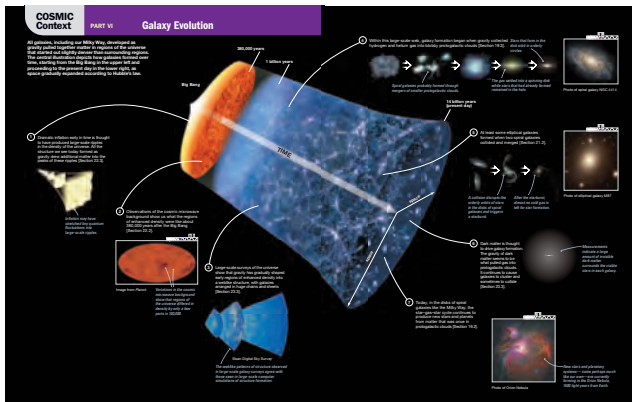


The Cosmic Context figure for Part V appears on pp. 586–587.

These are our chapters on stars and stellar life cycles. Chapter 14 covers the Sun in depth so that it can serve as a concrete model for building an understanding of other stars. Chapter 15 describes the general properties of other stars, how we measure these properties, and how we classify stars with the H-R diagram. Chapter 16 covers star birth, and the rest of stellar evolution is discussed in Chapter 17. Chapter 18 focuses on the end points of stellar evolution: white dwarfs, neutron stars, and black holes.

Part VI: Galaxies and Beyond (Chapters 19–23)

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



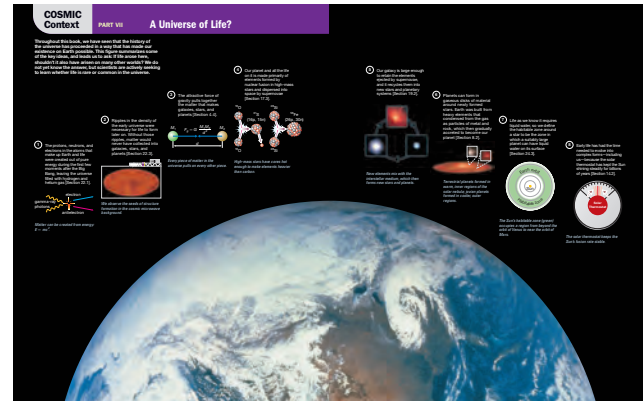
The Cosmic Context figure for Part VI appears on pp. 706–707.

These chapters cover galaxies and cosmology. Chapter 19 presents the Milky Way as a paradigm for galaxies in much the same way that Chapter 14 uses the Sun as a paradigm for stars. Chapter 20 describes the properties of galaxies and shows how the quest to measure galactic distances led to Hubble's law and laid the foundation for modern cosmology. Chapter 21 discusses how the current state of knowledge regarding galaxy evolution has emerged from our ability to look back through time. Chapter 22 presents the Big Bang theory and the evidence supporting it, setting

the stage for Chapter 23, which explores dark matter and its role in galaxy formation, as well as dark energy and its implications for the fate of the universe.

Part VII: Life on Earth and Beyond (Chapter 24)

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



The Cosmic Context figure for Part VII appears on pp. 738–739.

This part consists of a single chapter, designed to give students a brief introduction to the science of astrobiology. It may be considered optional, to be used as time allows. Those who wish to teach a more detailed course on astrobiology may wish to consider the text *Life in the Universe*, by Bennett, Shostak, Schneider, and MacGregor.

Chapter Structure

Each chapter is carefully structured to ensure that students understand the goals up front, learn the details, and pull all the ideas together at the end. Note the following key structural elements of each chapter:

- **Chapter Learning Goals:** Each chapter opens with a page offering an enticing image and a brief overview of the chapter, including a list of the section titles and associated learning goals. The learning goals are presented as key questions designed to help students both to understand what they will be learning about and to stay focused on these key goals as they work through the chapter.
- **Introduction and Epigraph:** The main chapter text begins with a one- to three-paragraph introduction to the chapter material and an inspirational quotation relevant to the chapter.
- **Section Structure:** Chapters are divided into numbered sections, each addressing one key aspect of the chapter material. Each section begins with a short introduction that leads into a set of learning goals relevant to the section—the same learning goals listed at the beginning of the chapter.
- **The Big Picture:** Every chapter narrative ends with this feature, designed to help students put what they have learned in the chapter into the context of the overall goal of gaining a broader perspective on ourselves, our planet, and our universe. The final entry in this section is always entitled “My Cosmic Perspective,” because it

aims to help students see a personal connection between themselves and the chapter content.

- **Chapter Summary:** The end-of-chapter summary offers a concise review of the learning goal questions, helping to reinforce student understanding of key concepts from the chapter. Thumbnail figures are included to remind students of key illustrations and photos in the chapter.
- **End-of-Chapter Exercises:** Each chapter concludes with an extensive set of exercises that can be used for study, discussion, or assignment, organized into the following subsets:
 - **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.
 - **Quick Quiz:** This short multiple-choice quiz allows students to check their basic understanding. Note that, for further self-testing, every chapter also has a Reading, Concept, and Visual Quiz available on the Mastering Astronomy website.
 - **Chapter Review Questions:** These questions are ones that students should be able to answer from the reading alone.
 - **Think Critically:** This set of questions consists of short statements designed to be critically evaluated by students. For example, students may be asked to decide whether or not a statement makes sense and to explain why (or why not). These exercises are generally easy once students understand a particular concept, but difficult otherwise, making these questions an excellent probe of comprehension.
 - **Inclusive Astronomy:** These questions are designed to stimulate discussion about participation in science, and in particular about the ideas that (1) astronomy belongs to everyone; (2) all cultures have made contributions to astronomical understanding; (3) opportunities for women and people of color have historically been limited; and (4) the scientific community can take active steps to provide more equitable opportunities for the future.
 - **Process of Science Questions:** These questions, which can be used for discussion or essays, are intended to help students think about how science progresses over time. This set always concludes with at least one activity designed for group work, in order to promote collaborative learning in class.
 - **Investigate Further:** The remaining questions are designed for homework assignment and are intended to go beyond the earlier review questions. These questions are separated into two groups: Short-Answer/Essay Questions, which focus on conceptual interpretation and sometimes on outside research or experiment, and Quantitative Problems, which require some mathematics and are usually based on topics covered in the Mathematical Insight boxes.
- **Think About It:** This feature, which appears throughout the book in the form of 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 also occurs throughout the book, integrated into the narrative; it 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 address supplementary discussion topics related to the chapter material but not prerequisite to the continuing discussion.
- **Extraordinary Claims Boxes:** Carl Sagan made famous the statement “extraordinary claims require extraordinary evidence.” These boxes provide students with examples of extraordinary claims about the universe and how they were either supported or debunked as scientists collected more evidence.
- **Mathematical Insight Boxes:** These boxes contain most of the mathematics used in the book and can be covered or skipped depending on the level of mathematics that you wish to include in your course. The Mathematical Insights use a three-step problem-solving strategy—Understand, Solve, and Explain—that gives students a consistent and explicit structure for solving quantitative homework problems.
- **Annotated Figures:** Key figures in each chapter use the research-proven technique of annotation—the placement on the figure of carefully crafted text (in blue)—to guide students in understanding and interpreting complex figures.
- **Cosmic Context Two-Page Figures:** These two-page spreads provide visual summaries of key processes and concepts.
- **Wavelength/Observatory Icons:** For astronomical images, simple icons indicate whether the image is a photo, artist’s impression, or computer simulation; whether a photo came from ground-based or space-based observations; and the wavelength band(s) used to take the photo.
- **Video Icons:** These icons point to videos available in the Study Area of Mastering Astronomy that are relevant to the topic at hand. Tutorial assessments based on these videos are available for assignment in the instructor Item Library.
- **Cross-References:** When a concept is covered in greater detail elsewhere in the book, a cross-reference to the relevant section is included in brackets (e.g., [Section 5.2]).
- **Glossary:** A detailed glossary makes it easy for students to look up important terms.
- **Appendixes:** The appendixes contain a number of useful references and tables, including key constants (Appendix A), key formulas (Appendix B), key mathematical skills (Appendix C), a periodic table color-coded to indicate origins of the elements (Appendix D), and numerous data tables and star charts (Appendixes E–I).

Additional Pedagogical Features

We also include a number of other features designed to increase student understanding, both within individual chapters and at the end of the book, including the following:

Mastering Astronomy

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 the textbook, students learn only when they spend adequate time learning and studying on their own. 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 adaptive learning designed to coach them individually—responding to their errors with specific, targeted feedback and giving optional hints for those who need additional guidance. For professors, Mastering Astronomy provides unprecedented ability to automatically monitor and record students' step-by-step work and evaluate the effectiveness of assignments and exams.

Note that nearly all the content available at the Mastering Astronomy site for *The Cosmic Perspective* has been written by the textbook authors. This means that students 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 can study in the most efficient possible way.

All students registered for Mastering Astronomy receive full access to the Study Area, which includes three self-study multiple-choice quizzes for each chapter; a large set of prelecture videos, narrated figures, interactive figures, and math review videos; a set of interactive self-guided tutorials that go into depth on topics that some students find particularly challenging; a downloadable set of group activities; and much more.

Instructors have access to many additional resources, including a large Item Library of assignable material that features more than 250 author-written tutorials, all of the end-of-chapter exercises, all the questions from the self-study quizzes in the Study Area, and a test bank. Instructors also have access to the author-written Instructor Guide and teaching resources including PowerPoint® Lecture Outlines, a complete set of high-resolution JPEGs of all images from the book, and PRS-enabled clicker quizzes based on the book and book-specific interactive media.

Supplements for *The Cosmic Perspective*

The 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 Mastering Astronomy (described above), the following supplements are available with this book:

Name of Supplement	Instructor or Student Supplement	Description
<i>Lecture Tutorials for Introductory Astronomy</i> (ISBN 978-0-135-80702-6) by Ed Prather, Tim Slater, Jeff Adams, and Gina Brissenden	Student Supplement	These forty-four lecture tutorials are designed to engage students in critical reasoning and spark classroom discussion.
<i>Observation Exercises in Astronomy</i> (ISBN 978-0-321-63812-0) by Lauren Jones	Student Supplement	This workbook includes fifteen observation activities that can be used with a number of different planetarium software packages.
<i>Astronomy Labs: A Concept Oriented Approach</i> (ISBN 978-0-133-88951-2) by Nate McCrady and Emily Rice	Student Supplement	This modular collection of forty conceptually oriented introductory astronomy labs, housed in the Pearson Custom Library, allows for easy creation of a customized lab manual.
<i>Instructor Resources</i>	Instructor Supplement	This comprehensive collection of instructor resources includes high-resolution JPEGs of all images from the book; Interactive Figures and Photos™ based on figures in the text; additional applets and animations to illustrate key concepts; PowerPoint® Lecture Outlines that incorporate figures, photos, checkpoint questions, and multimedia; and PRS-enabled clicker quizzes based on the book and book-specific interactive media, to make preparing for lectures quick and easy. These resources are located in the Mastering Astronomy Instructor Resource Area.
<i>Instructor Guide</i>	Instructor Supplement	The Instructor Guide contains a detailed overview of the text, sample syllabi for courses of different emphasis and duration, suggested teaching strategies, answers or discussion points for all Think About It and See It for Yourself questions in the text, solutions to all end-of-chapter problems, and a detailed reference guide summarizing media resources available for every chapter and section of the book.
<i>Test Bank</i>	Instructor Supplement	Available in both Word and TestGen formats in the Instructor Resource Center and Mastering Astronomy, the Test Bank contains a broad set of multiple-choice, true/false, and free-response questions for each chapter. The Test Bank is also assignable through Mastering Astronomy.

Acknowledgments

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Megan Donahue is a full professor in the Department of Physics and Astronomy at Michigan State University (MSU), a Fellow of the American Physical Society and of the American Association for the Advancement of Science, and has been President of the American Astronomical Society (2018–2020).

Her research focuses on using x-ray, UV, infrared, and visible light to study galaxies and clusters of galaxies: their contents—dark matter, hot gas, galaxies, 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 Robert 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 Institute Fellow at Space Telescope. Megan was a staff astronomer at the Space Telescope Science Institute until 2003, when she joined the MSU faculty. She is also actively involved in advising national and international astronomical facilities and NASA, including planning future NASA missions. Megan is married to Mark Voit, and they collaborate on many projects, including this textbook, over 70 peer-reviewed astrophysics papers, and the nurturing of their children, Michaela, Sebastian, and Angela. Megan has run three full marathons, including Boston. These days she runs trails with friends, orienteers, and plays piano and bass guitar for fun and no profit.



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Nicholas Schneider is a full 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

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Mark Voit

Mark Voit is a full professor in the Department of Physics and Astronomy and served as Associate Dean for Undergraduate Studies 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 contin-

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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

Learning requires study and effort, which means that 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, 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 amounts 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 are spending fewer hours than these guidelines suggest, you could probably improve your grade by studying more. 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 improve your study skills.

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, we recommend the following study plan.

- Begin by reading the key elements of an assigned chapter in the following order:
 1. Read 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 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 (e.g., Common Misconceptions, Special Topics) to read later. Take notes as you read to remind yourself of key ideas you'll want to review later, 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 Chapter Summary, 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 and Review 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 Mastering Astronomy 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 an exam. *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 what you will do if you are not meeting your commitment.
- 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, and 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.
- 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 will likely find friends, peers, or teachers who will be glad to help you learn.
- Although working together with friends can be valuable in helping you understand difficult concepts, 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 any distractions (especially alerts for email, texts, etc.), find a quiet spot, and concentrate on your work.

Preparing for Exams

- 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.
- Rework previously completed problems and other assignments, then try additional questions, including the online quizzes available at Mastering Astronomy, to be sure you understand the concepts.
- 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.
- 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. 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 $10E5$.
 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.

Foreword

The Meaning of *The Cosmic Perspective*



© Neil deGrasse Tyson

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, has hosted the PBS series NOVA scienceNOW and the globally popular Cosmos: A Spacetime Odyssey, 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 outside 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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1

A Modern View of the Universe

▲ **About the photo:** This image from the James Webb Space Telescope (JWST) shows thousands of galaxies in a region of the sky so small you could cover it with a grain of sand held at arm's length.

LEARNING GOALS

1.1 The Scale of the Universe

- What is our place in the universe?
- How big is the universe?

1.2 The History of the Universe

- How did we come to be?
- How do our lifetimes compare to the age of the universe?

1.3 Spaceship Earth

- How is Earth moving through space?
- How do galaxies move within the universe?

It suddenly struck me that that tiny pea, pretty and blue, was the Earth. I put up my thumb and shut one eye, and my thumb blotted out the planet Earth. I didn't feel like a giant. I felt very, very small.

—Neil Armstrong on looking back at the Earth from the Moon, July 1969

Chapter 1 Overview

Far from city lights on a clear night, you can gaze upward at a sky filled with stars. Lie back and watch for a few hours, and you will observe the stars marching steadily across the sky. Confronted by the seemingly infinite heavens, you might wonder how Earth and the universe came to be. If you do, you will be sharing an experience common to humans around the world and in thousands of generations past.

Modern science offers answers to many of our fundamental questions about the universe and our place within it. We now know the basic content and scale of the universe. We know the ages of Earth and the universe. And, although much remains to be discovered, we are rapidly learning how the simple ingredients of the early universe developed into the incredible diversity of life on Earth—and, perhaps, life on other worlds as well.

In this first chapter, we will survey the scale, history, and motion of the universe. This “big picture” perspective on our universe will provide a base on which you’ll be able to build a deeper understanding in the rest of the book.

1.1 The Scale of the Universe

For most of human history, our ancestors imagined Earth to be stationary at the center of a relatively small universe. This idea made sense at a time when understanding was built upon everyday experience. After all, we cannot feel the constant motion of Earth as it rotates on its axis and orbits the Sun, and if you observe the sky you’ll see that the Sun, Moon, planets, and stars all appear to revolve around us each day. Nevertheless, we now know that Earth is a planet orbiting a rather average star in a rather typical galaxy in a vast universe.

The historical path to this knowledge was long and complex. In later chapters, we’ll see that the ancient belief in an Earth-centered (or *geocentric*) universe changed only when people were confronted by strong evidence to the contrary, and we’ll explore how the method of learning that we call *science* enabled us to acquire this evidence. First, however, it’s useful to have a general picture of the universe as we know it today.

What is our place in the universe?

Take a look at the remarkable photo that opens this chapter (on page 1). This photo, taken by the James Webb Space Telescope (JWST), shows a piece of the sky so small that you could block your view of it with a grain of sand held at arm’s length. Yet it encompasses an almost unimaginable expanse of both space and time. Nearly every object within it is a *galaxy* filled with billions of stars, and some of the smaller smudges are galaxies so far away that their light has taken more than 13 billion years to reach us. Let’s begin our study of astronomy by exploring what a photo like this one tells us about our own place in the universe.

Our Cosmic Address The galaxies that we see in the JWST photo are just one of several key levels of structure in our universe, all illustrated as our “cosmic address” in

FIGURE 1.1.

Earth is a *planet* in our **solar system**, which consists of the Sun, the planets and their moons, and countless smaller objects that include rocky *asteroids* and icy *comets*. Keep in mind that our Sun is a *star*, just like the stars we see in our night sky.

Our solar system belongs to the huge, disk-shaped collection of stars called the **Milky Way Galaxy**. A **galaxy** is a great island of stars in space, all held together by gravity and orbiting a common center. The Milky Way is a relatively large galaxy, containing more than 100 billion stars, and we think that most of these stars are orbited by planets. Our solar system is located a little over halfway from the galactic center to the edge of the galactic disk.

Billions of other galaxies are scattered throughout space. Some galaxies are fairly isolated, but most are found in groups. Our Milky Way, for example, is one of the two largest among more than 80 galaxies (most relatively small) in the **Local Group**. Groups of galaxies with many more large members are often called **galaxy clusters**.

On a very large scale, galaxies and galaxy clusters appear to be arranged in giant chains and sheets with huge voids between them; the background of Figure 1.1 represents this large-scale structure. The regions in which galaxies and galaxy clusters are most tightly packed are called **superclusters**, which are essentially clusters of galaxy clusters. Our Local Group is located in the outskirts of the Local Supercluster (also called *Laniakea*, Hawai’ian for “immense heaven”).

Together, all these structures make up our **universe**. In other words, the universe is the sum total of all matter and energy, encompassing the superclusters and voids and everything within them.

Think about it Some people think that our tiny physical size in the vast universe makes us insignificant. Others think that our ability to learn about the wonders of the universe gives us significance despite our small size. What do you think?

Astronomical Distance Measurements The labels in Figure 1.1 give an approximate size for each structure in kilometers (recall that 1 kilometer \approx 0.6 mile), but many distances in astronomy are so large that kilometers are not the most convenient unit. Instead, we often use two other units:

- One **astronomical unit (AU)** is Earth’s average distance from the Sun, which is about 150 million kilometers (93 million miles). We commonly describe distances within our solar system in AU.
- One **light-year (ly)** is the distance that light can travel in 1 year, which is about 10 trillion kilometers (6 trillion miles). We generally use light-years to describe the distances of stars and galaxies.

Be sure to note that a light-year is a unit of *distance*, not of time. Light travels at the speed of light, which is 300,000 kilometers per second. We therefore say that one *light-second* is about 300,000 kilometers, because that is the distance light travels in 1 second. Similarly, one

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