Preface

APPROACH

There are many astronomy textbooks available today, but *Pathways to Astronomy* offers something different.

Created by two veteran teachers of astronomy, both recipients of outstanding teaching awards, *Pathways* breaks down introductory astronomy into its component parts. The huge and fascinating field of astronomy is divided into 86 Units from which you can selectively choose topics according to your interests, while maintaining a natural flow of presentation.

One of the frustrations created by other current astronomy textbooks is that each chapter covers such a wide array of topics that it is difficult for students to absorb the large amount of material, and the texts are wed to such a specific order of presentation that it is difficult for the professor to link the chapter readings and review questions to his or her own particular approach to teaching the subject. Whether you are learning astronomy for the first time or teaching it for the tenth, *Pathways* offers greater flexibility for exploring astronomy in the way you want to.

The Unit structure allows the new learner and the veteran professor to relate the text more clearly to college lectures. Each Unit is small enough to be easily tackled on its own or read as an adjunct to the classroom lecture. For the faculty member who is designing a course to relate to current events in astronomy or a particular theme, the structure of *Pathways* makes it easier to assign reading and worked problems that are relevant to each topic. For the student of astronomy, *Pathways* makes it easier to digest each topic and to clearly relate each Unit to lecture material.

Each Unit of *Pathways to Astronomy* is like a mini-lecture on a single topic or closely related set of ideas. The same material covered in other introductory astronomy texts is included, but it is broken up into smaller, self-contained parts. This gives greater flexibility in selecting topics than is possible with the wide-ranging chapter in a traditional text that covers the same material as four or five *Pathways* Units.

Even though the Units are written to be as independent as possible, they still flow naturally from one to the next or even in alternative orders—different *pathways*—through the book. Professors can select Units to fit their course needs and cover them in the order they prefer. They can choose individual Units that will be explored in lecture while assigning other Units for self-study. Or they can cover all the Units in full depth in a content-rich course. With the short length of Units, students can more easily digest the material covered in an individual Unit before moving on to the next Unit. And because the questions and problems are focused on a single topic, it is much easier to determine mastery of each topic.

The Unit format also provides an opportunity to take some extra steps beyond the ordinary text. The authors have included some material of special interest that introduces topics most introductory texts do not offer—for example, Units on calendar systems and special relativity. More advanced material within a particular Unit topic is also organized toward the end of the Unit so that the essentials are covered first—also providing flexibility for assigning readings.

Pathways to Astronomy makes it easy to tailor readings and exercises so they fit best within a course's structure. It also provides opportunities to travel down some fascinating paths to enhance a course or to provide additional reading for advanced students.

NEW TO THE FIFTH EDITION

In addition to our own monitoring of new and interesting results in the field, many readers and reviewers offered excellent suggestions for updates and improvements to *Pathways*. One of the more challenging aspects of revising the text is that we want to address new topics and improve the clarity of the presentation without letting the text become needlessly longer. Sometimes new results, such as the data on Pluto from *New Horizons,* allows us to replace old speculative material. Other results, such as the wealth of new material on exoplanets from the *Kepler* mission, require some expansion of the text, but we have made other adjustments to keep the text from growing substantially longer.

In all, more than 100 figures were added, updated, or replaced throughout the book to improve clarity and to include some of the best new images available. More than 50 new Test Yourself questions were also added. The Unit topics remain the same as the third and fourth editions, although a few Unit sections were shifted. Notably, in light of the growing compositional information on asteroids from the *Dawn* spacecraft and other sources, we shifted the section on meteorites from Unit 50 ("Impacts on Earth") to Unit 43 ("Asteroids"). We also shifted a few sections within Units as discussed in the detailed notes below.

We used information gleaned from LearnSmart, McGraw-Hill's adaptive learning program to aid in the revisions. LearnSmart links readers' responses to questions about the content to the sections of the text where the question's subject matter is discussed. We focused revisions on the topics that students found most challenging.

Details of Changes The following list of changes includes the most significant updates and additions:

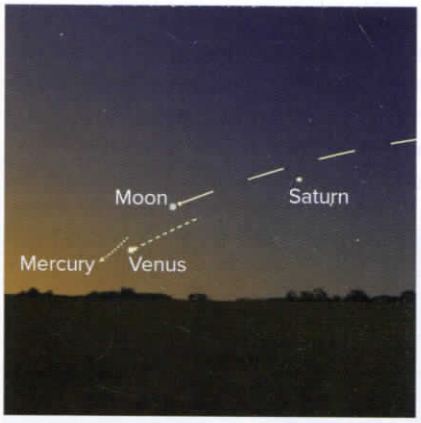
Unit 2 Beyond the Solar System: Some material rearranged between Sections 2.2 and 2.3 for clarity.

Unit 3 Astronomical Numbers: Clarifications about the purpose and procedure of rounding off.

Unit 5 The Night Sky: New figure using a star chart from the free open source software program *Stellarium.* We have mentioned and used diagrams from this excellent program in a few places in the text to encourage its use as a resource for students.

Unit 6 The Year: New image and graphics of Chichén Itzá. Modified graphics and expanded discussion of motion of the Sun through the zodiac and explanation of connection to horoscope "signs"; new image and diagram of Stonehenge.

Unit 8 Lunar Cycles: New and modified figures to better relate phases to positions in orbit. Clarified discussion of frequency of partial eclipses; extracted image of Earth eclipsing Sun from video by Apollo astronauts; clarified exact count of days in the saros.



Unit 10 Geometry of the Earth, Moon, and Sun: Revised text and made new figures to better illustrate Eratosthenes' measurement of Earth's circumference; reorganized text and figures to clarify discussion of angular size formula.

Unit 11 Planets: The Wandering Stars: Added figures to illustrate direct and retrograde motions of the planets both as seen from Earth and their explanation in a heliocentric model.

Unit 12 The Beginnings of Modern Astronomy: Figure12.3C now illustrates ellipses of specific eccentricities.

Unit 13 Observing the Sky: New image of star trails around Polaris; expanded discussion of variations of length of solar day and equation of time with figure showing effects of both the tilt of Earth's axis and its orbit's eccentricity.

Unit 21 The Dual Nature of Light and Matter: New figure to illustrate de Broglie's explanation of electron orbitals.

Unit 23 Thermal Radiation: Examples and calculations modified in last section to simplify discussion of Stefan-Boltzmann law.

Unit 27 General Relativity: Modified text and new figure to describe the *LIGO* detection of gravitational waves.

Unit 29 Collecting Light: New images of Gran Telescopio Canarias and the Large Millimeter Telescope.

Unit 30 Focusing Light: New image of Yerkes telescope.

Unit 31 Telescope Resolution: New image of Atacama Large Millimeter Array (ALMA).

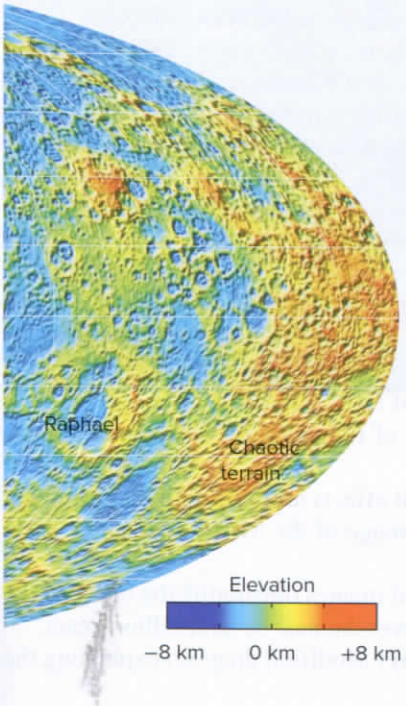
Unit 32 Earth's Atmosphere and Space Observatories: Section on space observatories reorganized for clarity, with new text and figure about *JWST*.

Unit 35 The Origin of the Solar System: Expanded discussion of condensation temperature.

Unit 36 Other Planetary Systems: Extensive revisions and additions on exoplanets; new figures highlighting results mainly from *Kepler,* including projected population of different types of exoplanets, multiple-planet systems discovered to date, radius versus mass, and absorption studies of exoplanet atmosphere.

Unit 38 Earth's Atmosphere and Hydrosphere: New image of the aurora from the international space station.

Unit 40 Mercury: New global topographic map of Mercury based on *Messenger* data; reorganized discussion of surface features; new figure showing likely regions of polar ice. Note that the topographic map has been generated in the same Mollweide equal-area projection as other global maps throughout the text. The consistent projection makes comparisons of the planets clearer.

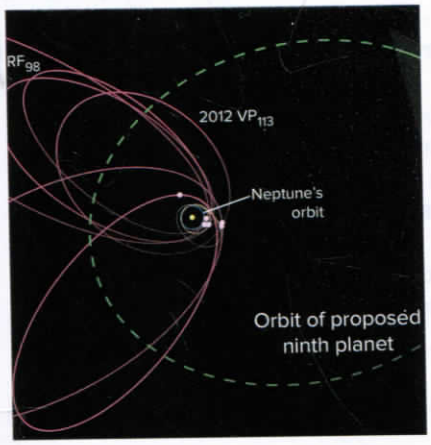


Unit 41 Venus: Mention of recent *Venus Express* finding of temperature changes likely associated with volcanic activity.

Unit 42 Mars: New *Curiosity* image of layered rocks at base of Mt. Sharp; mentions of recent spectroscopic findings of hydrated salts in seeps and *MAVEN* orbiter measurements of atmospheric losses due to solar wind; note about recent estimate of timescale for Phobos to break up into ring; new images of Phobos and Deimos.

Unit 43 Asteroids: Extensive reorganization and updates in light of recent results from the *Dawn* spacecraft; Section 43.2, now on Asteroid Orbits, moved from later in Unit to help provide underpinnings for discussion of asteroid compositions; Section 43.3 now includes images from *Dawn* with comparisons of Ceres to the Moon and smaller asteroids; Section 43.4 on Meteorites moved from Unit 50 to explore compositional connections to astronomical spectroscopic data on asteroids; Section 43.5 on compositions now includes recent *Dawn* data and images of Ceres' bright spots and Vesta surface composition map as well as updated data on asteroid densities.

Unit 44 Comparative Planetology: New figure provides comparison of surface topography of the terrestrial planets to the same scale.



Unit 45 Jupiter and Saturn: Gas Giants: Added emphasis to using the term "gas giants" for Jupiter and Saturn in light of the increasing use of this term to describe similar size and mass of exoplanets. Some reorganization of the introductory material and the first section, with addition of an image of Saturn's cloud bands to emphasize physical similarities of the gas giants' atmospheres; revised discussion of Coriolis motions and their relationship to atmospheric features; new infrared image showing changing heat loss from Jupiter's interior; new *Cassini* images of storm on Saturn and polar vortex.

Unit 46 Uranus and Neptune: Ice Giants: The term "ice giants" for Uranus and Neptune has gained increasing usage for describing exoplanets of this size and mass, so we added it to the Unit title and throughout the text.

Unit 48 Ice Worlds, Pluto, and Beyond: Section on Pluto extensively revised to include early results and images from the *New Horizons* flyby; new figure and discussion of evidence for recent hypothesis that there is a planet at least 10 times more massive than Earth orbiting beyond the Kuiper belt.

Unit 49 Comets: New images and discussion of Comet Churyumov-Gerasimenko based on *Rosetta* findings.

Unit 50 Impacts on Earth: Former section on meteorites moved to Unit 43; new image of meteor from *ISS*.

Unit 51 The Sun, Our Star: Section on helioseismology moved immediately after Section 51.2 to emphasize its connection to understanding the Sun's internal structure; added figure to illustrate energy transport close to the text where it is discussed; new image of spicules from the *Hinode* satellite.

Unit 52 The Sun's Source of Power: New image of the interior of the Super-Kamiokande detector; added mention of IceCube neutrino experiment.

Unit 53 Solar Activity: New image of coronal mass ejection; updated graphs of sunspot and sea surface temperature data to include most recent data; expanded discussion of effects of solar activity on Earth's climate.

Unit 55 The Luminosities of Stars: Expanded and clarified discussion of magnitudes.

Unit 56 The Temperatures and Compositions of Stars: Combined Sections 56.4 and 56.5, reordering material to clarify the connection of spectral types to surface temperature; added coldest spectral type "Y" to spectral sequence.

Unit 61 Star Formation: New *Hubble* images of Eagle Nebula; new radio image showing Doppler data for bipolar outflow; new optical and IR images of bipolar outflow.

Unit 62 Main-Sequence Stars: New image of NGC 2264.

Unit 66 Exploding White Dwarfs: New set of optical/X-ray images of Type Ia supernovae.

Unit 69 Black Holes: New illustration of tidal effects around small black holes.

Unit 71 Discovering the Milky Way: New image of the Milky Way in the night sky.

Unit 72 Stars of the Milky Way: New series of images illustrating the likely future of the Milky Way as it collides with M31 over the next several billion years.

Unit 74 Mass and Motions in the Milky Way: Modified diagram explaining the "winding problem."

Unit 75 A Universe of Galaxies: Section 75.3 reorganized to place discussion of uncertainties about Hubble constant all together at end; latest Cepheid-variable estimate of Hubble constant noted.

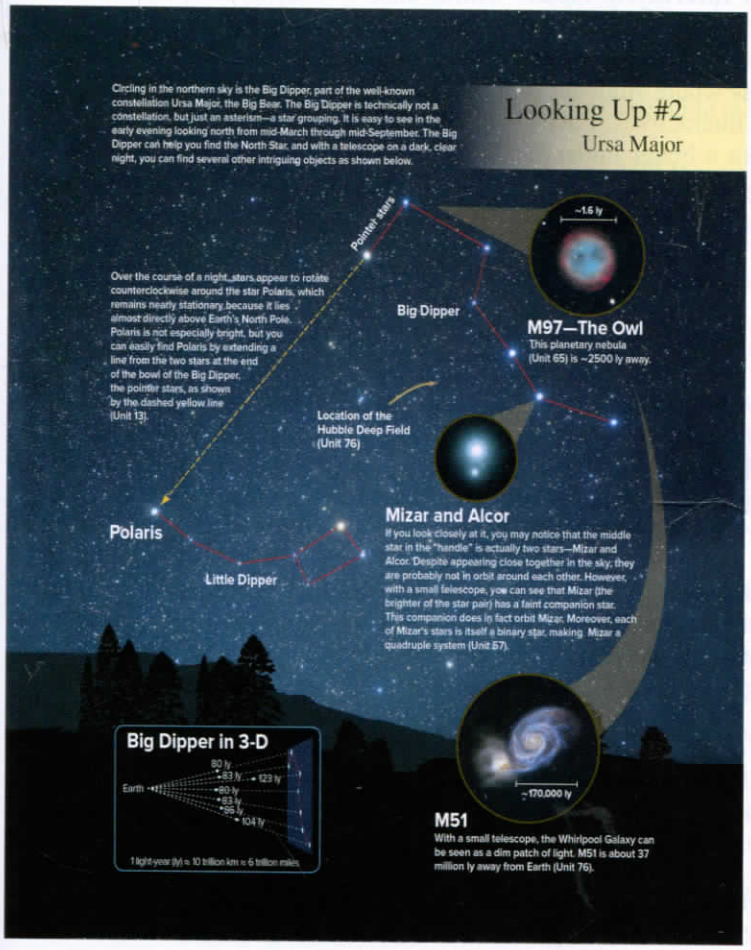
Unit 83 The Beginnings of the Universe: New image of Large Hadron Collider.

Unit 84 Dark Energy and the Fate of the Universe: Updated numbers based on the latest cosmological parameter estimates from *Planck* measurements of the cosmic microwave background.

Unit 86 The Search for Life Elsewhere: Diagram of habitable zones adjusted to improve clarity.

FEATURES OF THIS BOOK

Book Elements We suggest perusing the front and back of the book before reading individual Units. We have provided a variety of features that can help comprehend the wide-ranging material of this book:



Looking Up Illustrations: It can be challenging to link introductory astronomy to the sky around us. The nine "Looking Up" full-page art pieces at the front of the book provide another pathway to astronomy, connecting what we actually see when "looking up" at the night sky with the more theoretical side of astronomy. Each illustration displays a large-scale photograph of one or more constellations in the night sky. Each also contains close-up photographs and illustrations of some of the most interesting telescopic objects with cross-references to the text. Details are also given regarding the objects' distances from Earth, along with three-dimensional illustrations of some of the stars or other objects within the field of view. The Looking Up Illustrations begin on page ii at the front of the book.

Tables of Useful Data and Formulas: The appendix includes a brief discussion of basic mathematical techniques along with many tables of essential astronomical data that are regularly updated to include the latest measurements. Highlights include a table of useful astronomical formulas, the Messier catalog, and a cosmic periodic table of the elements specially designed by the authors. Several of the most useful of these tables are reproduced on the inside covers of the book.

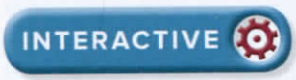
Glossary: Following the appendix is a full glossary of all key terms used throughout the text. The glossary also defines the symbols used in equations.

Star Charts: A good star chart helps link the study of astronomy to the night sky. Pathways to Astronomy offers a foldout star chart as well as seasonal star charts for Northern-Hemisphere observers. These will help students to take that next step beyond the book—exploring the night sky. The foldout chart now shows the location of the Messier objects as well as the positions of several other bright deep-sky objects that can be found with a small telescope or binoculars. The foldout chart is also useful for observing projects, such as tracking the positions of the Moon and planets.

Unit Elements As you read each Unit, there are a number of features designed to help you gain mastery of the material, including links to materials outside of the book and cross-references to help you gain a broader understanding of the material.

Learning Objectives: At the start of each Unit, a list of learning objectives describes the most important skills and abilities that readers should strive for in studying that Unit. These identify specific actions (such as describing, explaining, comparing, and calculating) that demonstrate a good mastery of the material.

Looking Up Icons: These marginal notes point out objects that can be seen in the Looking Up pages at the front of the book. Use the Looking Up figures to gain a clearer idea of how the textual descriptions relate to objects visible in the night sky. Most of these can be seen with the unaided eye or with binoculars.



Animation and Interactive Icons: Online animations and interactive resources are available on the *Pathways* website (www.mhhe.com/schneider5e) to help students gain a better grasp of key concepts. Icons have been placed near figures and selections where students can gain additional understanding through Animations and Interactives. Each Interactive allows users to manipulate parameters and gain a better understanding of topics such as blackbody radiation, the Bohr model, a "solar system builder," retrograde motion, cosmology, and the H-R diagram by watching the effects of these manipulations. Each Interactive includes an analysis tool (interactive model), a tutorial describing its function, content describing its principal themes, related exercises, and solutions to the exercises. Users can jump between these exercises and analysis tools with just a mouse click.

Clarification Point

Some widely held beliefs about astronomy are known to be incorrect!

Clarification Points: *Un*-learning a preconceived notion is one of the most challenging problems facing the student of astronomy. Marginal notes call attention to common misunderstandings that we have encountered among many of our own students. These points of confusion can be particularly difficult to overcome, so they deserve special attention.

Concept Question

These questions invite you to think about ideas that go beyond the text.

Concept Questions: Hundreds of Concept Questions are scattered throughout the margins of the Units. These questions are designed to invite readers to think beyond the text and to ponder questions that have no easy answer. Many also make good group discussion questions.

Mathematical Insight

These marginal notes explore the mathematics of the text more deeply.

Mathematical Insights: These marginal notes provide mathematical details to clarify the discussion in the text or expand beyond it. Derivations of some mathematical formulas, as well as worked examples of mathematical problems and insights into mathematical thinking, are placed in these boxes.

Key Points and Key Terms: At the end of each Unit, Key Points are summarized and Key Terms (which are shown in bold in the text) are cross-referenced to where they first appear. Reviewing the key points and terms may provide useful reminders of the important points covered in the Unit. Definitions for Key Terms are provided in the glossary.

End-of-Unit Questions: In addition to the Concept Questions, which are cross-referenced at the end of each Unit, we provide Review Questions, Quantitative Problems, and Test Yourself multiple-choice questions (including more than 50 additional test-yourself questions in this edition). Each of these categories of questions is designed for a different purpose. The Review Questions provide an opportunity to check your recollection of basic facts and ideas that are directly covered in the text. The quantitative problems take a step beyond basic comprehension and challenge you to carry out calculations related to the Unit's topic. Some of these problems are difficult, but all can be solved using the ideas and formulas presented in the book. The Test Yourself questions are structured to test your understanding of concepts as well as knowledge of important facts. To get the most out of these questions, write down your answers before checking the answers provided at the back of the text.

FOR THE INSTRUCTOR

A number of instructor resources are available through our Connect platform. These include:

- **Test Bank** The electronic test bank offers a bank of questions that can be used for homework assignments or the preparation of exams. The test bank can be utilized to quickly create customized exams. It allows instructors to sort questions by format or level of difficulty, edit existing questions or add new ones, and scramble questions and answer keys for multiple versions of the same test.
- **McGraw-Hill Presentation Tools** Accessed through *Pathways* Connect site, the Presentation Tools are an online digital library containing assets such as photos, artwork, animations, and other media types that can be used to create customized lectures, visually enhanced tests and quizzes, compelling course websites, or attractive printed support materials. Assets are copyrighted by McGraw-Hill Higher Education, but they can be used by instructors for classroom purposes. The visual resources in this collection include:
  - **Art** Full-color digital files of all illustrations in the book can be readily incorporated into lecture presentations, exams, or custom-made classroom materials. In addition, all files are preinserted into PowerPoint© slides for ease of lecture presentation.
  - **Photos** The photos collection contains digital files of photographs from the text, which can be reproduced for multiple classroom uses.
  - **Animations and Interactives** Numerous full-color animations and the astronomy interactives, illustrating important processes, are also provided.
  - **PowerPoint Lecture Outlines** Ready-made presentations that combine art and lecture notes are provided for each unit of the text.

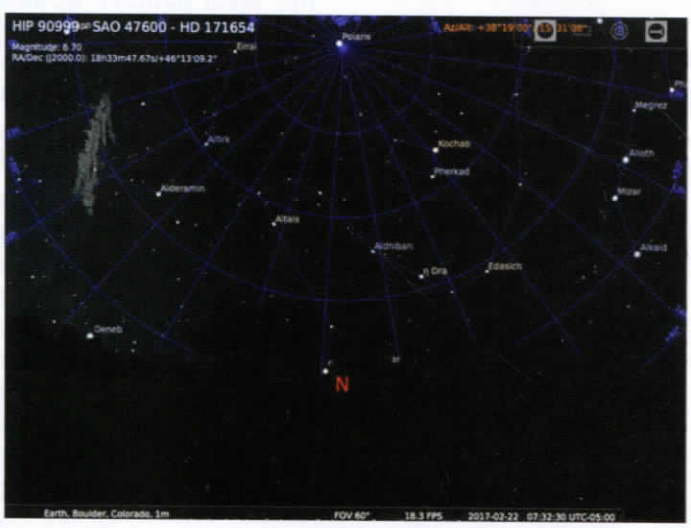
Also residing on your textbook's Connect site are:

- **Instructor's Manual** The Instructor's Manual is housed within the Connect site and can be accessed only by instructors. This manual includes solutions to the quantitative questions at the end of chapter.
- **Stellarium Exercises** The fifth edition marks the introduction of Connect exercises that can be used with the Stellarium open source planetarium software. Students will explore the sky through this dynamic tool and answer questions about their experience to reinforce the concepts in the text.

2. Which of the following relationships appears to be true for a northern hemisphere observer?

(Click to select)

Click the "Equatorial Grid" button on the lower menu  to check your answer.



ACKNOWLEDGMENTS

Writing and revising a text such as *Pathways* is a collaboration with everyone who reads or uses it. We are deeply grateful to everyone who offered a suggestion, pointed out a mistake, or found a place where we might improve the content. Our sincere thanks to all the reviewers who have offered suggestions throughout the life of this book. Special thanks to those who were instrumental in the preparation of LearnSmart and SmartBook for *Pathways to Astronomy* as well as to those who helped develop and enhance our online homework offerings in Connect.

Hugh H. Crowl, *Bennington College*
Beth Hufnagel, *Anne Arundel Community College*
Patrick L. Koehn, *Eastern Michigan University*
Christopher C. Shope, *Harrisburg Area Community College*

Finally, the authors would like to thank the team at McGraw-Hill for all their assistance with updating *Pathways,* including Andrea Pellerito, Robin Reed, Joan Weber, Noah Evans, Laura Bies, Carrie Burger, and Matt Backhaus. Thanks particularly to copyeditor John S. Murdzek for a close reading of the revised manuscript and many corrections and suggestions for improvement.