UNDERSTANDING OUR UNIVERSE

SECOND EDITION

PALEN | KAY | SMITH | BLUMENTHAL

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Stacy Palen dedicates this book to Helene Detwiler, Everett Boles, Keith Palen, Dutchie Armstrong and "Miss T."

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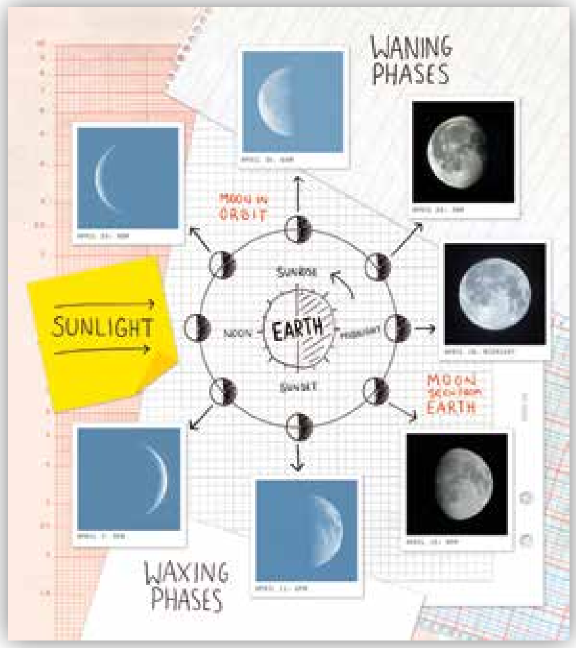

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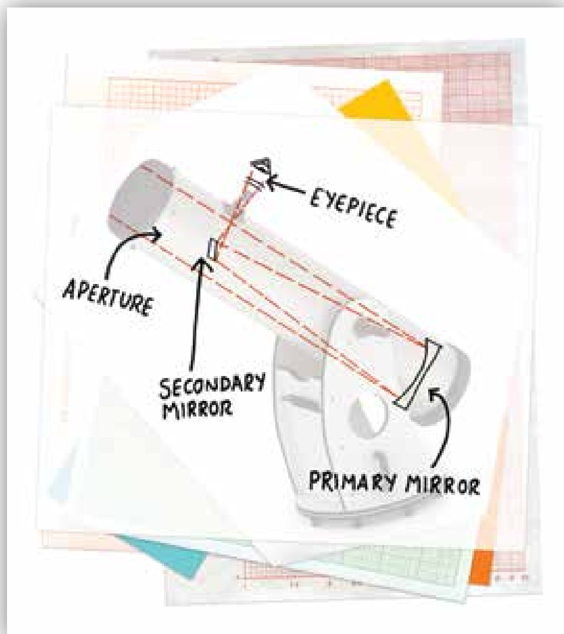

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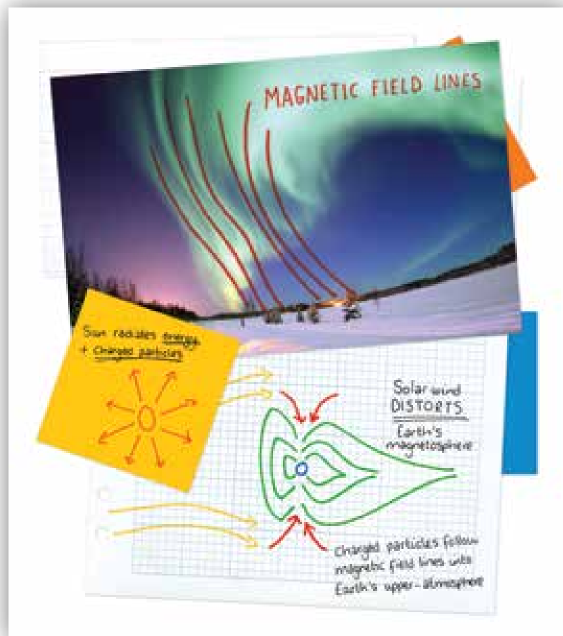

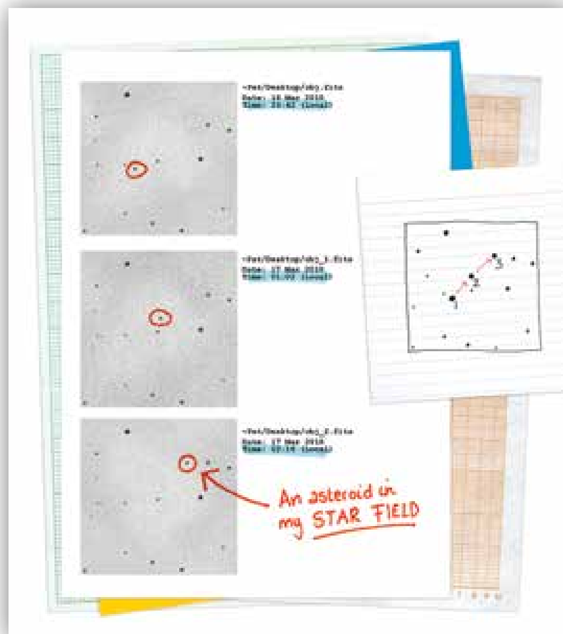

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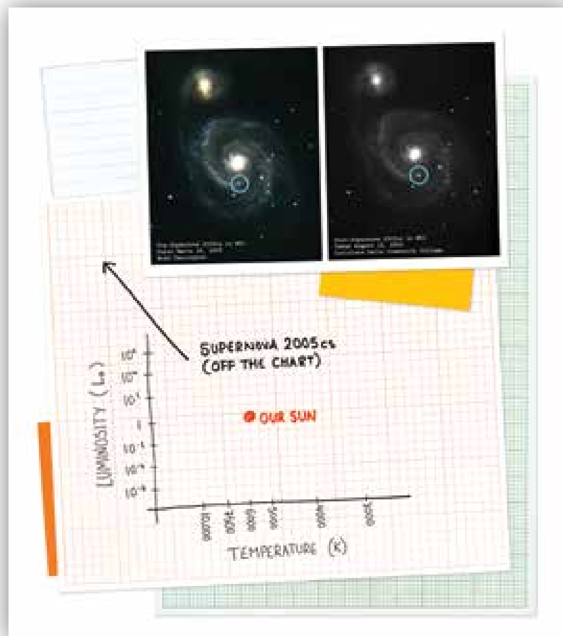

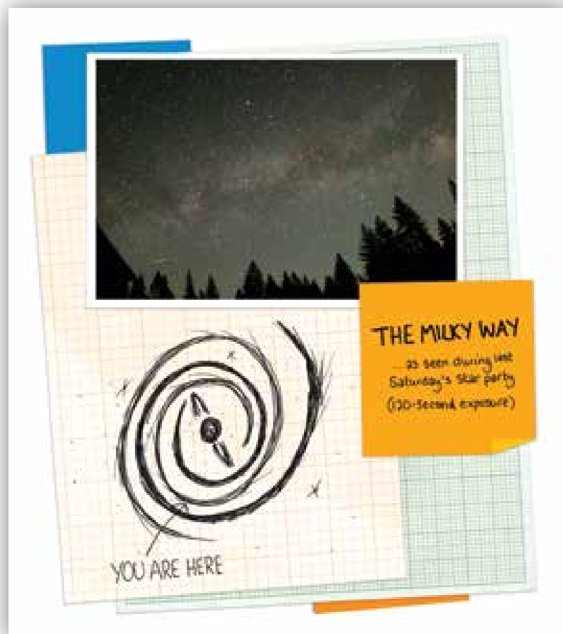

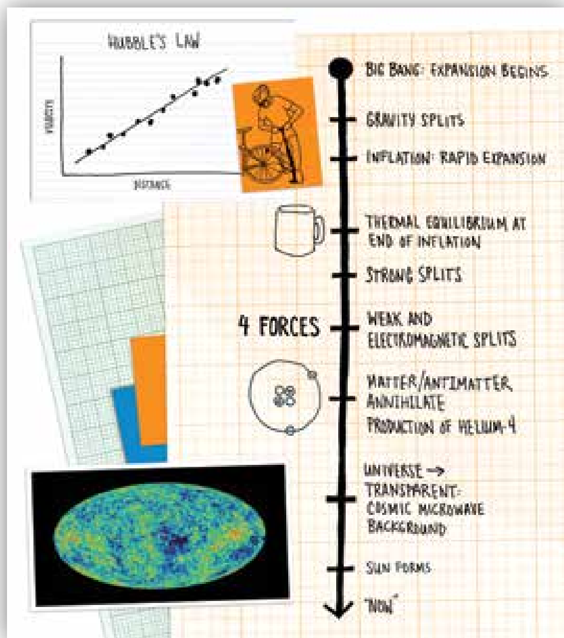

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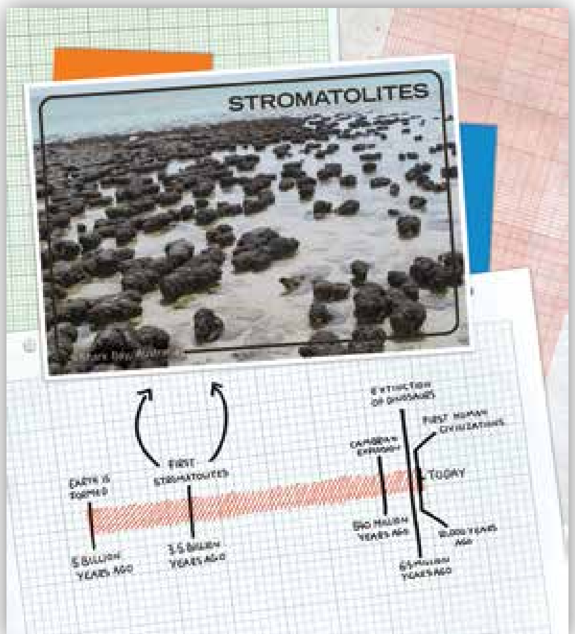


Dear Student,

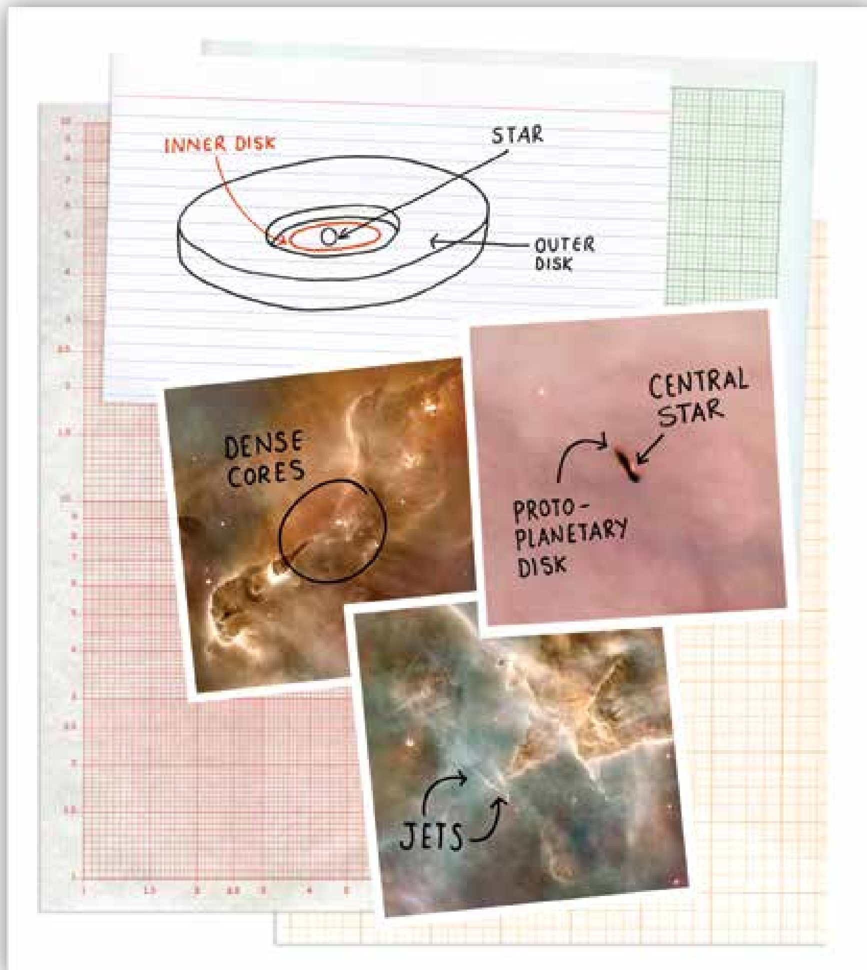
You may wonder why it is a good idea to take a general-education science course. Throughout your education, you have been exposed to different ways of thinking—different approaches to solving problems, different definitions of *understanding*, and different meanings of the verb *to know*. Astronomy offers one example of the scientific viewpoint. Scientists, including astronomers, have a specific approach to problem solving (sometimes called the scientific method, although the common understanding of this term only skims the surface of the process). Astronomers "understand" when they can make correct predictions about what will happen next. Astronomers "know" when an idea has been tested dozens or even hundreds of times and that the idea has stood the test of time.

Your instructor likely has two basic goals in mind for you as you take this course. The first is to understand some basic physical concepts and be familiar with the night sky. The second is to think like a scientist and learn to use the scientific method not only to answer questions in this course but also to make decisions in your life. We have written the Second Edition of *Understanding Our Universe* with these two goals in mind.

Throughout this book, we emphasize not only the content of astronomy (the masses of the planets, the compositions of stellar atmospheres) but also *how* we know what we know. We believe the scientific method is a valuable tool that you can carry with you, and use, for the rest of your life.

Astronomy is one of the purest expressions of one of the more distinctive impulses of humanity—curiosity. Astronomy does not capture the public interest because it is profitable, will cure cancer, or build better bridges. People choose to learn about astronomy because they are curious about the universe.

The most effective way to learn something is to "do" it. Whether playing an instrument or a sport or becoming a good cook, reading "how" can only take you so far. The same is true of learning astronomy. This book helps you "do" as you learn. We start with the illustrations at the beginning of each chapter. These **chapter-opening figures** demonstrate different ways you might interact with the material. They are presented from the viewpoint of a student who is wondering about the universe, asking questions, and keeping a journal of experiments that investigate the answers. Your instructor may ask you to keep such a journal. Or you may choose to keep one on your own, as a useful way of investigating the world around you.



As you learn any new subject, one of the stumbling blocks is often the language of the subject itself. This can be jargon—the specialized words unique to that subject—for example, *supernova* or *Cepheid variable*. But it can also be ordinary words that are used in a special way. As an example, the common word *inflation* usually applies to balloons or tires in everyday life, but economists use it very differently, and astronomers use it differently still. Throughout the book, we have included **Vocabulary Alerts** that point out the astronomical uses of common words to help you recognize how those terms are used by astronomers.

Vocabulary Alert

pressure In common language, we often use *pressure* interchangeably with the word *force*. Astronomers specifically use pressure to mean the force per unit area that atoms or molecules exert as they speed around and collide with each other and their surroundings.

dense In common language, we use this word in many ways, some of which are metaphorical and unkind, as in "You can't understand this? You are so dense!" Astronomers specifically use *density* to mean "the amount of mass packed into a volume"; denser material contains more mass in the same amount of space. In practical terms, you are familiar with density by how heavy an object feels for its size: a pool ball and a tennis ball are roughly the same size, but the pool ball has greater mass and therefore feels heavier because it is denser.

In learning science, there is another potential language issue. The language of science is mathematics, and it can be as challenging to learn as any other language. The choice to use mathematics as the language of science is not arbitrary; nature "speaks" math. To learn about nature, you will also need to speak its language. We don't want the language of math to obscure the concepts, so we have placed this book's mathematics in **Working It Out** boxes to make it clear when we are beginning and ending a mathematical argument, so that you can spend time with the concepts in the chapter text and then revisit the mathematics to study the formal language of the argument. Read through a Working It Out box once, then cover the worked example with a piece of paper, and work through the example until you can do it on your own. When you can do this, you will have learned a bit of the language of science. You will learn to work with data and identify when someone else's data isn't quite right. We want you to be comfortable reading, hearing, and speaking the language of science, and we will provide you with tools to make it easier.

Working It Out 5.2 Making Use of the Doppler Shift

We noted in Section 4.2 that atoms and molecules emit and absorb light only at certain wavelengths. The spectrum of an atom or molecule has absorption or emission lines that look something like a bar code instead of a rainbow, and each type of atom or molecule has a unique set of lines. These lines are called *spectral lines*. A prominent spectral line of hydrogen atoms has a rest wavelength, λ_{rest}, of 656.3 nanometers (nm). Suppose that using a telescope, you measure the wavelength of this line in the spectrum of a distant object and find that instead of seeing the line at 656.3 nm, you see it at an observed wavelength, λ_{obs}, of 659.0 nm. The mathematical form of the Doppler effect shows that the object is moving at a radial velocity (v_r) of

$$v_r = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} \times c$$

$$v_r = \frac{659.0\,\text{nm} - 656.3\,\text{nm}}{656.3\ \text{nm}} \times (3 \times 10^8\,\text{m/s})$$

$$v_r = 1.2 \times 10^6\,\text{m/s}$$

The object is moving away from you (because the wavelength became longer and redder) with a speed of 1.2×10^6 m/s, or 1,200 kilometers per second (km/s).

Now consider our stellar neighbor, Alpha Centauri, which is moving toward us with a radial velocity of –21.6 km/s (-2.16×10^4 m/s). (Negative velocity means the object is moving toward us.) What is the observed wavelength, λ_{obs}, of a magnesium line in Alpha Centauri's spectrum having a rest wavelength, λ_{rest}, of 517.27 nm? First, we need to manipulate the Doppler equation to get λ_{obs} all by itself. Then we can plug in all the numbers.

$$v_r = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} \times c$$

Solve this equation for λ_{obs} to get

$$\lambda_{obs} = \lambda_{rest} + \frac{v_r}{c}\,\lambda_{rest}$$

Both terms on the right contain λ_{rest}. Factor it out to make the equation a little more convenient:

$$\lambda_{obs} = \left(1 + \frac{v_r}{c}\right)\lambda_{rest}$$

We are ready to plug in some numbers to solve for the observed wavelength:

$$\lambda_{obs} = \left(1 + \frac{-2.16 \times 10^4\,\text{m/s}}{3 \times 10^8\,\text{m/s}}\right) \times 517.27\,\text{nm}$$

$$\lambda_{obs} = 517.23\,\text{nm}$$

Although the observed Doppler blueshift (517.23 – 517.27) is only –0.04 nm, it is easily measurable with modern instrumentation.

Back in Section 7.2 . . .

. . . you learned that objects reach thermal equilibrium when they exchange energy and come to the same temperature.

There are a few physical concepts that are applicable in many astronomical situations. Rather than placing them all at the front of the text and asking you to remember them later, we have integrated them into the astronomy content, placing them where you first need them to understand the science. In later chapters, we have provided you with **Concept Connection** icons to remind you where you first saw the concept, so you can go back and review it as needed.

Many of these physical concepts, among others, are further explained in a series of short **Astronomy in Action** videos available on the student website. Those videos feature one of the authors (and several students) demonstrating physical concepts at work. Your instructor might assign these videos to you or you might choose to watch them on your own to create a better picture of each concept in your mind.

As a citizen of the world, you make judgments about science, distinguishing between good science and pseudo-science. You use these judgments to make decisions in the grocery store, pharmacy, car dealership, and voting booth. You base these decisions on the presentation of information you receive through the media, which is very different from the presentation in class. Recognizing what is credible and questioning what is not is an important skill. To help you hone this skill, we have provided **Reading Astronomy News** sections at the end of every chapter. These boxes include a news article with questions to help you make sense of how science is presented to you. It is important that you learn to be critical of the information you receive, and these boxes will help you do that.

At the end of each chapter, we have provided several types of questions, problems, and activities for you to practice your skills. The **Summary Self-Test** may be

NASA's Kepler mission may be disabled, but researchers say the best results are yet to come!

READING ASTRONOMY News

Kepler's Continuing Mission

By **RACHEL COURTLAND, IEEE Spectrum**

In early August, the moment that Bill Borucki had been dreading finally arrived. As the principal investigator of NASA's Kepler space telescope, Borucki had been working with his colleagues to restore the spacecraft's ability precisely to point itself. The planet-hunting telescope has four reaction wheels—essentially, electrically driven flywheels—and at least three must be functional to maintain positioning. But in the past year, two of those wheels had been on the fritz. One went off line in July 2012 after showing elevated levels of friction, and a second followed suit in May 2013, effectively ending science operations. After a few months of recovery efforts, the telescope team was finally forced to call it quits, 6 months after the mission was originally scheduled to finish but years before they hoped it would.

The failures mark the end of an era for Kepler. With only two reaction wheels, the telescope can't steady itself well enough to ensure that light from each star hits the same fraction of a pixel on its charge-coupled devices for months on end without deviation. That's what Kepler needs in order to detect, with high precision, the transit of a planet: the slight dip in the brightness of a star that occurs when an orbiting planet crosses in front of it.

But the Kepler spacecraft might still have its uses, and the data it has already gathered almost certainly will. The telescope's managers are currently evaluating proposals for what might be done with a two-wheeled spacecraft. And the telescope's analysis team is gearing up for the rest of the science mission: a 2- to 3-year effort to crawl systematically through the 4 years of data that Kepler has collected since its launch in 2009.

That analysis effort, which will incorporate new machine-learning techniques and a bit of human experimentation, could yield a bounty of new potential planets on top of the 3,500 that Kepler has found so far. "We expect somewhere between several hundred more planets to maybe as many as a thousand," Borucki says. If all goes well, the revised hunt might even uncover the first handful of terrestrial twins—or at the very least, near cousins: roughly Earth-size planets on nearly yearlong orbits around Sun-like stars.

Uncovering those Earth analogues won't be easy. The orbits are slow and the planets themselves are small. "You're looking for a percent of a percent" dip in the brightness of a star, says Jon Jenkins, the telescope's analysis lead. "That's a very demanding and challenging measurement to make."

The task will be made even more difficult by an unexpected complication: Stars vary in brightness due to sunspots and flares, and Kepler's observations reveal that these variations are greater than scientists had previously estimated. Those fluctuations can hide the presence of a planet, reducing the telescope's sensitivity to terrestrial transits by 50 percent.

In April 2012, NASA granted Kepler a 4-year extension that would have compensated for the extra noise. But with the failure of the reaction wheels, Jenkins and his colleagues now must find a different way to uncover planetary signals.

Earlier this year, they moved the data processing from a set of computer clusters containing 700 microprocessors to the Pleiades supercomputer at the NASA Ames Research Center in Moffett Field, California, where they have the use of up to 15,000 of the machine's more than 160,000 cores. The team is also working on implementing a machine-learning process using an algorithm called the random forest, which will be trained with data already categorized by Kepler scientists. Once it's up and running, the software should be able to speedily differentiate false positives and data artifacts from promising candidates. Eventually, Jenkins says, the analysis team will insert fake data into the pipeline to test the performance of both the humans that ordinarily do the processing and the automated algorithms. "We need to know for every planet we detect how many we missed," Jenkins says.

No one can predict exactly how many planets Kepler will find. The telescope's main goal was to determine how common planets are in and around the habitable zones of stars—the areas around stars with the right temperature range for liquid water to be present. Such statistics could help astrophysicists decide how practical it would be to build a space telescope capable of directly detecting light from Earth-like planets, which is necessary to determine whether they have atmospheres that could support life.

For Earth-size planets in settings similar to our own, developing a good statistical estimate will be difficult. With small numbers, the uncertainty in the size of the overall population will be large. "The best-case scenario is that Kepler could still have, with very large error bars, a number for us at the end of the day," says Sara Seager, a professor of planetary

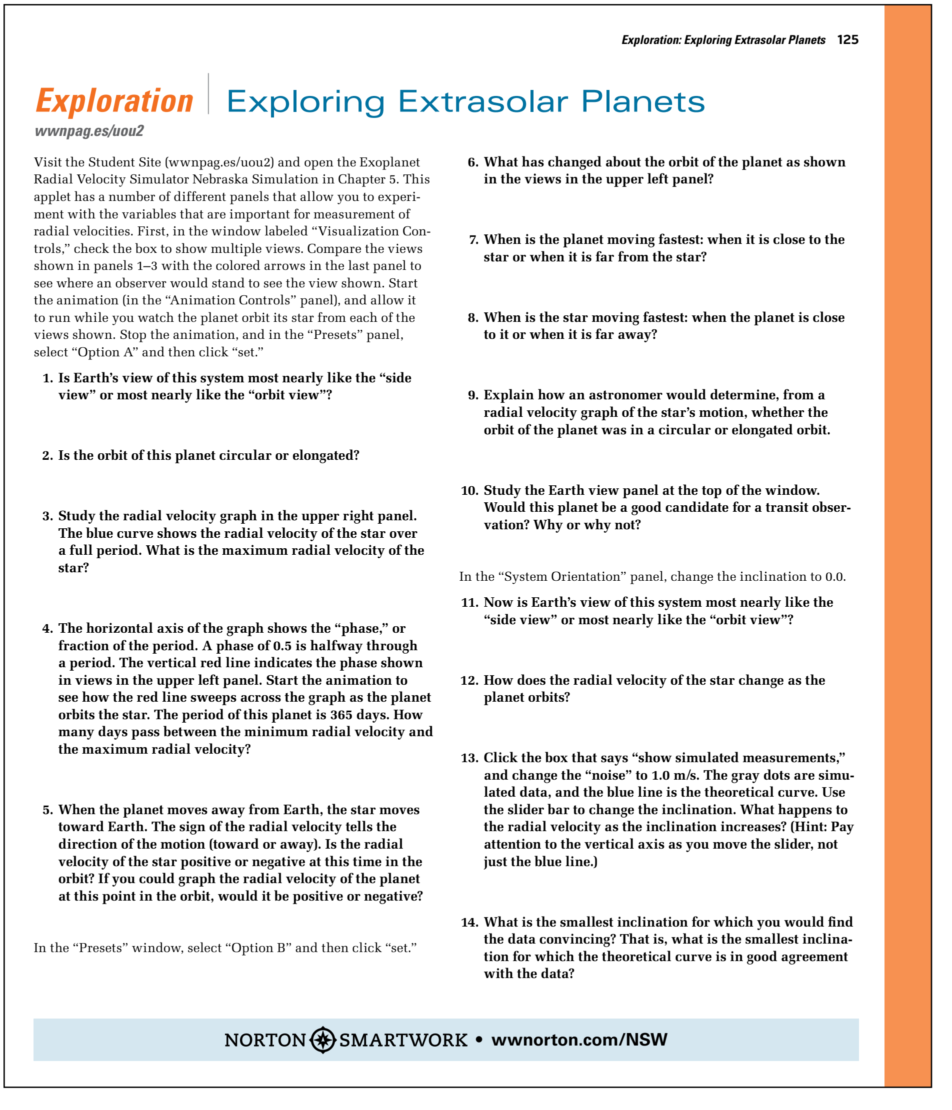
AstroTour: Star Formation

Nebraska Simulation: Exoplanet Radial Velocity Simulator

used to check your understanding. If you can answer these questions correctly, you have a basic grasp of the information in the chapter. Next, a separate group of true/false and multiple-choice questions focuses on more detailed facts and concepts from the chapter. Conceptual questions ask you to synthesize information and explain the "how" or "why" of a situation. Problems give you a chance to practice the quantitative skills you learned in the chapter and to work through a situation mathematically.

Each chapter has an **Exploration** activity that shows you how to use the concepts and skills you learned in an interactive way. About half of the book's Explorations ask you to use animations and simulations on the student website, while the others are hands-on, paper-and-pencil activities that use everyday objects such as ice cubes or balloons.

If you think of human knowledge as an island, each scientific experiment makes the island a little bigger by adding a pebble or a grain of sand to the shoreline. But each of those pebbles also increases our exposure to the ocean of the unknown: The bigger the island of knowledge, the longer the shoreline of ignorance. Throughout this book, we have tried to show clearly which pebbles



Exploration: Exploring Extrasolar Planets 125

Exploration | Exploring Extrasolar Planets

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Visit the Student Site (wwnpag.es/uou2) and open the Exoplanet Radial Velocity Simulator Nebraska Simulation in Chapter 5. This applet has a number of different panels that allow you to experiment with the variables that are important for measurement of radial velocities. First, in the window labeled "Visualization Controls," check the box to show multiple views. Compare the views shown in panels 1–3 with the colored arrows in the last panel to see where an observer would stand to see the view shown. Start the animation (in the "Animation Controls" panel), and allow it to run while you watch the planet orbit its star from each of the views shown. Stop the animation, and in the "Presets" panel, select "Option A" and then click "set."

1. **Is Earth's view of this system most nearly like the "side view" or most nearly like the "orbit view"?**
2. **Is the orbit of this planet circular or elongated?**
3. **Study the radial velocity graph in the upper right panel. The blue curve shows the radial velocity of the star over a full period. What is the maximum radial velocity of the star?**
4. **The horizontal axis of the graph shows the "phase," or fraction of the period. A phase of 0.5 is halfway through a period. The vertical red line indicates the phase shown in views in the upper left panel. Start the animation to see how the red line sweeps across the graph as the planet orbits the star. The period of this planet is 365 days. How many days pass between the minimum radial velocity and the maximum radial velocity?**
5. **When the planet moves away from Earth, the star moves toward Earth. The sign of the radial velocity tells the direction of the motion (toward or away). Is the radial velocity of the star positive or negative at this time in the orbit? If you could graph the radial velocity of the planet at this point in the orbit, would it be positive or negative?**

In the "Presets" window, select "Option B" and then click "set."

6. **What has changed about the orbit of the planet as shown in the views in the upper left panel?**
7. **When is the planet moving fastest: when it is close to the star or when it is far from the star?**
8. **When is the star moving fastest: when the planet is close to it or when it is far away?**
9. **Explain how an astronomer would determine, from a radial velocity graph of the star's motion, whether the orbit of the planet was in a circular or elongated orbit.**
10. **Study the Earth view panel at the top of the window. Would this planet be a good candidate for a transit observation? Why or why not?**

In the "System Orientation" panel, change the inclination to 0.0.

11. **Now is Earth's view of this system most nearly like the "side view" or most nearly like the "orbit view"?**
12. **How does the radial velocity of the star change as the planet orbits?**
13. **Click the box that says "show simulated measurements," and change the "noise" to 1.0 m/s. The gray dots are simulated data, and the blue line is the theoretical curve. Use the slider bar to change the inclination. What happens to the radial velocity as the inclination increases? (Hint: Pay attention to the vertical axis as you move the slider, not just the blue line.)**
14. **What is the smallest inclination for which you would find the data convincing? That is, what is the smallest inclination for which the theoretical curve is in good agreement with the data?**

NORTON SMARTWORK • wwnorton.com/NSW

of knowledge are on the shore, which we are just catching a glimpse of under the water, and which are only thought to be there because of the way the water smoothes out as it passes over them. Sometimes the most speculative ideas are the most interesting because they show how astronomers approach unsolved problems and explore the unknown. As astronomers, we authors know that one of the greatest feelings in the world is to forge a pebble yourself and place it on the shoreline.

Astronomy gives you a sense of perspective that no other field of study offers. The universe is vast, fascinating, and beautiful, filled with a wealth of objects that, surprisingly, can be understood using only a handful of principles. By the end of this book, you will have gained a sense of your place in the universe—both how incredibly small and insignificant you are and how incredibly unique and important you are.

Dear Instructor,

We wrote this book with a few overarching goals: to inspire students, to make the material interactive, and to create a useful and flexible tool that can support multiple learning styles.

As scientists and as teachers, we are passionate about the work we do. We hope to share that passion with students and inspire them to engage in science on their own. As authors, one way we do this is through the "student notebook"–style sketches at the beginning of each chapter. These figures model student engagement, and the Learning Goals on the facing page challenge them to try something similar on their own. Elsewhere in a chapter, we remind students of this chapter-opening figure to encourage them to interact with the content and make it their own.

Through our own experience, familiarity with education research, and surveys of instructors, we have come to know a great deal about how students learn and what goals teachers have for their students. We have explicitly addressed many of these goals and learning styles in this book, sometimes in large, immediately visible ways such as the inclusion of feature boxes but also through less obvious efforts such as questions and problems that relate astronomical concepts to everyday situations or take fresh approaches to organizing material.

For example, many teachers state that they would like their students to become "educated scientific consumers" and "critical thinkers" or that their students should "be able to read a news story about science and understand its significance." We have specifically addressed these goals in our Reading Astronomy News feature, which presents a news article and a series of questions that guide a student's critical thinking about the article, the data presented, and the sources.

Many teachers want students to develop better spatial reasoning and visualization skills. We address this explicitly by teaching students to make and use spatial models. One example is in Chapter 2, where we ask students to use an orange and a lamp to understand the celestial sphere and the phases of the Moon. In nearly every chapter, we have Visual Analogy figures that compare astronomy concepts to everyday events or objects. Through these analogies, we strive to make the material more interesting, relevant, and memorable.

Education research shows that the most effective way to learn is by doing. Exploration activities at the end of each chapter are hands-on, asking students to take the concepts they've learned in the chapter and apply them as they interact with animations and simulations on the student website or work through pencil-and-paper activities. Many of these Explorations incorporate everyday objects and can be used either in your classroom or as activities at home.

To learn astronomy, students must also learn the language of science—not just the jargon, but the everyday words we scientists use in special ways. *Theory* is a famous example of a word that students think they understand, but their definition is very different from ours. The first time we use an ordinary word in a special way, a Vocabulary Alert in the margin calls attention to it, helping to reduce student confusion. This is in addition to the back-of-the-book Glossary, which includes all the text's boldface words in addition to other terms students may be unfamiliar with.

We also believe students should be fairly fluent in the more formal language of science—mathematics. We have placed the math in Working It Out boxes, so it does not interrupt the flow of the text or get in the way of students' understanding of conceptual material. But we've gone further by beginning with fundamental ideas in early math boxes and slowly building complexity in math boxes that appear later in the book. We've also worked to remove some of the stumbling blocks that crush student confidence by providing calculator hints, references to earlier boxes, and detailed, fully worked examples.

In our overall organization, we have made several efforts to encourage students to engage with the material and build confidence in their scientific skills as they proceed through the book. We organize the physical principles with a "just-in-time" approach; for example, we cover the Stefan-Boltzmann law in Chapter 6, when it is used for the first time in an astronomical context. For both stars and galaxies, we have organized the material to cover the general case first and then delve into more details with specific examples. Thus, you will find "stars" before the Sun, and "galaxies" before the Milky Way. This allows us to avoid frustrating students by making assumptions about what they know about stars or galaxies or forward-referencing to basic definitions and overarching concepts. This organization also implicitly helps students to understand their place in the universe: our galaxy and our star are each one of many. They are specific examples of a physical universe in which the same laws apply everywhere. Planets have been organized comparatively, to emphasize that science is a process of studying individual examples that lead to collective conclusions. All of these organizational choices were made with the student perspective in mind and a clear sense of the logical hierarchy of the material.

Even our layout has been designed to maximize student engagement—one wide text column is interrupted as seldom as possible.

Norton SmartWork, an online tutorial and homework system, puts student assessment at your fingertips. Norton Smartwork contains more than 1,300 questions and problems that are tied directly to this text, including the Summary Self-Test questions and versions of the Reading Astronomy News and Exploration questions. Any of these could be used as a reading quiz to be completed before class or as homework. Every question in Smartwork has hints and answer-specific feedback so that students are coached to work toward the correct answer. Instructors can easily modify any of the provided questions, answers, and feedback or can create their own questions.

We approached this text by asking: What do teachers want students to learn, and how can we best help students learn those things? Where possible, we consulted the education research to help guide us, and that guidance has led us down some previously unexplored paths. That research has continued to be useful in this second edition, but we have had another excellent resource to draw on.

In this edition, we have responded to commentary from you, our colleagues. You were concerned that students would not be able to find the "just-in-time" material, so we have added a Concept Connection icon in the margin, which points students back to the original explanation of these topics. They will be better able to find the material on Wien's law and the Stefan-Boltzmann law, which we moved to Chapter 5, where these concepts are first needed. There is no opportunity for students to forget the material before they actually need to use it in an astronomical context, and yet the Concept Connection icon allows them to find the material again and again. This icon reinforces the important fact that the universe is governed by a small number of physical concepts that appear again and again in very different contexts.

We revised each chapter, updating the science, to reflect the fast pace of astronomical research today. This is especially noticeable in the material on extrasolar planets and on the very latest results in cosmology; however, each chapter has been revised to reflect the progress in the field.

We better balanced the cognitive load between chapters, for example by moving material between Chapters 3 and 4 so that students are not grappling with both complex three-dimensional visualization skills and fundamental physics at the same time. We reorganized Chapter 6, moving the impact coverage forward for similar reasons. This also allowed us to streamline some of the text, reducing the need to remind students of earlier material.

We added further skill-building text with a new section on reading graphs in Chapter 1 and new Working It Out boxes that continue to build students' mathematical fluency throughout the text. We also developed new end-of-chapter problems that address student understanding at multiple skill levels. Even more skill-building content is available in the accompanying workbook, *Learning Astronomy by Doing Astronomy*.

We made descriptions of complex relationships even more accessible. For example, we have new visual analogies, such as the one of the solar wind shaping magnetospheres. We have revised figures to be more straightforward, such as the one showing the structure of the Sun. The Hertzsprung-Russell (H-R) diagram showing the evolution of low-mass stars has been split into multiple figures to match the narrative of the text better—each part of the evolution is shown separately, and then the entire sequence is shown in a culminating figure. This requires more space but is worth the effort, as it allows students to focus on each step individually and then put the whole picture together once each part is understood.

We reorganized Part IV: Galaxies, the Universe, and Cosmology to improve the logical flow of the cosmology concepts, balance cognitive load, and emphasize the process of science that has led to understanding that the universe began in the Big Bang. We begin in Chapter 14 by introducing galaxies as a whole and our measurements of them, including recession velocities. Then we address the Milky Way in Chapter 15—a specific example of a galaxy that we can discuss in detail. This follows the repeating motif of moving from the general to the specific that exists throughout the text and gives students a basic grounding in the concepts of spiral galaxies, supermassive black holes, and dark matter before they need to apply those concepts to the specific example of our own galaxy. In Chapter 16, we return to the implications of extragalactic recession velocities, showing how the Big Bang was derived from observational evidence, then was used to make predictions which have been later verified. In Chapter 17, we address issues of large-scale structure and the evolution of the universe over time.

Many professors find themselves under pressure from accrediting bodies or internal assessment offices to assess their courses in terms of learning goals and to update their teaching methods. To help you with this, we've revised each chapter's Learning Goals and organized the end-of-chapter Summary by Learning Goal. In Norton Smartwork, questions and problems are tagged and can be sorted by Learning Goal.

We've also created a series of 23 videos explaining and demonstrating concepts from the text, accompanied by questions integrated into Norton Smartwork. You might assign these videos prior to lecture—either as part of a flipped modality or as a "reading quiz." In either case, you can use Norton Smartwork's diagnostic feedback from the questions to tailor your in-class discussions. Or you might show the videos in class to stimulate discussion. Or you might simply use them as a jumping-off point—to get ideas for activities to do with your own students.

We continue to look for better ways to engage students, so please let us know how these features work for your students.

Sincerely,
Stacy Palen
Laura Kay
Brad Smith
George Blumenthal

Ancillaries for Students

Norton Smartwork

Steven Desch, Guilford Technical Community College; Violet Mager, Susquehanna University; Todd Young, Wayne State College

More than 1,700 questions support *Understanding Our Universe, Second Edition*—all with answer-specific feedback, hints, and ebook links. Questions include Summary Self-Tests and versions of the Explorations (based on AstroTours and the University of Nebraska simulations) and Reading Astronomy News questions. Image-labeling questions based on NASA images allow students to apply course knowledge to images that are not contained in the text. Astronomy in Action video questions focus on overcoming common misconceptions, while Process of Science questions take students through the steps of a discovery and ask them to participate in the decision-making process that leads to that discovery.

Student Website wwnpag.es/uou2

W. W. Norton's free and open student website features the following:

- Twenty-eight AstroTour animations. These animations, some of which are interactive, use art from the text to help students visualize important physical and astronomical concepts.
- Nebraska Simulations (sometimes called applets; or NAAPs, for Nebraska Astronomy Applet Program). These simulations allow students to manipulate variables and see how physical systems work.
- Astronomy in Action videos demonstrate the most important concepts in a visual, easy to understand, and memorable way.

Learning Astronomy by Doing Astronomy: Collaborative Lecture Activities

Stacy Palen, Weber State University, and Ana Larson, University of Washington

Many students learn best by doing. Devising, writing, testing, and revising suitable in-class activities that use real astronomical data, illuminate astronomical concepts, and ask probing questions requiring students to confront misconceptions can be challenging and time consuming. In this workbook, the authors draw on their experience teaching thousands of students in many different types of courses (large in-class, small in-class, hybrid, online, flipped, and so forth) to provide 30 field-tested activities that can be used in any classroom today. The activities have been designed to require no special software, materials, or equipment and to take no more than 50 minutes each to do.

Starry Night Planetarium Software (College Version 7) and Workbook

Steven Desch, Guilford Technical Community College

Starry Night is a realistic, user-friendly planetarium simulation program designed to allow students in urban areas to perform observational activities on a computer screen. Norton's unique accompanying workbook offers observation assignments that guide students' virtual explorations and help them apply what they've learned from the text reading assignments. The workbook is fully integrated with *Understanding Our Universe, Second Edition*.

For Instructors

Instructor's Manual

Ben Sugerman, Goucher College

This resource includes brief chapter overviews, suggested classroom discussions/activities, notes on the AstroTour animations and Nebraska Simulations contained on the Instructor's Resource Disk, teaching suggestions for how to use the Reading Astronomy News and the Exploration activity elements found in the textbook, and worked solutions to all end-of-chapter questions and problems.

Test Bank

Ray O'Neal, Florida A&M University; Todd Vaccaro, St. Cloud State University; Lisa M. Will, San Diego City College

The Test Bank has been revised using Bloom's Taxonomy and provides a quality bank of more than 900 items. Each chapter of the Test Bank consists of six question levels classified according to Bloom's Taxonomy:

Remembering
Understanding
Applying
Analyzing
Evaluating
Creating

Questions are further classified by section and difficulty, making it easy to construct tests and quizzes that are meaningful and diagnostic. The question types include short answer and multiple choice.

Norton Instructor's Resource Website

This Web resource contains the following resources to download:

- Test Bank, available in ExamView, Word RTF, and PDF formats.
- Instructor's Manual in PDF format.
- Lecture PowerPoint slides with lecture notes.
- All art and tables in JPEG and PPT formats.
- Starry Night College, W. W. Norton Edition, Instructor's Manual.
- AstroTour animations, some of which are interactive, use art from the text to help students visualize important physical and astronomical concepts.
- University of Nebraska simulations (sometimes called applets; or NAAPs, for Nebraska Astronomy Applet Program). Well known by introductory astronomy instructors, the simulations allow students to manipulate variables and see how physical systems work.
- Coursepacks, available in BlackBoard, Angel, Desire2Learn, and Moodle formats.

Coursepacks

Norton's Coursepacks, available for use in various Learning Management Systems (LMSs), feature all Quiz+ and Test Bank questions, links to the AstroTours and Applets, plus discussion questions from the Reading Astronomy News features, Astronomy in Action video quizzes, Explorations worksheets and pre- and post-tests from the *Learning Astronomy by Doing Astronomy* Workbook. Coursepacks are available in BlackBoard, Angel, Desire2Learn, and Moodle formats.

Instructor's Resource Folder

This two-disk set contains the Instructor's Resource DVD—which contains the same files as the Instructor's Resource Website—and the Test Bank on CD-ROM in ExamView format.

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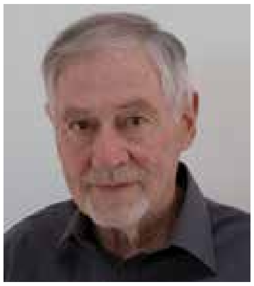
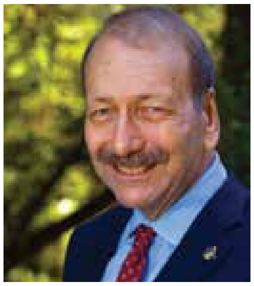


George Blumenthal is chancellor at the University of California–Santa Cruz, where he has been a professor of astronomy and astrophysics since 1972. He received his BS degree from the University of Wisconsin–Milwaukee and his PhD in physics from the University of California–San Diego. As a theoretical astrophysicist, George's research encompasses several broad areas, including the nature of the dark matter that constitutes most of the mass in the universe, the origin of galaxies and other large structures in the universe, the earliest moments in the universe, astrophysical radiation processes, and the structure of active galactic nuclei such as quasars. Besides teaching and conducting research, he has served as Chair of the UC–Santa Cruz Astronomy and Astrophysics Department, has chaired the Academic Senate for both the UC–Santa Cruz campus and the entire University of California system, and has served as the faculty representative to the UC Board of Regents.



1 Thinking Like an Astronomer

The illustration on the opposite page shows a pattern in the sky. Over the course of 6 months, a student in North America took photographs of the location where the Sun set along a ridgeline near his house and then compared them with a map of the area. He sees that the Sun gradually moves north as the year progresses from winter to summer. Understanding this pattern is part of what astronomy is all about. Loosely translated, the word **astronomy** means "finding patterns among the stars." However, modern astronomy is about far more than looking at the sky and cataloging the visible stars. What are the Sun and Moon made of? How far away are they? How do stars shine? How did the universe begin? How will it end? Astronomy is a living, dynamic science that seeks the answers to these and many other compelling questions. In this chapter, we will begin the study of astronomy by exploring our place in the universe and the methods of science.

LEARNING GOALS

Scientists seek knowledge using a very specific set of processes, sometimes collectively called the scientific method. Part of this procedure stems from recognizing patterns in nature. Part of it stems from putting those patterns together to understand how they apply in different places and at different times. In the illustration on the opposite page, the student has noticed a pattern in his observations of the setting Sun. By the end of this chapter, you should understand how patterns of observations like these fit into the development of a scientific law and a scientific theory. You should also be able to:

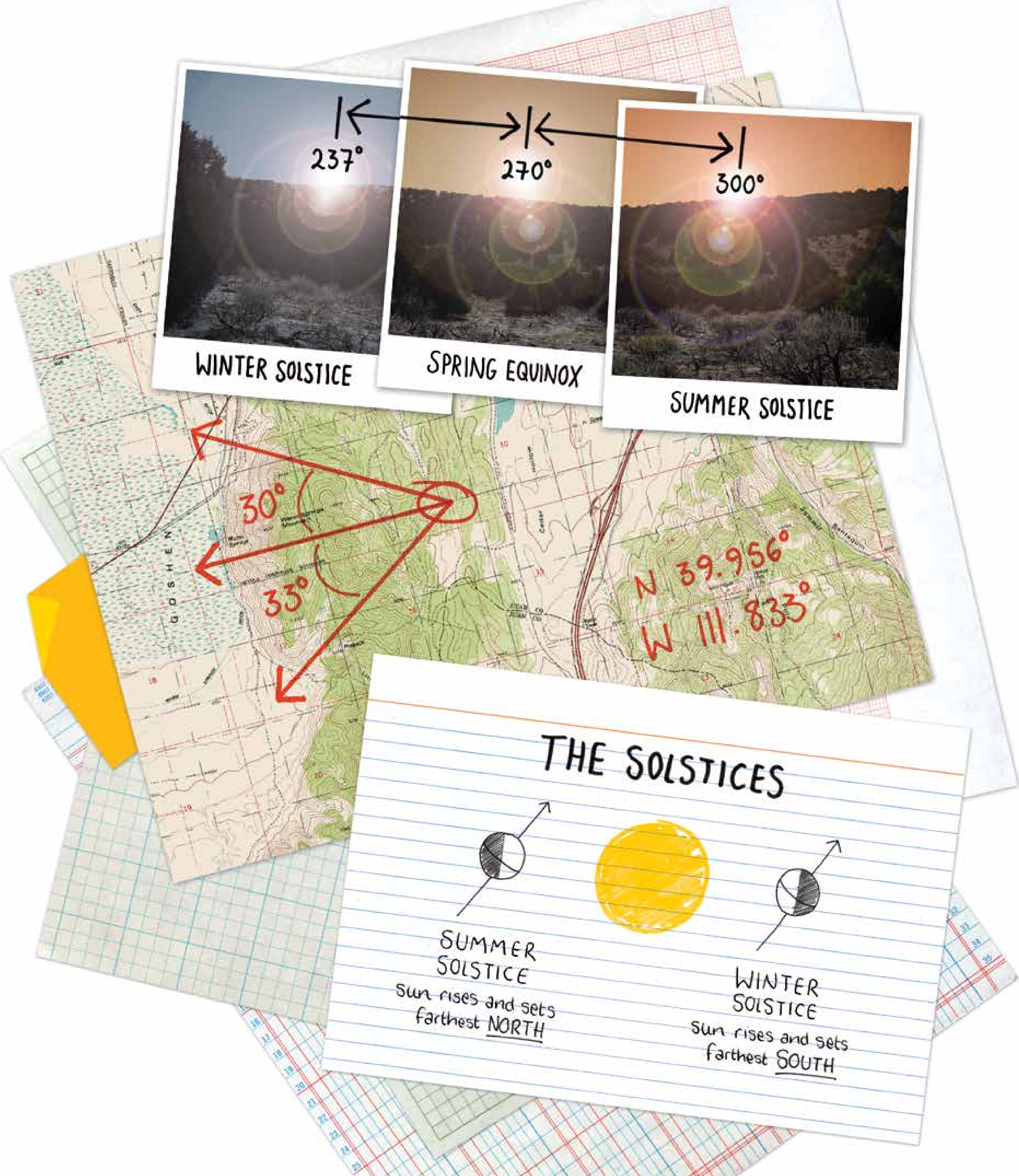
LG 1 **Relate our place in the universe to the rest of the universe.**

LG 2 **Explain how the patterns of our daily lives are connected to the larger universe.**

LG 3 **Describe our astronomical origins.**

LG 4 **Describe the scientific method.**

LG 5 **Extract meaning from a graph.**


237°
270°
300°
WINTER SOLSTICE
SPRING EQUINOX
SUMMER SOLSTICE
30°
33°
N 39.956°
W 111.833°
GOSHEN
THE SOLSTICES
SUMMER SOLSTICE
sun rises and sets farthest NORTH
WINTER SOLSTICE
sun rises and sets farthest SOUTH

1.1 Astronomy Gives Us a Universal Context

Astronomers think of our place in the universe as both a location and a time. Locating Earth in the larger universe is the first step in learning the science of astronomy.

Our Place in the Universe

Most people have an address where they receive mail—street number, street, city, state, country. But we can expand our view to include the enormously vast universe we live in. What is our "cosmic address"? It might include: planet, star, galaxy, galaxy group, galaxy cluster.

We reside on a planet called Earth, which is orbiting under the influence of gravity around a star called the Sun. The Sun is an ordinary, middle-aged star, more massive and luminous than some stars but less massive and luminous than others. The Sun is extraordinary only because of its importance to us within our own Solar System. Our Solar System consists of eight planets—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. It also contains many smaller bodies, which we will discuss in coming chapters, including *dwarf planets* (for example, Pluto, Ceres, or Eris), *asteroids* (for example, Ida or Eros), and *comets* (for example, Halley).

The Sun is located about halfway out from the center of the *Milky Way Galaxy*, a flattened collection of stars, gas, and dust. Our Sun is just one among several hundred billion stars scattered throughout our galaxy. Astronomers are discovering that many of these stars also have planets around them, which suggests that planetary systems are common.

The Milky Way, in turn, is part of a small collection of a few dozen galaxies called the Local Group. The Milky Way Galaxy and the Andromeda Galaxy are true giants within the Local Group. Most others are dwarf galaxies. The Local Group itself is part of a vastly larger collection of thousands of galaxies—a supercluster—called the Virgo Supercluster.

We can now define our cosmic address, illustrated in **Figure 1.1**: Earth, Solar System, Milky Way Galaxy, Local Group, Virgo Supercluster. Yet even this address is not complete because the vast structure we just described is only the local universe. The part of the universe that we can see extends much farther—a distance that light takes 13.8 billion years to travel. Within this volume, we estimate that there are *several hundred billion galaxies*—roughly as many galaxies as there are stars in the Milky Way.

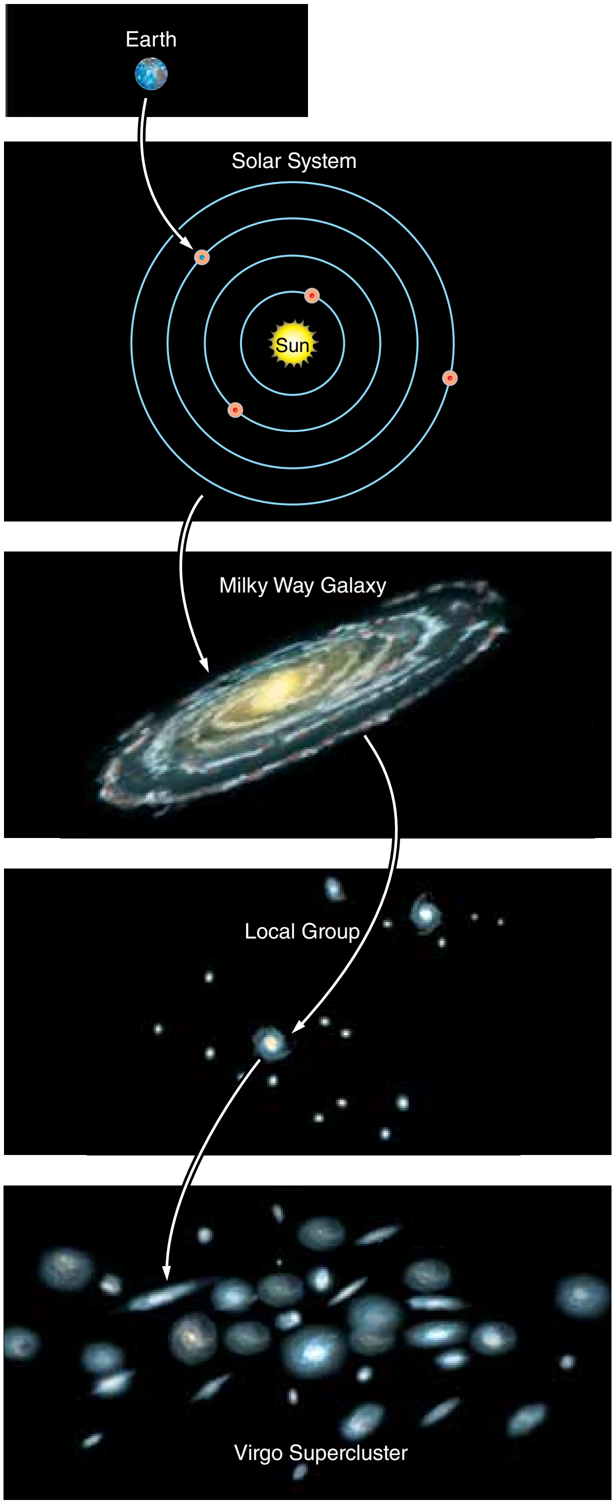


Figure 1.1 Our place in the universe is given by our cosmic address: Earth, Solar System, Milky Way Galaxy, Local Group, Virgo Supercluster. We live on Earth, a planet orbiting the Sun in our Solar System, which is a star in the Milky Way Galaxy. The Milky Way is a large galaxy within the Local Group of galaxies, which in turn is located in the Virgo Supercluster.

The Scale of the Universe

One of the first challenges we face as we begin to think about the universe is its sheer size. A hill is big, and a mountain is really big. If a mountain is really big, then Earth is enormous. But where do we go from there? As the scale of the universe comes to dwarf our human experience, we run out of words. To develop a sense of scale, we can change from talking about distance to talking about time. **Figure 1.2** begins with Earth and progresses outward to the observable universe and illustrates that even relatively small distances in astronomy are so vast that they are measured in units of **light-years (ly)**: the distance light travels in 1 year.

To understand how astronomers use time as a measure of distance, think

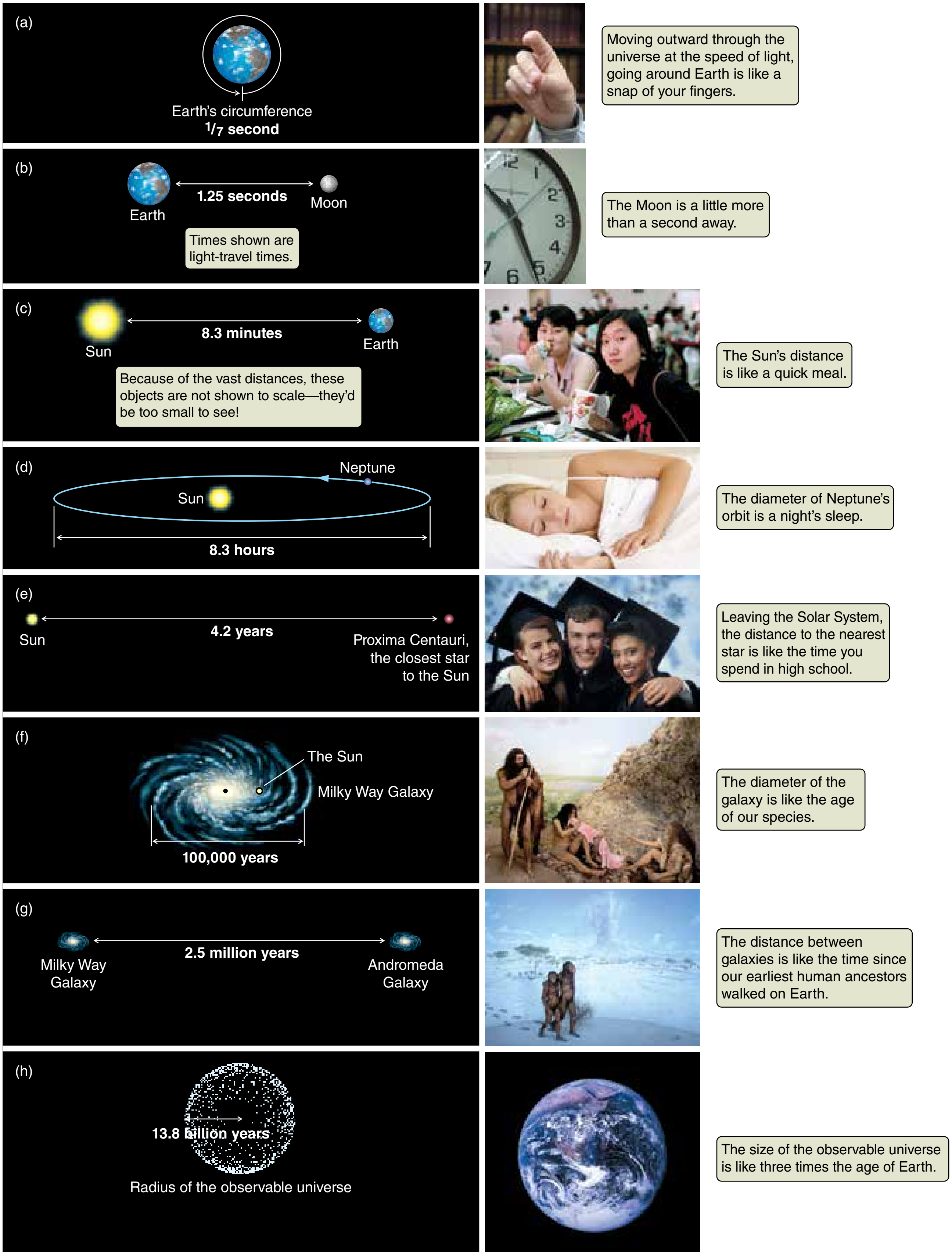


Figure 1.2 Thinking about the time it takes for light to travel between objects helps us to comprehend the vast distances in the observable universe.

VISUAL ANALOGY

Vocabulary Alert

massive In common language, *massive* can mean either "very large" or "very heavy." Astronomers specifically mean that more massive objects have more "stuff" in them.

satellite In common language, *satellite* typically refers to a human-made object. Astronomers use this word to describe any object, human-made or natural, that orbits another object.

about traveling in a car at 60 kilometers per hour (km/h). At 60 km/h, you travel 1 kilometer in 1 minute, or 60 kilometers in 1 hour. In 10 hours, you would travel 600 kilometers. To get a feel for the difference between 1 kilometer and 600 kilometers, you can think about the difference between 1 minute and 10 hours. In astronomy, the speed of a car on the highway is far too slow to be a useful measure of time. Instead, we use the fastest speed in the universe—the speed of light. Light travels at 300,000 kilometers per second (km/s). Light can circle Earth (a distance of 40,000 km) in just under one-seventh of a second—about the time it takes you to snap your fingers.

Figure 1.3 You and everything around you contain atoms that were forged in the interiors of stars that lived and died before the Sun and Earth were formed. The supermassive star Eta Carinae is currently ejecting a cloud of enriched material. This star is located about 7,500 light-years from Earth and emits 5 million times more light than the Sun.

The Origin and Evolution of the Universe

As we will discuss in detail in Chapter 16, both theory and observation tell us that the universe began 13.8 billion years ago in an event known as the *Big Bang*. The only chemical elements in the early universe were hydrogen and helium, plus tiny amounts of lithium, beryllium, and boron. Yet we live on a planet with a core of iron and nickel, surrounded by an outer layer made up of rocks that contain large amounts of silicon and various other elements. The human body contains carbon, nitrogen, oxygen, sodium, phosphorus, and a host of other chemical elements. If these elements were not present in the early universe, where did they come from?

The answer to this question begins deep within stars. In the core of a star, less **massive** atoms, like hydrogen, combine to form more massive atoms, eventually leading to atoms such as carbon. (Terms in red signify a "Vocabulary Alert" in the margin of the text.) When a star nears the end of its life, it loses much of its material back into space—including some of these more massive atoms. This material combines with material lost from other stars, some of which produced even more massive atoms as they exploded, to form large clouds of dust and gas. Those clouds go on to make new stars and planets, like our Sun and Solar System. Prior "generations" of stars supplied the building blocks for the chemical processes, such as life, that go on around us (**Figure 1.3**). Look around you. Everything you see is made of atoms that were formed in stars long ago.

An Astronomer's Toolkit

In 1957, the Soviet Union launched Sputnik, the first human-made **satellite.** Since that time, we have lived in an age of space exploration that has given us a new perspective on the universe. The atmosphere that shields us from harmful solar radiation also blocks much of the light that travels through space. Space astronomy shows views hidden from ground-based telescopes by our atmosphere. Satellite observatories have brought us discovery after surprising discovery. Each has forever altered our perception of the universe.

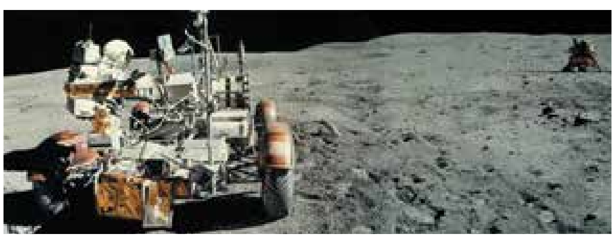


Figure 1.4 *Apollo 15* (1971) was the fourth U.S. mission to land on the moon. Here astronaut James B. Irwin stands by the lunar rover during an excursion to explore and collect samples from the Moon.

In addition to putting satellites into space around Earth, humans have walked on the Moon (**Figure 1.4**), and unmanned probes have visited all eight planets. Spacecraft have flown past asteroids, comets, and even the Sun. Spacecraft have also landed on Mars, Venus, Titan (Saturn's largest moon), and an asteroid and have plunged into both the atmosphere of Jupiter and the heart of a comet. Most of what we know of the Solar System has resulted from these past six decades of exploration since the space age began.

Astronomers collect information from many varieties of light, from highest-energy *gamma rays* (G) and *X-rays* (X), through *ultraviolet* (U), visible

(V), and *infrared* (I) radiation, down to the lowest-energy radio waves (R). **Figure 1.5** combines a visible-light image of the Parkes radio telescope and an image of the Milky Way in the radio part of the spectrum, illustrating the new perspectives we have gained from improved technology. The "R" beneath the photograph stands for radio waves (see the abbreviations defined earlier in this paragraph); in this text, the type of light used to obtain an image is indicated by the letter that is highlighted in the wave graphic appearing below the image.

Another tool of astronomy—telescopes—often comes to mind when we think of studying space. However, the 21st-century astronomer spends far more time staring at a computer screen than peering through the eyepiece of a telescope. Modern astronomers use computers to collect and analyze data from telescopes, calculate physical models of astronomical objects, and prepare reports on the results of their work. You may also be surprised to learn that much astronomy is now carried out in large physics facilities like the one shown in **Figure 1.6**. Astronomers work with scientists in related fields, such as physics, chemistry, geology, and planetary science, to develop a deeper understanding of physical laws and to make sense of their observations of the distant universe.

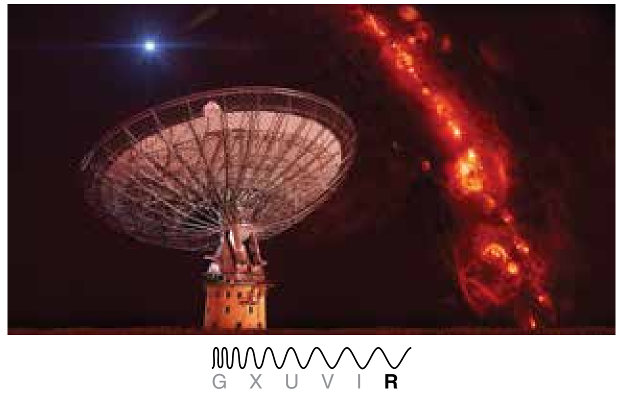


Figure 1.5 In the 20th century, advances in telescope technology opened new windows on the universe. This is the Milky Way as we would see it if our eyes were sensitive to radio waves, shown as a backdrop to the Parkes radio telescope in Australia. The bright blue object is an artist's impression of a fast radio burst.

1.2 Science Is a Way of Viewing the World

As we view the universe through the eyes of astronomers, we will also learn how science works. Science is a way of exploring the physical world through the scientific method.

The Scientific Method

The **scientific method** is a systematic way of testing new ideas or explanations. Often, the method begins with a fact—an observation or a measurement. For example, you might observe that the weather changes in a predictable way each year and wonder why that happens. You then create a **hypothesis**, a testable explanation of the observation: "I think that it is cold in the winter and warm in the summer because Earth is closer to the Sun in the summer." You and your colleagues come up with a test: if it is cold in the winter and warm in the summer because Earth is closer to the Sun in the summer, then it will be cold in the winter everywhere on the planet—Australia should have winter at the same time of year as the United States. This test can be used to falsify your hypothesis. You travel to the opposite hemisphere in the winter and find that it is summer there. Your hypothesis has just been **falsified**, which means that it has been proved incorrect. This is good! It means you know something you didn't know before. Now you must revise or completely change your hypothesis to be consistent with the new data.

Any idea that is not testable—that is not **falsifiable**—must be accepted or rejected based on intuition alone, so it is not scientific. A falsifiable hypothesis or idea does not have to be testable using current technology, but we must be able to imagine an experiment or observation that *could* prove the idea wrong if we could carry it out. As continuing tests support a hypothesis by failing to disprove it, scientists come to accept the hypothesis as a *theory*. A classic example is Einstein's theory of relativity, which has withstood more than a century of scientific efforts to disprove its predictions.

Figure 1.6 The high-energy particle collider at the European Organization for Nuclear Research (CERN), shown here as a circle drawn above the tunnels of the facility, has provided clues about the physical environment during the birth of the universe. Laboratory astrophysics, in which astronomers model important physical processes under controlled conditions, has become an important part of astronomy. The dashed line represents the boundary between France and Switzerland.

Vocabulary Alert

falsified/falsifiable: In common language, we are likely to think of "falsified" evidence as having been *manipulated* to misrepresent the truth. Astronomers (and scientists in general) use *falsifiable* in the sense of "being able to prove a hypothesis false," as we will throughout this book.

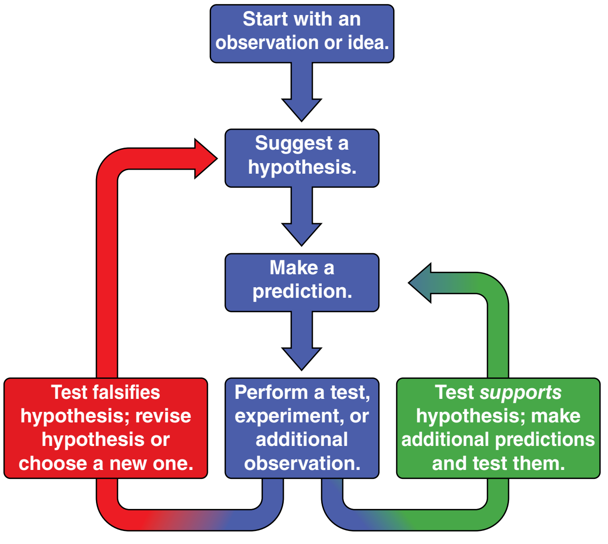


Figure 1.7 The scientific method is the path by which an idea or observation leads to a falsifiable hypothesis. The hypothesis is either accepted as a tested theory or rejected on the basis of observational or experimental tests of its predictions. The green loop goes on indefinitely as scientists continue to test the hypothesis.

The path to scientific knowledge is solidly based on the scientific method. **Figure 1.7** illustrates the pathway of the scientific method. It begins with an observation or idea, followed by a hypothesis, a prediction, further observation or experiments to test the prediction, and perhaps ending as a tested theory. Look back at the chapter-opening illustration. Where does the activity represented in that figure fit onto this simplified flowchart?

Still, science can no more be said to be the scientific method than music can be said to be the rules for writing down a musical score. The scientific method provides the rules for testing whether an idea is false, but it offers no insight into where the idea came from in the first place or how an experiment was designed. Scientists discussing their work use words such as *insight*, *intuition*, and *creativity*. Scientists speak of a beautiful theory in the same way that an artist speaks of a beautiful painting or a musician speaks of a beautiful performance. Science has an aesthetic that is as human and as profound as any found in the arts.

The Language of Science

We have already seen that scientists often use everyday words in special ways. For example, in everyday language, *theory* may mean something that is little more than a guess: "Do you have a theory about who might have done it?" "My theory is that a third party could win the next election." In everyday language, a theory isn't something we take too seriously. "After all," we say, "it is only a theory."

In stark contrast, scientists use the word **theory** to mean a carefully constructed proposition that takes into account every piece of data as well as our entire understanding of how the world works. A theory has been used to make testable predictions, and all of those predictions have come true. Every attempt to prove it false has failed. A theory such as the theory of general relativity is not a mere speculation but is instead a crowning achievement of science. Even so, scientific theories are accepted only as long as their predictions are correct. A theory that fails only a single test is proved false. In this sense, all scientific knowledge is subject to challenge.

Theories are at the top of the loosely defined hierarchy of scientific knowledge. At the bottom is an *idea*—a notion about how something might be. Moving up the hierarchy we come to a *fact*, which is an observation or measurement. The radius of Earth is a fact, for example. A *hypothesis* is an idea that leads to testable predictions. A hypothesis may be the forerunner of a scientific theory, or it may be based on an existing theory, or both. At the top we reach a *theory*: an idea that has been examined carefully, is consistent with all existing theoretical and experimental knowledge, and makes testable predictions. Ultimately, the success of the predictions is the deciding factor between competing theories. A *law* is a series of observations that lead to an ability to make predictions but has no underlying explanation of why the phenomenon occurs. So we might have a "law of daytime" that says the Sun rises and sets once each day. And we could have a "theory of daytime" that says the Sun rises and sets once each day because Earth spins on its axis. Scientists themselves are sometimes sloppy about the way they use these words, and you will sometimes see them used differently than in these formal definitions.

Underlying this hierarchy of knowledge are scientific principles. A scientific principle is a general idea about how the universe is that guides our construction of new theories. For example, at the heart of modern astronomy is the cosmological principle. The **cosmological principle** is the testable assumption that the same physical laws that apply here and now also apply everywhere and at

Vocabulary Alert

theory In common language, a *theory* is weak—just an idea or a guess. Scientists use this word to label the most well-known, well-tested, and well-supported principles in science.

all times. This implies that there are no special locations or directions in the universe. The physical laws that act in laboratories also act in the centers of stars or in the hearts of distant galaxies. Each new theory that succeeds in explaining patterns and relationships among objects in the sky adds to our confidence in this cornerstone of our worldview.

This principle provides an example of Occam's razor, another guiding principle in science. **Occam's razor** states that when we are faced with two hypotheses that explain all the observations equally well, we should use the one that requires the fewest assumptions, until we have evidence to the contrary. For example, we might hypothesize that atoms are constructed differently in the Andromeda Galaxy than in the Milky Way Galaxy. This would be a violation of the cosmological principle. But that hypothesis would require a large number of assumptions about how the atoms are constructed and yet still appear to behave identically to atoms in the Milky Way. For example, we might assume that the center of the atom is negatively charged in Andromeda, opposite to the Milky Way, where the center of the atom is positively charged. Then we would need to make an assumption about where the boundary is between Andromeda-like matter and Milky Way–like matter. And then we would need to make an assumption about why atoms on the boundary between the two regions did not destroy each other. And we would need an assumption about *why* atoms in the two regions are constructed so differently; and so on. If reasonable experimental evidence is ever found that the cosmological principle is not true, scientists will construct a new description of the universe that takes the new data into account. Until then, it is the hypothesis that has the fewest assumptions, satisfying Occam's razor. To date, the cosmological principle has been repeatedly tested and remains unfalsified.

Scientific Revolutions

Limiting our definition of science to the existing theories fails to convey the dynamic nature of scientific inquiry. Scientists do not have all the answers and must constantly refine their ideas in response to new data and new insights. The vulnerability of knowledge may seem like a weakness. "Gee, you really don't know anything," the cynical person might say. But this vulnerability is actually science's great strength, because it means that science self-corrects. Wrong ideas are eventually overturned by new information. In science, even our most cherished ideas about the nature of the physical world remain fair game, subject to challenge by new evidence. Many of history's best scientists earned their status by falsifying a universally accepted idea. This is a powerful motivation for scientists to challenge old ideas constantly, inventing new explanations for our observations.

For example, the classical physics developed by Sir Isaac Newton in the 17th century withstood the scrutiny of scientists for more than 200 years. It seemed that little remained but cleanup work—filling in the details. Yet during the late 19th and early 20th centuries, a series of scientific revolutions completely changed our understanding of the nature of reality. Albert Einstein (**Figure 1.8**) is representative of these scientific revolutions. Einstein's special and general theories of relativity replaced Newton's mechanics. Einstein did not prove Newton wrong, but instead showed that Newton's theories were a special case of a far more general and powerful set of physical laws. Einstein's new ideas unified the concepts of mass and energy and destroyed the conventional notion of space and time as separate entities.

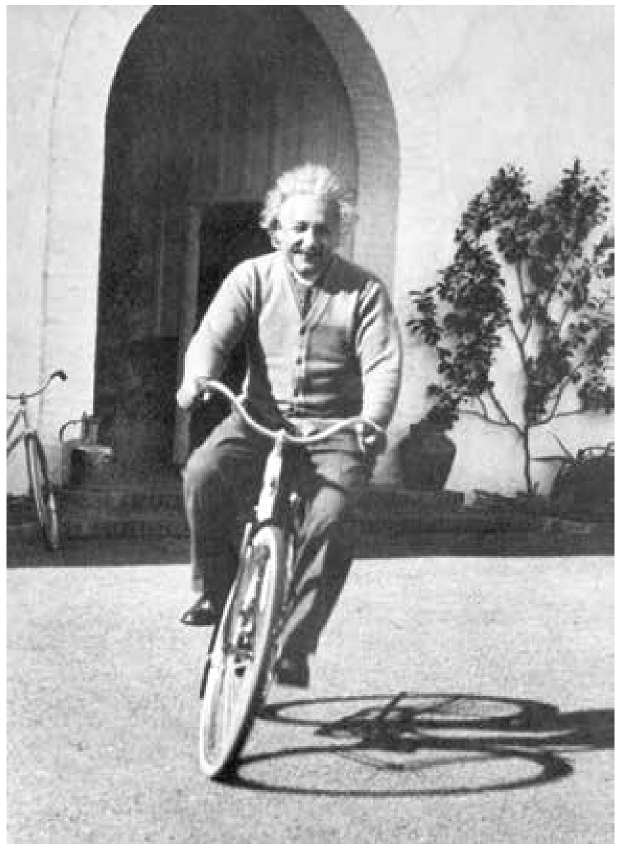


Figure 1.8 Albert Einstein is perhaps the most famous scientist of the 20th century. Einstein helped usher in two different scientific revolutions, one of which he was never able to accept.