STACY PALEN LAURA KAY GEORGE BLUMENTHAL

UNDERSTANDING OUR UNIVERSE

THIRD EDITION

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Stacy Palen dedicates this book to John Armstrong, with deep gratitude.

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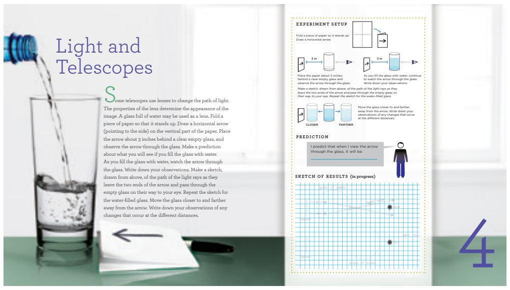
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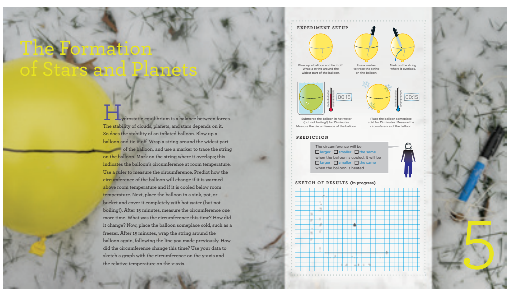
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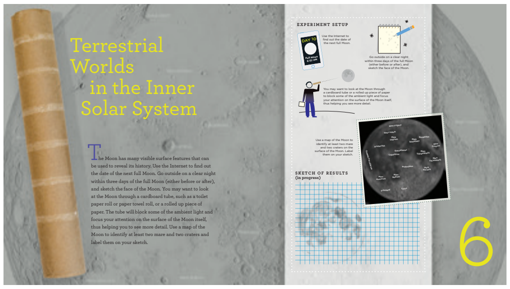
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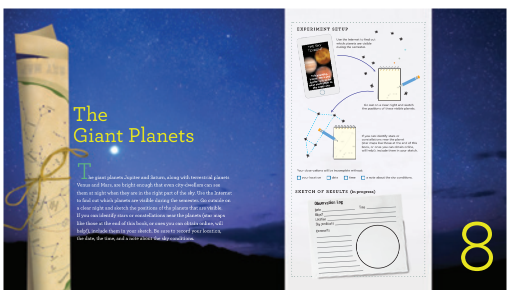
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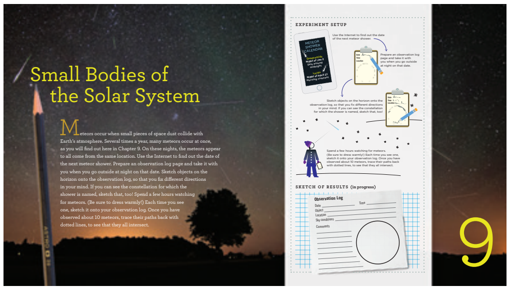
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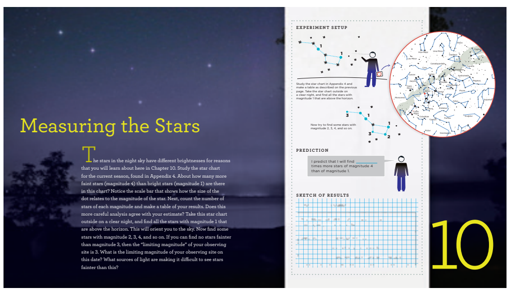
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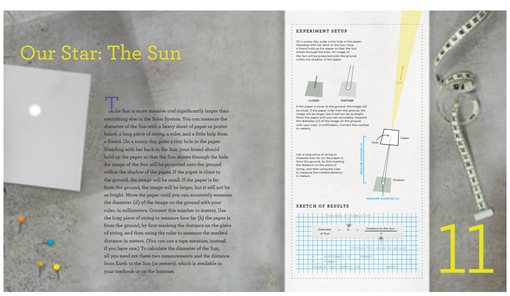
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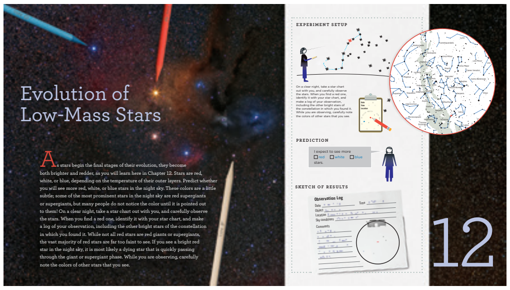

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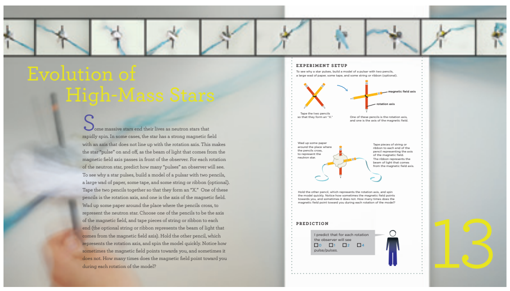

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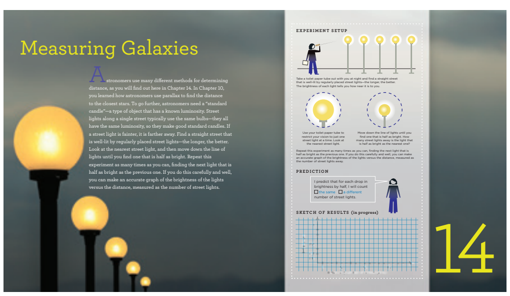

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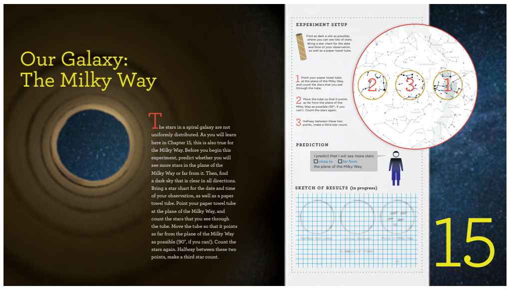
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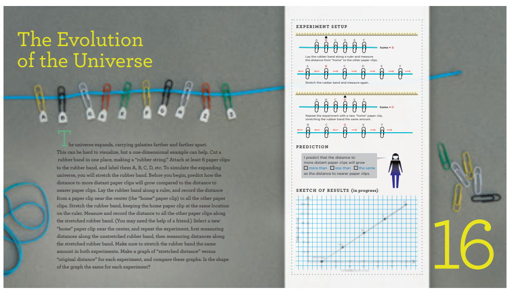
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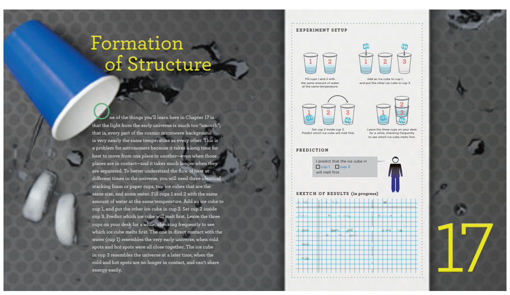
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Dear Student,

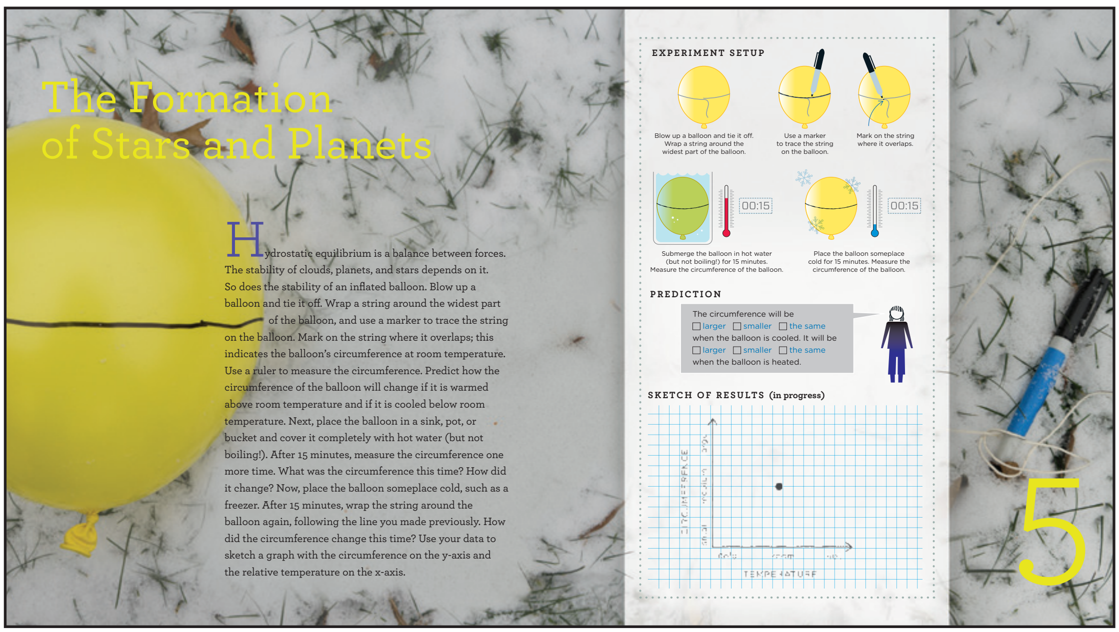
You may wonder why it is a good idea to take a general-education science course. Scientists, including astronomers, have a specific approach to understanding new information. Astronomers "understand" when they can make correct predictions about what will happen next. Astronomers "know" when an idea has been tested dozens or even hundreds of times and the idea has stood the test of time.

There are two fundamental goals to keep in mind as you take this course. The first is to understand some basic physical concepts and become familiar with the night sky. The second is to learn to think like a scientist and learn to use the scientific method, or process of science, to answer questions in this course and make decisions about science and technology in your life. We have written the third edition of *Understanding Our Universe* with these two goals in mind.

Throughout this book, we emphasize the content of astronomy (the masses of the planets, the compositions of stellar atmospheres) as well as *how* we know what we know. The scientific method is a valuable tool that you can carry with you, and use, for the rest of your life.

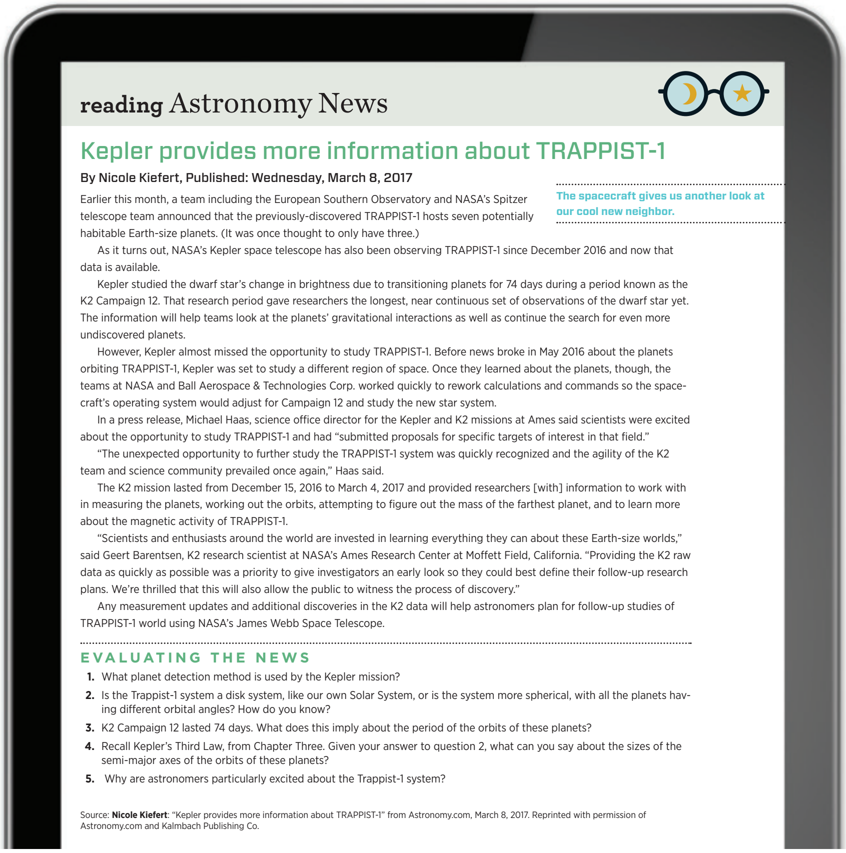
The most effective way to learn something is to "do" it. Whether playing an instrument or a sport or becoming a good cook, reading "how" can only take you so far. The same is true of learning astronomy. The following tools in each chapter help you "do" as you learn:

- **Active Learning Figures** open each chapter and ask you to "do" science by setting up an experiment and then making either a prediction or an observation and recording the results. We hope you find that the "answer" isn't the most important part of the activity. Rather, we want the experience of thinking about a physical phenomenon and predicting what will happen next to become a natural way for you to apply your knowledge and understand new concepts.



CHECK YOUR UNDERSTANDING **5.5**

The terrestrial planets are different from the giant planets because when they formed,
a. the inner Solar System was richer in heavy elements.
b. the inner Solar System was hotter than the outer Solar System.
c. the outer Solar System took up a bigger volume, so there was more material to form planets.
d. the inner Solar System was moving faster, so centrifugal force was more important.



reading Astronomy News

Kepler provides more information about TRAPPIST-1

By Nicole Kiefert, Published: Wednesday, March 8, 2017

The spacecraft gives us another look at our cool new neighbor.

Earlier this month, a team including the European Southern Observatory and NASA's Spitzer telescope team announced that the previously-discovered TRAPPIST-1 hosts seven potentially habitable Earth-size planets. (It was once thought to only have three.)

As it turns out, NASA's Kepler space telescope has also been observing TRAPPIST-1 since December 2016 and now that data is available.

Kepler studied the dwarf star's change in brightness due to transitioning planets for 74 days during a period known as the K2 Campaign 12. That research period gave researchers the longest, near continuous set of observations of the dwarf star yet. The information will help teams look at the planets' gravitational interactions as well as continue the search for even more undiscovered planets.

However, Kepler almost missed the opportunity to study TRAPPIST-1. Before news broke in May 2016 about the planets orbiting TRAPPIST-1, Kepler was set to study a different region of space. Once they learned about the planets, though, the teams at NASA and Ball Aerospace & Technologies Corp. worked quickly to rework calculations and commands so the spacecraft's operating system would adjust for Campaign 12 and study the new star system.

In a press release, Michael Haas, science office director for the Kepler and K2 missions at Ames said scientists were excited about the opportunity to study TRAPPIST-1 and had "submitted proposals for specific targets of interest in that field."

"The unexpected opportunity to further study the TRAPPIST-1 system was quickly recognized and the agility of the K2 team and science community prevailed once again," Haas said.

The K2 mission lasted from December 15, 2016 to March 4, 2017 and provided researchers [with] information to work with in measuring the planets, working out the orbits, attempting to figure out the mass of the farthest planet, and to learn more about the magnetic activity of TRAPPIST-1.

"Scientists and enthusiasts around the world are invested in learning everything they can about these Earth-size worlds," said Geert Barentsen, K2 research scientist at NASA's Ames Research Center at Moffett Field, California. "Providing the K2 raw data as quickly as possible was a priority to give investigators an early look so they could best define their follow-up research plans. We're thrilled that this will also allow the public to witness the process of discovery."

Any measurement updates and additional discoveries in the K2 data will help astronomers plan for follow-up studies of TRAPPIST-1 world using NASA's James Webb Space Telescope.

EVALUATING THE NEWS

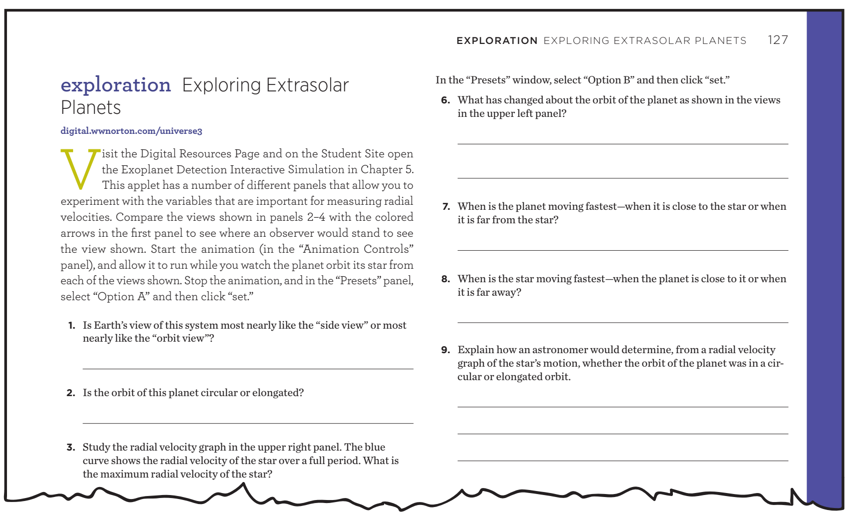
1. What planet detection method is used by the Kepler mission?
2. Is the Trappist-1 system a disk system, like our own Solar System, or is the system more spherical, with all the planets having different orbital angles? How do you know?
3. K2 Campaign 12 lasted 74 days. What does this imply about the period of the orbits of these planets?
4. Recall Kepler's Third Law, from Chapter Three. Given your answer to question 2, what can you say about the sizes of the semi-major axes of the orbits of these planets?
5. Why are astronomers particularly excited about the Trappist-1 system?

Source: **Nicole Kiefert**: "Kepler provides more information about TRAPPIST-1" from Astronomy.com, March 8, 2017. Reprinted with permission of Astronomy.com and Kalmbach Publishing Co.

- To promote active reading, **Check Your Understanding** questions have been placed at the end of each section of a chapter. These questions act as "speed bumps" so that you will pause and check your comprehension of the material prior to moving on to the next section. These, and the **questions and problems** at the end of each chapter, are a great way to check whether you have a basic understanding of the material.
- **Reading Astronomy News** sections toward the end of each chapter include a news article or press release with questions to help you make sense of how the science is presented. As a citizen of the world, recognizing what is credible and questioning what is not are important skills. You make judgments about science, distinguishing between good science and pseudoscience, in order 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 of information in class. The goal of Reading Astronomy News is to help you build your scientific literacy and your ability to challenge what you hear elsewhere.
- At the very end of each chapter, an **Exploration** activity 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 found on the Digital Resources Page on the Student Site, while the others are hands-on, paper-and-pencil activities that use everyday objects such as ice cubes or balloons.

We believe that the learn-by-doing approach not only helps you better understand the material but also makes the material more interesting and, perhaps, fun.

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.



EXPLORATION EXPLORING EXTRASOLAR PLANETS 127

exploration Exploring Extrasolar Planets

digital.wwnorton.com/universe3

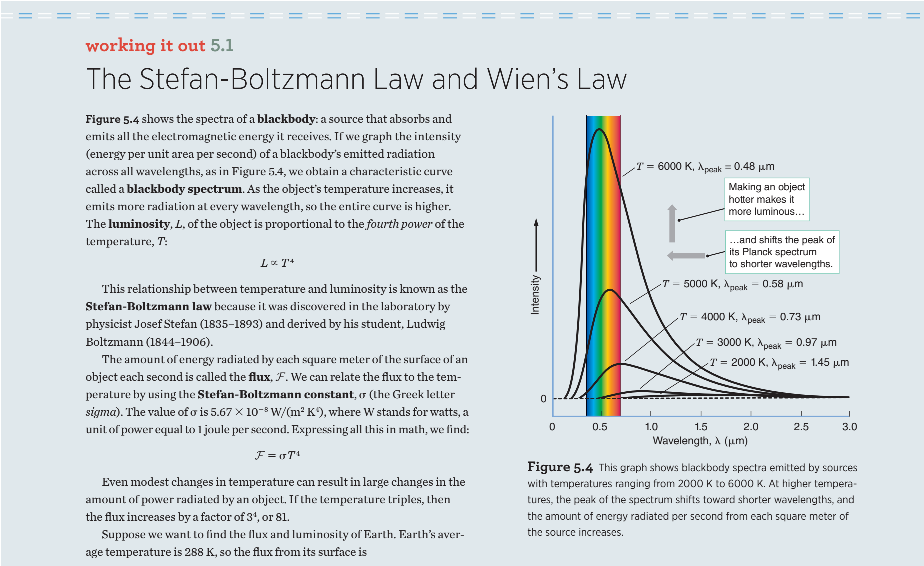
Visit the Digital Resources Page and on the Student Site open the Exoplanet Detection Interactive Simulation in Chapter 5. This applet has a number of different panels that allow you to experiment with the variables that are important for measuring radial velocities. Compare the views shown in panels 2–4 with the colored arrows in the first 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?

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.

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



working it out 5.1

The Stefan-Boltzmann Law and Wien's Law

Figure 5.4 shows the spectra of a **blackbody**: a source that absorbs and emits all the electromagnetic energy it receives. If we graph the intensity (energy per unit area per second) of a blackbody's emitted radiation across all wavelengths, as in Figure 5.4, we obtain a characteristic curve called a **blackbody spectrum**. As the object's temperature increases, it emits more radiation at every wavelength, so the entire curve is higher. The **luminosity**, L, of the object is proportional to the *fourth power* of the temperature, T:

$$L \propto T^4$$

This relationship between temperature and luminosity is known as the **Stefan-Boltzmann law** because it was discovered in the laboratory by physicist Josef Stefan (1835–1893) and derived by his student, Ludwig Boltzmann (1844–1906).

The amount of energy radiated by each square meter of the surface of an object each second is called the **flux**, $\mathcal{F}$. We can relate the flux to the temperature by using the **Stefan-Boltzmann constant**, σ (the Greek letter *sigma*). The value of σ is 5.67×10^{-8} W/(m^2 K^4), where W stands for watts, a unit of power equal to 1 joule per second. Expressing all this in math, we find:

$$\mathcal{F} = \sigma T^4$$

Even modest changes in temperature can result in large changes in the amount of power radiated by an object. If the temperature triples, then the flux increases by a factor of 3^4, or 81.

Suppose we want to find the flux and luminosity of Earth. Earth's average temperature is 288 K, so the flux from its surface is

Figure 5.4 This graph shows blackbody spectra emitted by sources with temperatures ranging from 2000 K to 6000 K. At higher temperatures, the peak of the spectrum shifts toward shorter wavelengths, and the amount of energy radiated per second from each square meter of the source increases.

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. We want you to be comfortable reading, hearing, and speaking the language of science, and we provide you with tools to make it easier.

In addition to learning the language of astronomy, visualizing a process or phenomenon will help you reach a deeper understanding. In addition to the illustrations in the book, many physical concepts are further explained in a series of short **Astronomy in Action** videos, **AstroTour** animations, and new **Interactive Simulations** available in the ebook, Coursepack, and on the Student Site. The videos feature one of the authors (and several students) demonstrating physical concepts at work. Each animation is a brief tutorial on a concept or process in the chapter. The simulations allow you to explore topics such as Moon phases, Kepler's laws, and the Hertzsprung-Russell diagram. Your instructor might assign the videos and animations to you or you might choose to watch them on your own to create a better picture of each concept in your mind.

Astronomy gives us 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.

Sincerely,
Stacy Palen
Laura Kay
George Blumenthal

VOCABULARY ALERT

pressure In everyday 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 everyday 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 billiard ball and a tennis ball are roughly the same size, but the billiard ball has greater mass and therefore feels heavier because it is denser.

Astronomy in Action: Wien's Law

AstroTour: Solar System Formation

Simulation: Exoplanet Detection

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 offers diverse approaches to the content.

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 new Active Learning Figures at the beginning of each chapter. These figures model student engagement and provide an opportunity for students to do an experiment or make an observation on their own using only everyday objects they can find around the house or dorm room.

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 in this book, sometimes in large, immediately visible ways such as the pedagogical structure but also through less obvious efforts such as questions and problems that relate astronomical concepts to everyday situations or fresh approaches to the organization of 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 use visual analogies to compare astronomical concepts to everyday events or objects. Through these analogies, we strive to make the material more interesting, relevant, and memorable. For example, in Chapter 8 ("The Giant Planets"), we show an image of moss flowing downstream from a rock to demonstrate how the magnetospheres of the giant planets are shaped by the solar wind.

Education research shows that the most effective way to learn is by doing. In addition to the Active Learning Figures and Reading Astronomy News features, the 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 Site on the Digital Resources Page 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 good 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-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 grow more comfortable with 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 skills 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 can reduce 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 introduce some physical principles with a "just-in-time" approach; for example, we cover atomic emission and absorption in Chapter 10 ("Measuring the Stars"), the first time that this level of detail is required to understand astronomical phenomena. Students are not required to flip back several chapters to remember the details. The material on stars is organized to cover the general case first and then to delves into more detail with specific examples. This organization implicitly helps students to understand their place in the universe: our star is one of many. The Sun is a specific example of a system that can be generalized to learn about all stars because we live in 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. The galaxies chapters have been reorganized to better balance the conceptual difficulty and to better differentiate between easily confused concepts. All of these organizational choices were made with the student perspective in mind.

Other items new to the third edition of *Understanding Our Universe* include the following:

- Active Learning Figures ask students to do a brief experiment or make an observation and record their results. Instructors looking for observational exercises or demos by students will find these especially useful. One way to use these activities is to ask students at the beginning of the semester to choose a small number of these to do throughout the term. Because several of the observing exercises require multiple observations, this will encourage students to plan ahead. Not all exercises require outdoor observation, so students will not be stuck during the cloudy weeks at the end of November trying to accomplish several observing exercises at once! To help you assess students on this information, we have questions in Smartwork5 that correspond to the Active Learning Figures.
- We added Check Your Understanding questions at the end of each section of a chapter so students could stop and briefly test their comprehension before moving to the next section. These questions, as well as the end of chapter questions and problems, form reading quizzes or a study guide for students to use before an exam. Versions of these questions are also available in Smartwork5.
- We revised each chapter, updating the science, to reflect the fast pace of astronomical research today. For example, the material on extrasolar planets includes the extremely interesting system Trappist-1. Of particular note is the discovery of gravitational waves, announced in February 2016. This exciting development has continued to delight astronomers. Our treatment is as up-to-date as we can make it and appears in several locations throughout the text.

- The Using the Web problems at the end of each chapter's Questions and Problems section encourage students to engage with scientific content on the Internet, guiding them to reliable websites and other media that broaden (and sometimes update) the content of the chapter.
- We reorganized the chapters about galaxies and cosmology (especially Chapters 14, 15, and 16) to better balance the conceptual difficulty. In the previous edition, the expanding universe and dark matter were covered in one chapter. This formed a heavy load for students that was made worse by the fact that both concepts rely on a graph of velocity versus distance. Introducing these concepts in such close proximity led to confusion. These two concepts have now been separated, so that Hubble's law is introduced and developed in Chapter 14 ("Galaxies"), while dark matter appears in Chapter 15 ("The Milky Way and Dark Matter"). This has the added benefit of allowing us to separate the treatment of supermassive black holes from the treatment of dark matter—another point of confusion for students. Hubble's law is revisited in Chapter 16, and the implications of Hubble's law for the origin of the universe are further developed in this chapter. This organization means that students visit this challenging material more than once.
- New Interactive Simulations, authored by Stacy Palen, pair with the Exploration activities in the text and Smartwork5, allowing students to explore topics such as Moon phases, Kepler's laws, and the Hertzsprung-Russell diagram.
- Teaching Astronomy by Doing Astronomy (tada101.com) is a blog for introductory astronomy instructors. Posts are written by Stacy Palen and provide suggestions for adding active learning to any size of class. Stacy will also post suggested Reading Astronomy News articles, discuss ways to integrate math into a course, and host discussions about recent developments in practical applications of astronomy education research.
- The Interactive Instructor's Guide is a searchable, online resource that allows instructors to find exactly what they need, right when they need it. Included are notes on teaching with the animations, simulations, and videos; guides to using the in-text learning-by-doing features such as Explorations and Reading Astronomy News; worked solutions to all end-of-chapter problems; PowerPoint Lecture and Update Slides; and information about incorporating the *Learning Astronomy by Doing Astronomy: Collaborative Lecture Activities* workbook activities into class.

Student engagement is not limited to the classroom or to the text. Norton's online tutorial and homework system, Smartwork5, allows you to engage students outside of the classroom and to easily assess students using interactive, visual content on both tablets and computers. Each of the more than 1,500 questions and problems offers students answer-specific feedback. Questions are tied directly to this text, including the end of chapter 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, and instructors can easily modify any of the provided questions, answers, and feedback or can create their own questions. You can easily set your course up with a range of premade assignments using the pedagogical elements of the book. New for this edition, Smartwork5 also integrates directly into your campus learning management system (LMS). Students will sign in to a single website, and their grades will automatically appear in the LMS gradebook.

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 third edition, but we continue to draw on another excellent resource—our colleagues who also teach introductory astronomy. We value your input, which often gives us ideas for new approaches, so we hope you will be part of the creative process by sharing your experiences with us on the Teaching Astronomy by Doing Astronomy blog.

Sincerely,
Stacy Palen
Laura Kay
George Blumenthal

Ancillaries for Students

Smartwork5

Ryan Oelkers, Vanderbilt University; Brett Salmon, Space Telescope Science Institute; Steven Desch, Guilford Technical Community College; Violet Mager, Susquehanna University; Todd Young, Wayne State College

More than 1,500 questions support *Understanding Our Universe*, Third Edition—all with answer-specific feedback, hints, and ebook links. Questions include selected end-of-chapter questions, versions of the Explorations (based on AstroTours and new simulations), and Reading Astronomy News. 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 led to the discovery.

Norton Digital Resources Page digital.wwnorton.com/universe3

This site contains:

- Twenty-eight AstroTour animations. These animations, some of which are interactive, use illustrations from the text to help students visualize important physical and astronomical concepts.
- Astronomy in Action videos demonstrate the most important concepts in a visual, easy-to-understand, and memorable way.
- Seven new Interactive Simulations, authored by Stacy Palen, pair with the Exploration activities in the text and Smartwork5, allowing students to explore topics such as Moon phases, Kepler's laws, and the Hertzsprung-Russell diagram.

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. Preactivities and postactivities are available for deployment in your campus LMS.

Starry Night Planetarium Software (College Version 7) and Workbook

Steven Desch, Guilford Technical Community College, and Michael Marks, Bristol 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,* Third Edition.

For Instructors

Instructor's Manual

Ana Larson, University of Washington

This resource includes brief chapter overviews, suggested classroom discussions/activities, notes on Active Learning Figures, AstroTour animations, Astronomy in Action videos, simulations, Reading Astronomy News (with alternate article suggestions), Explorations, and worked solutions to all Check Your Understanding and end-of-chapter questions and problems. Also included are notes on teaching with *Learning Astronomy by Doing Astronomy: Collaborative Lecture Activities* and answers to the *Starry Night Workbook* exercises.

Test Bank

Todd Vaccaro, St. Cloud State University

The Test Bank has been revised using Bloom's Taxonomy and provides a quality bank of more than 1,000 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 Interactive Instructor's Guide (IIG)

This new and searchable online resource is designed to help instructors prepare for lecture in real time. It contains the following resources, each tagged by topic, chapter, and learning objective:

- Test Bank, available in ExamView, Word RTF, and PDF formats
- Instructor's Manual in PDF format
- Discussion Points
- Notes for teaching with the Active Learning Figures
- AstroTour animations
- Astronomy in Action videos
- Interactive Simulations
- Notes and alternate articles for teaching with Reading Astronomy News
- Notes for teaching with *Learning Astronomy by Doing Astronomy: Collaborative Lecture Activities*
- Solutions to Check Your Understanding and end-of-chapter questions and problems
- Lecture PowerPoint slides
- All art, photos, and tables in JPEG and PPT formats
- Answers to the *Starry Night Workbook* exercises
- Learning Management System Coursepacks, available in Blackboard, Canvas, Desire2Learn, and Moodle formats

Learning Management System Coursepacks

Norton's Coursepacks, available for use in popular learning management systems (LMSs), feature vocabulary flashcards, preactivities and postactivities for *Learning Astronomy by Doing Astronomy: Collaborative Lecture Activities*, AstroTour animations, Astronomy in Action videos, Interactive Simulations, selected Check Your Understanding questions from the text as assignable worksheets, Explorations worksheets, and links to the Test Bank in LMS format.

Coursepacks are available in Blackboard, Canvas, Desire2Learn, and Moodle formats.

Instructor's Resource USB Drive

This portable thumb drive contains the same files as the Interactive Instructor's Guide.

Acknowledgments

Many people collaborated to produce this book. Most of these people worked hard in the background, keeping track of the thousands of small details that no one person could possibly remember. The authors would like to acknowledge the extraordinary efforts of the staff at W. W. Norton: Sara Bonacum, who jumped into the middle of the project with both feet and figured out how to herd authors and reviewers in only a few short days; Diane Cipollone, who shepherded the manuscript through the layout process and was very patient with all the late updates to the science material (especially the eclipse updates!); the copy editor, Christopher Curioli, who made sure that all the grammar and punctuation survived the multiple rounds of the editing process. We would especially like to thank John Murdzek, who brought dry wit and a love of science to the developmental editing process; and Erik Fahlgren, who lined up such a great team for us to work with and also reined in the excessive use of exclamation points.

We'd especially like to thank Anne DeMarinis for her creative, insightful, and thoughtful work on the new Active Learning Figures that open each chapter: Each figure captures a small piece of the wonder that scientists bring to studying the universe. Andy Ensor managed the production. Jillian Burr was the design director. Rob Bellinger and Arielle Holstein worked on the media and supplements, and Katie Sweeney helped get this book into your hands.

And we would like to thank the reviewers, whose input at every stage improved the final product:

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Understanding Our Universe

THIRD EDITION

Our Place in the Universe

The location of the sunrise changes throughout the year. This pattern can be used as part of the scientific method—which you will learn about in this chapter—to investigate Earth's orbit.

Three times throughout this course (at the beginning, near the middle, and at the end), go outside to the same location and take a picture of the western horizon just after sunset. Before you begin, write down what you expect to see when you compare these images. When you are finished, compare the images and see if you were right!

EXPERIMENT SETUP

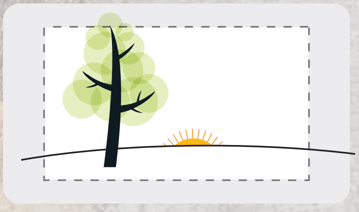


PHOTO 1

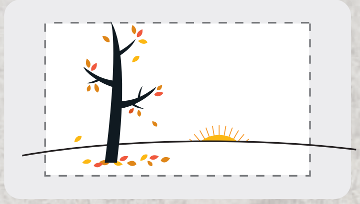


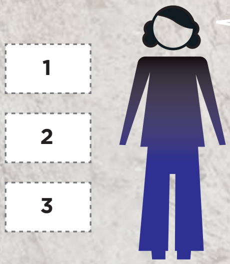
PHOTO 2

PHOTO 3

Go to the same location and take three photos of the horizon at a time of day when the Sun is just below the horizon. Be sure that you have a stationary object (like a tree) in each photo. Take a photo at the:

1 beginning of semester
2 middle of semester
3 end of semester

PREDICTION

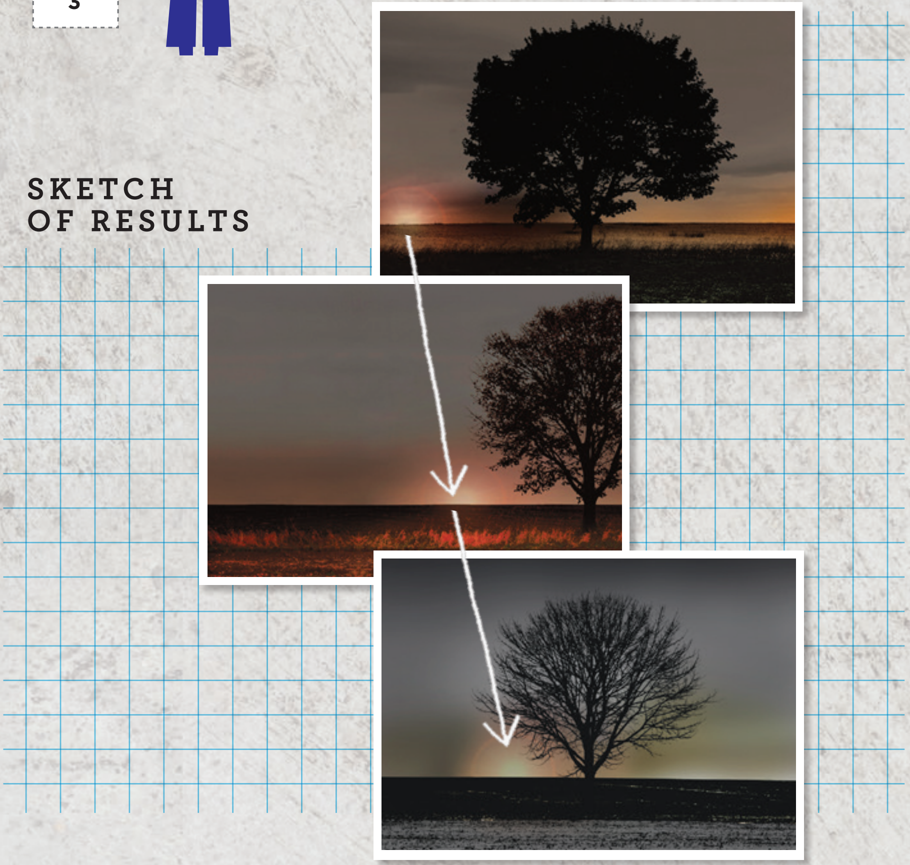


When I compare the three images, I expect to see:

____

____

SKETCH OF RESULTS



1

Historically, the science of astronomy was about measuring positions of and finding patterns among the stars. However, modern **astronomy** seeks the answers to questions that early astronomers could not even imagine being able to answer: 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 way modern science is done. Scientists use a very specific set of processes, sometimes collectively called the scientific method, to seek and obtain knowledge. Part of this procedure stems from recognizing patterns in nature. Part of it also stems from putting those patterns together to understand how they apply in different places and at different times.

LEARNING GOALS

1. Relate our place in the universe to larger structures in the universe.
2. Explain how science connects the patterns of our daily lives to the laws that govern the larger universe.
3. Describe our astronomical origins.
4. Describe the scientific method.
5. Interpret and draw conclusions from graphs.

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 a home address that consists of a street number, street name, city, state, and country. If we expand our view to include the enormously vast universe, however, our "cosmic address" might include our planet, star, galaxy, galaxy group, and 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. (Terms in red signify a "Vocabulary Alert" in the margin of the text.) 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* (such as Pluto, Ceres, and Eris), *asteroids* (such as Ida and Eros), and *comets* (such as 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 more than a

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.

hundred billion stars scattered throughout the Milky Way. 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, which is part of an even larger grouping called the Laniakea Supercluster.

We can now define our cosmic address, illustrated in **Figure 1.1**: Earth, Solar System, Milky Way Galaxy, Local Group, Virgo Supercluster, Laniakea Supercluster. Yet even this address is incomplete 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 thousand billion galaxies*—roughly as many galaxies as there are stars in the Milky Way.

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.

To understand how astronomers use time as a measure of distance, think 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 1.2** begins with Earth and progresses outward through 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.

The Origin and Evolution of the Elements

According to both theory and observation, 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 possibly boron. Nevertheless 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. Moreover, 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?

To answer this question, we must begin deep within stars. In the core of a star, less massive elements, like hydrogen, combine to form more massive elements, eventually leading to atoms such as carbon. When a star nears the end of its life, it

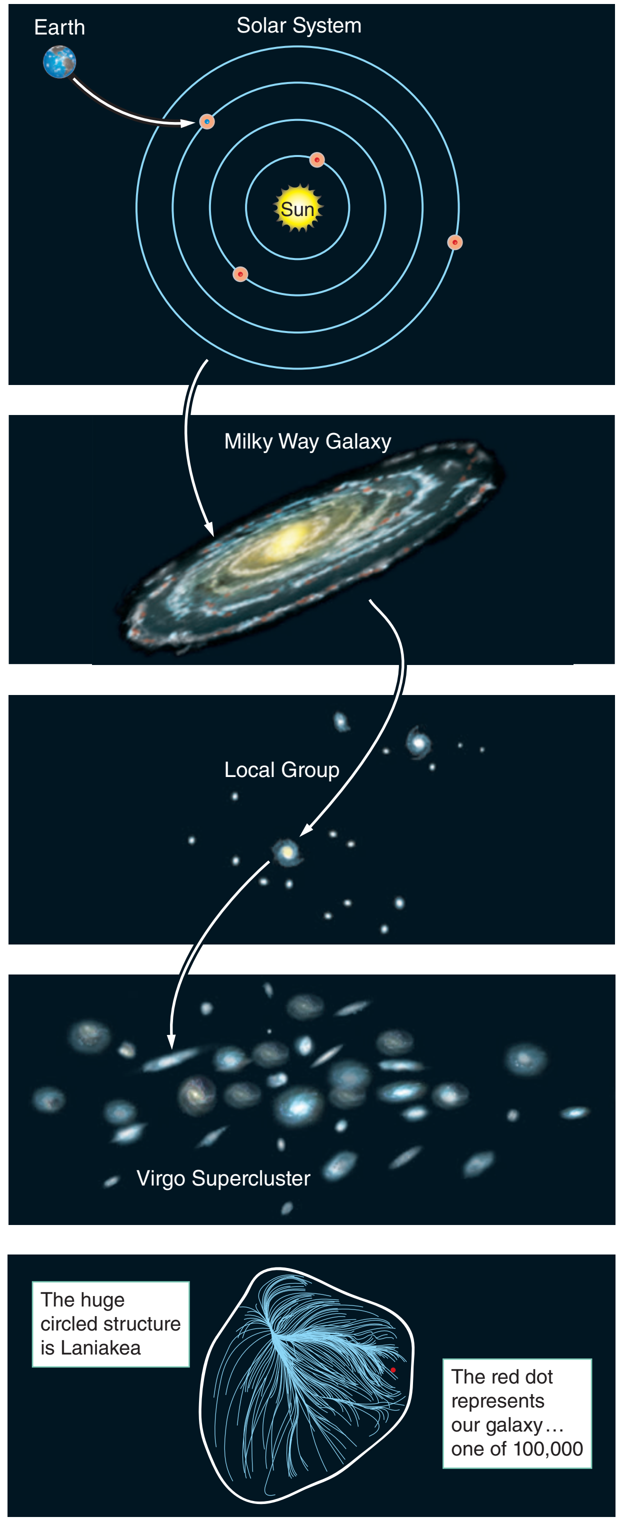


Figure 1.1 Our place in the universe is given by our cosmic address: Earth, Solar System, Milky Way Galaxy, Local Group, Virgo Supercluster, and Laniakea Supercluster. We live on Earth, a planet orbiting the Sun in our Solar System, which is a star in the Milky Way Galaxy. The Milky Way is a large galaxy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

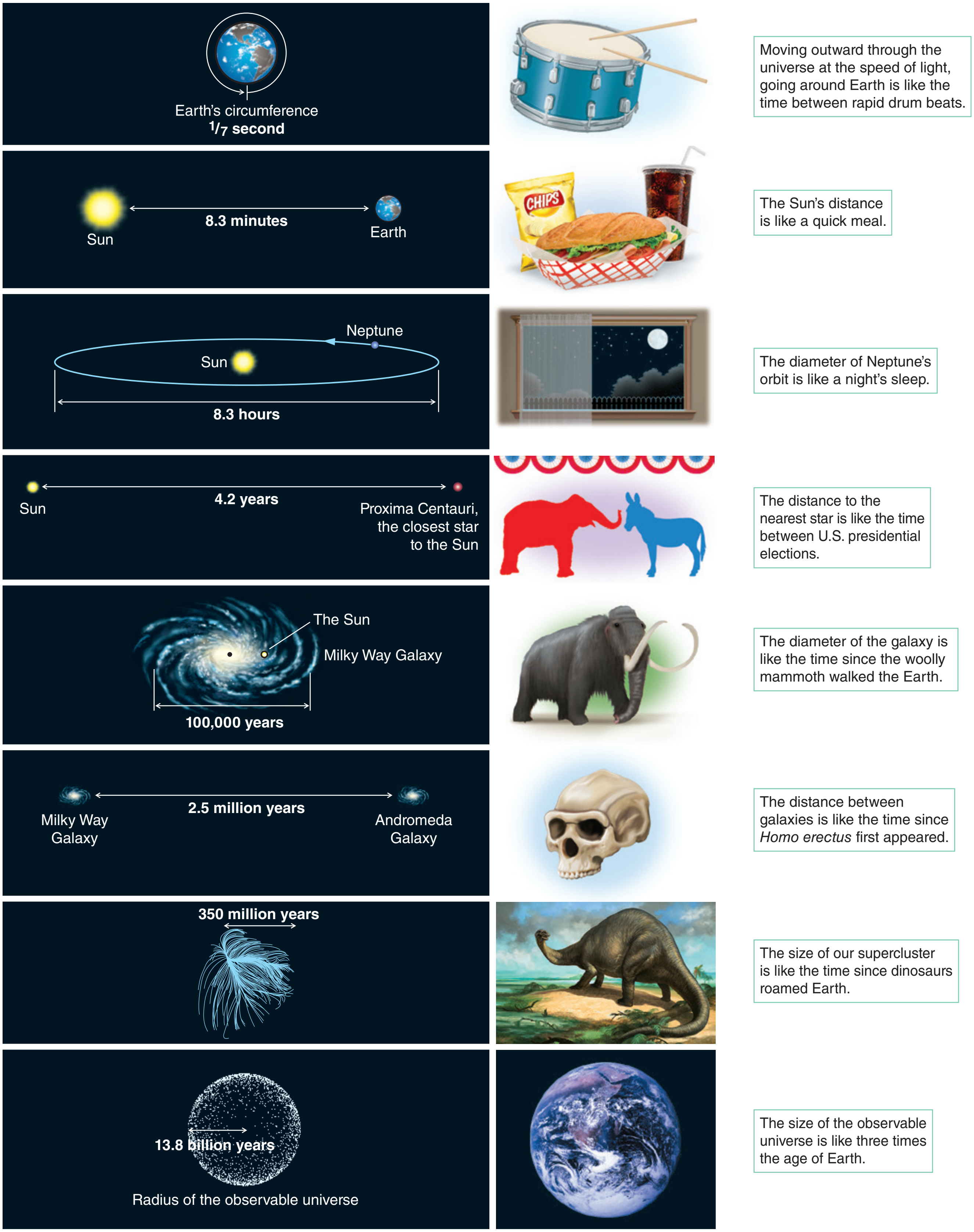


Figure 1.2 Thinking about the time it takes for light to travel between objects helps us to comprehend the vast distances in the observable universe.

loses much of its material back into space—including some of these more massive elements. This material combines with material lost from other stars, some of which produced even more massive elements as they exploded (**Figure 1.3**), to form large clouds of dust and gas. Those clouds go on to make new stars and planets, such as our Sun and Solar System. Thus, prior "generations" of stars supplied the building blocks for the chemical processes that make it possible for you to read and understand this book. Look around you. Everything you see contains atoms of elements that were formed in stars long ago.

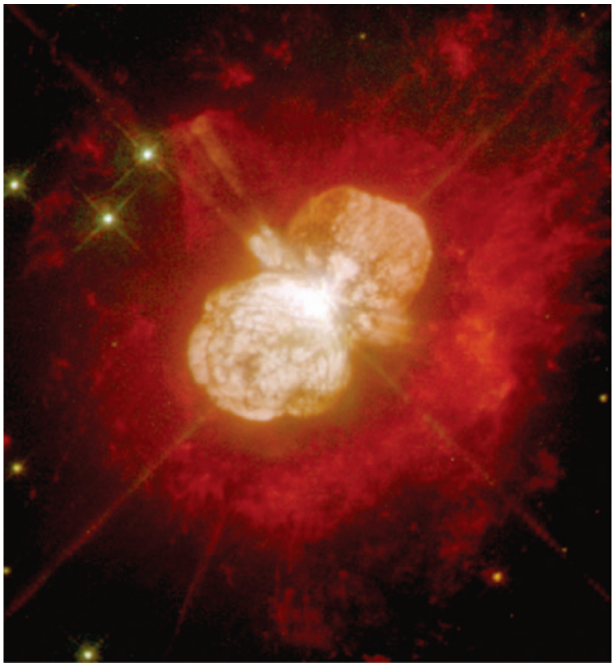


Figure 1.3 You and everything around you contain atoms of chemical elements that were forged in the interiors of stars that lived and died before the Sun and Earth were formed. The supermassive star Eta Carinae is currently ejecting a cloud of enriched material. This star is located about 7,500 light-years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

An Astronomer's Toolkit

Telescopes often come 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. In part, this is because astronomers collect information from many varieties of light, not just the kind of light we can see with our eyes. From the highest-energy *gamma rays* and *X-rays*, through *ultraviolet*, *visible*, and *infrared* radiation, down to the lowest-energy *radio waves*, each part of the spectrum carries different information about the universe. **Figure 1.4** 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. 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. Most recently, the discovery of gravitational waves has opened another window on the universe that astronomers are just beginning to explore.

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, which has forever altered our perception of the universe.

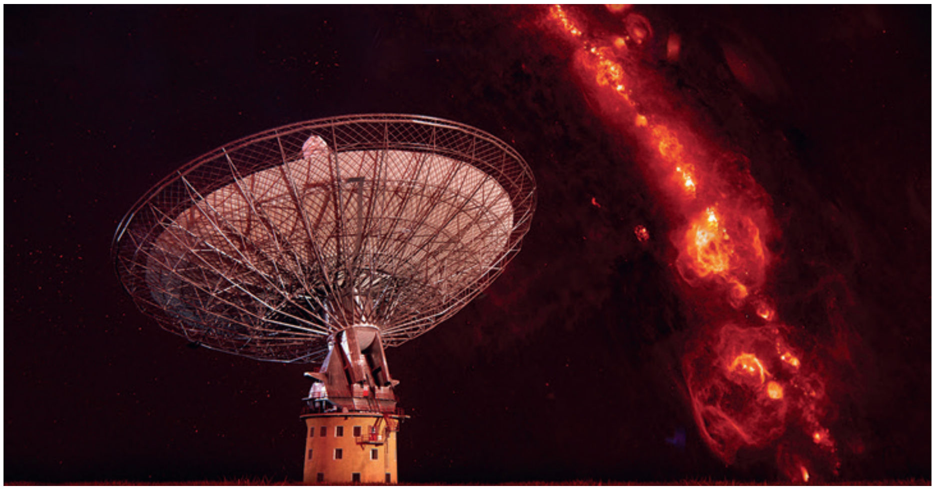


Figure 1.4 In the 20th century, advances in telescope technology opened new windows on the universe. This is the Milky Way as we would see it if our eyes were sensitive to radio waves, shown as a backdrop to the Parkes radio telescope in Australia.

VOCABULARY ALERT

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.

(a)

(b)

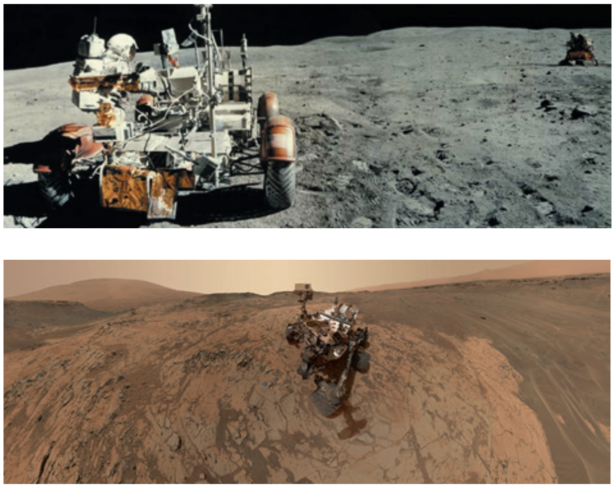


Figure 1.5 Exploring the universe has included travels in the Solar System. (a) *Apollo 15* (1971) was the fourth U.S. mission to land on the Moon. Here astronaut James B. Irwin stands by the lunar rover during an excursion to explore and collect samples from the Moon. (b) Robotic missions have visited all the planets (as well as some other objects). The *Curiosity* rover even took "selfies" on the surface of Mars.

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. The inset shows a view of the instrumentation inside the 27-km tunnel.

In addition to putting satellites into space around Earth, 12 people have walked on the Moon (**Figure 1.5**), and dozens of 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 both an asteroid and a comet. Still others have plunged into the atmosphere of Jupiter and the heart of a comet. In the past few years, spacecraft have begun probing the outer reaches of the Solar System, with *New Horizons* visiting the dwarf planet Pluto, and *Voyager 1* reaching the edge of the Sun's influence on interstellar space. Most of what we know about the Solar System has resulted from the past six decades of exploration since the space age began.

You may also be surprised to learn that much astronomy is now carried out in large physics facilities such as 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.

CHECK YOUR UNDERSTANDING **1.1**

Rank the following in order from smallest to largest: Sun, Laniakea Supercluster, Earth, Solar System, Local Group, Milky Way Galaxy, universe.

Answers to Check Your Understanding questions are in the back of the book.

1.2 Science Is a Way of Viewing the World

As you view the universe through the eyes of astronomers, you 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 exploring the world on the basis of developing and then 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 (in the Southern Hemisphere) should have winter at the same time of year as the United States (in the Northern Hemisphere). You travel to the opposite hemisphere in the winter and find that it is summer there when it is winter back home. Your hypothesis has just been **falsified**, which means that it has been proved incorrect. This is good! It means you now know something you didn't know before. It also means 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 on the basis of 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 theories of relativity, which have withstood more than a century of scientific efforts to disprove their predictions.

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.

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.

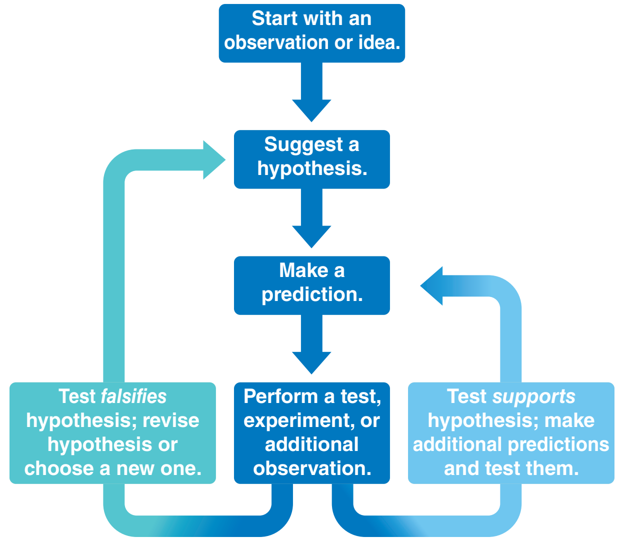


Figure 1.7 The scientific method is the path by which an idea or observation leads to a falsifiable hypothesis. The hypothesis is either accepted as a tested theory or rejected on the basis of observational or experimental tests of its predictions. The process goes on indefinitely as scientists continue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

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 general theory of 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 leads 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 the universe that guides our construction of new theories. For example, at the heart of modern astronomy is the cosmological principle. The **cosmological principle** includes the testable assumption that the same

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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.

theory In common language, a theory is weak—just an idea or a guess. For scientists, however, theories represent the most well-known, well-tested, and well-supported principles in science.