Explorations

an introduction to astronomy

third edition

Thomas T. Arny

Third Edition

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An Introduction to Astronomy

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Preface

When I began writing *Explorations: An Introduction to Astronomy,* many people asked me why I was writing an astronomy book. Much of my motivation comes from wanting to share my own sense of wonderment about the Universe. I hope that in an astronomy course, students can get some sense of where they fit in the astronomical Universe—a sense of location in the cosmic landscape. I also hope that students will come away from such a course with a sense of the richness of the Universe. When we look around us on our own planet, we see incredible biodiversity. So, too, when we look at the heavens, we see incredible astrodiversity. Stars, moons, and planets are as strange, colorful, and wonderful as tropical butterflies. Finally, I hope that students will gain some appreciation of the methods by which such tiny beings as we are have learned so much about the Universe. Those methods are not just laboratory techniques. Far more important is the process of learning: the steps by which we go from observation to hypothesis and then on to what we hope is understanding.

But why write your own astronomy book when so many already exist? Most of the current books have so much material that they are impossible to get through in a single semester, and much material is omitted. I therefore decided that my first goal was to make a book that was short. However, as I worked at it, I kept finding things that I didn't want to leave out, material such as calendars and the history of astronomy. But how could I write a short book and still include such topics? The solution was to organize the book so that instructors and students could omit the unwanted sections without interrupting the flow of ideas. Thus, I placed a number of topics such as time keeping and exo-biology into Essays that may be easily skipped. I also tried to make the book short by limiting its scope. Rather than covering everything, I have tried to focus on only what at the time seemed to me the most important ideas.

Another goal I set myself was to give simple explanations of why things happen. Such explanations generally involve physical principles that are unfamiliar to non-science students. However, many even very complicated physical ideas can be appreciated, if not fully understood, by appeal to analogy or to similarities with everyday phenomena. For example, diffraction effects can be seen by looking at a bright light through a lock of your hair pulled over your eyes or through glasses that you have fogged with your breath. By tying physical principles to everyday observations, many of the more abstract and remote ideas become more familiar. Thus, I have used analogies heavily throughout the book, and I have designed the illustrations to make those analogies more concrete.

An additional aim throughout this text is to explain *how* astronomers know the many curious things they have learned about our Universe. Such explanations often require mathematics, and so I have included it wherever it is crucial to understanding a method of measurement, as in the use of the modified form of Kepler's third law to determine a star's mass or in Wien's law to measure its temperature. However, because math is so intimidating to so many students, I have tried to begin these discussions by introducing the essence of the calculations in everyday language. Thus, if the student or instructor chooses to omit the math, it will not prevent an understanding of the basic idea involved. For example, Wien's law relates the temperature of a hot object to its color by a mathematical law. However, the consequences of the law can be seen in

everyday life when we estimate how hot an electric stove burner is by the color it glows. Similarly, I have tried to work through the math problems step by step, explaining that terms must be cross-multiplied, and so forth.

As a final goal, I have set many of the modern discoveries in their historical context. I want to demonstrate that science is a dynamic process and that it is subject to controversy. Ideas are often not immediately accepted, and to appreciate those that scientists finally settle on, it helps to understand the arguments for and against them, as well as the train of reasoning that leads to the "accepted" answer. On this point, I must digress and reveal my own amazement (and naiveté) at how many widely accepted ideas have such flimsy underpinnings and how many widely quoted values for astronomical quantities are very imperfectly known.

NEW TO THE THIRD EDITION

In this third edition of *Explorations*, I have tried to update the areas in which substantial changes in our knowledge have occurred or where different ideas are emerging. These include

- Migration of the giant planets within the Solar Nebula
- The shape of planetary nebulas
- Evidence from the cosmic microwave background that our Universe is flat
- Evidence for "recent" water flows on Mars
- Hypotheses for why Earth and Venus have such different surfaces
- The discovery of numerous brown dwarfs and low-temperature stars

I have made two shifts in the organization of the material. The discussion of seasons is now in chapter 1, and the chapter on telescopes now follows directly the chapter on light. Both these changes were urged by many reviewers, and, to be honest, I myself have generally discussed seasons with the material on aspects of the sky. Most of the other changes in this edition are minor or are corrections of typos or other points raised by reviewers. Foot and margin notes add a few topics that are of more specialized interest but that I wanted my own students to know of.

A new feature of the third edition is an animation icon placed next to topic headings that have related animations on the CD-ROM and the On-Line Learning Center. In addition, a description of the animation is next to the icon. There are approximately 80 animations that will help bring each concept to life as each shows its special simulated physical phenomena.

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HOW TO STUDY WITH THIS BOOK

Learning anything requires a certain amount of work. You certainly don't expect to be able to pick up a guitar and play it without practice, nor do you expect to be able to jog 5 miles without working out regularly. Learning astronomy also requires some work. The steps below may help you learn material better and more easily.

In reading any assignment, begin by looking at the pictures. Turn the pages of the chapter and familiarize yourself with what the objects you will be reading about look like. Then read the introduction. Next, jump to the summary. Finally, start again and read the assigned material through. As you read, make notes of things you don't understand and ask your instructor or teaching assistant for clarification. For example, if you are puzzled about why eclipses don't happen every month, make a note. I would urge you *not* to highlight as you read. Making a few short notes is much more effective than highlighting whole paragraphs.

Look carefully at the pictures and diagrams. If the figure caption has a question in it, try to answer it. Make your own sketch of diagrams to be sure you understand what they represent.

In a first reading of a chapter, I'd suggest that if you are troubled by math, you should simply skip it for the time being. Be sure, however, to read the material leading into the math so you at least understand what is being dealt with. When you encounter a mathematical expression of a physical law, put in words what the law relates. For example, the law of gravity relates the force of gravity to the mass of the objects and their distance from each other.

If you encounter words or terms as you read that you don't know, look them up in the glossary or index. You are just wasting your time if you read a description of some object and you don't know what it is.

When you finish the assignment, try to answer the review questions. They are short and are designed to show you whether you have assimilated the basic factual material of the assignment. Try to do this without looking back into the chapter, but if you can't remember, look it up rather than skip over the question. You might find it helpful to get a pile of scratch paper and actually write out short answers to the questions.

Having read the material once, go back and try to work through the math parts. Then try a practice problem to see if you can work through the material on your own.

If you get stuck at any point, see your teaching assistant or professor for help. Don't be shy about asking questions. I wish someone had beaten this into my head earlier. Learning is a thousand times easier if you ask questions when you get stuck.

Throughout the book, I have also tried to convey some of my own enthusiasm for astronomy. Many astronomical objects are strikingly beautiful. Others conjure up a sense of amazement. To me, it is the ultimate wonder that within the Universe, life has formed that can contemplate the Universe and ask what it is about. Seeing a clear night sky spangled with stars is for me a nearly religious experience. And yet the beauty that I see and my sense of wonder are enriched even more by an appreciation of the complex processes that make the Universe work. I hope this book will similarly increase your appreciation of our Universe's wonders.

If while using this book you find mistakes or if you have suggestions about how to make it better, *please* let me know. Write me at the Astronomy Program, University of Massachusetts, Amherst, MA 01003-4525, USA. If you have access to e-mail, please let me know that way. My address is arny@nova.astro.umass.edu. I really want your feedback.

ASTRONOMY ON THE INTERNET

Over the last few years, many teachers and students have gained access to an exciting new astronomy resource: the Internet. Hundreds of scientists around the world have

created picture galleries and accompanying explanations that can be read by any user with access to the Internet. All are available free with the click of a computer mouse. Moreover, no special computer expertise is needed.

To use this resource, get a computer account at your school on a machine that runs a browser such as Netscape or Microsoft Explorer. Check with your local computer guru about how to connect your personal computer to the network or go to your library or computer room and use one of the computers there that is already set up. Typically, you'll need about 10 minutes to learn how to use the system. It is time well spent, because the Internet has become one of the best ways to find out the latest news about astronomical discoveries (similar systems exist for many other disciplines and hobbies). It would be impossible to list all the sites: they number in the thousands and change daily. Using one of the search engines such as Yahoo or Google will allow you to type in a few words that describe what you are interested in, and in a minute or so, you may have literally hundreds of suggested addresses that you can go to by simply clicking your computer mouse.

To help you navigate the labyrinth of the Internet, sites covering material in each chapter are featured on the *Explorations* web site at **www.mhhe.com/arny.**

To help you get started, I've listed below a few addresses of general interest.

"Yahoo." An amazing collection of special-interest pages on many subjects, including academic fields, travel, and entertainment. It also has a very good list of astronomical sources, including the beginnings of an on-line introductory astronomy text.
www.yahoo.com/Science/Astronomy/

"Welcome to the Planets." Many pretty pictures, fact sheets on the planets and the other Solar System objects, and a glossary. Prepared by the Jet Propulsion Laboratory.
pds.jpl.nasa.gov/planets

"Views of the Solar System," by Calvin Hamilton. Excellent pictures, fact sheets, and glossary. Lots of links to other sites.
www.hawastsoc.org/solar/homepage.html

"Students for the Exploration and Development of Space". Lots of excellent links, pictures, text, and glossary. Among the fine links are "The Nine Planets," by Bill Arnett, and "Tour the Galaxy," by Guy Smiley.
www.seds.org

"Astronomy Picture of the Day." This site features images from both professional and amateur astronomers. It is a good place to find new pictures from various space observatories and ground based instruments.
http://antwrp.gsfc.nasa.gov/apod/archivepix.html

"Astronomy and Space." A site with diverse links, including a simulated view of Earth that shows what portion is lit at the time you are logged in and "Solar System Live," a program that shows the position of the planets with a simulated Solar System for a huge range of dates that you can enter.
fourmilab.ch/nav/topics/astrospace.html

Note: Most of these addresses will suggest links to many additional sources, thus creating a web of information. Hence the name, "worldwide web."

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I owe thanks to many people for their help in this book, both for the first edition and for this new one. Help came in the form of advice, pictures, information, encourage-

ment, and improvements to my own understanding of things. I have pestered all of my colleagues in the Five College Astronomy Department and many of them in the Department of Physics and Astronomy. Neal Katz, Eric Linder, James Lowenthal, Mike Skrutskie, and Martin Weinberg, as neighbors down the hall, bore a disproportionate share of questions, and I owe them special thanks. Gene Golowich read over an early draft on inflationary cosmology and made valuable suggestions. I profited from many conversations with Ted Harrison, the late Ed Phinney (of the Classics Department), Peter Schloerb, and David Van Blerkom. Other people who contributed were Bill Bates and Rick Newton, who helped with setting up and taking pictures, and Linda Ray Arny, who helped me locate many references. I also want to thank Amy Lovell for her careful proofreading of the first edition.

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Although innumerable people have read the manuscript, any errors that remain are my responsibility. If you find mistakes, please let me know. I want to make *Explorations*—as error-free as possible.

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REVIEWERS

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NEW ANCILLARY PACKAGE

The third edition of *Explorations* has a new set of ancillary materials. They include:

An **Essential Study Partner CD-ROM** has study aids organized by topic. Each section includes animations modeling key concepts discussed in the book, practice quizzes, flashcards, and crossword puzzles using key terms and glossary definitions. Also included on the CD-ROM are guest essays written by professors that expose students to a different viewpoint on a topic or a new research project. This interactive resource is packaged free with each new textbook.

The **Astronomy PowerWeb,** linked to from the Arny On-Line Learning Center, is the first on-line supplement to offer students access to course-specific current articles refereed by content experts; course-specific real-time news; weekly course updates; interactive exercises and assessment tools; study tips; web research tips and exercises; refereed and updated research links; daily news; and access to the Northernlight.com Special Collection™ of journals and articles. A pass card is packaged free with each new textbook.

An **OnLine Learning Center** offering unlimited resources for both the student and the instructor is found at **www.mhhe.com/arny**. Instructors can access Powerpoint presentations, sample syllabi, an online instructor's manual, plus other on-line teaching tools. Students will be able to use an astronomy timeline, scorable practice quizzes, questions and problems, and more. By way of this text-specific web site, students and instructors will be better able to quickly incorporate the Internet into their classroom.

NetTutor offers students *live, personalized tutoring* via the Internet. Using NetTutor's powerful WWWhiteboard software, students can post a question and receive prompt feedback from an expert in their subject. The WWWhiteboard allows students and tutors to use proper mathematical notation as well as other highlighting features—truly making this a unique learning experience. Students may also post questions to the Q&A Center and receive a reply within 24 hours. Visiting the Message Center allows students to discuss difficult concepts among themselves, while the Archive Center provides a browseable list of questions and answers maintained by the subject tutor. NetTutor comes FREE with *Explorations: An Introduction to Astronomy,* third edition, by Tom Arny, and is an invaluable aid for all students. It's the study partner who always has all of the answers.

An **Instructor's Manual** that includes references to additional articles and books, lecture outlines, and syllabi for a variety of course formats.

A **Computerized Test Bank** available for both Macintosh and Windows programs.

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Explorations gives you the tools to make the most of your journey through the wonders of the cosmos. Learn more about the world of astronomy through a package that includes imaginative features, updated information, spectacular photographs, and interactive software.

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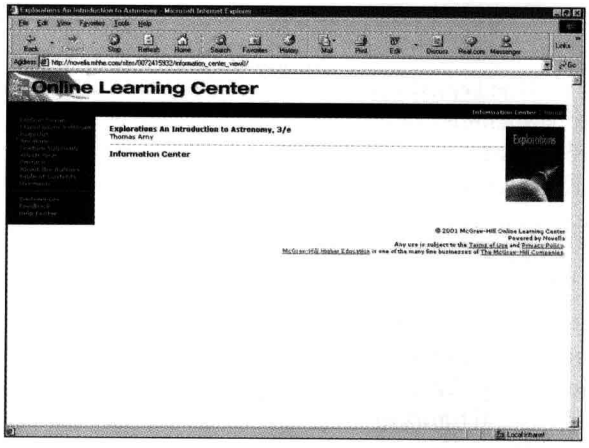
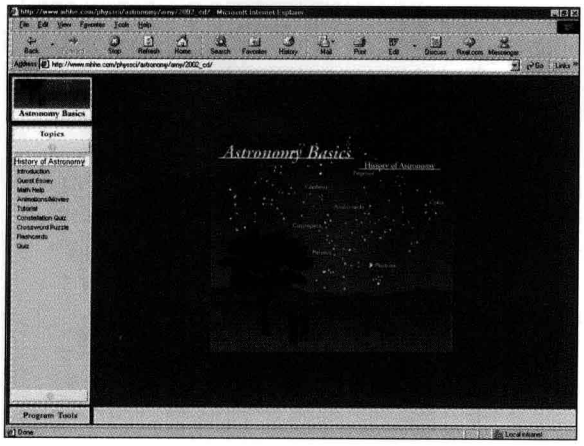
This text-specific website **www.mhhe.com/arny** takes instructors and students into an online learning experience. You have access to hundreds of images, animations, practice quizzes, additional links, crossword puzzles, and flashcards. Much more can be transformed into an online course via PageOut, Blackboard, or WebCT. Plus, the author will be adding updated material to the website as it becomes available, keeping instructors and students as current as possible.





Astronomy Essential Study Partner

This extraordinary CD-ROM, organized by topic, provides your students with animations and movies, additional essays, help with math problems, flashcards, and crossword puzzles. There is also a direct link to the OnLine Learning Center.

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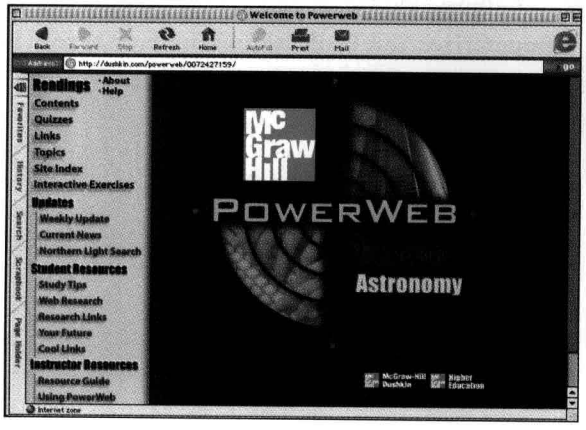


UP-TO-DATE

With every new edition, great emphasis is placed on making sure the text is as current as possible. The following are some of the new topics that are covered in this edition:

- Migration of the giant planets within the Solar Nebula.
- Shape of planetary nebulas.
- Evidence from the cosmic microwave background that our Universe is flat.
- Evidence of "recent" water flows on Mars.
- Hypotheses for why Earth and Venus have such different surfaces.
- Discovery of numerous brown dwarfs and low-temperature stars.


Essay One

Backyard Astronomy

You can learn many of the same things classical astronomers did by simply watching the night sky. But there is a bonus as well. Backyard astronomy is just plain fun, as evidenced by the many thousands of amateur astronomers who in their spare time pursue activities ranging from simply stargazing to searching for new comets.

This section is intended to give you some hints on how to become a backyard astronomer, beginning with learning the constellations and some of the stories associated with them. We will then briefly discuss small telescopes and star charts. We will conclude with a description of some of the physical changes in your eye when you are observing in very dim light.

Learning the Constellations

One of the best ways to get started as a backyard astronomer is to learn the constellations. All it takes is a star chart, a dim flashlight, and a place that is dark and has an unobstructed view of the night sky. The star chart will generally tell you how to hold it so that it matches the sky for the date and time that you are observing.

Start by determining which way is north, using a compass if necessary. Then try to locate a few of the brighter stars matching them up with the chart. This will give you some sense of how big a piece of the sky the chart corresponds to. Next, try to identify a few of the constellations. Focus at first on just a few of the brighter ones. For example, if you live at midlatitude in the Northern Hemisphere, the Big Dipper—part of the constellation Ursa Major—is a good group to start with because it is always in the northern part of the sky.

As you attempt to find and identify stars, your spread hand held at arm's length makes a useful scale. For most people, a fully spread hand at arm's length covers about 20° of sky, or about the length of the Big Dipper from tip of handle to bowl, as shown in figure E1.1. For smaller distances, you can use finger widths (a few degrees).

This scaling of sky distances with your hand makes it easy to point out stars to other people. For example, you can say that a star is two hands away from the Moon and at the 4 o'clock position, as illustrated in figure E1.2.

Once you have some to recognize a few of the constellations, you may be interested in the stories associated with them, that is, star lore.

FIGURE E1.1
The Big Dipper, part of the constellation Ursa Major, the Great Bear. A line through the two pointer stars points toward Polaris, The Big Dipper spans about 20° on the sky, about a hand width at arm's length for most people.

16.2 Measuring Properties of Galaxies 491

stars, planetary nebulas, or supernovas when determining the distance to such remote systems. However, the method's accuracy depends on accurate knowledge of the luminosity of the standard candle employed—for example, supernovas—and such luminosities are still only approximately known. Astronomers therefore have sought other ways to measure the distance to galaxies, as we will discuss in the next section.

EXTENDING OUR REACH

MEASURING THE DISTANCE OF A GALAXY USING CEPHEID VARIABLES

Suppose we detect a Cepheid in a galaxy and find that the Cepheid appears 100 million (10^8) times dimmer than a Cepheid of the same pulsation period in the Milky Way. Because the stars have the same period, we assume that they have the same luminosity. Let us denote the brightness and distance of the Cepheid in the Milky Way as B_w and d_w, respectively, and denote the brightness and distance of the Cepheid in the distant galaxy by B_g and d_g. According to the inverse-square law, if two objects have the same luminosity, their apparent brightnesses B_w and B_g are related to their respective distances, d_w and d_g, by

$$\frac{B_w}{B_g} = \left(\frac{d_g}{d_w}\right)^2$$

B_w = Brightness of Cepheid in Milky Way
B_g = Brightness of Cepheid in distant galaxy
d_w = Distance to Cepheid in Milky Way
d_g = Distance to Cepheid in distant galaxy

To find their distances, we take the square root of both sides, getting

$$\sqrt{\frac{B_w}{B_g}} = \frac{d_g}{d_w}$$

In other words, the square root of the ratio of their brightness equals the ratio of their distances. Because the distant Cepheid in our problem looks 10^8 times dimmer than Cepheid in the Milky Way, $B_w/B_g = 10^8$. Thus, according to the inverse-square law, the ratio of the distance of the Cepheid in the galaxy to the distance of the Cepheid in the Milky Way must be

$$\frac{d_g}{d_w} = \sqrt{\frac{B_w}{B_g}} = \sqrt{10^8}$$

$$= 10^4$$

That is, the Cepheid in the remote galaxy is 10^4 times farther away than the one in our galaxy.

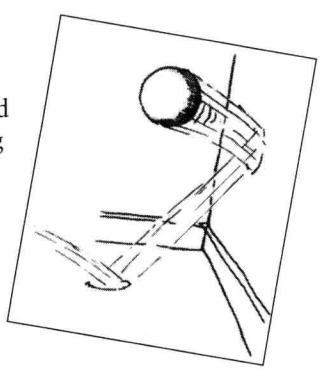
Suppose we know the Cepheid in our own galaxy is 1000 light-years away. Then the Cepheid in the other galaxy must be 10^4 times 1000 light-years away. The distant Cepheid, and hence the galaxy in which it is located, is therefore 10^7 light-years distant (look fig. 16.1).

BOX FIGURE 16.1
Finding the distance to a galaxy using Cepheid variables as standard candles. B_w and B_g are the apparent brightness of the Cepheid in the Milky Way and in the Cepheid distant galaxy, respectively. Their distances are d_w and d_g, respectively. From a measurement of the brightness ratio of the Cepheids, astronomers can calculate the ratio of their distances and, knowing the distance of the Cepheid in the Milky Way, they can therefore find the distance to the other galaxy.

LEARN WITH OUTSTANDING FEATURES

Along with providing the most current information available, the third edition of *Explorations* has much to offer within the framework of the text:

- *New Illustrations*—Stunning, full-color images emphasize text content and reflect current information and astronomical developments.
- *Overviews*—These overviews provide generously illustrated, brief previews of the materials in the following block of chapters.
- *Re-Modeling Bars*—This feature draws attention to recent changes in ideas about the Universe as well as some important historical shifts in perspective.
- *InterChapter Essays*—These optional readings focus on topics of general interest, such as time and life in the universe.
- *Projects*—Located throughout the text are non-intimidating activities that encourage participation.
- *Analogy Sketches*—These sketches provide visual clarification of important textual analogies.
- *Extending Our Reach*—These boxed applications address challenging topics that go beyond the usual introductory astronomy coverage.




PROJECTS

1. Motion of the Moon and planets. Obtain a star map (Sky Publishing Company's SC1 available from Sky Publishing Co., P.O. Box 9111, Belmont, MA 02178, is excellent and inexpensive). Determine from the calendar when the Moon is a few days past new so that it will be visible in the early evening. Go outside shortly after sunset and look for the Moon in the west near where the Sun went down. Next check the dates along the bottom of the star map to find what region of the sky is visible at that date and time. As the sky darkens, locate the brighter stars near the Moon and mark on the chart where the Moon is with respect to those stars. Finally, make a sketch of the Moon's shape.

Repeat this process for the next four or five nights. The Moon will set a little later each evening, so you need to adjust your observing time accordingly. After watching a few nights, mark out the Moon's path on the star map. Ideally, you might want to follow the Moon's track for about 2 weeks, although as the Moon reaches third quarter (3 weeks after new moon), you'll have to stay up pretty late because the third-quarter moon does not rise until midnight. If you are really ambitious, get up before dawn and watch the crescent moon shrink as it approaches the new phase.

You can also use this method to study the motion of the planets. Venus is a good choice because it is bright and moves rapidly across the sky. However, Venus may lie too close to the Sun to be easily visible.

To locate the planets, you can look in an almanac, which will tell you what constellation the planet is in on the day you are observing. You may also find this information in the local newspaper; or you can ask your instructor to mark off the planet's approximate position on the star chart to get you started. Because the outer planets move relatively slowly across the sky, you should space out your observations, perhaps marking positions once a week rather than every night.

As you progress in your project, you might ask whether the planets really follow the ecliptic! Can you see retrograde motion?

2. Motion of the stars across the sky. Many people are startled when they are told that the stars move across the sky the same way that the Sun does. However, it is easy to show that they do. Get a stick that you can poke into the ground so it will stand upright. Get a second smaller stick that you can tape or affix to the upright in some manner. A ruler taped to a camera tripod would be ideal, as sketched in Project figure 1.1.

Evening – Looking East

PROJECT FIGURE 1.1
Sketch illustrating how to observe the motion of the stars across the sky by sighting along a stick.

(continued)

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