Discovering the Essential Universe

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PREFACE

I wrote *Discovering the Essential Universe* to fill the need for a shorter, less expensive text with streamlined presentation of topics. The text was designed for instructors who have developed all their own teaching tools and prefer a book with only the essential information for their students' reference, enrichment and review. This book does not rely on technology and is perfectly suited for the instructor who wants complete flexibility in excluding or including a technology component in their course. Optional student study resource and activity material is available on the *Discovering the Essential Universe* Web site.

Discovering the Essential Universe evolved from my perceptions of the backgrounds, needs and expectations of over 7000 students to whom I have taught introductory astronomy over the last twenty years and my experience writing my other text, *Discovering the Universe* (DTU). Like my text DTU, *Discovering the Essential Universe* offers the same solid content and same lavish illustration program. *Discovering the Essential Universe* however, is briefer by over 100 pages and the book omits all pedagogy linking the text to a multimedia component. Other pedagogy potentially interrupting the flow of the main content of each chapter has also been kept to a minimum. This presentation allows for an efficient progression through the text content. The following are some of the specific steps taken to create the streamlined presentation of *Discovering the Essential Universe:*

★ The Foundations material upon which the four sections of DTU were built have been incorporated into the most convenient chapters. This cuts down on confusion some students had as to whether or not the Foundation material is really necessary.

★ The chapter on gravitation has been moved closer to the chapters on the solar system to help provide an easy transition from the theory of gravity through the formation of the solar system and into a study of the solar system's objects.

★ All the planets are presented in a single chapter to emphasize their similarities and differences.

★ Black holes have been put in the chapter on stellar deaths, since most black holes are stellar remnants.

Even though *Discovering the Essential Universe* is a new and briefer text, it still maintains the themes and approach to astronomy presented in my longer text. This book also provides a broad overview of the cosmos, from our nearest neighbors in the solar system to the secrets in the cores of distant galaxies to the origin and evolution of the universe. Moreover, it is designed to show that the physical laws governing distant stars and planets are the same as those that affect our lives on Earth.

To The Student

The Study of Astronomy

People study astronomy for a wide variety of reasons. For some it is a lifelong passion for the beauty of the sky and to understand how the Earth and universe got here. For others it is only a passing interest, maybe to fill a college science requirement. Regardless of the reason you have come to astronomy—you've come at the right time and to the right place. The range of topics that astronomers understand has skyrocketed in the last few decades. What you will be learning from *Discovering the Essential Universe* is far more accurate—and breathtaking—than the astronomy that your parents, your grade school teachers, or even your older siblings learned.

Your study of astronomy will begin with what people have seen for millennia. As a result, you will be starting with familiar sights and concepts related to naked-eye astronomy, moving into realms visible only through telescopes and which you may know less well. We explore the nature of light and how telescopes work, along with how stars and other astronomical bodies emit light and other radiation. This is followed by a study of the nature of gravity, and its effects on the planets and other bodies. With this physics under your belt, we next study the solar system, starting with the Earth and Moon. We explore each of the planets and their moons, then the smaller bodies in the solar system, and finally the Sun. Moving outward, we describes the nature and evolution of stars, including a discussion of black holes. Expanding even further, we encounter the Milky Way and other galaxies, quasars, and the entire universe. The book ends by exploring the age-old question of whether there is other life in the universe.

Scientists and Their Discoveries

Equally important to learning current knowledge about astronomy, you will see how science works and how discoveries in science are made—using careful observations, increasingly sensitive instruments, and constantly refined scientific models. The **"Insights Into Science"** scattered throughout the book reveal the approaches scientists use to uncover nature's secrets. At the beginning of a new century, we have amassed enough technology and trained so many scientists that astronomers are making new discoveries about the universe almost every day.

Examining Misconceptions Promotes Real Understanding

Discovering the Essential Universe also addresses misconceptions, deep-seated beliefs that are inconsistent with accepted scientific knowledge. These incorrect beliefs begin in childhood and are *inevitable* as we each struggle to understand our complex environment. Possessing incorrect beliefs does not imply that we are either naive or incapable of learning; rather, it shows how fertile and active are our minds. My research into misconceptions about astronomy has led me to identify over fifteen hundred of them, along with their origins and common reasoning that leads to incorrect beliefs.

The origins of misconceptions are numerous. Many occur because the laws of nature are often so counterintuitive, defying our common sense. Others occur because we misinterpret what our senses tell us. Still others occur because sources of scientific information are often incomplete or inaccurate, such as from television and the movies. Raise your hand if you believe that asteroids are crowded together as they were depicted in the movie *The Empire Strikes Back* from the *Star Wars* trilogy. They are not. Others occur because we misuse analogies and other common reasoning tools. For example, in analogy with being warmer the closer you are to a fire, it makes sense that the summer is hotter than the winter because we are closer to the Sun during the summer. However, that analogy is completely wrong – we are closest to the Sun in January!

To help you become aware of your beliefs, I present a series of numbered questions at the beginning of each chapter under the heading **What Do You Think?** Each question addresses a very common misconception. I urge you to honestly consider your own answers before reading the chapter. When the correct science is presented in the chapter, an icon with the corresponding number appears in the margin. The same questions and their answers are finally listed under the heading **What Did You Think?** at the end of each chapter. If you were wrong, please think about where your ideas came from and how the incorrect information has distorted your understanding of the natural world. Questioning old beliefs is extremely difficult and often disconcerting, but it prepares us to deal with the world rationally.

Learning Tools

People learn in different ways. Some of you are visual learners, while others rely more heavily on text. Several features of this book were designed to help you more easily understand and retain what you learn:

★ Full-sentence headings introduce each topic. Taken together later, they will also provide an outline for reviewing what you have learned. In addition, numbered, full-sentence headings are now grouped beneath a broader main heading of only a word or two.

★ When important astronomical terms are introduced, they appear in **boldface** type. Key terms are again defined in the Glossary.

★ Important terms not included in the glossary are first presented in *italics,* as are especially important concepts.

★ Review Questions at the end of the book and listed chapter by chapter will stimulate you to explore the important ideas presented here.

★ Illustrations designed to reinforce what the words say help you see processes step by step, and deepen your understanding. Astronomers view the universe through instruments that detect light at wavelengths our eyes cannot see. Wavelength tabs, RIVUXG, highlight in red the portion of the electromagnetic spectrum (R = radio waves, I = infrared radiation, V = visible light, U = ultraviolet radiation, X = X rays, and G = gamma rays) used to create the photos that illustrate each topic.

In addition to the above, a rich source of student study resource and activity material will be available for instructors and student, on the *Discovering the Essential Universe* Web site.

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Every effort has been made to make this book as error-free as possible. Nevertheless, some inaccuracies have inevitably crept in. I would appreciate hearing from you if you find an error or wish to comment on the book.

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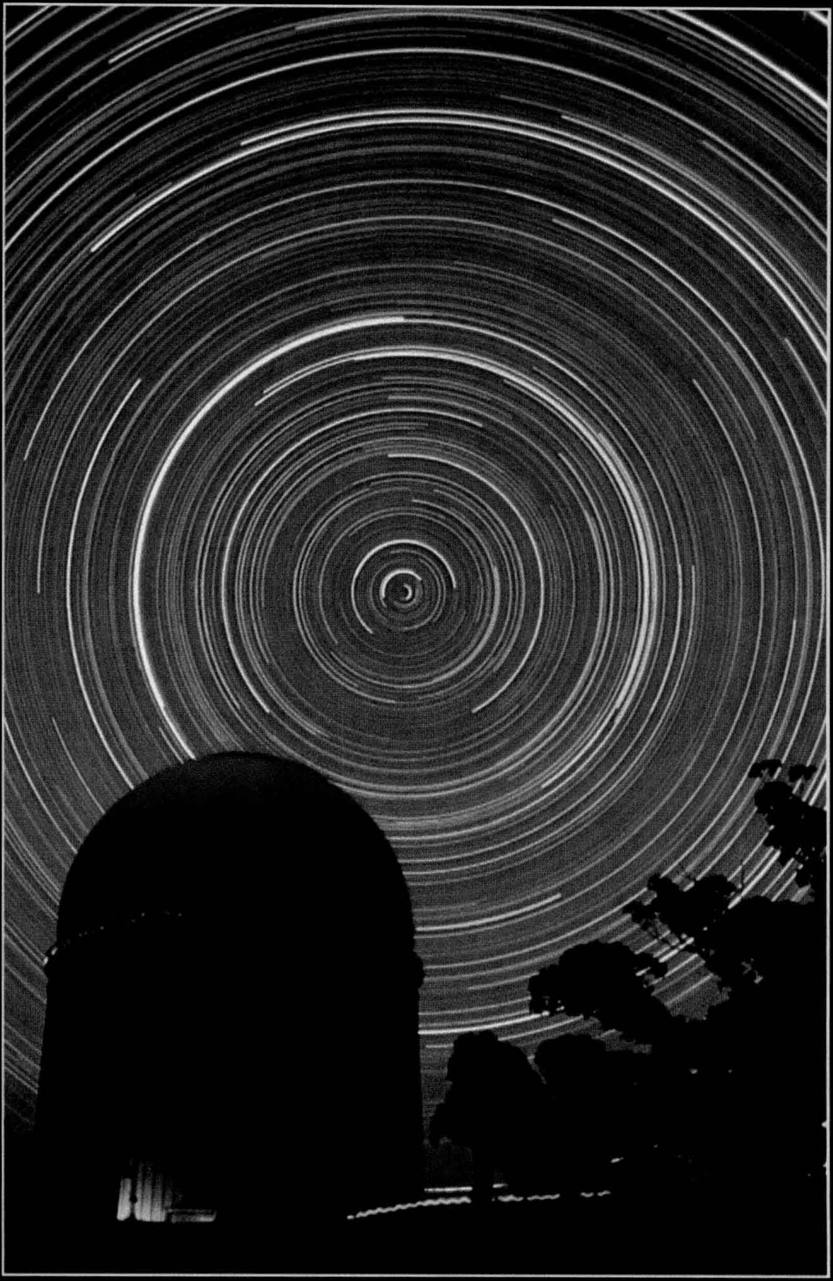
Text Overview

1 Discovering the Night Sky

In this chapter you will discover

- the scientific process astronomers use to study the universe
- how astronomers map the night sky to help them locate objects in it
- that the Earth's spin on its axis causes day and night
- how the tilt of the Earth's axis of rotation and the Earth's motion around the Sun combine to create the seasons
- that the Moon's orbit around the Earth creates the phases of the Moon and lunar and solar eclipses
- how the year is defined and how the calendar was developed



R I V U X G

Circumpolar Star Trails

This long exposure, taken from Australia's Siding Spring Mountain and aimed at the south celestial pole, shows the rotation of the sky. The building in the foreground houses the Anglo-Australian Telescope, one of the largest telescopes in the southern hemisphere. During the exposure, someone carrying a flashlight walked along the catwalk on the outside of the telescope dome. Another flashlight made the wavy trail at ground level.

WHAT DO YOU THINK?

1 What makes a theory scientific?

2 What do astronomers do?

3 Why is astronomy worth learning?

4 Is the North Star—Polaris—the brightest star in the night sky?

5 Do astronomers regard constellations as simply the familiar patterns of stars in the sky first identified by ancient stargazers?

6 What causes the seasons?

7 How many zodiac constellations are there?

8 Does the Moon have a dark side that we never see from Earth?

9 Is the Moon ever visible during the daytime?

Look for answers beside the boxed numbers in the text margins.

R I V U X G

Figure 1-1 **The Starry Sky** Daylight hides all signs of the stars and other wonders shining above the sky's azure curtain. Our thoughts about the universe overhead focus on the Sun, the Moon, and our ever-changing weather. But, ah, the night! No light show, artist's brush, or poet's words can truly capture the beauty of this breathtaking panorama. This photograph was taken in the Saguaro National Park, Arizona.

For thousands of years people have looked up at the sky and found themselves inspired to contemplate the nature of the universe. How was it created? Where did the Earth, Moon, and Sun come from? What are the planets and stars made of? What are our place and role in the cosmic scope of space and time?

The beauty of the star-filled night sky or the drama of an eclipse alone makes astronomy fascinating (Figure 1-1). But there are also practical reasons for an interest in the universe. The ancient Greeks knew the connection between the changing height of the noontime Sun and the different patterns of stars in the night throughout the year. This information enabled them to predict the seasons, a useful skill for farming. Many early seafaring cultures were also aware that the positions of the Moon and Sun influence the tides; this knowledge helped these people plan and navigate sailing voyages.

1-1 The universe is comprehensible

What causes these relationships between the Earth and heavenly bodies? Astronomical phenomena were first explained as the result of supernatural forces and divine intervention. The heavens were thought to be populated by demons and heroes, gods and goddesses. Yet, despite superstitious beliefs, some people have always realized that the universe is logical and comprehensible. Astronomical cycles, such as the seasons, the reappearance of stars, the tides, and day and night, led many early societies to study the patterns and motions found in the night sky. Progress in science is embodied in improved technology, such as the invention of the telescope. Improvements in technology have in turn led to further discoveries about the fundamental laws of **physics,** the science that investigates the nature of matter and energy and the relationships between them.

This section begins with the "everyday" aspects of astronomy, from naked-eye observations of the sky to the motion of the planets and the use of telescopes to widen our vistas. You will discover the process scientists use to explore natural phenomena through systematic observations and refined theories, and you will see how the knowledge gained by the scientific study of astronomy has led to an understanding of events and phenomena that our ancestors never could have imagined.

1-2 Science demands systematic observations

1 Astronomers gain knowledge by using the **scientific method** to observe, predict, and explain physical reality. Observations lead scientists to create a **scientific theory,** an idea or collection of ideas that proposes to explain the observed phenomenon. Scientific theories are expressed mathematically as **models.** For example, Newton's law (or theory, as such ideas are now called) of gravity is written as an equation that predicts how bodies attract each other. This model predicts that the Sun's gravitational force makes the planets move in elliptical orbits.

A scientific theory can be independently tested and potentially disproved. Newton's ideas can be tested and potentially disproved by observations and thus qualify as scientific theory. The idea that God created the Earth in six days cannot be tested, much less disproved. It is not a scientific theory but rather a matter of faith.

Scientific theories also make testable *predictions* that can be verified using new observations and experiments. Testing is a crucial aspect of the scientific method, which requires that the theory accurately forecast the results of new observations in its realm of validity.

If a theory proves inconsistent with observations, then the theory is either modified, applied only in limited circumstances, or discarded in favor of a more accurate explanation. For example, Newton's law of gravitation is entirely adequate for describing the motion of the Space Shuttle around the Earth or the Earth around the Sun, but it is inaccurate in the vicinity of a black hole, where matter is especially dense. In this latter realm, Newton's law of gravitation is supplanted by Einstein's theory of general relativity, which accurately describes gravitational behavior in a much wider range of conditions than Newton's, at the cost of greater mathematical complexity. When applied to the motion of the Earth around the Sun, general relativity gives the same results as Newton's law of gravitation.

Insight into science **Theories and beliefs** New theories are personal creations, but science is not a personal belief system. Scientific theories make predictions that can be tested independently. If everyone who performs tests of the theory's predictions gets results consistent with the theory, the theory is considered valid. In comparison, belief systems such as which sports team or political system is best are personal matters. People will always hold differing opinions about such issues.

Astronomy is the most engaging of the physical sciences because so much that we observe through telescopes is surrounded with mystery. We see so many objects, but we see them all from one vantage point in space and time, and, therefore, we cannot always be certain of their true shape and form or of their history. In applying the scientific method to astronomy, we necessarily form theories based on this limited observational data and hope that in time additional observations will substantiate these theories.

Many scientific theories discussed in the following chapters are supported by a broad range of observations while others are still largely unsubstantiated. These latter theories await confirming observations that may be made in the next few years or may prove to remain beyond our physical limits. Thus, the scientific method can be summarized in five words: observe, theorize, predict, test, modify. I urge you to watch for applications of the scientific method in action throughout this book.

The power of the scientific method was demonstrated centuries ago, during the late Renaissance, when a few

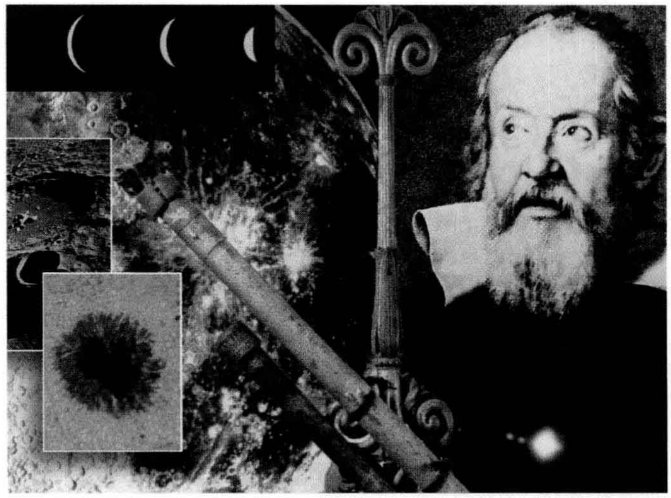


Figure 1-2 **Galileo's Telescope** When Galileo turned his telescope toward the sky in the early 1600s, he discovered craters on the Moon, spots on the Sun, the phases of Venus, and satellites orbiting Jupiter. These controversial discoveries flew in the face of conventional wisdom and threatened to undermine the teachings of organized religion of the time.

courageous scientists proposed that the Earth orbits the Sun. The prevailing belief system of the sixteenth century held that the Earth was the center of everything. This makes sense: To the untrained eye, all the astronomical objects appear to orbit our planet!

This Earth-centered theory ran into trouble when observations of the motions of the stars, planets, Moon, and Sun were shown to be inconsistent with the predictions of the theory. Centuries of modifications to the Earth-centered theory made it truly unwieldy, and even those changes could not keep it consistent with increasingly accurate observations. In the mid-1500s, the Polish mathematician Nicolaus Copernicus resurrected a theory first proposed nearly 15 centuries earlier—that the Earth orbits the Sun. He was motivated by an effort to simplify the celestial scheme. This Sun-centered theory of the known universe gained strength when Italian scientist Galileo Galilei (Figure 1-2), the first person to point a telescope toward the sky, saw the moons of Jupiter orbit that planet. This discovery flew in the face of the Earth-centered theory and fueled the search to discover the relationship between the Earth and the rest of the cosmos.

Insight into science **Shedding misconceptions** Ideally, a scientist must be willing to discard even the most cherished theories if they fail to agree with observation and experiment. However, scientists are human; they have beliefs that they are loath to let go. Often a disproved theory, such as the belief that the Earth is at the center of the universe, dies only with its advocates.

1-3 Powers of ten notation

Astronomy is a quantitative science; its discoveries are based on facts and expressed in terms of numbers and associated units, like 1800 seconds or 8.3×10^{12} kilograms. The incredible ranges of distances, sizes, and masses in astronomy require a shorthand for large and small numbers called "powers of ten" or **scientific notation.**

Astronomy is a science of extremes. As we examine various cosmic environments, we find an astonishing range of conditions, from the incredibly hot, dense centers of stars to the frigid, near-perfect vacuum of interstellar space. To describe such divergent conditions accurately, we need a wide range of both large and small numbers. Astronomers avoid such confusing terms as "a million billion billion"(1,000,000,000,000,000,000,000,000) by using a standard shorthand system. All the cumbersome zeros that accompany such a large number are consolidated into one term consisting of 10 followed by an *exponent,* which is written as a superscript and called the **power of ten.** The exponent merely indicates how many zeros you would need to write out the long form of the number. Thus,

$$10^0 = 1$$
$$10^1 = 10$$
$$10^2 = 100$$
$$10^3 = 1000$$
$$10^4 = 10{,}000$$

and so forth. The exponent tells you how many tens must be multiplied together to yield the desired number. For example, ten thousand can be written as 10^4 ("ten to the fourth") because $10^4 = 10 \times 10 \times 10 \times 10 = 10{,}000$. Similarly, 273,000 can be written 2.73×10^5.

In scientific notation, numbers are written as a figure between 1 and 10 multiplied by the appropriate power of 10. The distance between the Earth and the Sun, for example, can be written as 1.5×10^8 km. Once you get used to it, you will find this notation more convenient than writing "150,000,000 kilometers" or "one hundred and fifty million kilometers."

This powers-of-ten system can also be applied to numbers that are less than 1 by using a minus sign in front of the exponent. A negative exponent tells you that the location of the decimal point is as follows:

$$10^0 = 1$$
$$10^{-1} = 0.1$$
$$10^{-2} = 0.01$$
$$10^{-3} = 0.001$$
$$10^{-4} = 0.0001$$

and so forth. For example, the diameter of a hydrogen atom is 1.1×10^{-8} cm. That is more convenient than saying "0.000000011 centimeter" or "11 billionths of a centimeter." Similarly, .000728 equals 7.28×10^{-4}.

Using the powers-of-ten shorthand, one can write large or small numbers like these compactly:

$$3{,}416{,}000 = 3.416 \times 10^6$$
$$0.000000807 = 8.07 \times 10^{-7}$$

Because powers-of-ten notation bypasses all the awkward zeros, a wide range of circumstances can be numerically described conveniently:

$$\text{one thousand} = 10^3$$
$$\text{one million} = 10^6$$
$$\text{one billion} = 10^9$$
$$\text{one trillion} = 10^{12}$$

and also

$$\text{one thousandth} = 10^{-3} = 0.001$$
$$\text{one millionth} = 10^{-6} = 0.000001$$
$$\text{one billionth} = 10^{-9} = 0.000000001$$
$$\text{one trillionth} = 10^{-12} = 0.000000000001$$

Figure 1-3 shows how clearly the powers-of-ten notation expresses the scale of objects, ranging from subatomic particles like the proton to the size of the observable universe.

We will also use the metric system of units, which is now standard in science. Table 1-1 lists some comparisons and conversions between metric and the traditional British units of measure.

Table 1-1
Common Conversions Between British and Metric Units

1 inch	=	2.54 centimeter (cm)
1 cm	=	.394 inches
1 yard	=	.914 meters (m)
1 meter	=	1.09 yards = 39.37 in
1 mile	=	1.61 kilometer (km)
1 km	=	.621 miles

1-4 Astronomical distances

Throughout this book we will find that some of our traditional units of measure become cumbersome. It is fine to use kilometers to measure the diameters of craters on the Moon or the heights of volcanoes on Mars. However, it is as awkward to use kilometers to express distances to planets, stars, or galaxies as it is talk about the distance from New York City to San Francisco in millimeters. Astronomers have therefore devised new units of measure.

When discussing distances across the solar system, astronomers use a unit of length called the **astronomical**

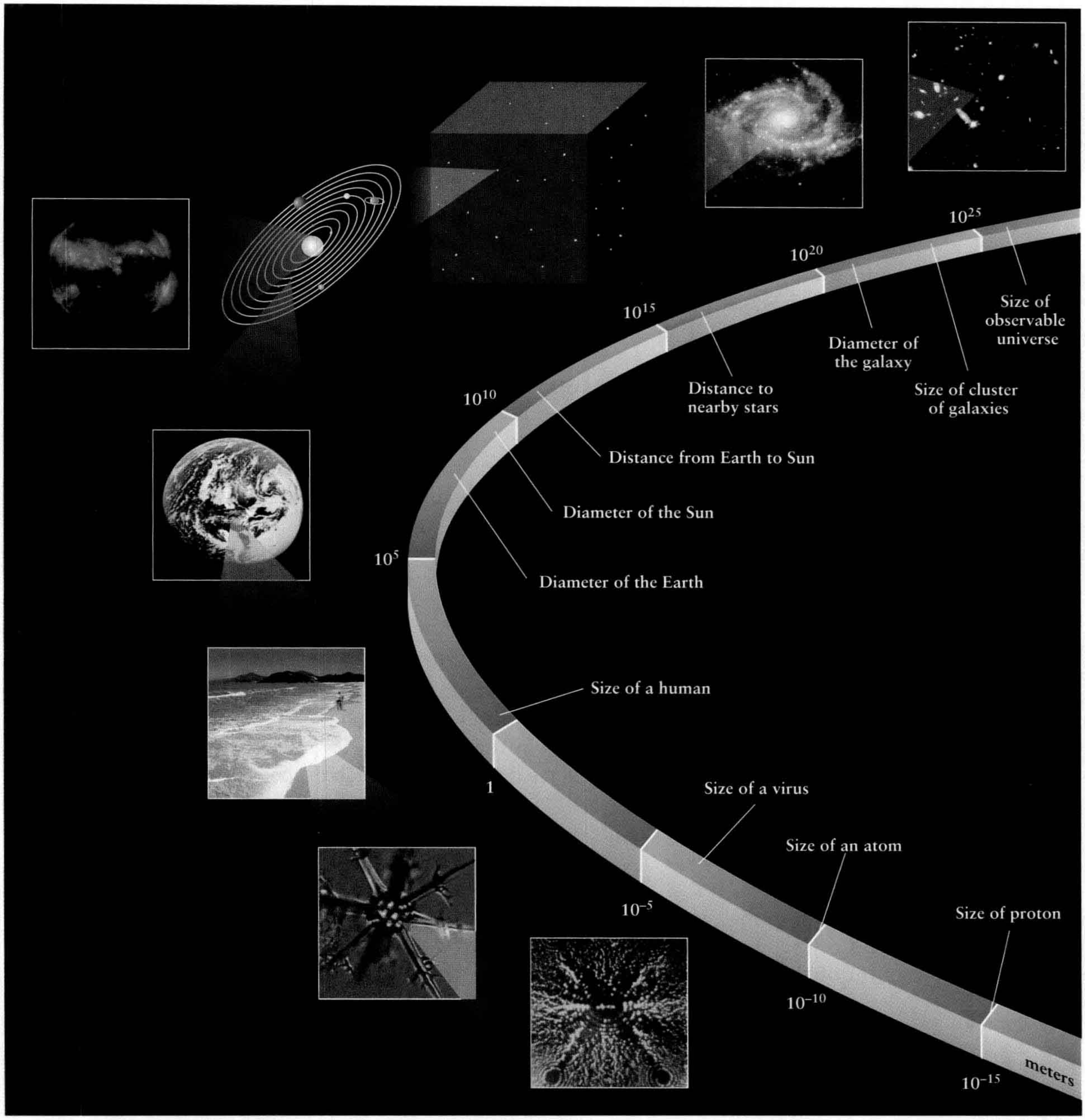


Figure 1-3 **Examples of Powers-of-Ten Notation** The scale gives the sizes of objects in meters, ranging from subatomic particles at the bottom to the entire observable universe. Keep in mind that every 0.56 cm up along the arc represents a factor of 10 larger.

unit (AU), which is the average distance between the Earth and the Sun:

$$1 \text{ AU} \approx 1.5 \times 10^8 \text{ km} \approx 9.3 \times 10^7 \text{ miles}$$

Jupiter, for example, is an average of 5.2 times farther from the Sun than is the Earth. Thus, the distance between the Sun and Jupiter can be conveniently stated as 5.2 AU. This can be converted into kilometers or miles using the relationship above.

When talking about distances to the stars, astronomers choose between two different units of length. One is the **light-year (ly)**, which is the distance that light travels in a vacuum (in the absence of air) in one year:

$$1 \text{ ly} \approx 9.46 \times 10^{12} \text{ km} \approx 63{,}000 \text{ AU}$$

One light-year is roughly equal to six trillion miles. Proxima Centauri, the star nearest to our solar system, is just over 4.2 ly from Earth.

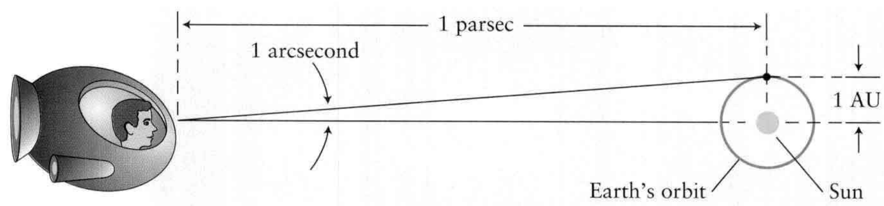


Figure 1-4 **A Parsec** The parsec, a unit of length commonly used by astronomers, is equal to 3.26 ly. The parsec is defined as the distance at which 1 AU perpendicular to the observer's line of sight makes an angle of 1 arcsecond.

The second commonly used unit of length is the **parsec (pc)** (the distance at which two objects separated by 1 AU make an angle of 1 arcsecond). Imagine taking a journey far into space, beyond the orbits of the outer planets. Watching the solar system as you move away, the angle between the Sun and the Earth becomes smaller and smaller. When the Sun and Earth are side by side and you measure the angle between them as 1/3600° (called 1 arcsecond), you have reached a distance astronomers call 1 parsec, as shown in Figure 1-4. The parsec turns out to be longer than the light-year. Specifically,

$$1 \text{ pc} \approx 3.09 \times 10^{13} \text{ km} \approx 3.26 \text{ ly}$$

Thus, the distance to the nearest star can be stated as 1.3 pc as well as 4.2 ly. Whether one uses light-years or parsecs is a matter of personal taste.

For even greater distances, astronomers commonly use *kiloparsecs* (kpc) and *megaparsecs* (Mpc), in which the prefixes simply mean "thousand" and "million," respectively:

$$1 \text{ kpc} = 10^3 \text{ pc}$$
$$1 \text{ Mpc} = 10^6 \text{ pc}$$

For example, the distance from Earth to the center of our Milky Way Galaxy is about 8.6 kpc, and the rich cluster of galaxies in the direction of the constellation Virgo is 20 Mpc away.

1-5 Astronomers do much more than just make observations

2 The process of astronomical discovery involves much more than observing and recording the heavens. The research activities of astronomers today fall into three rough categories: observing, recording, and analyzing observations; theorizing; and computer modeling. Most people think that an astronomer spends his or her time observing the sky, spending long nights directing the most powerful eyes on Earth to reveal the secrets of space. In reality, research telescopes are constantly booked, and most astronomers who get observing time—even a few weeks each year—consider themselves very lucky.

Planning observations and analyzing data takes up the majority of an observational astronomer's time. Most observational astronomers use data-collecting equipment provided by research observatories, but some design and build their own specialized apparatus, which they then connect to existing telescopes.

Other astronomers, theoreticians called *astrophysicists*, never use telescopes. Rather, they hypothesize or expand on theories in an effort to explain the observations of others. Some astrophysicists construct computer models to predict outcomes based upon existing theories.

Astronomical discovery is always exciting and sometimes totally unexpected. Unusual observations often lead astronomers and astrophysicists in new directions of research as they try to explain what they see or reconcile apparent contradictions between theories and observations. For example, astronomers recently observed evidence that neutrinos, particles created inside stars and previously believed to be massless, actually have mass. If confirmed, this result will have a major impact on theories about the evolution and fate of the entire universe.

3 In turn, the theories developed to explain the universe have led to a much deeper and richer understanding of the Earth. Many people think that astronomy deals only with the faraway and is of no significance to everyday life. But consider, as one example among many, how Newton's law of gravitation explains both the motions of the planets and also why we and everything around us is held to the Earth's surface. Gravity also explains the time it takes an egg falling off a table to hit the floor and the hang time for basketball players under the net. By understanding the law of gravitation, engineers can control the friction between your car's tires and the road or design an airplane wing to lift a jumbo jet. We begin our discovery of the universe where astronomy began, by exploring the night sky.

When you gaze at the sky on a clear, dark night, there seem to be millions of stars twinkling overhead. In reality, the unaided human eye can detect only about 6000 stars over the entire sky. At any one time, you can see roughly 3000 stars in dark skies, because only half of the stars are above the horizon, the boundary between the Earth and the sky.

You probably have noticed patterns formed by bright stars and are probably familiar with some common names for these patterns, such as the bowl-shaped Big Dipper and broad-shouldered Orion. These recognizable patterns of stars, which we call constellations in everyday conversation, have names derived from ancient legends (Figure 1-5a).

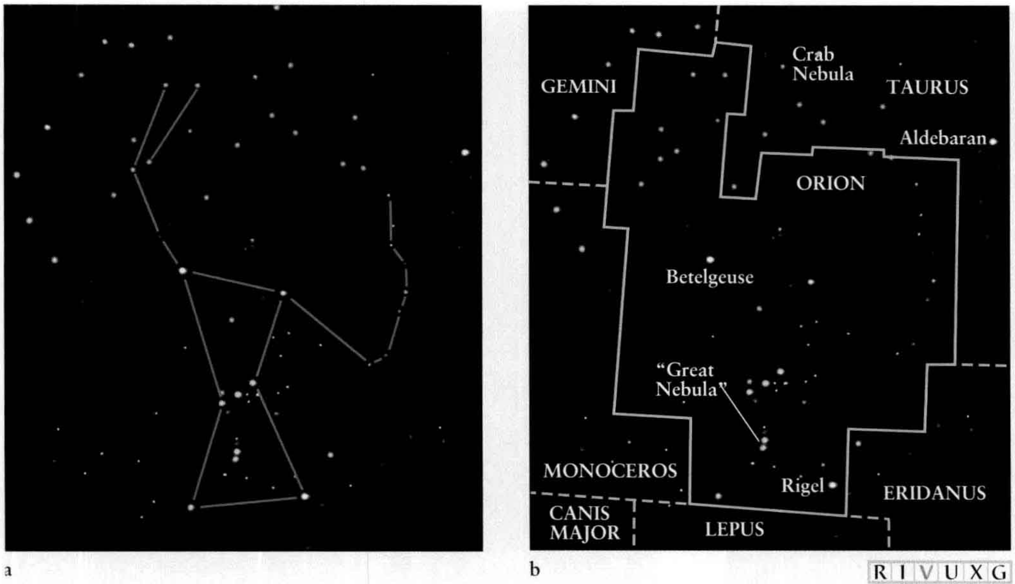


Figure 1-5 **The Constellation Orion** **(a)** The pattern of stars called Orion is a prominent winter constellation. From the United States, it is easily seen high above the southern horizon from December through March. You can see in this photograph that the various stars have different colors, something to watch for when you observe the night sky. **(b)** The region of the sky called Orion and parts of other nearby constellations are depicted on this photograph. *All* the stars inside the boundary of Orion are members of that constellation. The celestial sphere is covered by 88 constellations of differing sizes and shapes.

Patterns of Stars

1-6 Constellations make locating stars easy

You can orient yourself on Earth with the help of easily recognized constellations. For instance, if you live in the northern hemisphere, you can use the Big Dipper to find the direction north. To do this, locate the Big Dipper and imagine that its bowl is resting on a table. If you see the Dipper upside down in the sky, as you frequently will, imagine the dipper resting on an upside-down table above it. Locate the two stars of the bowl farthest from the Big Dipper's handle. These are called the *pointer stars*. Draw a mental line through these stars leading away from the table, as shown in Figure 1-6. The first
4 *moderately bright* star you then encounter is Polaris, also called the North Star because it is located almost directly over the Earth's north pole. So, while Polaris is not even among the 20 brightest stars (Appendix Table A-5), it *is* easy to locate. Whenever you face Polaris, you are facing north. East is then on your right, south is behind you, and west is on your left.

The Big Dipper example illustrates the fact that easily recognized constellations make it easy to locate other stars. The most effective way to do this is to use vivid visual connections, especially those of your own devising. For example, imagine gripping the handle of the Big Dipper and slamming its bowl through the imaginary table and onto the head of Leo (the Lion). Leo comprises the first group of bright stars your dipper encounters. As shown in Figure 1-6, the brightest star in this group is Regulus, the dot of the backward question mark that traces the lion's mane. As another example, put the Big Dipper back on its table and then follow the arc of its handle away from its bowl. The first bright star you encounter along that arc beyond the handle is Arcturus in Boötes (the Shepherd). Follow the same arc further to the prominent bluish star Spica in Virgo (the Virgin). Spotting these stars is easy if you remember the saying "Arc to Arcturus and speed on to Spica."

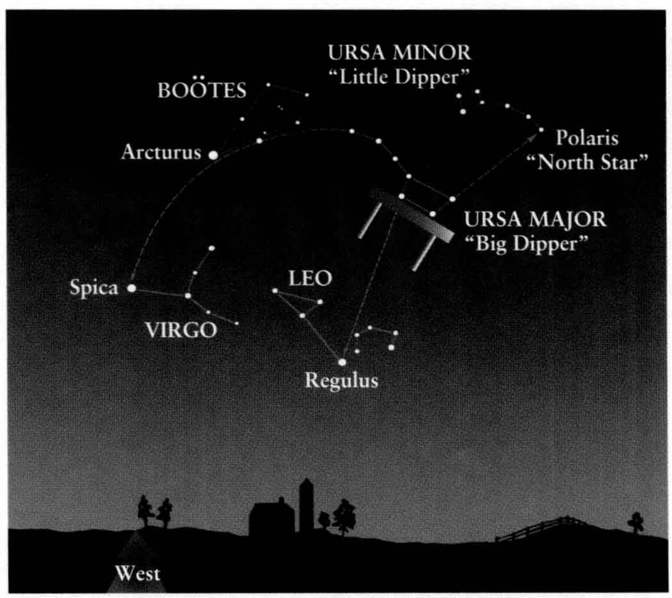


Figure 1-6 **The Big Dipper as a Guide** In the northern hemisphere, the Big Dipper is an easily recognized pattern of seven bright stars. This star chart shows how the Big Dipper can be used to point out the North Star as well as the brightest stars in three other constellations. Note that the Big Dipper appears right side up in this drawing, but at other times of the night it appears upside down. Why do you suppose this happens?

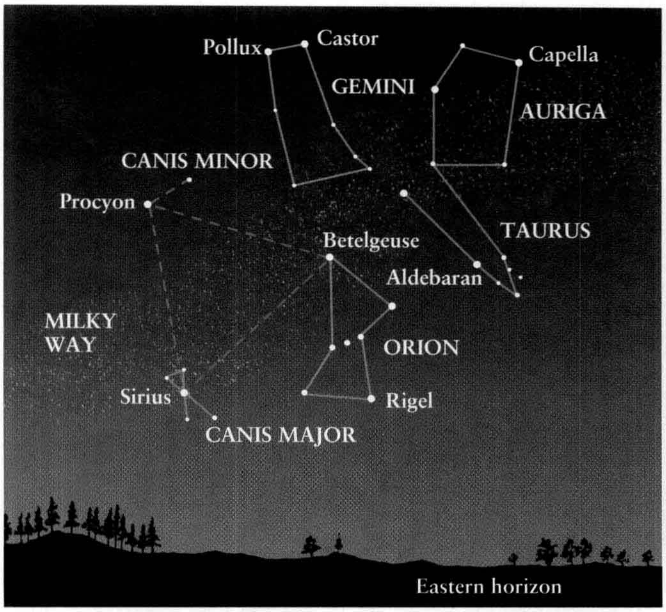


Figure 1-7 **The Winter Triangle** This star chart shows the eastern sky as it appears during the evening in December. Three of the brightest stars in the sky make up the winter triangle. In addition to the constellations involved in the triangle, Gemini (the Twins), Auriga (the Charioteer), and Taurus (the Bull) are also shown.

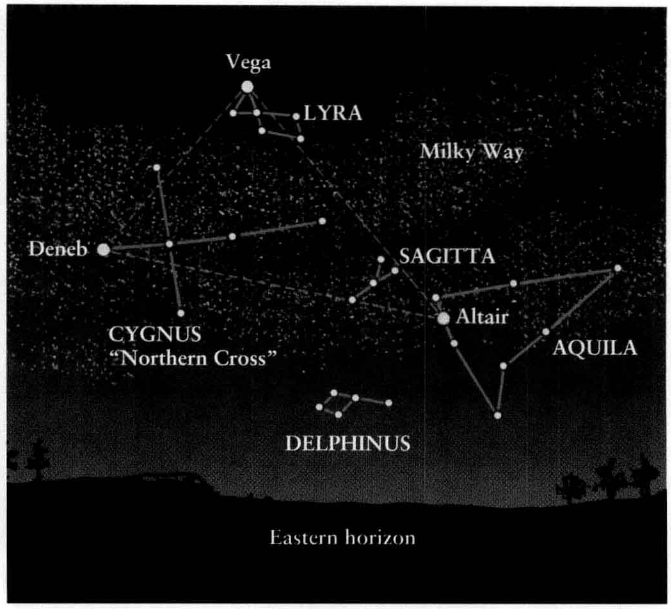


Figure 1-8 **The Summer Triangle** This star chart shows the northeastern sky as it appears in the evening in June. In addition to the three constellations involved in the summer triangle, the faint stars in the constellations of Sagitta (the Arrow) and Delphinus (the Dolphin) are also shown.

During the winter months in the northern hemisphere, you can see some of the brightest stars in the sky. Many of them are in the vicinity of the "winter triangle," which connects bright stars in the constellations of Orion (the Hunter), Canis Major (the Large Hunting Dog), and Canis Minor (the Small Hunting Dog), as shown in Figure 1-7. The winter triangle is nearly overhead during the middle of winter at midnight. It is easy to find Sirius, the brightest star in the night sky, by locating the belt of Orion and following a straight mental line from it to the left (as you face Orion). The first bright star you encounter is Sirius.

Insight into science **Flexible thinking** Part of learning science is learning to look at things from different perspectives. For example, when learning to identify the prominent constellations, be sure to learn them from different orientations (that is, with the star chart rotated at different angles), so that you can find them at different times of the night and the year.

The "summer triangle," which graces the summer sky as shown in Figure 1-8, connects the bright stars Vega in Lyra (the Harp), Deneb in Cygnus (the Swan), and Altair in Aquila (the Eagle). A conspicuous portion of the Milky Way forms a beautiful background for these constellations, which are nearly overhead during the middle of summer at midnight.

Astronomers require more accuracy in locating dim objects than is possible simply by moving from constellation to constellation. They have therefore created a celestial map and applied a coordinate system to it, analogous to the coordinate system of north-south latitude and east-west longitude used to navigate on the Earth. If a star's celestial coordinates are known, it can then be quickly located. For such a sky map to be useful in finding stars, the stars must be fixed on it as cities are fixed on maps of the Earth.

1-7 The celestial sphere aids in navigating the sky

If you look at the night sky year after year, you will see that the stars do indeed appear fixed relative to each other. Furthermore, throughout each night the entire pattern of stars appears to rigidly orbit the Earth. We employ this Earth-based view of the heavens to make celestial maps by pretending that the stars are attached to the inside of an enormous hollow shell, the **celestial sphere,** with the Earth at its center (Figure 1-9).

5 We discussed the common usage of the word *constellation* at the beginning of this chapter. Astronomers technically use the word to describe an entire region of the

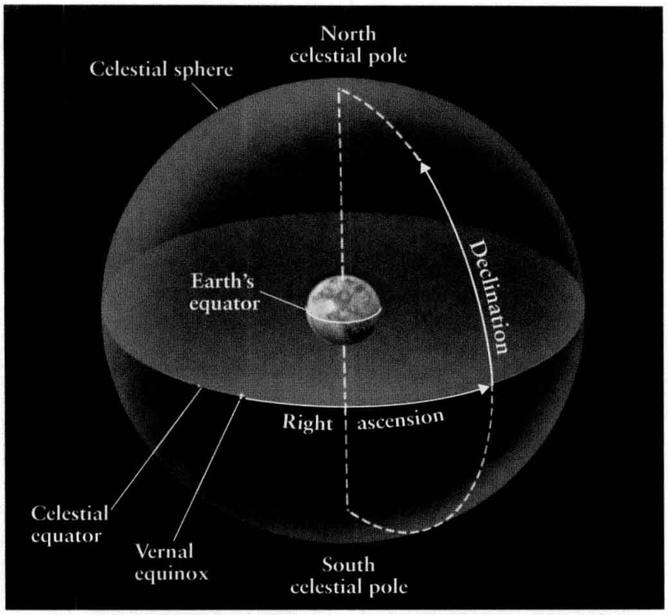


Figure 1-9 **The Celestial Sphere** The celestial sphere is the apparent "bowl" or hollow sphere of the sky. The celestial equator and poles are projections of the Earth's equator and axis of rotation out into space. The north celestial pole is therefore located directly over the Earth's north pole, while the south celestial pole is directly above the Earth's south pole.

sky and all the objects in that region (see Figure 1-5b). The celestial sphere is thereby divided into 88 unequal regions, and these regions are what astronomers refer to when they use the term **constellations.** (Astronomers call the traditional star patterns *asterisms* rather than constellations when there is a danger of confusion.) Some constellations (like Ursa Major) are very large, while others (like Sagitta) are relatively small. To locate stars, we might say "Albireo in the constellation Cygnus," much as we would refer to "Ithaca in New York State."

The stars seem fixed on the celestial sphere only because of their remoteness. In reality, they are at widely varying distances from the Earth, and they do move relative to each other. But we neither see their motion nor perceive their relative distances because the stars are so far from here. You can understand this by imagining a jet plane traveling at 1000 kilometers (620 miles) an hour roaring just overhead. Its motion is unmistakable. But the same plane, moving at the same speed, barely seems to budge when located along the distant horizon.

The stars (other than the Sun) are all more than 40 trillion kilometers (25 trillion miles) from us. Therefore, although the patterns of stars in the sky do change, their great distances prevent us from seeing those changes over the course of a human lifetime. Thus, as unrealistic as it is, the celestial sphere is so useful for navigating the heavens that it is used by astronomers even at the most sophisticated observatories around the world.

As shown in Figure 1-9, we can project key geographic features from Earth out into space to establish directions and bearings. If we expand the Earth's equator onto the celestial sphere, we obtain the **celestial equator.** The celestial equator divides the sky into northern and southern hemispheres, just as the Earth's equator divides the Earth into two hemispheres. We can also imagine extending the Earth's north and south poles out into space along the Earth's axis of rotation. Doing so gives us the **north celestial pole** and the **south celestial pole,** also shown in Figure 1-9. With the celestial equator and poles as reference features, astronomers denote the position of an object in the sky in much the same way that latitude and longitude are used to specify a location on Earth.

Just as we need two coordinates (latitude and longitude) to find any location on Earth, two coordinates are needed to locate any object on the celestial sphere. The equivalent to latitude on Earth is **declination** on the celestial sphere. It is measured north or south of the celestial equator. The equivalent of longitude on Earth is **right ascension** on the celestial sphere, measured around the celestial equator (Figure 1-9).

We will see later in this chapter that the Sun moves in a closed line around the celestial sphere during the course of a year. The celestial equator and the Sun's path intersect at two points. The equivalent on the celestial sphere of the Earth's prime meridian (from which degrees of longitude are measured on Earth) is where the Sun crosses the celestial equator moving northward. Angles of right ascension are measured from this point, called the *vernal equinox*. In navigating on the celestial sphere, astronomers measure the distance between objects in terms of angles.

1-8 Earth's rotation causes the stars to appear to move

The Earth spins on its axis. Such motion is called **rotation.** The Earth's 24-hour rotation causes the constellations—as well as the Sun, Moon, and planets—to appear to rise on the eastern horizon, move across the sky, and set on the western horizon. Bear in mind that the Sun and Moon rise due east and set due west only on certain days of the year. The **diurnal motion,** or daily motion, of the celestial bodies is apparent in time-exposure photographs, such as the one that opens this chapter. The Earth's rotation causes day and night because it makes the Sun appear to follow a diurnal path across the sky.

People who spend time outdoors at night are familiar with the diurnal motion of the stars. Take a friend outside on a clear, warm night to observe it for yourself. Soon after dark, find a spot away from bright lights and note the constellations in the sky relative to some prominent landmarks near you on Earth. A few hours later, check again from the same place. You will find that the entire pattern of stars (as