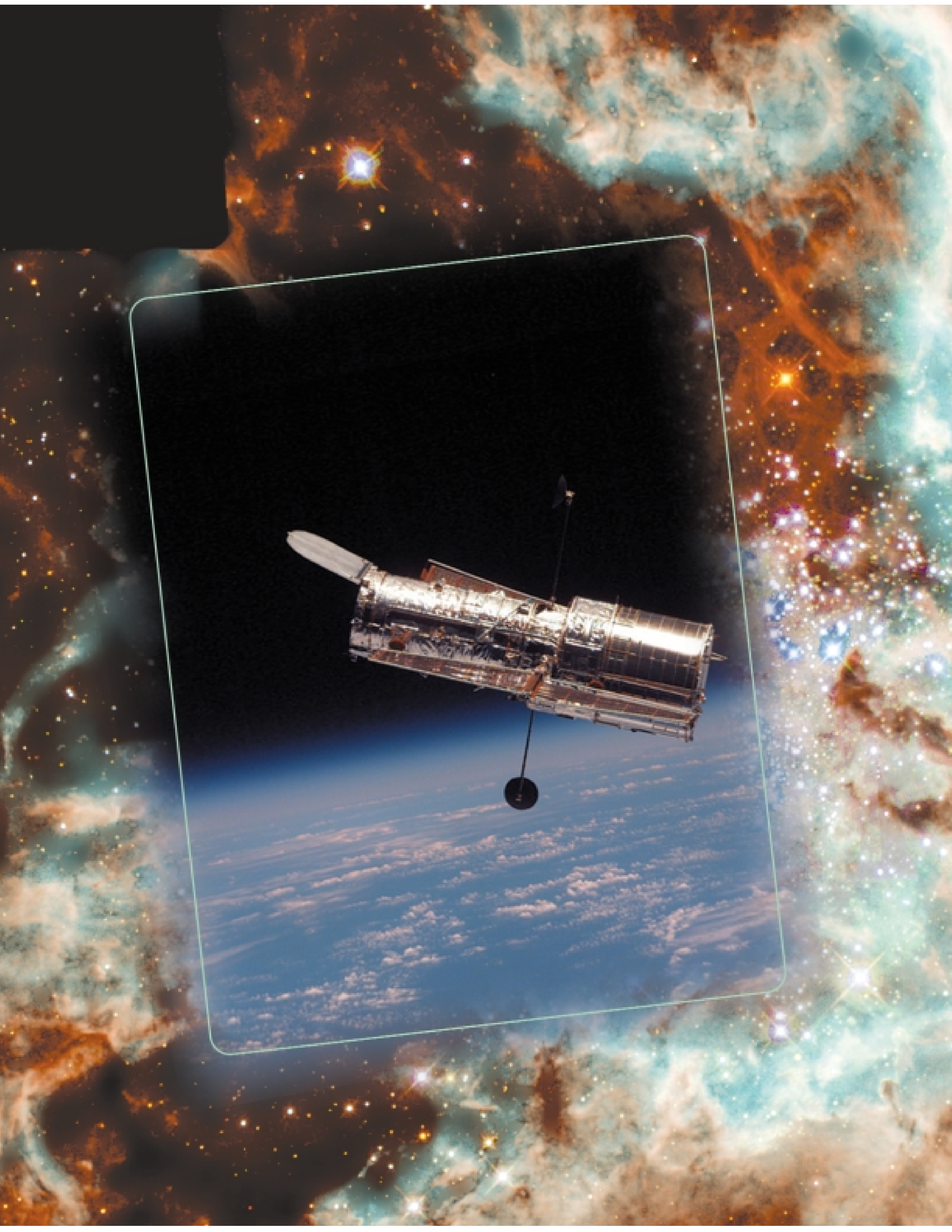


I ESSENTIALS FOR UNDERSTANDING ASTRONOMY

IN THIS SECTION OF THE BOOK YOU WILL DISCOVER

- the scientific process astronomers use to study the universe (Essentials I)
- how astronomers organize the night sky (Chapter 1)
- how the Earth's motion on its axis and its motion around the Sun cause changes on Earth and in what we see in the sky at night (Chapter 1)
- that the Moon's orbit causes eclipses and its changing phases (Chapter 1)
- Kepler's orbital laws and Newton's gravitational law (Chapter 2)
- the nature of light and how telescopes work (Chapter 3)
- the structure of atoms and what observing light from them reveals about the universe (Chapter 4)

WEB LINK I.1

THE HUBBLE SPACE TELESCOPE
Our quest for knowledge about the universe is epitomized by the building of such technological marvels as the Hubble Space Telescope (HST), shown here in 1997 after a servicing mission by members of the space shuttle DISCOVERY crew. HST is large enough—13.1 meters (43 feet) long and 4.3 meters (14 feet) wide—to be seen with the naked eye from the Earth's surface.

WHAT DO YOU THINK?

1 What makes a theory scientific?

2 What do astronomers do?

3 What practical value does astronomy have?

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

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 a comet majestically arching across the sky (Figure I-1) or the drama of an eclipse are just a few of the things that make astronomy fascinating. 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.

R I V U X G

FIGURE I-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 of saguaro cactus, the night sky, and Halley's Comet was taken in northern Mexico. (Courtesy of D. L. Mammana)

I-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.

I-2 Science demands systematic observations

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 gravitation 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. Gravitation is the unique attractive force between all matter in the universe. The word "gravity" is often used as shorthand for "gravitation" and both are used in this book.

A scientific theory can be independently tested and potentially disproved. Newton's law can be tested and potentially 1
disproved by observations and thus qualifies as a

scientific theory. The idea that the Earth was created 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, 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 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 law, but 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.

We see an enormous number of objects in the universe, but we see them all from one vantage point in space and time. Therefore, we cannot always be certain of their true shape and form or of their history. Fortunately, many of the bodies in space are similar. By categorizing them suitably and then applying the scientific method to these groups of objects, we form theories about them and their evolutionary histories that can be tested and modified.

Most scientific theories discussed in the following chapters are supported by a broad range of observations while a few are still largely unsubstantiated. These latter theories await confirming observations that may be made in the next few years. 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 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 (see Guided Discovery: The Earth-Centered Universe). This makes sense: To the untrained eye, all the astronomical objects appear to orbit our planet!

FIGURE I-2 Galileo's Telescope When Galileo turned his telescope toward the sky in the early 1600s, he discovered craters on the Moon, the phases of Venus, and satellites orbiting Jupiter, and he confirmed the historical observations that there are spots on the Sun. These controversial discoveries flew in the face of conventional wisdom and threatened to undermine the teachings of organized religion of the time. (Scala/Art Resource)

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 by Aristarchus nearly 18 centuries earlier—that the Earth orbits the Sun. Copernicus was motivated by an effort to simplify the celestial scheme. This Sun-centered theory of the known universe gained strength when the Italian scientist Galileo Galilei (Figure I-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.

GUIDED DISCOVERY The Earth-Centered Universe

At the dawn of the twenty-first century, most of us find it hard to understand why anyone would believe that the Sun, planets, and stars orbit the Earth. After all, we *know* that the Earth spins on its axis; we *know* that the gravitational force from the Sun holds the planets in orbit, just as the Earth's gravitational force holds the Moon in orbit. And we *know* that the stars in the night sky all lie far past the boundaries of our solar system. These facts have become part of our understanding of the motions of the heavenly bodies.

Psychologists call this, the background information that we use to help explain things, a conceptual framework. Any conceptual framework contains all the information we take for granted. For example, when the Sun rises, moves across the sky, and sets today, we take for granted that it is the Earth's rotation that causes the Sun's apparent motion.

Our ancestors possessed a different conceptual framework than one based on science's understanding of the cosmos. They didn't know that the Earth rotates. They didn't know that the then-mysterious force that held them to the ground is the same force that attracts the Earth to the Sun and the Moon to the Earth. They didn't know that the Sun is a star, just like the fixed points of light in the sky. And they didn't know any of the other laws of physics related to motion that we take for granted.

Because they did not feel the Earth move under their feet, nor see any other indication that the Earth is in motion, our forebears sensed nothing to support the belief that the Earth moves. The obvious conclusion for one who has a prescientific conceptual framework, even today, is that the Earth stays put while objects in the heavens move around it.

This prescientific conceptual framework for understanding the motions of the heavenly bodies was strictly based on the senses, that is, people observed motions and drew "obvious," commonsense conclusions. Today, we incorporate the known and tested laws of physics in our understanding of the natural world. Many of these concepts are utterly counterintuitive, and, therefore, the conceptual frameworks we possess are less consistent with common sense than those held in the past. Studying science helps us develop intuition that is consistent with the actual workings of nature.

I-3 Astronomical distances are, well, astronomical

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.** (Please read An Astronomer's Toolbox I-1 if you are not familiar with scientific notation.) We will also use the metric system of units, which is now standard in science. Table I-1 lists some comparisons and conversions between metric and the traditional British units of measure. Even the metric system is too cumbersome for studying such remote objects as stars, galaxies, and the farthest realms of the universe. An Astronomer's Toolbox I-2 thus introduces other important astronomical distance units.

In our everyday lives we typically deal with distances ranging from millimeters or fractions of an inch to thousands of kilometers or miles. These larger sizes are some 10^9 times bigger than the smaller ones. Astronomical distances are obviously greater, but how much so? When asked how far the closest stars (other than the Sun) are from Earth, most people give answers in the range of millions of kilometers or miles. To appreciate the range of sizes in the universe, let's briefly explore the true distances to some astronomical objects.

The Moon is typically about 384,000 km (239,000 mi) from the Earth, and the Sun's average distance is an impres-

TABLE I-1 Common Conversions Between British and Metric Units

1 inch	=	2.54 centimeters (cm)
1 cm	=	0.394 inch
1 yard	=	0.914 meter (m)
1 meter	=	1.09 yards = 39.37 inches
1 mile	=	1.61 kilometers (km)
1 km	=	0.621 mile

AN ASTRONOMER'S TOOLBOX I-1

Powers-of-Ten 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 as 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:

$$10^0 = 1.0$$
$$10^{-1} = 0.1$$
$$10^{-2} = 0.01$$
$$10^{-3} = 0.001$$
$$10^{-4} = 0.0001$$

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

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

Try these questions: Write 3141000000 and .0000000031831 in scientific notation. Write 2.718282×10^{10} and 3.67879×10^{-11} in standard notation.

(Answers appear at the end of the book.)

sive 1.5×10^8 km (93 million miles) from Earth. So, if the nearest stars were millions of miles away, they would be at roughly the same distance from Earth as the Sun. They should then appear as bright as the Sun, which clearly they do not. Astronomers have measured the actual distances of the nearest stars to be 4.0×10^{13} km (25 trillion miles), and the most distant stars in our Milky Way Galaxy are twenty-five thousand times farther away than that. Furthermore, the visible universe is populated with some fifty billion galaxies, the farthest of which are more than 10^{23} km away.

MORE TO KNOW I-1 Earth Satellites

AN ASTRONOMER'S TOOLBOX I-2

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 to 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 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:

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

ANIMATION I.1

One light-year is roughly equal to six trillion miles. Proxima Centauri, the star (other than the Sun) nearest to the Earth, is just over 4.2 ly from Earth.

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 the figure below. 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.

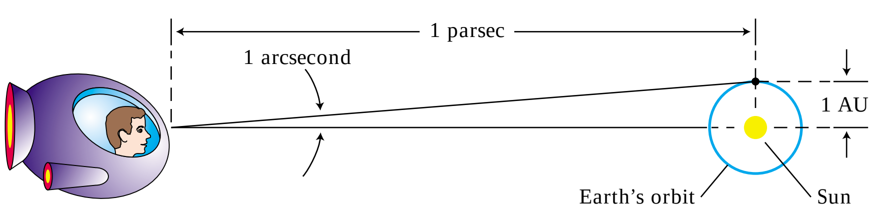
For even greater distances, astronomers commonly use *kiloparsecs* (kpc) and *megaparsecs* (Mpc), in which the prefixes simply mean "thousand" and "million," respectively:

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

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.

Try these questions: The nearest star (other than the Sun) is 4.22 ly away. How many miles away is it? How many kilometers? How many parsecs?

(Answers appear at the end of the book.)



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.

Figure I-3 summarizes lengths in the cosmos ranging from the sizes of atomic particles to the size of the entire universe visible to us. Unlike distance measured on a ruler, the clockwise arc in this figure shows distances increasing by powers of 10. For example, going from the size of a proton (roughly 10^{-15} meters) up to the size of an atom (roughly 10^{-10} meters) takes about the same space along the arc as going from the distance between the Earth and Sun to the distance between the Earth and the nearby stars. Therefore, the largest-sized objects represented here are more than 10^{40} times larger than the smallest.

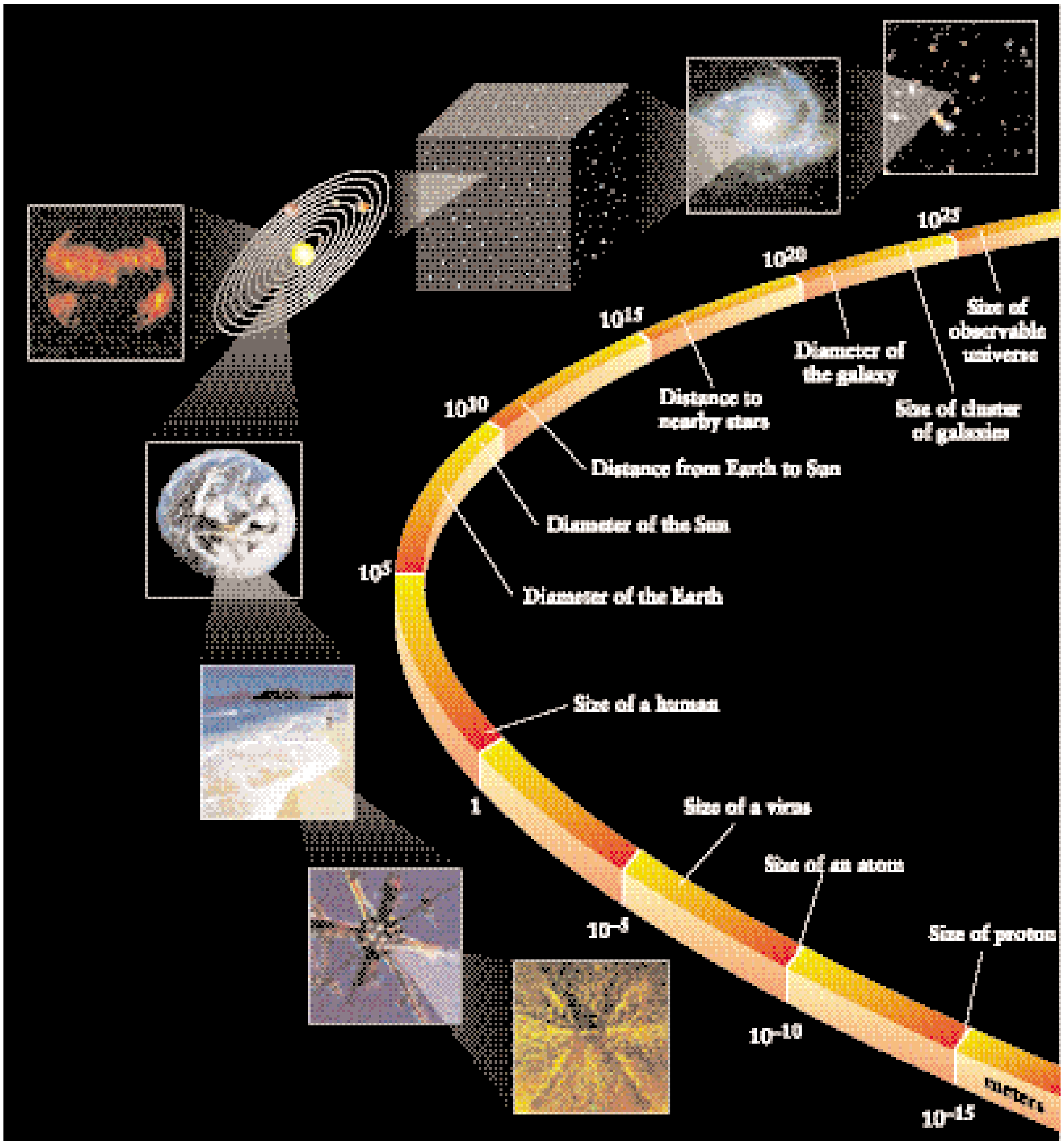


FIGURE I-3 Examples of Powers-of-Ten Notation The scale gives the sizes of objects in meters, ranging from subatomic particles at the bottom to the entire observable universe. Keep in mind that every 0.56 cm up along the arc represents a factor of 10 larger. (Top to bottom: R. Williams and the Hubble Deep Field Team [STScI] and NASA; AAT; L. Golub, Naval Observatory, IBM Research, NASA; Richard Bickel/Corbis; Scientific American Books)

I-4 Astronomers do much more than just make observations

The process of astronomical discovery involves more than observing and recording the heavens. The research activities of astronomers today fall into three basic 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 take 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.

Astronomers are found in a wide variety of professional positions. In North America alone there are about 6000 astronomers. About 30 percent are employed at observatories and by various governments. Another 60 percent teach at colleges and universities. About 5 percent work in museums, planetaria, or other facilities that help educate the public, while the remaining 5 percent work in industry.

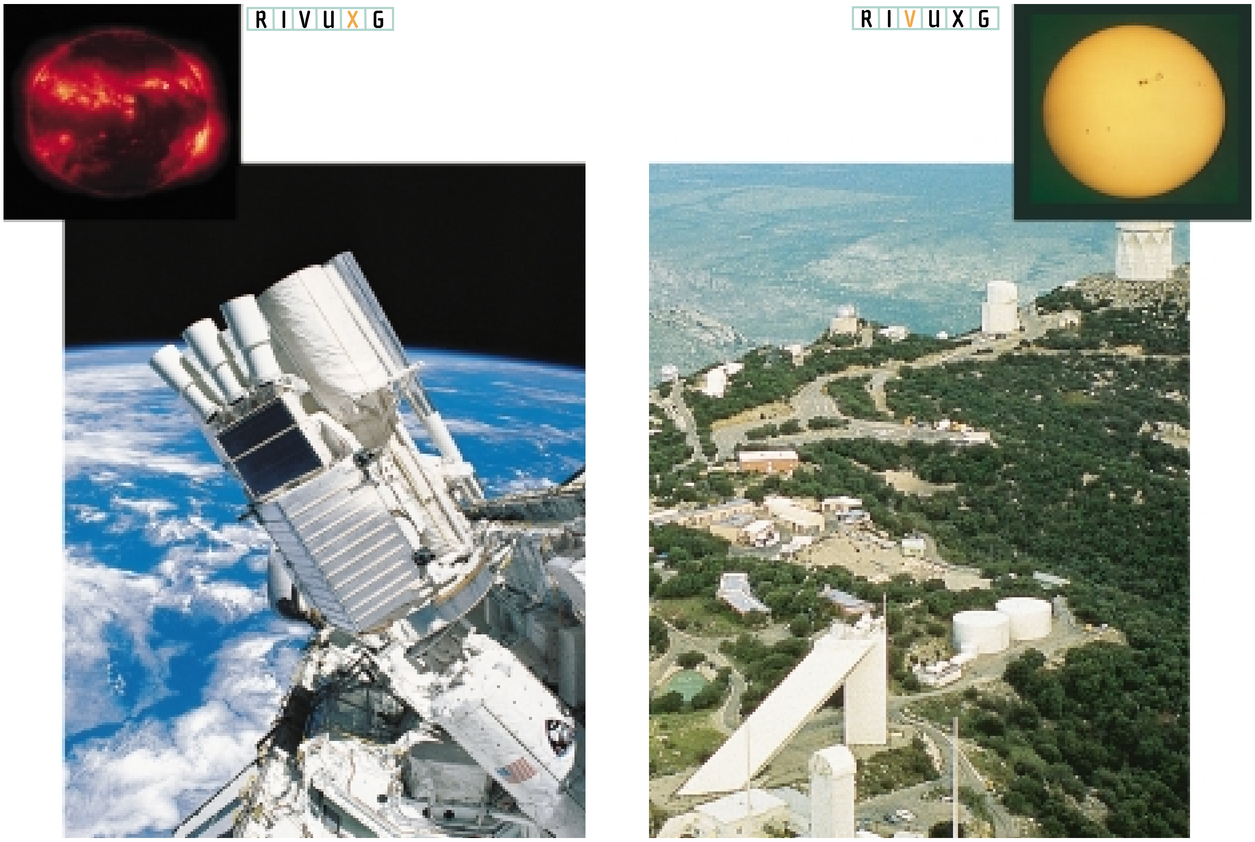


FIGURE I-4 **Visible and Nonvisible Radiation** (a) This X-ray telescope was carried aloft in 1994 by the Space Shuttle. The inset shows an X-ray image of the Sun. (b) This solar observatory in Arizona (the inverted V-shaped structure) takes visible light photographs of the Sun, such as the one shown in the inset. Comparing these images reveals how important observing nonvisible radiation from astronomical phenomena is to furthering our understanding of how the universe operates. (Top left and right, L. Golub Naval Observatory, IBM Research, NASA; bottom left, NASA; bottom right, NOAO)

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 to reconcile apparent contradictions between theories and observations. For example, at the end of the twentieth century astronomers observed that the universe is actually expanding faster and faster, contrary to the previous belief that the universe is expanding outward more slowly all the time. This was utterly unexpected and revolutionized how astronomers view the cosmos.

In turn, the theories developed to explain the universe
3 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, that Newton's law of gravitation explains both the motions of the planets and why we and everything around us are 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 also control the friction between your car's tires and the road or design an airplane wing to lift a jumbo jet.

I-5 Telescopes enlarge our vision of the universe

How do astronomers gather information? Beginning with Galileo, astronomers peered directly through telescopes to observe visible light from stars. Visible light is a form of energy, usually called **electromagnetic radiation,** that is emitted by stars and other objects. In 1800, William Herschel discovered infrared radiation, the first of a variety of nonvisible forms of electromagnetic radiation. These include radio waves, infrared radiation, ultraviolet rays, X rays, and gamma rays. By early in the twentieth century, all these types of electromagnetic radiation had been discovered.

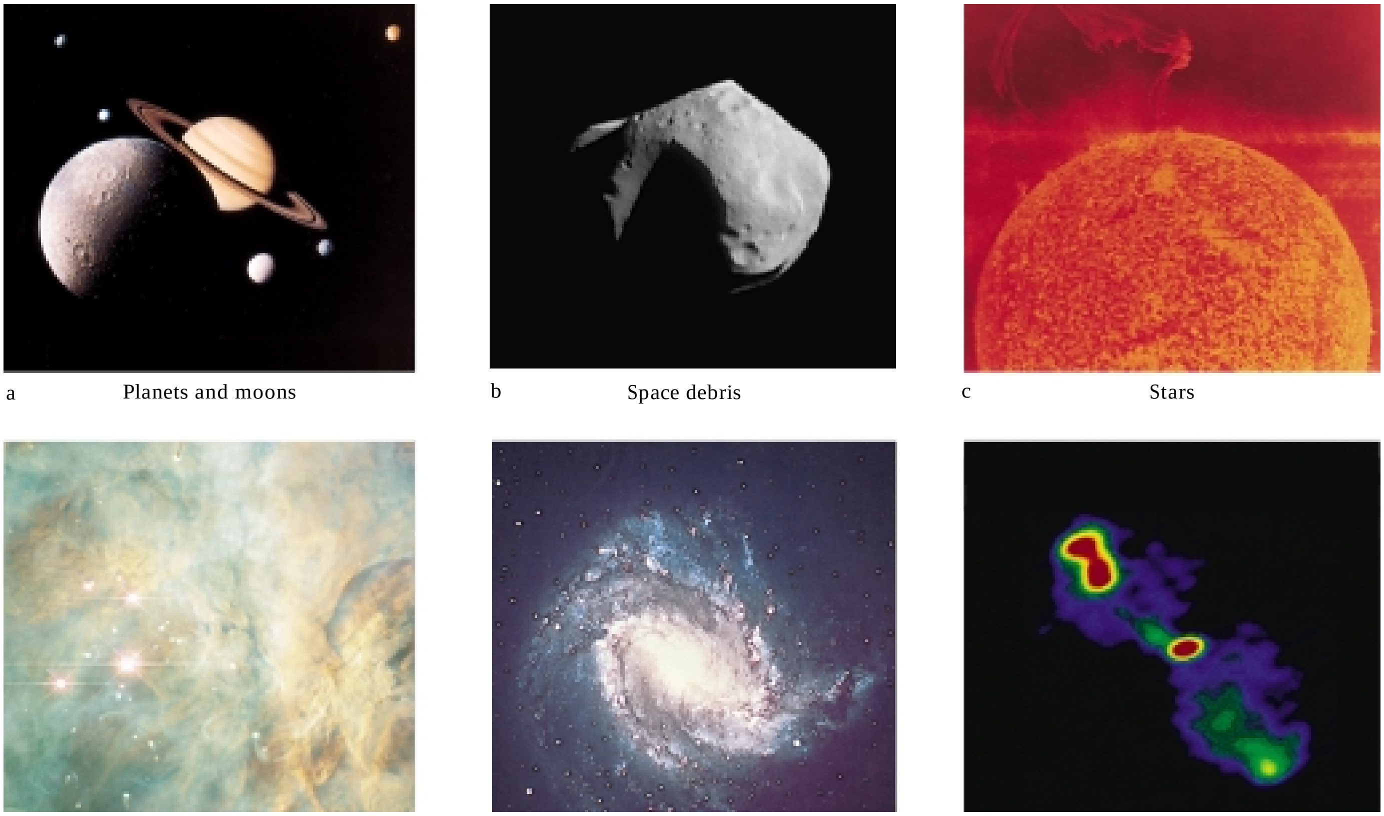


FIGURE I-5 Inventory of the Universe Pictured here are examples of the major categories of objects that have been found throughout the universe. You will discover more about each type in the chapters that follow. All these photographs are at visible wavelengths, except the last, exotic objects, which is a radio image. (a: NOAO; b: NASA; c: NASA; d: C. R. O'Dell, Rice University; John Bally, University of Colorado; Ralph Sutherland, University of Colorado; e: R. J. Dufour, Rice University; f: F. N. Owen and J. J. Puschell/NRAO/AUI)

In the middle of the nineteenth century, scientists began recording visible-light astronomical images on film. During the past half century, astronomers have constructed telescopes and image recording systems sensitive to all forms of nonvisible electromagnetic radiation. These telescopes are providing us with ever-more-detailed images of objects in space. Every form of electromagnetic radiation has revealed new information about cosmic bodies (Figure I-4).

Whether located on Earth or in orbit above the obscuring effects of our atmosphere, telescopes give us views vastly superior to anything our eyes can see. They are crucial to our understanding of familiar objects like the Sun, and they also provide important clues about the nature of such exotic objects as neutron stars, pulsars, quasars, and black holes.

What, then, have astronomers seen of the universe? Figure I-5 inventories some of the features we will explore in this text, including planets, stars, black holes, galaxies, and quasars. Each object is constantly changing; each had an origin and each will have an end. We will study these processes, too.

The ideas of science fiction writers, such as Jules Verne and H. G. Wells, pale when compared to current reality. Ours is an age of exploration and discovery more profound than any since the voyages of Columbus and Magellan began to reveal the surface features of the Earth. We have walked on the Moon, dug into Martian soil, and landed on an asteroid. Our probes have discovered active volcanoes and barren ice fields on the satellites of Jupiter. We have visited the shimmering rings of Saturn. We have seen evidence of planets orbiting other stars.

Never before has so much been revealed in so short a span of time. As you proceed through this book, you will gain a new appreciation of the awesome power of the human mind to reach out, to explore, to observe, and to comprehend. One of the great lessons of modern astronomy is that by gaining, sharing, and passing on knowledge, we can transcend the limitations of our bodies and the brevity of human life.

I-6 Frontiers yet to be discovered

Most of our information about the universe still comes from imaging the various forms of electromagnetic radiation. But today astronomers are gathering an ever-growing body of firsthand cosmic knowledge from space debris found on Earth and the Moon, as well as from exotic particles that pepper the Earth from space. Examples of the latter include neutrinos and so-called cosmic rays (misnamed, because cosmic rays are actually particles). Astronomers are also on the brink of directly detecting the fluctuations in the fabric of space called gravitational radiation predicted by Einstein's theory of general relativity. Using these nonelectromagnetic sources of information, we may soon be able to see directly into the hearts of stars and farther back toward the beginning of time than ever before.

For Further Readings

WHAT DID YOU THINK?

1 *What makes a theory scientific?* A theory is an idea or set of ideas proposed to explain something about the natural world. A theory is scientific if it makes objective predictions that can be objectively tested and potentially disproved.

2 *What do astronomers do?* Most astronomers spend their time analyzing observational data, building equipment to make better observations, creating theories, and carrying out computer simulations. Observational astronomers spend only a few days or weeks each year actually using research telescopes.

3 *What practical value does astronomy have?* It provides us with such information as the cause of the seasons and the nature and implications of the gravitational force for the existence of stars and other bodies. It explains why the various types of objects in the universe exist and why they behave in the ways they do. For example, astronomers have discovered (see Chapter 9) why the Sun shines and, therefore, why it has been able to keep the Earth inhabitable for billions of years. Astronomy also provides an explanation for why the universe has evolved as it has, as well as predicting the fate of the universe.

KEY WORDS

astronomical unit (AU), 8
electromagnetic radiation, 10
light-year (ly), 8
model, 1
parsec (pc), 8
physics, 1
power of ten, 7
scientific method, 1
scientific notation, 6
scientific theory, 1

KEY IDEAS

- The universe is comprehensible.
- The scientific method is a procedure for formulating theories that correctly predict how the universe behaves.
- A scientific theory must be testable, that is, capable of being disproved.
- Theories are tested and verified by observation or experimentation and result in a process that often leads to their refinement or replacement and to the progress of science.
- Observations of the heavens have led astronomers to discover some fundamental physical laws of the universe.
- Space debris collected on Earth, as well as particles from space, such as neutrinos and cosmic rays, and an exotic energy called gravitational radiation are providing astronomers with new insights into the universe.

REVIEW QUESTIONS

The answers to all computational problems, which are preceded by an asterisk (*), appear at the end of the book.

1 Compile a list of five examples of counterintuitive astronomy ideas, such as "the Earth rotates," that we now accept as correct.

***2** Convert the following into scientific notation: (a) Earth's mass: 5,974,000,000,000,000,000,000,000 kg; (b) Sun's mass: 1,989,000,000,000,000,000,000,000,000,000 kg; (c) Sun's radius: 696,000 km; (d) one year: 31,536,000 s.

***3** Convert: (a) 8.3 pc into light-years; (b) 6.52 ly into parsecs; (c) 8450 AU into kilometers; (d) 2.7×10^3 Mpc into kiloparsecs.

ADVANCED QUESTIONS

4 The dictionary defines *astrology* as "the study that assumes and attempts to interpret the influence of the heavenly bodies on human affairs." Based on what you know about scientific theory, is astrology a science? Why or why not? Feel free to explore astrology further if you wish before answering this question.

WHAT IF ...

5 The laws of physics changed from time to time? What coping skills would life require, if it could exist at all? What else besides the laws of physics would scientists need to comprehend in order to understand and make predictions about the universe?

6 Astronomers only collected data (made observations) about the universe and didn't create scientific theories? How would our perspective on the cosmos be different from what it is today?

7 The skies of Earth were perpetually cloudy? How might that have changed the history of our understanding of the cosmos and how might humans under such conditions eventually learn what is really "out there"?

8 Scientists remained believers in the first theory of the cosmos that they decided was correct? How might that change the dynamics by which science evolves in the face of new data that conflicts with earlier theories?

WEB/CD-ROM QUESTIONS

9 Search the Web for more information about the scientific method. Then explain in some detail what a theory and a hypothesis are in science and how they are related. What is Occam's razor (sometimes Ockham's razor) and how does it relate to the process of science? If requested by your instructor, make a flow chart of the scientific process.

OBSERVING PROJECTS

10 Install the *Starry Night Backyard™* planetarium software from the CD-ROM in your book into your computer. The manual and answers to FAQs about *Starry Night Backyard™* are provided at the Web link adjacent to this problem. Use *Starry Night Backyard™* to determine when the Moon is visible today during the day and when it is visible tonight. Determine which, if any, of the following planets, all visible to the naked eye, are observable in the sky tonight: Mercury, Venus, Mars, Jupiter, and Saturn.

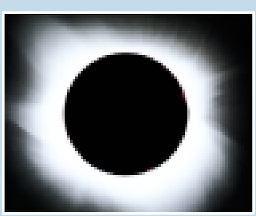
Hints: (1) If you are just learning to use *Starry Night Backyard™,* experiment with settings as much as necessary. Change the time to after sunset in order to see the stars or click on *Go* then *Atlas.* You can always return to your starting screen by clicking on the *Home* button in the window normally on the upper left of your screen or by clicking on *Go* then *Home.* To see the sky from your actual location on Earth, select *Set Home Location*… in the *Go* menu and click on the *Lookup*… button to find your city or town. (2) You can move the sky around by moving your mouse up until a little hand appears. Hold the mouse button (on a Windows computer the left button) as you move the mouse and you will move the sky. (3) You can change the time of day and change how rapidly time appears to pass using the Control Panel at the top of the main window. (4) Use the *Find*… command in the *Edit* menu to locate specific planets or stars by name. (5) To get more information about any object in the sky, point the cursor at the object and double-click the mouse (on a Windows computer, click the right button).

11 Observe the stars with your unaided eyes and record what you see. This is intentionally an open-ended question, so as to encourage you to think and observe as broadly as possible. For example, if Orion is up, look carefully at its sword. Reviewing the data you have written down, make a list of what *properties* of the stars you have recorded. If possible, compare your observations with those of your peers and discuss with them and with your teacher whether there are characteristics of stars that you might have missed.

AN ASTRONOMER'S ALMANAC

Greek Golden Age

2136 B.C.
Chinese astronomers record solar eclipse.

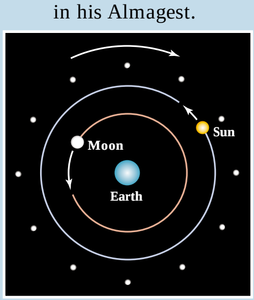


586 B.C.
Thales of Miletus predicts solar eclipse.

350 B.C.
Aristotle proposes spherical Earth, geocentric cosmology.

ca. 270 B.C.
Aristarchus of Samos proposes heliocentric cosmology.

ca. A.D. 125
Claudius Ptolemy refines and details geocentric cosmology in his Almagest.



European Renaissance

1512-1543
Nicolas Copernicus proposes heliocentric cosmology in his Commentariolus and De Revolutionibus Orbium Coelestium.

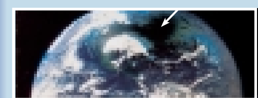
1576-1601
Tycho Brahe makes precise observations of stars and planets.

1589-1609
Galileo Galilei proposes that all objects fall with the same acceleration, independent of their masses; builds his first telescope, a refractor.

1609-1619
Johannes Kepler publishes his three laws of planetary motion.

1665-1704
Isaac Newton deduces gravitational force from the orbit of the Moon; builds first reflecting telescope; proves that planets moving under influence of gravitational force obey Kepler's laws; publishes compendium on light, Optics.

1715
Edmund Halley calculates shadow path of a solar eclipse over Earth's surface.



1766
Henry Cavendish discovers hydrogen.

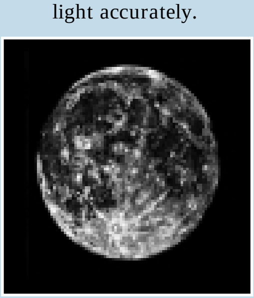
1800-1803
William Herschel discovers infrared radiation from the Sun. Thomas Young demonstrates wave nature of light. John Dalton proposes that matter is composed of atoms of different weights.

Discovering Astronomy

Industrial Revolution

1840-1849

J.W. Draper invents astronomical photography; takes first photographs of Moon. Christian Doppler proposes that wavelength is affected by motion. Lord Rosse completes 60-in. reflecting telescope at Birr Castle in Ireland. Armand Fizeau and Jean-Bernard Foucault measure speed of light accurately.



1871-1873

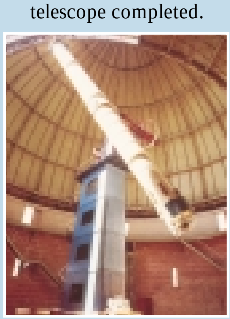
Dimitri Mendeleyev develops periodic table of the elements. Henry Draper develops spectroscopy. James Clerk Maxwell asserts that light is an electromagnetic phenomenon.

1885-1888

Johann Balmer expresses spectral lines of hydrogen mathematically. Heinrich Hertz detects radio waves.

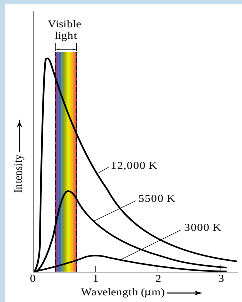
1895-1897

Wilhelm Roentgen discovers X-rays. Joseph Thomson detects the electron. Yerkes 40-in. optical refracting telescope completed.



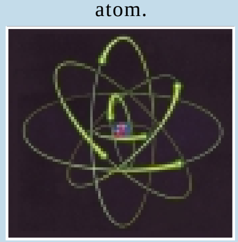
1900

Max Planck explains blackbody radiation. Paul Villard discovers gamma rays.



1913

Niels Bohr proposes quantum theory of the atom.

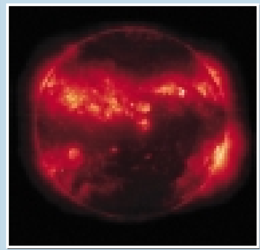


1930-1934

Karl Jansky builds first radio telescope. James Chadwick discovers the neutron. Bernhard Schmidt builds his Schmidt optical reflecting telescope.

1942-1949

J.S. Hey detects radio waves from the Sun. First astronomical telescope launched into space. Herbert Friedman detects X-rays from the Sun. 200-in. optical reflecting telescope begins operation on Mt. Palomar, California.



Information Age

1963-1967

Largest single-dish radio telescope, 300 meters across, begins operation at Arecibo, Puerto Rico. First VLBI images.

1975

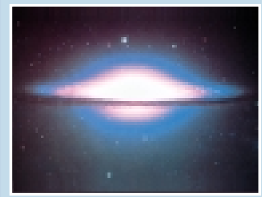
First CCD astronomical observations.

1980

VLA radio observatory completed, Socorro, New Mexico.

1990-1996

Hubble Space Telescope launched. Keck 10-meter optical/infrared telescopes begin operation at Mauna Kea, Hawaii. SOHO solar observatory launched.



1999

Chandra X-ray Telescope launched.