

Chapter 31

What You'll Learn

- What the Milky Way Galaxy is like.
- How galaxies are distributed and what their characteristics are.
- What astronomers know about the origin and history of the universe.

Why It's Important

The study of galaxies and the structure of the universe helps scientists to better understand the origin of our solar system as well as Earth's origin.



To find out more about galaxies and the universe, visit the Earth Science Web Site at earthgeu.com

Galaxies and the Universe

Collision between NGC 2207 and IC 2163

Discovery Lab

Model The Milky Way

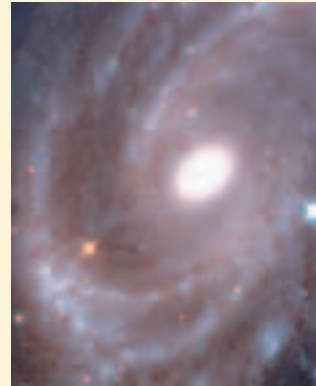
Our solar system seems large when we compare it to the size of Earth. However, the Milky Way dwarfs the size of our solar system.

1. The Milky Way has a diameter of approximately 8.25×10^9 AU. Given that $206\,265 \text{ AU} = 3.26 \text{ ly}$, what is the diameter of the Milky Way in light-years?
2. Given that the orbit of Pluto has a diameter of 80 AU, what is the diameter of Pluto's orbit in ly?
3. If you were to apply the scale $1 \text{ mm} = 1 \text{ ly}$, how large would the Milky Way be?
4. The Sun is located 28 000 ly from the center of the Milky Way. Based

on the scale that you used in question 3, how many millimeters away from the center of the Milky Way would the Sun be?

5. If you included Pluto's orbit in your model, how many millimeters across would its orbit be?

Observe In your science journal, describe what your model of the Milky Way would look like if you actually built it. Explain why it would be a problem to show the size of our solar system in comparison to the Milky Way. Explain how you would change your model to include the size of Earth.



SECTION

31.1

The Milky Way Galaxy

OBJECTIVES

- **Determine** the size and shape of the Milky Way, as well as Earth's location within it.
- **Describe** how the Milky Way formed.

VOCABULARY

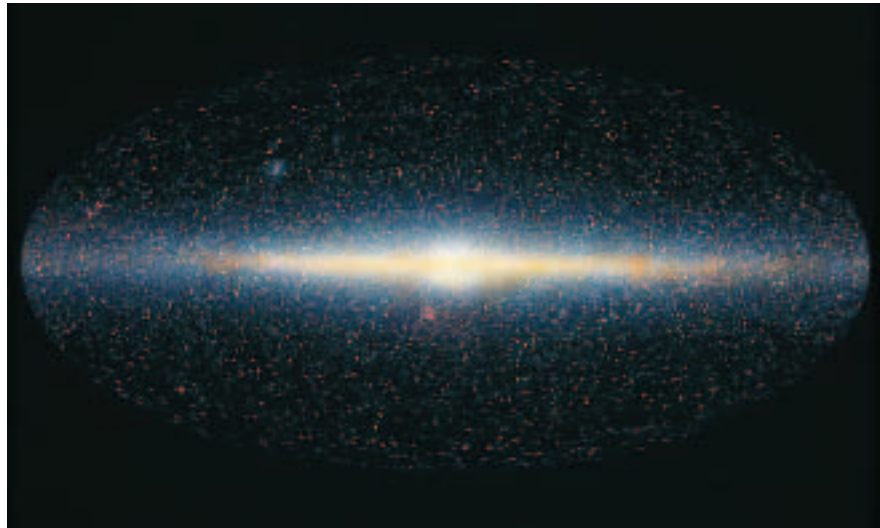
variable star
RR Lyrae variable
Cepheid variable
halo
spiral density wave

When you see the hazy band of light across the sky known as the Milky Way, you are looking at our galaxy from the inside. It is an awesome sight, but one that you can see only if you get away from city lights on a moonless night. The Milky Way is a great disk made of stars orbiting a central point in the disk. Our Sun is just one of perhaps 100 billion stars that make up the Milky Way.

DISCOVERING THE MILKY WAY

When we look at the Milky Way, it is difficult to see its size and shape because not only are we too close, but we are also inside the galaxy. We see the band of stars stretching across the sky, and it's not hard to imagine that this is an edge-on view of a disk. However, we can't tell how big it is, where its center is, or what Earth's location is within it. These were some of the mysteries that astronomers were interested in solving. In fact, astronomers are still refining their measurements.

Figure 31-1 Globular clusters are located above and below the plane of the disk of the Milky Way. The Milky Way is the white band across the middle of this photo.



Variable Stars In the 1920s, astronomers mapped out the locations of globular clusters. These huge, spherical star clusters are located above or below the plane of the galactic disk, shown in *Figure 31-1*. Astronomers estimated the distances to the clusters by identifying variable stars in them. **Variable stars** are stars in the giant branch of the Hertzsprung-Russell diagram, discussed in Chapter 30, that pulsate in brightness because of the expansion and contraction of their outer layers. For certain types of variable stars, there is a relationship between a star's luminosity and its pulsation period, which is the time between brightenings. For example, **RR Lyrae variables** have periods of pulsation between 1.5 hours and 1 day, and on average, they have the same luminosity. **Cepheid variables**, however, have pulsation periods between 1 and 100 days. The longer the period of pulsation, the greater the luminosity of the star. By measuring a star's period of pulsation, astronomers can determine the star's luminosity. This, in turn, allows them to compare the star's luminosity, or absolute magnitude, to its apparent magnitude and calculate how far away the star must be to appear as dim or bright as it does.

The Galactic Center Astronomers used RR Lyrae variables to determine the distances to the globular clusters. They discovered that these clusters are located very far from our solar system, and that their distribution in space is centered on a distant point, 28 000 ly away. Astronomers reasoned that the globular clusters were orbiting the center of the Milky Way. The center is a region of very high star density, as shown in *Figure 31-2*, much of which is obscured by interstellar gas and dust. The direction of the galactic center is toward the constellation Sagittarius.

THE SHAPE OF THE MILKY WAY

Only by mapping the galaxy with radio waves have astronomers been able to determine its shape. This is because radio waves can penetrate the interstellar gas and dust without being scattered or absorbed. Astronomers have discovered, by measuring radio waves as well as infrared radiation, that the galactic center, also called the nucleus, is surrounded by a nuclear bulge, which sticks out of the galactic disk much like the yolk in a fried egg. Around the nuclear bulge and disk is the **halo**, a spherical region where globular clusters are located, as illustrated in *Figure 31-3*.

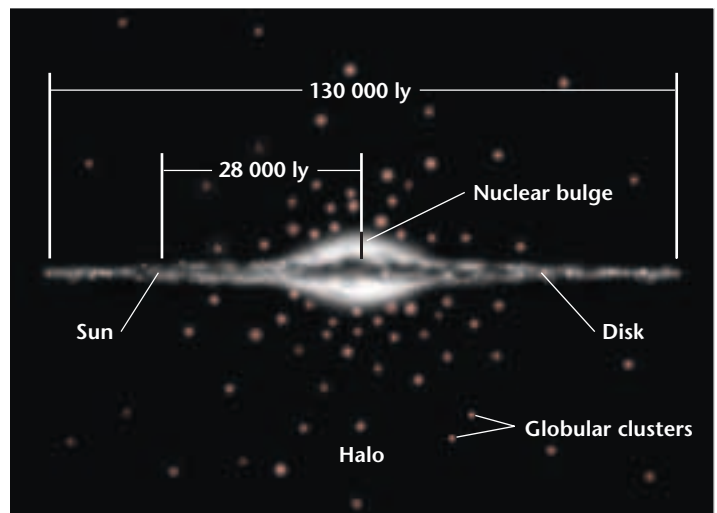
Spiral Arms Knowing that our galaxy has a disklike shape with a central bulge, astronomers speculated that it might also have spiral arms, as many other galaxies do. This was very difficult to prove, however, because astronomers have no way to get outside of the galaxy and look down on the disk. Astronomers have used hydrogen atoms to discover the spiral arms.

Hydrogen atoms in a very low-density gas can emit radiation at a wavelength of 21 cm. The use of this hydrogen emission for mapping the spiral arms of our galaxy has several advantages: first, hydrogen is the most abundant element in space; second, the interstellar gas, composed mostly of hydrogen, is concentrated in the spiral arms; and third, the 21-cm wavelength of hydrogen emission can penetrate the interstellar gas and dust and be detected all the way across the galactic disk. Using the 21-cm hydrogen emission as a guide, astronomers have identified four major spiral arms and numerous minor arms in the Milky Way. The Sun is located in the minor arm Orion at a distance of about 28 000 ly from the galactic center. The Sun's orbital speed is about 220 km/s, and thus its orbital period is about 240 million years. It is hypothesized that in its 5 billion-year life, the Sun has orbited the galaxy approximately 20 times.

Figure 31-3 The Milky Way consists of a nuclear bulge in the center of a disk. The disk and bulge are surrounded by a spherical region called the halo. (not to scale)



Figure 31-2 The center of the Milky Way is densely populated by stars, many of which are obscured by dust.



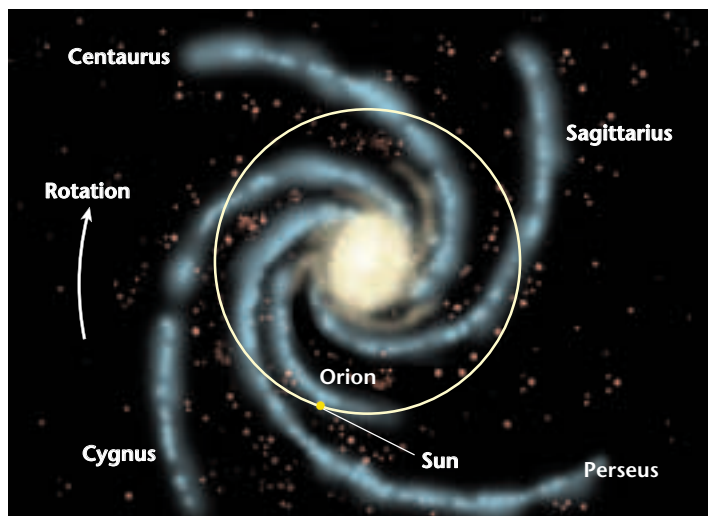


Figure 31-4 The Sun is located on the minor arm Orion and follows an orbital path around the nuclear bulge as shown. (not to scale)

MASS OF THE MILKY WAY

The mass located within the circle of the Sun's orbit through the galaxy, outlined in *Figure 31-4*, is about 100 billion times the mass of the Sun. Because the Sun is about average in mass, astronomers have concluded that the galaxy contains about 100 billion stars within its disk.

However, astronomers have found evidence that much more mass exists outside the disk of the galaxy. The stars and gas clouds that orbit in the outer disk are moving faster than they would if the galaxy's mass were concentrated near

the center of the disk. Evidence indicates that as much as 90 percent of the galaxy's mass is contained in the halo. This mass is not observed in the form of normal stars, however. Some of this unseen matter is probably in the form of dim stellar remnants such as white dwarfs, neutron stars, or black holes, but the nature of the remainder of this mass is a mystery. As you'll discover, the problem of unseen matter, usually called dark matter, extends to other galaxies and to the universe as a whole.

A Galactic Black Hole Careful studies of the motions of the stars that orbit close to Sagittarius A*, the center of the galaxy, indicate that this area has about 2.6 million times the mass of the Sun but is smaller than our solar system. Data gathered by the *Chandra X-Ray Observatory* reveal intense X-ray emissions as well. Astronomers believe that Sagittarius A* is a supermassive black hole that glows brightly because of the hot gas surrounding it and spiraling into it. This black hole probably formed early in the history of the galaxy, at the time when the galaxy's disk was forming. Gas clouds and stars within the disk probably collided and merged to form a single, massive object that collapsed to form a black hole.

STARS IN THE MILKY WAY

The halo of the Milky Way contains the oldest-known objects in the galaxy: globular clusters. These clusters are estimated to be as old as 12 to 14 billion years. Stars in the globular clusters have extremely small amounts of elements that are heavier than hydrogen and helium. All stars contain small amounts of these heavy elements, but in globular clusters, the amounts are mere traces. Stars like the Sun are composed of about 98 percent hydrogen and helium, whereas in

globular cluster stars, this proportion can be as high as 99.9 percent. This indicates their extreme age. The nuclear bulge of the galaxy also contains stars with compositions like those of globular cluster stars.

Stellar Populations Most of the young stars in the galaxy are located in the spiral arms of the disk, where the interstellar gas and dust are concentrated. Most star formation takes place in the arms. There is little interstellar material and very few stars currently forming in the halo or the nuclear bulge of the galaxy. In fact, the galaxy could be divided into two components: the round part made up of the halo and bulge, where the stars are old and contain only traces of heavy elements; and the disk, especially the spiral arms, where stars are still forming, as illustrated in *Figure 31-5*. Astronomers divide stars in these two regions into two classes. Population I stars are those in the disk and arms and have small amounts of heavy elements. Population II stars are those in the halo and bulge and contain only traces of heavy elements. The Sun is a Population I star.

FORMATION AND EVOLUTION OF THE MILKY WAY

The fact that the halo and bulge are made exclusively of old stars suggests that these parts of the galaxy formed first, before the disk that contains only younger stars. Astronomers therefore hypothesize that the galaxy began as a spherical cloud in space. The first stars formed while this cloud was round. This explains why the halo, which contains the oldest stars, is spherical. The nuclear bulge, which is also round, represents the inner portion of the original cloud. The cloud eventually collapsed under the force of its own gravity, and rotation forced it into a disklike shape. Stars that formed after this time have orbits lying in the plane of the disk.

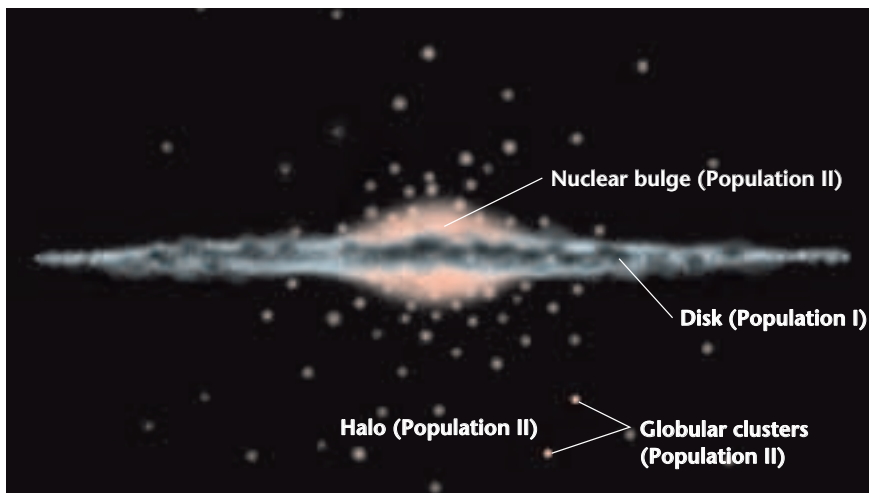


Figure 31-5 Globular clusters and the nuclear bulge contain old stars poor in heavy elements. The disk contains young stars that have a higher heavy element content. (not to scale)

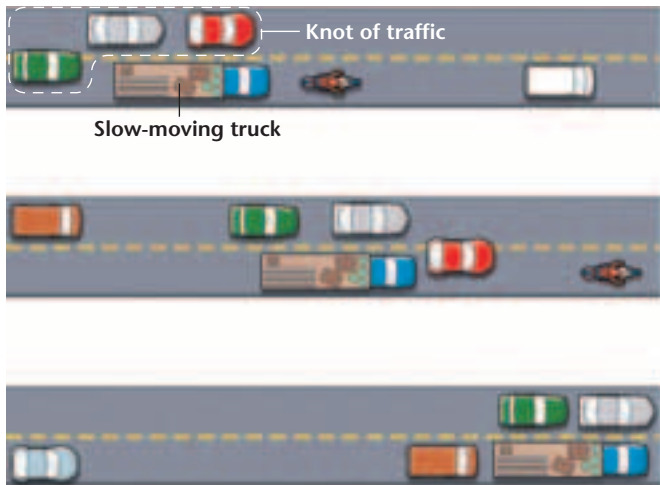


Figure 31-6 A slow truck on a highway causing a buildup of cars around it is similar to how spiral density waves create spiral arms in a galaxy.

about how these arms are maintained. One is that a kind of wave called a spiral density wave is responsible. You can think of a **spiral density wave** as alternating dense and less-dense regions that are frozen in place and rotate as a rigid pattern. As the wave moves through gas and dust, it causes a temporary buildup of material, like a slow truck on the highway that causes a buildup of cars, illustrated in **Figure 31-6**. The other theory is that the spiral arms are not permanent structures but instead are continually forming as a result of disturbances such as supernovae explosions. The Milky Way has a broken spiral-arm pattern, which most astronomers think fits this second model best. However, some galaxies have a prominent 2-armed pattern, almost certainly created by density waves.

They also contain greater quantities of heavy elements because they formed from gas that had been enriched by previous generations of massive stars.

MAINTAINING SPIRAL ARMS

Most of the main features of the galaxy are clearly understood by astronomers, except for the way in which the spiral arms are maintained. The Milky Way is subject to gravitational tugs by neighboring galaxies and is periodically disturbed by supernovae explosions, both of which can create spiral arms. There are two different theories

SECTION ASSESSMENT

1. How did astronomers determine where Earth is located within the Milky Way?
2. What do measurements of the mass of the Milky Way indicate?
3. How are Population I stars and Population II stars different?
4. How can variable stars be used to determine the distance to globular clusters?
5. **Thinking Critically** If our solar system were slightly above the disk of the Milky Way, why would astronomers still have difficulty determining the shape of the galaxy?

SKILL REVIEW

6. **Concept Mapping** Use the following terms to construct a concept map to organize the major ideas in this section. For more help, refer to the *Skill Handbook*.

1. cloud collapses

2. globular clusters form

3. spherical cloud

4. disk forms

5. stars and spiral arms form

6. galaxy nucleus forms

Our galaxy is just one of billions of galaxies in the universe. We live in a cosmos of galaxies that have a wide variety of sizes and shapes. By observing those galaxies that are farthest away, astronomers get an idea of how the universe looks as a whole. Because it takes so long for light to reach us from remote galaxies, these far away galaxies also provide an idea of what the universe was like long ago.

DISCOVERING OTHER GALAXIES

Astronomers were aware of galaxies outside the Milky Way long before they knew what these objects were. Many objects had been observed scattered throughout the sky, some with spiral shapes, but astronomers disagreed about their nature. Some astronomers hypothesized that these objects were nebulae or star clusters within the Milky Way. Others hypothesized that they were distant galaxies, as large as the Milky Way.

The question of what these objects were was answered by Edwin Hubble in 1924, when he discovered Cepheid variable stars in the Great Nebula in the Andromeda constellation. Using these stars to measure the distance to the nebula, Hubble showed that they were much too far away to be located in our own galaxy. The Andromeda Nebula then became known as the Andromeda Galaxy, shown in *Figure 31-7*.

Classification of Galaxies Hubble went on to study galaxies and sort them into categories according to their shapes. The disklike galaxies with spiral arms were called spiral galaxies. These were divided into two subclasses: normal spirals and barred spirals. Barred spirals have

OBJECTIVES

- **Describe** how astronomers classify galaxies.
- **Identify** how galaxies are organized into clusters and superclusters.
- **Describe** the expansion of the universe.

VOCABULARY

supercluster
Hubble constant
radio galaxy
active galactic nucleus
quasar



Figure 31-7 The Andromeda Galaxy is a spiral galaxy like the Milky Way. The two bright elliptical objects are small galaxies orbiting the Andromeda Galaxy.

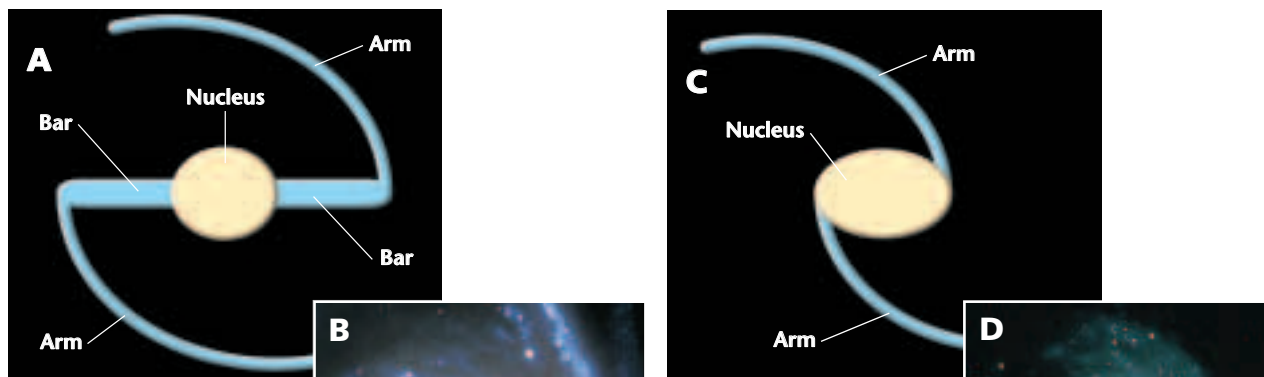
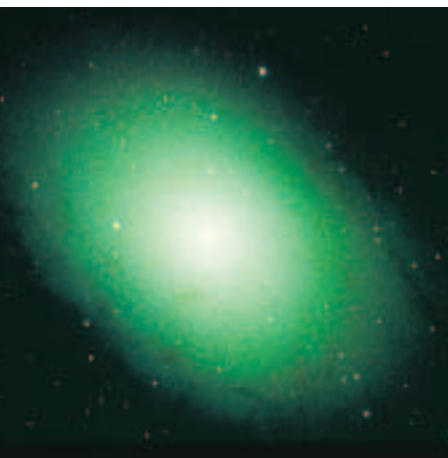


Figure 31-8 Barred spirals have a bar through the nucleus (A). NGC 1365 is a barred spiral galaxy (B). The arms of normal spirals extend directly from the nucleus (C). NGC 628 is a normal spiral galaxy (D).

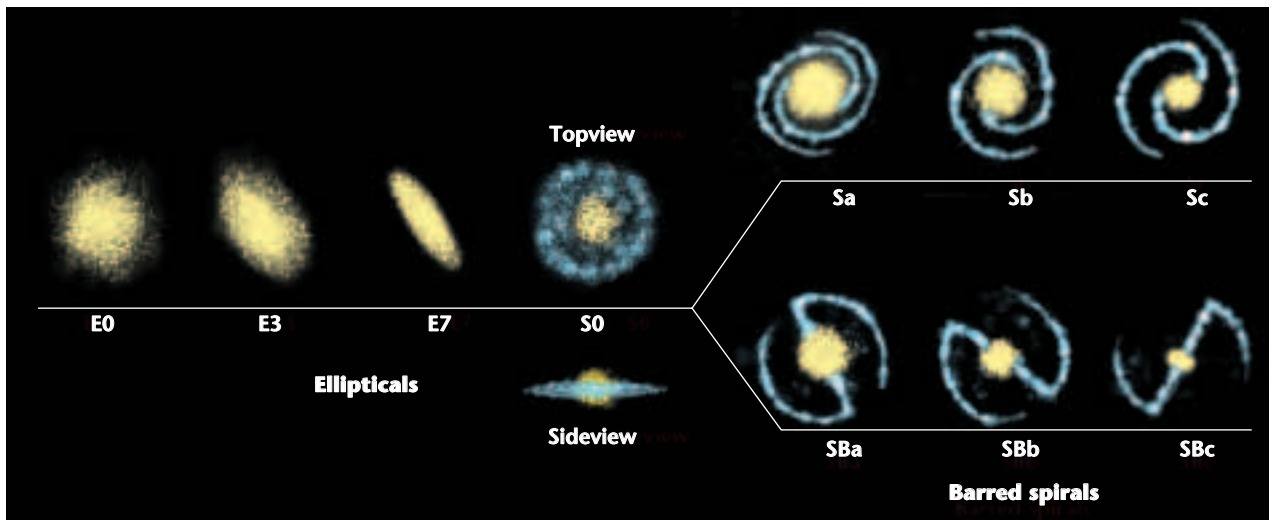
Figure 31-9 This galaxy, M32, is an elliptical galaxy. Notice the uniform distribution of stars throughout the galaxy. Despite their flat appearance, ellipticals are three-dimensional, and are similar in shape to a football.



an elongated central region, or a bar, from which the spiral arms extend, as shown in **Figures 31-8A** and **B**. Normal spirals do not have bars, as shown in **Figures 31-8C** and **D**. A normal spiral is denoted by the letter *S*, and a barred spiral is denoted by *SB*. Normal and barred spirals are further subdivided based on how tightly the spiral arms are wound, as well as the size and brightness of the nucleus. The letter *a* represents tightly wound arms and a large, bright nucleus. The letter *c* represents loosely wound arms and a small, dim nucleus. The letter *b* represents characteristics between those of *a* and *c*. Thus, a normal spiral with class *a* arms and nucleus is denoted *Sa*, while a barred spiral with class *a* arms and nucleus is denoted *SBa*. Galaxies with flat disks, that do not have spiral arms are denoted *SO*. When an *SO* galaxy is observed edge-on, it often has a band of dark dust crossing the nuclear bulge.

In addition to spiral galaxies, there are galaxies that are not flattened into disks and do not have spiral arms, as shown in **Figure 31-9**. These are called elliptical galaxies. Ellipticals are divided into subclasses based on the apparent ratio of their major and minor axes. Round ellipticals are classified as *E0*, while very elongated ellipticals are classified as *E7*. Others are denoted by the letter *E* followed by a numeral 1 through 6. The classification of both spiral and elliptical galaxies can be summarized by Hubble's tuning-fork diagram, illustrated in **Figure 31-10**. You will learn more about galaxy classification in the *Internet GeoLab* at the end of this chapter.

Some galaxies do not have distinct shapes, and thus do not fit into either the spiral or elliptical classification. These are called irregular galaxies and are denoted by *Irr*. The Large and Small Magellanic Clouds are irregular galaxies that are close to the Milky Way.



Masses of Galaxies Masses of galaxies range from the dwarf ellipticals, which have masses of perhaps one million Suns; to large spirals, such as the Milky Way, with masses of around 100 billion Suns; to the largest galaxies, called giant ellipticals, which have masses as high as 100 trillion times the Sun's mass. Measurements of the masses of many galaxies indicate that they have extensive halos containing more mass than is visible, just as the Milky Way does.

GROUPS AND CLUSTERS OF GALAXIES

Most galaxies are located in groups, rather than being spread uniformly throughout the universe. The Milky Way belongs to a small cluster of galaxies called the Local Group. The diameter of the Local Group is roughly 2 million ly. There are about 35 known members, most of which are dwarf ellipticals. The Milky Way and Andromeda Galaxies are the largest galaxies in the group.

Clusters larger than the Local Group may have hundreds of members and diameters in the range of about 5 to 30 million ly. The Virgo cluster is shown in *Figure 31-11*. Most of the galaxies in the inner region of a large cluster are ellipticals, while there is a more even mix of ellipticals and spirals in the outer portions.

In regions where galaxies are as close together as they are in large clusters, gravitational interactions among galaxies have many important effects. Galaxies often collide and form strangely shaped galaxies,

Figure 31-10 The Hubble tuning fork diagram summarizes the Hubble classification scheme for non-unusual galaxies. An S0 galaxy is related to both spirals and ellipticals.

Figure 31-11 Galaxies are located in groups, or clusters, like the Virgo cluster.



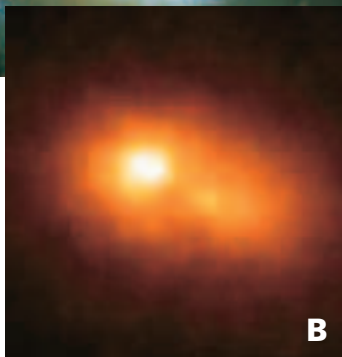
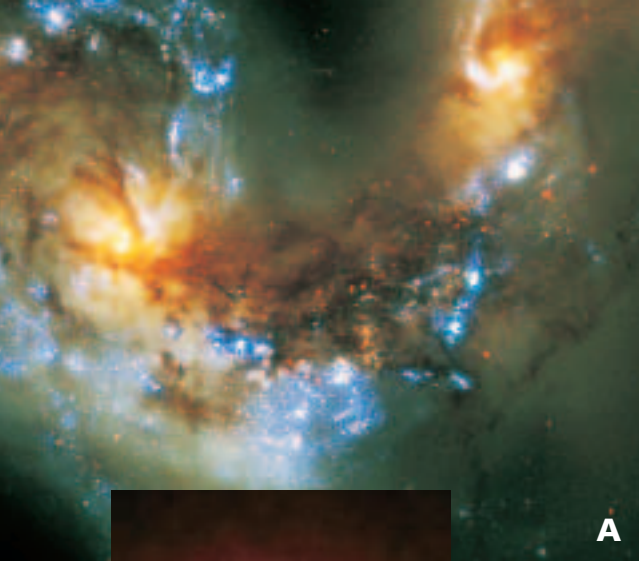


Figure 31-12 Strangely shaped galaxies, such as the Antennae Galaxies (NGC 4038 and NGC 4039) **(A)**, are often the result of a collision. At the center of the Andromeda Galaxy, the *Hubble Space Telescope* uncovered two nuclei **(B)**, which are probably a result of one galaxy being consumed by another.

such as those shown in *Figure 31-12A*, or galaxies with more than one nucleus, such as the Andromeda Galaxy, shown in *Figure 31-12B*.

Masses of Clusters For clusters of galaxies, the mass determined by analyzing the motion of member galaxies is always much larger than the sum of the visible masses of the galaxies. This suggests that most of the mass in a cluster of galaxies is invisible, which provides astronomers with the strongest evidence that the universe contains a great amount of dark matter. The nature of dark matter is still unknown.

Superclusters Clusters of galaxies are organized into even larger groups called **superclusters**. These gigantic formations, hundreds of millions of light-years in size, can be observed only when astronomers map out the locations of many galaxies ranging over huge distances. These superclusters appear in sheetlike and threadlike shapes, giving the appearance of a gigantic bubble bath with galaxies located on the surfaces of the bubbles, and the inner air pockets void of galaxies.

THE EXPANDING UNIVERSE

Edwin Hubble made yet another dramatic discovery, this time in 1929. It was known at the time that most galaxies have redshifts in their spectra, indicating that all galaxies are moving away from Earth. Hubble measured the redshifts and distances of many galaxies and found that the redshift of a galaxy depends on its distance from Earth. The farther away a galaxy is, the faster it is moving away. The universe is expanding.

You might infer from this that Earth is at the center of the universe. Actually, this is not the case. An observer located in any galaxy, at any place in the universe, will observe the same thing we do: all other galaxies move away with speeds that depend on their distances. In a medium that is uniformly expanding, all points are moving away from all other points, and no point has to be at the center. You will experiment with uniform expansion in the *MiniLab* later in this section.

Hubble's Law Hubble determined that the universe is expanding by making a graph of the speed at which a galaxy is moving versus its distance. The result is a straight line, which can be expressed as a simple equation, $v = Hd$, where v is the speed at which a galaxy is moving away measured in kilometers per second; d is the distance to the galaxy measured in megaparsecs (Mpc), where $1 \text{ Mpc} = 1 \times 10^6 \text{ pc}$; and H is

a number called the **Hubble constant**, that is measured in kilometers per second per megaparsec. H represents the slope of the line. You will plot Hubble's law in the *Problem-Solving Lab* on this page.

To measure H requires finding distances and speeds for many galaxies, out to the largest possible distance, and constructing a graph to find the slope. This is a difficult task, because it is hard to measure accurate distances to the most remote galaxies. Hubble himself could obtain only a crude value for H . Measuring an accurate value for H was one of the key goals of astronomers who designed the *Hubble Space Telescope*. It took nearly ten years after the *Hubble Space Telescope's* launch to gather enough data to pinpoint the value of H to the satisfaction of most astronomers. Currently, the best measurements indicate a value of approximately 70 kilometers per second per megaparsec.

Once the value of H is known, it can be used to find distances to far away galaxies. By measuring the speed at which a galaxy is moving, astronomers can locate that speed on the graph and can then determine the corresponding distance of the galaxy on the graph. This method works for the most remote galaxies that can be observed, and it allows astronomers to measure distances to the edge of the observable universe.



To learn more about the *Hubble Space Telescope*, go to the [National Geographic Expedition](#) on page 902.

Problem-Solving Lab

Making and Using Graphs

The Hubble constant The table lists distances and speeds for a number of galaxies.

Analysis

1. Use the data to construct a graph. Plot the distance on the x -axis and the speed on the y -axis.
2. Use a ruler to draw a straight line through the center of the band of points on the graph, so that about as many points lie above the line as below it. Make sure your line starts at the origin.
3. Measure the slope by choosing a point on the line and dividing the speed at that point by the distance.

Thinking Critically

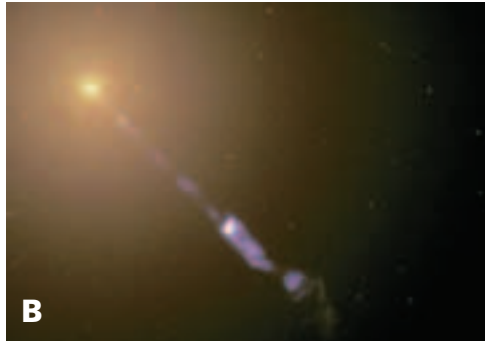
4. What does the slope represent?
5. How accurate do you think your value of H is? Explain.
6. How would an astronomer improve this measurement of H ?

Galaxy Data

Distance (Mpc)	Speed (km/s)	Distance (Mpc)	Speed (km/s)
3.0	210	26.5	2087
8.3	450	33.7	2813
10.9	972	36.8	2697
16.2	1383	38.7	3177
17.0	1202	43.9	3835
20.4	1685	45.1	3470
21.9	1594	47.6	3784



A



B

Figure 31-13 M87 is a large radio galaxy (**A**). In addition to radio lobes, M87 has a jet of gas that emits visible light (**B**).

ACTIVE GALAXIES

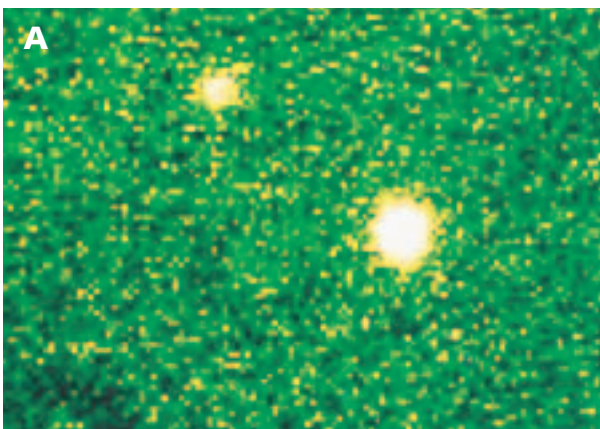
Radio-telescope surveys of the sky have revealed a number of galaxies that are extremely bright. These galaxies, called **radio galaxies**, are often giant elliptical galaxies that emit as much as or more energy in radio wavelengths than they do in wavelengths of visible light. Radio galaxies have many unusual properties. The radio emission usually comes from two huge lobes of very hot gas located on opposite sides of the visible galaxy. These lobes are linked to the galaxy by jets of very hot gas. The type of emission that comes from these regions indicates that the gas is ionized, and that electrons in the gas jets are traveling nearly at the speed of light. Many radio galaxies have jets that can be observed only at radio wavelengths. One of the brightest of the radio galaxies, a giant elliptical called M87, shown in **Figure 31-13**, also has a jet of gas that emits visible light extending from the galactic center out toward one of the radio-emitting lobes.

In some unusual galaxies, some sort of highly energetic object or activity exists in the core. This object or activity emits as much or more energy than the rest of the galaxy. The output of this energy often varies over time, sometimes as little as a few days. The cores of galaxies where these highly energetic objects or activities are located are called **active galactic nuclei**, or AGNs.

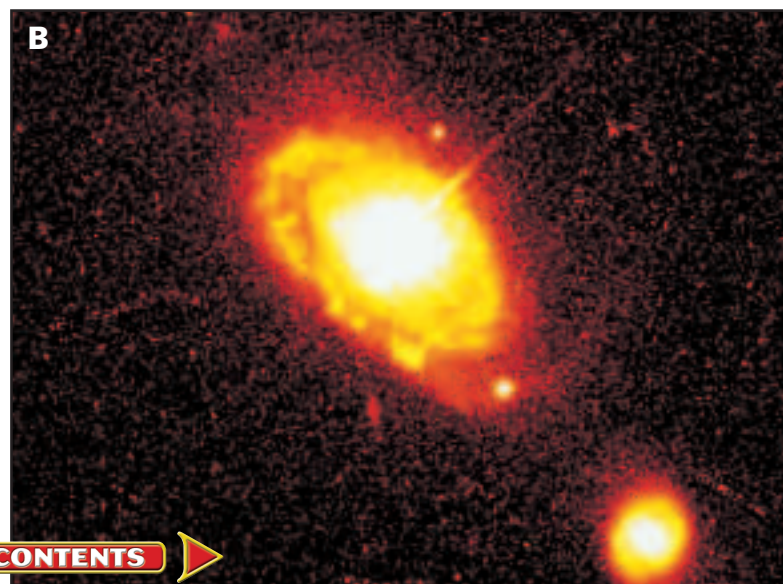
Figure 31-14 From a ground-based telescope, a quasar (right of center) looks much like a star (**A**). From the *Hubble Space Telescope*, a quasar can be seen in the nucleus of a dim galaxy (**B**).

QUASARS

In the 1960s, astronomers discovered another new type of object. These objects looked like ordinary stars, but some were strong radio emitters. Most stars are not. The spectra of these new objects were completely different from the spectra of normal stars. Whereas most stars have spectra with absorption lines, these new objects had mostly



A



B

emission lines in their spectra. These starlike objects with emission lines in their spectra are called **quasars**. A quasar is shown in *Figure 31-14A*. At first, astronomers could not identify the emission lines in the spectra of quasars. Finally, they realized that the emission lines were spectral lines of common elements, such as hydrogen, shifted very far toward longer wavelengths. Soon, astronomers also discovered that many quasars vary in brightness over a period of a few days. Once astronomers had identified the large spectral-line shifts of quasars, they wondered whether these could be redshifts caused by the expansion of the universe.

The redshifts of quasars were much larger than any that had been observed in galaxies up to that time, which would mean that the quasars were much farther away than any known galaxy. Some astronomers at first doubted that quasars were far away, but in the decades since quasars were discovered, more evidence supports the hypothesis that quasars are indeed far away. One bit of supporting evidence is that some quasars are associated with clusters of galaxies with the same redshift, verifying that they are the same distance away. Another, more important discovery is that most quasars are nuclei of very dim galaxies, as shown in *Figure 31-14B*. The quasars appear to be extra-bright active galactic nuclei—so much brighter than their surrounding galaxies that astronomers could not even see the galaxies at first.

Looking Back in Time Because many quasars are far away, it takes their light a long time to reach Earth. For this reason, astronomers observing a quasar are seeing it as it was a long time ago. For example, it takes light from the Sun approximately eight minutes to reach Earth. When we observe that light, we are seeing the Sun as it

MiniLab

Measuring Redshifts

Model uniform expansion of the universe and the redshifts of galaxies that result from expansion.



Procedure

1. Use a felt tip marking pen to make four dots in a row, each separated by 1 cm, on the surface of an uninflated balloon. Label the dots 1, 2, 3, and 4.
2. Partially inflate the balloon. Using a piece of string and a meterstick, measure the distance from dot 1 to each of the other dots. Record your measurements.
3. Inflate the balloon further, and again measure the distance from dot 1 to each of the other dots. Record your measurements.
4. Repeat step 3 with the balloon fully inflated.

Analyze and Conclude

1. Are the dots still separated from each other by equal distances? Explain.
2. How far did each dot move away from dot 1 after each inflation?
3. What would be the result if you had measured the distances from dot 4 instead of dot 1? From dot 2?
4. How does this activity illustrate uniform expansion of the universe and redshifts of galaxies?

was eight minutes earlier. When we observe the Andromeda Galaxy, we see the way it looked two million years earlier. The most remote quasars are several billion light-years away, which indicates that they existed billions of years ago. If quasars are extra-bright galactic nuclei, then the many distant ones are nuclei of galaxies as they existed when the universe was young. This suggests that many galaxies went through a quasar stage when they were young. In that case, today's active galactic nuclei might be former quasars that are not quite as energetic as they were long ago.

Source of Power The AGNs and quasars emit far more energy than ordinary galaxies, but they are as small as solar systems. This suggests that all of these objects are supermassive black holes. Recall that our own galaxy is hypothesized to contain such an object within its core, and that this object has a mass of about one million Suns. The black holes in the cores of AGNs and quasars are much more massive, up to hundreds of millions of times the mass of the Sun. The beams of charged particles that stream out of the cores of radio galaxies and form jets are probably created by magnetic forces. As material falls into a black hole, the magnetic forces push the charged particles out into jets. There is evidence that similar beams or jets occur in other types of AGNs and in quasars. In fact, radio-lobed quasars have jets that are essentially related to radio galaxies.

The role of AGNs and especially quasars as early stages in the evolution of galaxies provide important clues for astronomers as they study the origin and evolution of the universe itself. With the discovery of new and more distant objects, astronomers are getting closer to unraveling the story of the universe.



Update For an online update on quasars, visit the Earth Science Web Site at earthgeu.com

SECTION ASSESSMENT

1. How did astronomers discover that there are other galaxies beyond the Milky Way?
2. Why do astronomers theorize that most of the matter in galaxies and clusters of galaxies is dark matter?
3. Why is it difficult for astronomers to accurately measure a value for the Hubble constant, H ? Once a value is determined, what can it be used for?
4. Explain the differences among normal spiral, barred spiral, elliptical, and irregular galaxies.
5. **Thinking Critically** How would the nighttime sky look from Earth if we lived in an elliptical galaxy?

SKILL REVIEW

6. **Using Numbers** Suppose that a distant galaxy is moving away from Earth at a velocity of 20 000 km/s. Assuming that the value of the Hubble constant is 70 kilometers per second per megaparsec, how far away is this galaxy? For more help, refer to the *Skill Handbook*.

You've learned about Earth, the planets, the Sun, stars, and galaxies. Now you are ready to consider the universe as a whole. The study of the universe, its current nature, and its origin and evolution, is called **cosmology**.

As in other areas of science, astronomers use a combination of observations and theoretical models in cosmology. One difference between cosmology and other areas of study is that in cosmology, objects that have a range of properties cannot be compared, as they can be in the study of stars, for example. Astronomers have only one universe to consider and nothing to compare it with. However astronomers can use particle accelerators to learn about the universe, as you'll learn in the *Science & Technology* feature at the end of this chapter.

MODELS OF THE UNIVERSE

The fact that the universe is expanding implies that it had a beginning. The theory that the universe began as a point and has been expanding ever since is called the **Big Bang theory**. The Big Bang theory is not an explosion into space, but instead is an expansion of space with matter going along for the ride. Not all astronomers agree that the universe had a beginning, which led to an alternative theory. The **steady-state theory** proposes that the universe looks the same on large scales to all observers, and that it has always looked that way. The steady-state universe doesn't change with time. However, if the universe is expanding, how can this be true? Supporters of the steady-state theory propose that new matter is created and added to the universe as it expands, and thus, the overall density of the universe does not change, as illustrated in **Figure 31-15**.

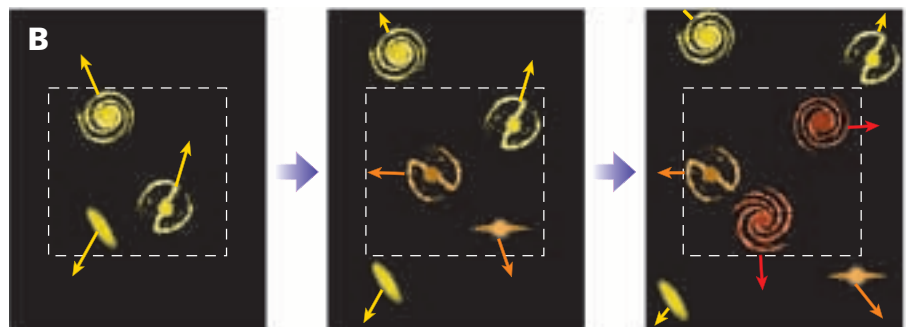
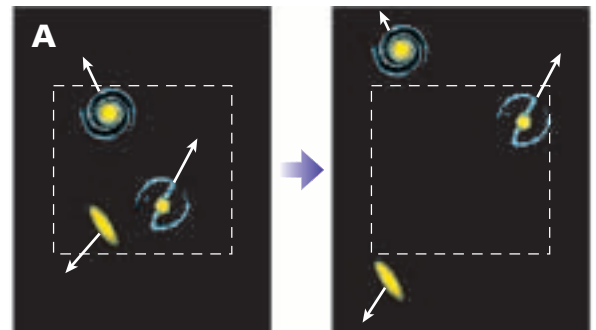


Figure 31-15 Without the creation of new matter, the area within the dotted box would not contain 3 galaxies after a time **(A)**. The steady-state theory requires new matter to be added so that the area within the dotted box always contains 3 galaxies **(B)**.

OBJECTIVES

- **Explain** the different theories about the formation of the universe.
- **Describe** the possible outcomes of universal expansion.

VOCABULARY

cosmology
Big Bang theory
steady-state theory
cosmic background radiation
inflationary universe

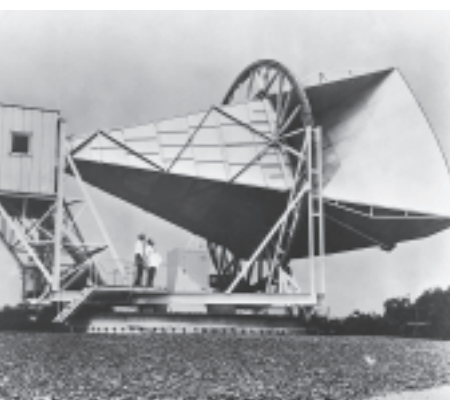
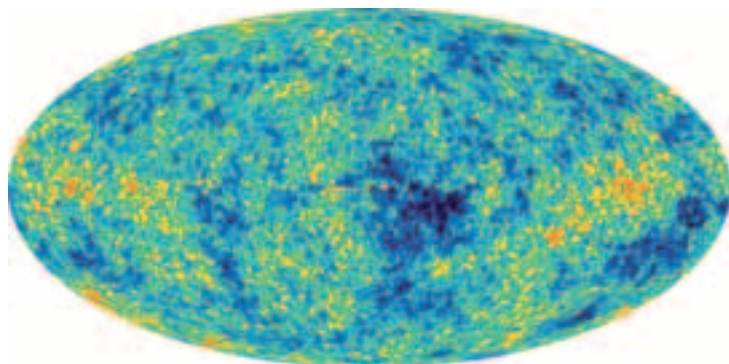


Figure 31-16 The cosmic background radiation was discovered accidentally with this radio antenna at Bell Labs, in Holmdel, New Jersey.

Figure 31-17 The map of the cosmic background radiation made by *WMAP* shows slight temperature differences of only a few millionths of a degree.



Many observational tests can be conducted to provide support for either the Big Bang or the steady-state theory. Each theory predicts what the universe should look like. By observing the universe, astronomers can determine which predictions are actually met. This in turn provides support for one theory or the other. Today, the evidence weighs in favor of the Big Bang.

Cosmic Background Radiation If the universe began in a highly compressed state, as the Big Bang theory suggests, it would have been very hot, and the high temperatures would have filled it with radiation. If radiation filled the universe back then, that same radiation should still fill the universe. Originally, when the radiation was able to escape, it would have been in the form of visible light and infrared radiation, which have high energy and short wavelengths. However, as the universe expanded and cooled, the radiation would have been Doppler shifted to lower energies and longer wavelengths.

The existence of such radiation in the universe today would not support the steady-state theory of the universe, which does not predict such radiation. In 1965, some scientists discovered a persistent background noise in their radio antenna, shown in *Figure 31-16*. This noise was caused by weak radiation, called the **cosmic background radiation**, that appeared to come from all directions in space and corresponded to an emitting object having a temperature of about 2.735 K (-270°C). This was very close to the temperature predicted by the Big Bang theory, and the radiation was interpreted to be from the beginning of the Big Bang.

Mapping the Radiation Since the discovery of the cosmic background radiation, extensive observations have confirmed that it matches the properties of the predicted leftover radiation from the early, hot phase in the expansion of the universe. Earth's atmosphere blocks much of the radiation, so it is best observed from high-altitude balloons or satellites. An orbiting observatory called the *Wilkinson Microwave Anisotropy Probe* (*WMAP*), launched by NASA in 2001, mapped the radiation in greater detail, as shown in *Figure 31-17*. The peak of the radiation it measured has a wavelength of approximately 1 mm; thus, it is microwave radiation in the radio portion of the electromagnetic spectrum.

Proponents of the steady-state universe theory have not succeeded in explaining the cosmic background radiation. This is one of the major reasons that most astronomers do not accept this model. Other tests that can be used to validate either the steady-state theory or the Big Bang theory are whether or not each theory can explain redshifts of galaxies, the evolution of galaxies, and quasars.

THE BIG BANG MODEL

In the Big Bang model, there is a competition between the outward momentum of the expansion of the universe and the inward force of gravity as the matter in the universe acts to slow the expansion, as illustrated in **Figure 31-18A**. What ultimately will happen depends on which of these two forces is stronger. There are three possible outcomes for the universe: an open universe, in which the expansion will never stop; a closed universe, in which the expansion will stop and turn into a contraction; and a flat universe, in which the expansion will slow to a halt in an infinite amount of time—but it will never contract. All three cases, illustrated in **Figure 31-18B**, are based on the premise that the rate of expansion has slowed down since the beginning of the universe. The question would then appear to be, How much further will it slow down?

The Critical Density The total amount of matter in the universe is one of the factors that will determine whether or not the expansion will stop. The total amount of matter in the universe is expressed in terms of the average density of matter, something that astronomers can observe. The *critical density*, about 10^{-26} kg/m³, is the dividing point between a closed or open universe. If the average density is higher than the critical density, the universe is closed, but if the average density is lower than the critical density, the universe is open. If the density equals the critical density, the universe is flat. By observing the average density of matter, astronomers can predict how the universe will change on a large scale. Observations of visible galaxies reveal an average density much less than the critical density. However, as you've learned, there is evidence that a great amount of dark matter exists in the universe, which impacts the average density.

Figure 31-18 Gravity competes with the momentum of the expansion (**A**). The universe could be open, flat, or closed (**B**). The flat universe line will gradually become a horizontal line, while the open universe line will keep increasing.

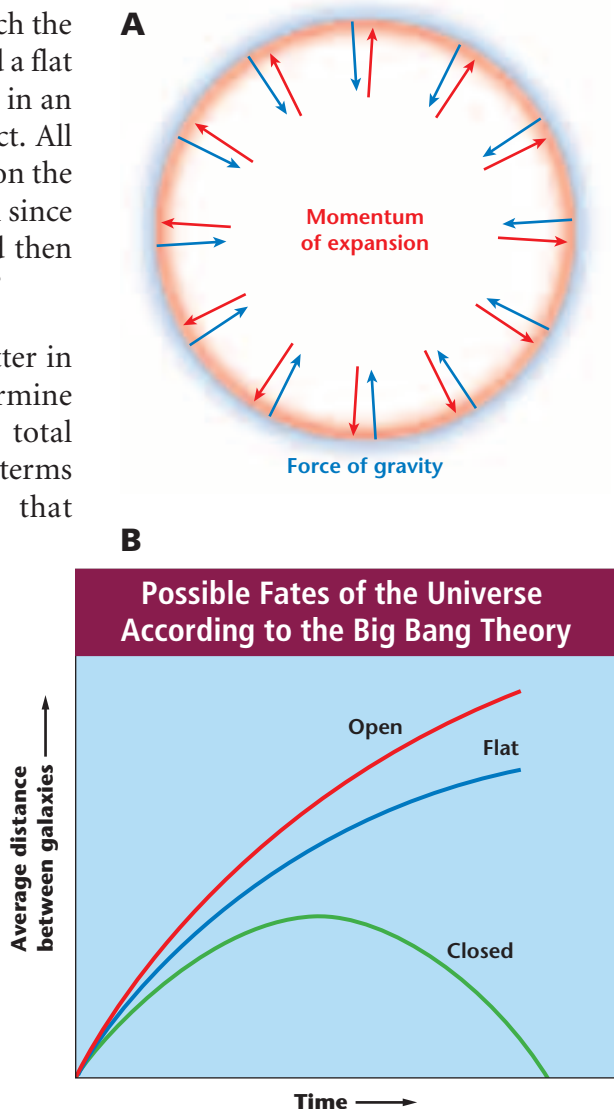




Figure 31-19 This distant cluster of galaxies, Abell 2218, allows astronomers to look back into time.

Expansion Rate Another approach to determining the fate of the universe is to measure how much slowing has occurred so far in its expansion. This will indicate how much further it will slow down. The slowing of the expansion of the universe can be measured by comparing the expansion rate today with the rate long ago. Recall that when astronomers observe the most distant galaxies, such as the ones shown in **Figure 31-19**, they are observing the galaxies as they existed far back in time. By measuring the redshifts of the most remote galaxies, it is possible for astronomers to determine the expansion rate long ago. This also requires finding the distances to those very far away galaxies.

The most recent observations of the change in the expansion rate of the universe have been startling. Astronomers have found that the rate of expansion is speeding up! It appears that the rate of expansion slowed for a while but is now gathering speed. The only explanation offered so far is that a previously unknown force is acting to push the galaxies apart. According to this explanation, when the universe was smaller and denser, gravity was strong enough to slow the expansion, but some time ago this unknown force began to dominate over gravity.



Using Math

Using Numbers The time since the expansion of the universe began can be calculated by

$$t = \frac{1}{H}$$

Astronomers hypothesize that H is somewhere between 50 and 100 kilometers per second per megaparsec. What age does each value of H predict?

Remember to convert Mpc to km, using $1 \text{ Mpc} = 3.1 \times 10^{19} \text{ km}$.

The Inflationary Model The combination of the observed density of the universe, including an allowance for dark matter, and the apparent acceleration of the expansion, fit together into a model in which the universe is flat. A flat universe was predicted in the 1980s by a version of the Big Bang model called the inflationary universe. In the **inflationary universe** model, the universe began as a fluctuation in a vacuum and expanded very rapidly for a fraction of a second, as illustrated in **Figure 31-20**, before settling into a more orderly expansion. The initial inflationary step is similar to what can happen in water that is supersaturated with soap: if the water is disturbed, it forms a sea of bubbles almost instantaneously.

When the rate of expansion of the universe is known, it is possible to calculate the time since the expansion started, or the age of the universe. When the distance to a galaxy and the rate at which it is moving away from Earth are known, it is simple to calculate how long ago that galaxy and the Milky Way were together. In astronomical terms,

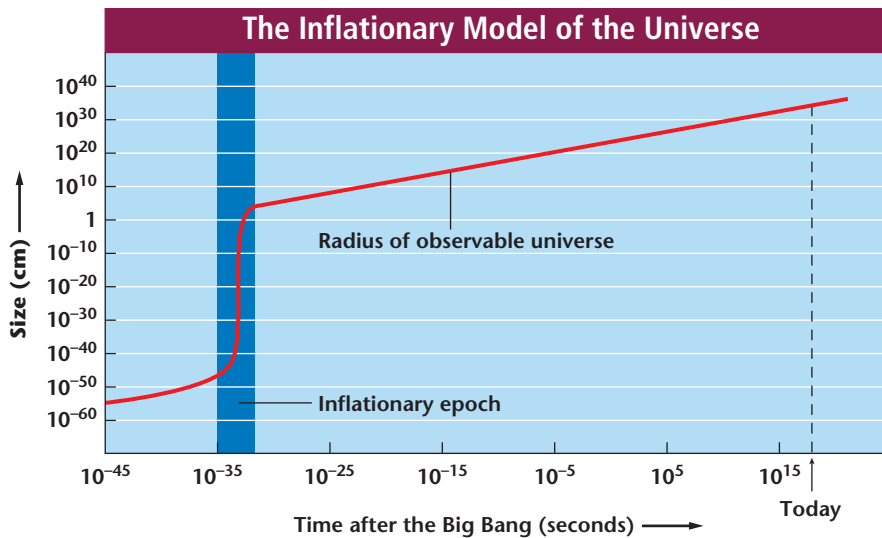


Figure 31-20 According to the inflationary model, the universe expanded very quickly in the early portion of the Big Bang. The time in which inflation occurred is the shaded portion of the graph, where the size of the universe increases drastically.

if the value of H , the expansion constant, is known, then the age of the universe can be determined. A correction is needed to allow for the fact that the expansion was more rapid at the beginning, and now it seems that this correction must also take into account the acceleration of the expansion that is occurring now. Based on the best value for H that has been calculated from *Hubble Space Telescope* data, as well as the appropriate corrections, the age of the universe is hypothesized to be about 13.5 billion years. This fits with what astronomers know about the age of our own galaxy, which is estimated to be between 12 and 14 billion years, based on the ages of the oldest star clusters. However, refinements to these measurements are still being made.

SECTION ASSESSMENT

1. What are the differences between the steady-state model of the universe and the Big Bang model of the universe?
2. Describe the inflationary model and its predicted impact on the structure of the universe.
3. Why is dark matter important in determining the density of matter in the universe?
4. Why was the cosmic background radiation an important discovery?
5. **Thinking Critically** How would a large value of H , the Hubble constant, affect the age of the universe? What about a small value of H ?

SKILL REVIEW

6. **Comparing and Contrasting** Compare and contrast an open universe, a closed universe, and a flat universe. For more help, refer to the *Skill Handbook*.

Classifying Galaxies

Edwin Hubble developed rules for classifying galaxies according to their shapes as seen in telescopic images. Astronomers are interested in the classification of galaxies. This information can indicate whether a certain type of galaxy is more likely to form than another and helps astronomers unravel the mystery of galaxy formation in the universe. Using the resources of the Internet and sharing data with your peers, you can learn how galaxies are classified.

Preparation

Problem

How can different galaxies be classified?

Hypothesis

How might galaxies be classified using Hubble's classification system? Are there absolute classifications based solely on shape? **Form a hypothesis** about how you can apply Hubble's galaxy classification system to galaxy images on the Internet.

Objectives

- **Gather** and **communicate** details about galaxy images on the Internet.
- **Form conclusions** about the classification of different galaxies.
- **Reconstruct** the tuning-fork diagram with images that you find.

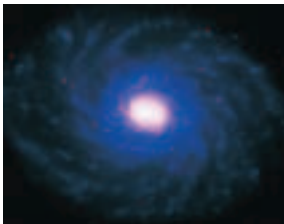
Data Sources

Go to the Earth Science Web Site at earthgeu.com to find links to galaxy images on the Internet. You can also visit a local library or observatory to gather images of galaxies and information about them.

Plan the Experiment

1. Find a resource with multiple images of galaxies and, if possible, names or catalog numbers for the galaxies. The Earth Science Web Site lists sites that have galaxy images.
2. Choose one of the following types of galaxies to start your classification: spirals, ellipticals, or irregular galaxies.
3. Gather images and information, such as catalog numbers and names of galaxies, from the links on the Earth Science Web Site or the library.
4. Sort the images by basic types: spirals, ellipticals, or irregular galaxies.

- For each basic type, compare the galaxies to each other and decide which galaxy best represents each class and subclass of Hubble's galaxy classification system: Sa, Sb, Sc, SBa, SBb, SBc, S0, E0–E7, and Irr. Try to find at least one galaxy for each subclass.
- Arrange the galaxy images to construct a tuning-fork diagram like Hubble's.

GALAXY DATA			
Galaxy Name	Sketch of Galaxy	Classification	Notes
NGC 3486		Sc	

Procedure

- Complete the data table. Add any additional information that you think is important.
- Go to the Earth Science Web Site at earthgeu.com to post your data.
- Visit sites listed on the Earth Science Web Site for information about other galaxies.

Conclude & Apply

Sharing Your Data Find this Internet GeoLab on the Earth Science Web Site at earthgeu.com. Post your data in the table provided for this activity. Use the additional data from other students to complete your chart and answer the Conclude & Apply questions.

- Were there any galaxy classes or subclasses that were difficult to find images for? If so, which ones?
- How many of each type of galaxy—normal spiral, barred spiral, elliptical, and irregular—did you find?
- Calculate the percentages of the total number of galaxies that each type represents. Do you think this reflects the actual percentage of each type of galaxy in the universe? Explain.
- Were there any galaxy images that you found that didn't fit your classification scheme? If so, why?
- Was it difficult to distinguish between a normal spiral and a barred spiral in some cases? Explain your method.
- What problems did you have with galaxies that are edge-on as seen from Earth?
- Ellipticals are usually a difficult type of galaxy to classify. Why?

Science & Technology



The Early Universe

Imagine looking back 10 billion years to a time when the universe was young and galaxies were just beginning to form. The Hubble Deep Field (HDF), pictured at left, is a snapshot of the early universe by the Hubble Space Telescope. The HDF shows at least 1500 galaxies in various stages of evolution. Some are so far away that we see them now as they looked less than 1 billion years after the Big Bang.

Back in Time

Images such as the HDF offer tantalizing clues to questions about conditions in the early universe. Did it resemble the universe we know today? How did the universe begin? Most astronomers hypothesize that the universe was formed by the Big Bang. This violent event left particles rushing away from each other at tremendous speeds. The energy created billions of years ago still propels galaxies away from each other as the universe continues to expand.

Accelerated Particles

Scientists learn about the world by making observations about events in progress, or by creating specific conditions that will cause an event to occur. Because the Big Bang can neither be observed nor recreated, other methods must be used to study it. One tool that scientists use to replicate conditions in the early universe is the particle accelerator, a machine that smashes charged particles into various targets at speeds close to the speed of light. The particle accelerator allows scientists to test models of how matter and energy behaved as soon as 1×10^{-11} s after the Big Bang.

All particle accelerators are based on the principle that electrically charged objects exert a force on each other. Intense magnetic fields are

applied to charged particles moving through tubes. Particles gain speed until they crash into some target. High-speed collisions between particles often result in strange particles that scientists have never before observed.

Limitations

In 1989, workers began digging miles of tunnels in a geologically stable area in Texas where the Supercolliding Superconductor (SCC) was to be built. A 54-mile (86.9-km) oval, the SCC would have been the world's largest, most powerful particle accelerator, allowing astronomers to probe deeper into the early conditions of the universe. Despite the efforts of physicists and astronomers worldwide, however, Congress cut off funding for the project in 1993. Until larger, more powerful particle accelerators are built, scientists are limited in what they can learn about the early universe.

Activity

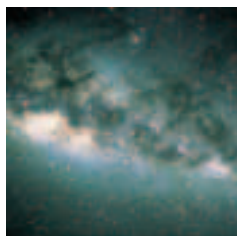
The Fermilab Tevatron is the world's most powerful accelerator. Go to the Earth Science Web Site at earthgeu.com to research Fermilab. Do you think particle accelerators should be built despite their large cost? Why?

CHAPTER 31 Study Guide

Summary

SECTION 31.1

The Milky Way Galaxy



Main Ideas

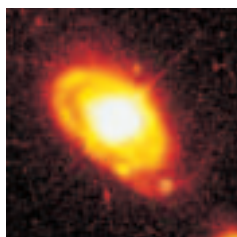
- Because our solar system is inside the Milky Way galaxy, it was difficult at first for astronomers to determine the size and shape of our galaxy, and where Earth is located within it.
- The Milky Way consists of a nuclear bulge, a disk, and a halo. Much of the mass of the galaxy is not visible.
- It is hypothesized that the Milky Way began as a spherical cloud of gas that eventually collapsed into a disk.
- Population I stars contain small amounts of heavy elements and are located in the arms and disk. Population II stars are located in the bulge and halo, and contain only trace amounts of heavy elements.

Vocabulary

Cepheid variable (p. 834)
halo (p. 835)
RR Lyrae variable (p. 834)
spiral density wave (p. 838)
variable star (p. 834)

SECTION 31.2

Other Galaxies in the Universe



Main Ideas

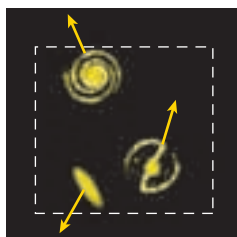
- Galaxies are classified according to their shapes as normal spirals, barred spirals, ellipticals, irregulars, or dwarf ellipticals.
- Most galaxies occur in clusters, which are further organized into superclusters.
- The universe is expanding, and the Hubble constant, H , measures the rate of expansion.
- Because it takes the light from very distant galaxies so long to reach Earth, when astronomers observe these galaxies, they are looking back in time.
- Many galaxies have energetic objects or activities at their cores called active galactic nuclei.

Vocabulary

active galactic nucleus (p. 844)
Hubble constant (p. 843)
quasar (p. 845)
radio galaxy (p. 844)
supercluster (p. 842)

SECTION 31.3

Cosmology



Main Ideas

- The Big Bang theory proposes that the universe began as a single point and has been expanding ever since.
- The steady-state theory proposes that the universe is the same as it always has been.
- The universe is filled with cosmic background radiation that is left over from the early, hot stages in the Big Bang expansion of the universe.
- In the Big Bang model, the universe could be open, closed, or flat.
- The inflationary model can explain the walls and voids of the distribution of galaxies. It also predicts that the universe is flat, which is supported by observations.
- Current observations indicate that an unknown force is accelerating the expansion of the universe.

Vocabulary

Big Bang theory (p. 847)
cosmic background radiation (p. 848)
cosmology (p. 847)
inflationary universe (p. 850)
steady-state theory (p. 847)



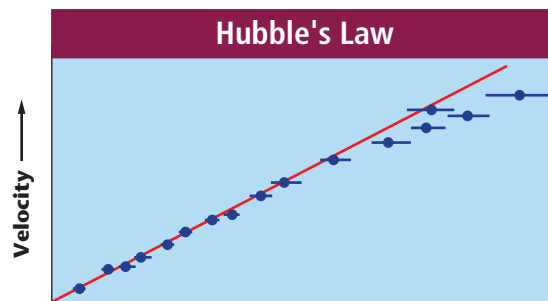
CHAPTER 31 Assessment

Understanding Main Ideas

1. What are the oldest objects in the Milky Way?
 - a. globular clusters
 - b. Cepheid variables
 - c. spiral arms
 - d. Population I stars
2. Where in the Milky Way are new stars being formed?
 - a. in the nuclear bulge
 - b. in globular clusters
 - c. in the spiral arms
 - d. in the halo
3. Where does the energy emitted by AGNs and quasars most probably come from?
 - a. material falling into a supermassive black hole
 - b. a neutron star
 - c. a supernova explosion
 - d. a pulsar
4. What theory proposes that the universe does not change with time?
 - a. the Big Bang
 - b. the cosmological constant
 - c. the heliocentric universe theory
 - d. the steady-state universe theory
5. What is the origin of the cosmic background radiation?
 - a. It is emitted by stars.
 - b. It is a remnant of the Big Bang.
 - c. It is emitted by radio galaxies.
 - d. It comes from the steady-state universe.
6. In the Big Bang model, which of the following describes a universe that will stop expanding and begin to contract?
 - a. open
 - b. flat
 - c. closed
 - d. inflationary
7. Why are pulsating variable stars useful for finding distances to globular clusters?
8. How do astronomers observe the spiral structure of our galaxy?

9. Why do astronomers think that there is a great amount of mass in the halo of the Milky Way?
10. What possible forms might the dark matter in the halo of the Milky Way be in?
11. Why do astronomers hypothesize that there is a supermassive black hole at the center of the Milky Way?

Use the diagram below to answer question 12.



12. The straight line represents Hubble's law, $v = Hd$, and the points are actual data for galaxies. Why don't the points agree with the straight line of Hubble's law?
13. Why are the stars in globular clusters classified as Population II stars?
14. Does the fact that all galaxies are receding from Earth suggest that it is located at the center of the universe? Explain.
15. What is the significance of the Hubble constant?
16. What evidence indicates that many quasars existed long ago?

Test-Taking Tip

MISTAKES Your mistakes can teach you. The mistakes you make before the test are helpful because they show you the areas in which you need more work.

CHAPTER 31 Assessment

17. What are the main differences between the steady-state model and the Big Bang model of the universe?
18. What would be the different outcomes of the open, flat, and closed universe models?

Applying Main Ideas

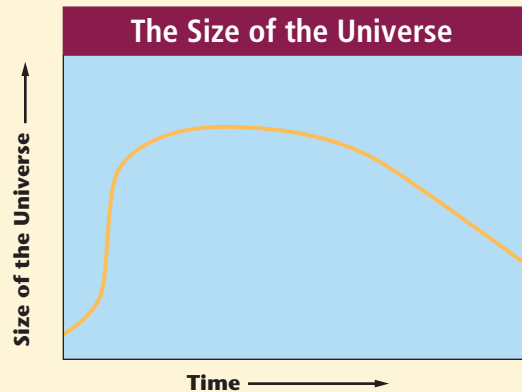
19. Why are astronomers actually looking into the past when they observe objects that are very far away?
20. What evidence indicates that much of the mass in the universe is in an invisible form called dark matter?
21. Why is it important for astronomers to determine the average density of the universe?
22. How did Edwin Hubble reach the conclusion that the universe is expanding?
23. Why do astronomers theorize that many quasars are active nuclei of young galaxies?

Thinking Critically

24. How would a star that forms in our galaxy a few billion years in the future compare with the Sun?
25. How is the formation of our galaxy like the formation of a star?
26. A quasar and three galaxies are observed, and the ranking of their redshifts is as follows: galaxy 1, largest redshift; galaxy 2, second-largest redshift; the quasar, third-largest redshift; and galaxy 3, fourth-largest redshift. List these objects in order from the nearest to the farthest from Earth.
27. How do the properties of quasars suggest that the steady-state model of the universe is not accurate?

Standardized Test Practice

USING GRAPHS Use the graph below to answer question 1.



1. What possible fate of the universe does this represent?
 - a. flat
 - b. open
 - c. closed
 - d. steady
2. Without doing any calculations, what can astronomers determine from a variable star's period of pulsation?
 - a. distance
 - b. apparent magnitude
 - c. luminosity
 - d. age
3. What two measurements are required to determine the Hubble constant?
 - a. distance and speed
 - b. distance and absolute magnitude
 - c. apparent magnitude and speed
 - d. apparent and absolute magnitudes
4. Which of the following does the existence of the cosmic background radiation support?
 - a. critical density
 - b. the steady-state theory
 - c. the inflationary model
 - d. the Big Bang theory

For a **preview** of the universe beyond Earth, study this GeoDigest before you read the chapters. After you have studied these chapters, you can use the GeoDigest to **review** the unit.

Beyond Earth

The Sun-Earth-Moon System

Tools of Astronomy Different types of telescopes make use of all types of electromagnetic radiation: visible light, radio waves, infrared and ultraviolet radiation, X rays, and gamma rays. Telescopes collect electromagnetic radiation over large areas. They can make time exposures and be used with cameras and other equipment to analyze and measure electromagnetic radiation. Refracting telescopes use lenses to bring light to a focus, whereas reflecting telescopes use mirrors. Some forms of radiation are blocked by Earth's atmosphere, and thus telescopes that collect these forms of radiation must be placed in space. Space probes make observations from space or land and take samples for analysis.

The Moon The Moon has surface features that survive due to its lack of an atmosphere and erosion. Earth's moon is larger and more distant, relative to the size of its planet, than any other satellite in the solar system. These characteristics may be a result of the Moon's being formed in a collision between Earth and a Mars-sized body. The Moon is covered with highlands and maria.

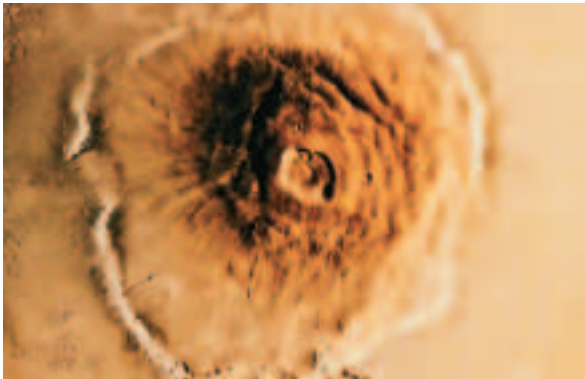
The Sun-Earth-Moon System From a rotating Earth, the sky appears to rotate daily. Our timekeeping system is based on the solar day as observed from Earth. On Earth, we see the Moon go through phases that complete a lunar month. The phases correspond to our changing view of the sunlit side of the Moon. A lunar eclipse occurs when the Moon passes through Earth's shadow; a solar eclipse occurs when the Moon passes between Earth and the Sun, and the Moon's shadow intersects the surface of Earth. Earth's tilt on its axis and its changing position in orbit causes seasons. Tides are caused by the gravitational pull of the Moon and the Sun on the water on Earth's surface.

The Solar System

Motion and Formation Early astronomers explained the motions of the planets with geocentric models. Copernicus, Brahe, Kepler, and Galileo collected data that supported a heliocentric model of the solar system. Newton's law of gravitation demonstrated the validity of the heliocentric model. The solar system formed from a collapsing



John Glenn with suit technicians, 1998



Olympus Mons, Mars

interstellar cloud that flattened into a disk. The terrestrial planets formed from refractory materials in the hot, inner disk; the gas giants formed from volatile elements in the cold, outer disk. Planets orbiting other stars have recently been discovered.

The Planets The terrestrial planets are the four planets closest to the Sun. Mercury has a surface similar to the Moon's. Venus's surface is heated to extreme temperatures through the greenhouse effect. Liquid water exists on Earth, making it suitable for life. Mars may have once had active tectonics. Between Mars and Jupiter is a belt of asteroids, which are rocky remnants of the early solar system. The huge gas giant planets have low densities, no solid surfaces, ring systems, and many moons. Jupiter, the largest and most massive planet, has a fluid (gas or liquid) interior, a small, rocky core, and many moons. Saturn is slightly smaller than Jupiter and has an extensive ring system. Uranus and Neptune are similar in size, composition, and the presence of moons and rings. Pluto is neither a gas giant nor a terrestrial planet. Its moon is close to its own size. Comets are made of rock and ice, and they have highly eccentric orbits. When comets are close to the Sun, they glow brightly and have tails of gas and dust that point away from the Sun.

Stars

The Sun Astronomers learn about the Sun through observations and models. They have found that the Sun contains most of the mass in the solar system and is made primarily of hydrogen and helium. The layers of its atmosphere are the photosphere, chromosphere, and corona. The interior of the Sun consists of radiative and convective zones that transfer energy. The nuclear fusion of hydrogen into helium within the core powers the Sun. Surface features of the Sun include sunspots, solar flares, and prominences. The Sun has an 11-year sunspot cycle and a 22-year activity cycle.

Measurement of Stars Positional measurements of the stars are important for measuring distances through apparent shifts in position, called parallax. Stellar brightness is expressed by apparent and absolute magnitude. The appearance of stars' spectra classifies them by their surface temperatures. Stellar characteristics—class, mass, temperature, magnitude, diameter, and luminosity—are related on a diagram called the Hertzsprung-Russell diagram. The mass of a star determines its internal structure and other properties; gravity and pressure are balanced in a star.

Evolution of Stars If the temperature in the core of a star becomes high enough, elements heavier than hydrogen but lighter than iron can fuse together. When the hydrogen in a star is used up, the star may go through several red-giant phases as reaction stages begin and end. Stars like the Sun end as white dwarfs. Stars up to about 8 times the Sun's mass also become white dwarfs after losing mass. Stars between 8 and 20 times the Sun's mass become supernovae and end as neutron stars. Stars more than 20 times as massive as the Sun end as black holes.

Galaxies

The Milky Way The Milky Way consists of a nuclear bulge, a disk, and a halo; much of its mass is not visible. In the galaxy, Population I stars contain small amounts of heavy elements and are located in the arms and disk. Population II stars are located in the bulge and halo, and contain only trace amounts of heavy elements. Because Earth is inside the Milky Way, it has been difficult to determine the size and shape of the galaxy, and also where Earth is located within it.

Other Galaxies Most galaxies occur in clusters that are further organized into superclusters. Galaxies are classified according to their shapes as normal spirals, barred spirals, ellipticals, or irregulars. Some galaxies have energetic objects or activities at their cores called active galactic nuclei. The universe is expanding, as measured by the Hubble constant. When astronomers observe distant galaxies, they are looking back in time because the light takes so long to reach Earth.

Cosmology Cosmology is the study of the universe as a whole. The Big Bang model proposes that



Star trails around Polaris

the universe began as a single point and has been expanding ever since. The universe is filled with cosmic background radiation that is left over from the early, hot stages in the Big Bang's expansion. According to the Big Bang model, the universe could be open, closed, or flat. The steady state theory of cosmology, which proposes that the universe is and always will be the same, is not accepted by most astronomers. The inflationary theory explains the walls and voids in the distribution of galaxies. Current observations indicate that the expansion of the universe is accelerating.

Vital Statistics

The Sun's Nearest Neighbors

Star	Distance from the Sun
1. Proxima Centauri	4.24 ly
2. Alpha Centauri	4.34 ly
3. Barnard's Star	5.97 ly
4. Wolf 359	7.80 ly
5. Lalande 21185	8.19 ly
6. Luyten 726-8	8.55 ly
7. Sirius	8.68 ly
8. Ross 154	9.52 ly
9. Ross 248	10.37 ly

FOCUS ON CAREERS

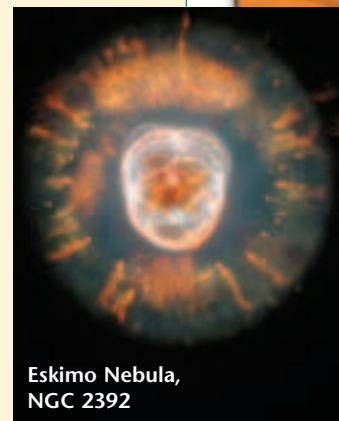
Cosmologist

Cosmologists study the universe as a whole in an attempt to discover how it formed and how it will end. They usually obtain doctoral degrees in physics, astronomy, or both and have a strong background in math and computer analysis. Cosmologists usually work and teach at universities, or other research institutions.

ASSESSMENT

Understanding Main Ideas

- A telescope that uses mirrors rather than lenses to bring light to a focus is what kind of telescope?
 - refracting
 - reflecting
 - electromagnetic
 - probing
- What is one theory about how the Moon formed?
 - Numerous asteroids were pulled together.
 - Earth and Mars collided.
 - Earth and a Mars-sized body collided.
 - Earth captured an existing moon from Mars.
- The planets formed from a collapsing interstellar cloud that flattened into a disk. From which part of the disk did terrestrial planets form?
 - the inner section of the disk
 - the outer section of the disk
 - the exact center of the disk
 - sections throughout the entire disk
- Which planets have low densities, no solid surfaces, ring systems, and many moons?
 - the terrestrial planets
 - the gas giants
 - Pluto and Mercury
 - Mars and Earth
- The atmosphere of which object in the solar system is made up of the photosphere, the chromosphere, and the corona?
 - Earth
 - Jupiter
 - Venus
 - the Sun
- What tool of astronomy relates the class, mass, temperature, magnitude, diameter, and luminosity of stars?
 - parallax
 - absolute magnitude
 - absolute brightness
 - the Hertzsprung-Russell diagram
- Stars that are 8 to 20 times more massive than the Sun end up as what kind of stars?
 - red giants
 - white dwarfs
 - neutron stars
 - black holes
- Where are Population II stars located in the Milky Way?
 - in the bulge and halo
 - in the arms
 - in the disk
 - in the heavy elements
- How are galaxies classified?
 - by size
 - by closeness to Earth
 - by shape
 - by the Hubble constant
- What is the study of the universe as a whole?
 - astronomy
 - cosmology
 - physics
 - astrometry

Eskimo Nebula,
NGC 2392

Thinking Critically

- Compare lunar and solar eclipses.
- Sequence the following star outcomes in order of the mass of the original star, with the smallest mass first: neutron star, white dwarf, and black hole.
- Explain the Big Bang model of the formation of the universe.