Section 30.1

Objectives

- **Determine** the size and shape of our galaxy.
- **Distinguish** the different kinds of variable stars.
- **Identify** the different kinds of stars in a galaxy and their locations.

Review Vocabulary

galaxy: any of the very large groups of stars and associated matter found throughout the universe

New Vocabulary

variable star
RR Lyrae variable
Cepheid variable
halo
Population I star
Population II star
spiral density wave

The Milky Way Galaxy

MAIN Idea Stars with varying light output allowed astronomers to map the Milky Way, which has a halo, spiral arms, and a massive black hole at its center.

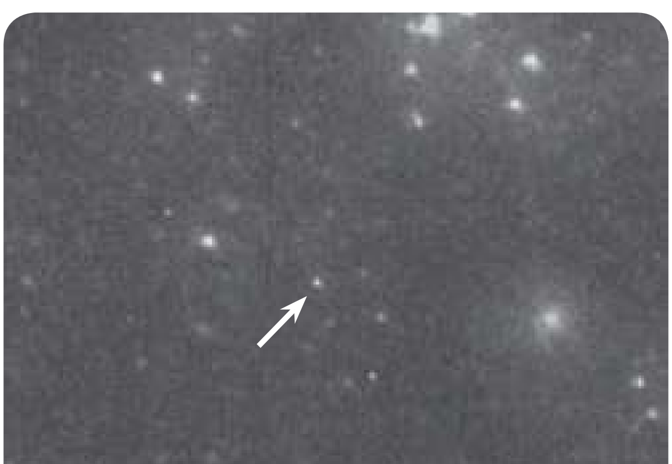
Real-World Reading Link From inside your home, you have only a few ways to find out what is going on outside. You can look out a window or door, use a telephone or a computer, or bring in news and entertainment on a radio or TV. Similarly, scientists also have a few ways to learn about the stars in the galaxy around us.

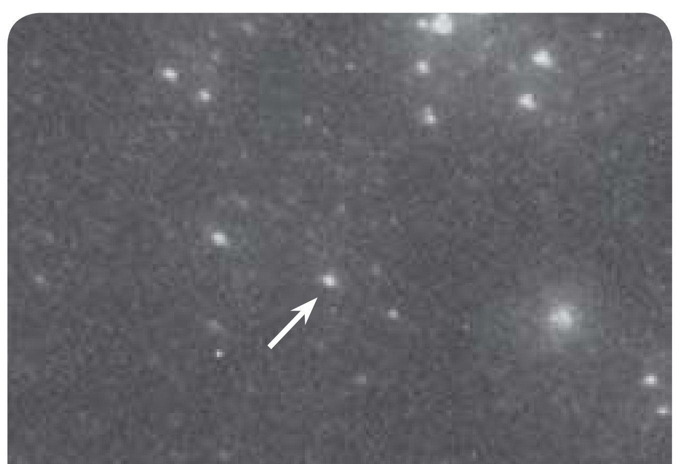
Discovering the Milky Way

When looking at the Milky Way galaxy, it is difficult to see its size and shape because not only is the observer too close, but he or she is also inside the galaxy. Observing the band of stars stretching across the sky, you are looking at the edge of a disk from the inside of the disk. However, it is difficult to tell how big the galaxy is, where its center is, or what Earth's location is within this vast expanse of stars. Though astronomers have answers to these questions, they are still refining their measurements.

Variable stars In the 1920s, astronomers focused their attention on mapping out the locations of globular clusters of stars. These huge, spherical star clusters are located above or below the plane of the galactic disk. Astronomers estimated the distances to the clusters by identifying variable stars in them. **Variable stars** are located in the giant branch of the Hertzsprung-Russell diagram, discussed in Chapter 29, and pulsate in brightness because of the expansion and contraction of their outer layers. Variable stars are brightest at their largest diameters and and dimmest at their smallest diameters. **Figure 30.1** shows the dim and bright extremes of a variable star.

Figure 30.1 The diameters of variable stars change over a period of 1 to 100 days, causing them to brighten and dim.


Variable star dim


Variable star bright

Types of variables For certain types of variable stars, there is a relationship between a star's luminosity and its pulsation period, which is the time between its brightest pulses. The longer the period of pulsation takes, the greater the luminosity of the star. **RR Lyrae variables** are stars that 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, and the luminosity as much as doubles from dimmest to brightest. By measuring the star's period of pulsation, astronomers can determine the star's absolute luminosity. This, in turn, allows them to compare the star's luminosity (energy) to its apparent magnitude (brightness) and calculate how far away the star must be to appear this dim or bright.

The galactic center After reasoning there were globular clusters orbiting the center of the Milky Way, astronomers then used RR Lyrae variables to determine the distances to them. They discovered that these clusters are located far from our solar system, and that their distribution in space is centered on a distant point 28,000 light-years (ly) away. The galactic center is a region of high star density, shown in **Figure 30.2,** much of which is obscured by interstellar gas and dust. The direction of the galactic center is toward the constellation Sagittarius. The other view of the Milky Way that is shown is along the disk into space.

Reading Check **Describe** how astronomers located the galactic center of the Milky Way.

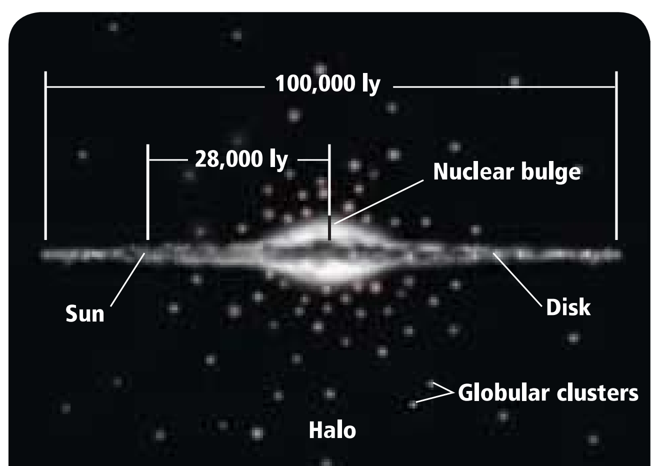
The Shape of the Milky Way

Only by mapping the galaxy with radio waves have astronomers been able to determine its shape. This is because radio waves are long enough that they can penetrate the interstellar gas and dust without being scattered or absorbed. By measuring radio waves as well as infrared radiation, astronomers have discovered that the galactic center 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 30.2.**

Figure 30.2 The top two images are views of the Milky Way—one toward the outer galaxy and one close to the center. The third figure is an artist's concept of what the Milky Way galaxy looks like from space.

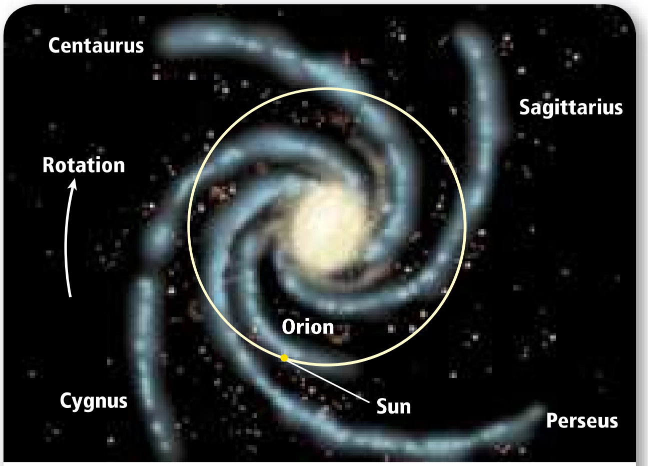
Along the disk toward space

View toward the galactic center



The Milky Way galaxy

(t)Jerry Schad/Photo Researchers, (b)Ronald Royer/Science Photo Library/Photo Researchers



■ **Figure 30.3** The Sun is located on the minor Orion spiral arm and follows an orbital path around the nuclear center as shown. (Note: *Drawing is not to scale.*)
Infer *how the arms were named.*

■ **Figure 30.4** A barred galaxy has an elongated central bulge.

Spiral arms Knowing that the Milky Way galaxy has a disklike shape with a central bulge, astronomers speculated that it might also have spiral arms, as do many other galaxies. This was difficult to prove. Because of the distance, astronomers have no way to get outside of the galaxy and look down on the disk. Astronomers decided to use hydrogen atoms to look for the spiral arms.

To locate the spiral arms, hydrogen emission spectra are helpful for three reasons. 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 hydrogen emission as a guide, astronomers have identified four major spiral arms and numerous minor arms in the Milky Way. Using these data, scientists discovered that the Sun is located in the minor Orion arm 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. In its 5-billion-year life, the Sun has orbited the galaxy approximately 20 times. **Figure 30.3** shows the orbit that the Sun follows in a spinning galaxy.

Reading Check **Explain** how astronomers used the Milky Way's hydrogen emission spectrum to locate the arms.

Nuclear bulge or bar? Many spiral galaxies have a barlike shape rather than having a round disk to which the arms are attached. Recent radio observation of interstellar gas indicates that the Milky Way has a slightly elongated shape. Astronomers theorize that the gas density in the halo determines whether a bar will form. **Figure 30.4** shows a barred galaxy.

Using a variety of wavelengths, astronomers are discovering what the center of the Milky Way looks like. The nuclear bulge of a galaxy is typically made up of older, red stars. The bar in a galaxy center, however, is associated with younger stars and a disk that forms from neutral hydrogen gas. Star formation does continue to occur in the bulge, and most stars are about 1000 AU apart compared to 207,000 AU separation in the locale of the Sun. Recent measurements of 30 million stars in the Milky Way indicate a bar about 27,000 ly in length.

Mass of the Milky Way

The mass located within the circle of the Sun's orbit through the galaxy, outlined in **Figure 30.3,** is about 100 billion times the mass of the Sun. Using this figure, astronomers have concluded that the galaxy contains about 100 billion stars within its disk.

Mass of the halo Evidence of the movement of outer disk stars and gas suggests that as much as 90 percent of the galaxy's mass is contained in the halo. 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 unknown. As you will read in Section 30.2, the nature of unseen matter extends to other galaxies and to the universe as a whole. **Figure 30.5** shows the halo of the Sombrero galaxy.

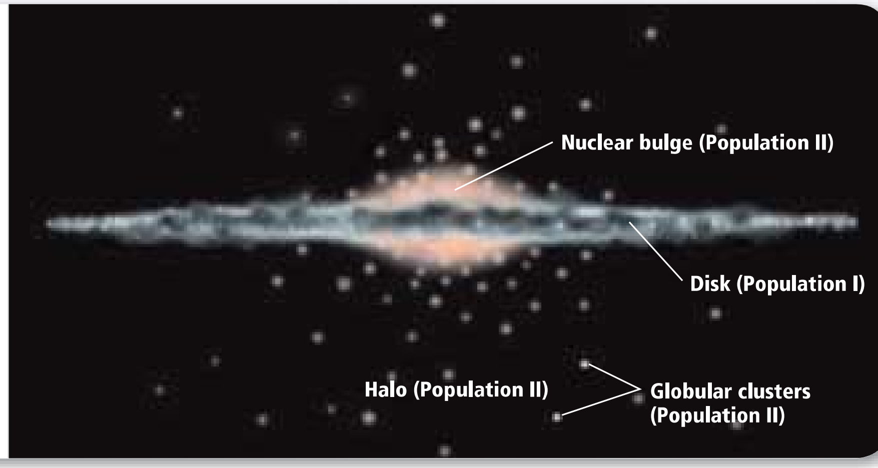
A galactic black hole Weighing in at a few million to a few billion times the mass of the Sun, supermassive black holes occupy the centers of most galaxies. When the center of the galaxy is observed at infrared and radio wavelengths, several dense star clusters and supernova remnants stand out. Among them is a complex source called Sagittarius A (Sgr A), with sub-source called Sgr* (Sagittarius star), which appears to be an actual point around which the whole galaxy rotates.

Careful studies of the motions of the stars that orbit close to Sagittarius A* (pronounced A star) indicate that this region 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. Astronomers think 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. **Figure 30.6** illustrates how a supermassive black hole develops. This kind of black hole should not be confused with the much smaller, stellar black hole, which is usually made from the collapsing core of a massive star.

■ **Figure 30.5** The galaxy halo is populated by older, dimmer stars, while the central bulge is populated by newer, brighter stars, as shown in this view of the Sombrero galaxy.

■ **Figure 30.6** The formation of a supermassive black hole begins with the collapse of a dense gas cloud. The accumulation of mass releases photons of many wavelengths, and perhaps even a jet of matter, as shown here.

■ **Figure 30.7** 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. (Note: *Drawing is not to scale.*)



Stellar populations in the Milky Way Even though the basic compositions of all stars are the same, there are several distinct differences in detail. The differences among stars include differences in location, motion, and age, leading to the notion of stellar populations. The population of a star provides information about its galactic history. In fact, the galaxy could be divided into two components: the round part made up of the halo and bulge noted in **Figure 30.7,** where the stars are old and contain only traces of heavy elements; and the disk, especially the spiral arms. To astronomers, heavy elements are any elements with a mass larger than helium.

Astronomers divide stars in these two regions into two classes. **Population I stars** are in the disk and arms and have small amounts of heavy elements. **Population II stars** are found in the halo and bulge and contain even smaller traces of heavy elements. Refer to **Table 30.1** for more details.

Population I 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. Population I stars tend to follow circular orbits with low (flat) eccentricity, and their orbits lie close to the plane of the disk. Finally, Population I stars have normal compositions, meaning that approximately 2 percent of their mass is made up of elements heavier than helium. The Sun is a Population I star.

Table 30.1 Population I and II Stars of the Milky Way

Concepts in Motion
Interactive Table To explore more about Population I and II stars, visit glencoe.com.

	Location in Galaxy	Percent of H & He	Percent Heavy Elements	Age (years)	Type of Star	Type of Galaxy	Example
Population I stars	disk arms and open clusters	98	2.0	<10 billion	young sequence stars	spiral and irregular	Sun, most giants, and supergiants
Population II stars	bulge and halo	99.9	0.1	>15 billion	old main-sequence stars (type K and M)	elliptical and spiral halos and bulges	HD 92531 and most white dwarfs

Population II There are few stars and little interstellar material currently forming in the halo or the nuclear bulge of the galaxy, and this is one of the distinguishing features of Population II stars. Age is another. The halo of the Milky Way contains the oldest known objects in the galaxy—globular clusters. These clusters are estimated to be 12 to 14 billion years old. 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 composition 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. **Table 30.1** points out some other comparisons of Population I and II stars.

Formation and Evolution of the Milky Way

The fact that the halo and nuclear 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. They also contain greater quantities of heavy elements because they formed from gas that had been enriched by previous generations of massive stars. In **Figure 30.8,** the nuclear bulge makes up the hat of the Sombrero galaxy.

Figure 30.8 Easily seen through small telescopes, the Sombrero galaxy gets its name from the bright glow of the nuclear bulge and the dust and gas lanes along the outer edge of its disk.
Predict ***which type of stars would be found in the nuclear bulge.***

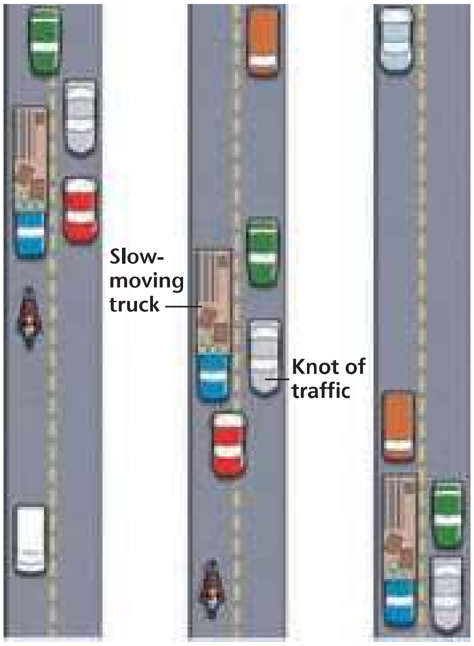


Figure 30.9 A slow truck on a highway causing a build up of cars around it illustrates one theory as to how spiral density waves maintain spiral arms in a galaxy.

Spiral Arms

Most of the main features of the galaxy are understood by astronomers, except for the way in which the spiral arms are retained. The Milky Way is subject to gravitational tugs by neighboring galaxies and is periodically disturbed by supernova explosions from within, both of which can create or affect spiral arms. There are several hypotheses about why galaxies keep this spiral shape.

One hypothesis is that a kind of wave called a spiral density wave is responsible. A **spiral density wave** has spiral regions of alternating density, which 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 causes a buildup of cars, shown in **Figure 30.9.**

A second hypothesis is that the spiral arms are not permanent structures but instead are continually forming as a result of disturbances such as supernova 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 two-armed pattern, that was more likely created by density waves.

A third possibility is considered for faraway galaxies. It suggests that the arms are only visible because they contain hot, blue stars that stand out more brightly than dimmer, redder stars. When viewed in UV wavelengths, the arms stand out, but when viewed in infrared wavelengths, they seem to disappear.

Section 30.1 Assessment

Section Summary

- The discovery of variable stars aided in determining the shape of the Milky Way.
- RR Lyrae and Cepheid are two types of variable stars used to measure distances.
- The nuclear bulge and halo of the Milky Way is a globular cluster of old stars.
- The spiral arms of the Milky Way are made of younger stars and gaseous nebulae.
- Population I stars are found in the spiral arms, while Population II stars are in the central bulge and halo.

Understand Main Ideas

1. MAIN Idea **Explain** How did astronomers determine where Earth is located within the Milky Way?
2. **Determine** What do measurements of the mass of the Milky Way indicate?
3. **Analyze** How are Population I stars and Population II stars different?
4. **Summarize** How can variable stars be used to determine the distance to globular clusters?

Think Critically

5. **Explain** 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?
6. **Hypothesize** What would happen to the stellar orbits near the center of the Milky Way galaxy if there were no black hole?

WRITING in Earth Science

7. Write a description of riding a spaceship from above the Milky Way galaxy into its center. Point out all of the galaxy's parts and star types.

Earth Science Online Self-Check Quiz glencoe.com

Section 30.2

Objectives

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

Review Vocabulary

elliptical: relating to or shaped like an ellipse or oval

New Vocabulary

dark matter
supercluster
Hubble constant
radio galaxy
active galactic nucleus
quasar

FOLDABLES
Incorporate information from this section into your Foldable.

Other Galaxies in the Universe

MAIN Idea Finding galaxies with different shapes reveals the past, present, and future of the universe.

Real-World Reading Link Have you ever read an old newspaper to find out what life was like in the past? Astronomers observe distant, older galaxies to get an idea of what the universe was like long ago.

Discovering Other Galaxies

Long before they knew what galaxies were, astronomers observed many objects scattered throughout the sky. Some astronomers hypothesized that these objects were nebulae or star clusters within the Milky Way. Others hypothesized that they were distant galaxies that were as large as the Milky Way.

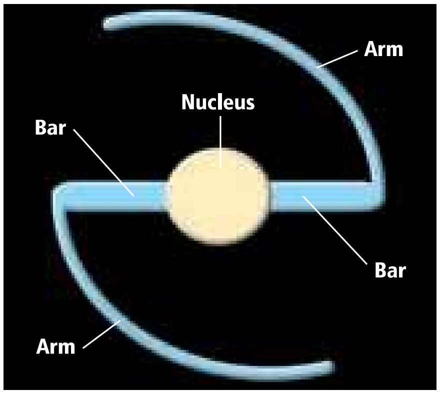
The question of what these objects were was answered by Edwin Hubble in 1924, when he discovered Cepheid variable stars in the Great Nebula in the Andromeda constellation. Using these stars to measure the distance to the nebula, Hubble showed that they were too far away to be located in our own galaxy. The Andromeda nebula then became known as the Andromeda galaxy, shown in **Figure 30.10.**

Properties of galaxies Masses of galaxies range from the dwarf ellipticals, which have masses of approximately 1 million times the mass of the Sun; to large spirals, such as the Milky Way, with masses of around 100 billion times the mass of the Sun; to the largest galaxies, called giant ellipticals, which have masses as high as 1 trillion times that of the Sun. 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. **Figure 30.10** shows a large spiral and several elliptical and dwarf galaxies.

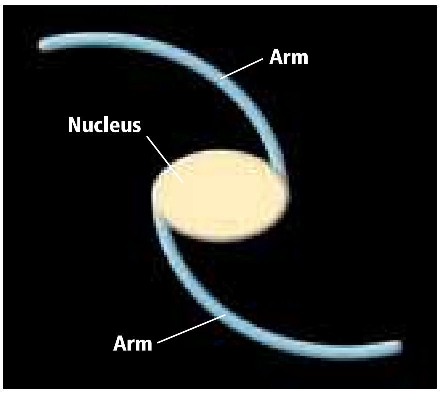
Figure 30.10 Andromeda is a spiral galaxy like the Milky Way. The bright elliptical object and the sphere-shaped object near the center are small galaxies orbiting the Andromeda galaxy.

John Chumack/Photo Researchers

Barred Spiral Galaxy



Spiral Galaxy



■ **Figure 30.11** Measurements have indicated that the Milky Way's central region might be a bar, not a spiral.

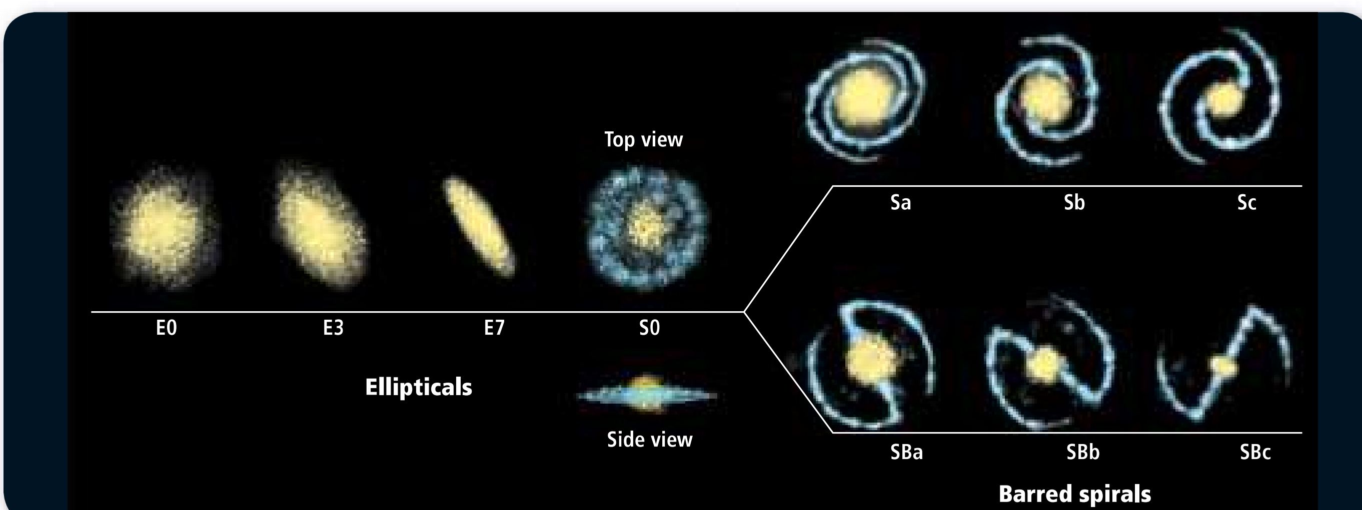
■ **Figure 30.12** The Hubble tuning-fork diagram summarizes Hubble classification for normal galaxies.
Explain ***How is an S0 galaxy related to both spirals and ellipticals?***

Luminosities of galaxies also vary over a wide range, from the dwarf spheroidals—not much larger or more brilliant than a globular cluster—to supergiant elliptical galaxies, more than 100 times more luminous than the Milky Way. All galaxies show evidence that an unknown substance called dark matter dominates their masses. **Dark matter** is thought to be made up of a form of subatomic particle that interacts only weakly with other matter.

Classification of galaxies Hubble went on to study galaxies and categorize them according to their shapes.

Disklike galaxies Hubble classified the disklike galaxies with spiral arms as spiral galaxies. These were subdivided into normal spirals and barred spirals. As shown in **Figures 30.11** and **30.13,** barred spirals have an elongated central region—a bar—from which the spiral arms extend, while normal spirals do not have bars. A normal spiral is denoted by the letter *S,* and a barred spiral is denoted by *SB.* Normal and barred spirals are further subdivided by how tightly the spiral arms are wound and how large and bright the nucleus is. The letter *a* represents tightly wound arms and a large, bright nucleus. The letter *c* represents loosely wound arms and a small, dim nucleus. 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 as *S0.*

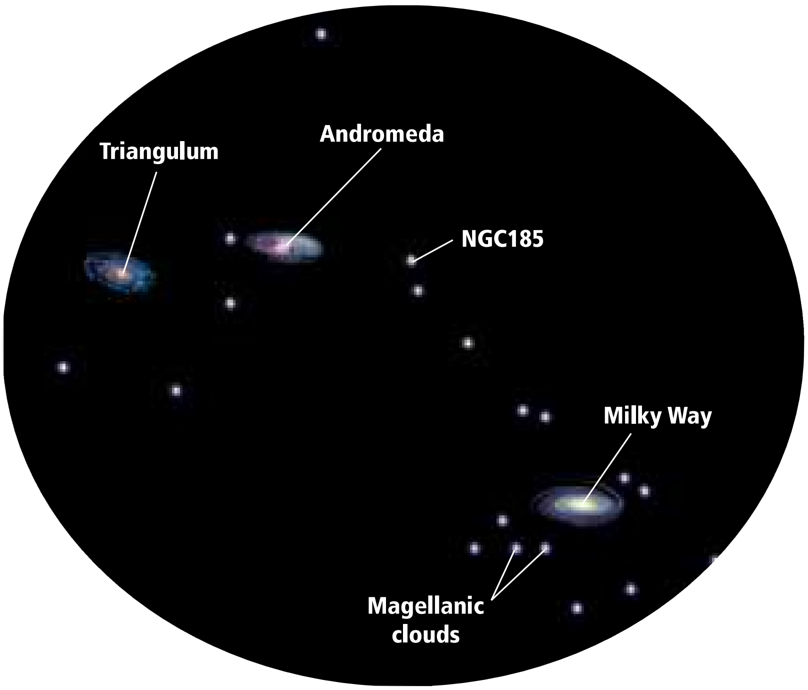
Elliptical galaxies In addition to spiral galaxies, there are galaxies that are not flattened into disks and do not have spiral arms, as shown in **Figure 30.13.** Called elliptical galaxies, they are divided into subclasses based on the apparent ratio of their major and minor axes. Round ellipticals are classified as *E0,* while 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, which is illustrated in **Figure 30.12.**



Visualizing The Local Group

NATIONAL GEOGRAPHIC

Figure 30.13 All of the stars visible in the night sky belong to a single galaxy, the Milky Way. Just as stars compose galaxies, galaxies are gravitationally drawn into galactic groups, or clusters. The 30 galaxies closest to Earth are members of the Local Group of galaxies.



▲ **Spiral galaxies** The two largest galaxies in the Local Group, Andromeda and the Milky Way, are large, flat disks of interstellar gas and dust with arms of stars extending from the disk.

▲ **Barred spiral galaxies** Sometimes the flat disk that forms the center of a spiral galaxy is elongated into a bar shape. Recent evidence suggests that the Milky Way galaxy has a bar.

▲ **Elliptical galaxies** like NGC 185 are nearly spherical in shape and consist of a tightly packed group of relatively old stars. Nearly half of the Local Group are ellipticals.

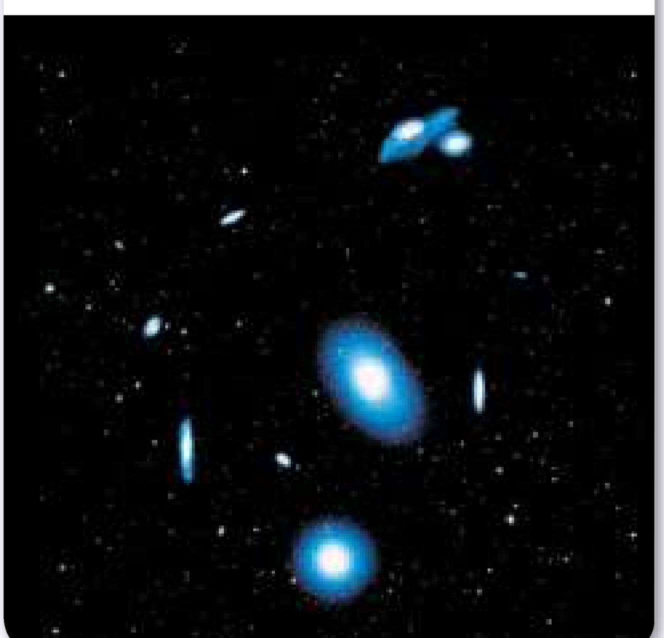
Irregular galaxies Some galaxies are neither spiral or elliptical. Their shape seems to follow no set pattern, so astronomers have given them the classification of irregular. ▶

Concepts In Motion To explore more about the Local Group and galaxy types, visit glencoe.com.

Earth Science Online

■ **Figure 30.14** The Large and Small Magellanic Clouds are small galaxies that orbit the Milky Way.

■ **Figure 30.15** The nearby Virgo cluster of approximately 2000 galaxies has a gravity so strong it is pulling the Milky Way toward it.



Irregular galaxies Some galaxies do not have distinct shapes. These irregular galaxies are denoted by *Irr.* The Large and Small Magellanic Clouds, shown in **Figure 30.14,** the nearest neighbors of the Milky Way, are irregular galaxies.

Groups and Clusters of Galaxies

Most galaxies are located in groups, rather than being spread uniformly throughout the universe. **Figure 30.13** shows some of the features of the Local Group of galaxies.

Local Group 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 40 known members, of which the Milky Way and Andromeda galaxies are the largest. Most of the members are dwarf ellipticals that are companions to the larger galaxies. The closest galaxies to the Milky Way are the Large and Small Magellanic Clouds and the small Sagittarius galaxy which is merging with the Milky Way. There are several dim galaxies that recently have been found behind the dust and gas of the Milky Way. In 2006, a newly discovered galaxy was added to the Local Group. There are two more galaxies that could be added in the future and six other galaxies that are near the Local Group.

Reading Check **Identify** the kinds of galaxies in the Local Group.

Large clusters Galaxy clusters larger than the Local Group might have hundreds or thousands of members and diameters in the range of about 5 to 30 million ly. The Virgo cluster is shown in **Figure 30.15.** 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, as shown in **Figure 30.16,** or they form galaxies with more than one nucleus, such as the Andromeda galaxy.

STScI/NASA/CORBIS

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 total masses of each the galaxies, as determined by their total luminosity. This suggests that most of the mass in a cluster of galaxies is invisible, which provides astronomers with strong evidence that the universe contains a great amount of dark matter.

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.

Figure 30.16 This galactic merger that began 40 mya will be complete in a few billion years.

The Expanding Universe

In 1929, Edwin Hubble made another dramatic discovery. 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 redshift 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. In other words, the universe is expanding.

MiniLab

Model Expansion

What does a uniform expansion look like? The discovery of redshifts of distant galaxies indicated that the universe is rapidly expanding.

Procedure

1. Read and complete the lab safety form.
2. Use a **felt-tipped 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.*
3. Partially inflate the balloon. *Do not tie the neck.* With a piece of **string** and a **meterstick,** measure the distance from Dot 1 to each of the other dots. Record your measurements.
4. Inflate the balloon more, and again measure the distance from Dot 1 to each of the other dots. Record your measurements.
5. Repeat Step 4 with the balloon fully inflated.

Analysis

1. **Identify** whether the dots are still separated from each other by equal distances after you fully inflated the balloon.
2. **Determine** how far each dot moved away from Dot 1 following each change in inflation.
3. **Infer** what the result would be if you had measured the distances from Dot 4 instead of Dot 1. From Dot 2?
4. **Explain** how this activity illustrates uniform expansion of the universe.

PROBLEM-SOLVING LAB

Make and Use Graphs

How was the Hubble constant derived? Plotting the distances and speeds for a number of galaxies created the expansion constant for Hubble's Law.

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 approximately as many points lie above the line as lie 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.

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

Think Critically

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

Implications of redshift You might infer that Earth is at the center of the universe, but this is not the case. An observer located in any galaxy, at any place in the universe, will observe the same thing in a medium that is uniformly expanding—all points are moving away from all other points, and no point is at the center. At greater distances the expansion increases the rate of motion.

A second inference is that the universe is changing with time. If it is expanding now, it must have been smaller and denser in the past. In fact, there must have been a time when all contents of the universe were compressed together. The Big Bang theory has been proposed to explain this expansion.

Hubble's law Hubble determined that the universe is expanding by making a graph comparing a galaxy's distance to the speed at which it is moving. The result is a straight line, which can be expressed as a simple equation, $v = Hd$, where v is the velocity 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 Mpc = 3,260,000 ly; and H is a number called the **Hubble constant,** measured in kilometers per second per megaparsec. H represents the slope of the line.

Measuring *H* Determining the value of *H* requires finding distances and speeds for many galaxies 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 could obtain only a crude value for *H*. Obtaining an accurate value for *H* was one of the key goals of astronomers who designed the *Hubble Space Telescope (HST).* It took nearly ten years after the launch of the *HST* to gather enough data to pinpoint the value of *H*. Currently, the best measurements indicate a value of approximately 70 km/s/Mpc.

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

The only galaxies that do not seem to be moving apart are those within a cluster. The internal gravity of the galactic cluster keeps them from separating.

Active Galaxies

Radio-telescope surveys of the sky have revealed a number of galaxies that are extremely luminous. These galaxies, called **radio galaxies,** are often giant elliptical galaxies that emit as much 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 30.17,** 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** (AGN).

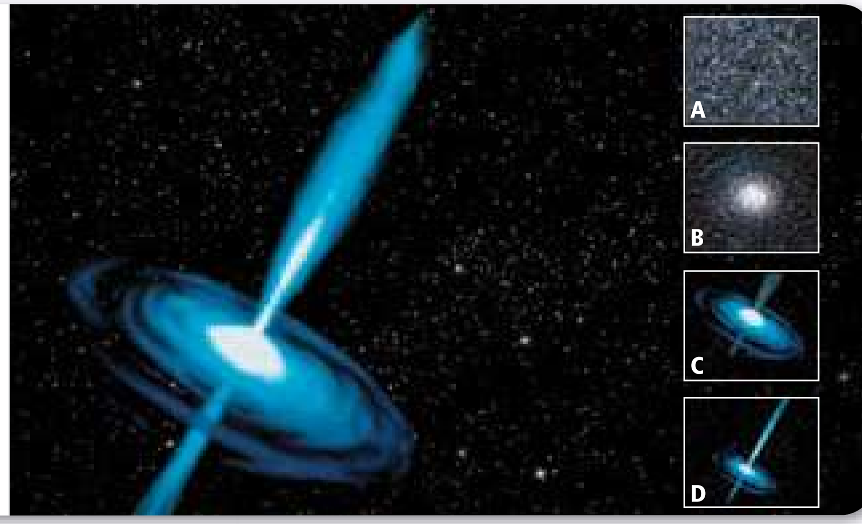
Reading Check **Describe** the unusual properties of a radio galaxy.

Quasars

In the 1960s, astronomers discovered another new type of object. These objects looked like ordinary stars, but some emitted strong radio waves. Most stars do 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 emission lines in their spectra. These starlike objects with emission lines in their spectra were called **quasars.** Two quasars are shown in **Figure 30.18.** 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 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 they could have redshifts caused by the expansion of the universe.

Figure 30.17 In addition to radio lobes, M87 has a jet that emits visible light.

Figure 30.18 Quasars are old and distant celestial objects that emit several thousand times more energy than does our entire galaxy.
Recall ***What other objects emit jets of matter?***



■ **Figure 30.19** An interstellar gas cloud (A) collapses gravitationally (B) on its way to forming a galaxy. The nucleus (C) forms a black hole as the gas there is compressed. Magnetic fields of the rapidly rotating disk surrounding the black hole form two highly energetic jets (D) that are perpendicular to the disk's equatorial plane.

Quasar redshift The redshift of quasars was 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. At first, some astronomers doubted that quasars were far away, but in the decades since quasars were discovered, more evidence supports the hypothesis that quasars are distant. One piece of supporting evidence indicates that those quasars associated with clusters of galaxies have 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, shown in **Figure 30.19.** The quasars appear to be extra-bright active galactic nuclei—so much brighter than their surrounding galaxies that astronomers could not initially see those galaxies.

Reading Check **Explain** how astronomers determined distances to quasars.

Looking back in time Because quasars are distant, it takes their light a long time to reach Earth. Therefore, observing a quasar is seeing it as it was a long time ago. For example, it takes light from the Sun approximately 8 minutes to reach Earth. When you observe the Sun, you are seeing it as it was 8 minutes earlier. When you observe the Andromeda galaxy, you see the way it looked 2 million years earlier. The most remote quasars are several billion light-years away, which indicates the stage you see is from 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. Consequently, today's active galactic nuclei might be former quasars that are not as energetic as they were long ago.

Looking far back into time, the early universe had many quasars. Current theory suggests that they existed around supermassive black holes that pulled gas into the center, where in a violent swirl, friction heated the gas to extreme temperatures resulting in the bright light energy that was first detected.

CAREERS IN EARTH SCIENCE

Computer Programmer Many astronomers use equipment that does not observe light. A computer programmer writes programs astronomers can use to observe spectra, calculate, and decipher the data collected by telescopes. To learn more about Earth science careers, visit glencoe.com.

Chandra X-Ray Observatory/NASA/Photo Researchers

Source of power The AGN 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 the black hole thought to exist in the core of our own galaxy has a mass of about 1 million Suns. The black holes in the cores of AGN 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 AGN and in quasars. In fact, radio-lobed quasars have jets that are essentially related to radio galaxies.

Figure 30.20 shows a supermassive black hole. In modeling a supermassive black hole of this magnitude, the mass of nearly 3 billion Suns would be needed to pull the stars in this galaxy into the center. A plasma jet, ejected from the nucleus, extends nearly 5000 light-years into space.

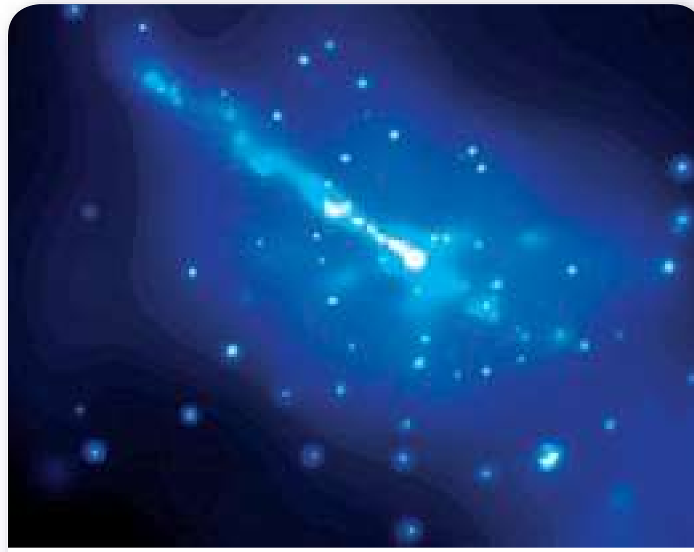


Figure 30.20 A jet of energetic X-ray particles is emitted from the AGN, which probably hides a supermassive black hole. The other white areas are probably X-ray-emitting neutron stars or black hole binaries.

Section 30.2 Assessment

Section Summary

- Galaxies can be elliptical, disk-shaped, or irregular.
- Galaxies range in mass from 1 million Suns to more than a trillion Suns.
- Many galaxies seem to be organized in groups called clusters.
- Quasars are the nuclei of faraway galaxies that are dim and seen as they were long ago, due to their great distances.
- Hubble's law helped astronomers discover that the universe is expanding.

Understand Main Ideas

1. MAIN Idea **Explain** how astronomers discovered that there are other galaxies beyond the Milky Way.
2. **Summarize** why astronomers theorize that most of the matter in galaxies and clusters of galaxies is dark matter.
3. **Explain** why it is difficult for astronomers to accurately measure a value for the Hubble constant, *H*. Once a value is determined, describe how it is used.
4. **Explain** the differences among normal spiral, barred spiral, elliptical, and irregular galaxies.

Think Critically

5. **Deduce** how the nighttime sky would look from Earth if the Milky Way were an elliptical galaxy.
6. **Infer** what similarities between AGN and quasars are due to black holes.

MATH in Earth Science

7. Convert the distance across the Milky Way to Mpc if the diameter of the Milky Way is 100,000 ly. What is the distance in Mpc across a supercluster of galaxies whose diameter is 200 million ly? (1 Mpc = 3,260,000 ly)