CHAPTER 19

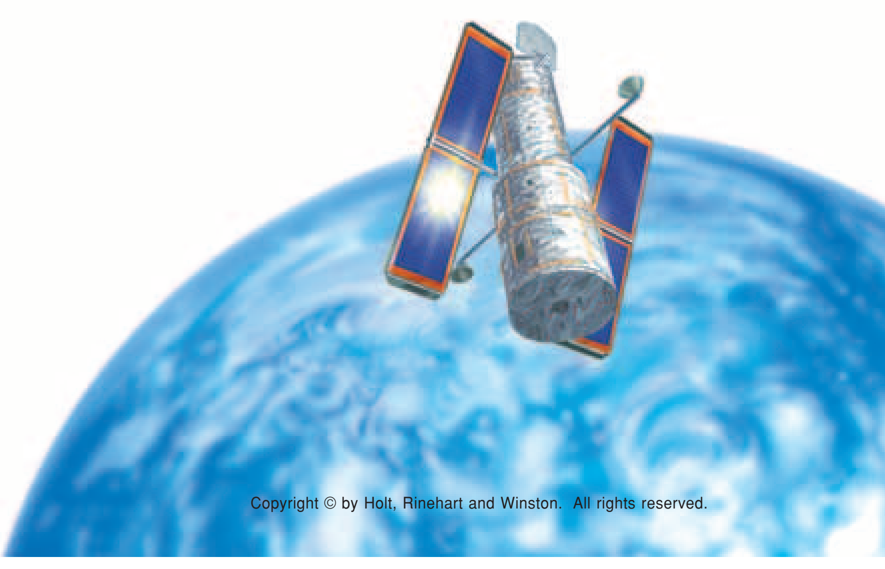
The Universe Beyond

To get an idea of how much area the Hubble Deep Field covers, hold a grain of sand at arm's length while looking up at the sky. The sand grain covers an area about the same size as the one that Robert Williams studied.

Imagine . . .

Suppose you are the director of the Hubble Space Telescope Science Institute and you are allowed some of the precious observing time on the Hubble Space Telescope (HST) for any project you want. While other astronomers have to write long requests to use this special telescope, you get to use it without doing all the paperwork. You can look at *anything* in the universe! If you were to ask your friends for suggestions, what would they say? What kinds of things are *you* curious about? Would you choose a planet, like Jupiter, to look at, or would you focus on a strangely shaped cloud of gas or perhaps a galaxy? Would you look at a big part of the sky or just a tiny piece?

In 1995, Robert Williams was the director of the institute, and he had this very problem. He finally decided to look at what seemed like an empty piece of sky—but to look at it longer than any one else had done with the HST. Over a 10-day period, the HST took 342 pictures of the same small part of the sky. Later, computers combined the pictures to get a single image called the Hubble Deep Field. The Hubble Deep Field shows almost 2,000 galaxies in that one spot of sky. As you can see in the photo above, the galaxies have different shapes, sizes, and colors. Some are even colliding with each other. In this chapter, you will learn about galaxies and the stars they are made of.



What Do You Think?

In your ScienceLog, try to answer the following questions based on what you already know:

1. Why do stars shine?
2. What is a galaxy?
3. How did the universe begin, and how will it end? or will it?

Investigate!

Exploring Galaxies

Galaxies are groups of stars and other material floating like islands in the sea of space. Each galaxy contains billions and billions of stars. But not all galaxies are the same. As you saw in the Hubble Deep Field, they come in different sizes and shapes. Let's explore some of these differences.

Procedure

1. Look at the different galaxies in the Hubble Deep Field image on the previous page. (The two bright spots with spikes are stars that are much closer to Earth; you can ignore them.)
2. Can you find different types of galaxies? Look for different shapes and colors. In your ScienceLog, make sketches of at least three different types. Make up a name that describes each type of galaxy.
3. With a **metric ruler,** measure the size of at least four galaxies of each type in millimeters. Record your measurements in your ScienceLog.

Analysis

4. Why did you classify the galaxies the way you did?
5. Compare your types of galaxies with those of your classmates. Are there similarities? Did you give them similar names?
6. What conclusions can you draw about galaxies from the measurements you took in step 3?

Section 1

Stars

NEW TERMS

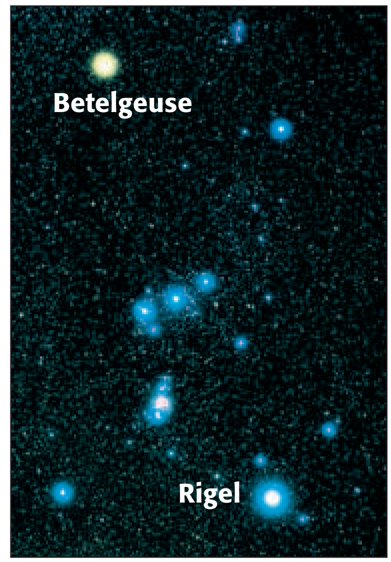
spectrum
apparent magnitude
absolute magnitude
light-year
parallax

OBJECTIVES

- Describe how color indicates temperature.
- Compare absolute magnitude with apparent magnitude, and discuss how each measures brightness.
- Describe the difference between the apparent motion of stars and the real motion of stars.

Most stars look like faint dots of light in the night sky. But stars are actually huge, hot, brilliant balls of gas trillions of kilometers away from Earth. How do astronomers learn about stars when they are too far away to visit? They study starlight!

Color of Stars



Look closely at the flames on the candle and the Bunsen burner in **Figure 1.** Which one has the hotter flame? How can you tell? If you draw the colors in the candle flame, in what order are they? Although artists may speak of *red* as a "hot" color, to a scientist, *red* is a "cool" color. The blue flame of the Bunsen burner is much hotter than the yellow flame of the candle. The candle's flame, however, would be hotter than the red glowing embers of a campfire.

If you allow time for your eyes to adjust to the night sky and look carefully, you might notice the different colors of some familiar stars. Betelgeuse, which is red, and Rigel, which is blue, are the stars that form the top left and bottom right corners of the constellation Orion, as shown above. This constellation is easy to see in the evenings during the winter months. Because stars are different colors, we can infer that they have different temperatures.

Figure 1 *What colors do you see when you examine the flames of a Bunsen burner and an ordinary candle?*

Composition of Stars

When you look at white light through a glass prism, you see a rainbow. This rainbow of colors is called a **spectrum.** The spectrum contains the colors we recognize as red, orange, yellow, green, blue, indigo, and violet. A hot solid object, like the glowing wire inside a light bulb or a piece of molten metal, gives off a *continuous spectrum*—one that shows all the colors. Astronomers use an instrument called a *spectrograph* to spread starlight out into its colors, just as you might use a prism to spread sunlight. Stars, however, don't have continuous spectra. Because they are not solid objects, stars give off spectra that are different from those of light bulbs.

Making an ID Stars are made of various gases that are so dense, they act like a hot solid. For this reason, the "surface" of a star, or the part that we see, gives off a continuous spectrum. But the light we see passes through the star's "atmosphere," which is made of somewhat cooler gases than the star itself is made of. A star therefore produces a spectrum with various lines in it. To understand what these lines are, let's look at something you might be more familiar with than stars.

Many restaurants use neon signs to attract customers. The gas in a neon sign glows orange-red when an electric current flows through it. If we were to look at the sign with an astronomer's spectrograph, we would not see a continuous spectrum. Instead we would see *emission lines*. Emission lines are bright lines that are made when certain wavelengths of light are given off, or emitted, by hot gases. Only some colors in the spectrum show up, while all the other colors that make up white light are missing. Every tube of neon gas, for example, emits light with the same emission lines. Every other element has its own set of emission lines. Emission lines are like fingerprints for the elements. You can see some of these "fingerprints" in **Figure 2.**

physical science CONNECTION

Police use spectrographs to "fingerprint" cars. Automobile manufacturers put trace elements in the paint of cars. Each make of car has its own special paint and therefore its own trace element. When a car is involved in a hit-and-run accident, the police can identify the make of the car by the paint that is left behind.

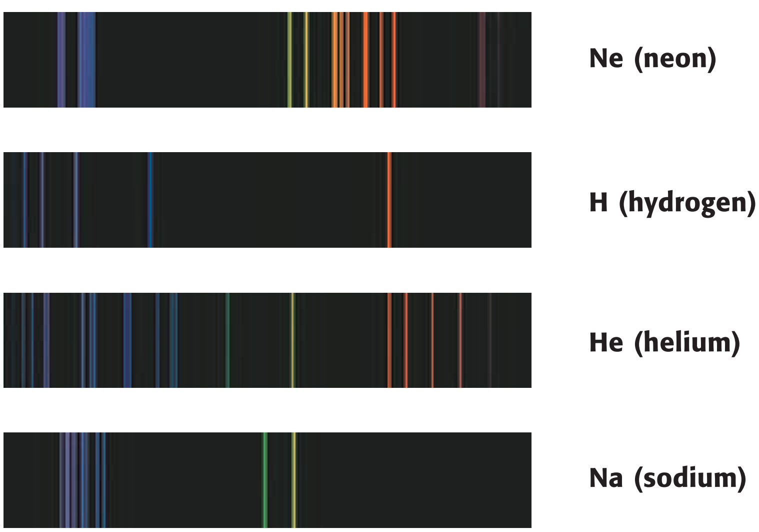


Figure 2 *Neon gas produces its own characteristic pattern of emission lines, as do hydrogen, helium, and sodium.*

One More Thing If we could look at *just* the gas in a star's atmosphere, that gas would produce emission lines. But we cannot see the star's atmosphere without also seeing the star behind it, which makes a continuous spectrum. One more thing to learn—cool gases behave differently from hot gases. The relatively cooler gases in a star's atmosphere absorb light and remove certain colors of light from the continuous spectrum of the hot star. In fact, the colors that the atmosphere absorbs are the same colors it would emit if heated.

LabBook

To learn more about the color and temperature of stars, turn to page 592 in the LabBook.

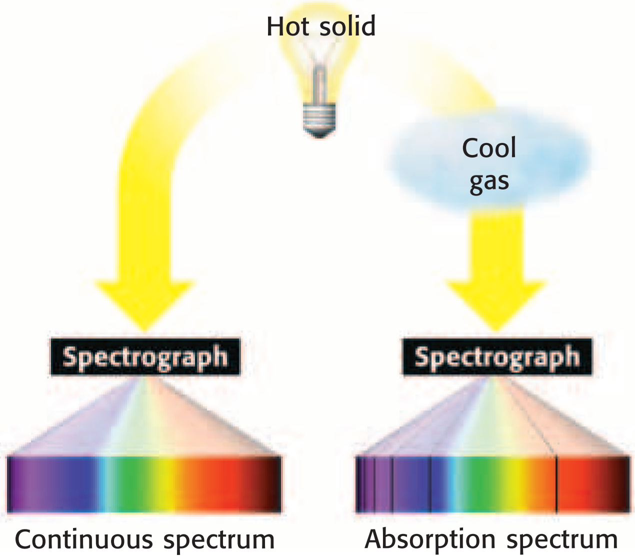


Figure 3 *An absorption spectrum (right) is produced when light passes through a cooler gas. Notice the dark lines in the spectrum.*

If light from a hot solid passes through a cooler gas, it produces an *absorption spectrum*—a continuous spectrum with dark lines where less light gets through. Take a look at **Figure 3.** Can you identify the element in the gas by comparing the position of the dark lines in its spectrum with the bright lines in Figure 2?

An astronomer's spectrum of a star shows an absorption spectrum. The pattern of lines shows some of the elements that are in the star's atmosphere. If a star were made of just one element, it would be simple to identify the element. But stars are a mixture of things, and all the different sets of lines for its elements appear together in a star's spectrum. Sorting out the patterns is often a puzzle.

Classifying Stars

In the 1800s, the first people to look at spectra found that different stars had different spectra. They started to collect the spectra of lots of stars and tried to classify them. At first, letters were assigned to each type of spectra. Stars with spectra that had very noticeable hydrogen patterns were classified as A type stars. Other stars were classified as B, and so on.

Later, when scientists finally understood why spectra are different, they realized that the stars were classified in the wrong order. Stars are now classified by how hot they are. The main differences in the spectra of stars are related to the temperature of the stars. We see the temperature differences as colors. The original class O stars are blue—they are very hot, the hottest of all stars. If you arrange the letters in order of temperature, they are no longer in alphabetical order. The resulting order of star classes—OBAFGKM—is shown in the table on the next page.

If you see a certain pattern of absorption lines in a star, you know that a certain element or molecule is in the star or at least in its atmosphere. But the absence of a pattern doesn't mean the element isn't there; the temperature might not be high enough or low enough for absorption lines to be produced.

life science CONNECTION

Imagine you are almost asleep in a darkened room when your grandmother comes in to say goodnight. You can make out her shape, but you can't tell what color her dress is.

Our eyes are not sensitive to colors when light levels are low. There are two types of light-sensitive cells inside the eye: rods and cones. Rods are good at distinguishing shades of light and dark as well as shape and movement. Cones are good for distinguishing colors. Cones, however, do not work well in low light. This is why it is hard to distinguish between star colors.

Types of Stars				
Class	**Color**	**Surface temperature (°C)**	**Elements detected**	**Examples of stars**
O	blue	above 30,000	helium	10 Lacertae
B	blue-white	10,000–30,000	helium and hydrogen	Rigel, Spica
A	blue-white	7,500–10,000	hydrogen	Vega, Sirius
F	yellow-white	6,000–7,500	hydrogen and heavier elements	Canopus, Procyon
G	yellow	5,000–6,000	calcium and other metals	the sun, Capella
K	orange	3,500–5,000	calcium and molecules	Arcturus, Aldebaran
M	red	less than 3,500	molecules	Betelgeuse, Antares

How Bright Is That Star?

When you look up at the sky on a dark night, you might see lots of stars. It is easy to see that some stars are bright and some are faint. Look at **Figure 4.** It shows the constellation Ursa Major (Big Bear), which includes the Big Dipper. Ancient astronomers saw the same stars that you see today. They called the brightest stars in the sky *first magnitude* stars and the faintest stars *sixth magnitude* stars. *Magnitude* means size, or in this case brightness. A first magnitude star is 100 times brighter than a sixth magnitude star. Notice that a smaller number means a brighter star.

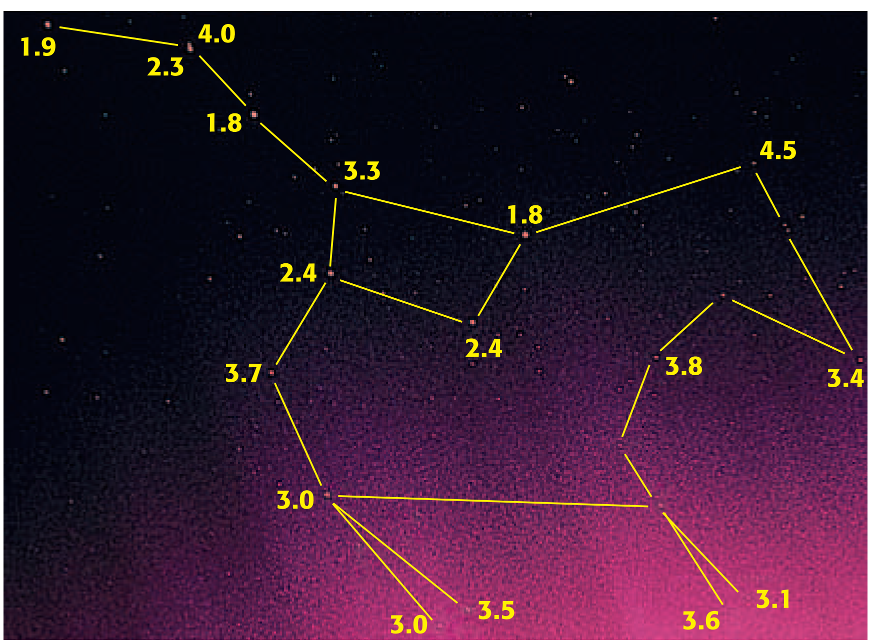


Figure 4 *Although you may recognize this constellation by its bright stars, it has many fainter stars as well. Numbers indicate their relative brightness.*

MATH BREAK

Starlight, Star Bright

Magnitude is used to indicate how bright one object is compared with another. Five magnitudes equal a factor of 100 times in brightness. The brightest blue stars, for example, have an absolute magnitude of –10. The sun is about +5. How much brighter is a blue star than the sun? Since each five magnitudes is a factor of 100 and the blue star and the sun are 15 magnitudes different, the blue star must be 100 × 100 × 100 times brighter than the sun. This is 1,000,000 (one million) times!

Figure 5 *You can estimate how far away each street light is by looking at its apparent brightness. Does this work with stars?*

The ancient astronomers probably thought they could see all the stars that existed. But in 1609, the telescope was invented. With a telescope, astronomers could see many more stars. But no one wanted to change the system of magnitudes that was already in place. Instead, modern astronomers simply added higher numbers for fainter stars. Now, with large telescopes, very faint stars of 29th magnitude have been found. Stars brighter than the original first magnitude stars are now given negative numbers. Sirius, the brightest star in the night sky, has a magnitude of –1.4.

Apparent Magnitude If you look at a row of street lights along a highway, like those shown in **Figure 5,** do they all look exactly the same? Does the light you are standing under look the same as a light several blocks away? Of course not! The nearest ones look bright, and the farthest ones look dim.

How bright a light looks, or appears, is called **apparent magnitude.** If you measure the brightness of a street light with a light meter, you will find that its brightness depends on the square of the distance between them. For example, a light that is 10 m away will appear four (2×2 or 2^2) times as bright as a light that is 20 m away. The same light will appear nine (3×3 or 3^2) times as bright as a light that is 30 m away.

Self-Check

If two identical stars are located the same distance away from Earth, what can you say about their apparent magnitudes? *(See page 596 to check your answer.)*

But unlike street lights, some stars are brighter than others because of their size or energy output, not their distance from Earth. So how can you tell the difference?

Absolute Magnitude Astronomers use a star's apparent magnitude (how bright it seems to be) and its distance from Earth to calculate its absolute magnitude. **Absolute magnitude** is the actual brightness of a star. In other words, if all stars could be placed the same distance away, their absolute magnitudes would be the same as their apparent magnitudes and the brighter stars would look brighter. The sun, for example, has an absolute magnitude of +4.8—pretty ordinary for a star. But because the sun is so close to Earth, its apparent magnitude is –26.8, making it the brightest object in the sky.

environmental science CONNECTION

And speaking of street lights . . . Cities have many street lights and other lights from buildings and homes. Because of this, someone looking at the night sky in a city would not see as many stars as someone looking at the sky in the country. Light pollution is a big problem for astronomers and backyard stargazers alike. Certain types of lighting can help reduce glare, but there will continue to be a conflict between lighting buildings at night and seeing the stars.

Distance to the Stars

Because they are so far away, astronomers use light-years to give the distances to the stars. A **light-year** is the distance that light travels in one year. Because the speed of light is about 300,000 km/s, it travels almost 9.5 trillion kilometers in one year. Obviously it would be easier to give the distance to the North Star as 431 light-years than 4,080,000,000,000,000 km. But how do astronomers measure a star's distance?

To get a clue, take a look at the QuickLab at right. Just as your thumb appeared to move, stars near the Earth seem to move compared with more-distant stars as Earth revolves around the sun, as shown in **Figure 6.** This apparent shift in position is called **parallax.** While this shift can be seen only through telescopes, using parallax and simple trigonometry (a type of math), astronomers can find the actual distance to stars that are close to Earth. Farther stars, however, are measured in more-complicated ways.

QuickLab

Not All Thumbs!

1. Hold your **thumb** in front of your face at arm's length.
2. Close one **eye** and focus on an **object** some distance behind your thumb.
3. Slowly move your **head** back and forth a small amount, and notice how your thumb seems to be moving compared with the background you are looking at.
4. Now move your thumb in close to your face and move your head the same amount. Notice how much more your thumb moves.

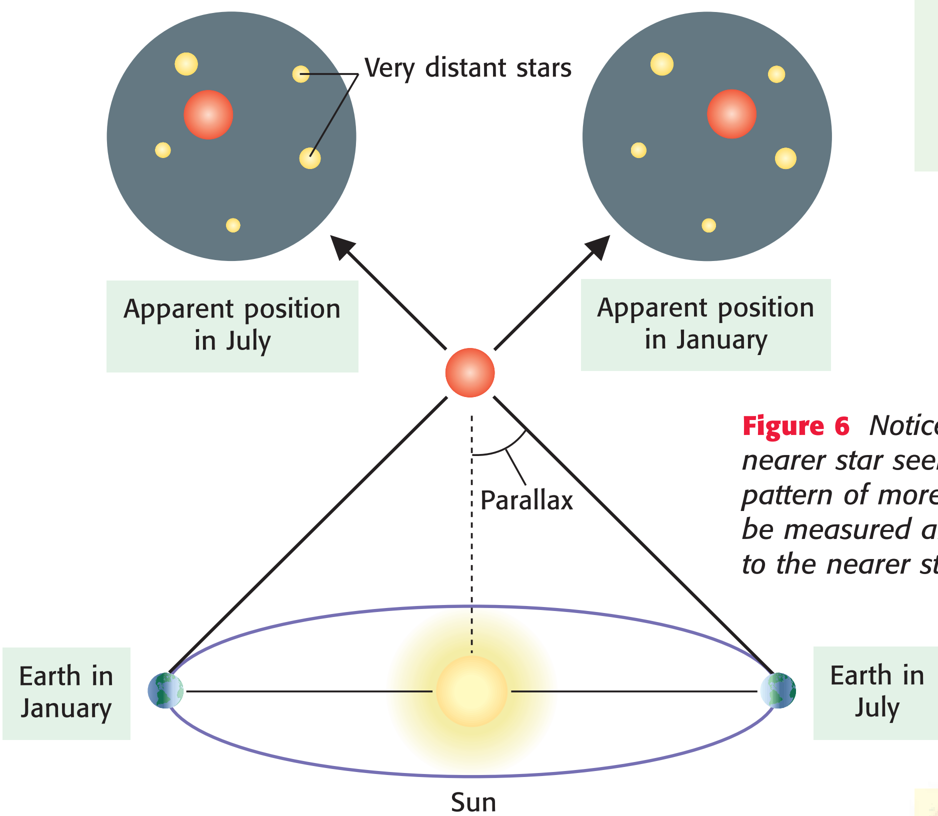


Figure 6 *Notice that the location of the nearer star seems to shift in relation to the pattern of more-distant stars. This shift can be measured and used to find the distance to the nearer star.*

Motions of Stars

As you know, the Earth rotates on its axis. As the Earth turns, different parts of its surface face the sun. This is why we have days and nights. The Earth also revolves around the sun. At different times of the year, you see different stars in the night sky. This is because the side of Earth that is away from the sun at night faces a different part of the universe.

LabBook

To learn more about parallax, turn to page 594 in the LabBook.

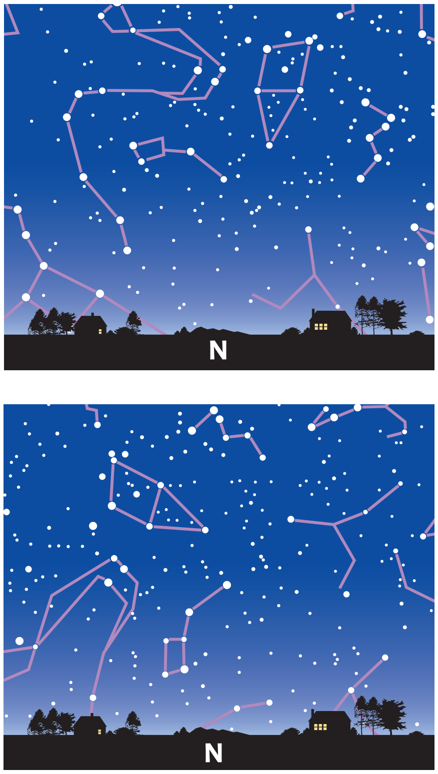
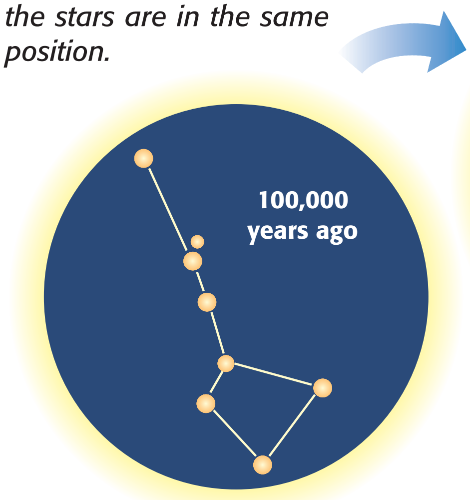


Figure 7 *As Earth rotates on its axis, stars set in the western horizon. About 24 hours later, the stars are in the same position.*

Apparent Motion Because of our location on the Earth's surface, the sun appears to rise in the east and set in the west. Stars also seem to rise and set, as shown in **Figure 7.** During the day the atmosphere scatters light from the sun, and we can't see the stars because the sky is too bright.

Actual Motion You now know that the rising and setting of the sun and stars that we see is due to Earth's rotation. But each star is also really moving in space. Because the stars are so distant, though, their motion is hard for us to measure. Most of the stars nearest the sun are traveling in the same direction as the sun. This is like driving on a highway while all the cars are going about the same speed and direction. It would be difficult to measure the speed of the cars in the lane next to you by just watching them. If you could watch stars over thousands of years, their movement would be obvious. Because the stars in constellations only look like they belong together, the constellations will slowly change shape. This is shown in **Figure 8.**



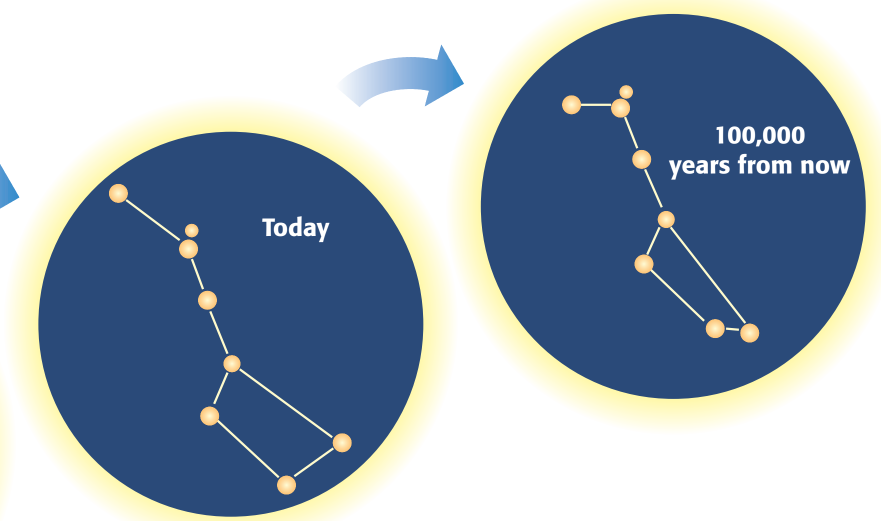


Figure 8 *Over time, the shapes of the constellations and other star groups change. Notice how the individual motion of stars will cause the Big Dipper to change its shape over 200,000 years.*

REVIEW

1. Is a yellow star, such as the sun, hotter or cooler than an orange star? Explain.
2. Suppose you see two stars that have the same apparent magnitude. If one star is actually four times as far away as the other, how much brighter would the farther star really be?
3. **Interpreting Illustrations** Look back at Figure 7. How many hours passed between the first image and the second image? How can you tell?

Section 2

The Life Cycle of Stars

NEW TERMS

H-R diagram
main sequence
white dwarf
red giant
supernova
neutron star
pulsar
black hole

OBJECTIVES

- Describe the quantities that are plotted in the H-R diagram.
- Explain how stars at different stages in their life cycle appear on different parts of the H-R diagram.

Just like people, stars are born, grow old, and eventually die. But unlike people, stars exist for billions of years. They are born when clouds of gas and dust come together and become very hot and dense. As stars get older, they lose some of their material. Usually this is a gradual change, but sometimes it happens in a big explosion. Either way, when a star dies, much of its material returns to space. There some of it combines with more gas and dust to form new stars. How do scientists know these things about stars? Read on to find out.

Explore

If you wanted to compare people, you might consider their height, age, or shirt size. You could then graph one variable against another to see what patterns show up.

If you graphed the heights of your school's basketball team, you might get a different result than if you graphed the heights of your classmates. In your classroom, ages might be almost the same. So choosing *what* to graph is important.

Think of two variables about your classmates, gather the data, and plot a graph. What does the graph tell you?

The Diagram That Did It!

In 1911 a Danish astronomer named Ejnar Hertzsprung plotted the temperature and brightness of stars on a graph. Two years later, American astronomer Henry Norris Russell made some graphs of his own. Although they used different data, these astronomers had similar results. By plotting the temperature of a star against its absolute magnitude, both came up with an interesting graph. The combination of their ideas is now called the *Hertzsprung-Russell,* or *H-R, diagram.* The **H-R diagram** is a graph showing the relationship between a star's surface temperature and its absolute magnitude. Russell's original diagram is shown in **Figure 9.**

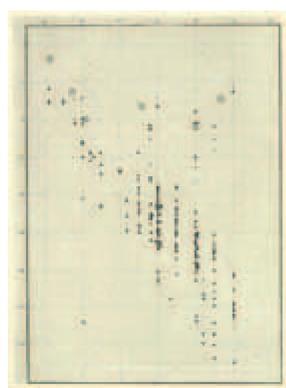


Figure 9 *Notice that a pattern begins to appear from the lower right to the upper left of the graph. Although it may not look like much, this graph began a revolution in astronomy.*

Some of the data in Russell's diagram seemed to show a trend, but the two astronomers didn't have very much data to go on because measuring the distance to stars is difficult. And as you know, distance is needed to calculate absolute magnitude.

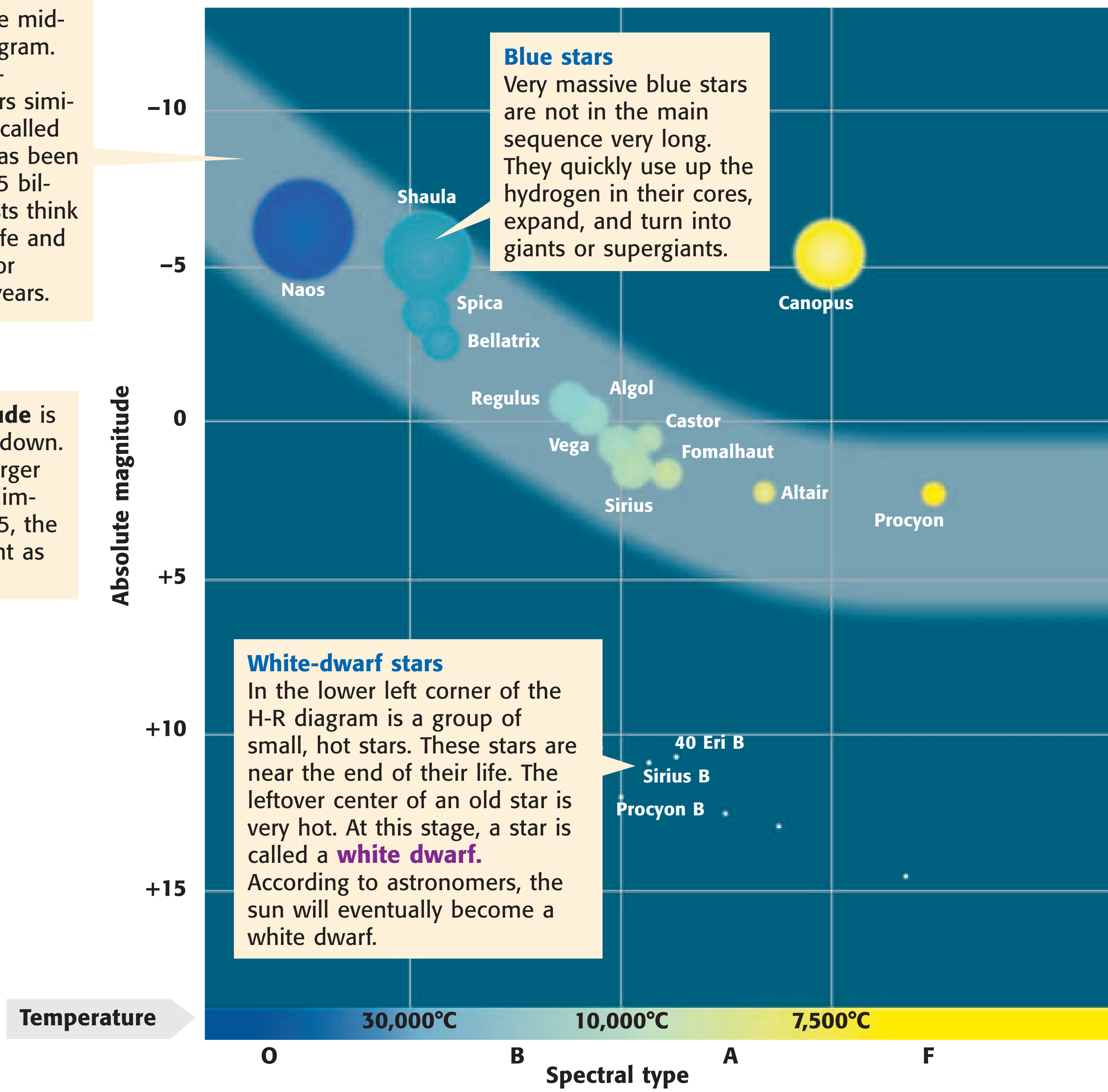
Over the years, the H-R diagram has become a tool for studying the nature of stars. It not only shows how stars are classified by temperature and brightness but also is a good way to illustrate how stars change over time. Turn the page to see a modern version of this diagram.

The H-R Diagram

Look closely at the diagram on these two pages. Temperature is given along the bottom of the diagram. Absolute magnitude, or brightness, is given along the left side. Hot (blue) stars are located on the left, and cool (red) stars are on the right. Bright stars are at the top, and faint stars are at the bottom. The brightest stars are a million times brighter than the sun. The faintest are 1/10,000 as bright as the sun. As you can see, there seems to be a band of stars going from the top left to the bottom right corner. This diagonal pattern of stars is called the **main sequence.** A star spends most of its lifetime as a main-sequence star and then changes into one of the other types of stars shown here.

Main sequence
Stars in the main sequence form a band that runs along the middle of the H-R diagram. The sun is a main-sequence star. Stars similar to the sun are called *dwarfs.* The sun has been shining for about 5 billion years. Scientists think the sun is in midlife and that it will shine for another 5 billion years.

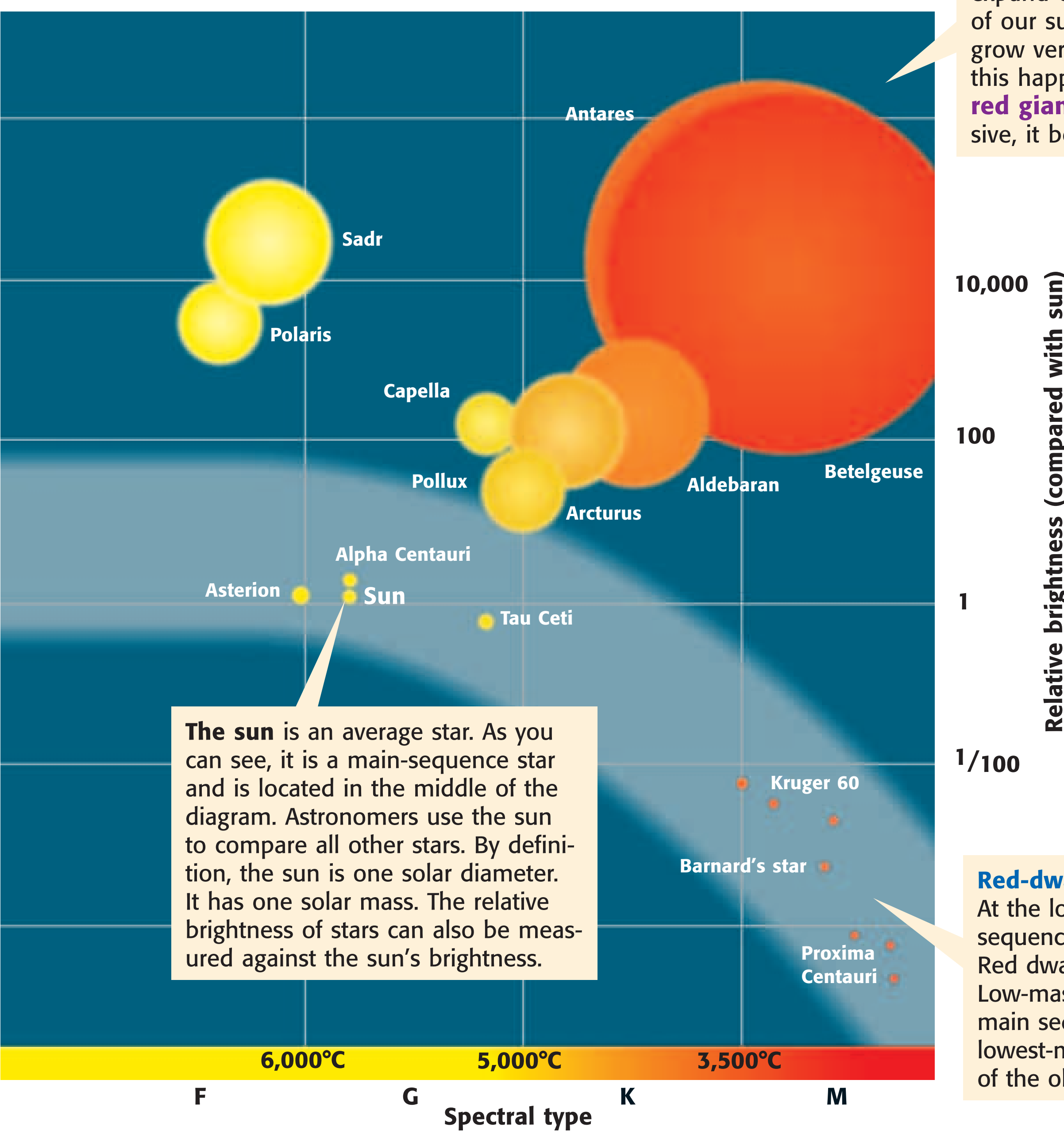
Absolute magnitude is measured upside down. That means the larger the number, the dimmer the star. At +5, the sun is not as bright as a −7 star.



All stars begin as a ball of gas and dust in space. Gravity pulls the gas and dust together. The gas becomes hotter as it becomes more dense. When it is hot enough in the center, hydrogen turns into helium in a process called *nuclear fusion,* and lots of energy is given off. A star is born.

Most stars can be plotted on the main sequence. Small-mass stars tend to be located at the lower right end of the main sequence; larger stars are found at the left end. As main-sequence stars age, they move up and to the right on the H-R diagram to become giants or supergiants. Such stars can then lose their atmospheres, leaving small cores behind, which end up in the lower left corner of the diagram as white dwarfs.

Giants and supergiants
When a star runs out of hydrogen in its core, the center of the star shrinks and the outer parts expand outward. In a star the size of our sun, the atmosphere will grow very large and cool. When this happens, the star becomes a **red giant.** If the star is very massive, it becomes a *supergiant.*



The sun is an average star. As you can see, it is a main-sequence star and is located in the middle of the diagram. Astronomers use the sun to compare all other stars. By definition, the sun is one solar diameter. It has one solar mass. The relative brightness of stars can also be measured against the sun's brightness.

Red-dwarf stars
At the lower end of the main sequence are the red-dwarf stars. Red dwarfs are low-mass stars. Low-mass stars remain on the main sequence a long time. The lowest-mass stars may be some of the oldest stars in the galaxy.

When Stars Get Old

BRAIN FOOD

Many of the elements in your body were made during supernova explosions. In other words, you are made of "starstuff"!

While stars may stay on the main sequence for a long time, they don't stay there forever. You have already seen that average stars, such as the sun, turn into red giants and then white dwarfs. But when massive stars get old, they may leave the main sequence in a more spectacular fashion. Stars much larger than the sun may explode with such violence that they turn into a variety of strange new objects. Let's take a look at some of these objects.

Supernovas Large blue stars use up their hydrogen much faster than stars like the sun. This means they make a lot more energy, which makes them very hot and therefore blue! And compared with other stars, they don't last long. At the end of its life, a blue star may explode in a tremendous flash of light called a *supernova*. A **supernova** is basically the death of a large star by explosion. A supernova explosion is so powerful it can be brighter than an entire galaxy. It may shine for several days after the initial explosion and then gradually dim. Heavy elements, such as silver, gold, and lead, are made during a supernova explosion and are then scattered into space.

The ringed structure shown in **Figure 10** is the result of a supernova explosion that was first observed on February 23, 1987. In the years that followed, parts of the star were thrown out to form a double ring of gas and dust around the remains of the original star. The star, located in a nearby galaxy, actually exploded before civilization began here on Earth, but it took 169,000 years for the light from the explosion to reach our planet.

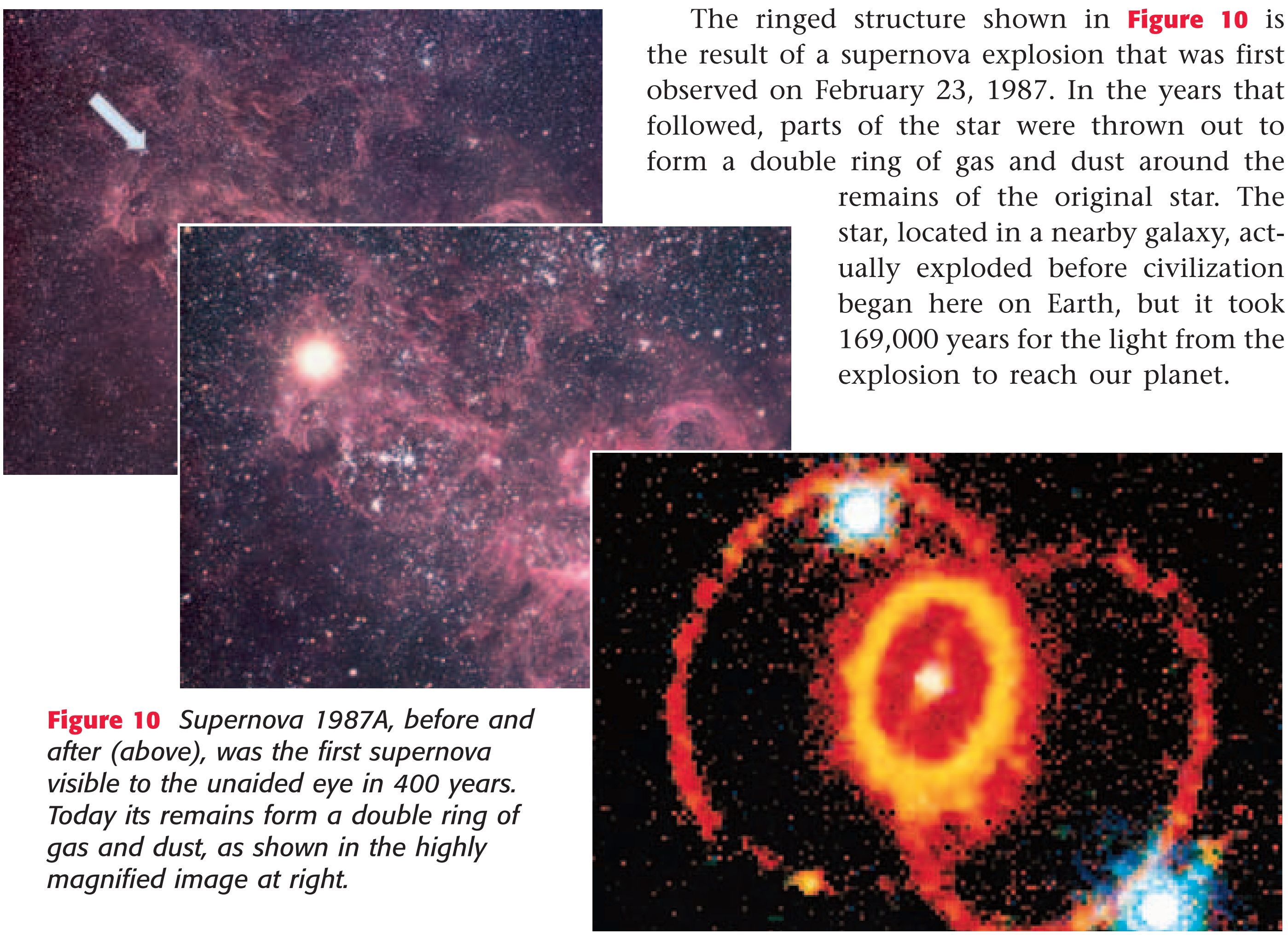


Figure 10 *Supernova 1987A, before and after (above), was the first supernova visible to the unaided eye in 400 years. Today its remains form a double ring of gas and dust, as shown in the highly magnified image at right.*

Neutron Stars and Pulsars So what happens to a star that becomes a supernova? The leftover materials in the center of a supernova are squeezed together to form a star of about two solar masses. But all the material is found in a sphere only about 20 km in diameter. The particles inside the star become neutrons, so this star is called a **neutron star.** The squeezed material in a neutron star is so dense, a teaspoon of neutron star matter brought back to Earth would weigh a billion tons.

Figure 11 *A pulsar is a swiftly rotating neutron star. Pulsars can be detected on Earth only if their beams of radiation sweep past the Earth.*

If a neutron star is also spinning, it is called a **pulsar.** A pulsar sends out beams of radiation that also spin around very rapidly. These beams, shown in **Figure 11,** are much like the beams from a lighthouse. The beams are detected as rapid clicks or pulses by radio telescopes.

Black Holes Sometimes the leftovers of a supernova are so massive that they collapse to form a *black hole*. A **black hole** is an object with more than three solar masses squeezed into a ball only 10 km across—100 football fields long. A black hole is so small and massive and its gravity is so strong that not even light can escape. That is why it is called a *black* hole. Contrary to some movie depictions, a black hole doesn't gobble up other stars. But if a star is nearby, some gas or dust from the star will spiral into the black hole, as shown in **Figure 12,** giving off X rays. It is by these X rays that astronomers can detect the existence of black holes.

Figure 12 *A black hole's gravity is so strong that it can pull in material from a nearby star, as shown in this artist's drawing.*

REVIEW

1. Are blue stars young or old? How can you tell?
2. In main-sequence stars, what is the relationship between brightness and temperature?
3. Arrange the following in order of their appearance in the life cycle of a star: white dwarf, red giant, main-sequence star. Explain your answer.
4. **Applying Concepts** Given that there are more low-mass stars than high-mass stars in the universe, do you think there are more white dwarfs or more black holes? Explain.

As a famous astronomer once said, "The black hole seems much more at home in science fiction or in ancient myth than in the real universe." Turn to page 508 to learn more about these mysterious objects in space.

Section 3

Galaxies

NEW TERMS

galaxy	nebula
spiral galaxy	open cluster
elliptical galaxy	globular cluster
irregular galaxy	quasar

OBJECTIVES

- Identify the various types of galaxies from pictures.
- Describe the contents of galaxies.
- Summarize one theory of the origin of galaxies.

Stars don't exist alone in space. They belong to larger groups that are held together by the attraction of gravity. The most common groupings are galaxies. **Galaxies** are large groupings of stars in space. Galaxies come in a variety of sizes and shapes. The largest galaxies contain more than a trillion stars. Some of the smaller ones have only a few million. Astronomers don't count the stars, of course; they estimate from the size and brightness of the galaxy how many sun-sized stars the galaxy might have.

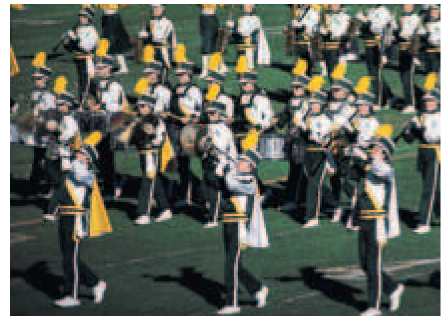
Types of Galaxies

Look again at the Hubble Deep Field image at the beginning of this chapter. You'll notice many different types of *galaxies*. Edwin Hubble, the astronomer for whom the Hubble Space Telescope is named, began to classify galaxies in the 1920s, mostly by their shapes. We still use the galaxy names that Hubble originally assigned.

Spiral Galaxies Spiral galaxies are what most people think of when you say *galaxy*. **Spiral galaxies** have a bulge at the center and very distinctive spiral arms. When the center has a bar shape, the galaxy is called a *barred spiral*. Hot blue stars in the spiral arms make the arms in spiral galaxies appear blue. The central region, or *nuclear bulge*, appears yellow because it contains cooler stars. **Figure 13** shows a spiral galaxy tilted so you can see its pinwheel shape. Other spiral galaxies appear to be "edge-on." These galaxies are harder to classify. With them, the relative shape and size of the nuclear bulge is an important clue to determining the type of galaxy it is.

Figure 13 *The Milky Way galaxy is thought to be a spiral galaxy similar to the galaxy in Andromeda, shown here.*

Our sun is located about two-thirds the distance from the center to the outer edge of our galaxy, the *Milky Way*. It is hard to tell what type of galaxy we are in because the gas, dust, and stars keep us from having a good view. It is like trying to figure out what pattern a marching band is making while you are in the band, as shown in **Figure 14.** Observing other galaxies and making measurements inside our galaxy lead astronomers to think that Earth is in a spiral galaxy.



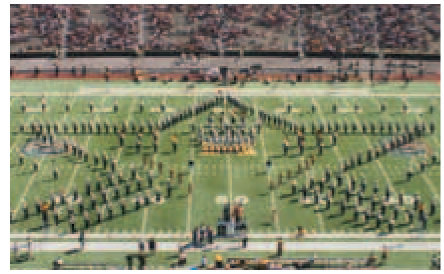


Figure 14 *The members of a marching band cannot see the formation the band is making while they are in the formation. We have the same problem inside the Milky Way.*

M87

Elliptical Galaxies About one-third of all galaxies are simply massive blobs of stars. Many look like spheres, while others are more elongated. Because we don't know how they are oriented, these galaxies could be cucumber shaped, with the round end facing us. These galaxies are called *elliptical galaxies*. **Elliptical galaxies** have very bright centers and very little dust and gas. Because there is so little gas, there are no new stars forming, and therefore elliptical galaxies contain only old stars. Some elliptical galaxies, like M87, above, are huge and are therefore called *giant elliptical galaxies*. Others are much smaller than the Milky Way and are called *dwarf elliptical galaxies*. There are probably lots of dwarf ellipticals, but because they are small and faint, they are very hard to detect. Astronomers have only recently begun intense searches to find more dwarf elliptical galaxies.

Irregular Galaxies When Hubble first classified galaxies, he had a group of leftovers. He named them "irregulars." **Irregular galaxies** are galaxies that don't fit into any other class. As their name suggests, their shape is irregular. Many of these galaxies, such as the Large Magellanic Cloud, shown at right, are close companions of large spiral galaxies, whose gravity may be distorting the shape of their smaller neighbors.

Large Magellanic Cloud

Explore

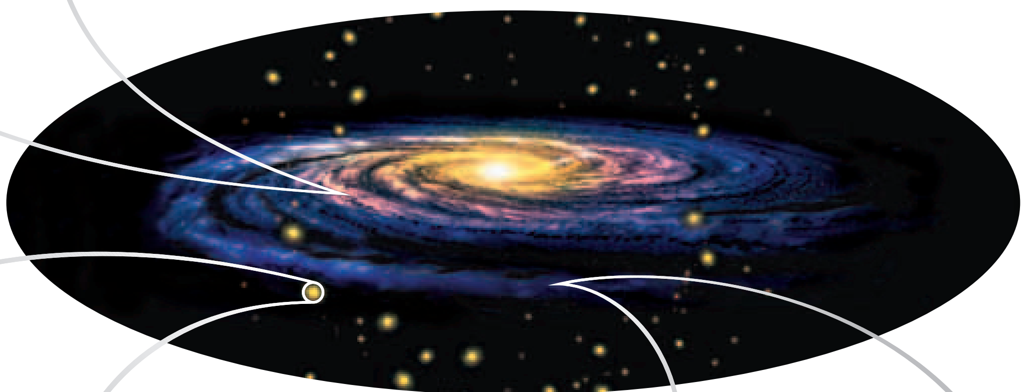
Now that you know the names Edwin Hubble gave to different shapes of galaxies, look at the names you gave the galaxies in the Hubble Deep Field activity at the beginning of this chapter. Rename your types with the Hubble names. Look for examples of spirals, ellipticals, and irregular galaxies.

Contents of Galaxies

Galaxies are composed of billions and billions of stars. But besides the stars and the planetary systems many of them probably have, there are larger features within galaxies that are made up of stars or the material of stars. Among these are gas clouds and star clusters.

Gas Clouds The Latin word for "cloud" is *nebula*. In space, **nebulas** (or *nebulae*) are giant clouds of gas and dust. Some types of nebulas glow by themselves, while others absorb light and hide stars. Still others reflect starlight, producing some amazing images. Some nebulas are regions where new stars are formed. **Figure 15** shows part of the Eagle nebula. Spiral galaxies generally contain nebulas, but elliptical galaxies don't. When two galaxies collide, new stars may form where the gas and dust from the galaxies mix.

Figure 15 *Part of a nebula in which stars are born is shown above. The finger-like shape to the left of the bright star is slightly wider than our solar system.*



Open Clusters **Open clusters** are groups of stars that formed when large amounts of gas and dust came together. They are usually located along the spiral disk of a galaxy. Newly formed open clusters have many bright blue stars, as shown in **Figure 16.** There may be a few hundred to a few thousand stars in an open cluster.

Figure 16 *The open cluster Pleiades is just visible without a telescope.*

Globular Clusters **Globular clusters** are groups of older stars that also formed from a large gas cloud. A globular cluster looks like a ball of stars, as shown in **Figure 17.** There may be 20,000 to 100,000 stars in an average globular cluster. Globular clusters are located in a spherical *halo* that surrounds spiral galaxies such as the Milky Way. Globular clusters are also common around giant elliptical galaxies.

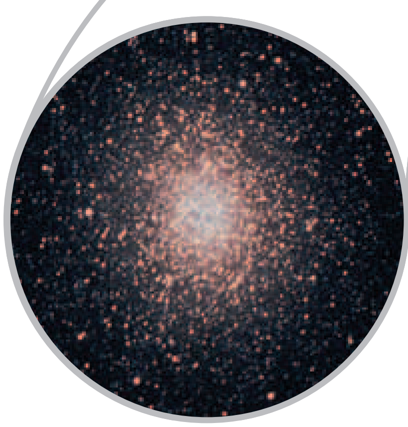


Figure 17 *Omega Centauri is the largest globular cluster in the Milky Way. It contains 5 to 10 million stars. The Milky Way galaxy is surrounded by globular clusters.*

Origin of Galaxies

Astronomers do not know for sure how galaxies form. One theory is that galaxies form from collapsing clouds of gas and dust. If the cloud is rotating, a spiral galaxy will form. Some of the material will form stars during the collapse to become the galaxy's bulge. The rest of the material will collapse into a disk and form the spiral arms, where new stars will continue to form. If the cloud is not rotating fast enough, an elliptical galaxy will form. Because most of the gas and dust will be used up during the collapse, stars will no longer form once the galaxy is complete. See **Figure 18.**

Another theory is that most galaxies form as spirals. Some of these spiral galaxies then collide and merge their stars together, causing any remaining gas and dust to form stars. The rotations of the merging galaxies are affected by the collision, and once they merge completely, they become an elliptical galaxy.

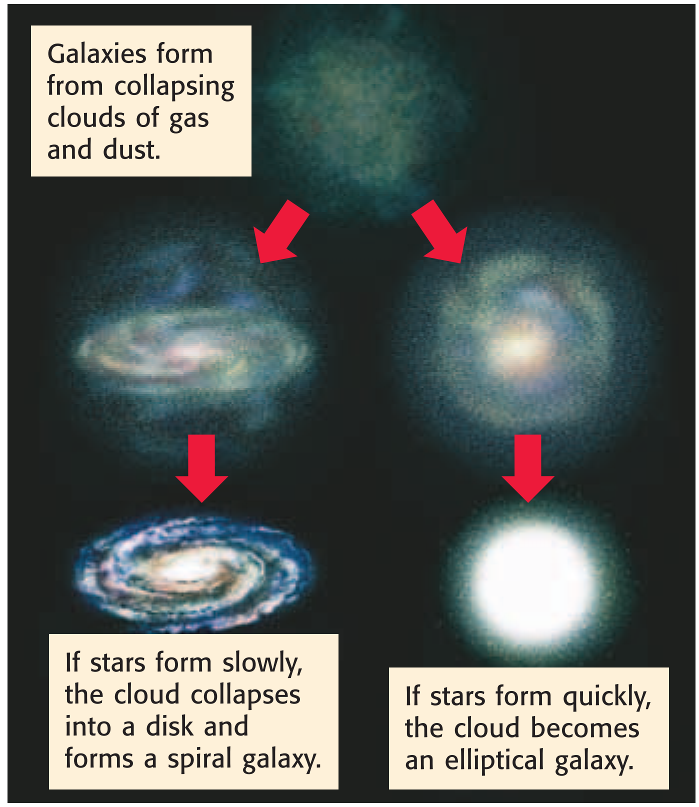
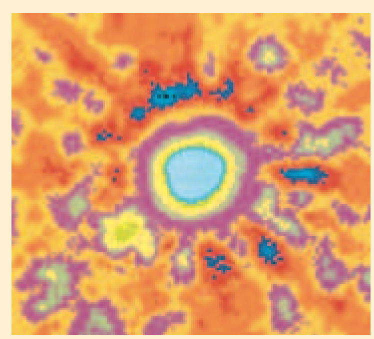


Figure 18 *The formation of galaxies can follow one of two paths, according to one theory.*

Back in Time Because it takes time for light to travel through space, looking through a telescope is like looking back in time. The farther out one looks, the further back in time one travels. Because of this, distant galaxies should reveal what early galaxies looked like. Among the most distant objects are **quasars,** which look like tiny points of light. But because they are very far away, they must be extremely bright for their size. Quasars are among the most powerful energy sources in the universe. They may be young galaxies with enormous black holes at their centers.

REVIEW

1. Arrange these galaxies in order of decreasing size: spiral, giant elliptical, dwarf elliptical, irregular.
2. Describe the difference between an elliptical galaxy and a globular cluster.
3. **Analyzing Relationships** If you could observe very distant galaxies just as they begin to form stars, would you expect them to have more red or more blue stars? Why?



What happens when you're looking for quasars and find something else? You get famous! Turn to page 509 and see who it is.

Section 4

Formation of the Universe

NEW TERMS

cosmology
big bang theory
cosmic background radiation

OBJECTIVES

- Describe the big bang theory.
- Explain evidence used to show support for the big bang theory.
- Explain how the expansion of the universe is explained by the big bang theory.

So far you've learned about the contents of the universe. But what about its history? How did the universe begin? How might it end? Questions like these are a special part of astronomy called *cosmology.* **Cosmology** is the study of the origin and future of the universe. Like other scientific theories, theories about the beginning and end of the universe must be tested by observations or experiments. Because the universe is so large, theories about its origin are difficult to test.

The Big Bang Theory

One of the most important theories in cosmology is the big bang theory. The **big bang theory** states that the universe began with a tremendous explosion. According to the theory, 12 billion to 15 billion years ago, all the contents of the universe were gathered together under extreme pressure, temperature, and density in a very tiny spot. Then, for some reason, it rapidly expanded outward. In the early moments of the universe, some of the expanding energy turned into matter that eventually became the galaxies, as shown in **Figure 19.**

As the galaxies move apart, they get older and eventually stop forming stars. What happens next depends on how much matter is contained in the universe. If there is enough matter, gravity will slow and eventually stop the expansion of the universe. The universe may even start collapsing, causing a "big crunch." If there is not enough matter to stop the expansion of the universe, galaxies will become more widely separated. Then as stars age and die, the universe will eventually become cold and dark. Recent observations suggest that there may not be enough matter to stop the universe from expanding forever, but the answer is still uncertain.

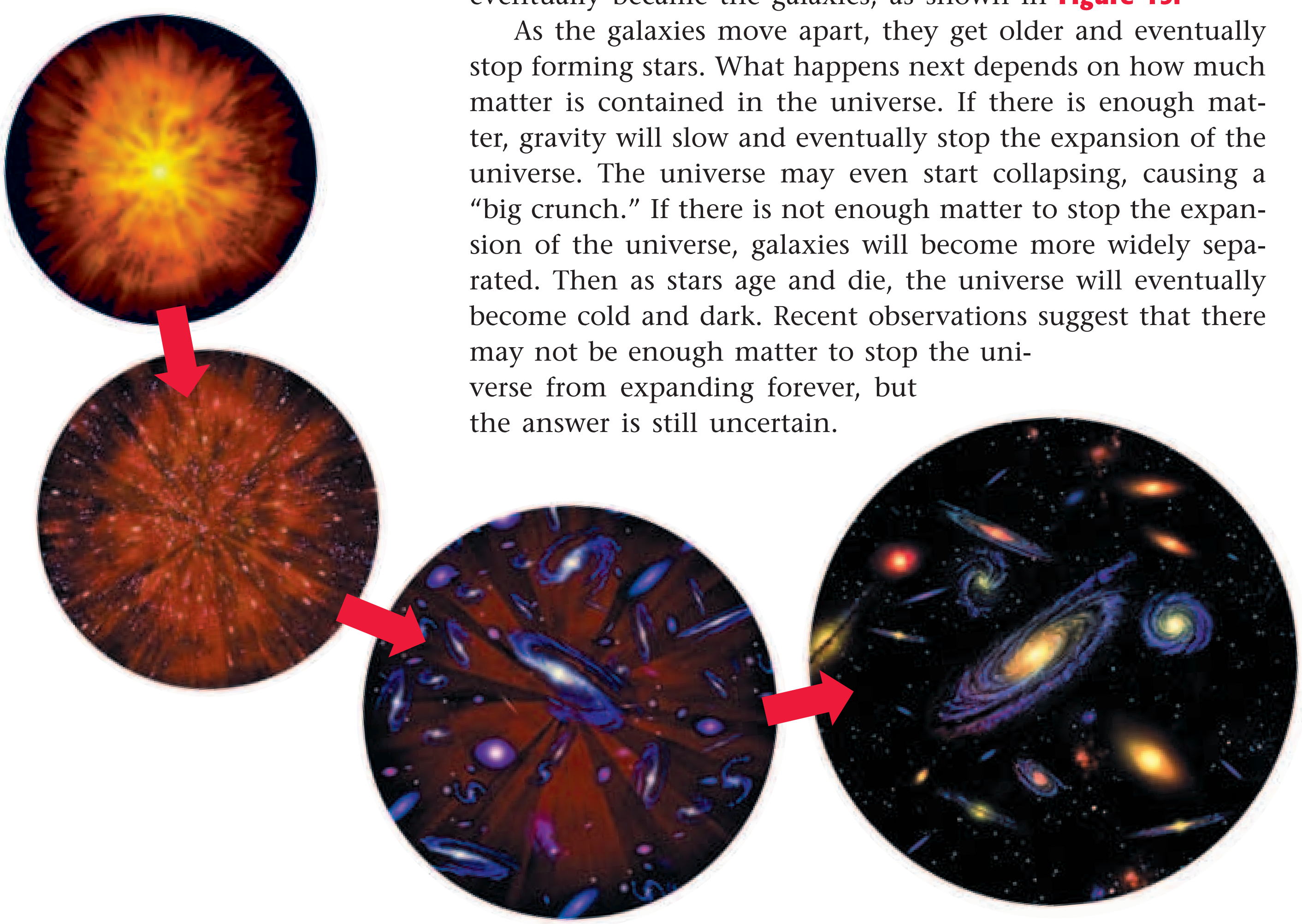


Figure 19 *The big bang caused the universe to expand in all directions.*

Supporting the Theory So how do we know if the big bang really happened? In 1964, two scientists, using the antenna shown in **Figure 20,** accidentally found radiation coming from all directions in space. One explanation for this radiation is that it is **cosmic background radiation** left over from the big bang. Think about what happens when an oven door is left open after the oven has been used. The heat spreads out through the kitchen as the oven cools. Eventually the room and the oven are the same temperature. According to the big bang theory, the heat from the original explosion became scattered as it traveled outward. It now fills all of space at the same temperature—a chilly –270°C, or three Celsius degrees above absolute zero.

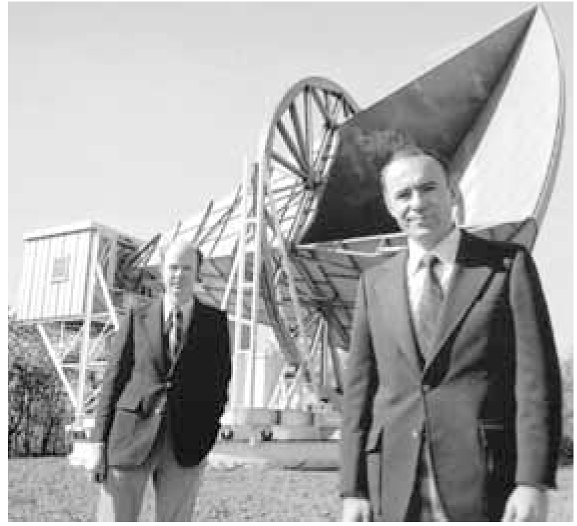


Figure 20 *Arno Penzias (left) and Robert Wilson (right) used this strange-looking horn antenna to discover the cosmic background radiation, giving a big boost to the big bang theory.*

Today the big bang theory is widely accepted by astronomers. It seems to explain all of their observations so far. However, it is possible that new observations may not fit this theory. Scientists must remain open to new theories that might give alternative explanations for the cosmic background radiation.

Universal Expansion

But where did the idea of a big bang come from? The answer is found in deep space. No matter what direction we look, the galaxies are moving away from us, as shown in **Figure 21.** Distant galaxies are moving faster than nearby galaxies. When scientists first measured the speeds of galaxies, they observed that almost everything in the universe is moving away from our galaxy. There doesn't seem to be anything special about our galaxy, except for the fact that we live here. Are we the center of the universe? Well, not quite. A close measurement of speed and distances has shown that all galaxies are moving away from all other galaxies. But what does this mean?

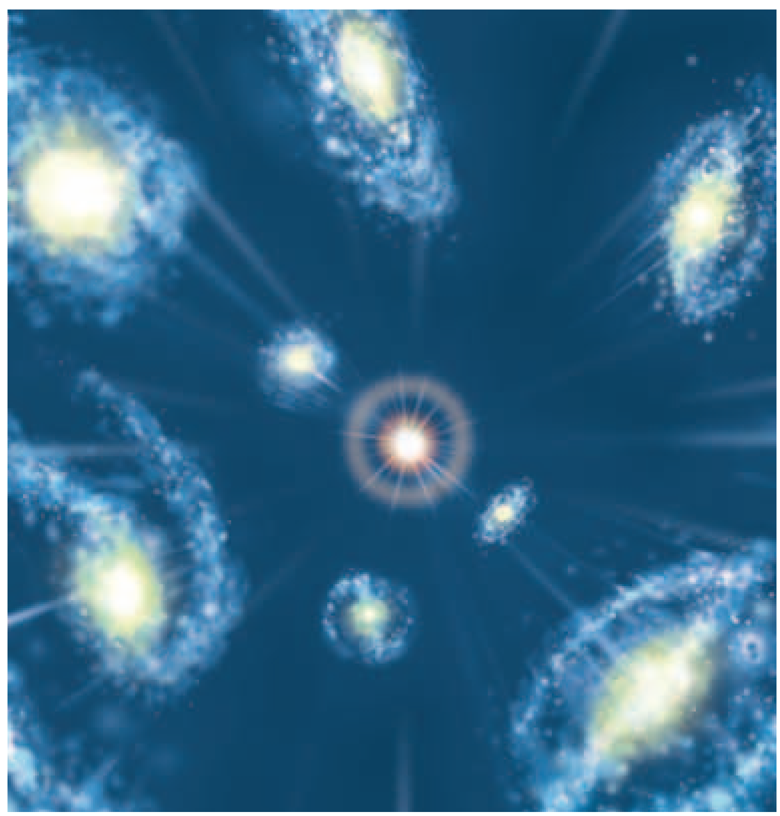


Figure 21 *The big bang theory explains the expansion of the universe we observe as galaxies move outward in all directions.*

Imagine a loaf of raisin bread before it is baked. Inside the dough, each raisin is a certain distance from each other raisin. None are moving. As the dough gets warm and rises, however, all the raisins move away from each other. No matter which raisin you choose, the others are farther from it at each moment of time. The most distant raisins seem to move fastest. In a similar way, almost all galaxies are moving away from each other. Our Milky Way galaxy, for example, is like one of the raisins. All other distant galaxies are moving away from us. And the same would be true for observers in any other galaxy. In other words, there isn't any way to find the "center" of the universe.

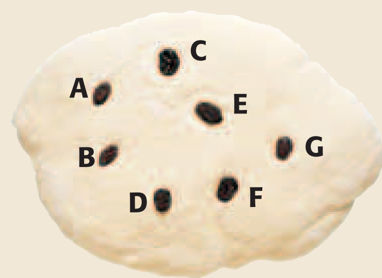
BRAIN FOOD

Objects in very distant space look "younger" than they really are. In fact, we cannot even be sure they still exist. If a distant galaxy disappeared, for example, people on Earth wouldn't know about it for billions of years.

Some Puzzling Questions While astronomers have learned a lot about the universe, there are still some unanswered questions. For one, we are not certain about the age of the universe. Remember, since light travels at a certain speed, looking at very distant parts of the universe is like looking back in time. Because the light from distant galaxies took a long time to travel to us, we see the galaxies as they were a long time ago. Scientists can measure how old the universe is by determining the distance of these early galaxies. But because measurements of distance to galaxies are uncertain, our calculation of the age of the universe is also uncertain.

APPLY

Suppose you decide to make some raisin bread. You would form a lump of dough, as shown in the top image. The lower image represents dough that has been rising for 2 hours. Look at raisin **B** in the top image. Measure how far it is from each of the other raisins—**A, C, D, E, F,** and **G**—in millimeters. Now measure how far each raisin has moved away from **B** in the lower image. Make a graph of speed (in units of mm/h) versus original distance (in mm). Remember that speed equals distance divided by time. For example, if raisin **E** was originally 15 mm from raisin **B** and is now 30 mm away, it moved 15 mm in 2 hours. Its speed is therefore 7.5 mm/h. Repeat the procedure, starting with raisin **D.** Plot your results on the same graph, and compare the two results. What can you conclude from the information you graphed?



Other scientists have calculated the ages of stars by comparing theories of how stars change over time with observations of stars in and around our galaxy. Since the universe must be at least as old as the oldest stars it contains, their ages might provide a clue to the age of the universe. However, these calculations indicate that some stars are older than the universe itself! This is clearly a contradiction. Is the problem with calculating stellar ages or with measuring galaxy distances? Astronomers continue to search for scientific answers to these questions.

Structure of the Universe

The universe is an amazing place. From our home on planet Earth, it stretches out farther than we can see with our most sensitive instruments. It contains a variety of objects, some of which you have just learned about. But these objects are not simply scattered through the universe at random.

The universe has a structure that is repeated over and over again. You already know that the Earth is a planet. But planets are part of planetary systems. Our solar system is the only example we actually know about, but other stars with planets around them have been identified. Stars sprinkle the sky. But stars are grouped in larger systems, ranging from star clusters to galaxies. Galaxies themselves are arranged in groups bound together by gravity. Even galaxy groups form galaxy clusters and superclusters, as shown in **Figure 22.**

Farther than the eye can see, the universe continues with this pattern, with great collections of galaxy clusters and vast empty regions of space in between. But is the universe itself alone? Some cosmologists think that our universe is only one of a great many other universes, perhaps similar to ours or perhaps not. At present, we cannot observe other universes. But someday, who knows? Maybe students in future classrooms will have much more to study!

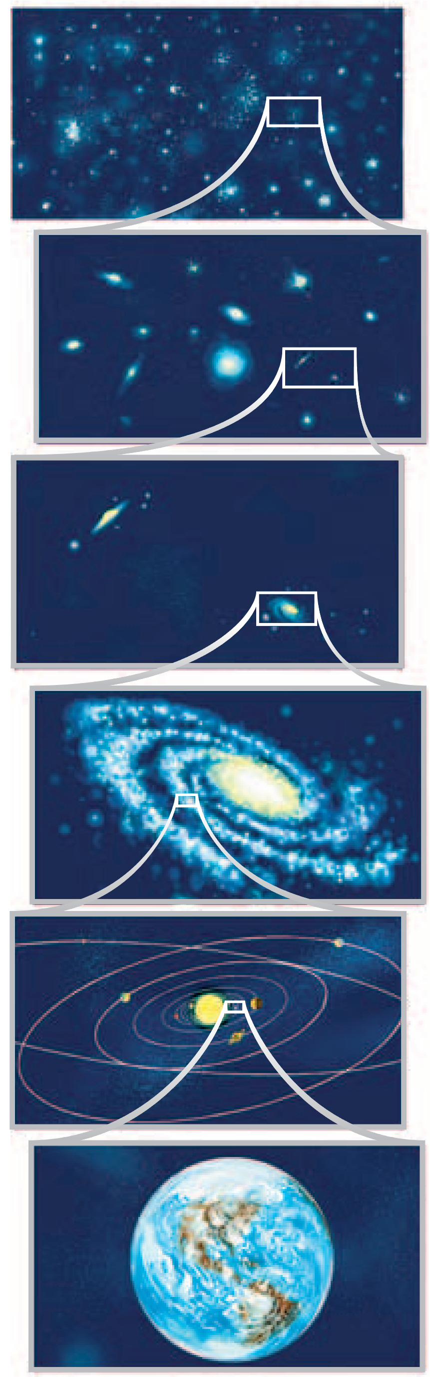


Figure 22 *The Earth is only part of a vast system of matter.*

REVIEW

1. Name one observation that supports the big bang theory.
2. How does the big bang theory explain the observed expansion of the universe?
3. **Understanding Technology** Large telescopes gather more light than small telescopes gather. Why are large telescopes used to study very distant galaxies?

Chapter Highlights

SECTION 1

Vocabulary

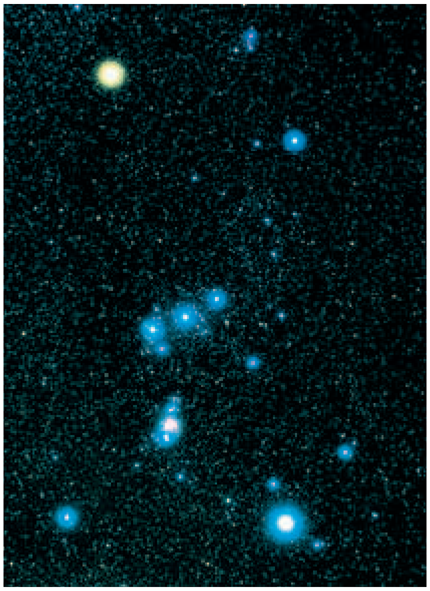
spectrum *(p. 484)*
apparent magnitude *(p. 488)*
absolute magnitude *(p. 488)*
light-year *(p. 489)*
parallax *(p. 489)*

Section Notes

- The color of a star depends on its temperature. Hot stars are blue. Cool stars are red.
- The spectra of stars indicate their composition. Spectra are also used to classify stars.
- The magnitude of a star is a measure of its brightness.
- Apparent magnitude is how bright a star appears from Earth.
- Absolute magnitude is how bright a star actually is. Lower absolute magnitude numbers indicate brighter stars.
- Distance to nearby stars can be measured by their movement relative to stars farther away.

Labs

Red Hot, or Not? *(p. 592)*
I See the Light! *(p. 594)*



SECTION 2

Vocabulary

H-R diagram *(p. 491)*
main sequence *(p. 492)*
white dwarf *(p. 492)*
red giant *(p. 493)*
supernova *(p. 494)*
neutron star *(p. 495)*
pulsar *(p. 495)*
black hole *(p. 495)*

Section Notes

- New stars form from the material of old stars that have gone through their life cycles.
- The H-R diagram relates the temperature and brightness of a star. It also illustrates the life cycle of stars.
- Most stars are main-sequence stars. Red giants and white dwarfs are later stages in a star's life cycle.
- Massive stars become supernovas. Their cores turn into neutron stars or black holes.

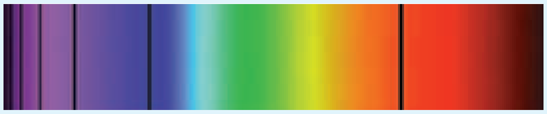
Skills Check

Math Concepts

SQUARING THE DIFFERENCE The difference in brightness (apparent magnitude) between a pair of similar stars depends on the difference in their distances from Earth. Compare a star that is 10 light-years away with a star that is 5 light-years away. One star is twice as close, so it is $2 \times 2 = 4$ times brighter than the other star. The star that is 5 light-years away is also 3^2, or 9, times brighter than one that is 15 light-years away.

Visual Understanding

READING BETWEEN THE LINES The composition of a star is determined by the absorption spectra it displays. Dark lines in the spectrum of a star indicate which elements are present. Look back at Figure 3 to review.



SECTION 3

Vocabulary

galaxy *(p. 496)*
spiral galaxy *(p. 496)*
elliptical galaxy *(p. 497)*
irregular galaxy *(p. 497)*
nebula *(p. 498)*
open cluster *(p. 498)*
globular cluster *(p. 498)*
quasar *(p. 499)*

Section Notes

- Edwin Hubble classified galaxies according to their shape. Major types include spiral, elliptical, and irregular galaxies.
- The Milky Way is our galaxy. Our sun is located in a spiral arm about two-thirds the distance from the galaxy's center to its edge.
- A nebula is a cloud of gas and dust. New stars are born in some nebulas.
- Open clusters are groups of stars located along the spiral disk of a galaxy. Globular star clusters are found in the halos of spiral galaxies and in elliptical galaxies.

SECTION 4

Vocabulary

cosmology *(p. 500)*
big bang theory *(p. 500)*
cosmic background radiation *(p. 501)*

Section Notes

- The big bang theory states that the universe began with an explosion about 12 billion to 15 billion years ago.
- Cosmic background radiation fills the universe with radiation that is left over from the big bang. It is the primary evidence supporting the big bang theory.
- Observations show that the universe is expanding outward. There is no measurable center and no apparent edge.
- All matter in the universe is a part of larger systems, from planets to superclusters of galaxies.

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TOPIC: Galaxies ***sci*LINKS NUMBER:** HSTP645

Chapter Review

USING VOCABULARY

For each pair of terms, explain the difference in their meanings.

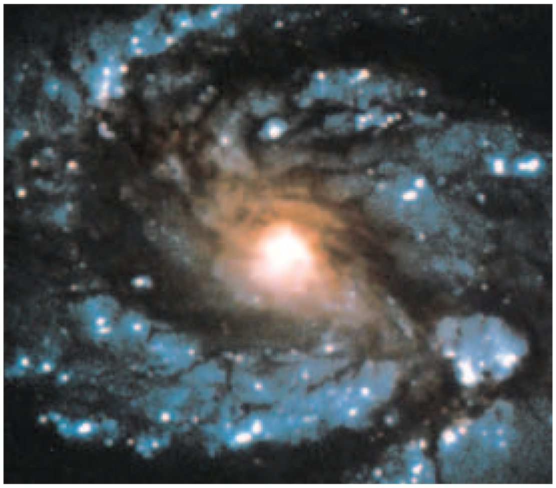
1. absolute magnitude/apparent magnitude
2. spectrum/parallax
3. main-sequence star/red giant
4. white dwarf/black hole
5. elliptical galaxy/spiral galaxy
6. big bang/cosmic background radiation

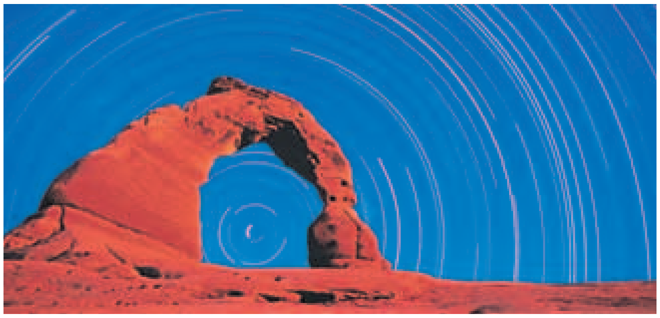
UNDERSTANDING CONCEPTS

Multiple Choice

7. The majority of stars in our galaxy are
   a. blue.
   b. white dwarfs.
   c. main-sequence stars.
   d. red giants.

8. Which would be seen as the brightest star in the following group?
   a. Alcyone—apparent magnitude of 3
   b. Alpheratz—apparent magnitude of 2
   c. Deneb—apparent magnitude of 1
   d. Rigel—apparent magnitude of 0





9. A cluster of stars forms in a nebula. There are red stars, blue stars, yellow stars, and white stars. Which stars are most like the sun?
   a. red **c.** blue
   b. yellow **d.** white

10. Individual stars are moving in space. How long will it take to see a noticeable difference without using a telescope?
   a. 24 hours **c.** 100 years
   b. 1 year **d.** 100,000 years

11. You visited an observatory and looked through the telescope. You saw a ball of stars through the telescope. What type of object did you see?
   a. a spiral galaxy
   b. an open cluster
   c. a globular cluster
   d. a barred spiral galaxy

12. In which part of a spiral galaxy do you expect to find nebulas?
   a. the spiral arms
   b. the nuclear bulge
   c. the halo
   d. all parts of the galaxy

13. Which statement about the big bang theory is accurate?
   a. The universe will never end.
   b. New matter is being continuously created in the universe.
   c. The universe is filled with radiation coming from all directions in space.
   d. We can locate the center of the universe.

Short Answer

14. Describe how the apparent magnitude of a star varies with its distance from Earth.

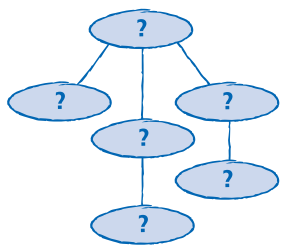
15. Name six types of astronomical objects in the universe. Arrange them by size.

16. What happens when two spiral galaxies collide with each other?

17. What does the big bang theory have to say about how the universe will end?

Concept Mapping

18. Use the following terms to create a concept map: black hole, neutron star, main-sequence star, red giant, nebula, white dwarf.



CRITICAL THINKING AND PROBLEM SOLVING

Write one or two sentences to answer the following questions:

19. If a certain star displayed a large parallax, what could you say about its distance from Earth?

20. Two M-type stars have the same apparent magnitude. Their spectra show that one is a red giant and the other is a red-dwarf star. Which one is farther from Earth? Explain your answer.

21. Look back at the H-R diagram in Section 2. Why do astronomers use absolute magnitudes to plot the stars? Why don't they use apparent magnitudes?

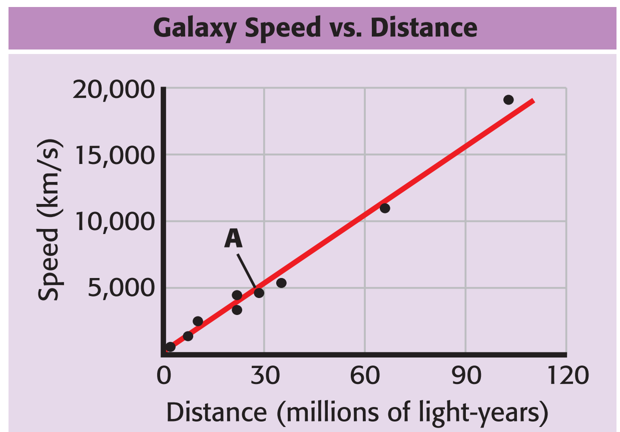
22. While looking at a galaxy through a nearby university's telescope, you notice that there are no blue stars present. What kind of galaxy is it most likely to be?

MATH IN SCIENCE

23. An astronomer observes two stars of about the same temperature and size. Alpha Centauri B is about 4 light-years away, and $sigma^2$ Eridani A is about 16 light-years away. How much brighter does Alpha Centauri B appear?

INTERPRETING GRAPHICS

The following graph illustrates the Hubble law relating the distances of galaxies and their speed away from us.



24. Look at the galaxy marked **A** in the graph. What is its speed and distance?

25. If a new galaxy with a speed of 15,000 km/s were found, at what distance would you expect it to be?

NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 483. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

WEIRD SCIENCE

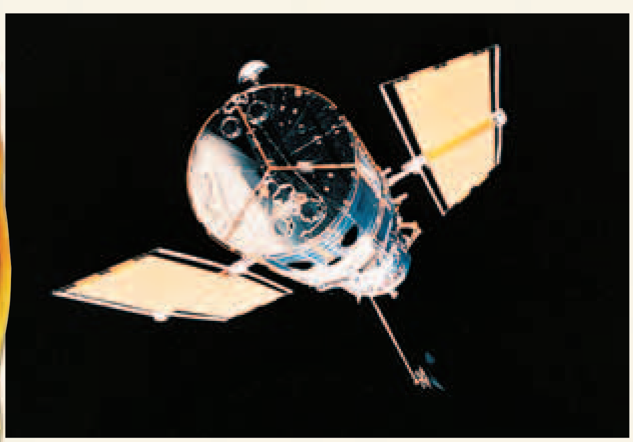
HOLES WHERE STARS ONCE WERE

An invisible phantom lurks in outer space, ready to swallow up everything that comes near it. Once trapped in its grasp, matter is stretched, torn, and crushed into oblivion. Does this sound like a horror story? Guess again! Scientists call it a black hole.

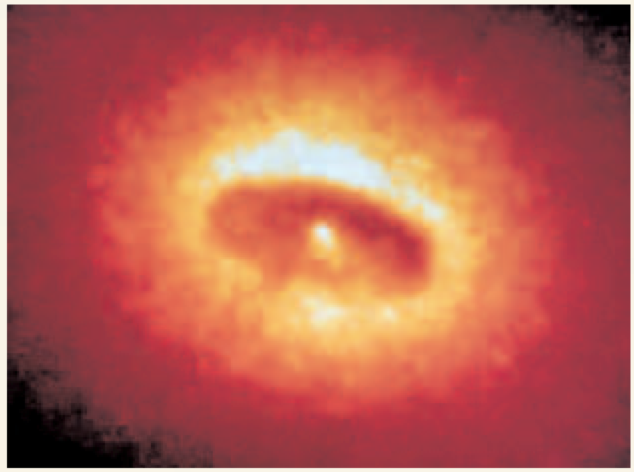
Born of a Collapsing Star

As a star runs out of fuel, it cools and eventually collapses under the force of its own gravity. If the collapsing star is large enough, it may shrink enough to become a black hole. One spoonful of the matter in a black hole would be heavier than the Earth! The resulting gravitational attraction is so enormous that even light cannot escape.

Scientists predict that at the center of the black hole is a *singularity,* a tiny point of incredible density, temperature, and pressure. The area around the singularity is called the *event horizon.* The event horizon represents the boundary of the black hole. Anything that crosses the event horizon, including light, will eventually be pulled into the black hole. As matter comes near the event horizon, the matter begins to swirl in much the same way that water swirls down a drain.



▲ *The Hubble Space Telescope*



▲ *This photograph of M87 was taken by the Hubble Space Telescope.*

The Story of M87

For years, scientists had theorized about black holes but hadn't actually found one. Then in 1994, scientists found something strange at the core of a galaxy called M87. Scientists detected a disk-shaped cloud of gas with a diameter of 60 light-years, rotating at about 2 million kilometers per hour. When scientists realized that a mass more than 2 billion times that of the sun was crammed into a space no bigger than our solar system, they knew that something was pulling in the gases at the center of the galaxy.

Many astronomers think that black holes, such as the one in M87, lie at the heart of many galaxies. Some scientists suggest that there is a giant black hole at the center of our own Milky Way galaxy. But don't worry. The Earth is too far away to be caught.

Modeling a Black Hole

► Make a model to show how a black hole pulls in the matter surrounding it. Indicate the singularity and event horizon.

CAREERS

ASTROPHYSICIST

Jocelyn Bell-Burnell became fascinated with astronomy at an early age. As a research student at Cambridge University, Bell-Burnell discovered pulsars, celestial objects that emit radio waves at short and regular intervals. Today Bell-Burnell is a leading expert in the field of astrophysics and the study of stars. She is currently head of the physics department at the Open University, in Milton Keynes, England.

At Cambridge University in 1967, Bell-Burnell and her adviser, Antony Hewish, completed work on a gigantic radio telescope designed to pick up signals from quasars. Bell-Burnell's job was to operate the telescope and analyze the "chart paper" recordings of the telescope on a graph. Each day, the telescope recorded 29.2 m of chart paper! After a month of operating the telescope, Bell-Burnell noticed a few "bits of scruff" that she could not explain—they were very short, pulsating radio signals. The signals were only 6.3 mm long, and they occurred only once every 4 days. What Bell-Burnell had accidentally found was a needle in a cosmic haystack!

LGM 1

Bell-Burnell and Hewish struggled to find the source of this mysterious new signal. They double-checked the equipment and began eliminating all of the possible sources of the signal, such as satellites, television, and radar. Because they could not rule out that the signal was coming from aliens, Bell-Burnell and Hewish called it LGM 1. Can you guess why? LGM stood for "Little Green Men"!

The Answer: Neutron Stars

Shortly after finding the first signal, Bell-Burnell discovered yet another strange, pulsing signal within the vast quantity of chart paper. This signal was similar to the first, except that it came from the other side of the sky. To Bell-Burnell, this second signal was exciting because it meant that her first signal was not of local origin and that she had stumbled on a new and unknown signal from space! By January 1968, Bell-Burnell had discovered two more pulsating signals. In March of that year, her findings were published, to the amazement of the scientific community. The scientific press coined the term *pulsars,* from pulsating radio stars. Bell-Burnell and other scientists reached the conclusion that her "bits of scruff" were caused by rapidly spinning neutron stars!

Star Tracking

▶ Pick out a bright star in the sky, and keep a record of its position in relation to a reference point, such as a tree or building. Each night, record what time the star appears at this point in the sky. Do you notice a pattern?

▲ *An artist's depiction of a pulsar*