

# Stars

## as you read

### What You'll Learn

- Explain why some constellations are visible only during certain seasons.
- Distinguish between absolute magnitude and apparent magnitude.

### Why It's Important

The Sun is a typical star.



### Review Vocabulary

**star:** a large, spherical mass of gas that gives off light and other types of radiation

### New Vocabulary

- constellation
- absolute magnitude
- apparent magnitude
- light-year

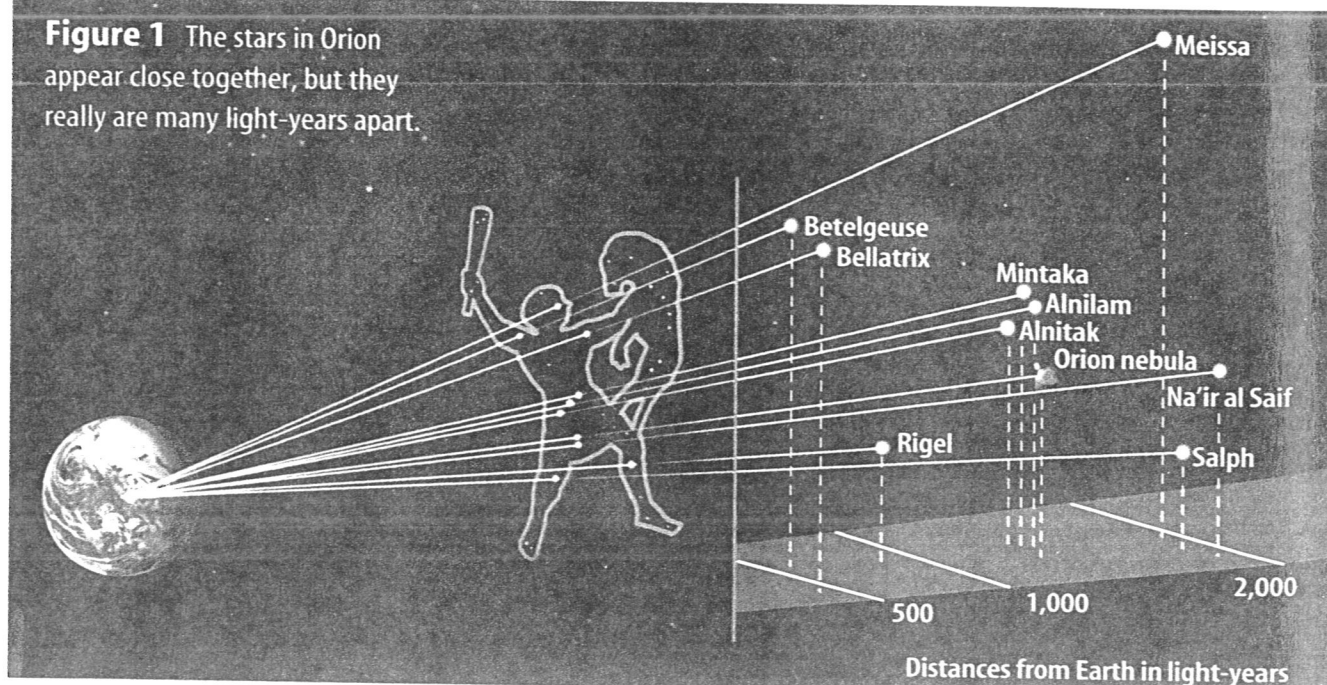
## Constellations

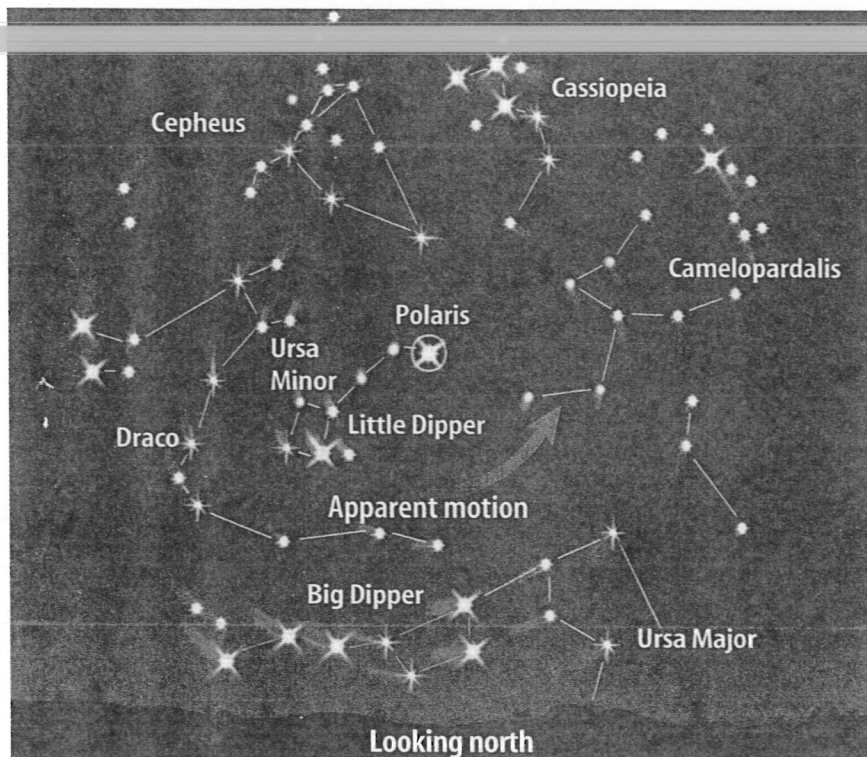
It's fun to look at clouds and find ones that remind you of animals, people, or objects that you recognize. It takes more imagination to play this game with stars. Ancient Greeks, Romans, and other early cultures observed patterns of stars in the night sky called **constellations**. They imagined that the constellations represented mythological characters, animals, or familiar objects.

From Earth, a constellation looks like spots of light arranged in a particular shape against the dark night sky. **Figure 1** shows how the constellation of the mythological Greek hunter Orion appears from Earth. It also shows that the stars in a constellation often have no relationship to each other in space.

Stars in the sky can be found at specific locations within a constellation. For example, you can find the star Betelgeuse (BEE tul jooz) in the shoulder of the mighty hunter Orion. Orion's faithful companion is his dog, Canis Major. Sirius, the brightest star that is visible from the northern hemisphere, is in Canis Major.

**Figure 1** The stars in Orion appear close together, but they really are many light-years apart.





**Figure 2** The Big Dipper is part of the constellation Ursa Major. It is visible year-round in the northern hemisphere. Constellations close to Polaris rotate around Polaris, which is almost directly over the north pole.

**Modern Constellations** Modern astronomy divides the sky into 88 constellations, many of which were named by early astronomers. You probably know some of them. Can you recognize the Big Dipper? It's part of the constellation Ursa Major, shown in **Figure 2**. Notice how the front two stars of the Big Dipper point almost directly at Polaris, which often is called the North Star. Polaris is located at the end of the Little Dipper in the constellation Ursa Minor. It is positioned almost directly over Earth's north pole.

**Circumpolar Constellations** As Earth rotates, Ursa Major, Ursa Minor, and other constellations in the northern sky circle around Polaris. Because of this, they are called circumpolar constellations. The constellations appear to move, as shown in **Figure 2**, because Earth is in motion. The stars appear to complete one full circle in the sky in about 24 h as Earth rotates on its axis. One circumpolar constellation that's easy to find is Cassiopeia (ka see uh PEE uh). You can look for five bright stars that form a big W or a big M in the northern sky, depending on the season.

As Earth orbits the Sun, different constellations come into view while others disappear. Because of their unique position, circumpolar constellations are visible all year long. Other constellations are not. Orion, which is visible in the winter in the northern hemisphere, can't be seen there in the summer because the daytime side of Earth is facing it.

## Mini LAB

### Observing Star Patterns

#### Procedure

1. On a clear night, go outside after dark and study the stars. Take an adult with you.
2. Let your imagination flow to find patterns of stars that look like something familiar.
3. Draw the stars you see, note their positions, and include a drawing of what you think each star pattern resembles.

#### Analysis

1. Which of your constellations match those observed by your classmates?
2. How can recognizing star patterns be useful?



## Absolute and Apparent Magnitudes

When you look at constellations, you'll notice that some stars are brighter than others. For example, Sirius looks much brighter than Rigel. Is Sirius a brighter star, or is it just closer to Earth, making it appear to be brighter? As it turns out, Sirius is 100 times closer to Earth than Rigel is. If Sirius and Rigel were the same distance from Earth, Rigel would appear much brighter in the night sky than Sirius would.

When you refer to the brightness of a star, you can refer to its absolute magnitude or its apparent magnitude. The **absolute magnitude** of a star is a measure of the amount of light it gives off. A measure of the amount of light received on Earth is the **apparent magnitude**. A star that's dim can appear bright in the sky if it's close to Earth, and a star that's bright can appear dim if it's far away. If two stars are the same distance away, what might cause one of them to be brighter than the other?



### Reading Check

*What is the difference between absolute and apparent magnitude?*

## Applying Science

### Are distance and brightness related?

**T**he apparent magnitude of a star is affected by its distance from Earth. This activity will help you determine the relationship between distance and brightness.

#### Identifying the Problem

Luisa conducted an experiment to determine the relationship between distance and the brightness of stars. She used a meterstick, a light meter, and a lightbulb. She placed the bulb at the zero end of the meterstick, then placed the light meter at the 20-cm mark and recorded the distance and the light-meter reading in her data table. Readings are in luxes, which are units for measuring light intensity. Luisa then increased the distance from the bulb to the light meter and took more readings. By examining the data in the table, can you see a relationship between the two variables?

#### Effect of Distance on Light

| Distance (cm) | Meter Reading (luxes) |
|---------------|-----------------------|
| 20            | 4150.0                |
| 40            | 1037.5                |
| 60            | 461.1                 |
| 80            | 259.4                 |

#### Solving the Problem

1. What happened to the amount of light recorded when the distance was increased from 20 cm to 40 cm? When the distance was increased from 20 cm to 60 cm?
2. What does this indicate about the relationship between light intensity and distance? What would the light intensity be at 100 cm? Would making a graph help you visualize the relationship?

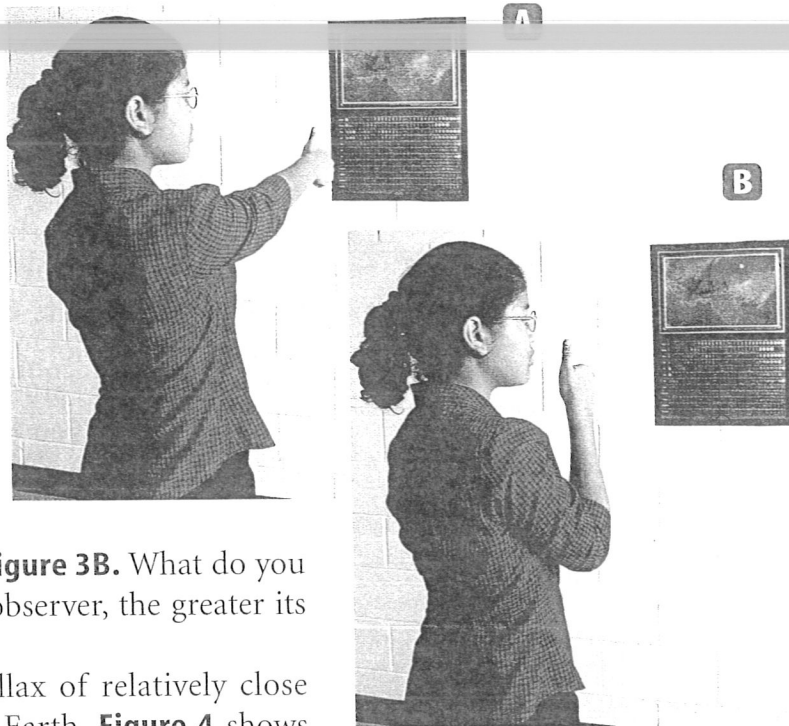


## Measurement in Space

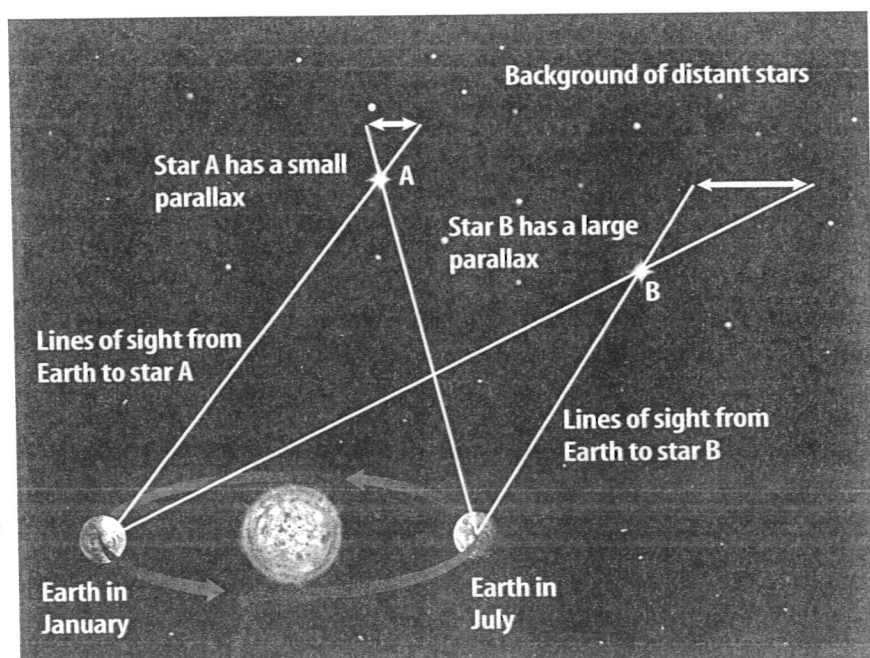
How do scientists determine the distance from Earth to nearby stars? One way is to measure parallax—the apparent shift in the position of an object when viewed from two different positions. Extend your arm and look at your thumb first with your left eye closed and then with your right eye closed, as the girl in **Figure 3A** is doing. Your thumb appears to change position with respect to the background. Now do the same experiment with your thumb closer to your face, as shown in **Figure 3B**. What do you observe? The nearer an object is to the observer, the greater its parallax is.

Astronomers can measure the parallax of relatively close stars to determine their distances from Earth. **Figure 4** shows how a close star's position appears to change. Knowing the angle that the star's position changes and the size of Earth's orbit, astronomers can calculate the distance of the star from Earth.

Because space is so vast, a special unit of measure is needed to record distances. Distances between stars and galaxies are measured in light-years. A **light-year** is the distance that light travels in one year. Light travels at 300,000 km/s, or about 9.5 trillion km in one year. The nearest star to Earth, other than the Sun, is Proxima Centauri. Proxima Centauri is a mere 4.3 light-years away, or about 40 trillion km.



**Figure 3** **A** Your thumb appears to move less against the background when it is farther away from your eyes. **B** It appears to move more when it is closer to your eyes.



**Figure 4** Parallax is determined by observing the same star when Earth is at two different points in its orbit around the Sun. The star's position relative to more distant background stars will appear to change. *Infer whether star A or B is farther from Earth.*



**Figure 5** This star spectrum was made by placing a diffraction grating over a telescope's objective lens. A diffraction grating produces a spectrum by causing interference of light waves.

**Explain** what causes the lines in spectra.

## Properties of Stars

The color of a star indicates its temperature. For example, hot stars are a blue-white color. A relatively cool star looks orange or red. Stars that have the same temperature as the Sun have a yellow color.

Astronomers study the composition of stars by observing their spectra. When fitted into a telescope, a spectroscope acts like a prism. It spreads light out in the rainbow band called a spectrum. When light from a star passes through a spectroscope, it breaks into its component colors. Look at the spectrum of a star in **Figure 5**. Notice the dark lines caused by elements in the star's atmosphere. Light radiated from a star passes through the star's atmosphere. As it does, elements in the atmosphere absorb some of this light. The wavelengths of visible light that are absorbed appear as dark lines in the spectrum. Each element absorbs certain wavelengths, producing a unique pattern of dark lines. Like a fingerprint, the patterns of lines can be used to identify the elements in a star's atmosphere.

### section 1 review

#### Summary

##### Constellations

- Constellations are patterns of stars in the night sky.
- The stars in a constellation often have no relationship to each other in space.

##### Absolute and Apparent Magnitudes

- Absolute magnitude is a measure of how much light is given off by a star.
- Apparent magnitude is a measure of how much light from a star is received on Earth.

##### Measurement in Space

- Distances between stars are measured in light-years.

##### Properties of Stars

- Astronomers study the composition of stars by observing their spectra.

#### Self Check

1. Describe circumpolar constellations.
2. Explain why some constellations are visible only during certain seasons.
3. Infer how two stars could have the same apparent magnitude but different absolute magnitudes.
4. Explain how a star is similar to the Sun if it has the same absorption lines in its spectrum that occur in the Sun's spectrum.
5. **Think Critically** If a star's parallax angle is too small to measure, what can you conclude about the star's distance from Earth?

#### Applying Skills

6. **Recognize Cause and Effect** Suppose you viewed Proxima Centauri, which is 4.3 light-years from Earth, through a telescope. How old were you when the light that you see left this star?

# The Sun

## The Sun's Layers

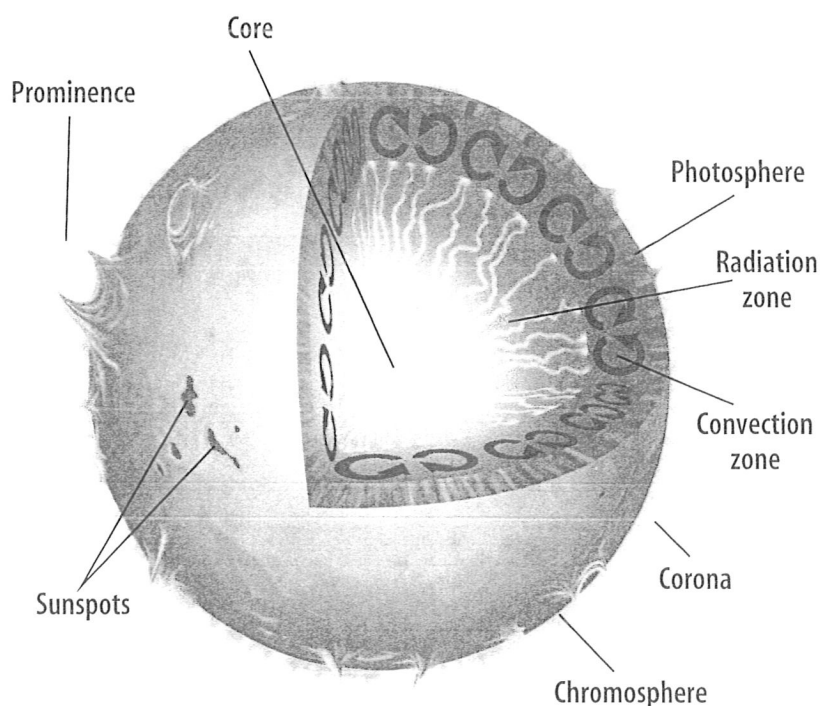
The Sun is an ordinary star, but it's important to you. The Sun is the center of the solar system, and the closest star to Earth. Almost all of the life on Earth depends on energy from the Sun.

Notice the different layers of the Sun, shown in **Figure 6**, as you read about them. Like other stars, the Sun is an enormous ball of gas that produces energy by fusing hydrogen into helium in its core. This energy travels outward through the radiation zone and the convection zone. In the convection zone, gases circulate in giant swirls. Finally, energy passes into the Sun's atmosphere.

## The Sun's Atmosphere

The lowest layer of the Sun's atmosphere and the layer from which light is given off is the **photosphere**. The photosphere often is called the surface of the Sun, although the surface is not a smooth feature. Temperatures there are about 6,000 K. Above the photosphere is the **chromosphere**. This layer extends upward about 2,000 km above the photosphere. A transition zone occurs between 2,000 km and 10,000 km above the photosphere. Above the transition zone is the **corona**. This is the largest layer of the Sun's atmosphere and extends millions of kilometers into space. Temperatures in the corona are as high as 2 million K. Charged particles continually escape from the corona and move through space as solar wind.

**Figure 6** Energy produced in the Sun's core by fusion travels outward by radiation and convection. The Sun's atmosphere shines by the energy produced in the core.



### as you read

#### What You'll Learn

- Explain that the Sun is the closest star to Earth.
- Describe the structure of the Sun.
- Describe sunspots, prominences, and solar flares.

#### Why It's Important

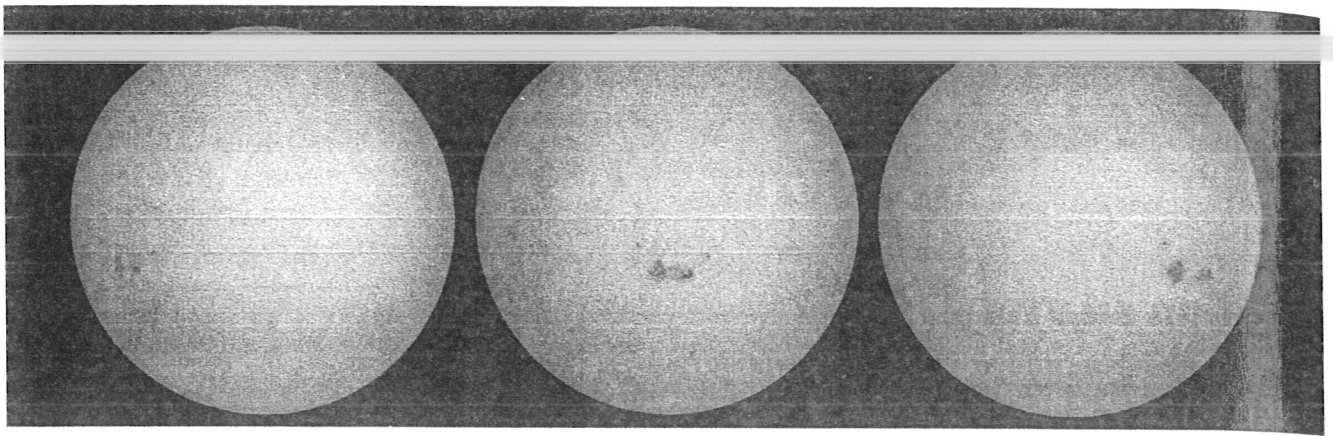
The Sun is the source of most energy on Earth.

#### Review Vocabulary

**cycle:** a repeating sequence of events, such as the sunspot cycle

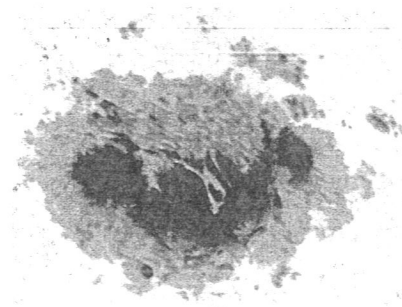
#### New Vocabulary

- photosphere
- corona
- chromosphere
- sunspot



**Figure 7** Sunspots are bright, but when viewed against the rest of the photosphere, they appear dark. Notice how these sunspots move as the Sun rotates.

**Describe** the Sun's direction of rotation.



This is a close-up photo of a large sunspot.

## Surface Features

From the viewpoint that you observe the Sun, its surface appears to be a smooth layer. But the Sun's surface has many features, including sunspots, prominences, flares, and CMEs.

**Sunspots** Areas of the Sun's surface that appear dark because they are cooler than surrounding areas are called **sunspots**. Ever since Galileo Galilei made drawings of sunspots, scientists have been studying them. Because scientists could observe the movement of individual sunspots, shown in **Figure 7**, they concluded that the Sun rotates. However, the Sun doesn't rotate as a solid body, as Earth does. It rotates faster at its equator than at its poles. Sunspots at the equator take about 25 days to complete one rotation. Near the poles, they take about 35 days.

Sunspots aren't permanent features on the Sun. They appear and disappear over a period of several days, weeks, or months. The number of sunspots increases and decreases in a fairly regular pattern called the sunspot, or solar activity, cycle. Times when many large sunspots occur are called sunspot maximums. Sunspot maximums occur about every 10 to 11 years. Periods of sunspot minimum occur in between.

 **Reading Check** What is a sunspot cycle?

**Prominences and Flares** Sunspots are related to several features on the Sun's surface. The intense magnetic fields associated with sunspots might cause prominences, which are huge, arching columns of gas. Notice the huge prominence in **Figure 8**. Some prominences blast material from the Sun into space at speeds ranging from 600 km/s to more than 1,000 km/s.

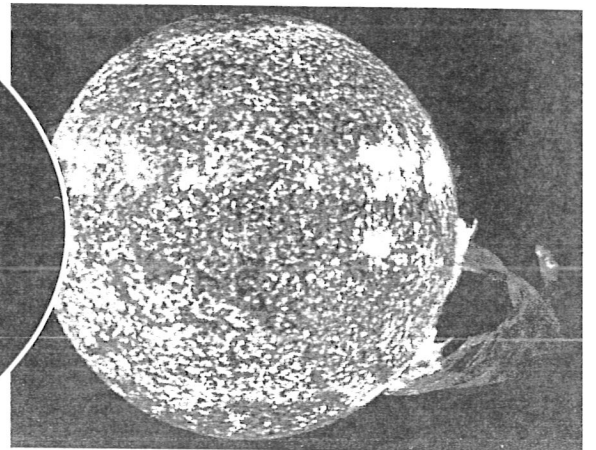
Gases near a sunspot sometimes brighten suddenly, shooting outward at high speed. These violent eruptions are called solar flares. You can see a solar flare in **Figure 8**.



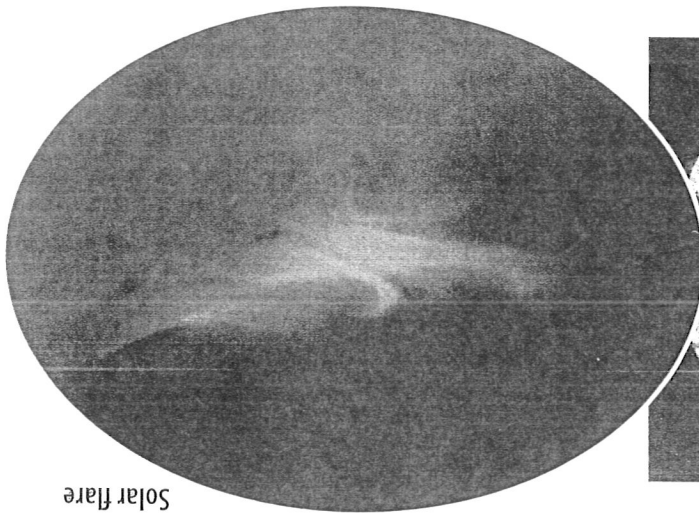
**CMEs** Coronal mass ejections (CMEs) occur when large amounts of electrically-charged gas are ejected suddenly from the Sun's corona. CMEs can occur as often as two or three times each day during a sunspot maximum.

CMEs present little danger to life on Earth, but they do have some effects. CMEs can damage satellites in orbit around Earth. They also can interfere with radio and power distribution equipment. CMEs often cause auroras. High-energy particles contained in CMEs and the solar wind are carried past Earth's magnetic field. This generates electric currents that flow toward Earth's poles. These electric currents ionize gases in Earth's atmosphere. When these ions recombine with electrons, they produce the light of an aurora, shown in **Figure 8**.

**Figure 8** Features such as solar prominences and solar flares can reach hundreds of thousands of kilometers into space. CMEs are generated as magnetic fields above sunspot groups rearrange. CMEs can trigger events that produce auroras.



Solar prominence



Solar flare



Aurora borealis,  
or northern lights

**Topic: Space Weather**  
Visit [earth.msscience.com](http://earth.msscience.com) for Web links to information about space weather and its effects.

**Activity** Record space weather conditions for several weeks. How does space weather affect Earth?





**Figure 9** Most stars originally formed in large clusters containing hundreds, or even thousands, of stars.

**Draw and label** a sketch of the double cluster.

## The Sun—An Average Star

The Sun is an average star. It is middle-aged, and its absolute magnitude is about average. It shines with a yellow light. Although the Sun is an average star, it is much closer to Earth than other stars. Light from the Sun reaches Earth in about eight minutes. Light from other stars takes from many years to many millions of years to reach Earth.

The Sun is unusual in one way. It is not close to any other stars. Most stars are part of a system in which two or more stars orbit each other. When two stars orbit each other, it is called a binary system. When three stars orbit each other, it is called a triple star system. The closest star system to the Sun—the Alpha Centauri system, including Proxima Centauri—is a triple star.

Stars also can move through space as a cluster. In a star cluster, many stars are relatively close, so the gravitational attraction among the stars is strong. Most star clusters are far from the solar system. They sometimes appear as a fuzzy patch in the night sky. The double cluster in the northern part of the constellation Perseus is shown in **Figure 9**. On a dark night in autumn, you can see the double cluster with binoculars, but you can't see its individual stars. The Pleiades star cluster can be seen in the constellation of Taurus in the winter sky. On a clear, dark night, you might be able to see seven of the stars in this cluster.

### section 2 review

#### Summary

##### The Sun's Layers

- The Sun's interior has layers that include the core, radiation zone, and convection zone.

##### The Sun's Atmosphere

- The Sun's atmosphere includes the photosphere, chromosphere, and corona.

##### Surface Features

- The number of sunspots on the Sun varies in a 10- to 11-year cycle.
- Auroras occur when charged particles from the Sun interact with Earth's magnetic field.

##### The Sun—An Average Star

- The Sun is an average star, but it is much closer to Earth than any other star.

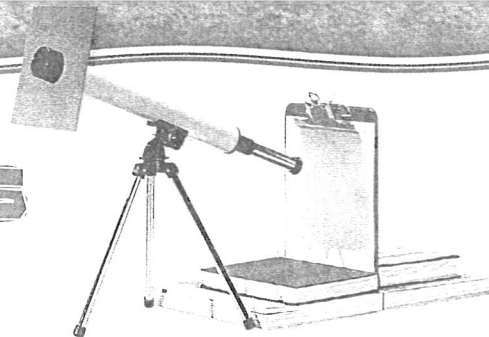
#### Self Check

1. Explain why the Sun is important for life on Earth.
2. Describe the sunspot cycle.
3. Explain why sunspots appear dark.
4. Explain why the Sun, which is an average star, appears so much brighter from Earth than other stars do.
5. **Think Critically** When a CME occurs on the Sun, it takes a couple of days for effects to be noticed on Earth. Explain.

#### Applying Skills

6. **Communicate** Make a sketch that shows the Sun's layers in your Science Journal. Write a short description of each layer.

## Sunspots



Sunspots can be observed moving across the face of the Sun as it rotates. Measure the movement of sunspots, and use your data to determine the Sun's period of rotation.

### Real-World Question

Can sunspot motion be used to determine the Sun's period of rotation?

#### Goals

- **Observe** sunspots and estimate their size.
- **Estimate** the rate at which sunspots move across the face of the Sun.

#### Materials

|                      |              |
|----------------------|--------------|
| several books        | clipboard    |
| piece of cardboard   | small tripod |
| drawing paper        | scissors     |
| refracting telescope |              |

#### Safety Precautions

**WARNING:** Handle scissors with care.

### Procedure

1. Find a location where the Sun can be viewed at the same time of day for a minimum of five days. **WARNING:** Do not look directly at the Sun. Do not look through the telescope at the Sun. You could damage your eyes.
2. If the telescope has a small finder scope attached, remove it or keep it covered.
3. Set up the telescope with the eyepiece facing away from the Sun, as shown. Align the telescope so that the shadow it casts on the ground is the smallest size possible. Cut and attach the cardboard as shown in the photo.
4. Use books to prop the clipboard upright. Point the eyepiece at the drawing paper.
5. Move the clipboard back and forth until you have the largest image of the Sun on the paper. Adjust the telescope to form a clear image. Trace the outline of the Sun on the paper.
6. Trace any sunspots that appear as dark areas on the Sun's image. Repeat this step at the same time each day for a week.
7. Using the Sun's diameter (approximately 1,390,000 km), estimate the size of the largest sunspots that you observed.
8. **Calculate** how many kilometers the sunspots move each day.
9. **Predict** how many days it will take for the same group of sunspots to return to the same position in which they appeared on day 1.

### Conclude and Apply

1. What was the estimated size and rate of motion of the largest sunspots?
2. **Infer** how sunspots can be used to determine that the Sun's surface is not solid like Earth's surface.

### Communicating Your Data

Compare your conclusions with those of other students in your class. For more help, refer to the Science Skill Handbook.



# Evolution of Stars

## as you read

### What You'll Learn

- Describe how stars are classified.
- Compare the Sun to other types of stars on the H-R diagram.
- Describe how stars evolve.

### Why It's Important

Earth and your body contain elements that were made in stars.

### Review Vocabulary

**gravity:** an attractive force between objects that have mass

### New Vocabulary

- nebula
- supergiant
- giant
- neutron star
- white dwarf
- black hole

## Classifying Stars

When you look at the night sky, all stars might appear to be similar, but they are quite different. Like people, they vary in age and size, but stars also vary in temperature and brightness.

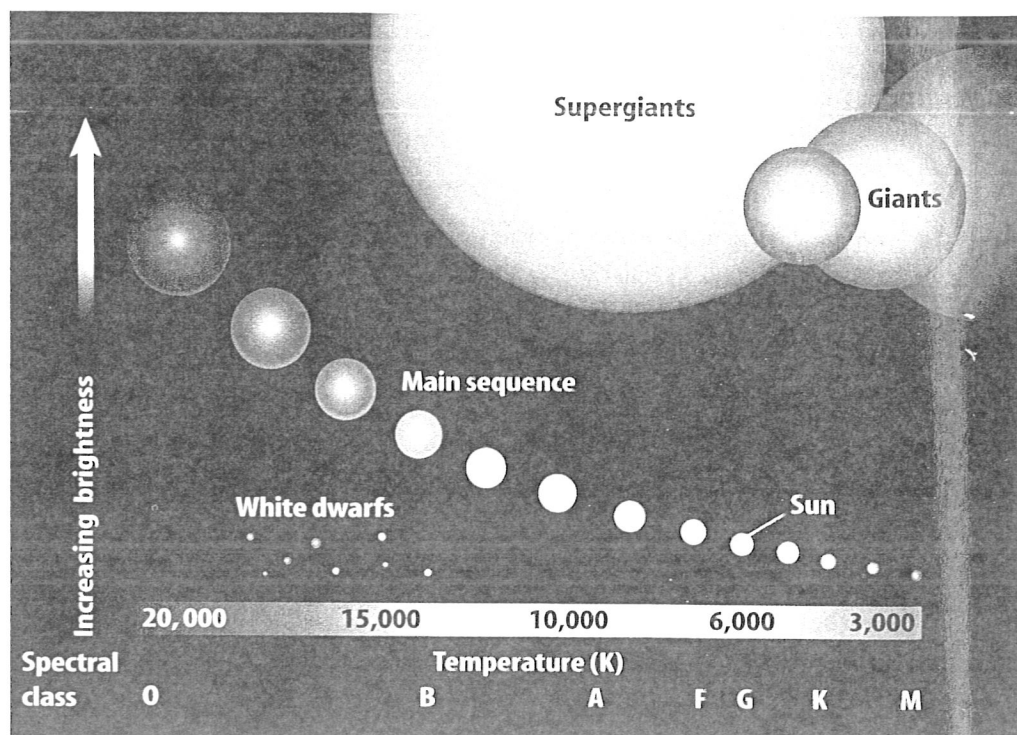
In the early 1900s, Ejnar Hertzsprung and Henry Russell made some important observations. They noticed that, in general, stars with higher temperatures also have brighter absolute magnitudes.

Hertzsprung and Russell developed a graph, shown in **Figure 10**, to show this relationship. They placed temperatures across the bottom and absolute magnitudes up one side. A graph that shows the relationship of a star's temperature to its absolute magnitude is called a Hertzsprung-Russell (H-R) diagram.

**The Main Sequence** As you can see, stars seem to fit into specific areas of the graph. Most stars fit into a diagonal band that runs from the upper left to the lower right of the graph. This band, called the main sequence, contains hot, blue, bright stars in the upper left and cool, red, dim stars in the lower right. Yellow main sequence stars, like the Sun, fall in between.

**Figure 10** The relationships among a star's color, temperature, and brightness are shown in this H-R diagram. Stars in the upper left are hot, bright stars, and stars in the lower right are cool, dim stars.

**Classify** Which type of star shown in the diagram is the hottest, dimmest star?



## Dwarfs and Giants

About 90 percent of all stars are main sequence stars. Most of these are small, red stars found in the lower right of the H-R diagram. Among main sequence stars, the hottest stars generate the most light and the coolest ones generate the least. What about the ten percent of stars that are not part of the main sequence? Some of these stars are hot but not bright. These small stars are located on the lower left of the H-R diagram and are called white dwarfs. Other stars are extremely bright but not hot. These large stars on the upper right of the H-R diagram are called giants, or red giants, because they are usually red in color. The largest giants are called supergiants. **Figure 11** shows the supergiant, Antares—in the constellation Scorpius. It is more than 11,000 times as bright as the Sun.

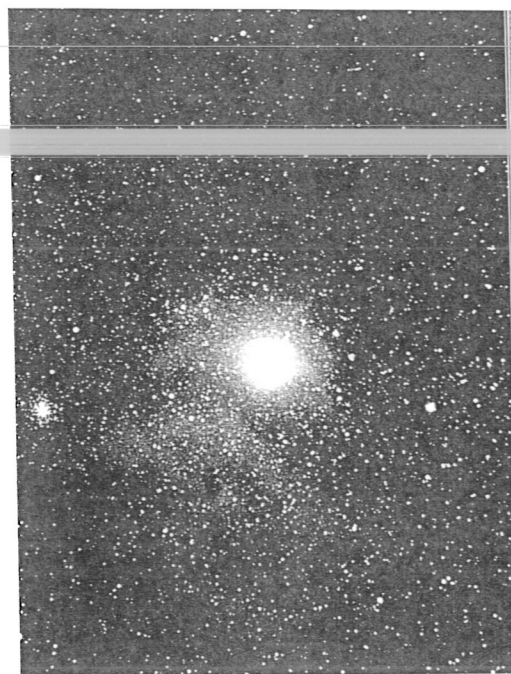
**✓ Reading Check** What kinds of stars are on the main sequence?

## How do stars shine?

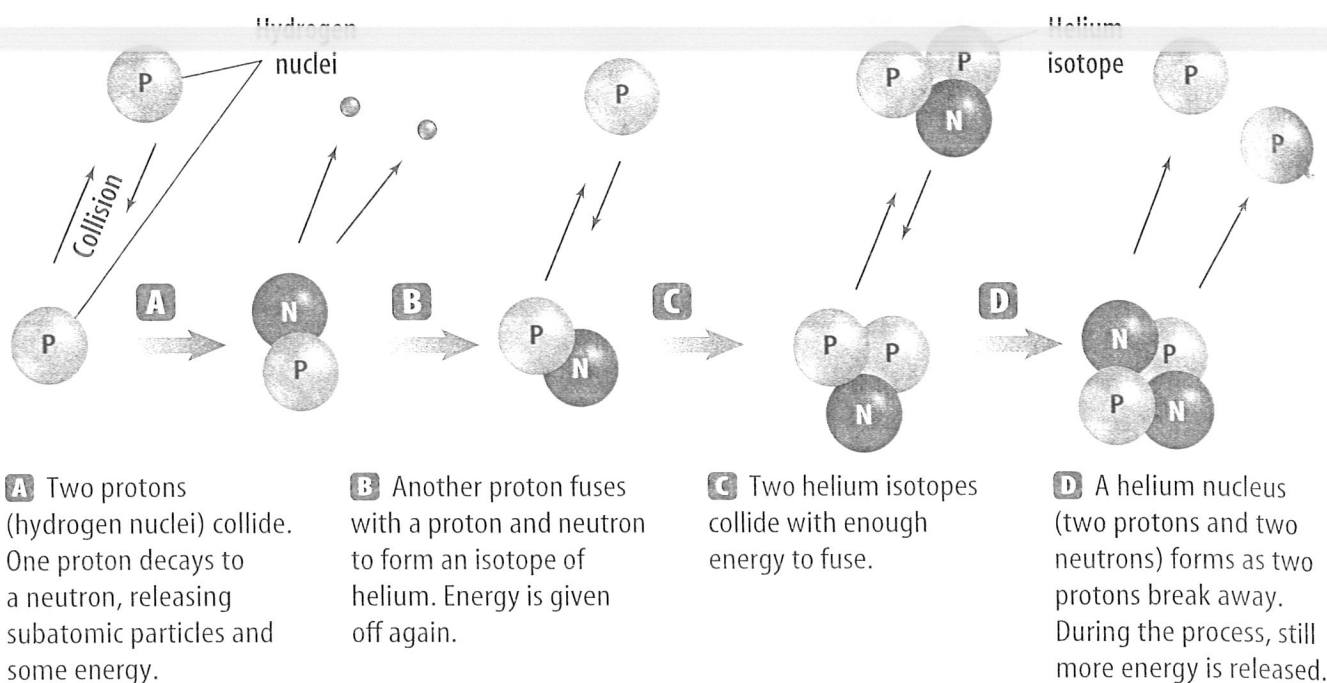
For centuries, people were puzzled by the questions of what stars were made of and how they produced light. Many people had estimated that Earth was only a few thousand years old. The Sun could have been made of coal and shined for that long. However, when people realized that Earth was much older, they wondered what material possibly could burn for so many years. Early in the twentieth century, scientists began to understand the process that keeps stars shining for billions of years.

**Generating Energy** In the 1930s, scientists discovered reactions between the nuclei of atoms. They hypothesized that temperatures in the center of the Sun must be high enough to cause hydrogen to fuse to make helium. This reaction releases tremendous amounts of energy. Much of this energy is emitted as different wavelengths of light, including visible, infrared, and ultraviolet light. Only a tiny fraction of this light comes to Earth. During the fusion reaction, four hydrogen nuclei combine to create one helium nucleus. The mass of one helium nucleus is less than the mass of four hydrogen nuclei, so some mass is lost in the reaction.

Years earlier, in 1905, Albert Einstein had proposed a theory stating that mass can be converted into energy. This was stated as the famous equation  $E = mc^2$ . In this equation,  $E$  is the energy produced,  $m$  is the mass, and  $c$  is the speed of light. The small amount of mass “lost” when hydrogen atoms fuse to form a helium atom is converted to a large amount of energy.



**Figure 11** Antares is a bright supergiant located 400 light-years from Earth. Although its temperature is only about 3,500 K, it is the 16th brightest star in the sky.



**Figure 12** Fusion of hydrogen into helium occurs in a star's core. **Infer** what happens to the "lost" mass during this process.

**Fusion** Shown in **Figure 12**, fusion occurs in the cores of stars. Only in the core are temperatures high enough to cause atoms to fuse. Normally, they would repel each other, but in the core of a star where temperatures can exceed 15,000,000 K, atoms can move so fast that some of them fuse upon colliding.

## Evolution of Stars



The H-R diagram explained a lot about stars. However, it also led to more questions. Many wondered why some stars didn't fit in the main sequence group and what happened when a star depleted its supply of hydrogen fuel. Today, scientists have theories about how stars evolve, what makes them different from one another, and what happens when they die. **Figure 13** illustrates the lives of different types of stars.

When hydrogen fuel is depleted, a star loses its main sequence status. This can take less than 1 million years for the brightest stars to many billions of years for the dimmest stars. The Sun has a main sequence life span of about 10 billion years. Half of its life span is still in the future.

**Nebula** Stars begin as a large cloud of gas and dust called a **nebula**. As the particles of gas and dust exert a gravitational force on each other, the nebula begins to contract. Gravitational forces cause instability within the nebula. The nebula can break apart into smaller and smaller pieces. Each piece eventually might collapse to form a star.

### Science

#### Topic: Evolution of Stars

Visit [earth.msscience.com](http://earth.msscience.com) for Web links to information about the evolution of stars.

**Activity** Make a three-circle Venn diagram to compare and contrast white dwarfs, neutron stars, and black holes.



**A Star Is Born** As the particles in the smaller pieces of nebula move closer together, the temperatures in each nebula piece increase. When the temperature inside the core of a nebula piece reaches 10 million K, fusion begins. The energy released radiates outward through the condensing ball of gas. As the energy radiates into space, stars are born.

**✓ Reading Check** *How are stars born?*

**Main Sequence to Giant Stars** In the newly formed star, the heat from fusion causes pressure to increase. This pressure balances the attraction due to gravity. The star becomes a main sequence star. It continues to use its hydrogen fuel.

When hydrogen in the core of the star is depleted, a balance no longer exists between pressure and gravity. The core contracts, and temperatures inside the star increase. This causes the outer layers of the star to expand and cool. In this late stage of its life cycle, a star is called a **giant**.

After the core temperature reaches 100 million K, helium nuclei fuse to form carbon in the giant's core. By this time, the star has expanded to an enormous size, and its outer layers are much cooler than they were when it was a main sequence star. In about 5 billion years, the Sun will become a giant.

**White Dwarfs** After the star's core uses much of its helium, it contracts even more and its outer layers escape into space. This leaves behind the hot, dense core. At this stage in a star's evolution, it becomes a **white dwarf**. A white dwarf is about the size of Earth. Eventually, the white dwarf will cool and stop giving off light.

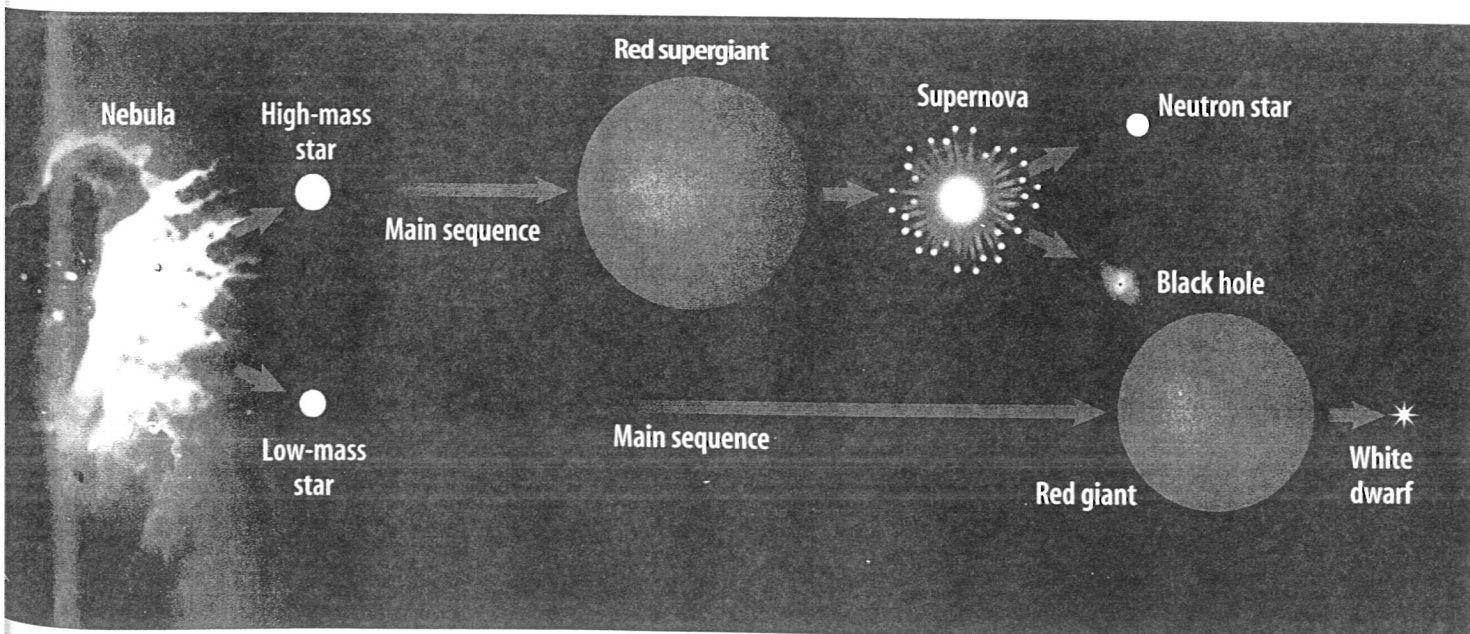


### White Dwarf Matter

The matter in white dwarf stars is more than 500,000 times as dense as the matter in Earth. In white dwarf matter, there are free electrons and atomic nuclei. The resistance of the electrons to pack together more provides pressure that keeps the star from collapsing. This state of matter is called electron degeneracy.

**Figure 13** The life of a star depends on its mass. Massive stars eventually become neutron stars or black holes.

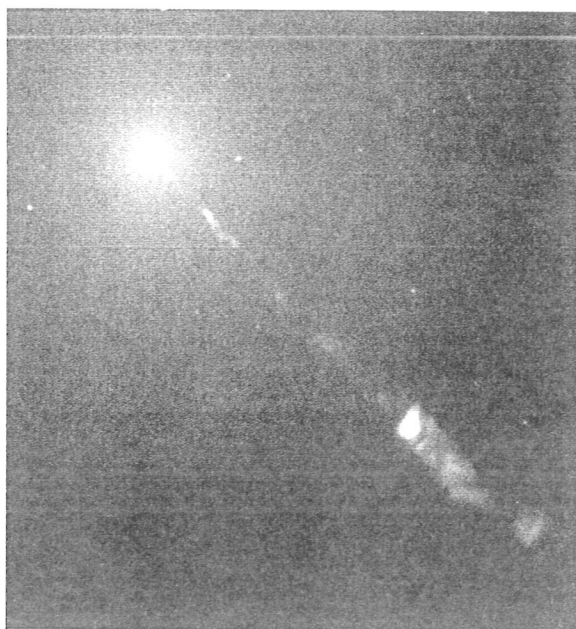
**Explain** *what happens to stars that are the size of the Sun.*





**386 Supernova** In 386 A.D., Chinese observers described a new star—a supernova—in the night sky. More recently, astronomers using the *Chandra X-ray Observatory* found evidence of a spinning neutron star, called a pulsar, in exactly the same location. Because of the Chinese account, astronomers better understand how neutron stars form and evolve.

**Figure 14** The black hole at the center of galaxy M87 pulls matter into it at extremely high velocities. Some matter is ejected to produce a jet of gas that streams away from the center of the galaxy at nearly light speed.



**Supergiants and Supernovas** In stars that are more than about eight times more massive than the Sun, the stages of evolution occur more quickly and more violently. Look back at **Figure 13**. In massive stars, the core heats up to much higher temperatures. Heavier and heavier elements form by fusion, and the star expands into a **supergiant**. Eventually, iron forms in the core. Because of iron's atomic structure, it cannot release energy through fusion. The core collapses violently, and a shock wave travels outward through the star. The outer portion of the star explodes, producing a supernova. A supernova can be millions of times brighter than the original star was.

**Neutron Stars** If the collapsed core of a supernova is between about 1.4 and 3 times as massive as the Sun, it will shrink to approximately 20 km in diameter. Only neutrons can exist in the dense core, and it becomes a **neutron star**. Neutron stars are so dense that a teaspoonful would weigh more than 600 million metric tons in Earth's gravity. As dense as neutron stars are, they can contract only so far because the neutrons resist the inward pull of gravity.

**Black Holes** If the remaining dense core from a supernova is more than about three times more massive than the Sun, probably nothing can stop the core's collapse. Under these conditions, all of the core's mass collapses to a point. The gravity near this mass is so strong that nothing can escape from it, not even light. Because light cannot escape, the region is called a **black hole**. If you could shine a flashlight on a black hole, the light simply would disappear into it.

**✓ Reading Check** What is a black hole?

Black holes, however, are not like giant vacuum cleaners, sucking in distant objects. A black hole has an event horizon, which is a region inside of which nothing can escape. If something—including light—crosses the event horizon, it will be pulled into the black hole. Beyond the event horizon, the black hole's gravity pulls on objects just as it would if the mass had not collapsed. Stars and planets can orbit around a black hole.

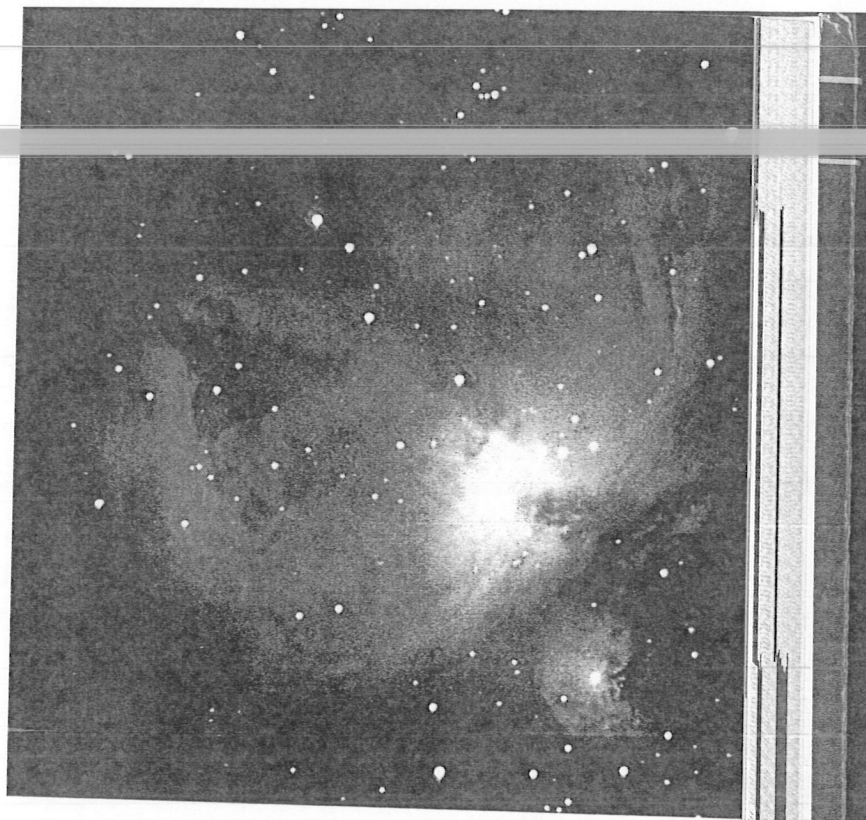
The photograph in **Figure 14** was taken by the *Hubble Space Telescope*. It shows a jet of gas streaming out of the center of galaxy M87. This jet of gas formed as matter flowed toward a black hole, and some of the gas was ejected along the polar axis.

## Recycling Matter

A star begins its life in a nebula, such as the one shown in **Figure 15**. Where does the matter in a nebula come from? Nebulas form partly from the matter that was once in other stars. A star ejects enormous amounts of matter during its lifetime. Some of this matter is incorporated into nebulas, which can evolve to form new stars. The matter in stars is recycled many times.

What about the matter created in the cores of stars and during supernova explosions? Are elements such as carbon and iron also recycled? These elements can become parts of new stars. In fact, spectrographs have shown that the Sun contains some carbon, iron, and other heavier elements. Because the Sun is an average, main sequence star, it is too young and its mass is too small to have formed these elements itself. The Sun condensed from material that was created in stars that died many billions of years ago.

Some elements condense to form planets and other bodies rather than stars. In fact, your body contains many atoms that were fused in the cores of ancient stars. Evidence suggests that the first stars formed from hydrogen and helium and that all the other elements have formed in the cores of stars or as stars explode.



**Figure 15** Stars are forming in the Orion Nebula and other similar nebulas.

**Describe** a star-forming nebula.

## section 3 review

### Summary

#### Classifying Stars

- Most stars plot on the main sequence of an H-R diagram.
- As stars near the end of their lives, they move off of the main sequence.

#### How do stars shine?

- Stars shine because of a process called fusion.
- During fusion, nuclei of a lighter element merge to form a heavier element.

#### Evolution of Stars

- Stars form in regions of gas and dust called nebulas.
- Stars evolve differently depending on how massive they are.

### Self Check

1. **Explain** how the Sun is different from other stars on the main sequence. How is it different from a giant star? How is it different from a white dwarf?
2. **Describe** how stars release energy.
3. **Outline** the past and probable future of the Sun.
4. **Define** a black hole.
5. **Think Critically** How can white dwarf stars be both hot and dim?

### Applying Math

6. **Convert Units** A neutron star has a diameter of 20 km. One kilometer equals 0.62 miles. What is the neutron star's diameter in miles?



# Galaxies and the Universe

## as you read

### What You'll Learn

- Describe the Sun's position in the Milky Way Galaxy.
- Explain that the same natural laws that apply to our solar system also apply in other galaxies.

### Why It's Important

Studying the universe could determine whether life exists elsewhere.



### Review Vocabulary

**universe:** the space that contains all known matter and energy

### New Vocabulary

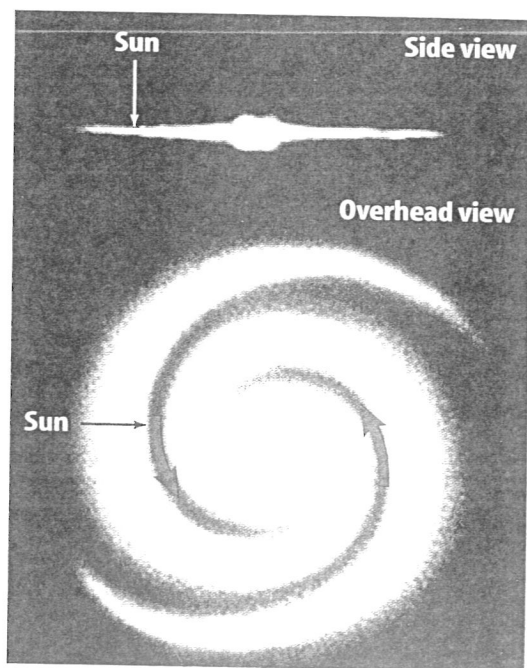
- galaxy
- big bang theory

## Galaxies

If you enjoy science fiction, you might have read about explorers traveling through the galaxy. On their way, they visit planets around other stars and encounter strange alien beings. Although this type of space exploration is futuristic, it is possible to explore galaxies today. Using a variety of telescopes, much is being learned about the Milky Way and other galaxies.

A **galaxy** is a large group of stars, gas, and dust held together by gravity. Earth and the solar system are in a galaxy called the Milky Way. It might contain as many as one trillion stars. Countless other galaxies also exist. Each of these galaxies contains the same elements, forces, and types of energy that occur in Earth's solar system. Galaxies are separated by huge distances—often millions of light-years.

In the same way that stars are grouped together within galaxies, galaxies are grouped into clusters. The cluster that the Milky Way belongs to is called the Local Group. It contains about 45 galaxies of various sizes and types. The three major types of galaxies are spiral, elliptical, and irregular.



**Spiral Galaxies** Spiral galaxies are galaxies that have spiral arms that wind outward from the center. The arms consist of bright stars, dust, and gas. The Milky Way Galaxy, shown in **Figure 16**, is a spiral galaxy. The Sun and the rest of the solar system are located near the outer edge of the Milky Way Galaxy.

Spiral galaxies can be normal or barred. Arms in a normal spiral start close to the center of the galaxy. Barred spirals have spiral arms extending from a large bar of stars and gas that passes through the center of the galaxy.

**Figure 16** This illustration shows a side view and an overhead view of the Milky Way. Describe where the Sun is in the Milky Way.

## Elliptical Galaxies

cal galaxy. **Figure 17** shows an elliptical galaxy in the constellation Andromeda. These galaxies are shaped like large, three-dimensional ellipses. Many are football shaped, but others are round. Some elliptical galaxies are small, while others are so large that several galaxies the size of the Milky Way would fit inside one of them.

**Irregular Galaxies** The third type—an irregular galaxy—includes most of those galaxies that don't fit into the other categories. Irregular galaxies have many different shapes. They are smaller than the other types of galaxies. Two irregular galaxies called the Clouds of Magellan orbit the Milky Way. The Large Magellanic Cloud is shown in **Figure 18**.

**✓ Reading Check** *How do the three different types of galaxies differ?*

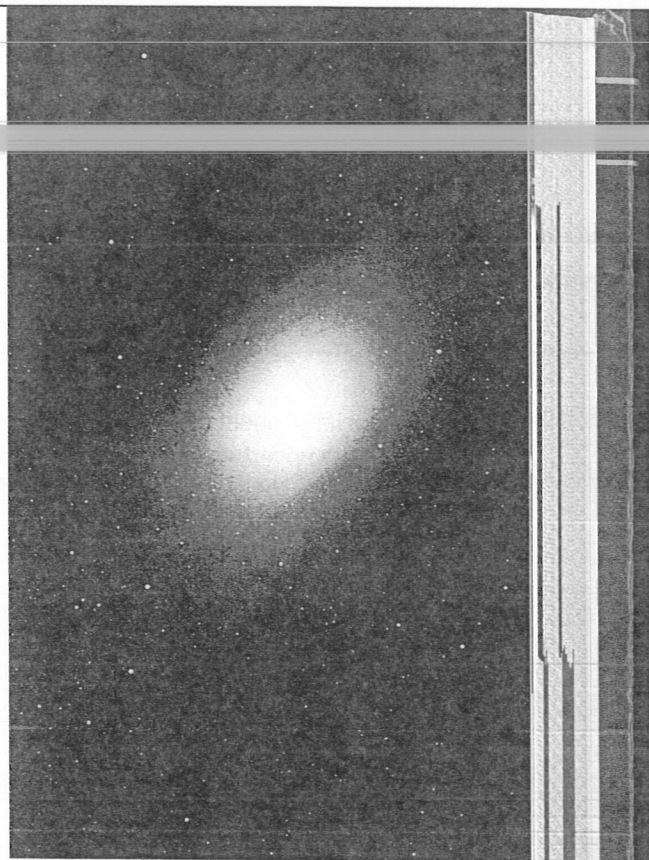
## The Milky Way Galaxy

The Milky Way might contain one trillion stars. The visible disk of stars shown in **Figure 16** is about 100,000 light-years across. Find the location of the Sun. Notice that it is located about 26,000 light-years from the galaxy's center in one of the spiral arms. In the galaxy, all stars orbit around a central region, or core. It takes about 225 million years for the Sun to orbit the center of the Milky Way.

The Milky Way often is classified as a normal spiral galaxy. However, recent evidence suggests that it might be a barred spiral. It is difficult to know for sure because astronomers have limited data about how the galaxy looks from the outside.

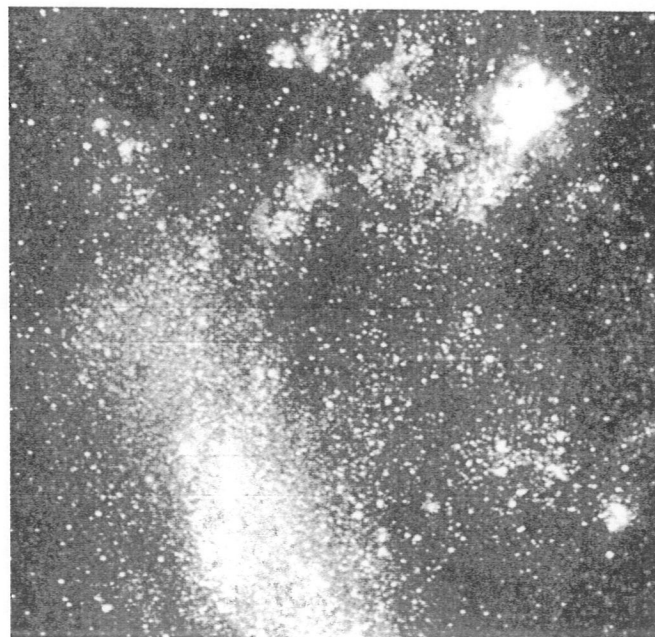
You can't see the shape of the Milky Way because you are located within one of its spiral arms. You can, however, see the Milky Way stretching across the sky as a misty band of faint light. You can see the brightest part of the Milky Way if you look low in the southern sky on a moonless summer night. All the stars you can see in the night sky belong to the Milky Way.

Like many other galaxies, the Milky Way has a supermassive black hole at its center. This black hole might be more than 2.5 million times as massive as the Sun. Evidence for the existence of the black hole comes from observing the orbit of a star near the galaxy's center. Additional evidence includes X-ray emissions detected by the *Chandra X-ray Observatory*. X rays are produced when matter spirals into a black hole.



**Figure 17** This photo shows an example of an elliptical galaxy. **Identify** the two other types of galaxies.

**Figure 18** The Large Magellanic Cloud is an irregular galaxy. It's a member of the Local Group, and it orbits the Milky Way.



## LAB

### Measuring Distance in Space

#### Procedure

1. On a large sheet of paper, draw an overhead view of the Milky Way. If necessary, refer to **Figure 16**. Choose a scale to show distance in light-years.
2. Mark the approximate location of the solar system, which is about two-thirds of the way out on one of the spiral arms.
3. Now, draw a side view of the Milky Way Galaxy. Mark the position of the solar system.

#### Analysis

1. What scale did you use to represent distance on your model of the Milky Way?
2. The Andromeda Galaxy is about 2.9 million light-years from Earth. What scale distance would this represent?

## Origin of the Universe

People long have wondered how the universe formed. Several models of its origin have been proposed. One model is the steady state theory. It suggests that the universe always has been the same as it is now. The universe always existed and always will. As the universe expands, new matter is created to keep the overall density of the universe the same or in a steady state. However, evidence indicates that the universe was much different in the past.

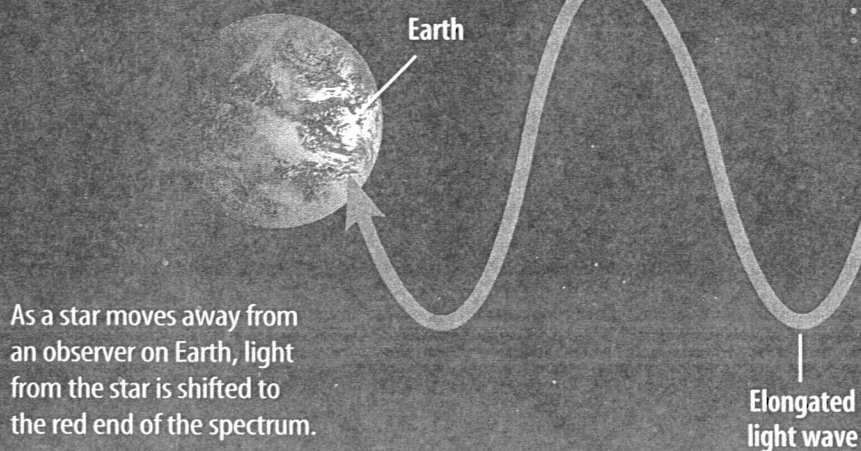
A second idea is called the oscillating model. In this model, the universe began with expansion. Over time, the expansion slowed and the universe contracted. Then the process began again, oscillating back and forth. Some scientists still hypothesize that the universe expands and contracts in a cycle.

A third model of how the universe formed is called the big bang theory. The universe started with a big bang and has been expanding ever since. This theory will be described later.

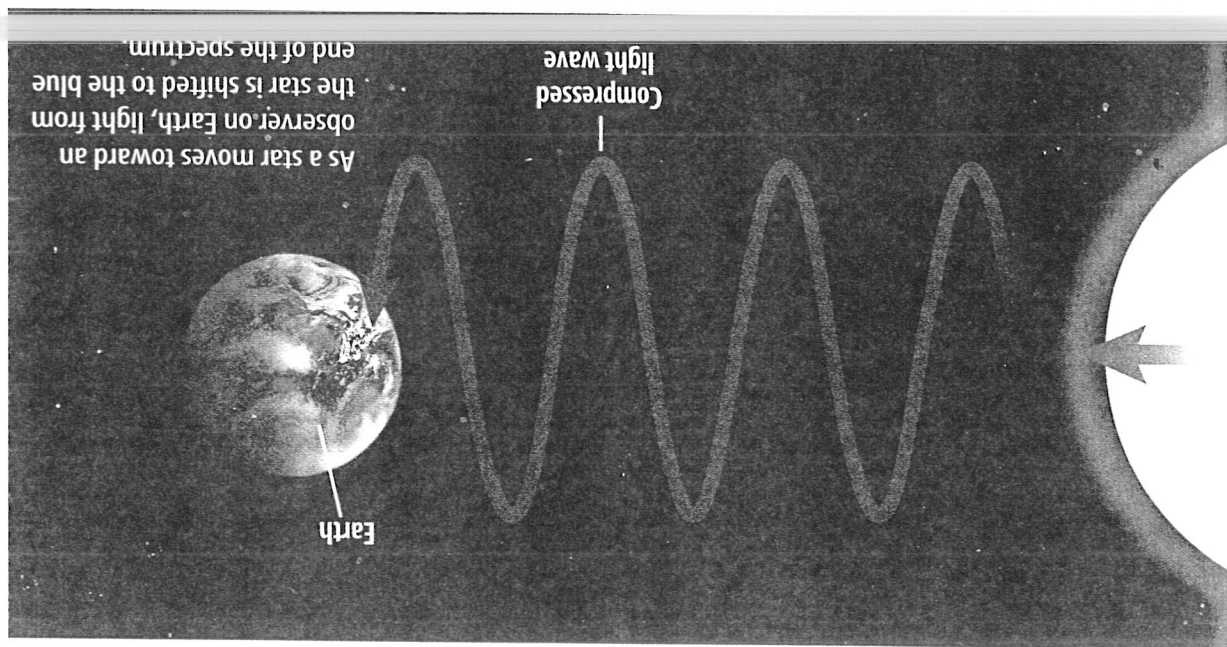
## Expansion of the Universe

What does it sound like when a train is blowing its whistle while it travels past you? The whistle has a higher pitch as the train approaches you. Then the whistle seems to drop in pitch as the train moves away. This effect is called the Doppler shift. The Doppler shift occurs with light as well as with sound. **Figure 19** shows how the Doppler shift causes changes in the light coming from distant stars and galaxies. If a star is moving toward Earth, its wavelengths of light are compressed. If a star is moving away from Earth, its wavelengths of light are stretched.

**Figure 19** The Doppler shift causes the wavelengths of light coming from stars and galaxies to be compressed or stretched.



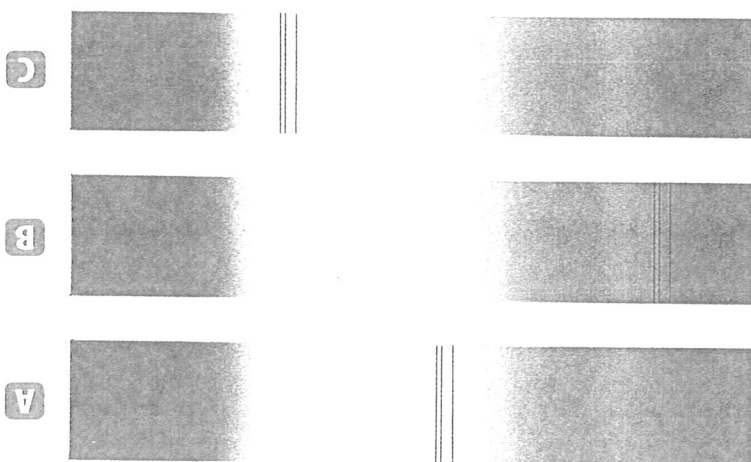




**Red Shift** In 1929, Edwin Hubble published an interesting fact about the light coming from most galaxies. When a spectrograph is used to study light from galaxies beyond the Local Group, a red shift occurs in the light. What does this red shift tell you about the universe?

Because all galaxies beyond the Local Group show a red shift in their spectra, they must be moving away from Earth. If all galaxies outside the Local Group are moving away from Earth, then the entire universe must be expanding. Remember the Launch Lab at the beginning of the chapter? The dots on the balloon moved apart as the model universe expanded. Regardless of which dot you picked, all the other dots moved away from it. In a similar way, galaxies beyond the Local Group are moving away from Earth.

**The Doppler Shift** Look at the spectrum of a star in **Figure 20A**. Note the position of the dark lines. How do they compare with the lines in **Figures 20B** and **20C**? They have shifted in position. What caused this shift? As you just read, when a star is moving toward Earth, its wavelengths of light are compressed, just as the sound waves from the train's whistle are. This causes the dark lines in the spectrum to shift toward the blue-violet end of the spectrum. A red shift in the spectrum occurs when a star is moving away from Earth. In a red shift, the dark lines shift toward the red end of the spectrum.



**Figure 20** **A** This spectrum

shows dark absorption lines. **B** The dark lines shift toward the blue-violet end for a star moving toward Earth. **C** The lines shift toward the red end for a star moving away from Earth.



NATIONAL

GEOGRAPHIC VISUALIZING THE BIG BANG THEORY

**Figure 21**

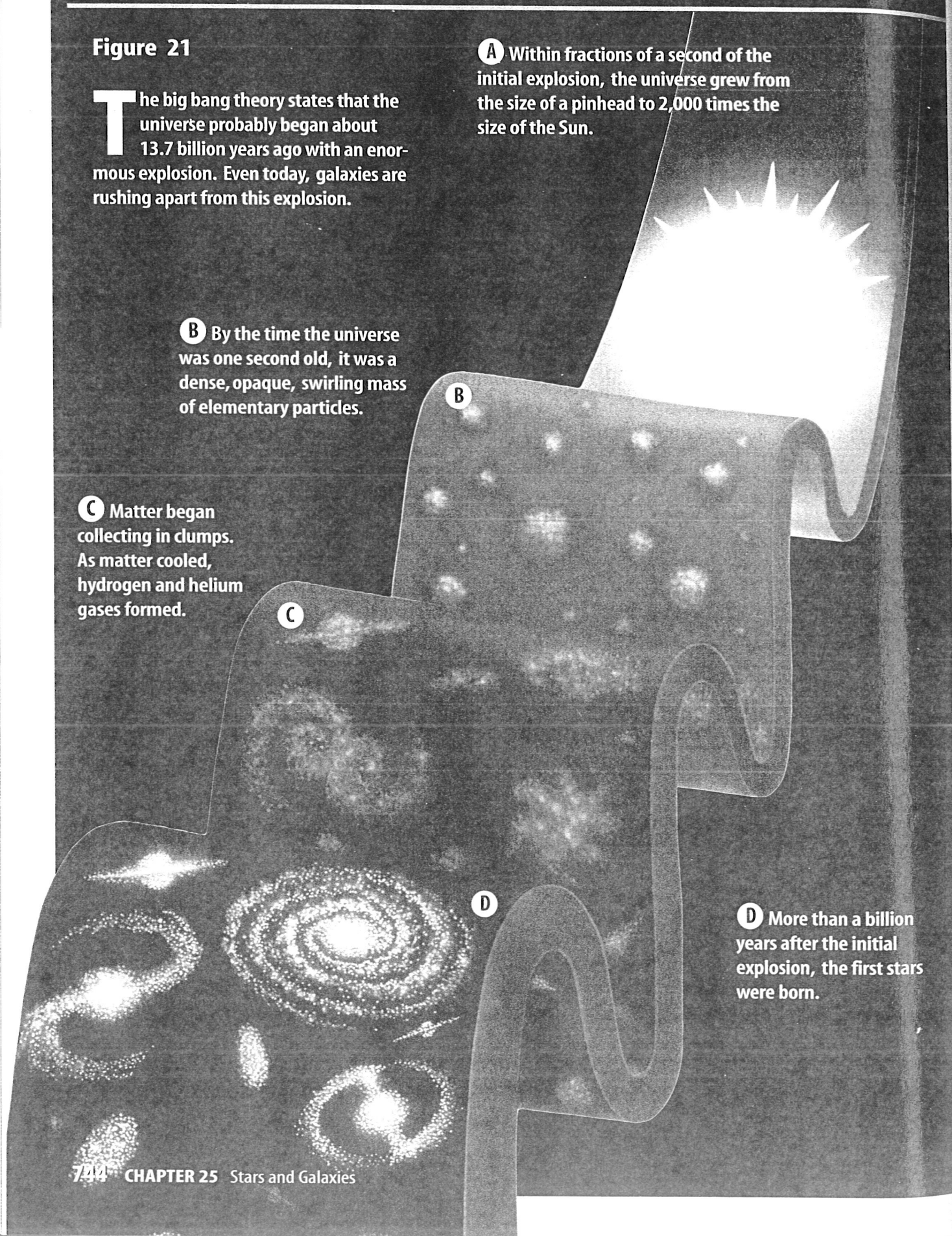
**T**he big bang theory states that the universe probably began about 13.7 billion years ago with an enormous explosion. Even today, galaxies are rushing apart from this explosion.

**A** Within fractions of a second of the initial explosion, the universe grew from the size of a pinhead to 2,000 times the size of the Sun.

**B** By the time the universe was one second old, it was a dense, opaque, swirling mass of elementary particles.

**C** Matter began collecting in clumps. As matter cooled, hydrogen and helium gases formed.

**D** More than a billion years after the initial explosion, the first stars were born.



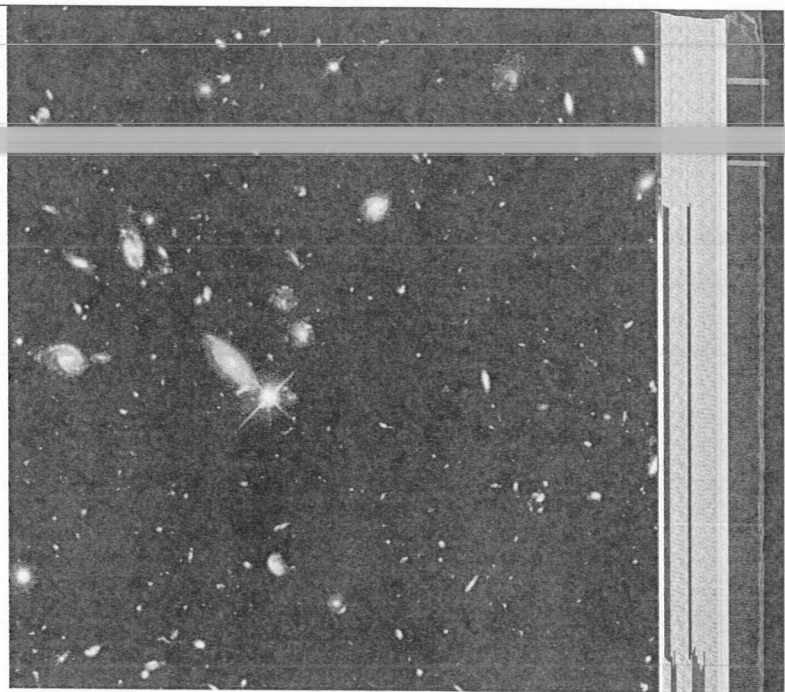


## The Big Bang Theory

When scientists determined that the universe was expanding, they developed a theory to explain their observations. The leading theory about the formation of the universe is called the **big bang theory**. **Figure 21** illustrates the big bang theory. According to this theory, approximately 13.7 billion years ago, the universe began with an enormous explosion. The entire universe began to expand everywhere at the same time.

**Looking Back in Time** The time-exposure photograph shown in **Figure 22** was taken by the *Hubble Space Telescope*. It shows more than 1,500 galaxies at distances of more than 10 billion light-years. These galaxies could date back to when the universe was no more than 1 billion years old. The galaxies are in various stages of development. One astronomer says that humans might be looking back to a time when the Milky Way was forming.

Whether the universe will expand forever or stop expanding is still unknown. If enough matter exists, gravity might halt the expansion, and the universe will contract until everything comes to a single point. However, studies of distant supernovae indicate that an energy, called dark energy, is causing the universe to expand faster. Scientists are trying to understand how dark energy might affect the fate of the universe.



**Figure 22** The light from the galaxies in this photo mosaic took billions of years to reach Earth.

### section 4 review

#### Summary

##### Galaxies

- The three main types of galaxies are spiral, elliptical, and irregular.

##### The Milky Way Galaxy

- The Milky Way is a spiral galaxy and the Sun is about 26,000 light-years from its center.

##### Origin of the Universe

- Theories about how the universe formed include the steady state theory, the oscillating universe theory, and the big bang theory.

##### The Big Bang Theory

- This theory states that the universe began with an explosion about 13.7 billion years ago.

#### Self Check

1. **Describe** elliptical galaxies. How are they different from spiral galaxies?
2. **Identify** the galaxy that you live in.
3. **Explain** the Doppler shift.
4. **Explain** how all galaxies are similar.
5. **Think Critically** All galaxies outside the Local Group show a red shift. Within the Local Group, some show a red shift and some show a blue shift. What does this tell you about the galaxies in the Local Group?

#### Applying Skills

6. **Compare and contrast** the theories about the origin of the universe.



### Measuring Parallax

#### Goals

- **Design** a model to show how the distance from an observer to an object affects the object's parallax shift.
- **Describe** how parallax can be used to determine the distance to a star.

#### Possible Materials

meterstick  
masking tape  
metric ruler  
pencil

#### Safety Precautions



**WARNING:** Be sure to wear goggles to protect your eyes.

#### Real-World Question

Parallax is the apparent shift in the position of an object when viewed from two locations. How can you build a model to show the relationship between distance and parallax?

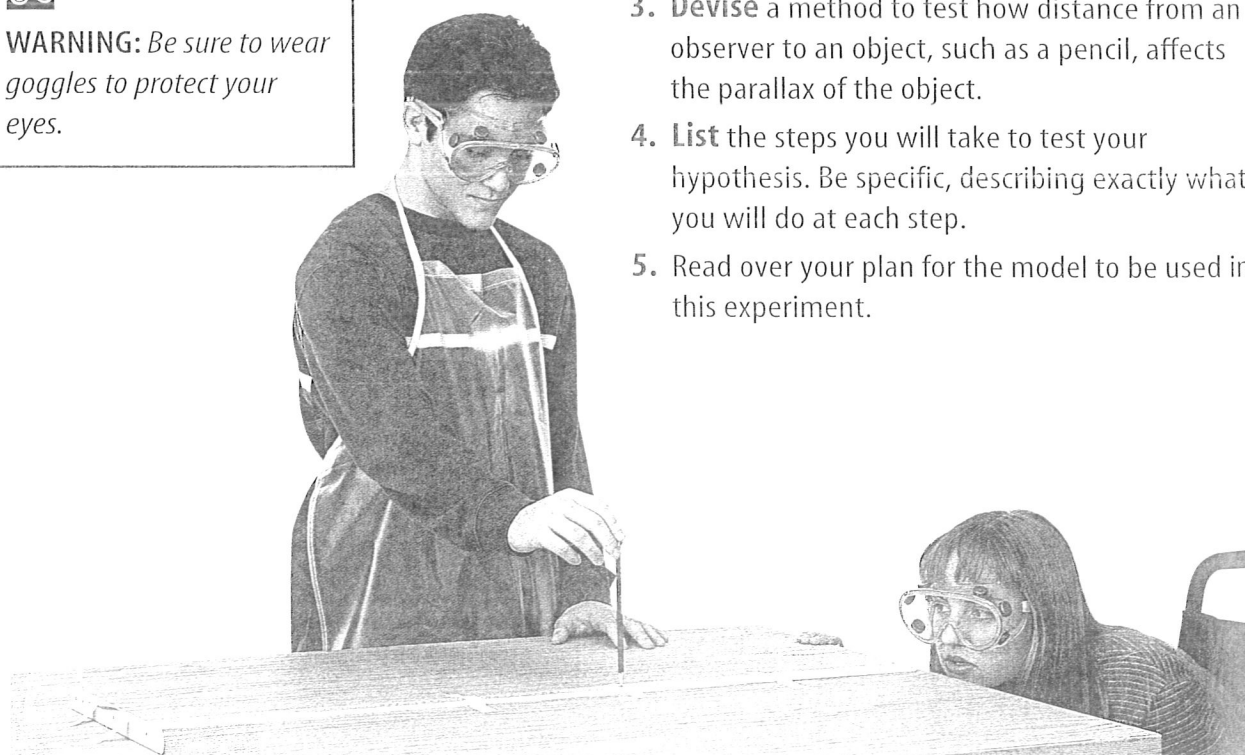
#### Form a Hypothesis

State a hypothesis about how parallax varies with distance.

#### Test Your Hypothesis

##### Make a Plan

1. As a group, agree upon and write your hypothesis statement.
2. **List** the steps you need to take to build your model. Be specific, describing exactly what you will do at each step.
3. **Devise** a method to test how distance from an observer to an object, such as a pencil, affects the parallax of the object.
4. **List** the steps you will take to test your hypothesis. Be specific, describing exactly what you will do at each step.
5. Read over your plan for the model to be used in this experiment.

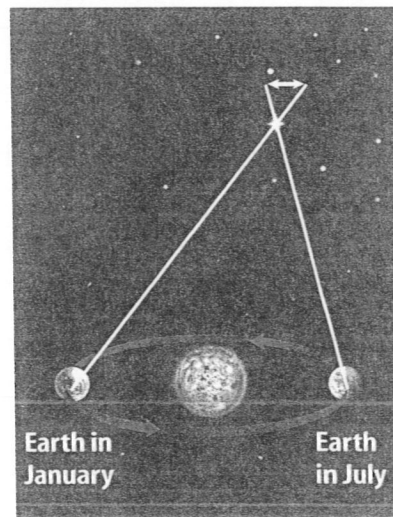


## Using Scientific Methods

6. How will you determine changes in observed parallax?  
Remember, these changes should occur when the distance from the observer to the object is changed.
7. You should measure shifts in parallax from several different positions. How will these positions differ?
8. How will you measure distances accurately and compare relative position shift?

### Follow Your Plan

1. Make sure your teacher approves your plan before you start.
2. **Construct** the model your team has planned.
3. Carry out the experiment as planned.
4. While conducting the experiment, record any observations that you or other members of your group make in your Science Journal.



### ► Analyze Your Data

1. **Compare** what happened to the object when it was viewed with one eye closed, then the other.
2. At what distance from the observer did the object appear to shift the most?
3. At what distance did it appear to shift the least?

### ► Conclude and Apply

1. **Infer** what happened to the apparent shift of the object's location as the distance from the observer was increased or decreased.
2. **Describe** how astronomers might use parallax to study stars.

### Communicating Your Data

Prepare a chart showing the results of your experiment. Share the chart with members of your class. For more help, refer to the Science Skill Handbook.

## Reviewing Main Ideas

### Section 1 Stars

1. Constellations are patterns of stars in the night sky. Some constellations can be seen all year. Other constellations are visible only during certain seasons.
2. Parallax is the apparent shift in the position of an object when viewed from two different positions. Parallax is used to find the distance to nearby stars.

### Section 2 The Sun

1. The Sun is the closest star to Earth.
2. Sunspots are areas on the Sun's surface that are cooler and less bright than surrounding areas.

### Section 3 Evolution of Stars

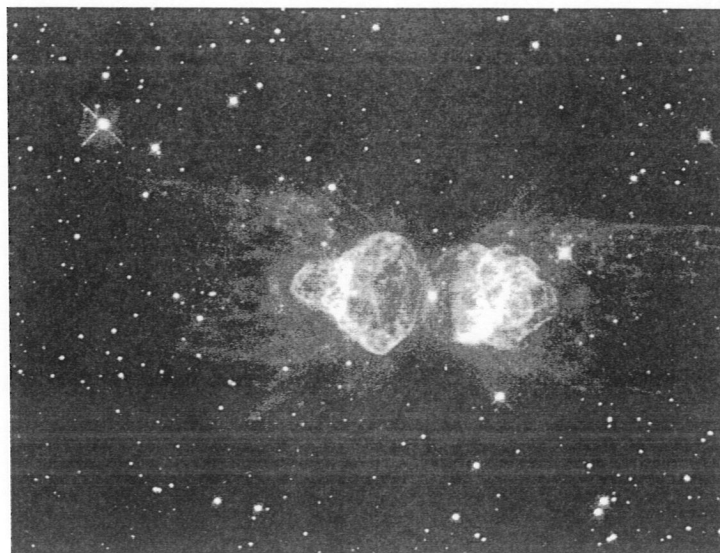
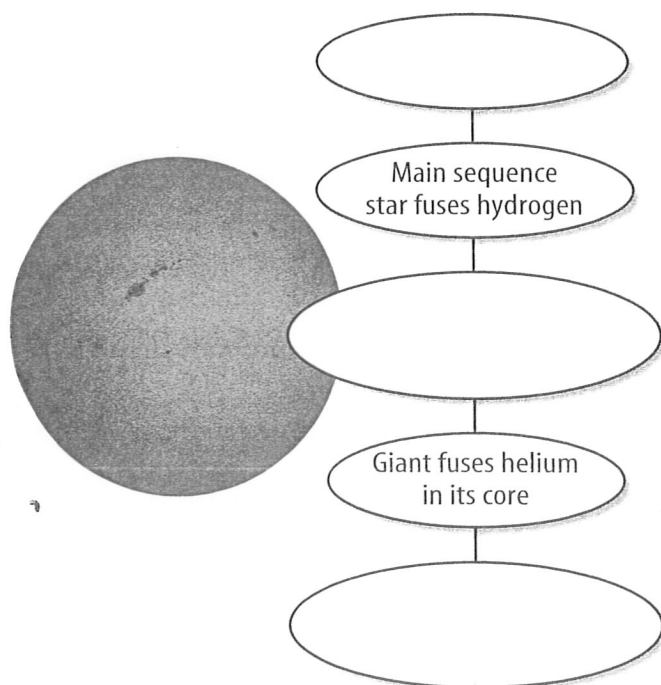
1. Stars are classified according to their position on the H-R diagram.
2. Low-mass stars end their lives as white dwarfs. High-mass stars become neutron stars or black holes.

### Section 4 Galaxies and the Universe

1. A galaxy consists of stars, gas, and dust held together by gravity.
2. Earth's solar system is in the Milky Way, a spiral galaxy.
3. The universe is expanding. Scientists don't know whether the universe will expand forever or contract to a single point.

## Visualizing Main Ideas

Copy and complete the following concept map that shows the evolution of a main sequence star with a mass similar to that of the Sun.



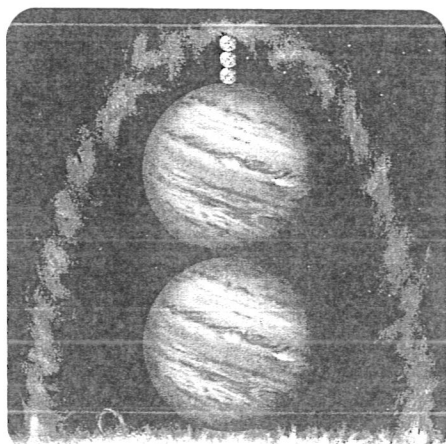
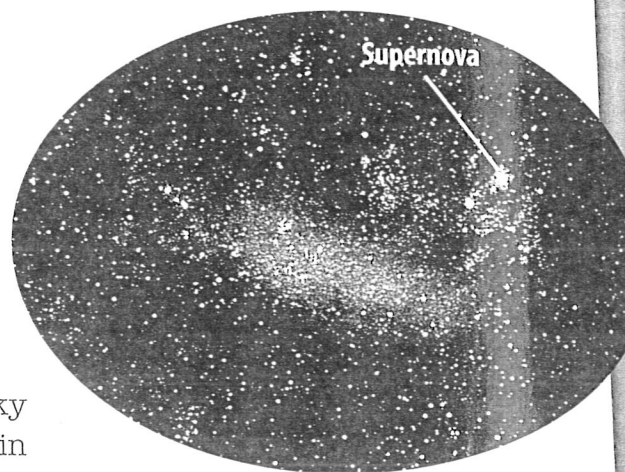


# SCIENCE Stats

## Stars and Galaxies

### Did you know...

... **A star in Earth's galaxy explodes** as a supernova about once a century. The most famous supernova of this galaxy occurred in 1054 and was recorded by the ancient Chinese and Koreans. The explosion was so powerful that it could be seen during the day, and its brightness lasted for weeks. Other major supernovas in the Milky Way that were observed from Earth occurred in 185, 386, 1006, 1181, 1572, and 1604.

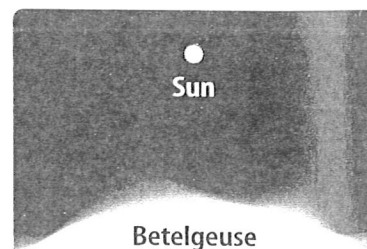


... **The large loops of material** called solar prominences can extend more than 320,000 km above the Sun's surface. This is so high that two Jupiters and three Earths could fit under the arch.

... **The red giant star Betelgeuse** has a diameter larger than that of Earth's Sun. This gigantic star measures 450,520,000 km in diameter, while the Sun's diameter is a mere 1,390,176 km.

#### Applying Math

Use words to express the number 450,520,000.



### Write About It

Visit [earth.msscience.com/science\\_stats](http://earth.msscience.com/science_stats) to learn whether it might be possible for Earth astronauts to travel to the nearest stars. How long would such a trip take? What problems would have to be overcome? Write a brief report about what you find.

## Using Vocabulary

|                           |                     |
|---------------------------|---------------------|
| absolute magnitude p. 726 | giant p. 737        |
| apparent magnitude p. 726 | light-year p. 727   |
| big bang theory p. 745    | nebula p. 736       |
| black hole p. 738         | neutron star p. 738 |
| chromosphere p. 729       | photosphere p. 729  |
| constellation p. 724      | sunspot p. 730      |
| corona p. 729             | supergiant p. 738   |
| galaxy p. 740             | white dwarf p. 737  |

Explain the difference between the terms in each of the following sets.

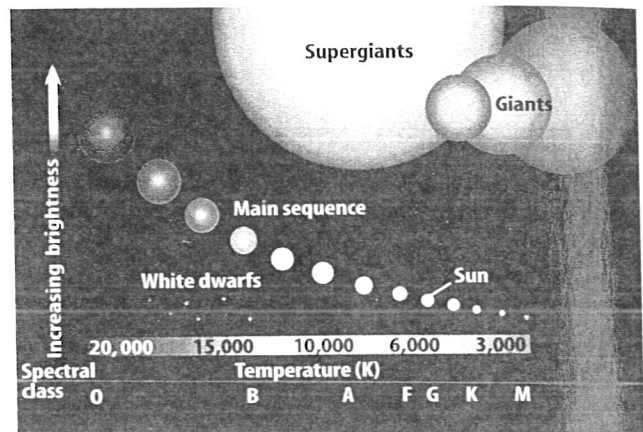
- absolute magnitude—apparent magnitude
- galaxy—constellation
- giant—supergiant
- chromosphere—photosphere
- black hole—neutron star

## Checking Concepts

Choose the word or phrase that best answers the question.

- What is a measure of the amount of a star's light that is received on Earth?
  - absolute magnitude
  - apparent magnitude
  - fusion
  - parallax
- What is higher for closer stars?
  - absolute magnitude
  - red shift
  - parallax
  - blue shift
- What happens after a nebula contracts and its temperature increases to 10 million K?
  - a black hole forms
  - a supernova occurs
  - fusion begins
  - a white dwarf forms
- Which of these has an event horizon?
  - giant
  - white dwarf
  - black hole
  - neutron star
- What forms when the Sun fuses hydrogen?
  - carbon
  - oxygen
  - iron
  - helium

Use the illustration below to answer question 11.



- Which of the following best describes giant stars?
  - hot, dim stars
  - cool, dim stars
  - hot, bright stars
  - cool, bright stars
- Which of the following are loops of matter flowing from the Sun?
  - sunspots
  - auroras
  - coronas
  - prominences
- What are groups of galaxies called?
  - clusters
  - supergiants
  - giants
  - binary systems
- Which galaxies are sometimes shaped like footballs?
  - spiral
  - elliptical
  - barred
  - irregular
- What do scientists study to determine shifts in wavelengths of light?
  - spectrum
  - parallax
  - corona
  - nebula

### Thinking Critically

Use the table below to answer question 16.

**Magnitude and Distance of Stars**

| Star | Apparent Magnitude | Absolute Magnitude | Distance in Light-Years |
|------|--------------------|--------------------|-------------------------|
| A    | -26                | 4.8                | 0.00002                 |
| B    | -1.5               | 1.4                | 8.7                     |
| C    | 0.1                | 4.4                | 4.3                     |
| D    | 0.1                | -7.0               | 815                     |
| E    | 0.4                | -5.9               | 520                     |
| F    | 1.0                | -0.6               | 45                      |

**16. Interpret Data** Use the table above to answer the following questions. *Hint: lower magnitude values are brighter than higher magnitude values.*

- Which star appears brightest from Earth?
- Which star would appear brightest from a distance of 10 light-years?
- Infer which star in the table above is the Sun.

**17. Infer** How do scientists know that black holes exist if these objects don't emit visible light?

**18. Recognize Cause and Effect** Why can parallax only be used to measure distances to stars that are relatively close to Earth?

**19. Compare and contrast** the Sun with other stars on the H-R diagram.

**20. Concept Map** Make a concept map showing the life history of a very large star.

**21. Make Models** Make a model of the Sun. Include all of the Sun's layers in your model.

### Performance Activities

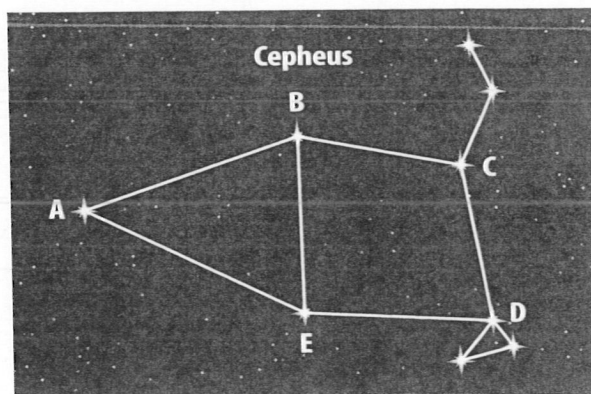
**22. Story** Write a short science-fiction story about an astronaut traveling through the universe. In your story, describe what the astronaut observes. Use as many vocabulary words as you can.

**23. Photomontage** Gather photographs of the aurora borealis from magazines and other sources. Use the photographs to create a photomontage. Write a caption for each photo.

### Applying Math

**24. Travel to Vega** Vega is a star that is 26 light-years away. If a spaceship could travel at one-tenth the speed of light, how long would it take to reach this star?

Use the illustration below to answer question 25.



**25. Constellation Cepheus** The illustration above shows the constellation Cepheus. Answer the following questions about this constellation.

- Which of the line segments are nearly parallel?
- Which line segments are nearly perpendicular?
- Which angles are obtuse?
- What geometric shape do the three stars at the left side of the drawing form?