

# Telescopes

## Reading Preview

### Key Concepts

- What are the regions of the electromagnetic spectrum?
- What are telescopes and how do they work?
- Where are most large telescopes located?

### Key Terms

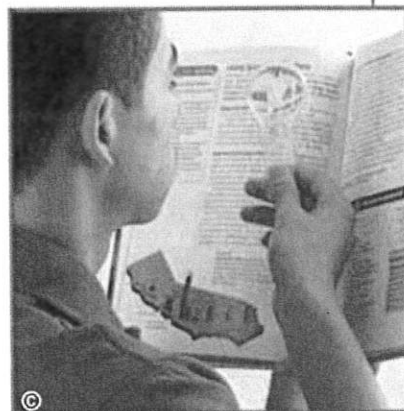
- telescope
- electromagnetic radiation
- visible light
- wavelength
- spectrum
- optical telescope
- refracting telescope
- convex lens
- reflecting telescope
- radio telescope
- observatory

Lab  
zone

## Discover Activity

### How Does Distance Affect an Image?

1. Hold a plastic hand lens about 7 cm away from your eye and about 5 cm away from a printed letter on a page. Move the lens slowly back and forth until the letter is in clear focus.
2. Keep the letter about 5 cm from the lens as you move your eye back to about 20 cm from the lens. Then, keeping the distance between your eye and the lens constant, slowly move the object away from the lens.

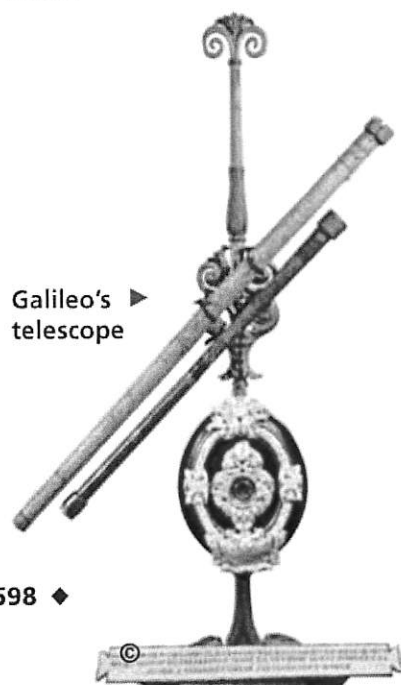


### Think It Over

**Observing** What did the letter look like through the lens in Step 1 compared with how it looked without the lens? How did the image change in Step 2?

## Target Reading Skill

**Building Vocabulary** Carefully read the definition of each key term. Also read the neighboring sentences. Then write a definition of each key term in your own words.



Galileo's  
telescope

Ancient peoples often gazed up in wonder at the many points of light in the night sky. But they could see few details with their eyes alone. It was not until the invention of the telescope in 1608 that people could observe objects in the sky more closely. Recall that a **telescope** is a device that makes distant objects appear to be closer. The telescope revolutionized astronomy. Scientists now had a tool that allowed them to see many objects in space for the first time.

Although Galileo was not the first to use a telescope, he soon made it famous as he turned his homemade instrument to the sky. With his telescope, Galileo saw things that no one had even dreamed of. He was the first to see sunspots, Saturn's rings, and the four large moons of Jupiter. Galileo could see fine details, such as mountains on the moon, which cannot be seen clearly by the unaided eye.

Since Galileo's time, astronomers have built ever larger and more powerful telescopes. These telescopes have opened up a whole universe of wonders that would have amazed even Galileo.



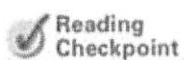
## Electromagnetic Radiation

To understand how telescopes work, it's useful to understand the nature of electromagnetic radiation. Light is a form of **electromagnetic radiation** (ih lek troh mag NET ik), or energy that can travel through space in the form of waves. You can see stars when the light that they produce reaches your eyes.

**Forms of Radiation** Scientists call the light you can see **visible light**. Visible light is just one of many types of electromagnetic radiation. Many objects give off radiation that you can't see. For example, in addition to their reddish light, the glowing coils of an electric heater give off infrared radiation, which you feel as heat. Radio transmitters produce radio waves that carry signals to radios and televisions. Objects in space give off all types of electromagnetic radiation.

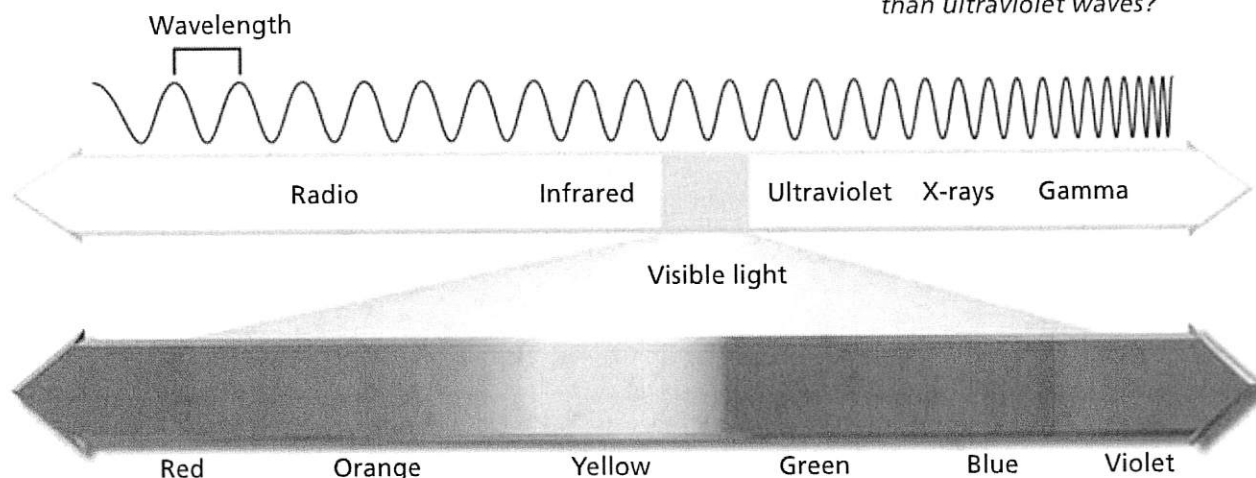
**The Electromagnetic Spectrum** As shown in Figure 1, the distance between the crest of one wave and the crest of the next wave is called **wavelength**. Visible light has very short wavelengths, less than one millionth of a meter. Some electromagnetic waves have even shorter wavelengths. Other waves have much longer wavelengths, even several meters long.

If you shine white light through a prism, the light spreads out to make a range of different colors with different wavelengths, called a **spectrum**. The spectrum of visible light is made of the colors red, orange, yellow, green, blue, and violet. **The electromagnetic spectrum includes the entire range of radio waves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays.**



Reading  
Checkpoint

What are two kinds of electromagnetic waves that you might experience every day?



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**FIGURE 1**  
**The Electromagnetic Spectrum**  
The electromagnetic spectrum ranges from long-wavelength radio waves through short-wavelength gamma rays. Interpreting Diagrams Are infrared waves longer or shorter than ultraviolet waves?

## Types of Telescopes

On a clear night, your eyes can see at most a few thousand stars. But with a telescope, you can see many millions. Why? The light from stars spreads out as it moves through space, and your eyes are too small to gather much light.

**Telescopes are instruments that collect and focus light and other forms of electromagnetic radiation.** Telescopes make distant objects appear larger and brighter. A telescope that uses lenses or mirrors to collect and focus visible light is called an **optical telescope**. The two major types of optical telescope are refracting telescopes and reflecting telescopes.

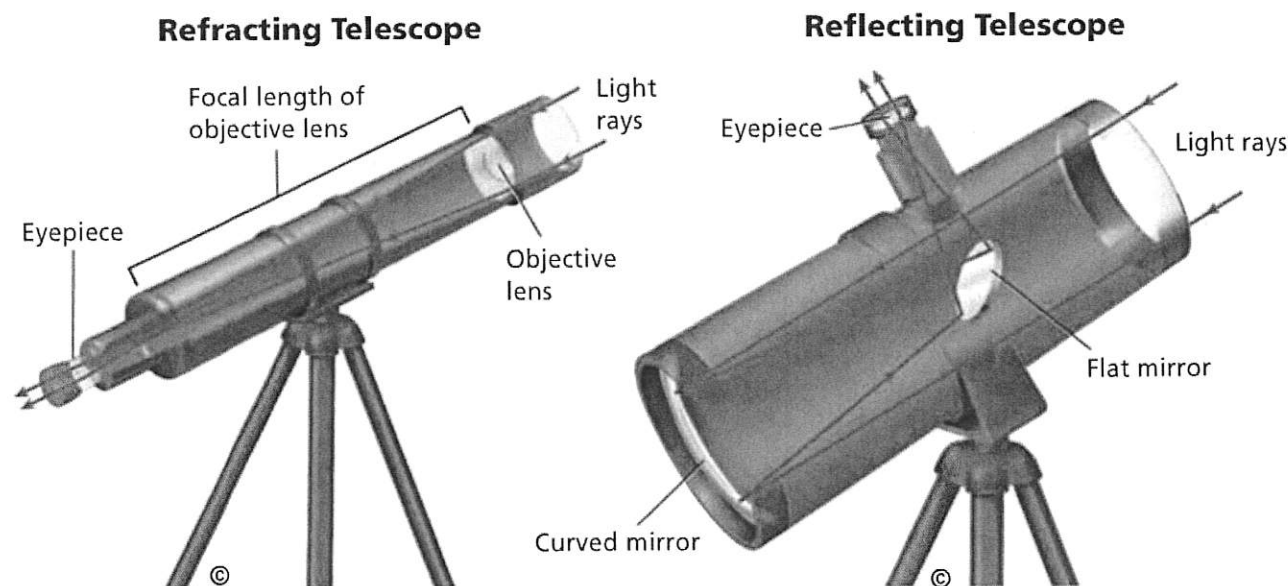
Modern astronomy is based on the detection of many forms of electromagnetic radiation besides visible light. Non-optical telescopes collect and focus different types of electromagnetic radiation, just as optical telescopes collect visible light.

**Refracting Telescopes** A **refracting telescope** uses convex lenses to gather and focus light. A **convex lens** is a piece of transparent glass, curved so that the middle is thicker than the edges.

Figure 2 shows a simple refracting telescope. This telescope has two convex lenses, one at each end of a long tube. Light enters the telescope through the large objective lens at the top. The objective lens focuses the light at a certain distance from the lens. This distance is the focal length of the lens. The larger the objective lens, the more light the telescope can collect. This makes it easier for astronomers to see faint objects.

The smaller lens at the lower end of a refracting telescope is called the eyepiece. The eyepiece magnifies the image produced by the objective lens.

**FIGURE 2**  
**Refracting and Reflecting Telescopes**  
A refracting telescope uses convex lenses to focus light. A reflecting telescope has a curved mirror in place of an objective lens.



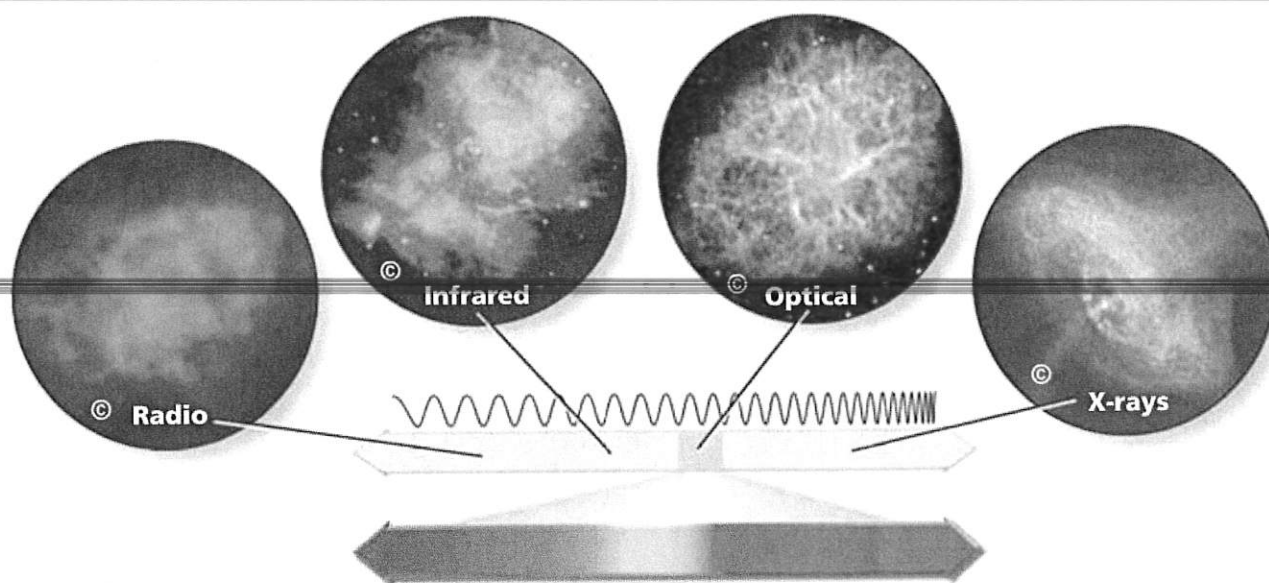


FIGURE 3

#### Four Views of the Crab Nebula

Different types of telescopes collect electromagnetic radiation at different wavelengths. Astronomers are able to learn a great deal about the Crab Nebula by examining these different images. The images are shown at different scales.

**Reflecting Telescopes** In 1668, Isaac Newton built the first reflecting telescope. A **reflecting telescope** uses a curved mirror to collect and focus light. Like the objective lens in a refracting telescope, the curved mirror in a reflecting telescope focuses a large amount of light onto a small area. The larger the mirror, the more light the telescope can collect. The largest optical telescopes today are all reflecting telescopes.

**Radio Telescopes** Devices used to detect radio waves from objects in space are called **radio telescopes**. Most radio telescopes have curved, reflecting surfaces—up to 305 meters in diameter. These surfaces focus radio waves the way the mirror in a reflecting telescope focuses light waves. The surfaces concentrate the faint radio waves from space onto small antennas like those on radios. As with optical telescopes, the larger a radio telescope is, the more radio waves it can collect.

**Other Telescopes** Some telescopes detect infrared radiation, which has longer wavelengths than visible light but shorter wavelengths than radio waves. There are also telescopes that detect the shortest wavelengths—ultraviolet radiation, X-rays, and gamma rays.



Reading  
Checkpoint

Who built the first reflecting telescope?

Lab  
zone

#### Try This Activity

##### Locating Radio Waves

You can use an umbrella to focus radio waves.

1. Line the inside of an open umbrella with aluminum foil.
2. Turn on a small radio and tune it to a station.
3. Move the radio up and down along the umbrella handle. Find the position where the station is clearest. Radio waves reflecting off the foil focus at this point. Tape the radio to the handle.
4. Hold the umbrella at different angles. At which angle is the station the clearest?

**Inferring** In which direction do you think the radio station's transmitter is located? Explain.





## Observatories

In general, an **observatory** is a building that contains one or more telescopes. However, some observatories are located in space. **Many large observatories are located on mountaintops or in space.** Why? Earth's atmosphere makes objects in space look blurry. The sky on some mountaintops is clearer than at sea level and is not brightened much by city lights. Unlike optical telescopes, radio telescopes do not need to be located on mountaintops.

One of the best observatory sites on Earth is on the top of Mauna Kea, a dormant volcano on the island of Hawaii. Mauna Kea is so tall—4,200 meters above sea level—that it is above 40 percent of Earth's atmosphere.

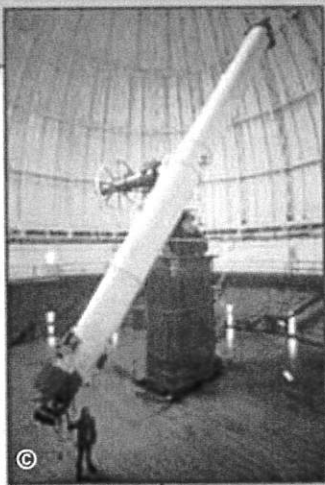
### • Tech & Design in History •

#### Development of Modern Telescopes

During the last century, astronomers have built larger telescopes, which can collect more visible light and other types of radiation. Today's astronomers use tools that could not have been imagined 100 years ago.

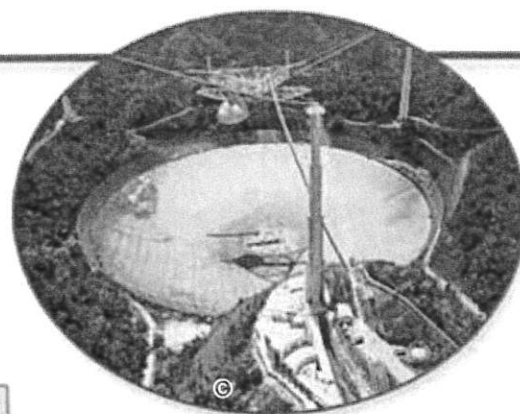
##### 1897 Yerkes Telescope

The 1-meter-diameter telescope at Yerkes Observatory in Wisconsin is the largest refracting telescope ever built. Because its main lens is so large, the Yerkes telescope can collect more light than any other refracting telescope.



##### 1931 Beginning of Radio Astronomy

Karl Jansky, an American engineer, was trying to find the source of static that was interfering with radio communications. Using a large antenna, he discovered that the static was radio waves given off by objects in space. Jansky's accidental discovery led to the beginning of radio astronomy.



##### 1963 Arecibo Radio Telescope

This radio telescope in Puerto Rico was built in a natural bowl in the ground. It is 305 meters in diameter, the largest radio telescope in existence.

1900

1940

1960

**Advanced Telescopes** Today, many large optical telescopes are equipped with systems that significantly improve the quality of their images. Optical telescopes on Earth equipped with such systems are able to produce images of small regions of the sky that rival those of optical telescopes based in space.

Some new telescopes are equipped with computer systems that correct images for problems such as telescope movement and changes in air temperature or mirror shape. Other advanced telescopes use lasers to monitor conditions in the atmosphere. The shape of the telescope's mirror is automatically adjusted thousands of times each second in response to changes in the atmosphere.

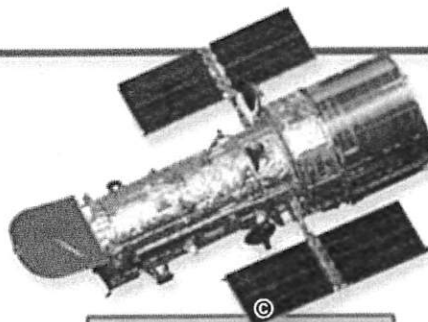
## Writing in Science

### Research and Write

Research one of these telescopes or another large telescope. Create a publicity brochure in which you describe the telescope's features, when and where it was built, and what types of research it is used for.

### 1980 Very Large Array

The Very Large Array is a set of 27 radio telescopes in New Mexico. The telescopes can be moved close together or far apart. The telescopes are linked, so they can be used as if they were one giant radio telescope 25 kilometers in diameter.

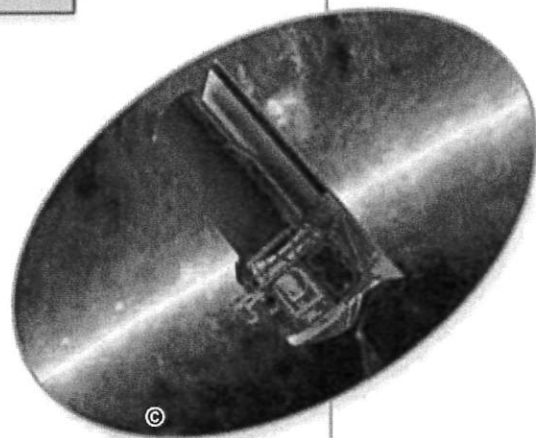
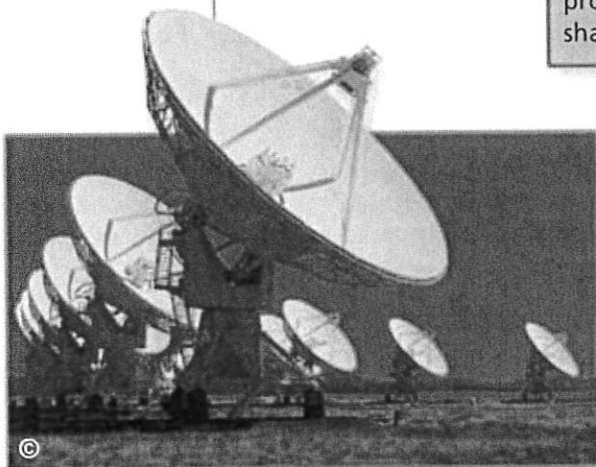


### 1990 Hubble Space Telescope

The Hubble Space Telescope views objects in space from high above the atmosphere. As a result, it can produce extremely sharp images.

### 2003 Spitzer Space Telescope

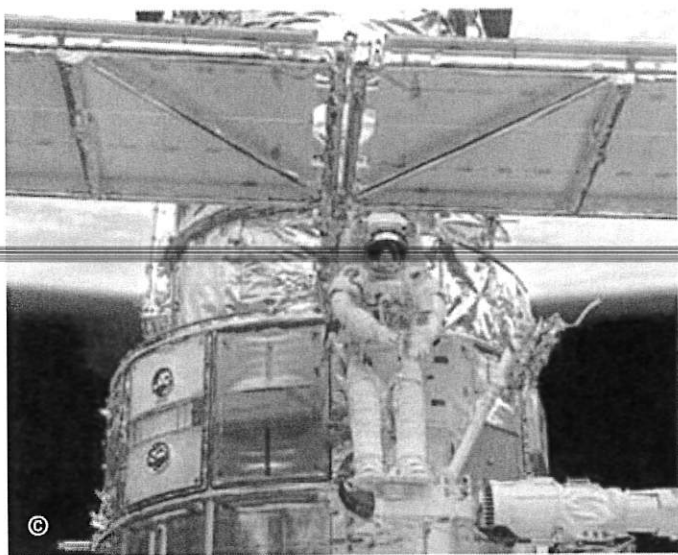
The Spitzer Space Telescope is a powerful 0.85-meter diameter telescope that surveys the sky in the infrared range of the spectrum.



1980

2000

2020



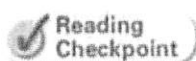
**FIGURE 4**  
**Repairing Hubble**  
 Astronauts have repaired and upgraded the Hubble Space Telescope on several occasions.

**Telescopes in Space** X-rays, gamma rays, and most ultraviolet radiation are blocked by Earth's atmosphere. To detect these wavelengths, astronomers have placed telescopes in space. Some space telescopes are designed to detect visible light or infrared radiation, since Earth's atmosphere interferes with the transmission of these forms of radiation.

The Hubble Space Telescope is a reflecting telescope with a mirror 2.4 meters in diameter. Because the Hubble telescope orbits Earth above the atmosphere, it can produce very detailed images in visible light. It also collects ultraviolet and infrared radiation. The spectacular Hubble telescope images have changed how astronomers view the universe.

The hottest objects in space give off X-rays. The Chandra X-ray Observatory produces images in the X-ray portion of the spectrum. Chandra's X-ray images are much more detailed than those of earlier X-ray telescopes.

The most recent addition to NASA's lineup of telescopes in space is the Spitzer Space Telescope. Launched in 2003, the Spitzer telescope produces images in the infrared portion of the spectrum.



What is an observatory?

## Section 1 Assessment

**Vocabulary Skill Suffixes** What suffix do you see in the word *electromagnetic*? What part of speech does it indicate? Define *electromagnetic radiation*.

### Reviewing Key Concepts

- HINT** 1. a. **Sequencing** List the main types of electromagnetic waves, from longest wavelength to shortest.
- HINT** b. **Applying Concepts** Why are images from the Hubble Space Telescope clearer than images from telescopes on Earth?
- HINT** 2. a. **Identifying** What are the two major types of optical telescope?
- HINT** b. **Explaining** How does a refracting telescope work?
- HINT** c. **Comparing and Contrasting** Use Figure 2 to explain the major differences between reflecting and refracting telescopes.

3. a. **Summarizing** How does the atmosphere affect electromagnetic radiation?
- HINT** b. **Explaining** Why are many large optical telescopes located on mountaintops?
- HINT** c. **Applying Concepts** Would it make sense to place an X-ray or gamma ray telescope on a mountaintop? Explain why or why not.

## Writing in Science

**Writing Instructions** Write a short explanation of how to build a reflecting telescope for a booklet to be included in a model telescope kit. Be sure to describe the shape and position of each of the lenses or mirrors. You may include drawings.



# Design and Build a Telescope



Foam holder

Eyepiece

©

Paper towel  
tubesObjective lens  
(tape to the  
end of tube)

## Problem

Can you design and build a telescope?

## Skills Focus

evaluating the design, redesigning

## Materials

- 2 paper towel tubes of slightly different diameters
- several plastic objective lenses
- several plastic eyepiece lenses
- meter stick
- foam holder for eyepiece
- transparent tape

## Procedure

1. Fit one of the paper towel tubes inside the other. Make sure you can move the tubes but that they will not slide on their own.
2. Place the large objective lens flat against the end of the outer tube. Tape the lens in place.
3. Insert the small eyepiece lens into the opening in the foam holder.
4. Place the foam eyepiece lens holder into the inner tube at the end of the telescope opposite to the objective lens.
5. Tape a meter stick to the wall. Look through the eyepiece at the meter stick from 5 m away. Slide the tubes in and out to focus your telescope so that you can clearly read the numbers on the meter stick. Draw your telescope. On the drawing, mark the tube position that allows you to read the numbers most clearly.
6. Use your telescope to look at other objects at different distances, both in your classroom and through the window. For each object you view, draw your telescope, marking the tube position at which you see the object most clearly. **CAUTION:** Do not look at the sun. You will damage your eyes.
7. Design and build a better telescope. Your new telescope should make objects appear larger than your first model from the same observing distance. It should have markings on the inner tube to enable you to pre-focus the telescope for a given observing distance.
8. Draw a design for your new telescope. List the materials you'll need. Obtain your teacher's approval. Then build your new model.

## Analyze and Conclude

1. **Inferring** Why do you need two tubes?
2. **Observing** If you focus on a nearby object and then focus on something farther away, do you have to move the tubes together or apart?
3. **Evaluating the Design** How could you improve on the design of your new telescope? What effects would different lenses or tubes have on its performance?
4. **Redesigning** Describe the most important factors in redesigning your telescope.

## Communicate

Write a product brochure for your new telescope. Be sure to describe in detail why your new telescope is better than the first telescope.





# Characteristics of Stars



## Reading Preview

### Key Concepts

- How are stars classified?
- How do astronomers measure distances to the stars?
- What is an H-R diagram and how do astronomers use it?

### Key Terms

- constellation
- spectrograph
- apparent brightness
- absolute brightness
- light-year
- parallax
- Hertzsprung-Russell diagram
- main sequence

## Target Reading Skill

**Using Prior Knowledge** Before you read, write what you know about the characteristics of stars in a graphic organizer like the one below. As you read, write what you learn.

### What You Know

1. Stars are bright and hot.
- 2.

### What You Learned

- 1.
- 2.

Lab zone

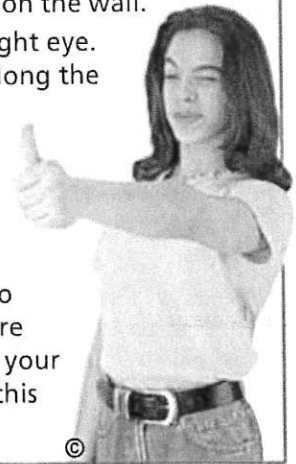
## Discover Activity

### How Does Your Thumb Move?

1. Stand facing a wall, at least an arm's length away. Stretch your arm out with your thumb up and your fingers curled.
2. Close your right eye and look at your thumb with your left eye. Line your thumb up with something on the wall.
3. Now close your left eye and open your right eye. How does your thumb appear to move along the wall?
4. Bring your thumb closer to your eye, about half the distance as before. Repeat Steps 2 and 3.

### Think It Over

**Observing** How does your thumb appear to move in Step 4 compared to Step 3? How are these observations related to how far away your thumb is at each step? How could you use this method to estimate distances?



When ancient observers around the world looked up at the night sky, they imagined that groups of stars formed pictures of people or animals. Today, we call these imaginary patterns of stars **constellations**.

Different cultures gave different names to the constellations. For example, a large constellation in the winter sky is named Orion, the Hunter, after a Greek myth. In this constellation, Orion is seen with a sword in his belt and an upraised arm. The ancient Sumerians thought that the stars in Orion formed the outline of a sheep. In ancient China, this group of stars was called "three," probably because of the three bright stars in Orion's belt.

Astronomers use the patterns of the constellations to locate objects in the night sky. But although the stars in a constellation look as if they are close to one another, they generally are not. They just happen to lie in the same part of the sky as seen from Earth.

Illustration of Orion ▼







## Classifying Stars

Like the sun, all stars are huge spheres of glowing gas. They are made up mostly of hydrogen, and they produce energy through the process of nuclear fusion. This energy makes stars shine brightly. Astronomers classify stars according to their physical characteristics. **Characteristics used to classify stars include color, temperature, size, composition, and brightness.**

**Color and Temperature** If you look at the night sky, you can see slight differences in the colors of the stars. For example, Betelgeuse (BAY tul jooz), the bright star in Orion's shoulder, looks reddish. Rigel, the star in Orion's heel, is blue-white.

Like hot objects on Earth, a star's color reveals its surface temperature. If you watch a toaster heat up, you can see the wires glow red-hot. The wires inside a light bulb are even hotter and glow white. Similarly, the coolest stars—with a surface temperature of about 3,200 degrees Celsius—appear reddish in the sky. With a surface temperature of about 5,500 degrees Celsius, the sun appears yellow. The hottest stars in the sky, with surface temperatures of over 20,000 degrees Celsius, appear bluish.

**Size** When you look at stars in the sky, they all appear to be points of light of the same size. Many stars are actually about the size of the sun, which is a medium-sized star. However, some stars are much larger than the sun. Very large stars are called giant stars or supergiant stars. If the supergiant star Betelgeuse were located where our sun is, it would be large enough to fill the solar system as far out as Jupiter.

Most stars are much smaller than the sun. White dwarf stars are about the size of Earth. Neutron stars are even smaller, only about 20 kilometers in diameter.

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FIGURE 5  
Star Size

Stars vary greatly in size. Giant stars are typically 10 to 100 times larger than the sun and more than 1,000 times the size of a white dwarf. Calculating *Betelgeuse* has a diameter of 420 million kilometers. How many times larger is this than the sun, which has a diameter of 1.4 million kilometers?

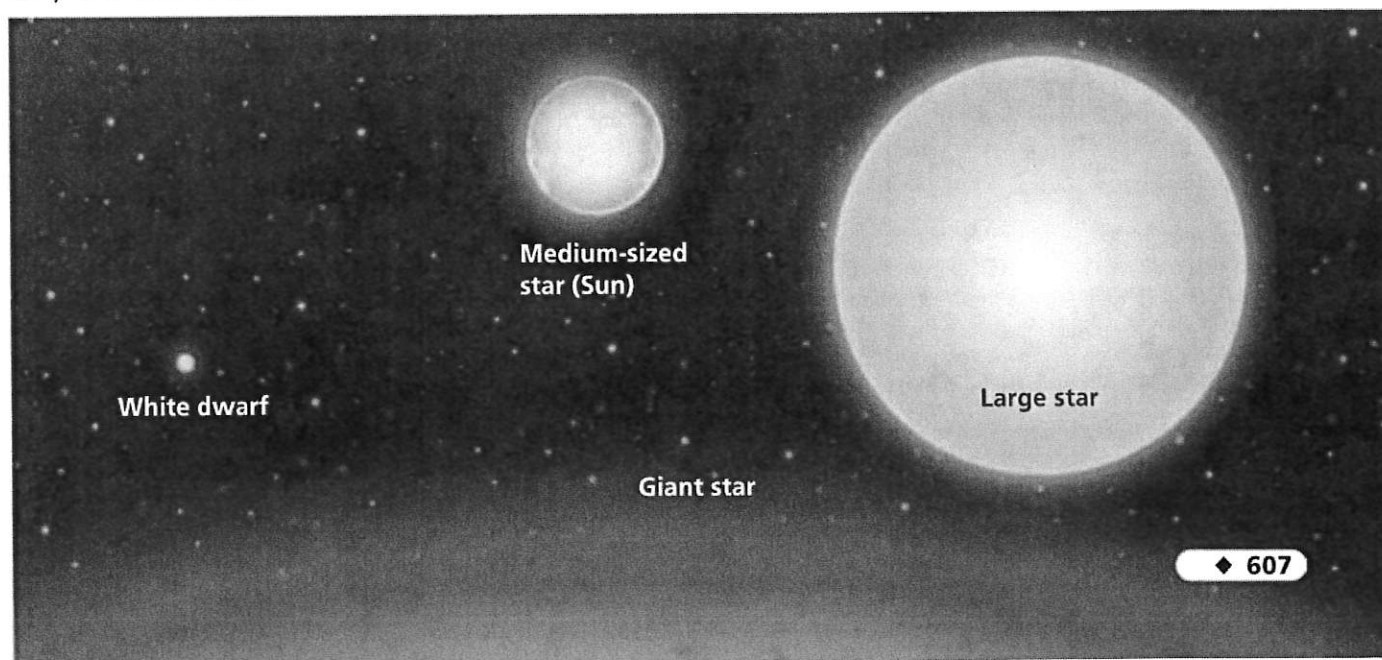
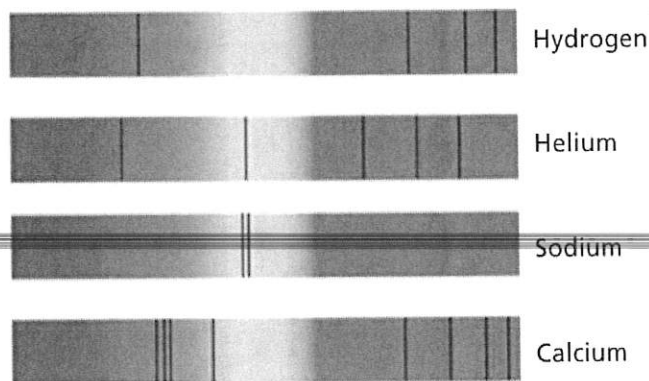


FIGURE 6

### Spectrums of Four Stars

Astronomers can use line spectrums to identify the chemical elements in a star. Each element produces a characteristic pattern of spectral lines.

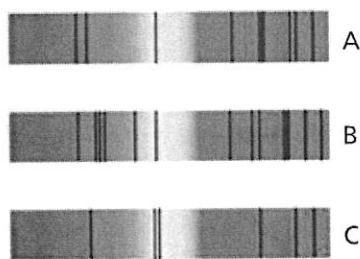


Lab  
zone

### Skills Activity

#### Inferring

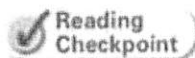
The lines on the spectrums below are from three different stars. Each of these star spectrums is made up of an overlap of spectrums from the individual elements shown in Figure 6. In star A, which elements have the strongest lines? Which are the strongest in star B? In star C?



**Chemical Composition** Stars vary in their chemical composition. The chemical composition of most stars is about 73 percent hydrogen, 25 percent helium, and 2 percent other elements by mass. This is similar to the composition of the sun.

Astronomers use spectrographs to determine the elements found in stars. A **spectrograph** (SPEK truh graf) is a device that breaks light into colors and produces an image of the resulting spectrum. Most large telescopes have spectrographs.

The gases in a star's atmosphere absorb some wavelengths of light produced within the star. When the star's light is seen through a spectrograph, each absorbed wavelength is shown as a dark line on a spectrum. Each chemical element absorbs light at particular wavelengths. Just as each person has a unique set of fingerprints, each element has a unique set of lines for a given temperature. Figure 6 shows the spectral lines of four elements. By comparing a star's spectrum with the spectrums of known elements, astronomers can infer how much of each element is found in the star.



What is a spectrograph?

### Brightness of Stars

Stars also differ in brightness, the amount of light they give off. **The brightness of a star depends upon both its size and temperature.** Recall that the photosphere is the layer of a star that gives off light. Betelgeuse is fairly cool, so a square meter of its photosphere doesn't give off much light. But Betelgeuse is very large, so it shines brightly.

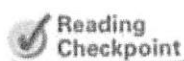
Rigel, on the other hand, is very hot, so each square meter of Rigel's photosphere gives off a lot of light. Even though it is smaller than Betelgeuse, Rigel shines more brightly.

How bright a star looks from Earth depends on both its distance from Earth and how bright the star truly is. Because of these two factors, the brightness of a star can be described in two ways: apparent brightness and absolute brightness.

**Apparent Brightness** A star's **apparent brightness** is its brightness as seen from Earth. Astronomers can measure apparent brightness fairly easily using electronic devices. However, astronomers can't tell how much light a star gives off just from the star's apparent brightness. Just as a flashlight looks brighter the closer it is to you, a star looks brighter the closer it is to Earth. For example, the sun looks very bright. This does not mean that the sun gives off more light than all other stars. The sun looks so bright simply because it is so close. In reality, the sun is a star of only average brightness.

**Absolute Brightness** A star's **absolute brightness** is the brightness the star would have if it were at a standard distance from Earth. Finding a star's absolute brightness is more complex than finding its apparent brightness. An astronomer must first find out both the star's apparent brightness and its distance from Earth. The astronomer can then calculate the star's absolute brightness.

Astronomers have found that the absolute brightness of stars can vary tremendously. The brightest stars are more than a billion times brighter than the dimmest stars!



What is a star's absolute brightness?

Lab  
zone

## Try This Activity

### Star Bright

You can compare absolute and apparent brightness.

1. Dim the lights. Put two equally bright flashlights next to each other on a table. Turn them on.
2. Look at the flashlights from the other side of the room. Think of the flashlights as two stars. Then compare them in terms of absolute and apparent brightness.
3. Move one of the flashlights closer to you and repeat Step 2.
4. Replace one of the flashlights with a brighter one. Repeat Steps 1 and 2 with the unequally bright flashlights.

**Making Models** How could you place the flashlights in Step 4 so that they have the same apparent brightness? Try it.



FIGURE 7

#### Absolute Brightness

The streetlights in this photo all give off about the same amount of light, and so have about the same absolute brightness. Applying Concepts *Why do the closer streetlights appear brighter than the more distant lights?*

## Measuring Distances to Stars

Imagine that you could travel to the stars at the speed of light. To travel from Earth to the sun would take about 8 minutes, not very much time for such a long trip. The next nearest star, Proxima Centauri, is much farther away. A trip to Proxima Centauri at the speed of light would take 4.2 years!

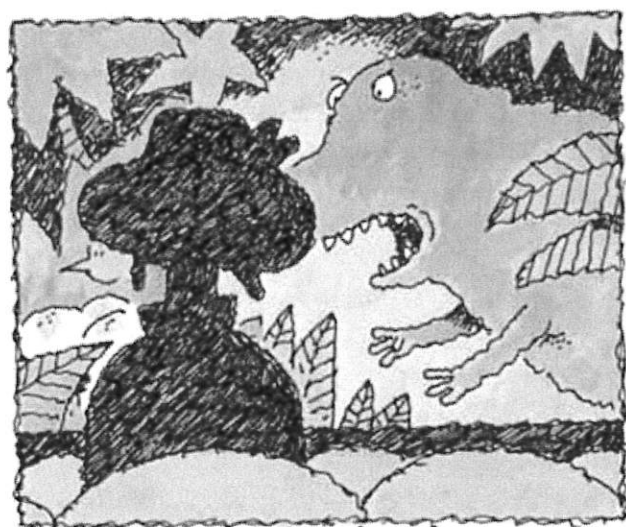
FIGURE 8

### Parallax at the Movies

You and your friend are sitting behind a woman with a large hat. Applying Concepts *Why is your view of the screen different from your friend's view?*



Your view



Your friend's view

**The Light-Year** Distances on Earth's surface are often measured in kilometers. However, distances to the stars are so large that kilometers are not very practical units. **Astronomers use a unit called the light-year to measure distances between the stars.** In space, light travels at a speed of about 300,000 kilometers per second. A **light-year** is the distance that light travels in one year, about 9.5 million million kilometers.

Note that the light-year is a unit of distance, not time. To help you understand this, consider an everyday example. If you bicycle at 10 kilometers per hour, it would take you 1 hour to go to a mall 10 kilometers away. You could say that the mall is "1 bicycle-hour" away.

**Parallax** Standing on Earth looking up at the sky, it may seem as if there is no way to tell how far away the stars are. However, astronomers have found ways to measure those distances. **Astronomers often use parallax to measure distances to nearby stars.**

**Parallax** is the apparent change in position of an object when you look at it from different places. For example, imagine that you and a friend have gone to a movie. A woman with a large hat sits down in front of you, as shown in Figure 8. Because you and your friend are sitting in different places, the woman's hat blocks different parts of the screen. If you are sitting on her left, the woman's hat appears to be in front of the large dinosaur. But to your friend on the right, she appears to be in front of the bird.

Have the woman and her hat moved? No. But because you changed your position, she appears to have moved. This apparent movement when you look from two different directions is parallax.



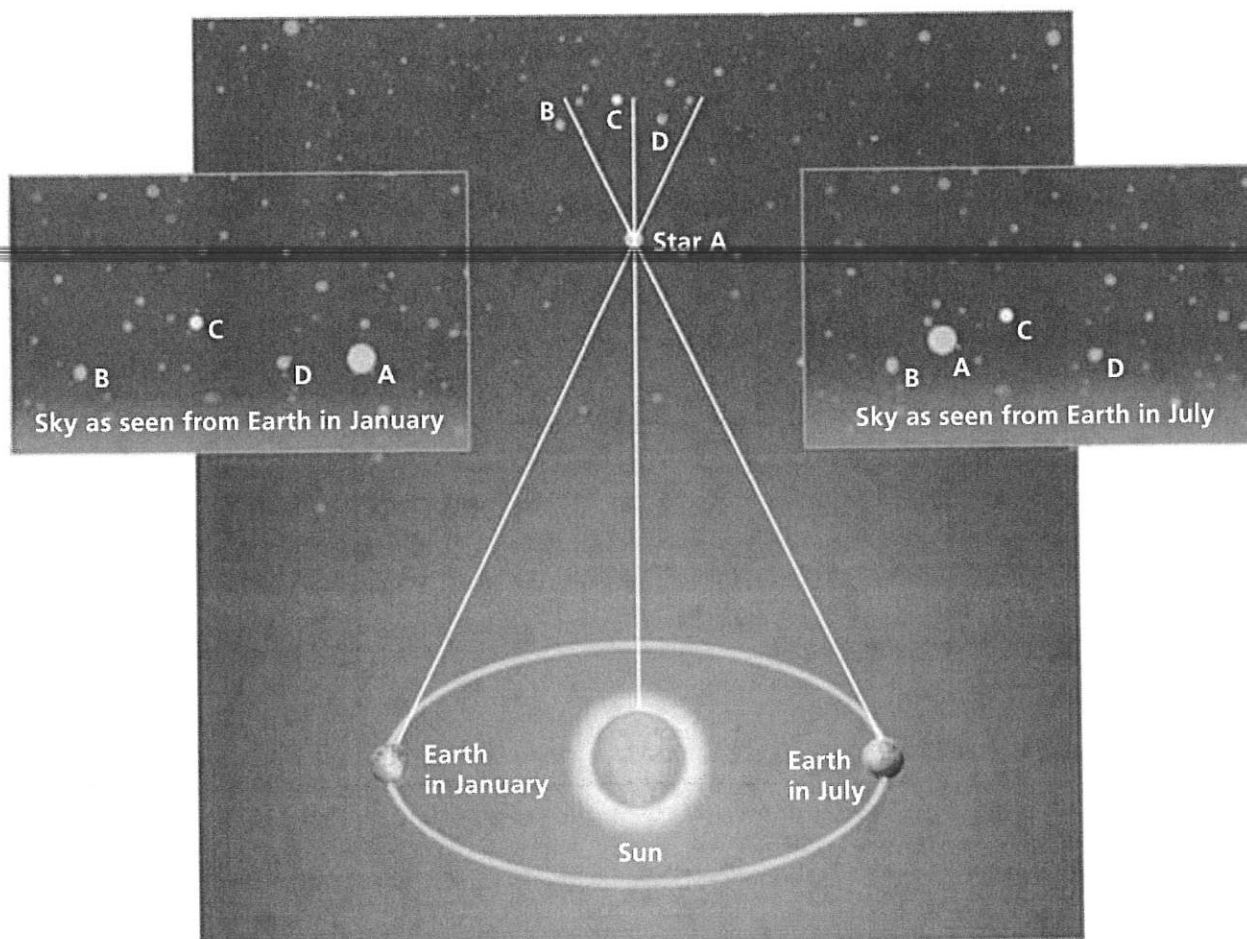


FIGURE 9

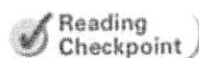
#### Parallax of Stars

The apparent movement of a star when seen from a different position is called parallax. Astronomers use parallax to calculate the distance to nearby stars. Note that the diagram is not to scale.

*Interpreting Diagrams* Why do nearby stars appear to change position between January and July?

**Parallax in Astronomy** Astronomers are able to measure the parallax of nearby stars to determine their distances. As shown in Figure 9, astronomers look at a nearby star when Earth is on one side of the sun. Then they look at the same star again six months later, when Earth is on the opposite side of the sun. Astronomers measure how much the nearby star appears to move against a background of stars that are much farther away. They can then use this measurement to calculate the distance to the nearby star. The less the nearby star appears to move, the farther away it is.

Astronomers can use parallax to measure distances up to a few hundred light-years from Earth. The parallax of any star that is farther away is too small to measure accurately.



Reading  
Checkpoint

How is parallax useful in astronomy?



## The Hertzsprung-Russell Diagram

About 100 years ago, two scientists working independently made the same discovery. Both Ejnar Hertzsprung (EYE nahr HURT sprung) in Denmark and Henry Norris Russell in the United States made graphs to find out if the temperature and the absolute brightness of stars are related. They plotted the surface temperatures of stars on the  $x$ -axis and their absolute brightness on the  $y$ -axis. The points formed a pattern. The graph they made is still used by astronomers today. It is called the **Hertzsprung-Russell diagram**, or H-R diagram.

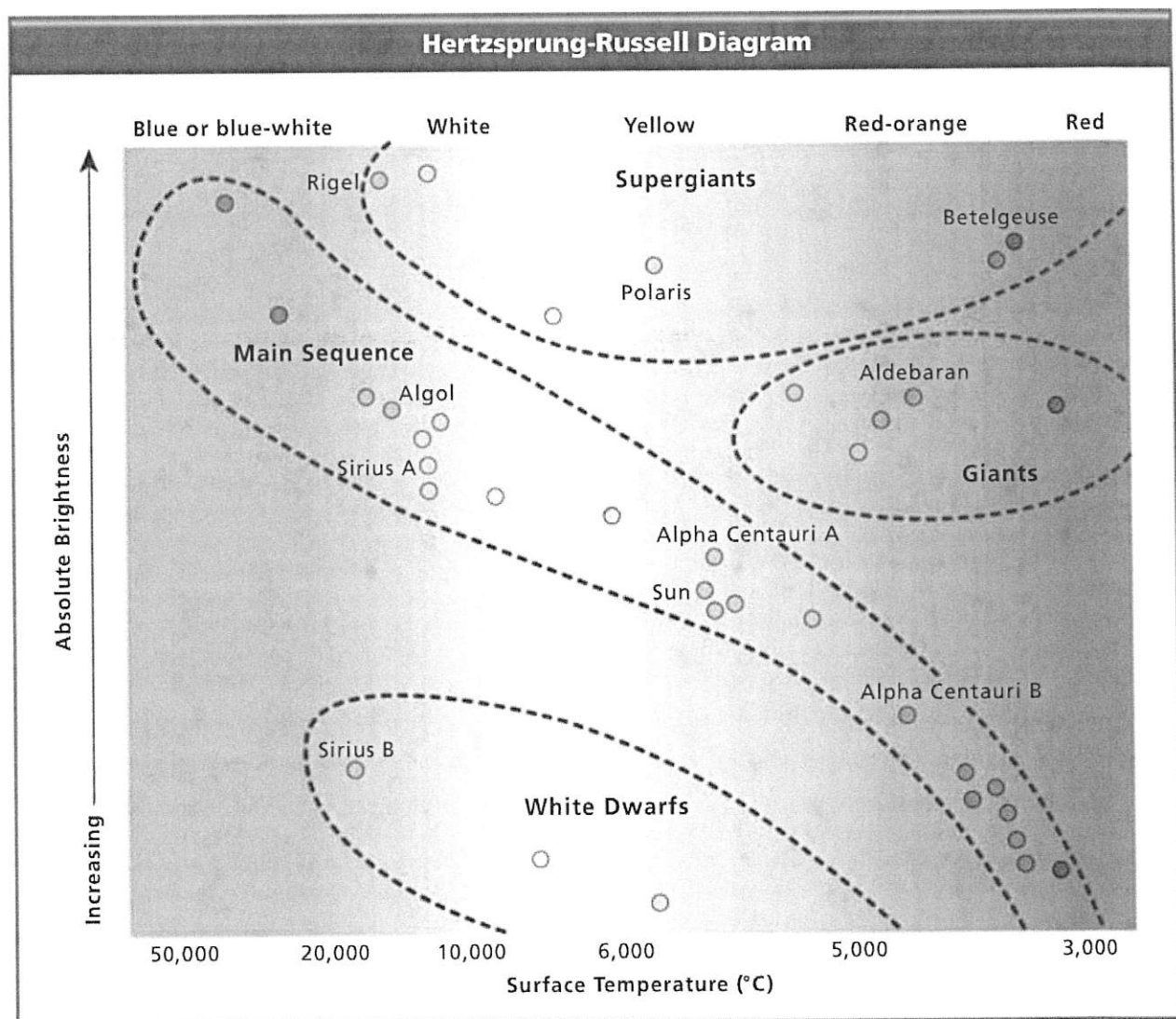


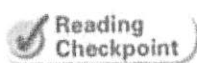
FIGURE 10

The Hertzsprung-Russell diagram shows the relationship between the surface temperature and absolute brightness of stars.

**Interpreting Diagrams** Which star has a hotter surface: Rigel or Aldebaran?

Astronomers use H-R diagrams to classify stars and to understand how stars change over time. As you can see in Figure 10, most of the stars in the H-R diagram form a diagonal area called the **main sequence**. More than 90 percent of all stars, including the sun, are main-sequence stars. Within the main sequence, surface temperature increases as absolute brightness increases. Thus, hot bluish stars are located at the left of an H-R diagram and cooler red-dish stars are located at the right of the diagram.

The brightest stars are located near the top of an H-R diagram, while the dimmest stars are located at the bottom. Giant and supergiant stars are very bright. They can be found near the top center and right of the diagram. White dwarfs are hot, but not very bright, so they appear at the bottom left or bottom center of the diagram.



Reading  
Checkpoint

What is the main sequence?

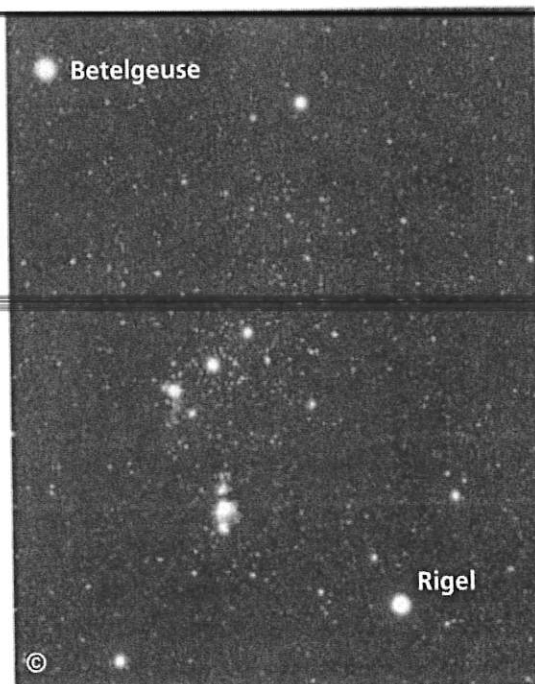


FIGURE 11

Orion

Orion includes the red supergiant Betelgeuse, the blue supergiant Rigel, and many other main-sequence and giant stars.

## Section 2 Assessment



### Target Reading Skill Using Prior Knowledge

Review your graphic organizer and revise it based on what you just learned in the section.

### Reviewing Key Concepts

HINT

1. a. **Listing** Name three characteristics used to classify stars.

HINT

- b. **Comparing and Contrasting** What is the difference between apparent brightness and absolute brightness?

- c. **Applying Concepts** Stars A and B have about the same apparent brightness, but Star A is about twice as far from Earth as Star B. Which star has the greater absolute brightness? Explain your answer.

HINT

2. a. **Measuring** What is a light-year?

HINT

- b. **Defining** What is parallax?

HINT

- c. **Predicting** Vega is 25.3 light-years from Earth and Arcturus is 36.7 light-years away. Which star would have a greater parallax? Explain.

3. a. **Summarizing** What two characteristics of stars are shown in an H-R diagram?

HINT

- b. **Identifying** Identify two ways in which astronomers can use an H-R diagram.

HINT

- c. **Classifying** The star Procyon B has a surface temperature of  $6,600^{\circ}\text{C}$  and an absolute brightness that is much less than the sun's. What type of star is Procyon B? (*Hint:* Refer to the H-R diagram.)

HINT

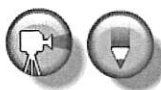
Lab  
zone

### At-Home Activity

**Observing Orion** With adult family members, go outside on a clear, dark night. Determine which way is south. Using the star charts in the appendix, look for the constellation Orion, which is visible in the evening during winter and spring. Find the stars Betelgeuse and Rigel in Orion and explain to your family why they are different colors.



# How Far Is That Star?



## Problem

How can parallax be used to determine distances?

## Skills Focus

inferring, calculating, predicting

## Materials

- masking tape • paper clips • pen
- black and red pencils • metric ruler • paper
- meter stick • calculator
- lamp without a shade, with 100-watt light bulb
- copier paper box (without the lid)
- flat rectangular table, about 1 m wide

## Procedure



### PART 1 Telescope Model

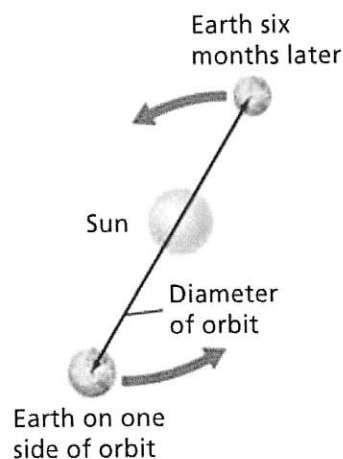
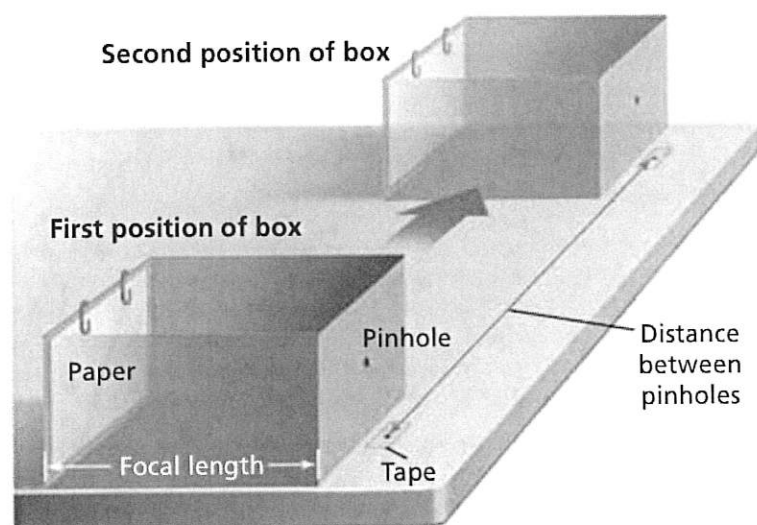
1. Place the lamp on a table in the middle of the classroom.
2. Carefully use the tip of the pen to make a small hole in the middle of one end of the box. The box represents a telescope.

3. At the front of the classroom, place the box on a flat table so the hole points toward the lamp. Line the left side of the box up with the left edge of the table.

4. Put a small piece of tape on the table below the hole. Use the pen to make a mark on the tape directly below the hole. The mark represents the position of the telescope when Earth is on one side of its orbit.

### PART 2 Star 1

5. Label a sheet of paper Star 1 and place it inside the box as shown in the drawing. Hold the paper in place with two paper clips. The paper represents the film in a telescope.
6. Darken the room. Turn on the light to represent the star.
7. With the red pencil, mark the paper where you see a dot of light. Label this dot A. Dot A represents the image of the star on the film.
8. Move the box so the right edge of the box lines up with the right edge of the table. Repeat Step 4. The mark on the tape represents the position of the telescope six months later, when Earth is on the other side of its orbit.



Data Table						
Star	Parallax Shift (mm)	Focal Length (mm)	Diameter of Orbit (mm)	Calculated Distance to Star (mm)	Calculated Distance to Star (m)	Actual Distance to Star (m)

- Repeat Step 7, using a black pencil to mark the second dot B. Dot B represents the image of the star as seen 6 months later from the other side of Earth's orbit.
- Remove the paper. Before you continue, copy the data table into your notebook.
- Measure and record the distance in millimeters between dots A and B. This distance represents the parallax shift for Star 1.
- Measure and record the distance from the hole in the box to the lamp. This distance represents the actual distance to the star.
- Measure and record the distance from the hole (lens) to the back of the box in millimeters. This distance represents the focal length of your telescope.
- Measure and record the distance in millimeters between the marks on the two pieces of masking tape. This distance represents the diameter of Earth's orbit.

### PART 3 Stars 2 and 3

- Move the lamp away from the table—about half the distance to the back of the room. The bulb now represents Star 2. Predict what you think will happen to the light images on your paper.
- Repeat Steps 6–12 with a new sheet of paper to find the parallax shift for Star 2.
- Move the lamp to the back of the classroom. The bulb now represents Star 3. Repeat Steps 6–12 with a new sheet of paper to find the parallax shift for Star 3.

## Analyze and Conclude

- Inferring** What caused the apparent change in position of the dots of light for each star? Explain.
- Calculating** Use the following formula to calculate the distance from the telescope to Star 1.  

$$\text{Distance} = \frac{\text{Diameter} \times \text{Focal length}}{\text{Parallax shift}}$$
- Calculating** Divide your result from Question 2 by 1,000 to get the distance to the light bulb in meters.
- Calculating** Repeat Questions 2 and 3 for Stars 2 and 3.
- Predicting** Was your prediction in Step 15 correct? Why or why not?
- Interpreting Data** How did your calculation for Star 3 compare with the actual distance? What could you do to improve your results?
- Communicating** Write a paragraph that explains how parallax shift varies with distance. Relate each star's parallax shift to its distance from Earth.

## Design an Experiment

What would happen if you kept moving the lamp away from the box? Is there a distance at which you can no longer find the distance to the star? Design an experiment to find out.



# Lives of Stars

## Reading Preview

### Key Concepts

- How does a star form?
- What determines how long a star will exist?
- What happens to a star when it runs out of fuel?

### Key Terms

- nebula • protostar
- planetary nebula
- white dwarf • supernova
- neutron star • pulsar
- black hole

## Target Reading Skill

**Sequencing** As you read, make a flowchart like the one below that shows the stages in the life of a star like the sun. Write each step of the process in a separate box in the flowchart in the order that it occurs.

### Life Cycle of a Sun-like Star

Protostar forms from a nebula.



A star is born as fusion begins.

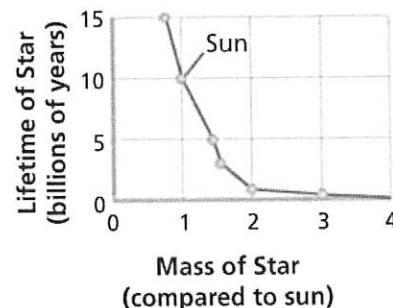


Lab  
zone

## Discover Activity

### What Determines How Long Stars Live?

1. This graph shows how the mass of a star is related to its lifetime—how long the star lives before it runs out of fuel.
2. How long does a star with 0.75 times the mass of the sun live? How long does a star with 3 times the mass of the sun live?

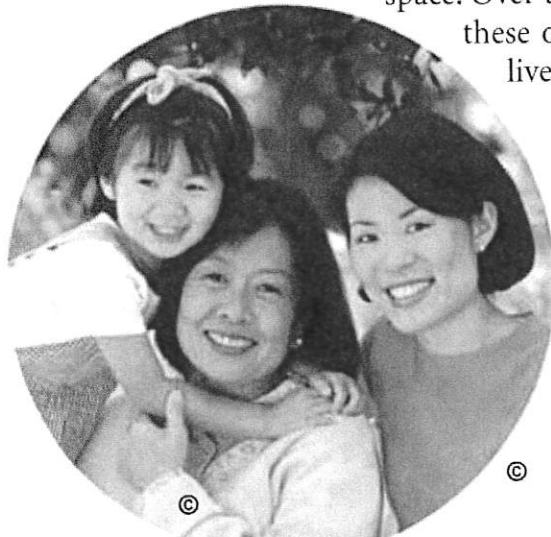


### Think It Over

**Drawing Conclusions** Describe the general relationship between a star's mass and its lifetime.

Imagine that you want to study how people age. You wish you could watch a few people for 50 years, but your project is due next week! You have to study a lot of people for a short time, and classify the people into different age groups. You may come up with groups like *babies*, *young adults*, and *elderly people*. You don't have time to see a single person go through all these stages, but you know the stages exist.

Astronomers have a similar problem in trying to understand how stars age. They can't watch a single star for billions of years. Instead, they study many stars and other objects in space. Over time, astronomers have figured out that these objects represent different stages in the lives of stars.



◀ Three generations





## The Lives of Stars

Stars do not last forever. Each star is born, goes through its life cycle, and eventually dies. (Of course, stars are not really alive. The words *born*, *live*, and *die* are just helpful comparisons.)

**A Star Is Born** All stars begin their lives as parts of nebulae. A **nebula** is a large cloud of gas and dust spread out in an immense volume. A star, on the other hand, is made up of a large amount of gas in a relatively small volume.

In the densest part of a nebula, gravity pulls gas and dust together. A contracting cloud of gas and dust with enough mass to form a star is called a **protostar**. *Proto* means “earliest” in Greek, so a protostar is the earliest stage of a star’s life.

**A star is born when the contracting gas and dust from a nebula become so dense and hot that nuclear fusion starts.** Recall that nuclear fusion is the process by which atoms combine to form heavier atoms. In the sun, for example, hydrogen atoms combine to form helium. During nuclear fusion, enormous amounts of energy are released. Nuclear fusion has not yet begun in a protostar.

**Lifetimes of Stars** How long a star lives depends on its **mass**. You might think that stars with more mass would last longer than stars with less mass. But the reverse is true. You can think of stars as being like cars. A small car has a small gas tank, but it also has a small engine that burns gas slowly. A large car has a larger gas tank, but it also has a larger engine that burns gas rapidly. So the small car can travel farther on a tank of gas than the larger car. Small-mass stars use up their fuel more slowly than large-mass stars, so they have much longer lives.

Generally, stars that have less mass than the sun use their fuel slowly, and can live for up to 200 billion years. Medium-mass stars like the sun live for about 10 billion years. Astronomers think the sun is about 4.6 billion years old, so it is almost halfway through its lifetime.

Stars that have more mass than the sun have shorter lifetimes. A star that is 15 times as massive as the sun may live only about ten million years. That may seem like a long time, but it is only one tenth of one percent of the lifetime of the sun.



Reading  
Checkpoint

How long will a star that is the mass of the sun live?

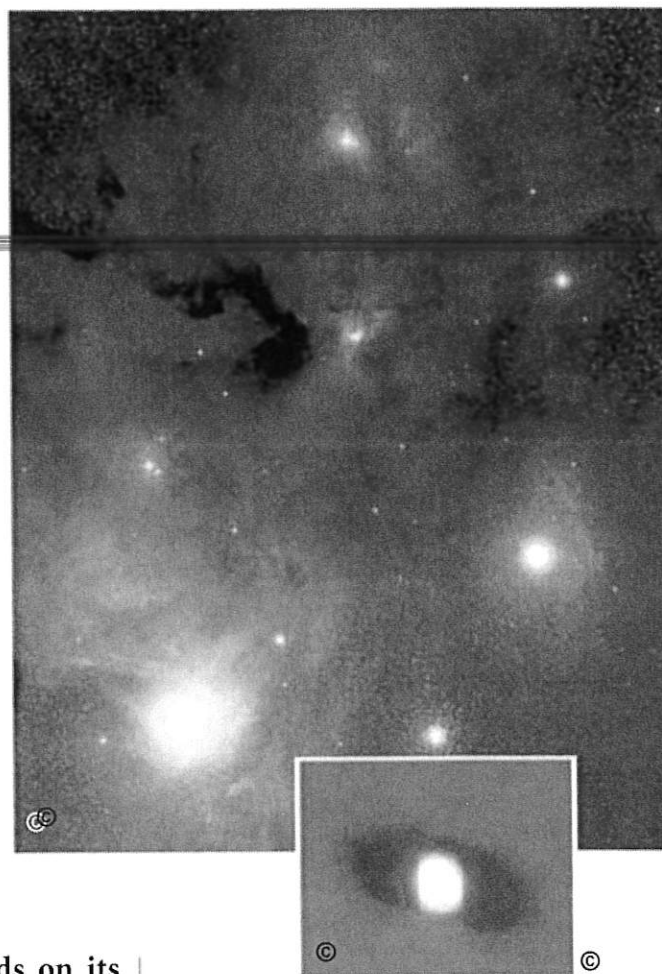


FIGURE 12  
Young Stars

New stars are forming in the nebula on top. The bottom photo shows a protostar in the Orion Nebula. Applying Concepts *How do some of the gas and dust in a nebula become a protostar?*

**Discovery**  
CHANNEL  
**SCHOOL**

*Stars, Galaxies,  
and the Universe*

Video Preview

► Video Field Trip

Video Assessment

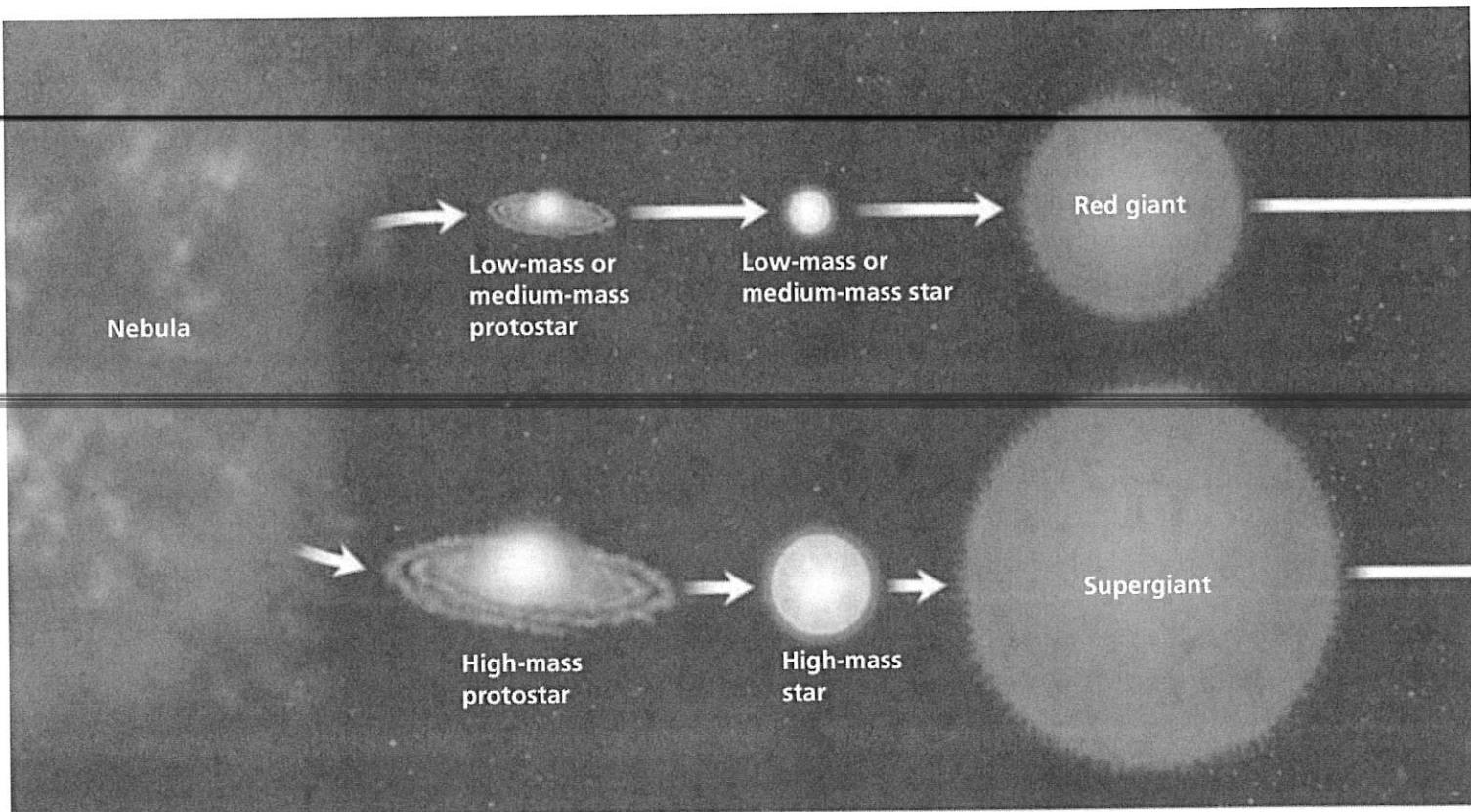


FIGURE 13

## The Lives of Stars

A star's life history depends on its mass. A low-mass main-sequence star uses up its fuel slowly and eventually becomes a white dwarf. A high-mass star uses up its fuel quickly. After its supergiant stage, it will explode as a supernova, producing a neutron star or a black hole.

**Interpreting Diagrams** What type of star produces a planetary nebula?

## Deaths of Stars

When a star begins to run out of fuel, its core shrinks and its outer portion expands. Depending on its mass, the star becomes either a red giant or a supergiant. All main-sequence stars eventually become red giants or supergiants. As shown in Figure 13, red giants and supergiants evolve in very different ways. **After a star runs out of fuel, it becomes a white dwarf, a neutron star, or a black hole.**

**White Dwarfs** Low-mass stars and medium-mass stars like the sun take billions of years to use up their nuclear fuel. As they start to run out of fuel, their outer layers expand, and they become red giants. Eventually, the outer parts grow larger still and drift out into space, forming a glowing cloud of gas called a **planetary nebula**. Many planetary nebula, such as the Cat's Eye Nebula on page 627, are spectacular in their beauty. The blue-white core of the star that is left behind cools and becomes a **white dwarf**.

White dwarfs are only about the size of Earth, but they have about as much mass as the sun. Since a white dwarf has the same mass as the sun but only one millionth the volume, it is one million times as dense as the sun. A spoonful of material from a white dwarf has as much mass as a large truck. White dwarfs have no fuel, but they continue to glow faintly for billions of years from leftover energy.

Lab  
zone

### Skills Activity

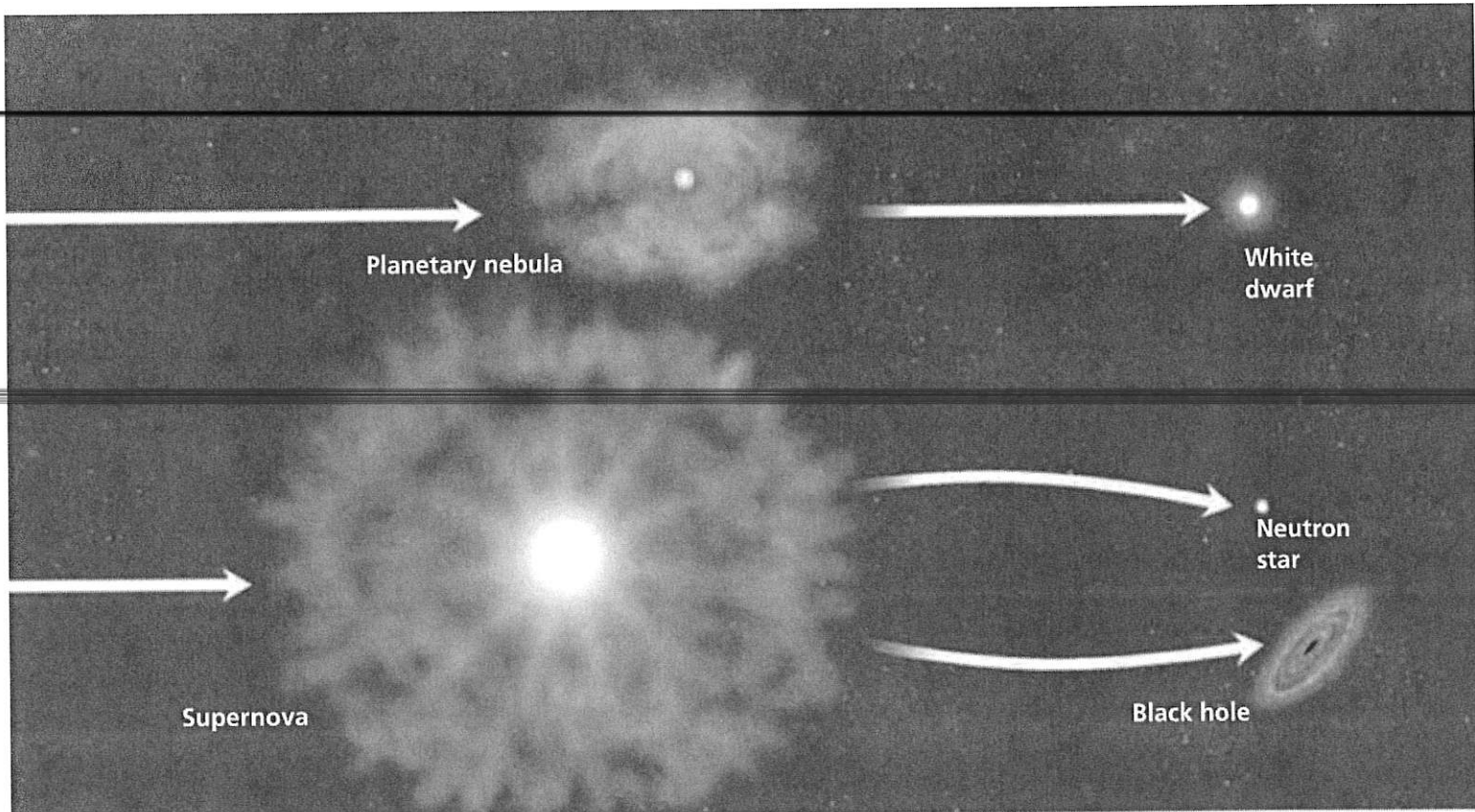
#### Predicting

Find Algol, Sirius B, and Polaris in Figure 10, the H-R diagram. What type of star is each of these now? Predict what the next stage in each star's life will be.



Reading  
Checkpoint

What is a white dwarf?



**Supernovas** The life cycle of a high-mass star is quite different from the life cycle of a low-mass or medium-mass star. High-mass stars quickly evolve into brilliant supergiants. When a supergiant runs out of fuel, it can explode suddenly. Within hours, the star blazes millions of times brighter. The explosion is called a **supernova**. After a supernova, some of the material from the star expands into space. This material may become part of a nebula. This nebula can then contract to form a new, partly recycled star. Astronomers think the sun began as a nebula that contained material from a supernova.

**Neutron Stars** After a supergiant explodes, some of the material from the star is left behind. This material may form a neutron star. **Neutron stars** are the remains of high-mass stars. They are even smaller and denser than white dwarfs. A neutron star may contain as much as three times the mass of the sun but be only about 25 kilometers in diameter, the size of a city.

In 1967, Jocelyn Bell, a British astronomy student, detected an object in space that appeared to give off regular pulses of radio waves. Some astronomers hypothesized that the pulses might be a signal from an extraterrestrial civilization. At first, astronomers even named the source LGM, for the “Little Green Men” in early science-fiction stories. Soon, however, astronomers concluded that the source of the radio waves was really a rapidly spinning neutron star. Spinning neutron stars are called **pulsars**, short for pulsating radio sources. Some pulsars spin hundreds of times per second!

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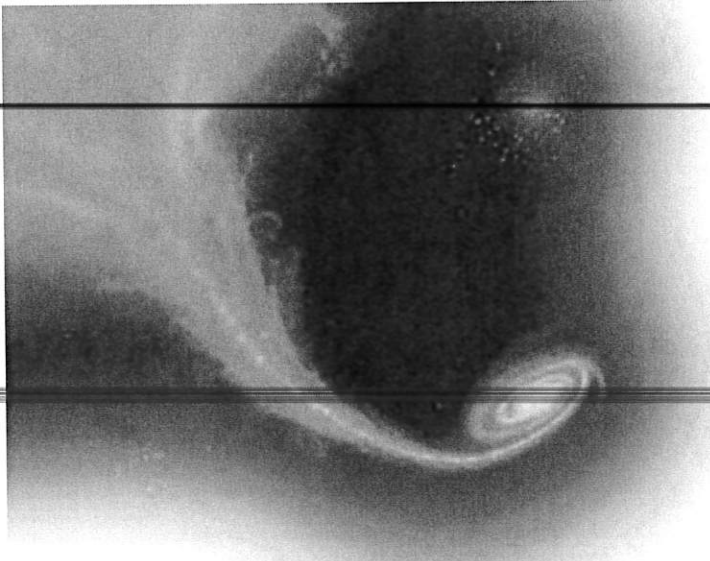
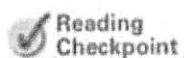


FIGURE 14  
**Black Holes**

The remains of the most massive stars collapse into black holes. This artist's impression shows a black hole pulling matter from a companion star. The material glows as it is pulled into the black hole. Applying Concepts *If it is impossible to detect a black hole directly, how do astronomers find them?*

**Black Holes** The most massive stars—those having more than 40 times the mass of the sun—may become black holes when they die. A **black hole** is an object with gravity so strong that nothing, not even light, can escape. After a very massive star dies in a supernova explosion, more than five times the mass of the sun may be left. The gravity of this mass is so strong that the gas is pulled inward, packing the gas into a smaller and smaller space. The gas becomes so densely packed that its intense gravity will not allow even light to escape. The remains of the star have become a black hole.


No light, radio waves, or any other form of radiation can ever get out of a black hole, so it is not possible to detect a black hole directly. But astronomers can detect black holes indirectly. For example, gas near a black hole is pulled so strongly that it revolves faster and faster around the black hole. Friction heats the gas up. Astronomers can detect X-rays coming from the hot gas and infer that a black hole is present. Similarly, if another star is near a black hole, astronomers can calculate the mass of the black hole from the effect of its gravity on the star. Scientists have detected dozens of star-size black holes with the Chandra X-ray Observatory. They have also detected huge black holes that are millions or billions of times the sun's mass.



Reading  
Checkpoint

What is a black hole?

## Section 3 Assessment

 **Target Reading Skill Sequencing** Refer to your flowchart as you answer the questions.

### Reviewing Key Concepts

- HINT** 1. a. Defining What is a nebula?
- HINT** b. Explaining How does a star form from a nebula?
- c. Comparing and Contrasting How is a protostar different from a star?
- HINT** 2. a. Identifying What factor determines how long a star lives?
- HINT** b. Applying Concepts A star is twice as massive as the sun. Will its lifespan be longer, shorter, or the same as that of the sun?
- HINT** 3. a. Comparing and Contrasting What is a white dwarf? How is it different from a neutron star?

- b. Relating Cause and Effect Why do some stars become white dwarfs and others become neutron stars or black holes?
- c. Predicting What will happen to the sun when it runs out of fuel? Explain.

**HINT**

**HINT**

### Writing in Science

**Descriptive Paragraph** Write a description of one of the stages in the life of a star, such as a nebula, red giant, supernova, or white dwarf. Include information on how it formed and what will happen next in the star's evolution.





# Star Systems and Galaxies

## Reading Preview

### Key Concepts

- What is a star system?
- What are the major types of galaxies?
- How do astronomers describe the scale of the universe?

### Key Terms

- binary star
- eclipsing binary
- open cluster
- globular cluster
- galaxy
- spiral galaxy
- elliptical galaxy
- irregular galaxy
- quasar
- universe
- scientific notation

Lab  
zone

## Discover Activity

### Why Does the Milky Way Look Hazy?

1. Using a pencil, carefully poke at least 20 holes close together in a sheet of white paper.
2. Tape the paper to a chalkboard or dark-colored wall.
3. Go to the other side of the room and look at the paper. From the far side of the room, what do the dots look like? Can you see individual dots?

### Think It Over

**Making Models** How is looking at the paper from the far side of the room like trying to see many very distant stars that are close together? How does your model compare to the photograph of the Milky Way below?



## Target Reading Skill

**Building Vocabulary** Carefully read the definition of each key term. Also read the neighboring sentences. Then write a definition of each key term in your own words.

On a clear, dark night in the country, you can see a hazy band of light stretched across the sky. This band of stars is called the Milky Way. It looks as if the Milky Way is very far away. Actually, though, Earth is inside the Milky Way! The Milky Way looks milky or hazy from Earth because the stars are too close together for your eyes to see them individually. The dark blotches in the Milky Way are clouds of dust that block light from stars behind them.

The Milky Way





FIGURE 15

#### Invisible Partners

If you saw someone dancing but couldn't see a partner, you could infer that the partner was there by watching the dancer you could see. Astronomers use a similar method to detect faint stars in star systems.

## Star Systems and Clusters

Our solar system has only one star, the sun. But this is not the most common situation for stars. **Most stars are members of groups of two or more stars, called star systems.** If you were on a planet in one of these star systems, at times you might see two or more suns in the sky! At other times, one or more of these suns would be below the horizon.

**Multiple Star Systems** Star systems that have two stars are called double stars or **binary stars**. (The prefix *bi* means "two.") Those with three stars are called triple stars. The nearby star Proxima Centauri may be part of a triple star system. The other two stars in the system, Alpha Centauri A and Alpha Centauri B, form a double star. Scientists are not sure whether Proxima Centauri is really part of the system or is just passing close to the other two stars temporarily.

Often one star in a binary star is much brighter and more massive than the other. Astronomers can sometimes detect a binary star even if only one of the stars can be seen from Earth. Astronomers can often tell that there is a dim star in a binary system by observing the effects of its gravity. As the dim companion star revolves around a bright star, the dim star's gravity causes the bright star to wobble back and forth. Imagine watching a pair of dancers who are twirling each other around. Even if one dancer were invisible, you could tell that the invisible dancer was there from watching the motion of the visible dancer.

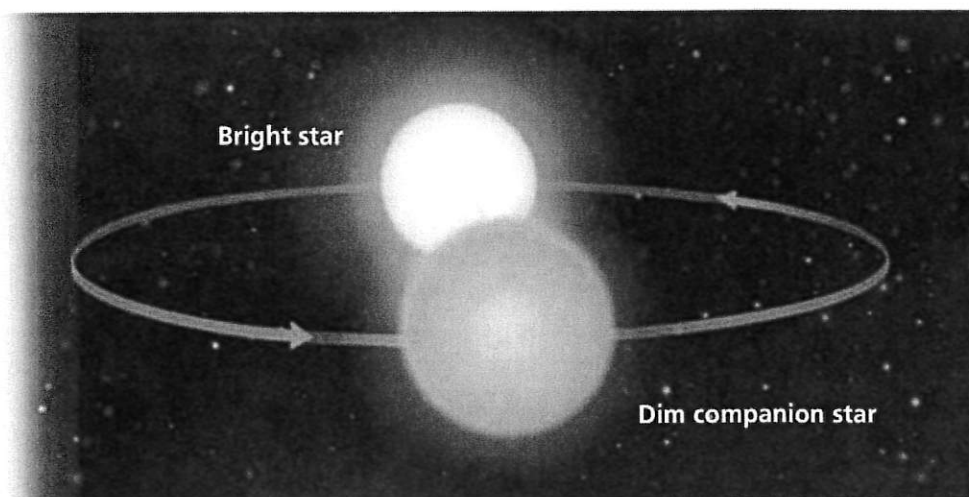
**Eclipsing Binaries** A wobble is not the only clue that a star has a dim companion. A dim star in a binary star may pass in front of a brighter star and eclipse it. From Earth, the binary star would suddenly look much dimmer. A system in which one star periodically blocks the light from another is called an **eclipsing binary**. As Figure 16 shows, the star Algol is actually an eclipsing binary star system.

FIGURE 16

#### Eclipsing Binary

Algol is an eclipsing binary star system consisting of a bright star and a dim companion. Each time the dimmer star passes in front of the brighter one, Algol appears less bright.

*Interpreting Diagrams* When does Algol appear brighter?



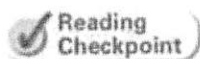
**Planets Around Other Stars** In 1995, astronomers first discovered a planet revolving around another ordinary star. They used a method similar to the one used in studying binary stars. The astronomers observed that a star was moving slightly toward and away from us. They knew that the invisible object causing the movement didn't have enough mass to be a star. They inferred that it must be a planet.

Since then, astronomers have discovered more than 100 planets around other stars, and new ones are being discovered all of the time. Most of these new planets are very large, with at least half of the mass of Jupiter. A small planet would be hard to detect because it would have little gravitational effect on the star it orbited.

Could there be life on planets in other solar systems? Some scientists think it is possible. A few astronomers are using radio telescopes to search for signals that could not have come from natural sources. Such a signal might be evidence that an extra-terrestrial civilization was sending out radio waves.

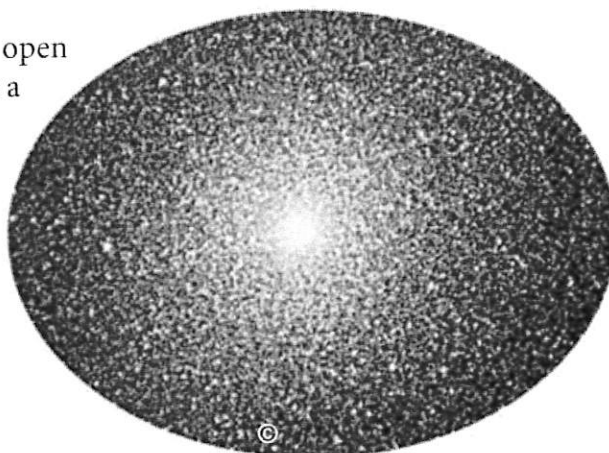
**Star Clusters** Many stars belong to larger groupings called star clusters. All of the stars in a particular cluster formed from the same nebula at about the same time and are about the same distance from Earth.

There are two major types of star clusters: open clusters and globular clusters. **Open clusters** have a loose, disorganized appearance and contain no more than a few thousand stars. They often contain many bright supergiants and much gas and dust. In contrast, **globular clusters** are large groupings of older stars. Globular clusters are round and densely packed with stars—some may contain more than a million stars.



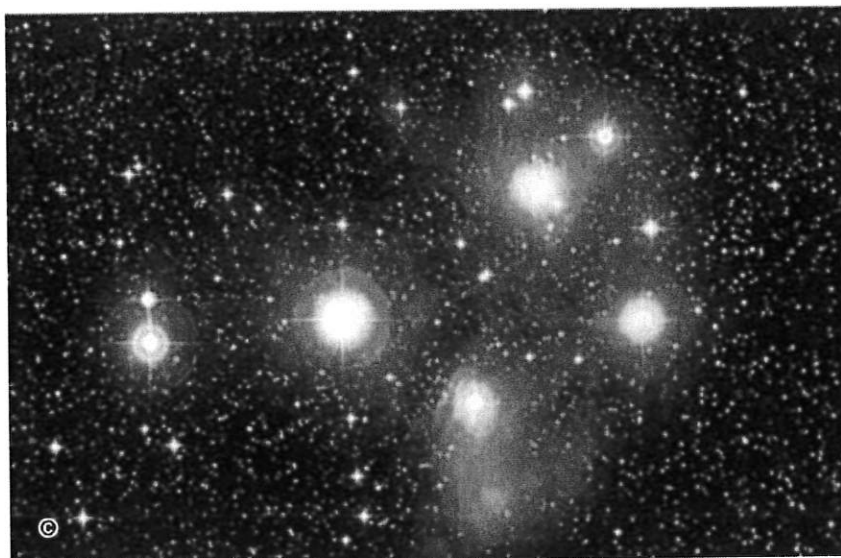
Reading  
Checkpoint

What is a globular cluster?

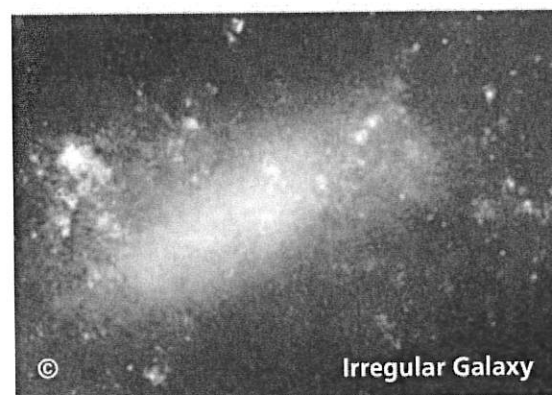
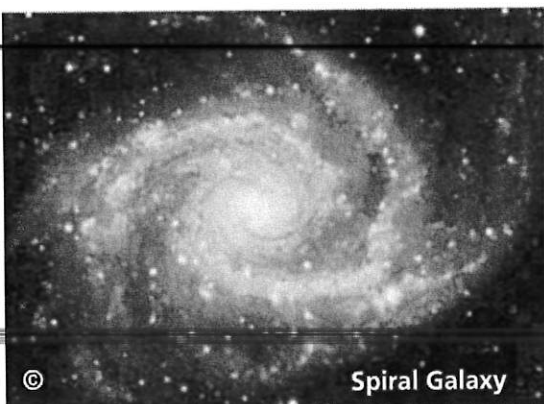


**FIGURE 17**  
**Star Clusters**

The stars in a globular cluster (above) are all about the same age and the same distance from Earth. The Pleiades (left), also called the *Seven Sisters*, is an open cluster.







**FIGURE 18**  
**Types of Galaxies**  
There are three major types of galaxies: spiral, elliptical, and irregular.

## Galaxies

A **galaxy** is a huge group of single stars, star systems, star clusters, dust, and gas bound together by gravity. There are billions of galaxies in the universe. The largest galaxies have more than a trillion stars. **Astronomers classify most galaxies into the following types: spiral, elliptical, and irregular.** Figure 18 shows examples of these three.

**Spiral Galaxies** Some galaxies appear to have a bulge in the middle and arms that spiral outward, like pinwheels. Such galaxies are called **spiral galaxies**. The spiral arms contain many bright, young stars as well as gas and dust. Most new stars in spiral galaxies form in these spiral arms. Relatively few new stars are forming in the central bulge. Some spiral galaxies, called barred-spiral galaxies, have a huge bar-shaped region of stars and gas that passes through their center.

**Elliptical Galaxies** Not all galaxies have spiral arms. **Elliptical galaxies** look like round or flattened balls. These galaxies contain billions of stars but have little gas and dust between the stars. Because there is little gas or dust, stars are no longer forming. Most elliptical galaxies contain only old stars.

**Irregular Galaxies** Some galaxies do not have regular shapes. These are known as **irregular galaxies**. Irregular galaxies are typically smaller than other types of galaxies. They generally have many bright, young stars and lots of gas and dust to form new stars.

**Quasars** In the 1960s, astronomers discovered objects that are very bright, but also very far away. Many of these objects are 10 billion light-years or more away, making them among the most distant objects in the universe. These distant, enormously bright objects looked almost like stars. Since *quasi* means “something like” in Latin, these objects were given the name quasi-stellar objects, or **quasars**.

What could be so bright at such a great distance from Earth? Astronomers have concluded that quasars are active young galaxies with giant black holes at their centers. Each of these black holes has a mass a billion times or more as great as that of the sun. As enormous amounts of gas revolve around the black hole, the gas heats up and shines brightly.

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For: Links on galaxies  
Visit: [www.SciLinks.org](http://www.SciLinks.org)  
Web Code: scn-0644



Reading  
Checkpoint

What is a quasar?



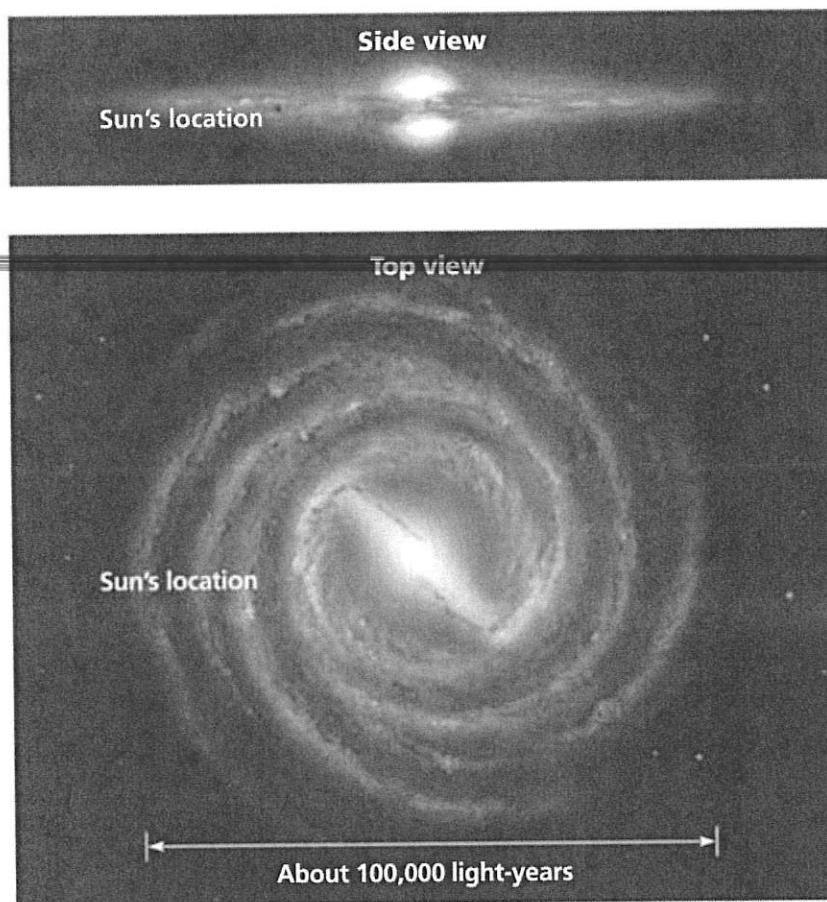


FIGURE 19

### Structure of the Milky Way

From the side, the Milky Way appears to be a narrow disk with a bulge in the middle. The galaxy's spiral structure is visible only from above or below the galaxy.

**Interpreting Diagrams** *Where in the galaxy is the sun located?*

## The Milky Way

Our solar system is located in a spiral galaxy called the Milky Way. As Figure 19 shows, the shape of the Milky Way varies depending on your vantage point. From the side, the Milky Way would look like a narrow disk with a large bulge in the middle. But from the top or bottom, the Milky Way would have a spiral, pinwheel shape. You can't see the spiral shape of the Milky Way from Earth because our solar system is inside the galaxy in one of the spiral arms.

The Milky Way is usually thought of as a standard spiral galaxy. However, recent evidence suggests that the Milky Way is a barred-spiral galaxy instead.

When you see the Milky Way at night during the summer, you are looking toward the center of our galaxy. The center of the galaxy is about 25,000 light-years away, but it is hidden from view by large clouds of dust and gas. However, astronomers can study the center using X-rays, infrared radiation, and radio waves.



Reading  
Checkpoint

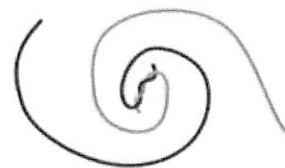
How far away is the center of the galaxy?

Lab  
zone

### Try This Activity

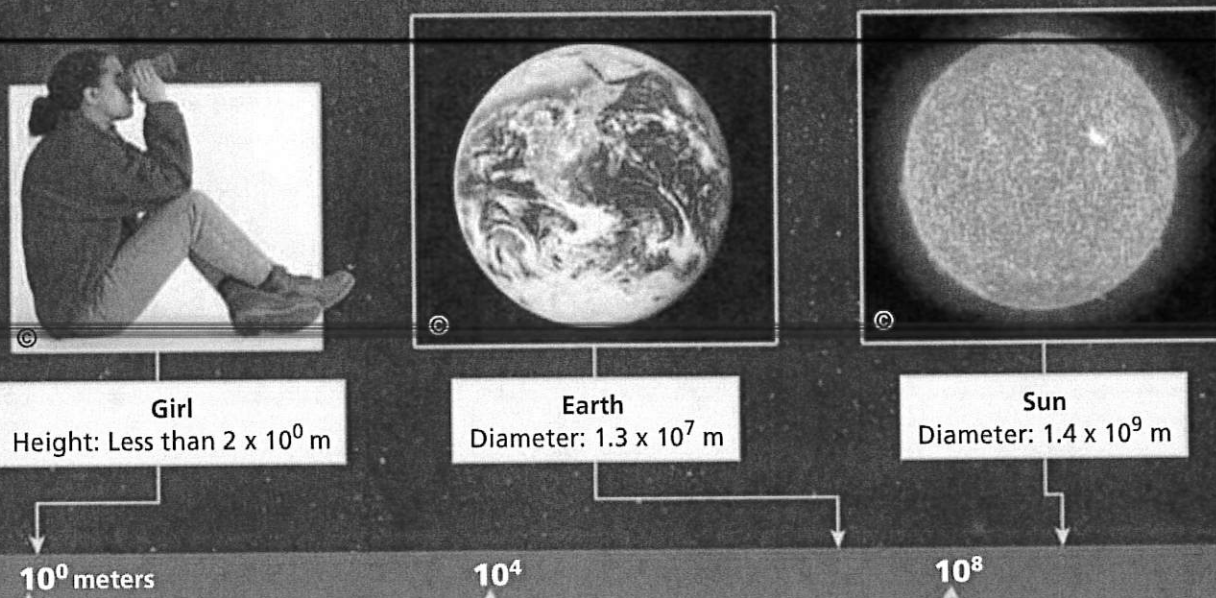
#### A Spiral Galaxy

You can make a model of our galaxy.



1. Using pipe cleaners, make a pinwheel with two spirals.
2. View the spirals along the surface of the table. Sketch what you see.
3. Next, view the spirals from above the table and sketch them.

**Observing** The sun is inside a flat spiral galaxy. From Earth's position on the flat surface, is it possible to get a good view of stars in the spiral arms? Why or why not?



## Math Skills

### Scientific Notation

The bright star Deneb is about 3,230 light-years from Earth. To express this number in scientific notation, first insert a decimal point in the original number so that you have a number between one and ten. In this case, the number is 3.23.

To determine the power of 10, count the number of places that the decimal point moved. Here the decimal point moved three places.

$$3,230 \text{ light-years} = 3.23 \times 10^3 \text{ light-years}$$

**Practice Problem** The sun takes about 220,000,000 years to revolve once around the center of the galaxy. Express this length of time in scientific notation.

## The Scale of the Universe

Astronomers define the **universe** as all of space and everything in it. The universe is enormous, almost beyond imagination. Astronomers study objects as close as the moon and as far away as quasars. They study incredibly large objects, such as galaxies that are millions of light-years across. They also study the behavior of tiny particles, such as the atoms within stars. **Since the numbers astronomers use are often very large or very small, they frequently use scientific notation to describe sizes and distances in the universe.**

**Scientific Notation** Scientific notation uses powers of ten to write very large or very small numbers in shorter form. Each number is written as the product of a number between 1 and 10 and a power of 10. For example: 1,200 is written as  $1.2 \times 10^3$ . One light-year is about 9,500,000,000,000,000 meters. Since there are 15 digits after the first digit, in scientific notation this number is written as  $9.5 \times 10^{15}$  meters.

**The Immensity of Space** The structures in the universe vary greatly in scale. To understand the scale of these structures, imagine that you are going on a journey through the universe. Refer to Figure 20 as you take your imaginary trip. Start at the left with something familiar—a girl looking through binoculars. She is about 1.5 meters tall. Now shift to the right and change the scale by 10,000,000 or  $10^7$ . You're now close to the diameter of Earth,  $1.28 \times 10^7$  meters. As you move from left to right across Figure 20, the scale increases. The diameter of the sun is about 100 times that of Earth.

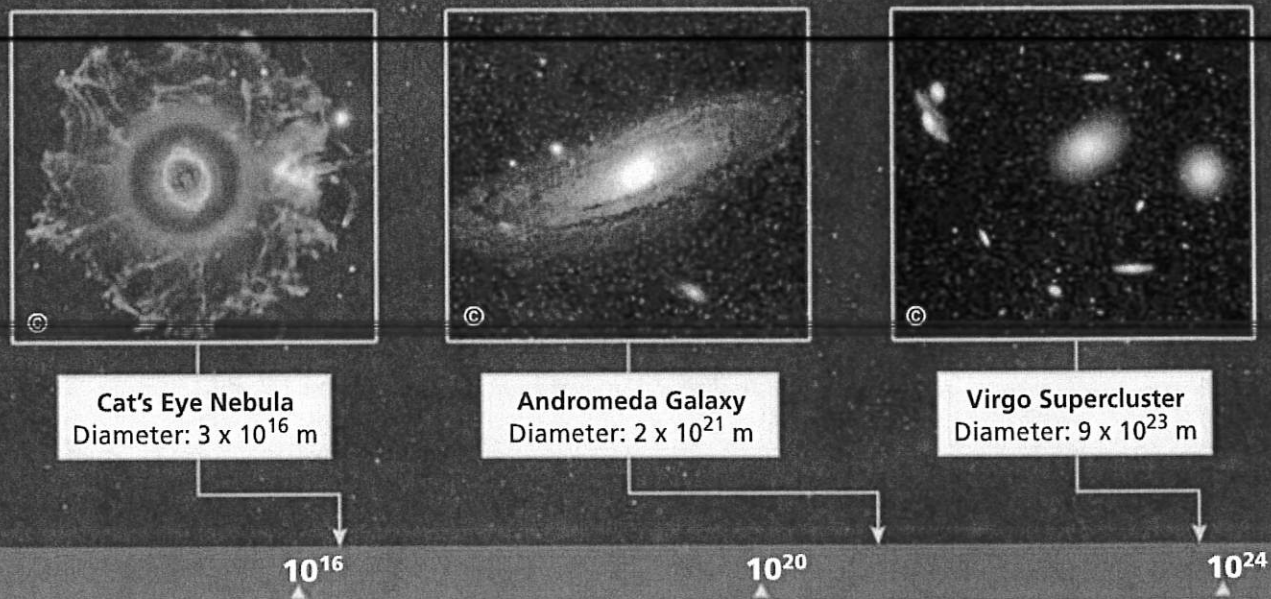


FIGURE 20

### Scientific Notation

Scientists often use scientific notation to help describe the vast sizes and distances in space. *Calculating About how many times larger is the Cat's Eye Nebula than Earth?*

Beyond the solar system, the sizes of observable objects become much larger. For example, within our galaxy, the beautiful Cat's Eye Nebula is about  $3 \times 10^{16}$  meters across.

Beyond our galaxy are billions of other galaxies, many of which contain billions of stars. For example, the nearby spiral galaxy Andromeda is about  $2 \times 10^{21}$  meters across. The Milky Way is part of a cluster of 50 or so galaxies called the Local Group. The Local Group is part of the Virgo Supercluster, which contains hundreds of galaxies. The size of the observable universe is about  $10^{10}$  light years, or  $10^{26}$  meters.

## Section 4 Assessment

**Vocabulary Skill Suffixes** What suffixes do you see in the words *elliptical* and *scientific*? What parts of speech do they indicate? Use the term *elliptical galaxy* in a sentence.

### Reviewing Key Concepts

1. a. **Defining** What is a binary star?  
 b. **Classifying** Are all binary stars part of star systems? Explain.  
 c. **Applying Concepts** Some binary stars are called eclipsing binaries. Explain why this term is appropriate. (*Hint:* Think about Algol as you write your answer.)
2. a. **Listing** Name the main types of galaxies.  
 b. **Classifying** What type of galaxy is the Milky Way?

- c. **Classifying** Suppose astronomers discover a galaxy that contains only old stars. What type of galaxy is it likely to be?
3. a. **Reviewing** What is scientific notation?  
 b. **Explaining** How is scientific notation useful to astronomers?  
 c. **Calculating** How large is the Cat's Eye Nebula in light-years? (*Hint:* Refer to Figure 20.)

### Math Practice

4. **Scientific Notation** The star Betelgeuse has a diameter of 940,000,000 km. Betelgeuse is 427 light-years from Earth. Write each of these figures in scientific notation.



# The Expanding Universe



## Reading Preview

### Key Concepts

- What is the big bang theory?
- How did the solar system form?
- What do astronomers predict about the future of the universe?

### Key Terms

- big bang • Hubble's law
- cosmic background radiation
- solar nebula • planetesimal
- dark matter • dark energy

Lab zone

## Discover Activity

### How Does the Universe Expand?

1. Use a marker to put 10 dots on an empty balloon. The dots represent galaxies.
2. Blow up the balloon. What happens to the distances between galaxies that are close together? Galaxies that are far apart?

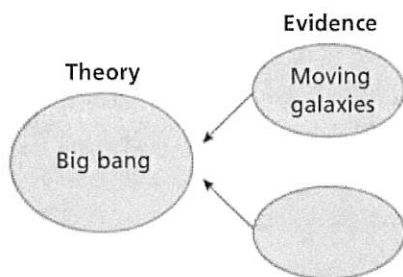
### Think It Over

**Inferring** If the universe is expanding, do galaxies that are close together move apart faster or slower than galaxies that are far apart? Explain.

## Target Reading Skill

### Identifying Supporting Evidence

As you read, identify the evidence that supports the big bang theory. Write the evidence in a graphic organizer like the one below.



The Andromeda Galaxy is the most distant object that the human eye can see. Light from this galaxy has traveled for about 3 million years before reaching Earth. When that light finally reaches your eye, you are seeing how the galaxy looked 3 million years ago. It is as though you are looking back in time.

Astronomers have photographed galaxies that are billions of light-years away. Light from these galaxies traveled for billions of years before it reached Earth. From these observations, astronomers are able to infer the age of the universe.

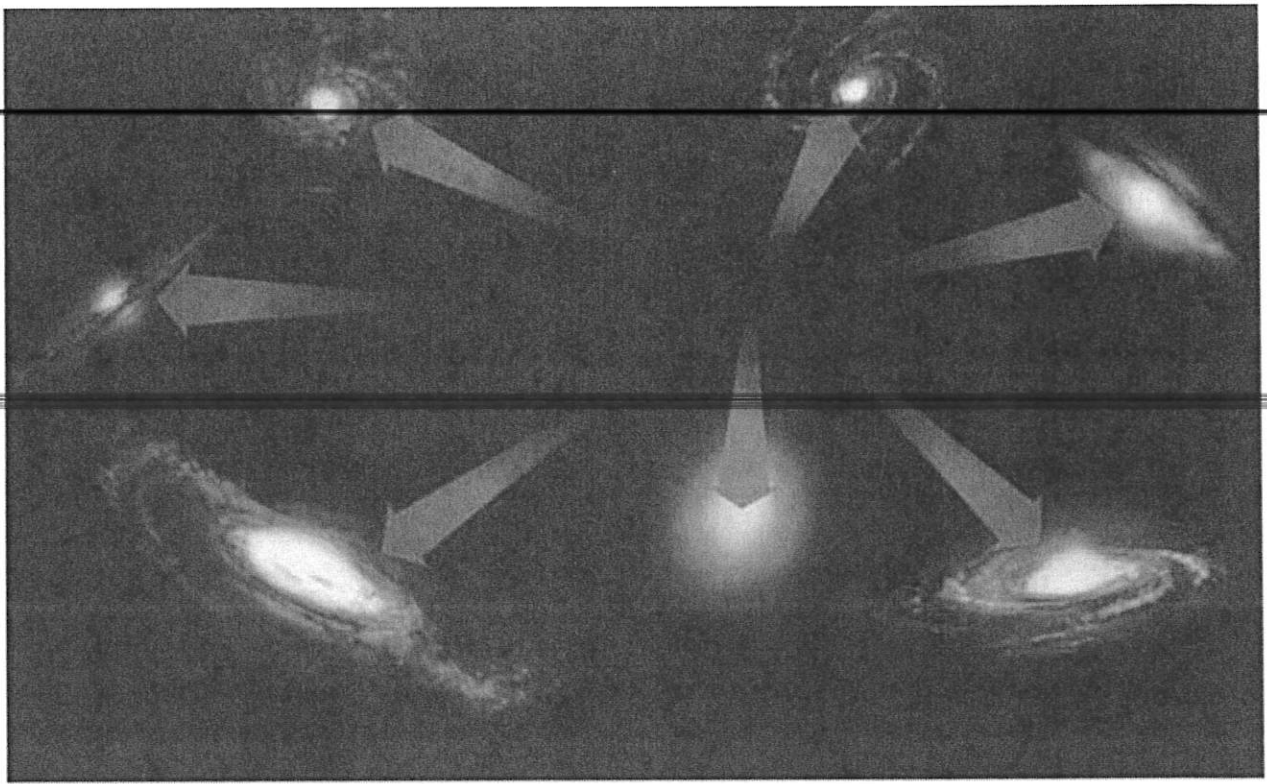
### How the Universe Formed

Astronomers theorize that the universe began billions of years ago. At that time, the part of the universe we can now see was no larger than the period at the end of this sentence. This tiny universe was incredibly hot and dense. The universe then exploded in what astronomers call the **big bang**.

◀ Nearly every visible object in this image is a distant galaxy.







**According to the big bang theory, the universe formed in an instant, billions of years ago, in an enormous explosion.** Since the big bang, the size of the universe has been increasing rapidly. The universe is billions of times larger now than it was early in its history.

As the universe expanded, it gradually cooled. After a few hundred thousand years, atoms formed. About 200 million years after the big bang, the first stars and galaxies formed.

If the big bang theory is accurate, what evidence might you expect to find in today's universe? You might expect that the matter that had been hurled apart by the big bang would still be moving apart. You might also expect to find evidence of energy left over from the explosion.

**Moving Galaxies** An American astronomer, Edwin Hubble, discovered important evidence that later helped astronomers to develop the big bang theory. In the 1920s, Hubble studied the spectrums of many galaxies at various distances from Earth. By examining a galaxy's spectrum, Hubble could tell how fast the galaxy is moving and whether it is moving toward our galaxy or away from it.

Hubble discovered that, with the exception of a few nearby galaxies, all galaxies are moving away from us and from each other. Hubble found that there is a relationship between the distance to a galaxy and its speed. **Hubble's law** states that the farther away a galaxy is, the faster it is moving away from us. Hubble's law strongly supports the big bang theory.

**FIGURE 21**

**Retreating Galaxies**

All of the distant galaxies astronomers have observed are moving rapidly away from our galaxy and from each other.

## Math

### Analyzing Data

#### Speeding Galaxies

Use the graph to answer the questions below about moving clusters of galaxies.

1. **Reading Graphs** How far away is the Bootes cluster? How fast is it moving?
2. **Reading Graphs** Which galaxy is moving away the fastest? Which galaxy is closest to Earth?
3. **Drawing Conclusions** How are the distance and speed of a galaxy related?
4. **Predicting** Predict the speed of a galaxy that is 5 billion light-years from Earth.

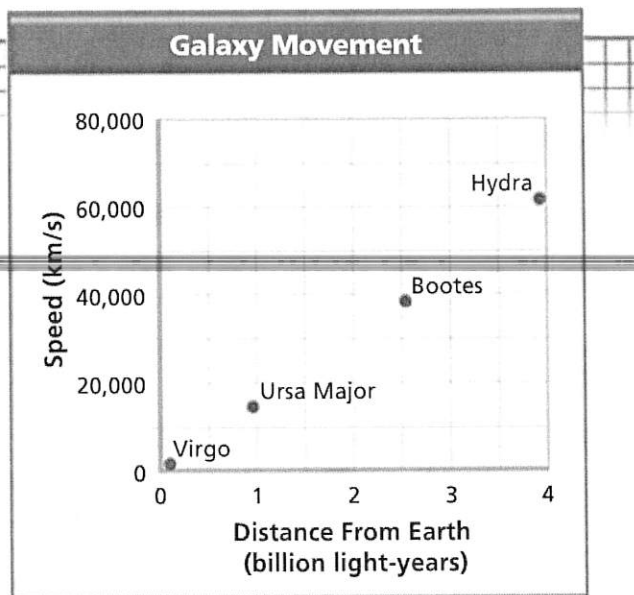


FIGURE 22

#### Rising Dough

The galaxies in the universe are like the raisins in rising bread dough. Making Models *How does rising raisin bread dough resemble the expanding universe?*



To understand how the galaxies are moving, think of raisin bread dough that is rising. If you could shrink yourself to sit on a raisin, you would see all the other raisins moving away from you. The farther a raisin was from you, the faster it would move away, because there would be more bread dough to expand between you and the raisin. No matter which raisin you sat on, all the other raisins would seem to be moving away from you. You could tell that the bread dough was expanding by watching the other raisins.

The universe is like the bread dough. Like the raisins in the dough, the galaxies in the universe are moving away from each other. In the universe, it is space that is expanding, like the dough between the raisins.

**Cosmic Background Radiation** In 1965, two American physicists, Arno Penzias and Robert Wilson, accidentally detected faint radiation on their radio telescope. This mysterious glow was coming from all directions in space. Scientists later concluded that this glow, now called **cosmic background radiation**, is the leftover thermal energy from the big bang. This energy was distributed in every direction as the universe expanded.

**Age of the Universe** Since astronomers can measure approximately how fast the universe is expanding now, they can infer how long it has been expanding. Based on careful measurements of how fast distant galaxies are moving away from us and the cosmic background radiation, astronomers estimate that the universe is about 13.7 billion years old.



## Formation of the Solar System

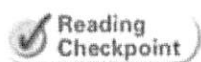
After the big bang, matter in the universe separated into galaxies. Gas and dust spread throughout space. Where the solar system is now, there was only cold, dark gas and dust. How did the solar system form? The leading hypothesis is explained below.

**The Solar Nebula** About five billion years ago, a giant cloud of gas and dust collapsed to form our solar system. A large cloud of gas and dust such as the one that formed our solar system is called a **solar nebula**. Slowly, gravity began to pull the solar nebula together. As the solar nebula shrank, it spun faster and faster. The solar nebula flattened, forming a rotating disk. Gravity pulled most of the gas into the center of the disk, where the gas eventually became hot and dense enough for nuclear fusion to begin. The sun was born.

**Planetesimals** In the outer parts of the disk, gas and dust formed small asteroid-like and comet-like bodies called **planetesimals**. These formed the building blocks of the planets. Planetesimals collided and grew larger by sticking together, eventually combining to form the planets.

**The Inner Planets** When the solar system formed, temperatures were very high. It was so hot close to the sun that most water and other ice-forming materials simply vaporized. Most gases escaped the gravity of the planets that were forming in this region. As a result, the inner planets, Mercury, Venus, Earth, and Mars, are relatively small and rocky.

**The Outer Planets** In contrast, farther from the sun it was much cooler. As the planets in this region grew, their gravity increased and they were able to capture much of the hydrogen and helium gas in the surrounding space. As a result, the planets Jupiter, Saturn, Uranus, and Neptune became very large. Beyond these gas giants, a huge disk of ice and other substances formed. Pluto also formed in this region. Most comets formed near Jupiter and Saturn. They were later flung out much farther away from the sun.



Reading  
Checkpoint

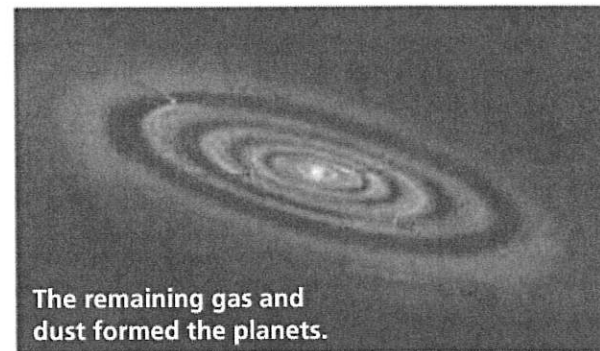
What is a solar nebula?



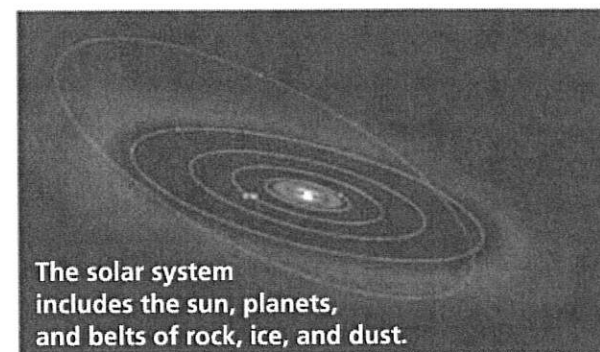
A cloud of gas and dust formed a spinning disk.



Gas in the center of the disk collapsed to form the sun.



The remaining gas and dust formed the planets.



The solar system includes the sun, planets, and belts of rock, ice, and dust.

FIGURE 23

### How the Solar System Formed

The solar system formed from a collapsing cloud of gas and dust.



## The Future of the Universe

What will happen to the universe in the future? One possibility is that the universe will continue to expand, as it is doing now. All of the stars will eventually run out of fuel and burn out, and the universe will be cold and dark. Another possibility is that the force of gravity will begin to pull the galaxies back together. The result would be a reverse big bang, or “big crunch.” All of the matter in the universe would be crushed into an enormous black hole.

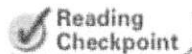
Which of these possibilities is more likely? Recent discoveries have produced a surprising new view of the universe that is still not well understood. **New observations lead many astronomers to conclude that the universe will likely expand forever.**

**Dark Matter** Until fairly recently, astronomers assumed that the universe consisted solely of the matter they could observe directly. But this idea was disproved by the American astronomer Vera Rubin. Rubin made detailed observations of the rotation of spiral galaxies. She discovered that the matter that astronomers can see, such as stars and nebulae, makes up as little as ten percent of the mass in galaxies. The remaining mass exists in the form of dark matter.

**Dark matter** is matter that does not give off electromagnetic radiation. Dark matter cannot be seen directly. However, its presence can be inferred by observing the effect of its gravity on visible objects, such as stars, or on light. Astronomers still don’t know much about dark matter—what it is made of or all of the places where it is found.

**An Accelerating Expansion** In the late 1990s, astronomers observed that the expansion of the universe appears to be accelerating. That is, galaxies seem to be moving apart at a faster rate now than in the past. This observation was puzzling, as no known force could account for it. Astronomers infer that a mysterious new force, which they call **dark energy**, is causing the expansion of the universe to accelerate. Current estimates indicate that most of the universe is made of dark energy and dark matter. Astronomers think that only a small fraction of the universe—less than 5 percent—is composed of “normal matter” that they can see.

Astronomy is one of the oldest sciences, but there are still many discoveries to be made and puzzles to be solved about this universe of ours!



Reading  
Checkpoint

What is the effect of dark energy?

FIGURE 24

Vera Rubin

Astronomer Vera Rubin’s observations proved the existence of dark matter.





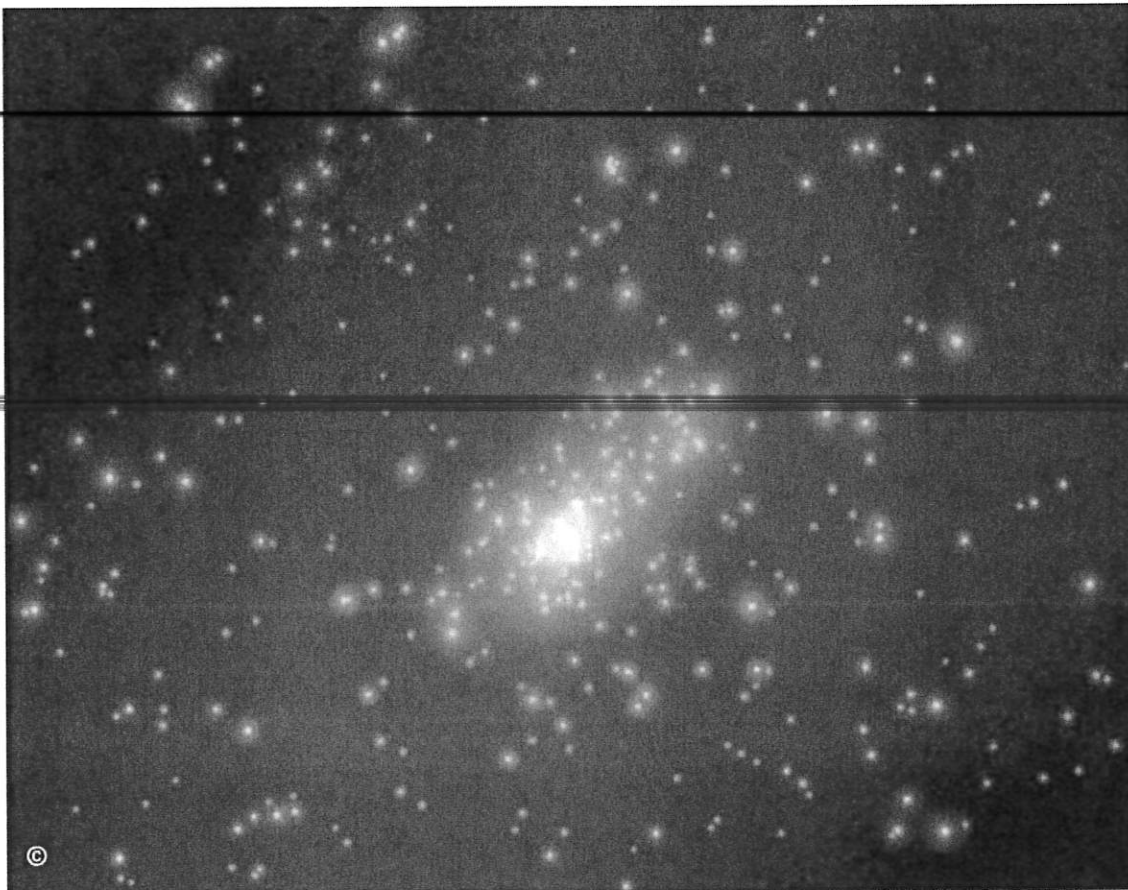



FIGURE 25

#### Dark Matter

Astronomers measured the effect of gravity on light to produce this computer image of how dark matter (in blue) is distributed across a cluster of galaxies.

## Section 5 Assessment

-  **Target Reading Skill Identifying Supporting Evidence** Refer to your graphic organizer about the big bang theory as you answer Question 1 below.

### Reviewing Key Concepts

1. a. Defining What was the big bang?  
b. Summarizing When did the big bang occur?  
c. Describing Describe two pieces of evidence that support the big bang theory.
2. a. Summarizing How old is the solar system?  
b. Relating Cause and Effect What force caused the solar system to form?  
c. Sequencing Place the following events in the proper order: planets form; planetesimals form; solar nebula shrinks; nuclear fusion begins in the sun.

3. a. Defining What is dark matter?  
b. Explaining How do scientists know that dark matter exists?  
c. Predicting What evidence has led scientists to predict that the universe will continue to expand forever?

HINT

HINT

HINT

HINT

HINT

HINT

HINT

HINT

HINT

Lab  
zone

### At-Home Activity

**Stargazing** Plan an evening of stargazing with adult family members. Choose a dark, clear night. Use binoculars if available and the star charts in the appendix to locate the Milky Way and some interesting stars that you have learned about. Explain to your family what you know about the Milky Way and each constellation that you observe.



The **BIG Idea**

**Structure of the universe** Astronomers learn about the structure of the universe and how it has changed over time by studying stars, galaxies, and other objects in space.

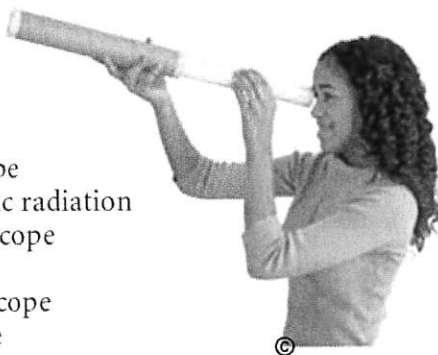
**1 Telescopes****Key Concepts**

The electromagnetic spectrum includes radio waves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. Telescopes are instruments that collect and focus light and other forms of electromagnetic radiation.

Many large observatories are located on mountaintops or in space.

**Key Terms**

- telescope
- visible light
- wavelength
- spectrum
- optical telescope
- electromagnetic radiation
- refracting telescope
- convex lens
- reflecting telescope
- radio telescope
- observatory

**2 Characteristics of Stars****Key Concepts**

Characteristics used to classify stars include color, temperature, size, composition, and brightness.

The brightness of a star depends upon both its size and temperature.

Astronomers use a unit called the light-year to measure distances between the stars.

Astronomers often use parallax to measure distances to nearby stars.

Astronomers use H-R diagrams to classify stars and to understand how stars change over time.

**Key Terms**

- constellation • spectrograph
- apparent brightness • absolute brightness
- light-year • parallax • main sequence
- Hertzsprung-Russell diagram

**3 Lives of Stars****Key Concepts**

A star is born when nuclear fusion starts.

How long a star lives depends on its mass.

After a star runs out of fuel, it becomes a white dwarf, a neutron star, or a black hole.

**Key Terms**

- nebula • protostar • planetary nebula
- white dwarf • supernova • neutron star
- pulsar • black hole

**4 Star Systems and Galaxies****Key Concepts**

Most stars are members of star systems.

Astronomers classify most galaxies into the following types: spiral, elliptical, and irregular.

Our solar system is located in a spiral galaxy called the Milky Way.

Astronomers often use scientific notation to describe sizes and distances in the universe.

**Key Terms**

- binary star • eclipsing binary • open cluster
- globular cluster • galaxy • spiral galaxy
- elliptical galaxy • irregular galaxy
- quasar • universe • scientific notation

**5 The Expanding Universe****Key Concepts**

According to the big bang theory, the universe formed in an instant, billions of years ago, in an enormous explosion.

About five billion years ago, a giant cloud of gas and dust collapsed to form our solar system.

New observations lead astronomers to conclude that the universe will likely expand forever.

**Key Terms**

- big bang • Hubble's law
- cosmic background radiation • solar nebula
- planetesimal • dark matter • dark energy

# Review and Assessment

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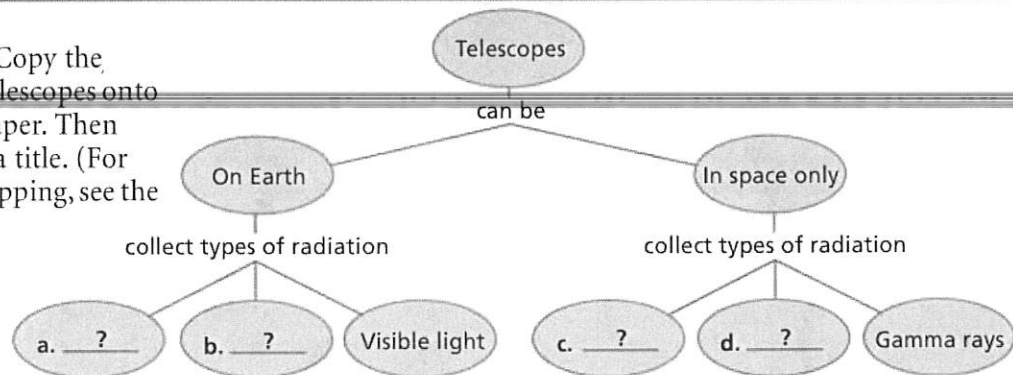
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## Organizing Information

**Concept Mapping** Copy the concept map about telescopes onto a separate sheet of paper. Then complete it and add a title. (For more on Concept Mapping, see the Skills Handbook.)



## Reviewing Key Terms

Choose the letter of the best answer.

HINT

1. Visible light is a form of
  - a. spectrum.
  - b. electromagnetic radiation.
  - c. wavelength.
  - d. cosmic background radiation.

HINT

2. An H-R diagram is a graph of stars' temperature and
  - a. apparent brightness.
  - b. main sequence.
  - c. absolute brightness.
  - d. parallax.

HINT

3. A low-mass main sequence star will eventually evolve into a
  - a. white dwarf.
  - b. protostar.
  - c. black hole.
  - d. nebula.

HINT

4. A star system in which one star blocks the light from another is called a(n)
  - a. open cluster.
  - b. quasar.
  - c. binary star.
  - d. eclipsing binary.

HINT

5. Astronomers theorize that the universe began in an enormous explosion called the
  - a. solar nebula.
  - b. supernova.
  - c. big bang.
  - d. big crunch.

If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.

HINT

6. A reflecting telescope uses convex lenses to gather and focus light.

HINT

7. Astronomers use spectrographs to determine the chemical composition of stars.

HINT

8. Pulsars are a kind of neutron star.

HINT

9. A galaxy shaped like a ball and containing only older stars is most likely a spiral galaxy.

HINT

10. Globular clusters are small asteroid-like bodies that formed the building blocks of the planets.

## Writing in Science

**News Article** Imagine that you are a journalist covering current research in astronomy, including stars and black holes. Write an article explaining what black holes are, how they form, and how they can be detected.

**Discovery**  
CHANNEL  
**SCHOOL**

*Stars, Galaxies, and the Universe*

Video Preview

Video Field Trip

▶ Video Assessment

# Review and Assessment

## Checking Concepts

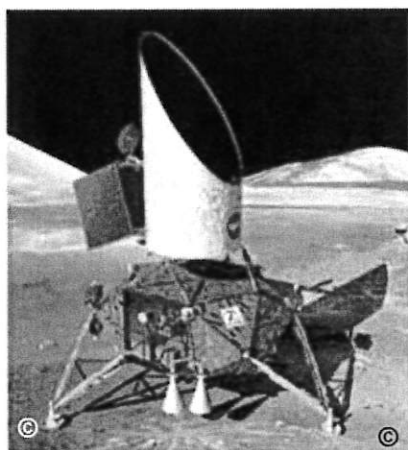
11. Is a light-year a unit of distance or a unit of time? Explain.
12. Why can't astronomers measure the parallax of a star that is a million light-years away?
13. At what point in the evolution of a star is the star actually born?
14. Where in our galaxy does most star formation take place?
15. What is Hubble's law?
16. How can astronomers detect dark matter if they cannot observe it directly?

## Math Practice

17. **Calculating** The bright star Spica is 262 light-years from our solar system. How many kilometers is this?
18. **Scientific Notation** The star Antares is approximately 604 light-years from Earth. Write this distance in scientific notation.

## Thinking Critically

19. **Inferring** What advantage might there be to locating a telescope, such as the one shown below, on the moon?



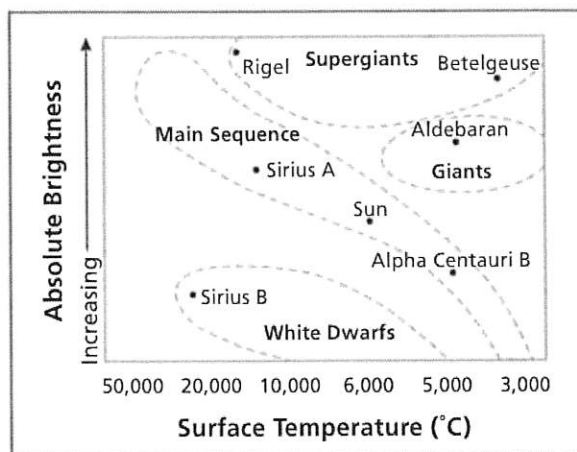
20. **Applying Concepts** Describe a real-world situation involving absolute and apparent brightness. (*Hint:* Think about riding in a car at night.)

21. **Relating Cause and Effect** How does a star's mass affect its lifetime?
22. **Comparing and Contrasting** Compare the conditions that led to the formation of the terrestrial planets with those that led to the formation of the gas giants.

## Applying Skills

Use the data in the H-R diagram below to answer Questions 23–26.

**Hertzsprung-Russell Diagram**



23. **Interpreting Diagrams** Which star has a greater absolute brightness, Aldebaran or Sirius B?
24. **Interpreting Diagrams** Which stars have higher surface temperatures than Sirius A?
25. **Applying Concepts** Which star is most likely to be red: Rigel, Sirius B, or Betelgeuse?
26. **Comparing and Contrasting** Compare Aldebaran and the sun in terms of size, temperature, and absolute brightness.

Lab  
zone

## Chapter Project

**Performance Assessment** Check the final draft of your constellation story for correct spelling, grammar, punctuation, and usage. Then decide how you will present your story. For example, you could make a poster, read your story aloud, or perform it as a skit or a play.





# Preparing for the CRCT

## Test-Taking Tip

### Sequencing Events

Some questions ask you to arrange a series of events in order. For example, you might be asked which event comes first or last, or which event comes before another event. Before looking at the answer choices, first try to recall the sequence of events in the entire process. If you have an idea of the sequence beforehand, you should find it easier to identify the correct answer.

### Sample Question

Which of the following correctly describes the evolution of a sun-like star from young to old?

- A white dwarf, red giant, main-sequence star, protostar
- B red giant, main-sequence star, white dwarf, protostar
- C protostar, main-sequence star, white dwarf, red giant
- D protostar, main-sequence star, red giant, white dwarf

### Answer

The correct answer is D. Choice A gives the correct order from old to young, rather than young to old. Choices B and C do not correctly sequence the life cycle of any star.

### Choose the letter of the best answer.

1. The most common chemical element in most stars is
  - A oxygen.
  - B hydrogen.
  - C helium.
  - D nitrogen.

S6E1.b
2. The main factor that affects the evolution of a star is its
  - A color.
  - B apparent brightness.
  - C mass.
  - D parallax.

S6E1.b

3. The color of a star is related to its temperature. Which of the following color sequences correctly identifies the temperatures of stars in order from hottest to coldest?

- A red, red-orange, yellow, white, blue
- B yellow, white, blue, red, red-orange
- C blue, yellow, red-orange, red, white
- D blue, white, yellow, red-orange, red

S6E1.b

The table below gives an estimate of the distribution of stars in the Milky Way galaxy. Use the table and your knowledge of science to answer Questions 4 and 5.

Type of Star	Percentage of Total
Main sequence	90.75%
Red Giant	0.50%
Supergiant	0.0001%
White Dwarf	8.75%

4. According to the table, the most common type of stars in the Milky Way is
  - A main-sequence stars.
  - B red giants.
  - C supergiants.
  - D white dwarfs.

S6E1.b
5. If there are a total of 400 billion stars in the Milky Way, about how many white dwarfs are there in the galaxy?
  - A 8.75 billion
  - B 35 billion
  - C 87.5 billion
  - D 3,500 billion

S6E1.b

## Constructed Response

6. Describe the appearance of the Milky Way as you would see it both from Earth and from a point directly above or below the galaxy. Why does the galaxy look different from different vantage points?

S6E1.b