

Chapter 30

Stars, Galaxies, and the Universe

Chapter Outline

1 Characteristics of Stars

Analyzing Starlight
Stellar Motion
Distances to Stars
Stellar Brightness

2 Stellar Evolution

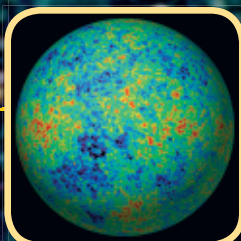
Classifying Stars
Star Formation
The Main-Sequence Stage
Leaving the Main Sequence
The Final Stages of a Sunlike Star
The Final Stages of Massive Stars

3 Star Groups

Constellations
Multiple-Star Systems
Star Clusters
Galaxies
Quasars

4 The Big Bang Theory

Hubble's Observations
A Theory Emerges
A Universe of Surprises



Inquiry Lab

 20 min

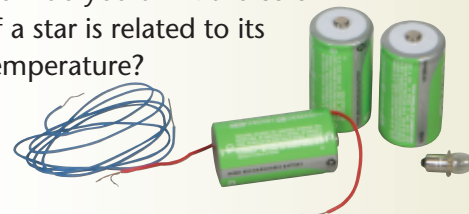
Color and Temperature



Attach a **flashlight bulb** to a **weak D-cell battery** using **electrical wire**. Record the color of the filament, and carefully touch the bulb to note how warm it feels. Then attach a **fully charged D-cell battery** to the bulb. Again, record the color of the filament and the warmth of the bulb. Finally, attach a **second fully charged D-cell battery**, and repeat your observations.

Questions to Get You Started

1. What is the relationship between the color of the filament and the temperature of the bulb?
2. How do you think the color of a star is related to its temperature?



Why It Matters

Our solar system is one small part of the universe. By studying stars and galaxies, we can learn more about the formation and evolution of the universe.

Science Terms

Everyday Words Used in Science Many terms that are used in science are familiar words, taken from everyday speech. Scientists sometimes choose familiar words to describe things that are new, unfamiliar, or difficult to understand.

Your Turn In Section 2, you will learn about the objects listed in the table below. Based on your understanding of the familiar words that make up these terms, explain what you would expect them to mean in a table of your own. After reading Section 2, write the scientific definitions in your table.

Term	What I think it means	Scientific definition
white dwarf		
red giant		
supergiant		
black hole		

Fact, Hypothesis, or Theory?

Scientific Theories A scientific law describes or summarizes a pattern in nature. Scientific theories are sometimes confused with scientific laws, but they are not the same. The following statements apply to scientific theories:

- They explain observations or patterns in nature.
- They can be used to predict other observations or patterns.
- They may be revised or abandoned if reliable evidence contradicts them.

Your Turn In Section 4, the big bang theory is discussed in detail. On a sheet of paper, write “Big Bang Theory” and a definition of this theory. Then write a paragraph explaining why it is a theory.

Note Taking

Pattern Puzzles Pattern puzzles can help you remember information in the correct order. They can also help you review the steps of a process, such as a lab procedure or math solution. Below are the instructions for making a pattern puzzle.

- 1 Write down the steps of a process on a sheet of paper. Write one step per line.
- 2 Cut the sheet of paper into strips, with only one step per strip. Shuffle the strips.
- 3 Put the strips in their proper order. Then check the order in your textbook.

Your Turn As you read Section 2, write down the steps in the life cycle of a main-sequence star in order. If a step is long, divide it into two or three shorter steps. Then cut the steps into strips, shuffle them, and put them in order again. The first two steps are shown below.

• An outside force compresses a nebula.

• Some of the particles of the nebula are pulled toward each other by gravity.

Characteristics of Stars

Key Ideas

- Describe how astronomers determine the composition and temperature of stars.
- Explain why stars appear to move in the sky.
- Describe one way astronomers measure the distances to stars.
- Explain the difference between absolute magnitude and apparent magnitude.

Key Terms

star
Doppler effect
light-year
parallax
apparent magnitude
absolute magnitude

Why It Matters

By analyzing sunlight, scientists discovered the element helium in the sun, a star, even before they found it on Earth. Today, we use helium in high-tech applications as well as in party balloons.

A **star** is a ball of gases that gives off a tremendous amount of electromagnetic energy. This energy comes from nuclear fusion within the star. *Nuclear fusion* is the combination of light atomic nuclei to form heavier atomic nuclei.

As seen from Earth, most stars in the night sky appear to be tiny specks of white light. However, if you look closely at the stars, you will notice that they vary in color. For example, the star Antares shines with a slightly reddish color, the star Rigel shines blue-white, and the star Arcturus shines with an orange tint. Our own star, the sun, is a yellow star.

Analyzing Starlight

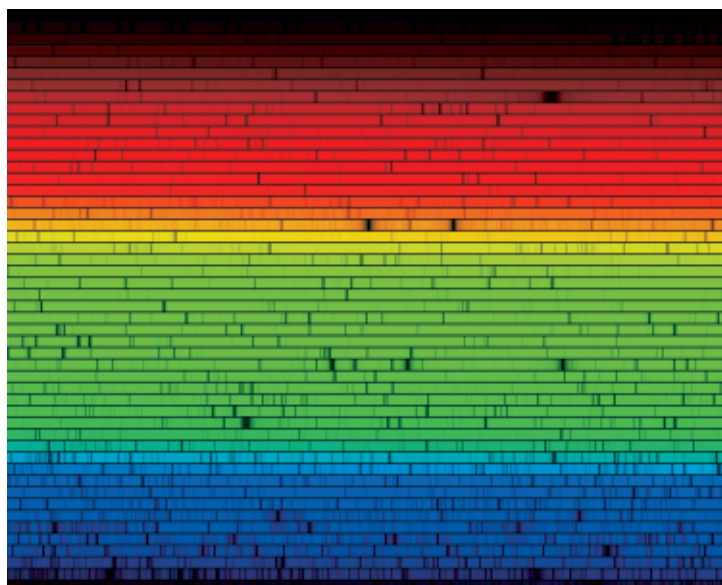
Astronomers learn about stars primarily by analyzing the light that the stars emit. Astronomers direct starlight through *spectrographs*, which are devices that separate light into different colors, or wavelengths. Starlight passing through a spectrograph produces a display of colors and lines called a *spectrum*. There are three types of spectra: *emission*, or bright-line; *absorption*, or dark-line; and *continuous*.

All stars have *dark-line spectra*—bands of color crossed by dark lines where the color is diminished, as shown in **Figure 1**. A star's dark-line spectrum reveals the star's composition and temperature.

Stars are made up of different elements in the form of gases. While the inner layers of a star's photosphere are very hot, the outer layers are somewhat cooler. Elements in the outer layers absorb some of the light radiating from lower in the photosphere. Because different elements absorb different wavelengths of light, scientists can study the elements that make up a star, and find out from them how hot the star is by studying its spectrum.

star a large celestial body that is composed of gas and that emits light

Figure 1 The solar spectrum is shown here with each colored section on a new band.



Classification of Stars		
Color	Surface temperature (°C)	Examples
Blue	above 30,000	10 Lacertae
Blue-white	10,000–30,000	Rigel, Spica
White	7,500–10,000	Vega, Sirius
Yellow-white	6,000–7,500	Canopus, Procyon
Yellow	5,000–6,000	sun, Capella
Orange	3,500–5,000	Arcturus, Aldebaran
Red	less than 3,500	Betelgeuse, Antares

Figure 2 Stars in the sky show tinges of different colors, which reveal the temperatures of the stars' surfaces. Blue stars shine with the hottest temperatures, and red stars shine with the coolest.

READING TOOLBOX

Pattern Puzzle

Make a pattern puzzle that outlines the steps used by scientists to determine the elements that make up a star. Follow the instructions for making a pattern puzzle, given at the beginning of the chapter. See Appendix A for further instructions.

The Compositions of Stars

Every chemical element has a characteristic spectrum in a given range of temperatures. The colors and lines in the spectrum of a star indicate the elements that make up the star. Through spectrum analysis, scientists have learned that stars are made up of the same elements that compose Earth. But while the most common element on Earth is oxygen, the most common element in stars is hydrogen. Helium is the second most common element in stars. Elements such as carbon, oxygen, and nitrogen, usually in small quantities, make up most of the remaining one percent or so of the mass of stars.

The Temperatures of Stars

The surface temperature of a star is indicated by its color, as shown in **Figure 2**. Most star temperatures range from 2,800 °C to 24,000 °C, although some are hotter. Generally, blue stars have an average surface temperature of 35,000 °C. Red stars are the coolest, with average surface temperatures of 3,000 °C. Yellow stars, such as the sun, have surface temperatures of about 5,500 °C.

The Sizes and Masses of Stars

Stars also vary in size and mass. The smallest stars are slightly bigger than Jupiter, about one-seventh the size of our sun. Most stars are smaller and less massive than the sun. The sun, a medium-sized star, has a diameter of about 1,390,000 km. Some giant stars have diameters that are 1,000 times the sun's diameter. Most of the stars you can see in the night sky are medium-sized stars that are similar in size to our sun.

Many stars also have about the same mass as the sun, though some stars may be significantly more or less massive. Stars that are very dense may have more mass than the sun and still be much smaller than the sun. Less-dense stars may have a larger diameter than the sun has but still have less mass than the sun.

Stellar Motion

Two kinds of motion are associated with stars—actual motion through space and apparent motion across the night sky. Because stars are so far from Earth, their actual motion can be measured only with high-powered telescopes and specialized spacecraft. Apparent motion on any given night, on the other hand, is much more noticeable.

Apparent Motion of Stars

The *apparent motion* of stars, or motion as it appears from Earth, is caused by the movement of Earth. By aiming a camera at the sky and leaving the shutter open for a few hours, you can photograph the apparent motion of the stars. The curves of light in **Figure 3** record the apparent motion of stars in the northern sky. The circular trails make it seem as though the stars are moving counter-clockwise around a central star called Polaris, or the North Star. The circular pattern is caused by the rotation of Earth on its axis. Polaris, which is not a very bright star, is almost directly above the North Pole, and thus the star does not appear to move much.

Earth's revolution around the sun causes the stars to appear to move in a second way. Stars located on the side of the sun opposite Earth are obscured by the sun. As Earth orbits the sun, however, different stars become visible during different seasons. The visible stars appear slightly to the west at a given time every night. Each night, most stars appear a small distance farther across the sky than they were at the same time the night before. After many months, some stars may finally disappear below the western horizon.

 **Reading Check** **Why does Polaris appear to remain stationary in the night sky?** (See Appendix G for answers to Reading Checks.)

SCILINKS

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Topic: Stars

Code: HQX1448

Figure 3 Stars appear as curved trails in this long-exposure photograph. These trails result from the rotation of Earth on its axis.



Circumpolar Stars

Some stars are always visible in the night sky. These stars never pass below the horizon in either their nightly or annual movements. In the Northern Hemisphere, the movement of these stars makes them appear to circle Polaris, the North Star. These circling stars are called *circumpolar stars*. The stars of the Little Dipper are circumpolar for most observers in the Northern Hemisphere. For a person at the North Pole, all visible stars are circumpolar. The farther the observer moves from the North Pole toward the equator, the fewer circumpolar stars the observer will be able to see.

Doppler effect an observed change in the frequency of a wave when the source or observer is moving

Academic Vocabulary

occur (uh KUHR) happen



INTERACT ONLINE

Keyword: HQXSTGF4

Figure 4 The light from stars is shifted based on the star's movement in relationship to Earth. For example, light from stars that are moving away from Earth is shifted slightly toward the red end of the spectrum.

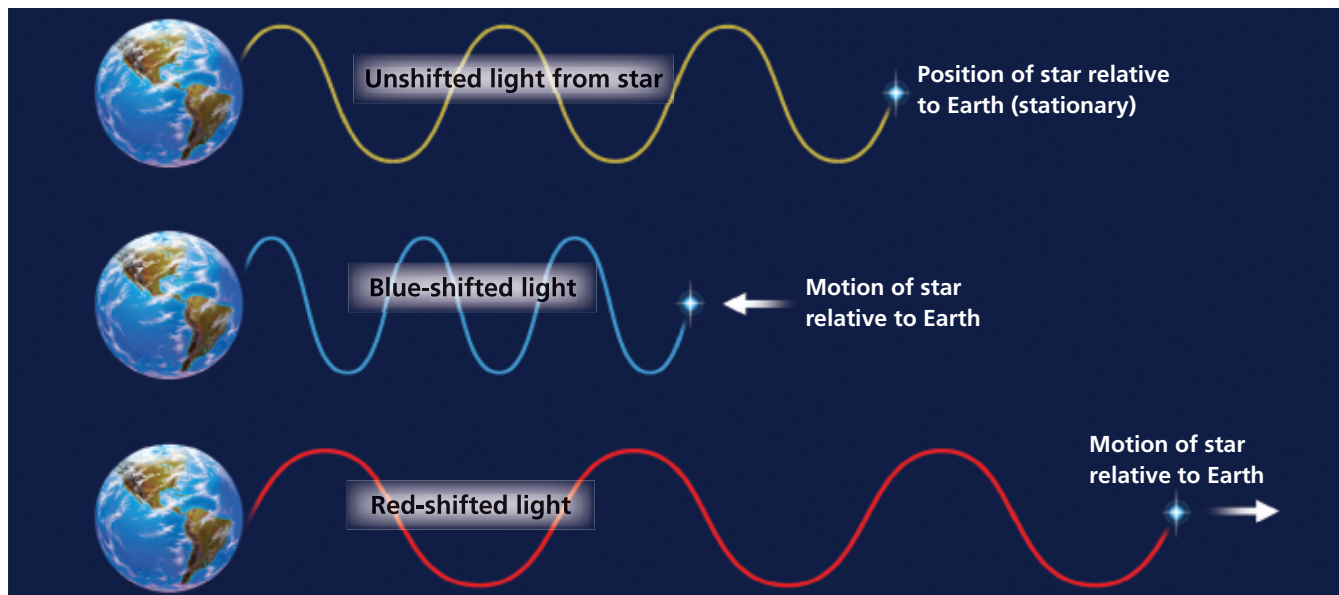
Actual Motion of Stars

Most stars have several types of *actual motion*. First, they move across the sky, which can be seen only for the closest stars. Second, they may revolve around another star. Third, they either move away from or toward our solar system.

From a star's spectrum, astronomers can learn more about how that star is moving in space toward or away from Earth. The spectrum of such a star appears to shift, as shown in **Figure 4**. The apparent shift in the wavelength of light emitted by a light source moving toward or away from an observer is called the **Doppler effect**. The colors in the spectrum of a star moving toward Earth are shifted slightly toward blue. This shift, called *blue shift*, occurs because the light waves from a star appear to have shorter wavelengths as the star moves toward Earth.

A star moving away from Earth has a spectrum that is shifted slightly toward red. This shift, called *red shift*, occurs because the wavelengths of light appear to be longer. Distant galaxies all have red-shifted spectra, which indicates that all these galaxies are moving away from Earth.

 **Reading Check** What causes starlight to shift toward the red end of the spectrum?



Distances to Stars

Because space is so vast, distances between the stars and Earth are measured in light-years. A **light-year** is the distance that light travels in one year. Because the speed of light is 300,000 km/s, light travels about 9.46 trillion km in one year. The light you see when you look at a star left that star sometime in the past. Light from the sun, for example, takes about 8 minutes to reach Earth. The sun is therefore 8 light-minutes from Earth. When we witness an event on the sun, such as a solar flare, the event actually took place about 8 minutes before we saw it.

Apart from the sun, the star nearest Earth is Proxima Centauri. This star is 4.2 light-years from Earth, nearly 300,000 times the distance from Earth to the sun. Polaris is about 430 light-years from Earth. When you look at Polaris, you see the star the way it was 430 years ago.

For relatively close stars, scientists can determine a star's distance by measuring **parallax**, the apparent shift in a star's position when viewed from different locations. As Earth orbits the sun, observers can study the stars from different perspectives, as shown in **Figure 5**. As Earth moves halfway around its orbit, a nearby star will appear to shift slightly relative to stars that are farther from Earth. The closer the star is to Earth, the larger the shift will be. Using this method from a spacecraft, astronomers measured the distance to about a million stars within 1,000 light-years of Earth.

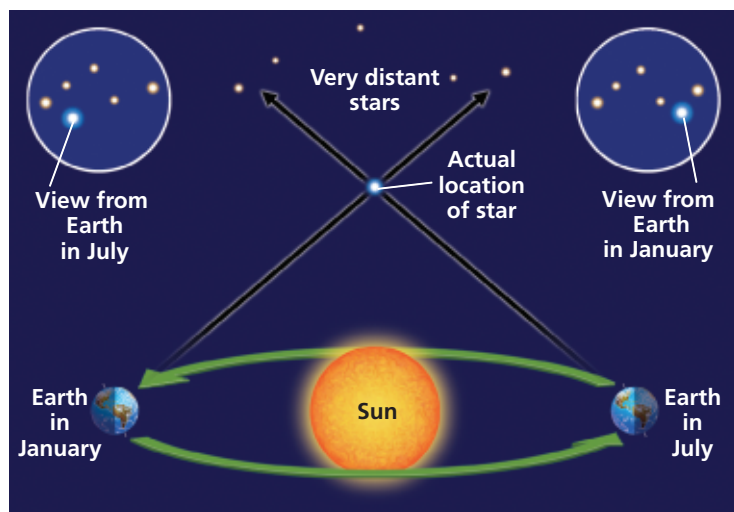


Figure 5 Observers on Earth see nearby stars against those in the distant background. The movement of Earth causes nearby stars to appear to move.

light-year the distance that light travels in one year

parallax an apparent shift in the position of an object when viewed from different locations

Quick Lab

Parallax



15 min

Procedure

- 1 Use a **metric ruler** and **scissors** to cut **five 1 m lengths of thread**. Use **masking tape** to tape one end of each piece of thread to the edge of a **paper plate**. Each plate should have the same diameter. One plate should be red, and four should be blue.
- 2 Stand on a **ladder**, and tape the free end of each piece of thread to the ceiling at various heights. Place the threads 30 cm apart in a staggered pattern. Hang the plates in a location that allows the widest field of view and movement.
- 3 Stand directly in front of and facing the red plate at a distance of several meters.
- 4 Close one eye, and sketch the position of the red plate in relation to the blue plates.
- 5 Take several steps back and to the right. Repeat step 4.

- 6 Take several more steps and make another sketch.
- 7 Repeat step 6.

Analysis

1. Compare your drawings. Did the red plate change position as you viewed it from different locations? Explain your answer.
2. What results would you expect if you continued to repeat step 6? Explain your answer.
3. If you noted the positions of several stars by using a powerful telescope, what would you expect to observe about their positions if you saw the same stars six months later? Explain.



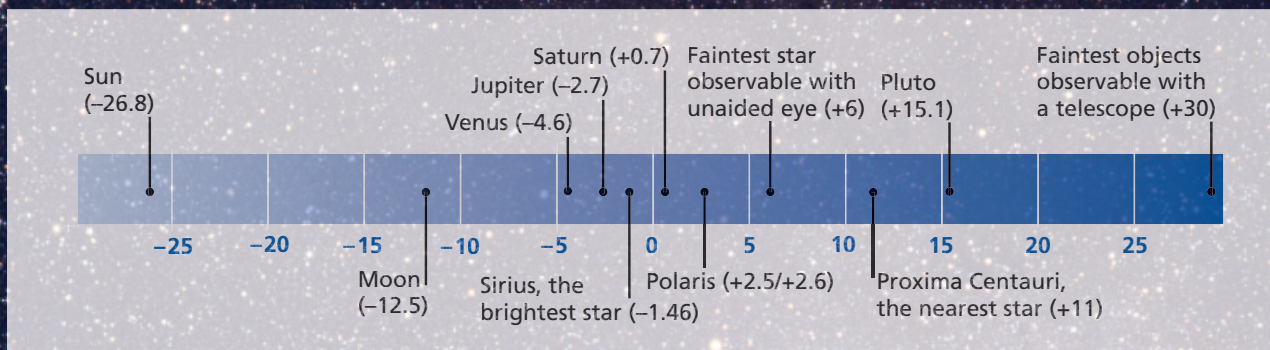


Figure 6 The sun, which has an apparent magnitude of -26.8 , is the brightest object in our sky. All other objects appear dimmer in the sky, so their apparent magnitudes are higher on the scale.

apparent magnitude the brightness of a star as seen from the Earth

absolute magnitude the brightness that a star would have at a distance of 32.6 light-years from Earth

Stellar Brightness

More than 3 billion stars can be seen through telescopes on Earth. Of these, only about 6,000 are visible without a telescope. Billions more stars can be observed from Earth-orbiting telescopes, such as the *Hubble Space Telescope*. The visibility of a star depends on its brightness and its distance from Earth. Astronomers use two scales to describe the brightness of a star.

The brightness of a star as it appears to us on Earth is called the star's **apparent magnitude**. The apparent magnitude of a star depends on both how much light the star emits and how far the star is from Earth. The lower the number of the star on the scale shown in **Figure 6**, the brighter the star appears to observers on Earth. The true brightness, or **absolute magnitude**, of a star is how bright the star would appear if all the stars were at a standard, uniform distance from Earth. The brighter a star actually is, the lower the number of its absolute magnitude.

Section 1 Review

Key Ideas

- Describe** what astronomers analyze to determine the composition and surface temperature of a star.
- Compare** the mass of the sun with the masses of most other stars in the universe.
- Explain** why, as you observe the night sky over time, stars appear to move westward across the sky.
- Describe** the units used to measure the distance to stars in terms of whether their starlight takes minutes or years to reach Earth.
- Describe** the method astronomers use to measure the distance to stars that are less than 1,000 light-years from Earth.
- Explain** the difference between apparent magnitude and absolute magnitude.

Critical Thinking

- Identifying Relationships** How does the movement of Earth affect the apparent movement of stars in the sky?
- Analyzing Ideas** Why is it better for astronomers to measure parallax by observing every six months instead of observing every year?
- Understanding Relationships** If two stars have the same absolute magnitude, but one of the stars is farther from Earth than the other one, which star would appear brighter in the night sky?

Concept Mapping

- Use the following terms to create a concept map: *star*, *apparent magnitude*, *red shift*, *Doppler effect*, *light-year*, *absolute magnitude*, and *blue shift*.

Stellar Evolution

Key Ideas

- Describe how a protostar becomes a star.
- Explain how a main-sequence star generates energy.
- Describe the evolution of a star after its main-sequence stage.

Key Terms

main sequence	nova
nebula	neutron star
giant	pulsar
white dwarf	black hole

Why It Matters

Theories of stellar evolution help us to predict the age of our sun, as well as when it will stop shining. In fact, there's nothing to worry about.

Because a typical star exists for billions of years, astronomers will never be able to observe one star throughout its entire lifetime. Instead, they have developed theories about the evolution of stars by studying stars in different stages of development.

Classifying Stars

Plotting the surface temperatures of stars against their *luminosity*, or the total amount of energy they give off each second, reveals a consistent pattern. The graph that illustrates this pattern is the *Hertzsprung-Russell diagram*, or *H-R diagram*, a simplified version of which is shown in **Figure 1**. The graph is named for Ejnar Hertzsprung and Henry Norris Russell, the astronomers who discovered the pattern nearly 100 years ago.

Astronomers plot the highest temperatures on the left and the highest luminosities at the top. The temperature and luminosity for most stars fall within a band that runs diagonally through the middle of the H-R diagram. This band, which extends from cool, dim, red stars at the lower right to hot, bright, blue stars at the upper left, is known as the **main sequence**. Stars within this band are called *main-sequence stars* or *dwarfs*. The sun is a main-sequence star.

main sequence the location on the H-R diagram where most stars lie; it has a diagonal pattern from the lower right to the upper left

Figure 1 The Hertzsprung-Russell Diagram

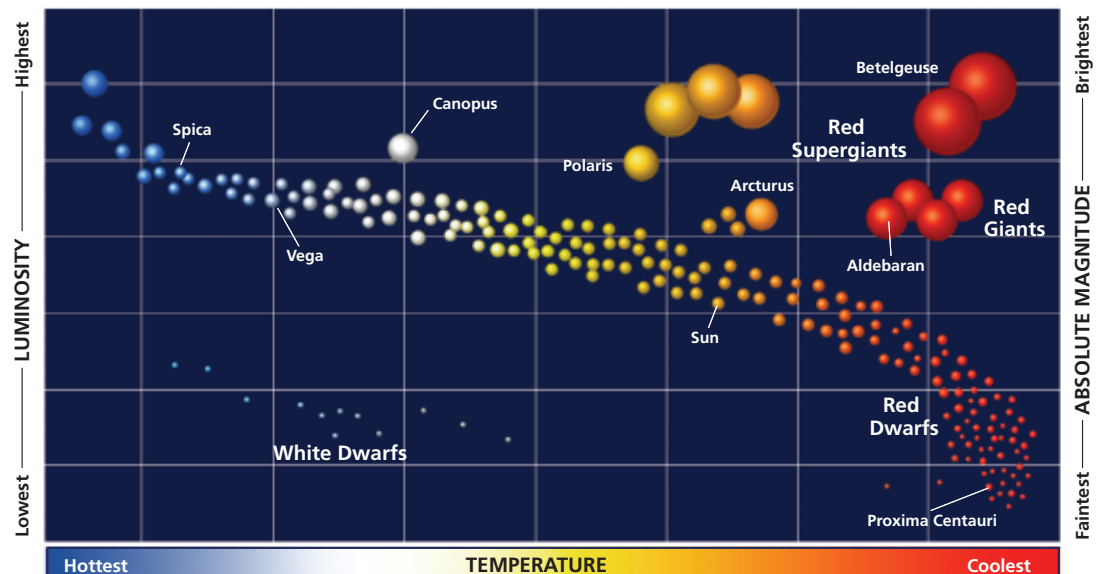


Figure 2 The Eagle Nebula is a region in which star formation is currently taking place. This false-color image of a small part of the Eagle Nebula was captured by the *Hubble Space Telescope*.

READING TOOLBOX

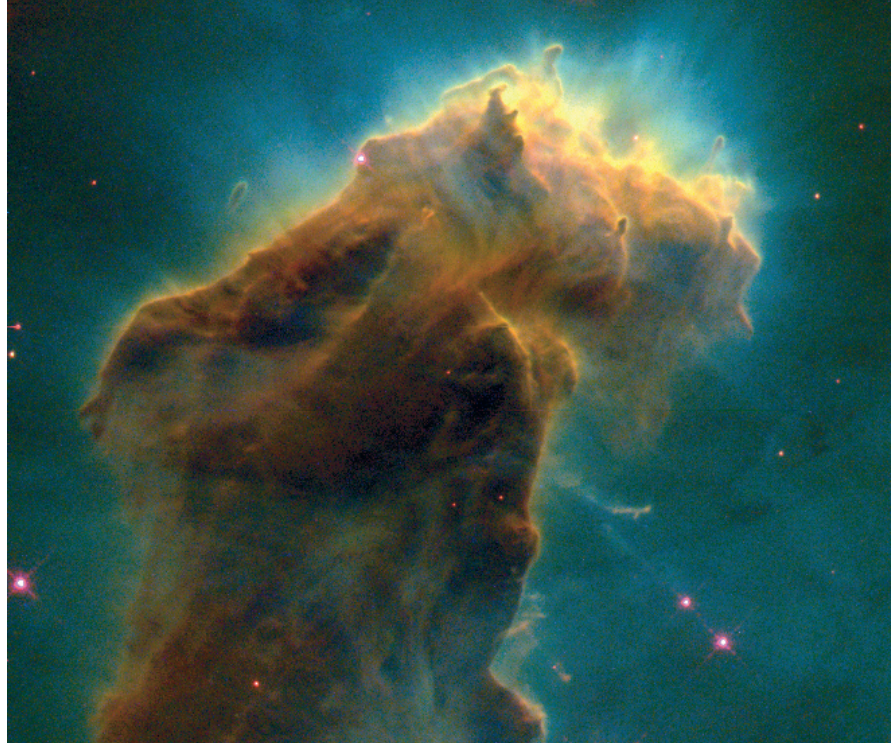
Scientific Theories vs. Scientific Laws

On a sheet of paper, write the name and definition of the law given on this page. Explain why it is a law, not a theory.

nebula a large cloud of gas and dust in interstellar space; a region in space where stars are born

Math Skills

Nuclear Fusion The sun converts nearly 545 million metric tons of hydrogen to helium every second. In the process, approximately 3.6 million metric tons of that hydrogen mass are changed into energy and radiated into space. What percentage of the converted hydrogen is changed into radiated energy? If the sun loses 3.6 million metric tons of mass per second, how many metric tons of mass will it lose in one year?



Star Formation

A star begins in a **nebula** (NEB yu luh), a cloud of gas and dust, such as the one shown in **Figure 2**. A nebula commonly consists of about 70% hydrogen, 28% helium, and 2% heavier elements. When an outside force, such as the explosion of a nearby star, compresses the cloud, some of the particles move close to each other and are pulled together by gravity. Alternatively, the collapse may start randomly, without an identifiable force.

According to Newton's *law of universal gravitation*, all objects in the universe attract each other with a force that increases as the mass of any object increases or as the distance between the objects decreases. Thus, as gravity pulls particles closer together, the attraction on each other increases. This pulls more nearby particles toward an area of increasing mass. As more particles come together, dense regions of matter build up within the nebula.

Protostars

As gravity makes these dense regions more compact, any spin the region has is greatly amplified. The shrinking, spinning region begins to flatten into a disk that has a central concentration of matter called a *protostar*. Gravitational energy is converted into heat energy as more matter is pulled into the protostar. This heat energy causes the temperature of the protostar to increase.

The protostar continues to contract and increase in temperature for several million years. Eventually, the gas becomes so hot that its electrons are stripped from their parent atoms. The nuclei and free electrons move independently, and the gas is then considered a separate state of matter called *plasma*. Plasma is a hot, ionized gas that has an equal number of free-moving positive ions and electrons.

The Birth of a Star

Temperature continues to increase in a protostar to about 10,000,000 °C. At this temperature, nuclear fusion begins. *Nuclear fusion* is a process that occurs when extremely high temperature and pressure cause less-massive atomic nuclei to combine to form more-massive nuclei and, in the process, release enormous amounts of energy. The onset of fusion marks the birth of a star. Once nuclear fusion begins in a star, the process can continue for billions of years.

A Delicate Balancing Act

As gravity increases the pressure on the matter within the star, the rate of fusion increases. In turn, the energy radiated from fusion reactions heats the gas inside the star. The outward pressures of the radiation and the hot gas resist the inward pull of gravity. The stabilizing effect of these forces is shown in **Figure 3**. This equilibrium makes the star stable in size. A main-sequence star maintains a stable size as long as the star has an ample supply of hydrogen to fuse into helium.

 **Reading Check** How does the pressure from fusion and hot gas interact with the force of gravity to maintain a star's stability?

The Main-Sequence Stage

The second and longest stage in the life of a star is the main-sequence stage. During this stage, energy continues to be generated in the core of the star as hydrogen fuses into helium. Fusion releases enormous amounts of energy. For example, when only 1 g of hydrogen is converted into helium, the energy released could keep a 100 W light bulb burning for more than 200 years.

A star that has a mass about the same as the sun's mass stays on the main sequence for about 10 billion years. More-massive stars, on the other hand, fuse hydrogen so rapidly that they may stay on the main sequence for only 10 million years. Because the universe is about 14 billion years old, massive stars that formed long ago have long since left the main sequence. Less massive stars, which are at the bottom right of the main sequence on the H-R diagram, are thought to be able to exist for hundreds of billions of years.

The stages in the life of a star cover an enormous period of time. Scientists estimate that over a period of almost 5 billion years, the sun, shown in **Figure 4**, has converted only 5% of its original hydrogen nuclei into helium nuclei. After another 5 billion years, though, with 10% of the sun's original hydrogen converted, the rate of fusion in the core will decrease significantly, causing the sun's temperature and luminosity to change. Then the sun will move off the main sequence.

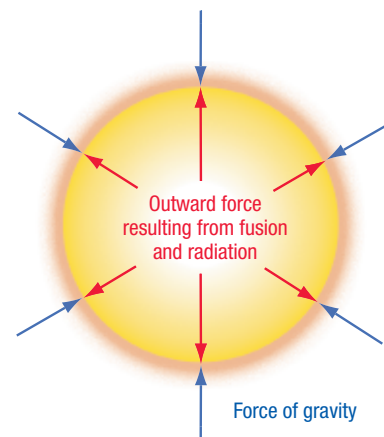


Figure 3 Stellar equilibrium is achieved when the inward force of gravity is balanced by the outward pressure from fusion and radiation inside the star.

Figure 4 Our sun is a yellow dwarf star. It is located in the diagonal band of main-sequence stars on the H-R diagram.



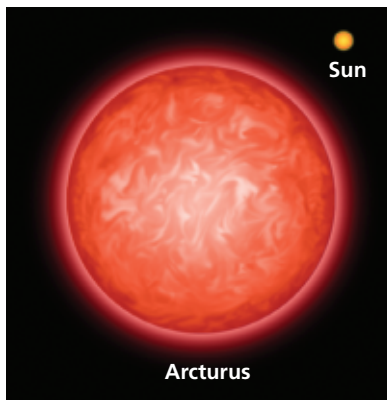


Figure 5 Arcturus is an orange giant that is about 23 times larger than the sun. Despite being about 1,000°C cooler than the sun, Arcturus gives off more than 100 times as much light as the sun does because it has so much surface area.

giant a very large and bright star whose hot core has used most of its hydrogen

Leaving the Main Sequence

A star enters its third stage when about 20% of the hydrogen atoms within its core have fused into helium atoms. The core of the star begins to contract under the force of its own gravity. This contraction increases the temperature in the core. As the helium core becomes hotter, it transfers energy into a thin shell of hydrogen surrounding the core. This energy causes hydrogen fusion to continue in the shell of gas. The on-going fusion of hydrogen radiates large amounts of energy outward, which causes the outer shell of the star to expand greatly.

Giant Stars

A star's shell of gases grows cooler as it expands. As the gases in the outer shell become cooler, their glow becomes reddish. These large, red stars are known as **giants** because they are larger than main-sequence stars of the same surface temperature.

Because of their large surface areas, giant stars are bright. Giants, such as the star Arcturus shown in **Figure 5**, are 10 or more times larger than the sun. Stars that contain about as much mass as the sun will become giants. As they become larger, more luminous, and cooler, they move off the main sequence. Giant stars are above the main sequence on the H-R diagram.

Supergiants

Main-sequence stars that are more massive than the sun will become larger than giants in their third stage. These highly luminous stars are called *supergiants*. These stars appear along the top of the H-R diagram. Supergiants are often at least 100 times larger than the sun. Betelgeuse, the large, orange-red star shown in **Figure 6**, is one example of a supergiant. Located in the constellation Orion, Betelgeuse is 1,000 times larger than the sun.

Though such supergiant stars make up only a small fraction of all the stars in the sky, their high luminosity makes the stars easy to find in a visual scan of the night sky. However, despite the high luminosity of supergiants, their surfaces are relatively cool.

Reading Check Where are giants and supergiants found on the H-R diagram?

Figure 6 If the sun were replaced by the red supergiant Betelgeuse, the surface of this star would be farther out than Jupiter's orbit. *How does the temperature of Betelgeuse compare with that of the sun?*



The Final Stages of a Sunlike Star

In the evolution of a medium-sized star, fusion in the core will stop after the helium atoms have fused into carbon and oxygen. With energy no longer available from fusion, the star enters its final stages.

Planetary Nebulas

As the star's outer gases drift away, the remaining core heats these expanding gases. The gases appear as a *planetary nebula*, a cloud of gas that forms around a sunlike star that is dying. Some of these clouds may form a simple sphere or ring around the star. However, many planetary nebulas form more-complex shapes. For example, the Ant nebula has a double-lobed shape, as shown in **Figure 7**.

White Dwarfs

As a planetary nebula disperses, gravity causes the remaining matter in the star to collapse inward. The matter collapses until it cannot be pressed further together. A hot, extremely dense core of matter—a **white dwarf**—is left. White dwarfs shine for billions of years before they cool completely.

White dwarfs are in the lower left of the H-R diagram. They are hot but dim. These stars are very small, about the size of Earth. As white dwarfs cool, they become fainter. This is the final stage in the life cycle of many stars.



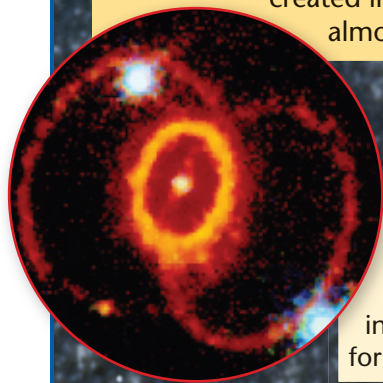
Figure 7 The Ant nebula is a planetary nebula that is located more than 3,000 light-years from Earth in the southern constellation Norma.

white dwarf a small, hot, dim star that is the leftover center of an old sunlike star

Why It Matters

Where Are Elements Made?

To live on the moon or Mars, people will need a reliable supply of oxygen. Fortunately, both places have plenty of oxygen in their rocks and soil. But oxygen atoms were first created in the hearts of stars, along with almost all other matter.



Supernovas such as 1987A, shown here, create all the atoms in the universe, except for hydrogen and helium.



About 20% of the air you breathe is oxygen, O₂.

YOUR TURN

CRITICAL THINKING

How can there be oxygen in lunar rocks and soil?

nova a star that suddenly becomes brighter

Novas and Supernovas

Some white dwarf stars are part of binary star systems. If a white dwarf revolves around a red giant, the gravity of the very dense white dwarf may capture loosely held gases from the red giant. As these gases accumulate on the surface of the white dwarf, pressure begins to build up. This pressure may cause large explosions, which release energy and stellar material into space. Such an explosion is called a **nova**.

A nova may cause a star to become many thousands of times brighter than it normally is. However, within days, the nova begins to fade to its normal brightness. Because these explosions rarely disrupt the stability of the binary system, the process may start again and a white dwarf may become a nova several times.

A white dwarf star in a binary system may also become a *supernova*, a star that has such a tremendous explosion that it blows itself apart. Unlike an ordinary nova, a white dwarf can sometimes accumulate so much mass on its surface that gravity overwhelms the outward pressure. The star collapses and becomes so dense that the outer layers rebound and explode outward. Supernovas are thousands of times more violent than novas. The explosions of supernovas completely destroy the white dwarf star and may destroy much of the red giant.

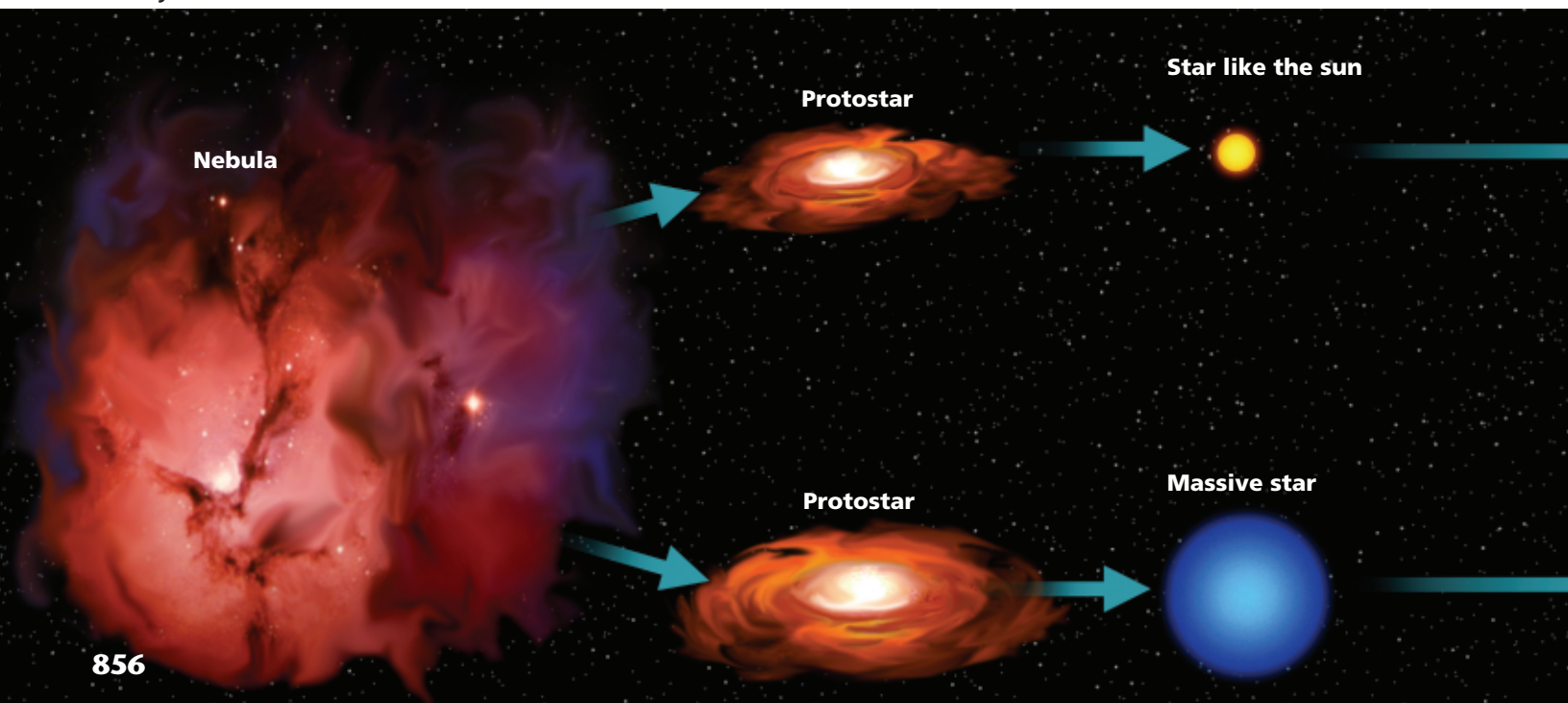
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Topic: How Stars Evolve
Code: HQX0764

The Final Stages of Massive Stars

Stars that have masses of more than 8 times the mass of the sun may produce supernovas without needing a secondary star to fuel them. In 1054, Chinese astronomers saw a supernova so bright that it was seen during the day for more than three weeks. At its peak, the supernova radiated an amount of energy that was equal to the output of about 400 million suns.

Life Cycle of Stars



Supernovas in Massive Stars

While only a small percentage of white dwarfs become supernovas, massive stars become supernovas as part of their life cycle, which is shown in **Figure 8**. After the supergiant stage, these stars contract with a gravitational force that is much greater than that of small-mass stars. The collapse produces such high pressures and temperatures that nuclear fusion begins again. This time, carbon atoms in the core of the star fuse into heavier elements such as oxygen, magnesium, or silicon.

Fusion continues until the core is almost entirely made of iron. Because iron has a very stable nuclear structure, fusion of iron into heavier elements takes energy from the star rather than giving off energy. Having used up its supply of fuel, the core begins to collapse under its own gravity. Energy released as the core collapses is transferred to the outer layers of the star, which explode outward with tremendous force. Within a few minutes, the energy released by the supernova may surpass the amount of energy radiated by a sunlike star over its entire lifetime.

 **Reading Check** What causes a supergiant star to explode as a supernova?

Neutron Stars

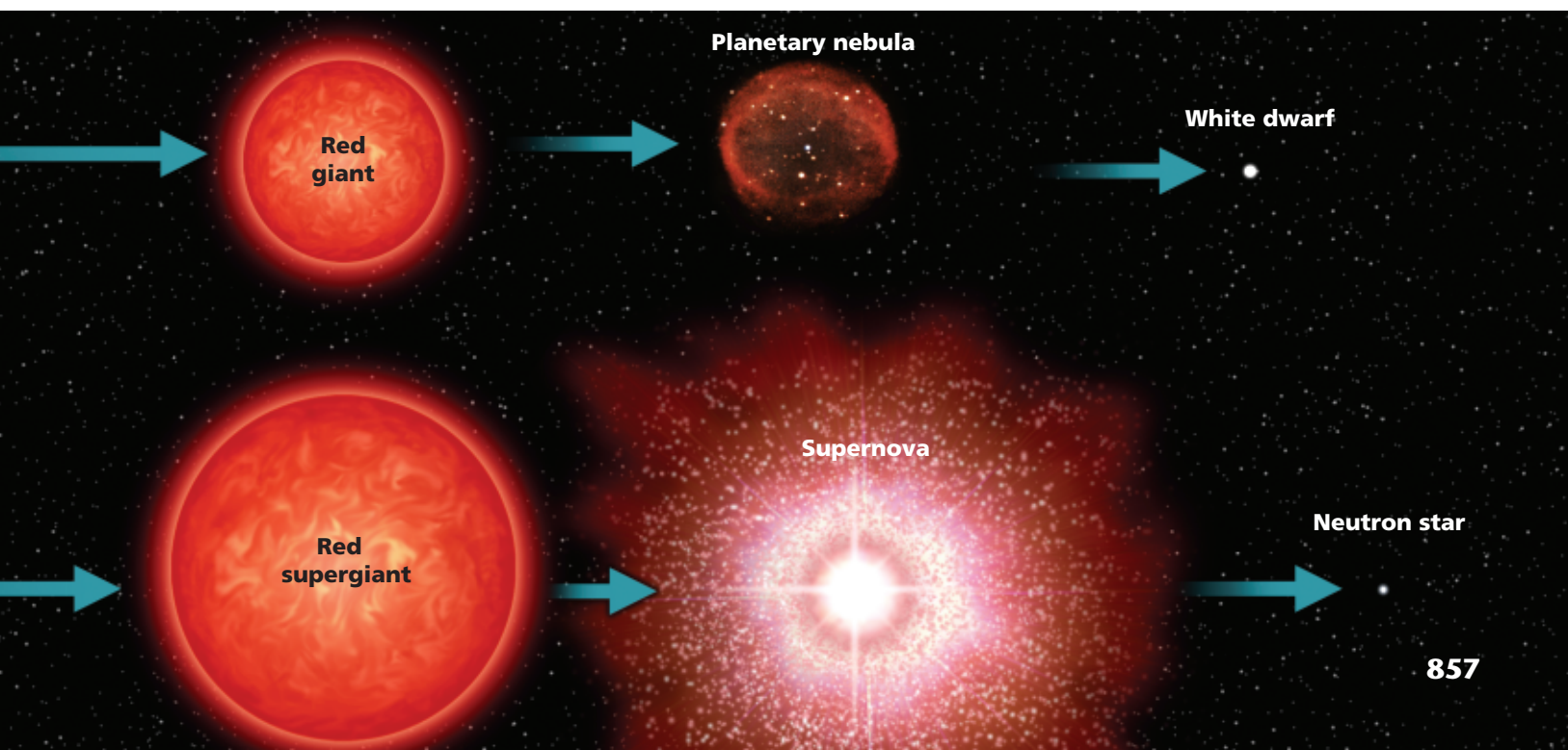
Stars that contain about 8 or more times the mass of the sun do not become white dwarfs. After a star explodes as a supernova, the core may contract into a very small but incredibly dense ball of neutrons, called a **neutron star**. A single teaspoon of matter from a neutron star would have a mass of 2×10^{30} kilograms (a 2 followed by 30 zeroes). A neutron star that has more mass than the sun may have a diameter of only about 20 km but may emit the same amount of energy as 100,000 suns. Neutron stars rotate very rapidly.

Academic Vocabulary

structure (STRUHK chuhr) the arrangement of the parts of a whole; a whole that is built or put together from parts

neutron star a star that has collapsed under gravity to the point that the electrons and protons have smashed together to form neutrons

Figure 8 A star the mass of the sun becomes a white dwarf near the end of its life cycle. A more massive star may become a neutron star.



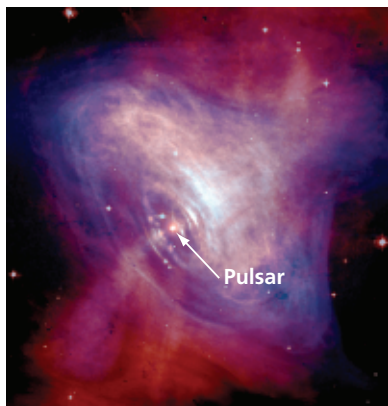


Figure 9 This pulsar, located in the heart of the Crab nebula, is still surrounded by the remains of a supernova explosion that took place less than 1,000 years ago.

pulsar a rapidly spinning neutron star that emits pulses of radio and optical energy
black hole an object so massive and dense that even light cannot escape its gravity

Pulsars

Some neutron stars emit a beam of radio waves that sweeps across space like a lighthouse light beam sweeps across water. Because we detect pulses of radio waves every time the beam sweeps by Earth, these stars are called **pulsars**. For each pulse we detect, we know that the star has rotated within that period. Newly formed pulsars, such as the one shown in **Figure 9**, are commonly surrounded by the remnants of a supernova. But most known pulsars are so old that these remnants have long since dispersed and have left behind only the spinning star.

Black Holes

Some massive stars produce leftovers too massive to become stable neutron stars. If the remaining core of a star contains more than 3 times the mass of the sun, the star may contract further under its greater gravity. The force of the contraction crushes the dense core of the star and leaves a **black hole**. The gravity of a black hole is so great that nothing, not even light, can escape it.

Because black holes do not give off light, locating them is difficult. But a black hole can be observed by its effect on a companion star. Matter from the companion star is pulled into the black hole. Just before the matter is absorbed, it swirls around the black hole. The gas becomes so hot that X rays are released. Astronomers locate black holes by detecting these X rays. Scientists then try to find the mass of the object that is affecting the companion star. Astronomers conclude that a black hole exists only if the companion star's motion shows that a massive, invisible object is present nearby.

Section 2 Review

Key Ideas

1. **Explain** the steps that the gas in a nebula goes through as it becomes a star.
2. **Describe** the process that generates energy in the core of a main-sequence star.
3. **Explain** how a main-sequence star like the sun is able to maintain a stable size.
4. **Describe** how nuclear fusion in a main-sequence star is different from nuclear fusion in a giant star.
5. **Describe** how a star similar to the sun changes after it leaves the main-sequence stage of its life cycle.
6. **Describe** what causes a nova explosion.
7. **Explain** why only very massive stars can form black holes.
8. **Describe** two types of supernovas.

Critical Thinking

9. **Identifying Relationships** How do astronomers conclude that a supergiant star is larger than a main-sequence star of the same temperature?
10. **Analyzing Ideas** Why would an older main-sequence star be composed of a higher percentage of helium than a young main-sequence star?
11. **Compare and Contrast** Why does temperature increase more rapidly in a more massive protostar than in a less massive protostar?
12. **Analyzing Ideas** How can astronomers detect a black hole if it is invisible to an optical telescope?

Concept Mapping

13. Use the following terms to create a concept map: *main-sequence star, nebula, supergiant, white dwarf, planetary nebula, black hole, supernova, protostar, giant, pulsar, and neutron star.*

Star Groups

Key Ideas

- Describe the characteristics that identify a constellation.
- Describe the three main types of galaxies.
- Explain how a quasar differs from a typical galaxy.

Key Terms

constellation
galaxy
quasar

Why It Matters

People have used the stars for thousands of years to help them navigate and to know when to plant crops.

When you look into the sky on a clear night, you see what appear to be individual stars. These visible stars are only some of the trillions of stars that make up the universe. Most of the ones we see are within 100 light-years of Earth. However, in the constellation Andromeda, there is a hazy region that is actually a huge collection of stars, gas, and dust. This region is more than two million light-years from Earth. It is the farthest one can see with the unaided eye.

Constellations

By using a star chart and observing carefully, you can identify many star groups that form star patterns or regions. Although the stars that make up a pattern appear to be close together, they are not all the same distance from Earth. In fact, they may be very distant from one another, as shown in **Figure 1**.

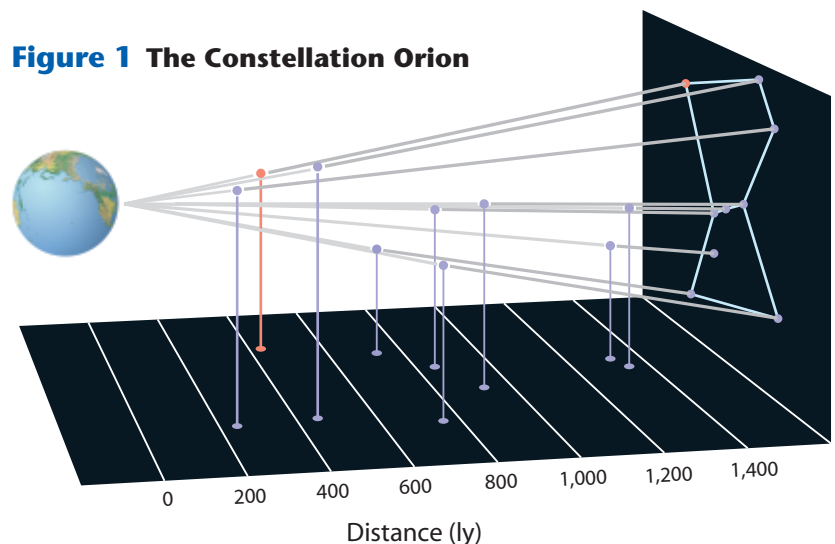
If you look at the same region of the sky for several nights, the positions of the stars in relation to one another do not appear to change. Because of the tremendous distance from which the stars are viewed, they appear fixed in their patterns. For more than 3,000 years, people have observed and recorded these patterns. These patterns of stars and the region of space around them are called **constellations**.

constellation one of 88 regions into which the sky has been divided in order to describe the locations of celestial objects; a group of stars organized in a recognizable pattern

Dividing Up the Sky

In 1930, astronomers around the world agreed upon a standard set of 88 constellations. The stars of these constellations and the regions around them divide the sky into sectors. Just as you can use a road map to locate a particular town, you can use a map of the constellations to locate a particular star. Star charts can be found in Appendix F.

Figure 1 The Constellation Orion



READING TOOLBOX

Everyday Words Used in Science

The word *glob* means “a rounded clump.” Based on what you know about the words *glob*, *open*, and *cluster*, do you think *globular cluster* and *open cluster* accurately describe the objects they represent? Why or why not?

Academic Vocabulary

association (uh soh see AY shuhn) a connection or combination

galaxy a collection of stars, dust, and gas bound together by gravity

Multiple-Star Systems

Stars are not always solitary objects isolated in space. When two or more stars are closely associated, they form multiple-star systems. *Binary stars* are pairs of stars that revolve around each other and are held together by gravity. In systems where the two stars have similar masses, the center of mass, or *barycenter*, will be somewhere between the stars. If one star is more massive than the other, the barycenter will be closer to the more massive star.

Multiple-star systems sometimes have more than two stars. In such a star system, two stars may revolve rapidly around a common barycenter, while a third star revolves more slowly at a greater distance from the pair. Astronomers estimate that more than half of all sunlike stars are part of multiple-star systems.

 **Reading Check** What percentage of stars similar to the sun are in multiple-star systems?

Star Clusters

Sometimes, nebulae collapse to form groups of hundreds or thousands of stars, called clusters. *Globular clusters* have a spherical shape and can contain up to one million stars. An *open cluster*, such as the one shown in **Figure 2**, is loosely shaped and rarely contains more than a few hundred stars.

Galaxies

A large-scale group of stars, gas, and dust that is bound together by gravity is called a **galaxy**. Galaxies are the major building blocks of the universe. A typical galaxy, such as the Milky Way galaxy in which we live, has a diameter of about 100,000 light-years and may contain more than 200 billion stars. Astronomers estimate that the universe contains hundreds of billions of galaxies.

Distances to Galaxies

Some stars allow astronomers to find distances to the galaxies that contain the stars. For example, giant stars called *Cepheid* (SEF ee id) *variables* brighten and fade in a regular pattern. Most Cepheids have regular cycles that range from 1 to 100 days. The longer a Cepheid’s cycle is, the brighter the star’s visual absolute magnitude is. By comparing the Cepheid’s absolute magnitude and the Cepheid’s apparent magnitude, astronomers calculate the distance to the Cepheid variable. This distance, in turn, tells them the distance to the galaxy in which the Cepheid is located.

Figure 2 The open cluster M50 is made up of hundreds of stars. It is located about 3,000 light-years from Earth.



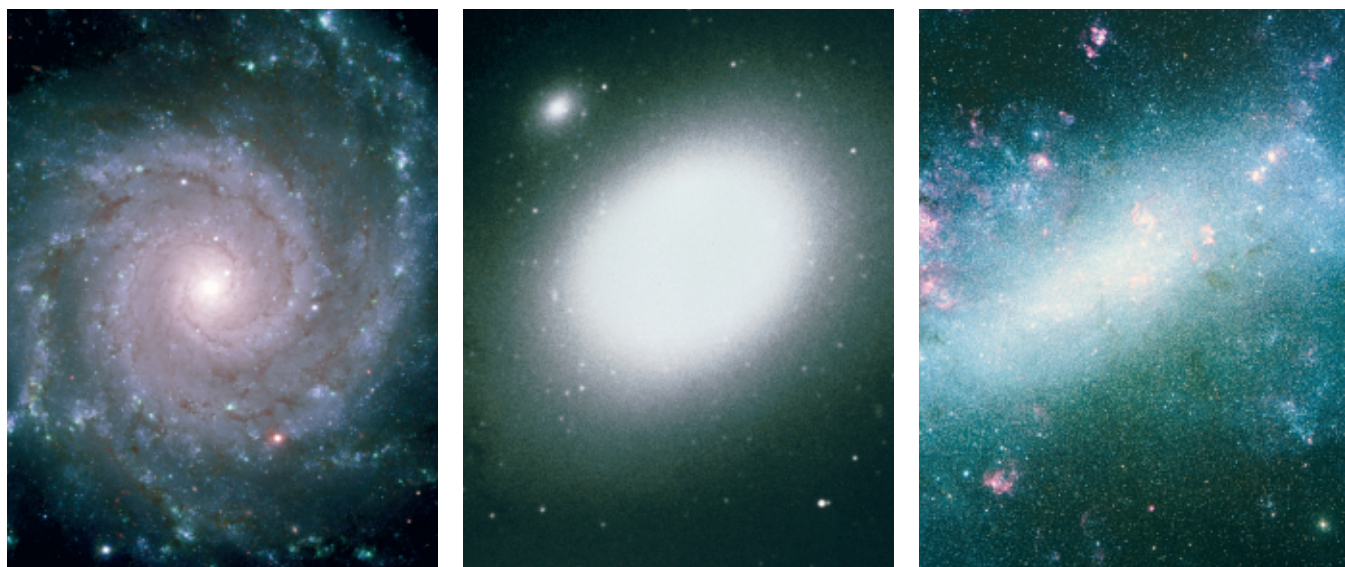


Figure 3 The three main types of galaxies are spiral (left), elliptical (center), and irregular (right).

Types of Galaxies

In studying galaxies, astronomers found that galaxies could be classified by shape into the three main types shown in **Figure 3**. The most common type of large galaxy, called a *spiral galaxy*, has a nucleus of bright stars and flattened arms that spiral around the nucleus. The spiral arms consist of billions of young stars, gas, and dust. Some have a straight bar of stars that runs through the center. These galaxies are called *barred spiral galaxies*.

Galaxies of the second type vary in shape from nearly spherical to very elongated, like a stretched-out football. These galaxies are called *elliptical galaxies*. They are extremely bright in the center and do not have spiral arms. Elliptical galaxies have few young stars and contain little dust and gas.

The third type of galaxy, called an *irregular galaxy*, has no particular shape. These galaxies usually have low total masses and are fairly rich in dust and gas. Irregular galaxies make up only a small percentage of the total number of observed galaxies.

The Milky Way

If you look into the night sky, you may see what appears to be a cloudlike band that stretches across the sky. Because of its milky appearance, this part of the sky is called the Milky Way. We see this band of stars when looking through the dense plane of our own galaxy.

The *Milky Way galaxy* is a spiral galaxy in which the sun is one of hundreds of billions of stars. Each star orbits around the center of the Milky Way galaxy. It takes the sun about 225 million years to complete one orbit around the galaxy.

Two irregular galaxies, the Large Magellanic Cloud and Small Magellanic Cloud, are our closest neighbors. Even so, these galaxies are each more than 170,000 light-years away from Earth. Within 5 million light-years of the Milky Way are about 30 other galaxies. These galaxies and the Milky Way galaxy are collectively called the *Local Group*.

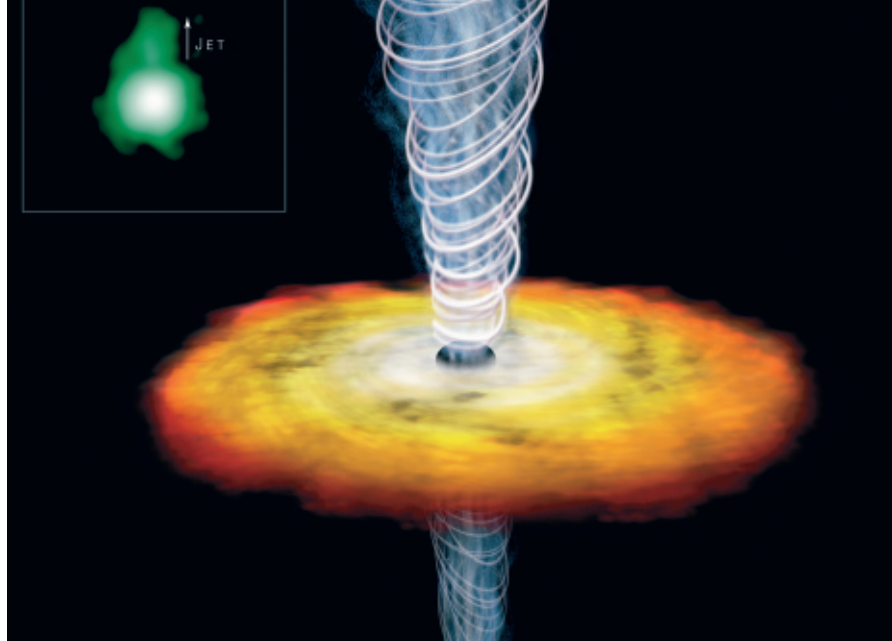
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Topic: Galaxies

Code: HQX0632

Figure 4 The jets of gas projected from a quasar can extend for more than 100,000 light-years. Quasars are too distant to be clearly photographed. The image shown is an artist's rendition of a quasar. The smaller inset is an actual image taken by the *Chandra X-Ray Observatory*.



quasar quasi-stellar radio source; a very luminous object that produces energy at a high rate

Quasars

Discovered in 1963, quasars used to be the most puzzling objects in the sky. Viewed through an optical telescope, a quasar appears as a point of light, almost in the same way that a small, faint star would appear. The word **quasar** is a shortened term for *quasi-stellar radio source*. The prefix *quasi-* means “similar to,” and the word *stellar* means “star.” Quasars are not related to stars, but quasars are related to galaxies. Some quasars project a jet of gas, as shown in **Figure 4**.

Astronomers have discovered that quasars are located in the centers of galaxies that are distant from Earth. Galaxies that have quasars in them differ from other galaxies in that the quasars in their centers are very bright. The large amount of energy emitted from such a small volume could be explained by the presence of a giant black hole. The mass of such black holes is estimated to be billions of times the mass of our sun. Quasars are among the most distant objects that have been observed from Earth.

Section 3 Review

Key Ideas

1. **Identify** the characteristics of a constellation.
2. **List** the three basic types of galaxies.
3. **Describe** the Milky Way galaxy in terms of galaxy types.
4. **Describe** the difference between a typical galaxy and a quasar.

Critical Thinking

5. **Identifying Relationships** Explain how stars can form a constellation when seen from Earth but can still be very far from each other.

6. **Making Calculations** The sun orbits the center of the Milky Way galaxy every 225 million years. How many revolutions has the sun made since the formation of Earth 4.6 billion years ago?

7. **Analyzing Ideas** Why are the constellations that are seen in the winter sky different from those seen in the summer sky?

Concept Mapping

8. Use the following terms to create a concept map: *galaxy*, *elliptical galaxy*, *Milky Way galaxy*, *irregular galaxy*, *barred spiral galaxy*, and *spiral galaxy*.

The Big Bang Theory

Key Ideas

- Explain how Hubble's discoveries led to an understanding that the universe is expanding.
- Summarize the big bang theory.
- List evidence for the big bang theory.

Key Terms

cosmology
big bang theory
cosmic background radiation

Why It Matters

Studying the origin, structure, and future of the universe helps us better understand our origins and our place in the universe.

The study of the origin, structure, and future of the universe is called **cosmology**. Cosmologists, or people who study cosmology, are concerned with processes that affect the universe as a whole. Like the parts found within it, the universe is always changing. While some astronomers study how planets, stars, or galaxies form and evolve, a cosmologist studies how the entire universe formed and tries to predict how it will change in the future.

Like all scientific theories, theories about the origin and evolution of the universe must constantly be tested against new observations and experiments. Many current theories of the universe began with observations made less than 100 years ago.

Hubble's Observations

Just as the light from a single star can be used to make a stellar spectrum, scientists can also use the light given off by an entire galaxy to create the spectrum for that galaxy. In the early 1900s, finding the spectrum of a galaxy could take the whole night, or even several nights. Although collecting new spectra was very time consuming, the astronomer Edwin Hubble used these galactic spectra to uncover new information about our universe.

cosmology the study of the origin, properties, processes, and evolution of the universe

Measuring Red Shifts

Near the end of the 1920s, Hubble found that the spectra of galaxies, except for the few closest to Earth, were shifted toward the red end of the spectrum. By examining the amount of red shift, he determined the speed at which the galaxies were moving away from Earth. Hubble found that the most distant galaxies showed the greatest red shift and thus were moving away from Earth the fastest.

Many distant galaxies are shown in **Figure 1**. Modern telescopes that have electronic cameras can take images of hundreds of spectra per hour. These spectra all confirm Hubble's original findings.

Figure 1 This image from the *Hubble Space Telescope* shows hundreds of galaxies. These galaxies all have large red shifts, so they are moving away from Earth very fast.



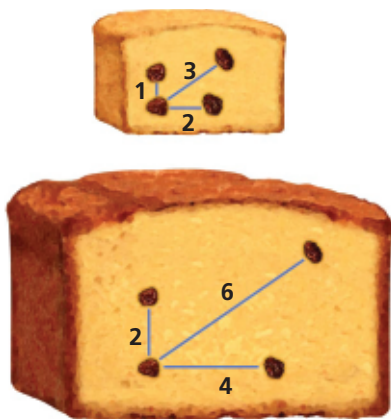


Figure 2 Like raisins in expanding cake batter, the farther galaxies are from each other, the faster they move away from each other.



big bang theory the theory that all matter and energy in the universe was compressed into an extremely small volume that 13 to 15 billion years ago exploded and began expanding in all directions

The Expanding Universe

Imagine a raisin cake rising in a kitchen oven. If you were able to sit on one raisin, you would see all the other raisins moving away from you. Raisins that are farther away in the dough when it begins rising move away faster because there is more cake between you and them and because the whole cake is expanding. The situation is similar with galaxies and the universe, as shown in **Figure 2**. By using Hubble's observations, astronomers were able to determine that the universe was expanding.

A Theory Emerges

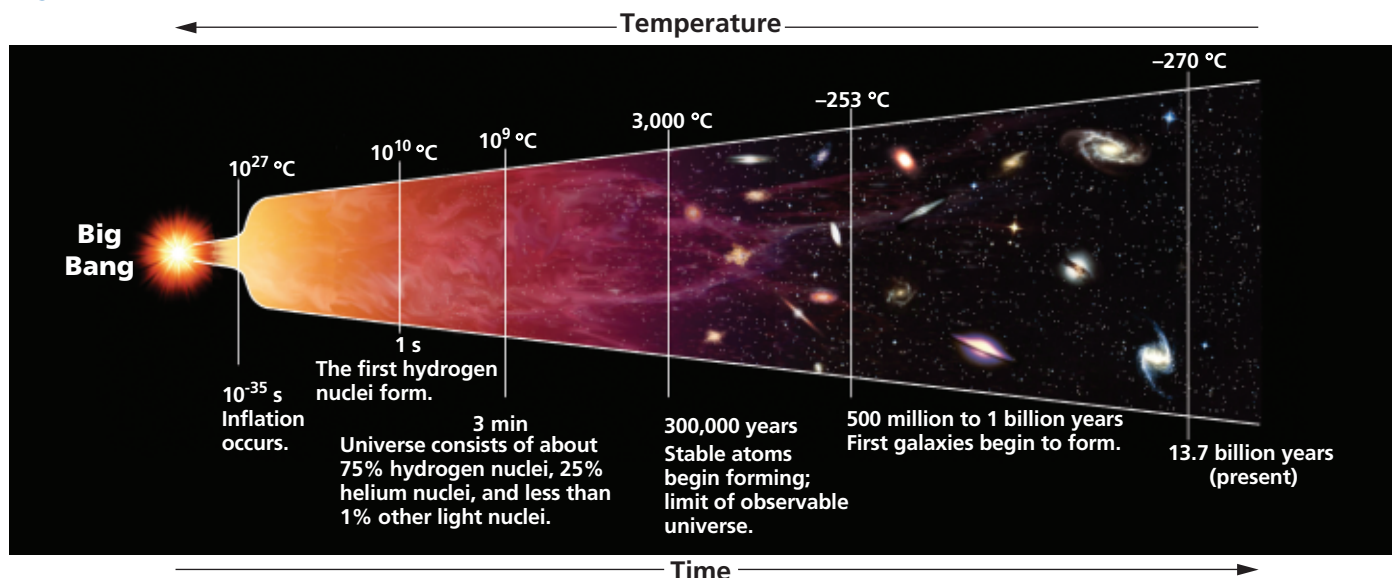
Although cosmologists have proposed several different theories to explain the expansion of the universe, the current and most widely accepted is the big bang theory. The **big bang theory** states that billions of years ago, all the matter and energy in the universe was compressed into an extremely small volume. If you trace the expanding universe back in time, all matter would have been close together at one point in time. About 14 billion years ago, a sudden event called the *big bang* sent all of the matter and energy outward in all directions.

As the universe expanded, some of the matter gathered into clumps that evolved into galaxies. Today, the universe is still expanding, and the galaxies continue to move apart from one another. This expansion of space explains the red shift that we detect in the spectra of galaxies. **Figure 3** shows a timeline of events following the big bang.

By the mid-20th century, almost all astronomers accepted the big bang theory. An important discovery in the 1960s finally convinced most of the remaining scientists that a sudden event, the big bang, had taken place.

Reading Check What does the big bang theory tell us about the early universe?

Figure 3 A Big Bang Timeline



Quick Lab The Expanding Universe

15 min

Procedure

- 1 Use a **marker** to make 3 dots in a row on an uninflated **balloon**. Label them "A," "B," and "C." Dot B should be closer to A than dot C is to B.
- 2 Blow the balloon up just until it is taut. Pinch the balloon to keep it inflated, but do not tie the neck.
- 3 Use **string** and a **ruler** to measure the distances between A and B, B and C, and A and C.
- 4 With the balloon still inflated, blow into the balloon until its diameter is twice as large.
- 5 Measure the distances between A and B, B and C, and A and C. For each set of dots, subtract the original distances measured in step 3 from the new distances. Then, divide by 2, because the balloon is about twice as large. This

calculation will give you the rate of change for each pair of dots.

- 6 Repeat steps 4 and 5.

Analysis

1. Did the distance between A and B, between B and C, or between A and C show the greatest rate of change?
2. Suppose dot A represents Earth and that dots B and C represent galaxies. How does the rate at which galaxies are moving away from us relate to how far they are from Earth?



Cosmic Background Radiation

In 1965, researchers using radio telescopes detected **cosmic background radiation**, or low levels of energy evenly distributed throughout the universe. Astronomers concluded that this background radiation formed shortly after the big bang.

The universe soon after the big bang would have been very hot and would have cooled to a great extent by now. The energy of the background radiation has a temperature of only about 3°C above *absolute zero*, the coldest temperature possible. Because absolute zero is about -273°C , the cosmic background radiation's temperature is about 270°C below zero.

Like any theory, the big bang theory must continue to be tested against each new discovery about the universe. But the big bang theory has been well tested, and any changes are likely to be modifications of the general concept.

Ripples in Space

Maps of cosmic background radiation over the whole sky look very smooth. But on satellite maps that show where temperatures differ from the average background temperature, "ripples" become apparent, as shown in **Figure 4**. These ripples are irregularities in the cosmic background radiation, which were caused by small fluctuations in the distribution of matter in the early universe. The ripples are thought to indicate the first stages in the formation of the universe's first galaxies.

cosmic background radiation radiation uniformly detected from every direction in space; considered a remnant of the big bang

Figure 4 This display is shown on half a globe that represents the sky as seen from Earth orbit. The temperature difference between the red spots and the blue spots is only $2/10,000^{\circ}\text{C}$.

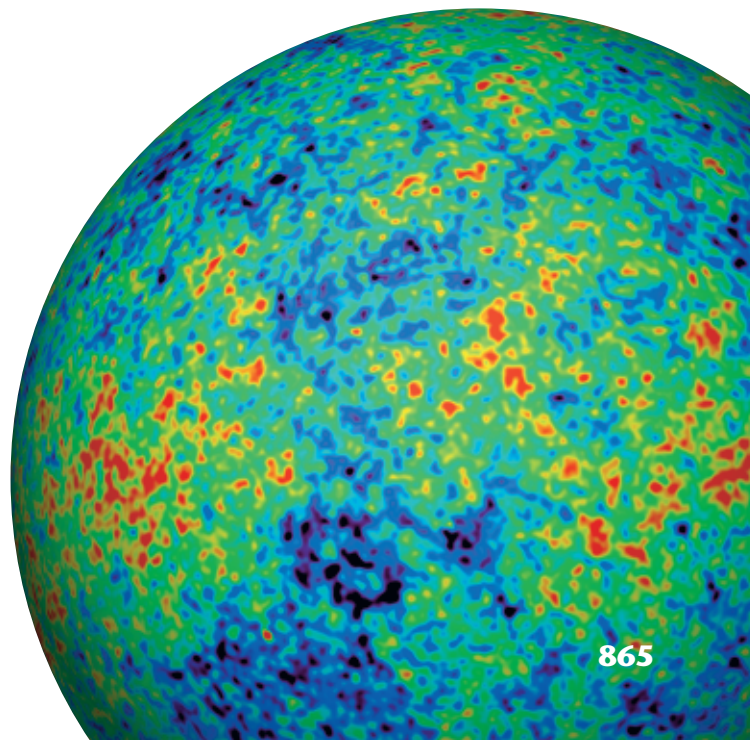
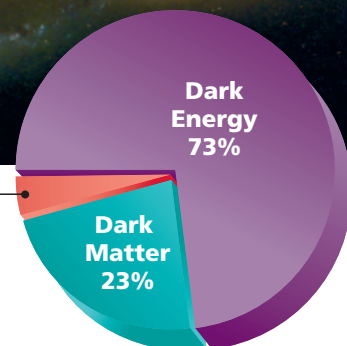




Figure 5 Normal matter may make up only a small portion of the universe.

Atoms
4%



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Topic: Big Bang
Code: HQX0146

READING TOOLBOX

Everyday Words Used in Science

How would you define *dark matter* and *dark energy*? Compare your definitions with those on this page.

A Universe of Surprises

Recent data based on the ripples in the cosmic background radiation and studies of the distance to supernovas found in ancient galaxies have forced astronomers to rethink some of the theories about what makes up the universe. Astronomers now think that the universe is made up of more mass and energy than they can currently detect.

Dark Matter

Surprisingly, analyzing the ripples in the cosmic background radiation suggests that the kinds of matter that humans, the planets, the stars, and the matter between the stars are

made of makes up only 4% of the universe, as shown in **Figure 5**. Another 23% of the universe is made up of a type of matter that does not give off light but that has gravity that we can detect. Because this type of matter does not give off light, it is called *dark matter*.

Dark Energy

Another surprise is that most of the universe is composed of something that we know almost nothing about. The unknown material is called *dark energy*, and scientists think that it acts as a force that opposes gravity. Recent evidence suggests that distant galaxies are farther from Earth than current theory would indicate. So, many scientists conclude that some form of undetectable dark energy is pushing galaxies apart. Because of dark energy, the universe is not only expanding, but the rate of expansion also seems to be accelerating.

Section 4 Review

Key Ideas

- 1. Describe** how red shifts were used by cosmologists to determine that the universe is expanding.
- 2. Summarize** the big bang theory.
- 3. List** evidence that supports the big bang theory.
- 4. Compare** the amount of visible matter in the universe with the total amount of matter and energy.

Critical Thinking

- 5. Inferring Relationships** How did the distribution of matter in the early universe affect how

we are able to detect cosmic background radiation today?

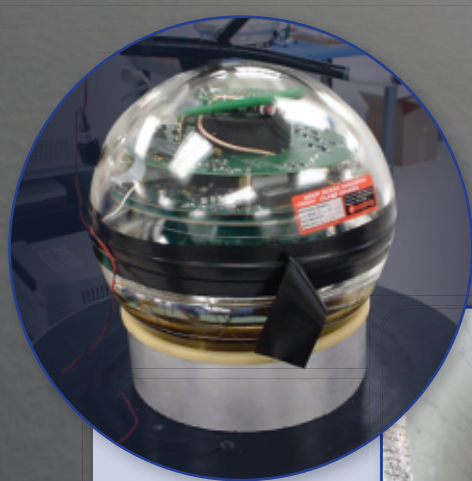
- 6. Evaluating Theories** Use the big bang theory to explain why scientists do not expect to find galaxies that have large blue shifts.
- 7. Identifying Relationships** Why do observations made of distant galaxies indicate that dark energy exists?

Concept Mapping

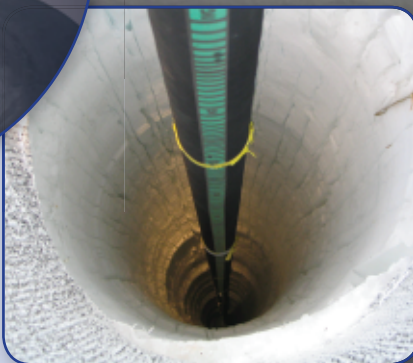
- 8.** Use the following terms to create a concept map: *cosmic background radiation*, *dark energy*, *red shift*, *dark matter*, *big bang theory*, and *galaxies*.

A Cool Telescope

Every year, over 100 researchers brave the coldest, windiest place on Earth to use a special telescope that looks deep inside Earth. Why? This special telescope, called IceCube, is searching for hints of the origins of the universe. Pure, deep Antarctic ice provides the perfect observatory for detecting subatomic particles called neutrinos that reach Earth from far across space.



The average depth of an IceCube hole is nearly 2.5 km below the surface. These holes are drilled using hot water, producing approximately 750,000 L of melted ice in the process. It took about 57 hours to drill IceCube's first hole.



**YOUR
TURN**

UNDERSTANDING CONCEPTS

What is the telescope IceCube designed to do?

CRITICAL THINKING

How might life at a research station on Antarctica be similar to, and different from, life on the International Space Station?

What You'll Do

- **Construct** a model photometer and two model stars.
- **Demonstrate** how distance affects the brightness of stars.
- **Explain** how color is related to the temperature of stars.

What You'll Need

aluminum foil, 12 cm × 12 cm
batteries, AA (3)
desk lamp with incandescent bulb
flashlight bulbs, 3-volt (2)
paraffin, 12 cm × 6 cm
bricks (2)
rubber band, large
ruler, metric
tape, electrical
wire, plastic-coated with stripped ends, 15 cm
wire, plastic-coated with stripped ends, 20 cm

Safety



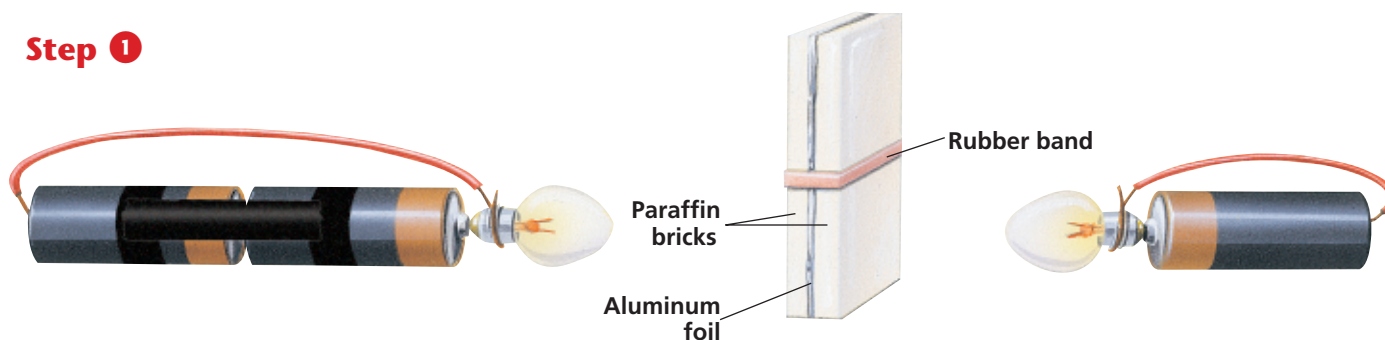
Star Magnitudes

Among other things, astronomers study the brightness, or magnitude, of stars. Except for the sun, stars are very faint and visible only at night. Thus, their brightness must be measured with a device called a *photometer* or, more recently, a CCD (charge-coupled device). An astronomical photometer consists of a surface that is sensitive to light and a device that measures the amount of light that reaches the surface. Photometers can also be used to compare the colors of different light sources. In this lab, you will determine the effect of distance on brightness and the relationship between temperature and color.

Procedure

- 1 Construct two flashlights:
 - a. Arrange the bulbs and batteries as shown in the figure below. Using electrical tape, attach the wires to the batteries and bulbs. The bulbs should be on. If they are not on, study the illustration again and make adjustments.
 - b. Tape the flashlight arrangements together so that they can be moved. Be sure to leave the wires loose at the negative ends of the batteries so that you can turn your flashlights on and off.
- 2 Construct a model photometer by folding the aluminum foil in half with the shiny side facing out, and placing it between two paraffin bricks. Hold the pieces together using a rubber band.
- 3 Place the two flashlights about 2 m apart on a table. Place the photometer between them with the largest sides of the bricks facing each flashlight bulb, as shown in the figure below.
- 4 Turn on both flashlights, and turn off all room lights.
- 5 Move the photometer until both sides are equally bright. Measure the distance, in centimeters, from each flashlight bulb to the center of the photometer. Record these measurements.

Step 1



- 6 Square the distances you recorded in step 5. Record these values.
- 7 Incandescent light bulbs have filaments that emit light at a temperature that is much cooler than the sun's surface. Place the photometer between the desk lamp and a window on a bright day. Sunlight coming through a window will be the same color as the sunlight outdoors. Turn off any fluorescent ceiling lighting, and turn on the desk lamp.
- 8 Compare the color differences between the paraffin sides of your photometer.
- 9 Darken the room once again, and compare the colors of the bulb powered by one battery with the colors of the bulb powered by two batteries.



Step 8

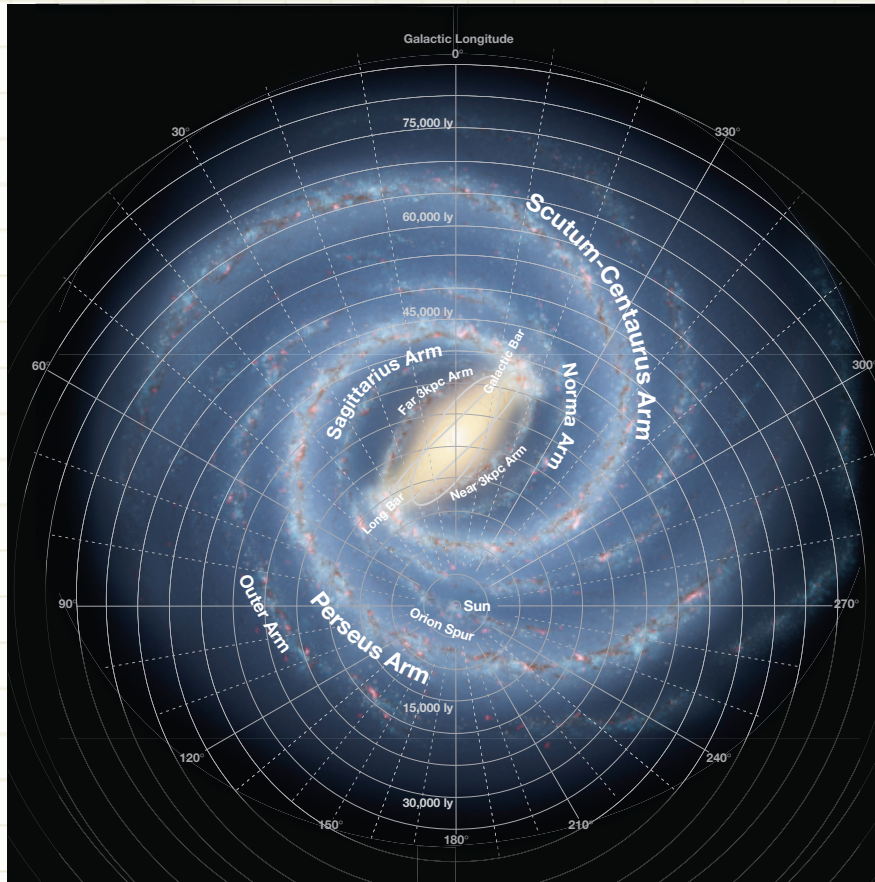
Analysis

1. **Analyzing Data** The ratio of the square of the distances you calculated in step 6 is equal to the ratio of the brightnesses of the bulbs. What is the ratio of the square of the distance of the two-battery flashlight to that of the one-battery flashlight? What does this information tell you about the relationship between the brightness of the two flashlights?
2. **Drawing Conclusions** Based on the results of the investigation, would you expect a white star to be hotter or cooler than a yellow star?
3. **Applying Conclusions** Using your knowledge of the spectrum, would you expect a white star to be hotter or cooler than an orange star? Predict whether a blue star is hotter or cooler than a white star. Also, predict whether a red star is hotter or cooler than an orange star.

Extension

Explaining Observations Find an incandescent bulb controlled by a dimmer. Watch the color of the light as it fades. Does it become more yellow or more white? Explain why.

The Milky Way



Map Skills Activity

The map above shows what astronomers think the Milky Way galaxy looks like. Because of Earth's position within the galaxy, scientists must hypothesize what our galaxy looks like from a perspective outside of the galaxy. They must also form a hypothesis about the shape and location of those spiral arms that are obscured by either the galactic core or other spiral arms that are closer to Earth. Use the map to answer the questions below.

- Using a Key** What is the approximate distance from one edge of the Milky Way to the other edge?
- Analyzing Data** What is the approximate width of the galactic core through its long axis?
- Inferring Relationships** How are the Sagittarius Arm and the Orion Spur related to each other?
- Identifying Locations** In which feature of the galaxy is the solar system located?
- Identifying Trends** What happens to the arms of the Milky Way as they radiate outward from the center of the galaxy?
- Evaluating Data** As shown on this map, the Milky Way is a barred spiral galaxy with two major arms each attached to opposite ends of the galactic core. Considering the shape of these arms, in which direction is the galaxy rotating when viewed from this perspective?

Section 1**Key Ideas****Characteristics of Stars**

- To determine its composition and surface temperature, astronomers study a star's spectrum.
- Stars appear to move in the sky because of the Earth's rotational movement.
- Astronomers measure the distance to stars using the distance light travels in one year (the light-year) and the apparent shift in a star's position when viewed from different locations (parallax).
- Apparent magnitude is a star's brightness as it appears to us on Earth. Absolute magnitude is its true brightness if all stars were at a standard, uniform distance from Earth.

Key Terms

star, p. 845
Doppler effect, p. 848
light-year, p. 849
parallax, p. 849
apparent magnitude, p. 850
absolute magnitude, p. 850

Section 2**Stellar Evolution**

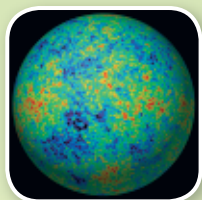
- A protostar becomes a star when its hydrogen begins to fuse to form helium.
- Main-sequence stars generate energy through hydrogen fusion.
- Sunlike stars may become planetary nebulas and then white dwarfs. Massive stars may become supernovas and then neutron stars, pulsars, or black holes.

main sequence, p. 851
nebula, p. 852
giant, p. 854
white dwarf, p. 855
nova, p. 856
neutron star, p. 857
pulsar, p. 858
black hole, p. 858

Section 3**Star Groups**

- A constellation contains a recognizable star pattern and can be used to locate celestial objects.
- The three types of galaxies are spiral, elliptical, and irregular.
- Quasars are very bright, distant galaxies that are thought to have enormous black holes in their centers.

constellation, p. 859
galaxy, p. 860
quasar, p. 862

Section 4**The Big Bang Theory**

- Hubble found that the spectra of galaxies are red-shifted, indicating they are moving away from Earth and from each other.
- The big bang theory states that, about 14 billion years ago, all matter and energy in the universe was compressed into an extremely small volume that began to expand in all directions.
- Evidence for the big bang theory includes red shifts, cosmic background radiation, and ripples in space.

cosmology, p. 863
big bang theory, p. 864
cosmic background radiation, p. 865

1. Scientific Theories vs. Scientific Laws

As you review Newton's law of universal gravitation and the big bang theory, think about why one is a law and the other is a

READING TOOLBOX

theory. Write a paragraph to explain your thoughts about this.

USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *light-year*
3. *cosmology*
4. *big bang theory*

For each pair of terms, explain how the meanings of the terms differ.

5. *constellation* and *cluster*
6. *spiral galaxy* and *elliptical galaxy*
7. *galaxy* and *quasar*
8. *cosmic background radiation* and *red shift*

UNDERSTANDING KEY IDEAS

9. The most common element in most stars is
 - a. oxygen.
 - b. hydrogen.
 - c. helium.
 - d. sodium.
10. Cosmic background radiation
 - a. is very hot.
 - b. is blue-green.
 - c. comes from supernovas.
 - d. comes almost equally from all directions.
11. Stars appear to move in circular paths through the sky because
 - a. Earth rotates on its axis.
 - b. Earth orbits the sun.
 - c. the stars orbit Polaris.
 - d. the Milky Way is a spiral galaxy.
12. A nebula begins the process of becoming a protostar when the nebula
 - a. develops a red shift.
 - b. changes color from red to blue.
 - c. begins to shrink and increases its spin.
 - d. explodes as a nova.

13. The brightest star in the night sky is
 - a. Polaris.
 - b. Mars.
 - c. Arcturus.
 - d. Sirius.
14. A main-sequence star generates energy by fusing
 - a. nitrogen into iron.
 - b. helium into carbon.
 - c. hydrogen into helium.
 - d. nitrogen into carbon.
15. Which of the following choices lists the colors of stars from hottest to coolest?
 - a. red, yellow, orange, white, blue
 - b. orange, red, white, blue, yellow
 - c. yellow, orange, red, blue, white
 - d. blue, white, yellow, orange, red
16. The heaviest element formed in the core of a star is
 - a. iron.
 - b. carbon.
 - c. helium.
 - d. nitrogen.
17. The change in position of a nearby star as seen from different points on Earth's orbit compared with the position of a faraway star is called
 - a. parallax.
 - b. blue shift.
 - c. red shift.
 - d. a Cepheid variable.

SHORT ANSWER

18. Describe what scientists think will happen to the sun in the next 5 billion years.
19. How can a black hole be detected if it is invisible?
20. How does a galaxy that contains a quasar differ from an ordinary galaxy?
21. What evidence indicates that the universe is expanding?
22. How does the presence of cosmic background radiation support the big bang theory?

CRITICAL THINKING

- 23. Inferring Relationships** If the spectrum of a star indicates that the star shines with red light, what is the approximate surface temperature of the star?
- 24. Analyzing Ideas** Why are different constellations visible during different seasons?
- 25. Analyzing Ideas** Explain why Polaris is considered to be a very significant star even though it is not the brightest star in Earth's sky.
- 26. Making Comparisons** Why does energy build up more rapidly in a massive protostar than in a less massive one?
- 27. Analyzing Ideas** Explain why an old main-sequence star is made of a higher percentage of helium than a young main-sequence star is.
- 28. Analyzing Ideas** If all galaxies began to show blue shifts, what would this change indicate about the fate of the universe?

CONCEPT MAPPING

- 29.** Use the following terms to create a concept map: *galaxy, star, black hole, white dwarf, neutron star, giant, spiral galaxy, supergiant, elliptical galaxy, planetary nebula, main sequence, irregular galaxy, and protostar.*

MATH SKILLS

Math Skills

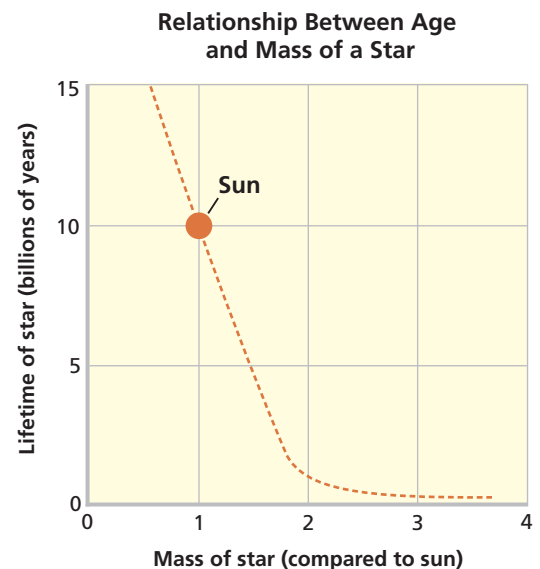
- 30. Making Calculations** The Milky Way galaxy has about 200 billion stars. If only 10% of an estimated 125 billion galaxies thought to exist in the universe were as large as the Milky Way, how many total stars would be in those galaxies?
- 31. Making Calculations** Given that the nearest star is about 4 light-years from Earth and a light-year is about 10,000,000,000,000 km, how many years would it take to travel to the nearest star if your spaceship goes 100 times faster than a car traveling 100 km/h?

WRITING SKILLS

- 32. Creative Writing** Imagine that you are navigating through the galaxy and seeing many kinds of objects. Write a brief tour article for a magazine that describes your trip.
- 33. Writing from Research** Use the Internet and library resources to research the function of constellations in ancient cultures. Write a short essay describing three different ways that ancient cultures used constellations.

INTERPRETING GRAPHICS

The graph below shows the relationship between a star's age and mass. Use the graph to answer the questions that follow.



- 34.** Which star would live longer, a star that has half the mass of the sun or a star that has 2 times the mass of the sun?
- 35.** Approximately how long would a main-sequence star that has a mass about 1.5 times that of our sun live?
- 36.** If the mass of the sun was reduced by one-half, approximately how much longer would the sun live than it would with its current mass?

Understanding Concepts

Directions (1–5): For each question, write on a separate sheet of paper the letter of the correct answer.

- What accounts for different stars being seen in the sky during different seasons of the year?
 - stellar motion around Polaris
 - Earth's rotation on its axis
 - Earth's revolution around the sun
 - position north or south of the equator
- How do stellar spectra provide evidence that stars are actually moving?
 - Dark-line spectra reveal a star's composition.
 - Long-exposure photos show curved trails.
 - Light separates into different wavelengths.
 - Doppler shifts occur in the star's spectrum.
- What happens to main-sequence stars like the sun when energy from fusion is no longer available?
 - They expand and become supergiants.
 - They collapse and become white dwarfs.
 - They switch to fission reactions.
 - They contract and turn into neutron stars.
- Which type of star is most likely to be found on the main sequence?
 - a white dwarf
 - a red supergiant
 - a yellow star
 - a neutron star
- Evidence for the big bang theory is provided by
 - cosmic background radiation.
 - apparent parallax shifts.
 - differences in stellar luminosity.
 - star patterns called constellations.

Directions (6–8): For each question, write a short response.

- What type of galaxy has no identifiable shape?
- What is the collective name for the Milky Way galaxy and a cluster of approximately 30 other galaxies located nearby?
- What is the name for stars that seem to circle around Polaris and never dip below the horizon?

Reading Skills

Directions (9–11): Read the passage below. Then, answer the questions.

DISCOVERING GALAXIES

Today, we know that Copernicus was right: the stars are very far from Earth. In fact, stars are so distant that a new unit of length—the light-year—was created to measure their distance. A light-year is a unit of length equal to the distance that light travels through space in 1 year. Because the speed of light through space is about 300,000 km/s, light travels approximately 9.46 trillion kilometers in one year.

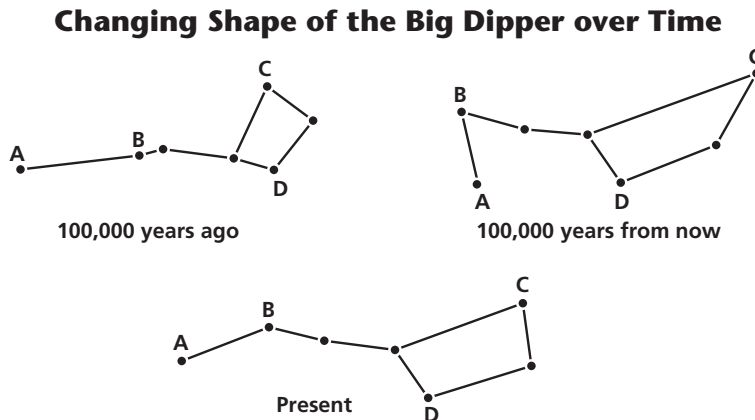
Even after astronomers figured out that stars were far from Earth, the nature of the universe was hard to understand. Some astronomers thought that our galaxy, the Milky Way, included every object in space. In the early 1920's, Edwin Hubble made one of the most important discoveries in astronomy. He discovered that the Andromeda galaxy, which is the closest major galaxy to our own, was past the edge of the Milky Way. This fact confirmed the belief of many astronomers that the universe is larger than our galaxy.

- Why was Edwin Hubble's discovery important?
 - Hubble's discovery showed scientists that the universe was smaller than previously thought.
 - Hubble showed that the Andromeda galaxy was larger than the Milky Way galaxy.
 - Hubble's discovery showed scientists that the universe was larger than our own galaxy.
 - Hubble showed that all of the stars exist in two galaxies, Andromeda and The Milky Way.
- Because the sun and Earth are close together, the distance between the sun and Earth is measured in light-minutes. A light-minute is the distance light travels in 1 minute. The sun is about 8 light-minutes from Earth. What is the approximate distance between the sun and Earth?
 - 2,400,000 km
 - 18,000,000 km
 - 144,000,000 km
 - 1,000,000,000 km
- Why might scientists use light-years as a measurement of distance between stars?

Interpreting Graphics

Directions (12–15): For each question below, record the correct answer on a separate sheet of paper.

The diagram below shows a group of stars called the Big Dipper moving over a period of 200,000 years. Use this diagram to answer question 12.



- 12.** What does this series of drawings demonstrate about the individual stars in such a star group?

The table below shows data about several well-known stars. Distance is given in light-years. Use this table to answer questions 13 through 15.

Stellar Characteristics

Name	Color	Magnitude	Distance
Arcturus	orange	0.0	36.8 ly
Betelgeuse	red	0.5	400 ly
Canopus	yellow-white	−0.6	310 ly
Capella	yellow	0.1	42.2 ly
Mintaka	blue-violet	2.2	915 ly
Rigel	blue-white	0.2	800 ly
Sirius	white	−1.4	8.6 ly
Vega	white	0.0	25.3 ly

- 13.** Which star has the brightest apparent magnitude as seen from Earth?
- F.** Rigel **H.** Mintaka
G. Betelgeuse **I.** Sirius
- 14.** Which of these stars is the coolest?
- A.** Arcturus **C.** Mintaka
B. Betelgeuse **D.** Vega
- 15.** Which star most likely has a temperature that is similar to the temperature of our sun? Explain how you are able to determine this information.

Test Tip

If you are unsure of an answer, eliminate the answers that you know are wrong before choosing your answer.