25 Beyond Our Solar System

Big idea: Earth and the Universe

Q: How do astronomers study objects in our galaxy and beyond?

A nebula is a dust cloud in space that consists mostly of hydrogen and nitrogen. The Lagoon Nebula, pictured here, is located about 5000 light-years from Earth in the part of the sky called Sagittarius. This image was captured by specialized cameras on the Hubble Space Telescope. Astronomers think that areas such as this are where stars are born. A nebula does not emit light on its own. Instead, energy from a nearby bright star is either reflected by the cloud or is absorbed and causes gases to give off light. In this image, light from hydrogen is red; light from nitrogen is green.

VIRGINIA SCIENCE STANDARDS OF LEARNING

ES.1.c, ES.1.e, ES.2.c, ES.3.d, ES.13.a, ES.13.b.
See lessons for details.

INQUIRY

TRY IT!

HOW DO ASTRONOMERS MEASURE DISTANCES TO NEARBY STARS?

Procedure

1. Close your left eye. Hold your index finger in a vertical position. Use your right eye to line up your finger with a distant object, such as a tree or edge of a building.
2. Without moving your finger, close your right eye and open your left eye. Notice the alignment now of your finger with the distant object.

Think About It

1. **Observe** What happened to the position of your finger when you observed it with your left eye?
2. **Predict** What might happen if you repeated the activity, holding your finger farther from your eyes? Test your prediction.

25.1 Properties of Stars

ES.3 The student will investigate and understand the characteristics of Earth and the solar system. Key concepts include **d.** the history and contributions of space exploration.

Key Questions

What can we learn by studying star properties?

How does distance affect parallax?

What factors determine a star's apparent magnitude?

What relationship is shown on a Hertzsprung-Russell diagram?

Vocabulary

- constellation
- binary star • light-year
- apparent magnitude
- absolute magnitude
- Hertzsprung-Russell diagram
- main-sequence star
- red giant • supergiant
- Cepheid variable
- nova

Reading Strategy

Preview Copy the table below. Before you read, find the Hertzsprung–Russell diagram in the lesson. Look at the diagram and write two questions about it. As you read, write answers to your questions.

Questions about the Hertzsprung-Russell Diagram	
Question	**Answer**
a. ?	b. ?
c. ?	d. ?

THE CLOSEST star to Earth is the sun—about 150,000,000 kilometers away. After that, the next closest star is Proxima Centauri, which is 39,900,000,000,000 kilometers from Earth. Even though Proxima Centauri and Earth are space neighbors, it still takes light from that star 4.3 years to reach Earth. The light from other stars takes billions of years to reach us. The universe is incomprehensibly large. Astronomers have developed units of length (distance) for use in measuring the distance of objects in space. These units enable us to express how far away a star is without writing so many zeros!

Thousands of years ago, humans didn't know how vast the universe was. Yet, people were fascinated with the star-studded skies and began to name the patterns they saw. Some of these patterns of stars were named after characters from mythology, such as Orion, shown in **Figure 1.**

A **constellation** is used to designate an area of the sky that contains a specific pattern of stars. A star within one of these areas is considered part of the constellation, even if that star is not part of the pattern. The International Astronomical Union (IAU) divided the nighttime sky into 88 separate constellations, similar to a world map of countries. Now, the location of any star can be referred to by which constellation the star is in.

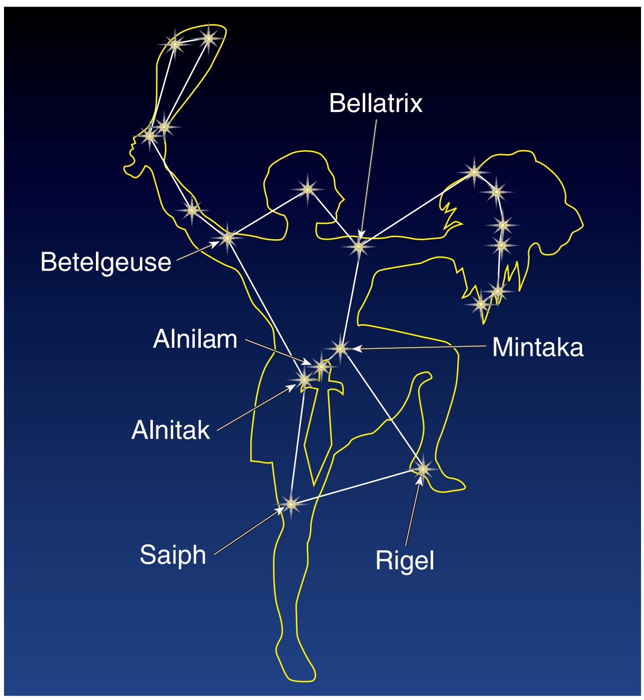


FIGURE 1 Orion This constellation was named after Orion—a great hunter from Greek mythology.

Characteristics of Stars

A great deal is known about the universe beyond our solar system. Th s knowledge hinges on the fact that stars, and even gases in the "empty" space between stars, radiate electromagnetic energy in all directions into space. The key to understanding the universe is to collect this radiation energy and study it. By analyzing the energy emitted or refl cted by objects in the universe, astronomers have been able to determine many properties of stars, such as color, temperature, and mass.

FIGURE 2 Stars of Orion This time-lapse photograph shows stars as streaks across the night sky as Earth rotates. The streaks clearly show different star colors.

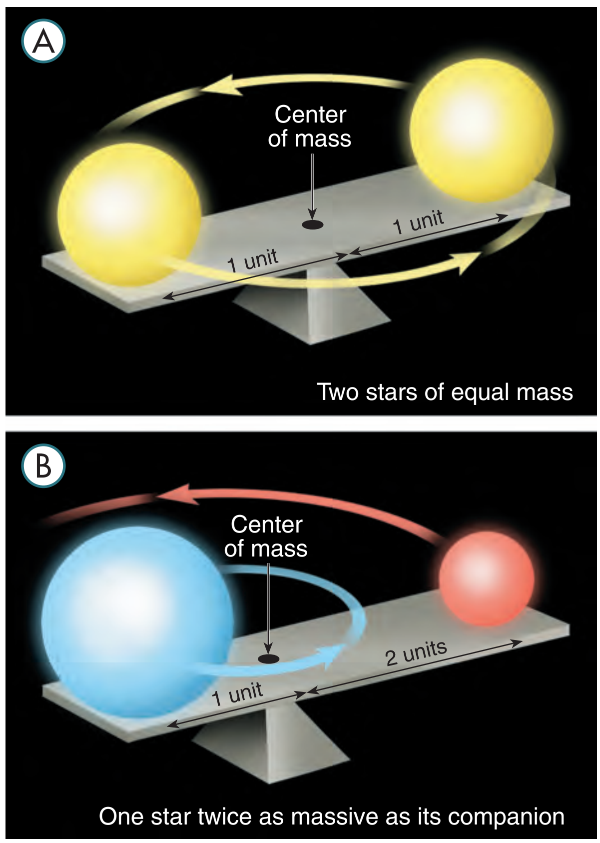
Star Color and Temperature All objects, including stars and planets, emit and absorb radiation. We can see planets because they refl ct some of the light that hits them. Stars, on the other hand, are *blackbody radiators*. A blackbody absorbs all of the electromagnetic radiation that strikes it. It also gives off he maximum amount of radiation possible at a given temperature. The energy of radiation given off y stars depends on their temperatures. Study the stars in **Figure 2** and note their color. **Color is a clue to a star's temperature.** Very hot stars with surface temperatures above 30,000 K emit most of their energy in the form of short-wavelength light and therefore appear blue. Cooler stars emit most of their energy as longer-wavelengths and appear red. Stars with temperatures between 5000 and 6000 K appear yellow, like the sun.

Binary Stars and Stellar Mass In the early nineteenth century, astronomers discovered that many stars orbit each other. These pairs of stars, pulled toward each other by gravity, are called **binary stars.** More than 50 percent of the stars in the universe may occur in pairs or multiples.

Binary stars are used to determine the star property most difficult to calculate—its mass. The mass of a body can be calculated if it is attached by gravity to a partner. As shown in **Figure 3,** binary stars orbit each other around a common point called the center of mass. For stars of equal mass, the center of mass lies exactly halfway between them. If one star is more massive than its partner, the center of mass moves closer to the more massive star, as shown in Figure 3B. If the sizes of the orbits of binary stars are known, the stars' masses can be calculated.

Reading Checkpoint *What is a binary star system?*

FIGURE 3 Common Center of Mass A For stars of equal mass, the center of mass lies in the middle. **B** A star twice as massive as its partner is twice as close to the center of mass. It therefore has a smaller orbit than its less massive partner.



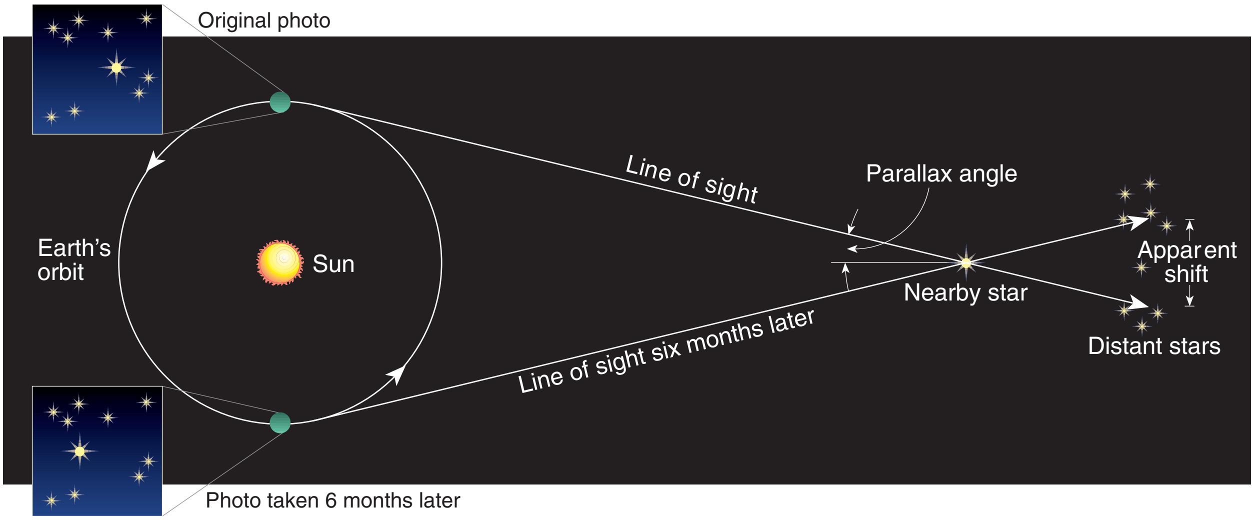


FIGURE 4 Parallax The parallax angle shown here is exaggerated to illustrate the principle. Because the distances to even the nearest stars are huge, astronomers work with very small angles.
Relate Cause and Effect *What caused the star to appear to shift?*

Measuring Distances to Stars

In order to accurately calculate the distance to stars, astronomers must make very precise measurements. Today's astronomers have a wide array of specialized instruments to help them make precise measurements.

Parallax The most basic way to measure star distance is parallax. *Parallax* is the slight shifting in the apparent position of a nearby star due to the orbital motion of Earth. Parallax is determined by photographing a nearby star against the background of distant stars. Then, six months later, when Earth has moved halfway around its orbit, a second photograph is taken. When these photographs are compared, the position of the nearby star appears to have shifted with respect to the background stars. **Figure 4** shows this shift nd the resulting parallax angle.

The nearest stars have the largest parallax angles, while those of distant stars are too small to measure. In fact, all parallax angles are very small. The parallax angle to the nearest star (besides the sun), Proxima Centauri, is less than 1 second of arc, which equals 1/3600 of a degree. To put this in perspective, fully extend your arm and raise your little fi ger—roughly 1 degree wide. Now imagine tracking a movement only 1/3600 as wide as your fi ger.

Before the invention of precise instruments for measuring parallax, astronomers did not understand the scale of the universe. Astronomers once inferred that the planets were closer than the stars because the planets could be seen to pass in front of the stars. They knew the principle of parallax, but the parallax angles of the stars were too small to be measured. It was not until 1673 that Gian Domenico Cassini used parallax to measure the distance between Earth and Mars. Later, in 1838, Friedrich Bessel and two other astronomers used parallax to determine the distances to several stars.

PLANET DIARY

For links on **Earth's orbit and parallax,** visit PlanetDiary.com/HSES.

Light-Year Distances to stars are so great that units such as kilometers or even astronomical units are often not practical to use. A better unit to express stellar distance is the **light-year,** which is the distance light travels in one year—about 9.5×10^{12} or 9.5 trillion kilometers (9,500,000,000,000 kilometers).

Stellar Brightness

The measure of a star's brightness is its magnitude. The stars in the night sky have an assortment of sizes, temperatures, and distances, so their brightnesses vary widely.

Apparent Magnitude Some stars may appear dimmer than others only because they are farther away. A star's brightness as it appears from Earth is called its **apparent magnitude.** **Th ee factors control the apparent brightness of a star as seen from Earth: how big it is, how hot it is, and how far away it is.**

Astronomers use numbers to rank apparent magnitude. The brighter a star is, the smaller the number. This is similar to the fi ishing order of a race—the best fi ish is fi st place, the next-best fi ish is second place, etc. The dimmest stars that are just barely visible from Earth through a telescope have an apparent magnitude of about 25. The brightest single star in our sky, other than the sun, has an apparent magnitude of −1.4. This star is called *Sirius*. As you can see from **Table 1,** Alpha Centauri has less magnitude—0.0—than Sirius. However, Alpha Centauri is actually a three-star system (similar to a binary system, except with three stars instead of two). Alpha Centauri appears brighter than Sirius, but that is because the combined brightness of the three stars appears brighter than the single star, Sirius.

Absolute Magnitude Astronomers are also interested in how bright a star actually is, or its **absolute magnitude.** Two stars of the same absolute magnitude usually do not have the same apparent magnitude because one may be much farther from us than the other. The star that is farther away will appear dimmer. To compare their absolute brightness, astronomers determine what magnitude the stars would have if they were at a standard distance of about 32.6 light-years. For example, the sun, which has an apparent magnitude of −26.7, would, if located at a distance of 32.6 light-years, have an absolute magnitude of about 5. Stars with absolute magnitude values lower than 5 are brighter than the sun. The absolute magnitude of Betelgeuse is much greater than the sun's absolute magnitude. Betelgeuse appears dimmer than the sun because it is 520 light-years from Earth.

Reading Checkpoint *If one star is closer to Earth than another star, will the closer star always appear brighter? Explain.*

Table 1 Distance, Apparent Magnitude, and Absolute Magnitude of Some Stars

Name	Distance (light-years)	Apparent Magnitude*	Absolute Magnitude*
Sun	NA	−26.7	5.0
Alpha Centauri	4.27	0.0	4.4
Sirius	8.70	−1.4	1.5
Arcturus	36	−0.1	−0.3
Betelgeuse	520	0.8	−5.5
Deneb	1600	1.3	−6.9

*The more negative, the brighter; the more positive, the dimmer.

Hertzsprung-Russell Diagram

An important tool used by astronomers when studying stars is the diagram shown in **Figure 5**—the Hertzsprung-Russell (H-R) diagram. **A Hertzsprung-Russell diagram shows the relationship between the absolute magnitude and temperature of stars.** The H-R diagram shows that about 90 percent of all stars are **main-sequence stars** that fall along a band that runs from the upper-left orner to the lower-right corner of the diagram. The hottest main-sequence stars are the brightest, and the coolest main-sequence stars are the dimmest.

The brightness of the main-sequence stars is also related to their mass. The hottest blue stars are about 50 times more massive than the sun, while the coolest red stars are only 1/10 as massive. Therefore, on the H-R diagram, the main-sequence stars appear in decreasing order, from hotter, more massive blue stars to cooler, less massive red stars.

Above and to the right of the main-sequence stars in the H-R diagram lies a group of very bright stars called **red giants.** Some stars are so large that they are called **supergiants.** Betelgeuse, a bright red supergiant in the constellation Orion, has a radius about 800 times that of the sun. Stars in the lower-central part of the H-R diagram are much fainter than main-sequence stars of the same temperature. Some probably are no bigger than Earth. This group is called *white dwarfs*, although not all are white.

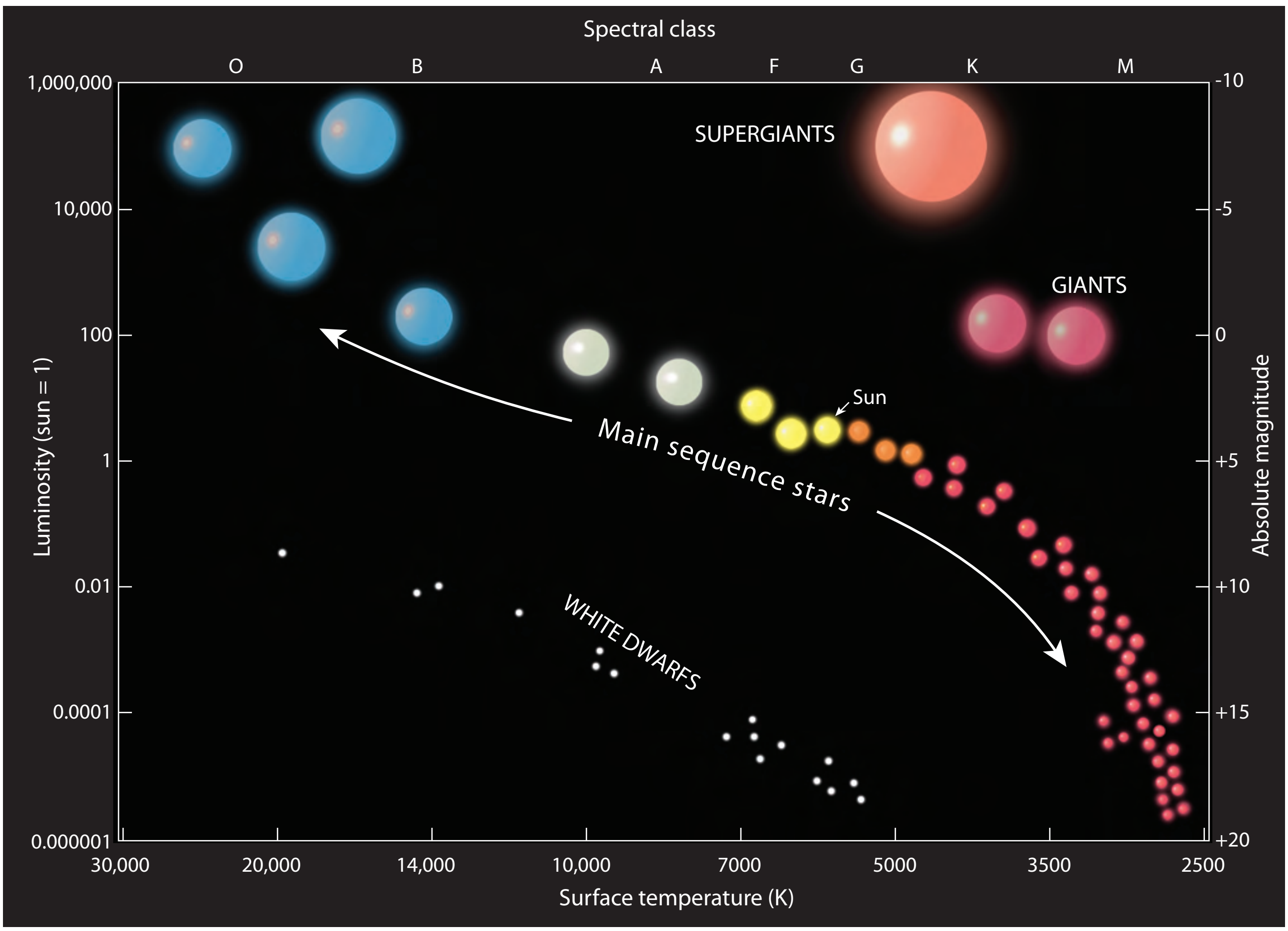


FIGURE 5 Hertzsprung-Russell (H-R) Diagram In this idealized chart, stars are plotted according to temperature and absolute magnitude. The H-R diagram also provides clues to stellar evolution—stars are born, age, and then die.

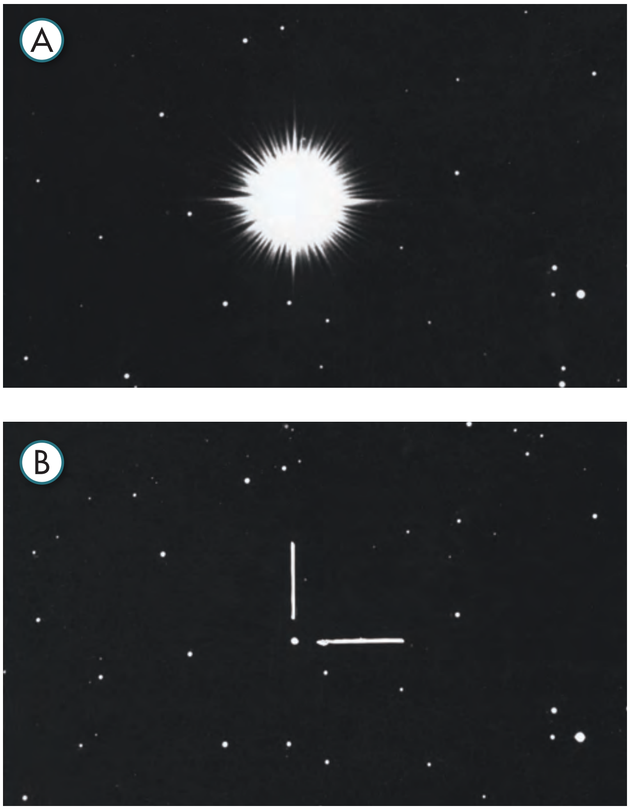


FIGURE 6 Nova
These photographs, taken two months apart, show the decrease in brightness that follows a nova flare-up.

Variable Stars Space scientists have learned that some stars fluctuate in brightness. **Cepheid variables** are stars that get brighter and fainter in a regular pattern. The interval between two successive occurrences of maximum brightness is called a *light period*. In general, the longer the light period of a Cepheid, the greater its absolute magnitude is. Once the absolute magnitude is known, it can be compared to the apparent magnitude of the Cepheid. Based on this comparison, astronomers can figu e out how far away the Cepheid is. Measuring Cepheid variable periods is an important means of determining distances within our universe.

A different type of variable is associated with a **nova,** or sudden brightening of a star. During a nova eruption, the outer layer of the star is ejected at high speed. A nova (shown in **Figure 6**) generally reaches maximum brightness in a few days, remains bright for only a few weeks, then slowly returns in a year or so to its original brightness. Only a small amount of its mass is lost during the flare-up. Some stars have experienced more than one such event. In fact, the process probably occurs repeatedly.

Scientists think that most novas occur in binary systems consisting of an expanding red giant and a nearby hot white dwarf. Hydrogen-rich gas from the oversized giant is transferred by gravity to the white dwarf. Eventually, the added gas causes the dwarf to ignite explosively. Such a reaction rapidly heats and expands the outer layer of the hot dwarf to produce a nova. In a relatively short time, the white dwarf returns to its prenova state, where it remains inactive until the next buildup occurs.

☑ **Reading Checkpoint** *What is a light period?*

FIGURE 7 Dark Nebula The Horsehead Nebula is found in the constellation Orion.

Interstellar Matter Between existing stars is "the vacuum of space." However, it is not a pure vacuum, for there are nebulae—clouds of dust and gases. If this interstellar matter is close to a very hot star, it will glow and is called a *bright nebula*. The two main types of bright nebulae are emission nebulae and reflection nebulae.

Emission nebulae consist largely of hydrogen. They absorb ultraviolet radiation emitted by a nearby hot star. Because these gases are under very low pressure, they emit this energy as visible light. This conversion of ultraviolet light to visible light is known as fluorescence. You can see this effect in fluorescent lights. *Reflection nebulae*, as the name implies, merely reflect the light of nearby stars. Reflection nebulae are thought to be composed of dense clouds of large particles called interstellar dust.

Some nebulae are not close enough to a bright star to absorb or reflect light. They are called *dark nebulae*. Dark nebulae, such as the one shown in **Figure 7**, can easily be seen as starless, or dark, regions when viewed against the backdrop of the Milky Way.

Although nebulae appear very dense, they actually consist of thinly scattered matter. Because of their enormous size, however, their total mass may be many times that of the sun. Astronomers study nebulae because it is thought that stars and planets form from this interstellar matter.

25.1 Assessment

Review Key Concepts

1. What can astronomers learn by studying a star's color?
2. Binary stars can be used to establish what property of stars?
3. How does distance affect parallax?
4. What factors determine a star's apparent magnitude?
5. The H-R diagram shows the relationship between what two factors?

Think Critically

6. **Compare and Contrast** What are similarities and differences between Cepheid variables and novas?
7. **Infer** Scientists think that only a small amount of a star's mass is lost during a nova. Based on what you have learned about stars and novas, infer what evidence scientists use to support this theory.

WRITING IN SCIENCE

8. **Summarize** Make an educational Web site about the H-R diagram for younger students. Use Figure 5 as a guide. Include a color key and other elements to help clarify concepts such as star temperature, the Kelvin scale, and absolute magnitude.

25.2 Stellar Evolution

ES.13 The student will investigate and understand scientific concepts related to the origin and evolution of the universe. Key concepts include **b.** the origin and evolution of stars, star systems, and galaxies.

A STAR IS NOT a living thing—at least not according to the biological defi ition of life. However, each star begins, progresses through certain stages, and ends. Astronomers call this progression the *life cycle* of a star. The stellar (meaning "pertaining to a star") life cycle is hard to study, because it can span billions of years. However, by studying stars of different ages, astronomers can piece together the typical progression of events of the stellar life cycle. This progression is called *stellar evolution*. It includes the changes that occur during the birth, life, and death of a star.

Key Questions

What stage marks the birth of a star?

Why do all stars eventually die?

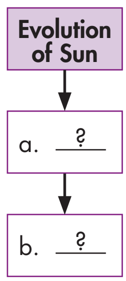
What stages make up the sun's life cycle?

Vocabulary

- protostar
- supernova
- white dwarf
- neutron star
- pulsar
- black hole

Reading Strategy

Sequence Copy the flowchart below. As you read, complete it to show how the sun evolved. Expand the chart to show the evolution of low-mass and high-mass stars.



Star Birth

In the Milky Way, nebulae consist of roughly 90 percent hydrogen, nine percent helium, and less than one percent of the remaining heavier elements. For some reason not yet fully understood, some nebulae become dense enough to begin to contract due to gravity. A shock wave from an explosion of a nearby star might trigger the contraction. Once the contraction process begins, gravity pulls every particle in the nebula toward the center. As the overall nebula shrinks, the center of the nebula increases in mass. As mass increases, the force of gravity also increases. Gradually, gravitational force is converted to heat energy. As heat builds to tremendous temperatures, the processes that shape stellar development begin to unfold. A star is born.

FIGURE 8 Nebula Large, interstellar clouds of dust and gas are thought to be areas where stars form.

Protostar Stage It is thought that the initial nebular contraction typically spans a million years or so. As time passes, the temperature slowly rises until the nebula is hot enough to radiate energy from its surface in the form of long-wavelength red light. This large red object is called a protostar. A **protostar** is a developing star not yet hot enough to engage in nuclear fusion.

During the protostar stage, gravitational contraction continues—slowly at fi st, then much more rapidly. This rapid contraction causes the core of the protostar to heat much more intensely than the outer layer. **When the core of a protostar reaches 10 million K, pressure within it is so great that nuclear fusion of hydrogen begins, forming helium and releasing energy.**

Heat from hydrogen fusion causes the gases to increase their motion. This in turn causes an increase in the outward gas pressure. At some point, this outward pressure exactly balances the inward force of gravity, as shown in **Figure 9.** When this balance is reached, the star becomes a stable main-sequence star. Stated another way, a stable main-sequence star is balanced between two forces: gravity, which is trying to squeeze it into a smaller sphere, and gas pressure, which is trying to expand it.

Main-Sequence Stage From this point in the evolution of a main-sequence star until its death, internal gas pressure struggles to offset the constant force of gravity. Typically, hydrogen fusion continues for a few billion years and provides the outward pressure required to support the star from gravitational collapse.

Different stars age at different rates. Hot, massive blue stars radiate energy at such an enormous rate that they deplete their hydrogen fuel in only a few million years. By contrast, the least massive main-sequence stars may remain stable for hundreds of billions of years. A yellow star, such as the sun, remains a main-sequence star for about 10 billion years.

By counting how many stars are in each life cycle stage, astronomers have determined that a very large percentage of stars are main-sequence stars. This information enables scientists to conclude that an average star spends 90 percent of its life as a hydrogen-fusion, main-sequence star. Once the hydrogen fuel in the star's core is depleted, it evolves rapidly and dies. However, with the exception of the least-massive red stars, a star may go into a different phase of nuclear reaction where heavier elements are fused. If this happens, the star becomes a giant and lives longer.

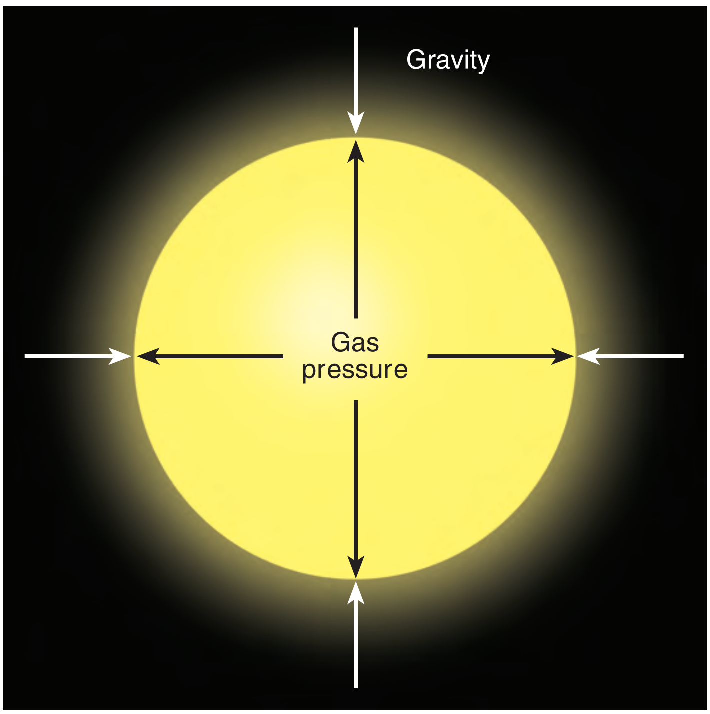


FIGURE 9 Balanced Forces A main-sequence star is balanced between gravity, which is trying to squeeze it, and gas pressure, which is trying to expand it.

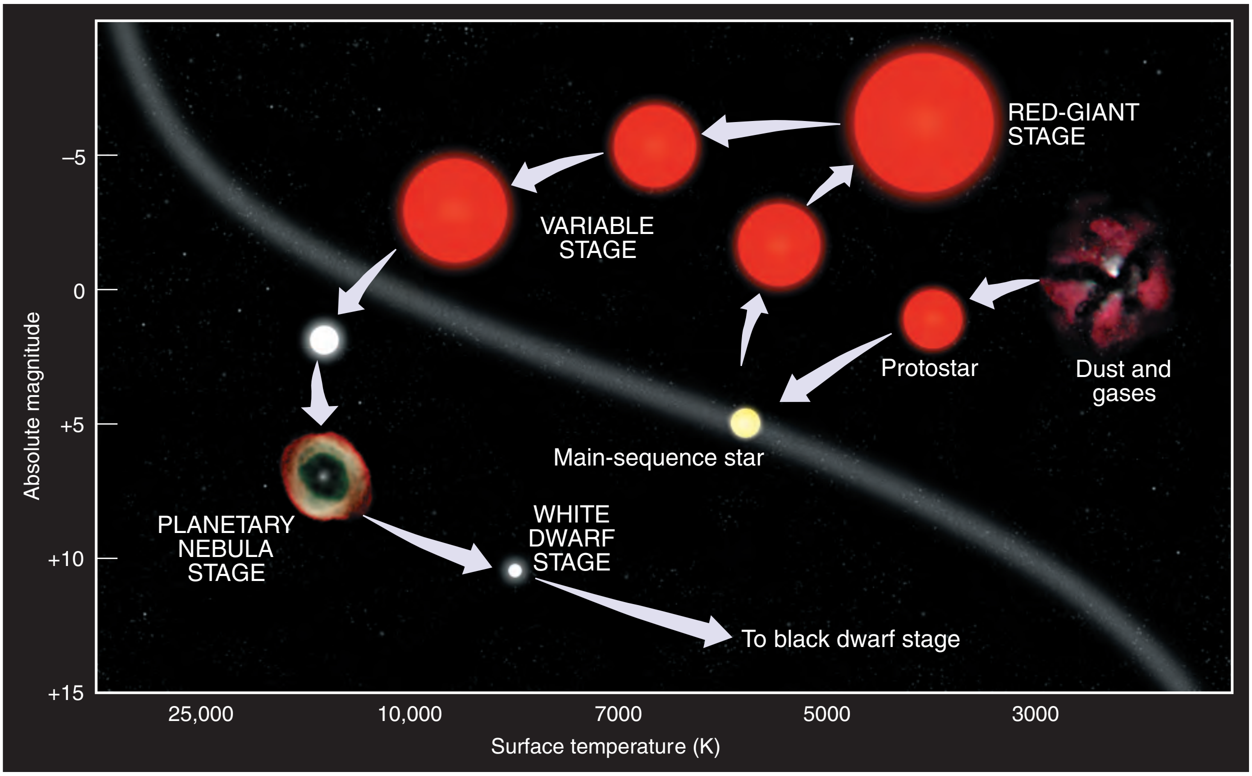


FIGURE 10 Life Cycle of a Sunlike Star A medium-mass star, similar to the sun, will evolve along the path shown here.
Interpret Diagrams *What is the first stage in the formation of the star? What is the last stage?*

Red-Giant Stage The red-giant stage occurs because the zone of hydrogen fusion continually moves outward, leaving behind a helium core. Eventually, all the hydrogen in the star's core is consumed. While hydrogen fusion is still progressing in the star's outer shell, no fusion is taking place in the core. Without a source of energy, the core no longer has enough pressure to support itself against the inward force of gravity. As a result, the core begins to contract.

As the core contracts, the overall star expands. The core grows hotter by converting gravitational energy into heat energy. Some of this energy is radiated outward, increasing the rate of hydrogen fusion in the star's outer shell. This additional energy heats and expands the star's outer layer. The result is a giant body hundreds to thousands of times its main-sequence size, as shown in **Figure 10.**

As the star expands, its surface cools, which explains the star's reddish appearance. During expansion, the core continues to collapse and heat until it reaches 100 million K. At this temperature, it is hot enough to convert helium to carbon. So, a red giant consumes both hydrogen and helium and produces energy.

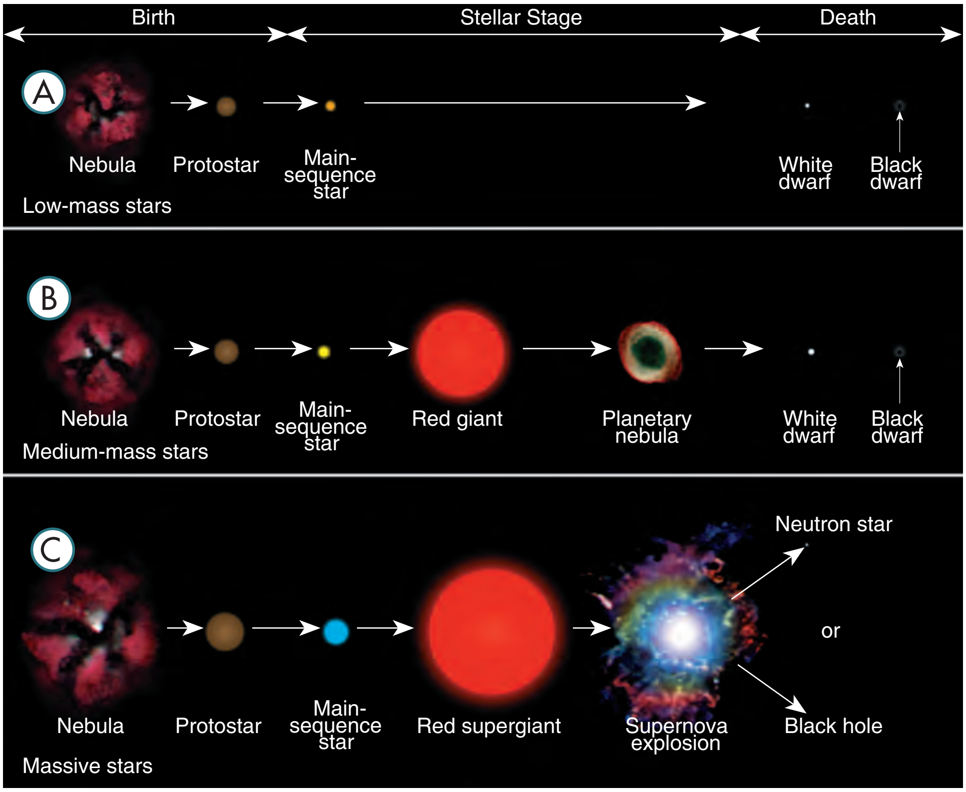
Eventually, all the usable nuclear fuel in these giants will be consumed. The sun, as a medium-sized star, will spend less than a billion years as a giant. More massive stars will pass through this stage more rapidly. The force of gravity will control the star's destiny as it squeezes the star into a much smaller, denser piece of matter.

☑ **Reading Checkpoint** *Why do red giants have a reddish appearance?*

ACTIVE ART

For: Lives of Stars activity
Visit: PearsonSchool.com
Web Code: czp–7252

FIGURE 11 **Stellar Evolution**
A A low-mass star uses fuel at a low rate and has a long life span.
B Similar to a low-mass star, a medium-mass star ends as a black dwarf.
C Massive stars end in huge explosions, then become either neutron stars or black holes.



Burnout and Death

The processes involved in the birth and life of stars are relatively easy to confi m by studying existing stars. By comparison, the last stages of the stellar life cycle are more theoretical. **We do know that all stars, regardless of their size, eventually run out of fuel and collapse due to gravity.** Exactly how this collapse occurs for various size stars is less well known.

Death of Low-Mass Stars As shown in **Figure 11A,** stars less than one half the mass of the sun consume their fuel at a slower rate than larger stars. Consequently, these small, cool red stars may remain on the main sequence for up to 100 billion years. Because the interior of a low-mass star never reaches high enough temperatures and pressures to fuse helium, its only energy source is hydrogen. So, low-mass stars never evolve into red giants. Instead, they remain as stable main-sequence stars until they consume their hydrogen fuel and collapse.

FIGURE 12 **Planetary Nebula** During its collapse from a red giant, a medium-mass star ejects its outer layer, which forms a round cloud of gas called a planetary nebula.

Death of Medium-Mass Stars As shown in **Figure 11B,** medium-mass stars evolve in a similar way as low-mass stars. During their red giant phase, medium-mass stars fuse hydrogen and helium fuel at a fast rate. Once this fuel is exhausted, they collapse.

During their collapse medium-mass stars are thought to cast off their enlarged outer layer, which forms an expanding round cloud of gas. The remaining hot, central star heats the gas cloud, causing it to glow. These often beautiful, gleaming spherical clouds are called *planetary nebulae*. An example of a planetary nebula is shown in **Figure 12.**

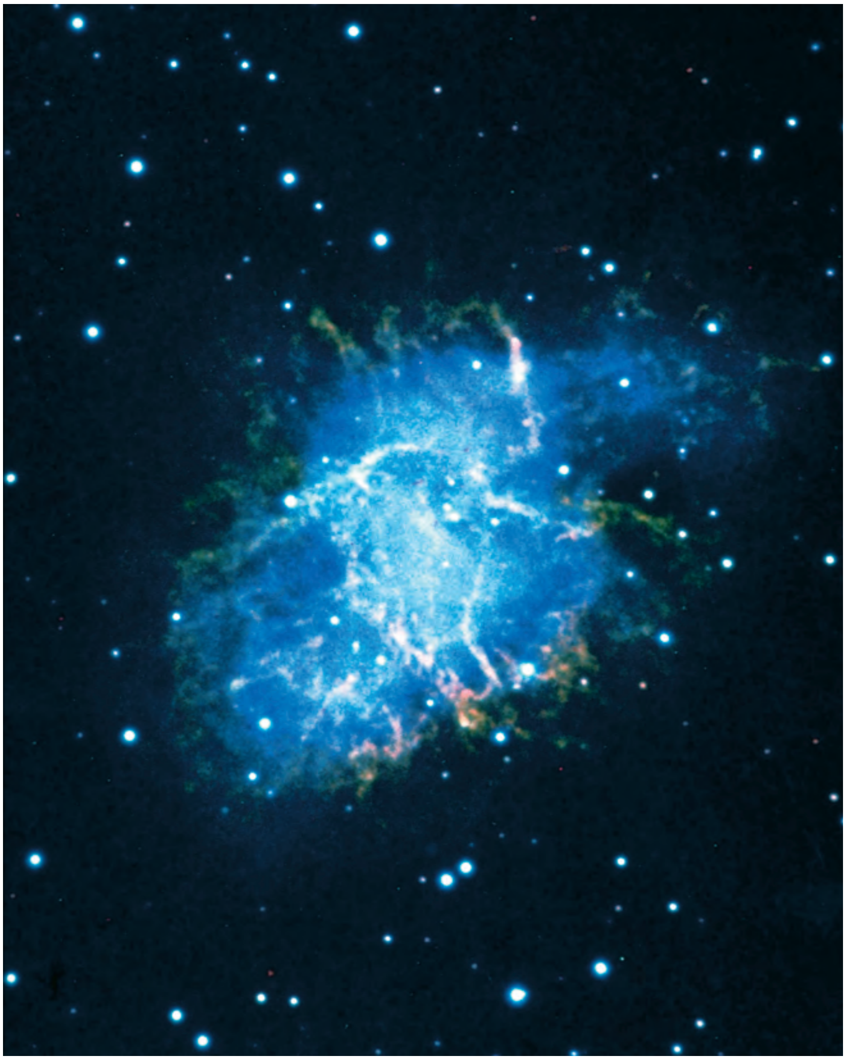


FIGURE 13 Crab Nebula
This nebula, found in the constellation Taurus, is the remains of a supernova that took place in the year 1054.

Death of Massive Stars In contrast to sunlike stars, stars with masses four times that of the sun have relatively short life spans. As shown in **Figure 11C,** these stars end in a brilliant explosion called a **supernova.** During a supernova, a star becomes millions of times brighter than its prenova stage—so bright that it can sometimes be seen during the day on Earth. Supernovae are rare. None have been observed in our galaxy since the invention of the telescope. However, astronomers Tycho Brahe recorded a supernova in 1572 and Galileo recorded one in 1604. An even larger supernova was recorded in 1054 by the Chinese. This supernova was apparently so bright, people could read at night by its light. Today, the remnant of this great outburst is the Crab Nebula, shown in **Figure 13.**

A supernova event is thought to be triggered when a massive star consumes most of its nuclear fuel. Without a heat engine to generate the gas pressure required to balance its immense gravitational field, the star collapses. This *implosion*, or bursting inward, is huge, resulting in a shock wave that moves out from the star's interior. This energetic shock wave destroys the star and blasts the outer shell into space, generating the supernova event.

Reading Checkpoint *What is a supernova?*

Nucleosynthesis A dying star can be a factory where new elements form. Stars produce all the naturally occurring chemical elements beyond helium in the periodic table. The process that produces chemical elements inside stars is called *nucleosynthesis*.

Nucleosynthesis starts with the fusion of hydrogen nuclei to form helium. Over time, the helium nuclei begin to fuse, forming nuclei of heavier elements. These heavier elements may also fuse. Elements between lithium and iron in the periodic table form in this way. Certain elements heavier than iron form as iron nuclei absorb neutrons released during fusion. The rarest heavy elements form at temperatures up to one billion degrees Celsius when a star explodes in a supernova. The explosion scatters the star's elements across space. There, they are available to form new stars and planets.

The mass of a star determines the highest atomic number of the elements it can produce. Only the most massive stars produce elements heavier than iron. By comparison, the sun will not be able to produce elements heavier than oxygen.

Stellar Remnants

Eventually, all stars consume their nuclear fuel and collapse into one of three states—white dwarf, neutron star, or black hole. Although different in some ways, these small, compact objects are all composed of incomprehensibly dense material with extreme surface gravity.

White Dwarfs **White dwarfs** are the remains of low-mass and medium-mass stars. They are extremely small stars with densities greater than any known material on Earth. Although some white dwarfs are no larger than Earth, the mass of such a dwarf can equal 1.4 times that of the sun. A spoonful of such matter would weigh several tons. Densities this great are possible only when electrons are displaced inward from their regular orbits, around an atom's nucleus, allowing these atoms to take up less than a "normal" amount of space.

As a star contracts into a white dwarf, its surface becomes very hot, sometimes exceeding 25,000 K. Even so, without a source of energy, a white dwarf can only evolve into a cooler and dimmer object. **Table 2** summarizes the evolution of stars of various masses. **The un began as a nebula, will spend much of its life as a main-sequence star, and then will become a red giant, planetary nebula, white dwarf, and fin lly, a black dwarf.**

Table 2 Summary of Evolution for Stars of Various Masses

Initial Mass of Interstellar Cloud (Sun = 1)	Main-Sequence Stage	Giant Phase	Evolution After Giant Phase	Final Stage
1–3	Yellow	Yes	Planetary nebula	White dwarf
6	White	Yes	Supernova	Neutron star
20	Blue	Yes (Supergiant)	Supernova	Black hole

Neutron Stars After studying white dwarfs, scientists made what might at fi st appear to be a surprising conclusion. The smallest white dwarfs are the most massive, and the largest are the least massive. The explanation for this is that a more massive star, because of its greater gravitational force, is able to squeeze itself into a smaller, more densely packed space than can a less massive star. So, the smaller white dwarfs are thought to have been produced from the collapse of larger, more massive stars than were the larger white dwarfs.

This conclusion led to the prediction that stars smaller and more massive than white dwarfs must exist. These objects, called **neutron stars,** are thought to be the remnants of supernova events. In a white dwarf, the electrons in the atoms are pushed close to the nucleus, while in a neutron star, the electrons are forced to combine with protons to produce neutrons. If Earth were to collapse to the density of a neutron star, it would have a diameter equal to the length of a football field. A pea-size sample of this matter would weigh more than 90 million kilograms. This is approximately the same density as an atomic nucleus. In a way, neutron stars can be thought of as large atomic nuclei.

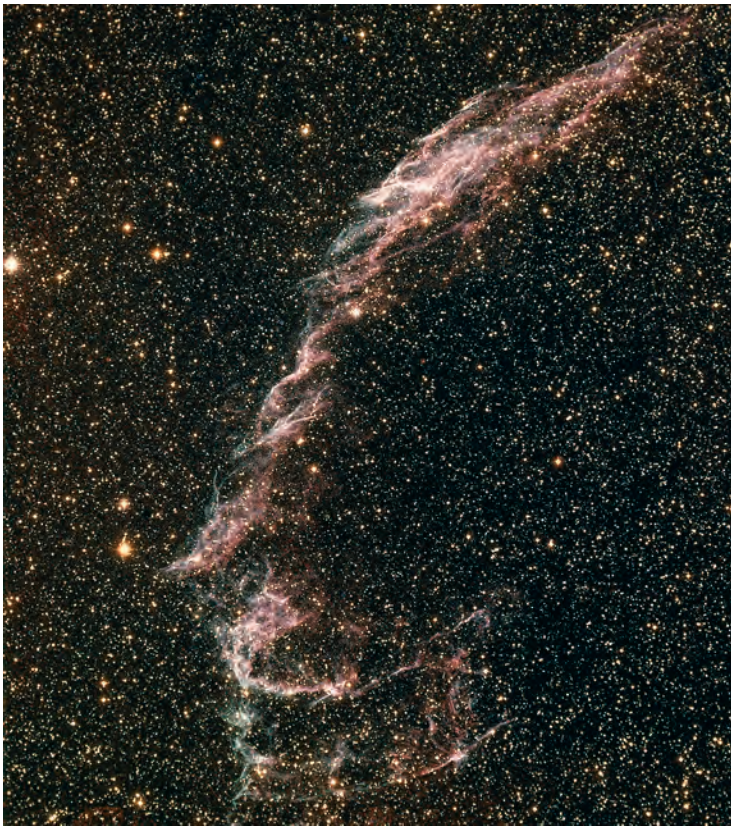


FIGURE 14 Veil Nebula Located in the constellation Cygnus, this nebula is the remnant of an ancient supernova.

Supernovae During a supernova, the outer layer of the star is ejected, while the core collapses into an extremely small, hot neutron star about 20 kilometers in diameter. Imagine an entire star becoming so small that it would almost fit inside the city limits of Dallas, Texas. Although neutron stars have high surface temperatures, their small sizes would greatly limit their brightness. Finding one with a telescope would be extremely difficult.

However, astronomers think that a neutron star would have a very strong magnetic field. As a star collapses, it rotates faster, for the same reason a spinning ice skater rotates faster when she pulls in her arms. Radio waves generated by these rotating stars would be concentrated into two narrow zones that would align with the star's magnetic poles. Consequently, these stars would resemble a rapidly rotating beacon emitting strong radio waves. If Earth happened to be in the path of these beacons, the star would appear to blink on and off, or pulsate, as the waves swept past. A spinning neutron star that appears to give off ulses of radio waves is called a **pulsar.**

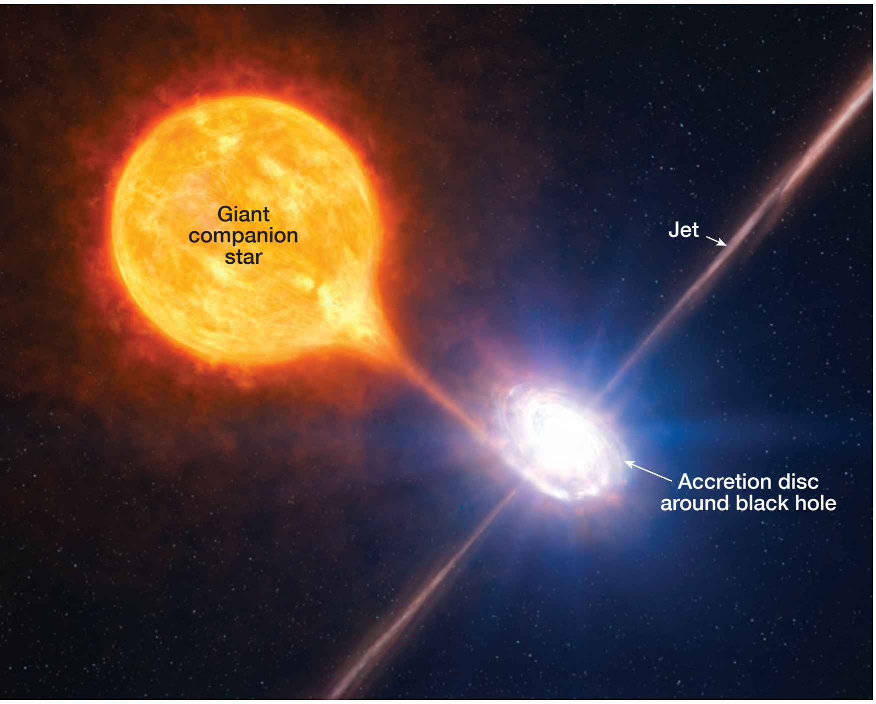
In the early 1970s, a pulsar was discovered in the Crab Nebula. This pulsar is undoubtedly the remains of the supernova of 1054. If so, that would mean the star evolved from supernova to pulsar in about 1000 years. By astronomical standards, that is a very short period of time.

Black Holes Are neutron stars made of the most dense materials possible? No. During a supernova event, remnants of stars at least 20 times more massive than the sun apparently collapse into objects even smaller and denser than neutron stars. Dense objects with gravity so strong that not even light can escape their surface are called **black holes.** Anything that moves too near a black hole would be swept in by its gravity and added to the mass of the black hole.

How can astronomers fi d an object whose gravitational field prevents the escape of all matter and energy? One strategy is to fi d evidence of matter being rapidly swept into a region of apparent nothingness. Scientists think that as matter is pulled into a black hole, it should become very hot and emit a flood of X-rays before being pulled in. Because isolated black holes would not have a source of matter to swallow up, astronomers fi st looked at binary-star systems.

A likely candidate for a black hole is Cygnus X-1, a strong X-ray source in the constellation Cygnus. In this case, the X-ray source can be observed orbiting a supergiant companion with a period of 5.6 Earth days. It appears that gases are pulled from this companion and spiral into the disk-shaped structure around the black hole. An artist's impression of this is shown in **Figure 15.** Some scientists also think that there are supermassive black holes in the centers of many galaxies. Our own galaxy may have a black hole in the center with a mass equivalent to 1 to 2 billion suns.

FIGURE 15 Black Hole
Gases from the red giant spiral into the black hole.



25.2 Assessment

Review Key Concepts

1. What is a protostar?
2. At what point is a star born?
3. What causes a star to die?
4. Describe the life cycle of the sun.

Think Critically

5. **Infer** Why are less massive stars thought to age more slowly than more massive stars, even though less massive stars have much less "fuel"?
6. **Relate Cause and Effect** Why is interstellar matter important to stellar evolution?

BIGIDEA EARTH AND THE UNIVERSE

7. **Compare and Contrast** Compare the sun with Deneb, a massive blue-white star that is 1600 light-years from Earth. How likely is it that each star will experience a supernova?

25.3 The Universe

ES.13 The student will investigate and understand scientific concepts related to the origin and evolution of the universe. Key concepts include **a.** cosmology including the Big Bang theory.

ON A CLEAR and moonless night away from city lights, you can see a truly marvelous sight—our own Milky Way Galaxy, as shown in **Figure 16.** **Galaxies** are large groups of stars, dust, and gases held together by gravity. There may be 400 billion stars in the Milky Way Galaxy alone. Our galaxy looks milky because our solar system is located within a flat disk of the galaxy—the galactic disk. We view the Milky Way from the inside and see a high concentration of stars when we look toward the center of the galaxy.

The Milky Way Galaxy

Imagine that you are hiking in an enormous forest. You look around and see equal numbers of trees in every direction. Are you in the center of the forest? Not necessarily. Because the trees block your view, almost anywhere in the forest could seem to be the center. When astronomers began to survey the stars located along the plane of the Milky Way, it appeared that equal numbers of stars lay in every direction. The stars made it look like Earth was at the center. But that is not actually the case.

Size of the Milky Way It's hard to study the Milky Way Galaxy with optical telescopes because large quantities of interstellar dust and gas block our view. Partly with the aid of radio telescopes, scientists can see "through" the dust and gas and have determined the likely structure of our galaxy. **The Milky Way is a large spiral galaxy whose disk is about 100,000 light-years wide and about 10,000 light-years thick at the nucleus.** As viewed from Earth, the center of the galaxy lies beyond the constellation Sagittarius.

☑ **Reading Checkpoint** *How big is the Milky Way Galaxy?*

FIGURE 16 **Milky Way Galaxy** Notice the dark band caused by interstellar dark nebulae.

Key Questions

- *What are the size and structure of the Milky Way Galaxy?*
- *In what ways do galaxies differ from one another?*
- *What evidence indicates that the universe is expanding?*
- *According to the big bang theory, how did the universe begin?*

Vocabulary

- galaxy
- galaxy cluster
- Hubble's law
- Big Bang theory

Reading Strategy

Outline As you read, make an outline of the most important ideas in this section.

I. The Universe
    A. Milky Way Galaxy
        1. ___?___
        2. ___?___
    B. ___?___
        1. Spiral Galaxy
        2. Elliptical Galaxy
        3. ___?___

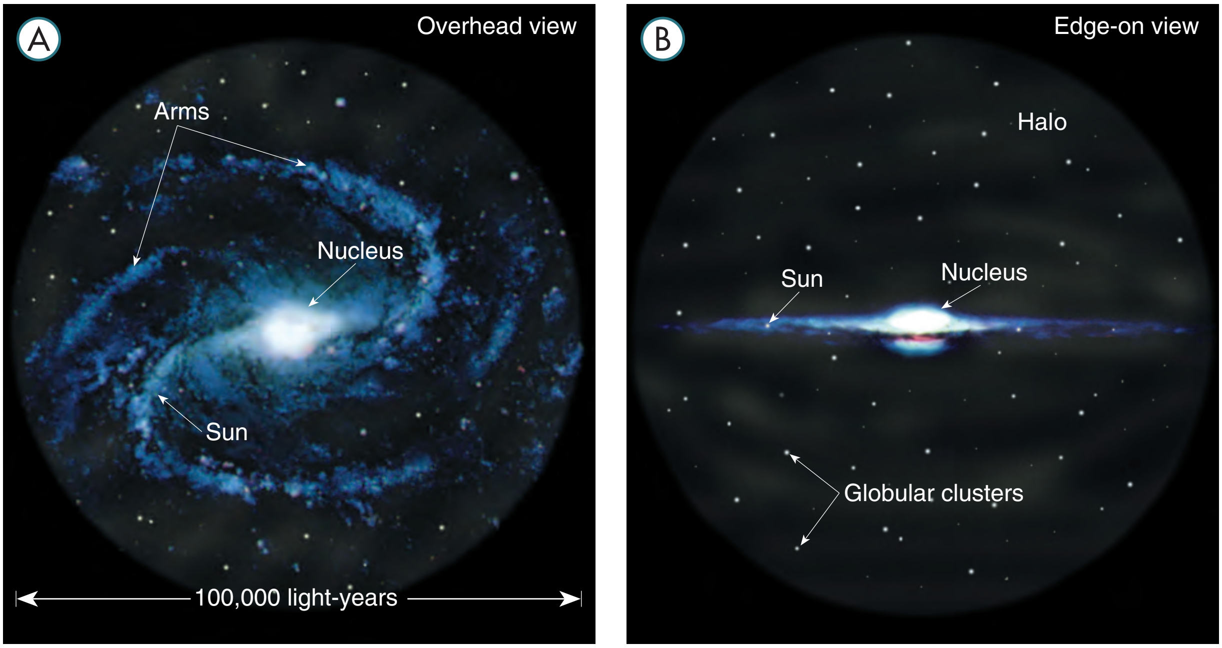


FIGURE 17 Structure of the Milky Way A The spiral arms are clearly visible in a simulated overhead view of our galaxy. **B** Our solar system is located about 30,000 light-years from the galactic nucleus.

Structure of the Milky Way Today's astronomer has a vast array of instruments to measure electromagnetic radiation emitted by the stars. These instruments are located on Earth, they orbit the planet in artific al satellites, and they are onboard spacecraft hat are streaking into various parts of space. By analyzing the readings of these instruments, astronomers know that the Milky Way has at least three distinct spiral arms. Some of the arms show signs of splintering. The sun is positioned in one of these arms about two thirds of the way from the center, or *galactic nucleus*, at a distance of about 30,000 light-years. The stars in the arms of the Milky Way rotate around the galactic nucleus. The most outward arms move the slowest, and the ends of the arms appear to trail behind the main bodies of the arms. Our solar system orbits the galactic nucleus once about every 230 million years.

Surrounding the galactic disk is a nearly round halo consisting of thin gas and numerous star clusters. These star clusters do not rotate around the nucleus in the same way that the stars in the spiral arms rotate. Instead, they have their own orbits that carry them through the disk. Although some star clusters are quite dense, they pass between the stars of the arms without colliding.

In recent years, NASA's *Fermi Gamma-ray Space Telescope* has aided astronomers in discovering new facts about the Milky Way. For example, there appears to be two very large bubbles of gamma radiation emerging from the "top" and "bottom" of the nucleus. The source of this gamma radiation is not known, but one possibility is that the radiation could be related to a black hole in the nucleus.

Reading Checkpoint *Where is our solar system located within the Milky Way Galaxy?*

Types of Galaxies

In the mid-1700s, German philosopher Immanuel Kant proposed that the fuzzy patches of light scattered among the stars were actually distant galaxies like the Milky Way. Today we know that the universe includes hundreds of billions of galaxies, each containing hundreds of billions of stars. From these hundreds of billions of galaxies, scientists have identifi d several basic types.

Spiral Galaxies As shown in **Figure 18A,** spiral galaxies are usually disk-shaped, with a greater concentration of stars near their nuclei. There are numerous variations, though. Viewed broadside, the arms are often seen extending from the central nucleus and sweeping gracefully away. The outermost stars of these arms rotate most slowly, giving the galaxy the appearance of a pinwheel.

One type of spiral galaxy, however, has its stars arranged in the shape of a bar, which rotates as a rigid system. Attached to each end of these bars are curved spiral arms. These have become known as barred spiral galaxies, as shown in **Figure 18B.** Recent evidence indicates that the Milky Way may be a barred spiral galaxy. Spiral galaxies are generally quite large. About 10 percent of all galaxies are thought to be barred spirals, and another 20 percent are regular spiral galaxies.

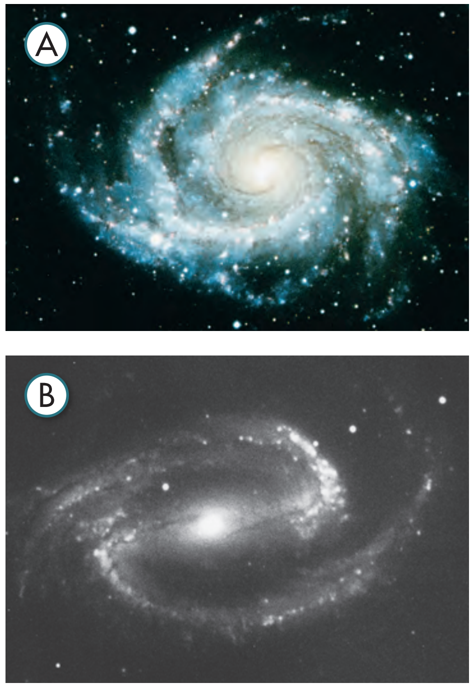


FIGURE 18 Spiral Galaxies
A A spiral galaxy looks somewhat like a pinwheel. **B** A barred spiral galaxy has a bar through its center, with arms extending outward from the bar.

Elliptical Galaxies About 60 percent of galaxies are classifi d as elliptical galaxies. Elliptical galaxies range in shape from round to oval. Although most are small, the very largest known galaxies—200,000 light-years in diameter—are elliptical. Th s type of galaxy, shown in **Figure 19,** was once thought to be very old galaxies with limited star-making capabilities. However, thanks to Hubble imagery, scientists are learning that elliptical galaxies do, indeed, give birth to new, young stars.

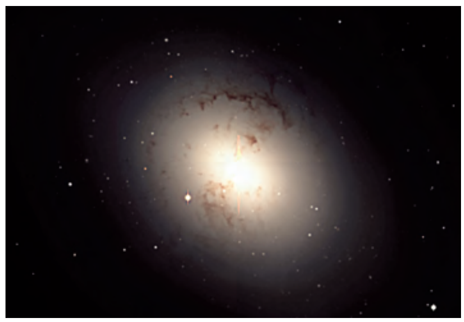


FIGURE 19 Elliptical Galaxy Most galaxies are classified as elliptical with shapes ranging from round to oval.

Irregular Galaxies Only 10 percent of the known galaxies have irregular shapes and are classifi d as irregular galaxies. The best-known irregular galaxies, the Large and Small Magellanic Clouds, are easily visible from the Southern Hemisphere with the unaided eye. These galaxies were named after the explorer Ferdinand Magellan, who observed them when he sailed around Earth in 1520. They are our nearest galactic neighbors—only 150,000 light-years away. An irregular galaxy is shown in **Figure 20.**

In addition to shape and size, one of the major differences among different types of galaxies is the age of their stars. Irregular galaxies are composed mostly of young stars, while elliptical galaxies contain many old stars. The Milky Way and other spiral galaxies have both young and old stars, with the youngest located in the arms.

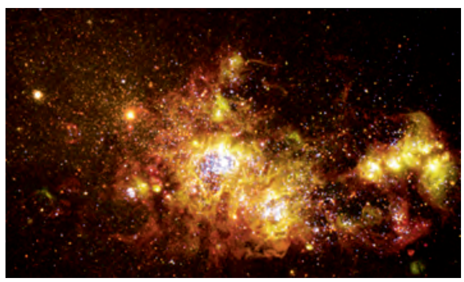


FIGURE 20 Irregular Galaxy Irregular galaxies have a variety of shapes. **Describe** *What type of stars would you find in an irregular galaxy?*

FIGURE 21 Galaxy Cluster This cluster of galaxies is located about 1 million light-years from Earth.

Galaxy Clusters Once astronomers discovered that stars were found in groups, they wondered whether galaxies also were grouped or just randomly distributed throughout the universe. They found that, like stars, galaxies are grouped in **galaxy clusters.** One such cluster is shown in **Figure 21.** Some clusters may contain thousands of galaxies. The Milky Way Galaxy is part of a galaxy cluster, called the Local Group. It contains at least 28 galaxies. Of these, three galaxies are spiral, 11 are irregular, and 14 are elliptical. Galaxy clusters also make up huge groups called superclusters, which make up vast threadlike structures called *filaments*, the largest known structures in the universe.

Quasars In the 1960s, astronomers discovered objects that were very bright and very far away. They called them quasi-stellar radio sources, or *quasars,* since they looked like stars. Because it takes their light billions of years to reach Earth, quasars must have existed when the universe was very young. Quasars must emit huge amounts of radiation, or they would be too dim for us to detect. The leading theory is that they are massive black holes in the center of very young galaxies.

The Expanding Universe

When a source is moving away from an observer, its light appears redder than it actually is, because its waves appear lengthened. This is called the *Doppler effect*. Objects approaching have their frequency shifted toward the blue or shorter wavelengths. Therefore, the Doppler effect reveals whether a star or other body in space is moving away from Earth or toward Earth. The amount of shift allows us to calculate the rate of this relative movement. Large Doppler shifts i dicate higher speeds; smaller Doppler shifts indicate lower speeds.

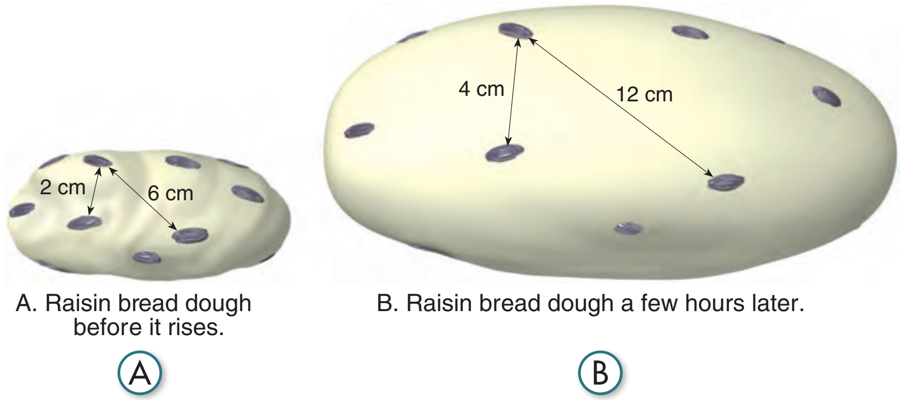
Red Shifts One of the most important discoveries of modern astronomy was made in 1929 by Edwin Hubble. Observations completed several years earlier revealed that most galaxies have Doppler shifts oward the red end of the spectrum. The red shift occurs because the light wave frequency is reduced, which shows that Earth and the source are moving away from each other. Hubble set out to explain this red shift henomenon.

Hubble realized that dimmer galaxies were probably farther away than were brighter galaxies. He tried to determine whether a relationship existed between the distances to galaxies and their red shifts. ubble used estimated distances based on relative brightness and Doppler red shifts o discover that galaxies that exhibit the greatest red shifts re the most distant.

Hubble's Law A consequence of the universal red shift s that it predicts that most galaxies—except for a few nearby—are moving away from us. The amount of Doppler red shift epends on the speed at which the object is moving away. Greater red shifts i dicate faster speeds. Because more distant galaxies have greater red shifts, Hubble concluded that they must be retreating from us at greater speeds. This idea is currently termed **Hubble's law.** It states that galaxies are retreating from us at a speed that is proportional to their distance—the farthest galaxies are retreating the fastest.

Hubble was surprised at this discovery because it implied that the most distant galaxies are moving away from us many times faster than those nearby. What does this mean? **The red shifts f distant galaxies indicate that the universe is expanding.**

FIGURE 22
Raisin Dough Analogy
As the dough rises, raisins that are farther apart travel a greater distance in the same time than those that are closer together. Like galaxies in an expanding universe, the distant raisins move away from one another more rapidly than those that are near one another.



To visualize the nature of this expanding universe, imagine a loaf of raisin bread dough that has been set out to rise for a few hours. As shown in **Figure 22,** raisins are distributed throughout the dough. As the dough doubles in size, so does the distance between all of the raisins. However, the raisins that were initially farther apart traveled a greater distance in the same time span than those located closer together. Any object covering a greater distance in the same amount of time as an object moving a shorter distance must be traveling faster. Scientists can therefore conclude that in an expanding universe, as in the raisin bread dough analogy, those space objects located farther apart move away from each other more rapidly than objects located closer to each other.

Another feature of the expanding universe can also be demonstrated using the raisin dough analogy. No matter which raisin you select, it will move away from all the other raisins. Likewise, no matter where a galaxy is located in the universe, every other galaxy—except those in the same cluster—will be moving away. Hubble indeed advanced our understanding of the universe. The Hubble Space Telescope is named in his honor.

Reading Checkpoint *What is Hubble's law?*

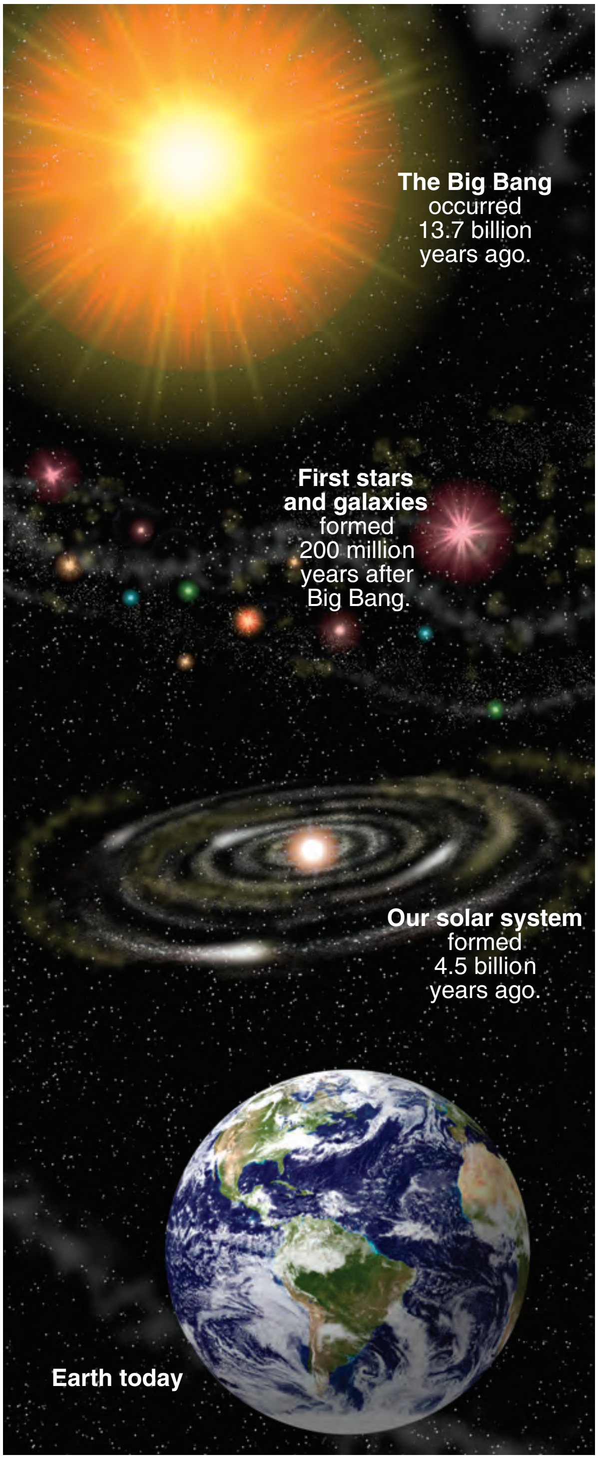


FIGURE 23 The Big Bang According to the Big Bang theory, the universe began 13.7 billion years ago. Two hundred million years later, the first stars and galaxies began to form.

The Big Bang

How did the universe begin? Any theory about the origin of the universe must account for the fact that all distant galaxies are moving away from us at a faster rate than are nearby galaxies. Although all galaxies appear to be moving away from Earth, it seems unlikely that our planet is the center of the universe.

A more probable explanation exists. Imagine a balloon with paper-punch dots glued to its surface. When the balloon is inflated, each dot spreads apart from every other dot. Similarly, if the universe is expanding, every galaxy would be moving away from every other galaxy.

This concept of an expanding universe led to the widely accepted Big Bang theory. According to the **Big Bang theory,** the universe began as a violent explosion from which the universe continues to expand, evolve, and cool. **The Big Bang theory states that at one time, the entire universe was confined to a dense, hot, supermassive ball. Then, about 13.7 billion years ago, a violent explosion occurred, hurling this material in all directions.** The Big Bang, illustrated in **Figure 23,** marks the beginning of the universe.

Scientists think that protons, neutrons, and electrons formed from the energy of the Big Bang. Scientists can model conditions in the early universe, using machines called particle accelerators. These devices smash subatomic particles together at very high speeds. The collision produces other particles that may exist for only a few billionths of a second. But they give scientists a brief glimpse of matter in the early universe. After several hundred thousand years, the universe became cool enough for atoms to form. As time passed, gases in the universe continued to cool and condense and eventually formed the stars.

Supporting Evidence Scientists have gathered substantial evidence that supports the Big Bang theory. For example, the red shift of galaxies indicates that the universe is still expanding. Scientists also discovered a type of energy called cosmic microwave background radiation. This energy has been detected as faint radio signals coming from every direction in space. Scientists think that this radiation was produced during the Big Bang.

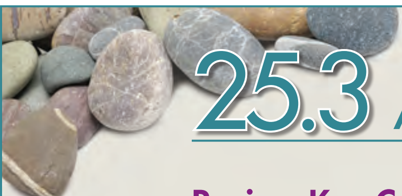
☑ **Reading Checkpoint** *What evidence supports the Big Bang theory?*

The Big Crunch? If the universe began with a big bang, how will it end? One view is that the universe will last forever. In this scenario, the stars will slowly burn out, being replaced by an invisible form of matter and black holes that will travel outward through an endless, dark, cold universe. The other possibility is that the outward fli ht of the galaxies will slow and eventually stop. Gravitational contraction could follow, causing the galaxies to collapse into the high-energy, high-density mass from which the universe began. Th s scenario, the big bang operating in reverse, has been called the "big crunch."

Material called "dark matter" could affect the rate at which the universe expands. Dark matter is matter that cannot be directly observed because it does not give off radiation. Galaxies contain most of the visible mass of the universe, but there is evidence that what we see makes up less than one-tenth its total mass. Measurements of galactic rotation suggest that dark matter accounts for the rest of the universe's mass.

Whether the universe will expand forever or collapse upon itself depends on its average density. If the average density of the universe is more than its critical density—about one atom for every cubic meter—the gravitational fi ld is enough to stop the outward expansion and cause the universe to contract. But, if the density of the universe is less than the critical value, it will expand forever. Current estimates place the density of the universe below the critical density, which predicts an ever-expanding, or open, universe. However, the universe is expanding even faster now than in the past. Th s may be due to a theoretical new force that astronomers have named "dark energy." The view currently favored by most scientists is that we live in an expanding universe with no ending point.

☑ **Reading Checkpoint** *How will the universe end?*



25.3 Assessment

Review Key Concepts

1. What is a galaxy?

2. Describe the size and structure of the Milky Way Galaxy.

3. How do galaxies differ?

4. What evidence indicates that the universe is expanding?

5. What is the Big Bang theory?

Think Critically

6. Compare and Contrast Compare and contrast the three types of galaxies.

7. Infer If the universe is an open universe, what can you infer about its average density?

WRITING IN SCIENCE

8. Summarize Scientists are continuously searching the Milky Way Galaxy for other stars that may have planets. What types of stars would most likely have a planet or planets suitable for life as we know it? Write a paragraph describing these stars.

EARTH & HISTORY

How Can Constellations Help Someone Locate a Star?

For centuries, human stargazers have identified patterns in the nighttime sky, called *constellations*. Early Greek philosophers believed that the position of the constellations could influence, and be used to predict, human behavior and natural events. This belief developed into the practice called *astrology*. In order to make their predictions, astrologists had to make precise measurements.

These early measurements laid a valuable foundation for the scientific study of the stars, planets, and other celestial bodies. By the 1600s, the study of the stars developed into the science of astronomy—a science because each hypothesis can be tested. By comparison, astrology is a *pseudoscience* (meaning *false science*), because the claims of astrology lack evidence and cannot be reliably tested.

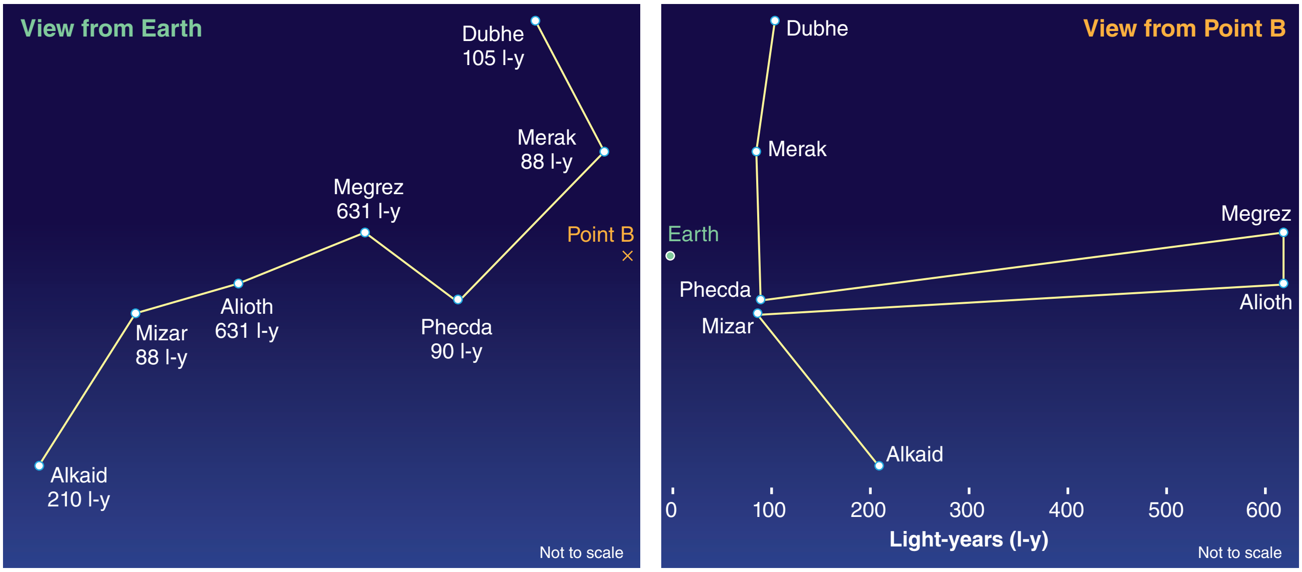


FIGURE 24 Different Views of the Big Dipper Drawing imaginary lines that connect the seven stars above, you see a shape of a dipper. **A** This arrangement of stars only produces a dipper shape when viewed from Earth. **B** If these same stars are viewed from a different location in space—*Point B* in Figure 24A—the same lines result in a much different shape. The reason for the difference is some stars are closer to Earth and some farther away.

If someone asked you to find the town of Gretna on a map of the United States, it might take you a while. However, if your map was divided into states and you were told that Gretna is in Virginia, you'd at least have a better idea of where to start looking.

In a similar way, if someone asked you to locate the red star Betelgeuse somewhere in the nighttime sky, it would be a daunting task. Several decades ago the International Astronomical Union (IAU) recognized this challenge and did something to help. The IAU divided the sky around Earth into 88 sections. Why 88 sections? At the time of their action, there were 88 named constellations. So they divided the sky and named each section after the constellation that is located in that section. Any star located in that segment of the sky, even if the star isn't part of the constellation shape, is considered "in" that constellation.

As a result of the IAU action, your search for the location of Betelgeuse would now be much easier. Betelgeuse is a red star in the constellation Orion. With a star map in hand, you could quickly complete your task.

However, the constellation-reference system is only useful for observers on or near Earth. As explained in **Figure 24,** once you journey beyond our solar system, the constellations no longer have the same shape. The IAU developed a coordinate system that is not geocentric. The International Celestial Reference System (ICRS) is a detailed coordinate system that helps astronomers describe the position of any celestial body. For amateur sky watchers there is an easier method. Computer applications for smartphones and tablets do all the work for you. Type in "betelgeuse" and the device will show you exactly where to look.

INQUIRY

EXPLORATION LAB

Observing Stars

Problem How can you use star charts to identify constellations and track star movements?

Materials star charts (in the Appendix), penlight, notebook

Skills Observe, Summarize, Interpret Data

Connect to the Big idea Throughout history, people have been recording the nightly movement of stars that results from Earth's rotation, as well as the seasonal changes in the constellations as Earth revolves around the sun. Early astronomers offered many explanations for these changes before the true nature of the motions was understood in the seventeenth century. In this lab, you'll observe and identify stars.

Procedure

1. On a clear, moonless night as far from street lights as safely possible, go outside and observe the stars.
2. In a data table like the one below, make a list of the different colors of stars that you see.
3. Select one star that is directly overhead or nearly so. Observe and record its movement over a period of one hour. Also note the direction of its movement (eastward, westward).
4. Select a star chart suitable for your location and season. Locate several constellations. Sketch and label the constellations in your notebook.
5. Locate the North Star (Polaris) in the night sky. Observe the motion of stars that surround the North Star.
6. Return to the exact same location several weeks later and repeat Steps 1–5.

Analyze and Conclude

1. **Observe** How many different colors of stars did you observe? How do these colors relate to star temperature?
2. **Interpret Data** In which direction did the star that you observed appear to move? How is this movement related to the direction of Earth's rotation?
3. **Summarize** Write a brief summary of the motion of the stars that surround the North Star. Be sure to include any changes you observed during your second viewing.

GO FURTHER Find the Big Dipper, which is part of the constellation Ursa Major. A binary star system makes up the stars of the Big Dipper. Locate the star pair and sketch them in their proper location in the Big Dipper.

Data Table

Date	Star Colors	Star Movement	Constellations	Motions of Stars Around North Star

ES.1 The student will plan and conduct investigations in which **c.** scales, diagrams, charts, graphs, tables, imagery, models, and profiles are constructed and interpreted; and **e.** variables are manipulated with repeated trials. **ES.2** The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include **c.** observation and logic are essential for reaching a conclusion.

25 Study Guide

Big idea Earth and the Universe

25.1 Properties of Stars

Color is a clue to a star's temperature.

Binary stars can be used to determine stellar mass.

The nearest stars have the largest parallax angles, while those of distant stars are too small to measure.

Three factors control the apparent brightness of a star as seen from Earth: how big it is, how hot it is, and how far away it is.

A Hertzsprung-Russell diagram shows the relationship between the absolute magnitude and temperature of stars.

constellation (700)
binary star (701)
light-year (702)
apparent magnitude (703)
absolute magnitude (703)
Hertzsprung-Russell diagram (704)
main-sequence star (704)
red giant (704)
supergiant (704)
Cepheid variable (705)
nova (705)

25.2 Stellar Evolution

When the core of a protostar has reached at least 10 million K, pressure within it is so great that nuclear fusion of hydrogen begins.

All stars, regardless of their size, eventually run out of fuel and collapse due to gravity.

Stars similar to the sun begin as a nebula, spend much of their lives as main-sequence stars, become red giants, planetary nebulae, white dwarfs, and finally, black dwarfs.

protostar (708)
supernova (711)
white dwarf (712)
neutron star (713)
pulsar (713)
black hole (714)

25.3 The Universe

The Milky Way is a large spiral galaxy whose disk is about 100,000 light-years wide and about 10,000 light-years thick at the nucleus.

In addition to shape and size, one of the major differences among different types of galaxies is the age of their stars.

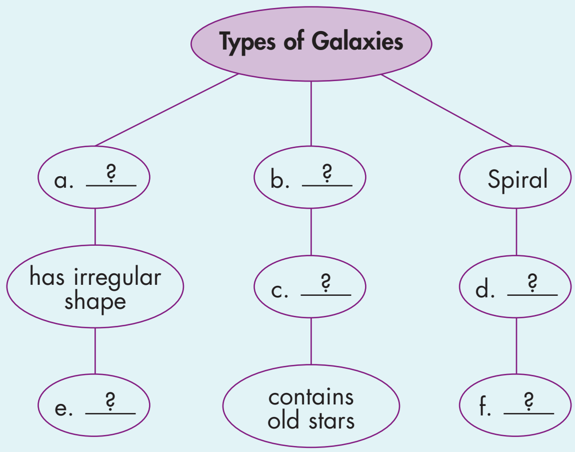
The red shifts of distant galaxies indicate that the universe is expanding.

The Big Bang theory states that at one time, the entire universe was confined to a dense, hot, supermassive ball. Then, about 13.7 billion years ago, a violent explosion occurred, hurling this material in all directions.

galaxy (715)
galaxy cluster (718)
Hubble's law (719)
Big Bang theory (720)

Think Visually

Summarize Use information from the chapter to complete the concept map below.



25 Assessment

Review Content

Choose the letter that best answers the question or completes the statement.

1. Distances to stars are usually expressed in units called
a. miles.
b. kilometers.
c. light-years.
d. astronomical units.

2. The measure of a star's brightness is called its
a. parallax.
b. color index.
c. visual binary.
d. magnitude.

3. Distances to nearby stars can be determined from
a. fluorescence.
b. stellar parallax.
c. stellar mass.
d. emission nebulae.

4. Which color stars have the highest surface temperature?
a. red
b. orange
c. yellow
d. blue

5. Which type of star is the sun?
a. black hole
b. black dwarf
c. main sequence
d. red giant

6. What does a sunlike star become after it has burned the fuel in its core?
a. supernova
b. neutron star
c. red giant
d. nebula

7. Which object has such a strong surface gravity that light cannot escape it?
a. black hole
b. black dwarf
c. red giant
d. white dwarf

8. Stars that are composed of matter in which electrons have combined with protons are called
a. black holes.
b. neutron stars.
c. red giants.
d. white dwarfs.

9. Hubble's law states that galaxies are retreating from Earth at a speed that is proportional to their
a. distance from Earth.
b. volume.
c. mass.
d. temperature.

10. What theory states that the universe began in a violent explosion?
a. the big crunch
b. the Doppler effect
c. Hubble's law
d. the Big Bang

Understand Concepts

11. Which property of a star can be determined by its color?

12. Approximately what percentage of stars in the universe are estimated to occur in pairs or multiples?

13. What is parallax?

14. Compare and contrast apparent magnitude and absolute magnitude.

15. What color is the most massive type of main-sequence star? The least massive?

16. At what temperature does nuclear fusion begin?

17. A stable main-sequence star is balanced between which two forces?

18. What element is the main fuel for main-sequence stars? For red giants?

19. What type of stars end their lives as supernovae?

20. What is a pulsar?

21. How long does it take our solar system to orbit the nucleus of the Milky Way Galaxy?

22. The farther a galaxy is from the Milky Way, the greater its red shift. What does this indicate about the universe?

23. What is cosmic microwave background radiation?

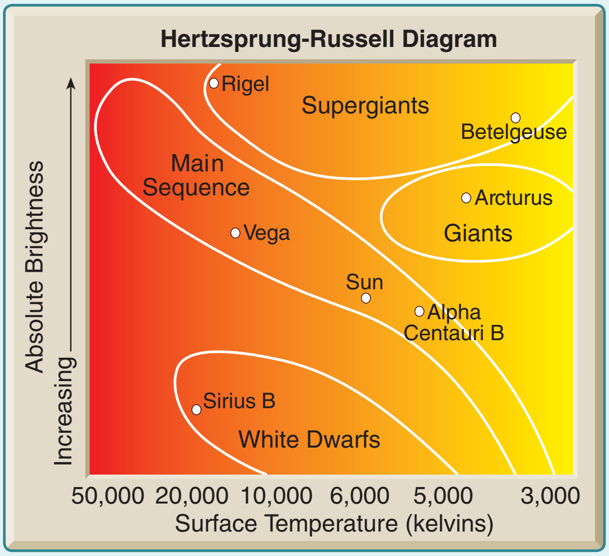
Think Critically

24. **Explain** Why are radio telescopes instead of optical telescopes used to determine the structure of the Milky Way Galaxy?

25. **Draw Conclusions** Imagine that you are a scientist studying the birth of stars in a spiral galaxy. Which part of the galaxy would you study? Explain your answer.

Analyze Data

Use the diagram below to answer Questions 26–28.



26. **Interpret Graphs** What is the brightest star in the diagram? The hottest?

27. **Analyze Data** How does the absolute brightness of white dwarfs compare with that of supergiants?

28. **Summarize** What is the relationship between absolute brightness and temperature for a main-sequence star?

Concepts in Action

29. **Explain** How can a binary star system be used to determine a star's mass?

30. **Infer** Would you use parallax to determine the distance to a faraway star? Why or why not?

31. **Calculate** The closest star to the sun, *Proxima Centauri*, is 4.3 light-years away. How many kilometers from the sun is *Proxima Centauri*?

Performance-Based Assessment

Use Models Use materials provided by your teacher to construct a scale model of the Milky Way Galaxy. Before you begin, be sure to develop a workable scale for your model.

Virginia SOL Test Prep

Tips for Success

Sequencing a Series of Events When a test question requires you to sequence a series of events, first try to predict the correct sequence before looking at the answer choices. Then compare your sequence to those listed. Be sure to pay attention to qualifiers in the question, such as *first, earliest, increasing,* or *decreasing,* as these may help you eliminate choices.

Which sequence of events describes the big bang theory? Begin with the earliest event.

A explosion; atoms form; stars form; all matter concentrated at a single point
B all matter concentrated at a single point; explosion; atoms form; stars form.
C explosion; stars form; all matter concentrated at a single point; atoms form.
D stars form; atoms form; all matter concentrated at a single point; explosion.

(Answer: B)

Choose the letter that best answers the question or completes the statement.

1 What can you estimate about a Cepheid variable if you know its absolute magnitude and apparent magnitude?

A mass
B distance
C temperature
D volume

ES.13.b

2 Based on the red shifts of distant galaxies, astronomers conclude that—

F Earth is in the center of the universe
G the universe is contracting
H the universe is expanding
J new galaxies are continually being added to the universe

ES.13.b

3 What types of stars are thought to be the remnants of supernova explosions?

A protostars
B neutron stars
C red giant stars
D white dwarf stars

ES.13.b

4 Which sequence of events describes the evolution of a medium-mass star, such as the sun? Begin with the earliest event.

F dust and gases, protostar, main-sequence star, white dwarf, black dwarf
G dust and gases, protostar, main-sequence star, giant, planetary nebula, white dwarf, black dwarf
H dust and gases, protostar, main-sequence star, supergiant, supernova explosion, black hole
J dust and gases, protostar, main-sequence star, supergiant, supernova explosion, neutron star

ES.13.b

If You Have Trouble With . . .

Question	1	2	3	4
See Lesson	25.1	25.3	25.2	25.2