Section 3

Lives of Stars

Reading Preview

Key Concepts

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

Key Terms

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

Target Reading Skill

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

Life Cycle of a Sun-like Star

Protostar forms from a nebula.

↓

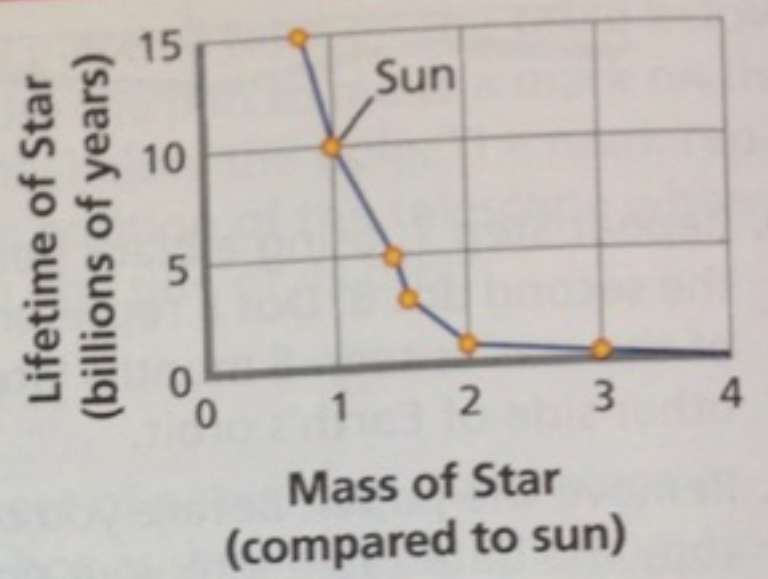
A star is born as fusion begins.

↓

Lab zone Discover Activity

What Determines How Long Stars Live?

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



Think It Over

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

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

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

◀ Three generations

The Lives of Stars

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

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

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

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

FIGURE 12
Young Stars
New stars are forming in the nebula on top. The bottom photo shows a protostar in the Orion Nebula. **Applying Concepts** *How do some of the gas and dust in a nebula become a protostar?*

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

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

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

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

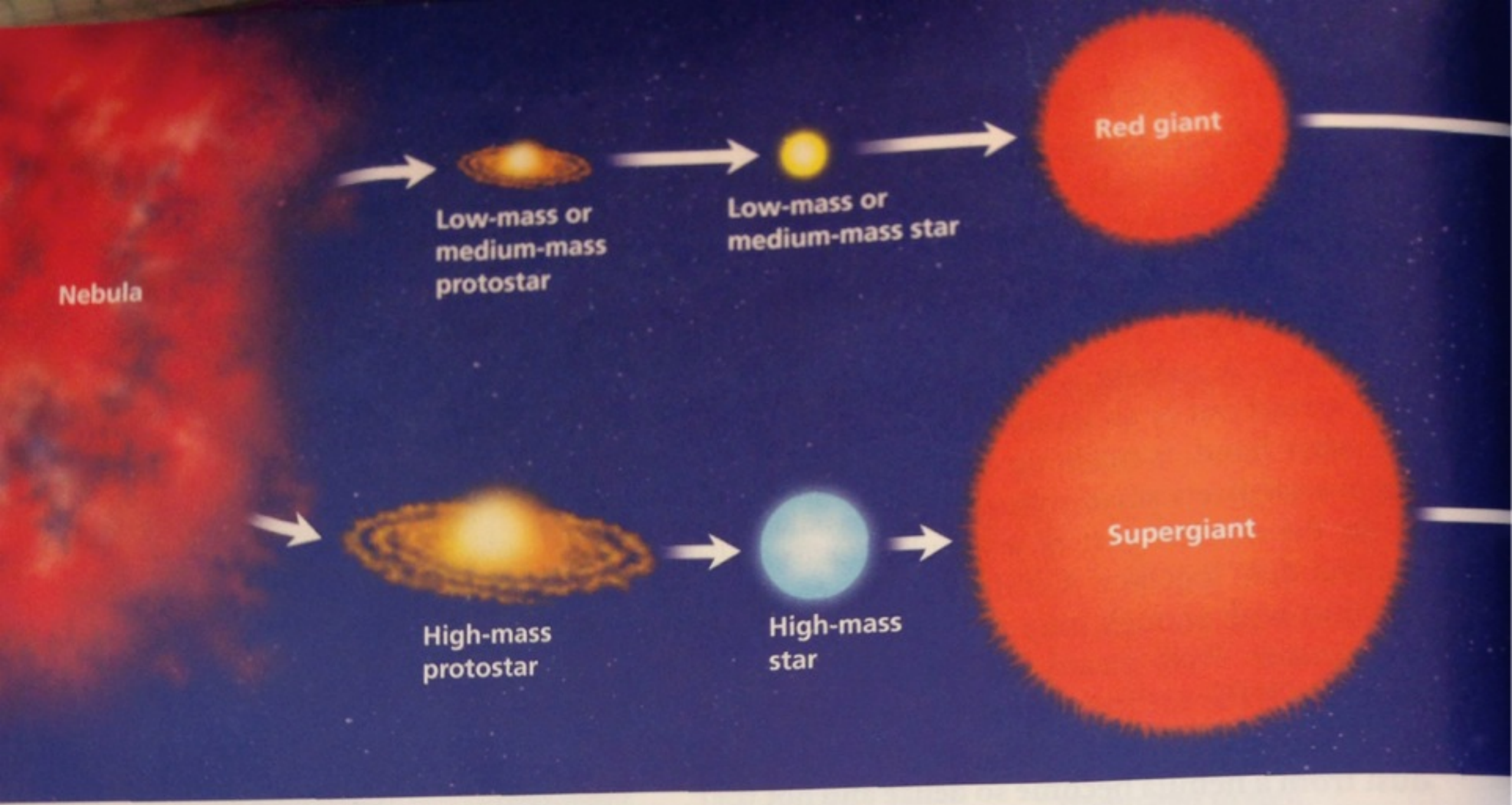


FIGURE 13

The Lives of Stars

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

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

Lab zone Skills Activity

Predicting

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

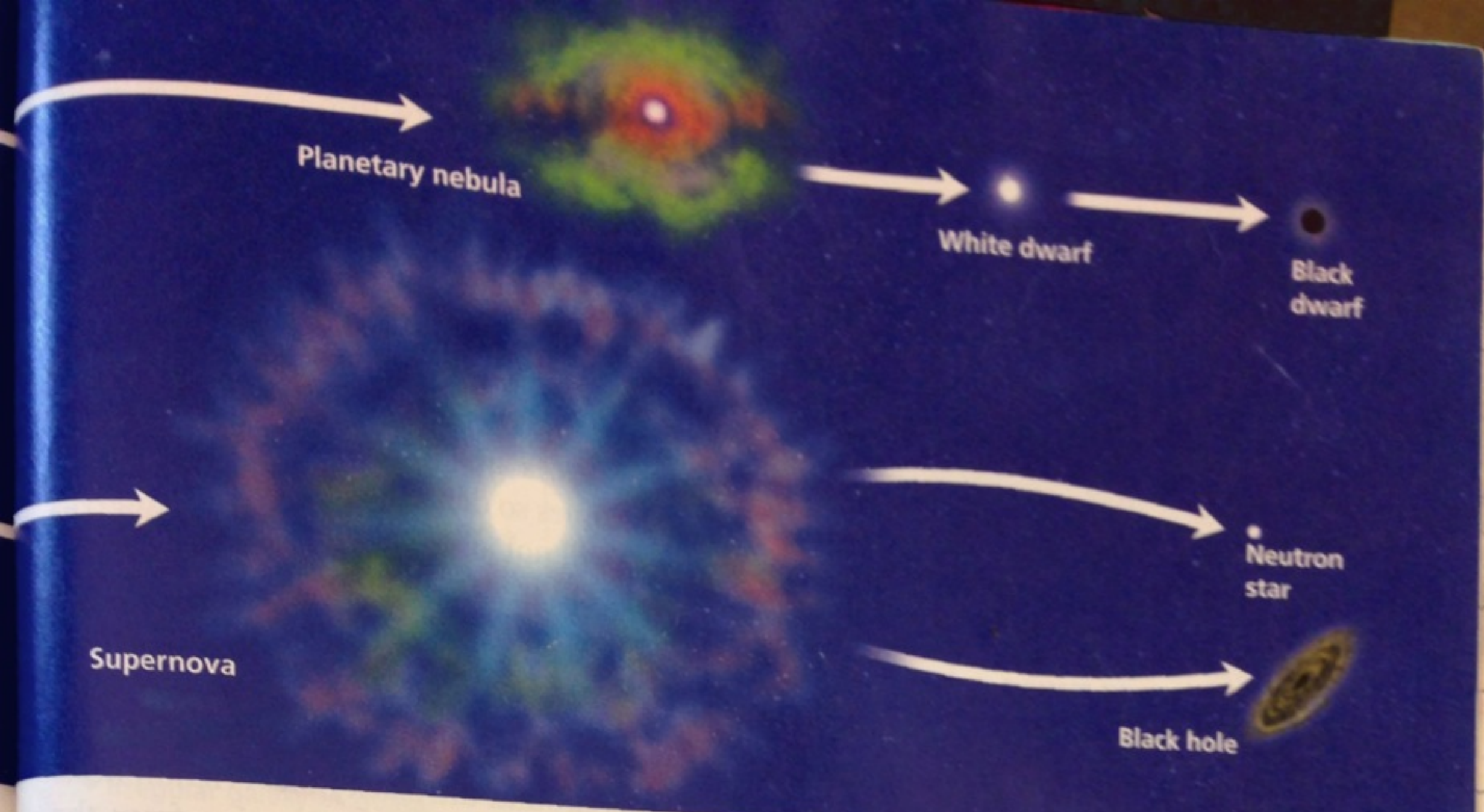
Deaths of Stars

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

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

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

Reading Checkpoint **What is a white dwarf?**



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

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

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

FIGURE 14
Black Holes
The remains of the most massive stars collapse into black holes. This artist's impression shows a black hole pulling matter from a companion star. The material glows as it is pulled into the black hole. **Applying Concepts** *If it is impossible to detect a black hole directly, how do astronomers find them?*

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

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

Reading Checkpoint **What is a black hole?**

Section 3 Assessment

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

Reviewing Key Concepts

1. a. **Defining** What is a nebula?
   b. **Explaining** How does a star form from a nebula?
   c. **Comparing and Contrasting** How is a protostar different from a star?
2. a. **Identifying** What factor determines how long a star lives?
   b. **Applying Concepts** A star is twice as massive as the sun. Will its lifespan be longer, shorter, or the same as that of the sun?
3. a. **Comparing and Contrasting** What is a white dwarf? How is it different from a neutron star?
   b. **Relating Cause and Effect** Why do some stars become white dwarfs and others become neutron stars or black holes?
   c. **Predicting** What will happen to the sun when it runs out of fuel? Explain.

Writing in Science

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