CHAPTER 20 The Universe

SECTION 1

The Life and Death of Stars

KEY IDEAS

As you read this section, keep these questions in mind:

- What affects the brightness of a star?
- How do stars produce energy?
- How do stars form and change over time?

What Are Stars?

For thousands of years, people on Earth have looked up at the stars. For most of that time, they could observe only the 6,000 stars visible with the naked eye. Today, scientists can use telescopes to learn about stars.

Stars are huge spheres of very hot plasma that give off light and other types of radiation. From Earth, most stars look like tiny points of light. Our sun appears larger than other stars because it is much closer to Earth. ☑

READING TOOLBOX

Ask Questions As you read this section, write down any questions you have. When you finish reading, work with a partner to try to find answers to your questions.

READING CHECK

1. Explain Why does our sun seem to be much larger than other stars?

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MEASURING DISTANCES IN SPACE

The distance between our solar system and most other objects in the universe is huge. Therefore, scientists use a special unit to describe distances in space. This unit is the light-year. One **light-year** (ly) is the distance that light travels in one year. One light-year is equal to about 9.46×10^{12} km.

What Affects the Brightness of a Star?

If you look into the sky on a clear night, you may notice that some stars appear brighter than others. You may think that the brightest stars are the largest. However, this is not always true. Many factors can affect how bright a star appears to people on Earth. The table below describes the effects of three of these factors.

Factor	How It Affects the Brightness of a Star
Distance from Earth	Stars that are far away appear dimmer than closer stars that are the same size and temperature.
Temperature	Cooler stars appear dimmer than hotter stars that are the same size and distance from Earth.
Size	Small stars appear dimmer than larger stars that are the same temperature and distance from Earth.

LOOKING CLOSER

2. Identify What are three factors that affect how bright a star appears?

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What Happens Inside a Star?

Most stars, including our sun, contain mainly hydrogen and helium gas. The atoms of these gases are pulled together by gravity. The gravitational pull produces very high pressure inside the core of a star. In fact, the pressure inside a star's core can be more than one billion times greater than Earth's atmospheric pressure. The temperature inside this incredibly dense core is also very high—more than 15 million K.

All stars contain several layers. However, the temperature and depth of each layer is different in different stars. The figure below shows the layers of our sun. Other stars may have different layers.

Critical Thinking

3. Predict Consequences If gravity did not exist, would there be any stars? Explain your answer.

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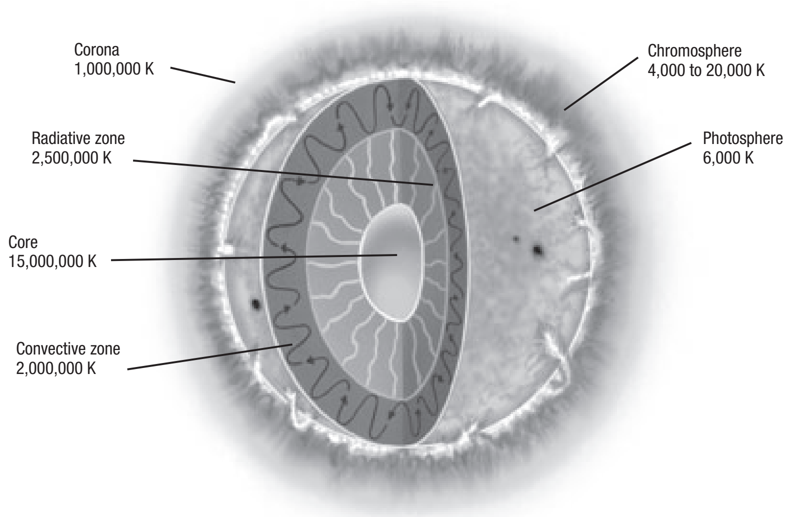

LOOKING CLOSER

4. Identify What is the hottest layer of the sun?

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The enormous temperature and pressure inside stars allow hydrogen nuclei to combine, or *fuse*. Stars get their energy from this nuclear fusion, which takes place in their cores. This fusion has several steps.

First, hydrogen nuclei collide. Each hydrogen nucleus is made of a single proton. They fuse to form new nuclei called *deuterons*. Each deuteron is made of one proton and one neutron. ☑

READING CHECK

5. Define What particles make up a deuteron?

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After a deuteron forms, another hydrogen nucleus can collide with it. This forms a nucleus of an isotope of helium called helium-3. Two helium-3 nuclei can collide to form the nucleus of a helium-4 atom, as well as two protons.

Each of these fusion reactions releases a great deal of energy. The star gives off this energy as heat, light, and other forms of electromagnetic radiation.

How Does Energy Travel Through a Star?

The energy produced in a star's core moves slowly toward the star's surface. In fact, it may take tens of thousands of years for energy to travel from the core to the surface. The energy travels at different speeds through different layers within the star.

Energy moves from the core of a star to its surface in different ways. For example, hot gases circulate within the convective zone. The convection carries energy away from the core. Energy can also move through a star by radiation. Most energy that leaves the sun travels by radiation. ☑

READING CHECK

6. Identify What are two ways that energy can move through a star?

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How Do Scientists Study Distant Stars?

Although stars give off a great deal of visible light energy, they also produce other kinds of electromagnetic radiation. This radiation can include radio waves, infrared rays, ultraviolet waves, X rays, and gamma rays.

Scientists use telescopes to measure the radiation from different stars. They can use these measurements to determine the age, temperature, and composition of stars. In this way, scientists can study stars that are far away. ☑

READING CHECK

7. Explain How do scientists learn about stars that are very far away?

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Scientists use different kinds of telescopes to study the different forms of energy. For example, scientists use optical telescopes to study visible light from stars. They use radio telescopes to study radio waves from stars.

Earth's atmosphere can block many kinds of electromagnetic radiation. This prevents telescopes on Earth's surface from detecting the radiation. Therefore, scientists also put telescopes in space to study radiation from stars. These space telescopes can study different forms of radiation than telescopes on Earth. ☑

READING CHECK

8. Explain How can a telescope in space be more useful to a scientist than one on the ground?

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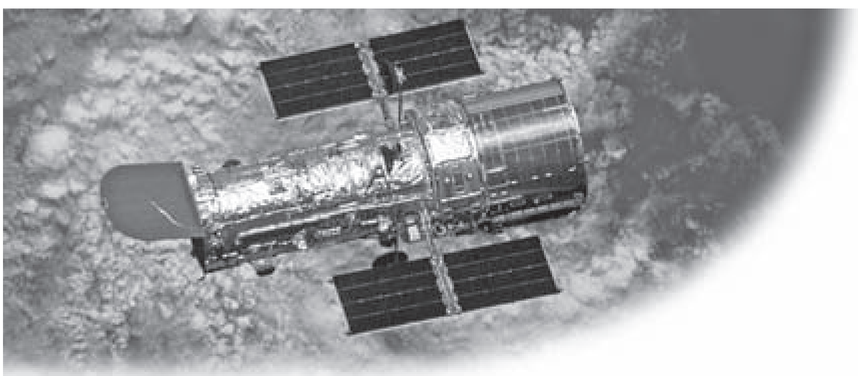

Scientists use space telescopes, such as the Hubble Space Telescope, to study stars.

COLOR AND TEMPERATURE

Scientists can use the color of a star to determine how hot the star is. This is because the temperature of a star determines the colors of light it gives off. The hotter the star, the bluer it appears. In fact, this relationship between temperature and color is true for many different objects.

A hot, glowing object (such as a star) gives off visible light of many different wavelengths. However, the temperature of the object affects how much light of each wavelength it gives off. Hotter objects give off more blue light. Cooler objects give off more red light. Our sun is a moderately cool star. It gives off mostly yellow light.

The temperature of a star also affects the *intensity*, or brightness, of the light it gives off. Hotter stars give off more intense light than cooler stars. Therefore, by examining the intensity and color of light from a star, scientists can learn how hot the star is. The figure below shows the relationship between temperature, color, and intensity of light for three different stars.

Critical Thinking

9. Apply Concepts A scientist observes two stars. One looks dim and red. The other looks brighter and yellow. Which star is probably hotter? Explain your answer.

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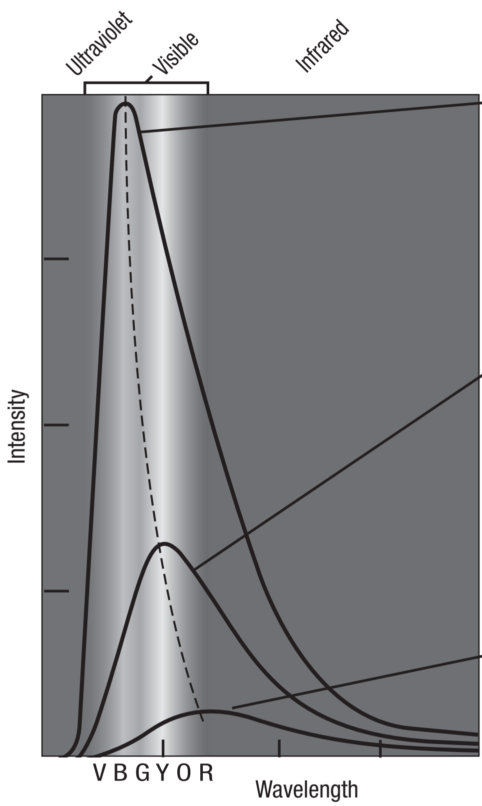

This curve shows the light emitted by a star with a surface temperature of 7,500 K. Most of the light is blue. In addition, the intensity of the light is high. Therefore, this star looks very bright and blue in color.

This curve shows the light emitted by our sun. Our sun's surface temperature is about 6,000 K. Most of the light it gives off is yellow and of moderate intensity. Therefore, our sun looks moderately bright and yellow in color.

This curve shows the light emitted by a star with a temperature of 4,500 K. Most of the light is red, and its intensity is low. Therefore, this star looks dim and red in color.

LOOKING CLOSER

10. Explain How can you tell that the blue star's light is most intense?

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DETERMINING THE COMPOSITION OF A STAR

Scientists can learn what a star is made of by studying the light the star gives off. They study the star's light using a tool called a spectrograph. A *spectrograph* separates the light from a star into different wavelengths. The separated wavelengths are called the *spectrum* (plural, *spectra*) of the star. Scientists can use a star's spectrum to determine what elements are in the star. ☑

READING CHECK

11. Define What is a spectrograph?

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The spectra of most stars contain dark lines at certain wavelengths. These occur because gases in the stars' outer layers absorb the light at those wavelengths. Different elements absorb light at different wavelengths. Therefore, each element produces a specific pattern of dark lines.

By studying the dark lines in the spectrum of a star, scientists can determine what elements are in the star. For example, scientists have determined that our sun contains mainly hydrogen and helium. They learned this by studying the sun's spectrum. ☑

READING CHECK

12. Explain How do scientists know what our sun is made of?

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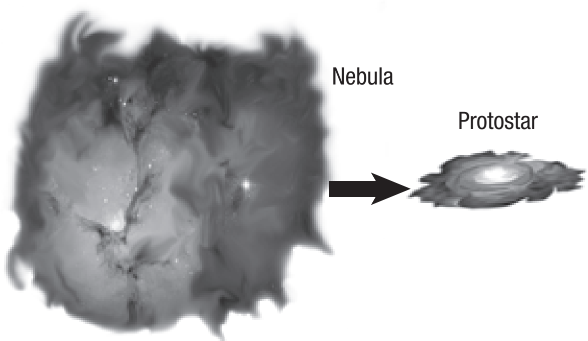
How Do Stars Form and Change?

All of the stars in the universe are not the same age. Some stars are very old. Other stars are just beginning to form. Our sun is in the middle of its life. By studying stars of different ages, scientists have learned how stars can form, change over time, and eventually die.

Scientists think our sun formed about 4.5 billion years ago. At that time, only a large, thin, slowly spinning cloud of gas and dust, or *nebula*, existed where our sun is today. Gravity caused the nebula to collapse. As the nebula collapsed, it began to spin faster. Material was pulled into the center of the nebula, and its temperature and density increased. Eventually, a *protostar* formed. Its core had a temperature of about 15 million K.



Scientists think that our sun formed from a nebula. As the nebula collapsed, a protostar formed.

LOOKING CLOSER

13. Define What is a protostar?

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READING CHECK

14. Explain What caused hydrogen atoms in the protostar to lose their electrons?

LOOKING CLOSER

15. Identify What force balances the force of gravity in our sun?

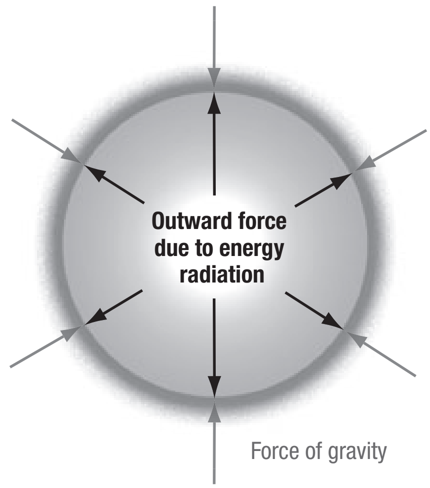
READING CHECK

16. Explain Why won't the sun be able to maintain a constant size when fusion becomes more difficult?

NUCLEAR FUSION BEGINS

The intense heat within the protostar caused hydrogen atoms to break down into a plasma. The plasma was made of separate protons and electrons. High pressure pushed the protons very close together. The strong nuclear force caused the protons to fuse and form helium. The beginning of fusion marked the birth of our sun. ☑

Remember that fusion reactions in the sun's core generate energy. This energy creates pressure that pushes material in the sun outward. That pressure balances the inward force of gravity. Because the forces balance, the sun has kept a stable size for more than 4 billion years.



In our sun, gravity pulls matter inward. The energy from nuclear fusion pushes matter outward. These forces balance each other, allowing our sun to maintain a constant size.

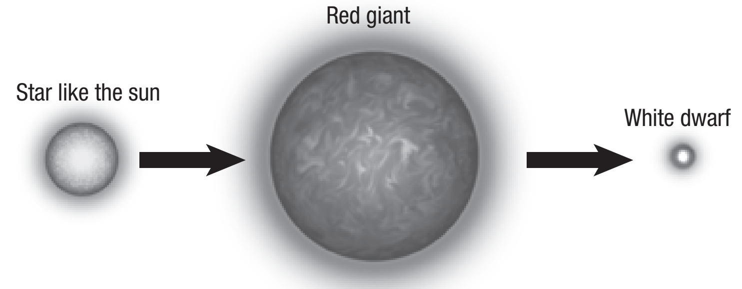
How Will the Sun Die?

Scientists think that in about 5 billion years, our sun's core will have used up about 25% of its hydrogen. Then, fusion will become more difficult. As the number of fusion reactions falls, the pressure from the production of energy in the sun's core will drop. The core will contract under the weight of the sun's outer layers. ☑

As the sun contracts, the core's temperature will rise. The increasing temperatures will cause the sun's outer layers to expand again. This will form a type of star called a **red giant**. Red giants are red because their surfaces are fairly cool. However, their cores stay hot enough to allow the nuclear fusion of helium into carbon and oxygen.

FORMATION OF A WHITE DWARF

When a red giant's core has consumed most of its helium, it contracts even more. That causes the outer layers to expand again. Eventually, they are blown away from the star. The parts they leave behind become a **white dwarf**—a small, dim, dense star about the size of Earth. It slowly cools down because fusion cannot occur within it.



Stars up to 1.4 times more massive than our sun will become red giants. Then, they will lose their outer layers and become white dwarfs.

LOOKING CLOSER

17. Apply Concepts A star's mass is 1.2 times the mass of our sun. What will happen to the star when its hydrogen and helium are used up?

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SUPERGIANTS TO SUPERNOVAS

Massive stars, or *supergiants*, are hotter than smaller stars. Because they are hotter, they use their fuel faster than smaller stars. Therefore, they have shorter life spans. When a massive star uses up its hydrogen, heavier elements can form in its core. Elements as heavy as iron can form in the cores of massive stars.

Once iron has formed in its core, the star cannot carry out nuclear fusion anymore. This is because fusing iron nuclei takes in energy instead of giving it off. When nuclear fusion stops, the core collapses because of its own gravity. Then, it rebounds violently with a shock wave. The shock wave blows the star's outer layers away from the core. That huge, bright explosion is a **supernova**.

Critical Thinking

18. Compare How are supergiants different from red giants?

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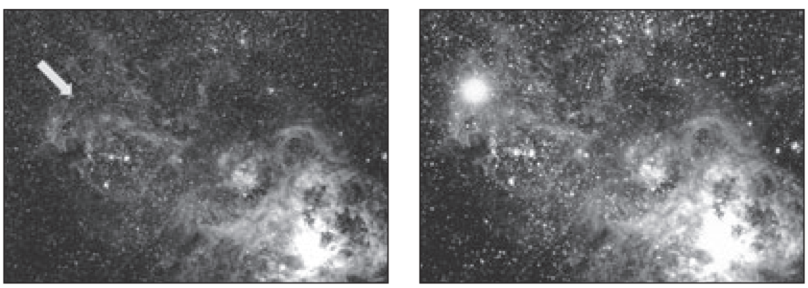

Supernova 1987a was one of the few supernovas visible from Earth with the unaided eye. The image on the left-hand side shows what the star looked like before the supernova. The image on the right-hand side shows what the supernova looked like.

LOOKING CLOSER

19. Apply Concepts Was the star that formed supernova 1987a a small star or a massive star? Explain your answer.

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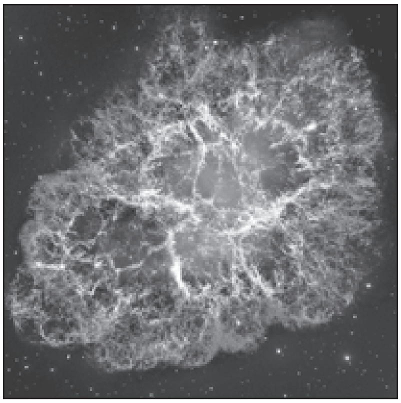
NEUTRON STARS AND BLACK HOLES

After a supernova, the remains of the star can form a nebula, such as the one in the figure below. The nebula contains gas and dust that was blown out of the star during the supernova. This material may end up in other stars or planets at a later time. The core of the star may also be left in the nebula.



The Crab Nebula formed from the remains of a supernova. Chinese astronomers observed this supernova in the year 1054.

LOOKING CLOSER

20. Explain How did the Crab Nebula form?

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Supernova cores that are 1.4 to 3 times more massive than our sun can become neutron stars. A *neutron star* is a small, dense core of a star. A neutron star can have a density of up to 10^{17} kg/m^3. A teaspoon of matter from a neutron star would weigh more than 100 million tons on Earth. Some neutron stars spin and give off radio waves. Scientists can detect these pulsars by studying the radio waves. ☑

A supernova core with a mass more than 3 times the sun's will collapse to form a black hole. A **black hole** consists of matter so massive that nothing, including light, can escape its gravitational pull. Because no light can escape from a black hole, we cannot see one directly. However, astronomers can detect black holes by observing the effects of their gravity on objects near them. ☑

READING CHECK

21. Identify How massive must a star be to become a neutron star?

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READING CHECK

22. Explain How can astronomers detect black holes?

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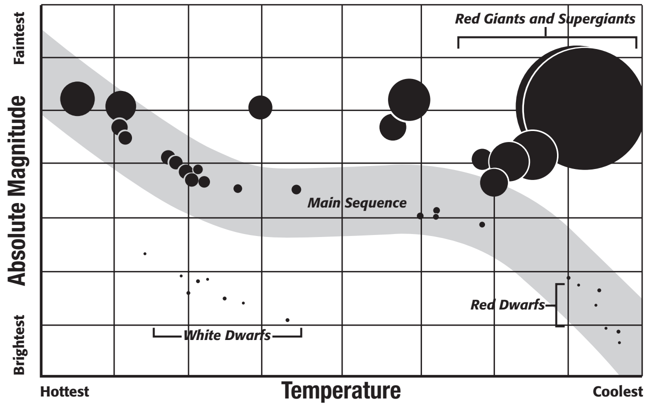
What Is an H-R Diagram?

Scientists use a Hertzsprung-Russell diagram, or H-R diagram, to show how the temperature and brightness of a star are related. An *H-R diagram* is a graph of temperature versus absolute magnitude for all observable stars. *Absolute magnitude* is a measure of how bright a star would appear if it were a certain distance from Earth. Scientists can use the H-R diagram to learn how stars change as they age.

The Hertzsprung-Russell Diagram



The Hertzsprung-Russell diagram is named after the two astronomers who first created it.

LOOKING CLOSER

23. Interpret What is shown on the *x*-axis of an H-R diagram?

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THE MAIN SEQUENCE

As stars age and pass through different stages in their life cycles, their positions on the H-R diagram change. Most stars appear on a diagonal line in the diagram called the *main sequence*. A star's position on the main sequence depends on its initial mass.

As stars age, they leave the main sequence. Red giant stars, which are cool and bright, appear in the upper right of the H-R diagram. White dwarfs, which are hot and dim, appear in the lower left. ☑

Our sun will stay on the main sequence for about 5 billion more years. As it develops into a red giant, it will become brighter, cooler, and redder. It will move up and to the right on the H-R diagram. Then, it will become a white dwarf. It will end up in the lower left of the diagram, among the other white dwarfs.

READING CHECK

24. Identify Where on the H-R diagram are red giants located?

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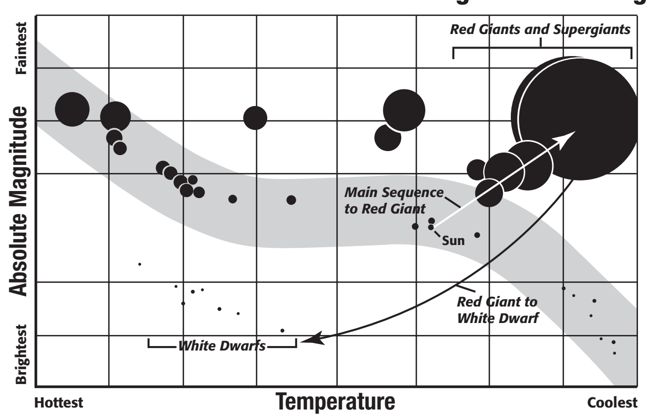
How Our Sun's Position on the H-R Diagram Will Change



LOOKING CLOSER

25. Describe What will happen to our sun after it becomes a red giant?

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Name ______________________ Class ______________ Date ______________

Section 1 Review

SECTION VOCABULARY

black hole an object so massive and dense that even light cannot escape its gravity

light-year the distance that light travels in one year; about 9.46 trillion kilometers

red giant a large, reddish star late in its life cycle

star a large celestial body that is composed of gas and that emits light; the sun is a typical star

supernova a gigantic explosion in which a massive star collapses and throws its outer layers into space

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

1. **Explain** Why do scientists use light-years to measure most distances in space?

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2. **Describe Relationships** Fill in the blank spaces in the table below.

Mass of Star	Life Span	Temperature	Brightness	Color
Low	long			red
Medium		moderate	moderate	
High				

3. **Describe** How can scientists use the spectrum of a star to determine what the star is made of?

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4. **Explain** What allows our sun to maintain a constant size?

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5. **Apply Concepts** A star's mass is four times the mass of our sun. What will probably happen to the star when its fuel runs out?

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6. **Describe** What do scientists think will happen to our sun when its fuel runs out?

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