8.3 Exploring Other Stars

Key Terms
- luminosity
- absolute magnitude
- spectroscope
- spectral lines
- Hertzsprung-Russell (H-R) diagram
- main sequence
- white dwarf
- supernova
- neutron star

When you look at the night sky, you see that some stars are brighter than others, as shown in **Figure 8.24**. But are the stars brighter because they are emitting more light, or are they brighter because they are closer to Earth? A star can seem brighter than another because it is larger or because it is closer to Earth. The closest stars to Earth are not necessarily the brightest.

How Bright Is That Star?

Astronomers refer to luminosity when talking about the brightness of stars. A star's **luminosity** is a measure of the total amount of energy it radiates per second. The star that astronomers know the best is the Sun, so it is helpful to compare other stars with the Sun. Astronomers have found that some stars are about 10 000 times less luminous than the Sun, while others are more than 30 000 times more luminous than the Sun.

Another term referring to a star's brightness is absolute magnitude. A star's **absolute magnitude** is defined as how bright the star would be at a distance of 32.6 light-years from Earth. The absolute magnitude of the Sun is about 4.7. (Recall from Chapter 7 that a 4.7 magnitude star is not that bright.) This means that, compared with other stars, the Sun is rather faint.

luminosity a star's total energy output per second; its power in joules per second (J/s)

absolute magnitude the magnitude of a star that we would observe if the star were placed 32.6 light-years from Earth

Figure 8.24 The night sky is filled with stars at all levels of brightness.

> **Suggested Investigation**
> Plan Your Own Investigation 8-A, The Brightness of Stars, on page 350

The Colour and Temperature of Stars

Stars in the night sky generally look like small points of white light. If you were able to view them through a powerful telescope, however, you would see that some are bluish, some are bluish-white, and some are yellow, orangish, or reddish.

Astronomers use the colour of a star to determine the star's surface temperature. (Think of a stove element that has become so hot that it turns red.) Recall from Section 8.2 that the temperature of the Sun's photosphere is about 6000°C. The Sun is yellow, so astronomers infer that yellow stars have a similar surface temperature. Bluish stars are much hotter. The surface temperature of a bluish star typically varies between 21 000°C and 35 000°C. On the other end of the scale, the temperatures of reddish stars are typically much cooler, about 3300°C.

> **spectroscope** an optical instrument that produces a spectrum from a narrow beam of light, and usually projects the spectrum onto a photographic plate or a digital detector
>
> **spectral lines** certain specific wavelengths within a spectrum characterized by lines; spectral lines identify specific chemical elements

The Composition of Stars

How do astronomers know that the Sun and other stars are made of hydrogen and helium? They use a spectroscope to analyze the light from stars. A **spectroscope** is an instrument that produces a pattern of colours and lines, called a spectrum, from a narrow beam of light. In the 1820s, Joseph von Fraunhofer, a German optician, used a spectroscope to observe the Sun's spectrum and noticed hundreds of lines. These lines are called **spectral lines**. He mapped the Sun's spectrum completely, although he did not know what the spectral lines meant. Today, astronomers know that a star's spectrum identifies the elements within the star's photosphere, as shown in **Figure 8.25**.

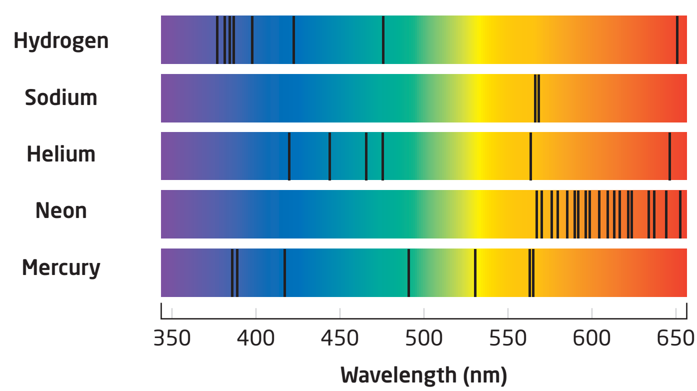

Figure 8.25 Every element is uniquely identified by its spectrum. A nanometre (nm) is 10^{-9} m.

> **Suggested Investigation**
> Inquiry Investigation 8-B, Using Spectral Analysis to Identify Star Composition, page 352

Learning Check

1. Write a definition for luminosity.
2. Does a star's apparent brightness depend on just its distance from Earth? Explain your answer.
3. List four properties of stars.
4. What can you learn about a star by looking at its spectrum? Review **Figure 8.25**.

The Mass of Stars

Determining the mass of stars was not possible until astronomers discovered that most of the stars seen from Earth are binary stars. *Binary stars* are two stars that orbit each other. The Sun is unusual in that it is not part of a binary star system. By knowing the size of the orbit of a binary pair and the time the two stars take to complete one orbit, astronomers were then able to calculate the mass of each star. Star mass is expressed in terms of *solar mass*. The Sun is 1 solar mass. Other stars range from 0.08 solar masses to over 100 solar masses.

The Hertzsprung-Russell Diagram

As astronomers learned more about the properties of stars, they began to look for patterns in the data. In the 1920s, two astronomers were studying data from large numbers of stars visible from Earth. Ejnar Hertzsprung in the Netherlands and Henry Norris Russell in the United States were working independently of each other. But both observed that each star type has certain properties. These relationships can be shown on a graph called the **Hertzsprung–Russell (H-R) diagram**. Their graph had star colour (ranging from blue to red) on the *x*-axis. Absolute magnitude (ranging from dimmer to brighter) was on the *y*-axis of their graph. **Figure 8.26** shows an H-R diagram in which the absolute magnitude has been replaced by the luminosity. Astronomers discovered from the H-R diagram that there are several different categories of stars.

Hertzsprung-Russell (H-R) diagram a graph that compares the properties of stars

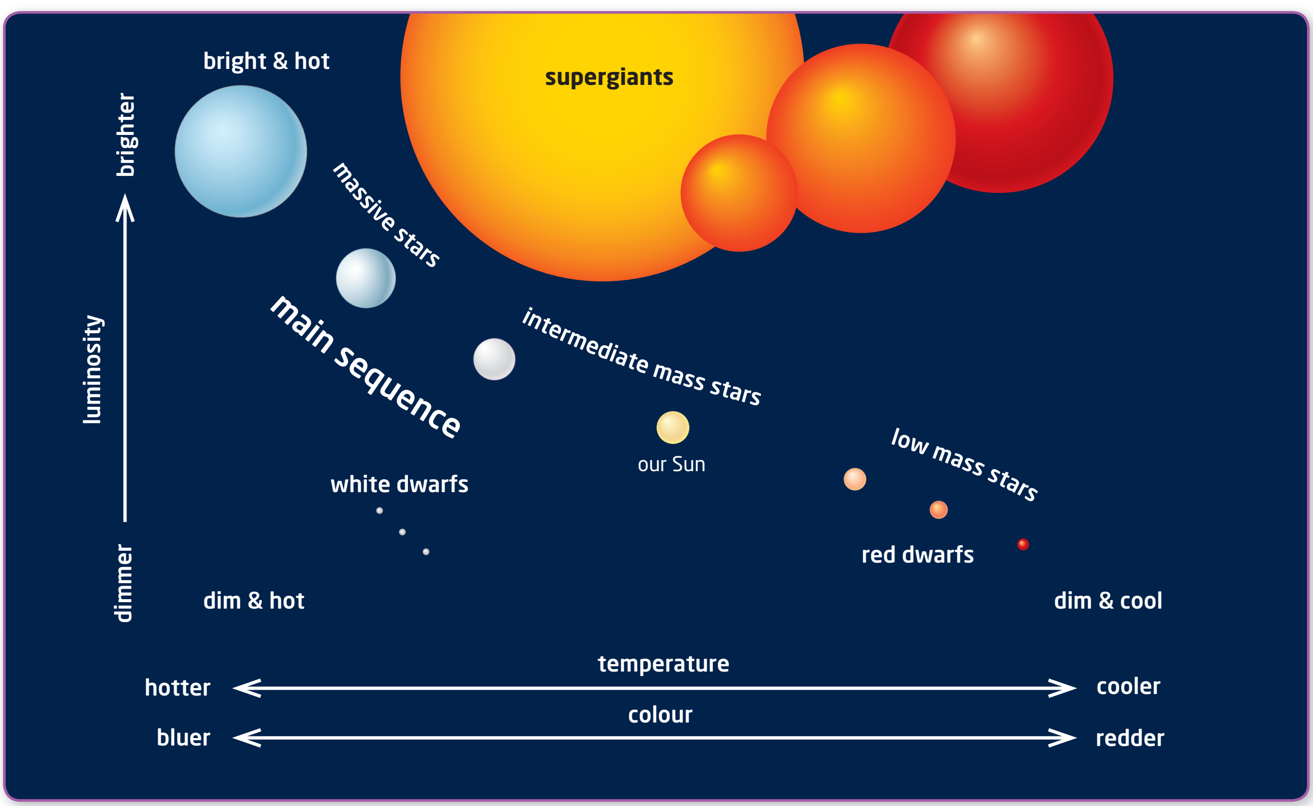

Figure 8.26 Hertzsprung-Russell diagrams like this one show trends in the evolution of stars. For example, most cool stars are much dimmer than hot stars, and most hot stars tend to be more massive than cool stars.

main sequence a narrow band of stars on the H-R diagram that runs diagonally from the upper left (bright, hot stars) to the lower right (dim, cool stars); about 90 percent of stars, including the Sun, are in the main sequence

The Main Sequence

The central band of stars stretching from the upper left to the lower right of the H-R diagram in **Figure 8.26** is called the **main sequence**. The main sequence accounts for about 90 percent of the stars that you can see from Earth. What about the 10 percent of known stars not in the main sequence? Hertzsprung and Russell found that some stars were cooler but very bright. The star Antares, for example, shown in **Figure 8.27**, has a surface temperature of only 3500°C, but it is the 15th brightest star in the night sky.

Figure 8.27 Antares is a bright supergiant located approximately 600 light-years from Earth. Its surface temperature is relatively cool, yet it is extremely bright.

When placed on the H-R diagram, the cool, bright stars are far above the main sequence. Find these red giants and supergiants on the H-R diagram in **Figure 8.26** and note their sizes. **Table 8.4** summarizes some properties of main-sequence stars.

Table 8.4 Some Properties of Main-Sequence Stars

Colour	Surface Temperature (°C)	Mass*	Luminosity*
Blue	35 000	40	405 000
Blue-white	21 000	15	13 000
White	10 000	3.5	80
Yellow-white	7 500	1.7	6.4
Yellow	6 000	1.1	1.4
Orange	4 700	0.8	0.46
Red	3 300	0.5	0.08

* These properties are relative to the Sun.

Questions about why some stars are not in the main sequence led astronomers to wonder how these stars came to be. Were they special, rare types of stars that formed in a different way? Or were they examples of main-sequence stars that had gone through dramatic changes at some stage in their life? Astronomers have worked out the basic features of star formation. But, as you will read in the rest of this section, there are lots of details missing, and many puzzles still remain.

Suggested Investigation

Data Analysis Investigation 8-C, Building an H-R Diagram, on page 354

How Stars Evolve

Stars, in general, do not change very rapidly. Stars like the Sun shine for billions of years with little or no change. Nevertheless, stars radiate huge amounts of energy into space, and they cannot do that forever. Eventually, they run out of fuel. In the final stages of a star's life, it becomes a white dwarf, a neutron star, or a black hole. What the star evolves into depends on its initial mass on the main sequence. **Figure 8.28** illustrates the evolution of different types of stars. Refer to this figure as you read the following text.

Study Toolkit

Interpreting Diagrams
One strategy to help you understand a labelled diagram such as the one in **Figure 8.28** is to first read the caption to identify the main idea. Then read the labels with each illustration to follow the life cycles of the different stars.

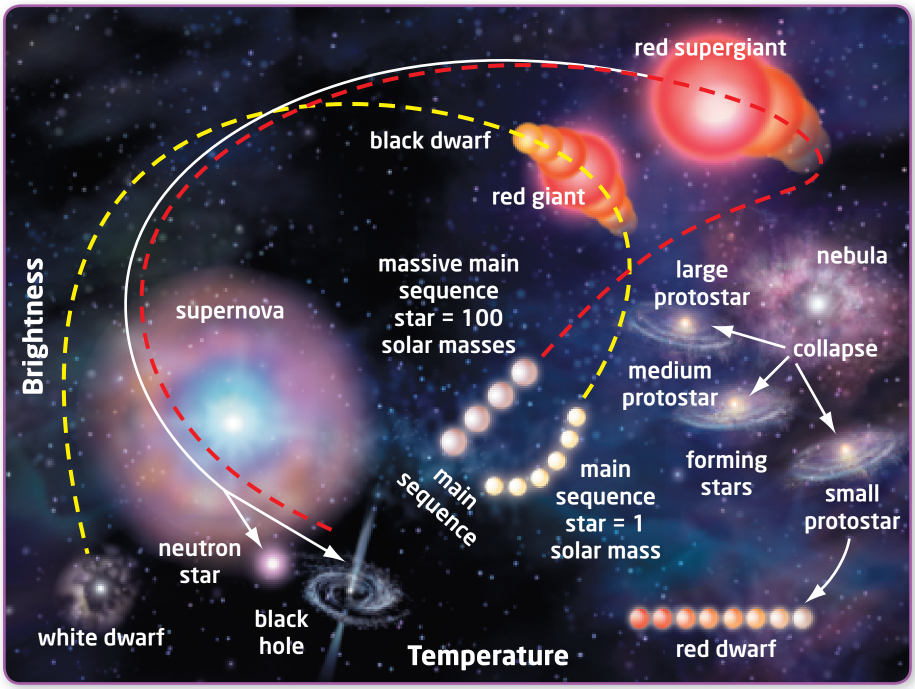

Figure 8.28 A star's life cycle depends on its initial mass.

Low-Mass Stars

Low-mass stars (red dwarfs) have less mass than the Sun. They consume their hydrogen slowly over a period that may be as long as 100 billion years. During that time, they lose significant mass, essentially evaporating. In the end, all that remains of them is a very faint **white dwarf**. While white dwarfs no longer produce energy of their own, they are incredibly hot. It takes tens of billions of years for them to cool down. Astronomers theorize that when they do cool down, they will become nothing more than dark embers called black dwarfs. The universe is not old enough to contain any black dwarfs.

white dwarf a small, dim, hot star

Intermediate-Mass Stars

Intermediate-mass stars, such as the Sun, consume their hydrogen faster than low-mass stars, over a period of about 10 billion years. When their hydrogen is used up, the core collapses. As the core contracts, the temperature increases and the outer layers begin to expand. The expanded layers are cooler and appear red. At this phase the star is called a red giant. In about five billion years the Sun will become a red giant. It will become so large that its diameter will extend out to the current orbit of Mars. Eventually, the layers will disappear into space, and the Sun will become a white dwarf.

High-Mass Stars

Stars that are 12 or more solar masses are high-mass stars. These stars consume their fuel even faster than the intermediate-mass stars. As a result, high-mass stars die more quickly and more violently. In massive stars, the core heats up to much higher temperatures. Heavier elements form by fusion, and the star expands into a supergiant. Eventually, iron forms in the core. Since iron cannot release energy through fusion, the core collapses violently, and a shock wave travels through the star. The outer portion of the star explodes, producing a **supernova**. A supernova can be millions of times brighter than the original star was. **Figure 8.29** shows the remains of a supernova.

During a supernova explosion, the heavier elements formed are ejected into the universe. Some of these elements become parts of new stars, and some form planets and other bodies. Your body, in fact, contains many atoms that were fused in the cores of old stars.

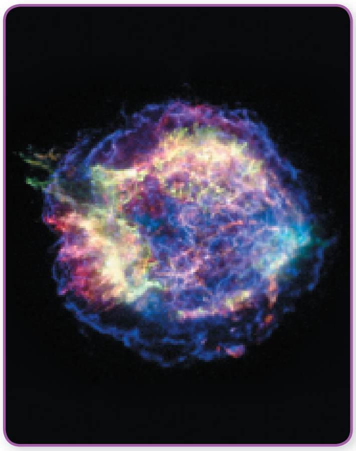

Figure 8.29 This image shows what is left of a star in the constellation Cassiopeia. The star exploded at the end of its life.

supernova a massive explosion in which the entire outer portion of a star is blown off

Supernova Discovery

In 1987, Canadian astronomer Ian Shelton discovered a supernova while working at a University of Toronto observatory in Chile. Shelton was examining images of stars, and he noticed something unusual in one of them. He decided to step outside and look up. Among thousands of stars he spotted a bright one that was not previously visible. See **Figure 8.30**. Shelton had discovered a supernova. Called SN 1987A, the supernova was the closest one to Earth since 1604. SN 1987A is 163 000 light-years from Earth.

Depending on the initial mass of the star before it became a supernova, the remaining star will become either a neutron star or a black hole.

Figure 8.30 The image on the left shows the supernova discovered by Ian Shelton. The image on the right shows the same area before the supernova.

Neutron Stars

If the star began with a mass of about 12 to 15 solar masses, the core will shrink to approximately 20 km in diameter. In such stars, the pressure is so great that electrons are squeezed into protons, and the star eventually becomes a **neutron star**. The first neutron star to be discovered is in the centre of the Crab Nebula. The Crab Nebula is shown in **Figure 8.31A**.

neutron star a star so dense that only neutrons can exist in the core

The Crab Nebula is the remnant of a supernova explosion that occurred in 1054. Chinese historical records from that year reveal that Chinese astronomers observed it. They called it a "guest star." Astronomers have since discovered that the neutron star in the Crab Nebula is spinning about 30 times per second. **Figures 8.31B** and **C** show that as the neutron star spins, it sends pulses of radiation into space. The Crab Nebula neutron star was among the first discoveries of a type of neutron stars called pulsars. *Pulsars* send *pulses* of radiation toward Earth, much like an extremely fast-sweeping searchlight.

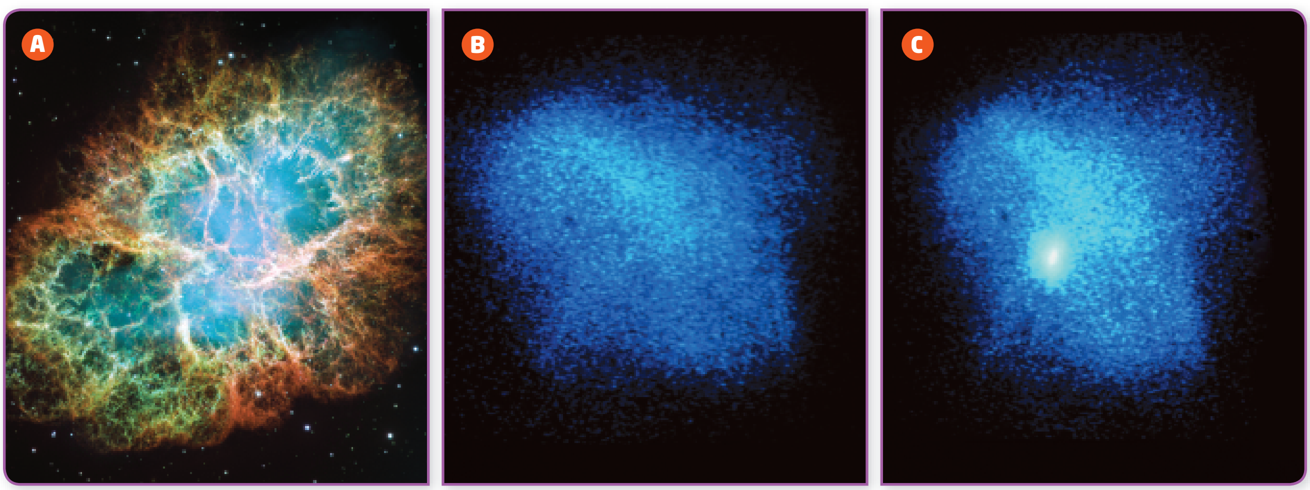

Figure 8.31 **A** The Crab Nebula in visible light. In **B**, the beam is pointing away from Earth. In **C**, you can see a pulse of radiation. This pulsar flashes about 30 times per second. The images in **B** and **C** are from the Einstein X-ray Observatory (in space).

Learning Check

5. What is the fate of the Sun? Review **Figure 8.28**.
6. Can a star less massive than the Sun become a supernova? Explain your answer.
7. What is a neutron star?
8. The Canadian songwriter Joni Mitchell wrote, "We are stardust" in her song called "Woodstock". She was being factual as well as poetic. Explain why.

Black Holes

The most spectacular deaths happen to stars whose initial masses are more than 25 solar masses. The remnant of the supernova explosion is so massive that nothing can compete with the crushing force of gravity. The remnant is crushed into a black hole. A *black hole* is a tiny patch of space that has no volume, but it does have mass. Therefore, there is still gravity. In fact, the gravitational force of a black hole is so strong that nothing can escape it. Even light cannot escape a black hole's gravity.

Black holes are among the strangest objects in the universe. Astronomers predicted the existence of black holes before the first one was discovered. Recall how Mendeleev's periodic table modelled the elements that were known at the time. Mendeleev's model led to predictions of missing elements, which then led to discoveries. In a similar way, scientists build mathematical models of how stars evolve and eventually die. The models seemed to fit what scientists were seeing, so when the models pointed to the possibility that a strange object like a black hole could exist, scientists started looking for them.

Finding a Black Hole

Go to **scienceontario** to find out more

When astronomers say they have detected a black hole, they do not mean that they have seen one. What they mean is that they have detected the *gravitational effects* of an object whose mass and size match those predicted by physics. For example, black holes that exist in congested regions of space sometimes swallow up matter and compress it until enormous temperatures are reached before it disappears. When this happens, the black hole emits intense radiation that uncloaks the normally invisible black hole. Astronomers look for the telltale signature of black holes devouring gas, dust, and stars using radio, X-ray, and gamma ray telescopes.

Dr. Tom Bolton, of the University of Toronto, identified the first black hole in 1972. The name of the black hole is Cygnus X-1. Astronomers now know that black holes are everywhere. They may exist in the core of every galaxy. You will learn more about galaxies in Chapter 9.

Section 8.3 Review

Section Summary

- A star's apparent brightness depends on its luminosity and distance from Earth.
- Hertzsprung and Russell independently discovered that each type of star has specific properties. They organized their findings into what is now called a Hertzsprung–Russell (H-R) diagram.
- The main sequence is a narrow band of stars on the H-R diagram that runs diagonally from the upper left (bright, hot stars) to the lower right (dim, cool stars). About 90 percent of stars are on the main sequence, including the Sun.
- A star's position on the main sequence is determined by its initial mass.
- A star will become a white dwarf, a neutron star, or a black hole, depending on its initial mass.
- Canadian researchers contribute to our understanding of space.

Review Questions

K/U **1.** If a star's surface temperature is around 7200°C, what colour is the star?

C **2.** Create a poster to describe the Hertzsprung–Russell diagram.

K/U **3.** Place the following in order from youngest to oldest: A. star; B. nebula; C. red giant; D. white dwarf.

K/U **4.** Why are the more massive stars the only important contributors in enriching the universe with heavy elements?

C **5.** Pick one type of star, and write a short story on its life cycle.

A **6.** Copy the table on the right into your notebook. Complete the table after studying **Figure 8.26**. Refer to **Table 8.4** as well.

Star Properties

Star	Colour	Approximate Surface Temperature (°C)	Bright or Dim
Aldebaran		3 300	
Arcturus		4 700	
Betelgeuse		3 300	
Polaris		7 500	
Proxima Centauri		3 300	
Rigel		21 000	
Sirius		10 000	

A **7.** Describe one contribution from a Canadian researcher to the study of space. Say how the contribution is important to the study of space.

T/I **8.** Why do you think Chinese astronomers called the 1054 supernova explosion a "guest star"?