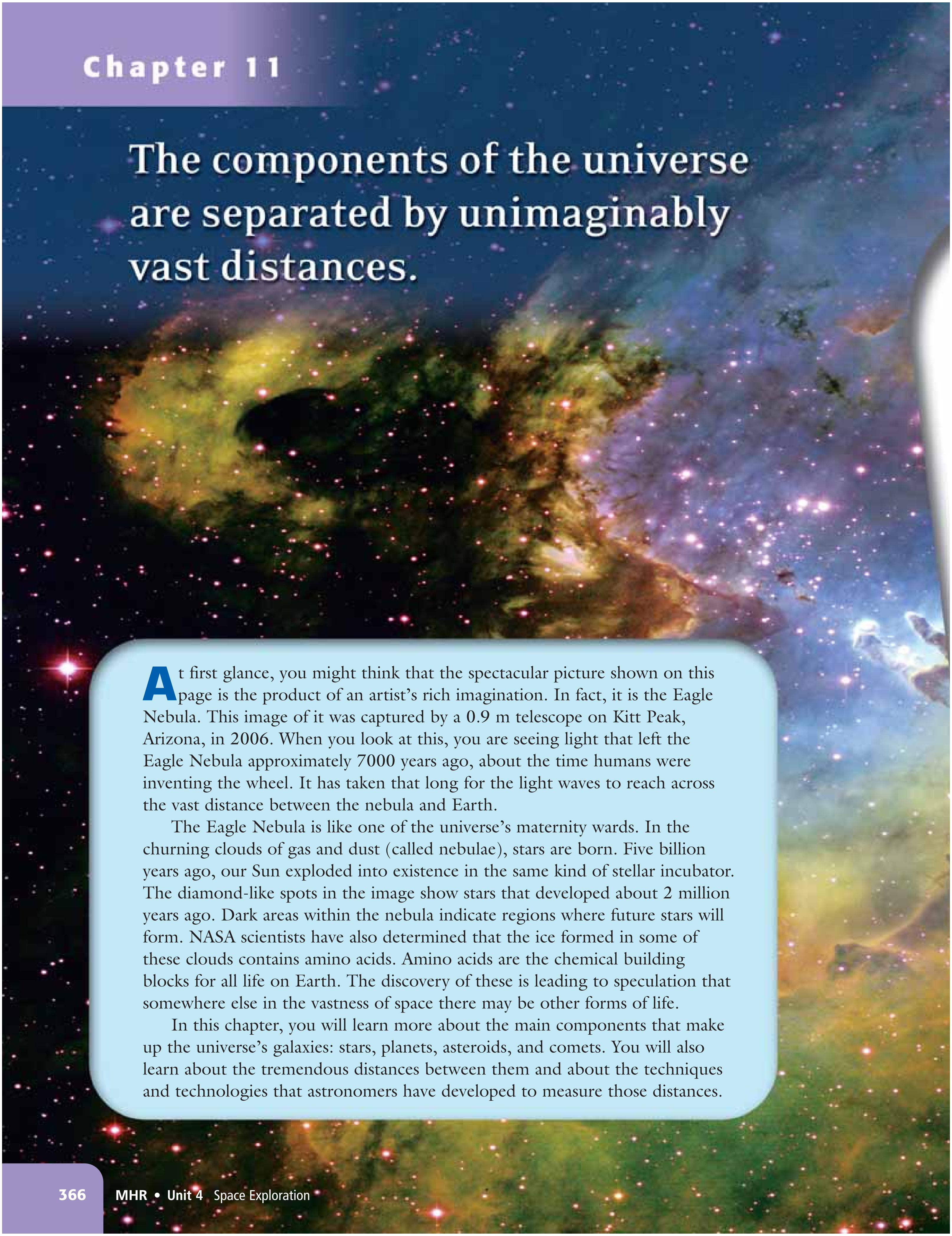
Chapter 11

The components of the universe are separated by unimaginably vast distances.



At first glance, you might think that the spectacular picture shown on this page is the product of an artist's rich imagination. In fact, it is the Eagle Nebula. This image of it was captured by a 0.9 m telescope on Kitt Peak, Arizona, in 2006. When you look at this, you are seeing light that left the Eagle Nebula approximately 7000 years ago, about the time humans were inventing the wheel. It has taken that long for the light waves to reach across the vast distance between the nebula and Earth.

The Eagle Nebula is like one of the universe's maternity wards. In the churning clouds of gas and dust (called nebulae), stars are born. Five billion years ago, our Sun exploded into existence in the same kind of stellar incubator. The diamond-like spots in the image show stars that developed about 2 million years ago. Dark areas within the nebula indicate regions where future stars will form. NASA scientists have also determined that the ice formed in some of these clouds contains amino acids. Amino acids are the chemical building blocks for all life on Earth. The discovery of these is leading to speculation that somewhere else in the vastness of space there may be other forms of life.

In this chapter, you will learn more about the main components that make up the universe's galaxies: stars, planets, asteroids, and comets. You will also learn about the tremendous distances between them and about the techniques and technologies that astronomers have developed to measure those distances.

What You Will Learn

In this chapter, you will
- **distinguish** stars based on their different types and characteristics
- **describe** the formation and components of the solar system
- **explain** the measuring units astronomers have devised to describe the vast distances in space
- **explain** how triangulation and parallax are used to measure distance

Why It Is Important

Understanding the formation and characteristics of stars and planets and the vastness of the distances between them enables us to better appreciate how technology and human ingenuity have extended our ability to observe the universe.

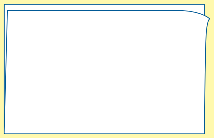
Skills You Will Use

In this chapter, you will:
- **classify** stars
- **graph** the period of revolution of seven planets
- **observe** a variety of spectra
- **model** the size of bodies in the solar system and the distances between them

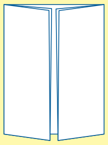
FOLDABLES™
Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 11.

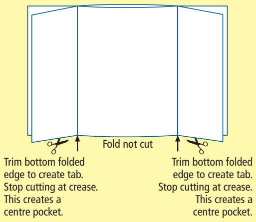
STEP 1 **Fold** a large sheet of paper in half.



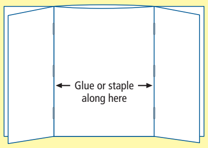
STEP 2 **Fold** it into a shutterfold as shown.



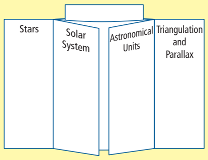
STEP 3 **Cut** away the fold on the bottom left and bottom right sides of the shutterfold; do not cut the fold in the centre of the Foldable.



STEP 4 **Glue** or **staple** along the left and right fold lines to form a large pocket in the centre of the Foldable.



STEP 5 With the side tabs closed, write the title of the chapter across the front tabs. Open the tabs and label the inside left tabs "Stars" and "Solar System". Open and label the inside of the right tabs "Astronomical Units" and "Triangulation and Parallax."



Note-taking Skills Use this Foldable to practise note-taking skills and to organize main ideas, supporting facts, diagrams, self-questions, terms, and definitions you encounter in the chapter. The pocket can hold notes and worksheets collected during the study of this chapter.

11.1 Stars

Stars are spherical objects in space that radiate energy from their hot cores. They outnumber by far all other celestial bodies in the universe. Stars have a life span (like humans do, only much longer). They are formed in clouds of gas and dust. How long a star lives depends on its mass.

Words to Know

- black hole
- Doppler effect
- fusion
- interstellar matter
- star
- supernova

A **star** is an object in space made up of hot gases, with a core that is like a thermonuclear reactor. Astronomers estimate that 9000 billion billion stars have formed in the observable universe over its 13.7 billion year history. As Carl Sagan, an American astronomer and writer, once expressed it, there are more stars in the universe than grains of sand on all the beaches of Earth. In this section, you will learn about how stars form and change over time.

Space is not empty but filled with **interstellar matter**, which is made up of gas (mostly hydrogen) and dust. The dust accounts for only about 1 percent of the total mass of all interstellar matter. Even at such a small amount, interstellar dust makes it hard for astronomers to see the light

Figure 11.1 The Carina Nebula as it appears in the visible spectrum (A). A section of the same nebula, but this time as it is revealed in the infrared spectrum (B). Note the detail in (B) that was not clear in the visible spectrum.

from distant stars. If you have ever stood beside a dirt road when a vehicle has just driven by, you know how the dust that fills the air makes visibility poor for a few minutes. Fortunately, technology has enabled astronomers to "see" through the dusty curtains of interstellar matter and into what are often called stellar nurseries. Radio and infrared telescopes, for example, are able to detect and record wavelengths of electromagnetic radiation that we cannot see with our eyes. Figure 11.1 on the previous page shows this difference in images of the Carina Nebula.

Word Connect

"Interstellar" (from "inter" and "stellar") means "between stars." It describes material found in the regions of space between stars.

11-1A Light Beam Behaviour

Find Out ACTIVITY

Teacher Demonstration

Visible light is only a small part of the entire electromagnetic spectrum. A warm object will give off infrared radiation. When you turn on the element of an electric stove, for example, you will feel heat long before you see the element glow. This principle is used in astronomy. Astronomers search space for infrared radiation that comes from the dust heated by new stars. This means that stars can be detected even before they are hot enough to generate visible light. In this activity, you will model how interstellar gases and dust in space affect both infrared and visible light.

Materials

- television
- infrared remote control
- flashlight
- water glass or beaker
- fine powder (baby powder, alum, or cornstarch)
- water

What to Do

1. Copy the table below into your notebook, but make it large enough so that you can fill in your predictions and observations.
2. The teacher will shine first the flashlight and then the remote control at the television to illustrate a light beam that has no obstacles. Predict what will happen when the different beams travel through the materials. Record your predictions in the table.
3. The teacher will then aim both sources of light through the empty glass.
4. As the teacher shines the flashlight and the remote through each of the other materials, record your observations.

What Did You Find Out?

1. Did your predictions match your observations?
2. What material interfered with the light from the:
   (a) flashlight?
   (b) infrared remote?
3. (a) Refer to the electromagnetic spectrum in Figure 10.3. Which has a longer wavelength: infrared light or visible light?
   (b) How do you think the wavelength of infrared light might account for what you observed?
4. Why would infrared be useful for finding young stars hidden in dust but not useful for finding comets or asteroids?

Light Beam	Empty Glass		Glass with Water		Fine Powder	
	Predicted	Observed	Predicted	Observed	Predicted	Observed
Visible						
Infrared						

Figure 11.2 Stages in the formation of a star

The Birth of a Star

A star begins to form from the materials in a nebula when gravity starts acting on chunks of gas and dust, pulling them together. As gravity keeps working, the mass grows and the material collapses in on itself and contracts. An early phase of star, called a "protostar," is created. "Proto" means earliest (Figure 11.2).

If its mass stays small, the protostar may just shrink away, never reaching full star status. However, if it collects enough mass of dust and gas, the protostar's core will eventually reach about 10 000 000°C. At that point, the atoms fuse together to form larger single atoms. Hydrogen atoms combine to form the heavier element helium. This process, called nuclear **fusion**, creates an enormous amount of energy.

When this stage is reached, the star begins to glow. Leftover gas and dust that surround it gradually disperse. The energy radiates from the core in every direction in the form of electromagnetic waves. This is the way the star nearest to us, the Sun, creates radiation that keeps Earth warm.

The Evolution of Stars

Just as living things have a life cycle, stars go through predictable changes as they age. All stars start in a nebula, but the path of development each star takes differs depending on the mass of the newborn star. There are three main life paths for stars (Figure 11.3 on the next page).

Low mass stars

As the name implies, these stars start small and exist that way for most of their life as dim, cool red dwarfs. Red dwarfs burn their hydrogen fuel very slowly, which means that they may last for as long as 100 billion years. They eventually change into very hot, but small, dim white dwarfs and quietly burn out.

Intermediate mass stars

These are stars of similar mass to the Sun. Compared with their low mass cousins, they burn their hydrogen fuel faster, which means that the life of a typical "middle mass" star lasts only about 10 billion years. After a long period of stability, an intermediate mass star expands into a red giant. Gradually, it sheds much of its material into space and collapses in on itself, slowly shrinking into a small, dim white dwarf. As it cools even more, it turns into a black dwarf, a dense, dark body made up mostly of carbon and oxygen.

The Sun will expand to a red giant in about 5 billion years.

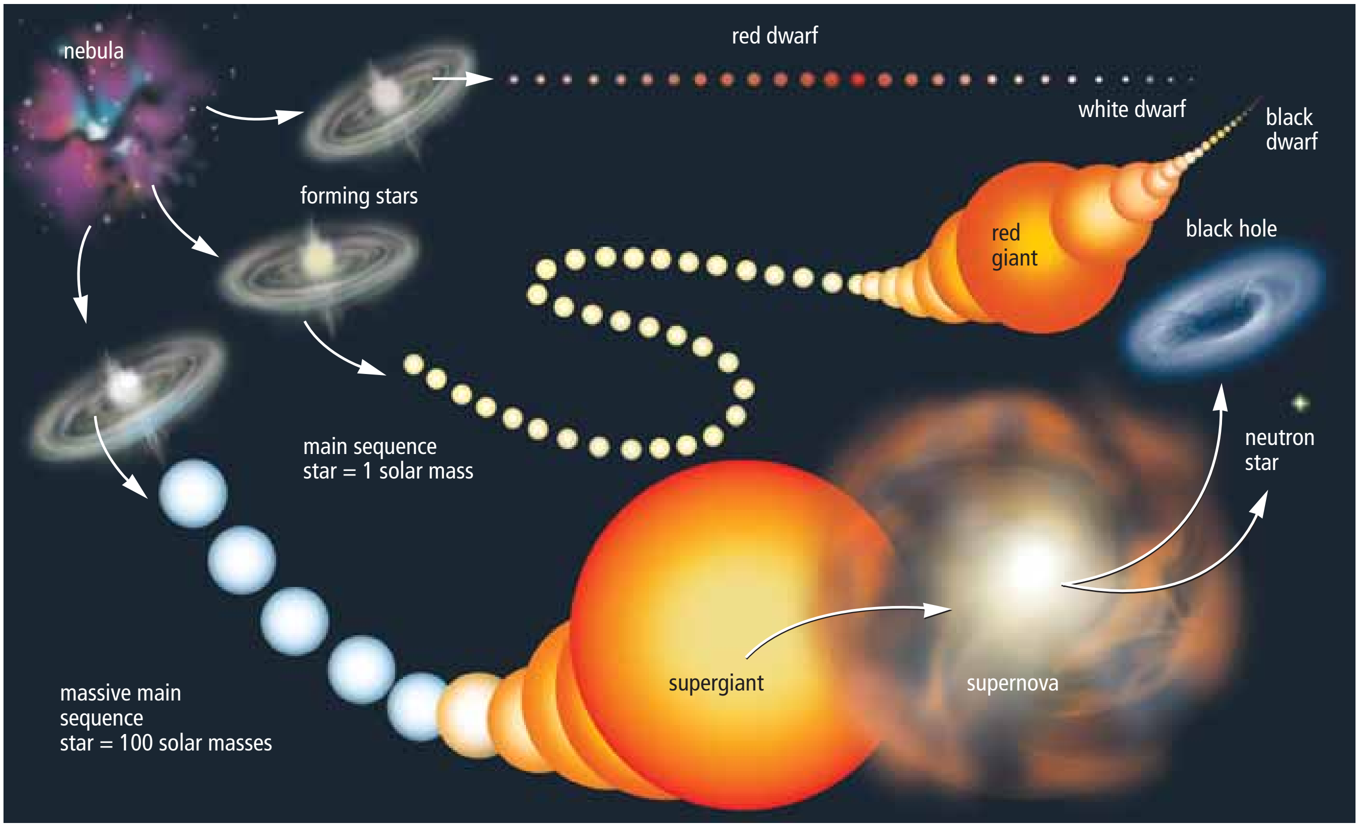


Figure 11.3 The three main life paths of stars

High mass stars

A high mass star is one that has 12 or more times the mass of the Sun. These stars consume their fuel faster than any of their smaller cousins do, becoming red giants. Because they grow rapidly and to large size, they expend much energy and burn out faster, too. The life of an average high mass star will last for only 7 billion years. In star years, that is considered a very short life.

Compared with smaller stars, high mass stars also come to a much more violent end. Massive stars that have used all their fuel become supergiants. Before long, they collapse in on themselves causing a dramatic, massive explosion called a **supernova**. Some supernovas shine so brightly that they can be seen from Earth even in daylight. Supernovas play an extremely important role in the universe. In a forest, plants die, decompose, and provide nutrients for other things to grow. In the universe, when stars die, heavy elements spread out through space. The carbon in your bones, the oxygen you breathe, and the hydrogen in the water you drink all resulted from the death of a star (Figure 11.4 on the next page).

internet connect

In 1987, a team of Canadian and Chilean astronomers reported a supernova, Supernova 1987A, that was clearly visible during the day in the southern hemisphere. To learn more about this supernova, go to **www.bcscience9.ca** and follow the links.

Figure 11.4 The elements created in stars and scattered with each supernova explosion are the building blocks of all matter in the universe, including Earth and every atom in your body.

Explore More

The mass of a typical black hole is 10 times the mass of the Sun, but black holes with a million times the mass of the Sun have been detected in the centres of extremely large galaxies, including our Milky Way. Find out more about black holes and how they affect objects around them. Begin your research at **www.bcscience9.ca**.

If the star began with a mass about 12 to 15 times that of the Sun, the remaining core of the supernova will eventually collapse back in on itself and form a neutron star. The average neutron star starts out being more than 1 million km wide but collapses into a sphere only 10 km wide. This would be like collapsing the mass of your school into the size of the head of a pin. The cores of neutron stars are thought to be as hot as 100 000 000°C and may take trillions of years to cool.

Black holes

A star more than 25 times as massive as the Sun faces a different end. After exploding as a supernova, it becomes a **black hole** and collapses into itself. Because the material is so dense, it has an extraordinary amount of gravitational pull. Black holes are called "black" because nothing, not even light, can escape their powerful gravitational force.

How do astronomers know black holes exist if they cannot see them? There are several pieces of evidence. One is that the material pulled toward the black hole emits electromagnetic radiation, and this can be measured. Another is the effect that the gravity of black holes has on passing stars and galaxies (Figure 11.5 on the next page). Third is from the results suggested by computer models that show how super-dense objects would distort light from distant stars. The computer simulations match the observations astronomers have been making.

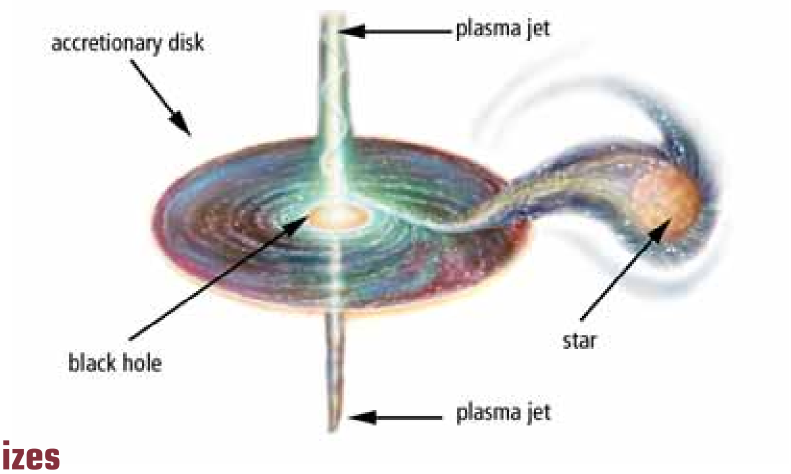


Figure 11.5 A black hole's effects on its surroundings. A star is being drawn into the black hole, and jets of material are shooting out of the centre.

Star Sizes

Many stars visible from Earth are much larger than our Sun. Some of these are shown in Figure 11.6. Imagine the Sun being the size of a volleyball, which has a diameter of about 26 cm. By comparison, the giant star Arcturus would be about 6.5 m in diameter and the red supergiant Betelgeuse would be nearly 170.0 m in diameter. The largest star discovered so far might be VY Canis Majoris. Astronomers are still debating its full size, but some observations suggest it could have a diameter 3000 times larger than that of the Sun.

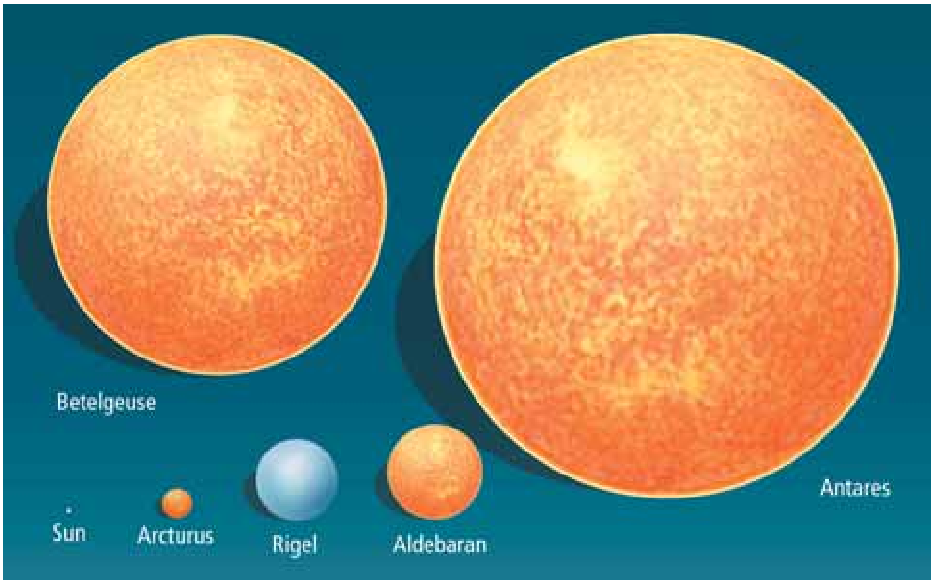


Figure 11.6 The size of the Sun compared with five other stars

Reading Check

1. What nuclear process combines two atomic nuclei to form one heavier element?
2. What are the three basic classifications of stars?
3. How is our star, the Sun, classified?
4. What is the explosion of a very large star called?
5. Why do astronomers call a black hole "black"?

The Hertzsprung-Russell Diagram

How did we come to learn that all stars have naturally progressing life cycles? Almost 100 years ago, two astronomers began studying data from large numbers of stars that were visible from Earth. Ejnar Hertzsprung in Holland and Henry Norris Russell in the United States were working independently of each other, but both came to the same conclusion: stars do not stay the same forever. Rather, they follow a clear pattern of evolutionary stages, much as humans go through clear stages of development in their lives.

The results of the two scientists' research were brought together in what is called the Hertzsprung-Russell diagram (Figure 11.7). Their plotted data showed the relationship between a star's luminosity, or brightness, and its temperature. Luminosity is the amount of energy it releases. The central band of stars on the diagram marks the "main sequence" stars. Astronomers estimate that about 90 percent of all stars are in this phase. These are the stars whose energy comes from converting hydrogen to helium. When these stars age and start to run out of hydrogen, they begin to expand and undergo changes in temperature, colour, and luminosity. Older stars are the ones no longer on the main sequence band. This change signals the final stages of a star's life.

Suggested Activity

Conduct an Investigation 11-1C on page 378

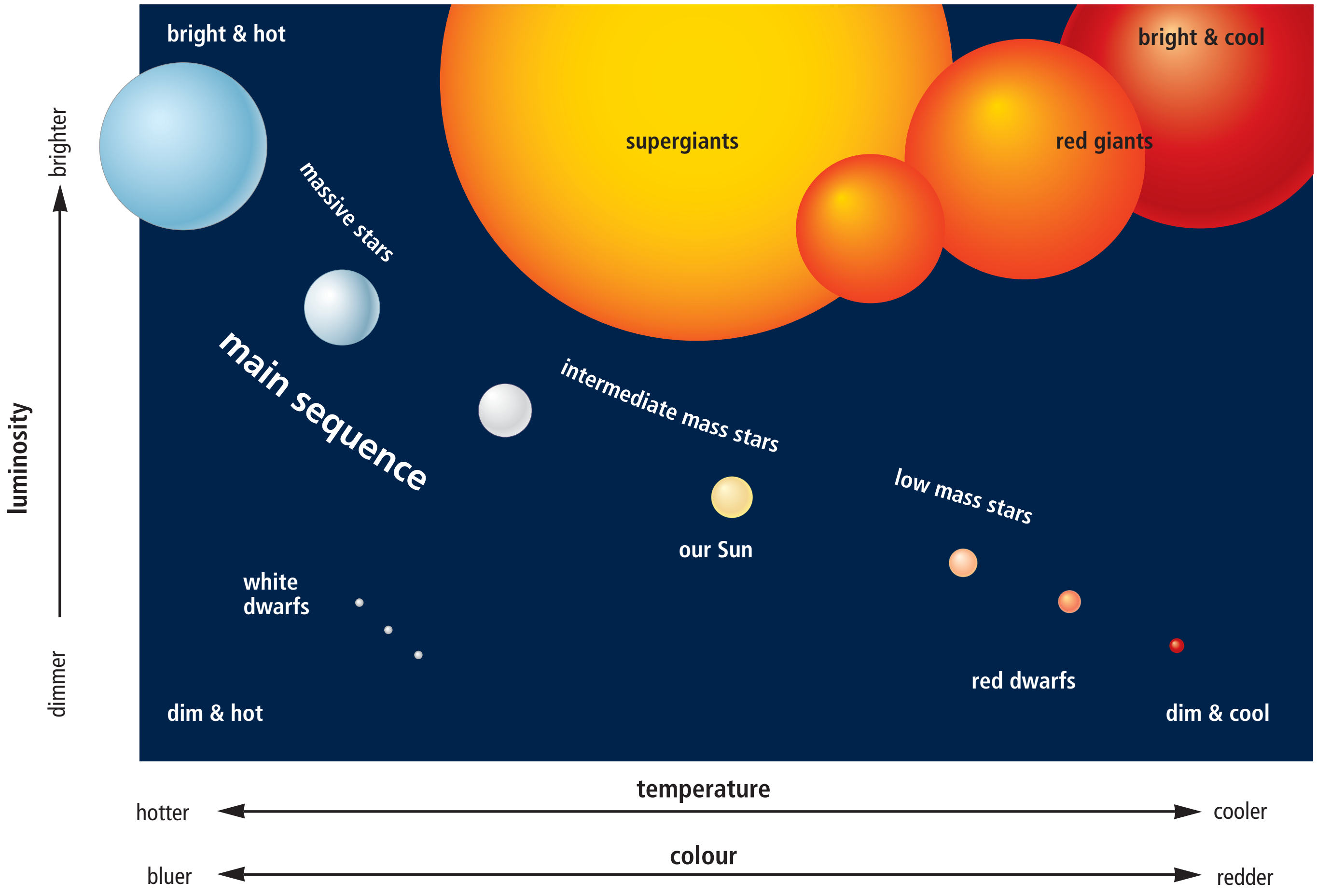


Figure 11.7 The relationships of star properties shown by the Hertzsprung-Russell diagram make this work one of the most important astronomical discoveries of the 20th century.

Analyzing Star Colour

When you look at the night sky, the stars you see usually all look like tiny specks of white light. However, if you looked at them through a powerful telescope, you would see that they really exist in a range of colours (Figure 11.8). A star's colour reveals information about the star's temperature and composition. A star's colour even reveals whether the star is moving toward or away from Earth and how fast it is moving.

Did You Know?

The Sun is made up mostly of hydrogen and helium gas, but it also contains more than 70 percent of all the elements that naturally occur on Earth. However, the Sun is not hot enough to have produced some of these other elements. Scientists believe that the Sun "inherited" some leftover material from larger, more violent stars that once occupied this area of space.

Figure 11.8 The colour of a star reveals its temperature, composition, and motion.

Colour and temperature

As you know if you watch a stove element heat up or cool down, its colour can be a key to its temperature. In a similar way, astronomers use the evidence of a star's colour to tell them what its surface temperature likely is. After much research, astronomers now know that a red star is relatively cool, averaging about 3000°C, and a yellow star is relatively hot. Our Sun, for example, is about 6000°C. Blue stars are the hottest of all, ranging from about 20 000°C to 35 000°C. If you look at the Hertzsprung-Russell diagram, you will see how this corresponds to the pattern shown there.

Colour and composition

As discussed in section 10.1, star light can be analyzed through a spectroscope. The spectral lines that appear indicate that some of the light's wavelengths have been absorbed by the particular gases in the star's composition. Hydrogen, for example, will leave a specific pattern of lines on the spectrum, just as you have left your unique fingerprints on this textbook. Mercury will leave a different "spectral line fingerprint" on the spectrum, and so will every other element. Figure 11.9 shows these patterns for hydrogen and mercury. By knowing the spectral patterns for a range of elements, astronomers can analyze any star's spectrum. This way they can determine what gases make up the star's atmosphere.

Figure 11.9 The spectral patterns that characterize hydrogen and mercury

Colour and motion

Spectroscopes can be used for more than determining a star's composition. Astronomers also use spectroscopes to analyze the star's relative movement. To understand how they do this, you first need to know about an interesting phenomenon called the Doppler effect.

As you have learned, light energy travels in waves. Think of the ripples on the surface of a pond that radiate out from the spot where you throw in a pebble (Figure 11.10A). In a similar way, light waves "ripple" out from a source such as a desk lamp or the Sun. The waves are there even though we cannot see them with our naked eye.

Imagine a duck swimming quickly on a pond. Its motion creates waves on the water's surface, but the wavelengths become compressed (shorter) in front of the duck as it swims along. Behind the duck, the waves stretch out (Figure 11.10B). This change in wavelength because of motion is called the **Doppler effect**.

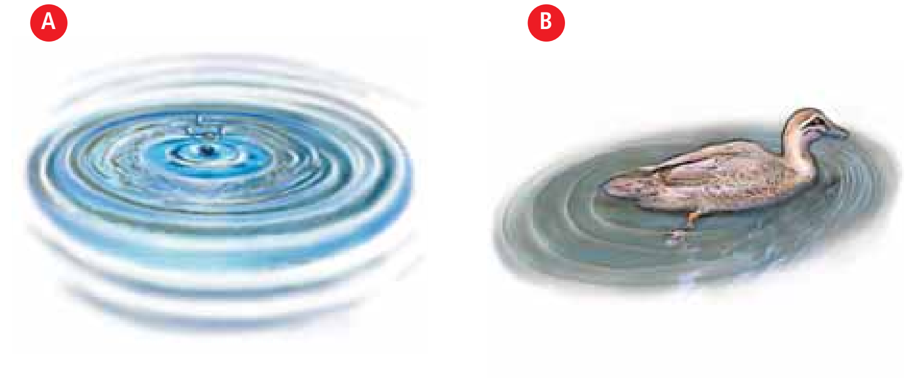


Figure 11.10 A pebble tossed into a still pond causes small waves to move out evenly in all directions (A). The wavelengths on the water change when the duck swims across the pond, becoming shorter in front of the moving duck and longer behind it (B).

Figure 11.11 The pattern of short and long waves indicates the direction that even an unseen object is moving.

Now imagine that the duck on the pond became invisible for a few minutes but continued to swim quickly. From the evidence of the wavelengths you observe, you would still be able to tell whether the duck was swimming toward you or away from you (Figure 11.11). Changes in sound wavelengths can also be detected. For example, the sound of a siren approaching you differs from the sound of a siren moving away from you (Figure 11.12 on the next page).

In section 10.1, you learned about the technique of measuring the spectral red shift of thousands of stars to determine the motion of galaxies. Astronomers use the same technique, combined with their knowledge of the Doppler effect, to analyze the pattern of light emitted by individual stars. If a star is moving, its spectrum is shifted.

The way in which the shift occurs shows whether the wavelengths are being compressed or extended. As discussed earlier and shown in Figure 10.5, if the star is moving toward Earth, the wavelengths of its light become compressed (just as the pond waves in front of the duck do as the bird swims toward you). This compression is demonstrated by the star's spectral lines shifting toward the blue end. If the star is moving away from Earth, then the light wavelengths become longer. This is demonstrated by the spectral lines in the star's spectrum shifting toward the red end. In other words, they become red-shifted.

Astronomers measure the length and frequency of a star's light waves to determine the direction the spectral shift is occurring. From this evidence, they can tell how fast a star is moving.

Figure 11.12 The sound waves between you and an approaching police car with its siren on become compressed. As the police car travels away from you, the siren's sound waves stretch out. The change in the sound's pitch indicates this change in direction.

Reading Check

1. What two star characteristics does the Hertzsprung-Russell diagram compare?
2. What is a star's spectrum?
3. What two things can the colour of a star tell astronomers?
4. Describe the Doppler effect.
5. If astronomers observe a star's spectrum shifted toward the red end, how is the star moving relative to Earth?

11-1B Detecting the Doppler Effect

Find Out ACTIVITY

In space, the Doppler effect occurs because the motion of stars changes the wavelength of light. In this activity, you will imitate the Doppler effect using sound waves instead of light waves.

Safety

- Be aware of where your partner is before you begin swinging the ball on the string.

Materials

- electronic noisemaker (with battery)
- Wiffle ball (baseball or softball size), with a small opening cut by the teacher
- masking tape
- ~ 3 m twine or strong string

What to Do

1. Put the battery into the noisemaker. Carefully insert the noisemaker into the ball and seal the opening with the tape.
2. Tie one end of the twine to the ball and tape the twine down securely.
3. Move to an open, safe area. Swing the ball above your head, holding onto the twine. Gradually let out about 2 m of twine.
4. Have a partner, who is standing a safe distance from the swinging ball, record what he or she hears as the ball moves around.
5. Trade places with your partner and repeat steps 3 and 4.

What Did You Find Out?

1. How was the sound of the approaching ball different from the sound as it was moving away?
2. Was the person swinging the ball able to hear any difference in sound? Explain.
3. How does this activity model the Doppler effect of the spectra of stars?

11-1C Classifying Stars Using the Hertzsprung-Russell Diagram

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Graphing
- Classifying
- Evaluating information
- Communicating

Materials

- pencil
- Hertzsprung-Russell diagram
- graph paper

In this activity, you will follow the model of the Hertzsprung-Russell diagram and plot on a graph the luminosity and temperature of a group of stars. You will then analyze this information to determine the size and classification of each star.

Question

How are stars classified?

Procedure

Part 1 Plotting Luminosity against Temperature

1. The data table below shows the luminosity and temperature of a variety of stars. Read the table to review the data.
2. Plot the luminosity versus temperature for each star on the graph paper provided by your teacher. Pay attention to the numbering of the axes. This graph is not like a typical graph. Do not connect the dots with lines.

Star	Temperature (degrees kelvin)	Luminosity (Sun = 1)	Star	Temperature (degrees kelvin)	Luminosity (Sun = 1)
Altair	8 000	11	Delta Minor	20 000	100
Deneb	9 900	60 000	Alpha Centauri C	2 700	0.0001
Canopus	7 400	1 500	Achernar	14 000	4 000
02 Eridani B	11 000	0.003	Sirius	10 000	23
Antares	3 500	65 000	Betelgeuse	3 600	55 000
Sun	5 800	1	Arcturus	4 500	110

Part 2 Classifying Stars

3. After you have plotted all the stars on the graph, compare the patterns with the Hertzsprung-Russell diagram in the textbook (Figure 11.7 on page 37).
4. Make a two-column table in your notebook. Write the star names in the left column and the size classification (that is, dwarf, main sequence, or giant) in the right column.

Science Skills

Go to Science Skill 5 for information about how to organize and communicate scientific results with graphs.

Analyze

1. How is the *x*-axis on this graph different from that on typical graphs?
2. (a) How is the *y*-axis different from graphs you are used to?
   (b) Why do you think the units on this *y*-axis were used?
3. Describe any problems you found with achieving accuracy when plotting your points.

Conclude and Apply

1. (a) Where on the graph is the Sun located?
   (b) What does this suggest about the size of the Sun relative to other stars?
2. Write a general statement relating temperature to luminosity for:
   (a) supergiants (b) white dwarfs

11-1D Spying Spectra

Find Out ACTIVITY

Many characteristics of a star are revealed in the light it produces. Temperature, composition, age, and direction of travel are contained in a star's spectrum. In this activity, you will observe how different sources of light and gas produce different spectra.

Safety

- NEVER look directly at the Sun.

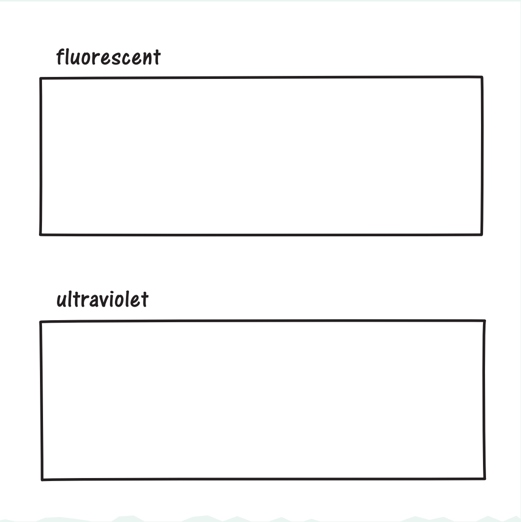
Materials

- spectroscope
- four different light sources (for example, Sun, fluorescent, incandescent, ultraviolet, energy-saver lamp, frosted light, holiday lights)
- gas discharge tubes (for example, mercury, xenon, hydrogen, sodium)
- paper
- pencil
- ruler
- pencil crayons

What to Do

Part 1 Analyzing Light Spectra

1. On a piece of paper, draw four rectangles as shown below. Make one rectangle for each of the four light sources you plan to observe, and label the rectangles with the name of the source.



2. Carefully look at each light source, one at a time, through the spectroscope. With the pencil crayons, colour the spectrum you observe for each light source in the appropriate rectangle.
3. Experiment with viewing the light sources through the spectroscope at different angles. Record what you observe.

Part 2 Analyzing Gas Spectra

4. On a second piece of paper, draw a series of rectangles as you did in step 1 of Part 1. Label them with the names of the specific gas discharge tubes selected by your teacher.
5. With the teacher's assistance, observe each of the elements in the gas discharge tubes. Use the pencil crayons to colour the spectrum for each gas.

What Did You Find Out?

Part 1 Analyzing Light Spectra

1. Where do you see the spectra in the spectroscope?
2. In which order do the colours appear?
3. How did changing the angle of the spectroscope affect the appearance of the spectra?

Part 2 Analyzing Gas Spectra

4. How were the spectra from the gas discharge tubes different from the spectra of the light sources in Part 1?
5. How would knowing the spectra for specific elements help astronomers determine the composition of stars?

Radio Astronomer

Collapsing stars. Supernova explosions. Magnetic fields. These are a few of the topics that Dr. Ingrid Stairs, an assistant professor at the University of British Columbia, studies as part of her research on neutron stars. Dr. Stairs teaches courses for both undergraduate and graduate students and conducts research as a radio astronomer.

Dr. Ingrid Stairs

Q. What do you research?

A. I study a type of dead star called neutron stars, which are the leftover cores of high mass stars. Such a massive star ends its life in a big supernova explosion. Its central core collapses down to something about the size of a city (10 km in radius) that contains one and a half times the mass of our Sun. This is as dense as matter can get before it collapses into a black hole. Many of these neutron stars become spinning "radio pulsars." These have strong magnetic fields and give off radio beams from their magnetic poles. The spinning star acts like a lighthouse. If the telescope is pointing in the right direction, we can detect a blip of radio waves every time the star spins.

Q. What type of instruments do you use?

A. I use radio telescopes to observe and record these blips. The data from these telescopes allow us to study the stars, our galaxy, and the properties of binary systems. Binary systems are systems where two stars orbit each other. The three main telescopes I use are the 100 m Green Bank telescope in West Virginia (shown in the photograph here), the 300 m Arecibo telescope in Puerto Rico, and the 64 m Parkes telescope in Australia. Travelling to the telescopes is exciting. I travel to each locale about once every 12 to 18 months but do the rest of my observing from my computer here in Vancouver. I log in to the telescope, program it to point where I want it to go, and then start the data collection.

Q. What is exciting about binary systems with neutron stars?

A. For one thing, studying binary systems provides information about how the stars evolve and interact with each other. Also, my collaborators and I are researching the only known binary system in which both stars are radio pulsars. The system has a 2.5 hour orbit (compared with Earth's year-long orbit). Einstein's theory of relativity predicts that the orbit should change in very particular ways over the course of a few years, and we have been able to show that the system is behaving exactly as predicted by the theory. It is fascinating to me that I can use the same sets of observations to study so many different problems.

Q. What training do you need to become an astronomer?

A. You need to complete a university undergraduate degree in astronomy or physics. If you want to do research, you should get your PhD as well. But it is never too early to satisfy your curiosity: ask questions, visit planetariums, and attend open houses at observatories. Take advantage of the opportunities to use local telescopes.

Questions

1. Name the three radio telescopes Dr. Stairs uses, from smallest to largest.
2. What is a radio pulsar?
3. What is unique about the binary system Dr. Stairs is studying?

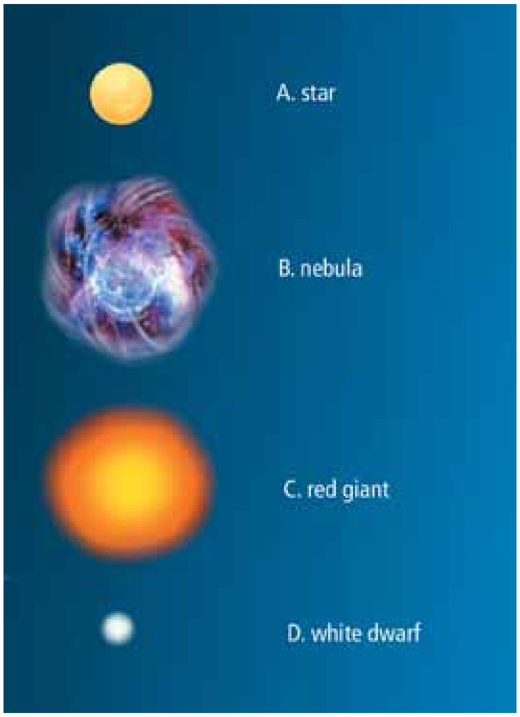
Check Your Understanding

Checking Concepts

1. What makes up most of interstellar matter?
2. Briefly explain how a star forms.
3. Is our Sun a low mass, intermediate mass, or high mass star?
4. Describe a supernova.
5. How does a black hole form?
6. What is a star's spectrum?
7. Explain the Doppler effect.

Understanding Key Ideas

8. (a) Describe the process of fusion in a star.
   (b) What else is produced from a fusion reaction?
9. Why do black holes have such extraordinary gravitational pull?
10. What will eventually happen to all the stars in the universe?
11. Place the following in order from youngest to oldest.



12. (a) Using the Hertzsprung-Russell diagram for guidance, describe the temperature-luminosity relationship for each of the following types of stars.
    (i) white dwarfs
    (ii) red giants
    (iii) supergiants
    (b) Why is it more difficult to describe the position of a main sequence star than the ones above on the Hertzsprung-Russell diagram?
13. How is the colour of a star related to its temperature?
14. How is the colour of a star related to its luminosity (brightness)?

Pause and Reflect

In this section, a duck swimming in a pond was used to illustrate the way wavelengths can be affected by motion. The Doppler effect describes the shortening of wavelengths as stars move toward Earth and the lengthening of them as stars move away from Earth. In a few short sentences, describe other examples of the Doppler effect here on Earth.