Now, imagine yourself standing on the shore, watching the duck. If the duck swims toward you, the ripples in front of it are squeezed together and therefore have shorter wavelengths (**Figure 3**). Meanwhile, the waves behind the duck are spread farther apart and so have longer wavelengths. Even if you could not see the duck itself, you could observe from the changing wavelengths which way the duck was moving. Shorter wavelengths indicate that the duck is moving toward you; longer wavelengths indicate that the duck is moving away from you. Of course you have to know what the wavelengths would be if the energy source were stationary, relative to you.

When astronomers look at a distant source of light, such as a galaxy, through a spectroscope, they recognize the *pattern* of the spectrum but observe that the *colours* of its lines are not the same as they would expect. The lines are moved toward the red end of the spectrum (**Figure 4**) meaning that they have a longer wavelength. Searching for an explanation, astronomers concluded that the light has a longer wavelength than normal because the galaxy is moving away from us. This movement, or shift, into the red end of the spectrum is called **red shift**.

The light energy from all distant galaxies shows red shift. However, there are different amounts of red shift. The greatest shifts occur for galaxies that are farthest away from us. From this information, we can infer that all galaxies are moving away from us and away from each other. But what is causing this movement? Why is the universe expanding? Astronomers are investigating the answers to these questions.

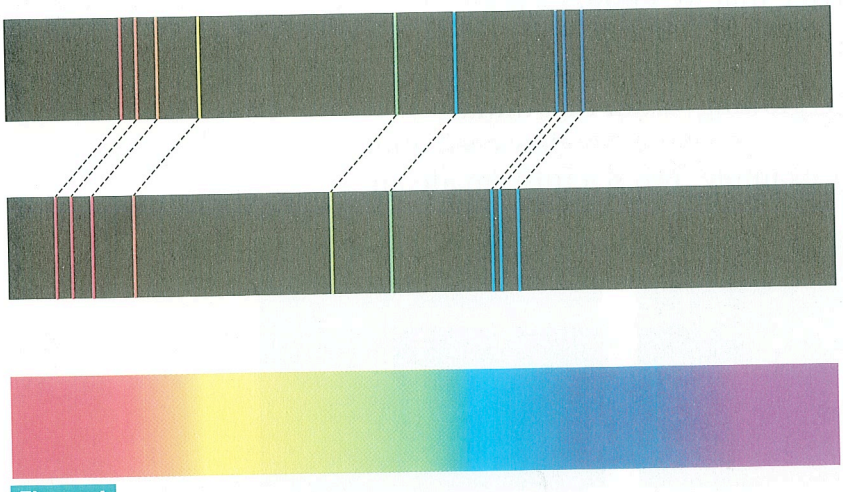

Figure 4

The top diagram represents the nine lines of a spectrum emitted by a stationary galaxy. The second diagram represents the same nine lines of the same spectrum emitted by the galaxy if it were moving away from us rapidly. The wavelengths of all the lines in the spectrum have shifted (moved) toward the red end. The bottom white light spectrum is shown for reference.

Understanding Concepts

1. Copy **Figure 5** into your notebook. It is a pattern of ripples. Label the ripples that have shorter wavelengths and those that have longer wavelengths. Indicate the direction of movement of the "object" causing the waves. Explain your answer.

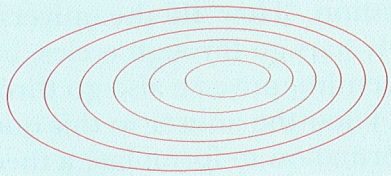

Figure 5

2. What does "red shift" mean?
3. What evidence do astronomers have that the universe is expanding?
4. If astronomers were to observe a "violet shift" for a certain star, what could they infer? Explain why.
5. If the duck in **Figure 3a** were travelling from the top of the diagram toward the bottom, what would you observe? Draw a diagram and explain why.

Exploring

6. How could you use water in a flat container and a bobbing finger to illustrate changes in wavelength as the source of the waves moves?
7. The scientific name for the cause of red shift is the "Doppler effect." Research this effect and relate it to what you have learned about red shift. (The Doppler effect relates to all types of waves, including sound waves. For now, focus on light waves.)

15.5

The Origin of the Universe

Do you enjoy solving mysteries or putting the pieces of a puzzle together? If so, perhaps a career in astronomy is ideal for you! One of the main goals of many astronomers is to solve the mystery of the origin of the universe. These astronomers search for an answer to the question, "How did the universe begin?"

If stars go through cycles, beginning and ending as nebulas, does the entire universe also go through some type of cycle? Scientists do not know the answer to this question, but they have gathered enough information to formulate a theory. This theory is based on evidence that the size of the universe is not constant but is expanding. This is the accepted theory, but it may be modified as more evidence is collected and analyzed.

The study of the origin and changes of the universe is called **cosmology**.

The Big Bang Theory

If the galaxies are moving apart, then presumably they used to be closer together. Still earlier, they must have been even closer together. Continue to move backward in time in your imagination and you will reach what we call "time zero." Scientists estimate time zero as being between 10 and 15 billion years ago. At that time, all the matter of the entire universe was packed together into one small, extremely dense, hot mass under enormous pressure. The event that occurred when the universe emerged from this state of enormous density and temperature is known as the Big Bang (**Figure 1**). Scientists use the **Big Bang theory** to describe the beginning of the universe that we know.

Scientists have more than just the red shift of distant galaxies as evidence of the Big Bang. They have also collected data that suggest that, even today, the entire universe is "glowing" from that initial explosive event, just as a piece of firewood continues to glow even after the fire has been put out. In 1965, for example, two scientists made an

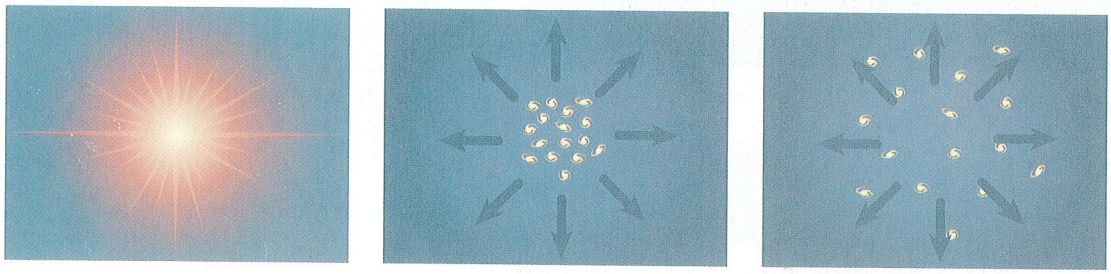

Figure 1

These diagrams illustrate the Big Bang theory of the formation of the universe. The density of the material that made up the universe shortly after the Big Bang was immense. One cubic centimetre of the material is estimated to have had a mass of one billion kilograms!

accidental discovery using a radio telescope. They detected unexpected radiation coming from all directions in space. After checking that there were no defects in their equipment, they concluded that this faint, unknown energy is all that remains of the enormous amount of energy that exploded outwards at the time of the Big Bang. The intense radiation from the tremendous explosion has faded to only a faint "whisper" after travelling for thousands of millions of years through space.

The Big Bang theory can be used to explain our observation that the universe is expanding. But we still don't know everything about how the universe began. For example, while scientists can describe what they think occurred a fraction of a second after the Big Bang, they do not know what the universe was like (or even if it existed) just before the Big Bang explosion. Changing our theories about the universe is a continuing scientific process as we try to explain the new discoveries that astronomers make year after year (**Figure 2**).

However, the Big Bang theory is not the only way that the origin of the universe has been explained. In the past, many cultures have held different beliefs of their own. These beliefs, however, are not the same as scientific theories—they cannot be tested, explored, and either supported or disproved by evidence. But each is a kind of model that helps people understand how the world works.

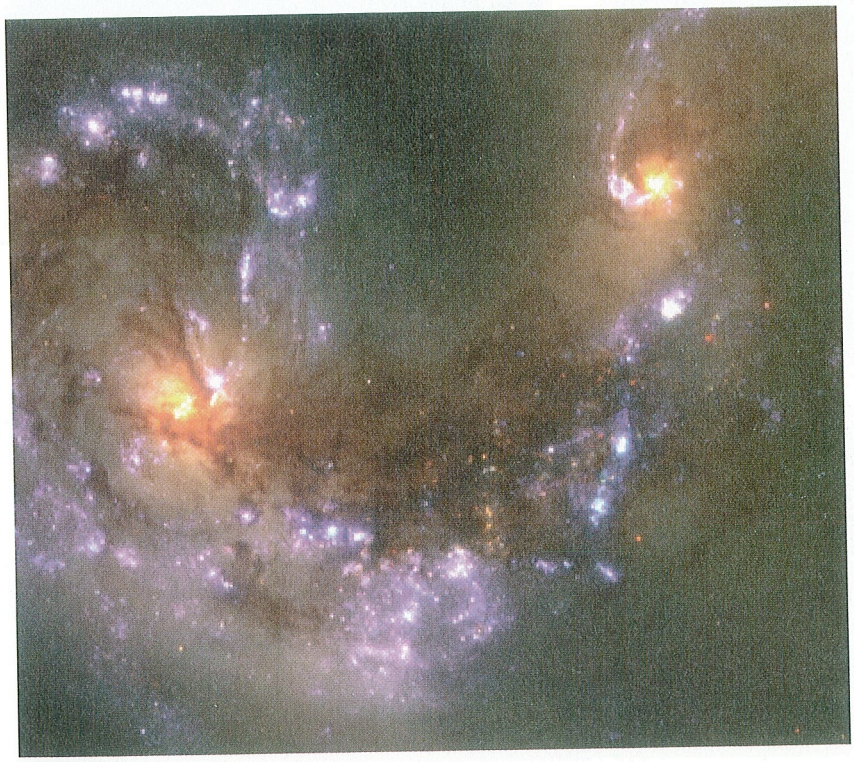

Figure 2
The Antennae galaxies are a pair of galaxies whose collision has resulted in a firestorm of star birth activity. It is proving to be an excellent "laboratory" for studying the formation of stars and star clusters.

Understanding Concepts

1. How does the Big Bang theory explain an expanding universe?
2. How does the development of the Big Bang theory illustrate the scientific process?
3. How could you use all the students in your class to act out a model of the expanding universe shortly after the Big Bang?

Exploring

4. Older theories about the universe include the oscillating theory and the steady state theory. Find out about these theories, then write an article for a science magazine describing one of them. Draw illustrations representing the theories to go with your article.
5. People in all parts of the world have had, and still do have, other ideas about the origin of the universe. Research and compare at least two contrasting cultural views. Present your findings in a creative way.

Reflecting

6. How does a scientific theory, such as the Big Bang theory, differ from a belief?

Challenge

The Big Bang theory is a difficult idea to conceptualize. What model or diagrams will you use to explain it to the general public?

15.6 Case Study

The Hubble Deep Field

Figure 1 shows one of the most amazing images ever taken of outer space. It is called the *Hubble Deep Field.* When you look at it, you are peering back in time up to 8 billion years, into a part of the sky that appears no bigger than a grain of sand resting on a fingernail of your outstretched hand! Although this picture only shows you a tiny piece of the sky, it contains a lot of information. The only stars in the photograph are the objects that appear to have spikes. (This feature results from the wave nature of light.) All the other objects are galaxies.

Figure 1

This image was captured by the Hubble Space Telescope when it was aimed toward a part of the sky above the Northern Hemisphere.

(a) What can you infer about the number of galaxies in the universe? (In your answer, be sure to consider the concept of the "grain of sand" mentioned above.)

(b) Which types of galaxies can you see?

The image in Figure 1 was obtained by the Hubble Space Telescope over a period of about 100 h. It is similar to a time-lapse photo that might be taken here on Earth.

(c) Why is time-lapse imaging important when viewing faraway galaxies?

The "optical" portion of the Hubble Space Telescope includes a very large mirror, specially engineered with great precision. Unfortunately, there was an error in the manufacturing that was not detected until the telescope was launched: the curvature of the mirror was out by the thickness of a human hair, so it could not focus as well as had been hoped. Fortunately, astronauts were able to correct the problem in 1993 by adding a secondary mirror during a series of space walks. It was a delicate but successful operation. Other instruments have since been added to Hubble, improving its performance still further.

(d) Why are more instruments added to the Hubble Space Telescope, instead of being put into orbit separately? What might be the advantages of each alternative?

Advanced technology is needed to keep a telescope, travelling at almost 30 000 km/h while orbiting Earth, aimed steadily at one tiny spot for such a long time.

(e) Why wouldn't the telescope naturally stay pointed in the same direction? Make some predictions.

This image sees deeper into space than any previous image. That is why it is called the "Hubble Deep Field." The farthest objects, which are galaxies, are up to 8 billion light-years away. Galaxies 8 billion years ago had less structured shapes than galaxies now appear to have. This feature helps support the Big Bang theory.

(f) Explain how the less structured shape of early galaxies supports the Big Bang theory.

Astronomers observe evidence of several galaxies colliding with each other shortly after the Big Bang.

(g) Propose a reason why galaxies in the past were more likely to collide than they are now.

Studying such images in more detail will help scientists better predict what might happen to the universe in the future.

(h) If you were a scientist studying images like this, what would you look for? Why?

Understanding Concepts

1. How was the universe different 8 billion years ago than it is now?
2. Explain how this image allows scientists to "peer back in time."

Exploring

3. If you were responsible for aiming the Hubble Space Telescope to take a new Deep Field image, in which direction would you aim it? Give reasons.
4. Research the problems with Hubble's mirror and how they were corrected. Draw a labelled diagram to explain the repairs.
5. Research the costs involved with the Hubble (3A) Space Telescope. Do you think it is a good use for the money? Explain reasons for your opinion in a brief letter to a science magazine.
6. Find out what other Deep Field images have been taken. View the images on a NASA web site.

15.7

How Astronomers Use Computers

When you imagine an astronomer at work, you probably think of someone gazing up at the sky or perhaps peering through a telescope. Actually, today's astronomers spend most of their time in front of computers. The computers analyze the vast amounts of data that are collected by various instruments and reorganize the information into forms that help the astronomer pick out what is important (**Figure 1**). Without computers, most research in astronomy would be slowed down because we would not be able to analyze information as fast as we are collecting it. Computer technology has made a large contribution to the extensive knowledge and understanding we now have of Earth and its place in the universe.

Figure 1
This is a false-colour image generated by computer using the image from a telescope. It shows Eta Carinae—a dying star.

For example, an astronomer can study the glowing image of an exploding star on a computer screen. The computer created the image from data gathered by a series of radio telescopes. The information is stored in the computer, which creates a radio-wave "picture" of the exploding star—what you would see if you had eyes that could see radio waves. Images like this give astronomers a new view of the universe. The astronomer may use the computer to display the image in different ways to show certain features more clearly and to take measurements and make comparisons with previous data.

Computers are also essential in the radio search for extraterrestrial life. Only by using computers can scientists listen to all parts of space, at many different radio frequencies, for long periods of time. Scientists hope to detect radio signals that unknown beings might have sent from other parts of the universe.

The Hubble Space Telescope (**Figure 2**) is constantly sending computerized images of space to Earth. Astronomers can display these images on their computer screens, explore certain features, and make calculations. They can also store the data, keeping it on hand for easy retrieval, should it be needed again.

As well as helping astronomers analyze, display, and store data, computers are used to control the operation of astronomical instruments. Imagine the problem of focusing on a galaxy when your telescope is moving along with Earth as it rotates. In the past, astronomers had to constantly turn their telescopes in the opposite direction to Earth's rotation. Now, computers do all the calculations and control the movement of the instruments.

Simulations are another important use of computers. Scientists may apply known equations to simulate conditions deep within the Sun or test models of the formation of the universe. Simulations can help

Did You Know

Earth may be the only planet in our solar system with the right conditions to support life. But does life exist only on this one planet in the entire universe? Scientists look at many factors when trying to determine if a planet can support life. In one ongoing investigation, a radio telescope scans the sky 24 h a day. It is linked to computers that sift through all the incoming radio signals in a search for signs of intelligent civilizations. So far, no signals have been observed, but research continues. This kind of search is called SETI, which stands for Search for ExtraTerrestrial Intelligence.

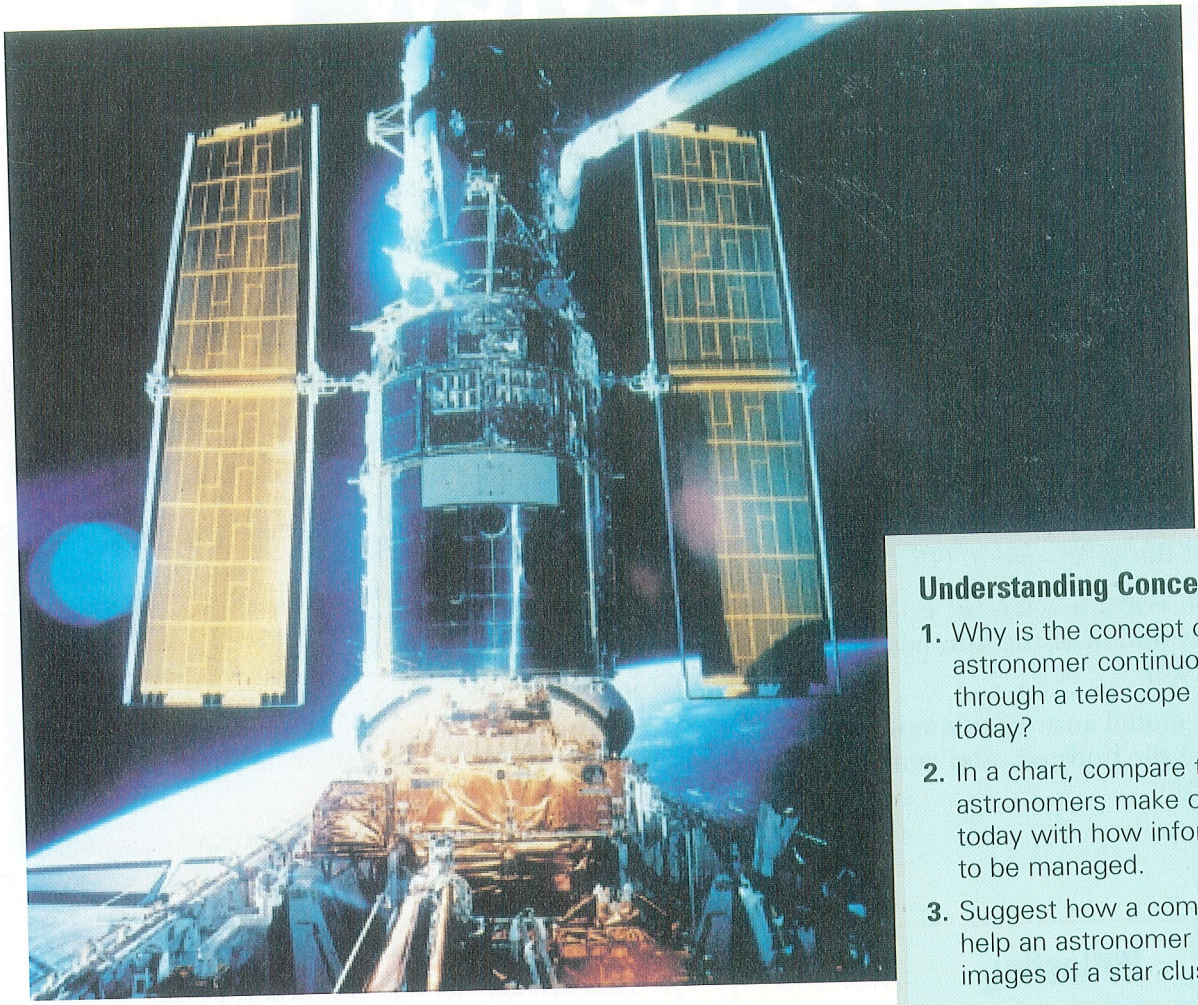

Figure 2
This view of the Hubble Space Telescope shows the solar panels that change light energy into electrical energy. Earth is seen in the background.

people learn about the universe and our own fragile and beautiful planet as it travels in one tiny corner of a galaxy that contains about 400 billion stars.

Computers record large amounts of data, analyze them, create pictures, do mathematical calculations, and operate complicated astronomical instruments. They help to bring the past into the present. But to some astronomers, the most exciting thing computers do is electronically link scientists all over the world. Through their computer networks, astronomers can share ideas, data, calculations, computer images, and the latest scientific information.

Understanding Concepts

1. Why is the concept of an astronomer continuously peering through a telescope not valid today?
2. In a chart, compare three uses astronomers make of computers today with how information used to be managed.
3. Suggest how a computer could help an astronomer analyze images of a star cluster.

Making Connections

4. How can computers help in time-lapse imaging of components of the sky? How do these images enhance our understanding of the history of the universe?

Exploring

5. List concepts in the study of astronomy that you think you could understand better if you could watch computer simulations of the concepts. If a simulation program is available, try it out and evaluate its benefits.

Challenge

How can you use your computer as a tool to help you in the challenge you have chosen?

Chapter 15 Review

Key Expectations

Throughout the chapter, you have had opportunities to do the following things:

- Outline the current theory explaining the origin, evolution, and fate of the Sun and other stars. (15.1)
- Describe these components of the universe: nebulas; supernovas; neutron stars; black holes. (15.1)
- Outline the current theory explaining the formation of the solar system. (15.2)
- Describe and evaluate scientific evidence of origin and evolution of the universe. (15.1, 15.4, 15.5, 15.6)
- Plan ways to model answers to questions about the history of the universe, and communicate results. (15.3)
- Formulate and research questions related to the history of the universe, and communicate results. (all sections)
- Describe how computers are used to enhance our understanding of the universe. (15.7)
- Identify contributions of Canadian scientists to the exploration of the universe. (15.1)
- Explore careers related to the exploration of space. (Career Profile)

KEY TERMS

Big Bang theory
black hole
cosmology
gravity
nebula
neutron star
planetary system
pulsar
red giant
red shift
red supergiant
supernova
white dwarf

Reflecting

- "Scientists use models and simulations to visualize and explain the dynamic processes that form the universe." Reflect on this idea. How does it connect with what you've done in this chapter? (To review, check the sections indicated above.)
- Revise your answers to the questions raised in Getting Started. How has your thinking changed?
- What new questions do you have? How will you answer them?

Understanding Concepts

1. Make a concept map to summarize the material that you have studied in this chapter. Start with the words "Big Bang."
2. (a) Arrange the following stages of the life of a star in the order in which they occur: black hole; supernova; nebula; red supergiant.
   (b) Is there more than one possible answer in (a)? Explain.
   (c) Which type of star would go through these stages?
3. (a) What is a nebula?
   (b) How are nebulas important to the formation of stars and planets?
4. What process causes stars to reach "old age"?
5. What force leads to the formation of planets?
6. Why are white dwarf stars much more common than black holes in the universe?
7. Describe the relationship between a red giant and a white dwarf.
8. The following is a list of stages in the lives of stars: white dwarf, supernova, red giant, neutron star, black hole.
   (a) Which of these stages, if any, will the Sun pass through in the future?
   (b) Explain why the Sun will not pass through the other stages.
9. (a) Since the invention of the telescope, how many supernovas have been observed with the unaided eye?
   (b) How do astronomers benefit from studying supernovas?
10. Describe the Big Bang theory.

11. Why is it difficult to observe planets in orbit around distant stars?

12. Describe the current theory of the formation of the planets of our solar system. Illustrate your answer with drawings.

13. (a) What is red shift?
    (b) How does red shift provide evidence for the Big Bang?

14. What evidence besides red shift supports the Big Bang theory?

15. As scientists continue to observe the spectra of stars and galaxies, what do you think they would conclude if they observed the following?
    (a) Red shift continued.
    (b) Red shift was no longer observed for any star or galaxy.
    (c) A shift was observed toward the violet end of the spectrum.

16. State, with reasons, whether you agree with this statement: "Nebulas provide a good example of recycling in the universe."

Applying Skills

17. If you look at photographs of the Moon, Mercury, Mars, and the moons of other planets, you will see evidence of collisions.
    (a) What is this evidence?
    (b) How does this evidence support the theory of the formation of the solar system?
    (c) What evidence of collisions on Earth supports the theory?

18. Describe examples in this chapter of indirect evidence used by astronomers.

19. Make a physical model or a computer model to illustrate one of the concepts covered in this chapter, such as the life of a star, or the expanding universe.

20. The discovery of red shift supports the theory of an expanding universe. However, it is indirect evidence, not proof, that galaxies are moving away from each other. What other interpretations could there be of red shift?

21. Write at least five questions about the universe that you would like more complete answers to.

22. Choose one of the questions from your list in 21. Describe how you would go about finding the answer(s) to that question.

23. Research the most recent ideas about black holes and prepare a presentation.

24. The light from two distant galaxies, A and B, is examined through a spectroscope. The two line spectra have a similar pattern of lines, but the lines of Galaxy A's spectrum have slightly longer wavelengths than those of Galaxy B.
    (a) Draw what their two spectra might look like.
    (b) What might you conclude about the motions of the two galaxies, relative to Earth?

25. The star probe *Stardust* was launched in 1999 to collect dust from the tail of comet Wild-2. Research the purpose and current status of this mission.

Making Connections

26. Design a visual image that could be attached to a space probe leaving the solar system. The image should communicate information about ourselves and our planet to intelligent aliens discovering the probe. Remember, they would not be able to read our written communications! Research plaques that have been attached to probes that have already been launched.

27. Assume you have unlimited funds to carry out investigations to test one of the theories presented in this chapter. Which theory would you test? How would you test it? Predict your results.

28. Some radio telescopes are used to try to detect intelligent life that may exist on planets revolving around other stars in the universe. What other methods could you suggest for trying to find evidence of intelligent life beyond Earth (extraterrestrial intelligence)? Explain your answer.

29. Do you expect computers will be more or less important in the study of astronomy in the future? Why?

CHAPTER

16 Space Research and Exploration

Getting Started

1 This is what the *International Space Station (ISS)* will look like when it is completed. The *ISS* will be the biggest technological project ever built. It involves the cooperation of many different countries, including Canada. What is Canada's role in the *ISS*? What would it be like to work up in space? *ISS* is a kind of satellite. What is the purpose of other satellites?