3 Canadian astronomers join other astronomers in the search for answers to questions about the universe. Did the universe have a beginning? If so, when was it? What evidence do we have that supports theories of the origin, growth, and future of the universe? If astronomers are unable to find direct evidence to support their hypotheses, how could they use indirect evidence?

Reflecting

Think about the questions in 1, 2, 3. What ideas do you already have? What other questions do you have about the history of the universe? Think about your answers and questions as you read the chapter.

Try This: Using Indirect Evidence

Many scientists, from space scientists to chemists, are sometimes unable to make direct measurements or collect direct evidence for their investigations. Instead they use many kinds of indirect evidence. You have already used an indirect method to measure distances that you could not measure directly. Now you can discover features of something you can't see by gathering indirect evidence.

1. At a station set up by your teacher, a flat, horizontal board hides something from your direct view. Observe carefully as one student at a time rolls a small steel ball along the surface of the board.
2. Continue observing until you are satisfied that you can describe what is hidden.
3. Draw a diagram of what you think is hidden beneath the board.
4. What is "indirect evidence"?

15.1

The Life of a Star

We say that stars have a "life" because they evolve from clouds of gas and dust and follow a predictable series of stages: they begin (are "born"), develop, and end ("die"). Each life may take billions of years or more, a length of time that is difficult for humans to imagine.

Using modern instruments and looking at stars billions of light-years away, astronomers have been able to examine millions of stars at different stages in their lives. Scientists have put together many pieces of information, like the pieces of a puzzle, to develop a theory of the life of a star.

One of the first pieces of information came in 1678 with Isaac Newton's discovery of **gravity**. We now know that gravity is a force that pulls objects toward each other. The more mass an object has, the more gravity it exerts, so the Sun has stronger gravity than Earth. But the force gets smaller as the distance between objects increases.

All stars begin their lives in **nebulas**, which are huge clouds of dust and gases, mainly hydrogen and helium (**Figure 1**). The dust and gases swirl around, breaking into clumps and contracting because of gravitational forces. As the clumps bump into each other and get bigger, their gravity gets stronger, and they are able to attract more particles and pack more tightly together. Eventually, the clumps are dense and hot enough for nuclear fusion to start. They have become new stars.

Just as no two clouds on Earth are identical, no two stars are identical. Although scientists understand the stages of stars fairly well (**Figure 2**), our knowledge of the details is far from complete. That is part of the excitement of studying astronomy. All these ideas are theories that are undergoing confirmation, development, or change based on further observations and evidence.

Figure 1

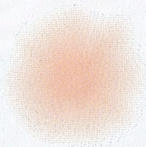
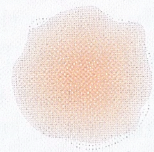
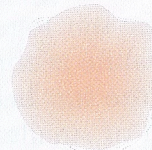
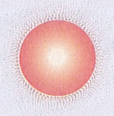
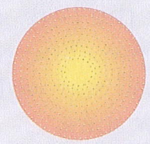
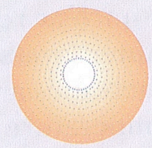
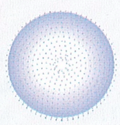
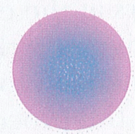
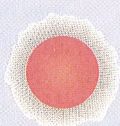
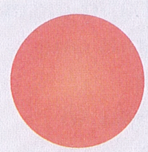
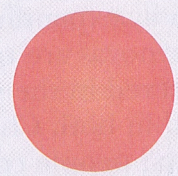
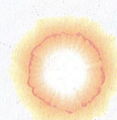
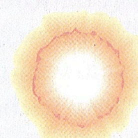
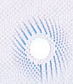
The Trifid Nebula has two separate regions. The pink region has a high concentration of hydrogen, and the bluish-violet region is reflecting light from nearby stars. The dark patches are caused by dust clouds located between the nebula and Earth.

Try This — Graphing Gravity

What factors affect the force of gravity between two objects? Make a prediction. The equation for two objects interacting is $F = (Gm_1m_2)/d^2$, where F is the force in newtons (N), G is a constant (6.67×10^{-11} Nm^2/kg^2), m_1 is the mass of object 1, m_2 is the mass of object 2, and d is the distance between the centres of the objects.

1. Find the masses and radii of the planets in our solar system and calculate the force of gravity on a 1.0-kg rock at the surface of each one.
2. Determine the force of gravity on the rock when its distance from the centre of Earth is 2, 4, 6, and 8 Earth radii. Plot a graph to show your discoveries.
3. How accurate was your prediction?

Figure 2 **The Life of Different Types of Stars**

Type of Star	Small or Medium Star (mass the same as the Sun's or less; the most common type of star)	Large Star (mass about 10 times the mass of the Sun; rare)	Extremely Large Star (mass about 30 times the mass of the Sun; very rare)
Birth	 Forms from a small- or medium-sized nebula.	 Forms from a large nebula.	 Forms from an extremely large nebula.
Early Life	 Gradually turns into a hot, dense clump that begins producing energy.	 In a fairly short time turns into a hot, dense clump that produces large amounts of energy.	 In a very short time turns into a hot, dense clump that produces very large amounts of energy.
Major Part of Life	 Uses nuclear fusion to produce energy for about 10 billion years if the mass is the same as the Sun's, or 100 billion years or more if the mass is less than the Sun's.	 Uses nuclear fusion to produce energy for only a few million years. It is perhaps 5000 times as bright as our Sun.	 Uses nuclear fusion to produce energy for only about one million years. It is extremely bright.
Old Age	 Uses up hydrogen and other fuels, and swells up into a large, cool red giant.	 Uses up hydrogen and other fuels, and swells to become a red supergiant.	 Uses up hydrogen and other fuels, and swells to become a red supergiant.
Death	 Outer layers of gas drift away, and the core shrinks to become a small, hot, dense white dwarf star.	 Core collapses inward, sending the outer layers exploding as a supernova.	 Core collapses, sending the outside layers exploding in a very large supernova.
Remains	 White dwarf star eventually cools and fades.	 Core material packs together as a neutron star. Gases drift off as a nebula to be recycled.	 Core material packs together as a black hole. Gases drift off as a nebula to be recycled.

Note: These drawings are not to scale.

Giants and Dwarfs

You can see in **Figure 2** that when a star nears the end of its life it runs out of hydrogen and other fuels needed to produce energy. When this happens, the pressure holding the star together becomes reduced, so the star swells up while at the same time cooling down. Thus, in "old age" the star becomes larger and red. Stars the size of the Sun or smaller become **red giants**, while stars with masses 10 times (or more) larger than the Sun's become **red supergiants**.

A star the size of the Sun or smaller is said to "die" when the nuclear reactions die down, the core shrinks, and the outer layers of the star drift away. The remaining material becomes a **white dwarf**, a small star with a higher temperature than red or yellow stars.

Figure 3

The supernova that created the Crab Nebula was observed in 1054. Other nebulas seen in the sky provide evidence that supernovas have occurred many times.

Supernovas

A **supernova** is an enormous explosion that occurs at the end of a large star's life. By this stage, the star has used up the fuels needed to keep producing energy by the process of nuclear fusion. With reduced pressure on the core, the core collapses inward to become either a neutron star or a black hole (described below). At the same time, shock waves cause the outer layers to explode outward in a rapidly expanding nebula of dust and gases.

Supernovas are rare events. A famous one was observed in the year 1054 and was recorded in both China and India. It was so bright that people could see it even in daylight. It was visible for about 21 months. The gases spreading out from this supernova now form the Crab Nebula, which can be seen in the constellation Taurus (**Figure 3**).

Since the telescope was first invented about 400 years ago, only one supernova has ever been seen with the unaided eye. This event, now called Supernova 1987A (**Figure 4**), was discovered by a Canadian named Ian Shelton working at an observatory in Chile, South America.

Did You Know?

When our Sun eventually swells into a red giant star, its outer layers will grow to be about 100 times its present size swallowing up Mercury, Venus, Earth, and maybe even Mars.

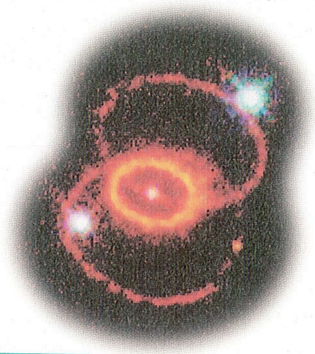


Figure 4

Supernova 1987A, photographed three years after the supernova was first seen by Ian Shelton. Astronomers are observing this supernova with great care. What they learn from their observations may help them improve their theories about the lives of stars.

Try This: Modelling a Black Hole

In a large, open area, securely tie a one-holed rubber stopper onto a 1-m length of string. Whirl the stopper around a finger (without hitting anybody!), allowing the string to wind up on your finger until the stopper crashes into the finger.

1. In this model, what acts as the black hole? What acts as the material near it? What force represents the force of gravity?
2. What happens to the motion of the rubber stopper as it gets closer and closer to the finger? Relate this to what happens to material near a black hole.

Neutron Stars

When a star about 10 times the mass of the Sun dies, the resulting core is called a **neutron star**, an extremely dense star composed of neutrons. The neutrons are so tightly packed, with no space between them, that a cupful of a neutron star would have a mass of millions of kilograms. A **pulsar** is one type of neutron star. Pulsars emit pulses of very high energy radio waves. Pulsars are very small, only about 20 km in diameter, but very dense, with about the same mass as a normal star. Pulsars rotate while emitting energy in the form of light and radio waves, like the rotating light of a lighthouse—the effect is the energy reaches us as pulses. Today more than 400 pulsars have been identified.

Black Holes

When a star about 30 times the mass of the Sun dies, the resulting core is called a **black hole**, which is a small, very dense object with a force of gravity so strong that nothing can escape from it. Even light cannot be radiated away from its surface. That is why it is called a black hole (**Figure 5**).

Because light cannot escape the surface of black holes, they can exist undetected. Yet a Canadian astronomer, Tom Bolton, was able to confirm the existence of black holes. What was his evidence? He observed a star that appeared to be circling an invisible partner and noticed that this partner was emitting X rays as it drew matter toward itself from the star. These X rays confirmed Bolton's suspicions that the "invisible partner" was a black hole. The word "hole" is misleading because it sounds as though there is nothing there; it actually has a huge amount of matter packed into a sphere only a few kilometres across. It is so dense that a handful of it would have a mass of perhaps 10 billion cars! This explains its strong gravitational pull. Perhaps "dark body" would be a better name for this extremely rare type of object.

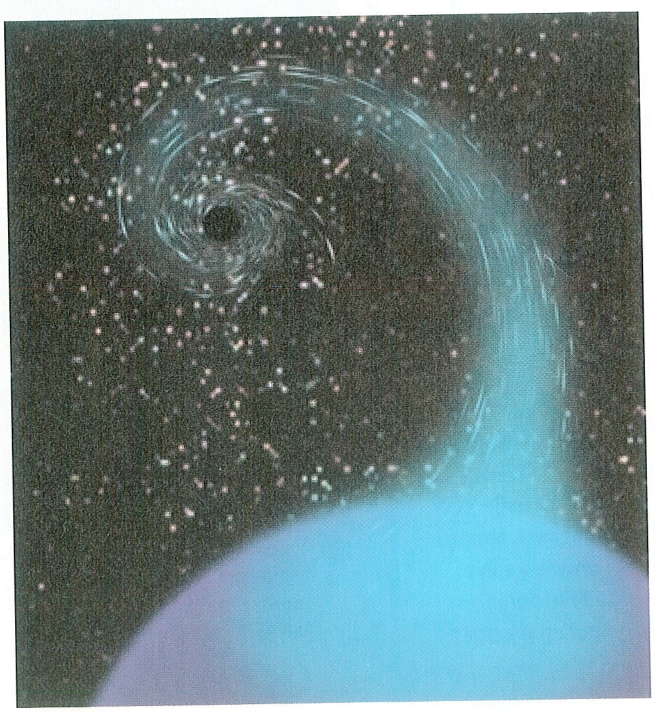


Figure 5

This is an artist's view of what happens near a black hole. As it twirls around, the hole attracts materials from a nearby star toward it. Why is this an example of indirect evidence?

Understanding Concepts

1. Describe how a star forms.
2. Describe the differences between the life of a low-mass star and that of a star 10 times the Sun's mass.
3. What is a supernova?

Exploring

4. Design and make a set of three-dimensional models to illustrate the life of one of the types of stars described in **Figure 2**.
5. Design a model of a black hole. Your model could use a circular magnet, metal washers, and thread. If your teacher approves your design, try it. In what ways is it accurate?

Reflecting

6. Describe why observing evidence of a black hole is an example of indirect evidence.
7. Think of circumstances in your life where you draw conclusions using indirect evidence. In each situation, what do you have to know already, before you believe the indirect evidence?

Challenge

How does the use of models help to communicate the information in the challenge you have chosen? What kind of models are most effective?

The Origin of the Planets

You know how difficult it is to see the planets in our own solar system. Now imagine looking for planets travelling around stars other than our own: other **planetary systems**. Planets are smaller than stars and do not emit light, so the task is not easy. Astronomers are continually using newer and better technology and making use of both direct and indirect evidence to search for other planetary systems in the universe. Learning about the formation of planets at various stages will help us better understand the development of the solar system and our own planet.

Evidence of Planetary Systems

What evidence do astronomers have of other planetary systems? Shortly after its launch into orbit in 1983, the Infrared Astronomical Satellite or IRAS made some exciting discoveries. It detected a large cloud of tiny particles in orbit around the star Vega. This was the first direct evidence that solid matter exists around a star other than our own Sun. Astronomers thought that the clouds of particles could be an early stage of the development of planets. Four months later, IRAS discovered solid material orbiting another star.

More recently, the Hubble Space Telescope has obtained images of planetary systems being formed. Astronomers also have indirect evidence of other planetary systems. The pull of gravity between a star and a nearby planet causes a slight wobble of the star's motion. This wobble can be detected by observing the star's spectrum.

Formation of the Solar System

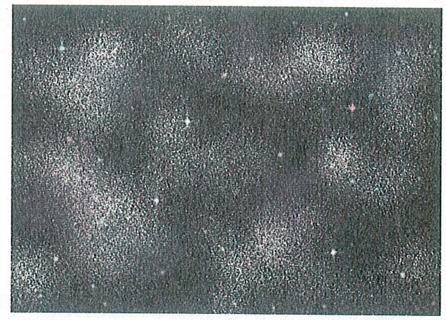
Figure 1 shows the steps that may have occurred in the formation of the Sun, planets, and other parts of our solar system. In its early stages, our solar system was part of a nebula consisting mainly of hydrogen and helium. Minute particles of matter, such as iron, rock, and ice, made up about 1% of the nebula. This solid matter formed as a result of neighbouring supernova explosions from nearby stars.

Scientists think that our Sun formed about 4.6 billion years ago. At the same time, smaller clumps of matter began to contract in the outer regions of the solar nebula. Attracted by the force of gravity, the clumps formed planets. This theory explains the formation of the gas giants

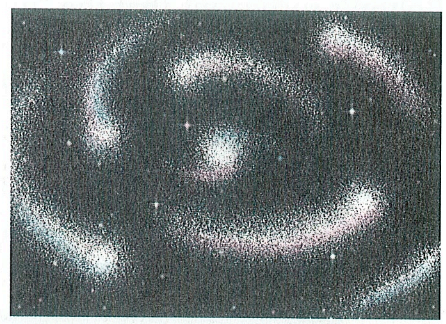
Did You Know?

The belt of asteroids located between Mars and Jupiter likely would have formed into a planet if Jupiter's strong force of gravity hadn't prevented the particles from gathering together.

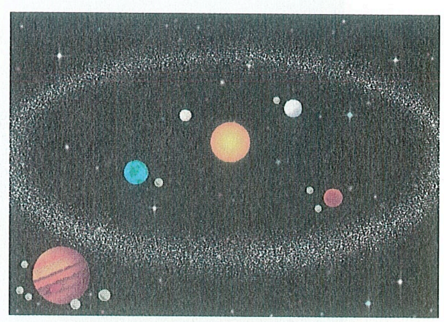
Figure 1
Astronomers think there were three main stages in the formation of the solar system.



(a) Gravity caused components of a rotating nebula to unite. Because of its rotation, the nebula flattened out as it contracted.



(b) As the process continued, a bulge formed toward the centre. This bulge later became the Sun. Some of the dusty disk of cooler material further from the centre gathered together to form smaller chunks.



(c) These smaller chunks away from the bulge gradually grew into larger chunks, which eventually formed into planets.

(Jupiter, Saturn, Uranus, and Neptune). The gas giants are composed mainly of hydrogen and helium gases: the same gases that make up much of the Sun. These planets probably formed in a way similar to the Sun—through the clouds of gases contracting due to gravity. But what about the terrestrial planets? What is the current theory about their formation?

The Terrestrial Planets and Minor Bodies

Mercury, Venus, Earth, and Mars are composed largely of rock and iron, with little hydrogen and helium. In the early stages of solar system formation, the gases in the inner regions of the solar system were probably too hot to condense. The young Sun produced enough solar wind (bursts of charged particles) to blast most of the hydrogen and helium out of the inner regions of the solar system. Only the chunks of heavier matter—iron and rock—were left behind (**Figure 2**).

The terrestrial planets formed from those solid chunks. As chunks of solid matter circled the Sun, they eventually collided with one another and joined together. During millions of years, some of the chunks grew in size until their mass was large enough to have strong gravity. The more massive chunks pulled in all the matter in the space around them. They eventually became the planets.

Over a long time (perhaps 10 million years), most of the matter in the solar system became concentrated into the terrestrial planets and gas giants. The remaining matter makes up the asteroids, meteoroids, and comets—the minor bodies. Studying these minor bodies provides information about the early stages of our solar system, before most of the matter formed into the planets.

Pluto's origin is not certain as it has characteristics of a minor body, but is too far from the Sun to be explained by the theory of formation for the terrestrial planets. It may be more like a giant comet nucleus. The research is

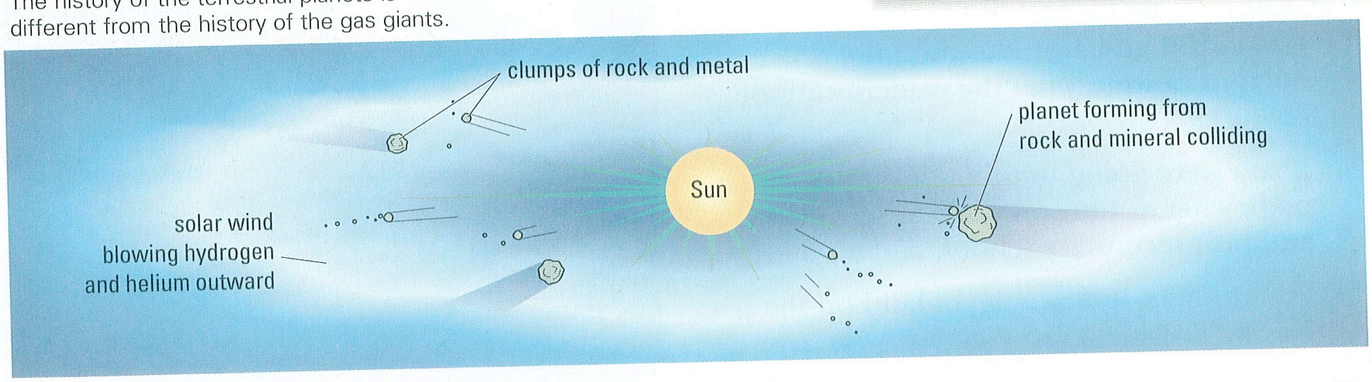
Understanding Concepts

1. What force is responsible for bringing together the particles found in space?
2. Describe, in order, the stages of the formation of the solar system.
3. (a) Which of the planets in the solar system are thought to have formed in a similar manner to the Sun?
   (b) Why is it unlikely that the other planets formed this way?
4. (a) What are the minor bodies of the solar system?
   (b) What do astronomers hope to learn from the minor bodies?
5. Assume that 10 years from now astronomers discover planets travelling around hundreds of different stars. Are the planets they discover more likely to be gas giants or terrestrial planets? Explain.

Exploring (3A)

6. Research the Kuiper Belt. Why is its discovery a good example of a theory being supported by observations? Why do astronomers think Pluto and Neptune's moon Triton may have come from the Kuiper Belt?
7. Research and report on the Oort cloud. Explain why comets provide an opportunity to study what the solar system may have been like before the planets formed.
8. Use an Internet resource to research recent discoveries of planetary systems. Make a visual display of your discoveries.

Figure 2
The history of the terrestrial planets is different from the history of the gas giants.



SKILLS HANDBOOK: (3A) Research Skills

Career Profile

Space Artist

Paul Fjeld gives a thumbs up sign as he steps out of the high performance jet in which he has just pulled 6 *g*'s. His call sign is "Fingers," and he flies in jet fighters whenever he can as part of his research: Paul Fjeld is a Canadian artist interested in space.

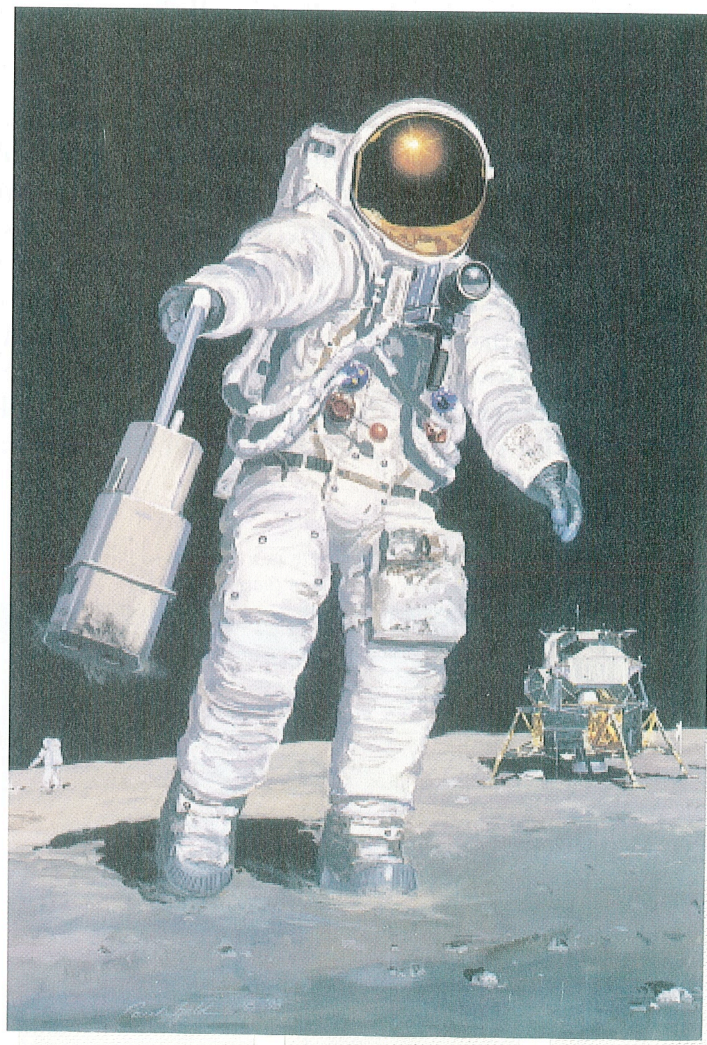
Between 1971 and 1973 the *Montreal Star* newspaper sent a young artist to cover the last three launches of *Apollo*. He convinced NASA to include him in their official Art Program; soon Fjeld got to go where even the press could not, including the *Apollo* simulator. His greatest thrill was working in Mission Control during the 1975 *Apollo/Soyuz* mission where he was made welcome and encouraged to "document what we were doing in a different way—for history."

> I want to paint a picture as if you are actually there.

Fjeld's first painting for NASA was of a crippled Skylab module with torn thermal shield and damaged solar arrays. Working with engineers from the manufacturer, he had to assess what the damage might look like and prepare a visual image for the press. The Canadian Space Agency has commissioned Fjeld to create large images of the *International Space Station*, the Canadarm, the SPDM (Figure 2, p. 499), and the various satellites. His work has appeared in *National Geographic* and on the cover of *Aviation Week*.

His favorite spacecraft is the *Apollo Lunar Module* (seen in the painting with Armstrong and Aldrin). The skin of the insect-like robot is a paper-thin wrapping of aluminum. It is a great subject to paint against the blackness of space. Actor Tom Hanks hired Fjeld to recreate that lunar moment on a huge set for the TV series *From the Earth to the Moon*.

What's next for Paul Fjeld? Another painting? A script for a movie? Whatever it is, it will almost certainly involve his passion: space.



Explore

1. What skills and attitudes does the artist need to capture what the camera cannot capture?
2. If you were going to follow a similar career path, what would you study at secondary and post-secondary school, and why?
3. When might humans again land on the Moon? Provide a rationale for your answer.

A Model of the Expanding Universe

In this activity, you will use a model to illustrate the concept of an expanding universe. As you use the model, think of ways it might be improved.

Materials

- 1 round balloon
- black, fine point, felt tip pen
- metric tape measure

Procedure

1 Copy **Table 1** into your notebook.

Table 1

	Measured distances (cm)			Calculated distances (cm)	
	A to B	B to C	C to D	A to C	B to D
"Orange" stage	?	?	?	?	?
"Basketball" stage	?	?	?	?	?

2 Blow up the balloon to the size of an orange. While your partner keeps the balloon at that size by pinching the opening, use the felt tip pen to mark the balloon with four dots, each separated by about 1 cm. Measure the exact distances between the dots with the metric tape. Label the dots in order, A, B, C, D.

(a) Record the measured distances between the dots in your data table.

3 Now inflate the balloon until it is about the size of a basketball. Measure the distances between the dots.

(a) Record the measured distances in your data table.

4 Calculate the distances A to C and B to D for both the first and second stages.

(a) Record these calculated distances in your data table.

5 Look at how much the distances A to B, B to C, and C to D increased when you inflated the balloon to the second stage.

(a) Compare those increases.

6 Suppose you continued to blow up the balloon.

(a) How do you think the change in the distances A to B, B to C, and C to D would compare with the change from the first stage to the second stage?

7 Imagine that you are standing on dot A while the balloon is expanding.

(a) Which dot would appear to be moving away from you most quickly?

(b) Which dot would appear to be moving away from you most slowly?

(c) Would any dot appear to be moving toward you?

8 Imagine that the dots on your expanding balloon are galaxies of stars in an expanding universe.

(a) What difference would you expect to find in how quickly nearby and distant galaxies are moving away from Earth?

9 Now imagine that you are on a planet in galaxy B looking at a planet in galaxy C.

(a) Do you think the spreading of the galaxies would appear to be any different from these two locations? Explain.

(b) If galaxy B is the Milky Way Galaxy, is it correct to say that galaxy B is the centre of an expanding universe? Explain.

Reflecting

1. Although the balloon model was useful to illustrate the concept of an expanding universe, it also had a major limitation. Identify the limitation and suggest a way to overcome it.

15.4

Evidence of an Expanding Universe

A balloon is a useful model in helping us imagine how the universe expands: as the balloon expands, closely spaced dots on the surface spread apart slowly; dots that are far apart spread apart more quickly. However, as a model, an expanding balloon has limitations. For example, galaxies are not found on a skin or membrane; instead, they are scattered throughout the universe.

How can we tell whether a galaxy is moving away from us? After all, the galaxies are very far away.

Before looking at evidence of an expanding universe, let's review the properties of light. Light is a form of energy that travels as a wave. Each colour has a wavelength, which is the length of one wave. The visible spectrum (**Figure 1**) consists of different colours, ranging from the longest wavelengths (red) to the shortest wavelengths (violet).

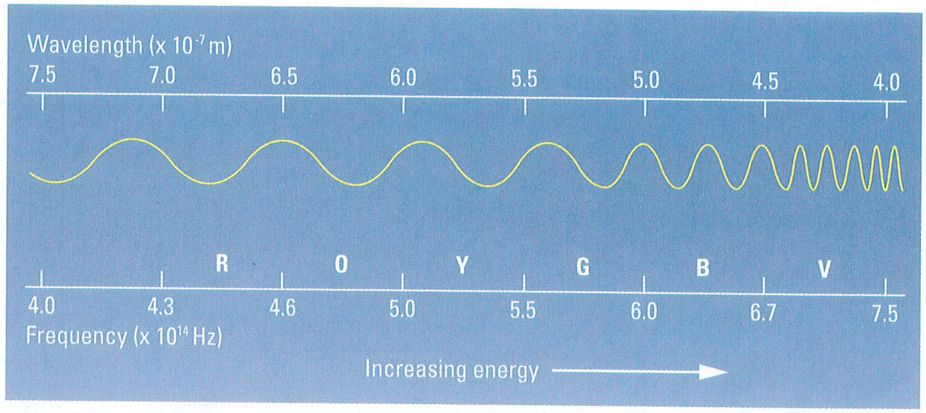
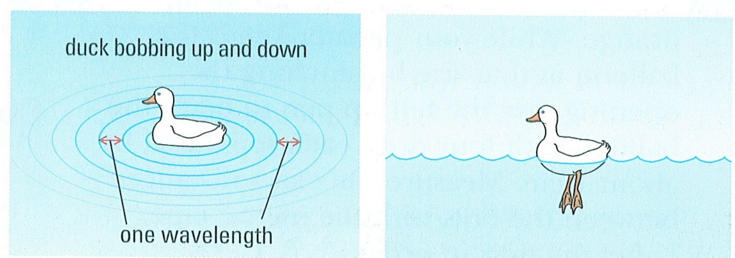


Figure 1
The visible spectrum

You already know that different stars have characteristic colours. The same is true for galaxies: each galaxy emits its own spectrum or range of colours in a pattern that astronomers recognize. As early as 1912, astronomers observed evidence that the galaxies are moving away from Earth and from one another. This evidence came from looking at the light spectra (patterns of colours) given off by nearby galaxies. The spectrum of a moving object in space is different from the spectrum of an object that is not moving. An example will help explain this.

Imagine a duck bobbing up and down on the surface of a pond (**Figure 2**). Suppose the duck represents a source of energy. The ripples that spread out from the duck represent waves of energy emitted by the source. The distance from the top of one ripple to the top of the next ripple represents one wavelength.

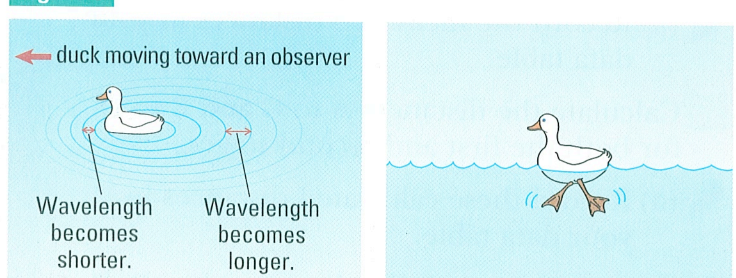
Figure 2



(a) This model shows an energy source (the duck) sending out waves (the water ripples) with a constant wavelength (the distance from the top of one ripple to the top of the next).

(b) Side view of the waves.

Figure 3



(a) The wavelengths become shorter in one direction and longer in the other direction.

(b) A side view of the waves created by a bobbing duck moving to the left.