OPTION B

Electric Vehicles

UBC is actively engaged in using, as well as further developing, electric cars. How do electric cars compare to gas-powered ones?

OPTION C

Fuel-cell Safety

How do fuel-cell vehicles compare to conventional ones in terms of safety for their human passengers?

Assessment Criteria

Did I and my group...

- Develop one or more questions that provided opportunities for rich investigation? QP
- Develop effective methods to collect and record reliable data and information? PC
- Analyze, reflect on, and draw meaningful conclusions as related to the inquiry? PA
- Evaluate the process and results of the inquiry, troubleshooting problems if they arose? E
- Compare at least one type of sustainable vehicle with a conventional vehicle? AI
- Present the results of the inquiry using language, conventions, and representations appropriate for a specific purpose and audience? C

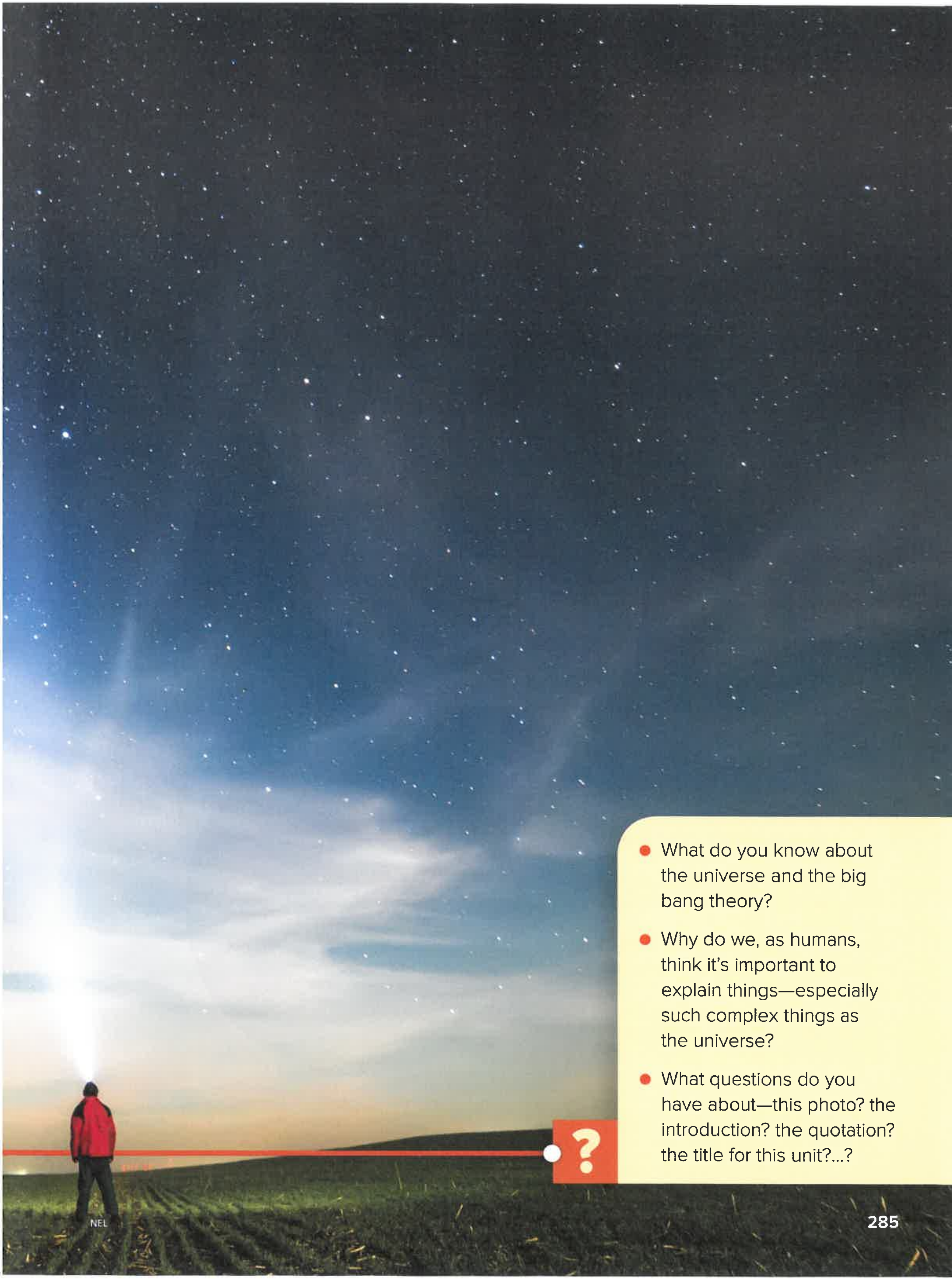
UNIT 4

The formation of the universe can be explained by the big bang theory.

Have you ever shone a flashlight into the vastness of a twilight or night sky? Many people have done so, especially in their youth. Perhaps they wondered if someone might, somehow, from somewhere, glimpse the dim beam. Maybe it helped them feel more connected to a universe that might otherwise seem impersonal. Could it have been a way of calling out to say "Hey, I'm here. I see you. Do you see me?"

"There's as many atoms in a single molecule of your DNA as there are stars in the typical galaxy. We are, each of us, a little universe."

Neil deGrasse Tyson, astrophysicist, cosmologist, science communicator



- What do you know about the universe and the big bang theory?
- Why do we, as humans, think it's important to explain things—especially such complex things as the universe?
- What questions do you have about—this photo? the introduction? the quotation? the title for this unit?...?

UNIT 4

At a Glance

You will demonstrate what you know, can do, and understand by being able to

- Perform investigations and use other investigative methods to explore the universe and our understanding of it
- Apply scientific understandings, First Peoples perspectives, and other ways of knowing to analyze, evaluate, and communicate ideas and information about the universe
- Develop and use models and other methods to describe and illustrate objects, events, and processes of the universe

ESSENTIAL QUESTION

How can we understand and explain the universe, its formation, and our place in it?

TOPIC 4.1:

What is the universe, and how do we make sense of it?

Some things you will do:

- observe and ask questions about the world around you
- contribute to care for self, others, community, and world through individual or collaborative approaches

Some things you will come to know:

- "Universe" is a word whose meaning depends on various factors.
- Different peoples in different places and at different times in history have different ways to perceive the universe.

TOPIC 4.2:

What do we know about the universe based on what we can see only with our eyes?

Some things you will do:

- use star maps to recognize different constellations and objects in the night sky
- generate and introduce new or refined ideas

Some things you will come to know:

- In terms of what we can see with our eyes alone, the universe is surprisingly small.
- We can navigate the night sky in ways that are similar to navigating on land.

TOPIC 4.3:

How has technology expanded our knowledge and understanding of the universe?

Some things you will do:

- seek and analyze patterns, trends, and connections in data
- consider changes in knowledge over time as tools and technologies have developed

Some things you will come to know:

- We use technology to help us observe the universe at all wavelengths and frequencies of radiant energy.
- Our ability to catalogue and classify stars has helped us develop ideas about their life cycles.

TOPIC 4.4:

How do we use the big bang theory to explain what we know about the universe?

Some things you will do:

- communicate scientific ideas, claims, and information
- generate and introduce new or refined ideas

Some things you will come to know:

- We have several powerful sources of evidence to support the big bang theory.
- Despite our current state of knowledge, there is still so much for us to learn about the universe.

UNIT 4

Connect To What You Already Know

This feature helps you reflect on what you know about some foundational ideas that you have learned in previous grades. Work alone or quietly in small groups to answer the questions. Reach out to your classmates to ask about things that you are unsure about or to offer assistance. Your teacher also can provide additional reinforcement materials to help you prepare for this unit.

1. Each of the following space-related technologies is shown in **Figure 1**. Match each technology to its illustration, and describe how it has contributed to our understanding of space.
   a) Discovery space shuttle
   b) Atlas V rocket
   c) Hubble Space Telescope (HST)
   d) International Space Station (ISS)

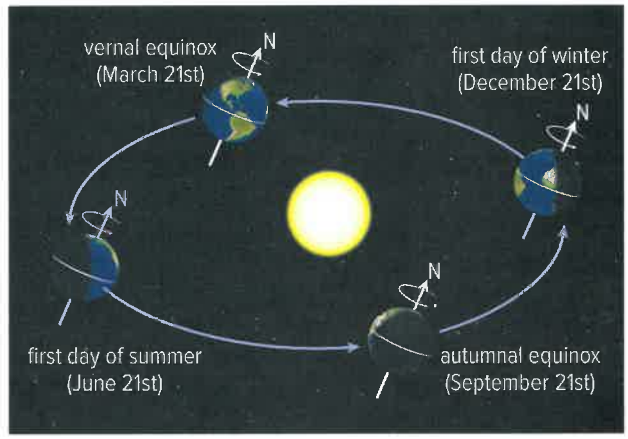


Figure 2 Use this diagram to answer question 4 below.

3. Use a sketch to identify the components of our solar system and their arrangement.
4. It takes 11.86 Earth-years for Jupiter to orbit the Sun. Each Jupiter day is 9 h, 50 min, and 30 s long.
   a) Which of the above statements describes Jupiter's period of rotation, and which describes Jupiter's period of revolution?
   b) Distinguish between these motions.
5. Refer to **Figure 2** at the top of this page. Use your understanding of rotation and revolution to explain what is being shown. Your explanation should include the words day, night, seasons, axis, hemisphere, and any other words you think are important.

6. Identify the effect that results from each of the following causes. The causes are listed below. Explain your answer in each case.

- seasons
- ocean tides
- Earth's orbit
- day and night
- yearly periods

a) Earth's rotation on its axis causes...

b) Earth's revolution around the Sun causes...

c) The Moon's gravitational pull on Earth causes...

d) Earth's tilt on its axis causes...

e) The Sun's gravitational pull on Earth causes...

7. Like all scientists, astronomers commonly use scientific notation to express sizes and distances. For example, the diameter of Earth's Moon is 3475 km, or 3.475×10^3 km.

a) Earth's diameter is 12 756 km. Express this measurement in scientific notation.

b) How much larger is the diameter of Earth compared to the diameter of the Moon?

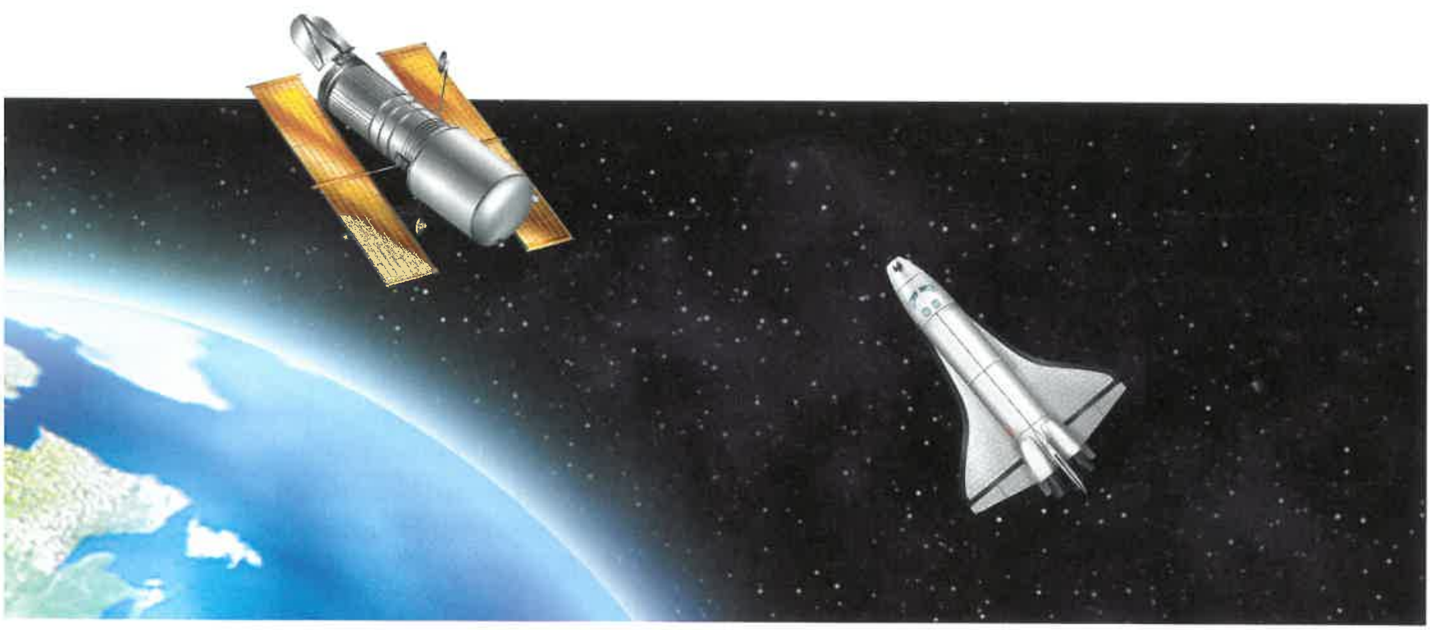
c) After the Sun, the next-nearest star to Earth is Proxima Centauri, at a distance of 40 208 000 000 000 km. Express this distance in scientific notation.

8. The changing appearance of the Moon over a period of about 29 days is referred to as the phases of the Moon, or lunar phases.

a) On paper or using found objects, design a model to show the relationship of the Earth, Moon, and Sun to create lunar phases.

b) When we look at the Moon from Earth, we always see the same lunar features. We never see what is often called "the dark side of the Moon." What motion or combination of motions could explain this?

9. While risky and expensive, space exploration technology is beneficial. For example, the technology that was developed for use in the space shuttles is also used to make better artificial hearts. Express your opinion about the money spent by our federal government for space exploration. In developing your answer, consider how spending on space exploration compares with spending in other areas such as health care, defence, and environmental initiatives. Think about other costs and benefits from space-related spending to help you develop an opinion that is shaped, as much as possible, by evidence.



Unit 4 Preparation *(continued)*

Table 1 Selected Data about Planets of Our Solar System

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Average distance from Sun (million km)	57.9	108.2	149.6	227.0	778.6	1433.5	2872.5	4495.1
Distance from Sun (Earth = 1)	0.387	0.723	1	1.52	5.20	9.58	19.20	30.05
Diameter at equator (Earth = 1)	0.383	0.949	1	0.532	11.21	9.45	4.01	3.88
Mass (Earth = 1)	0.0553	0.815	1	0.107	317.8	95.2	14.5	17.1
Density (Water = 1)	0.984	0.951	1	0.713	0.240	0.125	0.230	0.297
Ring System	no	no	no	no	yes	yes	yes	yes
Surface gravity (Earth = 1)	0.378	0.907	1	0.377	2.36	0.916	0.889	1.12
Time for one rotation on axis	58.8	−244	1	1.03	0.415	0.445	−0.720	0.673
Time for one revolution of Sun	0.241	0.615	1	1.88	11.9	29.4	83.7	163.7
Number of moons	0	0	1	2	67	62	27	14

10. On a large sheet of paper, draw a line 40 cm long. Mark the position to represent the Sun at one end of the line. Using Table 1, plot the positions of the planets according to distance.

11. There appear to be two groupings of planets according to distance. Make a list with two columns, one for each grouping. Fill in the planets that belong to each grouping, as well as your reasons for including them.

12. On a second sheet of paper, use a mathematical compass to draw circles that represent the sizes of the planets. Use a scale based on Earth being 1 cm.

13. List the planets most similar to Earth in density.

14. List the planets most similar to Earth in mass.

15. Planets that are similar to Earth are called terrestrial planets or rocky planets. Which planet is Earth-like in size but very different other ways?

16. Identify the terrestrial planets.

17. List the four planets that are usually referred to as the gas giants.

18. Saturn, with a diameter that is almost 9.5 times that of Earth, has a surface gravity fairly close to that of Earth. (Gravity is the force of attraction that acts between any given pair of objects.) Use the table to determine how two planets with great differences in size could have almost the same surface gravity.

19. Uranus and Jupiter have nearly identical densities, but Jupiter is much larger. Which would you expect to have a larger force of gravity? Explain why, and then check your prediction in the table.

20. Which planet has the shortest year? Which has the longest year?

21. a) Make a statement that relates the distance of a planet form the Sun and the length of its year.
    b) Does this statement apply in terms of the length of a planet's day? Explain.

22. Most planets have at least one moon. Why do you think Mercury and Venus have none?

23. What other data and facts do you know or can you find out about the planets of our solar system? (For example, what do those negative signs for the rotation of Venus and Uranus indicate?)

24. Our solar system has two regions that are referred to as "belts." Add these regions to the diagram you made in question X. What are these regions called, and how do their components compare?

25. What are comets and where are the majority of comets of our solar system thought to originate?

26. Distinguish among the following terms: meteoroid, meteor, meteorite.

27. Brainstorm ways in which stars differ from planets. Organize your comparisons in the form of a T-chart or a Venn diagram.

28. Figure 3 shows an imaginary solar system far, far from our own. Astronomers have classified the five planets as shown, and have determined their distances from the star they orbit. Astronomers think that there is a sixth planet in this solar system, and it is located somewhere in the region marked X.
    a) What type of planet would you expect to find in this region?
    b) Explain your answer to **a)**.
    c) At what distance would you expect the new planet to be found?
    d) Why did you choose this distance?
    e) How is this solar system arrangement different from ours?

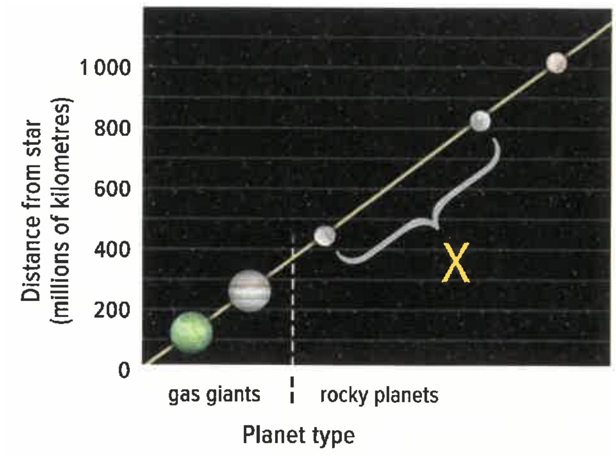


Figure 3 Use this diagram to answer question 28.

29. Describe at least three features of Earth that set it distinctly apart from the other planets of our solar system.

30. Refer to Figure 4 to answer the following questions.
    a) What does the diagram show?
    b) Is it partial or full? How do you know?
    c) A similar kind of event also involves the Sun, Earth, and Moon. Name this event and make a sketch to show how the Sun, Earth, and Moon are arranged when it is partial and when it is full.

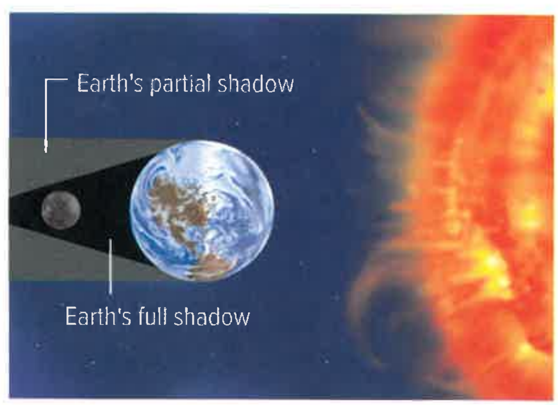


Figure 4 Use this diagram to answer question 29.

TOPIC 4.1

What is the universe, and how do we make sense of it?

Key Concepts

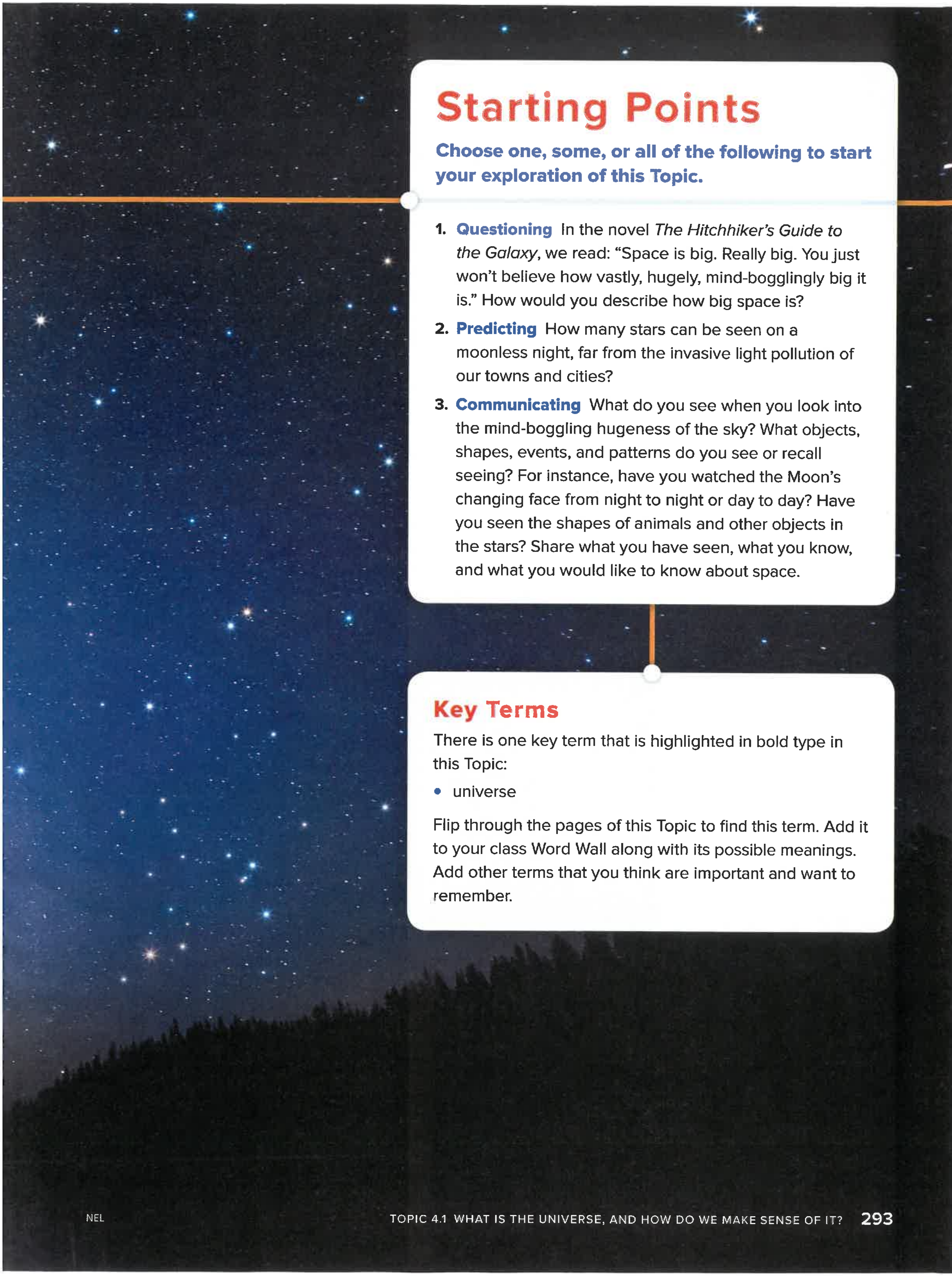
- "Universe" is understood as different things to different people.
- The sense we make of the universe depends on who we are, when we are, and what we know.

Curricular Competencies

- Make observations aimed at identifying questions about the natural world
- Experience and interpret the local environment
- Apply First Peoples perspectives and knowledge, other ways of knowing, and local knowledge as information sources
- Demonstrate an awareness of assumptions and bias
- Express and reflect on experiences, perspectives, and worldviews through place

You have many ways to describe and share what you see in the sky. Imagine sharing your ideas about the sky with friends, and they pass this information to others. Imagine this sharing takes place over months, years, centuries, and longer. This process of sharing is the act of storytelling. For millennia, the sky has inspired us to weave stories, to pass on ideas, explanations, and wisdom. We tell:

- ancient stories about shapes, patterns, and events our ancestors saw
- scientific stories to link observations with hypotheses and theories
- etched and painted stories on rock, hides, wood, paper, and pixels, to communicate our sense of wonder and connection
- visionary stories—written, spoken, sung, and danced—to amuse and teach
- inspirational stories from Elders, seers, and spiritual leaders to link space, Earth, and all creation in our hearts, minds, and spirits



Starting Points

Choose one, some, or all of the following to start your exploration of this Topic.

1. **Questioning** In the novel *The Hitchhiker's Guide to the Galaxy*, we read: "Space is big. Really big. You just won't believe how vastly, hugely, mind-bogglingly big it is." How would you describe how big space is?
2. **Predicting** How many stars can be seen on a moonless night, far from the invasive light pollution of our towns and cities?
3. **Communicating** What do you see when you look into the mind-boggling hugeness of the sky? What objects, shapes, events, and patterns do you see or recall seeing? For instance, have you watched the Moon's changing face from night to night or day to day? Have you seen the shapes of animals and other objects in the stars? Share what you have seen, what you know, and what you would like to know about space.

Key Terms

There is one key term that is highlighted in bold type in this Topic:

- universe

Flip through the pages of this Topic to find this term. Add it to your class Word Wall along with its possible meanings. Add other terms that you think are important and want to remember.

CONCEPT 1

"Universe" is understood as different things to different people.

Some stories begin in the present and move forward into the future, or they begin in the present and they flash back to the past. Some stories begin *in medias res*, which is a Latin term meaning "in the middle." Such stories are often epic tales like the *Iliad* of Homer, the first Star Wars film (which is Episode IV in the complete saga), and the video game *Final Fantasy X*.

Many stories, however, begin at the beginning. It might be the beginning of an action or event, or the beginning of the life of a character we will come to know more about, or some mixture of these.

If a scientist were to begin a story about the universe at the beginning, this story would take us back to a time approximately 13.8 billion years ago. See **Figure 4.1**.

Take a moment to think about that.

Many people find it a challenge to imagine the size of a number like 10 000. Even more find it a challenge to imagine a number as large as 100 000. Few people can fathom what 1 million looks like, let alone 1 billion. So what (on Earth? beyond Earth?) is the size of 13.8 billion?

Figure 4.1 This photo captures galaxies (collections of stars) at many different stages of their lives. Some are very young—barely 1 billion years old. It has taken their light almost 13 billion years to reach the telescope that photographed them. The area of sky represented by the photo, called the Hubble Ultra Deep Field, is tiny. Imagine a dime 23 m away from you. That dime is the size of the area of sky visible to the telescope.

Activity

Bringing Big Numbers Down to Earth

Consider the size of the numbers in each of the following. What does that number look like? How can you make it easy or easier to grasp? For example, could you develop an analogy? Could you make a scale model? Could you write computer code that generates that number of X's on a screen? What other ideas do you have to bring large numbers "down to Earth?"

- Gabriel has 250 followers on social media.
- Jen's comic book collection has reached nearly 2500.
- The tallest mountain peak in British Columbia is Mount Waddington, in the southwest of the province, at a little more than 4000 m.
- The deepest part of Earth's ocean is the Mariana Trench, east of the Philippines, at nearly 11 000 m.
- Data from the census conducted in 2016 showed that the city of Victoria had a population of nearly 86 000 people.
- Data from the 2016 census showed that BC's population was nearly 4.7 million.
- At the time this book was published, Earth's human population was more than 7.6 billion, and counting.
- A recently discovered lobster species, named *Yawunik kootenayi* in honour of the Ktunaxa of southeastern BC, lived about 500 million years ago.
- Add one more number of your own, as large as you want. Go ahead—reach for the stars!

Fossil of *Yawunik kootenayi* from Marble Canyon in Kootenay National Park. Yawunik is a key figure in the Ktunaxa creation story. The fossil now resides at the Royal Ontario Museum.

What Does It Mean to Talk about the Beginning of the Universe?

Talking about the beginning of the universe raises a host of questions. For example:

- What happened that made the universe begin?
- Was there anything that existed before the universe began?
- What happened after the universe began?
- How do we know the universe began about 13.8 billion years ago? Could it have been earlier? Could it have been later?
- Is there only one universe?
- Is it possible that the universe has begun more than once?
- Is it possible that the universe didn't begin at all? What could that even mean?

Take a moment. (Yes, another moment. After 13.8 billion years, we have time.) What questions of your own—about the universe, about time, about big numbers, about this unusual textbook discussion—do you have? As you pose and discuss your questions, consider one more, which might or might not be a simple one: What does the word "universe" mean in the first place? We'll pick up with this question when you turn the page.

universe all that exists everywhere, including all matter, energy, planets, stars, galaxies, and the space in which all of this exists

Reflecting on the Meaning of "Universe"

Consult any dictionary, and you will likely see **universe** defined as "all there is" or "all that exists." It is possible to add details about what "all" could mean, as in the definition in the margin. Does that definition seem reasonably simple and straightforward to you? If so, consider this. We know that there are billions of galaxies (collections of stars). However, barely 100 years ago, most scientists believed that the Milky Way galaxy—the galaxy in which our planet is found—was the *whole* universe. In other words, the universe was all that exists in the Milky Way!

This is like saying that a person living in a small room believes that the universe is everything in that room and the room itself. Imagine what it would be like for that person to step outside that room and witness all the other rooms and buildings and roads and cars and people and animals and clouds and sky—a daytime sky filled with clouds and a great yellow, glowing orb, and a nighttime sky filled with pinpoints of light. Imagine the shock to that person's senses. Imagine trying to shift your understanding to accommodate such a startling, different view of all that you thought before.

The "universe" may well be all that exists, but "all that exists" is relative. This means that your understanding of all that exists depends on who you are, where you live, and the time that you live. In the next Concept, you will begin to think further about this idea.

Activity

Life in the Bowl of the World

The country of Tanzania in Africa has one of the world's great wonders—a deep crater teeming with life, cut off from the surrounding countryside. Imagine that you live in this "bowl" of a world, called Ngorongoro Crater. All you need to sustain your life is found here. Because the rock walls around you are 600 m, your sense of place is well-defined by them.

1. Compare Ngorongoro Crater to the ideas discussed on this page. Imagine living in this place. How would your understanding of your world, the universe, and yourself be affected if you could rise above and see beyond the crater walls for the first time?
2. Is there anything in your own life, or in the life of someone you know or have learned about, that is like the scenario in this activity? Share your thoughts privately or with the class.

Before you leave this page . . .

1. What is your own personal understanding of the word "universe?"
2. In what ways is the meaning of "universe" relative, and how is that significant?

CONCEPT 2

The sense we make of the universe depends on who we are, when we are, and what we know.

Each photo in Figure 4.2 shows a technology that, at that time, was a major communication device. Would you know how to understand and use the device in Photos A and B if you could step out of Photo C and enter those earlier worlds? What about if the person in Photo A stepped into photo B, or if the people in Photos A and B stepped into Photo C?

The time frame in Figure 4.2 is only 100 years. What if the gulf of time were much broader? How would you feel if you stepped into the world of 16th century England, the world of 14th century North America, the world of 2nd century China, or any time and place of your choosing? What if someone your age from those periods and places stepped into your classroom right now?

The term culture shock is used to describe the sense of anxiety and disorientation that a person feels when they experience a dramatically new social and cultural situation. What kind of culture shock would you feel? What about your counterparts from those other times? What things would you know that they don't? What things would they know that you don't?

Return to the present, and consider: How does the period of time when you live affect what you think and believe and how you live your life? How does where you live affect these same things? How do all these things affect your understanding of who you are? (And what do you interpret the phrase "who you are" to mean?)

These are big questions, deep questions, essential questions. Ask yourself these questions every so often as you explore this unit.

Figure 4.2 Communications technologies at three moments in time over a period of about 100 years

Before you leave this page . . .

1. Re-read the last paragraph. Do you think your answers to questions like those in the paragraph could change over the course of the unit? Do they apply only to your study of this unit?

TAKE Action

Make a Difference

What should we do about light pollution?

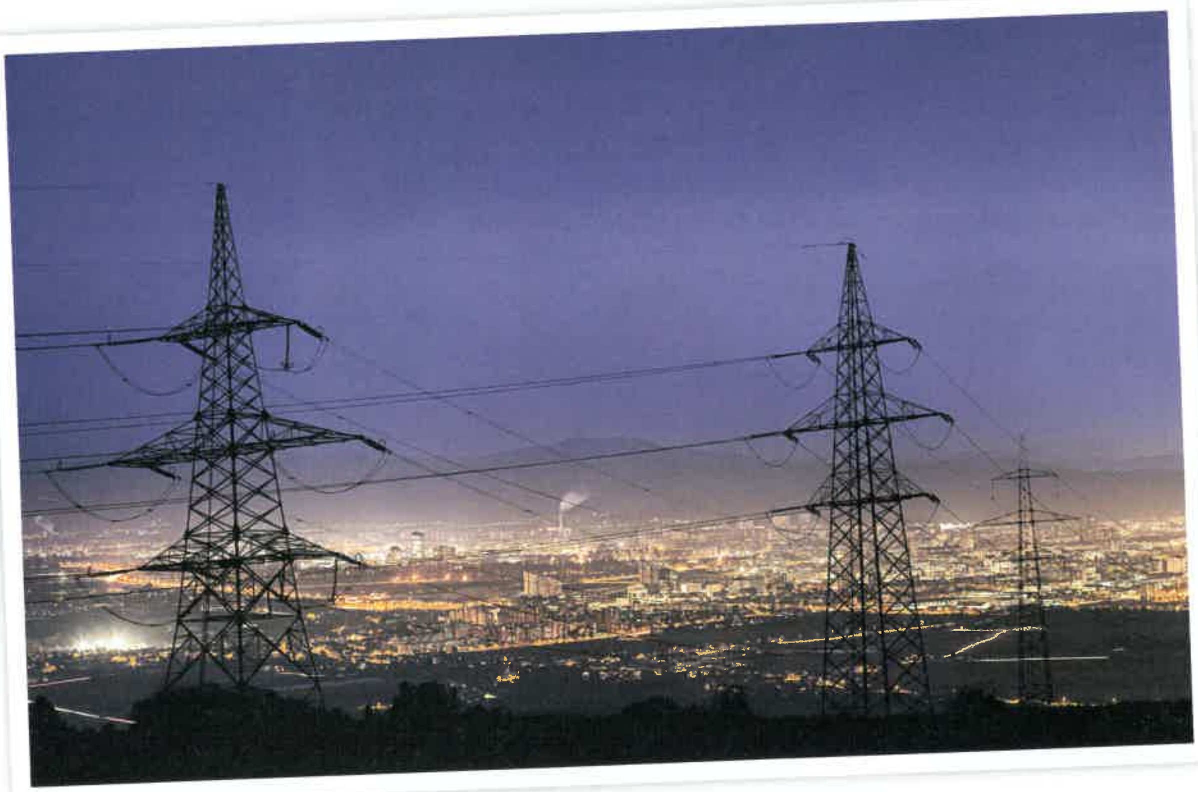
Most people who live in urban centres are unable to see the stars of our own galaxy. Since the invention of artificial lighting, our towns and cities have become polluted by our efforts to light up the night. Night lighting improves safety in cities. It also allows us to work and shop after the Sun sets. However, light pollution disrupts the cycles that govern sleeping, feeding, migration, and breeding of many living things. Birds can get lost flying over cities at night if they cannot see the stars to guide them. Newly hatched sea turtles are normally guided to the sea by starlight and moonlight reflecting off the water. However, bright beach lights can send them in the wrong direction, sometimes into the path of oncoming traffic.

Analyze and Evaluate

1. Who else is affected by light pollution, and in what ways? (Don't forget astronomers.)
2. What solutions have been proposed to reduce or combat light pollution? How effective are they?

Communicate

3. What arguments can be made in favour of having well-lit cities and towns, even at the expense of light pollution?
4. Provide a well-supported argument that expresses your views of light pollution and what, if anything, should be done about it.



Check Your Understanding of Topic 4.1

QP Questioning and Predicting PC Planning and Conducting PA Processing and Analyzing E Evaluating
AI Applying and Innovating C Communicating

Understanding Key Ideas

1. Think about the word universe.
   a) What is a simple, common-sense definition for this word?
   b) What observable evidence supports this definition? PA

2. You have probably heard or read the phrase, "It's all relative." This means that how you think about or perceive something depends on its situation or context. In what ways is the definition for universe relative? QP PA

Connecting Ideas

3. The Sun is millions of kilometres from Earth, and yet the Sun and its effects are present in our daily lives in many ways. For example, the food we eat depends on the Sun's energy. The gasoline that runs cars, chainsaws, and snow machines comes from ancient plants and marine algae that originally grew with energy from the Sun.
   a) Describe two ways that the faraway Sun is present in your daily life.
   b) The universe (whatever we mean by it) is also far away from us. In what ways is it present in your daily life? Note: Don't limit your thinking to just the physical. How might the universe be present in your life in other ways? Think about First Peoples perspectives in science and other ways of knowing to help you reflect on your responses. E AI

4. Early skywatchers paid close attention to the sky. Why might the sky be important to
   a) a hunter?
   b) a farmer?
   c) a sailor?
   d) a ruler or chief?
   e) an Elder or knowledge-keeper? E AI

5. Imagine that you are skywatching on a clear, dark night. You see a view of stars like the one shown in the photo. What questions can you formulate about the following?
   a) their distances from Earth
   b) their distances from one another
   c) their colours and/or brightness
   d) any other questions that occur to you

Note: The purpose of formulating these questions is to model the brainstorming stages of the process of scientific inquiry. Depending on your level of interest, and in consultation with your teacher, you could choose to further investigate one or more of your questions. QP C

Making New Connections

6. Stories that people tell about the universe and its creation or formation are often stories about Earth (or places on Earth) and its creation or formation. Does that surprise you? Explain why or why not. E AI

7. People who are interested in space and astronomy often have careers or interests in fields other than science. Do you think this is something unique to space and astronomy, or does it apply to any science-related field? Why do you think so? E AI C

TOPIC 4.2

What do we know about the universe based on what we can see only with our eyes?

Key Concepts

- We see a variety of objects that appear in the sky in mostly predictable ways.
- The appearance and motions of the objects we see can be described using a model called the celestial sphere.

Curricular Competencies

- Experience and interpret the local environment
- Apply First Peoples perspectives and knowledge, other ways of knowing, and local knowledge as information sources
- Evaluate the validity and limitations of a model or analogy
- Construct, analyze, and interpret models and diagrams

The sky is a part of our local environment wherever we live. For many, including First Peoples, knowledge of the observable universe is part of an interconnected world view that includes social, cultural, and spiritual aspects. This photo of a well-known medicine wheel in Wyoming is one example of how First Peoples connect with their world view. First Nations of the North American plains built hundreds of medicine wheels. Most are in Canada. The largest and oldest, in Alberta, dates back at least 5000 years. Many align with the Moon, Sun, and stars, and predict events such as solstices and the rising of sky objects at certain times of the year. Because people observe the sky from their local place, there is a great diversity of perspectives about the universe. All are respected.

Starting Points

Choose one, some, or all of the following to start your exploration of this Topic.

1. **Applying First Peoples Perspectives** First Peoples knowledge of space comes from observations specific to the places where they live. For example, medicine wheels developed in flat open prairies, but not in mountainous British Columbia. Find examples of connections between Indigenous knowledge about the universe and the local environment. Look for traditional stories, or information about how reading the skies helped people to survive.
2. **Questioning** Compare the title of this Topic with that of Topic 4.3. How does technology affect the ways we think about and interpret what we can observe?
3. **Identifying Preconceptions** Some human societies, of the past and in modern times, construct their calendars based on patterns related to the Sun. Other societies have used and continue to use the Moon. What are the advantages and disadvantages of using either or both the Sun and the Moon to define the cycle of the year? Which societies and peoples use either or both today?

Key Terms

There are three key terms that are highlighted in bold type in this Topic:

- constellation
- celestial sphere
- ecliptic

Flip through the pages of this Topic to find these terms. Add them to your class Word Wall along with their meaning. Add other terms that you think are important and want to remember.

CONCEPT 1

We see a variety of objects that appear in the sky in mostly predictable ways.

The things that you can see in the night sky, tonight, are the same as those that the first humans saw when they themselves looked up. Perhaps people with finely tuned eyesight can make out a few more details or even notice a dim star that you can't. However, until the telescope was turned to the sky in the early 1600s, the sky of 10 000 years ago and the sky of today mostly reveal the same objects and events. What are these?

The activity that fills the rest of this Concept tours and provides questions about some of the sky objects that are visible to the unaided eye. You will also be invited to add your own objects and questions.

Activity

A Tour of Visible Sky Objects

Use the questions below and the questions that appear with each photo to share, collect, and evaluate your ideas about visible sky objects.

Questions To Guide and Inspire Ideas

- How might place affect what you see in the sky? For example, how might observations from Prince Rupert compare with Yellowknife, Grand Forks, Tucson, or Mexico City? What if you lived in a valley, on the coast, or at a high elevation?
- What questions would you ask about these objects if you lived 10 000 years ago?
- What stories, past and present, do we tell about these objects and events, and how do they compare?

The Sun

The most obvious daytime object—the "ruler" of the daytime sky—is the Sun. **How does it appear to move in the sky? What path does it follow? Is it always visible each day? Why is the Sun equated with leadership and power in so many cultures?**

The Stars

On a clear, dark night, you can see about 5000 stars. **How do stars compare with one another in terms of location, colour, and brightness? How do they appear to move? Is there anything significant about the path they follow? Is there something special about the star in the north that never seems to move at all? Why do stars disappear when the Sun comes out? What patterns in appearance and movement are there, and how could they be understood or used?**

The Moon

The only moon that is visible to the unaided eye is our own. **How does the Moon change from night to night? How does its movement compare with the Sun? What patterns and movements can we observe? How can we use these observations?**

Five Planets

The only planets visible to the unaided eye are Mercury, Venus, Mars, Jupiter, and Saturn. **Are they always visible? How do they move, and how does that compare with stars and other sky objects?**

Over To You

Other objects and events that are visible to the unaided eye include comets, meteorites (shooting stars), "guest stars" (novas and supernovas), and the Milky Way. Are there others? Find images, and write one or two sentences to describe them. Then record questions (and answers) like those in the rest of this activity.

Before you leave this page . . .

1. How might people of the past have thought about the "universe" based on the objects and events they could see in their skies?

Evidence of People's Observations of Sky Objects Long Ago

How do we know that people of the past observed and recorded the sky objects you are now familiar with from the previous page? We know because they left evidence of what they saw and studied. You saw one example of this—a medicine wheel—at the start of this Topic. Figure 4.3 shows another example. This tiny piece of ivory from 32 000 years ago records a glimpse of what its maker saw in the sky. The mammoth tusk, found in Germany, is thought to show a pattern of stars in the night sky—possibly the constellation we call Orion.

Figure 4.3 The pose of the human figure on this ancient ivory is similar to the pose of the figure that later cultures saw in the stars of Orion.

Another example was left by ancient cousins of ours, the Cro-Magnon people, who lived in Europe more than 15 000 years ago. See Figure 4.4. They used their observations of the changing night sky to draw the first-known lunar calendar on cave walls near Lascaux, France. The 29 dots represent the 29 days of the Moon's cycle of phases. (It takes 29.5 days for the Moon to complete a full cycle from one new Moon to the next.)

Figure 4.4 This stunning painting is one of about 2000 made deep in caves in southern France 15 000 to 17 000 years ago.

One of the most famous monuments in the world is Stonehenge on England's Salisbury Plains (Figure 4.5). Although much of its purpose continues to be studied, the structure suggests one function was as an astronomical observatory. Built starting about 5000 years ago, Stonehenge is a circular arrangement of giant stones and boulders used to mark the movement of the Sun, the Moon, and their eclipses. The entrance aligns with the rising Sun on the summer solstice (longest day of the year).

Figure 4.5 Among its functions, some understood and some not, Stonehenge is a type of astronomical observatory, with key stones in alignment with the rising Sun and other sky objects on specific days and nights of the year.

In nearby Ireland, and dating from roughly the same time, is the tomb monument of Newgrange. As shown in **Figure 4.6**, the rising Sun on the winter solstice aligns with a passage and chamber built within this 80 m-diameter structure.

Figure 4.6 A UNESCO World Heritage Site, Newgrange is located about an hour car-drive north of Dublin in a place called Brú na Bóinne. People were farming and building great monuments here at least half a millennium before the great pyramids were being built in Egypt.

Records of sky observations were not limited to the stars, Sun, and Moon. The Maya of Central America are renowned for their meticulous observations of planets. For example, the Dresden Codex, shown in **Figure 4.7**, includes detailed mathematical calculations for the planet Venus.

Figure 4.7 The Maya wrote in "fold-out" books called codices (singular codex). Of the thousands that existed before European contact, only four remain. The rest were burned. **Questioning: What things—both material and otherwise—were lost by destroying the Maya codices?**

Before you leave this page . . .

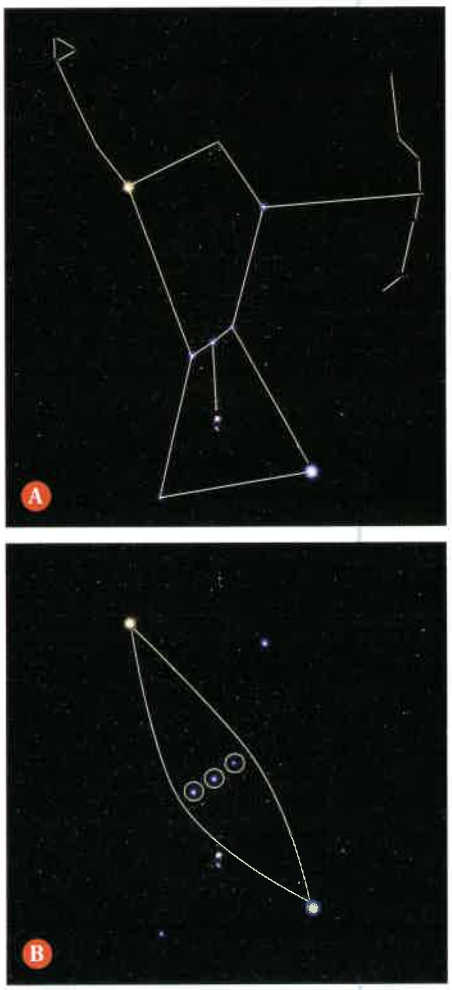
1. How do we know that people of the past observed the movements and patterns of sky objects?
2. How do you think people knew exactly where the Sun and other sky objects would rise on a particular day of the year?

CONCEPT 2

The appearance and motions of the objects we see can be described using a model called the celestial sphere.

Imagine you are a hunter thousands of years ago. You know the patterns of the night sky the way you know the land on which you live and the habits of the plants and animals that sustain you. On this day, you have followed the trail of animals to a place that is unfamiliar to you. As night approaches, you locate a safe spot, unfurl your bed roll, and lie back to stare up at the sky. Though the land on which you rest is new to you, the star-scape that twinkles down at you is much like what you know. The stars will guide you when is it time to return home. For now, their familiar patterns provide comfort. Beneath this sky you know, your sense of place, of home, is reinforced.

Figure 4.8 The stars that make up the constellation officially named Orion are shown in A. In B, the same stars are shown in the shape of a canoe.



Many peoples, both past and present, connect objects and events on Earth with objects and events in the sky. For example, many First Peoples noted that the appearance of certain patterns of stars and certain "faces" of the Moon marked the changing seasons. This helped them know when to plant and harvest crops, perform ceremonies, and carry out other aspects of life.

Stars were also used for navigation. People living in places surrounded by water had no land to use as a reference point, so stars were used as familiar "landmarks." Polynesians, for example, navigated the vast expanses between Pacific islands because of their understanding of stars, as well as of tides and currents.

Constellations

Over millennia, many cultures have observed that some stars in the night sky appear to form shapes. They named these shapes after heroes, animals, tricksters, and objects from their land, life, and stories. Today we call them **constellations**.

People used their imaginations to link up the stars like a huge connect-the-dots puzzle. Different cultures linked up the stars in different ways. For instance, ancient Greek skywatchers saw the stars in Figure 4.8A as making up the shape of Orion, a mighty hunter from their stories; the three stars at his waist are his belt. Some First Peoples saw in that same constellation and three-star grouping the shape of a canoe (Figure 4.8B). In southern Mexico, the Maya of a great city-state, Palenque, saw a turtle with the three stars forming part of its shell pattern. In the north the Inuit saw, instead, a bear chased by four hunters. The topmost star is the bear escaping by climbing high in the sky. Three hunters are in pursuit. The fourth hunter returned to Earth to retrieve a dropped mitten and remained to tell the story of the constellation.

constellation group of stars that form a pattern in the sky

Activity

Construct a Model Constellation

In the sky, the stars of a constellation look like they are all close to each other and at exactly the same distance from Earth. In fact, stars are separated from us and from each other by very large distances. Design a model to show how this is possible. Your model could be 3D, or you could render it on paper or digitally.

The International Astronomical Union lists 88 constellations. Orion is one of them. Smaller groups of stars that form shapes within the constellations are called *asterisms*, from the Greek word for star: *aster*. An example is one of the most famous and visible star patterns in the northern sky, the Big Dipper. The two end stars in its bowl are called "pointer stars", because they point toward the North Star, Polaris (Figure 4.9). Long before the invention of the compass, people used the North Star to tell direction.

Here in Canada, we cannot see all 88 constellations. There are about 20 that never rise above our horizon. These 20 can be seen only by people who live (or visit) south of the equator. Use Figure 4.9 to figure out why.

When European explorers of the 15th century first sailed around the world and travelled to places like Australia and South America, they saw these stars for the first time. The explorers imagined new constellations out of these stars, and they chose objects that were important to their lives, such as a ship, a clock, a microscope, and a compass.

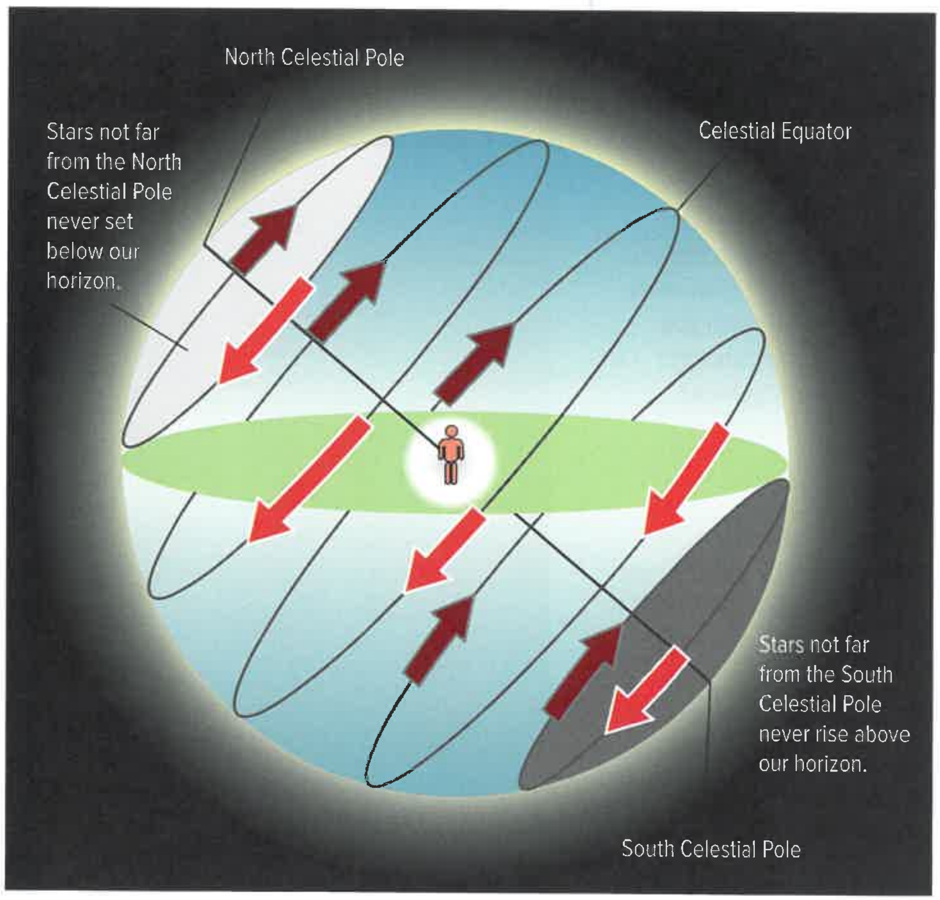


Figure 4.9 Imagine standing on flat land at night. As Earth turns, the stars appear to be on the inside surface of a sphere that moves slowly around Polaris, the North Star. You see stars in the sky above you. **Inferring: Can you see the stars in the grey area? Why or why not?**

The Celestial Sphere

From Earth, we observe the sky as it appears, not as it is. For millennia, people believed the sky to be a solid sphere with celestial objects in fixed positions. This imaginary sphere onto which all celestial objects are projected is called the **celestial sphere**. Today, we know that it is Earth that rotates, and not the sky. The celestial sphere extends around Earth. However, an observer on Earth can only see half of the sphere, the same way you can only see what is in front of you, and not behind (Figure 4.10).

celestial sphere an imaginary, rotating sphere on which lie all objects of the night sky

The celestial sphere is divided into northern and southern hemispheres by the celestial equator, which is an imaginary extension of Earth's equator projected into space. Astronomers mark the position of stars and other objects in the sky of each hemisphere using a grid system similar to latitude and longitude used on Earth. The North and South Celestial Poles are the imaginary points where Earth's axis of rotation extends out onto the celestial sphere above the North and South Poles on Earth. For observers in the northern hemisphere, the North Celestial Pole points very close to Polaris, the North Star. Even today, celestial navigation is widely used by sailors (Figure 4.11).

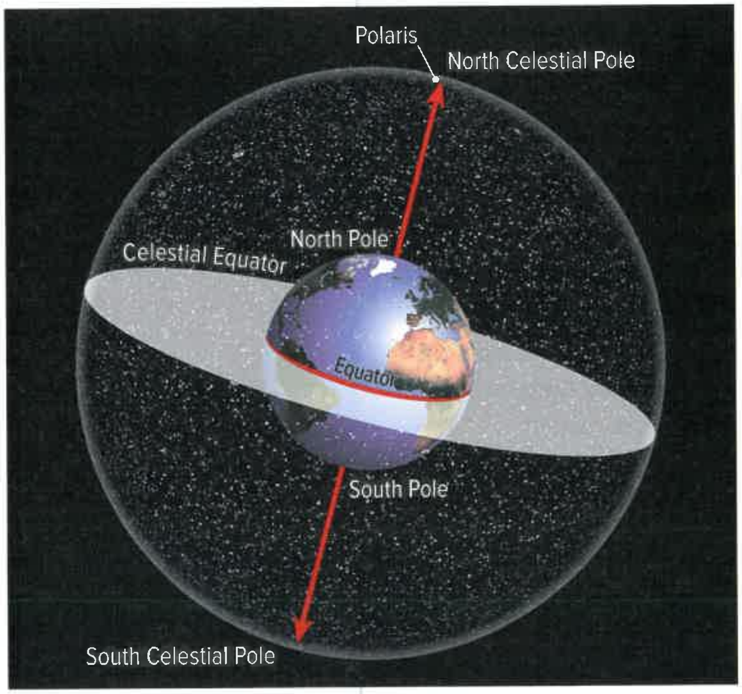


Figure 4.10 The celestial sphere **Analyzing: How does this diagram compare with Figure 4.9? How does examining each help you understand the concept of the celestial sphere?**

Figure 4.11 Modern technologies are widely used to navigate ships at sea. But batteries can run out, and GPS can malfunction. As a result, many navies and coast guards around the world have resumed learning the ancient art of celestial navigation, using an angle-measuring device called a sextant.

The Ecliptic

Over one year, the Sun seems to move against the constellations of the celestial sphere. The Sun's path across the celestial sphere is called the **ecliptic**, and is caused by Earth's orbit around the Sun. The ecliptic is best observed looking up at the sky toward the southern horizon (Figure 4.12).

ecliptic path the Sun and some other sky objects appear to take across the celestial sphere

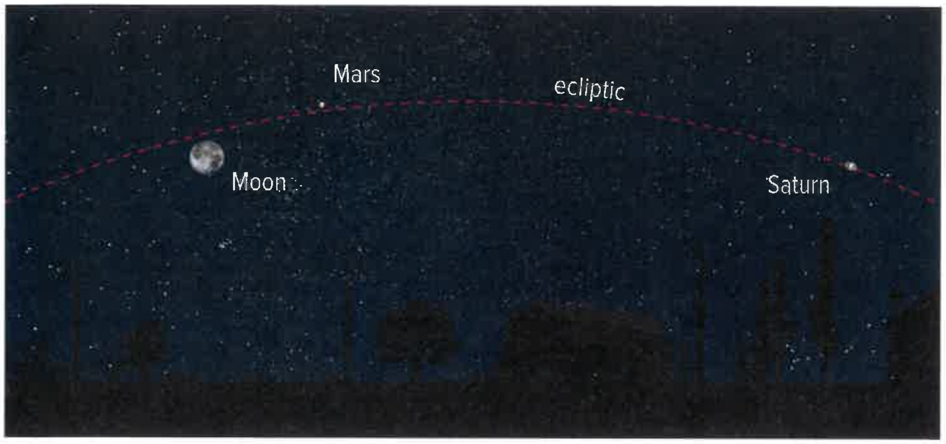


Figure 4.12 The ecliptic is an important reference pathway that helps us locate the positions of the Sun, Moon, planets, and constellations. (The ecliptic gets its name from the similar-looking word, eclipse. Eclipses of the Sun and Moon occur along or near the ecliptic.)

Changing Views of the Night Sky

You know that Earth's rotation causes celestial objects to appear to move across the sky from east to west. The distance of celestial objects can also play a role in how they are observed from Earth. For example, because the planets are much closer to Earth than the stars, their path along the ecliptic over time appears to change with respect to the constellations. A planet can be distinguished from a star in the night sky by observing its motion over weeks or months.

In addition, our view of the night sky changes with each passing season due to Earth's revolution around the Sun. For example, if we observe the northern hemisphere's night sky in winter we see stars that are opposite the Sun. The stars that are in the same direction as the Sun will only be in the northern hemisphere's sky during the day and will not be visible (Figure 4.13). Therefore, the constellations we see in the night sky are not the same at all times of the year.

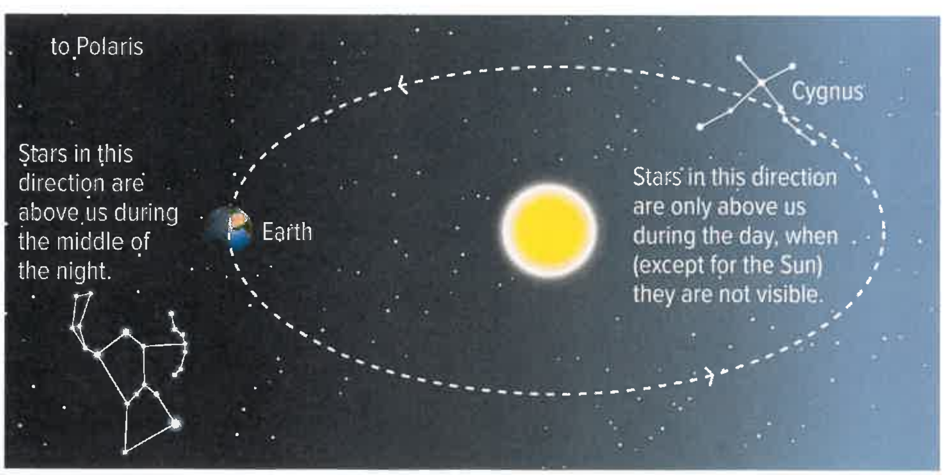


Figure 4.13 Orion is visible in the northern winter sky because it is opposite the Sun during that time. However, Cygnus is in the northern winter sky during the day, so it cannot be seen.

Retrograde Motion

Ancient astronomers observed that certain "stars" seemed to wander among the background of fixed stars. (These "stars" are really planets, from the Greek *planetes*, meaning wanderer.) As days pass, these objects appear to slow, stop, reverse direction, and loop back across the sky. This *retrograde motion* occurs because Earth orbits the Sun faster than the outer planets do. For example, as Earth passes Mars in its orbit, Mars seems to stop and then move backward. Earth continues past Mars, and forward motion appears again in the sky (**Figure 4.14**).

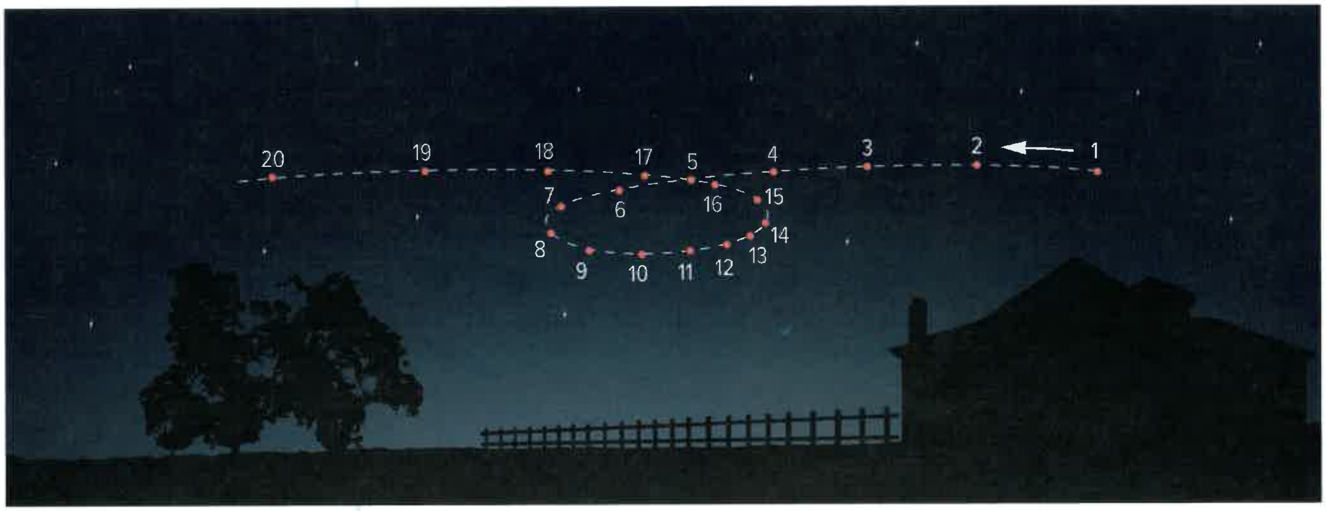


Figure 4.14 The position of Mars compared to the background stars during a period of retrograde motion. Each dot represents the planet's new position every 10 days over the period.

Activity

Demonstrate Retrograde Motion

1. Find a partner. One of you will represent Earth, and one will represent Mars.
2. Stand beside your partner. Mars walks slowly forward from the starting point. Earth stays at the starting point, pointing at Mars as Mars moves forward, as shown in the photo.

3. Earth leaves the starting point while still pointing at Mars, moving quickly to overtake the slower-moving Mars.
4. As Earth overtakes Mars, Earth begins to point backwards, as shown in the photo. This illusion of backwards motion is retrograde motion.

5. Switch roles, and repeat steps 2 to 4.
6. a) Why is retrograde motion visible only with planets farther from the Sun than Earth?

   b) While in retrograde motion, in which direction does Mars appear to move with respect to the background stars?

Navigating the Night Sky

Finding your way around the night sky can seem confusing at first. The first step is to learn how to describe the location of celestial objects that you can see with the unaided eye. In geography, latitude and longitude are used to pinpoint a place or object on Earth. For navigating the sky, one method you can use involves celestial coordinates called azimuth and altitude to describe the position of a celestial object relative to an observer on the ground for a particular time and place.

Azimuth and Altitude

Azimuth is the distance measured from north along the horizon to a point directly below the celestial object. North has an azimuth of 0°, east has an azimuth of 90°, south has an azimuth of 180°, and west has an azimuth of 270°. Altitude is the angular height of a celestial object, measured from the horizon. Figure 4.15 shows how the degrees of azimuth and altitude are measured.

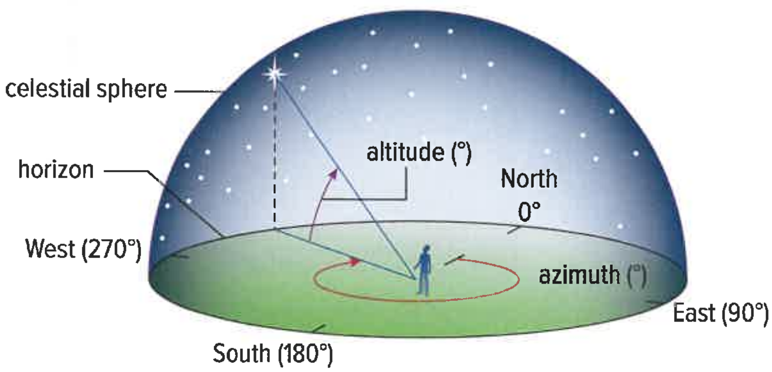


Figure 4.15 You measure azimuth and altitude with reference to the horizon.

You can use your hands to measure angles for determining the positions of celestial objects. For instance, when you hold your hand out at arm's length, the width of your index finger is approximately equal to 1° (Figure 4.16A). The width of a fist at arm's length is approximately equal to 10° (Figure 4.16B). If you extend the fingers of your hand, the width from the tip of your pinky finger to the tip of your thumb is approximately equal to 20° (Figure 4.16C). In this way, you can estimate the altitude and azimuth coordinates of any celestial object in the sky. Data obtained in this manner are relative to your position on Earth.

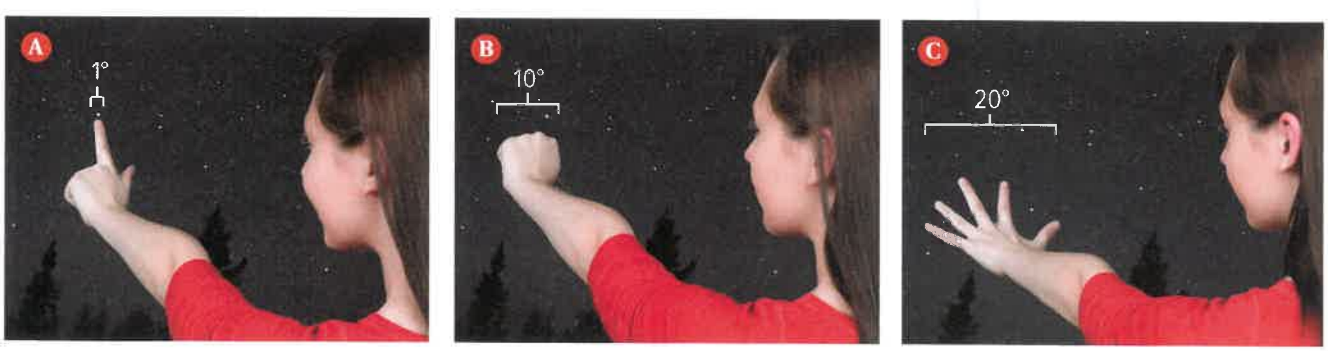


Figure 4.16 You can use your hand to estimate angles between objects in the sky.

Activity

Estimating Altitude and Azimuth

This activity is written using the Moon. However, your teacher may choose a different object depending on time of year and if the activity is being done during the day or evening. You will need a compass and notebook or digital recording device. There must be a trusted adult present as a safety precaution.

1. As your teacher instructs, go to a safe open area such as a park or parking lot.
2. Use a compass (or Polaris) to find north.
3. Start by facing north with your fists outstretched at eye level.
4. Keeping your arms straight out in front of you at eye level, use your fists as measuring tools while you slowly turn in a clockwise direction toward the east. Continue measuring until you reach the spot on the horizon directly below the Moon. Remember that each fist represents 10°.

5. You can also use your fingers to measure smaller increments as you get closer to the Moon. Each finger width is 1°.
6. When you reach the spot directly below the Moon, stop counting. The value you have counted, in degrees, is the azimuth of the Moon from your location on Earth.
7. With your arms still outstretched at eye level, begin counting degrees with your fist in an upward direction until the top of your fist reaches the Moon. Again, use your fingers to measure smaller increments as you get closer to the Moon. When your fist reaches the Moon, you have determined the altitude of the Moon from your position on Earth.

8. Record your results.
9. Compare your results with those of your classmates. Why do you think they are not exactly the same? Does that make this method invalid? Give reasons to justify your answer.
10. Would the altitude and azimuth of the Moon (or any other celestial object) be the same for people in different parts of the country? Why or why not?

Before you leave this page . . .

1. Using a globe as a guide, describe where you might find the celestial sphere, celestial equator, and celestial poles.
2. How can you distinguish a planet from a star in the night sky?
3. Use a sketch to explain the meaning of azimuth and altitude.
4. Describe how you can use your hands to determine the position of sky objects.

Check Your Understanding of Topic 4.2

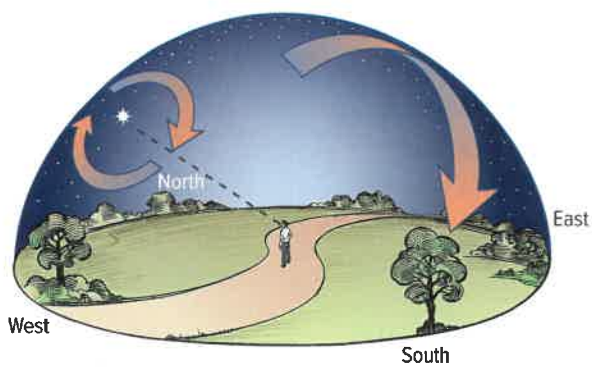
QP Questioning and Predicting PC Planning and Conducting PA Processing and Analyzing E Evaluating AI Applying and Innovating C Communicating

Understanding Key Ideas

1. Describe two ways that people have used motions of sky objects in relation to their daily lives. PA

2. How are constellations and asterisms similar and different? PA

3. Use the diagram to help you explain
   a) the direction that stars in the night sky appear to move
   b) why the star in the north has special significance to skywatchers who live north of the equator QP PA



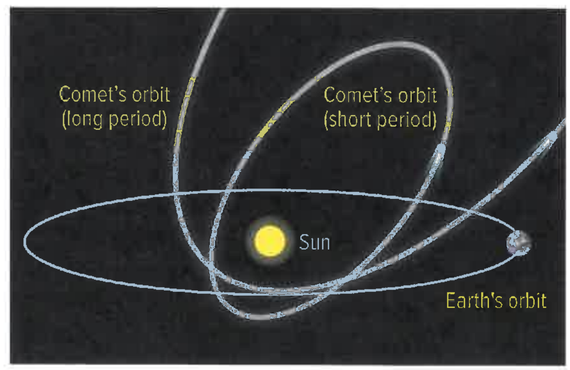
4. Everyone living in the northern hemisphere generally sees the same pattern of stars. If this is the case, why have the constellations and asterisms been interpreted in so many different ways? Give reasons for your views. E AI C

5. The International Astronomical Union lists 88 officially recognized constellations. Why can you not see all of them in the Canadian sky? PA

6. Some constellations represent signs of the zodiac and are associated with specific seasons. Why do we see different constellations at different times of the year? QP PA

Connecting Ideas

7. a) What is the name of the path across the sky that the Sun seems to follow?
   b) The planets follow the same path through the sky that the Sun appears to follow. Unlike these objects, when comets are visible to us, they can appear anywhere in the sky. Use the diagram below to infer why. AI



8. Imagine that you are lost in a desert at night. The desert is in the northern hemisphere. Explain how you could determine the four directions. AI C

Making New Connections

9. When you observe the sky at night, you can see hundreds or even thousands of tiny specks of light. Some are brighter than others, and some appear larger than others. Thousands of years ago, ancient astronomers noticed that some of the objects were different than others. These were planets. Describe at least two observations that you could make without telescopes that would suggest planets are different from stars. AI C

10. Would you search for a planet in the constellation Orion or Cygnus? Why or why not? AI

AT ISSUE Ursa Major: How many stories over time and space?

What's the Issue?

The name Ursa Major is Latin for "great bear," and the Romans inherited many of their tales about this constellation from the Greeks. However, stories from other ancient cultures saw different objects, animals, and beings in these stars. For example, Hindu astronomers saw the seven stars of the Big Dipper as seven great sages, ancient Egyptians saw a crocodile, and Babylonians saw a wagon. No doubt, many stories about this constellation have been lost to history. Perhaps they were never recorded orally or in writing. Perhaps they were never shared with anyone at all. We can, however, explore the lore and lessons that have been shared with us from various peoples of various times and places.

For example, in one First Peoples story, the stars forming the handle of the Big Dipper are three hunters chasing a bear. Because the stars are low in the sky during autumn, it is said that the hunters had injured the bear. Blood from the bear is turning the leaves red. Nova Scotia Mi'kmaq and St. Lawrence River Iroquois tell stories in which one of the handle stars is a hunter carrying a bow and arrow to kill the bear; another is a hunter carrying a pot to cook the bear in; and the third handle star is a hunter carrying firewood to use to heat the pot.

One of the ancient Greek stories told that Zeus, king of the Greek pantheon, changed a woman named Callisto into the great bear to save her from queen Hera. As a bear, Callisto was safe from Hera but was in danger of being killed by hunters. Callisto's son Arcas tried to kill her, not knowing the bear was his mother. Zeus changed Arcas into a bear too, to prevent him from killing Callisto. The pattern of stars representing Arcas is known as Ursa Minor, or Little Bear.

In many African cultures, the stars that make up the Big Dipper represent a drinking gourd. Africans who were enslaved in North America sang songs about the gourd and may have used the constellation to travel north to escape slavery.

An Arabic story interprets the stars in the Big Dipper's bowl as a coffin and the three stars in the handle as mourners following the coffin.

In China, the stars of the northern sky, including those of the Big Dipper, were part of a vast celestial empire that mirrored kingdoms and dynasties on Earth. Just as the terrestrial empire revolves around the emperor, the hub of the celestial empire was Polaris, around which all the northern stars circled.

From India, the seven stars of the Big Dipper were the Saptarishis, the seven semi-immortal sages whose stories appear notably in the longest-known epic in Earth's history, the *Mahabharata*.

Dig Deeper

Collaborate with your classmates to explore one or more of these questions—or generate your own questions to explore.

1. The names of the stars that make up the handle of the Big Dipper are Arabic: Alioth, Mizar, and Alkaid. The official names of many of the stars come from astronomers of the Islamic world. What role have they played in the history of astronomy, and what contributions have they made to our knowledge and understanding of the night sky?
2. The seven stars that make up the Pleiades (PLEE-ah-deez) are also known as the "seven sisters." This grouping is not a constellation, but it is a powerfully evocative cluster of stars for many peoples through human history. What can you discover about the lore and lessons of the Pleiades?
3. Imagine that you have been asked to contribute to a new program for BC's Knowledge Network called *Star Wisdom Planetarium*. Find or develop a story (old or new) about Ursa Major or a constellation of your choice. Your story can be in the form of a narrative, graphic novel, song, mural, or other creative work.

INVESTIGATION

4-A

STRUCTURED INQUIRY

Using a Star Map

Skills and Strategies

- Processing and Analyzing
- Evaluating
- Communicating
- Applying and Innovating

What You Need

- star map (from your teacher)
- ruler
- "Using Star Maps" in Appendix A

In this Investigation, you will learn how to use a star map. Star maps show the constellations and bright stars that are visible at a certain time of the year. The star map you will use can be used throughout the year and is specific to the northern hemisphere.

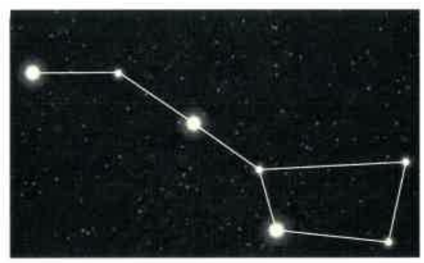
Question

How can you use the Big Dipper to locate other constellations?

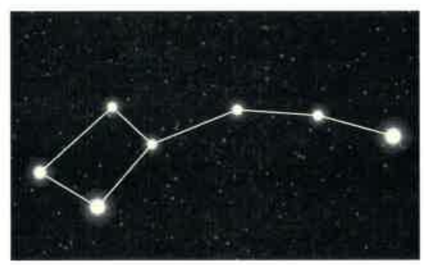
Procedure

Part 1: Circumpolar Constellations

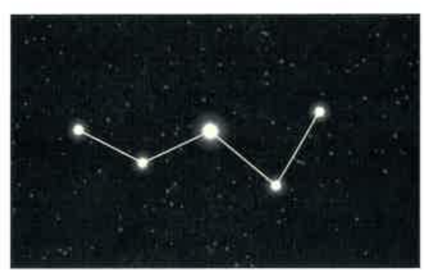
1. Look at the Big Dipper diagram below. Using a ruler, draw lines on your star map to join the stars of the Big Dipper.



2. Draw in the lines for the Little Dipper. Label the star at the tip of the handle "Polaris." Polaris is also called the North Star, because you need to face the geographic North Pole to see it.

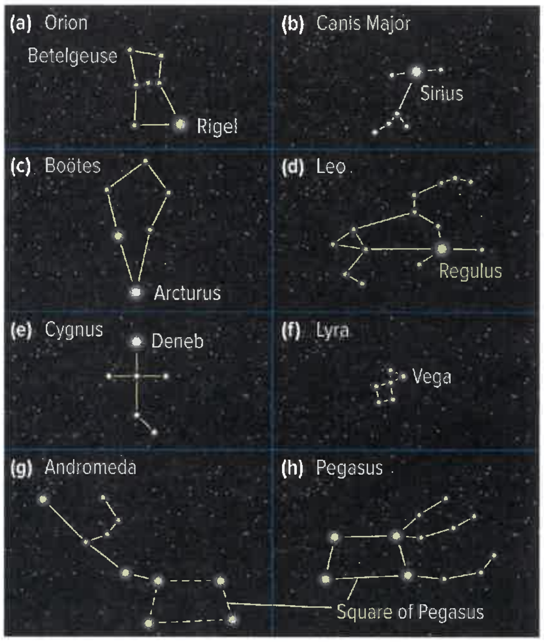


3. Locate the two stars of the Big Dipper farthest from the handle. These are called pointer stars, because you can use them to point to other constellations. Use them to draw a dashed line to Polaris.
4. Continue your dashed line until you reach Cassiopeia (Kah-see-oh-PEE-ah), which looks like a stretched-out W. Join its stars.



5. Label all three constellations on your star map.

6. Below are some other constellations visible during different seasons. Find the three stars in Orion that make up its belt. Draw in this constellation, which can be seen easily in December. Also label the stars Rigel and Betelgeuse (BEE-tuhl-juice).



7. Draw a dashed line to show how you would use Orion's belt to locate Sirius, the brightest star in the night sky. Draw Canis Major, which contains Sirius.

8. Locate and draw the constellation Boötes (boo-OH-teez) on your star map. To find it, first look for the star Arcturus, which is part of this constellation. Draw a dashed line to show how you would use the handle of the Big Dipper to find Arcturus.

9. Draw the constellation Leo on your star map. Leo contains the star Regulus. Draw dashed lines to show how you would use two stars of the Big Dipper as pointer stars to Regulus.

10. The three bright stars Deneb, Vega, and Altair form the Summer Triangle. Join them with dashed lines. Deneb and Vega are in the constellations Cygnus and Lyra. Draw these constellations on your star map.

11. Draw the lines for the remaining constellations on your star map. For each, use a dashed line from another constellation. When you have finished, share and compare your maps with the class.

Part 2: Locating the Zodiac Constellations

12. Notice there are still many unlabelled constellations on your star map. These are the zodiac constellations. They are visible during specific months, and the planets can be seen passing through them. You have already labelled one of the zodiac constellations, Leo. There are 11 more for you to find. The months in which they are best viewed are shown in the margin of the star map. Starting with Leo, label the rest of the zodiac constellations as follows: Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius, Pisces, Aries, Taurus, Gemini, and Cancer.

Conclude and Communicate

1. Which constellations are visible from Canada in all seasons?

2. Using your star map, identify two constellations that you can see from Canada during each of the four seasons.

3. Describe how you used pointer stars in the Big Dipper to find three other constellations.

Apply and Innovate

4. Look at your star map again. Can you find any other uses for pointer stars? Draw these uses with dashed lines, and describe them.

5. To locate the constellations at night, you stand facing north and hold the star map with the current month at the top. Why do you hold the star map this way?

INVESTIGATION

4-B

STRUCTURED INQUIRY

Skills and Strategies

- Questioning and Predicting
- Processing and Analyzing
- Evaluating
- Communicating

What You Need

- glue stick
- scissors
- copy of a star map and frame
- two file folders
- split pin

Modelling Motion in the Night Sky

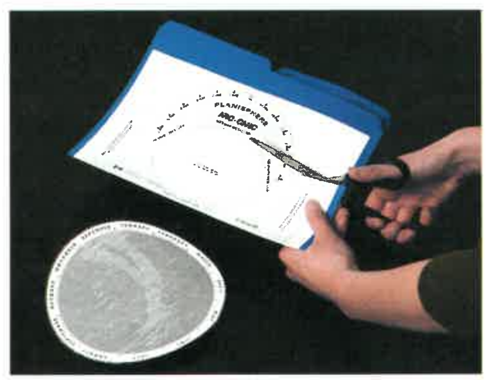
The motion of the stars in the night sky is caused by Earth's rotation around its axis and its revolution around the Sun. These are predictable movements. With careful observation, scientists can create models of the motion of celestial objects and predict where these objects will be at a later date. In this Investigation, you will construct a device called a planisphere to help you predict the positions of constellations in the night sky.

Question

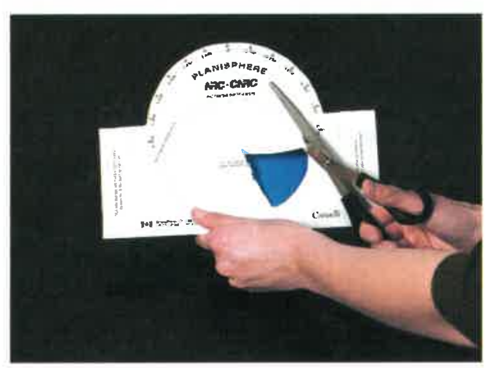
How can you use a planisphere to predict which constellations are visible in the night sky at a certain location and time?

Procedure

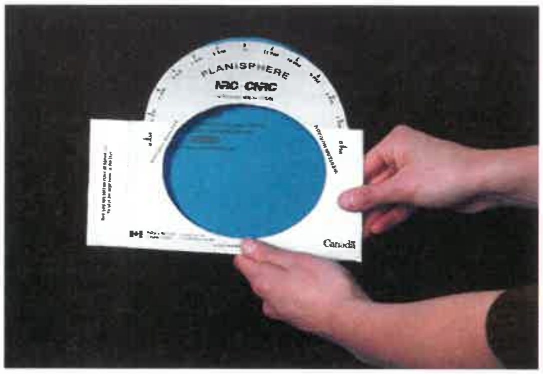
1. Obtain the materials you need to make your planisphere.
2. Glue the star map to one side of a file folder and cut it out.
3. Glue the star map frame to the second file folder so that the spine of the file folder is at the bottom of the frame.
4. Cut around the edge of the star map frame through both layers of the file folder.



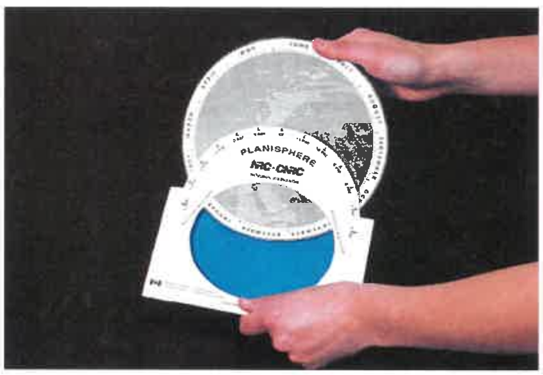
5. Cut out the inside of the star map frame through only the upper side of the file folder, so the backing is still uncut and shows through the inside of the frame.



6. Wrap the tabs around the back of the frame and glue them in place to the backing.



7. Slide the star map into the frame so that the constellations are visible through the frame.



8. Make a small hole through the star map and the backing at the location of the star Polaris.
9. Insert the split pin through the hole and fasten it so that the map can spin around this point.

Process and Analyze

1. Why do the constellations appear to rotate around Polaris?
2. Rotate the star map so that April 15 lines up with 8 P.M. Which constellations are visible on the southern horizon? Which ones are directly overhead?
3. Rotate the star map so that October 15 lines up with 8 P.M. How has the sky changed from your observations of April 15?
4. Rotate the star map so that today's date lines up with 8 P.M. Slowly rotate the wheel through 9 P.M., 10 P.M., and so on until the morning hours are visible. Describe the change in the position of the constellations throughout the night.

Evaluate and Communicate

5. Predict which constellations will be visible on the southern horizon during the winter solstice and the summer solstice. Use your planisphere to verify your predictions.
6. Rotate the star map so that it matches today's date. Which constellations will be visible tonight in the southern sky at 10 P.M.?
7. Why are the Sun and the planets not included on a planisphere?

Apply and Innovate

8. You can use the Big Dipper to tell time. Use your planisphere and your own ingenuity to help you figure out how this could be done. Check your ideas by researching online or using print reference materials.

TOPIC
4.3

How has technology expanded our knowledge and understanding of the universe?

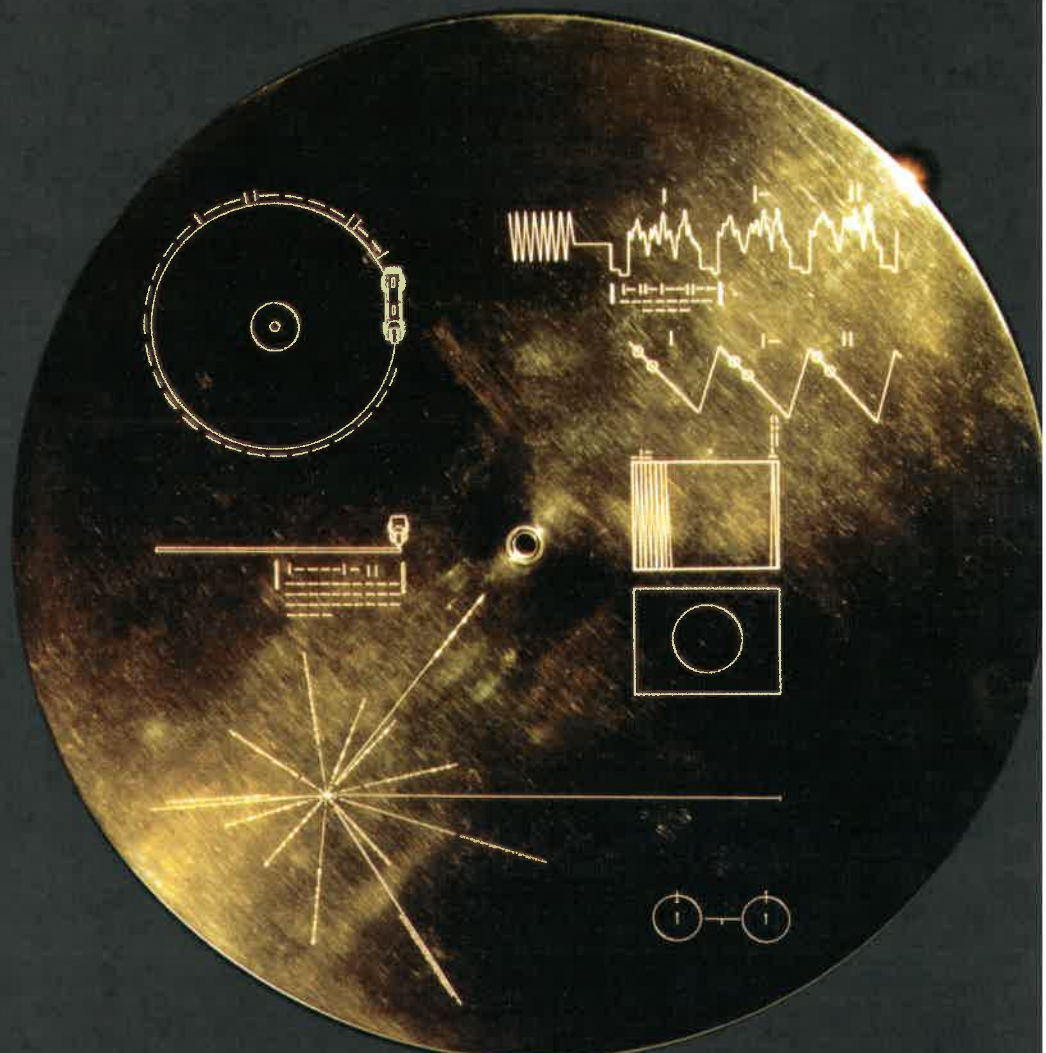
Key Concepts

- We have invented telescopes and other devices that extend and enhance our sense of sight.
- We know that our Milky Way galaxy is just one of many billions of galaxies in the universe.
- There are vast distances separating stars and separating galaxies.
- The properties of stars help us develop an understanding of their life cycles.

Curricular Competencies

- Construct, analyze, and interpret graphs, models, and diagrams.
- Analyze cause-and-effect relationships.
- Formulate physical or mental theoretical models.

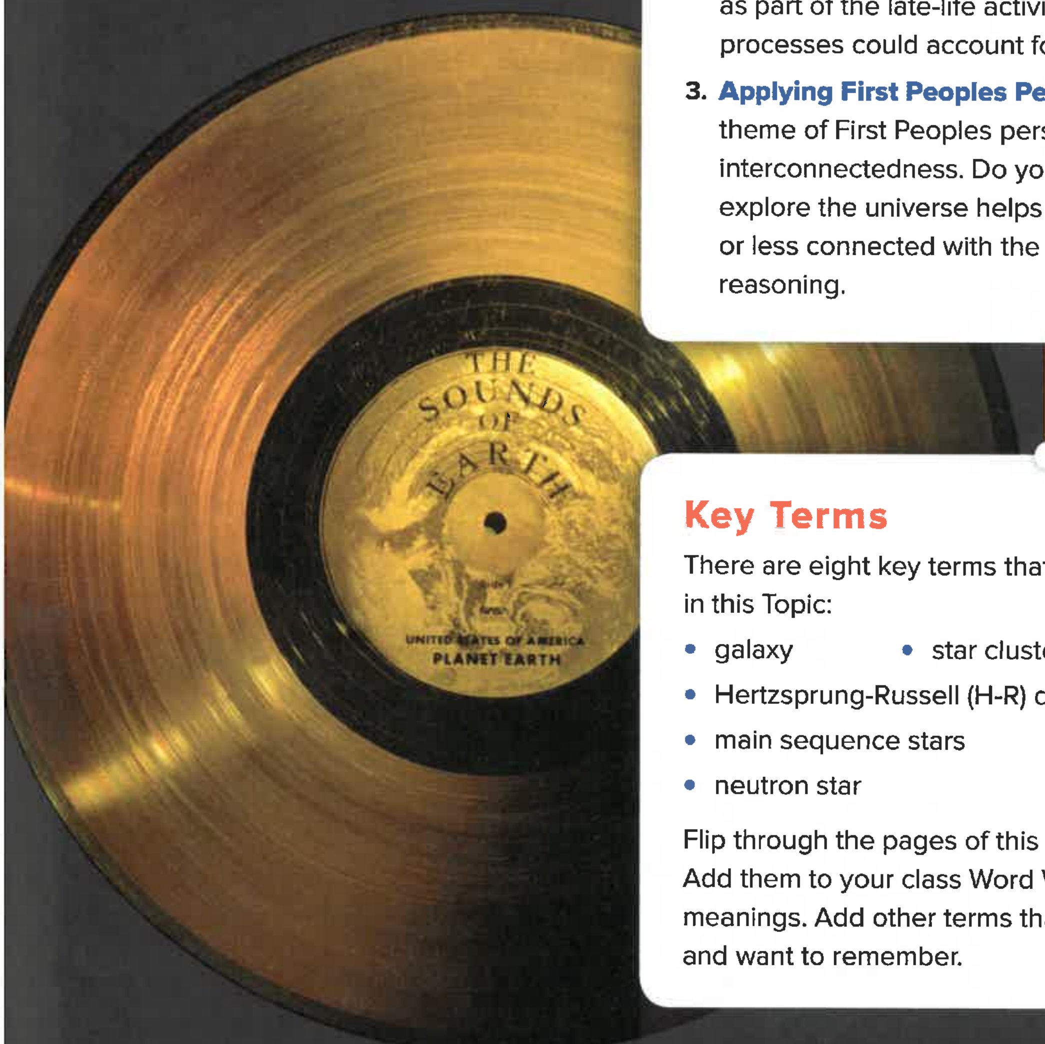
At this moment, more than 140 times the distance between the Sun and Earth, and counting, the *Voyager 2* spacecraft is hurtling at nearly 58 000 km/h through interstellar space. It carries gold-plated greetings, sights, and sounds from home, from us. And there is perhaps some irony in the fact that its lustrous gold came originally from the distant space into which it travels. Gold is thought to have been forged in cataclysmic cosmic events involving certain types of stars or star remnants in the late stages of their lives.



Starting Points

Choose one, some, or all of the following to start your exploration of this Topic.

1. **Communicating** You can access samples of the Voyager probe's golden record on the Internet. Because it was launched in 1977, many of the recordings on the golden record could fairly be called "golden oldies" by today's standards. If you were asked to create a new golden record to send into space, what sound, songs, and sights would you include? What would you be hoping to communicate to the universe with your choices?
2. **Questioning** How could gold (or any other element) form as part of the late-life activity of a star? What forces and processes could account for this?
3. **Applying First Peoples Perspectives** A key theme of First Peoples perspectives of science is interconnectedness. Do you think using technology to explore the universe helps us feel more connected or less connected with the universe? Explain your reasoning.



Key Terms

There are eight key terms that are highlighted in bold type in this Topic:

- galaxy
- star cluster
- light-year
- Hertzsprung-Russell (H-R) diagram
- main sequence stars
- supernova
- neutron star
- black hole

Flip through the pages of this Topic to find these terms. Add them to your class Word Wall along with their meanings. Add other terms that you think are important and want to remember.

CONCEPT 1

We have invented telescopes and other devices that extend and enhance our sense of sight.

Our exploration of the universe began with and depends on our sense of sight. As new technologies such as telescopes were invented, people began to use these tools to explore in new ways. By the time of Galileo Galilei in the early 1600s, the telescope had been invented. Galileo improved and turned this new instrument to the night sky and became the first person to observe moons around Jupiter and the rings of Saturn.

Telescopes of the type that Galileo used are called optical telescopes. They collect visible light from over a large area and concentrate it to form a brighter image. However, visible light is only one form of electromagnetic radiation that is given off by stars and other objects in space.

The ideal telescope would be able to detect not only visible light, but also radio waves and other forms of electromagnetic radiation. Such a device does not yet exist, but engineers have designed distinct telescopes that can detect non-visible radiation. One example is a radio telescope such as the one shown in **Figure 4.17**. Radio telescopes detect radio waves. Long-wavelength radio waves can penetrate clouds, so an advantage of using radio telescopes over optical devices is that they can be used on cloudy days as well as at night.

Figure 4.17 This 26 m radio telescope is part of the Dominion Astrophysical Observatory near Penticton. The observatory is owned and operated by Canada's National Research Council.

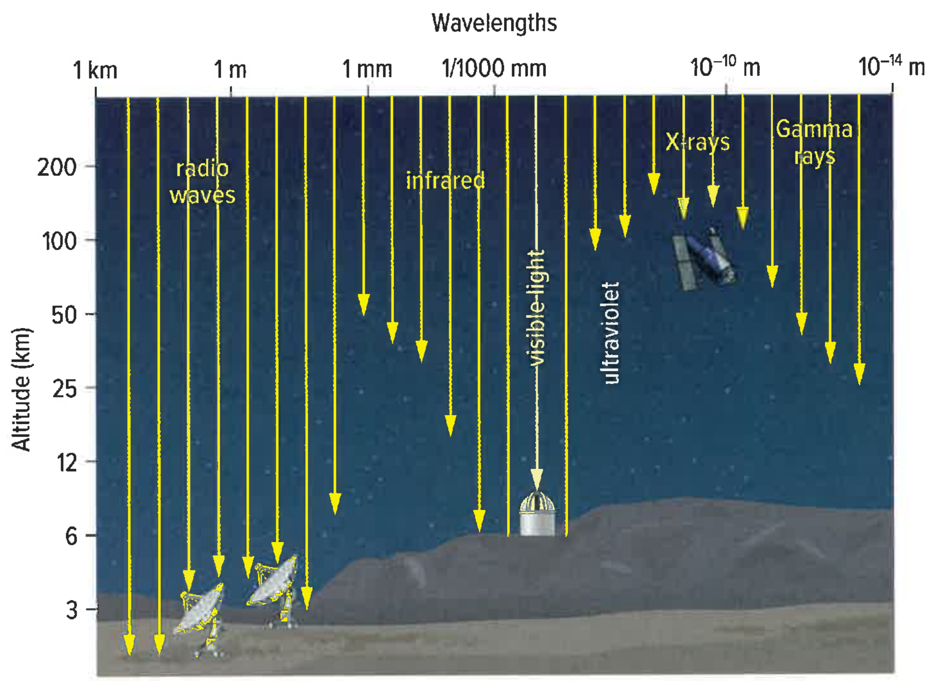


Figure 4.18 Only a fraction of electromagnetic radiation from space reaches Earth's surface. Therefore, some telescopes must be placed in orbit above the atmosphere to take advantage of the wealth of information the whole spectrum of this radiation provides.

Telescopes in Space

Much of the radiation that reaches Earth from space is absorbed by the atmosphere and does not reach the surface (Figure 4.18). For example, infrared radiation with a wavelength of 1 mm is absorbed about 50 km above Earth's surface. In order to observe space in more detail, some telescopes need to be placed above Earth's atmosphere. Some examples are the Chandra X-ray Observatory, the Spitzer Space Telescope (which detected infrared), and the Hubble Space Telescope. Hubble detects visible light as well as infrared and ultraviolet.

Studying Objects in Different Wavelengths

A range of telescopes can reveal different types of information about an object. For example, Figure 4.19 shows the planet Saturn in four different wavelengths. Comparing photo **A** and **B** reveals that Saturn has auroras (the glowing regions at the poles in **B**), just as Earth does. The infrared view in **C** shows detailed features in Saturn's atmosphere. The different colours represent different heights and compositions of the planet's clouds. Photo **D** shows that the planet gives off radio waves (the red portion) and that the rings (the blue) absorb this radiation.

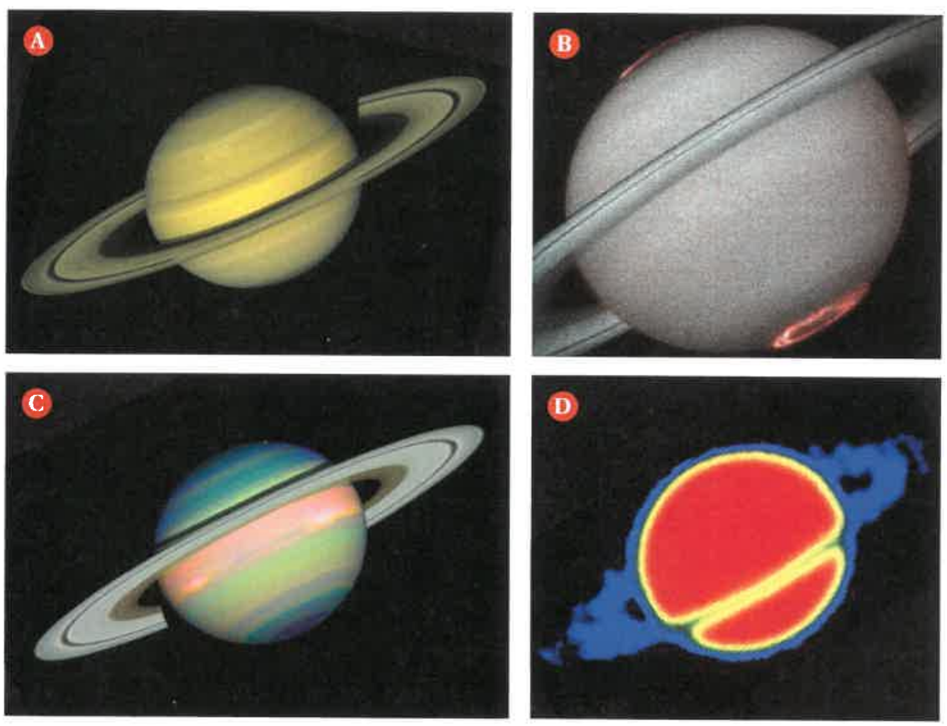


Figure 4.19 Saturn as viewed in visible light A, ultraviolet B, infrared C, and radio waves D. The colours in B, C, and D are false. They are added to highlight different features. **Applying: How does viewing the same object with different wavelengths affect our ability to understand it?**

Before you leave this page . . .

1. How did an optical telescope change the way that we can observe and explore space?
2. How do telescopes that detect non-optical radiation contribute to our understanding of space?

AT ISSUE Who has the MOST to lose?

What's the Issue?

It may be tiny and economical as space telescopes go. But an innovative Canadian satellite is making big discoveries that are currently out of reach of even the powerful Hubble Space Telescope. It is also helping to change the future of satellite design. MOST (Microvariability and Oscillation of Stars) is Canada's first space telescope. Launched in 2003, its mission is to uncover the secrets behind the life cycles of Sun-like stars.

With its onboard telescope, MOST measures tiny changes in the brightness of stars. Although the telescope is the size of a dinner plate, it is so sensitive that it can detect a change in the brightness of a star as small as one part per million. That is like looking at a skyscraper lit up at night and measuring the change in overall brightness when someone lowers a shade at one window by 3 cm. No other space telescope can do that.

MOST is able to monitor the same star for seven weeks and then send the data to Canadian-based ground stations. In comparison, the Hubble telescope can keep a star in view for only six days.

MOST has discovered new data that give astronomers clues about the Sun in its youth. For 29 days, MOST observed a "teenage" Sun-like star in the constellation Cetus (Whale), as well as a middle-aged Sun-like star in Canis Minor (Little Dog). MOST's observations support predictions of what we think the Sun was like when it was young.

With a mass of only 56 kg, MOST belongs to a class of compact satellites called microsatellites that are being placed in Earth orbit. These lightweight satellites cost much less to design, build, and launch than their larger counterparts.

The MOST satellite itself is about the size of a large suitcase, and it cost less than $10 million to develop and manufacture. In comparison, its larger cousin, the Hubble Space Telescope, is about the size of a school bus and cost more than $2 billion to develop. Astronomers and satellite engineers from the Canadian Space Agency, the University of British Columbia, and the University of Toronto, as well as Mississauga, Ontario-based company Dynacon Enterprises, worked together to design and build MOST.

Mission Over—Or Is It?

The MOST mission was originally planned to last one year, but its successes led to an extended life. Even so, in 2014, funding support was ended by the Canadian Space Agency. This did not deter UBC astrophysicist and MOST team leader Jaymie Matthews, who searched for and eventually secured a MOST excellent buyer: Microsat Systems Canada Inc. Astronomers are able to pay a relatively modest (by astronomy standards) sum to use the micro-satellite for a week or more.

Dig Deeper

Collaborate with your classmates to explore one or more of these questions—or generate your own questions to explore.

1. What are some of MOST's most impressive success stories?
2. Canada is a leader in developing miniaturized satellites. Its NEOSSat (Near Earth Object Surveillance Satellite) uses the same technology as MOST but is part of Earth's early warning system for asteroids and comets that could pose a threat to Earth in future. What other technologies and/or missions feature Canadian ingenuity and solutions?
3. Private aerospace companies such as SpaceX and Blue Origin both supplement and compete with publically funded organizations such as NASA and the European Space Agency. How has this commercialization affected the development of space-related science and technology?
4. What other space telescopes are currently in use or planned for the future? Which portion of the electromagnetic spectrum will they use to view objects, and what are the goals of the missions?

CONCEPT 2

We know that our Milky Way galaxy is just one of many billions of galaxies in the universe.

If you have viewed the night sky in a dark place, far from intruding urban lights, you have likely seen the Milky Way. Brightest in the summer, it appears as a hazy white band extending from the southern horizon and across the sky overhead (Figure 4.20). In fact, the band is a vast accumulation of about 400 billion stars that completely encircles Earth. The Milky Way is a **galaxy**—a collection of stars, gas, and dust held together by gravity. (The gas of a galaxy is made up mainly of hydrogen atoms. The dust is not like dust on Earth. Instead, space dust is made up of carbon and silicate particles about 100 nm in size.)

galaxy a collection of many billions of stars, plus gas and dust, held together by gravity

The Discovery of Galaxies

In 1610, using his telescope, Galileo became the first person to realize that the fuzzy Milky Way band was actually a collection of individual stars. It took another 170 years before further understanding of these stars developed. At that time, a British astronomer, William Herschel, was exploring the heavens. He and his sister, Caroline, were famous for building and selling fine telescopes. Together, using their inventions, they discovered that the Milky Way is a gigantic system of stars—what we now call a galaxy. Every star that you see in the sky on a clear night is part of the Milky Way galaxy.

Figure 4.20 In a dark sky, on a clear night, the Milky Way galaxy looks like a band of white in the night sky. The ancient Romans called it the *Via Lactea*, which means "way (or road) of milk." The term "galaxy" also comes from an ancient word (Greek, this time), *galactos*, meaning milk.

Activity

Model Galaxy Motion

Add about 250 mL of water to a 500 mL beaker. Hold it carefully, and swirl it slowly to give the water a circular motion. Put the beaker down, with water still swirling, and add a few drops of food colouring to the centre. Sketch your observations.

Repeat this process with water swirling faster and slower, and with a pinch of light, dry material such as dried oregano or cumin. Compare how the different materials behave in the swirling water. How is this model similar to real galaxy motion? What are the limitations of this model?

The Shapes of Galaxies

A galaxy forms when gravity causes a large, slowly spinning cloud of gas, dust, and stars to contract (draw together). The Sun is one of an estimated 400 billion stars in the Milky Way. All the stars in the universe belong to one of the billions of galaxies that exist.

Galaxies come in different shapes and sizes. Generally, they are classified as either elliptical or spiral, according to their appearance. Galaxies that do not fit into these general classifications are called irregular galaxies.

Elliptical galaxies vary in shape from spherical to a flattened oval (**Figure 4.21A**). They are older galaxies with very few young stars. Ellipticals account for 15% to 20% of all galaxies we can see.

Spiral galaxies look like pinwheels—flattened disks with a central bulge and two to four spiral arms (**Figure 4.21B**). Their central core is made of up old stars. The spiral arms contain clouds of gas and dust along with new and young stars. Our Milky Way is a spiral galaxy. A subclass of spirals are barred spiral galaxies (**Figure 4.21C**). They are similar to spiral galaxies, but they have a central bar pattern across the middle, with spiral arms trailing from the ends of these bars.

Irregular galaxies have no definite shape (**Figure 4.21D**). They contain more gas and dust than their spiral cousins. They have no spiral arms or central core, and they make up at least 10% of all galaxies.

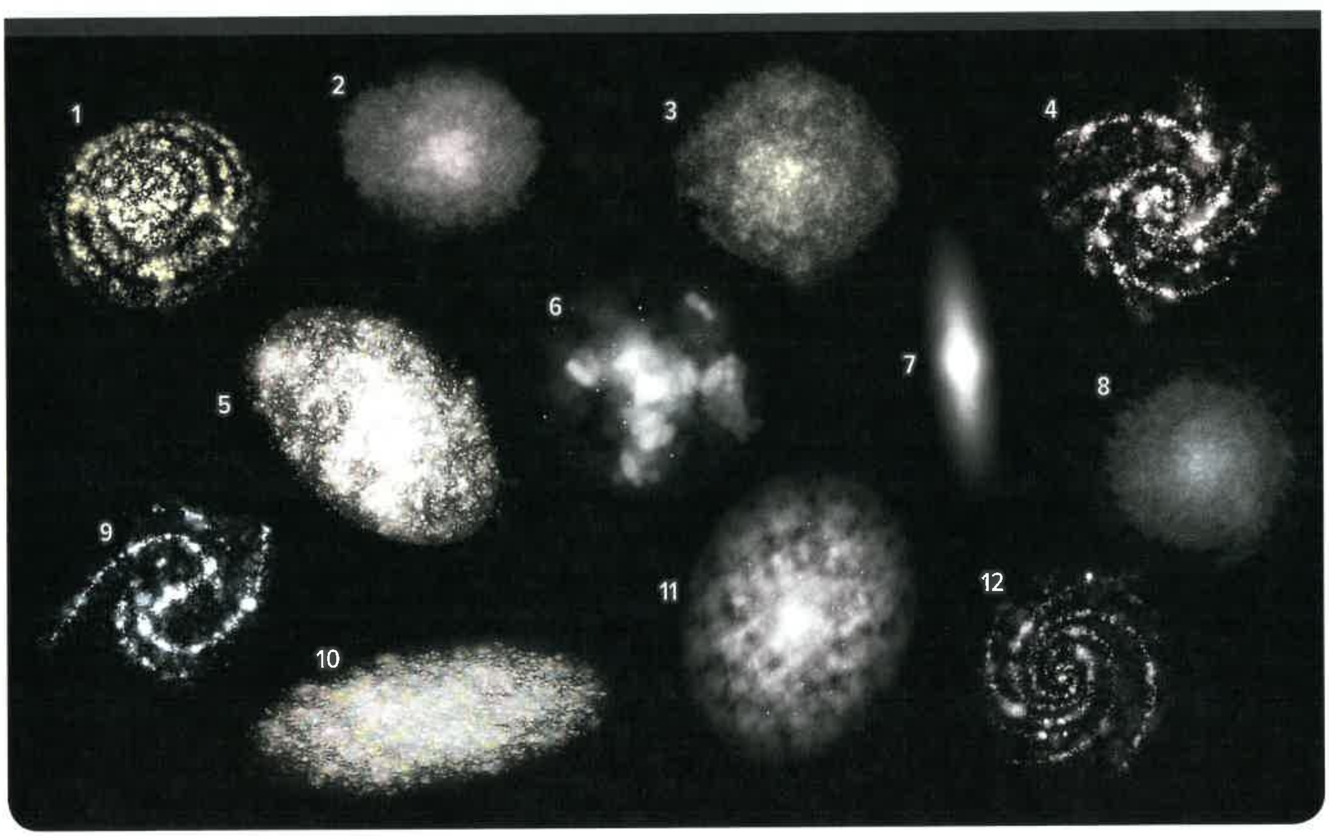
Figure 4.21 Main types of galaxies—an elliptical A, spiral B, barred spiral C, and irregular D.

Activity

Picturing Galaxies

Although astronomers can classify galaxies into different types based on their shape, it can be difficult to get clear images of their shape. Galaxies can be blocked by gas and dust or other celestial objects. Even when we get a clear view, the galaxy can be difficult to classify because of the angle we are observing it from.

1. Your teacher will give you four blank plastic sheets. Draw one type of galaxy in as much detail as you can on each of the sheets.
2. Have a classmate hold the sheets up one at a time on the other side of the room so they are facing you. Identify each type.
3. Have your classmate tilt each of the sheets at various angles while you try to identify the galaxy types.
4. Finally, have your classmate hold each sheet parallel to the floor while you try to identify the galaxy types.
   - Were the galaxies easy to identify on the other side of the room when they were facing you?
   - As your classmate tilted the sheets, did it become easier or harder to identify the types of galaxies?
   - When the sheets were parallel with the floor, could you see any detail that might help you decide what kinds of galaxies they were?
   - Explain how the angle of observation might make it difficult for astronomers to distinguish spiral galaxies from barred spiral galaxies.
   - The image below represents a random sample of galaxies from the universe. Decide how you would classify each galaxy, and give or discuss reasons in each case.



Understanding the Milky Way

It has taken astronomers many years to learn about the Milky Way galaxy. William Herschel started putting together the pieces of the puzzle. By counting stars, Herschel figured out the approximate shape of the Milky Way galaxy. Herschel proposed that the Milky Way is a huge disk of billions of stars, flattened like a dinner plate, in which the Sun is embedded. He also proposed that the Sun might be at the centre of the Milky Way.

Star Clusters

In the early 20th century, American astronomer Harlow Shapley helped to put together more pieces of the puzzle. While studying the Milky Way, he was also studying **star clusters**. A star cluster is a collection of stars held together by its own gravity. Like individual stars, star clusters are held inside or around galaxies by gravity. Figure 4.22 shows the two types: open clusters and globular clusters. Open clusters have 50 to 1000 stars and appear along the disk of the Milky Way. Globular clusters have a spherical shape with 100 000 to 1 000 000 stars.

star cluster a collection of stars held together by gravity

Shapley became interested in globular clusters in particular. He reasoned that globular clusters should be evenly distributed around the galaxy. He noticed, however, that they appear only in the direction of the constellations Hercules, Scorpius, Ophiuchus, and Sagittarius—not all around us. Shapley reasoned that his observations could only be explained if he were observing the globular clusters from a position well away from them. He concluded that if globular clusters were spread out around the Milky Way's centre, the Sun must be nowhere near the centre.

The Diameter of the Milky Way

Radio waves can travel through the clouds of Earth's atmosphere. They also can travel through the gas and dust between stars. By mapping the galaxy with radio waves, astronomers have been able to determine that its shape is disk-like and that its diameter is about 100 000 light-years across. (A light-year is the distance that light travels in one year: 9.5×10^{12} km. You will learn more about light-years and distances within and between galaxies in the next Concept.)

Figure 4.22 The Pleiades open cluster (A) is found in the constellation Taurus. Globular clusters (B) contain many more stars than open clusters do.

The Centre of the Milky Way Galaxy

Using radio waves as well as infrared radiation, astronomers next confirmed that the centre of the Milky Way galaxy is surrounded by a bulge of stars. Around the bulge, there is a sphere of globular clusters, as shown in **Figure 4.23**. When Shapley was observing globular clusters, he was looking toward the centre of the Milky Way galaxy and the halo of globular clusters that surround the galaxy from a position in the disk well away from the centre.

Figure 4.23 Globular clusters form a sphere around the centre of the Milky Way.

Some other Characteristics of the Milky Way Galaxy

Knowing that the Milky Way galaxy has a disk-like shape, with a central bulge of stars, astronomers have concluded that it is a spiral galaxy.

Using data from the European Space Agency's (ESA's) Gaia space telescope, which is creating a 3D map of our galaxy, astronomers from the University of Toronto have calculated our Sun's distance from the galactic centre to be 24 788 to 26 745 light years. With telescopes that use different parts of the electromagnetic spectrum, astronomers can also image various regions of the Milky Way (**Figure 4.24**).

Figure 4.24 The dark, reddish-brown areas across the centre of this image of the Milky Way galaxy are called lanes. This darkened zone is caused by enormous clouds of gas and dust that are blocking the light from the background stars in the galaxy. Using other electromagnetic frequencies enables astronomers to "see through" the lanes.

Galaxy Groups and Clusters

The Milky Way belongs to a group of about 50 galaxies called the Local Group. Some are shown in Figure 4.25. The diameter of the Local Group is about 10 million light-years. Our nearest comparable-size galactic neighbour is the spiral-shaped Andromeda galaxy. It lies about 2.6 million light-years away and is the farthest object in the sky that we can see with the unaided eye. The earliest recorded observation of the Andromeda galaxy was made by Persian-Islamic astronomer Abd al-Rahman al-Sufi. He described it as a fuzzy cloud in his famous *Book of Fixed Stars* in the year 964. Our galaxy is estimated to collide with the Andromeda galaxy in about 4 billion years.

Our Local Group belongs to a much larger collection of galaxies called the Virgo Supercluster. And this is just one of millions of superclusters in the universe!

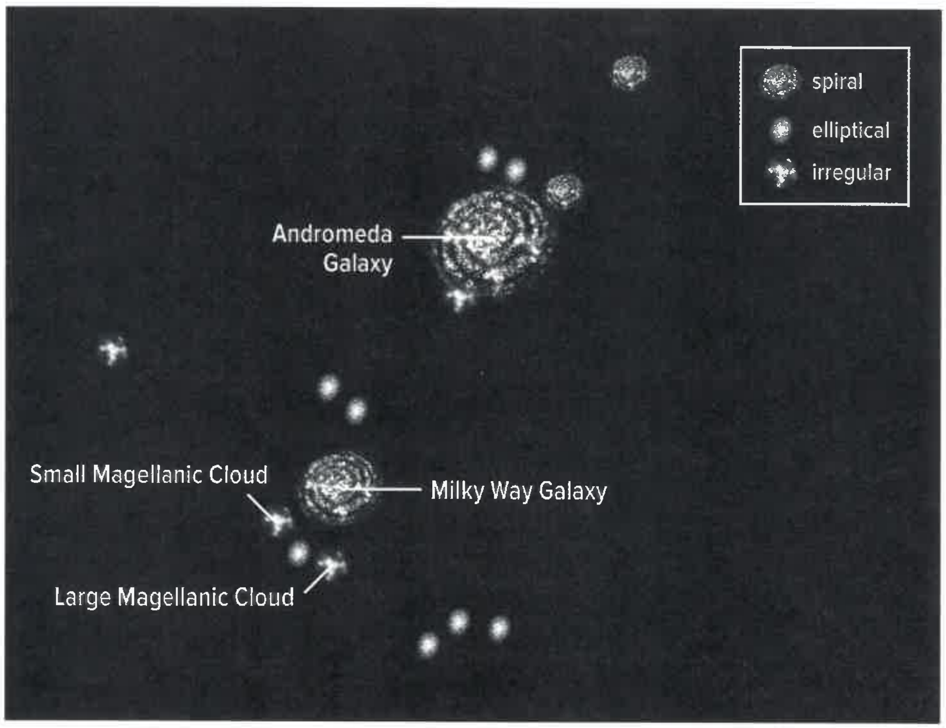


Figure 4.25 The Local Group, made up of many small irregular and elliptical galaxies, is dominated by two large spiral galaxies: our Milky Way and Andromeda.

Before you leave this page . . .

1. Compare the three basic shapes and sizes of galaxies.
2. How did we infer our position within the Milky Way galaxy?
3. How did we infer that the Milky Way is a spiral galaxy?
4. What is the Local Group?

Extending the Connection

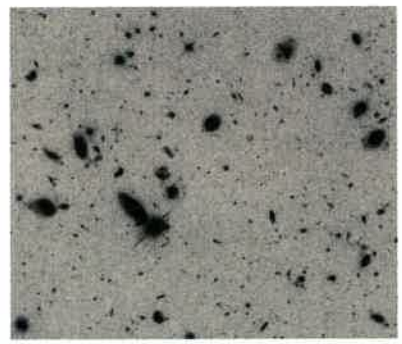
Determining our Distance from the Galactic Centre

Find out how U of T astronomers used Gaia to measure the speed and distance of our Sun's orbit around the centre of the Milky Way.

Activity

Counting Galaxies by Sampling

Have you ever wondered how scientists know how many hairs are on the average cat? Counting every hair on a cat would take a very long time. A mature domestic cat has about 3 million hairs. It would take more than a month, counting one hair per second, 24 h a day, non-stop, to count every hair. A more feasible (and realistic) strategy is to estimate the number using a technique called sampling. In this activity, you will use sampling to estimate the number of galaxies that the Hubble Space Telescope (HST) can observe in a small area of the sky.



Galaxies as viewed with the Hubble Space Telescope. The image inverts black and white to make it easier to count the galaxies.

1. Your teacher will give you a copy of the image shown here. Each group will study one section of the image.
2. Tally the number of galaxies in your section. Every small smudge on the image is a galaxy, except the smudges that have "spikes" radiating from them. The spiked smudges are stars. (The spikes are interference effects caused as light travels through the telescope.)
3. Collect the tallies for the other sections, add all the tallies together, and calculate the average number of galaxies per section.
4. Astronomers use degrees to represent measurements in the sky. For example, when measuring in degrees, the diameter of the full Moon is one half a degree, where the angle between the east horizon and the west horizon is 180°. One section in the image represents approximately 2.2×10^{-4} square degrees in the sky. The total area of the sky is 4.13×10^{4} square degrees. Estimate the total number of galaxies in the universe as follows:

$$\text{Total number of galaxies} = \frac{\text{total area of the sky in square degrees}}{\text{area of one section} \times \text{average number per section}}$$

$$= \frac{4.13 \times 10^{4}\ \text{square degrees}}{2.2 \times 10^{-4}\ \text{square degrees} \times \text{average number per section}}$$

- Approximately how many galaxies can HST see in this image?
- Why is it more accurate to average the tallies for all the sections to get the average number per section rather than use the results for a single section?
- Why is sampling more practical than trying to do a more detailed count?

Focus on Astronomy

What kinds of jobs involve astronomy?

- Astronaut
- Satellite Communications Operator
- Astrophysicist
- Radar Technician
- Aerospace Engineer

Space Educator

Space educators work at schools, museums, and planetariums like the one at Vancouver's H.R. MacMillan Space Centre. They need a solid understanding of astronomy and a talent for teaching or presenting.

Atmospheric Scientist

Some atmospheric scientists monitor disturbances in Earth's atmosphere due to space weather, such as solar radiation storms. They issue space weather alerts when storms threaten Earth's power grids, satellites, and radio communications.

Robotics Engineer

Robotics engineers design and build automated machines like the Canadarm2. This robotic arm is attached to the International Space Station. It helps transport supplies and equipment in space.

Questions

1. What other jobs and careers do you know or can you think of that involve astronomy?
2. Research a job or career related to Unit 4 that interests you. What attracts you to it? What kinds of things do you have to know, do, and understand for this job or career?

CONCEPT 3

There are vast distances separating stars and separating galaxies.

For distances on Earth, the kilometre serves us well. Within our solar system, it is more convenient to use the astronomical unit (AU). One AU is the distance between the Sun and Earth: 150 000 000 km. Thus, the Earth-Sun distance is 1 AU (Figure 4.26.) The distance from the Sun to the last planet of the solar system, Neptune, is about 30 AU. However, distances beyond the solar system are too great for AUs, since the distance to the closest star is more than 268 000 AU. This would be like measuring the distance from Victoria to Hope in metres.

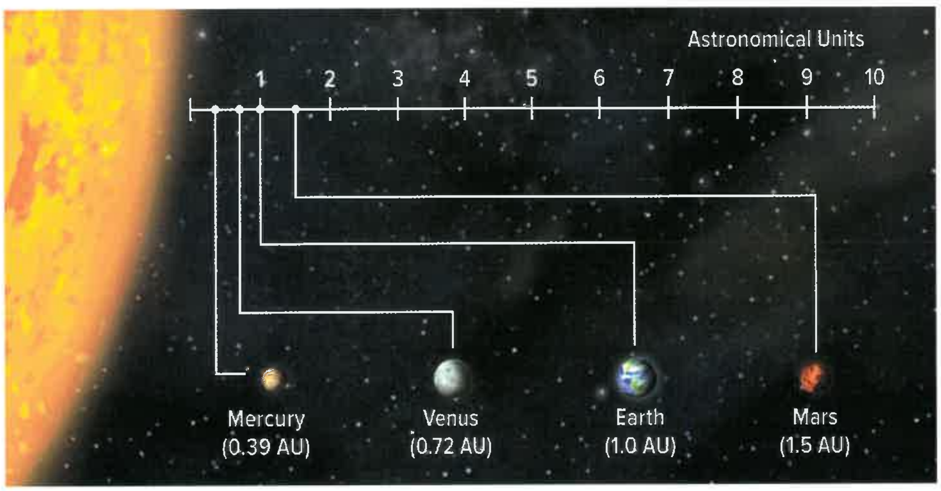


Figure 4.26 Using the AU to measure distances in the solar system is simpler and more convenient than using kilometres.

The Light-Year

Stellar and interstellar distances are typically measured in **light-years**. A light-year is the distance that light travels in a vacuum (empty space) in one year. In space, light travels at a constant speed of about 300 000 km/s. So 1 light-year (ly) is approximately equal to 10 trillion (9.46×10^{12}) km. Table 4.1 shows the distances of several stars and galaxies.

light-years a unit of distance equal to the distance light travels in one year

Table 4.1 Distance of Some Celestial Objects

Star or Galaxy	Approximate Distance from Earth (ly)
Proxima Centauri (star closest to ours)	4.24
Vega (part of the constellation Lyra)	25
Polaris (part of the constellation Ursa Minor)	400
Betelgeuse (part of the constellation Orion)	643 (plus or minus 46)
Deneb (part of the constellation Cygnus)	1400
Andromeda Galaxy (galaxy nearest to ours)	2 600 000

Extending the Connections

Why don't we know the distance to Betelgeuse?

Did you notice that value for Betelgeuse in Table 4.1? What are your questions, and how can you answer them?

Implications of the Light-Year

The farther a star is from Earth, the longer it takes for its light to reach us. For example, Vega is about 25 ly from Earth. The light from Vega travels at the speed limit of the universe—the speed of light. This means that it takes the light from Vega about 25 years to reach us here on Earth. When you observe Vega in the night sky, you see the light that has taken 25 years to reach your eyes. In other words, you see Vega as it was 25 years ago, not as it is today. It is, in fact, impossible to see Vega in "real time." You can't even see the Sun in real time. The light that travels from the Sun to Earth takes 8 minutes to reach us. The Sun is always 8 minutes old to our eyes. Whenever we look at celestial objects, with or without technology, we see what was, not what is. We are looking back in time.

Stellar Distances

Early astronomers discovered that over a period of weeks and months, the planets appeared to move against a background of stars. This led them to believe that stars are much farther away than the planets. However, we did not have a useful way to measure the distance between celestial objects or the distance between these objects and Earth.

Scientists have since developed various methods to measure interstellar distances—the distances between stars in our galaxy. One method, called *parallax*, relies on geometry. Parallax is the apparent change in position of an object against a fixed background when it is viewed from two different lines of sight. You can observe parallax using the method described in Figure 4.27.

A B

Figure 4.27 In A, a student looks through only his right eye as he lines up his thumb with an island in the distance. In B, the student views the same island through only the left eye, and the island seems to change its position. **Conducting: Try this out for yourself!**

Explaining Parallax

Figure 4.28 presents a different view of the phenomenon described in Figure 4.27. In Figure 4.28, each eye views your thumb (the object) from a slightly different position. This results in an apparent change in the position of your thumb when you close one eye. When you have both eyes open, your brain uses parallax to get a sense of the distance between your eyes and your thumb. If you move your thumb halfway to your nose, you can see that parallax increases as distance decreases.

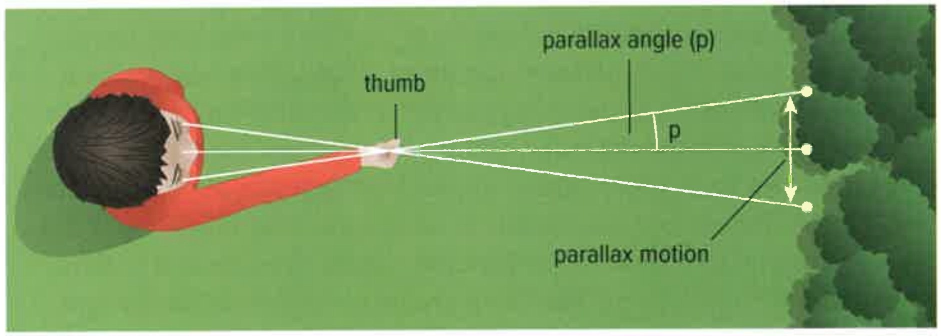


Figure 4.28 Parallax angle is the angle measured between two lines of sight, divided by two.

Parallax can be used to calculate the distance to stars using a method known as *triangulation*. With this method, if you know the length of one side of a triangle and the angles of two of the corners (vertices), you can calculate all the dimensions of the triangle.

Figure 4.29 shows how astronomers use triangulation to calculate the distance from Earth to a star. The diameter of Earth's orbit is the "known" side of the triangle. The star is then observed from two different positions in Earth's orbit around the Sun. To do this, astronomers observe the star and then wait six months to observe it again when Earth is at the opposite end of its orbit. The "triangle" formed by these observations can be used to calculate the distance to the star.

With the aid of extremely large telescopes, astronomers are able to use parallax to estimate the distances to stars as far as 100 ly away. For distances beyond this, using parallax becomes too imprecise. In the early 1990s, a unique satellite called HIPPARCOS (High Precision PARallax COllecting Satellite) was placed in orbit on a star-mapping mission. It was able to accurately measure star positions, parallaxes, and motions of stars up to 500 ly away. The ESA's Gaia telescope is measuring the parallax to about 1 billion stars in the Milky Way and other nearby galaxies.

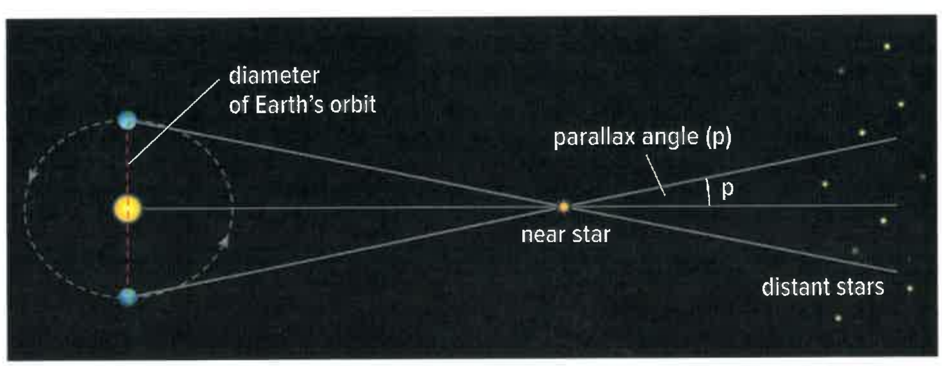


Figure 4.29 Because stars are distant, parallax must be determined from positions that are very far apart. **Innovating: Why is it ingenious to use Earth's orbit to determine the parallax of distant stars?**

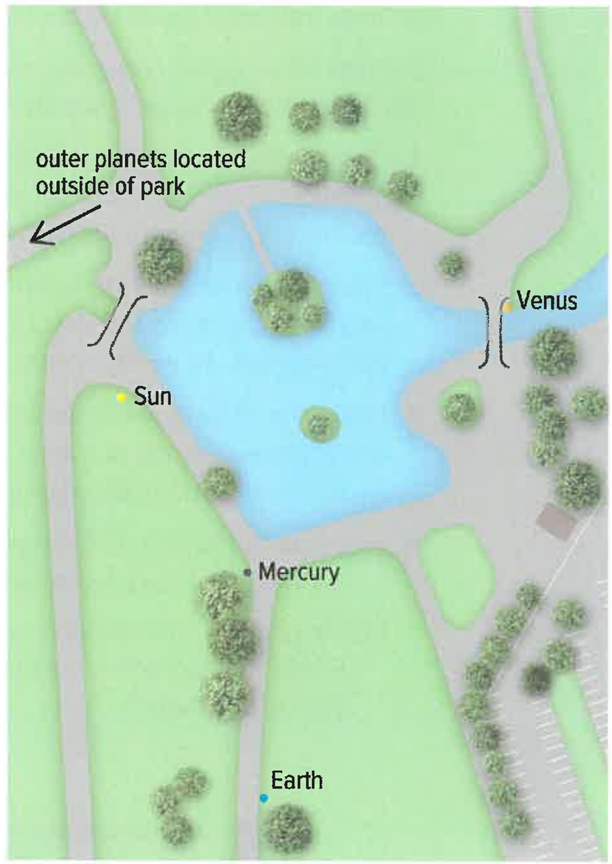
Activity

Cycle the Cosmos—A Local Community Distance Model

It began more than 25 years ago with a father's desire to help his fourth-grade child better understand the scale and structure of our neighbouring planets. Now, Alton Baker Park in Eugene, Oregon, is the site of a community-based model that enables people to walk (and ride) the distances separating the planets of the solar system. Similar models that map planets and planetary distances against places of interest have been designed in other communities around the world. What about yours?

In this activity, you are challenged to use your community as the foundation for a scale model of the solar system and beyond, far beyond. Go the distance—once you decide what the distance will be.

- What criteria will you consider to design a model that includes some of our interstellar neighbours?
- Is this a model that you can actually build in your community, or will you rely on virtual space to showcase it?
- Can you incorporate fitness, education, and/or other opportunities for community participation?
- What other decisions are needed to turn your ideas into reality?



Community-level scale model of the solar system at Alton Baker Park in Oregon: This model uses a scale of 1:1 billion and was designed to represent distances (and planet sizes) of the solar system. How can you include stars and galaxies that are more distant than the objects of our solar system?

Before you leave this page . . .

1. Describe a case where it might be convenient for astronomers to use **a)** AUs and **b)** light years.
2. Explain why kilometres are not adequate for measuring most distances in the universe.
3. The light-year is a unit of distance. Why does it seem like a unit of time?
4. How does parallax help us determine distance?

CONCEPT 4

The properties of stars help us develop an understanding of their life cycles.

Activity

Inferring Factors That Affect Brightness

Safety

Never use a laser pointer in place of a penlight or other small flashlight in this activity. Someone could be blinded.

For this activity, your group will use three flashlights—a small one (such as a penlight) and two larger ones identical in size and type.

1. One student stands at the back of the room holding one small and one large flashlight in each hand. At the front, with the room dark, have the student at the back turn on both flashlights. Record how their brightness compares.
2. Two group members stand side by side at the back, each holding one of the large flashlights. Again, stand at the front. Darken the room and have the students turn on the flashlights. Record your observations.
3. Have one student at the back walk toward you; the other stays still. Compare the brightness of the two lights. Have the approaching students use the small flashlight. How does the brightness of the two lights compare?
4. **a)** What factors affect the brightness of light? What might this suggest about the nature of stars and how bright they appear to be?

   b) Imagine two stars emit the same amount of light, but one appears to be 50 times brighter than the other. What might you infer about how far each star is from Earth?

Astronomers estimate that there are about 2 trillion galaxies in the observable universe. That's about 2×10^{23} stars. Like people, each star has unique properties such as brightness, colour, temperature, composition, and mass. These properties help astronomers understand the life cycles of stars—how they form and what can happen to them over their long and, in some cases, turbulent lives.

Brightness of Stars

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

Extending the Connections

Comparing Magnitudes

There are two scales that astronomers and other skywatchers use to describe star brightness. One, called apparent magnitude, was developed about 2200 years ago. The other, called absolute magnitude, is a much more recent invention. How do these scales work, and how do they compare? Why are both still in use?

Another term referring to a star's luminosity is absolute magnitude—how bright a star would be if it were at a distance of 32.6 light-years from Earth. The absolute magnitude of the Sun is about 4.7. This value reveals our Sun to be an average star in terms of luminosity. Some stars would be a million times brighter if they were as close to Earth as the Sun is. Others would be much more faint.

Colour and Temperature of Stars

The colour of a star gives scientists an indication of its surface temperature. A fairly hot star appears bluish in colour, while a fairly cool star appears reddish. See Figure 4.30 and Table 4.2. Rigel appears bluish-white, while Betelgeuse appears reddish-white. Our Sun, with a surface temperature of 6000°C, appears yellowish, which places it midway between bluish and reddish stars.

Figure 4.30 Comparing the colours and temperatures of two stars in the constellation Orion

Table 4.2 Colour and Temperature Ranges of Some Stars

Colour	Temperature Range (°C)	Examples
bluish	25 000–50 000	Zeta Orionis
bluish-white	11 000–25000	Rigel, Spica
whitish	7500–11 000	Vega, Sirius
yellowish-white	6000–7500	Polaris, Procyon
yellowish	5000–6000	Sun, Alpha Centauri
orangish	3500–5000	Arcturus, Aldebaran
reddish	2000–3500	Betelgeuse, Antares

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, we know that a star's spectrum identifies the elements of which it is composed (Figure 4.31).

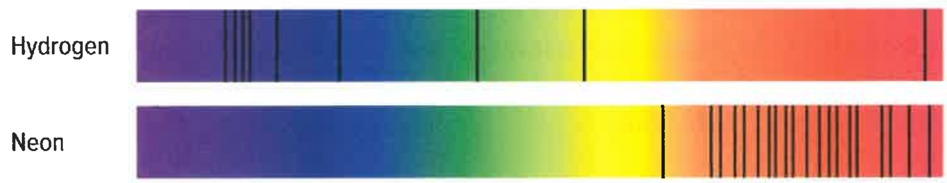
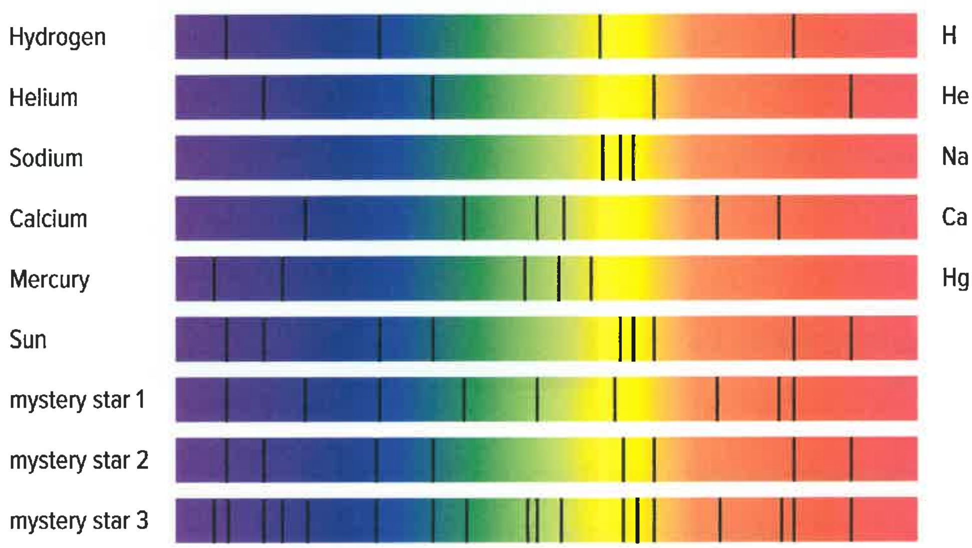


Figure 4.31 Each element is uniquely identified by its spectrum.

Activity

Identify the Composition of Three Mystery Stars

Examine the spectral lines below. Compare the patterns of the known elements to those of the Sun and the three unknown stars.



- Which elements are present in the Sun's spectrum?
- In which two mystery stars is calcium present?
- Which mystery star contains sodium?
- Only one mystery star contains mercury. Which one is it?
- Which mystery star's composition is least like that of the Sun?
- Describe, in writing or orally with a partner, how you can infer a star's composition by analyzing the pattern of its spectra.

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 can calculate the mass of each star. Star mass is expressed in terms of solar mass. The mass of the Sun is 10×10^{30} kg, which is given a value of 1 solar mass. Other stars range from 0.08 solar masses to over 100 solar masses.

The Hertzsprung-Russell Diagram and Stellar Evolution

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 was on the *y*-axis of their graph. Astronomers discovered from the H-R diagram that there are several different categories of stars (Figure 4.32).

Connect to Investigation 4-C on page 348

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

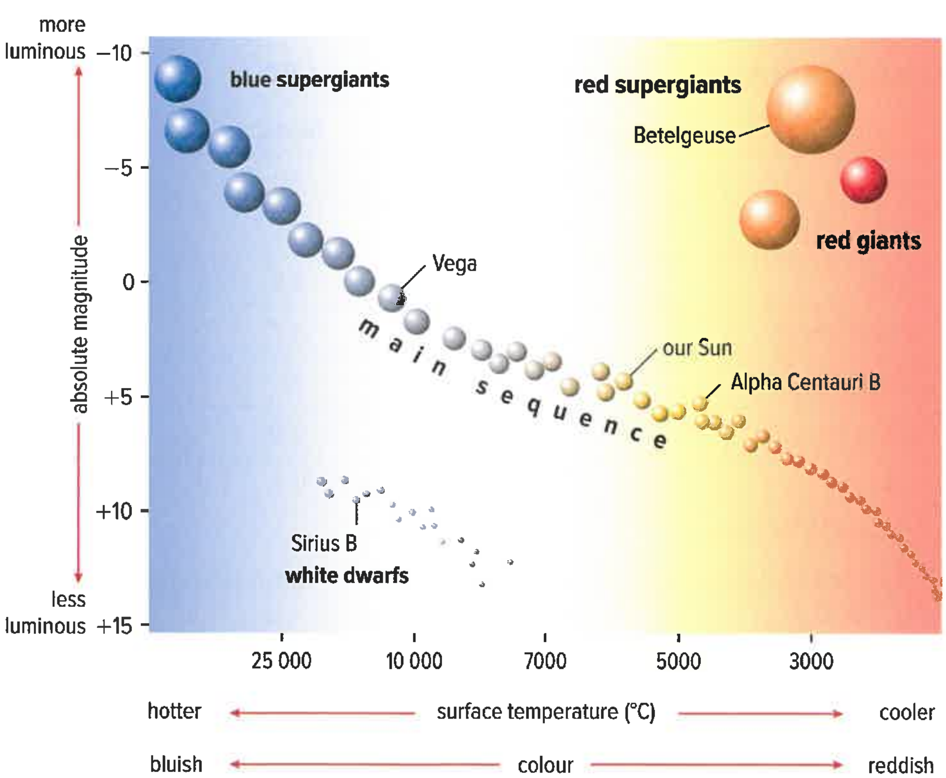


Figure 4.32 This simplified Herzsprung-Russell (H-R) diagram is based on data from thousands of stars. It shows that there is a relationship among the colour, temperature, luminosity, and mass of stars. **Inferring: Before deducing the patterns that led to the H-R diagram, most astronomers assumed that stars were unchanging and eternal. What can you see in the H-R diagram that challenges this assumption? What other assumptions could you make?**

The Main Sequence

The central band of stars stretching from the upper left to the lower right of the H-R diagram in Figure 4.32 is called the **main sequence**. The main sequence accounts for about 90% of the stars that you can see from Earth. What about the 10% of known stars *not* in the main sequence? Hertzsprung and Russell found that some stars were cooler but very luminous. The star Antares, for example, shown in Figure 4.33, has a surface temperature of only 3500°C, but it is the 15th brightest star in the night sky.

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)

When placed on the H-R diagram, the cool, bright stars are far above the main sequence. Find these red giant and supergiant stars on the H-R diagram in Figure 4.32 and note their sizes. Table 4.3 summarizes some properties of main-sequence stars.

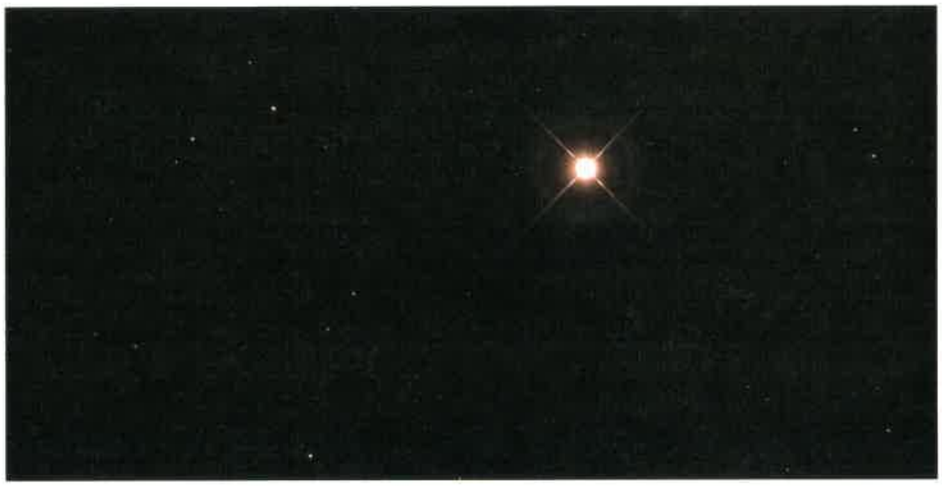


Figure 4.33 Antares is a bright supergiant located about 600 light-years from Earth. Its surface temperature is fairly cool, but it is extremely luminous.

Table 4.3 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

* 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? 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 stellar evolution. But, as you will read in the rest of this Concept, there are lots of details missing, and many puzzles still remain.

How Stars Evolve

Stars, in general, do not change very quickly. Stars like the Sun shine for billions of years with little or no change. Even so, stars radiate huge amounts of energy, 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 4.34 outlines the evolution of different types of stars. Refer to this diagram as you read the text that follows.

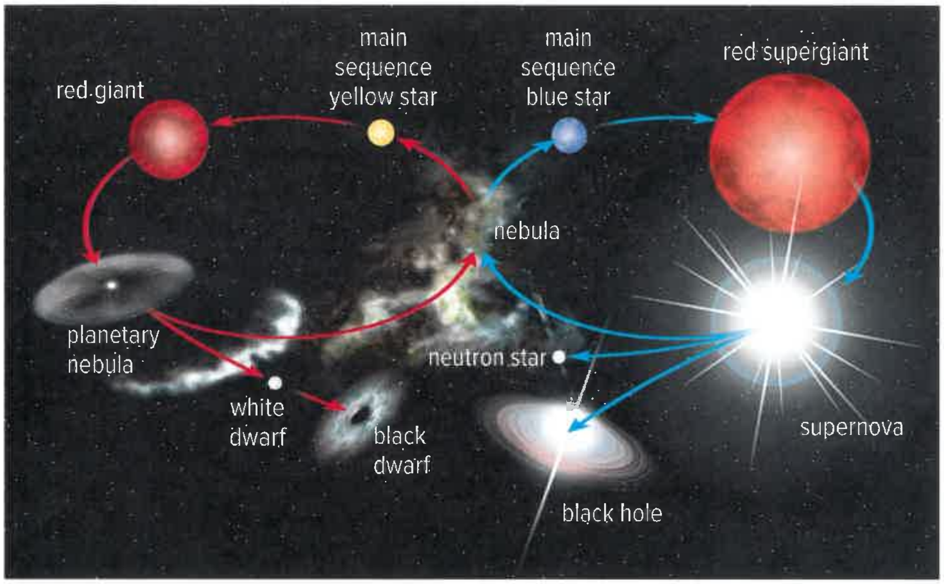


Figure 4.34 A star's life cycle depends on its initial mass.

Low-Mass Stars

Low-mass stars 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.

Intermediate-Mass Stars

Intermediate-mass stars, such as the Sun, consume their hydrogen over a period of about 10 billion years. When their hydrogen is used up, the core collapses, 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. Its gaseous diameter will extend to the current orbit of Mars. Now called a planetary nebula, these gaseous layers will get more diffuse over time, and the Sun will eventually become a white dwarf.

High-Mass Stars

Stars that are 10 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 such as carbon and oxygen 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 4.35 shows the remains of a supernova.

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

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 and the life-sustaining environment surrounding you contain atoms that were fused in the cores of old stars.

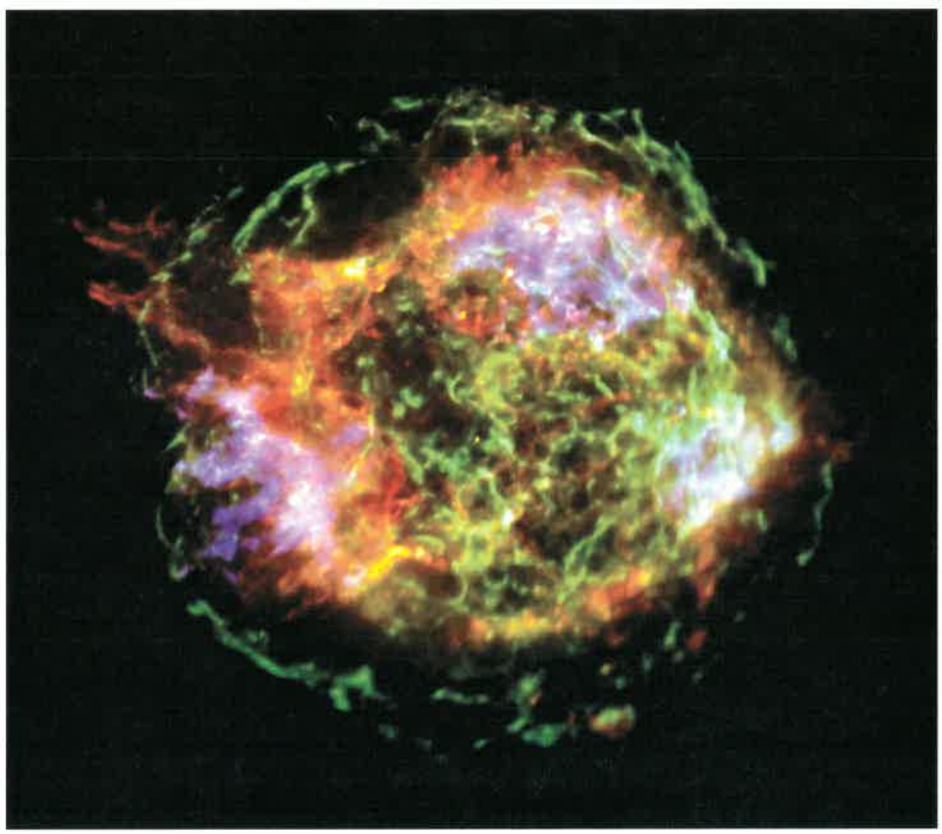


Figure 4.35 This is what is left of a star that exploded in the constellation Cassiopeia. Its light reached Earth 320 years ago after the star exploded about 11 000 light-years away in our Milky Way. **Analyzing: Elements that have been detected by the Chandra X-Ray Observatory, as well as earth-based equipment, include phosphorus, carbon, hydrogen, oxygen, and nitrogen. What is significant about these particular elements?**

Extending the Connections

Supernovae in Human History

Investigate supernovae that have been observed and recorded throughout human history. How reliable is the evidence that what people observed in each case was a supernova, rather than some other kind of celestial object or event?

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 4.36. 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 and is the only one visible to the unaided eye.

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.

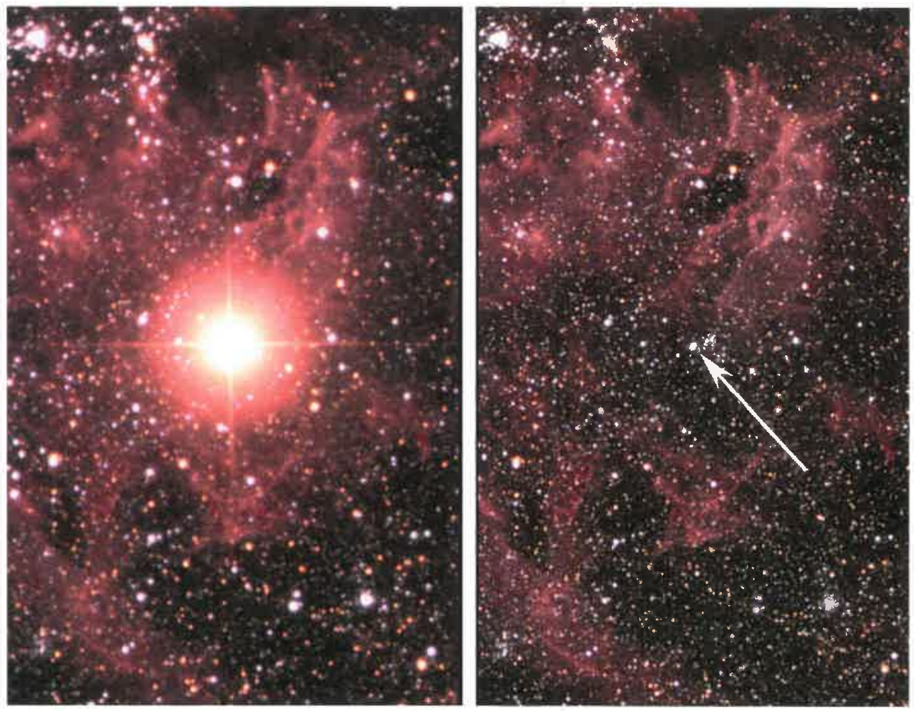


Figure 4.36 The photo on the left shows the supernova discovered by Ian Shelton. The photo on the right shows the same area before the recorded supernova.

Activity

Modelling a Supernova

When the core of a star collapses, it does so with such enormous force that it rebounds. As the core collapses, all the outer atmospheric layers are also collapsing. The less dense outer layers are still falling in toward the core when the core rebounds. The rebounding core collides with the outer layers with enough energy to blow the atmospheric layers away from the star. This is the supernova explosion. In this outdoor activity, a basketball models the core, and a tennis ball models the star's outer atmospheric layers.

1. Drop the basketball and then the tennis ball. Record your observations.
2. Place the tennis ball on top of the basketball, and hold them out in front of you. Predict how each ball will bounce if you release them at the same time. Then test your prediction.
3. How do your observations in step 1 compare with step 2?
4. What is the source of the extra energy that caused the result you observed?
5. How is this model like a supernova explosion?
6. What parts of this model are not like a supernova explosion?

Figure 4.37 The Crab Nebula is the remains of a supernova observed in 1054. Chinese historical records from that year referred to it as a "guest star."

Neutron Stars

If the star began with a mass of about 10 solar masses, its core will shrink to about 20 km in diameter. In such stars, the pressure is so great that electrons combine with protons to become neutrons, and the star eventually becomes a **neutron star**. The first neutron star to be discovered is in the centre of the Crab Nebula (Figure 4.37). Astronomers have discovered that it is spinning about 30 times per second. As it spins, it sends out pulses of radiation. This neutron star was among the first discoveries of a type of neutron star called a pulsar, which send out pulses of radiation, much like an extremely fast-sweeping searchlight.

neutron star a star so dense that only neutrons can exist throughout

black hole the remnant of a supernova explostion with a gravitational field so strong that nothing can escape its pull

Black Holes

The most spectacular deaths happen to stars whose initial masses are more than 20 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.

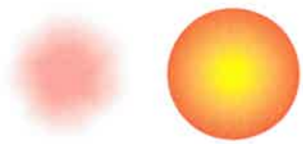
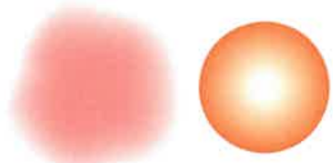
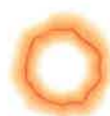
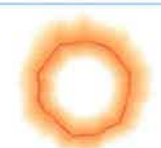
When astronomers say they have detected a black hole, they do not mean that they have seen one. What they mean is that they have detected the gravitational effects of an object whose mass and size match those predicted by physics. For example, black holes that exist in congested regions of space sometimes 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.

In 1972, Dr. Tom Bolton, of the University of Toronto, identified the first black hole. It is called Cygnus X-1 and is located in our Milky Way. Astronomers now know that, in the centre of most galaxies there are supermassive black holes with a mass millions of times that of the Sun's.

Summarizing the Life Cycles of Stars

Figure 4.38 summarizes the life cycle of stars, based on mass.

Figure 4.38 Life cycle pathways for stars based on their mass. (The drawings are not to scale.)

Star	Low-Mass (<5 solar masses)	Intermediate-Mass (10–20 solar masses)	High-Mass (>20 solar masses)
Birth and early life	 Forms from a small- or medium-sized portion of a nebula; gradually turns into a hot, dense clump that begins producing energy.	 Forms from a large portion of a nebula, and in a fairly short time turns into a hot, dense clump that produces large amounts of energy.	 Forms from an extremely large portion of a nebula, very quickly turning into a hot, dense clump that produces very large amounts of energy.
Main sequence phase	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 thousands of times brighter than the Sun.	 Uses nuclear fusion to produce energy for only a few million years. It is extremely bright.
Old age	 Uses up fuels and swells to become a large, cool red giant.	 Uses up fuels and swells to become a red supergiant.	 Uses up 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; outer layers explode as supernova.	 Core collapses; outer layers explode as huge 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.

Before you leave this page . . .

1. List and briefly describe four properties of stars.
2. Which two properties of stars are compared in an H-R diagram?
3. What does an H-R diagram help us understand about stars?
4. Use a sketch or flowchart to outline how a star's life cycle depends on its initial mass.

INVESTIGATION

4-C

STRUCTURED INQUIRY

Skills and Strategies

- Questioning and Predicting
- Processing and Analyzing
- Evaluating
- Communicating

Build an H-R Diagram

In this investigation, you will build an H-R diagram from the data in the table and use it to predict the absolute magnitudes of main-sequence stars.

Question

How can you predict the absolute magnitude of stars in the main sequence if you know its spectral type?

Procedure

1. Your teacher will give you a blank H-R diagram. To make it easier to refer to main-sequence stars, astronomers developed a series of star types based on their spectra. These spectral types are named O, B, A, F, G, K, and M. These are further broken down into subgroupings with numbers, such as O5 and B2. Using the table of data, graph each spectral class against its absolute magnitude.

Spectral Type	O5	O9	B0	B2	B5	A0	A2	F0	F2
Absolute Magnitude	−5.7	−4.5	−4.0	−2.45	−1.2	+0.65	+1.3	+2.7	+3.6

Spectral Type	F8	G2	G8	K0	K2	K5	M0	M2	M5
Absolute Magnitude	+0.44	+4.7	+5.5	+5.9	+6.4	+7.35	+8.8	+9.9	+12.3

Analyze and Interpret

1. Describe the pattern on your graph.
2. The Sun's spectral type is about G2. Use your chart to predict the Sun's absolute magnitude.
3. Vega's spectral type is A0. Predict Vega's absolute magnitude.
4. Predict the absolute magnitude of a star whose spectral type is B5.

Conclude and Communicate

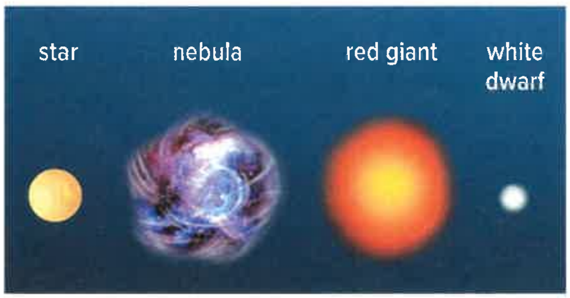
5. Summarize how you can use this pattern to predict a main-sequence star's absolute magnitude if you know its spectral type.

Check Your Understanding of Topic 4.3

QP Questioning and Predicting   PC Planning and Conducting   PA Processing and Analyzing   E Evaluating
AI Applying and Innovating   C Communicating

Understanding Key Ideas

1. How can the temperature of a star be inferred from its physical properties? PA
2. Which types of stars are thought to be the sources for enriching the universe with heavy elements? Explain why. PA
3. Place the following from youngest to oldest. Explain your sequence. PA



4. Can a star such as our Sun become a supernova? Explain why or why not. PA E
5. How can the evolution of a star over its life cycle be tracked using an H-R diagram? Use a specific example of a category of star. PA C
6. How far does light travel in one second? in one nanosecond? PA A
7. What are black holes, and why are they considered to be unusual? PA C

Connecting Ideas

8. Stars are grouped into seven colour types, and each is identified by a letter: O, B, A, F, G, K, or M. Use the table below, as well as Figure 4.38, and what you have learned about star evolution to answer the following questions. Explain your answer in each case. E AI C
   a) Which star type is a red dwarf?
   b) Which star type is most like the Sun?
   c) Which star types are likely to become supernovae? Why? How long will it be before this occurs?
   d) Our Sun is halfway through its life on the main sequence. If all seven stars formed at the same time as the Sun, which ones could we observe today?

Star Type	Colour	Lifetime on Main Sequence (Years)
O	blue	1 million
B	blue-white	11 million
A	white	440 million
F	yellow-white	3 billion
G	yellow	8 billion
K	orange	17 billion
M	red	56 billion

Making New Connections

9. Galaxies can collide with each other. This photo shows the Antennae galaxies as they are colliding. E AI C QP

   a) Galaxy collisions are common, but it is unlikely that stars within two colliding galaxies will strike each other. Infer why.
   b) Galaxy collisions can spawn the birth of stars. Infer why.
   c) Our galaxy is predicted to collide with the Andromeda Galaxy in the next 4 billion years. Predict how Earth would be affected by this.

AT ISSUE How did Jocelyn Bell make one of the most important astronomy discoveries of the 20th century?

What's the Issue?

Before neutron stars were discovered, the smallest and most dense stars were thought to be white dwarf stars. In fact, until the 1960s, most astronomers thought that all stars in the late stages of their life cycles would eventually become white dwarf stars. However, 30 years earlier, two astronomers had cautiously proposed the idea of an even smaller, denser object. "With all reserve," they began, "we advance the view that a super-nova represents the transition of an ordinary star into a new form of star, the *neutron star*, consisting mainly of neutrons. Such a star may possess a very small radius and an extremely high density." (This scientific paper, published in 1934 by Walter Baade and Fritz Zwicky, included the first published use of the term "supernova.")

With the gauntlet dropped, some astronomers started to search for neutron stars. One region of space that was studied closely was the Crab Nebula, because it was the result of a known supernova in 1054. If neutron stars existed, the centre of the Crab Nebula should yield a discovery. It did not, however, and astronomers mostly lost interest in seeking the hypothesized—and quite possibly fictional—neutron star.

The stellar landscape changed in 1967, due to a chance discovery by 24-year-old PhD student named Jocelyn Bell. There is a saying that "chance favours the prepared mind," and it is in the spirit of this saying that the word "chance" was used in the previous sentence. As part of her work as a research assistant, Bell had helped to build a large radio telescope at the Mullard Radio Astronomy Observatory in Cambridge, England. The aim of the work was to study quasars, and Bell was tasked with analyzing the reams of data collected by the telescope. (The data was in the form of huge rolls of chart paper—"red pen over moving paper", as Bell put it in her Presidential Address of 2003—

Artist's conception of a neutron star

which would then be analyzed. "In the six months that I personally operated the telescope," she said, "several miles of chart were recorded."

Bell had noticed a tiny anomaly—a quarter of an inch of what she called a "scruffy signal" in every 400 feet of the chart paper. The interval between each of these radio signals was a constant 1.3 seconds. No celestial object was known to emit a signal like this. Bell and her research associates were stumped. They took to calling these signals "little green men" and for a time used the abbreviation LGM to identify the signals on the chart paper.

By late December of 1967, Bell had found three more pulsing radio sources, which they gave the name *pulsars* in an interview with a newspaper journalist. The following year, a pulsar was discovered at the centre of the Crab Nebula. Based on this and other evidence linking pulsars with supernovas, Bell and other astronomers concluded that pulsars and the long-hypothesized neutron stars were the same thing. Since then, about 2000 pulsars have been identified.

Jocelyn Bell at the Mullard Radio Astronomy Observatory in 1968. She's holding a roll of the chart paper used to record the signals that led to the discovery of pulsars.

Dig Deeper

Collaborate with your classmates to explore one or more of these questions—or generate your own questions to explore.

1. The regularity of the pulsating radio signals led Bell and her associates to infer, early on, that the signals must be coming from a human-made source. What reasoning would lead to such an inference?
2. Jocelyn Bell's advisor, Anthony Hewish, and another colleague of his were awarded the Nobel Prize for Physics in 1974 for the discovery of pulsars. Bell was excluded from the reward, despite her principal role in the discovery and her name on the scientific paper that first presented it. How commonplace was it for the role of women in scientific achievement to be ignored or downplayed? How has the situation changed? Is there still more change necessary?
3. Find interviews and addresses that Jocelyn Bell has made since 1967. How does the process of scientific inquiry that you have been learning about in school compare with how she describes and characterizes it? (Note: Most references to Jocelyn Bell that you will encounter use her married name: Jocelyn Bell Burnell.)

TOPIC

4.4

How do we use the big bang theory to explain what we know about the universe?

Sitting in the Okanagan, this radio telescope has no moving parts and has a combined size of five professional hockey rinks. The Canadian Hydrogen Intensity Mapping Experiment—CHIME for short—is part of the Dominion Radio Astrophysical Observatory. Its mission is to map the first four billion years of the early history of the universe. As you will learn later in this Topic, this period of time is important because it features a key role played by something scientists have never seen and don't even understand: dark energy.

Key Concepts

- The big bang theory is based on two main sets of evidence: redshift and cosmic background radiation.
- The big bang theory helps us describe how the components of the universe formed and have changed over time.
- There is much about the universe that we still cannot explain.

Curricular Competencies

- Seek and analyze patterns, trends, and connections in data.
- Evaluate the validity and limitations of a model or analogy.
- Consider changes in knowledge over time as tools and technologies have developed.
- Generate and introduce new or refined ideas.

Starting Points

Choose one, some, or all of the following to start your exploration of this Topic.

1. **Generating new ideas** At the time that this very page was being written, the director of the Dominion Radio Astrophysical Observatory, Sean Dougherty, was selected to serve as director for the international facility, ALMA (Atacama Large Millimeter/submillimeter Array), in Chile. How does ALMA compare with the South Okanagan's Dominion facility in terms of location, technologies, and focus of study?
2. **Applying First Peoples Perspectives** Shared Sky is a celebration of our cultural wisdom involving Aboriginal artists from Western Australia and Indigenous artists from South Africa. Investigate the Shared Sky exhibit. How could you connect and collaborate with Shared Sky?

Key Terms

There are four key terms that are highlighted in bold type in this Topic:

- redshift
- blueshift
- big bang theory
- cosmic microwave background (CMB) radiation

Flip through the pages of this Topic to find these terms. Add them to your class Word Wall along with their meaning. Add other terms that you think are important and want to remember.

CONCEPT 1

The big bang theory is based on two main sets of evidence: redshift and cosmic background radiation.

Activity

Thinking about Waves: Part 1

Your teacher may do this as a demo. Fill a tub about half-full of water. Dip the end of a brush handle just below the surface at one end of the tub. Move it back and forth quickly (but without splashing). What do you notice about the waves at the surface of the water? How do waves in front of the handle compare with those behind it? Use a labelled sketch to record your observations.

The big bang theory is a comprehensive theory to explain the origin of the universe—how it began, how it has changed and is changing, how it will end (or will it)? Ideas like this belong to an area of study called *cosmology*. People who inquire about and investigate cosmology are often scientists, but they also may be philosophers, shamans, and even movie-makers. All such people are storytellers. The type of story you will investigate in this Concept, and in much of the rest of this Topic, is the one told by Western science.

The Big Bang Theory and its Evidence

American astronomer Edwin Hubble (1889–1953) began his career as a high school teacher before becoming an astronomer. Using the 2.5 m Mount Wilson Observatory telescope and later the 5 m Mount Palomar telescope (both in California), he photographed and recorded distant galaxies and studied their spectra (**Figure 4.39**).

Figure 4.39 Edwin Hubble using the 2.5 m telescope at Mount Wilson Observatory

The Doppler Effect

Hubble noticed something unusual about the spectra of galaxies. Their spectral lines were slightly displaced from their normal positions. This is known as the Doppler effect. An example of the Doppler effect is the change in pitch of an ambulance siren as it approaches you, passes you, and moves away. As it is moving toward you the siren's sound waves are compressed, resulting in a shorter wavelength and a higher pitch. When it is moving away from you, the siren's sound waves are lengthened, resulting in a longer wavelength and a lower pitch. Light waves behave in a similar way, but while sound waves from a moving object differ in pitch, light waves from a moving object differ in colour.

Redshift and Blueshift

Examine Figure 4.40. In spectrum A, the star is not moving. In spectrum B, the spectral lines have shifted toward the blue end of the spectrum. In spectrum C, the spectral lines have shifted toward the red end of the spectrum.

Longer wavelengths are associated with the red end of the spectrum. Since the wavelength of light from an object moving away from an observer is lengthened, toward the red end of the visible spectrum, astronomers say that the spectrum of the object is **redshifted**. Shorter wavelengths are associated with the blue end of the spectrum. Since the wavelength of light from an object moving toward an observer is shortened, toward the blue end of the visible spectrum, astronomers say that the spectrum of the object is **blueshifted**.

Hubble's study of the spectra of the observable distant galaxies revealed that the spectral lines of most of these galaxies are redshifted. Redshifted galaxies are moving away from the Milky Way galaxy. In honour of Hubble's observations, the first large space telescope was named the Hubble Space Telescope.

redshifted for objects moving away from an observer, the effect of lengthening of their wavelengths toward the red end of the visible spectrum

blueshifted for objects moving toward an observer, the effect of shortening of their wavelengths toward the blue end of the visible spectrum

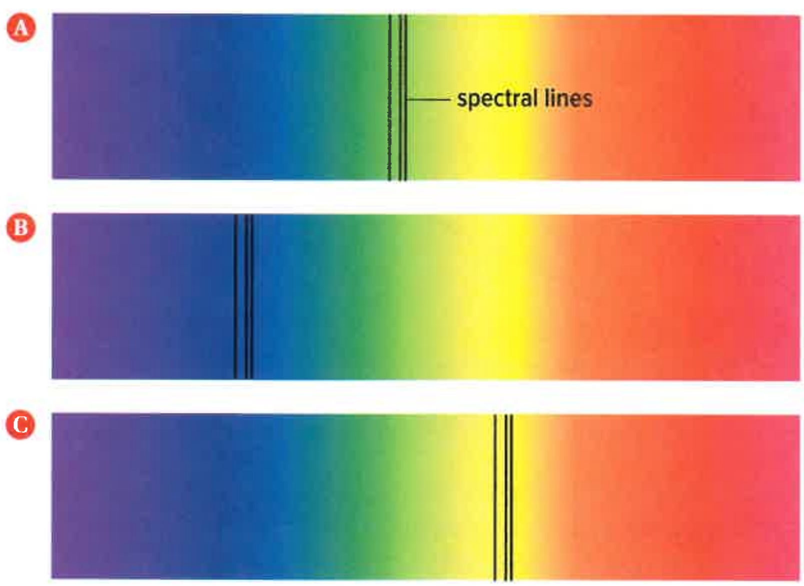


Figure 4.40 The spectral lines indicate the direction of motion of a star. In A, the distance to the star is not changing. In B, the lines have shifted toward the blue end of the spectrum, which indicates that the star is moving toward the observer. In C, the spectral lines have shifted toward the red end of the spectrum, which indicates that the star is moving away from the observer.

Activity

Thinking about Waves: Part 2

Return (in your mind) to the basin and brush activity. Imagine that the brush handle is a star and Earth is located on a spot at the left side of the basin. Sketch how the waves would look to an observer on Earth if the star is moving away. Then sketch how the waves would look if the star is moving toward Earth. Briefly summarize how this information can be used to infer a galaxy's motion in relation to the Milky Way. (Then briefly explain the strengths and limitations of this wave model.)

Conclusions Drawn from Redshift: The Universe Is Expanding

In 1929, Edwin Hubble and another American astronomer, Milton L. Humason (1891–1972), discovered that there is a relationship between a galaxy's redshift and the distance of that galaxy from Earth. They discovered that the speed of a galaxy, which can be determined from the amount or extent of its redshift, is proportional to the distance of the galaxy from Earth.

One explanation for this observation is that all the galaxies (or the space that they take up) began their outward motion at the same time. The galaxies that are moving twice as fast are now twice as far away. (Keep in mind that the galaxies themselves are not moving. The galaxies appear to move and to be getting farther away from us, and from each other, because the space between them is expanding. Galaxies that are farther from us have more space that is growing between them, which causes them to get farther away from us more quickly.

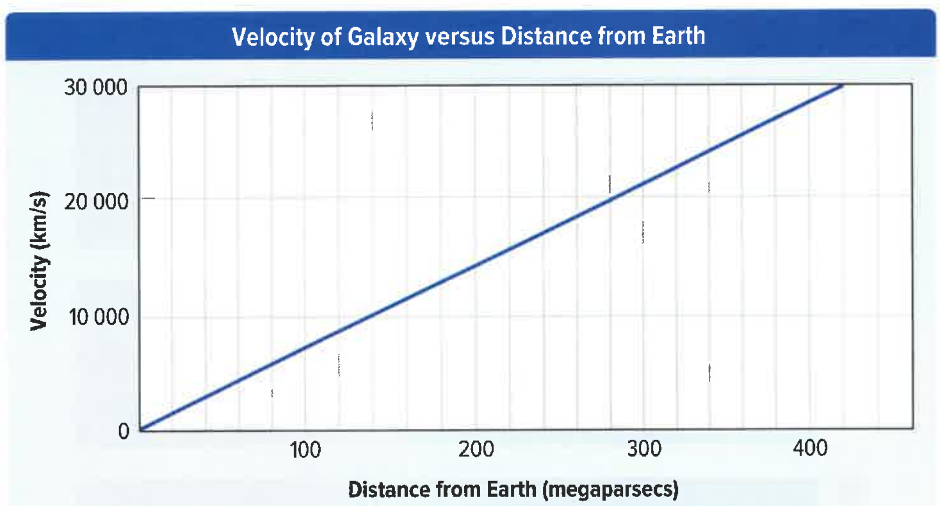


Figure 4.41 The value of the Hubble constant is the slope of the line. Note: The unit for distance in this graph is the megaparsec, which is 3.26×10^6 light-years. Astronomers prefer to use the megaparsec in graphs such as this. **Researching: Who invented the parsec, in what cases is it used in preference to the light-year, and for what reasons?**

Examine the graph shown in **Figure 4.41**. The straight line in the graph means that the speed of a galaxy is proportional to the galaxy's distance from Earth. This relationship is called the Hubble law. A Russian-American physicist, George Gamow (1904–1968), realized the significance of this relationship when he first learned of it: the universe is expanding. The slope of the line in the graph was later called the Hubble constant in honour, yet again, of the work of Edwin Hubble. The Hubble constant is the rate at which the universe is expanding.

The Big Bang Theory and Its Evidence: Cosmic Microwave Background Radiation

The idea of an expanding universe was proposed in 1922 by a Russian physicist, Alexander Friedmann, and further developed in 1927 by a Belgian priest and astrophysicist Georges Lemaître. He suggested that if the universe is expanding, it must have started out very small and dense.

Through the energies that they collect, modern space telescopes (such as the Hubble) can look back in time, almost to the very beginning of the universe. Observations from these technologies show that the universe began its expansion about 13.8 billion years ago. Therefore, the universe is about 13.8 billion years old. Cosmologists theorize that *there was nothing before*—they theorize that time and space in our universe both began 13.8 billion years ago.

No one knows what caused the "beginning." But whatever the cause, many cosmologists believe that our universe began in an event called the big bang. According to the **big bang theory**, the universe began expanding with unimaginable violence from a hot and incredibly dense state to its present state. British astronomer Sir Fred Hoyle (1915–2001) originally coined the term big bang as an insult to Lemaitre's ideas. Hoyle's own steady state theory of the universe stated that the universe did not begin, will not end, and does not change. Therefore, he considered the idea of a big-bang beginning unlikely. There is now convincing evidence of its likelihood.

big bang theory the theory that the universe began about 13.8 billion years ago when something unimaginably small and dense suddenly and rapidly expanded to immense size

Activity

Model an Expanding Universe

1. Fill a non-latex balloon with air until it is the size of a large grapefruit. Then twist the end and hold it closed. Don't tie it shut.
2. Use a pen to draw four galaxies on the balloon in a line, with 1 cm of space between each. Label them A, B, C, and D.

3. Finish inflating the balloon to the size of a volleyball and tie it off.
4. Measure and record the distances between the galaxies.
5. What happened to the distances between galaxies as you blew up the balloon?
6. Imagine you are standing within galaxy A while the balloon is expanding. Which galaxy would appear to move away from you more quickly? more slowly?
7. According to this model, what is moving here? Are the galaxies moving or is space expanding? What is the difference? Discuss your ideas with your classmates.
8. What are the strengths and limitations of this model?

Cosmic Microwave Background (CMB) Radiation

cosmic microwave background (CMB) radiation radiation left over from the big bang, which fills the universe

A second piece of evidence to support the big bang theory is the **cosmic microwave background (CMB) radiation.** This is radiation left over from the big bang. Imagine what happened to the radiation in the universe as the universe expanded. Initially, the universe was very hot. It was filled with short-wavelength gamma rays. As the universe expanded, the wavelengths of the gamma rays stretched. As the wavelengths stretched, the radiation changed from gamma rays to visible light. As the universe continued to expand, the wavelengths of the radiation stretched further into cooler parts of the electromagnetic spectrum. Today, the wavelength of CMB radiation that astronomers observe is about 1.07 mm. This is in the microwave part of the spectrum.

In 1948, Gamow predicted that the CMB radiation had cooled to about −269°C. In 1965, two American scientists, Robert Wilson and Arno Penzias, accidentally discovered this background radiation. They were working for the Bell Telephone Labs in the United States, looking for sources of "noise" (such as radio static) that could interfere with satellite communications. In the process, they kept detecting "static" from all directions in the sky. Other scientists determined that this interference was what we now call the CMB radiation. Its temperature was about −270°C, very close to Gamow's prediction.

COBE and WMAP

The two photos in Figure 4.42 are all-sky, false-colour maps of the cold microwave background radiation. They are called false-colour maps because the colours are added to indicate slight differences in temperature.

The photos in Figure 4.42 were taken by two NASA satellites: COBE (COsmic Background Explorer, launched in 1989) and WMAP (Wilkinson Microwave Anisotropy Probe, launched in 2001). Both were designed to measure the CMB radiation. The WMAP image has more detail. In fact, the detailed data gathered by WMAP confirmed the data gathered by COBE.

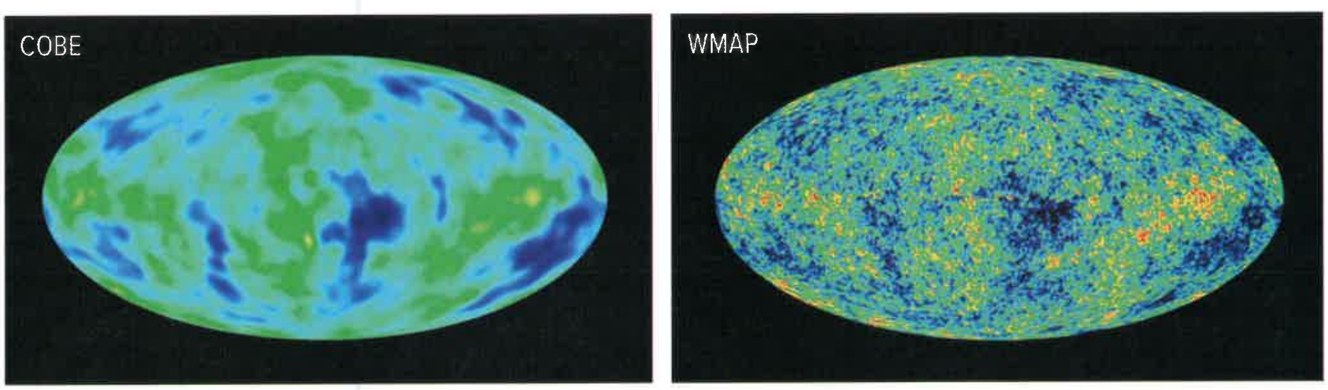


Figure 4.42 Both of these images show the CMB radiation. The colours represent slight variations in temperature. Blue is cooler, and yellow-red is warmer. The temperature variations are only a few millionths of a degree Celsius (10^{-6}°C).

Before you leave this page . . .

1. What is the big bang theory, and what main evidence supports it?

BE Inspired

Make a Difference

Dr. Stephen Hawking (1942–2018)

No one is as inspirational as a person who has defied incredible odds to achieve something equally incredible. What would you do if you were given three years to live? Would you act differently or change your plans for your life? Now imagine you will slowly lose control of your muscles and rely on a motorized wheelchair for mobility. Eventually, speaking and even breathing may become a desperate challenge.

As a student at Cambridge University in England, Stephen Hawking was diagnosed with ALS, a disease that affects muscle control. His future, although uncertain, was expected to be much like the one described above. ALS would soon bind him to a wheelchair for life and eventually cause him to rely on a computer system to communicate. However, his mind would remain free to wander, and to wonder. Early in his career, Hawking showed that matter can escape from the immediate vicinity of a black hole. In later years, he built upon Albert Einstein's ideas about time and space.

An acknowledged genius, Hawking is also remembered for his humanity. With his wisdom came wit, and the ability to laugh at himself and the world.

Evaluate and Communicate

1. Find out more about Stephen Hawking's ideas about the universe. How did he help change our view of the universe?
2. When he died in 2018, the Internet was flooded by posts, tweets, and remembrances of a man who inspired many to imagine what is possible. What do you find inspirational about Stephen Hawking?

CONCEPT 2

The big bang theory helps us describe how the components of the universe formed and have changed over time.

Connect to Investigation 4-D on page 366

Modern telescopes can see enormous distances into the universe, which means that they can see very far back into the past. The reason for this is the finite speed of light. For example, light from the Sun takes about 8 min to reach Earth. So, we always see the Sun as it was 8 min ago. The nearest stars are about 4 light-years away. Thus, their light takes 4 years to reach us. We see these stars as they were 4 years ago. Looking at galaxies that are 10 billion light-years away gives us a view of the universe as it was 10 billion years ago.

A Young Universe

The COBE and WMAP images are pictures of the CMB radiation (now cooled to about –270°C) when the universe was a mere 380 000 years old (about 0.002 percent of its present age). At that time, the universe was smaller. Yet, from our point of view in space and time, the tiny universe (in the past) appears to be a huge distant shell that surrounds us. We see it in all directions, at a very great (redshifted) distance when it was, in fact, smaller.

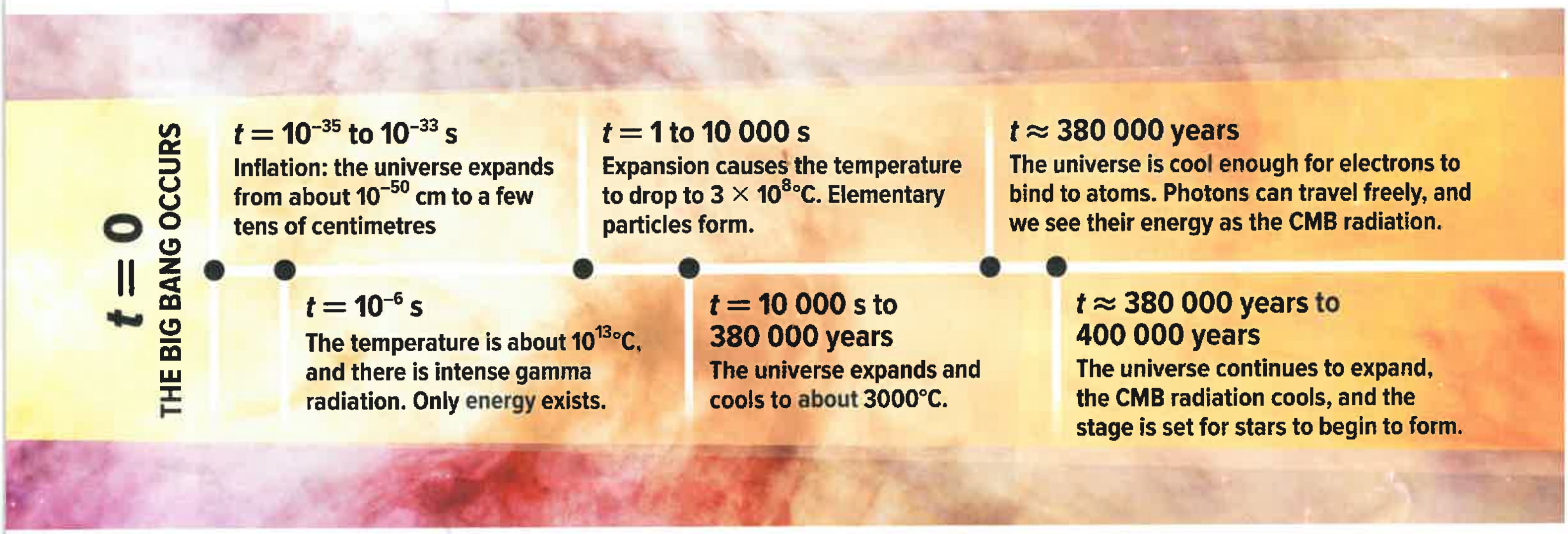


Figure 4.43 Timeline from the big bang to the present. **Questioning: What questions do you have as you read and reflect on the information in this timeline?**

Evolution of the Universe

Astronomers have collected enough observations from different types of telescopes to piece together a fairly detailed picture of how the universe has evolved since the big bang. Of course, the details are always being refined because new discoveries are made with surprising regularity. **Figure 4.43** presents a timeline of the evolution of the universe from the big bang until the present.

The James Webb Space Telescope

At the time this is being written, the Hubble Space Telescope (HST) is still in use, having had its scheduled retirement delayed several times. In 2020, NASA plans to launch its replacement: the James Webb Space Telescope (JWST). The JWST will see even farther than the HST can. Its mission will be to find the first galaxies that formed after the big bang. The Canadian Space Agency is a partner in the development of the JSWT.

CERN

In September 2008, an organization called CERN (Conseil Européen pour la Recherche Nucléaire), in Switzerland, began the full-scale operation of the world's most powerful machine for studying particles at high energies. This machine, called the Large Hadron Collider (LHC), can conduct experiments at energies that approach those found in the universe 10^{-12} s after the big bang. Scientists hope to unravel some of the secrets of the very early universe by studying what happens at these incredibly high energies.

Designing and building machines such as the LHC takes a great deal of creativity. Sometimes, new technologies have to be invented to make the machines and to enable scientists to share the information they learn. The technologies can then be modified and used by the public. For example, scientist Tim Berners-Lee invented the World Wide Web at CERN, in 1989, so that all the scientists could share the information on their computers.

t = 400 million to 1 billion years
The earliest stars and first galaxies begin to form.

t = 3 to 6 billion years
There is a relatively high abundance of massive galaxies in the universe.

t = 4 to 7 billion years
The expansion of the universe gradually slows, under the force of gravity.

t = 7 billion years
The expansion of the universe begins to increase.

t = 9 billion years
The Sun and solar system form.

t = about 14 billion years
The CMB radiation has cooled to −270°C. The expansion of the universe continues to increase.

Before you leave this page . . .

1. Use a flowchart to summarize the key events of the big bang.
2. Explain how technology has helped us understand the origins of the universe.

CONCEPT 3

There is much about the universe that we still cannot explain.

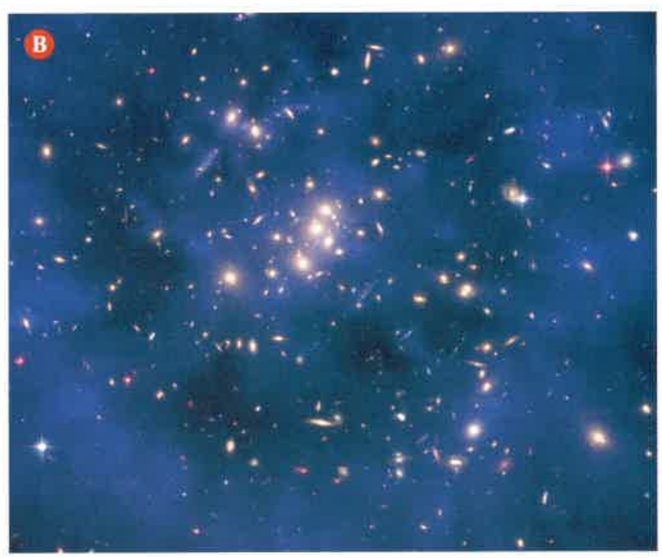
The universe as imagined through most of human history was huge. It contained the whole world—Earth, Sun, Moon, planets, and all the visible stars. And yet, prior to the 1930s, few people could have imagined the immense size estimated by astronomers today.

Over time, and with the advent of technology, astronomers have revised their view of the universe. First, astronomers included the Milky Way galaxy of an unimaginable size. Then they expanded their view to include an unknown number of galaxies. Today, astronomers are piecing together the story of the universe—its evolution, age, and size. However, in spite of everything that astronomers have discovered, the universe still holds many mysteries and secrets. One of these mysteries is *dark matter* (**Figure 4.44**).

Dark Matter and the Andromeda Galaxy

The structure of the Andromeda galaxy is similar to the structure of the Milky Way. Thus, astronomers have studied the Andromeda galaxy extensively, hoping to learn more about the Milky Way. By examining the total amount of light that the stars in the Andromeda galaxy emit, astronomers have been able to estimate the total mass of this galaxy with a high degree of confidence. The mass of the Andromeda galaxy is about the same mass as the Milky Way galaxy.

Figure 4.44 Photo A, taken by the HST, shows a galaxy cluster called Cl 0024+17. Photo B shows the same galaxy cluster, except there is a blue ring around it. The lighter blue overlay is a computer-generated model that indicates where the mysterious dark matter is inferred to be.



Hypothesizing Dark Matter

Figure 4.45 The Andromeda Galaxy is about 2.5 million light-years from Earth.

Just as the stars in the Milky Way orbit the centre of our galaxy, the stars in the Andromeda galaxy, shown in Figure 4.45, orbit its centre. Using the estimated mass of the Andromeda galaxy, astronomers predicted the speeds of the stars at various distances from its centre. To verify their predictions, astronomers studied the spectra of the stars within the galaxy. Their results were astonishing. The stars are moving much faster than predicted.

One way that astronomers could explain the speed of the stars was by assuming that the galaxy contains about 90 percent more mass than can be accounted for by visible matter. Visible matter is everything that can be seen—all the planets, stars, and galaxies. Astronomers could not see the missing mass. Wherever this mass was located, it did not emit any light. So the missing mass was at first called dark matter. The name was meant to be temporary, but it stuck. Astronomers still refer to the missing mass as dark matter. Dark matter is the most abundant form of matter in the universe. Except for the effects that astronomers have observed, dark matter has not been detected. Its true identity is unknown.

The Search for Dark Matter

The search for dark matter has been going on since the 1990s. Its elusiveness is partly due to the fact that it only seems to interact with visible matter through its weak gravitational effects. Dark matter seems to form a huge spherical halo around the galaxy, as shown in Figure 4.46.

Figure 4.46 Artist's impression of the inferred dark matter surrounding a galaxy, represented by the blue halo.

Dark Matter and the Milky Way Galaxy

The hypothesis about the dark matter around galaxies and galaxy clusters led astronomers to wonder if the Milky Way is also in the centre of a huge halo of dark matter. They think that it is. One clue comes from the motion of the galaxies within the Local Group. Astronomers have estimated the mass of the visible matter in the Milky Way to be about 200 billion solar masses. Yet the motion of small, nearby galaxies that are orbiting the Milky Way indicates that its actual (total) mass is at least 10 times larger. This would mean that only 10% of the Milky Way is made of visible matter.

When astronomers study other galaxies that are in groups or clusters, they find that the motion of the galaxies can be accounted for only by assuming that the galaxies are surrounded by huge halos of dark matter. Visible matter makes up less than 5% of the universe. Astronomers hypothesize that dark matter makes up nearly six times more than visible matter. What makes up the rest? The answer sounds even more mysterious than dark matter. It's *dark energy*.

Dark Energy

At the end of the 20th century, astronomers were observing light from extremely bright Type Ia supernovae, like the one shown in **Figure 4.47**. Type Ia supernovae are explosions of white dwarf stars that are part of a binary star system with a more massive star. The gravity for the white dwarf pulls material from its companion star. This matter accumulates on the surface of the white dwarf till it reaches a critical mass forcing a type Ia supernova explosion. The absolute magnitudes of these supernovae are well known and quite reliable. Astronomers plotted their absolute magnitudes against their redshifts and got quite a shock. The Type Ia supernovae were too faint. In other words, the supernovae were farther away than astronomers had inferred.

Figure 4.47 The Type Ia supernova is the bright object at the lower left of the galaxy. Details of this supernova led scientists to hypothesize the existence of dark energy.

Astronomers had predicted that, after the big bang, the expansion of the universe should be slowing down gradually due to gravity. But the Type Ia supernovae data show that expansion began to accelerate about 7 billion years ago, and it continues to accelerate. For some reason, something began to overcome the effect of gravity that was originally slowing the expansion and is now causing the rate of expansion to increase. Without understanding the cause of this effect, scientists have simply called it dark energy to reflect its elusive and mysterious nature.

Extending the Connections

Investigating Dark Matter and Energy

CERN is just the tip of the iceberg for inquiry into dark matter and energy. Other investigations include the Sudbury Neutrino Observatory Laboratory (SNOLAB), Large Underground Xenon (LUX), and the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX). What are these avenues of inquiry, what do they do, and what others can you find?

A Few Parting Thoughts

The WMAP survey and other experiments support the idea that dark energy is a stabilizing force in the universe. However it cannot be an anti-gravity force, because its strength increases with distance, while the strength of gravity weakens with distance.

How much of the universe is dark energy? The current best estimate of all the mass and energy of the universe yields the following distribution:

- dark energy: 73%
- dark matter: 23%
- visible matter (stars and galaxies): 4%

Take a moment to reflect on that last bit: The visible universe is thought to be just 4% of all that exists. How do you feel when you read that? Perhaps you feel many things. Maybe one of them is excitement.

Dark matter, dark energy—these ideas seem more like science fiction than science. And this unit has barely scratched the surface of the marvels and mysteries the universe has to offer the inquiring mind. As much as we know and have learned, there is still so much more that we don't know, so much more that awaits discovery, invention, and interpretation.

What stories will you tell about the universe and your place in it?

Before you leave this page . . .

1. How did dark matter get its name?
2. Why do scientists think that dark energy exists?

INVESTIGATION

4-D

STRUCTURED INQUIRY

Skills and Strategies

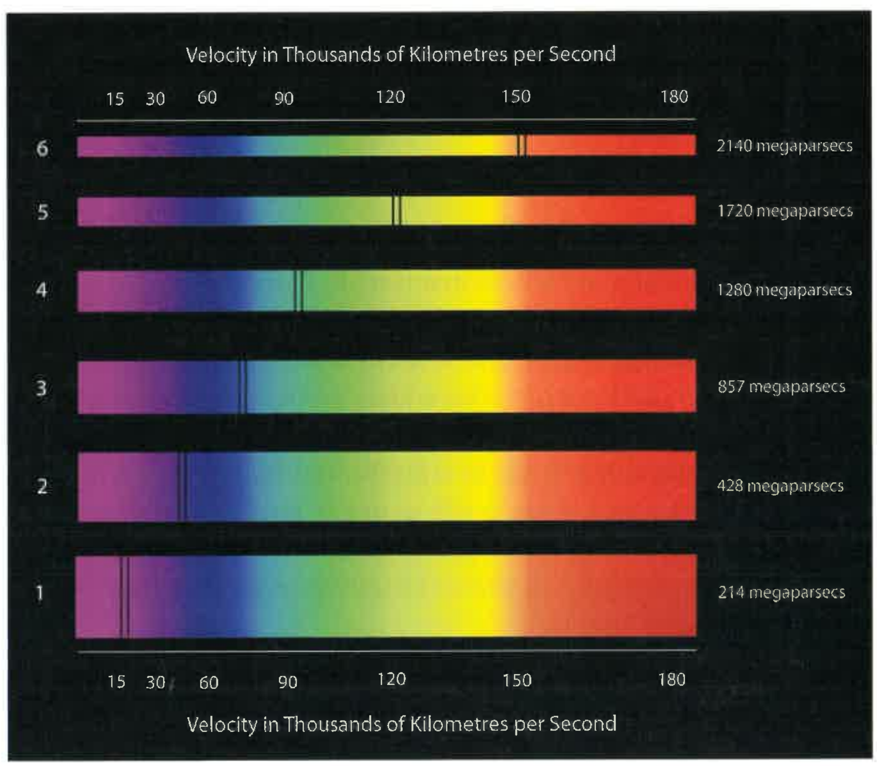
- Processing and Analyzing
- Applying and Innovating
- Evaluating
- Communicating

The Age of the Universe

There is a relationship between a galaxy's redshift and its distance from Earth. When this relationship is plotted, the slope of the line gives the Hubble constant, H. Once you have a value for H, you can estimate the age of the universe, in years, using the equation $\frac{10^{12}}{H}$. The units of the Hubble constant are kilometres per second per megaparsec (km/s/Mpc). See below for information about parsecs.

The spectra of six galaxies are shown below. Each spectrum contains a pair of spectral lines. The spectral lines are normally seen in the far ultraviolet part of the spectrum. Due to the apparent motion of each galaxy, however, these lines have been redshifted. The amount depends on the velocity of the galaxy. The velocity of each galaxy can therefore be determined from the redshifted position of the spectral lines.

Note that velocity is speed associated with a direction. Astronomers use velocity because galaxy motion is associated with a direction: either toward Earth (blueshift) or away from Earth (redshift). Also note that a parsec is 3.26 ly, so a megaparsec is 3.26×10^6 light-years. Astronomers use megaparsecs for graphs of this type.



Question

How can you estimate the age of the universe?

Procedure

1. Make a table like the one below. Leave space for six galaxies.

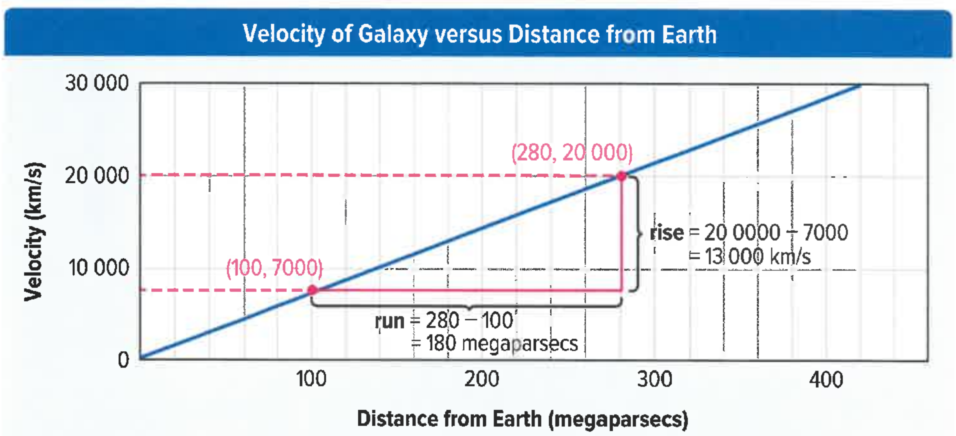
Galaxy	Distance from Earth (megaparsecs)	Velocity (thousands of km/s)
1	214	15
2		

2. Use the redshifted position of the spectral lines to determine the velocity of each galaxy. To do this, use a ruler to line up the centre of the left spectral line with the velocity scales at the top and bottom of the chart. Record the velocity and distance of each galaxy in your table. The first entry has been done for you.

3. Plot a line graph of galaxy velocity against galaxy distance. Put galaxy distance on the x-axis and galaxy velocity on the y-axis.

4. Draw a line of best fit through the points.

5. The slope is the Hubble constant, H. Calculate the slope of the line, which is the rise (vertical change in the y-axis) over the run (horizontal change in the x-axis). For help calculating slopes, see the graph below.



Analyze and Interpret

1. The age of the universe is given by the equation $\frac{10^{12}}{H}$. Use your value of the Hubble constant from step 5 to estimate the age of the universe in years.

Conclude and Communicate

2. How does your calculated age of the universe compare with the accepted age?

Apply

3. Predict the age you would calculate if you used the spectral line on the right. Repeat this investigation to check your prediction.

4. Research the Hubble constant, including the controversy surrounding it and how its value has changed over time.

TAKE a Stand

Make a Difference

Terraforming: Are we developers or caretakers?

Until the late 20th century, the only off-world options for human colonies were the planets of our own solar system. Since then, we know there are planets, referred to as exoplanets, outside of our own star system. Some scientists believe it is technologically possible to transform an alien, lifeless world or landscape into a life-sustaining ecosystem for future colonization—a process called terraforming.

At one time, terraforming was a topic fit only for science fiction. Now, as our population grows and as our concerns for our global climate systems mount, terraforming represents a possible solution for the future of our species.

Analyze and Evaluate

1. As a species, have we demonstrated that we can be responsible terraformers? Give supported reasons to justify your opinion.
2. What other solutions are there for the problems we face on Earth? Which of these, including terraforming, do you think represents a last best hope? Justify your ideas with reasonable and well-reasoned arguments.

Imagining grain fields on our terraformed Moon. What would it take to make such a thing possible?

Check Your Understanding of Topic 4.4

QP Questioning and Predicting PC Planning and Conducting PA Processing and Analyzing E Evaluating
AI Applying and Innovating C Communicating

Understanding Key Ideas

1. Identify the main two sets of evidence that form the basis of the big bang theory. Briefly explain their significance to the theory. PA

2. What is the Doppler effect? Give an example of the Doppler effect that occurs with sound. PA

3. The light from our nearest galaxy, the Andromeda Galaxy, is blueshifted. Explain what this means about its motion in relation to us. PA

4. How are spectral lines used to measure the amount of redshift in the light we receive from a distant galaxy? PA

5. What is the relationship between the speed of a galaxy away from the Earth and its distance from Earth? PA

6. What is Hubble's law? PA

7. How does the idea that the universe was once small and hot lead to the prediction that the present universe should be filled with microwave radiation? E AI

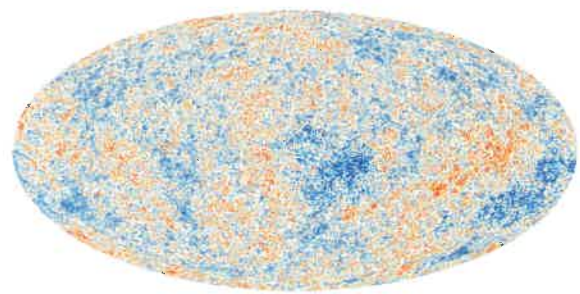
8. Explain how the idea of galaxies in an expanding universe can be compared to dots drawn onto a balloon which is then inflated. AI C

9. What is dark matter, and why is understanding it important to astronomers when they make models of the structure and evolution of the universe? PA

10. Why do astronomers hypothesize the existence of dark energy as part of our universe? PA

Connecting Ideas

11. The most recent mission to study the Cosmic Microwave Background radiation is European Space Agency's Planck space observatory, which was launched in 2009. How does the pattern shown in the Planck map below indicate that the presence of microwave radiation in the universe is not the same everywhere? PA E AI



12. Using light, we cannot look farther back in time than 380 000 years after the big bang. Explain this statement. AI

13. How could you use all the students in your class to act out a model of the expanding universe shortly after the big bang? QP PC

Making New Connections

14. Older theories about the universe include the oscillating theory and the steady state theory. Write an article or develop the script for a podcast or video blog in which you compare these theories, including the evidence used to support them. Explain why the big bang theory is accepted by more scientists now, rather than either of the other theories. QP PC E AI C

15. Reflect on the Essential Question for this unit. How do you understand and explain the universe, its formation, and our place in it? PA E AI C

UNIT 4

Summary

ESSENTIAL QUESTION

How can we understand and explain the universe, its formation, and our place in it?

TOPIC 4.1:

What is the universe, and how do we make sense of it?

- "Universe" is understood as different things to different people.
- The sense we make of the universe depends on who we are, when we are, and what we know.

Key Term

universe

TOPIC 4.2:

What do we know about the universe based on what we can see only with our eyes?

- We see a variety of objects that appear in the sky in mostly predictable ways.
- The appearance and motions of the objects we see can be described using a model called the celestial sphere.

Key Terms

constellation | celestial sphere | ecliptic

TOPIC 4.3:

How has technology expanded our knowledge and understanding of the universe?

- We have invented telescopes and other devices that extend and enhance our sense of sight.
- We know that our Milky Way galaxy in just one of many billions of galaxies in the universe.
- There are vast distances separating stars and separating galaxies.
- The properties of stars help us develop an understanding of their life cycles.

Key Terms

galaxy	star cluster
light-year	Hertzsprung-Russell (H-R) diagram
main sequence	supernova
neutron star	black hole

TOPIC 4.4:

How do we use the big bang theory to explain what we know about the universe?

- The big bang theory is based on two main sets of evidence: redshift and cosmic background radiation.
- The big bang theory helps us describe how the components of the universe formed and have changed over time.
- There is much about the universe that we still cannot explain.

Key Terms

redshifted blueshifted big bang theory
cosmic microwave background (CMB) radiation

UNIT 4 Review

What Do You Know?
Connecting to Concepts

Visualizing Key Ideas

1. Create a flowchart the outlines the life cycle for each of the following:
   a) a low-mass star
   b) an intermediate-mass star
   c) a high-mass star
2. Design an infographic for a non-science audience that combines the information from question 1. Include any other information that you think is relevant.
3. Design a graphic organizer or infographic for the big bang. Your organizer or infographic should be the simplest possible representation that still communicates the most essential elements of the big bang. Someone looking at it should be able to understand its key ideas.
4. Flip through the pages of this unit. Locate and identify three images that you think are good answers to the following question: How does the idea that light takes time to travel across space give us an understanding that the universe is vast and ancient? Explain your choices. Then choose one as the best, and explain why you think it is.
5. The ancient Greeks called the constellation in the photo below Orion the Hunter. Sketch this constellation in your notebook.
   a) Identify the name of any star that you know or recognize. Include the type of star it is, as well.
   b) Identify the group of stars that make up Orion's belt and sword.

   c) Describe this constellation as it was seen by another nation (such as one belonging to First Peoples) or culture.
   d) Create your own constellation narrative for this grouping of stars.

Using Key Terms

5. Write a brief paragraph that connects the following terms: ecliptic, constellations, celestial sphere.
6. Create a table with three columns. In the first column, list all the terms relating to what we can view in the sky with our own eyes and also how we can locate them on the celestial sphere. In the second column, record a definition for each term, written in your own words. In the third column, draw a sketch that can combine as many of these terms as possible to show how they are interrelated.
7. Using a format of your choice, show how the term big bang is related to the following terms: blueshift, cosmic microwave background radiation, dark energy, dark matter, redshift.

Communicating Concepts

8. Explain why objects in the day and night sky appear to move as time passes each day.
9. What are two reasons that some stars are brighter than others when you look at the night sky?

10. The telescope near Penticton, B.C., is able to view stars during the day as well as at night. It also works on cloudy days and if it is snowing. Why is this possible?

11. Explain the how the concept of the Doppler shift applies both to sound and to light, including the similarities and the differences.

12. When our star, the Sun, reaches the end of its life about 5 billion years from now, will it become a black hole? Why or why not?

13. The cosmic microwave background radiation is very cold, but it results from an event that was unimaginably hot. Explain how this is possible.

14. Explain how the positions of the stars and the Sun can be used for navigation.

15. a) The photo below shows a long-exposure image of the night sky. The bright tracings are called star trails. How does this photo provide evidence that stars in the northern hemisphere appear to revolve around a celestial object that remains stationary?

    b) Name the stationary celestial object.

16. Why are the more massive stars the only important contributors in enriching the universe with elements heavier than hydrogen, helium, and lithium?

17. Why are white dwarf stars hot as well as dim?

18. Explain how the spectrum of light from a galaxy is useful to astronomers.

What Do You Know?
Connecting to Competencies

Developing Skills

19. Use at least two examples to describe how to use Polaris to navigate the night sky.

20. Explain how the rate of expansion of the distance between two points is proportional to that distance. Use a diagram or an example of an expandable surface, such as a balloon or rubber sheet, to illustrate your explanation. Then relate the rate of expansion to Hubble's law.

21. a) What is the difference between altitude and azimuth?

    b) Describe two examples that illustrate how accuracy can be affected when you are using your hands to determine altitude and azimuth.

22. Nebulas can be formed by the explosion of supernovas. They are also the birth places of stars. Some have been given fanciful names based on how they appear in telescopes. Research a nebula that has been discovered using telescopes. Explain what it looks like, how it may have formed, how far away it is, what it is made of, and whether new stars are likely to form in it.

23. Explain why some stars on the Hertzsprung-Russell diagram are not located on the main sequence diagonal.

24. How did Indigenous people of the past depend on their knowledge of the skies for survival? Research to find out different ways that people applied their astronomical knowledge. Explain how these were tied to the places where they lived.

Unit 4 Review *(continued)*

Thinking Critically and Creatively

25. If the Earth did not rotate, could you still determine the ecliptic? Explain why, or why not.

26. Suppose that instead of seeing light, you perceived it as sound. In other words, suppose that you could "hear" light. What might it mean to hear different colours, and how would this change the way we might think of the cosmic redshift? (By the way, this kind of sensory ability—for example, to hear colour, smell sounds, or see flavours—has a name. Find out what it is. If this phenomenon interests you, investigate it further.)

27. Suppose you are an astronomer viewing a newly discovered galaxy. You record its spectrum and discover that some of its light is red-shifted, some of its light is blue shifted, and that most of its light is not shifted at all. What might be the cause of this effect? Could it be used to measure anything important about the galaxy?

Understanding Big Ideas

Making New Connections

Applying Your Understanding

28. Suppose you are sailing from Vancouver to Hawaii and navigating only by compass and observations of the sky. You have star charts to refer to and instruments to make precise measurements. Explain why you would also need to have a precise clock or some method of telling time in order to navigate correctly.

29. Does the position of Polaris change if the latitude of the observer changes? Draw a sketch to explain your ideas. (Hint: Think about where you might look for Polaris if you were standing on the equator, or on the North Pole. What is the relationship between the altitude of Polaris and the latitude of the observer.)

30. What does it mean when we say that much of what we understand about the universe has been learned by our ability to use light to look back in time.

Thinking Critically and Creatively

31. How does the structure of our solar system, in which planets orbit around the Sun, compare to the structure of the Milky Way galaxy? What in the galaxy corresponds to the solar system's planets? to the Sun? to the motion of the objects in both and how both are held together?

32. Many First Peoples have words to describe a person who is trained to observe the skies. Sometimes they are translated as stargazer or moon reader. Find examples of such words in the language of a local First Nations community or other First Peoples cultures.

33. **a)** Describe what globular clusters are.

b) Explain how the properties of globular clusters were investigated and how the resulting discoveries led to further understanding of the Milky Way.

34. Propose an investigation you could use to investigate the relationship between the brightness or luminosity of a star and its distance from Earth. Outline the materials and equipment you would need, any safety considerations, the plan or procedure for the investigation, and the results you would expect to obtain. Provide a rationale for your plan and your expected results. (Limitation: You cannot use flashlights or laser pointers.)

35. Explain the significance of the following observations.

a) Most stars that we see in the night sky from Earth are in a band that runs north-south across the sky.

b) Globular clusters are all located in one direction in the sky and not all around Earth.

36. The photo below shows a reconstruction of a device called the Antitkythera (an-tih-keh-THEE-rah) mechanism. The incomplete remains of this technology, at least 2200 years old, were discovered in the year 1900 as part of a sunken shipwreck off the cost of the Greek island of Antikythera. It has been described as an ancient computer whose purpose was to model the motions of celestial objects.

a) Find at least three reputable, reliable sources of information about the Antikythera mechanism to learn more about it and how it has been reconstructed. Summarize your findings.

b) Explain how you evaluated a site to be able to consider it reputable and reliable. In other words, what criteria did you use to judge each site?

37. The *Star Trek* "universe" invented warp drive to move through space at greater-than-light speed. Warp 9.9 is about 3000 times faster than light speed. Calculate how long it would take a starship with warp drive to reach

a) Proxima Centauri

b) the centre of the Milky Way

c) the region of the Andromeda Galaxy

Connecting to Self and Society

38. At the time of writing this question, a plan to build the largest telescope in the world, one with a diameter of 30 metres, is being considered for the top of the highest mountain in Hawaii, Mauna Kea. Canada is part of this plan. This same site is considered a sacred place by Hawaiian First Peoples, and many there do not want the telescope built on this site. Research this issue and imagine you are to be a mediator to help the sides come to a positive resolution to the issue. What approach would you take to help bring resolution?

39. The World Wide Web was invented, in part, to facilitate communication related to scientific investigations involving astronomers and physicists. How would your life be different if it had not been invented?

40. Canadian astronaut Chris Hadfield was inspired to explore space by novels and comics he read in his youth. African-American astronaut Mae Jemison was inspired by the ethnic diversity of the characters in *Star Trek*. At the time, no similar diversity existed in the American space program or on TV. Today, astronauts from many different nations and ethnic backgrounds work upon the International Space Station. What role might science fiction have played in inspiring this diversity. Justify your response.

Unit Assessment

What are our responsibilities as explorers of the universe?

With our eyes and imaginations, and then assisted by technology such as telescopes, satellites, and probes, we humans have always been exploring the universe. Many nations around the globe have launched technologies, and ourselves, beyond Earth's atmosphere—in a few cases, such as the *Voyager* space probes, *far* beyond. What, if any, cosmic conscience are we obliged to have to balance or inform our powerfully human sense of curiosity?

Work as part of a group to do the following.

STEP 1 ► Reflect on the three options, their photos, and the question asked for each option.

STEP 2 ► Brainstorm at least three more options and questions of your own about a situation related to the unit assessment question.

STEP 3 ► Decide on one of the six option questions to investigate.

STEP 4 ► Plan and conduct a scientific inquiry to explore your question.

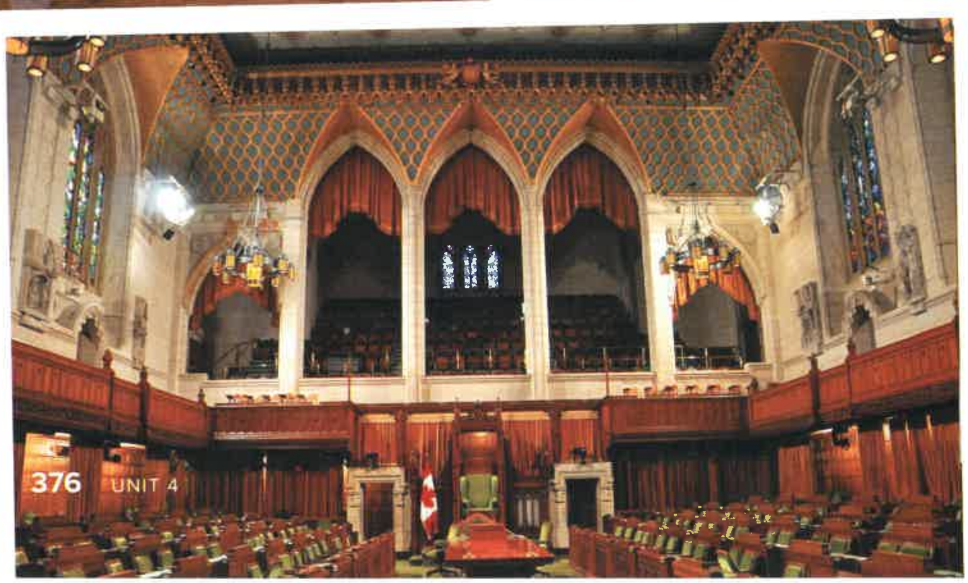
STEP 5 ► Organize and analyze the data and information that you find and collect.

STEP 6 ► Communicate the results of your inquiry in a suitable manner.

OPTION A

Protecting Life

How do we protect life on Earth from potential aliens as well as protect possible alien life from contamination by us?



OPTION B

Societal Responsibility

Is it responsible to spend taxpayer money on space investigation when so many on Earth live in poverty?

OPTION C

Ethical Dilemmas

No single nation "owns" Antarctica or the International Space Station. Who owns space? What are the implications of this question?

Assessment Criteria

Did I and my group...

- Develop one or more questions that provided opportunities for rich investigation? QP
- Develop effective methods to collect and record reliable data and information? PC
- Apply different ways of knowing to analyze, reflect on, and draw meaningful conclusions that are consistent with evidence? PA
- Consider and demonstrate an awareness of assumptions, bias, and social, ethical, and environmental implications over the whole process of our inquiry? E
- Propose alternative courses of thought and/or action that contribute to care for self, others, community, and world? AI
- Construct evidence-based arguments using language, conventions, and representations appropriate for a specific purpose and audience? C

Guide to the Appendices