TOPIC 4.4

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

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.

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.

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

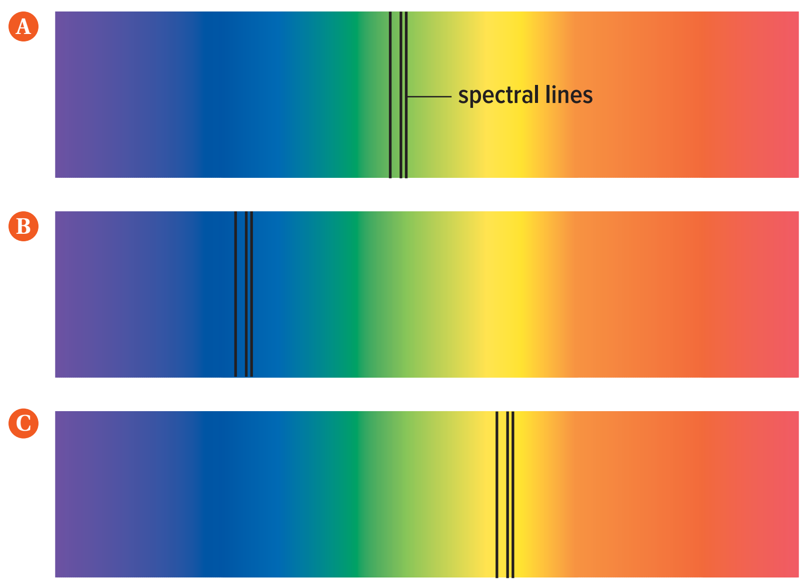


Figure 4.40 The spectral lines indicate the direction of motion of a star. In A, the distance to the star is not changing. In B, the lines have shifted toward the blue end of the spectrum, which indicates that the star is moving toward the observer. In C, the spectral lines have shifted toward the red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

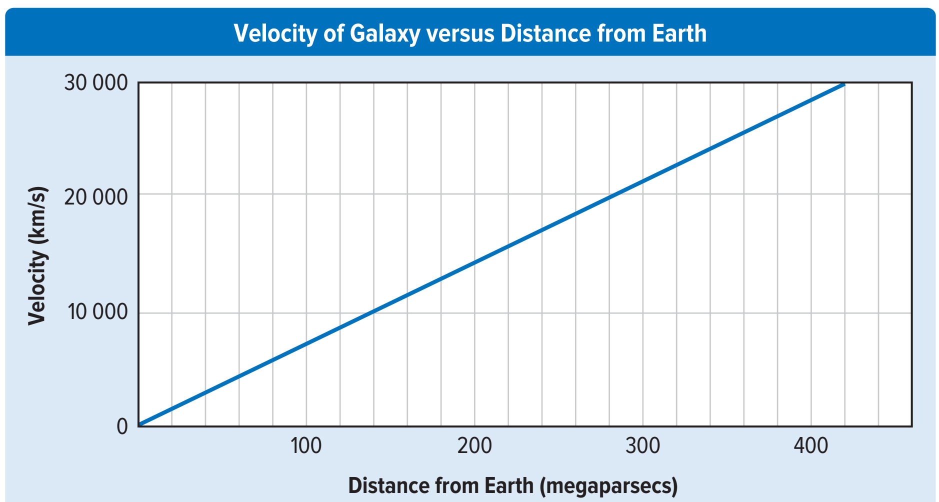


Figure 4.41 The value of the Hubble constant is the slope of the line. Note: The unit for distance in this graph is the megaparsec, which is 3.26×10^6 light-years. Astronomers prefer to use the megaparsec in graphs such as this. **Researching: Who invented the parsec, in what cases is it used in preference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

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.

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

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.

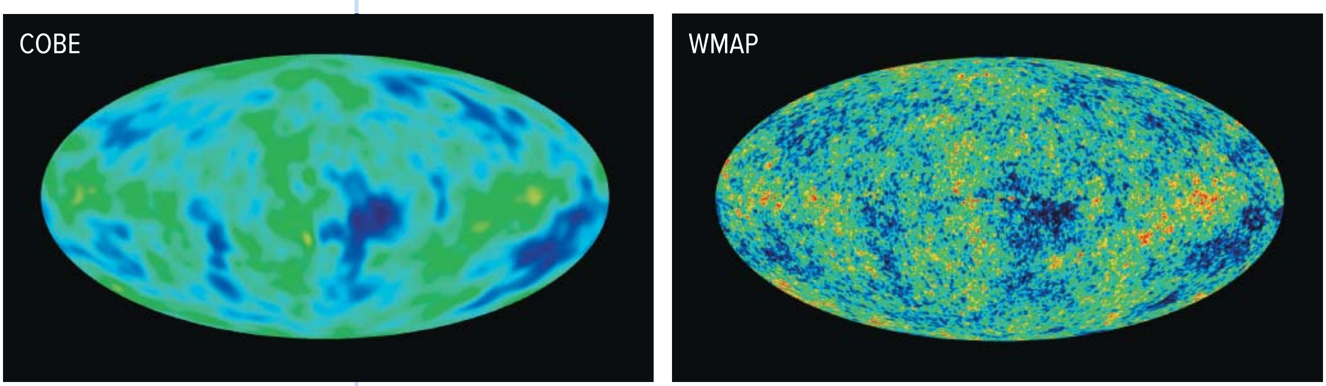


Figure 4.42 Both of these images show the CMB radiation. The colours represent slight variations in temperature. Blue is cooler, and yellow-red is warmer. The temperature variations are only a few millionths of a degree Celsius (10^{-6}°C).

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.

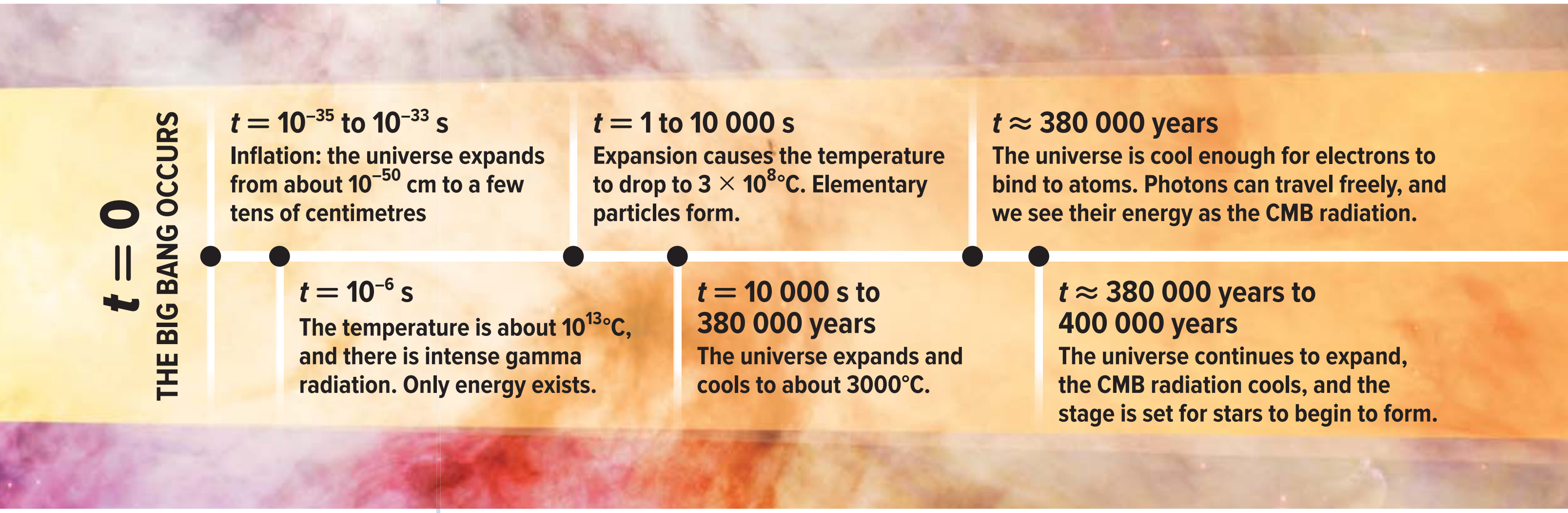


Figure 4.43 Timeline from the big bang to the present. **Questioning: What questions do you have as you read and reflect on the information in this timeline?**

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.

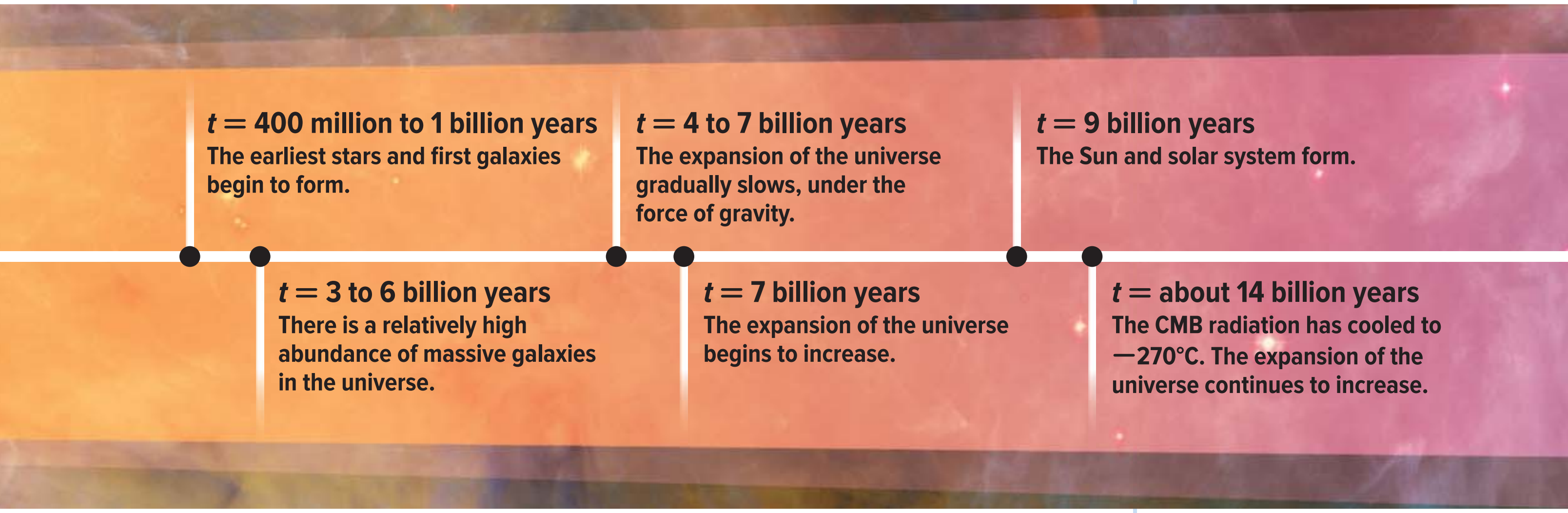
The James Webb Space Telescope

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.



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.

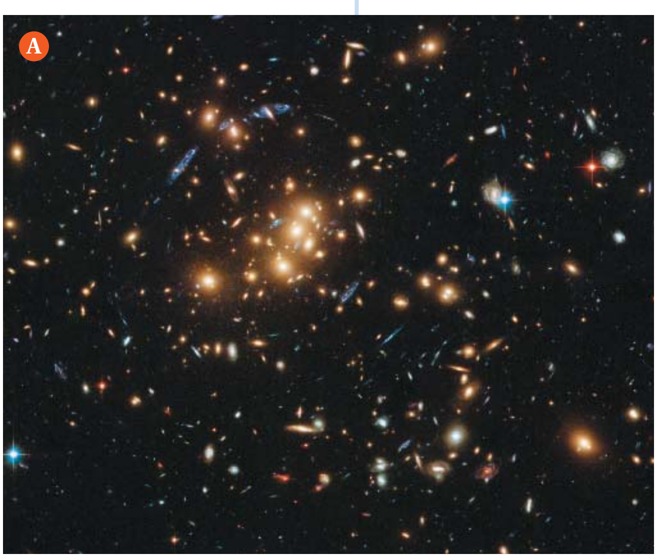
The universe as imagined through most of human history was huge. It contained the whole world—Earth, Sun, Moon, planets, and all the visible stars. And yet, prior to the 1930s, few people could have imagined the immense size estimated by astronomers today.

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

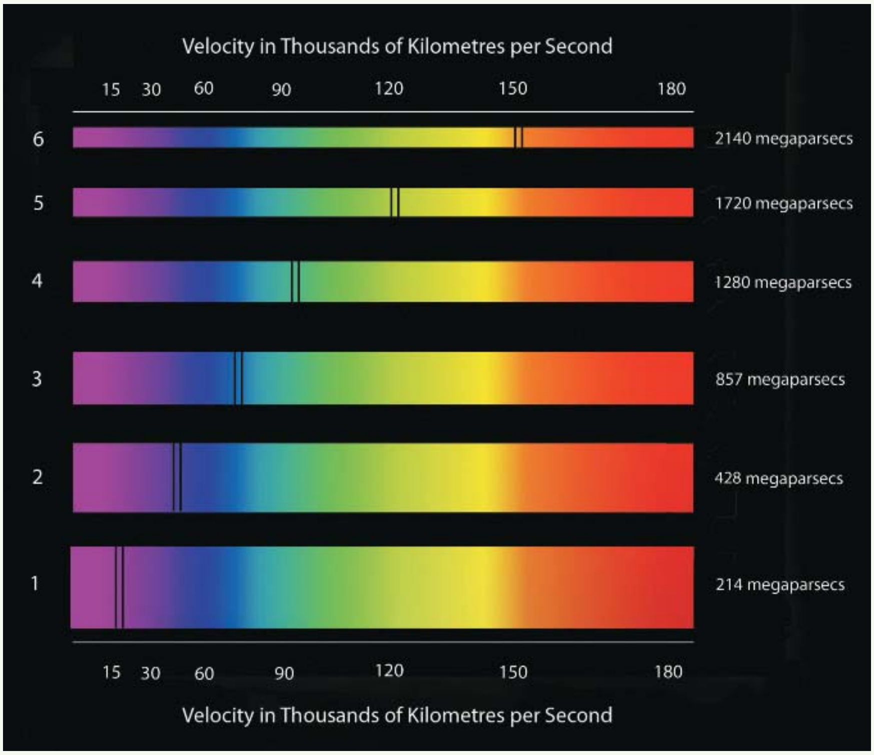
- Processing and Analyzing
- Applying and Innovating
- Evaluating
- Communicating

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

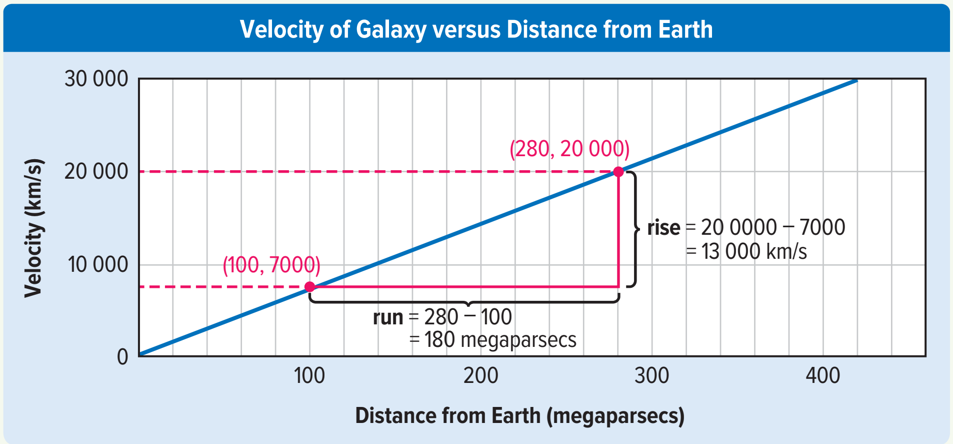
How can you estimate the age of the universe?

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.

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

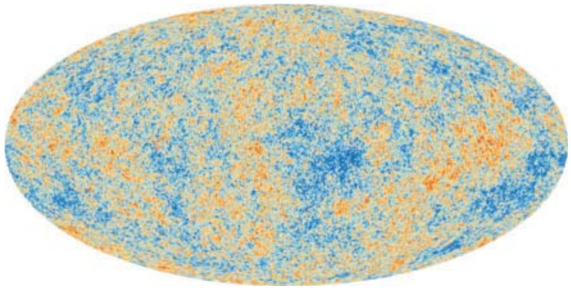
8. Explain how the idea of galaxies in an expanding universe can be compared to dots drawn onto a balloon which is then inflated. AI C

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