Key Terms
cosmology
Doppler effect
redshift
blueshift
big bang
cosmic microwave background (CMB) radiation

cosmology the study of the universe

9.2 The Universe

People have long wondered about the origin of the universe. How did the universe begin? Is it changing? Will it come to an end one day? **Cosmology** is the study of the universe. Cosmologists try to answer such questions about the universe. Using technology such as the Hubble Space Telescope and two satellites called COBE and WMAP, cosmologists have been able to see backward in time, to almost the very beginning of the universe. For example, the Hubble Space Telescope image in **Figure 9.7** shows many galaxies that are so old they must have formed shortly after the universe formed. In this section, you will learn how cosmologists and other astronomers, such as Edwin Hubble, have unravelled some of the universe's secrets and developed a theory about the formation of the universe.

Edwin Hubble

American astronomer Edwin Hubble (1889–1953) began his career as a high school teacher. Then he became a lawyer. He finally turned his attention to astronomy. 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.

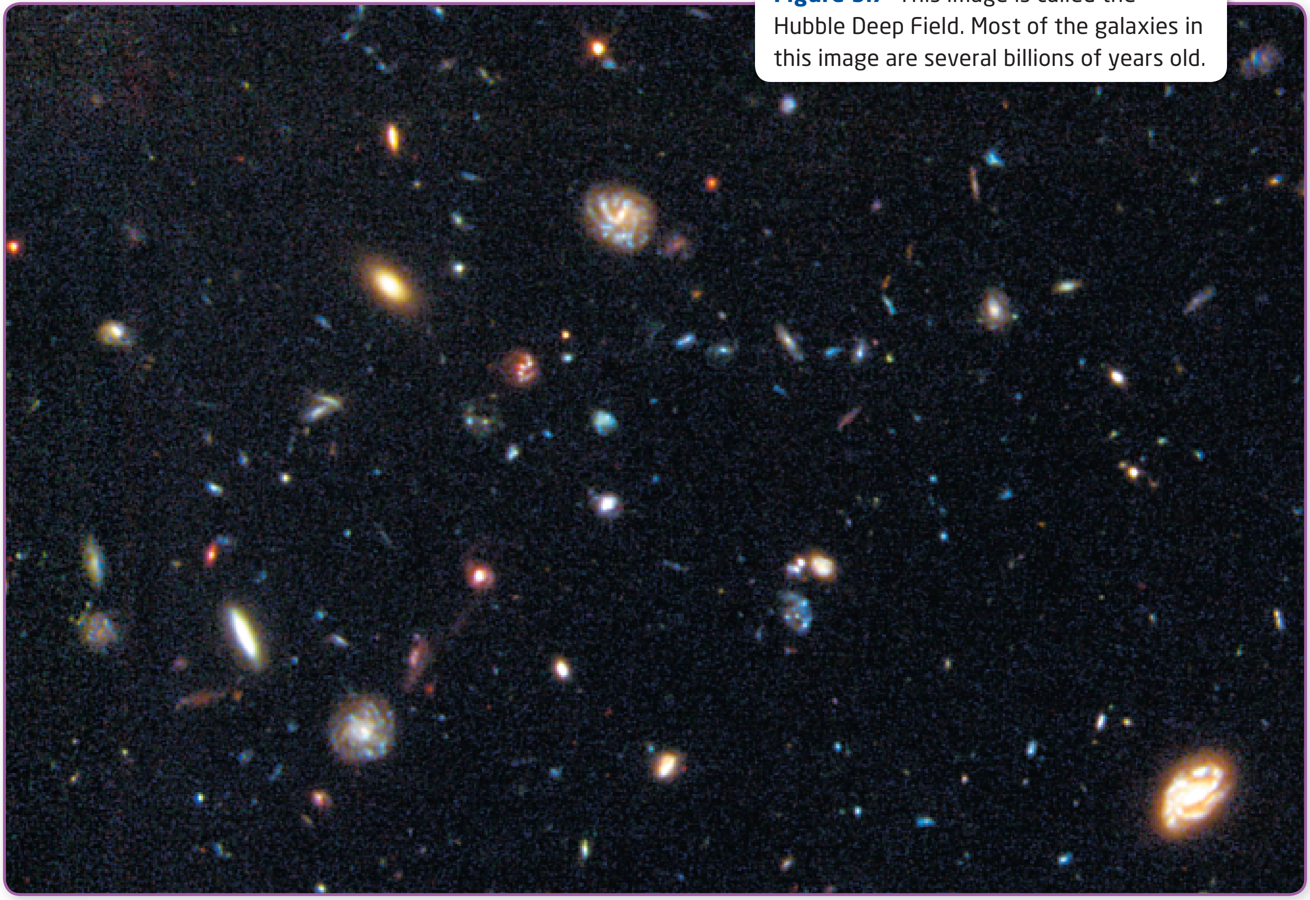


Figure 9.7 This image is called the Hubble Deep Field. Most of the galaxies in this image are several billions of years old.

The Doppler Effect

Hubble noticed something unusual about the spectra of galaxies. The 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 the ambulance approaches you, passes you, and then moves away. When the ambulance is moving toward you, the siren's sound waves are compressed, resulting in a higher frequency, or pitch. When the ambulance is moving away from you, the siren's sound waves are lengthened, resulting in a lower pitch. Light waves behave in a similar way.

Doppler effect the change in frequency of a light source due to its motion relative to an observer; also, the change in pitch of a sound due to the motion of the source relative to an observer

Redshift and Blueshift

Look at **Figure 9.8**. 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. (Spectra were introduced in Chapter 8.)

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.

redshift the effect in which objects moving away from an observer have their wavelengths lengthened, toward the red end of the visible spectrum

blueshift the effect in which objects moving toward an observer have their wavelengths shortened, toward the blue end of the visible spectrum

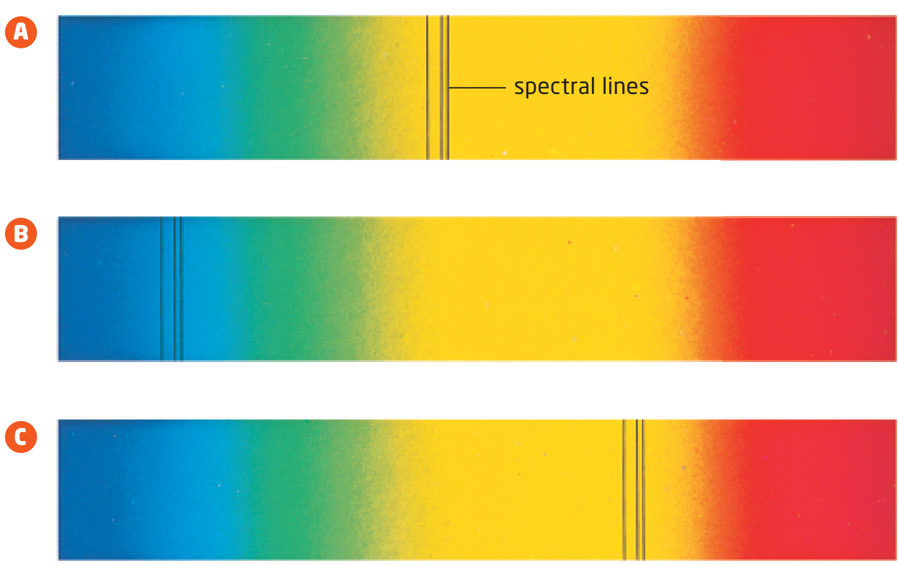


Figure 9.8 The spectral lines indicate the direction of motion of a star. In **A**, the star is not moving. In **B**, the lines have shifted toward the blue end of the spectrum, indicating that the star is moving toward the observer. In **C**, the spectral lines have shifted toward the red end of the spectrum, indicating that the star is moving away from the observer.

The Expanding Universe

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

Examine the graph shown in **Figure 9.9**. 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*. The slope of the line in the graph is called the *Hubble constant*. The Hubble constant is the rate at which the universe is expanding. (Like the Hubble Space Telescope, the Hubble law and the Hubble constant were named in honour of Edwin Hubble.) Russian-American physicist George Gamow (1904–1968) realized the significance of the speed–distance relationship: the universe is expanding.

Suggested Investigation

Inquiry Investigation 9-B, Modelling the Expanding Universe, on page 384

STSE Case Study

Space Exploration Spinoffs

Exploring space is a costly enterprise. Some space agencies spend billions of dollars a year, most of which goes to salaries. However, space exploration has generated some unexpected and useful spinoffs. A spinoff is a product that was originally invented and designed for one use but has been adapted for other everyday uses.

- The star-mapping technology used by the Hubble Space Telescope is now being used to detect breast cancer tumours in the early stages. This technology is an alternative to detection by surgery. It saves time and money and is not painful.
- Spacesuits have generated spinoffs such as breathing equipment for firefighters and specialized diving suits. U.S. Navy divers, for example, can now use suits designed with spacesuit technology to dive into ocean chemical spills. Thanks to the European Space Agency technology for spacesuits, some race-car crews now have suits made of fire-resistant materials. These suits also have a cooling system, so the crews do not get too hot.

The materials used to make the suits worn by racing crews are similar to the materials used to make spacesuits.

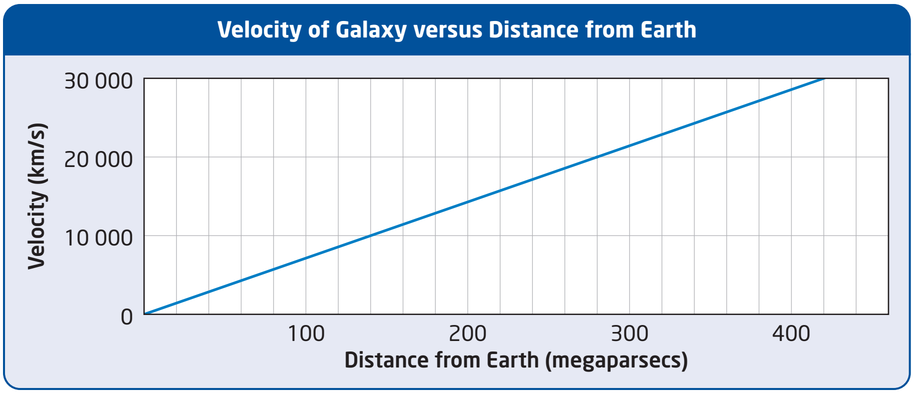


Figure 9.9 The value of the Hubble constant is the slope of the line. (**Note:** The unit that is used for distance is the megaparsec, which is 3.26×10^6 light-years. Astronomers prefer to use the megaparsec in graphs such as this.)

Learning Check

1. Review **Figure 9.8**. Define the term *redshift*.
2. If a galaxy is moving away from you, is its spectrum blueshifted? Explain your answer.
3. What evidence supports the expansion of the universe?
4. Explain the Doppler effect using the siren of a passing firetruck as an example.

NASA technology has resulted in eye-controlled computer technology, allowing someone with cerebral palsy, for example, to have more independence.

- During the Apollo rocket launches, the astronauts experienced extreme vibrations and high gravitational forces. As a result, they had limited arm and leg movement and found it difficult to control the switches. So, NASA developed eye-controlled switches. People who are confined to wheelchairs can now use this technology to write, speak, send e-mails, and even control their environment, for example, by turning up the heat.
- Astronauts on space walks need protection from the intense solar radiation. The Canadian Space Agency developed a radiation monitor, called the EVARM, to track astronauts' exposure to radiation from the Sun. This technology is now used in cancer treatment. The EVARM is placed on the part of the body receiving the radiation treatment to help doctors track how much of the radiation is reaching the tumour.
- To protect satellites from the extreme cold in space, NASA uses a very thin, lightweight, and shiny insulating material. This material reflects some of the infrared radiation to protect the instruments but absorbs some of the radiation to keep the instruments warm. Different businesses now manufacture this material as various products available to the public. One example is a protective blanket for marathon runners, which keeps the runners warm after the run.

Your Turn

1. What is a spinoff?
2. Name one hazard that astronauts face while in space. What technology was developed to protect astronauts from this hazard, and how has this technology been adapted for use on Earth?
3. Choose a spinoff from the case study. Research both the technology that generated the spinoff and the spinoff itself. Evaluate the costs and benefits of the technology and the spinoff. Organize your research in a graphic organizer of your choice.

The Big Bang Theory

Study Toolkit

Using Graphic Organizers
A graphic organizer would be helpful to summarize the main ideas on this page. Graphic organizers can help you remember and understand the main concepts in a piece of text.

Cosmologists observe that, at some time in the distant past, the universe was extremely compact, small, and unimaginably dense. Modern satellites can look back in time, almost to the very beginning of the universe. The observations from these satellites show that the universe began its expansion about 14 billion years ago. Therefore, the universe is about 14 billion years old. Cosmologists theorize that *there was no before*—that time and space both began 14 billion years ago.

No one knows what caused the "beginning." But whatever the cause, many cosmologists believe that the 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 insulting term. Hoyle did not believe that evidence for the big bang was very strong. Therefore, he thought that the big bang probably did not happen. There is now convincing evidence that the big bang may have actually occurred.

big bang the event that may have triggered the expansion of the universe 14 billion years ago

Evidence of the Big Bang

One piece of evidence to support the big bang theory is Hubble and Humason's distance–redshift relationship. Scientists have confirmed the expansion of the universe with their observations of very large distances and, therefore, a very early time in the history of the universe.

A second piece of evidence to support the big bang theory is the **cosmic microwave background (CMB) radiation**, which is radiation left over from the big bang.

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

To understand CMB radiation, imagine what happened to the radiation in the universe as the universe expanded. Initially, the universe was very hot. It was filled with gamma rays—electromagnetic radiation with very short wavelengths. 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 until they slipped into other parts of the electromagnetic spectrum.

Today, the CMB radiation that astronomers observe has a very short wavelength, only about 1.07 mm. As you can see in **Figure 9.10**, this is in the microwave part of the electromagnetic spectrum.

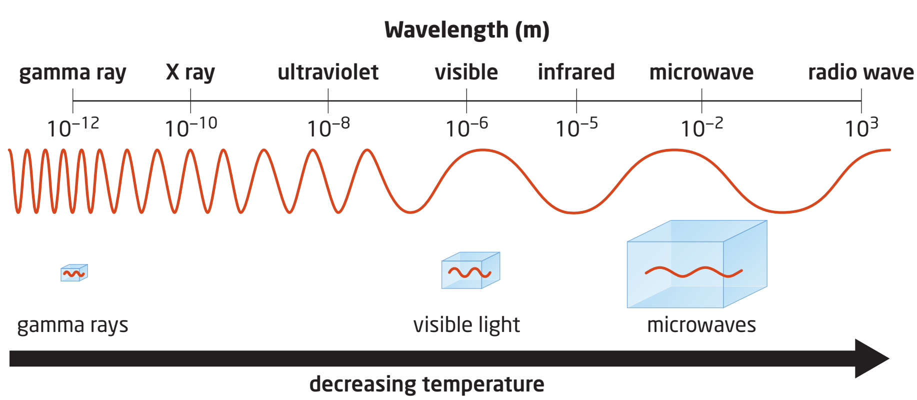


Figure 9.10 Today, the universe is filled with microwaves, the radiation left over from the big bang.

Uncovering the CMB Radiation Evidence

In 1948, Gamow predicted that the CMB radiation in the universe had cooled to about –269°C. In 1965, two American scientists, Robert Wilson and Arno Penzias, accidentally discovered this background radiation. Wilson and Penzias were working for the Bell Telephone Labs in New Jersey, in the United States. They were looking for sources of "noise" (such as static from a radio) that could interfere with satellite communications. In the process, they accidentally discovered the microwave noise that was produced by radiation left over from the big bang. The temperature of the CMB radiation was about –270°C, surprisingly close to Gamow's prediction. Wilson and Penzias's discovery was so important that they won the Noble Prize for physics in 1978.

COBE and WMAP

The two images in **Figure 9.11** 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, like the colours that show different elevations in a contour map of Earth. The colours are not observable colours. Microwaves are not in the visible part of the spectrum.

The images in **Figure 9.11** were taken by two different NASA satellites: COBE (COsmic Background Explorer, launched in 1989) and WMAP (Wilkinson Microwave Anisotropy Probe, launched in 2001). Both satellites were designed to measure the CMB radiation left over from the big bang. The satellites had to be above the atmosphere to detect this radiation. The WMAP image has more detail. In fact, the detailed data gathered by WMAP confirmed the data gathered by COBE. The tiny temperature variations in the WMAP map, indicated by the different colours, are exactly what scientists expected.

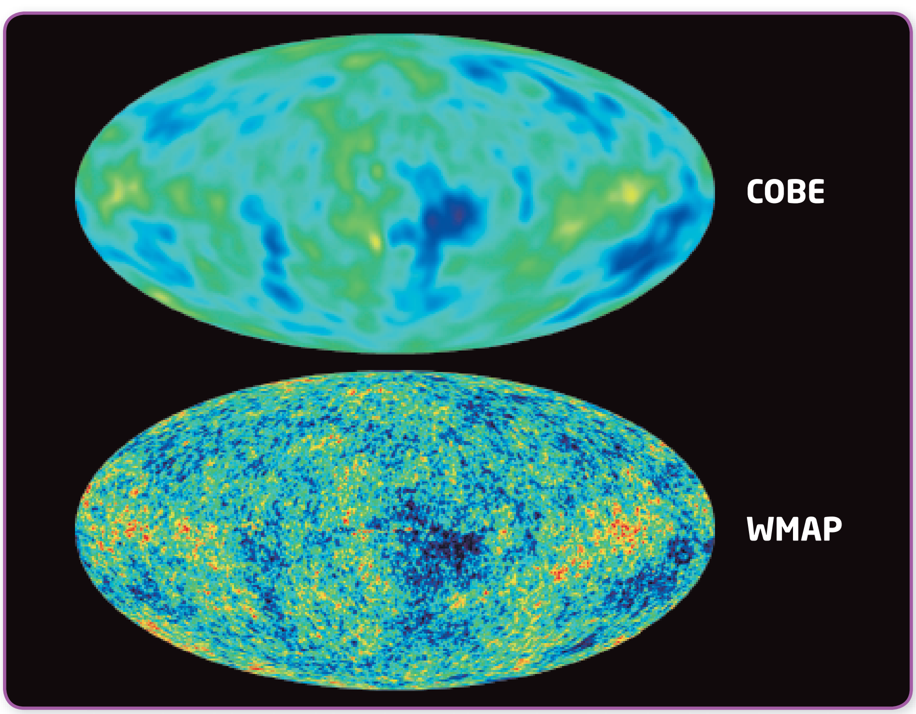


Figure 9.11 Both images show the CMB radiation, represented mostly in green. The colours represent slight variations in temperature. Blue is colder, and yellow-red is warmer. The temperature variations are only a few millionths of a degree Celsius (10^{-6} °C).

Looking Back in Time

Go to **scienceontario** to find out more

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 remarkably small. 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, very small.

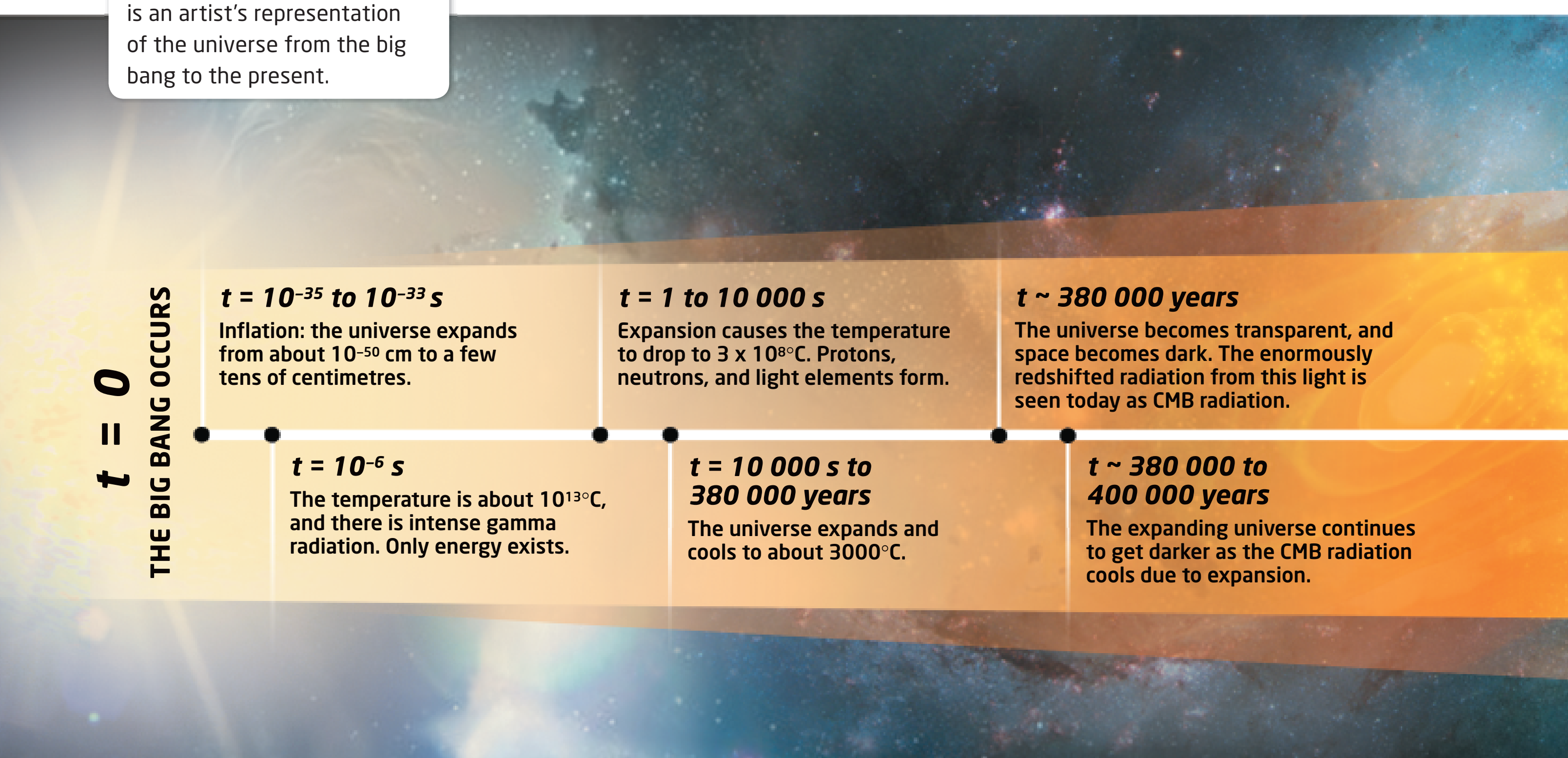
Suggested Investigation

Inquiry Investigation 9-A, Estimating the Age of the Universe, on page 382

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 9.12** presents a time line of the evolution of the universe from the big bang until the present.

Figure 9.12 This time line is an artist's representation of the universe from the big bang to the present.



The James Webb Space Telescope

Around 2014, NASA will be retiring the Hubble Space Telescope (HST). However, in 2013, NASA plans to launch its replacement: the James Webb Space Telescope (JWST). You can see a comparison of the HST's main mirror and the JWST's mirror in **Figure 9.13**. 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, along with NASA and the European Space Agency

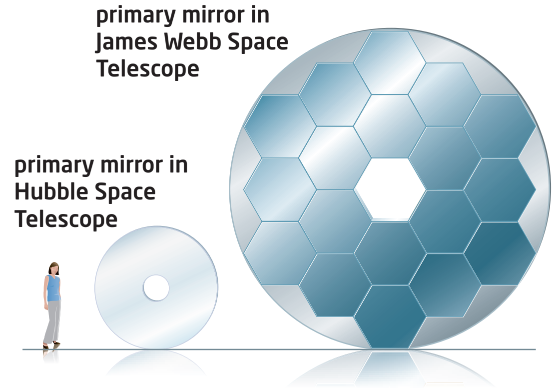
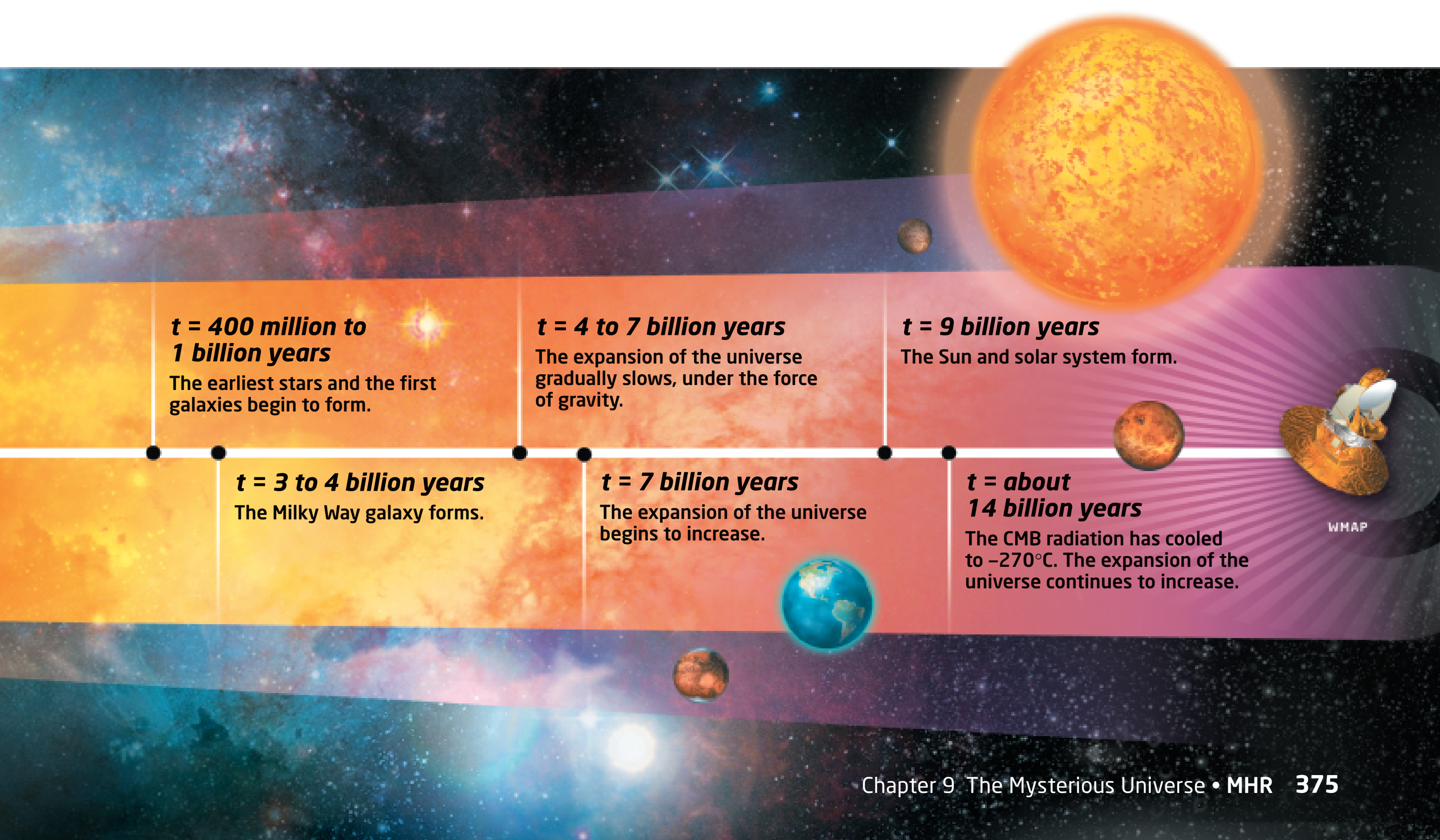


Figure 9.13 The mass of the JWST's mirror is half the mass of the HST's primary mirror, even though the HST's primary mirror is a lot smaller.

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 the energies 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, other 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 so that all the scientists could share their information on their computers.



Section 9.2 Review

Section Summary

- Edwin Hubble's observations of galaxies led to the discovery that the universe is expanding.
- Exploring space has generated valuable spinoff technologies.
- The most widely accepted theory of the beginning of the universe is called the big bang theory. According to this theory, an unimaginably tiny volume of space suddenly and rapidly expanded to an immense size about 14 billion years ago.

Review Questions

C **1.** What did Edwin Hubble discover about the spectra of the galaxies he observed? Support your answer with a diagram.

K/U **2.** What does the redshift suggest about the motion of galaxies?

K/U **3.** State the main idea of the big bang theory.

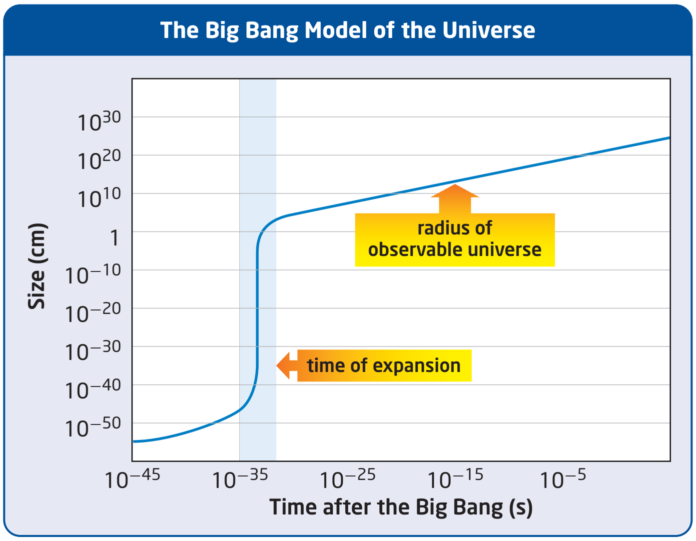
K/U **4.** How does cosmic microwave background radiation support the big bang theory?

T/I **5.** How does the pattern shown in the WMAP image in **Figure 9.11** indicate that microwave radiation is not the same everywhere in the universe?

T/I **6.** Analyze the graph below, and describe what happened to the universe from 10^{-45} s to 10^{-5} s.

K/U **7.** What other evidence, in addition to cosmic microwave background radiation, supports the big bang theory?

A **8.** If the World Wide Web had not been invented, how do you think your life would be different?



This graph shows the size of the universe versus time after the big bang.