UNIT C

The Study of the Universe

This astronaut, who is mounted on the end of the Canadarm2 robotic arm, is making repairs to the International Space Station in orbit around Earth.

Contents

Unit Task

In this unit, you will learn about the planets in our solar system and about robotic probes, space missions, and human voyages beyond Earth. For your Unit Task, you will assess which is the more reasonable action: sending humans or sending robotic probes on an extended mission to Mars.

Essential Question

Based on ethical, political, economic, scientific, and societal considerations, can a human mission to Mars be justified?

Exploring

A view of deep space taken by the Hubble Space Telescope

The area of the image above is about the size of the head of a pin if you were to hold the pin at arm's length up against the night sky.

Trying to Picture the Immensity of Space

On a still, clear night away from city lights, what you see in the sky might look like what is shown in the image here. All the thousands of twinkling stars we can see from Earth even without a telescope are part of the galaxy we live in, the Milky Way. A **galaxy** is a collection of hundreds of billions of stars held together by gravity.

Therefore, you might be surprised to learn that each speck of light visible in the image above is not a star. Rather, it is an individual galaxy. This picture was taken by the Hubble Space Telescope, which is in orbit (circling) high around Earth and looking far out into space. Consider for a moment that the area of sky that this image shows is equal to the area of the head of a pin held at arm's length. Even in a patch of sky as small as that, we can see all these galaxies. Think about what that means if each galaxy in the image contains hundreds of billions of stars.

The distance from Earth and the Milky Way to these other galaxies is extremely great. Not only that: scientists have also found that, with a few exceptions, all galaxies are moving farther away from ours and from each other. It seems that space between the galaxies is expanding, causing the distances to increase. These are incredible thoughts, yet scientific evidence supports them and many other intriguing conclusions about the nature of our universe. **Universe** is the term we use to refer to everything that physically exists: the entirety of space and time, and all forms of matter and energy.

Canada has long worked in cooperation with other countries to explore space — what many people have referred to as the "last frontier." Canadian astronomers have made many important discoveries through their work at observatories in this country and around the world. Canadian researchers and engineers have produced technological innovations such as robotic systems that are now helping to advance space exploration. Canadian astronauts have travelled into space, lived for weeks at a time on the International Space Station, and conducted many experiments, some on behalf of school students.

While exploring space is both costly and hazardous, it seems that humans have never been able to resist the urge to learn more about what lies beyond our own planet. The more we find out, the more we realize there is to discover.

Astronomers from around the world book time on telescopes such as this one, the Canada-France-Hawaii telescope, to study many aspects of space.

C1 **STSE** ***Science, Technology, Society, and the Environment***

Space Exploration in the News

The Internet, television, radio, and print media often report on discoveries and new advances in the exploration of space. Also widely available are stunning images of celestial objects, taken from Earth and from space-based cameras. In this activity, you will brainstorm a list of news items you have read, watched, or heard about space exploration.

You will consider how often space exploration news items are reported in the media and what their implications are for technology, society, and the environment.

1. As a class, brainstorm as many news items as you recall recently reading or hearing about related to the study and exploration of space. As an aid, if necessary, scan the news items brought to class by your teacher.
2. Record the main topics on the board or a flipchart.
3. For each topic, discuss as a class the implications of the event, action, or findings for:
   (a) society
   (b) technology
   (c) the environment

7 Scientific evidence suggests that the universe began expanding from a single point about 13.7 billion years ago.

The Sombrero galaxy contains more than 100 billion stars. The oldest stars are in the central bulge. New stars are still forming in the dust lanes, which lie in a ring around the centre.

Skills You Will Use

In this chapter, you will:

- use appropriate terminology related to the study of the universe
- represent the distance of stars from Earth using scientific notation
- compare and contrast properties of celestial objects visible in the night sky by researching and analyzing information

Concepts You Will Learn

In this chapter, you will:

- describe the major components of the universe, using appropriate scientific terminology and units
- describe the observational and theoretical evidence relating to the origin and evolution of the universe

Why This Is Important

Throughout their lives, most people ask themselves three key questions: Where did I come from? Where am I now? Where am I going? These questions can also be asked of our entire world, Earth. Assessing scientific evidence for how and when the universe formed and continues to change can help us find some answers to these questions.

Before Reading

Thinking Literacy

Making Connections to Prior Knowledge

Skim the titles, subheadings, and illustrations of section 7.1 to get a sense of the key ideas. Scan for terms that you know. Use familiar ideas and terms to create a mind map that connects all of your knowledge about space and the universe. What you know already will help you connect to new information and ideas.

Key Terms

• astronomy • astronomical unit • Big Bang theory
• celestial objects • galaxy • light-year • nebula
• nuclear fusion • solar system • star • supernova

Scientific evidence suggests that the universe began expanding from a single point about 13.7 billion years ago.

7.1 Space Flight to the Stars

Here is a summary of what you will learn in this section:

- Astronomy is the study of the universe and the celestial objects in it.
- The solar system is composed of the Sun, four rocky inner planets, four gas giant planets, and other objects such as asteroids, comets, and moons.
- An astronomical unit (AU) is a measure of distance, equal to the average distance from the Sun to Earth.
- A light-year (ly) is a measure of distance, equal to the distance light can travel in 1 year.

Figure 7.1 The Milky Way galaxy looks like a smudge in the sky shown above. The brightest point to the left is the planet Jupiter.

Looking Back in Time

In all societies, people have looked at the night sky for inspiration, to find directions, to decide when to plant or harvest crops, or just to appreciate its great beauty (Figure 7.1). "Celestial" is a term that refers to the sky. Objects we can see in the sky are called **celestial objects**. The Sun, the Moon, Earth, other planets, and comets are all examples of celestial objects.

WORDS MATTER

"Astron" is the Greek word for star, and the suffix "-nomy" means science or study of. So, astronomy is literally the study of the stars.

Astronomy is the study of the universe and the objects in it. An **astronomer** is a person who studies astronomy. At one time, astronomers had only two aids to help them understand celestial activity: sharp eyesight and a practical knowledge of mathematics. These days, highly powerful and sensitive instruments enable us to peer farther and farther out into the universe and to gather information about the celestial objects in it. Supercomputers can analyze the incoming data from 100 000 stars at the same time.

When astronomers look at a faraway celestial object, the distance they are looking across is so vast that they are really looking back in time. Light takes time to travel. When you look at your hand, for instance, you see it not as it is, but as it was a few billionths of a second ago. At short distances, this delay does not make a difference. However, when you are looking out into space, the delays begin to add up. For example, it takes about 1.5 s for the light to reach Earth from the Moon (Figure 7.2). We therefore always see the Moon as it was 1.5 s ago. The planet Jupiter, farther from Earth than the Moon is, appears to us as it did 45 min before.

Figure 7.2 The Moon over Toronto

C2 *Quick Lab*

A Map of the Universe

Purpose

To list all the objects you know of that exist in the universe and then to show their relationships to each other by arranging them on a map

Materials & Equipment

- poster paper or newsprint
- felt pens

Procedure

1. Working in pairs or a small group, brainstorm a list of all the different kinds of objects you know about in the universe. Examples include planets, comets, and stars. Write these down the side of a sheet of poster paper.
2. Copy the labels shown in Figure 7.3 onto the sheet of paper.
3. Arrange the objects in the order you might encounter them on a trip that begins at Earth and continues to the most distant reaches of the universe away from Earth (or as far out as you know about). If you know the shape of each object or a symbol to represent it, draw that. Do not concern yourself with trying to make your map to scale. Label each object.

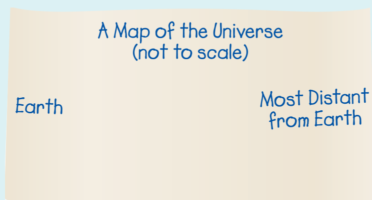


Figure 7.3 Step 2

4. Post your map on a wall in the classroom.

Questions

5. Compare your map with that of other groups. How do they differ? How are they similar?
6. Were there any new objects that you learned about during this activity? If so, what were they?

During Reading

Thinking Literacy

Using Prior Knowledge

Think about holidays or road trips you have taken. What were the destinations? What preparations did you make? How long was each journey? Now, for an imaginary voyage out among the stars, think about the preparations and travel details you would need to consider.

From Earth to the Stars of the Milky Way

Imagine that we could travel from Earth out among the stars in our Milky Way galaxy. In reality, a journey to other stars is impossible. The distances are much too great between objects and our lives are much too short to enable us to make such a journey. Still, an imaginary trip like this is a good way to let us examine much of what has recently been learned about the universe.

We would start the trip by heading out into the solar system. The **solar system** is the Sun together with all the planets and other celestial objects that are held by the Sun's gravitational attraction and orbit around it (Figure 7.4). Among the other celestial objects in the solar system are moons, comets, and asteroids. Chapter 8 describes these objects in more detail.

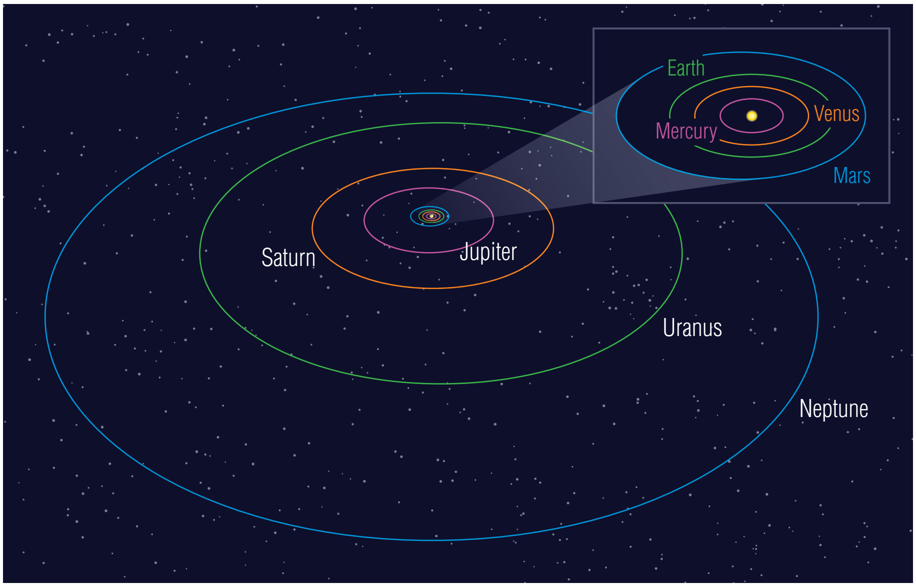


Figure 7.4 A comparison of the orbits of the eight planets in the solar system

The Sun and Inner Solar System

Leaving Earth on our imaginary journey, we first encounter the Moon. Twelve people have walked on the Moon, the last time in 1972. With their *Apollo* spacecraft travelling about 30 times the speed of a jet airplane, the astronauts' trip to the Moon took four days.

The Moon is smaller than Earth and has no atmosphere and little or no water. Thus, a footprint left by an astronaut can last for an indefinite length of time (Figure 7.5). As the Moon orbits Earth, it rotates at a speed that keeps the same side always facing Earth. The first and so far only people to see the far side of the Moon directly were the astronauts who flew there during the *Apollo* missions of 1968 to 1972.

Figure 7.5 An astronaut's footprint on the Moon's surface

Beyond the Moon is the rest of the solar system. At the centre of the solar system is the Sun, which is a star. A **star** is a hot ball of plasma, an electrically charged gas, that shines because nuclear fusion is taking place at its core. **Nuclear fusion** is the process in which the nuclei of atoms fuse together and form larger atoms. During this process, an enormous amount of energy is released. Between Earth and the Sun are two planets, Mercury and Venus (Figure 7.6). Turning and travelling away from the Sun, out past Mercury, Venus, and Earth, we next come to Mars, the last of the four rocky planets that make up the inner solar system (Figure 7.6).

WORDS MATTER

Plasmas are a fourth phase of matter, in addition to solids, liquids, and gases. A plasma is made up of charged particles. Flames, lightning, the aurora borealis, the neon in neon lights, and stars are all examples of plasmas. This use in physics of the word plasma comes originally from the medical world, where the term refers to the colourless fluid part of the blood.

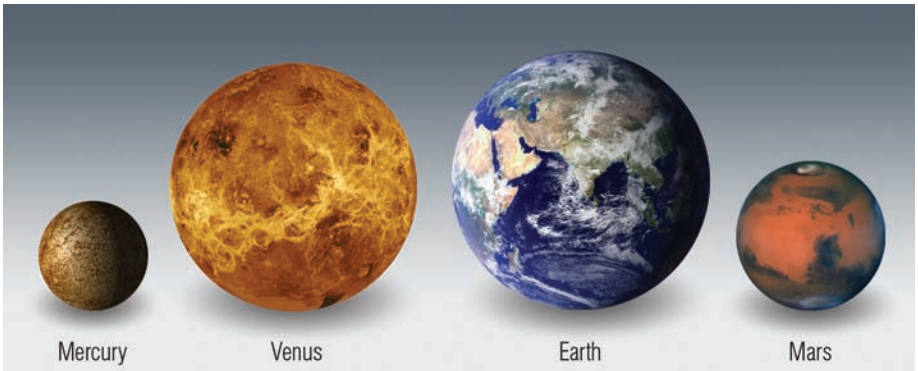


Figure 7.6 The four rocky planets of the inner solar system. Only Mars has some similarity to Earth in terms of temperature and gravity.

Measuring Distances in Space

Leaving the inner planets of the solar system, the distances we begin to travel become nearly impossible to envision. So vast are the distances in space that astronomers have had to develop special units of measure. Just as you would not find it practical to measure the length of your school gymnasium in millimetres, astronomers quickly learned that measuring distances in the solar system in kilometres was not practical.

For this reason, the astronomical unit was created. One **astronomical unit (AU)** equals the average distance between the Sun and Earth, about 150 million km. For example, the planet Mercury is 0.39 AU from the Sun. This value is less than 1 AU because Mercury is closer to the Sun than Earth is. Mars is farther from the Sun than Earth is. Its distance is 1.52 AU.

Outside the solar system, the distance to other celestial objects again becomes so great that even the AU is too small to be a useful unit of measure. For these immense distances, astronomers usually use a distance measure called the light-year. One **light-year (ly)** equals the distance that a beam of light can travel through space in 1 year. It is equivalent to 63 000 AU or 9000 billion km. At the speed of light, you could travel around Earth seven times in 1 s. A trip from the Sun to Neptune at the speed of light takes about 5 h.

The Outer Solar System

Out past Mars, we encounter the **asteroid belt**, a region of rocky debris that forms a ring all the way around the Sun at a distance of about 3 AU. The asteroid belt contains billions of pieces of rock of all sizes. Some of these chunks are smaller than a grain of sand. Others are huge. The largest is about 1000 km across, which is equal to the distance from Ottawa to Thunder Bay.

Beyond the asteroid belt lie the four gas giant planets: Jupiter, Saturn, Uranus, and Neptune (Figure 7.7). Jupiter is so large that several thousand Earths could fit inside it. The gas giant planets do not resemble Earth at all. Their atmospheres are made mostly of hydrogen and helium.

The planet farthest out in the solar system is Neptune, in orbit 30.1 AU away from the Sun.

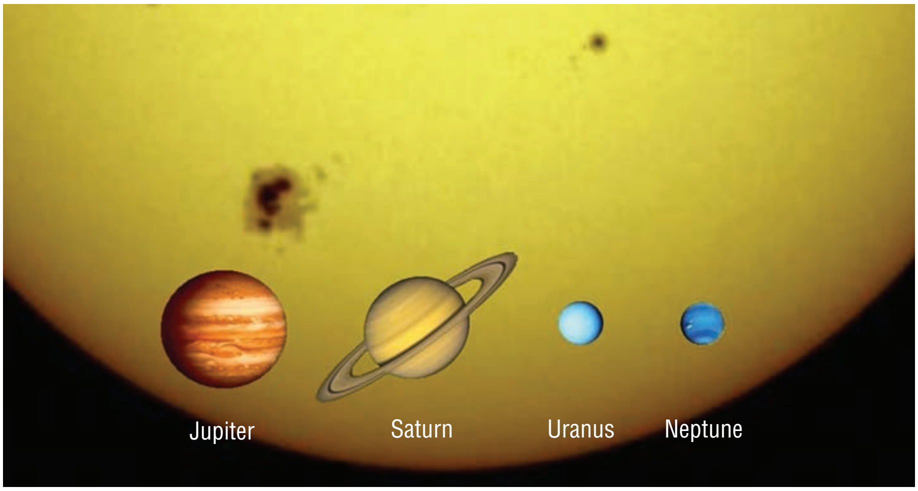


Figure 7.7 The four gaseous planets of the outer solar system, shown here with the Sun in the background for scale. Had Jupiter been a little larger, nuclear fusion might have started in its core and Jupiter might have become a star.

Many more objects exist in the solar system besides the eight major planets. These are smaller and include moons, comets, minor planets such as Pluto, and tiny grains of dust and ice. Some objects held in the Sun's gravitational grip orbit as far as 50 000 AU away, which is one-quarter of the way to the next nearest star.

Learning Checkpoint

1. What is the solar system?
2. (a) How are an astronomical unit and a light-year similar in terms of what they measure?
   (b) Which is the longer distance, 1 AU or 1 ly?
3. (a) What is a star?
   (b) Name the closest star to Earth.

To the Stars

With enough time and a fast enough spacecraft to transport us on this imaginary journey, we would eventually travel among the stars.

The next nearest star to Earth after the Sun is actually part of a group of three stars that orbit each other. This group is called the Centauri system (Figure 7.8). It lies about 4.3 ly away from the solar system. If it were possible for you to have a cellphone conversation with someone living near these stars, just saying hello to each other would require more than 8.5 years. That is how long it would take the radio signal, moving at the same speed as light, to travel to the Centauri system and back again to Earth.

As we continue our voyage out farther through deep space, we would start to notice that well over half of the star systems have two or more stars. A system with two stars is called a **binary system** (Figure 7.9). If the stars are close together, it might be possible for planets like ours to orbit all the way around both of them. Some astronomers suggest that Earth-like planets orbiting around tightly bound binary stars might be more common than our own one-star arrangement.

Although the stars in the Centauri system may be the closest to Earth after the Sun, none of them is the brightest star we can see at night. The title of "brightest star visible from Earth" goes to Sirius, even though it is nearly twice as far from us as the Centauri system is. Sirius is brighter because it is a different kind of star than the Centauri stars. Sirius is about twice the mass of our Sun.

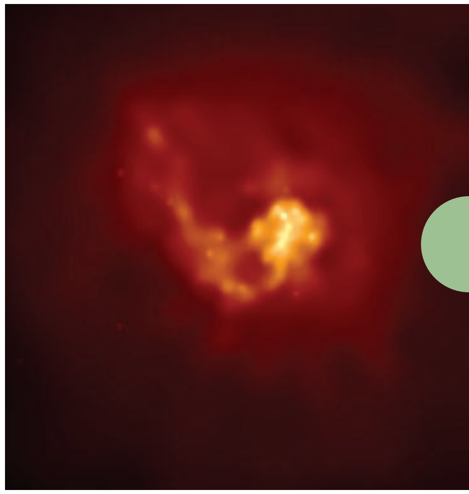


Figure 7.8 The Centauri system. Earth's nearest star after the Sun is part of this system.

Suggested Activity
C4 Quick Lab on page 266

Exploding Stars

During this journey, you might also see a star explode. If so, you should hope that the explosion occurs at least 100 ly away from the region of space you are travelling through. When a star explodes, it is called a **supernova**. A star might exist for millions or even billions of years and then suddenly come to an end in a few minutes. The gradual build-up of heavy elements in the star's centre causes the core to collapse.

Figure 7.9 Albireo is an example of a binary star system. When viewed by the unaided eye, Albireo looks like a single star. A telescope shows that it is really made up of two stars, shown clearly here.

(a) (b)

Figure 7.10 In 1987, Canadian astronomer Ian Shelton photographed the explosion of the brightest supernova seen by anyone since the invention of telescopes. The images here show supernova 1987A before the explosion (a) and after (b).

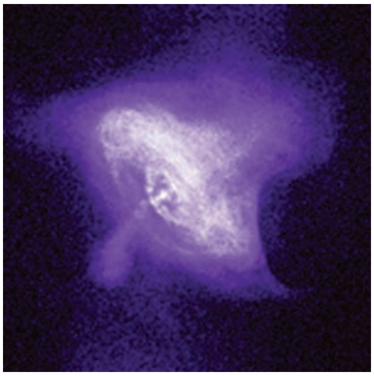


Figure 7.11 The Crab Nebula

Figure 7.12 These petroglyphs (rock drawings) on the walls of Chaco Canyon in Arizona record the supernova event that created the Crab Nebula.

Take It **Further**

Supernova 1987A, first spotted by Canadian astronomer Ian Shelton, was studied for many weeks after the event by astronomers around the world. Find out what was learned about stars from the observations made of supernova 1987A. Begin your research at ***ScienceSource***.

When this happens, the outer layers of the star are pulled into the core by gravity. As the outer material crashes into the inner core, the temperature and pressure increase and the star explodes (Figure 7.10).

High pressures and temperatures created during the supernova explosion lead to the formation of new elements. As the star rips apart, debris from the explosion provides the matter for another type of celestial object, a nebula.

A **nebula** is a large cloud of dust and gas. Nebulae are often called star nurseries, because it is from their dust and gas that stars develop. Figure 7.11 shows the Crab Nebula, whose beginning was observed and recorded by many observers on Earth in 1054. Among those were Arab and Chinese astronomers, as well as Aboriginal peoples in North America (Figure 7.12).

Stars capable of becoming supernovas are rare right now in the region of space nearest Earth. This is fortunate because a supernova explosion anywhere within 100 ly of Earth would roast the planet. Yet, in the wide expanse of the universe, they are very common. If we had a very sensitive telescope that could look in all directions of the visible universe at once, we could expect to see a supernova explosion every few seconds. Currently, about one supernova a week is detected by telescopes that are based in orbit and can scan deep space.

The View Back to Earth

So far, our trip has taken us past about 100 billion stars. If we looked back at them, we would see that most seem to be part of a thin disk, 100 000 ly across and swirling around a common centre. This group of stars is our galactic home, the Milky Way.

We cannot see the entire Milky Way directly because the solar system is inside it. However, if we could, it would look something like the collection of stars in the Pinwheel galaxy (Figure 7.13). A galaxy with this shape is known as a spiral galaxy.

Figure 7.13 The Pinwheel galaxy, which has a similar shape to our galaxy, the Milky Way

C3 *Just-in-Time Math*

Scientific Notation

Whether we are counting numbers of stars in a galaxy or the distance from the Sun to the next nearest star, we often deal with extremely large numbers. Scientific notation helps to make very large numbers shorter and easier to handle. Scientific notation is based on powers written using the base number 10.

For instance, using scientific notation to write the number 321 000 000 000 results in 3.21×10^{11}. The first part of the number (in this case, 3.21) is always greater than or equal to 1 but less than 10. The second part of the number is a power with base 10 and an exponent number (in this case, 11, written in superscript, raised and set up to the right of the 10).

Example: The speed of light is about 299 800 000 m/s. Write this in scientific notation.

Step 1: Put a decimal point after the first digit on the left. This gives 2.99 800 000 for the example.

Step 2: Count the number of places from the decimal point to the end of the zeros. For 2.99 800 000, there are eight places. This means the power of base 10 has an exponent of 8, written as 10^8.

Step 3: Delete the zeroes. The number written in scientific notation is 2.998×10^8 m/s.

Write the following numbers in scientific notation:

1. the distance from the Sun to the nearest star: 40 000 000 000 000 km
2. the average distance from Earth to the Sun: 150 000 000 000 m
3. the distance from the Milky Way to the farthest galaxies: 13 000 000 000 ly
4. the total number of celestial objects (mostly asteroids) in the solar system: 152 500
5. the mass of the Sun: 1 990 000 000 000 000 000 000 000 000 000 kg
6. the age of Earth: 4 550 000 000 years

C4 *Quick Lab*

All These Worlds

In addition to the eight major planets in the solar system, astronomers have already identified more than 300 planets orbiting stars other than the Sun. The question of whether there might be other life forms living in distant worlds is clearly related to the question of how many other worlds there might be. Most of the planets astronomers have already detected appear to be gas giants, not smaller rocky planets like Earth. We do not know whether this is because rocky planets are uncommon or because they are smaller and harder to detect.

In this activity, you will make a conservative estimate of the number of Earth-like planets likely to exist in the universe. A conservative estimate is a rough calculation in which assumptions are made that tend to underestimate how many of something there are. When you arrive at your conservative estimate, you can then say "There are at least this many, and probably there are more than this amount."

Listed in the next column are a number of assumptions for you to consider in finding your result.

Purpose

To make a conservative estimate of the number of planets in the universe that resemble Earth, and to compare that number to the number of people on Earth

Materials & Equipment

- calculator

Procedure

1. Working individually or in a small group, read the assumptions in the next column. Modify them if you can think of different ones that seem reasonable, but be prepared to explain any changes.

Assumptions
In the Hubble Ultra Deep Field image shown at the start of this unit, a computer counted the galaxies and determined there to be about 35 000, or 3.5×10^4.
The patch of sky viewed in the Hubble Deep Field is small, the size of the head of a pin held at a distance of 1 m. The number of pin heads needed to cover the inside of a sphere 1 m in radius is approximately 13 million, or 1.3×10^7.
A typical galaxy has 200 billion stars, or 2×10^{11}.
Assume (conservatively) that 1 star in every 100 has a planet around it, or 0.01 of stars has a planet.
Assume that of stars that have planets, only 1 in 1000 has an Earth-like planet around it, or 0.001 of stars has an Earth-like planet.

2. Using a calculator, combine the above terms by multiplying them together. When you get your result, check it with that of other students.

Questions

3. The human population of Earth is about 7 billion people (7×10^9). Divide your result in step 2 by the population of Earth to estimate how many Earth-like planets there are in the visible universe for every man, woman, and child on Earth.

4. Do the above calculations affect your assessment of whether there are other forms of life in the universe? Explain.

Figure 7.14 A tiny portion of the universe revealed by the Hubble Space Telescope

7.1 CHECK and REFLECT

Key Concept Review

1. List five different types of celestial objects in the solar system.
2. What is a star?
3. What happens in the core of a star that causes it to shine?
4. (a) Define astronomical unit.
   (b) What is 1 AU equal to in kilometres?
5. (a) Define light-year.
   (b) What is 1 ly equal to in astronomical units?
6. Name the four planets that lie beyond the asteroid belt, in order from closest to farthest from the Sun.
7. Binary systems account for approximately what proportion of star systems in the universe?
8. What is the relationship between a supernova and a nebula?

Connect Your Understanding

9. Explain why looking at an object, whether it is your hand or a distant star, is like looking back in time.
10. Several astronauts have flown to the Moon and even walked on its surface. Yet, a flight from Earth out to the stars in the Milky Way galaxy can only be imagined. Explain why that is.
11. Why are astronomical units not used for measuring distances between celestial objects that lie outside the solar system?
12. (a) Calculate how many years it would take a spacecraft to travel the 150 000 000 km distance between Earth and the Sun if the travel speed were 1000 km/h.
    (b) Using the answer you got for (a), calculate approximately how long it would take that same spacecraft to make a one-way trip from the Sun to Neptune.
13. The star Aldebaran, visible from Earth, lies about 65 ly away from us. What is the minimum amount of time that would be required to send a message to Aldebaran and receive a reply (assuming someone was there to receive it and respond)?

Question 13

14. Explain why scientific notation is useful for expressing many properties of celestial objects, such as the distance from Earth to the stars in the Milky Way galaxy.

Reflection

15. Many of the activities in this unit, such as the Quick Lab at the beginning of this section (C2, A Map of the Universe), suggest that you brainstorm in a small group or even as a class. What benefits do you think such a group approach offers in terms of helping to advance ideas about a topic?

For more questions, go to ***ScienceSource***.

7.2 Galaxies

Here is a summary of what you will learn in this section:

- Galaxies contain about 200 billion stars each and usually have a supermassive black hole at their centre.
- At least 90 percent of the mass in the universe may be composed of dark matter.
- Galaxies come in many shapes including spiral, barred spiral, elliptical, and irregular.
- Galaxies are often bound together in clusters. Clusters are often associated with other clusters.

Figure 7.15 A panoramic view of the night sky, featuring the Milky Way over the desert near Death Valley, California

WORDS MATTER

The word "galaxy" comes from an ancient Greek word *galaktos*, meaning milk.

Our Solar System: A Speck in the Milky Way

Figure 7.15 shows a panoramic view of the Milky Way as seen from Earth. The picture, which compresses the entire night sky into a rectangle, was made by combining 30 images. Taken in the middle of a desert far from artificial lights, these images capture the brilliance of the night sky that is not usually visible to most people.

The band of light arching across the sky in the composite photograph is actually a straight line. It looks curved because of the way the images were combined. The band is the result of the billions of stars that lie between Earth and the centre of the Milky Way, which is seen edge-on in the image. The dark smudgy line along the band is dust. This dust obscures our view into the centre of the galaxy. However, we are able to view stars at the very centre of our galaxy by using telescopes that detect infrared light (heat) rather than visible light.

Our galaxy is about 100 000 ly in diameter and about 2000 ly thick at its widest point, near the core (Figure 7.16). Such a size is very difficult to imagine. The solar system, which is enormous compared to the size of Earth, is very tiny compared to the whole Milky Way galaxy. While light from the Sun takes about 5 h to reach the most distant planet in the solar system, Neptune, that same beam of light would take 100 000 years to cross the entire Milky Way.

Another way to try to picture the size of our galaxy is to imagine the solar system was reduced to the size of a single bean. By comparison, the Milky Way would be slightly larger than the area of Lake Superior.

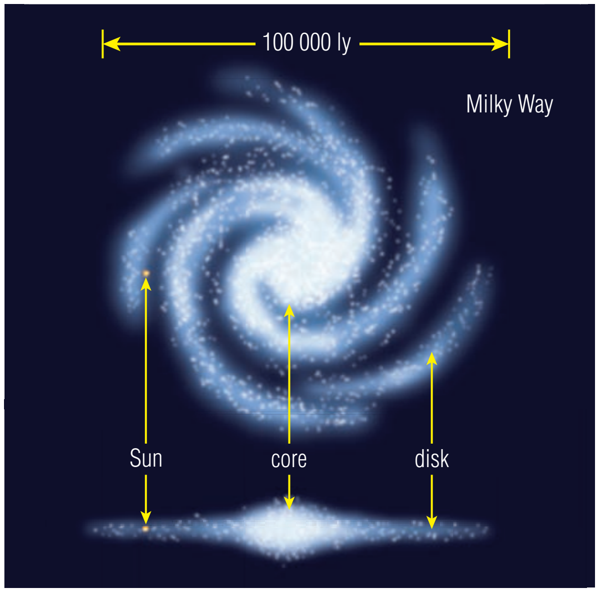


Figure 7.16 A top view and a side view of the Milky Way galaxy

C5 *Quick Lab*

Hunting for Galaxies in the Hubble Ultra Deep Field

Galaxies occur in many shapes and sizes. The Hubble Ultra Deep Field image reveals several thousand galaxies, providing a good sample of what is "out there." By identifying and counting different shapes of galaxies, you will become more familiar with the variety that occurs in the universe.

Purpose

To identify and classify some of the many galaxies found in the Hubble Ultra Deep Field image

Materials & Equipment

- handout showing galaxies of different shapes
- calculator

Procedure

1. Your teacher will give you a handout showing galaxies of several different shapes.
2. Study the image of the Hubble Ultra Deep Field shown in the Exploring section of this unit. Using the handout to help you, identify as many different kinds of galaxies as you can.
3. Record your results. Some galaxies will appear as a tiny dot, too difficult to classify. Count as many of those as you can and record them as "unclassified."

Questions

4. Based on your analysis, which type of galaxy is the most common and which kind is the least common?
5. Estimate the number of galaxies that were too small to classify compared with the number that you could classify. Add up the total number of galaxies that you looked at, including those labelled as "unclassified."
6. Calculate the percentage of each type of galaxy, including unclassified galaxies, in your study.
7. Arrange your classification from highest percentage to lowest percentage.
8. Suggest why some galaxies appeared large enough to classify, while others were too small.

Properties of Galaxies

Suggested Activity •
C7 Quick Lab on page 276

All galaxies contain stars, planets, and dust. Galaxies with more dust than others tend to produce more new stars, because stars form from dust and gases present in nebulae. Some galaxies, thought to be very ancient, have almost no dust because it has all been used up in star-making. The farthest galaxies we can see may also be the oldest, because the light has taken so long to reach us. Astronomers think that the stars of these galaxies were possibly larger than the largest stars that exist today. If that was the case, then those stars lived short, hot lives, usually ending in supernova explosions. Gravity pulled the material together again, repeating the cycle of star formation, explosion, and spreading of new elements into space.

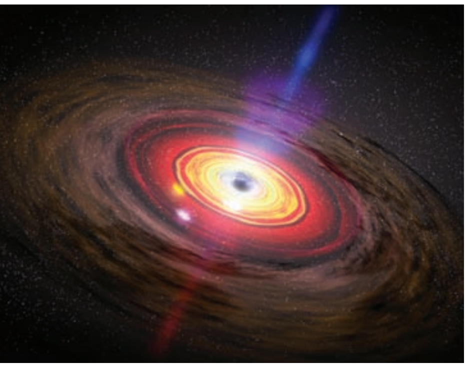


Figure 7.17 Artist's concept of a black hole

Black Holes

Through studies of hundreds of thousands of galaxies, astronomers now believe that each galaxy contains at least one supermassive black hole at its centre (Figure 7.17). A **black hole** is a region of space where gravity is so strong that nothing, not even light, can escape. The evidence for the existence of black holes is strong. For example, at the centre of the Milky Way, a number of stars can be seen rapidly orbiting around a point in space that seems to have nothing in it. At this spot is almost certainly a black hole.

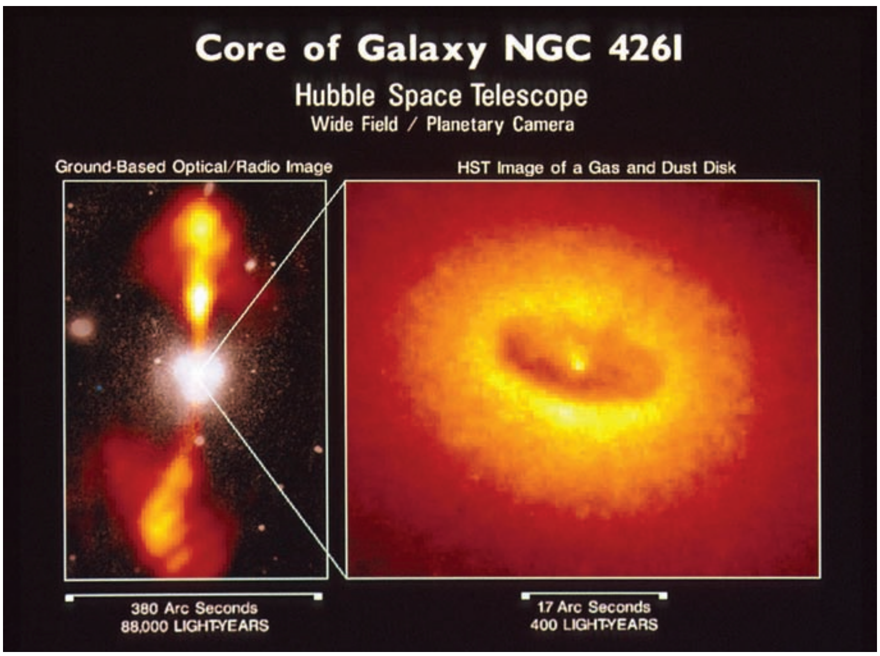


Figure 7.18 A region of space containing a black hole, as photographed by the Hubble Space Telescope

The main way that a black hole affects its surroundings is through its tremendous gravitational pull. Its gravity is so strong that it can pull a star right into it (Figure 7.18). This completely destroys the star. However, the mass of the star adds to the black hole's original mass, increasing the size of the black hole. It has been estimated that the Milky Way's black hole has been pulling stars in for at least 7 billion years. Currently, the black hole has a mass equal to about 3 million stars that are of similar size to our Sun.

Astronomers speculate that when galaxies collide, the black hole at the centre of each one gradually moves toward the other. After hundreds of millions of years, they will merge, with their masses combining into a single supermassive black hole. Figure 7.19 shows the two black holes at the centre of a galaxy that resulted from the collision of two smaller galaxies.

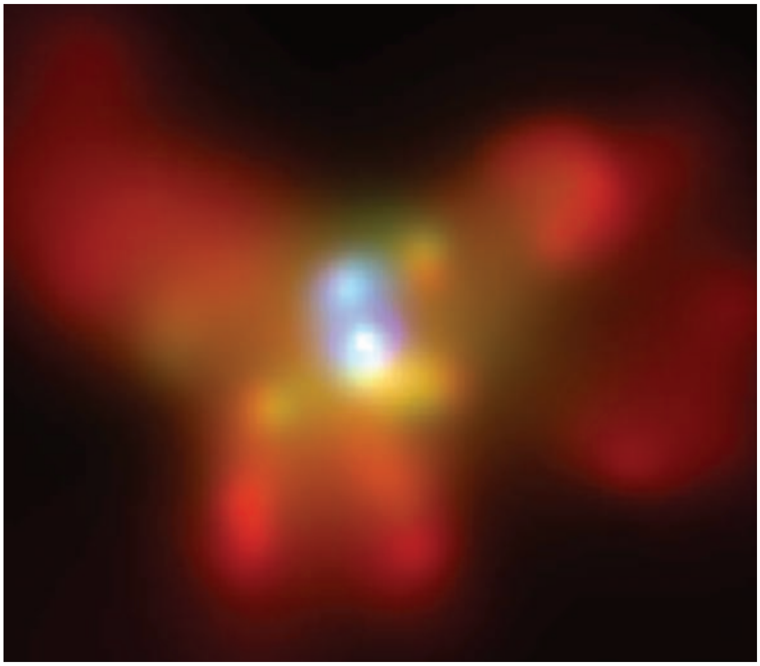


Figure 7.19 In the central region of galaxy NGC 6240, two black holes are visible (shown here in blue). This galaxy was formed by two small galaxies colliding.

Dark Matter

Although there are billions of celestial objects in space, even more astounding is that astronomers speculate that those objects add up to less than 10 percent of the total matter in space. At least 90 percent of the universe may be filled with matter that is not even visible. Astronomers have named this dark matter. **Dark matter** refers to matter in the universe that is invisible because it does not interact with light or any other kind of radiation. Because of this, dark matter is invisible to direct observation by telescopes.

If dark matter cannot be seen, then why would astronomers think it is there? The answer is that they have detected its presence indirectly.

Astronomers have long been puzzled by the unexpected motion of many galaxies. It appears as though gravitational forces are affecting them, yet the amount of visible mass (such as stars, moons, gas, and dust) does not seem to be enough to do that. For example, the stars in the Milky Way revolve around the galaxy's centre at such high speed that we would expect them to be flung off, just like a spinning water sprinkler sends drops of water flying out in all directions. The Milky Way is not coming apart, however. Instead, as astronomers have concluded, it is being kept together by the gravitational force of an enormous amount of matter that we cannot see directly (Figure 7. 20). Today, most of the gravity in the universe is thought to be produced by dark matter.

During Reading — Thinking Literacy

Using Prior Knowledge

How have scientists used their prior knowledge to define dark matter? Write down three key statements that define or describe dark matter and its characteristics.

Figure 7.20 By observing how matter in this galaxy cluster bends light rays, astronomers were able to compute and map out where they believe the dark matter (shown by the dark blue ring) is distributed in the cluster.

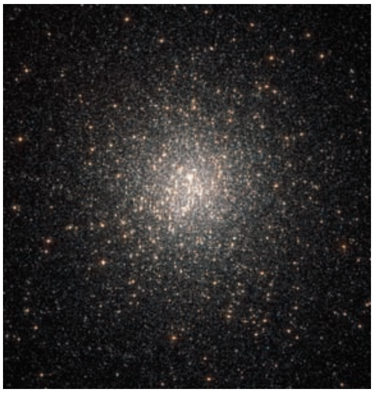


Figure 7.21 A globular cluster of stars

Star Clusters

Galaxies also contain distinct groupings of stars known as star clusters. A star cluster is a concentration of stars in a relatively small region of space. Star clusters occur in two broad types. One is an open cluster, which contains a few hundred to a few thousand stars. Open clusters are among the youngest star groups in a galaxy. The other type of star cluster is a globular cluster, which contains hundreds of thousands of stars, drawn together in a spherical form by the stars' gravity (Figure 7.21). Globular clusters are the oldest star groups in a galaxy.

Galaxy Shapes

Galaxies are commonly classified according to four main shapes: spiral, barred spiral, elliptical, and irregular.

Figure 7.22 The barred spiral galaxy known as NGC 1300

Spiral and Barred Spiral Galaxies

Spiral galaxies are named for the spiral-shaped arms that radiate out from the galaxy's centre (Figure 7.23(a)). About half of all spiral galaxies, including the Milky Way, have what appears to be a bar across them (Figure 7.22). These are called barred spiral galaxies.

A wave moving outward from the central regions of the galaxy causes the gas and dust to compress into arm-like bands that rotate around the central hub (Figure 23(a)). New arms continually form as older ones disappear or change shape. Gravity keeps the spirals from flying apart. A typical spiral galaxy completes a full rotation once about every 300 million years.

From the side, a spiral galaxy looks like a thin disk (Figure 7.23(b)). The disk is difficult to see through because of all the dust and gases between the stars. If you know how smog in a city or smoke from a forest fire makes it hard to see clearly into the distance, you will get an idea of how the view can be obscured. It is in these dusty regions that new stars form. Most spiral galaxies have hundreds to thousands of star clusters.

(a) (b)

Figure 7.23 Two spiral galaxies: (a) galaxy M81 shown from the top; and (b) galaxy NGC 5746 shown from the side

The disk of a spiral galaxy is not completely flat. Near the core is a widening called the central bulge. It consists mainly of very old stars. New stars rarely form here because of the lack of dust and gases between the stars. Surrounding the central bulge and most of the disk is the galactic halo. The halo is also made up of individual stars.

Elliptical Galaxies

An ellipsoid is a shape like a flattened sphere. Elliptical galaxies are those whose shape ranges from almost spherical to football-shaped (Figure 7.24) or long and cylindrical, like a pencil. Such galaxies are thought to result when other galaxies, such as spiral galaxies, merge. The largest galaxies in the universe are elliptical.

Elliptical galaxies contain very little dust. This means they have fewer young stars than spiral galaxies do. Many of the stars in elliptical galaxies are extremely old.

Irregular Galaxies

Some galaxies are neither spiral nor elliptical. Those without a regular shape are called irregular galaxies (Figure 7.25). The distorted form of an irregular galaxy may result because the galaxy collided with another one or got close enough that the gravitational force from the other galaxy drew stars away.

Figure 7.24 The bright patch at the upper centre of this image shows the giant elliptical galaxy ESO 325-G004.

Figure 7.25 The irregular galaxy known as NGC 1427A

Learning Checkpoint

1. What is a galaxy?
2. What is thought to be at the very centre of all galaxies?
3. What is dark matter?
4. Sketch the general shape of a spiral galaxy as viewed from the side and then as viewed from above.
5. State one possible way that elliptical galaxies form.

Take It **Further**

As better telescopes are developed, we continue to discover galaxies that are farther and farther away. The most distant galaxy discovered so far is called 10K-1. It was spotted by the Subaru telescope in Hawaii in 2008. It is 12.8 billion ly away. Find out more about this galaxy, the oldest one yet discovered. Begin your research at ***ScienceSource***.

Galaxy Clusters

Many of us have played the game of writing out our full address, from the street name and number to the city or town, province, country, Earth, and finally Milky Way. In fact, your universe address does not end there.

If you could get out beyond our own galaxy and look back at it, you would see that the Milky Way is part of a group of about 20 galaxies. Such a group is called a galaxy cluster, and the one containing the Milky Way is known as the Local Group (Figure 7.26). More than 2000 billion stars lie inside the cluster.

The Local Group is part of the Local Cluster of galaxies, and that in turn is part of the Local Supercluster.

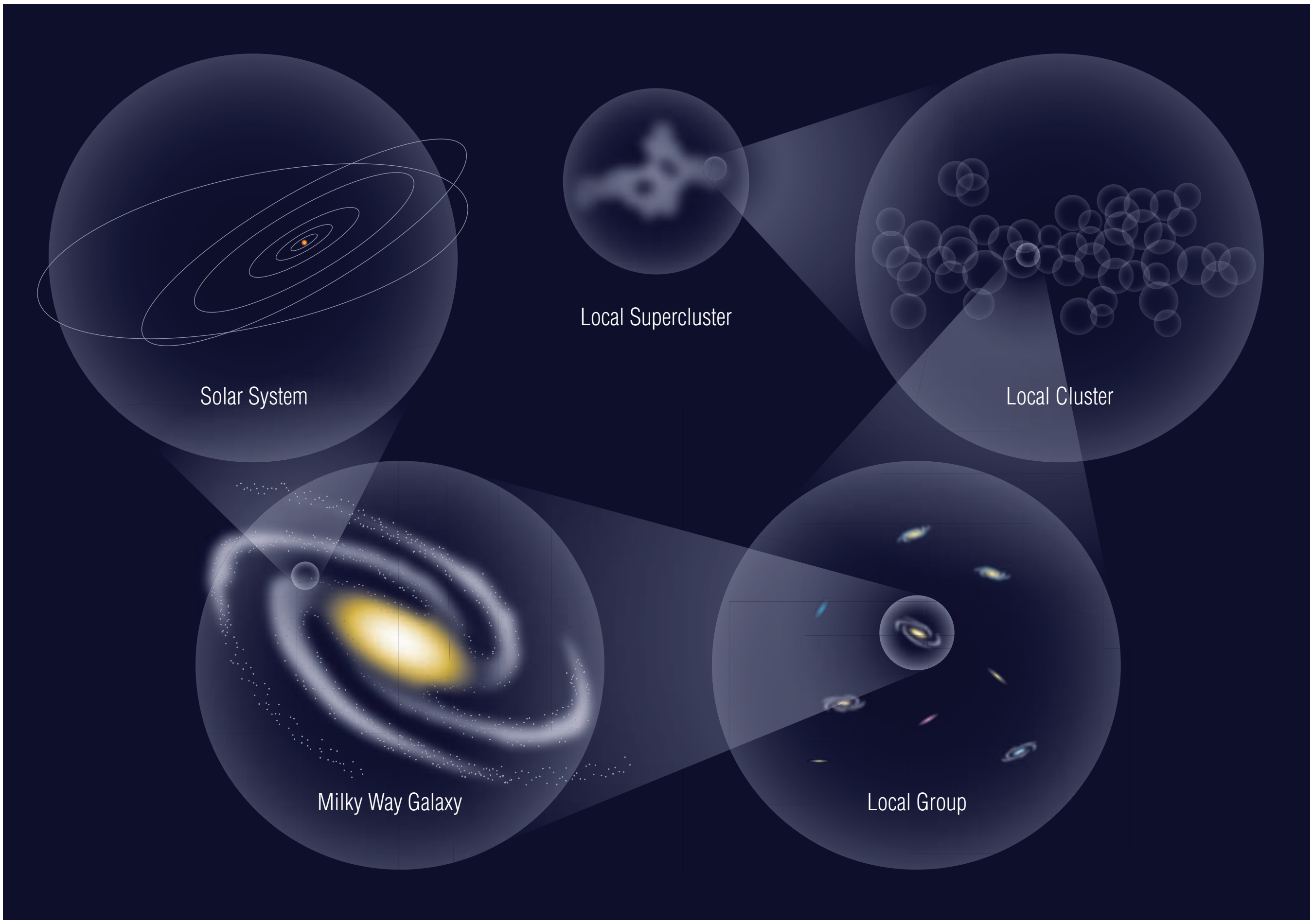


Figure 7.26 Galaxies tend to occur in groups called galaxy clusters. Galaxy clusters in turn form groups called superclusters. According to astronomers, there may be more than 100 billion galaxies in the universe.

Mapping the Visible Universe

Gone are the days when astronomers had to count stars or galaxies one by one. Now, a great wedge of sky can be surveyed and galaxies counted by computer. Figure 7.27 shows two wedges from a recent galactic survey. At the centre is the Milky Way galaxy.

Studies such as this do more than just make a map of places we can never expect to travel. It is from the study of galaxies and their motions that astronomers have been able to find answers to questions about the origin of the universe.

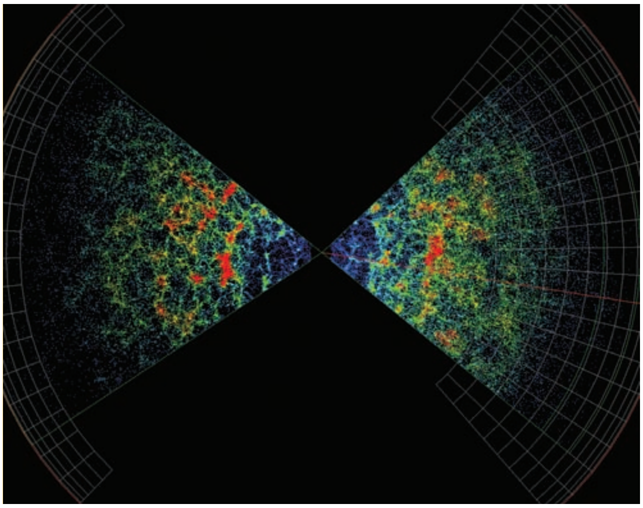


Figure 7.27 Two wedges of sky showing the positions of nearly 107 000 galaxies out to a distance of 5 billion ly

C6 ***Just-in-Time Math***

Math Scaling

A mathematical scale is a ratio between units of measure. Scales are used to show something in larger or smaller form, but in the same proportions as the original thing is. If you wanted to map your neighbourhood on a page in your notebook, you would have to create a scale to show the relative distances between streets and buildings accurately. For instance, you might choose to set your scale at 1 cm = 50 m or 1 cm = 200 m.

Because distances in space are so vast, they can only be represented by scaling.

Example: Imagine you are building a scale model to show the distance from Earth to the Andromeda galaxy and Magellanic galaxy NGC 2366. Say you know the real distance to the Andromeda galaxy is 2.5 million ly and its model distance is 1 m. You want to determine the model distance x for the Magellanic galaxy whose real distance is 12.5 million ly.

Step 1: Write an equation that compares the real distances on the left side with the model scale distances on the right side.

$$\frac{12.5 \text{ million ly}}{2.5 \text{ million ly}} = \frac{x}{1 \text{ m}}$$

Step 2: Simplify the left side by cancelling the units and doing the division.

$$5.0 = \frac{x}{1 \text{ m}}$$

Step 3: Multiply both sides by 1 m.

$$5.0 \times 1 \text{ m} = x$$

$$5.0 = x$$

The model scale distance is 5 m.

Solve the following scale distances (x):

1. The distance from your home to a store is 2 km. The scale distance is 10 cm. The distance from your home to a library is 3 km. What is the scale distance to the library?
2. The distance from the Sun to Earth is 1 AU and from the Sun to Jupiter is 5.2 AU. The scale distance from the Sun to Earth is 8 cm. What is the scale distance to Jupiter from the Sun?
3. The scale distance between the Milky Way galaxy and the Andromeda galaxy is 20 cm = 12.5 million ly. What is the scale distance to the Sombrero galaxy, 29 million ly away?

DI Key Activity

C7 Quick Lab

Modelling the Distances to Galaxies

The distance from the Milky Way to even its nearest neighbouring galaxy, Andromeda, is vast: 2.5 million ly. Yet, compared with the distances to other galaxies in the universe, Andromeda seems right next door to us. In this activity, you will create a scale and plot the distance to several galaxies on a local map, setting the distance from the Milky Way to Andromeda at 1 m.

Purpose

To create a model that shows the distance from the Milky Way to seven other galaxies

Materials & Equipment

- paper or notebook
- photocopy of a map of the local area around your school
- calculator
- ruler
- markers

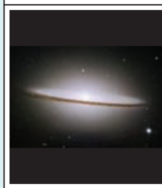
Procedure

1. Copy the data from Table 7.1 onto a piece of paper.
2. Using the data provided in the first three rows, estimate the model distance for the remaining four galaxies and record these distances in the table.
3. Mark an X at any point on the map of the school area to represent Earth (or the Milky Way galaxy). Label it.
4. Following the map's scale, measure 1 m on the map in any direction and plot this second point. Label it Andromeda galaxy.
5. Continue plotting all but the galaxies shown in the Hubble Deep Field photograph. The direction to each galaxy is not important for this activity, just the distance.

Question

6. Estimate how far your map would have to extend to include the galaxies in the Hubble Deep Field.

Table 7.1 Seven Galaxies and Their Real and Model Distances from the Milky Way

Appearance	Galaxy	Distance (ly)	Model Distance (m)
	Andromeda galaxy	2.5 million	1
	Magellanic galaxy NGC 2366	12.5 million	5
	Sombrero galaxy	38 million	15
	Antennae galaxies	90 million	?
	Seyfert's Sextet	190 million	?
	Cartwheel galaxy	620 million	?
	Galaxies in Hubble Deep Field	10 000 million	?

7.2 CHECK and REFLECT

Key Concept Review

1. Why do galaxies with more dust than other galaxies generally produce more new stars?

2. What is the diameter and thickness of the Milky Way in light-years?

3. Earth is estimated to be about 35 000 ly from the black hole at the centre of the Milky Way. Several stars have been observed to orbit the black hole. How long would it take light from these stars to reach Earth?

4. (a) What is a black hole?

(b) Are they rare or common? Explain your answer.

5. What do astronomers speculate makes up at least 90 percent of the matter in the universe?

6. Name the four main types of galaxy according to shape.

7. Make a simple diagram to show the relationship between the Milky Way galaxy and the Local Supercluster of galaxies.

Connect Your Understanding

8. Even when two galaxies collide, why do very few of their stars collide with each other as well?

9. How is it possible to detect the black hole at the centre of the Milky Way if the black hole itself is invisible?

10. The stars are held together in our galaxy by gravity. List three main sources of this gravity.

11. Spiral galaxies may be younger than other types of galaxies, still spinning from the time of their formation. How might an irregular galaxy or an elliptical galaxy form from one or more spiral galaxies?

12. Explain why our night sky would not be dark if the Sun were located inside a star cluster such as that one shown in the image below.

Question 12

Reflection

13. How have your ideas about the size and structure of galaxies been changed by what you read in this section? Explain.

14. Think of a way you could visually model what you have learned about the extent of the Milky Way galaxy to educate someone who knows little about it.

For more questions, go to ***ScienceSource***.

7.3 The Expanding Universe

Here is a summary of what you will learn in this section:

- Evidence suggests that the universe began 13.7 billion years ago at a single point and has been expanding since.
- The red shift of spectral lines in the light we see from galaxies shows that the light's wavelengths are getting longer. This indicates that the galaxies are moving away from us.
- The Big Bang theory of the formation and expansion of the universe is consistent with known laws of the universe.
- The cosmic background radiation in the universe, now mapped, is thought to be leftover energy from the moment the universe first formed.

Figure 7.28 The Hubble Space Telescope was named for astronomer Edwin Hubble.

Hubble's Ideas

Edwin Hubble was an American astronomer who was one of the first scientists to study galaxies (Figures 7.28 and 7.29). Between 1918 and 1929, two of his major findings changed astronomy. First, he confirmed that many other galaxies existed beyond the Milky Way. Second, he found that almost all galaxies are moving away from each other. These observations helped to support the proposal made in 1927 by Belgian priest and physicist Georges Lemaître that the universe is expanding.

The evidence Hubble used to reach his conclusions came from measuring the distance from Earth of 46 galaxies and the speed of their movement. After collecting the light from these galaxies, Hubble closely examined each one's light spectrum. The visible light **spectrum** is the rainbow band of colours into which white light separates when it passes through a prism.

Figure 7.29 American astronomer Edwin Hubble (1889–1953) using the 100-inch (250-cm) telescope at the Mount Wilson Observatory, Los Angeles, California, in 1937

In the years since Hubble's first measurements, evidence from observations of thousands of galaxies has confirmed his early findings. Hubble's work and ideas remain the foundation of modern understanding of the nature and origin of the universe.

WORDS MATTER

A "spectrum" in science refers to the separation of radiation, such as light into different wavelengths. When this happens in our sky, we call it a rainbow. This is pluralized as spectra, or sometimes as spectrums.

C8 Quick Lab

Comparing Light Spectra

Each kind of light source has its own unique spectrum. By studying different light spectra, it is possible to tell a lot about the properties of the sources that produced them, even if those sources are extremely far away. A device called a spectroscope enables us to split a light sample into its spectral colours. We can then record and analyze the spectrum's pattern.

Purpose

To use a spectroscope to observe and compare the spectra of a variety of light and gas sources

Materials & Equipment

- spectroscopes
- variety of light sources (for example, incandescent, fluorescent, holiday lights, sunlight)
- gas discharge tubes (for example, hydrogen, mercury, sodium)
- notebook and pencil

CAUTION: Never touch the ends of a spectroscope's power supply when it is in use. Tubes can become extremely hot when in use.

Procedure

1. Your teacher will set up a number of light sources and spectroscopes in the lab or classroom.
2. In small groups, take turns observing the spectrum of each light source. Record what you observe about each spectrum for each light source you view.
3. Next, take turns observing the spectrum of each element in the various gas discharge tubes. Record what you observe about each spectrum for each tube source you view.

Questions

4. What differences did you notice about the spectra for the different light sources?
5. (a) Which kind of light source produced the most distinct spectrum of all the sources?

   (b) Explain why you think that was the case.
6. How did the spectra from the gas discharge tubes differ from the spectra displayed by the light sources?
7. How could knowledge of the spectra of light created by particular elements help an astronomer determine the composition of a distant star or galaxy?

Figure 7.30 This student is using a spectroscope to observe the spectrum of the element hydrogen.

During Reading — Thinking Literacy

Connecting the Known to the New

As you read the text under each subheading, write in your notebook one thing you already know about the topic, two pieces of information that are new to you, and one question you still have about the topic.

Evidence for the Big Bang Theory

From the light spectrum of each galaxy he studied, Hubble was able to figure out the speed at which each galaxy was moving away from our own. Then, for those same galaxies, he separately determined the distance between each one and the Milky Way. Plotting both the speed and the distance measurements together, Hubble discovered a clear relationship between the two. The farther away a galaxy was, the faster it was moving away.

These findings, along with observations of many other scientists of the time, gave further support to Lemaître's idea that the universe is expanding. Out of this and the work of many other physicists, mathematicians, and other scientists of the day developed one of the most remarkable theories of the 20th century. The theory, which came to be called the **Big Bang theory**, states that the universe formed when an infinitely dense point suddenly and rapidly expanded in a single moment. All the matter and energy that exists today was created during the early minutes of that hot, rapid expansion. Credit for the Big Bang theory goes mostly to Russian-American physicist George Gamow and American mathematician Ralph Alpher.

It is now commonly accepted by scientists that the universe formed 13.7 billion years ago. That moment marks the beginning of the universe and also the beginning of time.

Today, at several research facilities around the world, scientists are trying to re-create, in a small way, various aspects of the conditions that might have existed in the early moments of the universe (Figure 7.31). In this way, they hope to gain a better understanding of the origin of everything

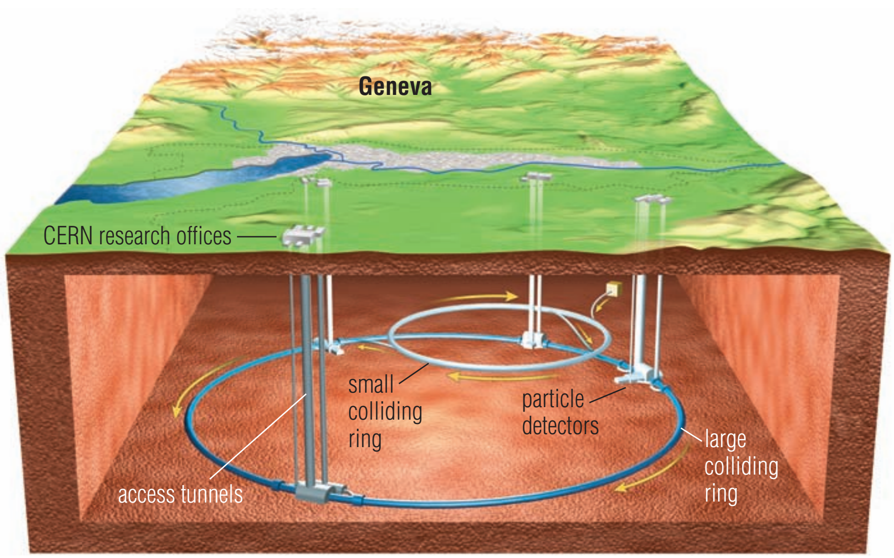


Figure 7.31 At CERN in Switzerland, scientists are trying to break down particles of matter inside a 27-km long "supercollider" (shown here in blue), located deep in the ground. These experiments may reveal how the smallest particles of matter were created when the universe first formed.

The Wave Nature of Light

Light is a form of energy that travels in waves. This kind of energy is also called **electromagnetic radiation**. Visible light is electromagnetic radiation that we can see with our eyes. There are other forms of electromagnetic radiation as well, including radio waves, microwaves, ultraviolet radiation, and X-rays. When visible light rays are split into a rainbow of colours, the result is called the visible spectrum.

Figure 7.32 shows the full **electromagnetic spectrum**, from radio waves with very long wavelengths, through visible light, to gamma rays with very short wavelengths.

Spectral Colour and Spectral Lines

Each of the different colours of the visible light spectrum, from red through to yellow and green and on to violet, varies in wavelength. The wavelength of red light, for instance, is longer than the wavelength for blue light. This distinctive characteristic gives astronomers an important way to analyze star light. A spectroscope helps in this analysis. A **spectroscope** is an optical instrument that, like a prism, separates light into its spectral colours.

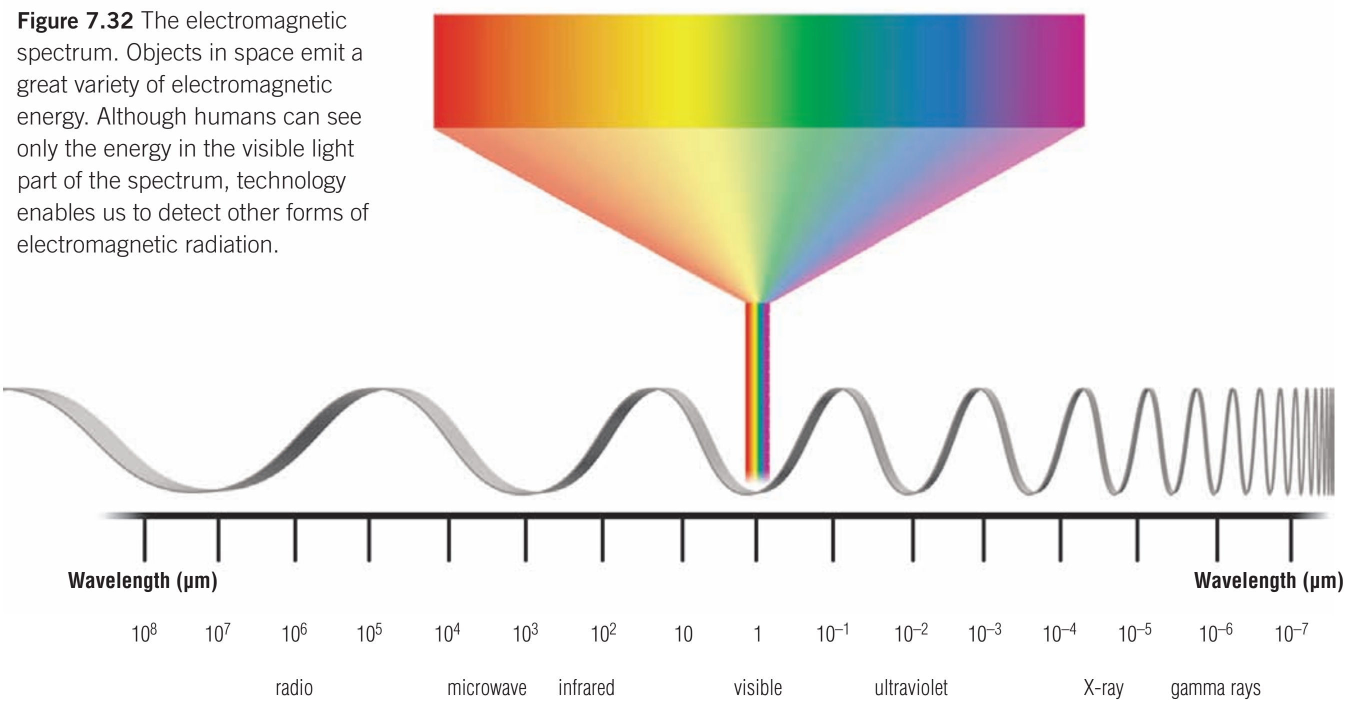


Figure 7.32 The electromagnetic spectrum. Objects in space emit a great variety of electromagnetic energy. Although humans can see only the energy in the visible light part of the spectrum, technology enables us to detect other forms of electromagnetic radiation.

In addition to colour, another characteristic of star or galaxy light that astronomers analyze is spectral pattern. Across a star's band of colour appears a series of dark lines. These are called **spectral lines**, and they look a little like the bar code you see on retail products. Spectral lines are created as each gas that makes up a star absorbs some of the light energy. Each element does this in a different way, creating its own particular pattern of spectral lines (Figure 7.33). Because astronomers can see the spectral lines of hydrogen in the spectra of nearly all celestial objects, it is clear that hydrogen is present throughout the universe.

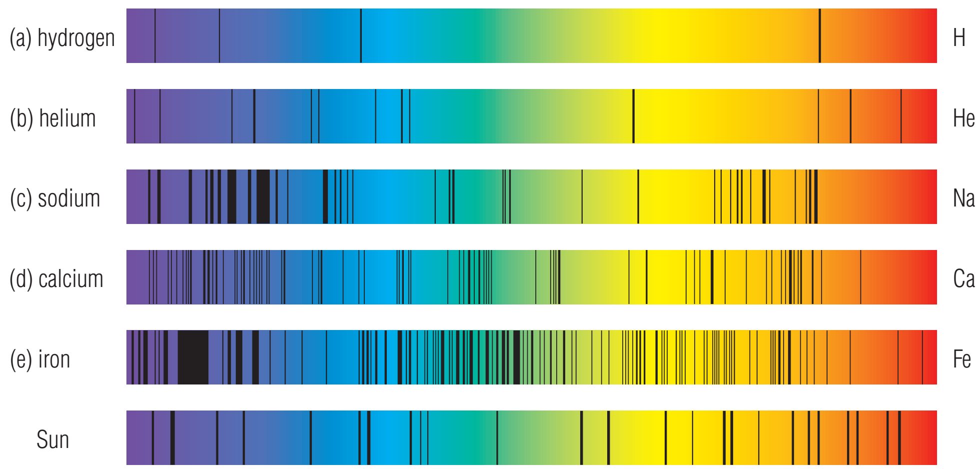


Figure 7.33 Analyzing spectral lines in a star's spectrum indicates what elements are present in the star.

Red-Shifted Spectral Lines

While Edwin Hubble was observing the 46 galaxies in his study, he and other astronomers began making careful measurements of the spectra he was collecting. Their knowledge of spectral patterns allowed them to determine that galaxies were moving apart. This conclusion was based on an important property of light called spectral shifting. **Spectral shifting** is the change in position of spectral lines to the left or the right of where they normally are in the spectrum of a light source that is not moving.

The astronomers noticed that in all of the galaxies Hubble was studying, the spectral lines were shifted toward the red end of the colour band. The only way for spectral lines to shift this way is if the light source and the observer are moving away from each other at very high speed.

Analyzing the Movement of Light Waves

To understand how this happens, remember that light waves move like waves on the surface of water. Picture a duck floating on a small, calm lake. Gentle movements of the duck create ripples on the water surface that spread out evenly all around the duck (Figure 7.34a). The wavelength of these ripples is measured as the distance from the crest of one wave to the crest of the next.

As the duck begins to swim, the ripples compress and the wavelength shortens in front of the duck. At the same time, the ripples behind the duck stretch out and the wavelength gets longer (Figure 7.34b). So, even if you could not see the duck directly and could only see the ripples on the water, you would still be able to tell whether the duck was moving toward you or away from you.

In a similar way, someone observing the light emitted by a galaxy can measure the light's wavelengths to determine whether the galaxy is moving and, if it is, in which direction.

Light Wavelength and Colour

When Hubble did his work and saw that the spectra of his sample galaxies were "red-shifted," he knew this meant that the wavelengths were stretched out. Remember, as Figure 7.32 shows, that red light has a longer wavelength than blue and violet at the other end of the specturm. Hubble therefore concluded that the galaxies were moving away from the Milky Way (Figure 7.35).

Had Hubble instead found that the spectral lines were shifted to the blue end of the galaxies' light spectra, he would have had to conclude that the wavelengths were shorter and more compressed. Just as with the duck example, shorter wavelengths between the observer and the moving object would have meant that the galaxies were moving toward us, not away.

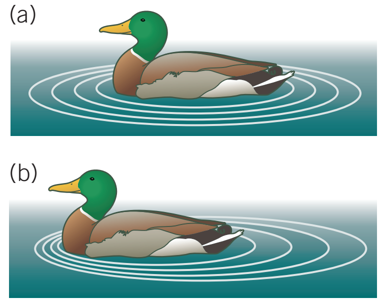


Figure 7.34 Light energy travels in waves, just as sound and other forms of energy do. By observing the pattern made by the waves, we can tell whether an object is moving and, if it is, whether it is moving toward or away from us. This phenomenon is called the Doppler effect. (a) When an object is hardly moving (stationary), its waves radiate out evenly in all directions. The distance between each wave, or wavelength, is the same. (b) When the object is moving, the waves in front of it become compressed (the wavelength shortens) and the waves behind it stretch out (the wavelength lengthens).

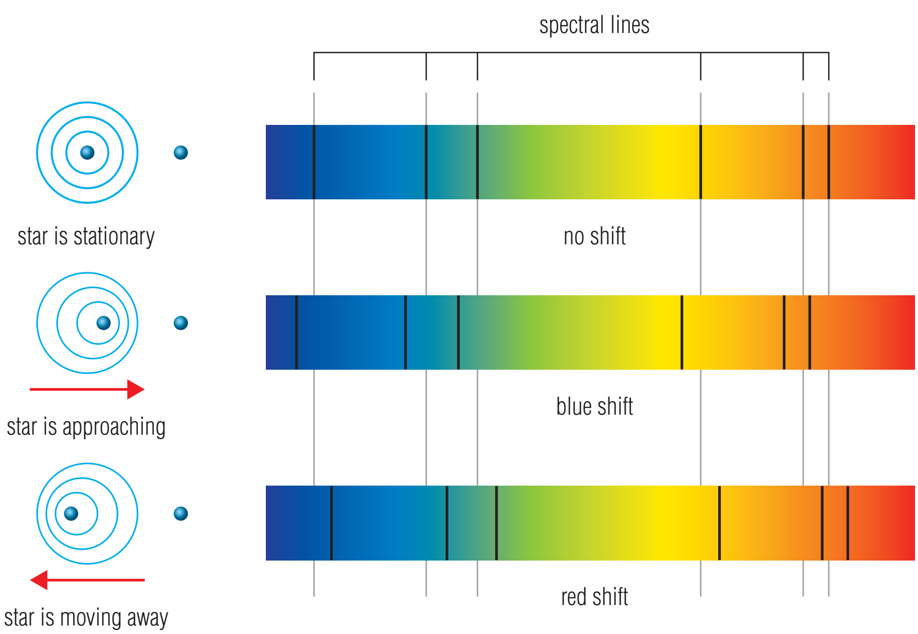


Figure 7.35 If the spectral lines in the light from a star or galaxy occur toward the blue end of the light spectrum, it means the observer is seeing short wavelengths. This "blue shift" indicates that the star or galaxy is approaching the observer. On the other hand, if the spectral lines occur toward the red end of the light spectrum, it means the observer is seeing long wavelengths. This "red shift" indicates that the star or galaxy is moving away from the observer.

Figure 7.36 The Keck telescope in Hawaii

When Hubble and other astronomers found this red-shift pattern in an increasing number of galaxies, it lent support to the idea that space was expanding. Since then, much more evidence has been collected.

The Keck telescope in Hawaii is one of the largest optical telescopes in the world (Figure 7.36). Astronomers recently used the Keck telescope to conduct a red-shift survey of galaxies, repeating Hubble's work. However, this newer survey, called DEEP2, measured the light from 60 000 galaxies instead of 46. The results of the DEEP2 survey supported and added to Hubble's original work.

Learning Checkpoint

1. What is a spectrum?
2. What is the name given to the generally accepted scientific theory that describes the origin and evolution of the universe?
3. How is it possible to know that the element hydrogen exists throughout the universe?
4. How does the idea that space itself is expanding relate to the observation that the spectra from distant galaxies are red-shifted?

Using Microwaves to Map Cosmic Background Radiation

Until 1965, a critical question related to the Big Bang theory remained unanswered. The theory stated that the very early universe was extremely hot, filled with short-wave gamma ray radiation. Then, as the universe rapidly expanded, it cooled and the wavelength of the radiation lengthened. The radiation became lower energy types, including Xrays, ultraviolet, visible light, infrared, and microwaves.

So, asked scientists, if the theory describing this series of events was reasonable, then where was the energy that should have been left over from the very early moments of the formation of the universe? Their prediction was that all of space should contain evidence of this radiation.

In 1965, as the scientists who predicted the presence of this energy set about to look for it, two other researchers, Arno Penzias and Robert Wilson, made the big discovery — a discovery they were not even looking for (Figure 7.37). Their new microwave antenna, intended for use in telecommunications, detected that the entire sky was bathed with microwave energy. It came from every direction, not just from individual stars. This energy is often called cosmic background radiation. It is believed to be the energy left over from the massive and split-second expansion of the universe from a single point some 13.7 billion years ago.

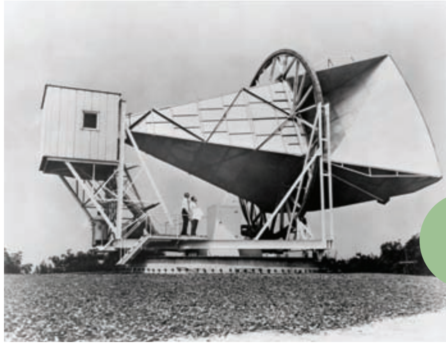


Figure 7.37 It was while using the Horn Antenna, located in New Jersey in the United States, that radio astronomers Penzias and Wilson unexpectedly discovered the microwave background radiation present in every part of the sky.

Radiation Maps: Evidence for the Big Bang Theory

In 1992, the Cosmic Background Explorer satellite (COBE) made detailed maps of the background radiation collected from the most distant parts of the visible universe. This was followed in 2006 when the Wilkinson Microwave Anisotropy Probe (WMAP) took even more precise measurements of the radiation and created a much enhanced map (Figure 7.38). Both the COBE and the WMAP results showed that the spectrum of the background radiation precisely fits the predictions consistent with the Big Bang theory.

In science, although evidence can support a theory, a theory is never considered to be proven correct. On the other hand, if new evidence conflicts with a theory, the theory can be proven incorrect. In this way, the COBE and WMAP surveys not only back up the Big Bang theory, but they also show that other theories of the formation of the universe cannot be supported. One of these not supported is the Steady State theory, which suggests that the universe is infinitely old and that matter and energy constantly enter and leave the universe at equal rates. To date, the Big Bang theory continues to be the only theory for the universe's formation that is supported by the entire body of scientific information gathered so far.

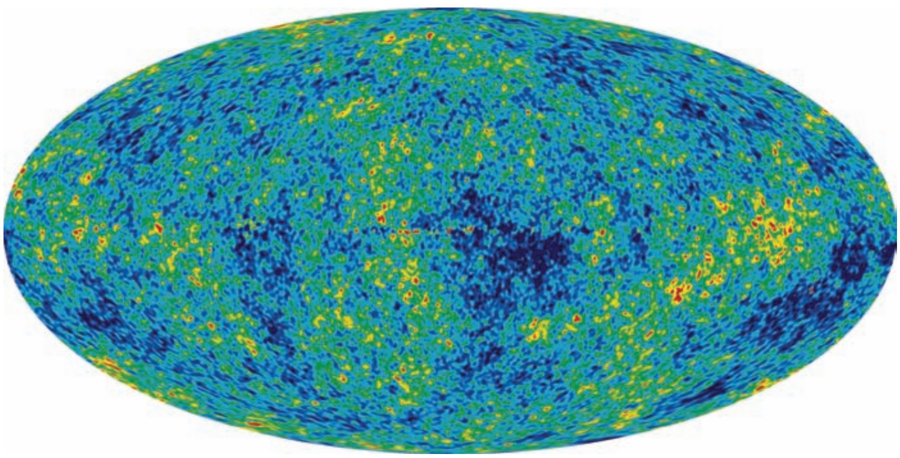


Figure 7.38 The universe's cosmic background radiation, mapped by the Wilkinson Microwave Anisotropy Probe (WMAP). The tiny variations in the radiation are thought to indicate hot regions that are now mostly empty space, and cooler regions where matter could collect to form the first galaxies.

Take It Further

While the Big Bang theory is now the one generally accepted to explain how the universe formed, others have been proposed in the past as well. These include the Steady State theory, the Big Crunch theory, and the Multiverse theory. The first two of these have been shown to be inconsistent with modern observational data. The third one may still be a possibility. Pick one of these theories and find out about its strengths and weaknesses. Begin your research at ***ScienceSource***.

An Ever Faster Expanding Universe

Many scientists have likened the expansion of space to the expanding surface of a balloon when it is inflated. Just as the dots drawn on the balloon would separate from each other as the balloon expands, so clusters of galaxies move away from each other as space opens up between them.

This does not mean that you are slowly getting larger or that Earth is moving farther from the Sun. The effects of the expansion of space are so small that even our Milky Way galaxy is not moving away noticeably from our nearest galaxies, such as Andromeda. Gravity and other forces are strong enough to keep these objects together. However, between clusters of galaxies there is an immense amount of empty space, and the tiny effects of the expansion of space add up.

In the last 20 years, data from the most distant galaxies show that the rate at which the most distant galaxies are receding from our view is increasing. In other words, not only are galaxies moving away from us, but they are doing so at an ever-faster rate.

C9 STSE *Science, Technology, Society, and the Environment*

The Power of Observation

Our understanding of space and the universe is directly connected to the technology we use to make observations.

Consider the Milky Way. Our ancestors, looking at the night sky with only their unaided eyes, saw the galaxy as a long smudge of light. They could not know that the light came from billions of stars. Over centuries, telescopes improved our ability to see, eventually enabling us to observe details of individual stars lying far outside our solar system. By the 1990s, very powerful telescopes allowed us to peer even greater distances into space, all the way into the centre of the Milky Way.

To put that in perspective, an astronomer being able to see a star moving at the galactic core is like a person in Ottawa being able to see the wagging tail of a small dog in Vancouver.

1. Read the following statements with a partner or in a small group. Discuss what each statement means, and give at least three astronomy examples to support your ideas.

(a) As our ability to see gets better, so does our understanding.

(b) As technology improves, so does our ability to find answers to our questions.

C10 *Quick Lab*

Modelling the Expansion of the Universe (Teacher Demonstration)

Edwin Hubble was the first to propose that all of the universe's galaxies are moving away from each other. Not only that, but he proposed that the galaxies already the most distant from our perspective are moving away faster than the nearer ones. Space, he concluded, is expanding.

This activity will help you visualize these ideas. It is presented here as a teacher demonstration but may be done as a group project by students who have access to a photocopier that can make enlargements.

Purpose

To model the way that the universe is expanding

Materials & Equipment

- paper and black marker
- access to photocopier with zoom function
- two sheets of acetate
- acetate marker
- overhead projector
- ruler

Procedure

1. Before class, your teacher will mark about 30 dots on a sheet of paper. Three dots that are fairly far apart will be labelled A, B, and C.
2. Using a photocopier with a zoom function, the teacher will copy the marked-up paper, enlarging it by about 5 percent. The teacher will then copy each of the two pages onto sheets of acetate to use on an overhead projector.
3. In class, the teacher will lay one sheet of acetate over the other so that the two dots marked A overlap exactly. Note the appearance of all the dots on the overlapped sheets.
4. The teacher will repeat step 3, once so that the two dots marked B overlap exactly, and then again so that the two dots marked C overlap.

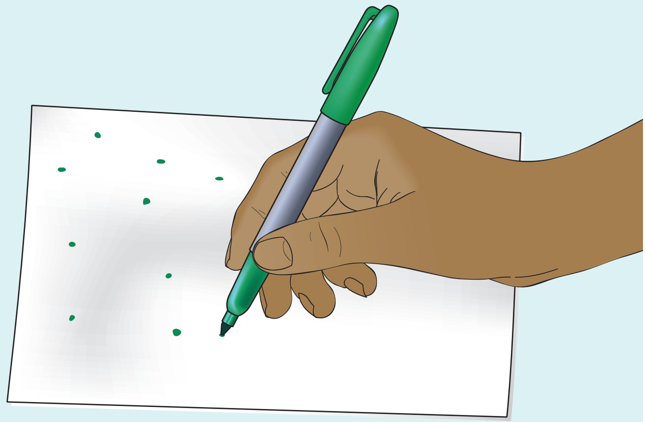


Figure 7.39 Step 1

Questions

5. (a) What does each dot represent?

   (b) What does each sheet of acetate represent?
6. How do the dots appear to have moved from the viewpoint of dot A?
7. How do the dots appear to have moved from the viewpoints of B and C?
8. Using the ruler, measure the actual change in the distance between dots A, B, and C from one sheet of acetate to the other.
9. Does the changing position of the dots represent galaxies moving through space, or does it represent galaxies being carried with space as it expands? Explain your answer.
10. Describe some of the weaknesses in this method of modelling the universe.

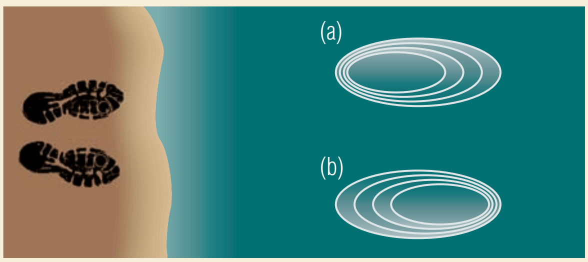
7.3 CHECK and REFLECT

Key Concept Review

1. List the two main discoveries by American astronomer Edwin Hubble that changed astronomy.
2. According to the Big Bang theory, how did the universe originate?
3. What does the visible light spectrum refer to?
4. Define the term spectral shifting.
5. Explain how the discovery and mapping of cosmic background radiation gave scientists evidence in support of the Big Bang theory.

Connect Your Understanding

6. Imagine there is an invisible duck swimming on a calm pond. For each example (a) and (b) shown below, state whether the duck is swimming toward you or away from you. Explain how you know the direction of movement.



Question 6

7. Explain how the examples in question 6 above are similar to the way in which astronomers can tell the direction galaxies are moving relative to Earth.
8. If the universe is expanding, is Earth getting bigger? Explain why or why not.
9. How does discovery of cosmic background radiation give support to the Big Bang theory?
10. Sometimes the expansion of the universe is described as being like the surface of a balloon that is slowly inflating. Dots on the balloon are like galaxies. Explain how this model predicts that our own galaxy is not the centre of the universe.
11. Science is based on the idea that a theory cannot be proven correct. It can only be proven incorrect. Imagine that the Cosmic Background Explorer (COBE) survey of background radiation in space had found that the spectrum of background radiation did not match the predictions of the Big Bang theory. In your opinion, what would such evidence have indicated about the theory?

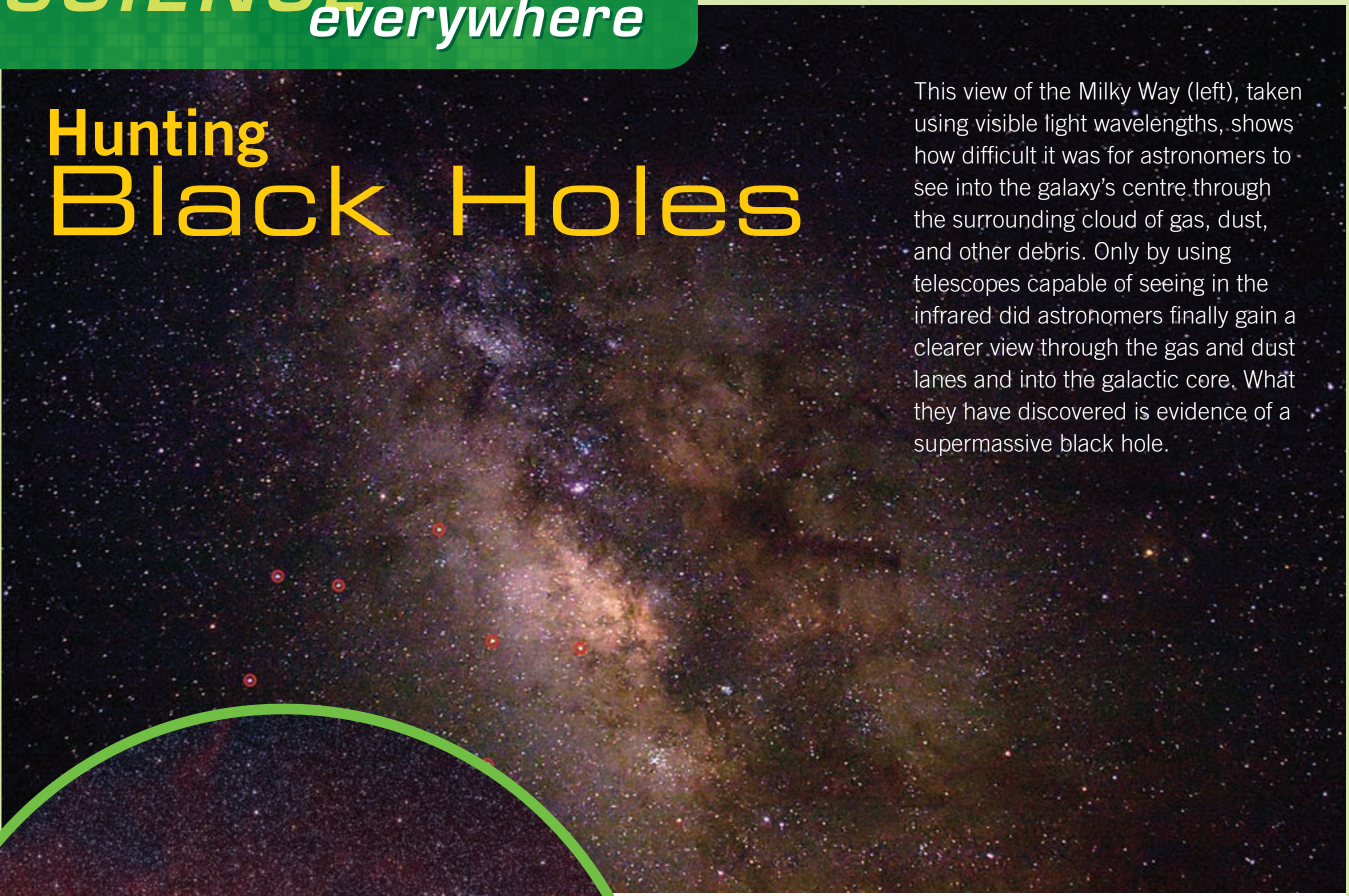
Reflection

12. For each of the following topics, describe three facts that you learned in this section that you did not know before.
    (a) formation of the universe
    (b) structure of the universe
    (c) evolution of the universe

For more questions, go to ***ScienceSource***.

SCIENCE everywhere

Hunting Black Holes



This view of the Milky Way (left), taken using visible light wavelengths, shows how difficult it was for astronomers to see into the galaxy's centre through the surrounding cloud of gas, dust, and other debris. Only by using telescopes capable of seeing in the infrared did astronomers finally gain a clearer view through the gas and dust lanes and into the galactic core. What they have discovered is evidence of a supermassive black hole.

Night-vision goggles enable a person to "see in the dark." They do this by detecting light in the infrared part of the electromagnetic spectrum and converting it to visible light. Telescopes can be designed to do the same thing. This is good news for astronomers because such telescopes are especially useful in helping scientists detect the presence of black holes in the universe. This image of the Milky Way (left) shows the same portion of the galaxy as the image above does, but this picture was taken using infrared telescopes. All the dust seems to be absent because it is invisible in the infrared.

The image on the right was taken with today's advanced telescopes. Views such as this have enabled astronomers to observe that some stars near the centre of the Milky Way are in tight and rapid orbit around something that is not visible. That "something," astronomers speculate, is a supermassive black hole. One of the orbiting stars is estimated to be moving at a speed of more than 15 million km/h.

7 CHAPTER REVIEW

ACHIEVEMENT CHART CATEGORIES

k Knowledge and understanding
t Thinking and investigation
c Communication
a Application

Key Concept Review

1. What is astronomy? k
2. (a) What type of celestial object orbits our planet? k
   (b) What type of celestial object does our planet orbit? k
3. What two units do astronomers use to measure the distances between celestial objects? k
4. (a) Explain the difference between a star and a galaxy. k
   (b) What is the name of the galaxy we live in? k
5. Galaxies are typically classified into four basic types. Name the four types. k
6. Identify the type of galaxy shown in each image below. k

(a)

(b)

Question 6

7. (a) What did Edwin Hubble discover about the motion of the 46 galaxies he first studied? k
   (b) How did Hubble's discovery provide evidence for what Georges Lemaître had proposed about the universe? k
8. How old is the universe thought to be? k
9. Does red light in the visible light spectrum have a longer or a shorter wavelength than blue light?
10. (a) Make a sketch to illustrate what astronomers mean when they say that light from a distant galaxy is "red-shifted." c
    (b) What does a large red shift indicate about a galaxy's motion? k
11. Explain how cosmic background radiation supports the Big Bang theory of how the universe formed. k
12. (a) Astronomers have learned in recent decades that the most distant galaxies from the Milky Way are moving away from us. At what rate are they moving away? k
    (b) What does the answer to (a) suggest about how the universe is evolving? k

Connect Your Understanding

13. Astronomers are able to observe distant regions of space and identify many kinds of celestial objects. Why, then, is it unlikely that we will ever be able to travel even across our own galaxy? t

14. Some galaxies are thought to produce many more new stars than others. What characteristics do galaxies with a high rate of production of stars have in common? t

15. Earth is located towards the edge of the Milky Way, in one of its spiral arms. How would the appearance of the night sky be different if Earth were much closer to the centre of the galaxy? t

16. Astronomy is in an interesting position right now. Most evidence collected by scientists supports the Big Bang theory of the origin and formation of the universe. All other scientific theories to explain the origin have so far largely been disproven by scientific evidence. Do you agree or disagree with the statement: "The Big Bang theory is correct because it is 'the last theory standing'"? Explain the reason for your answer. t

17. Astronomers speculate that thousands of billions of years from now, galaxies will have moved away from ours faster than their light can reach us. Our region of space, like all other regions, will be left in the dark. Is this something we should plan for on Earth? Explain. t

Reflection

18. Think about the activities in this chapter that you carried out. Make a list of the ones you did or observed your teacher demonstrating. Beside each activity, write down two points you learned from it that have helped you better understand the concepts presented in the text. c

After Reading

Thinking Literacy

Reflect and Evaluate

How did making connections to your prior knowledge about space and the universe help you to understand new ideas and information? On your mind map, highlight at least five connections between your "old" knowledge and the "new" knowledge that you learned in this unit. Share these connections with a partner.

Unit Task Link

Your imaginary trip to the stars in this chapter is meant to give you the "big picture" of Earth's place in the universe. Given the enormous distances between even our closest planetary neighbours in the solar system, a journey by humans to these destinations would be very long. A one-way trip by spacecraft to Mars would, scientists estimate, take nearly a year. What value would there be in sending humans to Mars? Make a list of the values you think of.