The Origin and Evolution of the Universe

9.7

People have been wondering about the Universe for a long time. They have asked questions such as Where did the Universe come from? How big is it? What will happen to it? In the last 100 years, technologies have been developed that help scientists find answers to these questions. By studying objects and events that occur in the Universe, astronomers continue to develop new theories and ideas about its origin and future.

Our Expanding Universe

Until the 1920s, astronomers thought that the Milky Way was the entire Universe. When they observed other galaxies, they thought that the galaxies were nebulas containing only gas and dust. The acceptance of this concept was so strong that when Albert Einstein's equations predicted that the Universe might be expanding, he changed them to reflect this belief that the Universe was unchanging.

Then Edwin Hubble made one of the most important discoveries in science. He identified individual stars inside the Andromeda galaxy (Figure 1) and realized that it was a separate galaxy far away from our Milky Way. When he determined that the Universe was filled with more galaxies, he noticed something even more surprising: all galaxies appeared to be moving away from each other, and the farther away a galaxy was, the faster it was moving away.

Figure 1 Andromeda is a large spiral galaxy that can be seen with binoculars on a clear autumn night.

TRY THIS THE CENTRE OF AN EXPANDING UNIVERSE

SKILLS: Observing, Analyzing, Communicating

SKILLS HANDBOOK 3.B.6., 3.B.7.

As the Universe expands, the space between all distant objects increases. This makes it appear as though the Universe is moving away from the observer in all directions. You will examine a pair of images that represent a collection of distant galaxies for evidence of an expanding universe.

Equipment and Materials: two overhead images representing galaxies; overhead projector

1. Your teacher will display an overhead image that contains dots representing distant galaxies. Notice that some galaxies are bigger and some are smaller.
2. Next, your teacher will overlay another image on the previous one, lining up the galaxies at point A. The new one represents the view of distant galaxies taken at a later time. This is how objects in space will appear to have moved relative to an observer at point A.
3. As your teacher slides the second overhead image to line up both at point B and then point C, observe how the patterns on the overhead change.

A. From the point of view of an observer at point A, where is the "centre of the Universe"? K/U

B. From the point of view of an observer at point B and at point C, where is the centre of the Universe? T/I

C. What can you conclude about the location of the centre of the Universe? T/I

D. How far do objects, near an observer at point A, appear to have moved compared with objects that are further away from the observer? How does this compare with Hubble's observations? T/I

Red Shift

Hubble made his revolutionary discovery by studying the patterns of light emitted from galaxies. He observed the following phenomena:

- Each galaxy emits its own distinctive spectrum of light (Figure 2(a)).
- Light spectra shift, depending on whether the light source is moving or stationary.

red shift the phenomenon of light from galaxies shifting toward the red end of the visible spectrum, indicating that the galaxies are moving away from Earth

While observing the light of distant galaxies, Hubble noticed a **red shift**—the light from the galaxies shifted toward the red end of the spectrum. This indicated that the galaxy itself is moving *away* from the Milky Way (Figure 2(b)).

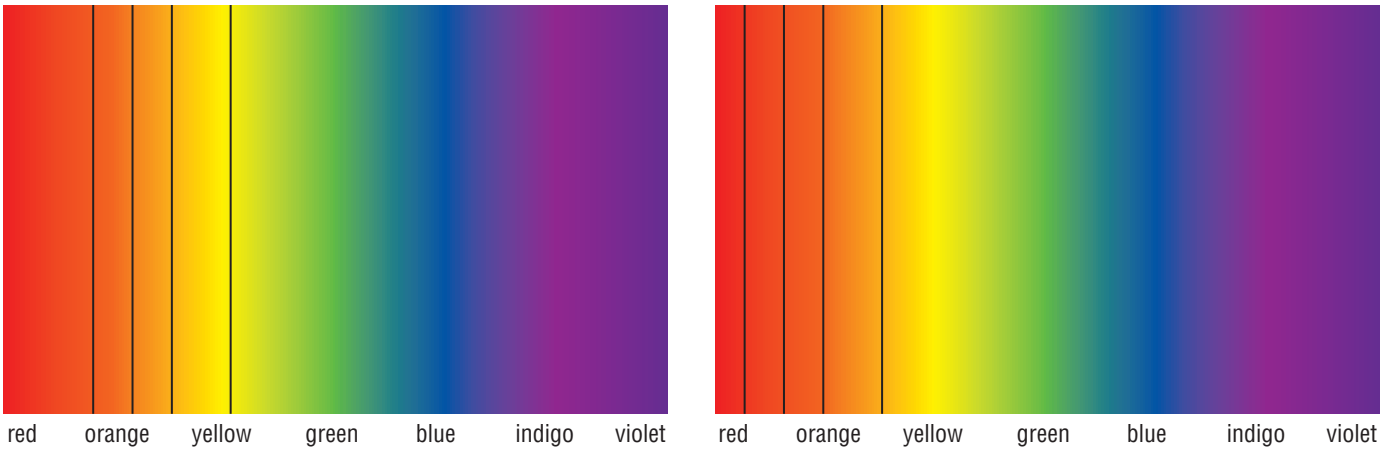

Figure 2 (a) The spectrum of a stationary galaxy (b) The same spectrum with the galaxy moving away from Earth. If a galaxy moves away from us, its spectrum shifts toward the red. The instruments used to detect this effect record the spectrum of light from red to violet. However, all of this light has shifted. We could not detect this shift except for the presence of dark lines in the solar spectrum. The dark lines are caused by gases in the upper atmosphere of stars absorbing some of the light emitted by the stars. This unique pattern of dark lines depends on the types of elements in the stars' atmosphere. Although the spectrum we see still looks largely like a rainbow, these lines have shifted toward the red because the galaxy is moving away from us.

Today, scientists observe the red shift in visible light and other radiation emitted from distant galaxies. The red shift indicates that the galaxies move farther apart from each other and from the Milky Way. This is evidence that the Universe is expanding. Hubble found that the farther away the galaxy, the greater the red shift, and, therefore, the faster it appeared to be moving. This relationship is called Hubble's Law.

Figure 3 Scientists hope to use specialized devices like this one to detect and study dark matter

Dark Matter

Stars travel at tremendous speeds within the galaxies themselves, and this speed depends on the overall mass of the galaxy to which they belong. However, astronomers were puzzled by the fact that these speeding stars were moving faster than expected, given the mass of the stars and matter that they could see. They concluded that there must be ten times more mass in the galaxy than we can detect with telescopes. It is the gravity of this hidden mass that is holding the galaxies together. Astronomers called the mass "dark matter" because it does not emit or absorb light (Figure 3).

This explains why astronomers have not been able to observe this matter with optical or other telescopes: it is not visible. We now understand that dark matter is the most abundant form of matter in the Universe, but little is known about its properties or behaviour.

To find out more about calculating the amount of matter in the Universe,
GO TO NELSON SCIENCE

Dark Energy

Before 1998, astronomers thought that the pull of gravity would cause the expansion of the Universe to slow down and eventually reverse. However, in 1998, astronomers noticed through observation of supernovas in distant galaxies that not only is the Universe expanding, but the rate of expansion is increasing. This discovery suggested that there is some strange form of energy working against the force of gravity. Called "dark energy," this phenomenon is causing the Universe to expand faster and faster. We do not yet understand the nature of dark energy or how it is able to oppose the effects of gravity.

READING TIP

Organizational Patterns
When summarizing a text, use the same organizational pattern that the text uses. If the text uses a concept/definition pattern to define a concept by describing its features or giving examples, do the same. This will help you to create an effective summary.

The Big Bang Theory

Cosmologists—people who study the components, evolution, and physics of the entire Universe—now believe that all matter and energy in the Universe expanded from a point that was smaller than the period at the end of this sentence. This theory is called the **Big Bang theory**.

Big Bang theory the theory that the Universe began in an incredibly hot, dense expansion approximately 13.7 billion years ago

Around the same time that Hubble was studying red shift, Georges Lemaître, a Belgian priest and astrophysicist, suggested that all matter and energy in the Universe expanded from a hot, dense mass with an incredibly small volume. This expansion is known as the Big Bang. Astronomers today estimate the Big Bang occurred between 13.6 and 13.8 billion years ago.

At this first instant of time and space, the Universe was extremely hot, and energy was spreading outward very quickly. As the Universe cooled, energy began turning into matter—mainly hydrogen. Over hundreds of millions of years, this matter formed clumps, which eventually formed the stars and galaxies we see today (remember the Solar Nebula theory from Section 9.5).

The Big Bang theory has become the most widely accepted scientific explanation of the origin of our universe. It makes predictions about the Universe's origin that can be verified by observation. For instance, Canadian astrophysicist Jim Peebles used the Big Bang theory to show that in the first few minutes of the Big Bang, about a quarter of the matter fused into helium, whereas the rest remained as hydrogen. This is confirmed by evidence from the observation of the oldest stars.

To learn more about cosmologists,
GO TO NELSON SCIENCE

Evidence for the Big Bang Theory

In 1965, strong evidence for the Big Bang was accidentally detected by Arno Penzias and Robert Wilson. The two physicists were conducting experiments with a supersensitive antenna in Crawford, New Jersey (Figure 4). They thought that the antenna was malfunctioning when they kept detecting radiation from all directions in the Universe.

Figure 4 The antenna that provided Penzias and Wilson with evidence to support the Big Bang theory

To learn more about how Penzias and Wilson discovered microwave static radiation,

GO TO NELSON SCIENCE

DID YOU KNOW?

Television and Static

Some of the static on your TV set is caused by leftover radiation from the Big Bang.

This radiation "interfered" with their radio experiments. Other scientists determined that the static interference represented the remnants of the energy released by the initial expansion of space that followed the Big Bang.

The quest for more evidence of the Big Bang theory continued. Physicists John Mather and George Smoot tried to determine what happened during the first trillionth of a second after the Big Bang. They researched the initial expansion of the Universe and the time when the first stars began to shine. In 1989, the Cosmic Background Explorer (COBE)—a satellite designed by Mather—precisely measured the temperature of background microwave radiation. The measurements matched the evidence collected by Penzias and Wilson. These temperature variations are similar to an imprint of the beginning of structure in the Universe, much like fossils are an imprint of past life on Earth.

In 2001, NASA launched a new cosmological satellite called the Wilkinson Microwave Anisotropy Probe (WMAP) (Figure 5). It can detect variations in temperatures in space as small as a millionth of a degree. The data collected so far provides more information about the early stages of our universe. WMAP found evidence that the first stars began to shine about 200 to 300 million years after the Big Bang.

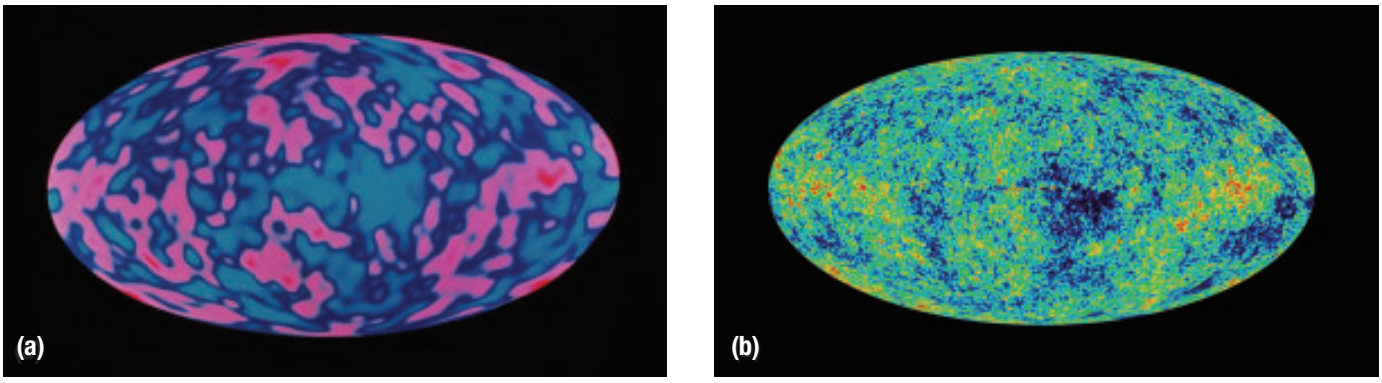

Figure 5 Readings from the (a) COBE and (b) WMAP satellites mapping the radiation in the Universe left over from the Big Bang. Examining the patterns in these images provides scientists with clues to the formation of the very first stars and galaxies, and supporting evidence for the Big Bang theory.

The Future of the Universe

Astronomers believe that over the course of the Universe's lifetime, there has been a constant battle between the gravitational pull of all matter—including dark matter—and the repulsive force of dark energy. Astronomers have discovered that the effect of dark energy was being felt 9 billion years ago and has steadily increased over time. Observations in 2006 confirmed that the expansion rate of the Universe began speeding up about 5 to 6 billion years ago. That is when astronomers believe that dark energy's repulsive force overcame the gravitational pull of matter. If their predictions are correct, over the course of the next billions of years, dark energy will continue to grow stronger, eventually pulling apart galaxies and leaving the Universe filled with even more cold, empty space.

TRY THIS MODEL THE EXPANDING UNIVERSE

SKILLS: Planning, Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK 3.B.

The Big Bang theory states that the Universe started as a tiny dot of matter that expanded rapidly and continues to expand to this day. In this activity, you will investigate the expansion of the Universe and its effect on the movement of galaxies.

Equipment and Materials: round balloon; felt tip pen; tape measure

Be careful when blowing up and writing on balloons. Pressing too hard on the balloon may cause it to burst and possibly cause injuries.

1. Fill your balloon with air until it is the size of a large apple. Then twist the end and hold it closed with one hand. Do not tie it shut.
2. Use the pen to draw four galaxies on the balloon in a line, with 1 cm of space between each one (Figure 6).

Figure 6

3. Label the galaxies A, B, C, and D.
4. Now inflate the balloon to the size of a volleyball and tie it off (Figure 7).

Figure 7

5. Measure the distances between the galaxies again and write down the measurements.

A. What happened to the distances between galaxies as you blew up the balloon? K/U T/I

B. Imagine that you are standing on galaxy "A" while the balloon is expanding. Which galaxy would appear to move away from you more quickly? T/I

C. Which one would appear to move more slowly? T/I

UNIT TASK Bookmark

How can you apply what you have learned about the Big Bang theory to the Unit Task described on page 446?

IN SUMMARY

- The observed red shift of distant galaxies suggests that the Universe is expanding at an increasing rate.
- Dark matter and dark energy are phenomena needed to explain the observed behaviour of distant galaxies.
- The Big Bang theory suggests that the Universe was born in a giant expansion 13.7 billion years ago.

CHECK YOUR LEARNING

1. How does red shift help astronomers determine the movement of distant galaxies? K/U
2. Summarize the conclusion that Edwin Hubble made about the Universe and the evidence he had to support his claim. K/U
3. Compare and contrast dark matter with dark energy. K/U
4. If dark energy has never been directly seen, what evidence do astronomers have that dark energy exists? K/U
5. According to the Big Bang theory, how long ago did the Universe begin? Who was the first person to suggest this theory? K/U
6. After the Big Bang, did stars and galaxies emerge fully formed? Why or why not? K/U
7. You have a friend who doubts that the Universe started billions of years ago during the Big Bang. Write a letter to your friend outlining two pieces of evidence that support the Big Bang theory. K/U C
8. Name two satellites that gathered evidence in support of the Big Bang theory. What kind of data did they capture? K/U
9. Describe the experiments Mather and Smoot performed that provided evidence for the Big Bang theory. K/U
10. What do astronomers predict will happen to our universe billions of years in the future? K/U