Section 5

The Expanding Universe

Reading Preview

Key Concepts

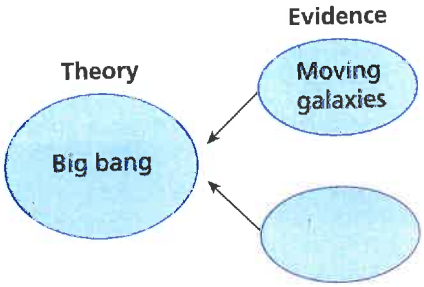
- What is the big bang theory?
- How did the solar system form?
- What do astronomers predict about the future of the universe?

Key Terms

- big bang
- Hubble's law
- cosmic background radiation
- solar nebula
- planetesimal
- dark matter
- dark energy

Target Reading Skill

Identifying Supporting Evidence As you read, identify the evidence that supports the big bang theory. Write the evidence in a graphic organizer like the one below.



Lab zone **Discover Activity**

How Does the Universe Expand?

1. Use a marker to put 10 dots on an empty balloon. The dots represent galaxies.
2. Blow up the balloon. What happens to the distances between galaxies that are close together? Galaxies that are far apart?

Think It Over

Inferring If the universe is expanding, do galaxies that are close together move apart faster or slower than galaxies that are far apart? Explain.

The Andromeda Galaxy is the most distant object that the human eye can see. Light from this galaxy has traveled for about 3 million years before reaching Earth. When that light finally reaches your eye, you are seeing how the galaxy looked 3 million years ago. It is as though you are looking back in time.

Astronomers have photographed galaxies that are billions of light-years away. Light from these galaxies traveled for billions of years before it reached Earth. From these observations, astronomers are able to infer the age of the universe.

How the Universe Formed

Astronomers theorize that the universe began billions of years ago. At that time, the part of the universe we can now see was no larger than the period at the end of this sentence. This tiny universe was incredibly hot and dense. The universe then exploded in what astronomers call the **big bang.**

◀ Nearly every visible object in this image is a distant galaxy.

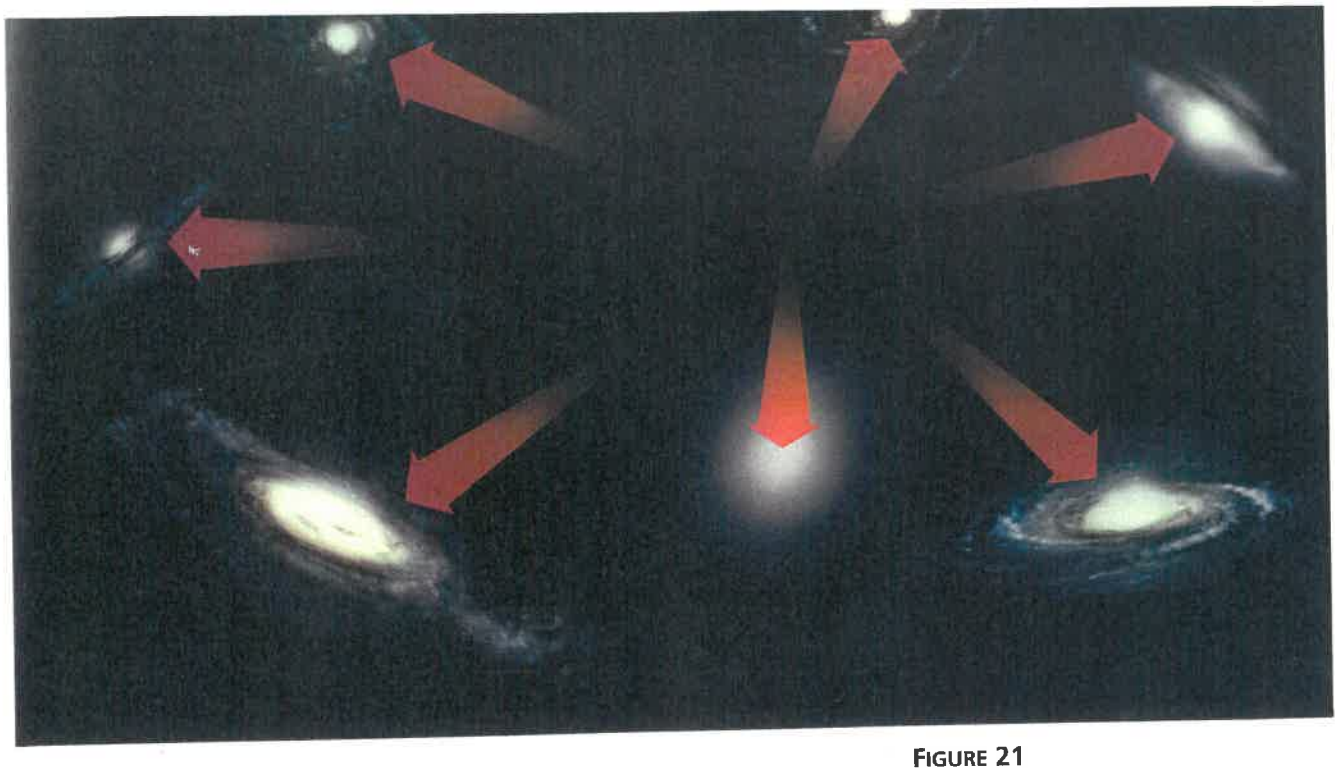


FIGURE 21
Retreating Galaxies
All of the distant galaxies astronomers have observed are moving rapidly away from our galaxy and from each other.

According to the big bang theory, the universe formed in an instant, billions of years ago, in an enormous explosion. Since the big bang, the size of the universe has been increasing rapidly. The universe is billions of times larger now than it was early in its history.

As the universe expanded, it gradually cooled. After a few hundred thousand years, atoms formed. About 200 million years after the big bang, the first stars and galaxies formed.

If the big bang theory is accurate, what evidence might you expect to find in today's universe? You might expect that the matter that had been hurled apart by the big bang would still be moving apart. You might also expect to find evidence of energy left over from the explosion.

Moving Galaxies An American astronomer, Edwin Hubble, discovered important evidence that later helped astronomers to develop the big bang theory. In the 1920s, Hubble studied the spectrums of many galaxies at various distances from Earth. By examining a galaxy's spectrum, Hubble could tell how fast the galaxy is moving and whether it is moving toward our galaxy or away from it.

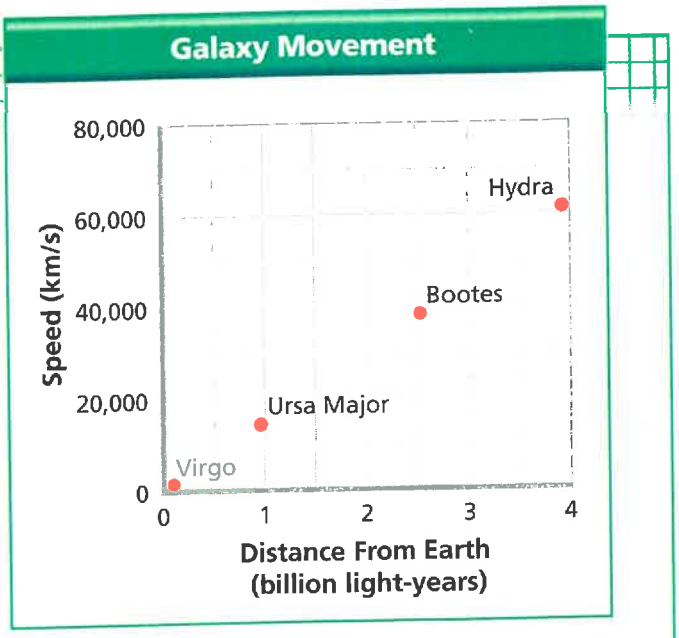
Hubble discovered that, with the exception of a few nearby galaxies, all galaxies are moving away from us and from each other. Hubble found that there is a relationship between the distance to a galaxy and its speed. **Hubble's law** states that the farther away a galaxy is, the faster it is moving away from us. Hubble's law strongly supports the big bang theory.

Math Analyzing Data

Speeding Galaxies

Use the graph to answer the questions below about moving clusters of galaxies.

1. **Reading Graphs** How far away is the Bootes cluster? How fast is it moving?
2. **Reading Graphs** Which galaxy is moving away the fastest? Which galaxy is closest to Earth?
3. **Drawing Conclusions** How are the distance and speed of a galaxy related?
4. **Predicting** Predict the speed of a galaxy that is 5 billion light-years from Earth.



To understand how the galaxies are moving, think of raisin bread dough that is rising. If you could shrink yourself to sit on a raisin, you would see all the other raisins moving away from you. The farther a raisin was from you, the faster it would move away, because there would be more bread dough to expand between you and the raisin. No matter which raisin you sat on, all the other raisins would seem to be moving away from you. You could tell that the bread dough was expanding by watching the other raisins.

The universe is like the bread dough. Like the raisins in the dough, the galaxies in the universe are moving away from each other. In the universe, it is space that is expanding, like the dough between the raisins.

Cosmic Background Radiation In 1965, two American physicists, Arno Penzias and Robert Wilson, accidentally detected faint radiation on their radio telescope. This mysterious glow was coming from all directions in space. Scientists later concluded that this glow, now called **cosmic background radiation,** is the leftover thermal energy from the big bang. This energy was distributed in every direction as the universe expanded.

Age of the Universe Since astronomers can measure approximately how fast the universe is expanding now, they can infer how long it has been expanding. Based on careful measurements of how fast distant galaxies are moving away from us and the cosmic background radiation, astronomers estimate that the universe is about 13.7 billion years old.

FIGURE 22
Rising Dough
The galaxies in the universe are like the raisins in rising bread dough. **Making Models** *How does rising raisin bread dough resemble the expanding universe?*

Formation of the Solar System

After the big bang, matter in the universe separated into galaxies. Gas and dust spread throughout space. Where the solar system is now, there was only cold, dark gas and dust. How did the solar system form? The leading hypothesis is explained below.

The Solar Nebula **About five billion years ago, a giant cloud of gas and dust collapsed to form our solar system.** A large cloud of gas and dust such as the one that formed our solar system is called a **solar nebula.** Slowly, gravity began to pull the solar nebula together. As the solar nebula shrank, it spun faster and faster. The solar nebula flattened, forming a rotating disk. Gravity pulled most of the gas into the center of the disk, where the gas eventually became hot and dense enough for nuclear fusion to begin. The sun was born.

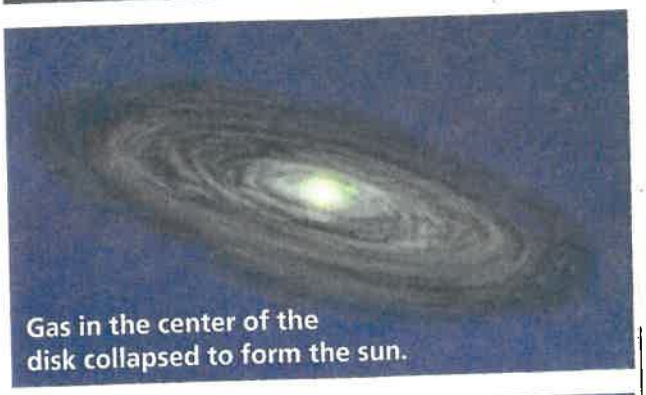
Planetesimals Meanwhile, in the outer parts of the disk, gas and dust formed small asteroid-like bodies called **planetesimals.** These formed the building blocks of the planets. Planetesimals collided and grew larger by sticking together, eventually combining to form the planets.

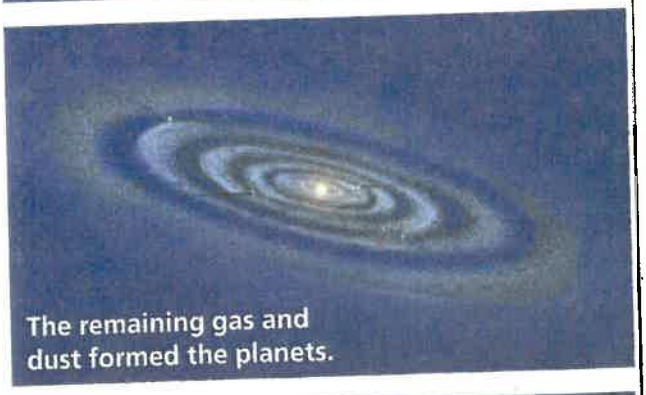
The Inner Planets When the solar system formed, temperatures were very high. It was so hot close to the sun that most water and other ice-forming materials simply vaporized. Most gases escaped the gravity of the planets that were forming in this region. As a result, the inner planets, Mercury, Venus, Earth, and Mars, are relatively small and rocky.

The Outer Planets In contrast, farther from the sun it was much cooler. As the planets in this region grew, their gravity increased and they were able to capture much of the hydrogen and helium gas in the surrounding space. As a result, the planets Jupiter, Saturn, Uranus, and Neptune became very large. Beyond these gas giants, a huge disk of ice and other substances formed, with a cloud of such substances farther out. This disk and cloud are the main sources of comets. Pluto also formed in this region as part of the icy outer disk.

Reading Checkpoint **What is a solar nebula?**


A cloud of gas and dust formed a spinning disk.


Gas in the center of the disk collapsed to form the sun.


The remaining gas and dust formed the planets.

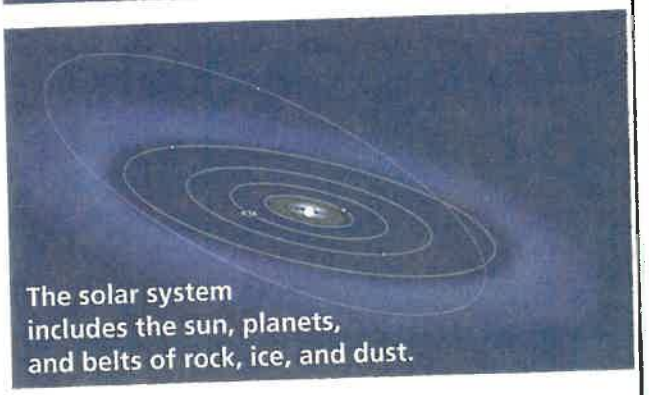

The solar system includes the sun, planets, and belts of rock, ice, and dust.

FIGURE 23
How the Solar System Formed
The solar system formed from a collapsing cloud of gas and dust.

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The Future of the Universe

What will happen to the universe in the future? One possibility is that the universe will continue to expand, as it is doing now. All of the stars will eventually run out of fuel and burn out, and the universe will be cold and dark. Another possibility is that the force of gravity will begin to pull the galaxies back together. The result would be a reverse big bang, or "big crunch." All of the matter in the universe would be crushed into an enormous black hole.

Which of these possibilities is more likely? Recent discoveries have produced a surprising new view of the universe that is still not well understood. **New observations lead many astronomers to conclude that the universe will likely expand forever.**

Dark Matter

Until fairly recently, astronomers assumed that the universe consisted solely of the matter they could observe directly. But this idea was disproved by the American astronomer Vera Rubin. Rubin made detailed observations of the rotation of spiral galaxies. She discovered that the matter that astronomers can see, such as stars and nebulas, makes up as little as ten percent of the mass in galaxies. The remaining mass exists in the form of dark matter.

Dark matter is matter that does not give off electromagnetic radiation. Dark matter cannot be seen directly. However, its presence can be inferred by observing the effect of its gravity on visible objects, such as stars, or on light.

Astronomers still don't know much about dark matter—what it is made of or all of the places where it is found. But astronomers estimate that about 23 percent of the universe's mass is made of dark matter.

An Accelerating Expansion

In the late 1990s, astronomers observed that the expansion of the universe appears be accelerating. That is, galaxies seem to be moving apart at a faster rate now than in the past. This observation was puzzling, as no known force could account for it. Astronomers infer that a mysterious new force, which they call **dark energy,** is causing the expansion of the universe to accelerate. Current estimates indicate that most of the universe is made of dark energy and dark matter.

Astronomy is one of the oldest sciences, but there are still many discoveries to be made and puzzles to be solved about this universe of ours!

Reading Checkpoint **What is the effect of dark energy?**

FIGURE 24
Vera Rubin
Astronomer Vera Rubin's observations proved the existence of dark matter.

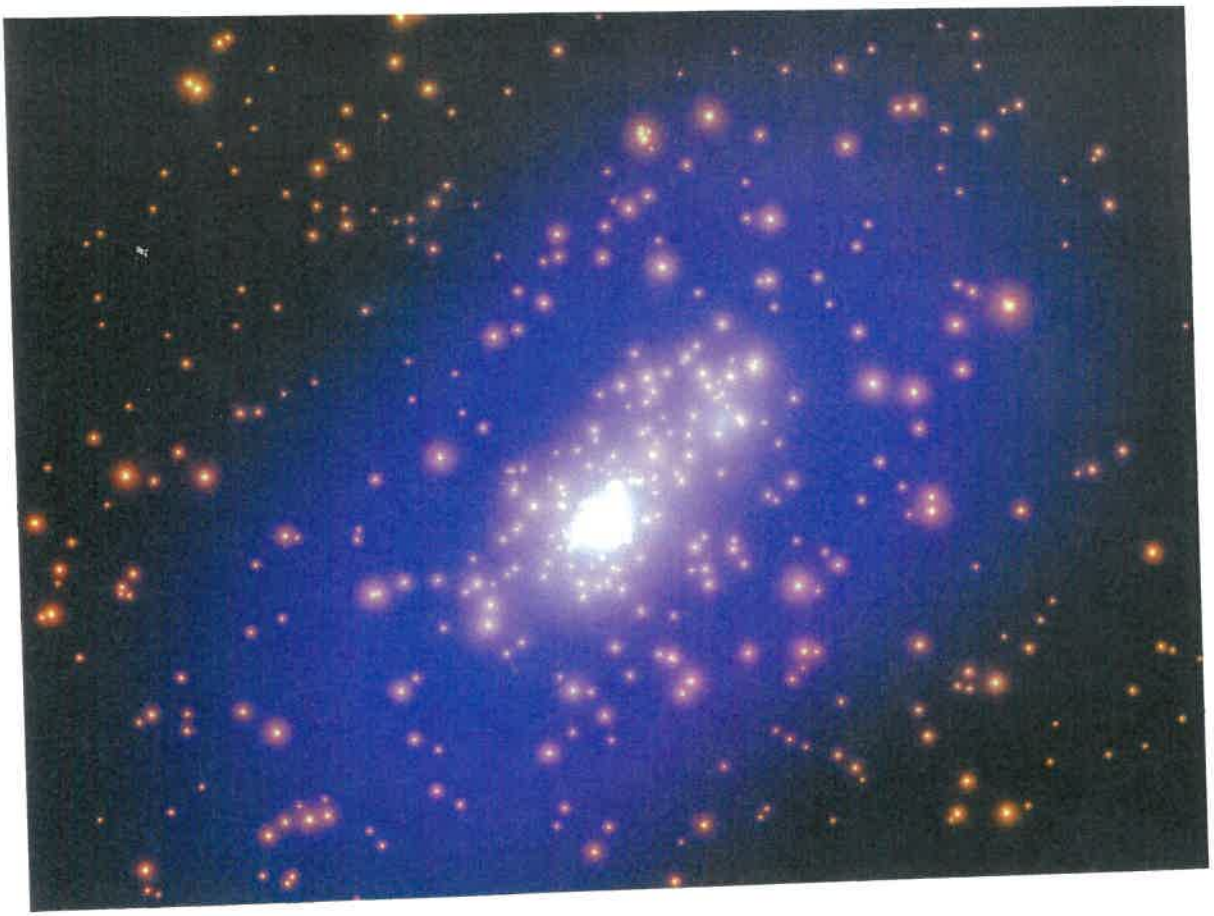

FIGURE 25
Dark Matter
Astronomers measured the effect of gravity on light to produce this computer image of how dark matter (in blue) is distributed across a cluster of galaxies.

Section 5 Assessment

Target Reading Skill Identifying Supporting Evidence Refer to your graphic organizer about the big bang theory as you answer Question 1 below.

Reviewing Key Concepts

1. a. Defining What was the big bang?
   b. Summarizing When did the big bang occur?
   c. Describing Describe two pieces of evidence that support the big bang theory.
2. a. Summarizing How old is the solar system?
   b. Relating Cause and Effect What force caused the solar system to form?
   c. Sequencing Place the following events in the proper order: planets form; planetesimals form; solar nebula shrinks; nuclear fusion begins in the sun.
3. a. Defining What is dark matter?
   b. Explaining How do scientists know that dark matter exists?
   c. Predicting What evidence has led scientists to predict that the universe will continue to expand forever?

Lab zone At-Home Activity

Stargazing Plan an evening of stargazing with adult family members. Choose a dark, clear night. Use binoculars if available and the star charts in the appendix to locate the Milky Way and some interesting stars that you have learned about. Explain to your family what you know about the Milky Way and each constellation that you observe.