19.3 Reading

19.3 Galaxies and the Universe

Early civilizations thought that Earth was the center of the universe. In the sixteenth century, we became aware that Earth is a small planet orbiting a medium-sized star. It was only in the twentieth century that we became aware that the Sun is one of billions of stars in the Milky Way galaxy, and that there are billions of other galaxies in the universe. In the past 50 years, astronomers have found evidence that the universe is expanding and that it originated 10 billion to 20 billion years ago. In this section, you will learn about galaxies and about a theory on how the universe began.

The discovery of galaxies

The discovery of other galaxies

In Section 1, you learned that a galaxy is a huge group of stars, dust, gas, and other objects bound together by gravitational forces. The Sun, along with an estimated 200 billion other stars, belongs to the Milky Way galaxy, a spiral-shaped galaxy (Figure 19.18). At the turn of the twentieth century, astronomers thought that the Milky Way galaxy was the entire universe. As telescopes got better, though, some "smudges" that were thought to be nebulae in the Milky Way were found to actually be whole galaxies far outside our own.

Edwin Hubble discovers a galaxy

This discovery was made in the 1920s by Edwin Hubble (1889– 1953), an American astronomer. When he focused a huge telescope on an object thought to be a nebula in the constellation Andromeda, Hubble could see that the "nebula" actually consisted of faint, distant stars. He named the object the Andromeda galaxy. Since Hubble's time, astronomers have discovered a large number of galaxies. In fact, many galaxies are detected each year using the famous telescope launched into orbit in 1990: the Hubble Space Telescope, or HST. Figure 19.19 shows a famous HST photo called Hubble Deep Field. The photo shows many galaxies and stars in a tiny speck of sky. There is a larger version of this photo on the first page of this chapter. Can you find the galaxies in the photo?

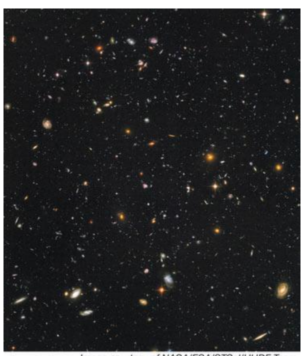
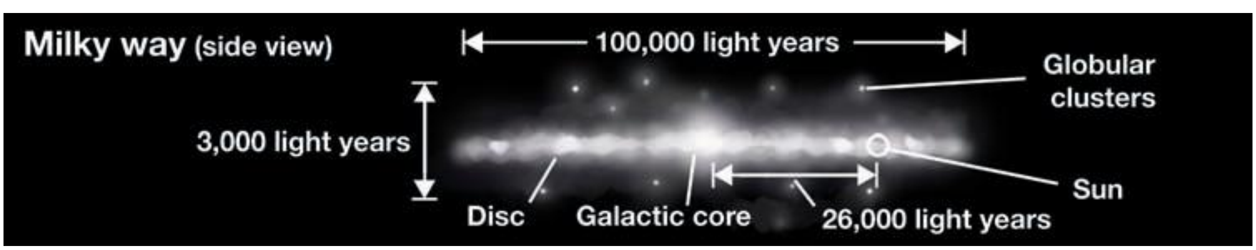


Image courtesy of NASA/ESA/STScI/HUDF Team.

Types of galaxies

Galaxy shapes

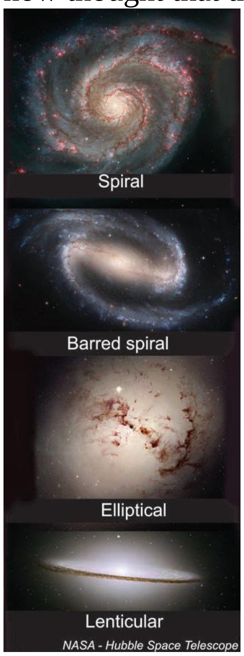
Astronomers classify galaxies according to their shape. *Spiral Galaxies* like the Milky Way consist of a central, dense area surrounded by spiraling arms. The Milky Way is a typical spiral galaxy. From above, it would look like a giant pinwheel (see Figure 19.20, top). Although some stars are in *globular clusters* above and below the main disk, the majority are arranged in a disk that is more than 100,000 light years across and only 3,000 light years thick.



Barred spiral galaxies have a bar-shaped structure in the center. *Elliptical galaxies* look like the central portion of a spiral galaxy without the arms. *Lenticular galaxies* are lens-shaped with a smooth, even distribution of stars and no central, denser area. *Irregular galaxies* exhibit peculiar shapes and do not appear to rotate like those galaxies of other shapes. Figure 19.20 shows examples of some galaxy shapes.

Galaxies change shape over time

The shapes of galaxies change over time. It is impossible to actually see the changes in a single galaxy, since the changes take hundreds of millions of years. However, by looking at many galaxies, astronomers can see similar galaxies at different times in their histories. This observational data has allowed astronomers to develop computer-based models that calculate how a galaxy changes over hundreds of millions of years. It is now thought that the barred spiral form is just one phase of a regular spiral galaxy.



The distance between galaxies

Galaxies are a million times farther away than stars

The distances between stars are 10,000 times greater than the distances between planets. *The distances between galaxies are a million times greater than the distances between stars*. For example, the distance from Earth to the nearest star is 4.3 light years, but from Earth to the Whirlpool galaxy is over 30 million light years.

The local group of galaxies

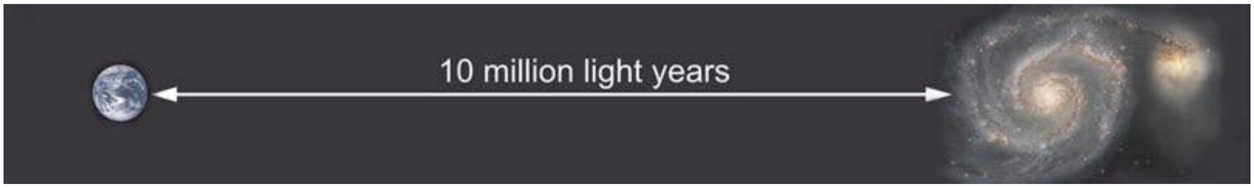
The Milky Way belongs to a group of about 30 galaxies called the local group. This group includes the Large Magellanic Cloud (179,000 ly from Earth) and the Small Magellanic Cloud (210,000 ly from Earth). These Magellanic Clouds are small, irregular galaxies of less than 100,000 stars. The local group also includes Andromeda, an elliptical galaxy 2.5 million light years away (Figure 19.21).

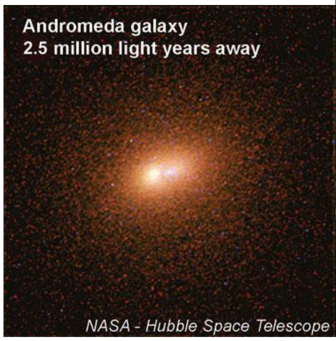
Galactic collisions

Galaxies move through space singly and in groups. Galaxies even collide with each other in slow dances of stars that take millions of years to complete (Figure 19.22).

Estimating the distance between galaxies

Estimating the distance between galaxies is one of the more difficult tasks in astronomy. A faint (low brightness) object in the night sky could be a dim object that is relatively nearby or a bright object that is farther away. The most reliable method for estimating the distance to a galaxy is to find a star whose luminosity is known. If the luminosity is known, then a mathematical relationship can be used to find the distance from the observed brightness. That distance is used to estimate the distance to the galaxy to which the star belongs.





The expanding universe

Sirius is moving away from Earth

In the 1860s, astronomers began to use spectroscopy to study the stars and other objects in space. One of the first stars they studied, Sirius, had spectral lines in the same pattern as the spectrum for hydrogen. However, these lines did not have the exact same measurements as those for hydrogen. Instead, they were shifted toward the red end of the visible spectrum. This was a puzzle at first, until scientists realized that a red-shifted spectrum meant Sirius was moving away from Earth (Figure 19.23).

Redshift

Redshift is caused by relative motion that increases the distance between the source and the observer. The faster the source of light is moving away from the observer, the greater the redshift. The opposite (blueshift) happens when an object is moving *toward* the observer. A star moving toward Earth would show a spectrum for hydrogen that was shifted toward the blue end of the scale.

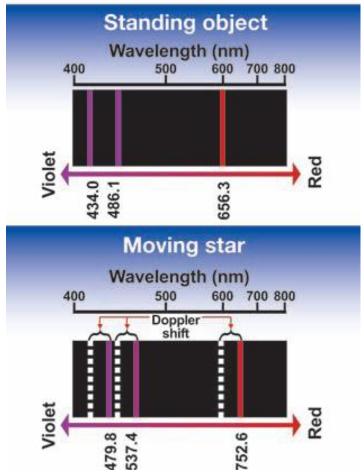
Discovery of the expanding universe

In the late 1920s, Edwin Hubble began to measure the distance and redshift of galaxies. Much to his surprise, he discovered that the farther away a galaxy was, the faster it was moving away from Earth. By the early 1930s, he had enough evidence to prove that galaxies were moving away from each other. This concept came to be known as the *expanding universe*.

The Big Bang theory

Before Hubble's discovery, people believed the universe had existed in its same form for all time. The fact that the universe is expanding is evidence that the universe must have been smaller in the past than it is today. In fact, it implies that the universe must have had a *beginning*. Astronomers today believe the universe exploded outward from a single point smaller than an atom into the vast expanse of galaxies and space we know today. This idea is known as the **Big Bang theory**.

Figure 19.23: *The top diagram shows the hydrogen spectrum for an object on Earth. The bottom diagram shows the hydrogen spectral lines for a moving star. While the lines are in the exact same pattern, they have shifted toward the red end of the spectrum*



The Big Bang theory

What does the Big Bang theory say?

The Big Bang theory says the universe began as a huge explosion between 10 billion and 20 billion years ago (Figure 19.24). According to this theory, all matter and energy started in a space smaller than the nucleus of an atom. Suddenly, a huge explosion occurred (no one knows why) that sent everything that makes up the universe out in all directions. For an instant, the universe was a hot ball of fire that began to expand rapidly. Extreme heat from the explosion (10 billion °C) caused the formation of subatomic particles.

Protons and neutrons form 4 minutes after the explosion

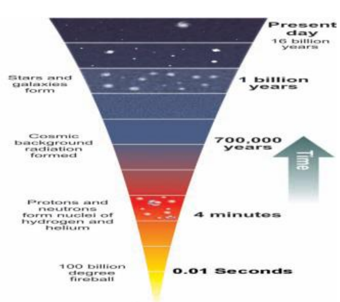
Immediately after the explosion, the universe began to expand, cool, and slow down. After a few minutes, hydrogen nuclei began forming. Next, hydrogen nuclei began fusing to form helium nuclei. Because atoms were still flying around with high energy, heavy nuclei were smashed apart. Only one helium atom survived for every 12 hydrogen atoms. Almost no elements heavier than helium survived. When we look at the matter in the universe today, we see this ratio of hydrogen to helium left by the Big Bang, with the exception of elements formed later in stars.

Matter and light decouple in 700,000 years

For the next 700,000 years, the universe was like the inside of a star: hot hydrogen and helium. The universe had expanded enough to become transparent to light. At this point, the light from the fireball was freed from constant interaction with hot matter. The light continued to expand separately from matter and became the *cosmic background radiation* we see today.

Stars and galaxies form

When the universe was about 1 billion years old, it had expanded and cooled enough that galaxies and stars could form. At this point, the universe probably began to look similar to how it looks today. The Sun and solar system formed about 4.6 billion years ago, by which time the universe was about 12 billion years old.



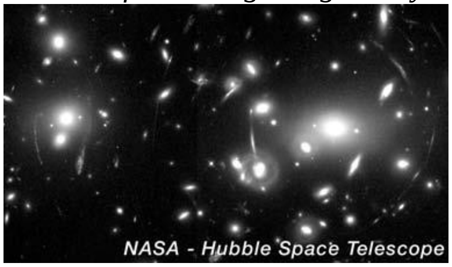
Evidence for the Big Bang theory

Evidence for the Big Bang
When it was first introduced, not everyone believed the Big Bang theory. In fact, the name "Big Bang" was made up by scientists to mock the theory. As with any new theory, the Big Bang became more accepted as new scientific tools and discoveries established more evidence. The fact that galaxies are expanding away from each other is a strong argument for the Big Bang. As far as we can look into the universe, we find galaxies are expanding away from each other (Figure 19.25).

Microwave background radiation
When you light a match, the flame bursts rapidly from the first spark and then cools as it expands. When the Big Bang exploded, it also created hot radiation. This radiation has been expanding and cooling for 16 billion years. The radiation is now at a temperature only 2.7 °C above absolute zero and it fills the universe. The *cosmic background radiation* is the "smoke" from the Big Bang that fills the room (that is, the universe), even 16 billion years later. It was discovered by Arno Penzias and Robert Wilson, two American astrophysicists in the 1960s (Figure 19.26).

Ratios of the elements
We have other evidence that supports the Big Bang theory. The proportion of hydrogen to helium is consistent with the physics of the Big Bang (Figure 19.27). Elements heavier than hydrogen and helium are formed in stars. When stars reach the end of their life cycles, they spread heavy elements such as carbon, oxygen, and iron out into the universe. If the universe were significantly older, there would be more heavy elements present compared with hydrogen and helium.

Figure 19.25: *The observed expansion of the universe is strong evidence for the Big Bang theory.*



Name___________________________________ **Date**____________ **Hour**_________

19.3 Section Review

1. In which galaxy do we live?

2. The number of stars in our home galaxy is closest to:
a. 200
b. 200,000
c. 200,000,000
d. 200 billion

3. Name an important discovery about the universe that is credited to astronomer Edwin Hubble.

4. List four galaxy shapes.

5. What is the shape of our galaxy?

6. The distances between galaxies are in the range of:
a. 100 kilometers
b. 100 light years
c. 1 million light years
d. 1 billion light years

7. How do astronomers estimate the distance between galaxies?

8. How did astronomers discover that the star Sirius was moving away from Earth?

9. What did Hubble discover about the relationship between a galaxy's location and speed?

10. According to the Big Bang theory, how large was the universe before it exploded and expanded in all directions?

11. How many years did it take for stars to begin to form after the Big Bang?

12. Describe the scientific evidence that supports the Big Bang theory.