Chapter 26: MS Stars, Galaxies, and the Universe

Chapter Outline

26.1 Stars
26.2 Galaxies
26.3 The Universe
26.4 References
Lesson Objectives

• Define constellation.
• Classify stars based on their color and temperature.
• Outline the stages of a star.
• Use light-years as a unit of distance.

Vocabulary

• binary star system
• black hole
• main sequence star
• neutron star
• red giant
• supernova
• star

Introduction

When you look at the sky on a clear night, you can see hundreds of stars. A star is a giant ball of glowing gas that is very, very hot. Most of these stars are like our Sun, but some are smaller than our Sun, and some are larger. Except for our own Sun, all stars are so far away that they only look like single points, even through a telescope.

Constellations

The stars that make up a constellation appear close to each other from Earth. In reality, they may be very distant from one another. Constellations were important to people, like the Ancient Greeks. People who spent a lot of time outdoors at night, like shepherds, named them and told stories about them. Figure 26.1 shows one of the most easily recognized constellations. The ancient Greeks thought this group of stars looked like a hunter. They named it Orion, after a great hunter in Greek mythology.

The constellations stay the same night after night. The patterns of the stars never change. However, each night the constellations move across the sky. They move because Earth is spinning on its axis. The constellations also move with the seasons. This is because Earth revolves around the Sun. Different constellations are up in the winter than in the summer. For example, Orion is high up in the winter sky. In the summer, it’s only up in the early morning.
Energy of Stars

Only a tiny bit of the Sun’s light reaches Earth. But that light supplies most of the energy at the surface. The Sun is just an ordinary star, but it appears much bigger and brighter than any of the other stars. Of course, this is just because it is very close. Some other stars produce much more energy than the Sun. How do stars generate so much energy?

Nuclear Fusion

Stars shine because of nuclear fusion. Fusion reactions in the Sun’s core keep our nearest star burning. Stars are made mostly of hydrogen and helium. Both are very lightweight gases. A star contains so much hydrogen and helium that the weight of these gases is enormous. The pressure at the center of a star is great enough to heat the gases. This causes nuclear fusion reactions.

A nuclear fusion reaction is named that because the nuclei (center) of two atoms fuse (join) together. In stars like our Sun, two hydrogen atoms join together to create a helium atom. Nuclear fusion reactions need a lot of energy to get started. Once they begin, they produce even more energy.
Particle Accelerators

Scientists have built machines called particle accelerators. These amazing tools smash particles that are smaller than atoms into each other head-on. This creates new particles. Scientists use particle accelerators to learn about nuclear fusion in stars. They can also learn about how atoms came together in the early universe. Two well-known accelerators are SLAC, in California, and CERN, in Switzerland.

How Stars Are Classified

Stars shine in many different colors. The color relates to a star’s temperature and often its size.

Color and Temperature

Think about the coil of an electric stove as it heats up. The coil changes in color as its temperature rises. When you first turn on the heat, the coil looks black. The air a few inches above the coil begins to feel warm. As the coil gets hotter, it starts to glow a dull red. As it gets even hotter, it becomes a brighter red. Next it turns orange. If it gets extremely hot, it might look yellow-white, or even blue-white. Like a coil on a stove, a star’s color is determined by the temperature of the star’s surface. Relatively cool stars are red. Warmer stars are orange or yellow. Extremely hot stars are blue or blue-white.

Classifying Stars by Color

The most common way of classifying stars is by color as shown, in Table 26.1. Each class of star is given a letter, a color, and a range of temperatures. The letters don’t match the color names because stars were first grouped as A through O. It wasn’t until later that their order was corrected to go by increasing temperature. When you try to remember the order, you can use this phrase: “Oh Be A Fine Good Kid, Man.”

<table>
<thead>
<tr>
<th>Class</th>
<th>Color</th>
<th>Temperature range</th>
<th>Sample Star</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Blue</td>
<td>30,000 K or more</td>
<td>An artist’s depiction of the O class star Zeta Puppis.</td>
</tr>
<tr>
<td>B</td>
<td>Blue-white</td>
<td>10,000–30,000 K</td>
<td>An artist’s depiction of Rigel, a Class B star.</td>
</tr>
</tbody>
</table>

Table 26.1: Classification of Stars By Color and Temperature
### Table 26.1: (continued)

<table>
<thead>
<tr>
<th>Class</th>
<th>Color</th>
<th>Temperature range</th>
<th>Sample Star</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>White</td>
<td>7,500–10,000 K</td>
<td><img src="https://example.com/sirius-a.png" alt="Image" /> Sirius A is the brightest star that we see in the night sky. The dot on the right, Sirius B, is a white dwarf.</td>
</tr>
<tr>
<td>F</td>
<td>Yellowish-white</td>
<td>6,000–7,500 K</td>
<td><img src="https://example.com/polaris-star.png" alt="Image" /> There are two F class stars in this image, the supergiant Polaris A and Polaris B. What we see in the night sky as the single star “Polaris,” we also know as the North Star.</td>
</tr>
<tr>
<td>G</td>
<td>Yellow</td>
<td>5,500–6,000 K</td>
<td><img src="https://example.com/sun.png" alt="Image" /> Our sun: the most important G class star in the Universe, at least for humans.</td>
</tr>
</tbody>
</table>
### Table 26.1: (continued)

<table>
<thead>
<tr>
<th>Class</th>
<th>Color</th>
<th>Temperature range</th>
<th>Sample Star</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Orange</td>
<td>3,500–5,000 K</td>
<td>Arcturus is a Class K star that looks like the sun but is much larger.</td>
</tr>
<tr>
<td>M</td>
<td>Red</td>
<td>2,000–3,500 K</td>
<td>There are two types of Class M stars: red dwarfs and red giants.</td>
</tr>
</tbody>
</table>

The surface temperature of most stars is due to its size. Bigger stars produce more energy, so their surfaces are hotter. But some very small stars are very hot. Some very big stars are cool.

### Lifetimes of Stars

We could say that stars are born, change over time, and eventually die. Most stars change in size, color, and class at least once during their lifetime.
Formation of Stars

Stars are born in clouds of gas and dust called nebulas. Our Sun and solar system formed out of a nebula. A nebula is shown in Figure 26.2. In Figure 26.1, the fuzzy area beneath the central three stars contains the Orion nebula.

For a star to form, gravity pulls gas and dust into the center of the nebula. As the material becomes denser, the pressure and the temperature increase. When the temperature of the center becomes hot enough, nuclear fusion begins. The ball of gas has become a star!

Main Sequence Stars

For most of a star’s life, hydrogen atoms fuse to form helium atoms. A star like this is a main sequence star. The hotter a main sequence star is, the brighter it is. A star remains on the main sequence as long as it is fusing hydrogen to form helium.

Our Sun has been a main sequence star for about 5 billion years. As a medium-sized star, it will continue to shine for about 5 billion more years. Large stars burn through their supply of hydrogen very quickly. These stars “live fast and die young!” A very large star may only be on the main sequence for 10 million years. A very small star may be on the main sequence for tens to hundreds of billions of years.

Red Giants and White Dwarfs

A star like our Sun will become a red giant in its next stage. When a star uses up its hydrogen, it begins to fuse helium atoms. Helium fuses into heavier atoms like carbon. At this time the star’s core starts to collapse inward. The star’s outer layers spread out and cool. The result is a larger star that is cooler on the surface, and red in color.
Eventually a red giant burns up all of the helium in its core. What happens next depends on the star’s mass. A star like the Sun stops fusion and shrinks into a white dwarf star. A white dwarf is a hot, white, glowing object about the size of Earth. Eventually, a white dwarf cools down and its light fades out.

**Supergiants and Supernovas**

A more massive star ends its life in a more dramatic way. Very massive stars become red supergiants, like Betelgeuse. In a red supergiant, fusion does not stop. Lighter atoms fuse into heavier atoms. Eventually iron atoms form. When there is nothing left to fuse, the star’s iron core explodes violently. This is called a *supernova* explosion. The incredible energy released fuses heavy atoms together. Gold, silver, uranium and the other heavy elements can only form in a supernova explosion. A supernova can shine as brightly as an entire galaxy, but only for a short time, as shown in Figure 26.3.

![Figure 26.3](http://www.ck12.org/book/CK-12-Astrophysics-Concepts-and-Applications/content/media/image26.png)

**Neutron Stars and Black Holes**

After a supernova explosion, the star’s core is left over. This material is extremely dense. If the core is less than about four times the mass of the Sun, the star will become a neutron star. A *neutron star* is shown in Figure 26.4. This type of star is made almost entirely of neutrons. A neutron star has more mass than the Sun, yet it is only a few kilometers in diameter.

If the core remaining after a supernova is more than about 5 times the mass of the Sun, the core collapses to become a *black hole*. Black holes are so dense that not even light can escape their gravity. For that reason, we can’t see black holes. How can we know something exists if radiation can’t escape it? We know a black hole is there by the effect that it has on objects around it. Also, some radiation leaks out around its edges. A black hole isn’t a hole at all. It is the tremendously dense core of a supermassive star.
Measuring Star Distances

Astronomers use light years as the unit to describe distances in space. Remember that a light year is the distance light travels in one year.

How do astronomers measure the distance to stars? For stars that are close to us, they measure shifts in their position over time. This is called parallax. For distant stars, they use the stars’ brightness. For example, if a star is like the Sun, it should be about as bright as the Sun. They then figure out the star’s distance from Earth by measuring how much less bright it is than expected.

Star Systems

Our solar system has only one star. But many stars are in systems of two or more stars. Two stars that orbit each other are called a binary star system. If more than two stars orbit each other, it is called a multiple star system. Figure 26.5 shows two binary star systems orbiting each other. This creates an unusual quadruple star system.

Lesson Summary

- A star generates energy by nuclear fusion reactions in its core.
- The color of a star is determined by its surface temperature.
- Stars are classified by color and temperature. The most common system uses the letters O (blue), B (blue-white), A (white), F (yellow-white), G (yellow), K (orange), and M (red), from hottest to coolest.
- Stars form from clouds of gas and dust called nebulae. Nebulas collapse until nuclear fusion starts.
• Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
• Sun-like stars expand into red giants, and then fade out as white dwarf stars.
• Very massive stars expand into red supergiants, explode in supernovas, then end up as neutron stars or black holes.
• Star distances can be measured in a number of creative ways.
• Many stars orbit another star to form a binary system. More than two stars may also orbit each other.

Lesson Review Questions

Recall

1. What is nuclear fusion?
2. What do the colors of stars mean?
3. What is a black hole? Why is it called that?
4. What is a binary star system?

Apply Concepts

5. Where are the stars in a constellation located relative to each other? Are they always near each other? Are they always far from each other?
6. What does a particle accelerator do? Why is it an important tool for astronomers?

Think Critically

7. Beginning with hydrogen how do the chemical elements form? You can think of them in groups.
8. Describe the Sun’s life from its beginning to its eventual end.
9. How do astronomers know how stars form? What evidence do they have?

**Points to Consider**

- Although stars in constellations appear to be close together, they are usually not close together out in space. Can you think of any groups of astronomical objects that are relatively close together in space?
- Most nebulae contain more mass than a single star. If a large nebula collapsed into several different stars, what would the result be like?
26.2 Galaxies

Lesson Objectives

• Identify different types of galaxies.
• Describe our own galaxy, the Milky Way Galaxy.

Vocabulary

• elliptical galaxy
• galaxy
• globular cluster
• irregular galaxy
• Milky Way Galaxy
• open cluster
• spiral arm
• spiral galaxy
• star cluster

Introduction

Compared to Earth, the solar system is a big place. But galaxies are bigger - a lot bigger. A galaxy is a very large group of stars held together by gravity. How enormous a galaxy is and how many stars it contains are impossible for us to really understand. A galaxy contains up to a few billion stars! Our solar system is in the Milky Way Galaxy. It is so large that if our solar system were the size of your fist, the galaxy’s disk would be wider than the entire United States! There are several different types of galaxies, and there are billions of galaxies in the universe.

Star Clusters

Star clusters are groups of stars smaller than a galaxy. There are two main types, open clusters and globular clusters. Open clusters are groups of up to a few thousand stars held together by gravity. The Jewel Box, shown in Figure 26.6, is an open cluster. Open clusters tend to be blue in color, and often contain glowing gas and dust. The stars in an open cluster are young stars that all formed from the same nebula.

Globular clusters are groups of tens to hundreds of thousands of stars held tightly together by gravity. Globular clusters have a definite, spherical shape. They contain mostly old, reddish stars. Near the center of a globular cluster, the stars are closer together. Figure 26.7 shows a globular cluster. The heart of the globular cluster M13 has hundreds of thousands of stars. M13 is 145 light years in diameter. The cluster contains red and blue giant stars.
FIGURE 26.6
These hot blue stars are in an open cluster known as the Jewel Box. The red star is a young red supergiant.

FIGURE 26.7
The globular cluster, M13, contains red and blue giant stars.

Types of Galaxies

The biggest groups of stars are called galaxies. A few million to many billions of stars may make up a galaxy. With the unaided eye, every star you can see is part of the Milky Way Galaxy. All the other galaxies are extremely far away. The closest spiral galaxy, the Andromeda Galaxy, shown in Figure 26.8, is 2,500,000 light years away and contains one trillion stars!

Spiral Galaxies

Galaxies are divided into three types, according to shape. There are spiral galaxies, elliptical galaxies, and irregular galaxies. Spiral galaxies are a rotating disk of stars and dust. In the center is a dense bulge of material. Several
arms spiral out from the center. Spiral galaxies have lots of gas and dust and many young stars. Figure 26.9 shows a spiral galaxy from the side. You can see the disk and central bulge.

Elliptical Galaxies

Figure 26.10 shows a typical elliptical galaxy. Elliptical galaxies are oval in shape. The smallest are called dwarf elliptical galaxies. Look back at the image of the Andromeda Galaxy. It has two dwarf elliptical galaxies as its companions. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

Giant elliptical galaxies contain over a trillion stars. Elliptical galaxies are red to yellow in color because they contain mostly old stars. Most contain very little gas and dust because the material has already formed into stars.
Irregular Galaxies

Look at the galaxy in Figure 26.11. Do you think this is a spiral galaxy or an elliptical galaxy? It doesn’t look like either! If a galaxy is not spiral or elliptical, it is an **irregular galaxy**. Most irregular galaxies have been deformed. This can occur either by the pull of a larger galaxy or by a collision with another galaxy.

The Milky Way Galaxy

If you get away from city lights and look up in the sky on a very clear night, you will see something spectacular. A band of milky light stretches across the sky, as in Figure 26.12. This band is the disk of the **Milky Way Galaxy**. This is the galaxy where we all live. The Milky Way Galaxy looks different to us than other galaxies because our view is from inside of it!

Shape and Size

The Milky Way Galaxy is a spiral galaxy that contains about 400 billion stars. Like other spiral galaxies, it has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across. It is about 3,000 light years thick. Most of the galaxy’s gas, dust, young stars, and open clusters are in the disk. Some astronomers think that there is a gigantic black hole at the center of the galaxy. Figure 26.13 shows what the Milky Way probably looks like from the outside.

Our solar system is within one of the spiral arms. Most of the stars we see in the sky are relatively nearby stars that are also in this spiral arm. We are a little more than halfway out from the center of the Galaxy to the edge, as shown in Figure 26.13.

Our solar system orbits the center of the galaxy as the galaxy spins. One orbit of the solar system takes about 225 to 250 million years. The solar system has orbited 20 to 25 times since it formed 4.6 billion years ago.
Lesson Summary

- Open clusters are groups of young stars loosely held together by gravity.
- Globular clusters are spherical groups of old stars held tightly together by gravity.
- Galaxies are collections of millions to many billions of stars.
- Spiral galaxies have a rotating disk of stars and dust, a bulge in the middle, and several arms spiraling out from the center. The disk and arms contain many young, blue stars.
- Typical elliptical galaxies are oval shaped, red or yellow, and contain mostly old stars.
- A galaxy that is not elliptical or spiral is an irregular galaxy. These galaxies were deformed by other galaxies.
- The band of light called the Milky Way is the disk of our galaxy, the Milky Way Galaxy, which is a typical spiral galaxy.
Our solar system is in a spiral arm of the Milky Way Galaxy, a little more than halfway from the center to the edge of the disk. Most of the stars we see are in our spiral arm.

**Lesson Review Questions**

**Recall**

1. What is the difference between a globular cluster and an open cluster?
2. What are the features of a spiral galaxy?
3. What are the features of an elliptical galaxy?

**Apply Concepts**

4. Where in the Milky Way galaxy is Earth?
5. How do irregular galaxies become irregular? Why do astronomers think that?

**Think Critically**

6. How do astronomers know that we live in a spiral galaxy if we’re inside it?
7. How can astronomers tell the age of a galaxy?
Points to Consider

• Objects in the universe tend to be grouped together. What might cause them to form and stay in groups?
• Can you think of anything that is bigger than a galaxy?
Lesson Objectives

- Explain the evidence for an expanding universe.
- Describe the formation of the universe according to the Big Bang Theory.
- Define dark matter and dark energy.

Vocabulary

- Big Bang Theory
- dark energy
- dark matter
- universe

Introduction

The universe contains all the matter and energy that exists and all of space and time. We are always learning more about the universe. In the early 20th century, Edwin Hubble used powerful telescopes to show that some distant specks of light seen through telescopes are actually other galaxies. (Figure 26.14) Hubble discovered that the Andromeda Nebula is over 2 million light years away. This is many times farther than the farthest distances we had measured before. He realized that galaxies were collections of millions or billions of stars. Hubble also measured the distances to hundreds of galaxies. Today, we know that the universe contains about a hundred billion galaxies.

FIGURE 26.14
Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California.
26.3 The Universe

Hubble measured the distances to galaxies. He also studied the motions of galaxies. In doing these things, Hubble noticed a relationship. This is now called Hubble’s Law: The farther away a galaxy is, the faster it is moving away from us. There was only one conclusion he could draw from this. The universe is expanding!

Figure 26.15 shows a simple diagram of the expanding universe. Imagine a balloon covered with tiny dots. When you blow up the balloon, the rubber stretches. The dots slowly move away from each other as the space between them increases. In an expanding universe, the space between galaxies is expanding. We see this as the other galaxies moving away from us. We also see that galaxies farther away from us move away faster than nearby galaxies.

![Figure 26.15](image)

**FIGURE 26.15**
This is a simplified diagram of the expansion of the universe. The distance between galaxies gets bigger, but the size of each galaxy stays about the same.

The Big Bang Theory

About 13.7 billion years ago, the entire universe was packed together. Everything was squeezed into a tiny volume. Then there was an enormous explosion. After this “big bang,” the universe expanded rapidly (Figure 26.16). All of the matter and energy in the universe has been expanding ever since. Scientists have evidence this is how the universe formed. One piece of evidence is that we see galaxies moving away from us. If they are moving apart, they must once have been together. Also, there is energy left over from this explosion throughout the universe. The theory for the origin of the universe is called the **Big Bang Theory**.

After the Big Bang

In the first few moments after the Big Bang, the universe was extremely hot and dense. As the universe expanded, it became less dense. It began to cool. First protons, neutrons, and electrons formed. From these particles came hydrogen. Nuclear fusion created helium atoms. Some parts of the universe had matter that was densely packed.
Enormous clumps of matter were held together by gravity. Eventually this material became the gas clouds, stars, galaxies, and other structures that we see in the universe today.

**Dark Matter**

We see many objects out in space that emit light. This matter is contained in stars, and the stars are contained in galaxies. Scientists think that stars and galaxies make up only a small part of the matter in the universe. The rest of the matter is called **dark matter**.

Dark matter doesn’t emit light, so we can’t see it. We know it is there because it affects the motion of objects around it. For example, astronomers measure how spiral galaxies rotate. The outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot more matter in the galaxy than we can see.

What is dark matter? Actually, we don’t really know. Dark matter could just be ordinary matter, like what makes up Earth. The universe could contain lots of objects that don’t have enough mass to glow on their own. There might just be a lot of black holes. Another possibility is that the universe contains a lot of matter that is different from anything we know. If it doesn’t interact much with ordinary matter, it would be very difficult or impossible to detect directly.

Most scientists who study dark matter think it is a combination. Ordinary matter is part of it. That is mixed with some kind of matter that we haven’t discovered yet. Most scientists think that ordinary matter is less than half of the total matter in the universe.

**Dark Energy**

We know that the universe is expanding. Astronomers have wondered if it is expanding fast enough to escape the pull of gravity. Would the universe just expand forever? If it could not escape the pull of gravity, would it someday
start to contract? This means it would eventually get squeezed together in a big crunch. This is the opposite of the Big Bang.

Scientists may now have an answer. Recently, astronomers have discovered that the universe is expanding even faster than before. What is causing the expansion to accelerate? One hypothesis is that there is energy out in the universe that we can’t see. Astronomers call this **dark energy**. We know even less about dark energy than we know about dark matter. Some scientists think that dark energy makes up more than half of the universe.

### Lesson Summary

- The universe contains all matter and all energy as well as all of space and time.
- We can see that galaxies are moving away from us which tells us that the universe is expanding.
- In the past the universe was squeezed into a very small volume.
- The Big Bang theory proposes that the universe formed in an enormous explosion about 13.7 billion years ago.
- Recent evidence shows that there is a lot of matter in the universe that we cannot see. This matter is called dark matter.
- The rate of the expansion of the universe is increasing. The cause of this increase is unknown; one possible explanation involves a new form of energy called dark energy.

### Lesson Review Questions

**Recall**

1. What is Hubble’s law?
2. How old is the universe?
3. What is dark matter?
4. What is dark energy?

**Apply Concepts**

5. Describe the Big Bang theory.
6. Why do scientists think that dark matter exists?

**Think Critically**

7. How do you think scientists can calculate the age of the universe?
8. How is the Big Bang theory different from other explanations of how the universe came to be?

### Points to Consider

- In what ways is an expanding balloon a good model of the universe, and in what ways is it incorrect? Can you think of a different way to model the expansion of the universe?
• The Big Bang theory is currently the most widely accepted scientific theory for how the universe formed. What is another explanation of how the universe could have formed? Is your explanation one that a scientist would accept?

For Table 26.1, from top to bottom,

• Windows to the Universe. http://www.windows2universe.org/the_universe/Arcturus.html&edu=high. The copyright holder of this file allows anyone to use it for any purpose, provided that Windows to the Universe be referenced and/or linked to.
26.4 References

1. Zachary Wilson. CK-12 Foundation. CC BY-NC 3.0
6. European Southern Observatory (ESO). http://commons.wikimedia.org/wiki/File:A_Snapshot_of_the_Jewel_Box_cluster_with_the_ESO_VLT.jpg. CC BY 3.0
10. Chris Mihos (Case Western Reserve University)/European Southern Observatory (ESO). http://commons.wikimedia.org/wiki/File:ESO-M87.jpg. CC BY 3.0
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