Beyond the Solar System

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CHAPTER 1 Beyond the Solar System

CHAPTER OUTLINE

Introduction

To infinity and beyond!

Astronomy has advanced by leaps and bounds in the past few decades. Tools like the Hubble Space Telescope have allowed astronomers to see and understand things that they'd never even dreamed of. As recently as a century ago, no one knew that there was anything out there beyond our galaxy. Now we can see fantastic images of pinwheels, sombreros, towers, and many other shapes. In this chapter we will explore a tiny bit of what is beyond our solar system and even beyond our galaxy. The questions asked by the scientists who study these features are often profound: How did the universe begin? How will it end? Are we alone?

1.1 Star Constellations

- Define constellation.
- Explain the difference between apparent and real distances.

How did astrology come to be?

Ancient Babylonian astronomers created the Zodiac, a circle that divides the ecliptic into twelve 30-degree zones. Each zone contains a constellation, many of them animals. Horoscopes based on these astrological signs first appeared in Ptolemaic Egypt in around 50 BC. These early people used astrology to explain things that are now much better explained by science.

Stars

When you look at the sky on a clear night, you can see dozens, perhaps even hundreds, of tiny points of light. Almost every one of these points of light is a **star**, a giant ball of glowing gas at a very, very high temperature. Stars differ in size, temperature, and age, but they all appear to be made up of the same elements and to behave according to the same principles.

Constellations

People of many different cultures, including the Greeks, identified patterns of stars in the sky. We call these patterns **constellations**. **Figure** 1.1 shows one of the most easily recognized constellations.

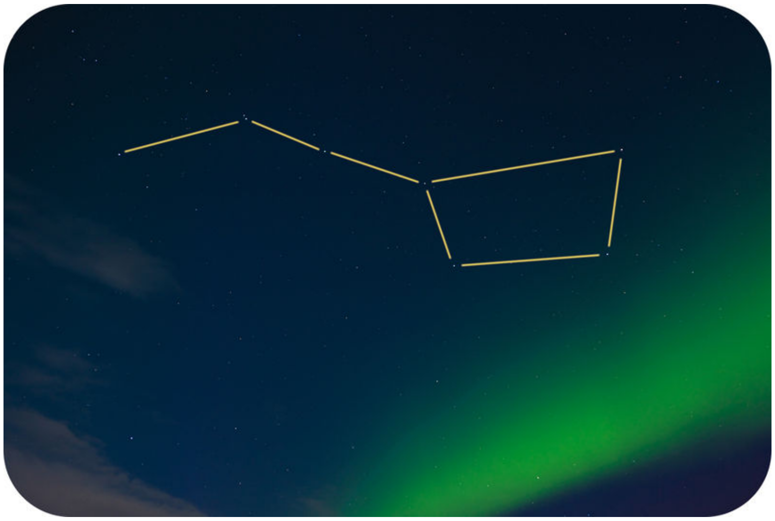


FIGURE 1.1
In this image the Big Dipper is outlined and shown next to the Aurora borealis near Fairbanks, Alaska.

Why do the patterns in constellations and in groups or clusters of stars, called **asterisms**, stay the same night after night? Although the stars move across the sky, they stay in the same patterns. This is because the apparent nightly motion of the stars is actually caused by the rotation of Earth on its axis. The patterns also shift in the sky with the seasons as Earth revolves around the Sun. As a result, people in a particular location can see different constellations in the winter than in the summer. For example, in the Northern Hemisphere Orion is a prominent constellation in the winter sky, but not in the summer sky. This is the annual traverse of the constellations.

Apparent Versus Real Distances

Although the stars in a constellation appear close together as we see them in our night sky, they are not at all close together out in space. In the constellation Orion, the stars visible to the naked eye are at distances ranging from just 26 light-years (which is relatively close to Earth) to several thousand light-years away.

Astrology

There is no reason to think that the alignment of the stars has anything to do with events that happen on Earth. The constellations were defined by people who noticed that patterns could be made from stars, but the patterns do not reflect any characteristics of the stars themselves. When scientific tests are done to provide evidence in support of astrological ideas, the tests fail. When a scientific idea fails, it is abandoned or modified. Astrologers do not change or abandon their ideas.

Summary

- The points of light in the night sky are stars that are balls of gas undergoing nuclear fusion.
- Constellations are patterns of stars that are usually not near each other but are the result of chance.
- Stars in a constellation may be fairly close together, but are more likely extremely far apart.

Practice

Use these resources to answer the questions that follow.

http://www.windows2universe.org/the_universe/Constellations/constnavi.html

1. Are constellations an astronomical phenomenon; for example, did they form from the same event in the same part of space? Explain your answer.
2. Why were planets, the moon and comets recognized as being different from stars?
3. What are the two groups of constellations? Define each.

http://www.windows2universe.org/the_universe/Constellations/circumpolar.html

1. List some of the constellations that are always visible in the Northern Hemisphere.
2. Why is Ursa Major unique?

Practice Answers

- Constellations

1. Constellations are stars that appear close together from Earth but they may be very far from each other in space.
2. Those objects moved past the constellations, but did not move with them so they were recognized as being different.
3. Some constellations never rise or set and they are called circumpolar. Some do rise and set and they are seasonal.

- Northern Hemisphere Constellations

1. Auriga, Camelopardalis, Cassiopeia, Cephus, Draco, Lynx, Perseus,Ursa Major and Ursa Minor.
2. Ursa major is full of unique celestial objects like pointer stars.

Review

1. Why do the constellations appear in the same patterns all the time?
2. Are constellations useful?
3. What is astrology? How is it different from astronomy?

Review Answers

1. The stars are so far away that any difference in position is not visible from Earth.
2. Constellations help people to locate objects in the sky. They can help people locate themselves.
3. Astrology is a system constructed by the ancients to explain phenomena that are now much better explained by science. Astronomy is the science that studies the stars and other real phenomena in space.

1.2 Star Power

- Describe nuclear fusion and explain its relationship to the shining of stars.

What's Marilyn Monroe doing in a science book?

Marilyn Monroe was a famous movie star, even a superstar. Movie stars shine brightly —and in some cases, as with Marilyn, die young. Stars also shine brightly, then die. Their power, like that of an atom bomb, comes from nuclear fusion.

Star Power

The Sun is Earth's major source of energy, yet the planet only receives a small portion of its energy. The Sun is just an ordinary star. Many stars produce much more energy than the Sun. The energy source for all stars is nuclear fusion.

Nuclear Fusion

Stars are made mostly of hydrogen and helium, which are packed so densely in a star that in the star's center the pressure is great enough to initiate nuclear fusion reactions. In a **nuclear fusion reaction**, the nuclei of two atoms combine to create a new atom. Most commonly, in the core of a star, two hydrogen atoms fuse to become a helium atom. Although nuclear fusion reactions require a lot of energy to get started, once they are going they produce enormous amounts of energy (**Figure** 1.2).

FIGURE 1.2
A thermonuclear bomb is an uncontrolled fusion reaction in which enormous amounts of energy are released.

In a star, the energy from fusion reactions in the core pushes outward to balance the inward pull of gravity. This energy moves outward through the layers of the star until it finally reaches the star's outer surface. The outer layer of the star glows brightly, sending the energy out into space as electromagnetic radiation, including visible light, heat, ultraviolet light, and radio waves (**Figure** 1.3).

Particle Accelerators

In particle accelerators, subatomic particles are propelled until they have attained almost the same amount of energy as found in the core of a star (**Figure** 1.4). When these particles collide head-on, new particles are created. This process simulates the nuclear fusion that takes place in the cores of stars. The process also simulates the conditions

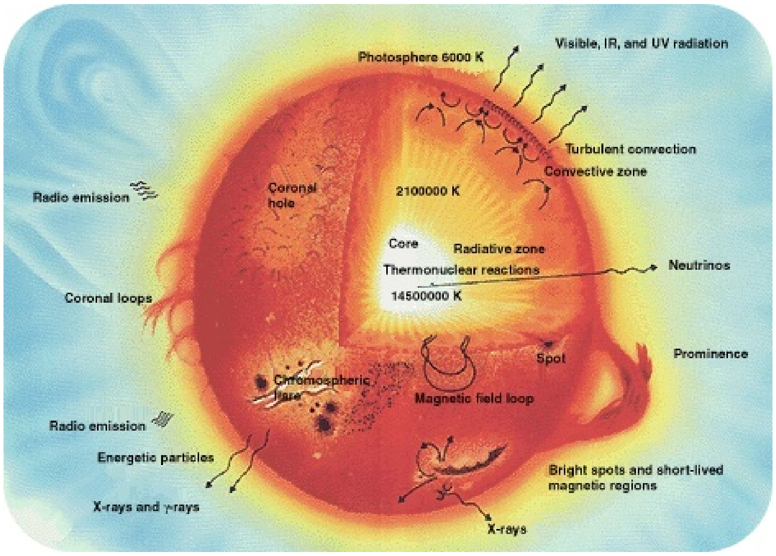
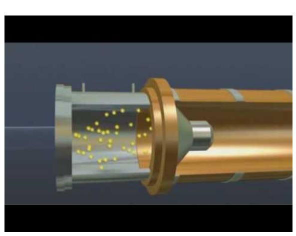


FIGURE 1.3
A diagram of a star like the Sun.

that allowed for the first helium atom to be produced from the collision of two hydrogen atoms in the first few minutes of the universe.

FIGURE 1.4
The SLAC National Accelerator Lab in California can propel particles a straight 2 mi (3.2 km).

The CERN Particle Accelerator presented in this video is the world's largest and most powerful particle accelerator. The accelerator can boost subatomic particles to energy levels that simulate conditions in the stars and in the early history of the universe before stars formed: http://www.youtube.com/watch?v=sxAxV7g3yf8 (6:16).



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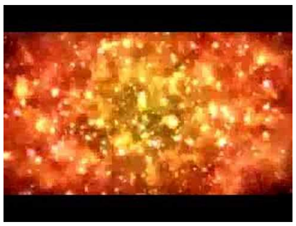
Summary

- In a nuclear fusion reaction, two nuclei combine to form a larger nucleus.
- The energy from fusion reactions keeps the star from collapsing from its own gravity.
- Particle accelerators simulate reactions at the cores of stars.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=uKqvjEE0wFg



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1. What are stars made up of at the beginning?
2. What happens during hydrogen fusion? What does this release?
3. What occurs when the star runs out of hydrogen?
4. How does it make heavier elements from helium? What are these elements the building blocks of?
5. What is the last element created in a star? Why?
6. When does a star die?
7. What does a supernova create?

Practice Answers

1. Stars are made of hydrogen and helium mostly.
2. Hydrogen fuses into helium, which releases a tremendous amount of energy.
3. Then it begins to fuse helium into heavier elements.
4. The star contracts and gets hotter. Three helium atoms can come together and create carbon; four helium atoms will make oxygen. These elements are the building blocks of life.
5. The last element is iron; there is nothing more it can fuse, there is no more fuel. Iron can't fuel the stellar furnace.
6. It builds up too much iron and then collapses and then explodes into a supernova.
7. All this energy overcomes the iron barrier; it cooks atoms into all the other elements on the periodic table.

Review

1. What type of fusion reaction takes place in most stars?
2. What do scientists learn from particle accelerators?
3. Why don't stars collapse on themselves?

Review Answers

1. Hydrogen fuses into helium.

2. subatomic particles are propelled so that they collide had on and create new particles. This replicates what goes on in the cores of stars and also what happened in the first few minutes of the universe.
3. The energy of fusion pushes outward to balance the inward pull of gravity.

1.3 Star Classification

- Describe how scientists classify stars.
- Explain the relationship between the color of a star and its temperature.

Why are the stars in Orion's Belt different colors?

The ancient Greeks thought this group of stars looked like a hunter, so they named it Orion after their mythical hunter. The line of three stars at the center is "Orion's Belt." The many different colors of stars reflect the star's temperature. The bright, red star in the upper left (with an arrow pointing to it), named Betelgeuse (pronounced BET-ul-juice), is not as hot than the blue star in the lower right, named Rigel.

Color and Temperature

Think about how the color of a piece of metal changes with temperature. A coil of an electric stove will start out black, but with added heat will start to glow a dull red. With more heat, the coil turns a brighter red, then orange. At extremely high temperatures the coil will turn yellow-white, or even blue-white (it's hard to imagine a stove coil getting that hot). A star's color is also determined by the temperature of the star's surface. Relatively cool stars are red, warmer stars are orange or yellow, and extremely hot stars are blue or blue-white (**Figure** 1.5).

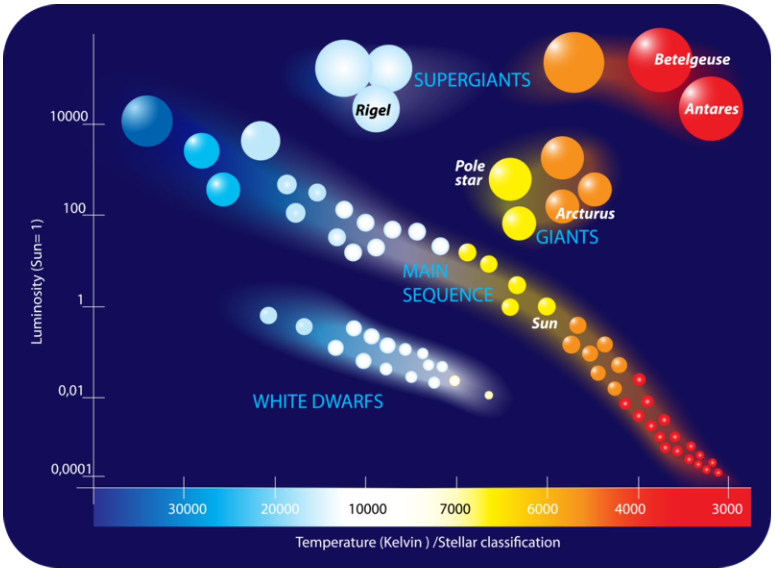

FIGURE 1.5

A Hertzsprung-Russell diagram shows the brightness and color of main sequence stars. The brightness is indicated by luminosity and is higher up the y-axis. The temperature is given in degrees Kelvin and is higher on the left side of the x-axis. How does our Sun fare in terms of brightness and color compared with other stars?

Classifying Stars by Color

Color is the most common way to classify stars. **Table** 1.1 shows the classification system. The class of a star is given by a letter. Each letter corresponds to a color, and also to a range of temperatures. Note that these letters don't match the color names; they are left over from an older system that is no longer used.

TABLE 1.1: Classification of Stars By Color and Temperature

Class	Color	Temperature Range	Sample Star
O	Blue	30,000 K or more	Zeta Ophiuchi
B	Blue-white	10,000–30,000 K	Rigel
A	White	7,500–10,000 K	Altair
F	Yellowish-white	6,000–7,500 K	Procyon A
G	Yellow	5,500–6,000 K	Sun
K	Orange	3,500–5,000 K	Epsilon Indi
M	Red	2,000–3,500 K	Betelgeuse, Proxima Centauri

For most stars, surface temperature is also related to size. Bigger stars produce more energy, so their surfaces are hotter.

Summary

- Stars are classified by color, which correlates with temperature.
- A Hertzsprung-Russell diagram is used to learn about the characteristics of a star.
- Red stars are the coolest and blue are the hottest in a continuum ranging from 2000 K to more than 30,000 K.

Practice

Use this resource to answer the questions that follow.

http://www.enchantedlearning.com/subjects/astronomy/stars/startypes.shtml

1. How are stars classified?
2. What is the Hertzsprung - Russell diagram?
3. What category are most stars in? What do stars in that category do?
4. What is our star? Be specific.
5. Define luminosity.
6. What is the Yerkes classification scheme?
7. Describe main sequence stars.
8. Explain the difference between a red and blue giant star.
9. What is a a white dwarf?
10. What is a brown dwarf?

Practice Answers

1. Stars are classified by their spectra and their temperature; there are seven main types of stars.
2. The H-R diagram is a graph that plots star color (spectral type or surface temperature) versus luminosity (intrinsic brightness or absolute magnitude).
3. Most stars are main sequence stars that fuse hydrogen into helium.
4. Our star is a smaller star on the main sequence. It is a G type star.
5. Luminosity is the total brightness of a star; it is the total amount of energy the star radiates each second.
6. In this scheme, stars are assigned to groups according to the width of their spectral lines.
7. Main sequence stars fuse hydrogen into helium, about 90% of stars are main sequence stars.
8. A red dwarf is an fairly old star that is cool and small. It is on the main sequence. A blue giant is older, but it is huge, very hot and blue. It burns helium so is not on the main sequence.
9. A white dwarf is small, but very dense. it is very hot and made mostly of carbon. They are what is left after a red giant loses its outer layers. they are very dense.
10. A brown dwarf is a star with a small mass so it is too small for fusion. It is not very luminous.

Review

1. What information is contained in a Hertzsprung-Russell diagram?
2. What is the order of star colors from coolest to hottest? How is that related to size?
3. Why do stars that are different colors appear in the same constellation?

Review Answers

1. The H-R diagram indicates brightness and color of stars on the main sequence. The luminosity and temperature are on the y and x axes.
2. red, orange, yellow, yellowish-white, white, blue-white, blue

3. Stars in a constellation are often not related to each other so they are different stars at different stages of their lives.

1.4 Life Cycles of Stars

- Describe the main stages in the life cycle of stars, including formation and main sequence.
- Describe the differences in the life cycles of different types of stars.
- Explain the relationship between a star's life cycle and its size.

What changes do stars undergo in their lifetimes?

Stars have a life cycle, just like people: they are born, grow, change over time, and eventually grow old and die. Most stars change in size, color, and class at least once in their lifetime. What astronomers know about the life cycles of stars is because of data gathered from visual, radio, and X-ray telescopes.

Star Formation

As discussed in the chapter The Solar System, stars are born in clouds of gas and dust called nebulas, like the one shown in **Figure** 1.6.

For more on star formation, check out http://www.spacetelescope.org/science/formation_of_stars.html and http://hurricanes.nasa.gov/universe/science/stars.html .

The Main Sequence

For most of a star's life, nuclear fusion in the core produces helium from hydrogen. A star in this stage is a **main sequence star**. This term comes from the Hertzsprung-Russell diagram shown in the **Figure** 1.7. For stars on the main sequence, temperature is directly related to brightness. A star is on the main sequence as long as it is able to balance the inward force of gravity with the outward force of nuclear fusion in its core. The more massive a star, the more it must burn hydrogen fuel to prevent gravitational collapse. Because they burn more fuel, more massive stars have higher temperatures. Massive stars also run out of hydrogen sooner than smaller stars do.

Our Sun has been a main sequence star for about 5 billion years and will continue on the main sequence for about 5 billion more years (**Figure** 1.8). Very large stars may be on the main sequence for only 10 million years. Very small stars may last tens to hundreds of billions of years.

The fate of the Sun and inner planets is explored in this video: http://www.space.com/common/media/video/player.php?videoRef=mm32_SunDeath .

Red Giants and White Dwarfs

As a star begins to use up its hydrogen, it fuses helium atoms together into heavier atoms such as carbon. A blue giant star has exhausted its hydrogen fuel and is in a transitional phase. When the light elements are mostly used

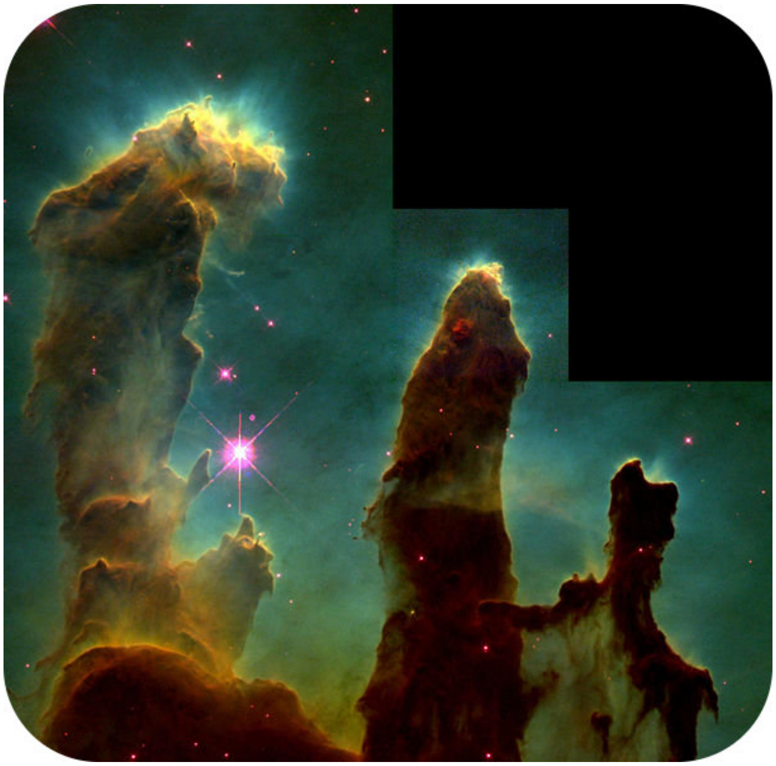

FIGURE 1.6
The Pillars of Creation within the Eagle Nebula are where gas and dust come together as a stellar nursery.

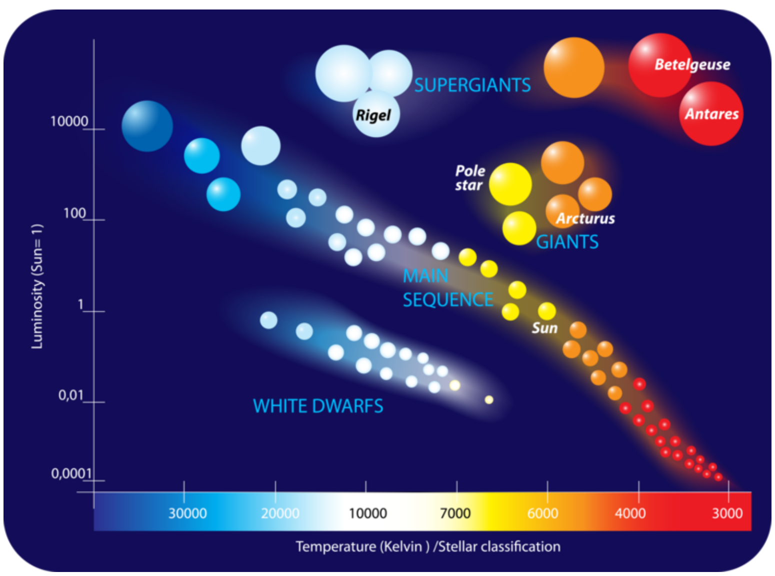

FIGURE 1.7
Hertzsprung-Russel diagram.

up, the star can no longer resist gravity and starts to collapse inward. The outer layers of the star grow outward and cool. The larger, cooler star turns red in color and so is called a **red giant**.

Eventually, a red giant burns up all of the helium in its core. What happens next depends on how massive the star is. A typical star, such as the Sun, stops fusion completely. Gravitational collapse shrinks the star's core to a white, glowing object about the size of Earth, called a **white dwarf** (**Figure** 1.9). A white dwarf will ultimately fade out.

FIGURE 1.8
Our Sun is a medium-sized star in about the middle of its main sequence life.

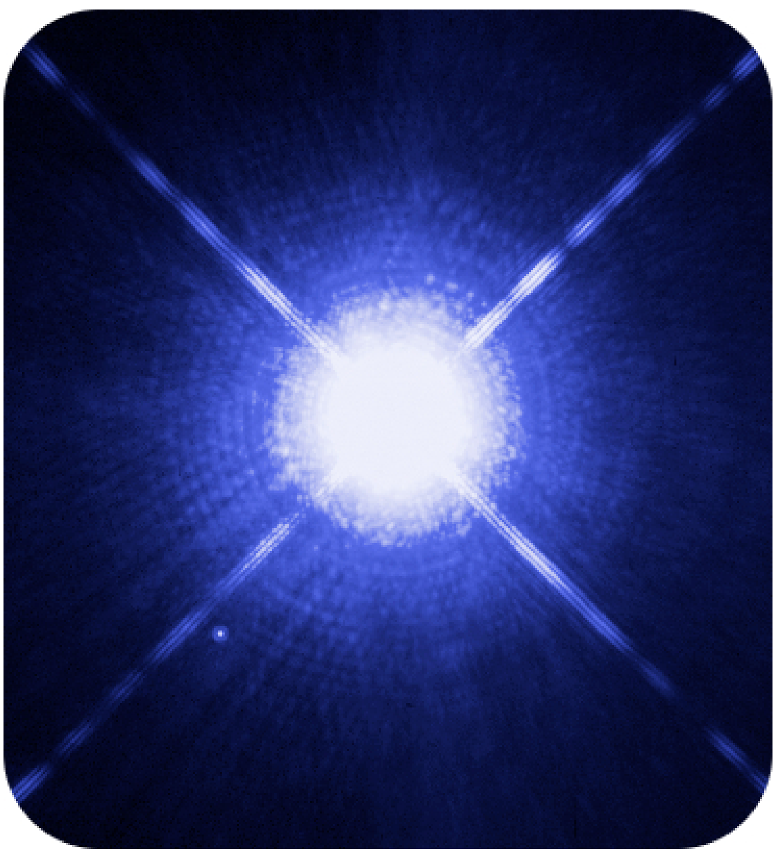

FIGURE 1.9
Sirius, the brightest star in the sky, is actually a binary star system. Sirius A is on the main sequence. Sirius B, the tiny dot on the lower left, is a white dwarf.

Supergiants and Supernovas

A star that runs out of helium will end its life much more dramatically. When very massive stars leave the main sequence, they become red supergiants (**Figure** 1.10).

FIGURE 1.10
The red star Betelgeuse in Orion is a red supergiant.

Unlike a red giant, when all the helium in a red supergiant is gone, fusion continues. Lighter atoms fuse into heavier atoms up to iron atoms. Creating elements heavier than iron through fusion uses more energy than it produces, so stars do not ordinarily form any heavier elements. When there are no more elements for the star to fuse, the core succumbs to gravity and collapses, creating a violent explosion called a **supernova** (**Figure** 1.11). A supernova explosion contains so much energy that atoms can fuse together to produce heavier elements such as gold, silver, and uranium. A supernova can shine as brightly as an entire galaxy for a short time. All elements with an atomic number greater than that of lithium were formed by nuclear fusion in stars.

An animation of the Crab Supernova is seen here: http://www.youtube.com/watch?v=0J8srN24pSQ .

Neutron Stars

After a supernova explosion, the leftover material in the core is extremely dense. If the core is less than about four times the mass of the Sun, the star becomes a **neutron star** (**Figure** 1.12). A neutron star is more massive than the Sun, but only a few kilometers in diameter. A neutron star is made almost entirely of neutrons, relatively large particles that have no electrical charge.

Black Hole

If the core remaining after a supernova is more than about five times the mass of the Sun, the core collapses into a **black hole**. Black holes are so dense that not even light can escape their gravity. With no light, a black hole cannot be observed directly. But a black hole can be identified by the effect that it has on objects around it, and by radiation that leaks out around its edges.

How to make a black hole: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop .

A video about black holes is seen on Space.com: http://www.space.com/common/media/video/player.php?videoRef=black_holes .

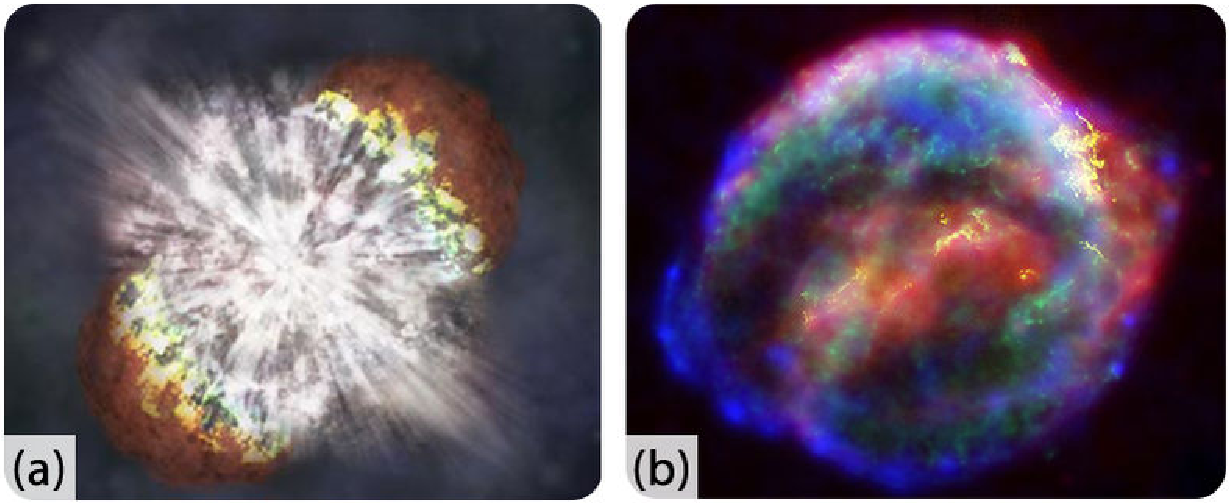

FIGURE 1.11

(a) NASA's Chandra X-ray observatory captured the brightest stellar explosion so far, 100 times more energetic than a typical supernova. (b) This false-color image of the supernova remnant SN 1604 was observed as a supernova in the Milky Way galaxy. At its peak it was brighter than all other stars and planets, except Venus, in the night sky.

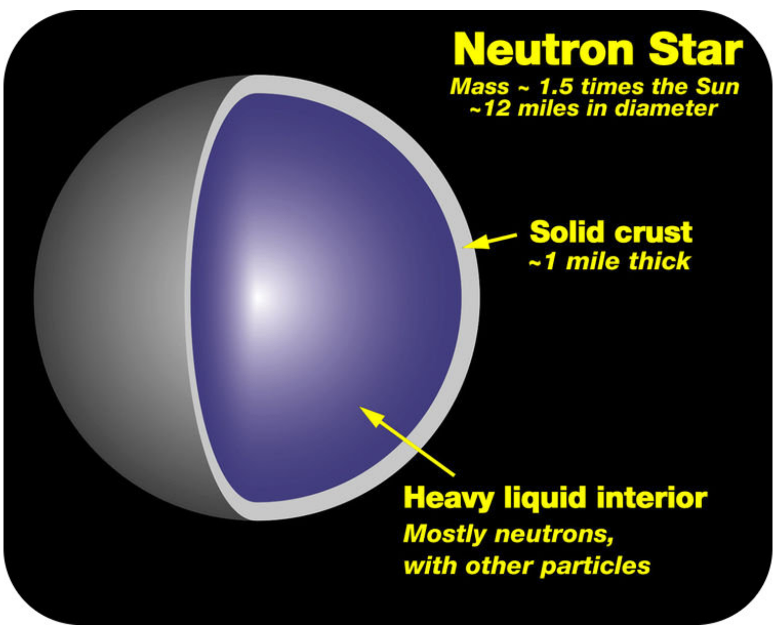

FIGURE 1.12

After a supernova, the remaining core may end up as a neutron star.

A Star's Life Cycle video from Discovery Channel describes how stars are born, age and die **(2f)**: http://www.youtube.com/watch?v=H8Jz6FU5D1A (3:11).

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A video of neutron stars is available at: http://www.youtube.com/watch?v=VMnLVkV_ovc (4:24).

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URL: http://gamma.ck12.org/flx/render/embeddedobject/1490

Summary

- Stars spend most of their lives on the main sequence, fusing hydrogen into helium for energy.
- As stars burn up their hydrogen and fuse helium into larger atoms they begin to collapse and become red giants. When the helium is gone they become white dwarfs.
- When a massive star has no more elements left to fuse it explodes as a supernova, from which the chemical elements heavier than lithium form.
- An extremely massive core will collapse after a supernova explosion to become a black hole, which is black because no light can escape it.

Making Connections

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Practice

Use this resource to answer the questions that follow.

http://www.odec.ca/projects/2002/wongj/public_html/animations.html

1. What is the birthplace of stars? What happens there?
2. Describe the main sequence star.
3. What causes a red giant to form?
4. Why does a red giant core collapse?
5. What does a red giant become?
6. What happens to a white dwarf?
7. What is the structure of high mass stars?

8. What happens as this star ages?
9. What do neon and magnesium fuse into?
10. How is an iron core produced?
11. What do high mass stars become?

Practice Answers

1. Stars are born in a nebula. Nebulae are low density clouds of interstellar dust and gas that provide material for the formation of young stars. Gravity pulls the material in and it collapses. This increases heat and the star ignites.
2. Most stars are main sequence stars; they fuse hydrogen into helium.
3. When the star runs out of hydrogen to fuse the outer layers expand in an attempt to conserve energy and a red giant forms.
4. A red giant collapses when it runs out of hydrogen for fusion.
5. It becomes a white dwarf.
6. A white dwarf is a low to medium mass star with super high density.
7. A high mass star has a helium core and a hydrogen shell.
8. Helium fuses into carbon and oxygen in the core. Carbon fuses into neon and magnesium.
9. Neon and magnesium fuse into oxygen.
10. The oxygen and magnesium core fuses into silicon and sulfur, which fuses into iron.
11. These high mass explode and become a supernova. After the explosion it becomes a neutron star or if it was really dense it becomes a black hole.

Review

1. Why do some stars become red giants and others become supernovae?
2. Why are supernovae crucial to the evolution of the universe?
3. How does a star become a black hole? What are the characteristics of a black hole?

Review Answers

1. Larger stars become supernovae than the stars that become red giants.
2. A supernova explosion releases so much energy that the elements heavier than iron form. If there were no supernova explosions these elements would not exist.
3. To be a black hole the star must be very massive. A black hole is so dense that not even light can escape.

1.5 Distance Between Stars

- Define parallax and explain how astronomers use parallax to measure distances to stars.

How far is that star?

How can you measure the distance of an object that is too far away to measure? What if you don't know the size of the object or the size or distance of any other objects like it? That is the problem facing astronomers when they try to measure the distances to stars.

Parallax

Distances to stars that are relatively close to us can be measured using **parallax**. Parallax is an apparent shift in position that takes place when the position of the observer changes.

To see an example of parallax, try holding your finger about 1 foot (30 cm) in front of your eyes. Now, while focusing on your finger, close one eye and then the other. Alternate back and forth between eyes, and pay attention to how your finger appears to move. The shift in position of your finger is an example of parallax. Now try moving your finger closer to your eyes, and repeat the experiment. Do you notice any difference? The closer your finger is to your eyes, the greater the position changes because of parallax.

As **Figure** 1.13 shows, astronomers use this same principle to measure the distance to stars. Instead of a finger, they focus on a star, and instead of switching back and forth between eyes, they switch between the biggest possible differences in observing position. To do this, an astronomer first looks at the star from one position and notes where the star is relative to more distant stars. Now where will the astronomer go to make an observation the greatest possible distance from the first observation? In six months, after Earth moves from one side of its orbit around the Sun to the other side, the astronomer looks at the star again. This time parallax causes the star to appear in a different position relative to more distant stars. From the size of this shift, astronomers can calculate the distance to the star.

For more about parallax, visit http://starchild.gsfc.nasa.gov/docs/StarChild/questions/parallax.html and http://imagine.gsfc.nasa.gov/YBA/HTCas-size/parallax1-more.html .

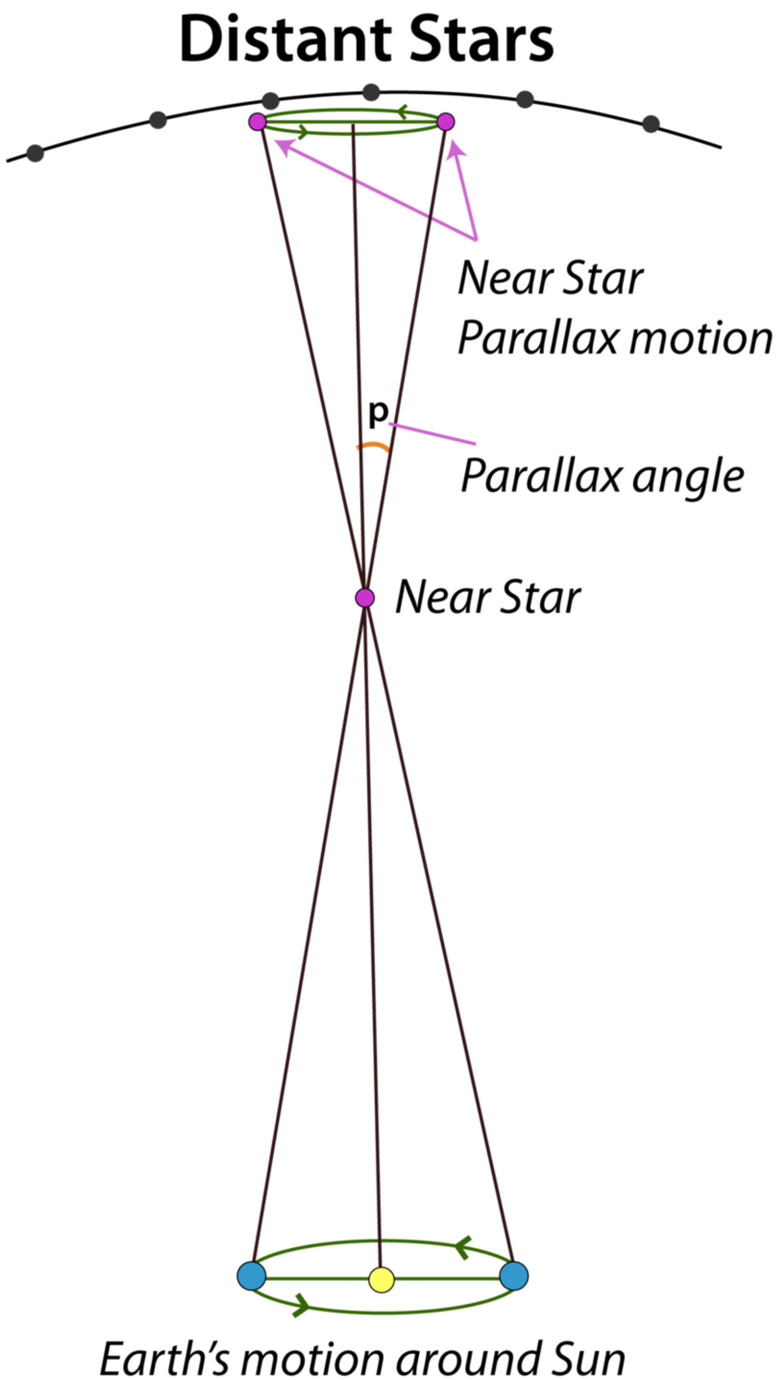


FIGURE 1.13
Parallax is used to measure the distance to stars that are relatively nearby.

A parallax exercise is seen here: http://www.astro.ubc.ca/~scharein/a311/Sim/new-parallax/Parallax.html .

Other Methods

Even with the most precise instruments available, parallax is too small to measure the distance to stars that are more than a few hundred light years away. For these more distant stars, astronomers must use more indirect methods of determining distance. Most of these methods involve determining how bright the star they are looking at really is. For example, if the star has properties similar to the Sun, then it should be about as bright as the Sun. The astronomer compares the observed brightness to the expected brightness.

Summary

- Parallax is the apparent shift in position of an object due to a change in the position of an observer.
- Parallax is useful for determining distances of stars that are a few hundred light years from Earth.
- Brightness is used to determine the distances of stars that are further away.

Practice

Use these resources to answer the questions that follow.

http://www.universetoday.com/47182/stellar-parallax/

1. What is parallax?
2. How can parallax be used to determine distances?
3. What is the farthest apart two locations on Earth's orbit can be? When can that happen?
4. What has produced the most accurate parallax measurements to date?
5. What will Gaia measure?

Practice Answers

1. Parallax is the apparent difference in the position of an object when the object is viewed from different locations.
2. If an object is views from two different positions a triangle can be created to determine the distance to the object.
3. 2 AU if the observations are 6 months apart.
4. The ones from the Hipparcos mission.
5. Gaia will measure gravitational deflection caused by the Sun across the whole sky.

Review

1. Why is parallax only good for measuring the distances of stars that are no more than a few hundred light years away?
2. Explain the process that you would use to determine the distance to a star that was about 100 light years away.
3. How do astronomers determine the distance to a star that is further than a few hundred light years away?

Practice Answers

1. The maximum length of the side of the triangle in which the two Earth observations are at farthest distance is not long enough to be accurate for objects that are very far away.
2. Measure distance to the object from a point on Earth's orbit around the Sun and then 6 months later at the furthest away point. The object will be measured against more distance stars and the distance can be calculated using trigonometry.
3. Mostly they determine how bright the star is and compare that against how bright they think it should be and determine the distance to account for that difference.

1.6 Galaxies

- Define galaxy, and describe types of galaxies.

What's happening with those galaxies?

Find a clear night sky and get out a good pair of binoculars or a telescope. You can see this feature (although not quite as well). The Whirlpool galaxy has an enhanced spiral structure due to its interactions with its companion galaxy NGC 5195.

Galaxies

Galaxies are the biggest groups of stars and can contain anywhere from a few million stars to many billions of stars. Every star that is visible in the night sky is part of the Milky Way Galaxy. To the naked eye, the closest major galaxy —the Andromeda Galaxy, shown in **Figure** 1.14 —looks like only a dim, fuzzy spot. But that fuzzy spot contains one trillion —1,000,000,000,000 —stars!

Galaxies are divided into three types according to shape: spiral galaxies, elliptical galaxies, and irregular galaxies.

Spiral Galaxies

Spiral galaxies spin, so they appear as a rotating disk of stars and dust, with a bulge in the middle, like the Sombrero Galaxy shown in **Figure** 1.15. Several arms spiral outward in the Pinwheel Galaxy (seen in **Figure** 1.15) and are appropriately called **spiral arms**. Spiral galaxies have lots of gas and dust and lots of young stars.

Elliptical Galaxies

Figure 1.16 shows a typical egg-shaped **elliptical galaxy**. The smallest elliptical galaxies are as small as some

FIGURE 1.14
The Andromeda Galaxy is a large spiral galaxy similar to the Milky Way.

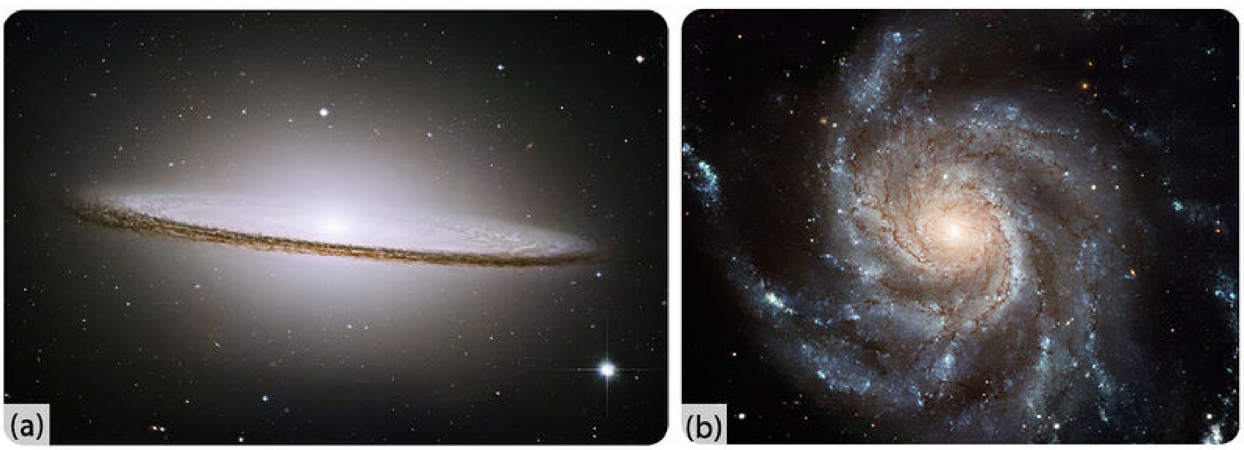


FIGURE 1.15
(a) The Sombrero Galaxy is a spiral galaxy that we see from the side so the disk and central bulge are visible. (b) The Pinwheel Galaxy is a spiral galaxy that we see face-on so we can see the spiral arms. Because they contain lots of young stars, spiral arms tend to be blue.

globular clusters. Giant elliptical galaxies, on the other hand, can contain over a trillion stars. Elliptical galaxies are reddish to yellowish in color because they contain mostly old stars.

Most elliptical galaxies contain very little gas and dust because the gas and dust have already formed into stars. However, some elliptical galaxies, such as the one shown in **Figure** 1.17, contain lots of dust. Why might some elliptical galaxies contain dust?

FIGURE 1.16
The large, reddish-yellow object in the middle of this figure is a typical elliptical galaxy. What other types of galaxies can you find in the figure?

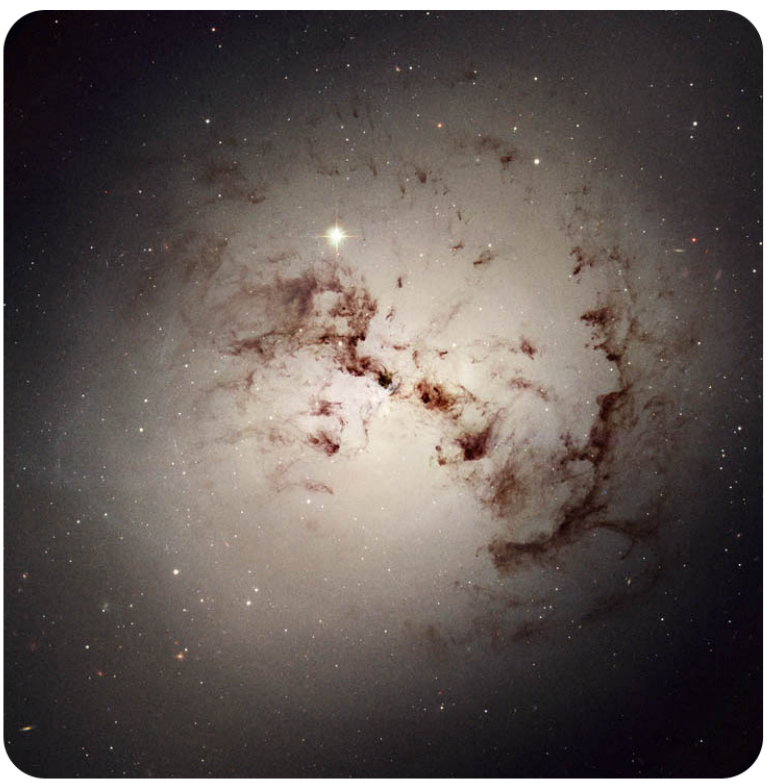


FIGURE 1.17
Astronomers believe that these dusty elliptical galaxies form when two galaxies of similar size collide.

Irregular Galaxies

Is the galaxy in **Figure** 1.18 a spiral galaxy or an elliptical galaxy? It is neither one! Galaxies that are not clearly elliptical galaxies or spiral galaxies are **irregular galaxies**. How might an irregular galaxy form? Most irregular galaxies were once spiral or elliptical galaxies that were then deformed either by gravitational attraction to a larger galaxy or by a collision with another galaxy.

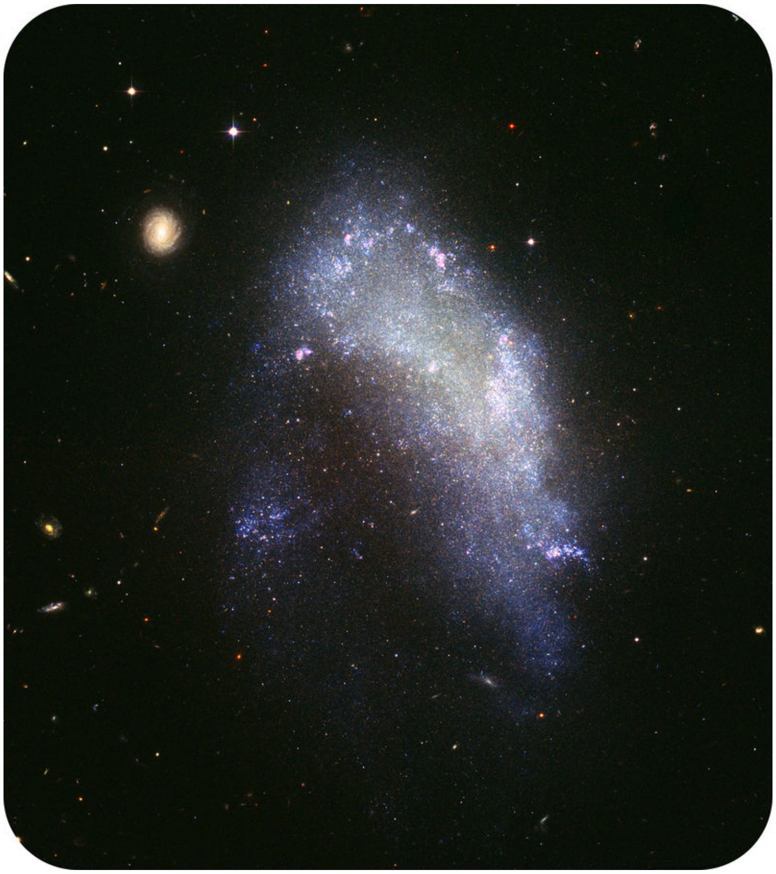


FIGURE 1.18
This galaxy, called NGC 1427A, has neither a spiral nor an elliptical shape.

Dwarf Galaxies

Dwarf galaxies are small galaxies containing only a few million to a few billion stars. Dwarf galaxies are the most common type in the universe. However, because they are relatively small and dim, we don't see as many dwarf galaxies from Earth. Most dwarf galaxies are irregular in shape. However, there are also dwarf elliptical galaxies and dwarf spiral galaxies.

Look back at the picture of the elliptical galaxy. In the figure, you can see two dwarf elliptical galaxies that are companions to the Andromeda Galaxy. One is a bright sphere to the left of center, and the other is a long ellipse below and to the right of center. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

Images from the Hubble Space Telescope are seen in this video: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop .

Summary

- A galaxy is composed of millions to billions of stars.
- Galaxies can be spiral, elliptical or irregular. Dwarf galaxies are smaller, but are more common than other galaxies.
- Galaxies that have lots of dust and gas are locations where stars are forming.

Practice

Use this resource to answer the questions that follow.

http://ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/galaxytypes.htm

1. List the different basic types of galaxies.
2. What determines the type of galaxy?
3. What is the bulge?
4. What is the disk?
5. Describe spiral galaxies.
6. Describe elliptical galaxies.
7. Describe irregular galaxies.

Practice Answers

1. spiral, barred, elliptical and irregular
2. The type is determined by its appearance.
3. The bulge is in the center where the stars are thickest.
4. The disk is the flat distribution around the bulge.
5. Spiral galaxies have a bulge in the center but the disk is made of arms spiraling out from the center.
6. Elliptical galaxies are all bulge and no disk. They can be spherical to elongate.
7. Irregular galaxies are not shaped in a specific way, but they can have many shapes.

Review

1. What makes a galaxy different from other galaxies or types of astronomical objects?
2. What makes irregular galaxies take an irregular shape?
3. How do dwarf galaxies interact with other galaxies?

Review Answers

1. Galaxies are made of many stars and can have distinct shapes; that's what makes the different types.
2. Irregular galaxies may have deformed by either gravitational attraction to a larger galaxy or by collision with another galaxy.
3. They are often found near other larger galaxies and will eventually merge with their neighbors.

1.7 Milky Way

- Describe the characteristics of the Milky Way Galaxy and our solar system's location within it.

"The Milky Way is nothing else but a mass of innumerable stars planted together in clusters." —Galileo Galilei

It's sad that there is so much light pollution in most cities that many people have never seen the Milky Way. On a clear night away from lights the view is of a bright white river of stars. You don't need a telescope or even binoculars to see it. The view of the Milky Way is so bright because you're looking at the stars in your own galaxy.

The Milky Way Galaxy

The **Milky Way Galaxy**, which is our galaxy. The Milky Way is made of millions of stars along with a lot of gas and dust. It looks different from other galaxies because we are looking at the main disk from within the galaxy. Astronomers estimate that the Milky Way contains 200 to 400 billion stars.

Shape and Size

Although it is difficult to know what the shape of the Milky Way Galaxy is because we are inside of it, astronomers have identified it as a typical spiral galaxy containing about 200 billion to 400 billion stars (**Figure** 1.19).

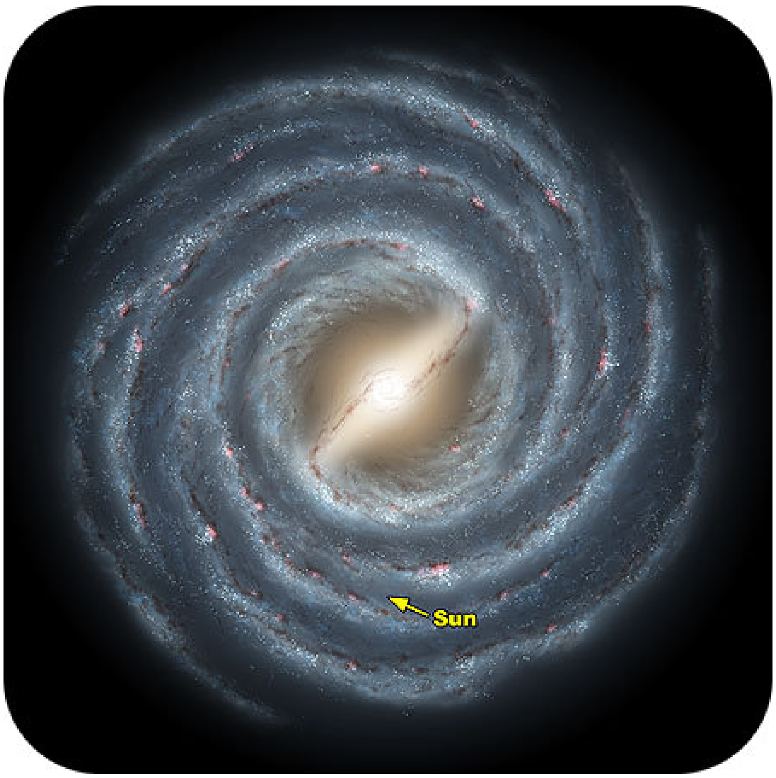


FIGURE 1.19
An artist's rendition of what astronomers think the Milky Way Galaxy would look like seen from above. The Sun is located approximately where the arrow points.

Like other spiral galaxies, our galaxy has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across and 3,000 light-years thick. Most of the Galaxy's gas, dust, young stars, and open clusters are in the disk.

What evidence do astronomers find that lets them know that the Milky Way is a spiral galaxy?

1. The shape of the galaxy as we see it (**Figure** 1.20).

2. The velocities of stars and gas in the galaxy show a rotational motion.

3. The gases, color, and dust are typical of spiral galaxies.

The central bulge is about 12,000 to 16,000 light-years wide and 6,000 to 10,000 light-years thick. The central bulge contains mostly older stars and globular clusters. Some recent evidence suggests the bulge might not be spherical, but is instead shaped like a bar. The bar might be as long as 27,000 light-years long. The disk and bulge are surrounded by a faint, spherical halo, which also contains old stars and globular clusters. Astronomers have discovered that there is a gigantic black hole at the center of the galaxy.

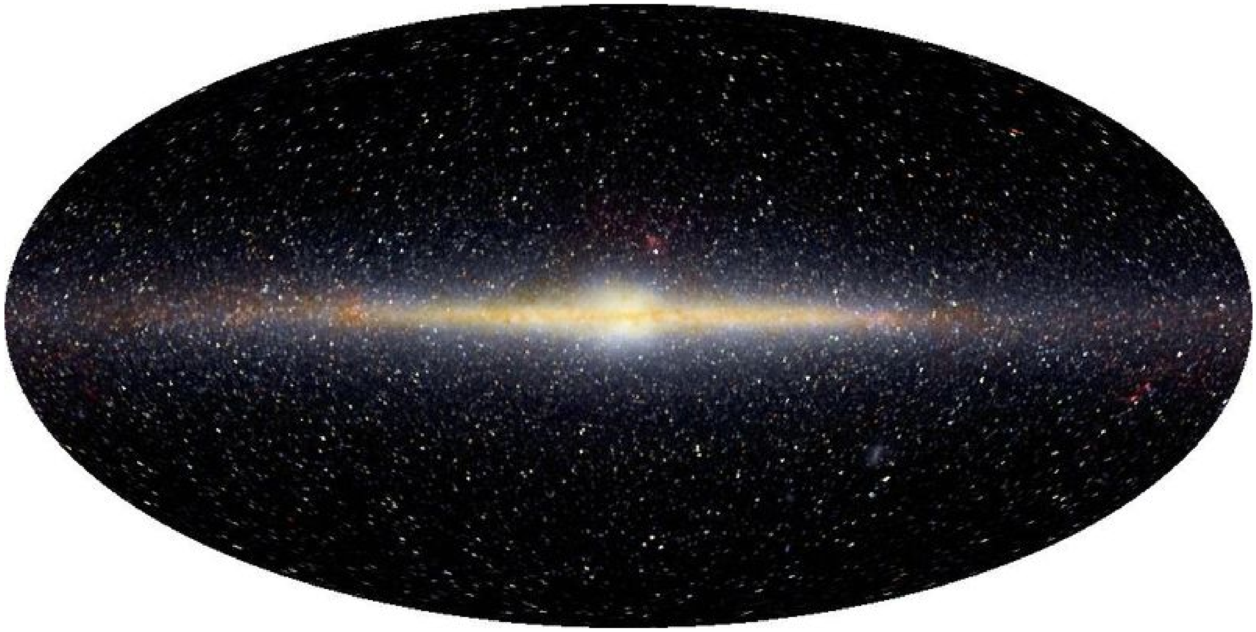


FIGURE 1.20
An infrared image of the Milky Way shows the long thin line of stars and the central bulge typical of spiral galaxies.

The Milky Way Galaxy is a big place. If our solar system were the size of your fist, the Galaxy's disk would still be wider than the entire United States!

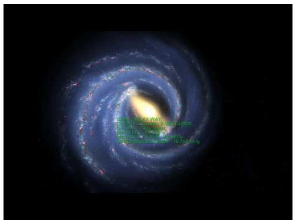
A video closeup of the Milky Way Galaxy is seen here: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTopjjj .

Where We Are

Our solar system, including the Sun, Earth, and all the other planets, is within one of the spiral arms in the disk of the Milky Way Galaxy. Most of the stars we see in the sky are relatively nearby stars that are also in this spiral arm. We are about 26,000 light-years from the center of the galaxy, a little more than halfway out from the center of the galaxy to the edge.

Just as Earth orbits the Sun, the Sun and solar system orbit the center of the Galaxy. 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. Astronomers have recently discovered that at the center of the Milky Way, and most other galaxies, is a supermassive black hole, although a black hole cannot be seen.

This video describes the solar system in which we live. It is located in an outer edge of the Milky Way galaxy, which spans 100,000 light years: http://www.youtube.com/watch?v=0Rt7FevNiRc (5:10).



MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1483

The Universe contains many billions of stars and there are many billions of galaxies. Our home, the Milky Way galaxy, is only one: http://www.youtube.com/watch?v=eRJvB3hM7K0 (5:59).

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1484

Summary

- We view the Milky Way Galaxy from within so it looks like a river of stars.
- From outside the galaxy, the Milky Way would appear as a spiral.
- A supermassive black hole resides at the center of the galaxy, just like within most other galaxies.

Practice

Use these resources to answer the questions that follow.

http://www.windows2universe.org/the_universe/Milkyway.html

1. What type of galaxy is our galaxy?
2. Where are we located in the galaxy?
3. How old is our galaxy? How do we know?

http://www.windows2universe.org/kids_space/milky_way_ask.html

1. How wide is our galaxy?
2. How long does it take our solar system to revolve around the center of our galaxy?
3. How far away is the center of our galaxy?
4. Explain the Local Group.

Practice Answers

1. Our galaxy is a spiral galaxy.
2. We are located halfway to the edge of the galaxy along a spiral arm.
3. The galaxy is at least 5 billion years old because our sun is that old, but we don't know how much older it is than that.

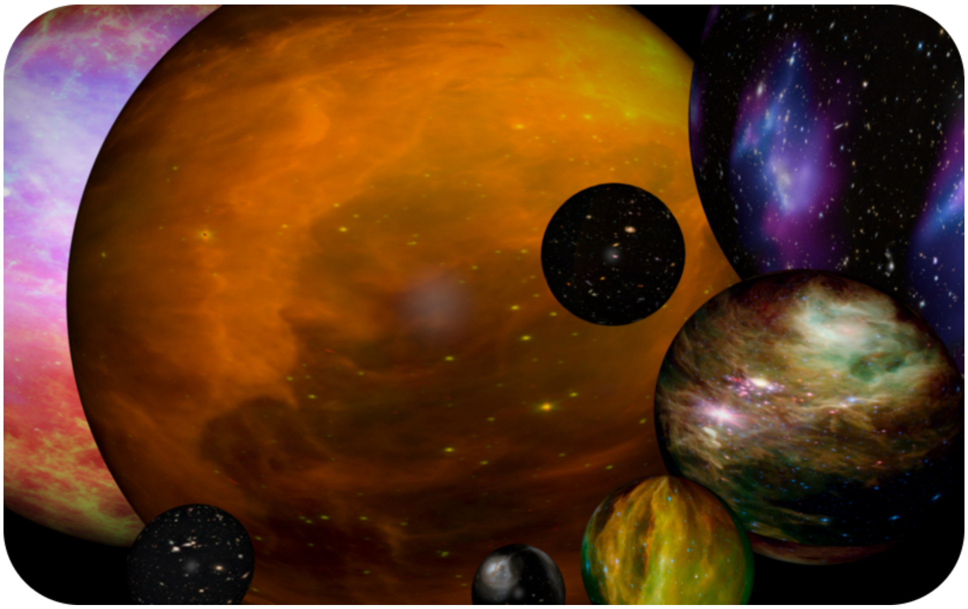
1. It is about 90,000 light years across.
2. It takes about 200 million years for the galaxy to go around once.
3. The center is about 28,000 light years away.
4. The Local group is a set of galaxies that are within 3 million light years.

Review

1. Why do astronomers think that the Milky Way is a spiral galaxy?
2. Where is Earth within the Milky Way Galaxy?
3. What are some of the features found within the Milky Way Galaxy?

1.8 Universe

- Define universe and describe the evolution of human understanding of the universe.



Is there more than one universe? Are there multiverses?

Some scientists think there may be more than one universe. This idea is called the multiverse hypothesis. This image is of a universe with different physical constants from our own.

The Universe

The study of the universe is called **cosmology**. Cosmologists study the structure and changes in the present universe. The **universe** contains all of the star systems, galaxies, gas, and dust, plus all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe includes all of space and time.

Evolution of Human Understanding of the Universe

What did the ancient Greeks recognize as the universe? In their model, the universe contained Earth at the center, the Sun, the Moon, five planets, and a sphere to which all the stars were attached. This idea held for many centuries until Galileo's telescope helped people recognize that Earth is not the center of the universe. They also found out that there are many more stars than were visible to the naked eye. All of those stars were in the Milky Way Galaxy.

In the early 20th century, an astronomer named Edwin Hubble (**Figure** 1.21) discovered that what scientists called the Andromeda Nebula was actually over 2 million light years away —many times farther than the farthest distances that had ever been measured. Hubble realized that many of the objects that astronomers called nebulas were not actually clouds of gas, but were collections of millions or billions of stars —what we now call galaxies.

Hubble showed that the universe was much larger than our own galaxy. Today, we know that the universe contains about a hundred billion galaxies —about the same number of galaxies as there are stars in the Milky Way Galaxy.

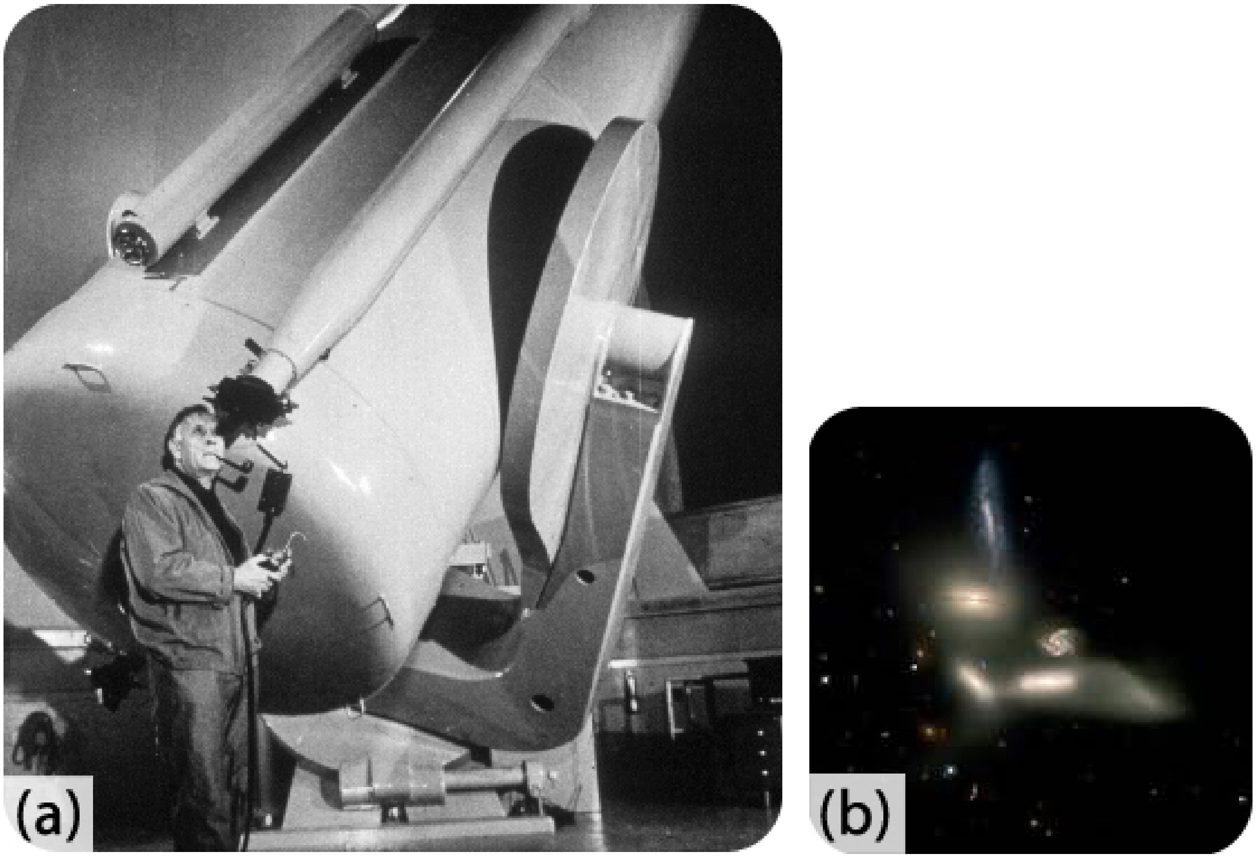


FIGURE 1.21

(a) Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California to show that some distant specks of light were galaxies. (b) Hubble's namesake space telescope spotted this six galaxy group. Edwin Hubble demonstrated the existence of galaxies.

Summary

- The universe contains about a hundred billion galaxies.
- The idea of a universe has changed through human history.
- Edwin Hubble saw the enormity of space and determined that there was much more than our own galaxy.

Practice

Use these resources to answer the questions that follow.

http://www.aip.org/history/cosmology/ideas/hubble.htm

1. When did Hubble join the Mount Wilson Observatory? Why did he rush through finishing his doctoral dissertation?
2. What did Hubble learn from his observations at Mount Wilson?
3. What did Hubble contribute to the war effort in World War II?

http://www.newscientist.com/article/dn9988-instant-expert-cosmology.html

1. What is cosmology?
2. How can the red shift of galaxies be explained?
3. What is the hubble constant?
4. What is the discover of the expansion of the universe lead to?

Practice Answers

1. He joined the observatory in 1919. He had hoped to join in 1917, but the U.S. declared war on Germany and he rushed through so he could join the army. He served in France.
2. He changed our understanding of the universe by demonstrating that spiral nebulae are independent galaxies at great distance from our own, and that the universe is expanding.
3. Hubble was chief of ballistics and director of the Supersonic Wind Tunnels.

1. Cosmology is the study of the universe as a whole: its birth, growth, shape, size and eventual fate.
2. The spectrum of the light of galaxies is moved to longer,redder wavelengths. It is explained because galaxies are moving away from us.
3. The hubble constant is the relationship between the distance of a galaxy and the amount of red shift it is experiencing.
4. If the universe is expanding it must have started at a point. This led to the big bang theory.

Review

1. What is cosmology?
2. Why does the human idea of the universe continue to change?
3. Why did Edwin Hubble come up with the idea of a universe?

Review Answers

1. Cosmology is the study of the universe.
2. We continue to learn more about the universe that we can see and that informs our understanding of what the universe was, is and will be.
3. He discovered that there were other galaxies beyond our Milky Way so he knew that the universe must be larger than our own galaxy.

1.9 Expansion of the Universe

- Explain how astronomers use red-shift to determine that the universe is expanding.

What is Doppler Effect?

The sound of a siren on an emergency vehicle changes as it passes you: it shifts from higher to lower pitch. As the vehicle moves toward you, the sound waves are pushed together. As the vehicle moves past you, the waves are spread apart. Though redshift involves light instead of sound, a similar principle operates in both situations.

Expansion of the Universe

After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show how the universe is changing, and would even yield clues as to how the universe formed.

Redshift

If you look at a star through a prism, you will see a spectrum, or a range of colors through the rainbow. The spectrum will have specific dark bands where elements in the star absorb light of certain energies. By examining the arrangement of these dark absorption lines, astronomers can determine the composition of elements that make up a distant star. In fact, the element helium was first discovered in our Sun —not on Earth —by analyzing the absorption lines in the spectrum of the Sun.

While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in **Figure** 1.22. This shift of absorption bands toward the red end of the spectrum is known as **redshift**.

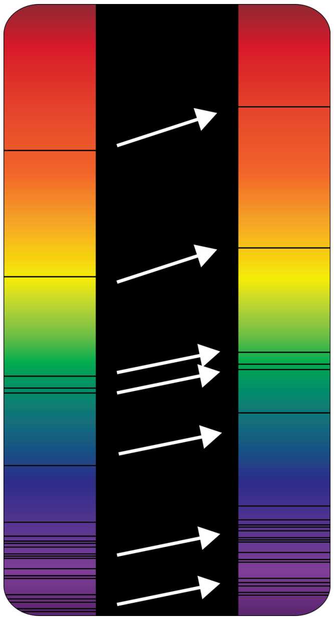


FIGURE 1.22
Redshift is a shift in absorption bands toward the red end of the spectrum. What could make the absorption bands of a star shift toward the red?

Redshift occurs when the light source is moving away from the observer or when the space between the observer and the source is stretched. What does it mean that stars and galaxies are redshifted? When astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth.

If galaxies were moving randomly, would some be redshifted but others be blueshifted? Of course. Since almost every galaxy in the universe has a redshift, almost every galaxy is moving away from Earth.

An animation of Doppler Effect: http://projects.astro.illinois.edu/data/Doppler/index.html .

The Expanding Universe

Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a relationship, which is now called Hubble's Law: the farther away a galaxy is, the faster it is moving away from us. What could this mean about the universe? It means that the universe is expanding.

Figure 1.23 shows a simplified diagram of the expansion of the universe. One way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. Also, the dots farther away from you on the balloon would move away faster than dots nearby.

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching out between galaxies, just as the rubber stretches when a balloon is inflated. This stretching of space, which increases the distance between galaxies, is what causes the expansion of the universe.

An animation of an expanding universe is shown here: http://www.astro.ubc.ca/~scharein/a311/Sim/bang/BigBang.html .

One other difference between the universe and a balloon involves the actual size of the galaxies. On a balloon, the dots will become larger in size as you inflate it. In the universe, the galaxies stay the same size; only the space between the galaxies increases.

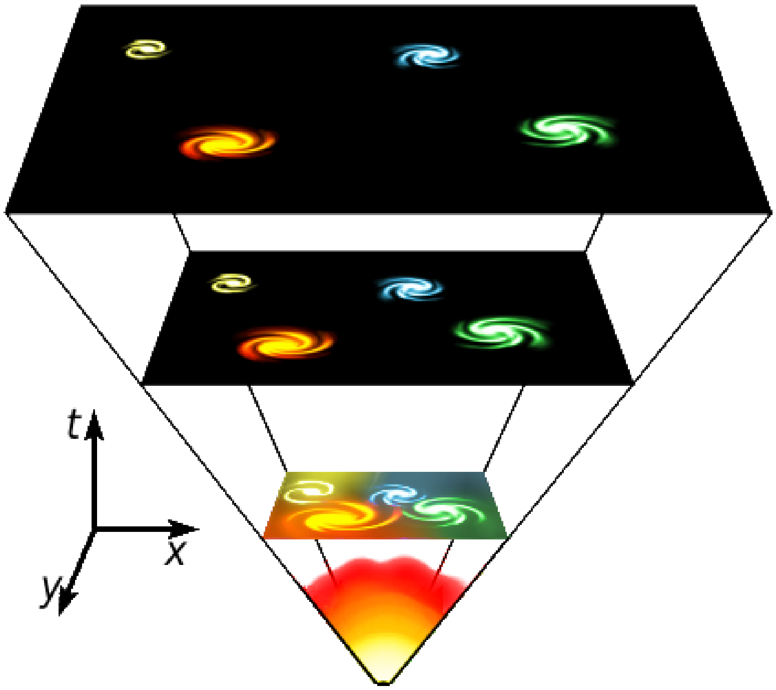


FIGURE 1.23
In this diagram of the expansion of the universe over time, the distance between galaxies gets bigger over time, although the size of each galaxy stays the same.

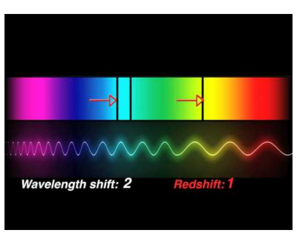
Summary

- Almost every galaxy is moving away from us.
- The spectrum from stars is shifted toward the red; this is known as red-shift and is evidence that the universe is expanding.
- Hubble's Law states that the farther away a galaxy is, the faster it is moving away from us.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=8FPVIV-LzYM



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1. What is the advantage of a space telescope over a ground-based telescope?
2. What does dark energy do?
3. What is the Hubble Deep Field?
4. What are Cephied variables?
5. What are the Cephieds used for?
6. What happens to light as it reaches us?
7. What is the Doppler effect?

8. What is red shift?
9. What is Hubble's law?
10. What causes red shift in galaxies moving away from us?
11. How is red shift measured?
12. What is the successor for the Hubble Space Telescope? What will it allow scientists to do?

Practice Answers

1. A space telescope doesn't need to see through the turbulent atmosphere.
2. Dark energy is a repulsive force that is causing the universe to expand faster.
3. It is a view of the deepest farthest away galaxies, meaning that it sees the early universe. It contains about 10,000 galaxies in a tiny part of the sky.
4. They change in brightness in a regular and predictable way.
5. They can be used to measure vast distances in space. They are used to determine the expansion rate of the universe.
6. The light has been red shifted into infrared wavelengths so it must be detected in IR.
7. There is a change when a source emitting sound or light waves is moving with respect to an observer. If it is moving toward the observer the waves are pressed together; if it is moving away from the observer, the waves are stretched.
8. Red shift is when the source is moving away from us and the light waves are shifted toward the red.
9. Hubble's Law says that the velocity of a galaxy moving away from us is direction proportional to its distance so it exhibits a larger red shift.
10. The expansion of the universe.
11. They are measured from the signature absorption and emission lines of atoms and molecules in the spectra of celestial objects. The wavelengths can be measured accurately and can be compared with the spectrum of a galaxy.
12. The James Webb is a telescope that is very sensitive in near and mid-infrared wavelengths. They can measure back to the earlist stars and galaxies.

Review

1. How did Hubble determine that the universe is expanding?
2. How do astronomers determine the composition of distant stars?
3. What is the significance of the idea that the universe is expanding?

Review Answers

1. The galaxies are red-shifted so they are moving away from us. The further away the galaxy is the grater its redshift. This means the universe is expanding.
2. They examine the arrangement of dark absorption lines. Different elements absorb different colors and present different spectra.
3. If the universe is expanding it must have been all together at some time. this leads to the idea that the universe began in a big bang.

1.10 Big Bang

- Define Big Bang theory and explain its relationship to the expansion of the universe.
- Describe what occurred after the Big Bang.
- Describe evidence scientists have discovered to support Big Bang theory.

How did everything begin in the Big Bang?

If the universe is expanding, the next logical thought is that in the past it had to have been smaller. A point even. The time when the universe began is the explosion known as the Big Bang.

The Big Bang Theory

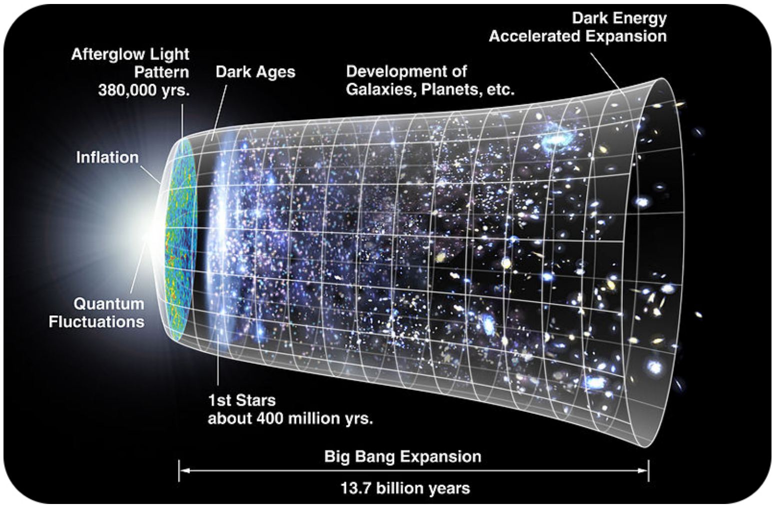

FIGURE 1.24
Timeline of the Big Bang and the expansion of the Universe.

The **Big Bang theory** is the most widely accepted cosmological explanation of how the universe formed. If we start at the present and go back into the past, the universe is contracting —getting smaller and smaller. What is the end result of a contracting universe?

According to the Big Bang theory, the universe began about 13.7 billion years ago. Everything that is now in the universe was squeezed into a very small volume. Imagine all of the known universe in a single, hot, chaotic mass. An enormous explosion —a big bang —caused the universe to start expanding rapidly. All the matter and energy in the universe, and even space itself, came out of this explosion.

What came before the Big Bang? There is no way for scientists to know since there is no remaining evidence.

After the Big Bang

In the first few moments after the Big Bang, the universe was unimaginably hot and dense. As the universe expanded, it became less dense and began to cool. After only a few seconds, protons, neutrons, and electrons could form. After a few minutes, those subatomic particles came together to create hydrogen. Energy in the universe was great enough to initiate nuclear fusion, and hydrogen nuclei were fused into helium nuclei. The first neutral atoms that included electrons did not form until about 380,000 years later.

The matter in the early universe was not smoothly distributed across space. Dense clumps of matter held close together by gravity were spread around. Eventually, these clumps formed countless trillions of stars, billions of galaxies, and other structures that now form most of the visible mass of the universe.

If you look at an image of galaxies at the far edge of what we can see, you are looking at great distances. But you are also looking across a different type of distance. What do those far away galaxies represent? Because it takes so long for light from so far away to reach us, you are also looking back in time (**Figure** 1.25).

Background Radiation

After the origin of the Big Bang hypothesis, many astronomers still thought the universe was static. Nearly all came around when an important line of evidence for the Big Bang was discovered in 1964. In a static universe, the space between objects should have no heat at all; the temperature should measure 0 K (Kelvin is an absolute temperature scale). But two researchers at Bell Laboratories used a microwave receiver to learn that the background radiation in the universe is not 0 K, but 3 K (**Figure** 1.26). This tiny amount of heat is left over from the Big Bang. Since nearly

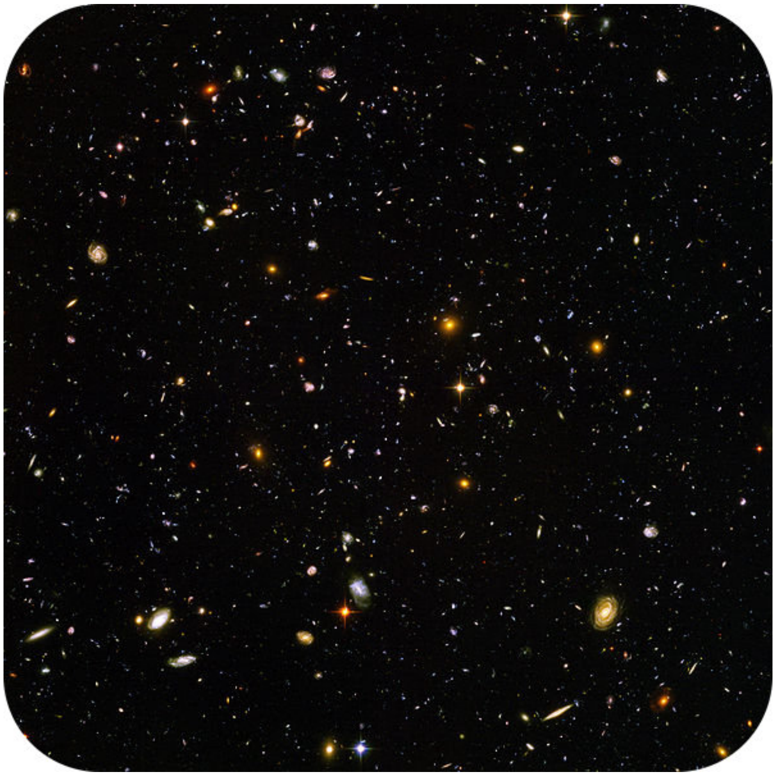

FIGURE 1.25
Images from very far away show what the universe was like not too long after the Big Bang.

all astronomers now accept the Big Bang hypothesis, what is it usually referred to as?

An explanation of the Big Bang: http://dvice.com/archives/2009/08/big-bang-animat.php .

How we know about the early universe: http://www.youtube.com/watch?v=uihNu9Icaeo .

"History of the Universe," part 2: http://www.youtube.com/watch?v=bK6_p5a-Hbo .

"The Evidence for the Big Bang in 10 Little Minutes" provides a great deal of scientific evidence for the Big Bang: http://www.youtube.com/watch?v=uyCkADmNdNo (10:10).

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KQED: Nobel Laureate George Smoot and the Origin of the Universe

George Smoot, a scientist at Lawrence Berkeley National Lab, shared the 2006 Nobel Prize in Physics for his work on the origin of the universe. Using background radiation detected by the Cosmic Background Explorer Satellite (COBE), Smoot was able to make a picture of the universe when it was 12 hours old. Learn more at: http://science.kqed.org/quest/video/nobel-laureate-george-smoot-and-the-origin-of-the-universe/

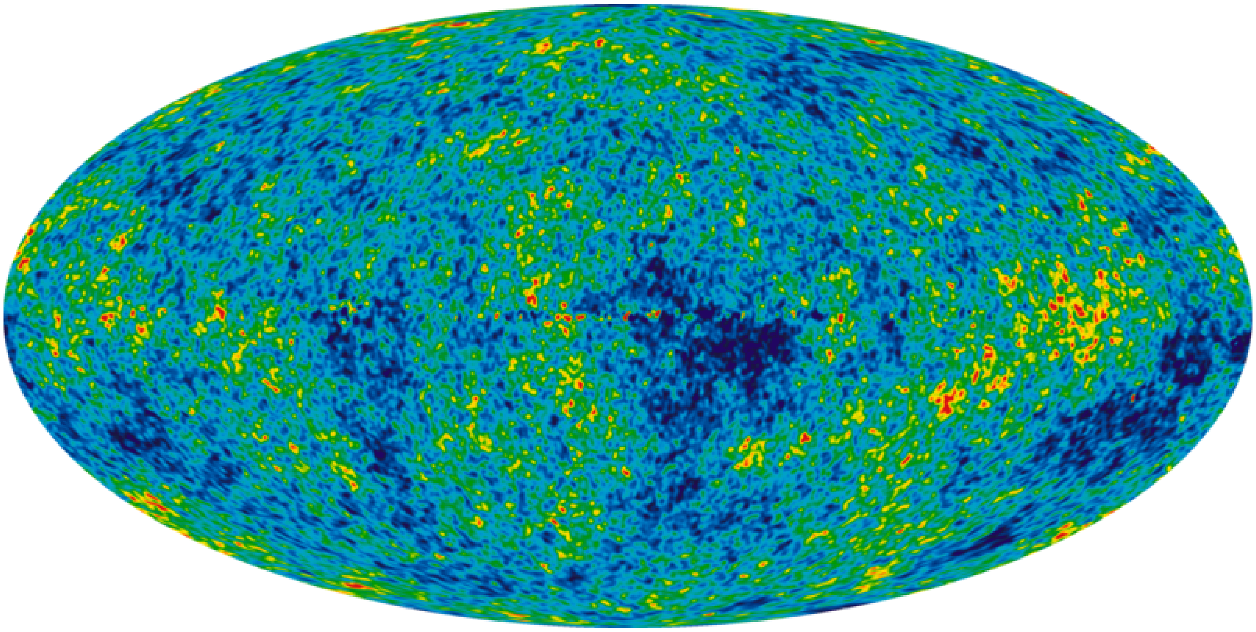

FIGURE 1.26
Background radiation in the universe was good evidence for the Big Bang theory.

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Summary

- The Big Bang theory states that the universe began as a point and expanded outward.
- No one can know what came before the Big Bang because there is no remaining evidence.
- The tiny bit of background radiation in the universe is energy remaining from the Big Bang.

Practice

Use this resource to answer the questions that follow.

http://science.nationalgeographic.com/science/space/universe/origins-universe-article/

1. Explain the Big Bang Theory.
2. Who suggested the Big Bang Theory?
3. Who discovered cosmic microwave radiation? What does cosmic microwave radiation indicate?
4. What questions are not answered with the Big Bang Theory?

Practice Answers

1. The entire vastness of the observable universe, including all matter and radiation, was compressed into a tiny mass that existed for a fraction of a second. Then the universe expanded outward until everything that exists came to be.
2. A Belgian priest named Georges Lemaitre suggested that Earth started in a single primordial atom.
3. Penzias and Wilson discovered cosmic microwave radiation, which is the heat left over from the explosion of the big bang.
4. What caused the big bang? What was there before the big bang?

Review

1. How is the idea that the universe started in a big bang a logical extension from a fact?
2. What evidence is there that the universe began in a big bang?
3. What happened in the first minutes after the Big Bang?

Review Answers

1. If the universe is expanding, then tracking that expansion backwards leads to the universe beginning as a point.
2. The background radiation that is the leftover heat from the explosion. The expanding universe.
3. The universe was unimaginably hot and dense. As it expanded it became less dense and cooler. Subatomic particles could form and in a few minutes they came together to create hydrogen. Fusion began.

1.11 Dark Matter

- Define dark matter and dark energy.
- Describe evidence for and hypotheses about the existence of dark matter and dark energy and the roles they play in the universe.

Why is dark matter hot?

It's not hot in temperature; it's a hot topic in cosmology. Many lines of evidence support the Big Bang theory for explaining the formation of the universe. However, scientists are now wrestling with some unanswered questions about what the universe is made of and why it is expanding.

Dark Matter

The things we observe in space are objects that emit some type of electromagnetic radiation. However, scientists think that matter that emits light makes up only a small part of the matter in the universe. The rest of the matter, about 80%, is dark matter.

Dark matter emits no electromagnetic radiation, so we can't observe it directly. However, astronomers know that dark matter exists because its gravity affects the motion of objects around it. When astronomers measure how spiral galaxies rotate, they find that 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 they can see.

Gravitational lensing occurs when light is bent from a very distant bright source around a super-massive object (**Figure** 1.27). To explain strong gravitational lensing, more matter than is observed must be present.

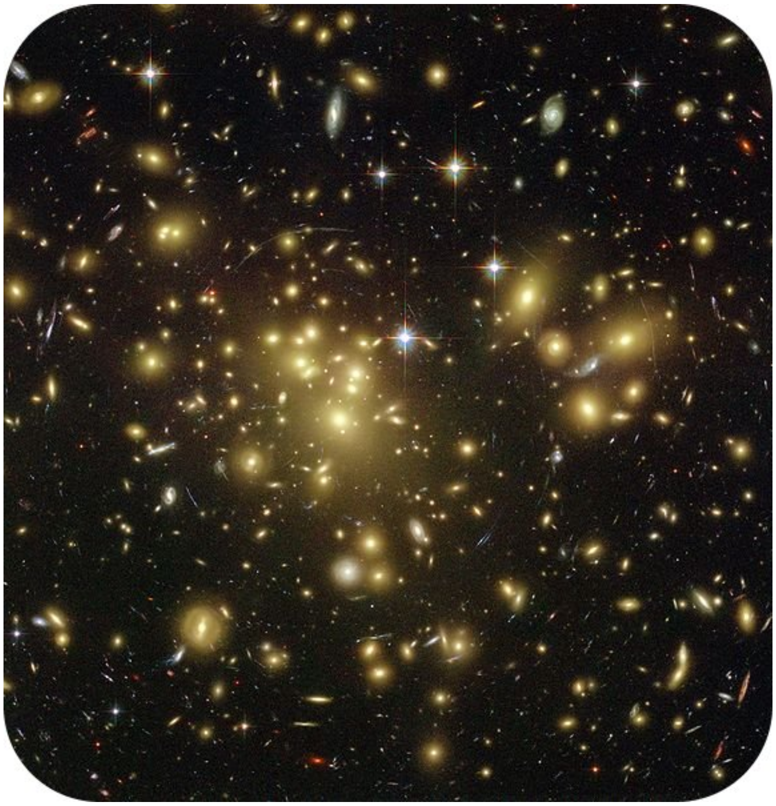


FIGURE 1.27
The arc around the galaxies at the center of this image is caused by gravitational lensing. The addition of gravitational pull from dark matter is required to explain this phenomenon.

With so little to go on, astronomers don't really know much about the nature of dark matter. One possibility is that it could just be ordinary matter that does not emit radiation in objects such as black holes, neutron stars, and brown dwarfs —objects larger than Jupiter but smaller than the smallest stars. But astronomers cannot find enough of these types of objects, which they have named MACHOs (massive astrophyiscal compact halo object), to account for all the dark matter, so they are thought to be only a small part of the total.

Another possibility is that the dark matter is very different from the ordinary matter we see. Some appear to be particles that have gravity, but don't otherwise appear to interact with other particles. Scientists call these theoretical particles WIMPs, which stands for Weakly Interactive Massive Particles.

Most scientists who study dark matter think that the dark matter in the universe is a combination of MACHOs and some type of exotic matter, such as WIMPs. Researching dark matter is an active area of scientific research, and astronomers' knowledge about dark matter is changing rapidly.

Dark Energy

Astronomers who study the expansion of the universe are interested in knowing the rate of that expansion. Is the rate fast enough to overcome the attractive pull of gravity?

- If yes, then the universe will expand forever, although the expansion will slow down over time.

- If no, then the universe would someday start to contract, and eventually get squeezed together in a big crunch, the opposite of the Big Bang.

Recently, astronomers have made a discovery that answers that question: the rate at which the universe is expanding is actually increasing. In other words, the universe is expanding faster now than ever before, and in the future it will expand even faster. So now astronomers think that the universe will keep expanding forever. But it also proposes a perplexing new question: what is causing the expansion of the universe to accelerate?

One possible hypothesis involves a new, hypothetical form of energy called **dark energy** (**Figure** 1.28). Some scientists think that dark energy makes up as much as 71% of the total energy content of the universe.

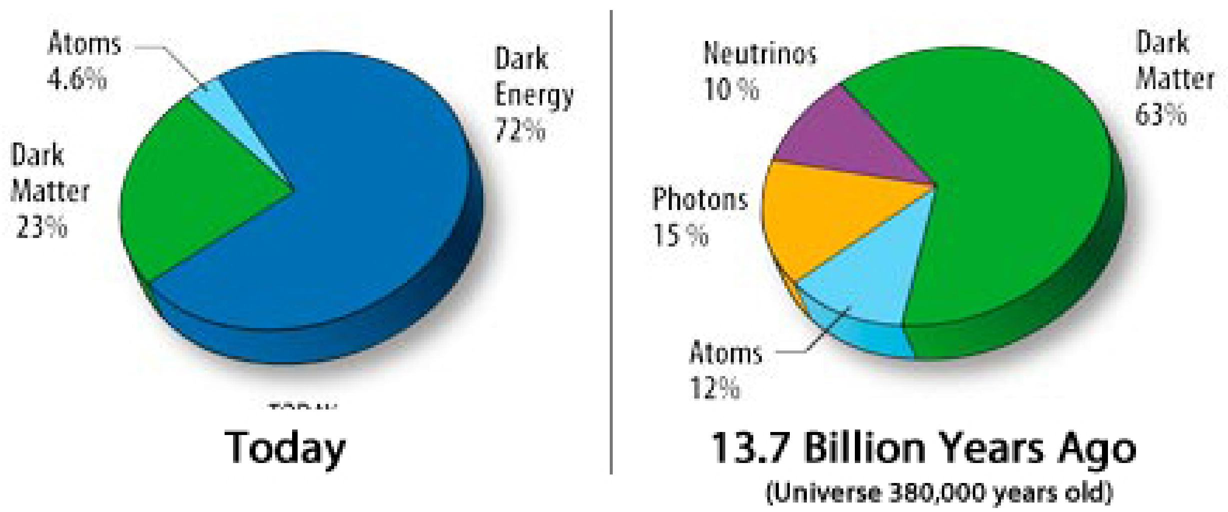
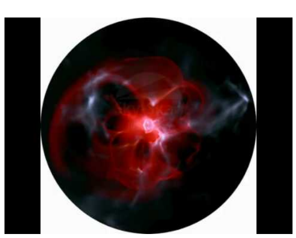


FIGURE 1.28
Today matter makes up a small percentage of the universe, but at the start of the universe it made up much more. Where did dark energy, if it even exists, come from?

Other scientists have other hypotheses about why the universe is continuing to expand; the causes of the universe's expansion is another unanswered question that scientists are researching.

A video explaining dark matter is here: http://www.youtube.com/watch?v=gCgTJ6ID6ZA .

This video looks at the origin of the universe, star formation, and the formation of the chemical elements in supernovas **(2c)**: http://www.youtube.com/watch?v=8AKXpBeddu0 (8:30).



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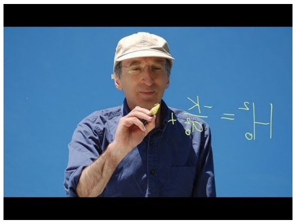
KQED: Dark Energy

Meet one of the three winners of the 2011 Nobel Prize in Physics, Lawrence Berkeley Lab astrophysicist Saul Perlmutter. He explains how dark energy, which makes up 70 percent of the universe, is causing our universe to expand. Learn more at: http://science.kqed.org/quest/video/dark-energy/ .



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Summary

- Dark matter cannot be sensed by astronomers, but the effect of its gravity is seen on the motion of nearby objects.
- Dark matter may be a combination of WIMPs and MACHOs.
- Dark energy is still hypothetical, but if it exists it could be a significant portion of the energy of the universe.

Practice

Use this resource to answer the questions that follow.

http://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy/

1. What do we know about dark energy?
2. How much of the universe is made up of dark energy?
3. How much of the universe is made up of dark matter?
4. What is dark matter? What do we know about dark matter?

Practice Answers

1. Not much! We know how much there is because we know how much it affects the expansion of the universe.
2. About 68%
3. About 27%
4. Dark matter is also poorly understood. It is not the matter we see in stars and planets. It is not normal matter that is dark. It is not antimatter. It is not made of black holes. It could be baryonic matter tied up in brown dwarfs or in heavy elements or MACHOS. It could be exotic particles like axions or WIMPS.

Review

1. Why can't scientists see dark matter? Since they can't see it, how do they know that it exists?
2. What are WIMPs and MACHOs and why are they important?
3. What might dark energy be and why is it important?

Review Answers

1. It doesn't emit electromagnetic radiation, but it does affect the motion of objects around it with its gravity.

2. WIMPS are Weakly Interactive Massive Particles and MACHOS are Massive Astrophysical Compact Halo Objects. They are important because they may be what makes up dark matter.
3. Dark energy is the energy that is driving the universe to continue to expand faster. It makes up as much as 71% of the energy of the universe.

Summary

Stars have a life cycle that begins with birth, goes through middle age and ends in some sort of death. The exact path and the exact result depends on the size of the star. We can see different types of stars in the sky; they vary by size and brightness, which is how they are classified. Stars cluster in galaxies, which are fantastic structures in the sky. Our own Sun and solar system lies within an arm of a spiral galaxy, the Milky Way. Scientists have used observations, measurements, and mathematical calculations to hypothesize an origin for the universe, known as the Big Bang. These scientists continue to learn new things about the universe. For example, dark matter and dark energy have only recently been discovered.

1.12 References

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