MODULE 1

MYSTERIES OF THE UNIVERSE

Universal Truths

The universe, just what is it? The best explanation is that it is a huge space that contains everything from the smallest atomic particle to the largest star and galaxy. Just how big is it? Astronomers have tried to measure the size of the universe, but in reality, nobody really knows. The only information that astronomers have to study the universe comes to Earth in the form of electromagnetic energy and high-energy particles. We will talk more about energy in Modules 3 and 5 and how it is used to understand “what is out there.” But for now, let’s explore some of the interesting facts and current mysteries of our beautiful universe.

SPACE

Just where does **space** begin? How far away from the surface of the Earth is that location? Believe it or not, scientists over the years have disagreed and redefined this distance. Why? Well, it is about how they choose to define it.

The first official definition of space came from the National Advisory Committee for Aeronautics (now called **NASA – National Aeronautics and Space Administration**). NASA defined the beginning of space as the location in the atmosphere where an airplane could no longer be controllable. This location was roughly 50 miles (264,000 feet) above the surface of the Earth. However, as time went on and we started sending spacecraft into orbit around the Earth, the definition changed to the location where satellites can maintain their orbits for a reasonable time without slowing down. It is a location where the Earth’s atmosphere is very, very thin, and it is approximately 100 miles (528,000 feet) above Earth’s surface. Notice how these definitions are all related to the Earth’s atmosphere? Think of it as a location where airplanes stop flying

Figure 1.1
Just Where Does Space Begin?

and spaceships begin to explore. Today, with further refinement and agreement among scientists, space is defined to start at 62 miles (327,360 feet) above the Earth. So when you look up at the sky at night, outer space is considered to start 62 miles above you.

Think about this.

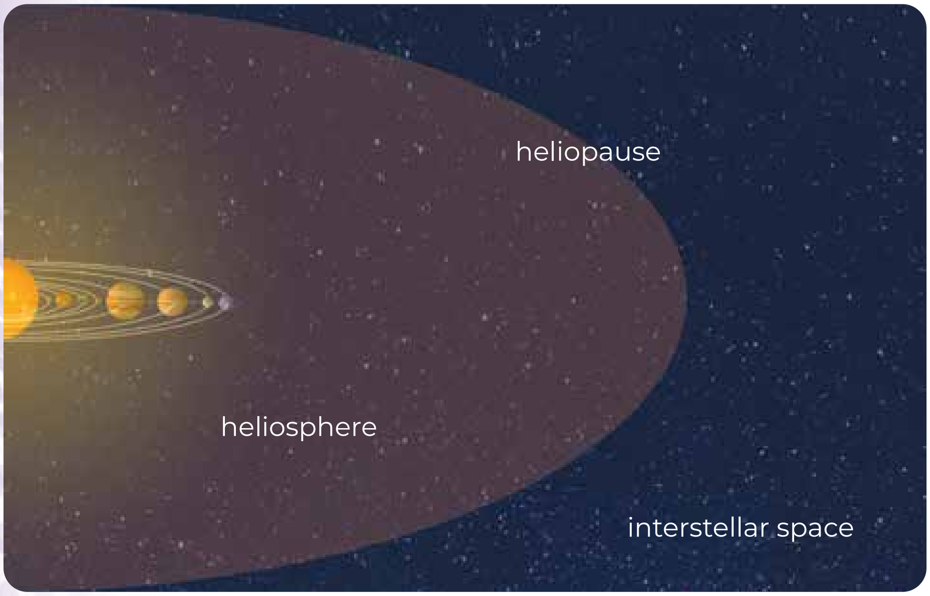
Even at 621 miles (3,278,880 feet) above the Earth's surface, there is a trace of the Earth's atmosphere. This distant and thin atmospheric "cloud" is called the geocorona and consists mostly of hydrogen.

INTERSTELLAR SPACE

Astronomers define the beginning of **interstellar space** as the place where our Sun's magnetic field and its high-energy particles come to a stop. It is "the space between the stars." It is beyond our own solar system. To visualize where interstellar space begins, think of the high-energy particles coming from the Sun as a type of wind. I think we have all experienced wind on Earth as air blows across our face and hair. But the wind from the Sun is in the form of those high-energy particles. Astronomers have called this type of wind the **solar wind.** As the solar wind moves away from the Sun, it heads out into the space between our planets. We think of this space as "empty" but it contains tiny pieces of gas and dust, clearing out a bubble-like region called the **heliosphere.** But this bubble has a boundary where the solar wind comes to a stop. This boundary is called the **heliopause.** Beyond the heliopause boundary is interstellar space.

Figure 1.2

Where Interstellar Space Begins—at the Heliopause Boundary



If you could jump in a spaceship and travel away from our Sun, you would know that you have arrived at interstellar space when you detected an increase in cold particles all around you. Inside the heliosphere, the particles are hot and farther apart because of their high energy. As they move away from the Sun, they hit pieces of gas and dust and lose energy, slow down, and start to accumulate. And beyond the heliopause, the particles from the Sun are mixed with the matter of interstellar space. With all this in mind, scientists have concluded that interstellar space begins about 11,625,000,000 miles from the Sun. Thats almost 12 billion miles! To put this in perspective, the dwarf planet Pluto is about 3,600,000,000 miles from the Sun, so interstellar space starts at a distance that is about 3.2 times the distance between the Sun and Pluto.

Think about this.

NASA announced in 2013 that the *Voyager 1* spacecraft had arrived in interstellar space. This spacecraft is more than 12,900,000,000 miles from our Sun and was launched by NASA on September 5, 1977. That means it took 36 years to reach interstellar space! *Voyager 1* has traveled farther than anyone, or anything, in history.

THE UNIVERSE

The **universe** is defined as all of space, including interstellar space and its contents, which includes planets, moons, solar systems, stars, and galaxies. Think of it as everything in space including all types of matter and energy.

So the universe includes all planets, moons, solar systems, stars, and galaxies. These objects are made of what we call normal matter. But besides these objects, what else exists in the universe? When we think about the universe, most of us think that it is an empty vacuum with the occasional planet or star. But that is not accurate because the space between the stars, or interstellar space, is not empty. In this space, scientists believe we would find dust particles, stray molecules of alcohol, the occasional hydrogen, carbon or silicon atom, ice, and clouds of various gases. Scientists believe that the universe consists of normal matter, antimatter, energy, dark matter, and dark energy. Most of the universe is thought to be composed of dark energy. With this in mind, let's talk about all of the normal matter in the universe.

Normal Matter

Normal matter is defined as anything that has mass and volume. Normal matter makes up the Earth, the Moon, all of the visible stars, all planets, and galaxies. Amazingly, less than 5% of the universe is made of normal matter.

Examples of normal matter are solids, liquids, gases, and plasma—things like ice, water, air, and rocks. In a solid, particles of matter are packed tightly together so they are unable to move about very much. Solids have a definite shape and volume and do not conform to the shape of any container. In the liquid phase, the particles of matter are not held in a regular arrangement but are still very close to each other, so liquids have a definite volume. However, liquids will change shape to that of the container they are placed into. Gas particles of matter, on the other hand, have a great deal of space between them and will spread out to fill the container's space entirely. Although plasma is not commonly found on Earth, it may be the most common

Figure 1.3
All Known Parts of the Universe

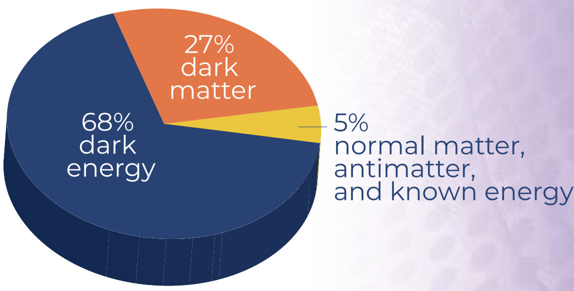


Figure 1.4
Hubble Space Telescope Picture of a Small Portion of the Universe Showing Distant Stars and Galaxies

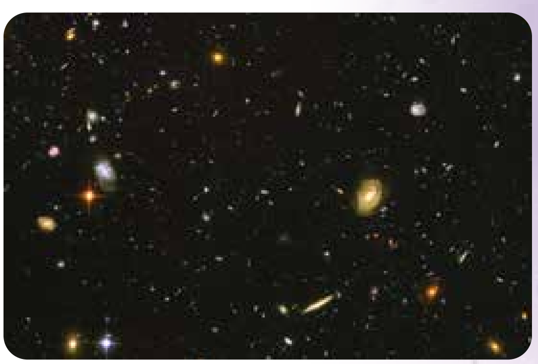
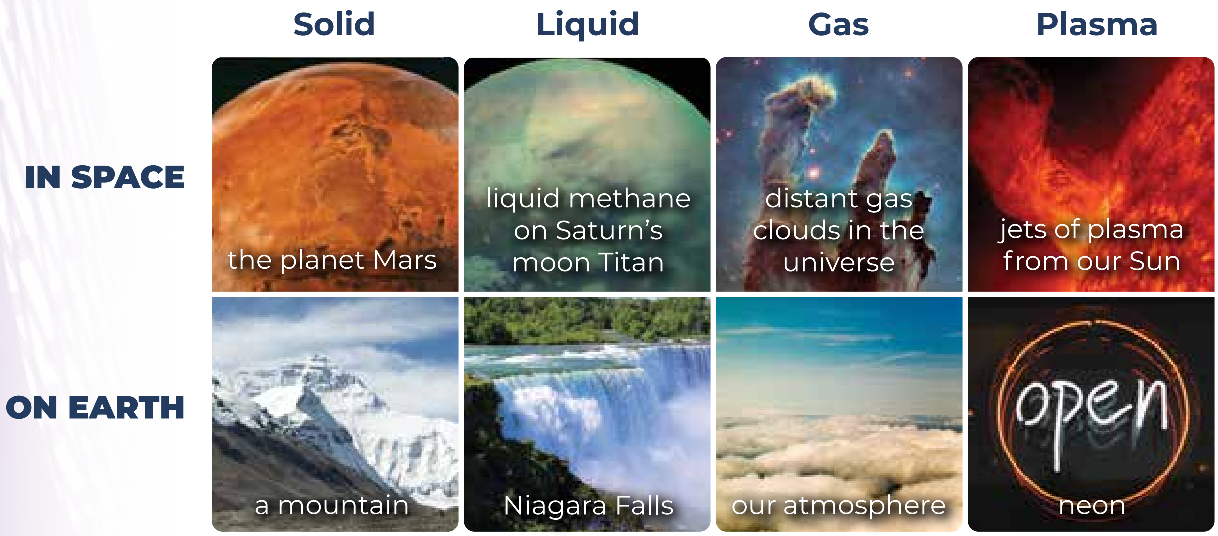


Figure 1.5
Horsehead Nebula

The Horsehead Nebula is an example of an interstellar gas cloud as taken by the Hubble Space Telescope.

state of matter in the universe. Plasma is basically a superheated gas. Electricity is used to ionize neon gas to a plasma state to make glowing signs. Stars are essentially superheated balls of plasma.

Figure 1.6
Examples of Normal Matter



The space between the stars is not empty, or what we call a vacuum. This space also contains a strange mix of normal matter such as stray atoms, molecules, and microscopic dust particles. This strange mix of matter is called the **interstellar medium** or ISM. The ISM has less than 20 atoms per cubic inch. This is much less than a deep vacuum as defined on Earth. When laboratories create what is called a deep vacuum, there are still on average about 2,000 atoms per cubic inch of volume. So yes, space could be considered nearly empty, or a near vacuum, but the ISM exists, so there is no such thing as a complete vacuum, or a space void of anything, in interstellar space.

Figure 1.7
Our Milky Way Is Huge

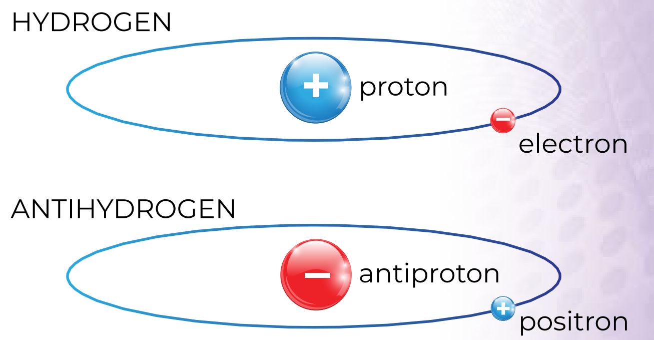
Although this small amount of interstellar medium seems insignificant (less than 20 atoms per cubic inch), in the vast distances of space it starts to add up. In the galaxy in which our solar system sits, which we call the Milky Way galaxy, the ISM makes up about 10% of the total mass of the galaxy. This is enough normal matter to make 20,000,000,000 Suns. How can this be true? Well, the Milky Way is 100,000 light-years across (which is equivalent to 586,569,600,000,000,000 miles). This is a huge volume and a lot of interstellar medium! We will talk more about this in Module 11.

But there are other types of matter in the universe in addition to normal matter. These other types of matter are antimatter and dark matter.

Antimatter

Antimatter is one of the top exciting discoveries in physics of the 20th century. Many people think of it as some sort of science fiction term, but in reality, it is being produced every day. Think of it as the opposite of the particles that we currently know. For instance, we know that atoms are composed of electrons, and electrons have a negative charge. The antimatter equivalent to an electron is a positron. A positron has the same mass as an electron, but it has a positive charge. For example, there exists in the universe both hydrogen and antihydrogen. Hydrogen has a proton particle (positive charge) and an electron particle (negative charge). Anti-hydrogen has an anti-proton (negative charge) and a positron (positive charge). The charges are just opposite. What would happen if you combined a container of hydrogen and antihydrogen? A tremendous explosion would happen, and the 2 types of matter would disappear, creating heat and a burst of light in the process.

Figure 1.8
Matter (Hydrogen) and Antimatter (Antihydrogen)



Antimatter exists on a very small scale because when it interacts with real matter, both it and the real matter react and both disappear. Scientists have determined that small amounts of antimatter hit the Earth in the form of cosmic rays every day. In addition, scientists using NASA's Fermi Gamma-Ray Space Telescope have detected antimatter being produced above thunderstorms here on Earth. And believe it or not, scientists have proved that bananas produce antimatter, releasing one positron about every 75 minutes. Why bananas? The positron is created from the radiation decay of the potassium-40 atom, which bananas contain in small amounts. An important use of antimatter in modern medicine is in a medical imaging technique called a positron emission tomography scan otherwise known as a PET scan. This type of scan is an imaging method that helps reveal how your tissues and organs are functioning, helping doctors diagnose a medical problem and a corresponding treatment. Without getting too involved in the chemistry and physics of how antimatter is produced, just remember that it is real, but scientists believe it exists in relatively small amounts when compared to real matter. So don't worry about all of the real matter interacting with antimatter and going away.

Cosmic Rays

Cosmic rays are high-energy particles that come to Earth from outer space. The term *cosmic ray* is a bit misleading in that more than 99% of cosmic rays are solid particles of normal matter. There are low, intermediate, and high-energy cosmic rays. The compositions of cosmic rays are mostly made up of normal matter such as protons, alpha particles, electrons, and gamma rays, but some are made from antimatter.

Figure 1.9
Artist's Concept of Cosmic Rays Hitting the Earth

Scientists believe that low-energy cosmic rays come from supernova explosions. Higher energy cosmic rays are believed to come from the centers of extremely bright galaxies. But what really creates them remains a mystery.

High-energy cosmic rays are very rare and come from outside our galaxy. They have traveled millions of light-years before they arrive at Earth. In some cases, the cosmic ray might be magnetically charged, and these rays do not travel in a straight line. This is because the interstellar magnetic fields act upon them and cause them to move in strange paths. We would never know the point where they were created.

Cosmic rays were discovered in the year 1912 by Austrian physicist Victor Hess. He took a radiation detector with him on a balloon ride to a height of 17,500 feet above Earth's surface. When he did this, he discovered that the radiation levels increased the higher he went in the balloon. This proved that some of the radiation in Earth's atmosphere came from space. Mr. Hess originally called these radiation particles "penetration radiation." The term we use now, **cosmic rays,** began in 1925 by a United States physicist named Robert Millikan.

Interesting Fact

In 1970, the Apollo 13 astronauts saw flashes of white light with their eyes. These flashes of white light were caused by cosmic rays passing through their spaceship and into the water of their eyes.

Low-energy cosmic rays impact the Earth at a rate of several thousand rays per square foot of Earth's atmosphere every second. High-energy cosmic rays impact the Earth at a rate of one ray for every square mile of Earth's atmosphere every 40 years! They are very rare, so don't worry about getting hit by one.

Cosmic Ray Energy

The highest energy cosmic ray ever detected had the same energy as a tennis ball traveling at 180 miles per hour!

Dark Matter

Since dark matter makes up 27% of the universe, let's discuss how scientists know it exists. In some cases, the interstellar space between galaxies is filled with gas so hot, scientists cannot see it using visible light telescopes. This is because the frequency of this energy is well above that of visible light and transmits through space as X-rays or gamma rays. We will learn more about light (electromagnetic) energy in Module 5.

Figure 1.10
Mysterious Dark Matter?

Using an X-ray or gamma ray telescope, scientists study this hot gas and estimate how much matter exists. When they do this, scientists have discovered that in many cases, there must be many times more matter at this location than what they estimate. This matter that we can't detect is called **dark matter.** Scientists cannot "see" dark matter, but rather they can only detect the influence of the dark matter on light energy. It was given the label "dark," just like a dark room where you cannot see anything. Just because you can't see anything in the dark room does not mean that there is nothing there, such as pieces of furniture or a wall.

Basically, scientists know more about what dark matter is not, versus what it really is. They have concluded that:

1. Dark matter emits no light and cannot be seen directly, so it cannot be stars or planets.

2. Dark matter is not clouds of normal matter since it is not detectable through reflected light.

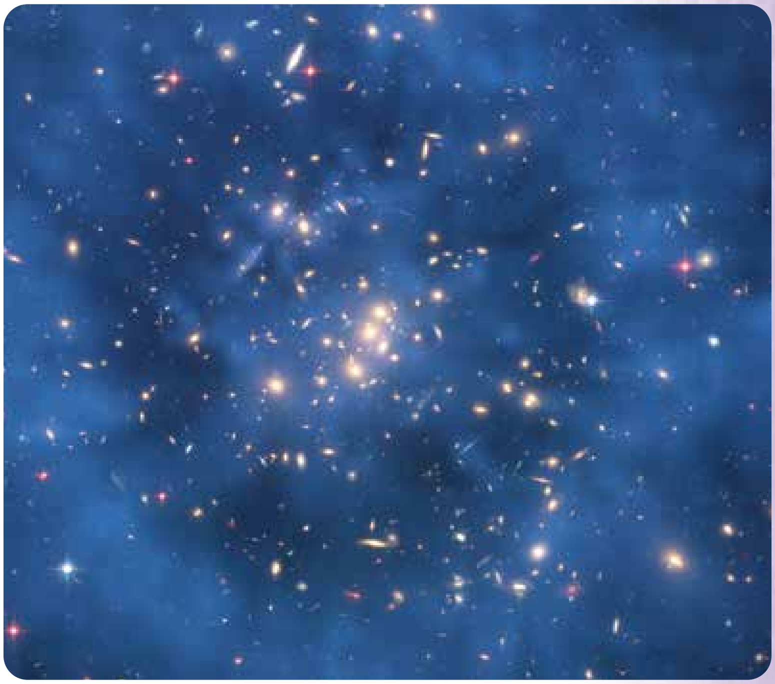
3. Dark matter is not antimatter.

4. Dark matter is not a black hole.

5. Dark matter interacts with the rest of the universe through its gravity.

Just what "dark matter" really is remains a true mystery of our wonderful universe. Just think of this matter as a different form than the stars and planets that we can see with our eyes and telescopes.

Figure 1.11
A "Dark Matter" Ring in a Galaxy Cluster Showing the Influence of the Dark Matter Gravity on Light Energy



Dark Energy

The remaining 68% of the universe is made up of **dark energy.** Just like dark matter, scientists know more about what dark energy is not, versus what it really is. Scientists estimate how much dark energy there is from our current knowledge of how it affects whether the universe is expanding or shrinking. Because of the forces of gravity, our universe should be shrinking, but because of new data provided by the Hubble Space Telescope showing distant galaxies moving away from us, scientists now have data showing that the universe is actually expanding. This implies that just as gravity is trying to pull the universe together, dark energy must be acting to push it apart. But just what is it?

Scientists like Albert Einstein theorized that empty space is really not empty, but there is something that exists in this empty space. These scientists have predicted that empty space can have its own energy. This energy would be the source of what has been labeled dark energy, and this energy would be causing the universe to expand.

Another explanation of dark energy could be that it is a new type of energy field that has an effect on the universe to cause it to expand.

Figure 1.12
Mysterious Dark Energy?

A final possibility is that our current knowledge of how gravity works is wrong. If the theory of gravity were incorrect, then how gravity affects the expansion of the universe and all of the normal matter would be different. If the theory were wrong, the solution to the dark energy problem may be a new gravitational theory.

As a final note, scientists currently cannot explain dark energy. They can just theorize its existence due to what they observe. We need to know whether dark energy is a property of space, a new type of energy field, or a new theory of how gravity works. To make this decision, scientists will need more and better data. Perhaps you will be one of these scientists who help figure out what makes up our wonderful universe!

Black Holes

Other fascinating objects in our universe are **black holes.** A black hole is a region in space where the force of gravity is so strong that nothing, not even light waves, can escape the pull of this force. Why is gravity so strong at a black hole? You will learn in Module 3 that the force of gravity depends on the mass of an object. At the center of a black hole, there is a small but very massive object. In some cases, this object is thought to be the result of a star exploding and then collapsing onto itself.

Here is an example of what scientists believe is at the center of a black hole: think of an object that has a diameter of 10 miles, but the mass of 20 of our Suns. This type of black hole is called a *stellar black hole.* There are other types of black holes too. *Primordial black holes* are believed to be the size of a single atom but have the equivalent mass of a large mountain.

Scientists can observe the effects of the black hole's gravity on the objects around them. These objects include stars and interstellar gases. For instance, if a star is orbiting a certain point in space, scientists study this motion to determine if the star is orbiting a black hole. Also, when a star is orbiting a black hole at a very close distance, high-energy light is produced.

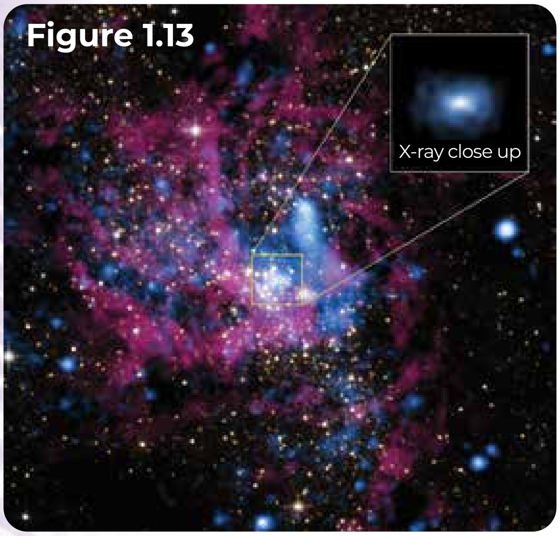
This high-energy light is captured by scientific instruments and the data are studied by scientists. Some of this high-energy light comes from superheated gases as they are captured by the gravity of black holes, and in the process, they emit X-rays. When these high-energy and concentrated X-rays are detected, the existence of a black hole is probably near.

Don't worry about black holes. They follow the laws of gravity just like all other objects we know. We are fortunate that there are no black holes near the Earth, and our Sun does not have enough mass to ever become a black hole. In the year 2000, scientists discovered the nearest black hole to Earth is 1,600 light-years away. That's really far!

X-ray of a Black Hole

At the center of the Milky Way galaxy, is a black hole called Sagittarius A* as seen in this picture. NASA's Chandra X-ray Observatory was used to measure the X-rays coming from the superheated gases as they are being captured by the gravity of a black hole.

Figure 1.13



The image above shows the X-rays, measured by the Chandra X-ray Observatory, in blue and infrared waves, measured by the Hubble Space Telescope, in purple and yellow.

The inset shows a close-up view of Sagittarius A* X-rays only. The X-ray close-up region is about 2,939,305,000,000 miles wide.

Think about this.

Astronomers have just spotted a star orbiting around a vast black hole. This star is called 47 Tuc X9. It sits in a cluster of stars about 14,800 light-years away from Earth. The orbit distance between the black hole and the star is about 2.5 times the distance between Earth and the Moon, and it takes the star only 28 minutes to complete one orbit. To put that into perspective, it takes roughly 28 days for our Moon to orbit the Earth traveling at 2,288 miles per hour. In the case of the star orbiting the black hole, the star is moving at nearly 8,000,000 miles per hour. This is about 1% the speed of light!

Wormholes

The concept of **wormholes** is really amazing. Have you ever taken a long car ride and just thought how nice it would be to get to your destination much quicker? For instance, driving from Cleveland, Ohio, to Williamsburg, Virginia, takes about 10 hours in a car. If you could use a wormhole, the trip might take you 5 seconds or less! With wormholes, a reduction in travel time is possible. Although wormholes have not been "seen" using our telescopes and scientific instruments, astronomers believe they could exist in the universe.

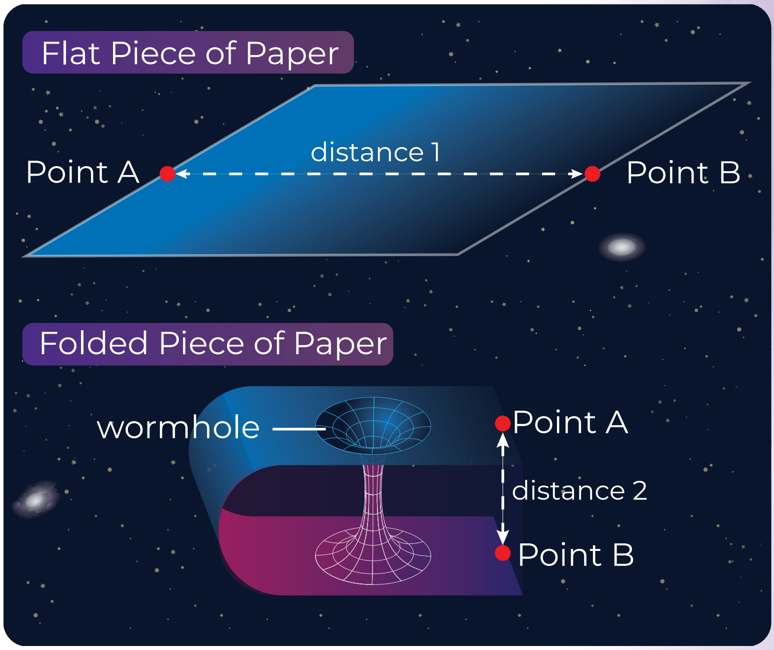
Scientists describe a wormhole as a passage or bridge between 2 places separated by extremely long distances. The name *wormhole* comes from the description of a worm crawling on the outside of an apple. It would take the worm a longer time to go from one side of the apple to the other if it went along the surface of the apple. But if the worm made a hole through the apple, it could get to the other side much faster.

In astronomical terms, extremely long distances are thought of as distances of a million light-years or more. Scientists believe that a wormhole could make traveling across these extremely long distances happen almost instantaneously. The idea came from the famous scientist Albert Einstein. The overall wormhole theory is rather complicated and will not be discussed in any great mathematical detail in this book. However, the wormhole theory is based on the theory that space and time are connected, and that space-time can bend. When it bends, points in the universe that are far away from each other suddenly become closer.

I know this sounds complicated, so to understand this better, let's come up with a simple example. Look at Figure 1.14. Imagine a piece of paper with points A and B on it. With the paper in a flat position, the points have some distance between them. If we take the piece of paper and fold it so that points A and B are closer to each other, the distance between them gets much smaller, and you could move from point A to point B through the wormhole.

If this were outer space, the wormhole would act like a bridge between points A and point B. The distance between these 2 points would be greatly reduced and so would the time required to go from point A to point B.

Figure 1.14
Visual Example of a Wormhole



Distance 2 is much less than distance 1.

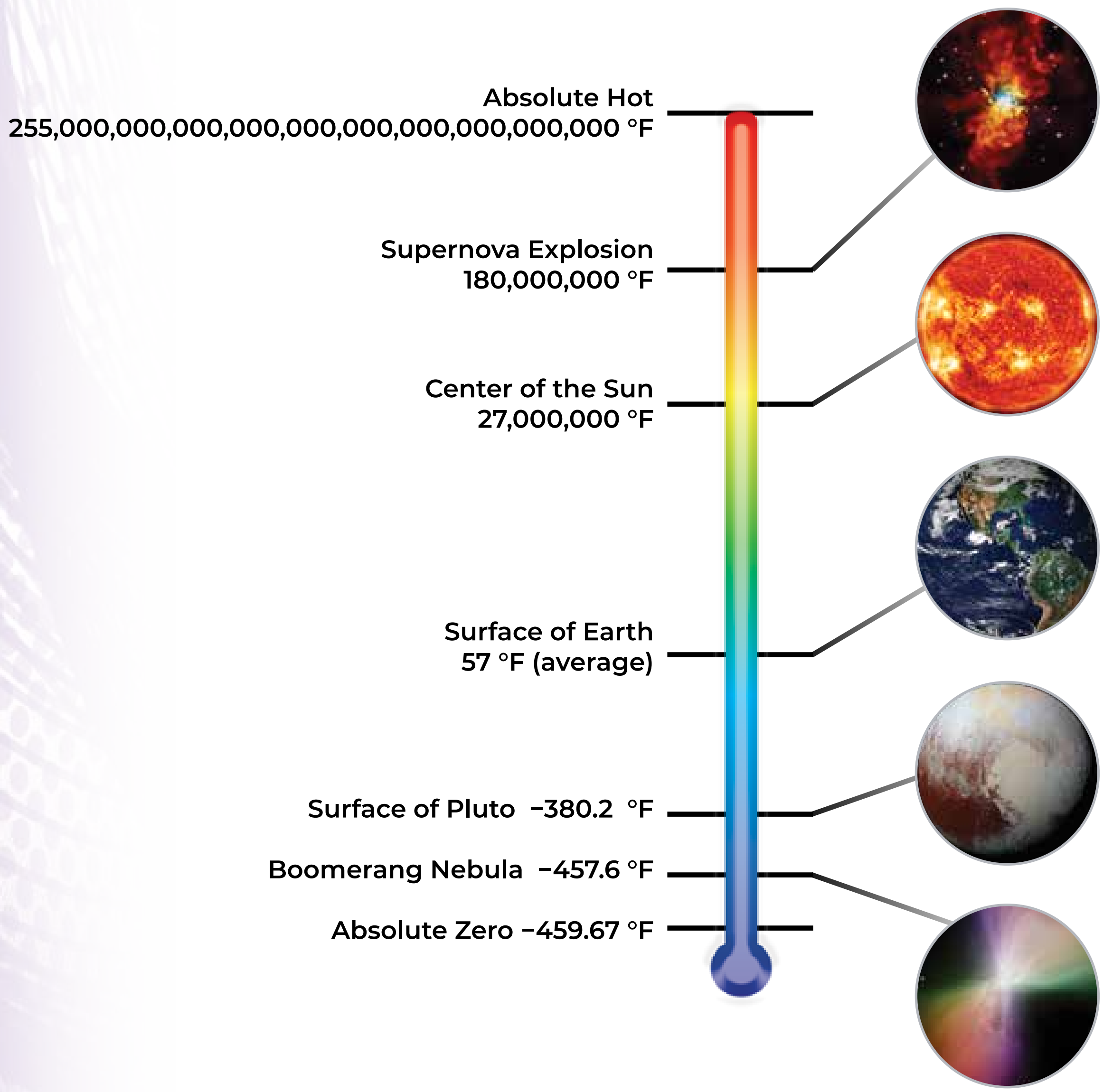
Temperature of the Universe

When we use the word *temperature*, we often think of how hot or cold an object is when we touch it. **Temperature,** therefore, is a measure of how hot or cold an object is, or in other words, how much thermal energy it contains. The unit of measurement is degrees Fahrenheit, °F. The magnitude of hotness or coldness is depends on how fast the molecules of an object are moving. We call this **thermal motion.** A hot object will have higher molecular speeds than a colder object, and it will contain more heat.

The coldest temperature possible is called **absolute zero.** This temperature is –459.67 °F. At this temperature, the speed of the molecules is zero. There is a total absence of thermal energy, as it is defined, at absolute zero and zero motion of the molecules in an object.

The highest possible temperature is called **absolute hot.** This temperature is defined based on the limits of theoretical physics, and some scientists place this value at 2.55×10^{32} °F. That is the number 255 with 30 zeros after it! At this temperature, the speed of the molecules can go no faster due to gravitational limitations.

Figure 1.15
Temperature Ranges in the Universe



As we study the solar system and the universe, we will find that the hottest known object is superheated interstellar plasma gas from a supernova explosion at 180,000,000 °F. The coldest known object is the Boomerang Nebula at –457.6 °F. As far as we know, all of the other known objects in our universe have a temperature that is between these 2 temperatures extremes. I will discuss in later modules how astronomers use the electromagnetic spectrum to calculate these temperatures.

On Your Own

1.1 Where does space begin relative to the Earth's surface? How is this location defined?

1.2 In your own words, where does interstellar space begin?

1.3 What is the definition of the universe?

1.4 What do scientists believe the universe is made of?

1.5 List 5 examples of normal matter.

1.6 What is the interstellar medium (ISM)?

1.7 List 2 examples of antimatter.

1.8 What are cosmic rays made of?

1.9 Explain in your own words what dark matter is. Include in your explanation how much of the universe is made of dark matter.

1.10 Explain in your own words what dark energy is. Include in your explanation how much of the universe is made of dark energy.

1.11 What are black holes, and how do scientists know that they exist?

1.12 How far away is the nearest black hole to Earth?

1.13 Does the concept of wormholes speed up or slow down the time it takes to travel in the universe?

1.14 What scientific theory allows the possibility of wormholes to exist?

1.15 What is temperature?

1.16 What is the term given to the coldest temperature theoretically possible? What is the value of this temperature in °F?

1.17 What is the coldest known object in the universe?

1.18 What is the term given to the hottest temperature theoretically possible? What is the value of this temperature in °F?

1.19 What is the hottest known object in the universe?

Where Do We Go From Here?

I hope that I have piqued your interest in learning about astronomy and the universe. It is amazing what types of objects and energy exist beyond the surface of the Earth. As we progress through future modules, it is my intent to discuss the history of astronomy and to explain the details of our solar system and details about what we know about the planets and other objects in the solar system.

You will learn about how the Sun and stars work, and also how scientists estimate how far a distant object is to Earth and whether it is moving toward us or away from us. We will learn about electromagnetic energy and why it is important to astronomers. You will learn how optical telescopes work and about the other type of telescopes astronomers use to study outer space. We will study galaxies, neutron stars, and pulsars. You will learn about star classifications and the definition of brightness and luminosity. At the end of this book, we will explore how stars are used to locate your position on Earth and how they can be used in navigation.

God created our wonderful universe. Let's go forward now and learn about it. By the time you finish this book, you will have a much more detailed knowledge of what is out there and how scientists believe it all works.