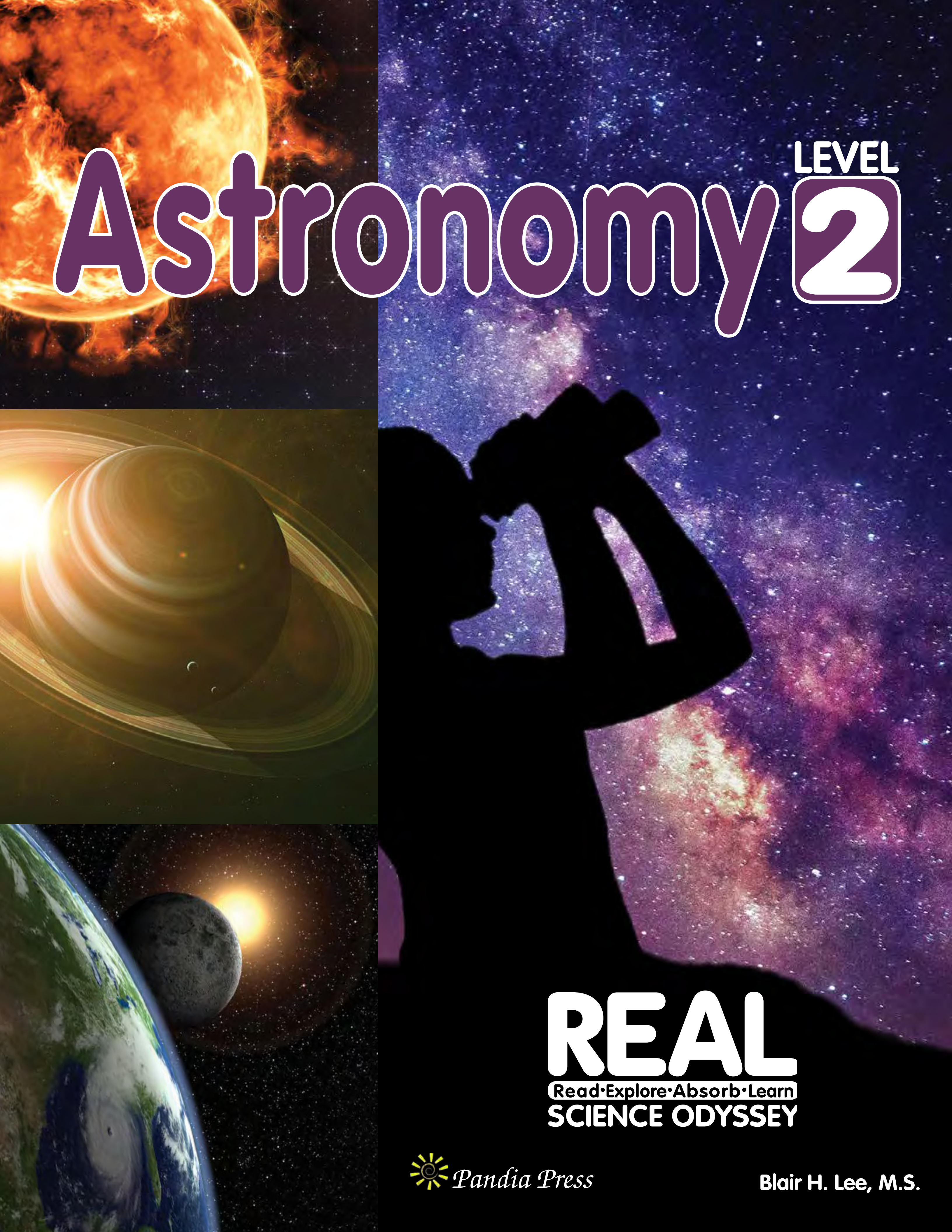
Astronomy
LEVEL 2
REAL
Read·Explore·Absorb·Learn
SCIENCE ODYSSEY
Pandia Press
Blair H. Lee, M.S.

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Chapter 1 - Introduction to Astronomy
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Dedication

This course is dedicated to the future stargazers in my family: Makenna, Savannah, and Dylan. And, as always Sean, thank you for giving me a reason to write it.

This course is also dedicated to all of you who have sat outside at night and dreamed about the possibilities of what is out there on planets far, far away.

REAL Science Odyssey

Astronomy 2

Blair H. Lee, M.S.

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Illustrations by Donald McIntire

ISBN: 978-0-9977963-3-9

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REAL Science Odyssey Astronomy 2

Read·Explore·Absorb·Learn

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FSS= Famous Science Series (research assignment)
SWYK= Show What You Know (chapter quiz)

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Introduction

While using this course you are an astronomer . . .

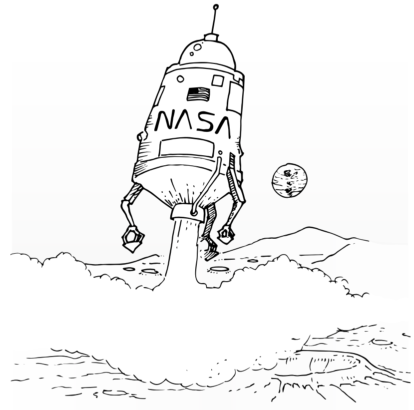
Let's start this course with a puzzle. Astronomers must love puzzles, as you will see. Everything outside the solar system is so far away (and even most of the solar system takes years to travel to), so how can astronomers know anything about the universe and what is in it? Take the time to stop and really think about the answer to this puzzling question. The answer is something you are surrounded by every day.

People have been puzzling about the universe for millennia. There are cave paintings showing galaxies, stars, and planets. There are ancient texts entirely devoted to explanations about astronomy. As you will learn while studying this course, even with all the curiosity about the stars over the centuries, most of the science facts, models, and theories explaining the science of astronomy were discovered and worked out during the past 500 years. Have you figured out the puzzle yet? You are going to have to wait, like an astronomer of old, for the answer in Chapter 1.

This course starts with an explanation of the tools astronomers use to study the universe. It is important when learning about an area of science to understand the tools scientists use to acquire knowledge about the area of science being studied. After that you will learn how the universe started and how it has been expanding and evolving since its beginning 13.82 billion years ago. Next, you will learn about stars and how different elements are made in them. This course starts big and then telescopes down to focus on the solar system and how it formed. You will learn about the sun, the planets in the solar system, and why there are two distinct types of planets: rocky planets and gaseous planets. Finally, the focus will be on our own planet Earth and its moon. This final section looks at mapping, how Earth and the moon formed, and how Earth and the moon move through space.

Introduction

Astronomers use math . . .



Have you ever wondered why you have to learn math? Or maybe you love math and you wonder why I would ask such a silly question. Whether you love math or not, when you study astronomy, you have the opportunity to apply the math you spent all those years studying. That is because astronomers use math to help them understand how the universe works.

To be an astronomer, you must be able to apply math to the science of astronomy. Many of the questions asked by astronomers can be answered with a mathematical equation. If that sounds daunting, don't worry, in this course everything is explained using words as well. When you encounter these equations, like the one explaining gravity or Newton's 2nd law, give it a try and really think about what each part means in the math equation. With some practice, you might find you prefer using the math equations. Using a math equation instead of words to explain something is like using an abbreviation. An important part of studying science in middle school and high school is learning how to use applied math and math equations, just like astronomers.

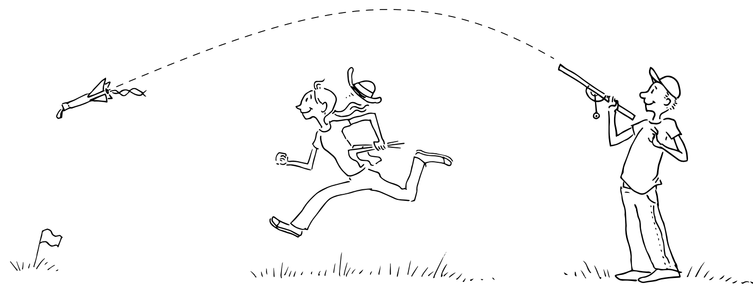
Astronomers use the metric system . . .

The metric system is used in every area of science; this astronomy course is no exception. It is important that all scientists use the same system of measurement. The purpose of science is to explain how the natural and physical world (and in the case of astronomy—the universe) works. To understand this, scientists past and present from all over the world, build on other scientist's research and discoveries. It is important that scientists use a standardized system of measurement. The metric system was chosen as the standard, because it is the easiest to use. That is because it is a base 10 system. I think you will agree it is much easier to divide and multiply by 10 than by 8, 12, or 16.

In most cases, this course also gives measurements in the U.S. system of measurement. But why not work to learn the metric system. Working with the metric system is important in astronomy, where you will encounter new units of measurement, such as the light-year, that are parts of compound units. A compound unit is a unit that consists of more than one unit. The compound units used by scientists have metric units incorporated into them. A light-year, for example, measures the distance light travels in a year in meters per second. No astronomer, or student of astronomy, wants to have to convert that unit to feet or yards per second. What a hassle. If the metric system causes you problems, you can use a conversion calculator on a cellphone app or online. Or, you can just stick with it, and before you know it you will be an expert at the metric system, too.

Introduction

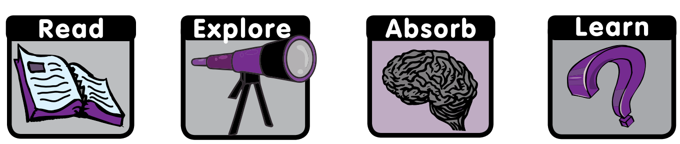
Astronomers use scientific models . . .



If you do not know what a scientific model is, you will by the end of this course. A scientific model is a simplified representation of a real system. You have probably been unknowingly building and using scientific models most of your life. Have you ever launched a model rocket, made a papier-mache volcano erupt with baking soda and vinegar, flown a paper airplane across a room, built a spaceship out of Legos, or looked at planet Earth on a globe? All areas of science use scientific models. Using scientific models, scientists are able to study large complex scientific principles and systems. They are critically important to astronomy, where often what is being studied is very far away, very large, and/or happened billions of years ago. Woven throughout this course are labs, exercises, and activities that will help you learn how to interpret, develop, and understand scientific models. At the same time you are learning how scientific models work, you will be learning about astronomy. You might be surprised how a model that focuses on one aspect of a large system can help you understand the entire system better.

Astronomers use systematic study . . .

Scientists study and apply the scientific method systematically. They pursue knowledge through reading, observation, research, and careful record keeping.



This course is a systematic study of astronomy. There are elements and methods of learning that you will find in every chapter. You will begin by reading one of the 12 lessons in the course. You will explore what you read, and build on it with hands-on labs and activities. Next, it's your turn to research the subject matter and further absorb the material through the Famous Science Series. Here you research scientists who made advances in this area, or maybe you will study famous discoveries. Finally, it's time to demonstrate what you have learned in Show What You Know.

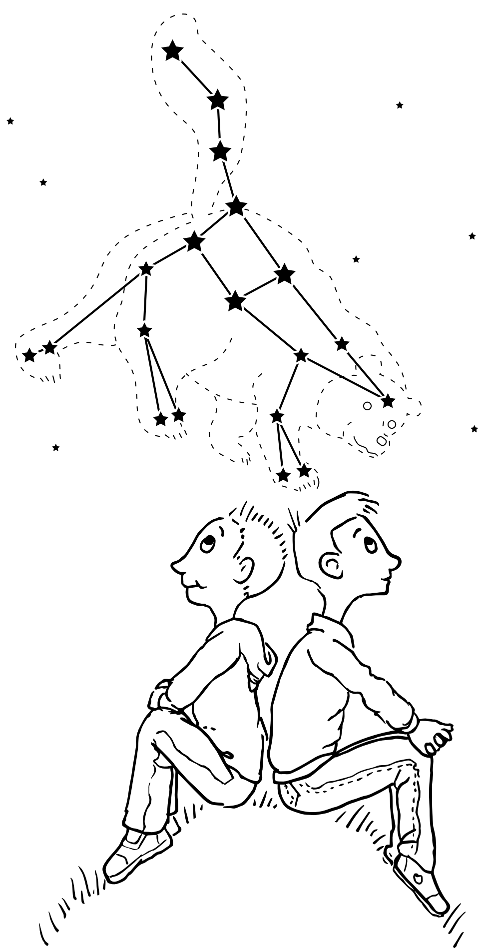
Introduction

Astronomers are interested in learning about the universe and all that is in it . . .

Whether it is why there are seasons, what stars are made of, where the elements that make matter came from, or what conditions are needed for there to be life on another planet, astronomers find the study of the universe and everything in it fascinating. Science is best learned where there is a thoughtful pairing of theory with labs and activities that apply that theory. This requires some sitting while you learn the theory. Then it requires you to get up and actively participate in hands-on work as you apply the theory you just learned.

I hope you take the time this year to go outside at night and look at the stars, moon, and planets, imagine what might be out there in the vast universe, and maybe even close your eyes one night and wonder if on another planet somewhere there is an astronomy student, like you, wondering about life out there far, far away.

Astronomy compels the soul to look upwards and leads us from this world to another. –Plato



Unit I: Universe and Cosmology

Unit I: Universe and Cosmology

Chapter 1: Introduction to Astronomy

The Universe

by Sean Lee

I am everything
Blue and black
From meteors to stars

Look up at me
I am the sun that sparkles off the moon
And the street lamp that shines above your home

Look back down
See dogs
See naughty kittens who lost their mittens

Then look back up on a rainy day
While thunder booms and lightning hurls

Look inside a house on a cold night
A blazing fire burning bright

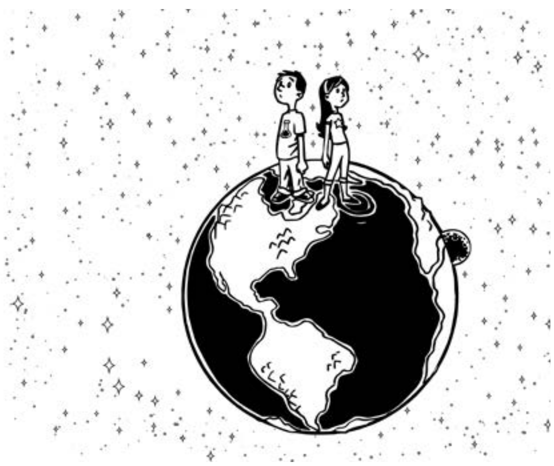
Look back up
I am swirling, whirling, twirling
Sparkling and dancing
Beyond and being

I am the universe
The thing you see
The universe
Everything

Read

What Is Astronomy?

Chapter 1: Lesson



Have you ever looked up at the sky at night and wondered what was out there? Do any of the stars have planets orbiting them—planets with life? If there is life on those planets, would it be like the life on Earth? Maybe you have been out collecting rocks. Do you wonder how those rocks were formed? If you have wondered about these, you have been thinking about astronomy. Astronomy is the study of the universe.

The universe you live in and the earth you live on are constantly changing. In this course you will learn about changes that have happened to the universe and Earth in the past, changes that are happening now, and predictions about what will happen in the future.

Each principle, theory, and law in science started with a question. That is how most scientific discoveries start. Take some time to think of five questions you have about astronomy. Some of the questions I have are:

1) Are there organisms on any of Jupiter's moons? 2) What is the Hubble Space telescope seeing now? 3) Can black holes be used for time travel? 4) As the moon moves farther away from Earth, tides are gradually becoming less dramatic. What would happen if there were no tides? 5) What will Earth be like in one million years?

What are your 5 questions?

1)

2)

3)

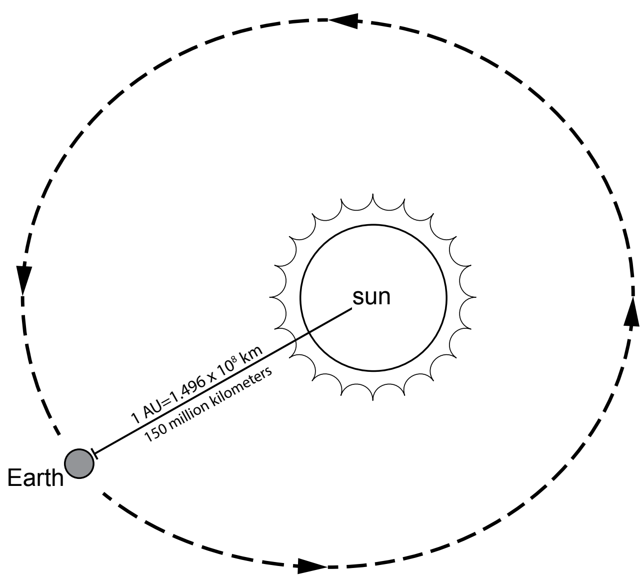
4)

5)

Astronomical Distances

How far is it from your big toe to your heel? How far is it from where you are sitting to the refrigerator? How about to the grocery store? What units did you use in your answers: centimeters (inches), meters (feet), or kilometers (miles)? Did you notice how you changed the units you use depending on the distance? It doesn't make sense to measure the length of your foot in kilometers or the distance to the grocery store in centimeters, does it? Different units are used for different amounts of distance. Distances in space are so large that astronomers use special units to measure those distances. They use two different units, **astronomical units** and **light-years**.

Astronomical units measure distances within the solar system.



- The abbreviation for astronomical unit is AU.
- The average distance between Earth and the sun is 1 AU.
- 1 AU = 1.496×10^8 km: Earth is an average distance of 1.496×10^8 km from the sun. That's about 150 million km.

The solar system is big, but the universe is so much bigger that astronomers need a different unit to measure distances in it. Astronomers use the speed of light to measure distances in space. Light travels at a speed of 3×10^8 m/sec. Light is FAST! That is a speed of 300,000 km/sec (186,282.4 miles per second). In one year, light travels 9,460,528,000 km (5,878,499,817 miles).

The unit astronomers use to measure distances in space is the light-year. A light-year sounds like it measures time, but it doesn't. One light-year measures the distance light travels through space in one Earth year.

Now, it's your turn

The Milky Way Galaxy is about 100,000 ly across in diameter. How many years does it take light to travel across the Milky Way Galaxy?

Light-year measure distances in the universe.

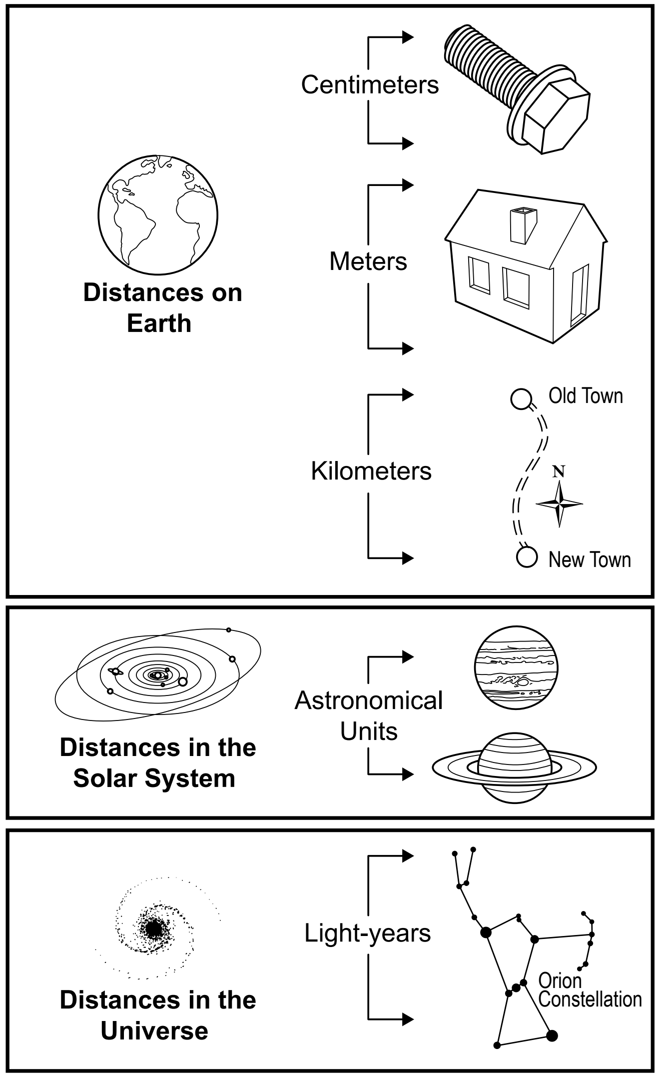
- The abbreviation for light-year is ly.
- The distance of one light-year is 9,460,528,000 km

Calculations with Light-years

Example: When you look at stars it is like traveling back in time. It takes 4.2 years for light from Proxima Centauri, the nearest star to Earth, to get here. Proxima Centauri is 4.2 light-years away (4.2 ly).

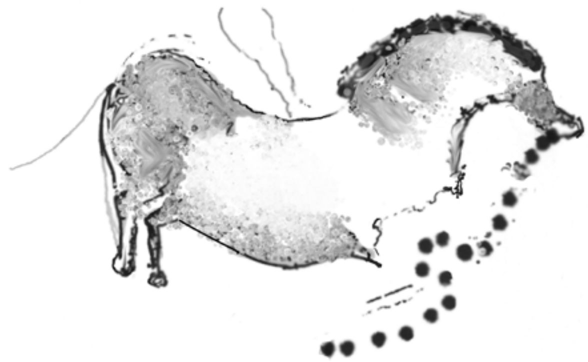
The unit of measurement used depends upon the amount of distance.

Light-year measures the distance light travels through space in one Earth year.



What units should you use?

Circle the appropriate units for each of the measurements below. Write the unit abbreviation.	
The distance between the planet Saturn and the sun: What is the abbreviation for this unit? _________	centimeters meters kilometers astronomical units light-years
The distance between your two eyes: What is the abbreviation for this unit? _________	centimeters meters kilometers astronomical units light-years
The distance between the star Vega and the star Betelgeuse: What is the abbreviation for this unit? _________	centimeters meters kilometers astronomical units light-years
The length of a room: What is the abbreviation for this unit? _________	centimeters meters kilometers astronomical units light-years
The distance between New York and Minnesota: What is the abbreviation for this unit? _________	centimeters meters kilometers astronomical units light-years



Paleolithic cave paintings discovered in France may chart galaxies in space.

The oldest astronomical records are 30,000 years old. Drawings found in caves in France are thought to be of a **galaxy** (a large group of stars) called the Pleiades Galaxy. During the past 30,000 years astronomers have learned many things about the universe. What are the modern tools that help today's astronomers study the universe?

The Astronomer's Toolbox

Let's Shed Some Electromagnetic Radiation on the Universe

Scientists use experimentation, observation, and reasoning—the **scientific method**—to learn how things in the physical world work. When biologists study biology they observe organisms. When chemists study chemistry they experiment with chemicals, atoms, and molecules. When geologists study geology they experiment on and observe Earth.

What about astronomers? What do they use to learn about space? How do astronomers study things that are so far away? How do they know what the sun is made of, the temperature of a star, what the shapes of galaxies are, and how the expanding universe got started? They cannot touch or travel to planets, stars, and galaxies. Can you think of anything that comes to Earth from space?

Did you answer light? You are partly correct if you did. The complete answer is **electromagnetic radiation**. Light is the electromagnetic radiation that is visible. Scientists do study the light, but they don't stop there. They study all the electromagnetic radiation coming to Earth. Electromagnetic radiation is made up of electric and magnetic disturbances that travel as waves through space carrying energy and information.

How do astronomers know what they know about stars and planets?

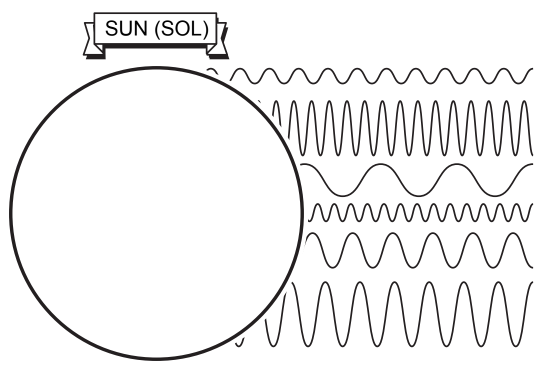
Astronomers use electromagnetic radiation to understand the universe.

Electromagnetic radiation is the most important tool in the astronomer's toolbox. It carries energy and information from its source to astronomers on Earth.

The unit of distance for the universe should really be "electromagnetic radiation-year," because all electromagnetic radiation travels through space at the speed of light.

All objects in the universe, including Earth, the sun, this book, and even you, radiate electromagnetic radiation.

The sun is a source of electromagnetic radiation.

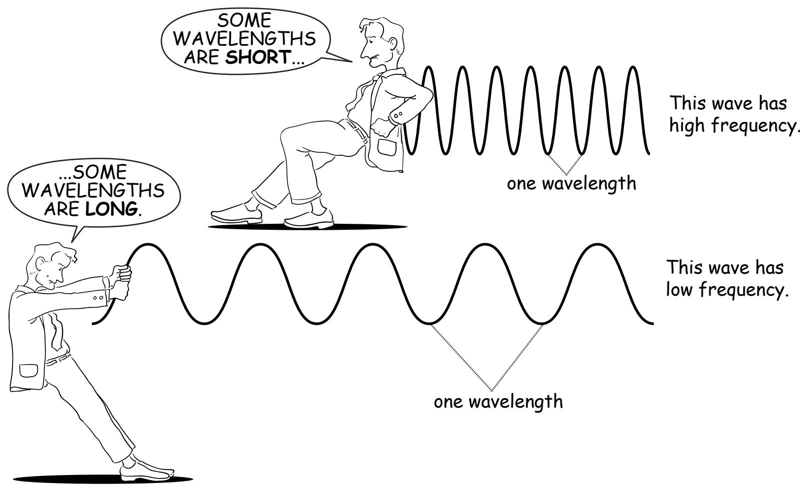


Astronomers use four properties of electromagnetic radiation to understand the universe.

Scientists get information about the source of the electromagnetic radiation from the distance between the waves.

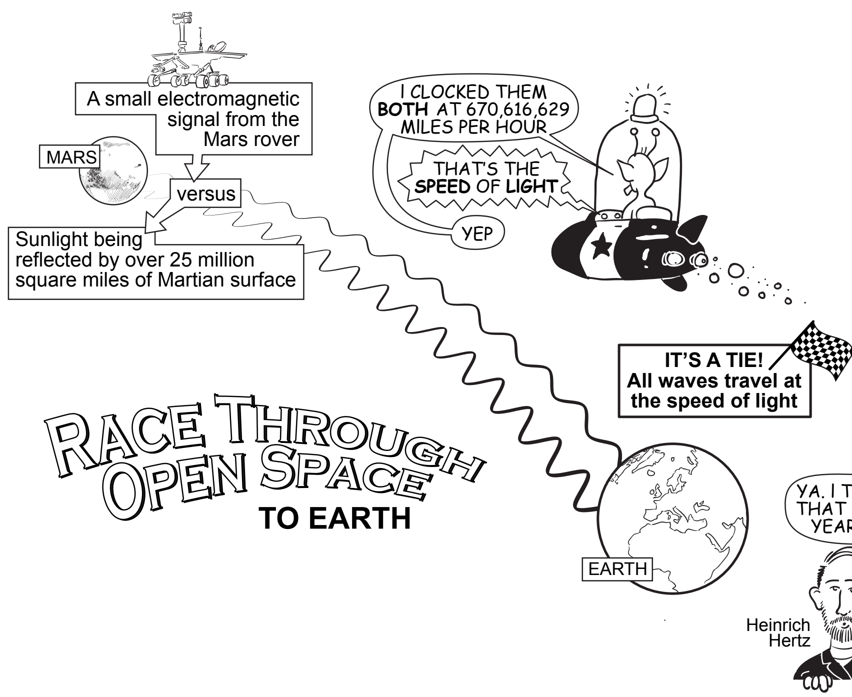
1. **Wavelength**: Have you ever thrown a rock into water and watched waves move away from where the rock went into the water? Like water, electromagnetic radiation travels in waves. The waves can be close together or far apart. Scientists get information about the source of the electromagnetic radiation from the distance between the waves. The distance from the peak of a wave to the peak of the wave right next to it is called wavelength. A star emits electromagnetic radiation in a range of wavelengths.

2. **Frequency**: If you understand how wavelengths work, frequency shouldn't give you any problem. Frequency is the number of wavelengths passing a given point every second. When wavelengths are short, the frequency is high. When wavelengths are long, the frequency is low. Frequency is inversely proportional to wavelength.



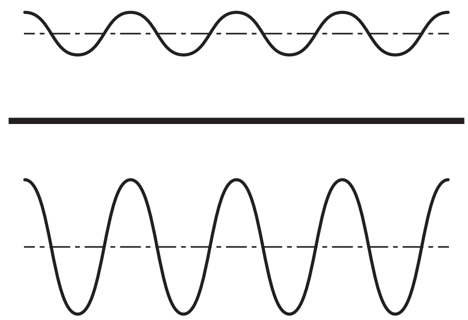
3. **Speed**: All wavelengths of electromagnetic radiation travel through space at a constant rate, the speed of light. Using the speed of light, scientists can calculate distances for objects far from Earth.

In 1887, Heinrich Hertz (physicist) definitively proved that in open space, all electromagnetic waves move at the speed of light.



4. **Amplitude**: Amplitude is the height of the wave. Waves traveling through space have different heights, just like those traveling along the surface in the ocean. Astronomers use the amplitude of a wave to measure how much energy a wave carries.
    - If a star emits wavelengths with high amplitude it comes from a high energy source.
    - If a star emits wavelengths with low amplitude it comes from a low energy source.
    - Two waves can have the same wavelength but have different amplitudes.

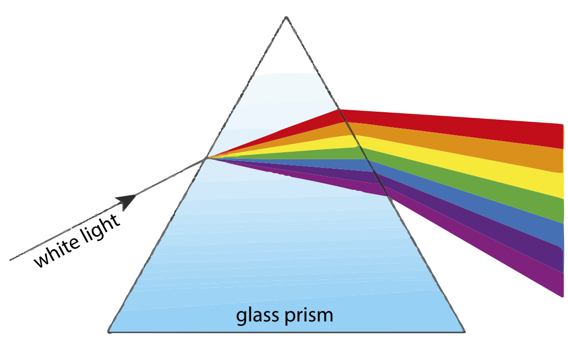
These waves have the same wavelength but different amplitudes. The wave on the top comes from a lower energy source than the wave below it.



Electromagnetic Spectrum

When all the different wavelengths are put together they form the **electromagnetic spectrum**. Astronomers use different parts of the electromagnetic spectrum to study different things in the universe. For example, different wavelengths are used to study black holes than are used to determine the concentration of water in a comet.

The wavelengths which make light are in the middle of the electromagnetic spectrum. Scientists use special instruments to detect wavelengths which are too long or too short to be seen.



Astronomers use the electromagnetic spectrum to:

1) learn the chemical composition of stars and nearby planets
2) learn the age of stars and the universe
3) learn the temperature, mass, and gravity of stars
4) learn the direction of movement of stars, galaxies, and the universe
5) detect the speed of the movement of stars, galaxies, and the universe
6) detect the presence of planets orbiting distant stars
7) detect the presence of black holes
8) map the universe

Telescopes

Telescopes are able to capture electromagnetic radiation across the electromagnetic spectrum. There are different types of telescopes that look at different wavelengths of the electromagnetic spectrum. The one an astronomer uses depends on the wavelengths he wants to observe.

The Australian Astronomical Observatory in New South Wales is a good place to look at the stars.

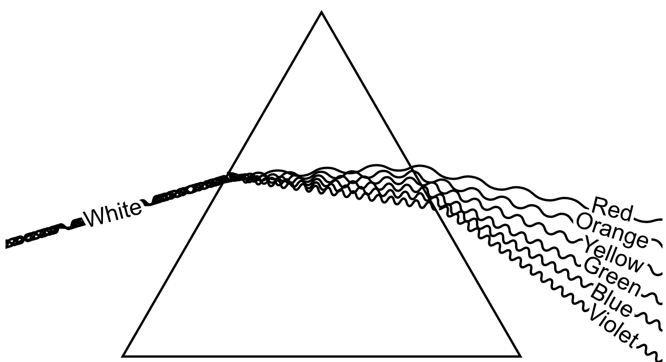
Earth is surrounded by a mixture of gases called its **atmosphere**. Most wavelengths of electromagnetic radiation either cannot get through Earth's atmosphere or are blurred by it. To decrease or avoid the interference of the atmosphere, scientists use special high-altitude locations for their telescopes, or they look through them above the atmosphere. At an elevation of 5,640 m (18,500 ft), the University of Tokyo Atacama Observatory located in the Atacama Desert in Chile has the highest elevation of any permanent observatory on Earth, while the International Space Station orbits at an altitude between 330 km (205 miles) and 435 km (270 miles).

The Hubble Space Telescope orbits 559 km (347 miles) above Earth. It can measure wavelengths from 0.1150 to 2 micrometers. This range of wavelengths includes and is larger than the range for visible light.

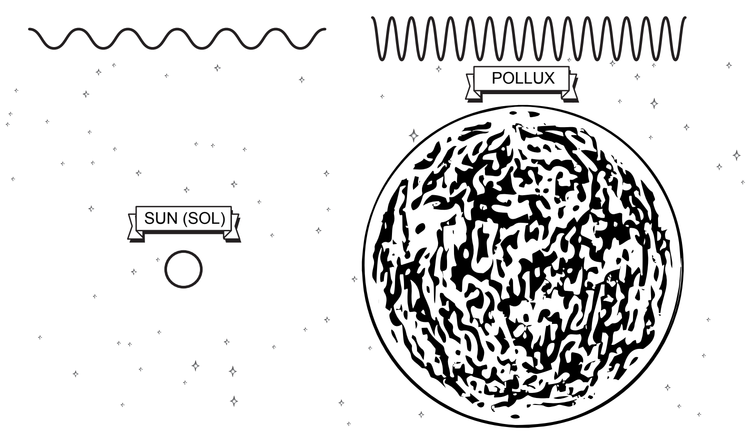
Astronomical Spectroscopy

All objects have their own electromagnetic spectrum. Astronomical spectroscopy studies the electromagnetic spectrum radiated by an object to learn about its temperature, mass, age, gravity, and chemical composition.

The wavelengths of electromagnetic radiation an object radiates depend on many factors, such as the chemical elements it is made of, its mass and temperature, and its relative movement.



The sun and the red giant, Pollux, have different electromagnetic spectrums because of differences in their temperature and chemical composition.



Space Exploration

On the International Space Station (ISS), scientists study more than just the electromagnetic radiation of objects in space. Over 400 experiments have been conducted on the ISS.

Scientists on the ISS have been studying to see if humans can live in outer space, where the gravity is low.

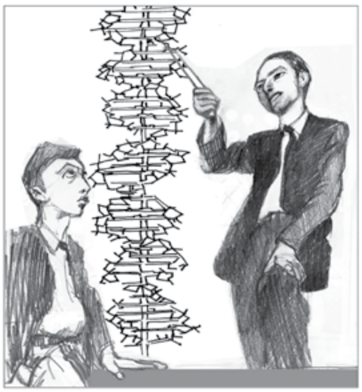
Unmanned (no people onboard) spacecraft are launched into space with scientific instruments on them. Two unmanned space programs are the Voyager program and Mars Science Laboratory. The Voyager program has two unmanned spacecraft, Voyager 1 and Voyager 2. Voyager 1 was launched in 1977 and has traveled farther from Earth than any other man-made object. The Mars Science Laboratory is on an unmanned vehicle called Curiosity. Curiosity is a rover that drives itself around Mars making observations.

Wow, think of everything scientists have learned just from studying the electromagnetic spectrum!

Explore

Model This: Investigating Shadows

Chapter 1: A Long-term Lab



Watson and Crick constructed stick-and-ball models to test their ideas about the structure of DNA.

Scientists have another tool they use to study the universe. It is called **scientific modeling**. Scientists in every area of science use scientific models. A scientific model is a simplified representation of a real system. Scientific models make it possible to study large, complex scientific principles and systems.

Making a Scientific Model

Scientific models use the scientific method. Scientists develop models using data and observations from experiments. They use deductive reasoning, bringing together the data, the observations, and their general knowledge of science when they develop a scientific model. It is similar to what Sherlock Holmes does when solving a crime.

The Purpose of a Scientific Model

Scientific models are developed to explain observations and data that has been collected, and to predict what will happen in the future.

All Scientific Models Must . . .

1) explain the data and observations, and
2) predict new observations as they come up

Scientific models are utilized only as long as they are accurate.

A scientific model is used as long as it continues to explain and accurately predict scientific observations and data. If there comes a time when the scientific model no longer does that, changes are made to the model or the model is discarded in favor of a new model.

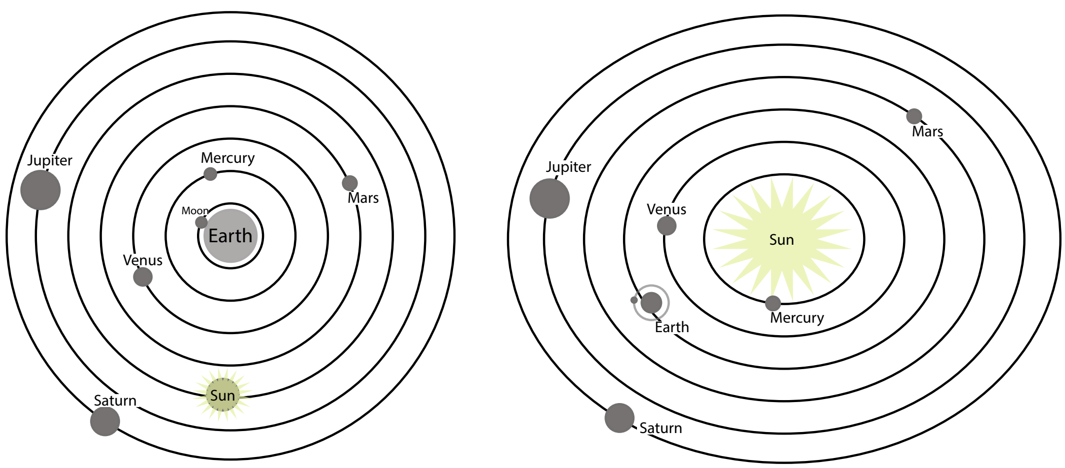
In this course, you are going to learn how to develop and understand scientific models by conducting a long-term experiment. You will look at how experiments are used to test scientific models.

Chapter 1: A Long-term Lab *(continued)*

How Do Scientists Use Scientific Models?

- Astronomers study the universe. They use scientific models because what they study is too far away to perform direct experiments on.
- Astronomers create scientific models based on results from experiments done on Earth. They use the results when developing scientific models.
- Geologists study Earth. They use scientific models when studying things that cannot directly be looked at, such as Earth's core.
- Oceanographers study the ocean. They use scientific models when studying the ocean's depths.
- Scientists also use scientific models when studying weather, climate, medicine, genetics, and evolution.

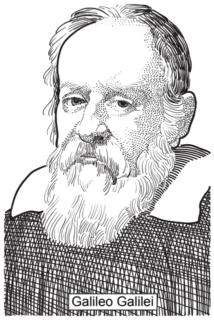
You probably already know that Earth revolves around the sun. But for over 1000 years people thought the geocentric model was correct. The **geocentric model** puts Earth at the center of the solar system with the sun and planets revolving around it. Geo is Latin for *earth*. There was a time people believed Earth was the center of the universe, and the geocentric model fits that belief. The question is: does it fit all the observations? If a scientific model does not hold true for all the observations, then a new model is needed that does fit the observations.



Geocentric and heliocentric models of the solar system

The **heliocentric model** places the sun at the center of the solar system with the planets revolving around it. Helio is Latin for *sun*. The heliocentric model was first proposed in the third century BCE by Aristarchus of Samos, but people didn't believe it was correct. It wasn't until 1513 CE that Nicolaus Copernicus presented a mathematical model which proposed that the planets revolve around the sun. It was a bumpy road for the heliocentric model. When

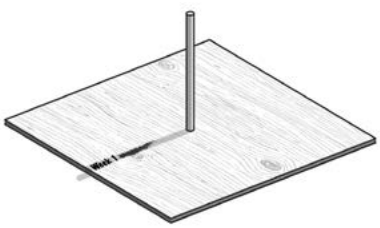
Chapter 1: A Long-term Lab *(continued)*



the Catholic Church first became aware of Copernicus's model, they supported it. Sixty-three years after his death, when Galileo Galilei published his findings supporting a heliocentric model, the Church denounced him. Eventually, they put Galileo under house arrest.

If you think about it, you can understand why people thought the geocentric model was correct. It doesn't seem like you are standing on a ball rapidly spinning around the sun, does it? It certainly looks like the sun and moon are moving across the sky, doesn't it? Can you imagine the arguments about this back in Galileo's time? It is extremely difficult to make observations that establish whether the sun orbits Earth or Earth orbits the sun. Scientists choose what experiments to perform based on whether the experiment will help them get a better understanding of what they are researching.

Scientific models use the scientific method. They are based on experimentation, observation, and deductive reasoning. There are two types of observations used for a scientific model. First there are the observations used to design the model. Scientists use these observations along with deductive reasoning to determine the parameters (the defining conditions) for the model. There are also observations that come out of experiments conducted that validate or disprove a model.



A scientific model to investigate the angle of sunlight striking the earth.

Investigating Shadows Long-term Lab

This long-term lab looks at the angle of sunlight striking the earth. Light comes from the sun in waves. The waves strike the earth at different angles depending on the position of the sun relative to Earth. Consider whether shadows change during the course of the day, or even the course of the year. What would you expect if the heliocentric model were correct? What would you expect if the geocentric model were correct? It turns out that shadows would stay the same length at the same time of day throughout the year if either model was correct. As you make your measurements, what will you find? If the shadows change in length over the course of the year, what could account for this? You will be learning about the missing pieces of this puzzle as you make your observations this year. At the end of the year, you will be able to explain how the changing length of shadows is consistent with a slightly modified version of the heliocentric model—a version which is more complete and more accurate than merely saying that Earth orbits the sun in a circle.

The heliocentric model states that Earth revolves around the sun. Earth's movement around the sun is more complicated than that, however. As you will learn later in this course, Earth does not orbit the sun in a circle, and Earth's axis of rotation is at an angle. This modeling experiment gives evidence for

Chapter 1: A Long-term Lab *(continued)*

both of those. When you get to those sections in this course, there will be information that discusses the observations you make while conducting this lab. Most science research takes many days (even years) of investigation. This is a long-term lab that takes several months to complete and it will be referenced several times throughout this course.

The figure-8 path the sun makes in the sky as observed from a fixed point is called the analemma.

If you monitor the sun's apparent position at the same time of day for an entire year, you will be able to graph the **analemma**. A graph of the analemma shows the position of the sun in the sky as measured at the same time from the same position over the course of an entire year. You will find out why the sun's analemma is a figure-8 on its side, later in the course.

Materials

- Flat plywood of any thickness– approximately 60 cm x 60 cm (24 in x 24 in). Size is not critical, it may be square or rectangular.
- Wooden dowel– approximately 0.6 cm (¼ in) thick x 25 cm (10 in) long
- Drill with drill bit equal to thickness of the dowel. If you do not have access to a drill you could use glue to attach the dowel to the plywood (the project will not be as sturdy).
- Wood glue
- Permanent marker
- Drawing tools or camera
- Protractor or string and ruler (optional)

Procedure

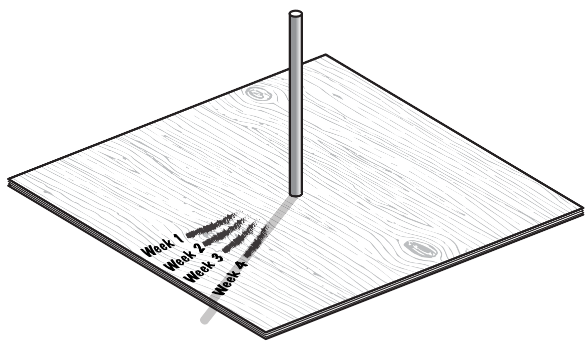
For this experiment you will monitor the shadow cast by the dowel when the sun strikes it at the same time of day for several months.

NEVER LOOK DIRECTLY AT THE SUN! Doing so is very harmful to your eyes.

1. Find and mark the approximate center point of the plywood. With help from your parent or teacher, drill a hole as straight up (perpendicular) as possible.

Chapter 1: A Long-term Lab *(continued)*

2. Insert the dowel into the hole. Be sure it does not protrude beyond the bottom of the plywood, causing the plywood to not lay flat. Use a little glue to help hold the dowel in place.
3. Find a time of day when the sun shines against a permanent structure. The side of your house or a wall is perfect.
4. Place the project up against the wall so that the dowel casts a shadow on the plywood. You want to place the project against the wall always in the same position each time you observe the shadow throughout this long-term lab.
5. Today you will be completing Lab Sheet Part 1. Parts 2 and 3 will be completed later in the course after you have collected more data from your model. Complete the Hypothesis portion of Lab Sheet Part 1. Draw (or paste) a picture of the setup at the start of your project on the Data Sheet.
6. On the same day and same time each week for one year, place your project up against the same wall and trace the shadow you see with a marker. Start your tracing mark at the dowel and stop at the end of the shadow. Write the week number next to the shadow tracing. Make sure the project is in exactly the same position each week.



7. At the end of every month, draw (or paste) a picture of your project on the Data Sheet.
   Optional: Use a protractor (or string and ruler) to record the distance (in centimeters) that the shadow moved every month from its original position. (To measure a curved line with a string and ruler, lay the string over the curve you want to measure and mark the string, then measure the length of the string segment on the ruler.)
8. Complete the Lab Sheet Part 2 while completing Chapter 6. Complete Lab Sheet Part 3 while completing Chapter 11.

Helpful hints:

- You will need to adjust for daylight savings time by recording an hour earlier or later as appropriate.
- Mark your calender or set a reminder on your phone to make sure you are recording at the same time of the day and on the same day of the week.
- Don't worry too much if you miss a week or two over the year. You should still be able to observe the overall result.
- This lab takes 12 months to complete. It is a lot of fun to chart your own analemma!

Model This: Investigating Shadows

Chapter 1: A Long-term Lab - Data Sheet p. 1

Name______________________________ **Date**____________

Record your results on this data sheet every month for a year.

Picture of model setup	Picture of model setup
Start	End month #1 The shadow moved_____cm.
End month #2 The shadow moved_____cm.	End month #3 The shadow moved_____cm.
End month #4 The shadow moved_____cm.	End month #5 The shadow moved_____cm.

Model This: Investigating Shadows

Chapter 1: A Long-term Lab - Data Sheet p. 2

End month #6 The shadow moved_____cm.	End month #7 The shadow moved_____cm.
End month #8 The shadow moved_____cm.	End month #9 The shadow moved_____cm.
End month #10 The shadow moved_____cm.	End month #11 The shadow moved_____cm.
End month #12 The shadow moved_____cm.	

Model This: Investigating Shadows

Chapter 1: A Long-term Lab–Lab Sheet Part 1

Name____ **Date**_____________

Look for instructions for completing this lab sheet as you work through the course.

Hypothesis: Good scientists conduct experiments to validate or disprove their scientific models. Explain what you expect to notice as you monitor the shadow of the dowel on the plywood.

Part I–Observations to make today

What is coming to Earth from the sun that you are using for this experiment?

What do you observe about the sun's position in the sky over your house?

How do apparent changes in the sun's position affect shadows? (If you have never observed this, take the time today to observe how shadows change as the sun's position, as observed from Earth, changes over the course of the day.) Based on these observations, what do you think it means if there is a change in the position of a shadow measured from the same location at the same time of day over several months?

Model This: Investigating Shadows

Chapter 1: A Long-term Lab–Lab Sheet Part 2

Part 2–Answer these questions while completing Chapter 6

How is your chart on the plywood going? Are you starting to see an analemma?

Have you been tracking the sun's apparent movement across the sky? Why is it called the sun's *apparent* movement? What is really moving?

In Chapter 6, you learned how Earth orbits the sun. You learned that the shape of Earth's orbit is an ellipse, and that the sun's distance from Earth changes over time. How does this affect the speed Earth is moving during its orbit?

Ask another person to walk quickly across a room while you count to 10 with your eyes closed. When you get to 10, tell the person to stop. Open your eyes and note the location of the person in the room. Repeat this task, but this time ask the person to walk slowly. Open your eyes and again note the location of the person in the room. Did changing speed over the same time period affect the person's location?

Considering the simple example above, imagine that you are the sun shining on the person. When you open your eyes, will the position of the shadow you see be different or the same for the two locations? Apply this concept to the model explaining why a shadow cast by the sun changes position.

Why do you think the analemma circles back around to where it starts?

Model This: Investigating Shadows

Chapter 1: A Long-term Lab–Lab Sheet Part 3

Part 3–Answer these questions while completing Chapter 11

How is your chart on the plywood going? Is the analemma starting to appear?

For Lab 11, you monitored the sun's apparent movement across the sky. Draw a rough illustration of the sun's path over the course of the day. Does it look like an analemma? Like many things in science it takes more than one data set to really understand what is happening.

In this lab you have been monitoring the change in the angle and direction of the dowel's shadow as Earth orbits the sun. What did you learn about in Chapter 11 that would cause a change in the angle of a shadow cast by the sun? (Do not peek below. You can puzzle this out.)

Because of Earth's axial tilt and elliptical orbit (which causes Earth to speed up and to slow down) the location of the sun above the horizon changes during the year. Why does Earth's axial tilt cause the location to change? (Hint: Think about what is coming to Earth from the sun and how that changes during the year because of Earth's tilt.)

Circle the correct answer for the following questions:

The one-day graph of the sun's apparent movement across the sky is an arc. The arc is (lower / higher) in winter. The arc is (lower / higher) in summer. This is because the (angle of incidence of light from the sun / orbital speed) changes over the course of a year.

The day of the year when the arc is lowest is (summer solstice / winter solstice / equinox).

The day of the year when the arc is highest is (summer solstice / winter solstice / equinox).

Explore

It's a Big, Big Universe

Chapter 1: Activity

The Universe Is Really, Really BIG
Objects in It Are Really, Really Far Apart
Light Moves Really, Really Fast

The universe is so big, objects in it are so far apart, and electromagnetic radiation coming from those objects is moving so fast it is hard for people to imagine it. We do not have a good reference point. The biggest object you have ever encountered, whatever it is, would have to fit on Earth. But even the entire planet Earth is small on the cosmic scale. The sun is about 109 times larger than Earth. To imagine how much bigger that is, think if you had one watermelon. How much more space would 108 watermelons take up?

One of the problems with figuring out how big objects in outer space are is that they are so far away that they look much smaller than they are. Have you ever looked out the window of a plane when you were flying somewhere and seen how the cars look like ants from that distance? Or maybe you have noticed how much smaller a building looks from a few blocks away. The farther something is from you the smaller it looks. The objects you can see from Earth look small because their distance from Earth is so great.

You can't leave Earth, so you won't get to experience how big the universe is and how far apart objects in it are, but this activity will help. It will also give you a reference point for how fast the speed of light really is.

Materials

- Computer with Internet access

Procedure

1. Go to the following Web address and complete the activity on Smithsonian Museum's website:
   http://www.smithsonianeducation.org/idealabs/universe/index.html
2. Watch this 45-minute video to get a feel for the masses and distances in the universe:
   The Universe: How Big, How Far, How Fast, https://www.youtube.com/watch?v=1g2IGCLrAio

(If the link is broken, try entering " Video, The Universe: How Big, How Far, How Fast" into a search engine.)

Absorb

Famous Space Vessel

Chapter 1: Famous Science Series

In every chapter, you will find a Famous Science Series (FSS) assignment. FSS is a research activity. You will need to conduct research outside of this text (Internet, library, etc.) to answer the FSS questions.

In 2011, scientists at NASA sent the rover Curiosity to Mars. Curiosity was designed to conduct a long-term robotic exploration of Mars. One goal for Curiosity is to look for evidence of past or present life on Mars. There are certain elements and conditions scientists think are needed for life. Aren't you curious if Mars has them? So are scientists. Some scientists believe Mars will be the site of the first extraterrestrial colony. Just think: You could possibly visit Mars in the future!

1. Curiosity needed a launch vehicle to carry it to Mars. What is the name of the launch vehicle that carried Curiosity to Mars?

2. What date and time did it launch?

3. What date and time did it land on Mars?

4. Do the math: How long did it take Curiosity to get from Earth to Mars*?

* Don't forget about daylight savings time and leap years in your calculations.

Chapter 1: Famous Science Series *(continued)*

5. Curiosity is packed with scientific instruments that make observations about conditions on Mars. Below is a list of eleven of those instruments. Choose at least three of these to learn about. Write a short description of what each of these three instruments is studying.

Mars Science Laboratory Entry Descent and Landing Instrument (MEDLI):

Rover Environmental Monitoring Station (REMS):

Radiation Assessment Detector (RAD):

Dynamic Albedo of Neutrons (DAN):

Sample Analysis at Mars (SAM):

Chemistry & Mineralogy X-Ray Diffraction (CheMin):

Chemistry & Camera (ChemCam):

Alpha Particle X-Ray Spectrometer (APXS):

Mars Descent Imager (MARDI):

Mars Hand Lens Imager (MAHLI):

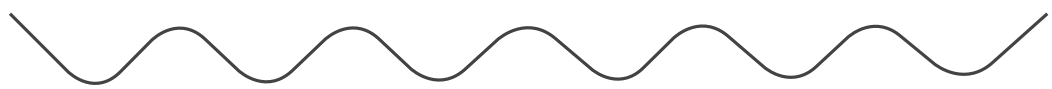
Mast Camera (MastCam):

Introduction to Astronomy

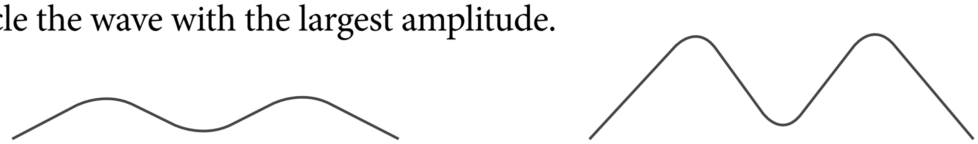
Learn

Chapter 1: Show What You Know

1. The line below has been drawn in a series of waves. Label one of the wavelengths.

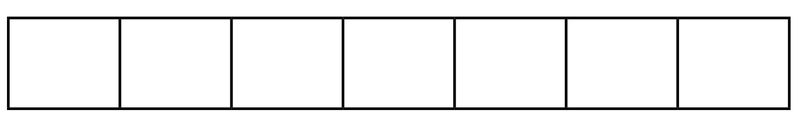


2. Circle the wave with the largest amplitude.



The wavelength is the same for these two waves. What does it mean that the amplitude is different?

3. Below is a series of boxes meant to represent the visible part of the electromagnetic spectrum. Color this in using the correct color pattern. Label the colors across the spectrum with the first letter of the color's name.



4. Earth is a planet in the Milky Way Galaxy. At the center of the Milky Way Galaxy is a supermassive black hole. This black hole is 28,000 light-years away from Earth. How long would it take to travel to this black hole traveling at the speed of light? For the mathematically inclined: How many km and miles away is this black hole? The speed of light is 300,000 km/sec, 186,282.4 miles per second. (Hint for solving: You will need to find the number of seconds

Chapter 1: Show What You Know *(continued)*

in a year.) Give yourself bonus points for using scientific notation in your answers and rounding to the 4th decimal point.

5. Why are observatories at high elevations?

6. Use the words from the textbox to fill in the blanks of the paragraph below it.

amplitude	light	wavelength	waves	electromagnetic radiation

Astronomers use ______________________________ to learn about the universe.

________________ is a type of this. Electromagnetic radiation travels through

space in ___________. The ______________ and _____________of the waves

depend on the source of the electromagnetic radiation.

7. Astronomers use the electromagnetic spectrum to learn more about many characteristics of the universe. Which three things from the list on page 20 are you most interested in learning more about?

   1).

Chapter 1: Show What You Know *(continued)*

2).

3).

8. Match each unit with its abbreviation.

centimeter	m
meter	AU
kilometer	cm
astronomical unit	ly
light-year	km

9. Give an example of something you would use each unit to measure.

1). I would measure ________________________ in centimeters.

2). I would measure ________________________ in meters.

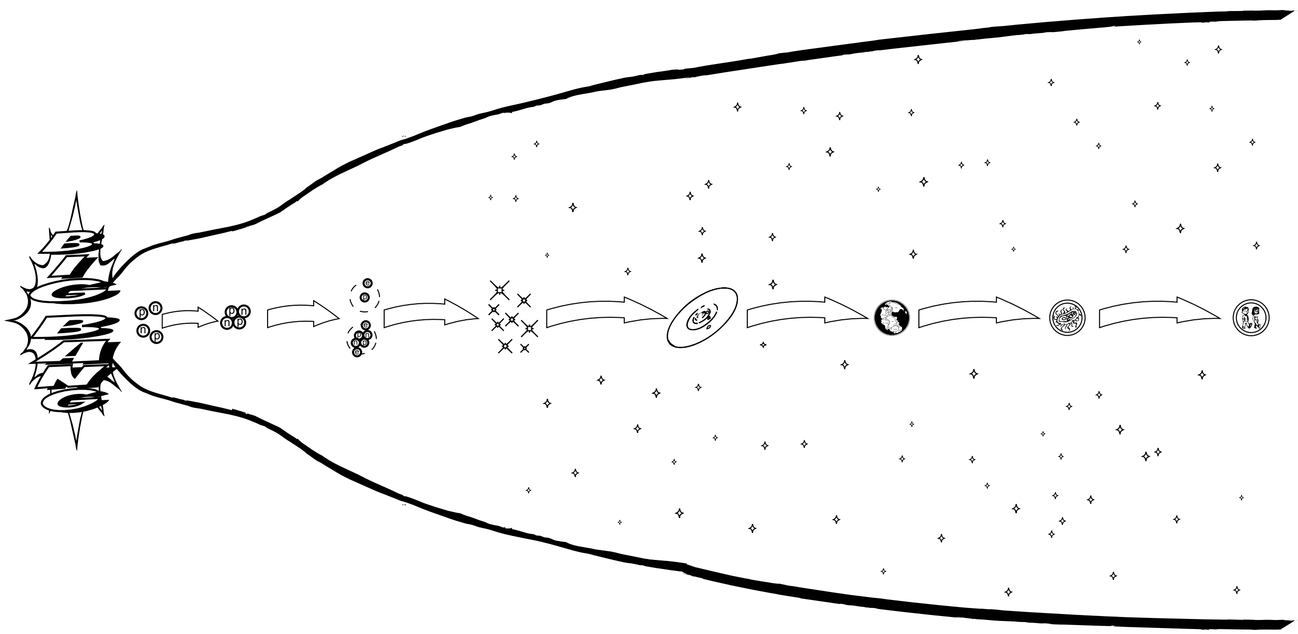
3). I would measure ________________________ in kilometers.

4). I would measure ________________________ in astronomical units.

5). I would measure ________________________ in light-years.

Unit I: Universe and Cosmology

Chapter 2: The Big Bang



Read

Bang! Let's Get This Universe Started

Chapter 2: Lesson

** Long-term Lab: Remember to monitor the position of the sun this week.*

The universe is defined as all of the matter, energy, and space that exists now, in the past, and in the future.

When you think of the universe you probably think of all the places in it. The **universe** is more than just a group of places, though. The universe is defined as all of the matter, energy, and space that exists now, in the past, and in the future. The definition of the universe also includes all of time—past, present, and future. The universe is about 13.82 billion years old. Scientists use a scientific model to explain how the universe began.

I am 13.82 years old.

I am the universe, and I am 13,820,000,000 years old.
I am 100 million times older than you are.
Now that's a *lot* of birthday candles!

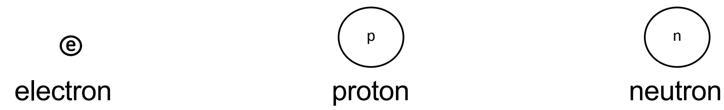
A Quick Chemistry Review

Stars and planets are made of matter. Matter is made from atoms and molecules. Atoms are so small you can't see them, but they group together to make things that are so big you can see them from outer space.

Atoms → make → Molecules → make → Planets & Stars → make → Galaxies → make → Universe

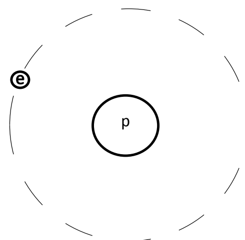
The Parts of an Atom

These parts group together to make atoms:



Neutrons have no charge.
Protons have a positive charge.
Electrons have a negative charge.

Hydrogen is the most abundant element in the universe. Usually hydrogen does not have any neutrons in its nucleus.

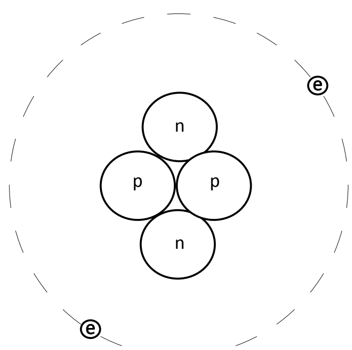


Hydrogen Atom

Neutrons and protons group together forming the **nucleus** of the atom. The number of protons (but not neutrons) in the nucleus determine what **element** the atom is. An element is a group of all the same type of atom.

The electrons **orbit** the nucleus. The positive charge of the proton and the negative charge of the electron are attracted to each other. Electrons and protons pair up 1 to 1. Neutral atoms, such as the hydrogen and helium atoms shown on this page, have equal numbers of protons and electrons.

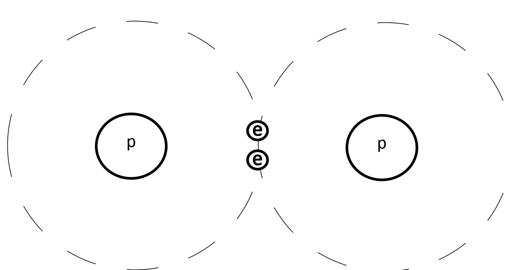
Helium is the second most abundant element in the universe.



Helium Atom

Atoms link to other atoms to make **molecules**. This link is called a bond. **Bonds** are formed through the electrons of atoms. Molecules and atoms group together to make **matter**.

Two hydrogen atoms share electrons to bond and form a molecule of hydrogen gas.



Hydrogen Molecule

It Started with a Bang! Sort of . . .

The Big Bang Model for the Universe

The big bang theory developed from a scientific model, the big bang model.

The **big bang model** is a scientific model explaining how the universe began and how it has evolved during its 13.82 billion years. The **big bang theory** explains how the universe began and has evolved (changed) since then. The big bang model was used to develop the big bang theory.

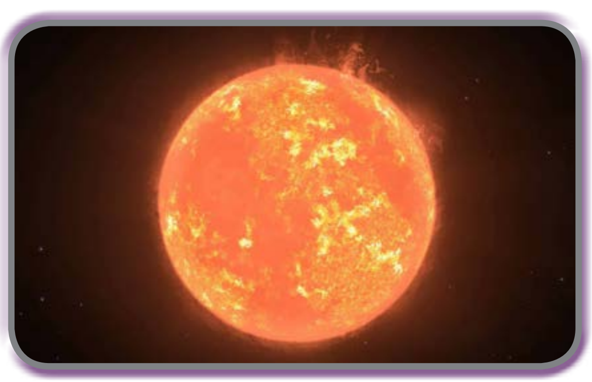
Scientific Theory

A **scientific theory** is a widely accepted explanation of something observed in science. Theories are based on experimentation, observation, and reasoning—the scientific method. Before something can be called a scientific theory, it must be tested many times by different researchers, who get results consistent with the theory.

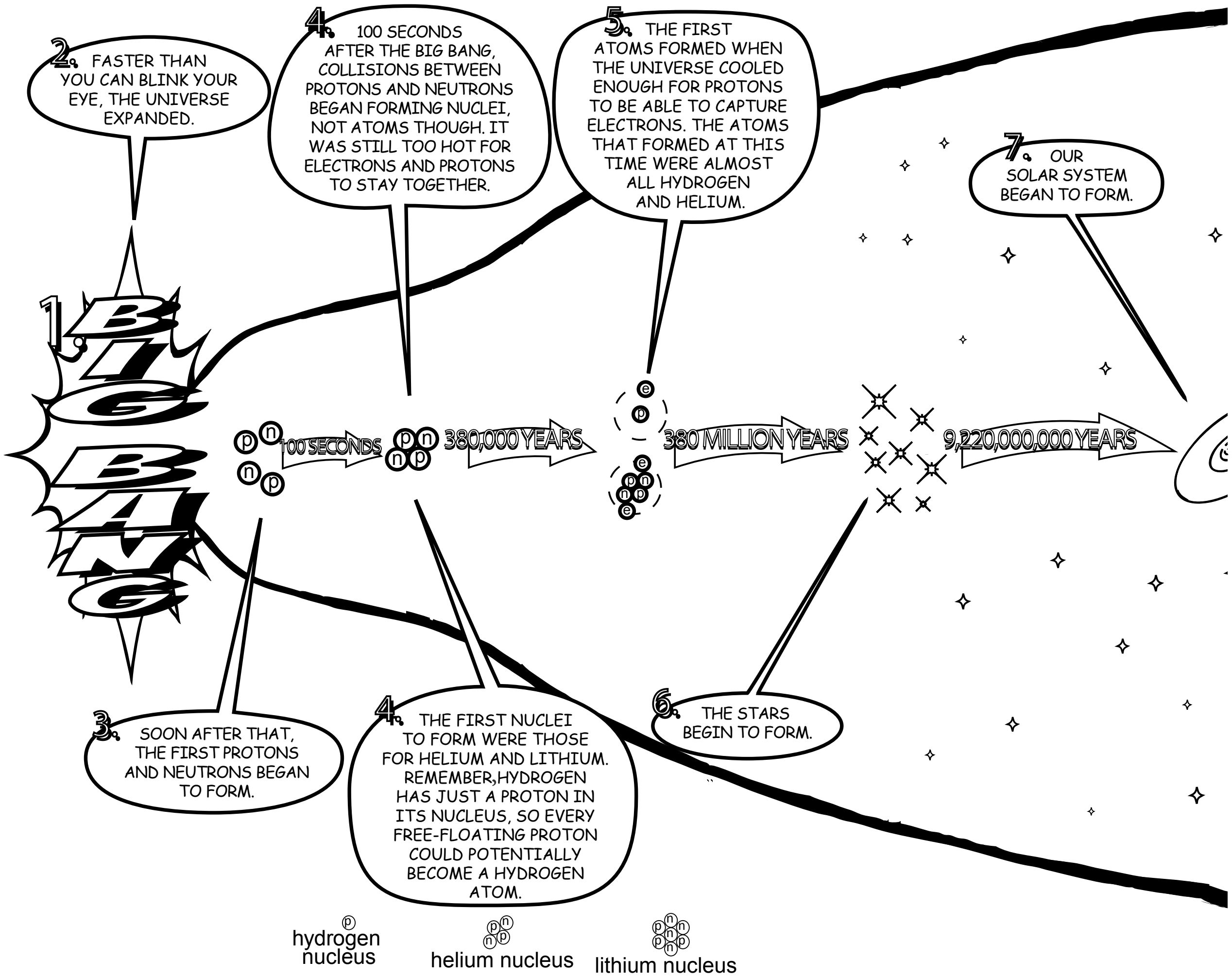
According to the big bang model, the universe started from pure energy. In an instant it formed all matter, energy, and space; and time began. It was incredibly hot and dense. It was so small you could not have seen it with your eyes. Faster than you can blink, it expanded in size to be the size of a swimming pool. Just like you, the universe started small and has grown since its beginning. Scientists don't know exactly what happened before the universe came into being.

In recent years, scientists have studied the electromagnetic radiation of stars that are 11 billion light-years away. The electromagnetic radiation from these stars is 11 billion years old! This gives them information about the universe when it was 2.82 billion years old.

VY Canis Majoris is the largest star visible from Earth. It is 4,892 light-years away. When astronomers study it, they are looking at it as it was 4,892 years ago. It will be 4,892 years before they can study how it looks right now.



Timeline of the Universe



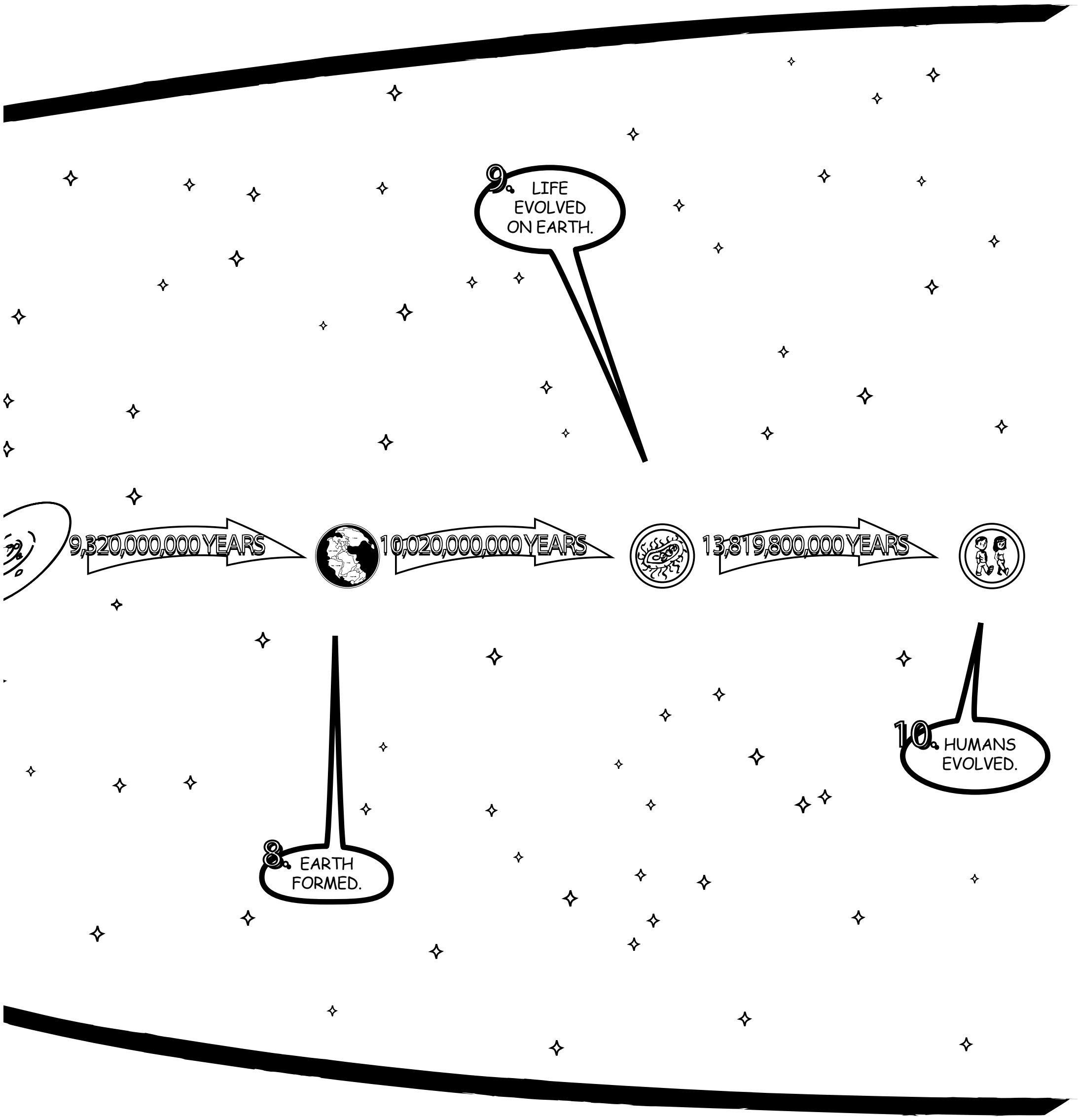
98% of all helium nuclei in the universe formed at this time.

Evidence for the Big Bang Theory

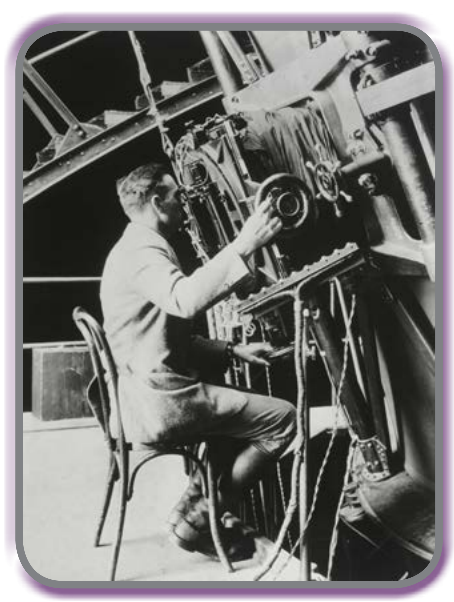
What Edwin Hubble Observed

Did you know your fingerprints are different from anyone else's? Your fingerprints can be used to tell you apart from anyone else on the earth! Elements, types of atoms, and molecules do not have fingerprints, but they do have unique properties that can be used to tell them apart.

In 1929, Edwin Hubble was looking at the electromagnetic radiation from stars with the telescope at the Mount Wilson Observatory in California. Hubble used a spectroscope attached to a telescope. A **spectroscope** is an instrument which takes electromagnetic radiation and separates out each individual wavelength present in the electromagnetic radiation from a source. It detects the elements and molecules that make the star.



Edwin Hubble, at Mount Wilson Observatory, looking at the electromagnetic radiation of stars in the universe.

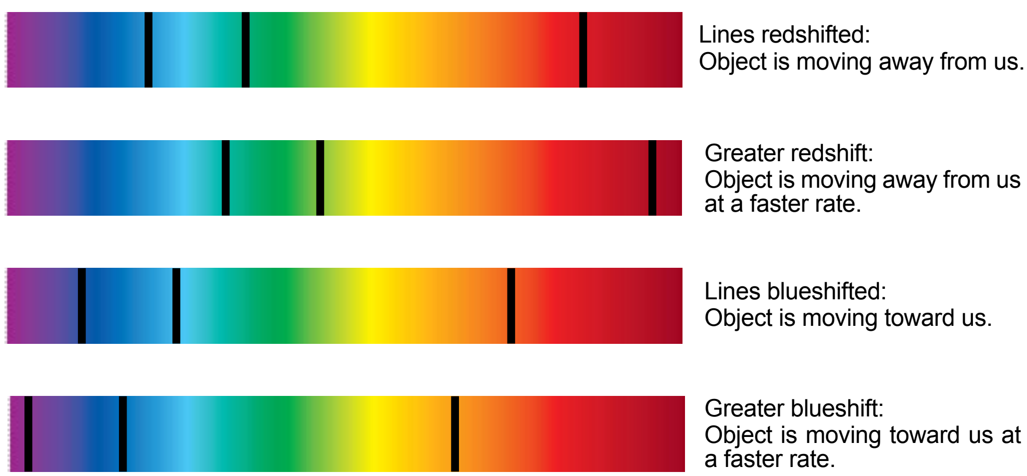


When the electromagnetic radiation from a star is spread out across its spectrum, patterns of thin black lines are recorded at specific wavelengths. These lines tell astronomers which chemical elements and molecules the star is made of. This type of spectrum is called an **absorption spectrum**.

A star only emits certain wavelengths.

All stars have the elements hydrogen and helium in them. Because of this, when Edwin Hubble looked at the stars with his spectroscope, he saw the three-line pattern for hydrogen but it was redshifted. **Redshift** means that the line patterns of the absorption spectrum have shifted toward the red end of the electromagnetic spectrum. Remember the red end has longer wavelengths. The absorption spectra still had lines in the same pattern. They still had the same fingerprint, but the lines were at longer wavelengths.

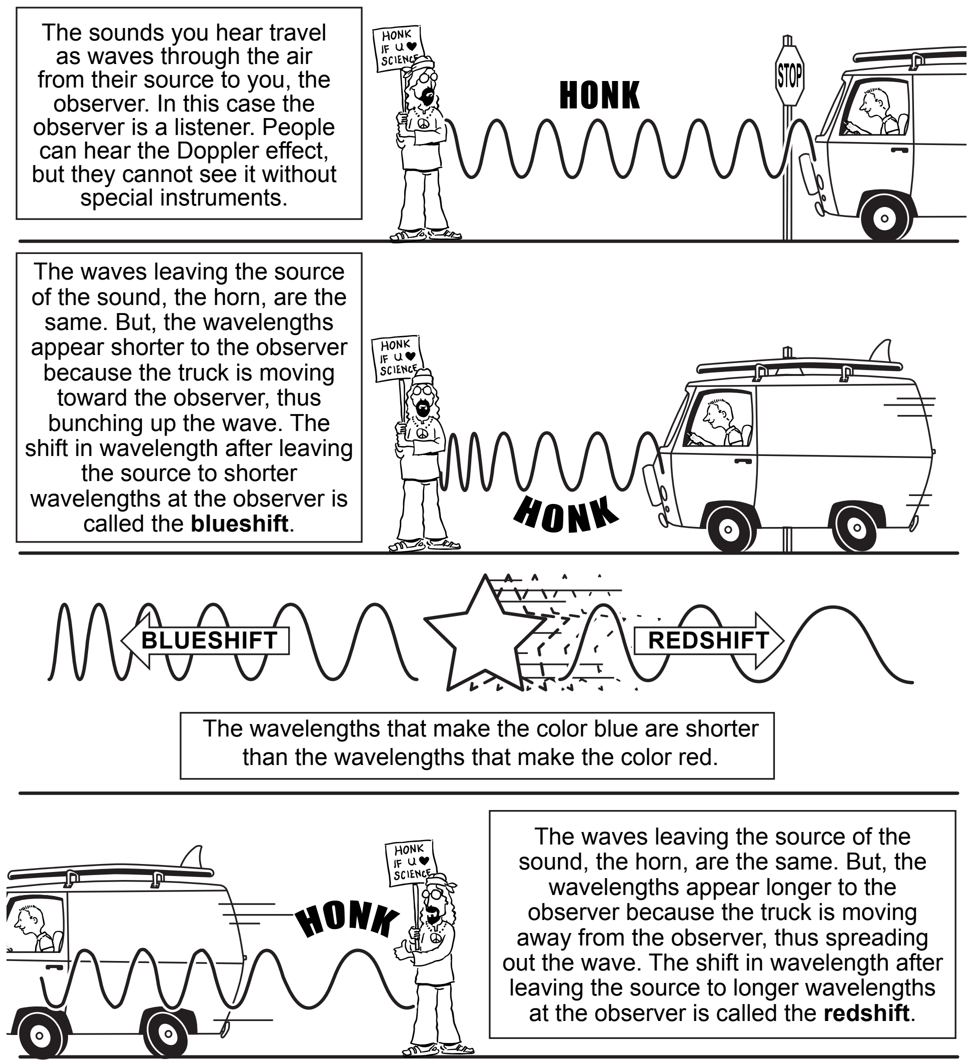
During a redshift, wavelengths are longer and the object is moving away. During a blueshift, wavelengths are shorter and the object is moving closer.



Doppler Effect

This might seem very complicated and like something that only happens in space. You have experienced redshift and its opposite, **blueshift**, but with sound instead of light. The redshift and blueshift of waves, like sound waves, occur because of the Doppler effect. The **Doppler effect** is the change in wavelength when the source of the wavelength is moving away from or toward an observer.

The Doppler effect explains why the pitch of a car horn is high as the car moves toward you, and low as the car moves away from you.



Hubble's Deductive Reasoning: The Universe Is Expanding

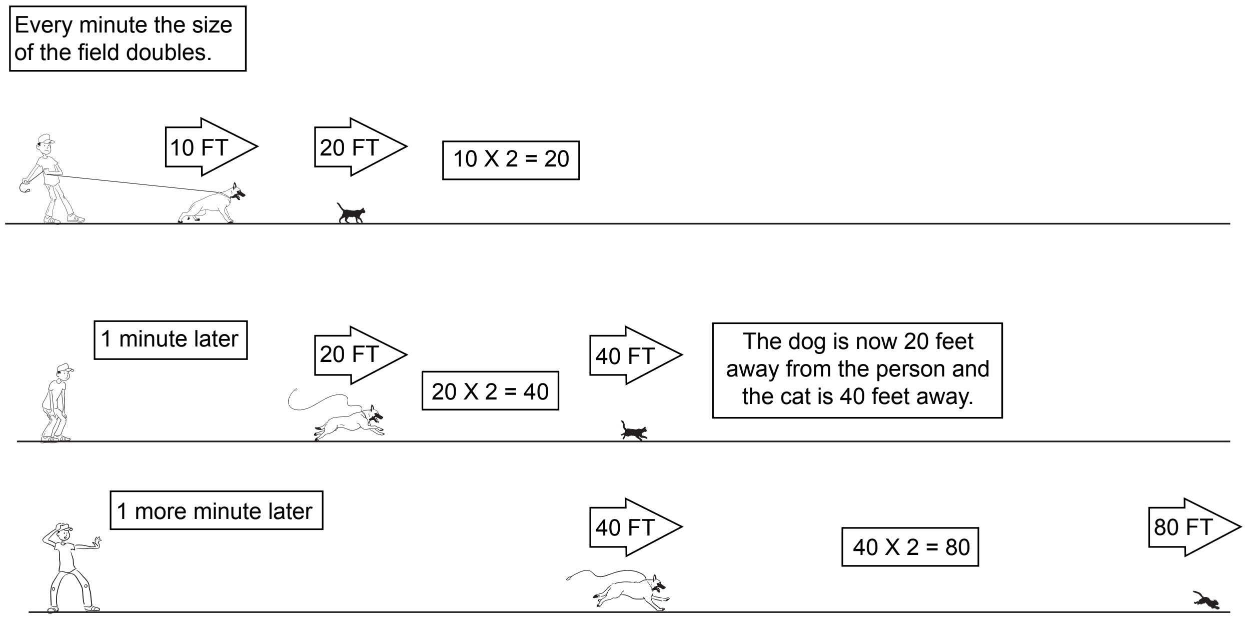
Hubble's Law describes the expansion of the universe as evidenced by redshifts.

A redshift happens when the source of sound or light is moving away from the observer. When Hubble looked into space he saw that the electromagnetic radiation from every galaxy (group of stars) he looked at in every direction was redshifted. This told him all the galaxies in the universe are moving away from Earth. This means the universe is expanding. These galaxies are not just rushing away from Earth; they are rushing away from each other too. If the galaxies are rushing away from each other now, according to the Big Band Model, they were once closer together. If you go far enough back in time, say 13.82 billion years ago, the universe was so small you couldn't see it. This might seem like something out of a science fiction story, but the evidence for it is very strong.

Hubble's Law

Based on his observations, Hubble realized there was a mathematical constant for the rate of expansion for the universe. This observation became the scientific model known as **Hubble's law**. One of the things Hubble's law showed was that the farther away a galaxy was, the faster it was expanding away. This seems confusing doesn't it? Think of it this way:

Hubble's Law as Demonstrated by Dog Chases Cat



If something expands at a constant rate, the farther away something is, the faster it expands away from a central point.

A Look at the Distant Past: Cosmic Microwave Background Radiation

In the 1940s, physicist George Gamow hypothesized that if the big bang had occurred, the universe would have started out extremely hot with a burst of radiation and then cooled over time. He thought there would be leftover radiation making the universe warmer than expected.

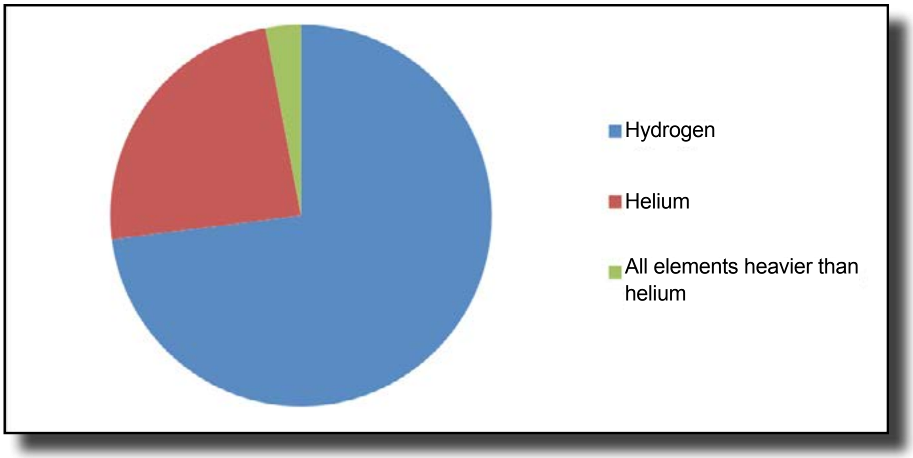
In 1964, Arno Penzias and Robert Wilson discovered the leftover radiation from the early universe as hypothesized by Gamow. It is called the **Cosmic Microwave Background Radiation** (CMBR). This radiation exists everywhere in the universe. It keeps the universe a frigid 2.73 K above absolute zero, (–273.16 ° C or –459.69 ° F), which is warmer than it would be if there had not been the big bang.

Products of the Big Bang: Cosmic Abundance of the Elements

If you make a cheese pizza you expect cheese pizza, don't you? Not pepperoni pizza or mushroom pizza. It was too hot right after the big bang for elements larger than hydrogen, helium, and lithium to form. (A very small amount of

lithium was made. Most lithium in the universe was made in stars.) If hydrogen and helium were the main elements made when the universe formed, scientists expected there to be lots of hydrogen and helium in the universe but not many of the heavier elements. Just like with pizza, scientists understood if these two elements formed in abundance they would still be abundant in the universe Using spectroscopy, scientists calculated the abundance of the elements in the universe. What they discovered was what was predicted by the big bang model.

Cosmic Abundance of Elements Chart (as a percentage of the number of atoms)



Summary of Evidence for the Big Bang

The Evidence	The Prediction Based on the Big Bang Model	The Observation
The Redshift Observed (the Doppler effect)	The universe is expanding. When things expand they move away from the source of the expansion. If you have ever seen fireworks explode, you have seen this happen.	If the big bang started as an expansion, you would expect it to still be expanding in all directions. It is. The Doppler effect is, in fact, observed in all directions and is greater for more distant galaxies.
Cosmic Microwave Background Radiation	The violent expansion at the start of the universe would be accompanied by a large release of radiation at an extremely high temperature.	If this was the case, then even 13.82 billion years later there should still be evidence of this radiation in the form of heat energy. There is.
The Cosmic Abundance of the Elements	The high temperatures of the universe for the first 200 million years would prevent elements heavier than hydrogen, helium, and lithium from forming.	If this were the case, there should be an abundance of hydrogen, helium, and lithium compared to the heavier elements. There is.

Explore

Model This: Expanding Universe

Chapter 2: Lab

Have you ever heard the saying that truth can be stranger than fiction? It doesn't feel like we are moving through space does it? It is easy to understand how people from ancient times believed Earth stood still while the sun, planets, and stars revolved around it. Whether you feel like you are revolving, rotating, and moving in the direction the universe is expanding or not, you are. It is all very strange nonfiction, isn't it?

The galaxies in the universe, including ours, are expanding away from each other. This means that the volume of space occupied by the universe is expanding. It does not mean that the galaxies are growing in mass; it means that galaxies are getting farther apart so that the amount of space the universe takes up is growing.

You can use a balloon to model how this works. The balloon is a scientific model for the expanding universe. As you blow air into the balloon it expands and takes up more space just like the universe is doing. The number of atoms that make the balloon does not change as the size of the balloon expands. When you blow up your balloon, the dots you drew on it will grow in size; that is a problem with our simple model. It is not really what is happening in the "real" universe. Scientific models are often made to a smaller scale or they are simplified. This model is smaller and simpler. The universe is too big to do an experiment on though. A balloon, on the other hand, can only get so large before it pops.

Materials

- Spherical balloon (not inflated)
- Black permanent marker
- String that measures around the balloon when it is inflated, about 2 feet (60 cm)
- Metric ruler (measures centimeters)
- Another person

Chapter 2: Lab *(continued)*

Procedure

1. Lay the balloon flat. Use the marker to make a black circle about the size of a dime on the balloon. Do not draw too close to the end where you will blow up the balloon. The black circle is the home galaxy.
2. Write the numbers 1, 2, 3, 4, and 5 randomly on the balloon. Spread the numbers out. Do not put them all in a line. Each number represents a galaxy. You can turn the balloon over or write them all on one side.
3. The balloon will be blown up successively from smallest to largest with two stops in between, so do not blow it up too much for the first measurements. Blow the balloon up to a small but spherical size. Have one person twist and hold the bottom so no air escapes, while the other person measures the distance between the home galaxy and each of the other five galaxies. Use the string to mark the distances, and then use the ruler to measure the length of the string in centimeters. Write your distance measurements down in the data box on the lab sheet. Do this three more times, each time adding more air to the balloon until it's fully inflated for the fourth (last) measurement. You can tie the balloon off at the last measurement if you want.
4. Answer the questions on the Lab Sheet.

Model This: Expanding Universe

Chapter 2: Lab Sheet

Name____ **Date**______________

Why do we use a scientific model to study the expansion of the universe?

Observations

Distance from the home galaxy	Distance at 1st measurement	Distance at 2nd measurement	Distance at 3rd measurement	Distance at 4th measurement
Galaxy 1				
Galaxy 2				
Galaxy 3				
Galaxy 4				
Galaxy 5				

Results/Discussion

Use words to describe how the balloon represents what is occurring in the universe. How could this model be used as evidence for the big bang?

What happened to the distance between the home galaxy and the other galaxies as you blew up the balloon? Which galaxies moved the greatest distance from the home galaxy, those closer to or farther away from it?

If you were standing on the home galaxy when these galaxies moved farther away from it, would you have observed the color of the galaxies shifting towards the red end or the blue end of the color spectrum? What is this color shift called?

The balloon model demonstrated the principle it was supposed to. But like all simplified models it has limitations. Can you think of any?

Absorb

Edwin Hubble

Chapter 2: Famous Science Series


Edwin Hubble

Edwin Hubble has been called the Founder of Modern Cosmology. What does the word *cosmology* mean?

What did Edwin Hubble do to earn this moniker (nickname)?

Hubble's law led to the proposal of the big bang theory. What is Hubble's law?

Chapter 2: Famous Science Series *(continued)*

Edwin Hubble formulated his law in 1929. In 1917, a very famous scientist produced a model showing that the universe was expanding. This scientist did not believe in his own model. Instead he decided that the universe must be a constant size. Who was this scientist? And what did he have to say after Hubble's discoveries?

The Big Bang

Chapter 2: Show What You Know

Multiple Choice

1. When you look at a star 25 light-years away you are seeing the star as
   - ○ it is today.
   - ○ it was 25 years ago.
   - ○ it will be in 25 years.
   - ○ it was 45 years ago.

2. The universe is
   - ○ matter.
   - ○ space.
   - ○ energy.
   - ○ time.
   - ○ all of the above

3. The two most abundant elements in the universe are
   - ○ hydrogen and lithium.
   - ○ helium and lithium.
   - ○ hydrogen and helium.
   - ○ hydrogen and oxygen.

4. Hubble discovered that light from galaxies has
   - ○ a redshift.
   - ○ a blueshift.
   - ○ no shift.

5. Based on his discovery about light from galaxies, Hubble concluded that
   - ○ the universe is contracting.
   - ○ the universe stays the same size.
   - ○ the universe is expanding.

Chapter 2: Show What You Know *(continued)*

6. Cosmic Microwave Background Radiation
   - O exists everywhere in the universe.
   - O has a temperature of 2.73 K above absolute zero.
   - O is leftover radiation from the early universe.
   - O all of the above
   - O none of the above

Define

Write definitions for the following terms:

1. The big bang model–

2. Cosmology–

3. Scientific theory–

4. Doppler effect–

Chapter 2: Show What You Know *(continued)*

Matching

Match each term to its definition. Write the number for the correct definition in the space before the word it defines.

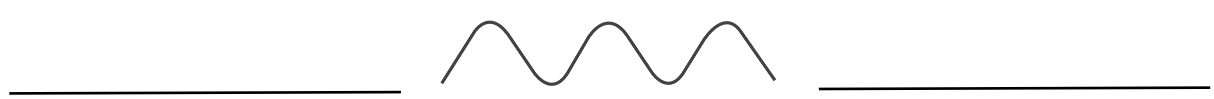
_____ Atoms	1. A group of all the same type of atoms.
_____ Nucleus	2. The neutral particle inside the nucleus.
_____ Neutron	3. This element has 2 protons in its nucleus, with 2 electrons orbiting.
_____ Proton	4. This element has 1 proton in its nucleus, with 1 electron orbiting.
_____ Electron	5. The negative particle that orbits outside the nucleus
_____ Molecules	6. The positive particle inside the nucleus. These determine the type of element.
_____ Hydrogen	7. Atoms create these by linking together and sharing electrons.
_____ Helium	8. The center of an atom, where the protons and neutrons are.
_____ Element	9. The building blocks of molecules and matter.

Draw

Below is a wavelength.

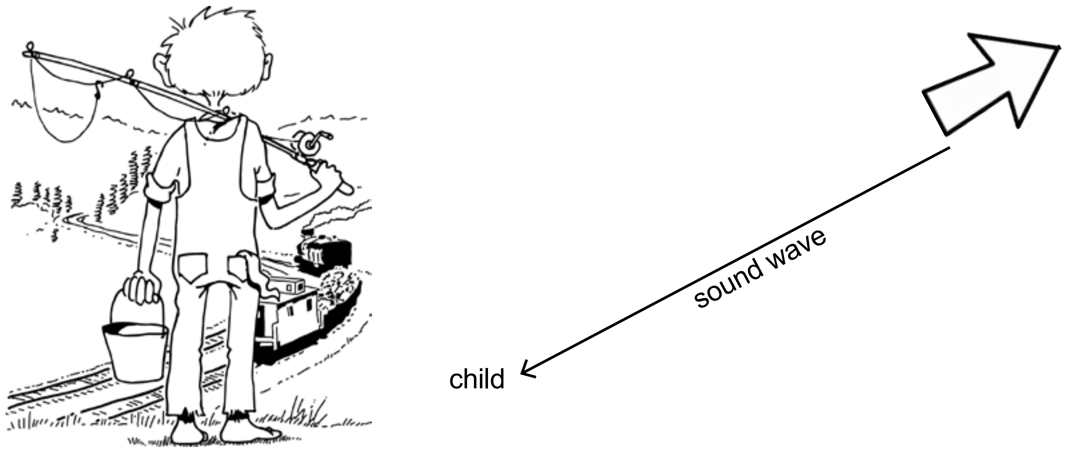
#1. On the left side, redraw the wavelength as if it has blueshifted.

#2. On the right side, redraw the wavelength as if it has redshifted.



Chapter 2: Show What You Know *(continued)*

This train is blowing its whistle as it chugs away from the child. Draw a wave on the line demonstrating how the sound wavelength changes as it travels from the train to the child.



Timeline

Next to the dates below, write the event that occurred. (The first one has been done for you.)

A. 13.82 billion years ago: <u>the big bang, the universe began</u>

B. Immediately after the big bang: ______________________________

C. Soon after the big bang: ______________________________

D. 100 seconds after the universe began: ______________________________

E. 380,000 years after the universe began: ______________________________

F. 2 million years after the universe began: ______________________________

G. 9.22 billion years after the universe began: ______________________________

H. 9.32 billion years after the universe began: ______________________________

I. 10.02 billion years after the universe began: ______________________________

J. 13.8198 billion years after the universe began: ______________________________

Math

Do the math: How long have humans walked on the earth?

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ISBN 978-0-9977963-3-9
9 780997 796339