How the Sun Works – Week 3 Labwork

Name: ____ Hour_______Date: __________________

Date Packet is due:______________ Why late? ____________________________________Score: ______
Day of Week Date If your project was late, describe why

Driving Question: What is inside the sun?

Anchoring Phenomenon: How can we measure the sun?

Deeper Questions

1. How can we determine the distance between the sun and the earth?
2. How can we determine the size of the sun?
3. How can we determine the temperature of the sun?

Weekly Schedule

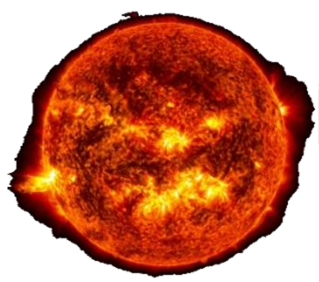
Part 1: Introduction
- Initial Ideas – Eratosthenes Measurements
- Discussion & Developing Explanations

Part 2: Core Ideas
- Core Ideas
- Revisions of Part 1 Explanations

Part 3: Investigation
- Measuring the Earth
- Sample Equations

Part 4: Review & Assessment
- Critiquing Ideas
- Assessment

Part 5: Side Quest
- Weekly Recap
- Side Quests



NGSS Standards:
HS-ESS1-1: Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.

Semester Schedule

How the Sun Works

Week 1: What is matter? What is energy?
Week 2: What's inside the sun?
Week 3: How can we measure the sun?
Week 4: Where does the sun's energy come from?
Week 5: Unit Assessment

The Life of Stars

Week 1: How long do stars last?
Week 2: Why do stars die?
Week 3: What happens after stars die?
Week 4: Unit Assessment

How It All Began

Week 1: How can we determine the universe's size?
Week 2: How can expansion determine the universe's age?
Week 3: What can we learn from background radiation?
Week 4: Unit Assessment

Navigating Space

Week 1: How and why do things orbit in space?
Week 2: How can we predict orbits?
Week 3: Unit Assessments

Part 1: Intro – Eratosthenes' Measurements

Overview: In this activity, you will read a short passage. You will then use this as the basis for a discussion about the content and structure of the sun.

Directions: Individually read the passage below. Then work with your group to address the questions below. Your instructor will determine if you should use scratch paper, a white board, an online document, etc.

By around 500 B.C., most ancient Greeks believed that Earth was round, not flat. But they had no idea how big the planet is until about 240 B.C., when Eratosthenes devised a clever method of estimating its circumference.

It was around 500 B.C. that Pythagoras first proposed a spherical Earth, mainly on aesthetic grounds rather than on any physical evidence. Like many Greeks, he believed the sphere was the most perfect shape. Possibly the first to propose a spherical Earth based on actual physical evidence was Aristotle (384-322 B.C.), who listed several arguments for a spherical Earth: ships disappear hull first when they sail over the horizon, Earth casts a round shadow on the moon during a lunar eclipse, and different constellations are visible at different latitudes.

Around this time Greek philosophers had begun to believe the world could be explained by natural processes rather than invoking the gods, and early astronomers began making physical measurements, in part to better predict the seasons. The first person to determine the size of Earth was Eratosthenes of Cyrene, who produced a surprisingly good measurement using a simple scheme that combined geometrical calculations with physical observations.

Eratosthenes was born around 276 B.C., which is now Shahhat, Libya. He studied in Athens at the Lyceum. Around 240 B.C., King Ptolemy III of Alexandria appointed him chief librarian of the library of Alexandria.

Known as one of the foremost scholars of the time, Eratosthenes produced impressive works in astronomy, mathematics, geography, philosophy, and poetry. His contemporaries gave him the nickname "Beta" because he was very good, though not quite first-rate, in all these areas of scholarship. Eratosthenes was especially proud of his solution to the problem of doubling a cube, and is now well known for developing the sieve of Eratosthenes, a method of finding prime numbers.

Eratosthenes' most famous accomplishment is his measurement of the circumference of Earth. He recorded the details of this measurement in a manuscript that is now lost, but his technique has been described by other Greek historians and writers.

Eratosthenes was fascinated with geography and planned to make a map of the entire world. He realized he needed to know the size of Earth. Obviously, one couldn't walk all the way around to figure it out.

Eratosthenes had heard from travelers about a well in Syene (now Aswan, Egypt) with an interesting property: at noon on the summer solstice, which occurs about June 21 every year, the sun illuminated the entire bottom of this well, without casting any shadows, indicating that the sun was directly overhead. Eratosthenes then measured the angle of a shadow cast by a stick at noon on the summer solstice in Alexandria, and found it made an angle of about 7.2 degrees, or about 1/50 of a complete circle.

He realized that if he knew the distance from Alexandria to Syene, he could easily calculate the circumference of Earth. But in those days it was extremely difficult to determine distance with any accuracy. Some distances between cities were measured by the time it took a camel caravan to travel from one city to the other. But camels have a tendency to wander and to walk at varying speeds. So Eratosthenes hired bematists, professional surveyors trained to walk with equal length steps. They found that Syene lies about 5000 stadia from Alexandria.

Eratosthenes then used this to calculate the circumference of the Earth to be about 250,000 stadia. Modern scholars disagree about the length of the stadium used by Eratosthenes. Values between 500 and about 600 feet have been suggested, putting Eratosthenes' calculated circumference between about 24,000 miles and about 29,000 miles. The Earth is now known to measure about 24,900 miles around the equator, slightly less around the poles.

Eratosthenes had made the assumption that the sun was so far away that its rays were essentially parallel, that Alexandria is due north of Syene, and that Syene is exactly on the tropic of cancer. While not exactly correct, these assumptions are good enough to make a quite accurate measurement using Eratosthenes' method. His basic method is sound, and is even used by schoolchildren around the world today.

Other Greek scholars repeated the feat of measuring the Earth using a procedure similar to Eratosthenes' method. Several decades after Eratosthenes measurement, Posidonius used the star Canopus as his light source and the cities of Rhodes and Alexandria as his baseline. But because he had an incorrect value for the distance between Rhodes and Alexandria, he came up with a value for Earth's circumference of about 18,000 miles, nearly 7,000 miles too small.

Ptolemy included this smaller value in his treatise on geography in the second century A.D. Later explorers, including Christopher Columbus, believed Ptolemy's value and became convinced that Earth was small enough to sail around. If Columbus had instead known Eratosthenes larger, and more accurate, value, perhaps he might never have set sail.

Questions

1. What evidence did Aristotle cite to support his claim that the earth was spherical and not flat?
2. Summarize how Eratosthenes determined the circumference of the earth.
3. As a team, develop a strategy for measuring the distance between the sun and the earth similar to what Eratosthenes developed to measure the circumference of the earth. Address the following:
    a. What would you need to know to determine this distance?
    b. How could you obtain this information without leaving the earth?

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4. Repeat these steps for determining the size of the sun.

Part 2: Core Ideas

Overview: In this activity, you will look at a short slideshow presentation. This will provide you with core ideas that will help you clarify your initial ideas. Your instructor will decide on how to implement this portion depending on your previous experience and capabilities with this content.

You will then work in small teams to answer the questions listed below. You should take notes in a notebook, on a dry erase board, or on scratch paper so that you are prepared to deliver your responses during the class discussion that will follow. *Note: your instructor may assign specific questions to your group if time is limited.*

Summary Video: https://www.youtube.com/watch?v=dh8HyWZO7Ko

Core Ideas Presentation: https://bit.ly/WUHS-Astro-Sun-W3

Driving Questions:

1. What is a parallax? What is a non-astronomical example of a parallax?
2. What is the 'transit of Venus'? How could this astronomical event be used to determine the distance between the earth and the sun?
3. What is an astronomical unit (AU)? Why is this value important?
4. How did Eratosthenes use shadows to determine the circumference of the earth?
5. How can the value of an AU be used to determine the size of the sun?
6. What is an arcsecond? What is an arcminute? How are these values determined?
7. What is a blackbody? What is a blackbody radiation curve?
8. How can a blackbody radiation curve be used to determine the temperature of the surface of the sun or any star?
9. What is photometry and how is it different from spectral analysis?
10. **Revising Explanations**: How can we measure the distance to the sun? How can we measure the size of the sun?

Part 3: Investigation A – Measuring the Earth

Adapted from Scientific American: https://www.scientificamerican.com/article/measure-earths-circumference-with-a-shadow/

Overview: The Greek mathematician Eratosthenes was able to estimate Earth's circumference more than 2,000 years ago, without the aid of any modern technology. How? He used a little knowledge about geometry!

At the time Eratosthenes was in the city of Alexandria in Egypt. He read that in a city named Syene south of Alexandria, on a particular day of the year at noon, the sun's reflection was visible at the bottom of a deep well. This meant the sun had to be directly overhead. (Another way to think about this is that perfectly vertical objects would cast no shadow.) On that same day in Alexandria a vertical object did cast a shadow.

Using geometry, he calculated the circumference of Earth based on a few things that he knew:

- He knew there are 360 degrees in a circle.
- He could measure the angle of the shadow cast by a tall object in Alexandria.
- He knew the overland distance between Alexandria and Syene. (The two cities were close enough that the distance could be measured on foot.)
- The only unknown in the equation is the circumference of Earth!

The resulting equation was:
Shadow angle in Alexandria / 360 degrees = Distance between Alexandria and Syene / Circumference of Earth

In this project you will do this calculation yourself by measuring the angle formed by a meterstick's shadow at your location. You will need to do the test within two weeks of the fall or spring equinoxes, when the sun is directly overhead at Earth's equator. Ideally you should perform this activity as close to noon as possible. Then you can look up the distance between your city and the equator and use the same equation Eratosthenes used to calculate Earth's circumference. How close do you think your result will be to the "real" value?

Materials: Flat, level ground that will be in direct sunlight around noon; Meterstick; Stick or rock to mark the location of the shadow; Calculator; Protractor; Long piece of string; a level or plumb bob.

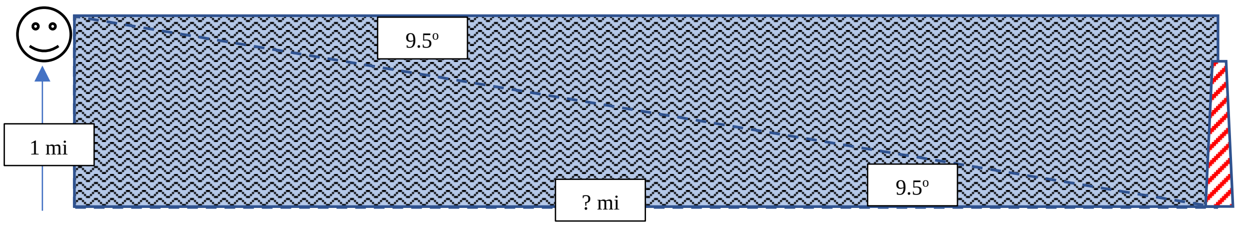
Directions:

1. At solar noon, mark the end of the meterstick's shadow on the ground with a stick or a rock.
2. Draw an imaginary line between the top of the meterstick and the tip of its shadow. Your goal is to measure the angle between this line and the meterstick. Have your volunteer stretch a piece of string between the top of the meterstick and the end of its shadow.
3. Use a protractor to measure the angle between the string and the meterstick in degrees. Write this angle down.
4. Look up the distance between your city and the equator.
5. Calculate the circumference of the Earth using this equation:
6. Circumference = 360 x distance between your city and the equator / angle of shadow that you measured

Part 3: Investigation B – Sample Equations

Overview: The following questions are meant to provide you with scenarios similar to what astronomers encountered when trying to determine the size, distance, and temperature of the sun.

1. You are walking along the beach and notice a lighthouse that is east of you. You walk a mile directly north. The lighthouse is now southeast of you. Using a map, you determine that the angle between your current position and your previous position in comparison to the lighthouse is 9.5°. You determine that the angle between these lines is 9.5°. How far away is the lighthouse? Use the formula: [Distance $_{\text{lighthouse}}$] = [Distance $_{\text{beach}}$] * tan (90-α) (where α = 9.5). Show your work.



Note: you can search "Google Calc" online if you don't have a calculator. Be sure you are in degrees mode (not radians) →

2. How is this question similar to how astronomers determined the size of an astronomical unit (AU)? Be sure to address the following in your response: *definition of an AU; transit of Venus; radius of the earth.*

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3. You are at a baseball game in Milwaukee. You are sitting next to the foul and determine that the angle of its shadow is 43°. You see a novelty sign at a souvenir stand indicating that Milwaukee is 4,785.71 km from the equator. Using this information, determine the circumference of the earth with this formula: *Shadow angle / 360 = Distance to Equator / Circum. of Earth*. Be sure to show your work below.

4. Betelgeuse is the nearest "red supergiant" star to Earth. Because of its size, someday it will explode as a supernova. Lately, Betelgeuse has been visibly dimming, leading some to believe that it may explode soon. Betelgeuse has an angular size of 0.125 arcseconds, or 0.000035°. It is located 427 light years from earth (or 4 thousand trillion km = 4.04×10^{15} km). Using the formula for calculating a star's size (d * tan (a/2)), determine the size of Betelgeuse. Show your work below.

5. Our solar system's sun is 700,000 km across. Look at the chart to the right. Which is bigger, Betelgeuse or our own sun? Which is hotter?

   Bigger: ______________________________

   Hotter: ______________________________

Surface Temp (K)	Color	Example
30,000	Blue-violet	Mintaka
20,000	Blue	Rigel
10,000	White	Vega, Sirius
7000	Yellow-White	Canopus
6000	Yellow	Sun, Alpha Centauri
4000	Orange	Arcturus, Aldebaran
3000	Red	Betelgeuse, Barnard's

6. How can we determine the surface heat of our own sun and other stars? Explain the terms *blackbody* and *blackbody radiation curve* in your response.

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Part 4: Review & Assessment

Overview: you will begin by reviewing the driving questions below in your small groups. For each objective, rank it as a 1 (*completely unsure*), 2 (*somewhat unsure*), or 3 (*completely sure*) based on your comfort with that objective. Then work in teams to create responses to the questions (your instructor will determine if you will answer all the questions or only a portion).

After you have had time to create your responses, you will critique the responses of another group before coming together as a whole class. Be sure to use the "rules" for matter and energy as you do so. You will conclude by completing an assessment for this week's ideas.

Driving Questions

1. What is a parallax? What is a non-astronomical example of a parallax?
2. What is the 'transit of Venus'? How could this astronomical event be used to determine the distance between the earth and the sun?
3. What is an astronomical unit (AU)? Why is this value important?
4. How did Eratosthenes use shadows to determine the circumference of the earth?
5. How can the value of an AU be used to determine the size of the sun?
6. What is an arcsecond? What is an arcminute? How are these values determined?
7. What is a blackbody? What is a blackbody radiation curve?
8. How can a blackbody radiation curve be used to determine the temperature of the surface of the sun or any star?
9. What is photometry and how is it different from spectral analysis?

Part 5: Side Quest

Overview: For this activity, you will begin with a recap of the things that you learned in this packet. You will then identify topics related to astronomy that you personally find interesting to investigate more deeply over the remainder of the semester.

Weekly Recap (use a whiteboard, scratch paper, online document, etc.)

1. Summarize everything that you have learned through this packet within your group. Try to identify the common themes, major ideas, and most important concepts from the content you have learned.
2. Is there anything that anyone still doesn't completely understand? Is there anything that anyone maybe disputes or disagrees with? Did anything seem particularly surprising or noteworthy?
3. What you think are the most important ideas and concepts that you have learned so far. Aim to have at least 5 or 6 ideas written down. It is ok to have more than this.

Side Quest: In this activity, you will begin to identify some topics related to astronomy to investigate more deeply over the course of the semester. Be prepared to discuss your ideas.

1. In the space below, summarize the topic that you would like to investigate as your side quest.

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2. Why did you choose this topic? Why do you find this topic interesting or intriguing?

    *I chose this because…*____

    ____

3. What is your learning objective for this project? In other words, what do you want to learn and what do you want others to know by the time you finish your presentation?

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4. Is this something that will be addressed at some point in this course? ________ (Ideally, you should be focusing on a topic that isn't in the syllabus. Check with your instructor to be certain.)
5. Can/should you work with someone else? ___________ (If this is a very broad topic, and/or if others are interested in the same topic, it may make sense to split up the work to make it more feasible.).
6. Are you excited about this topic? Is it something that is personally interesting to you? ____________

How the Sun Works – Week 3 Assessment

Name: ____ Hour_______ Date:_________ Score:_________/____

Directions: This is an open-notes quiz. You should work with your assigned team to complete responses to the questions below. Each person should write the response to at least one question. Write your initials next to the answer(s) you wrote. Those who are not writing should collaborate to create the response that will be written.

In 1761, astronomers engaged in a project to measure an astronomical event of great importance: the passage of the planet Venus across the face of the Sun. Unfortunately, transits of Venus, as they are known, are an irregular occurrence. They come in pairs eight years apart, but then are absent for a century or more. With the instinct for ordeal that characterized the age, scientists set off for more than a hundred locations around the globe—to Siberia, China, South Africa, Indonesia, and the woods of Wisconsin, among many others. France dispatched thirty-two observers, Britain eighteen more, and still others set out from Sweden, Russia, Italy, Germany, Ireland, and elsewhere. It was history's first cooperative international scientific venture, and almost everywhere it ran into problems. Many observers were waylaid by war, sickness, or shipwreck. Others made their destinations but opened their crates to find equipment broken or warped by tropical heat.

Adapted from Bill Bryson's *A Short History of Nearly Everything*

1. How could the transit of Venus enable astronomers to determine the distance between the earth and the sun? Define and use the term *parallax* in your response.

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Initials:

2. Global travel was exceedingly difficult in the mid-1700s. Places like South Africa and Wisconsin were often remote and extremely difficult to reach from Europe. Why couldn't scientists remain in their home countries? Why was it necessary to travel to such remote places?

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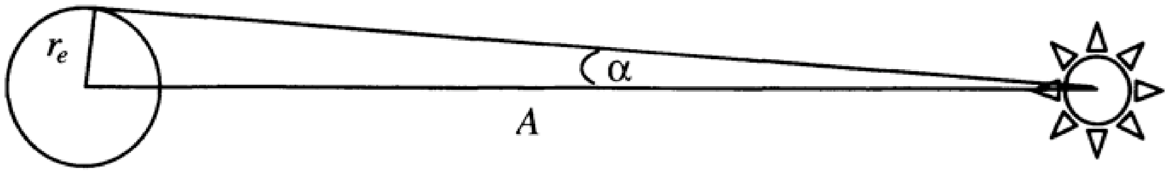

3. The image above shows a simplified version of how astronomers used the transit of Venus to determine the size of an AU. This requires them to know the radius of the earth. How could this value be determined without digging a hole to the center of the earth?

Initials:

4. How could knowing the size of an AU enable astronomers to determine the size of the sun?

Initials:

5. To understand what is happening inside the sun, you need to know both the size of the sun as well as its temperature. How could astronomers measure the sun's temperature if they have never visited it?

Initials: