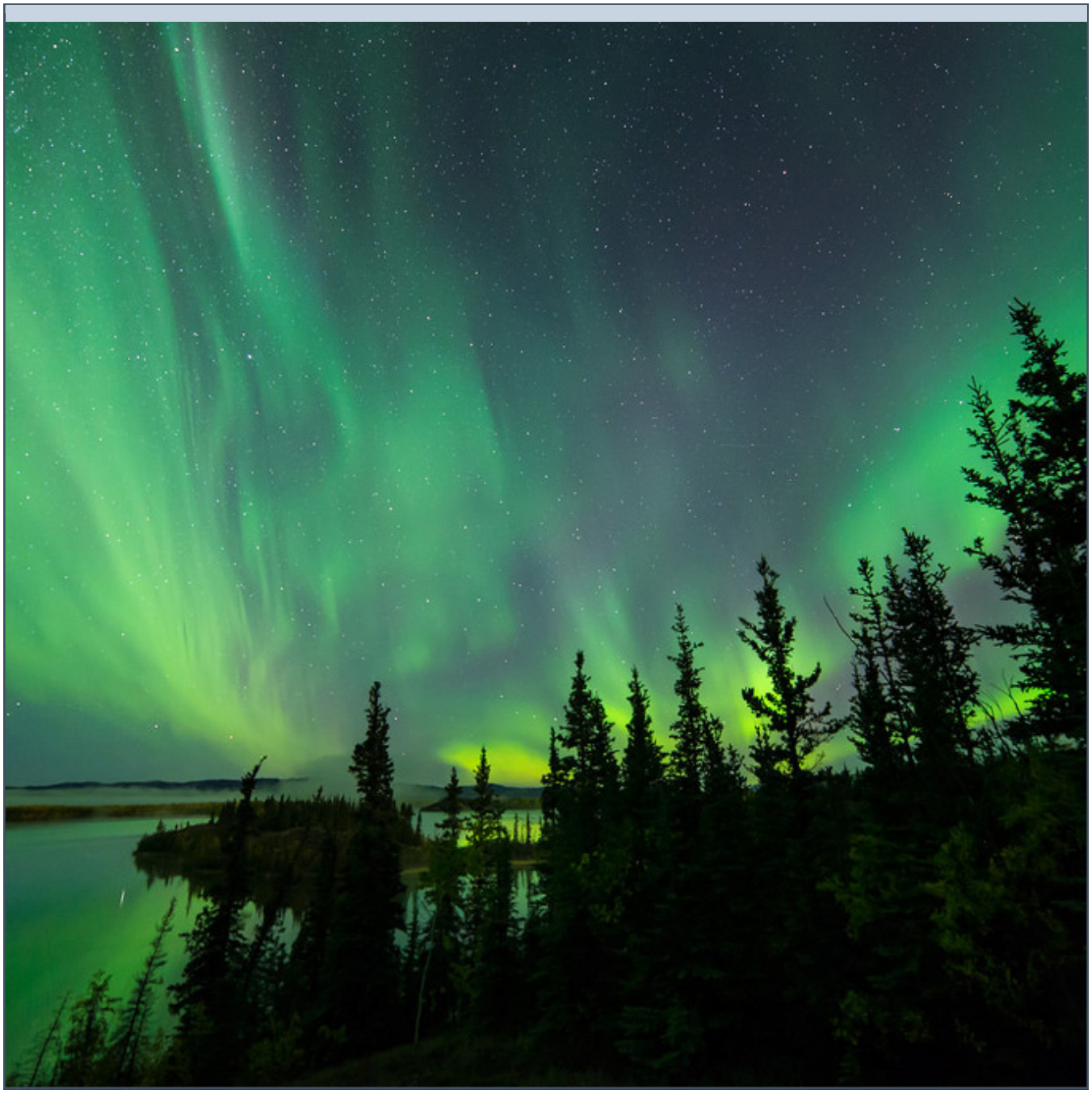
Journey To The Sun Teacher Guide Lesson 5

Grades: 6 - 8

Duration: 1-2 class periods

Standards: MS-ESS1-1
SC.8.2.1
SC.8.8.10



How the Sun Affects Earth

NSO National Solar Observatory

Funded by the National Science Foundation

NSF

www.nso.edu

Objectives

At the end of this lesson, students will be able to:

1. Compare and contrast the effects of solar flares vs. coronal mass ejections.
2. Investigate the solar cause of mysterious events that could impact society.
3. Explain how solar events and space weather affect Earth and society.
4. Plot Coronal Mass Ejection (CME) locations and map their paths from the Sun.

Standards

MS-ESS1-1
Patterns of the apparent motion of the sun, moon, and stars in the sky can be observed, described, predicted, and explained with models.

SC.8.2.1
Describe significant relationships among society, science, and technology and how one impacts the other.

SC.8.8.10
Compare the characteristics and movement patterns in our solar system.

Key Vocabulary

CMEs

Electrons

Light Energy

Particles

Protons

Solar Flares

Materials

- ☐ Lesson Packet: www.nso.edu/educators/jtts-curriculum
- ☐ Slideshow: "***How the Sun Affects Earth***"
- ☐ How the Sun Affects Earth.mp4 (For Teachers)
- ☐ Activity Materials (See activity sheets)

Background

***Note:** This lesson will be most effective if taught after students have a basic understanding of radiation energy and the electromagnetic spectrum. Please see the following activities as optional pre-requisites to this lesson: Electromagnetic Spectrum Poster, Interactive EM Quiz, and The Herschel Experiment.

In lesson 4, students learned of the different events such as solar flares and CMEs occuring on the Sun. In this lesson, students get to make valuable connections between these events and how they affect our society. Additionally, students are re-introduced to the importance of solar science and how it is applied to keep the public prepared in the event that important societal technologies, such as radio communications and power grids, are disrupted.

Directions

Using the slideshow provided, review with students the information provided on each slide.

Slide #

2. Allow students to brainstorm, think-pair-share, etc. on the reasons for why solar scientists study the Sun. Why is solar science important?
3. Remind students that the solar events they learned of in the previous lesson can affect human society on Earth.
4. Informational slide displaying how CMEs and Solar Flares compare and contrast in terms of the material they release, the speed at which their effects reach Earth, and the disruptions they may cause. This information will become useful as students complete the included activities.
5. Real-world example of a CME impacting Earth: On March 10th 1989 astronomers observed a powerful explosion on the Sun. Three days later on March 13th, the entire province of Quebec, Canada suffered an electrical power blackout as a result. The blackout lasted 12 hours. This meant 12 hours without light, heat, elevators, etc. Additionally during this time, other "mysterious" problems arose, including space satellites temporarily losing control. These problems went away as the solar storm subsided.

   For more information on "The Day the Sun Brought Darkness" visit:
   https://www.nasa.gov/topics/earth/features/sun_darkness.html
6. CMEs happen all the time. This is a simulation of a real event from 2012 that narrowly missed Earth. Had this been directed at Earth, it could have had very severe consequences
7. ***Enrichment Option:*** Have students research this phenomenon and present their findings. Real-world example of solar flare impacts on Earth: Solar flares can increase radiation exposure to flight crews and passengers flying at high altitudes where there is less atmospheric protection. They can also impact long-wave radio communications, rendering them unreliable.
8. Introduction to the student activity "Calling all Hawai'i Solar Scientists". In this activity, students use the artifacts provided on the worksheet to investigate the solar causes of mysterious events. This worksheet may be used as a formative assessment.
9. Introduce students to the "CME Plotting Activity" (activity sheet provided). In this activity, students plot CME locations over time and map their paths to determine how likely they are to hit Earth.

Activity - Calling All Hawai'i Solar Scientists

Adapted by NSO from: NASA. 2003. Living with a Star-GEMS Teacher's Guide for Grades 6-8. University of California, Berkley, CA.

Objective

In this activity, students investigate a series of mysterious events on Earth, and build a hypothesis to explain what happened. This activity is based on real events with fictionalized emergencies.

Materials

- Student activity sheets
- Pen or pencil

Background

Solar events such as coronal mass ejections and solar flares, also known as space weather, can cause technological disruptions and mishaps when they hit Earth. In this lesson, students are the solar scientists who determine the solar causes of mysterious events that have the potential to affect thousands of people. Similar real-life events like the ones described in this activity have occured and impacted the lives of many.

In our present day society, we are heavily dependent on modern technologies such as radio wave communications, satellites, global positioning systems, and electrical power grids. In the event that a solar storm powerful enough to cause large-scale damage to these sytems occurs, early prediction and preparedness will make all the difference in how society's technologies will recover.

Calling all Hawai'i Solar Scientists!

Student Activity Sheet

There have been a series of mysterious events here on Earth. Figure out what's caused these events and use your knowledge to keep the public safe in the future.

Mysterious Events

September 6

Rescue services lost communication fishermen out of Kahului port when their radios stopped working at 12:01pm.

September 8

Night time security guards recorded red and green lights on the horizon around 11:50pm.

September 8

A sudden impulse was observed at several of Earth's magnetic field instruments (magnetometers) at 3:48am.

September 6

NASA's SoHO satellite suffered radiation damage at 12:00pm.

September 8

10:30pm: UHMC students out stargazing in Waihee reported unusual clouds and colors in the sky in the north and northeast directions.

September 6

12:01pm: Astronauts on the International Space Station detected a sudden increase in X-rays and Gamma-rays and were directed to take cover immediately.

September 8

Voltage irregularities registered across Hawai'i electrical grid through the day.

September 6

The number of dropped cell phone calls increased drastically throughout the day.

Mysterious Events Continued

September 7

Television broadcasts interrupted temporarily across the USA. Effect most noticeable with satellite television channels.

September 7

Department of Defense issued a memo regarding poor GPS reliability for drone operators for the next 24-36 hours.

September 6

Federal Aviation Authority has announced delays in flights from Hawai'i to Europe. Airlines are forbidden from flying over the north or south poles due to concern about radio communication stability until further notice.

September 8

Scientists at Antarctica's Amundsen–Scott South Pole Station noted irregularities in the location of the magnetic south pole today.

September 5

The National Solar Observatory observe highly complex sunspots near the center of the Sun.

September 9

Verizon, AT&T and T-Mobile have announced that cell phone services have returned to normal as of noon today.

September 6

The National Weather Service have issued a warning to electricity companies regarding possible nationwide outages for the next 24-36 hours.

September 9

Scientists at Antarctica's Amundsen–Scott South Pole Station report that magnetic south has returned to its normal position.

September 6

11:59pm: Astronauts report X-ray and Gamma-ray radiation levels returned to normal.

September 9

Federal Aviation Authority has declared flights from Hawai'i to Europe may resume flightpaths over the poles.

Directions

1. Catalogue the mysterious events using the calendar below.
2. Use the calendar of events, along with the artifacts below to find evidence for what may have caused the mysterious events. Use the hints provided to guide you along the way.

September 6	September 7
September 8	**September 9**

ARTIFACTS

Artifact #1: "Internet Research"

You've done some research and have come across the following chart:

Coronal Mass Ejections	Solar Flares
Release explosions of magnetic field, protons and electrons (matter)	Release electromagnetic radiation
Particles take 2-3 days to reach Earth	Travels at the speed of light; takes 8 minutes to reach Earth
Carries a magnetic field that can interact with Earth's magnetic field.	Increase in EM radiation can cause disruptions in radio communications and GPS

Evidence :

_____
_____
_____
_____

Hint: How long does it take CME particles and Solar Flare energy to reach Earth?

Artifact #2: "Military Satellite Report"

Sept. 5 - Normal

Sept 6 - Alert

12:01pm - Increase in X-ray and gamma ray levels detected. Defense system on alert: Def Con 3.
12:11pm - Increased X-rays and gamma rays identified as not coming from Earth. Defense system taken off alert.
12:34pm - Communications with all other nuclear powers confirm that no detonation of nuclear weapons occured.
11:59pm X-ray and Gamma-ray levels returned to normal

Sept. 7 - Normal

Sept. 8 - Normal

Evidence :

_____

Hint: On what day and times did the alert occur? When was the increase in rays detected?

Artifact #3: "Hourly Record of Sept 6th Solar Flares and CMEs"

S = small

M = Medium

L = Large

Time	Solar Flares			Coronal Mass Ejection		
	S	M	L	S	M	L
00:00 - 00:59	1					
01:00 - 01:59		1			1	
02:00 - 02:59						
03:00 - 03:59		1				
04:00 - 04:59		1			1	
05:00 - 05:59						
06:00 - 06:59						
07:00 - 07:59	1					
08:00 - 08:59						
09:00 - 09:59		1				
10:00 - 10:59	1					
11:00 - 11:59			1			1
12:00 - 12:59	1					
13:00 - 13:59	1					
14:00 - 14:59						
15:00 - 15:59						
16:00 - 16:59	1			1		
17:00 - 17:59	1	1			1	
18:00 - 18:59						
19:00 - 19:59						
20:00 - 20:59	1					
21:00 - 21:59						
22:00 - 22:59						
23:00 - 23:59						

Flare Data from www.solarmonitor.org/?date=20170906

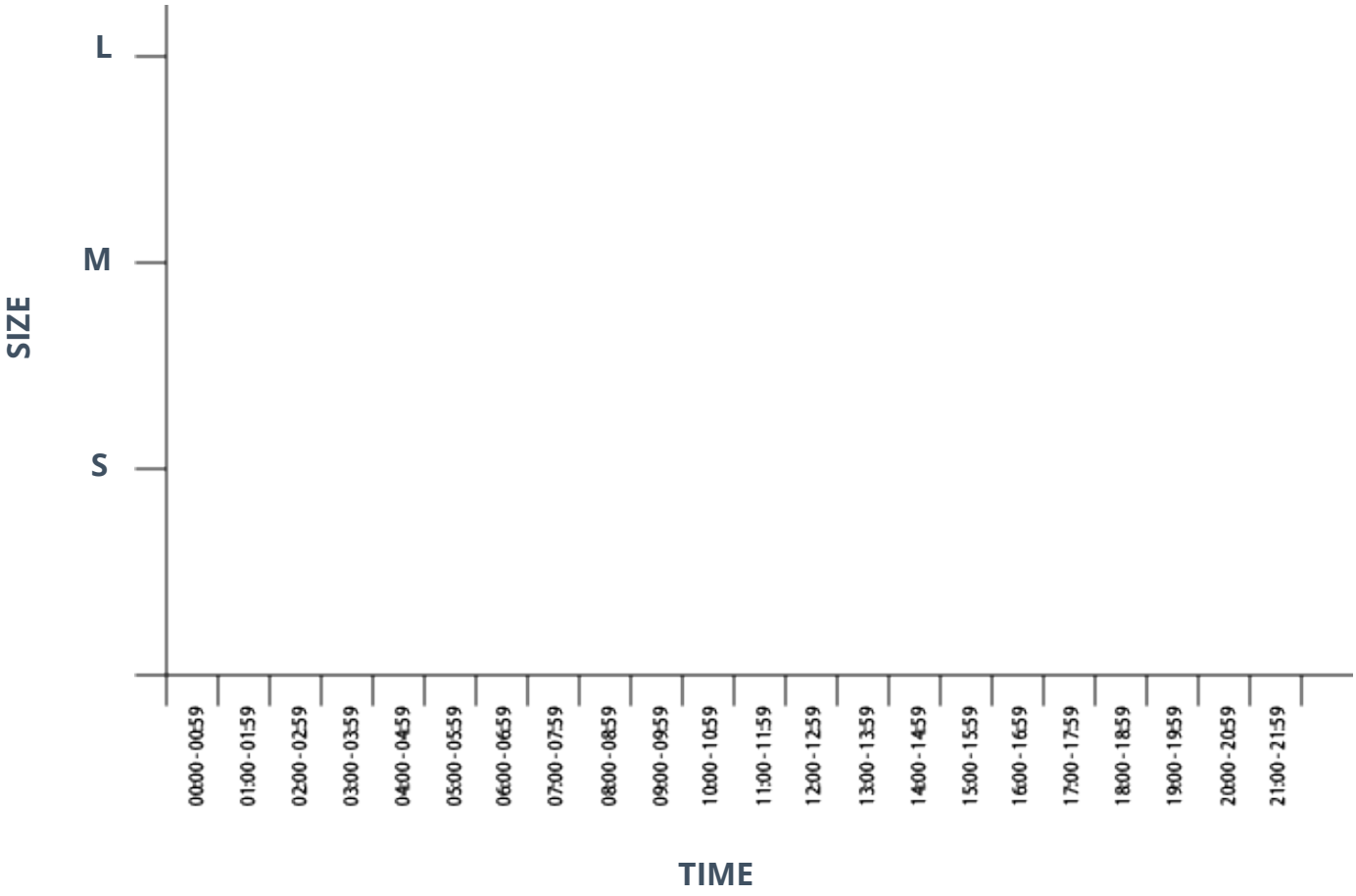
Evidence :

_____

Hint: At what time did the largest CME and Solar Flare occur?

Graph the Data from Artifact #3

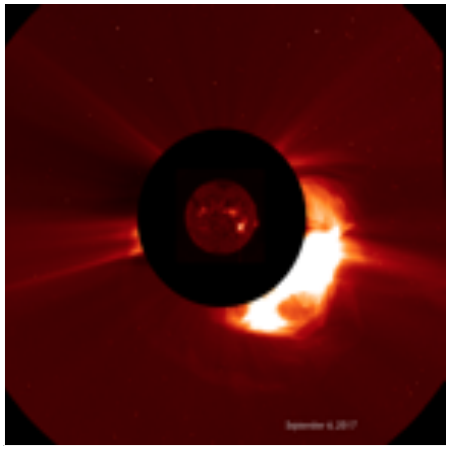
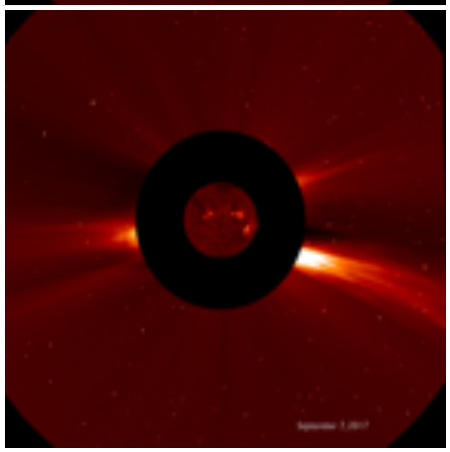
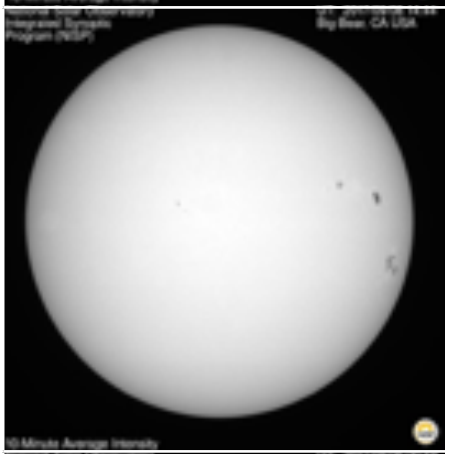
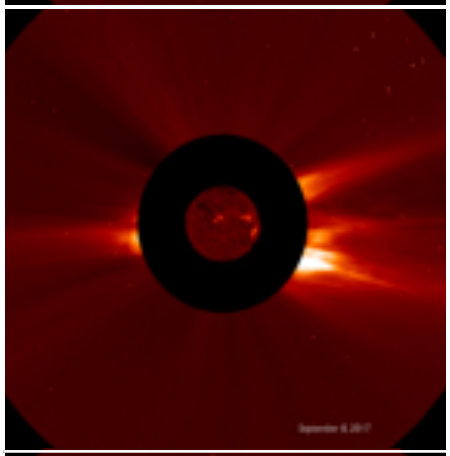
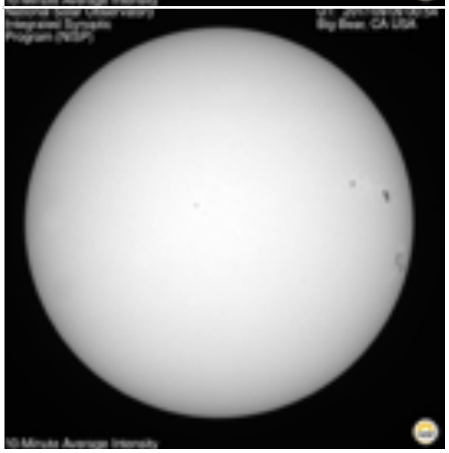
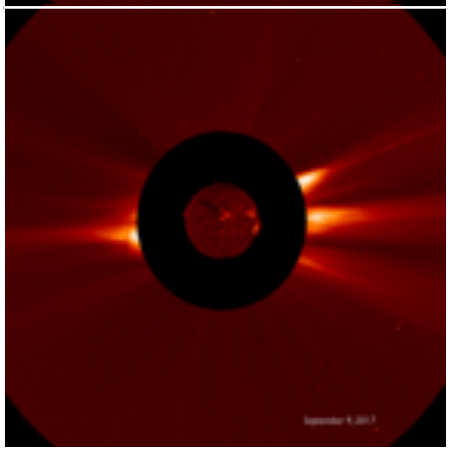
Graph Title _____



□ = Solar Flare

○ = Coronal Mass Ejection

Artifact #4: Sunspot and CME observations

Date	Sunspot activity	CME activity
Sept. 6		
Sept. 7		
Sept. 8		
Sept. 9		

Evidence :

Hint: On what day does the CME activity look different?

Conclusions

Questions:

1. What was the cause of all of these disruptions?

_____

_____

_____

2. The largest solar flare on Sept 6th happened at 11:53am. Why did the loss of radio communications at Earth not happen until 12:01pm?

_____

_____

_____

3. If the largest solar flare and CMEs occured on Sept 6th, what explains the disturbances that happened on Sept 8th?

_____

_____

_____

Write your conclusions in the space below. Be sure to explain what caused the events and provide specific examples of evidences that validate your conclusions. Use what you know about solar flares and CMEs in your explanation.

_____

_____

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_____

Teacher Answer Key

Artifact #1: "Internet Research"

You've done some research and have learned that it takes 8 minutes to travel from the Sun to Earth at the speed of light.

You've learned that it takes CME gusts two to three days to reach the Earth from the Sun.

Evidence :

It takes light energy 8 minutes to get from the Sun to the Earth.

It takes protons and electrons from CME gusts 2-3 days to reach Earth.

Artifact #2: "Military Satellite Report"

Sept. 5- Normal

Sept 6 - Alert

12:01pm - Increase in X-ray and gamma ray levels detected. Defense system on alert: Def Con 3.
12:11pm - Increased X-rays and gamma rays identified as not coming from Earth. Defense system taken off alert.
12:34pm - Communications with all other nuclear powers confirm that no detonation of nuclear weapons occured.
11:59pm X-ray and Gamma-ray levels returned to normal

Sept. 7 - Normal

Sept. 8 - Normal

Evidence :

Increased X-ray and Gamma rays, which can be released by solar flares, were detected on Sept. 6 @ 12:01pm

Hint: On what day and times did the alert occur?
When was the increase in rays detected?

Artifact #3: "Hourly Record of Sept 6th Solar Flares and CMEs"

S = small

M = Medium

L = Large

Time	Solar Flares			Coronal Mass Ejection		
	S	M	L	S	M	L
00:00 - 00:59	1					
01:00 - 01:59		1			1	
02:00 - 02:59						
03:00 - 03:59		1				
04:00 - 04:59		1			1	
05:00 - 05:59						
06:00 - 06:59						
07:00 - 07:59	1					
08:00 - 08:59						
09:00 - 09:59		1				
10:00 - 10:59	1					
11:00 - 11:59			1			1
12:00 - 12:59	1					
13:00 - 13:59	1					
14:00 - 14:59						
15:00 - 15:59						
16:00 - 16:59	1			1		
17:00 - 17:59	1	1			1	
18:00 - 18:59						
19:00 - 19:59						
20:00 - 20:59	1					
21:00 - 21:59						
22:00 - 22:59						
23:00 - 23:59						

Flare Data from www.solarmonitor.org/?date=20170906

Evidence :

The largest solar flare and CME both occured on Sept. 6th between 11am and noon

Hint: At what time did the largest CME and Solar Flare occur?

Questions:

1. What was the cause of all of these disruptions?

A large solar flare occurred on Sept. 6th between 11am and noon. There was a large CME that happened at the same time.

2. The largest solar flare on Sept 6th happened at 11:53am. Why did the loss of radio communications at Earth not happen until 12:01pm?

Solar flares release light energy. It takes light 8 minutes to reach Earth from the Sun.

3. If the largest solar flare and CMEs occured on Sept 6th, what explains the disturbances that happened on Sept 8th?

These issues could have been caused by increased magnetic field and particles ejected from the sun interfering with the Earth's magnetic field. The protons and electrons and magnetic field released in the large CME take 2-3 days to reach Earth from the Sun. This is why it took 2 days after the big CME for these disturbances to happen..

Write your conclusions in the space below. Be sure to explain what caused the events and provide specific examples of evidences that validate your conclusions. Use what you know about solar flares and CMEs in your explanation.

These events seem to have been caused by a large solar flare and CME that occurred on Sept 6th at 11:53am. Evidence to support solar flare involvement include increased x-ray and gamma rays detected at Earth on Sept. 6th @ 12:01pm. Solar flares release large amounts of light energy such as x-rays and gamma rays. These types of light energy take approximaely 8 minutes to reach Earth from the Sun. Thus, a large solar flare occuring at 11:53am, was likely the source of the increase in energy rays detected on Earth at 12:01pm (8 minutes later). This is what caused interference with radio waves and communications. [Note to teachers: Flare radiation doesn't directly interefere with radio waves. The actual cause of radio interference is as a result of solar flare radiation ionizing the Earth's outer atmosphere, making our ionosphere thicker. Radio waves bounce off the ionosphere to travel long distances, so unexpected changes in that layer of the atmosphere can cause radio signals to be lost.]

CMEs release protons and electrons along with magnetic field. These protons and electrons take 2-3 days to reach Earth (evidence from artifact #1) and can sometimes interfere with Earth's magnetic field. This explains why disturbances continued to happen until Sept. 8th. CMEs can also excite the atoms in our atmosphere, causing them to glow (i.e. Aurora Borealis). Although it would be extremely rare to see aurora in Hawai'i, it would be possible if the CME was large enough. This would explain the unusual colors in the sky that were observed by the UHMC students.

Activity - Coronal Mass Ejection Plotting

Adapted by NSO from the NASA IMAGE/POETRY Teacher and Student Consortium.
https://image.gsfc.nasa.gov/poetry/activities.html

Objective

In this activity, students map the paths of Coronal Mass Ejections (CMEs) by plotting their positions over the course of a few days.

Materials

- □ Student activity sheet
- □ Ruler
- □ Protractor
- □ Pen or pencil

Background

A Coronal Mass Ejection (CME) is a storm of particles ejected from the Sun. These particles can shoot out from any of the 360° around the Sun. Therefore, the probability of a CME being directed towards Earth is relatively small. Students will plot CME locations and map their paths in order to spot trends and draw conclusions on CME behavior. As students add more CMEs to their activity sheets, it becomes apparent that in order for a CME to hit Earth, it must be ejected from a specific region of the Sun facing Earth.

Assuming that every 12 hours or so, a CME with an initial width of 0.5 million kilometers, will:

- Travel a distance of approximately 20 million kilometers
- Move approximately 7° counter clockwise
- Spread over a width of approximately 6.5 million kilometers.

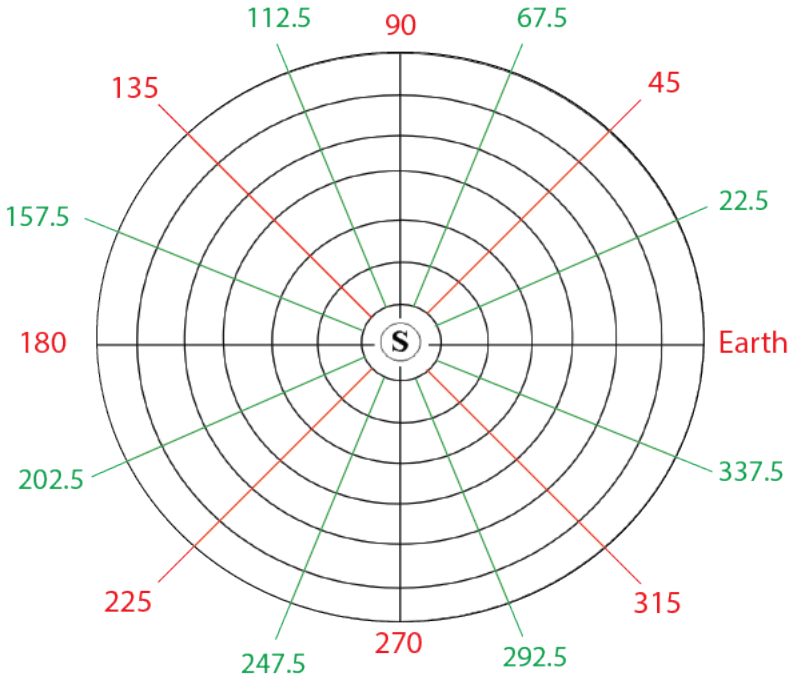
Students can generate and map other probable paths of CMEs ejected from the Sun at many different angles from 0° to 360°.

Note: Different CMEs travel at different speeds, which affect the distance that they travel over time, among other factors. The assumed values above are provided to simplify this activity for students.

Teacher Directions

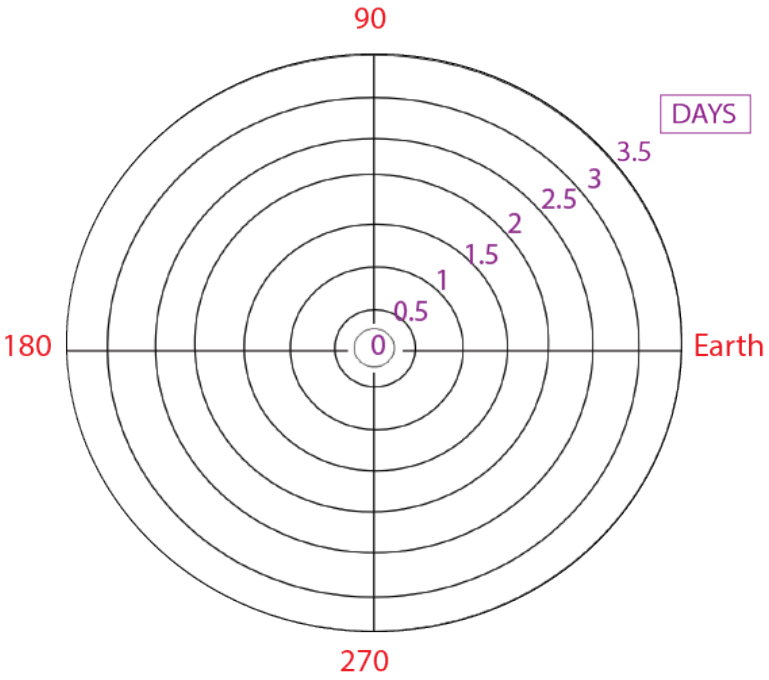
1. Label each angle on the grid using degrees as your unit. Draw and label additional angle lines between each 90° interval for more precise plotting

Example:



2. Because the provided CMEs' distances from the Sun increase linearly in approximate intervals of 20 million kilometers per 0.5 day, it is possible to label each circle as time in days, starting from Day 0 and increasing in 0.5 day intervals for each concentric circle.

Example:



Teacher Directions Cont...

3. Now that the grid is ready, start plotting CME locations over time, using the data table provided. You will use the data in the "Day" and "Angle" columns to plot your points.

4. Once each location is plotted, draw to scale the width of the CME as indicated in the "Width" column of the data table. *Distances and widths are given in millions of kilometers. Students can calculate their own scale for drawing width measurements, or you can give them the conversion:

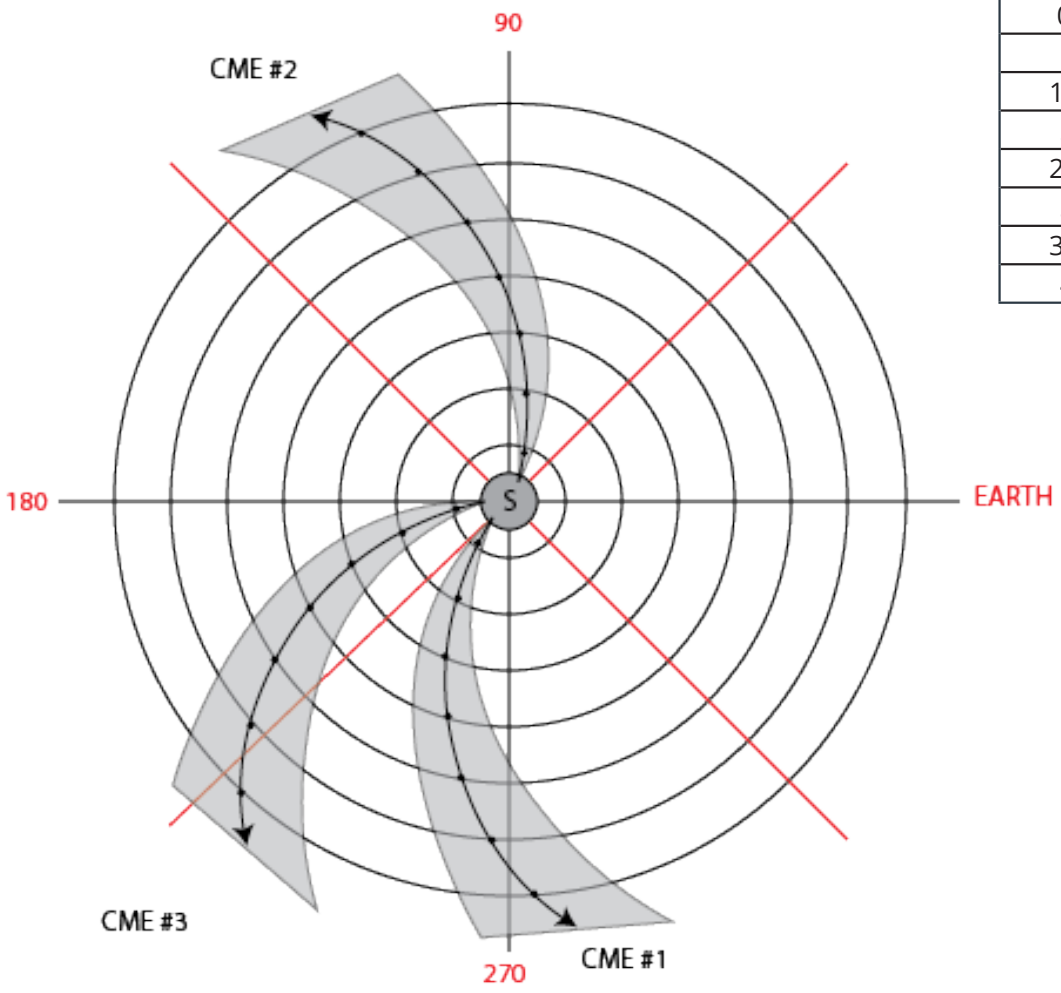
5. 20 million kilometers = 1 centimeter = 10 millimeters

6. Hand sketch the path of each CME and complete the shape by shading in between the width measurements.

Teacher Answer Key:

Key for Student Activity Sheet width scale

WIDTH (millions of kilometers)	WIDTH TO SCALE (MM)
0.5	0.25
7	3.5
13.5	6.75
20	10
26.5	13.25
33	16.5
39.5	19.75
46	23

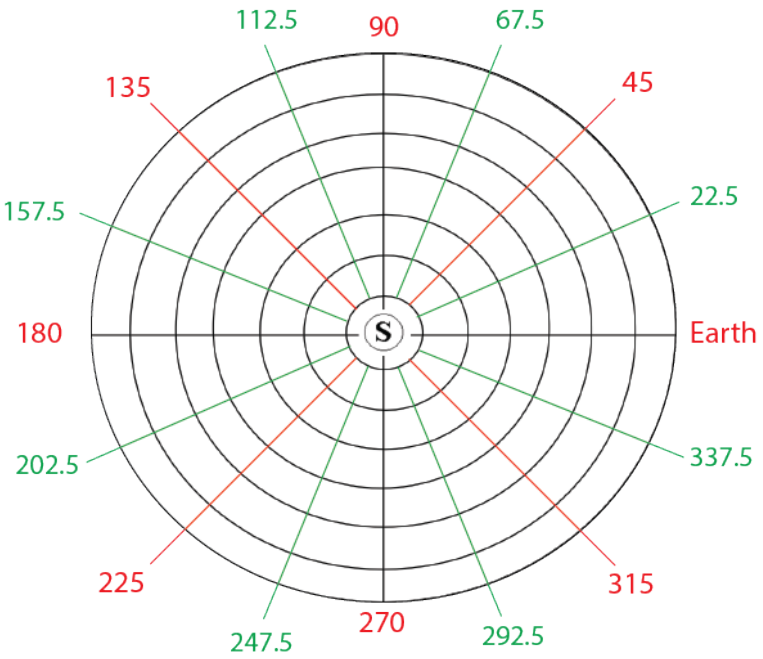


CME Plotting - Student Activity Sheet

Directions

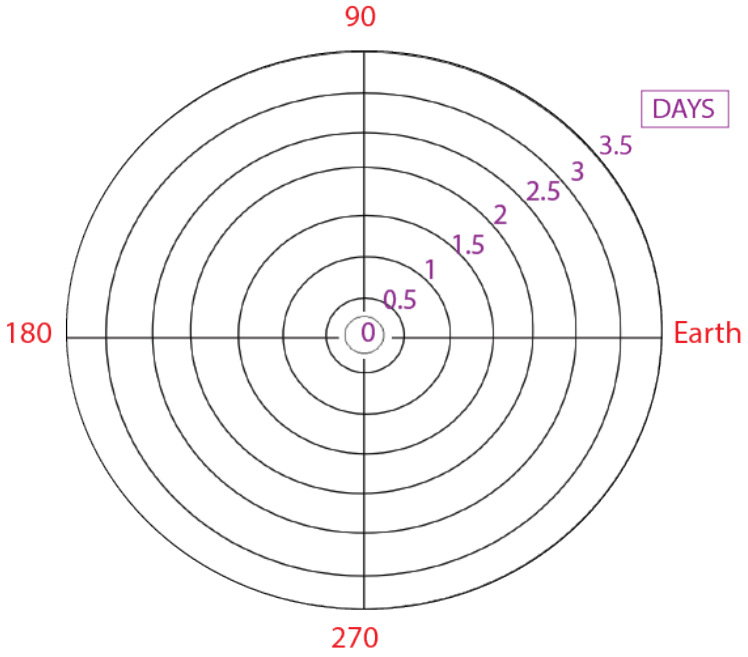
1. Label each angle on the grid using degrees as your unit. Draw and label additional angle lines between each 90° interval for more precise plotting.

Example:



2. Because the provided CMEs' distances from the Sun increase linearly in approximate intervals of 20 million kilometers per 0.5 day, it is possible to label each circle as time in days, starting from Day 0 and increasing in 0.5 day intervals for each concentric circle.

Example:



CME Plotting - Student Activity Sheet

Directions Cont...

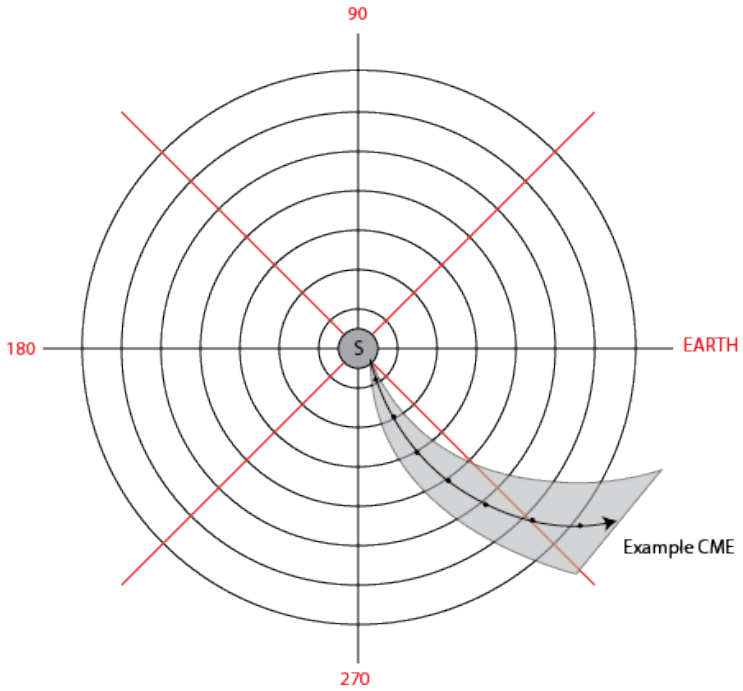
3. Calculate the scale width of each CME and record the values in the "WIDTH TO SCALE (mm)" column of each data table provided. Use the map grid provided to calibrate your measurements. Hint: the distance between concentric rings represent 20 million kilometers and measure 10 millimeters apart.

4. Using the data tables provided, plot the path of CME #1, CME #2, and CME #3 as they leave the Sun during their 3.5-day journey. You will use the data in the "DAY" and "ANGLE" columns to plot your points.

5. Using a ruler, draw to scale the width of each CME indicated in the "WIDTH TO SCALE (mm)" column.

6. Hand sketch the path of each CME by connecting your location points and drawing an arrow to indicate the direction that the CME is moving (away from the Sun). Complete the shape of the CME by shading in your width measurements.

Example:



7. Use the data provided for CMEs 1, 2, and 3, to determine at which angle a CME can emerge from the Sun and hit Earth. Then, fill in the "ANGLE" and "WIDTH TO SCALE (mm)" columns in the data table provided for "CME that hits Earth". Lastly, plot the path of this CME on your map grid and label it CME #4.

Student Activity Sheet - Data Tables

CME #1

DAY	DISTANCE (millions of kilometers)	ANGLE (degrees)	WIDTH (millions of kilometers)	WIDTH TO SCALE (MM)
0	0	225	0.5	
0.5	20	232	7	
1	40	239	13.5	
1.5	60	246	20	
2	80	253	26.5	
2.5	100	260	33	
3	120	267	39.5	
3.5	140	274	46	

CME #2

DAY	DISTANCE (millions of kilometers)	ANGLE (degrees)	WIDTH (millions of kilometers)	WIDTH TO SCALE (MM)
0	0	67.5	0.5	
0.5	20	74.5	7	
1	40	81.5	13.5	
1.5	60	88.5	20	
2	80	95.5	26.5	
2.5	100	102.5	33	
3	120	109.5	39.5	
3.5	140	116.5	46	

CME #3

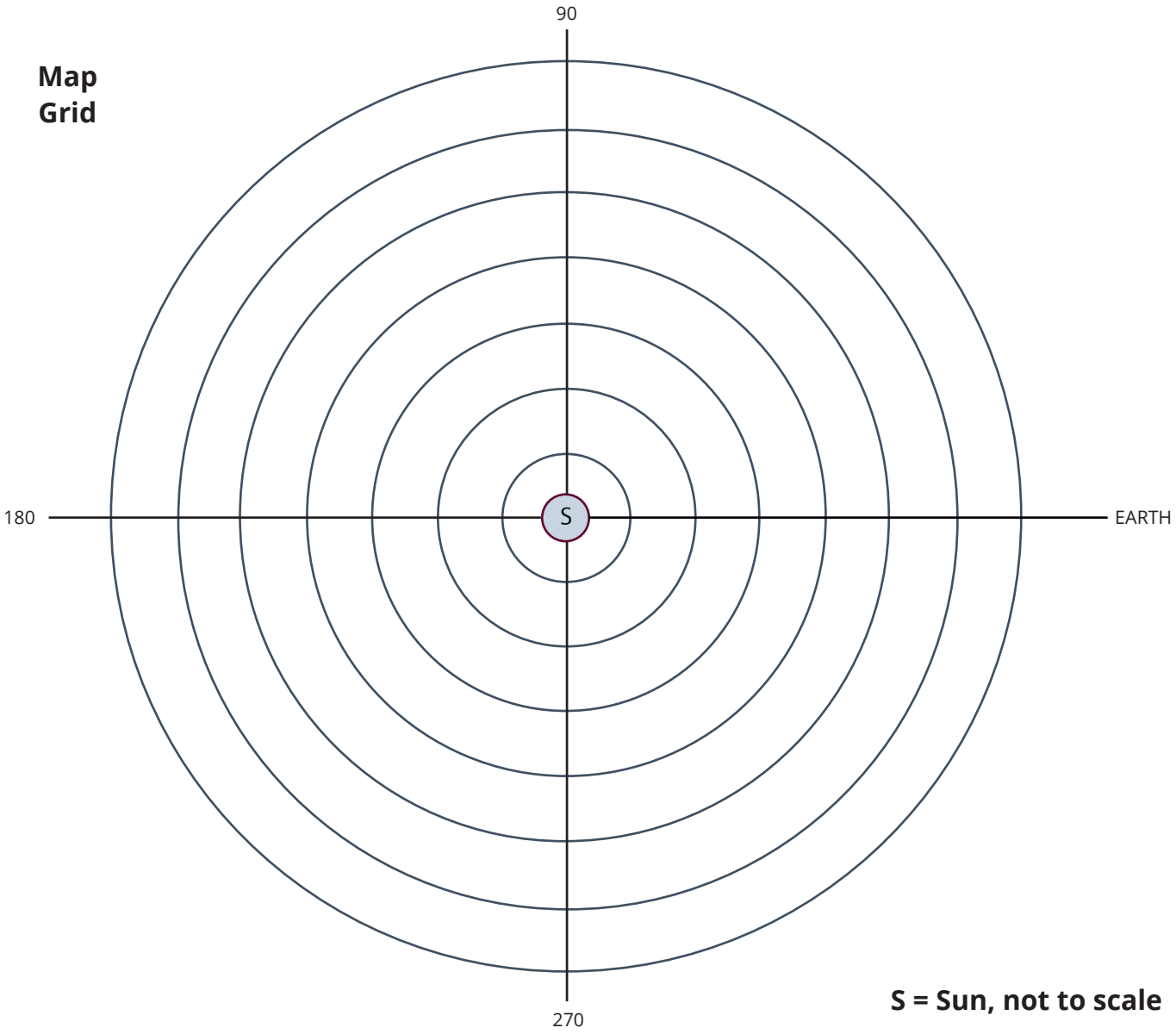
DAY	DISTANCE (millions of kilometers)	ANGLE (degrees)	WIDTH (millions of kilometers)	WIDTH TO SCALE (MM)
0	0	180	0.5	
0.5	20	187	7	
1	40	194	13.5	
1.5	60	201	20	
2	80	208	26.5	
2.5	100	215	33	
3	120	222	39.5	
3.5	140	229	46	

Student Activity Sheet - CME Plotting

CME that hits Earth:

DAY	DISTANCE (millions of kilometers)	ANGLE (degrees)	WIDTH (millions of kilometers)	WIDTH TO SCALE (MM)
0	0		0.5	
0.5	20		7	
1	40		13.5	
1.5	60		20	
2	80		26.5	
2.5	100		33	
3	120		39.5	
3.5	140		46	

Map Grid



S = Sun, not to scale

Conclusions

1. Based on your CME plot, do most Coronal Mass Ejections (CMEs) hit Earth? Why or why not?

2. The points in the tables were calculated for an assumed CME speed of 450 km/sec. How do you think CME paths or shapes might change if traveling at a speed twice as fast (900 km/sec.)? Challenge yourself by re-calculating the table entries for different speeds.

3. What are the limitations of this plotting activity? In other words, what other factors might be missing or not accounted for in this exercise. How might your results be different if you were tracking "real-life" CMEs? Explain.

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