National Aeronautics and Space Administration

NASA Helio Club

Session 4
Predicting Space Weather

NASA Heliophysics Education Activation Team

Session 4: Predicting Space Weather

Table of Contents

Time

120 minutes for the full progression of activities
-or- three **25- minute** activities that stand alone

Learning Goal

To expand learners' knowledge of the Sun's influence on Earth's systems.

Full Session Overview

This session starts with a Know, Want-to-know, Learned (KWL) strategy for finding out what learners already know about the space weather. Start by engaging learners with a 2-minute video on the difference between a solar flare and a coronal mass ejection (CME), which leads into a discussion of the solar cycle and how increased activity on the Sun can cause geomagnetic storms here on Earth. This leads into a discussion of the potential hazards of space weather. Learners then explore the force of magnetism and the shape of magnetic fields and the role of magnetism in the complex interactions between the Sun and Earth. They are introduced to a NASA mission that studies these magnetic fields, the Magnetospheric Multiscale Mission (MMS) (Activity 1). Next, learners analyze sunspot data, make predictions of space weather using the KP Index, and learn how predicting space weather is important for keeping astronauts and technology safe, both in orbit and on Earth (Activity 2). The session ends with learners constructing a 2D model of the MMS spacecraft and exploring more about the types of instruments the spacecraft use to measure fluctuations in Earth's magnetosphere (Activity 3). Use the KWL to assess knowledge gains.

- ➢ **Prior Knowledge:** What do you already know about space weather? KWL (15 minutes)
- ➢ **Engage:** Introduction to Space Weather (15 minutes)
- ➢ **Explore: Activity 1:** Modeling Magnetic Fields (25 minutes)
- ➢ **Explain**: **Activity 2:** Predicting Space Weather (25 minutes)
- ➢ **Extend: Activity 3:** Magnetospheric Multiscale (MMS) Mission Model (25 minutes)
- ➢ **Evaluate:** KWL (15 minutes)

Materials

NASA Helio Club Youth Guide (optional) includes all handouts for all six sessions.
Quantities are per learner.

Basics

- ☐ Writing tools (pens or pencils)
- ☐ Art supplies (markers or crayons)
- ☐ (1) Pair of scissors
- ☐ (1) Roll of tape

Prior Knowledge/Evaluate

- ☐ (1) Handout_KWL_Session 4

Engage

- ☐ Digital Resources

Explore: Activity 1

- ☐ (1) Handout_Modeling Magnetic Fields
- ☐ (1) Compass
- ☐ (1) Large bar magnet
- ☐ (1) Case of iron filings

Explain: Activity 2

- ☐ (1) Handout_NOAA Sunspot Data 1986-present

Extend: Activity 3

- ☐ (1) Handout_MMS Model/Bookmark, print one-sided
- ☐ (5) Pennies
- ☐ (8) Pieces of spaghetti
- ☐ Scissors
- ☐ Tape

Digital Resources

- Educator Resource: Educator Background Information
- Educator Resource: Slides Session 4
- Educator Resource: Activity 3: MMS Bookmark and Scale Model Activity
- Video: Engage: The Difference Between CMEs and Solar Flares
- Video: Engage: The Solar Cycle as Seen from Space
- Video: Activity 1: Comparative Magnetospheres: A Noteworthy Coronal Mass Ejection
- Video: Activity 1: NASA ScienceCasts: Earth's Magnetosphere
- Video: Activity 1: Plotting a Magnetic Field Lines
- Video: Activity 3: How Will the 4 MMS Spacecraft Launch and Deploy?
- Webpage: Engage: NASA Solar Dynamics Observatory (SDO) Mission
- Webpage: Engage: NASA Solar and Heliospheric Observatory (SOHO) Mission
- Webpage: Activity 2: NOAA Solar Cycle Sunspot Progression Graph
- Webpage: Activity 2: NOAA Space Weather Kp Index Data
- Webpage: Activity 3: NASA Magnetosphere Multiscale (MMS) Mission
- Webpage: Activity 3: NASA Themis and ARTEMIS Program
- Webpage: Activity 3: Artemis Missions

Learning Objectives: At the end of the session, learners will be able to…

1. Describe what causes solar wind.
2. Identify how magnetic fields create space weather.
3. Describe why scientists want to predict space weather.
4. Compare different ways scientists predict space weather.
5. Analyze and interpret real-time space-weather data.

Key Vocabulary

- **Coronal Mass Ejection (CME) -** A large cloud of solar plasma and embedded magnetic fields released into space after a solar eruption.
- **Dayside Magnetopause -** The location in space where Earth's magnetic field balances the pressure of the solar wind. It is located at the edge of the **magnetosphere**.
- **Interplanetary Magnetic Field (IMF) -** The solar magnetic field carried by the **solar wind** among the planets of the solar system.
- **Kp-Index –** A nine-point scale that tells scientists how disturbed Earth's magnetic field is based on an average of magnetic observations from around the world, measured every three hours.
- **Magnetic Field –** A region of influence in the space around a magnet.
- **Magnetic Reconnection –** Process in which magnetic field lines come together and explosively realign, often sending particles in the area flying off near the speed of light.
- **Magnetism –** A physical phenomenon produced by the motion of electric charge, resulting in attractive and repulsive forces between objects.
- **Magnetosphere –** A region around our planet created by Earth's internal magnetism. It plays a crucial role in our planet's habitability.
- **Magnetotail -** the extreme extension of a **magnetosphere**, on the side of a planet opposite the Sun, shaped by the **solar wind**.
- **Photosphere –** The first layer of the solar atmosphere, often called the "surface" of the Sun.
- **Plasma –** A state of matter. Plasmas are so incredibly hot that the electrons leave their atoms, making it essentially a gas of charged particles. While uncommon on Earth, 99% of the matter we can see in the universe is made of plasma.
- **Solar Cycle, Solar Maximum, Solar Minimum –** The cycle that the Sun's magnetic field goes through approximately every 11 years when the north and south poles of the Sun flip. The beginning of a solar cycle is a **solar minimum**, or when the Sun has the least sunspots. Over time, solar activity — and the number of sunspots — increases. The middle of the solar cycle is the **solar maximum**, or when the Sun has the most sunspots. As the cycle ends, it fades back to the solar minimum and then a new cycle begins.
- **Solar Flare –** An energetic burst of light and particles triggered by the release of magnetic energy on the Sun.
- **Solar Wind –** A gusty stream of material that flows from the Sun in all directions, all the time, carrying the Sun's magnetic field out into space.
- **Space Weather –** Describes the impact of the solar wind on Earth, our technologies, and other bodies in the solar system.
- **Sunspot –** A cooler region on the Sun's visible surface caused by a concentration of magnetic field lines.

Review the Educator Background Information **for more information on major concepts.**

Next Generation Science Standards (NGSS) Connections

MS-ESS1-1. Space Systems: **Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.** Learners explore the solar cycle throughout the session.

MS-PS1-4. Structures and Properties of Matter: **Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.** Learners explore how plasma creates the solar wind in the Engage activity.

MS-PS2-5. Forces and Interactions: **Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.** Throughout the session learners explore the magnetic fields of Earth and the Sun and how they interact..

MS-PS4-2. Waves and Electromagnetic Radiation: **Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.**

Targeted STEM Skills

Asking questions: Learners ask questions using a KWL.

Making predictions: Activity 1: Learners make predictions about how magnetic fields affect a compass.

Planning and carrying out investigations [MS-PS2-5]: Activity 1: Learners experiment with magnetic fields.

Developing and using models [MS-PS1-4]: Activity 3: Learners use a model to explore the Magnetospheric Multiscale Mission (MMS) spacecraft.

Recognizing patterns [MS-ESS1-1]: Activity 2: Learners identify patterns in the solar cycle.

Gathering and evaluating information [MS-PS4-3]: Activity 2: Learners analyze space-weather data.

Steps: Full Session

Italics indicate recommended scripts to use with students.

Use the accompanying slides to help keep learners engaged.

- ➢ **Prior Knowledge:** What do you already know about space weather? KWL (15 minutes)
- ➢ **Engage:** Introduction to Space Weather (15 minutes)
- ➢ **Explore: Activity 1:** Modeling Magnetic Fields (25 minutes)
- ➢ **Explain: Activity 2:** Predicting Space Weather (25 minutes)
- ➢ **Extend: Activity 3:** Magnetospheric Multiscale (MMS) Mission Model (25 minutes)
- ➢ **Evaluate:** KWL (15 minutes)

Prior Knowledge: What do you already know about space weather?

Overview (15 Minutes)	Materials
A KWL chart is an effective way to assess learners' prior knowledge, identify misconceptions, and measure growth. Use the guiding questions provided in the chart below to focus learners on the content that is explored in this session. As students share their ideas and predictions, don't give them the answers just yet; rather, encourage them to investigate their questions throughout the session. If you don't use the Youth Guide, have learners use a notebook to record their observations, draw diagrams, and collect data.	• Handout_KWL_Session 4 **Instructions** A. **Direct learners to page 48** in the NASA Helio-Club Youth Guide, or print the Handout_KWL_Session 4 B. Have learners complete the **K [Know Column]** and the **W [Wonder Column]** of the KWL chart. Instruct them to leave the L [Learn Column] blank until the end of the session. [Slide 4]

KWL

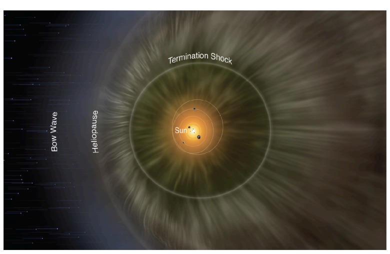
[K] – What do you already know?	[W] – What do you wonder about?	[L] – What did you learn?
What do you already know about space weather? • *What is it?* • *What causes it?* • *Is it similar to Earth weather?*	*Record questions you have about space weather in this column.*	*Record what you learned about space weather in this column.*

Engage: What is space weather?

Overview
(15 Minutes)

This introduction activity is intended to build a foundation of knowledge of the solar cycle.

During the last few sessions, learners were introduced to **solar wind, plasma,** and the **heliosphere**. They learned that the Sun's super-heated **plasma** makes the **solar wind**, which influences space around the Sun, a bubble of space called the **heliosphere**.



Heliosphere Model
Credit: NASA / IBEX

In this session learners are introduced to the **solar cycle**, **solar flares** and **coronal mass ejections (CMEs)**. This activity will lead into the exploration of magnetic fields in the next activity.

Materials

- Digital Resources

Instructions

A. **Provide Context:** *The Sun is made of hot, electrically-charged* ***plasma,*** *which creates enormous, chaotic* ***magnetic fields****. These magnetic fields get all twisted and tangled up as the Sun rotates, creating enormous amounts of energy that results in the* ***solar wind****.*

Well, it is no coincidence that the ***solar wind*** *causes something called* ***space weather****, and can cause storms throughout the* ***heliosphere****, kind of like how Earth wind causes storms on Earth.*

While the ***solar wind*** *is constantly flowing from the Sun, sometimes it can intensify because of increased activity on the surface of the Sun. This activity includes solar storms like* ***solar flares*** *and* ***coronal mass ejections (CMEs).***

Solar flares *are eruptions of light and particles triggered by the release of magnetic energy on the Sun.* ***Coronal mass ejections*** *are large clouds of solar plasma released into space after a solar eruption.*

B. **Watch:** Video: The Difference Between CMEs and Solar Flares. The images in this video were captured by two of NASA's heliophysics missions: Solar Dynamics Observatory (SDO) and Solar and Heliospheric Observatory (SOHO) [Slide 5]

Direct learners to record their observations about the differences between **solar flares** and **CMEs**.

	C. **Provide Context:** *Just like Earth goes through cycles of seasons, bringing both fair and stormy weather, the Sun has its own cycle of periods of both low and high activity.* [Slide 6] *The **solar cycle** is about 11 years long. During this cycle, solar activity increases during a period called **solar maximum (solar max)** and decreases during a period called **solar minimum (solar min).*** *During **solar max,** the Sun's **magnetic fields** are very active and become entangled, causing huge bursts of energy in the form of **solar flares** and **coronal mass ejections (CMEs)**.* *On the other hand, during a period of **solar minimum (solar min)**, the likelihood of **geomagnetic storms** is very low. This approximate 11-year fluctuation in magnetic activity from low to high and to low again is called the **solar cycle**.* **D.** **Watch:** Direct learners to view this video: The Solar Cycle as Seen from Space. This video shows the difference between the Sun during **solar minimum** and **solar maximum**. [Slide 7] Direct learners to record their observations about the differences between solar **minimum** and **solar maximum**. Ask them to make specific observations about the number of **solar flares** and **CMEs** during each period of time.

Major Concepts

- ★ The Sun is made of a superheated matter called **plasma**, which constantly flows outward from the Sun as the **solar wind**.
- ★ While the **solar wind** is constantly flowing from the Sun, sometimes it can intensify because of complex **magnetic fields** on the Sun, which cause solar eruptions that release enormous amounts of energy into the **heliosphere**.
- ★ **Solar flares** are eruptions of light and particles triggered by the release of magnetic energy on the Sun.
- ★ **Coronal mass ejections (CMEs)** are large clouds of solar **plasma** released into space after a solar eruption.
- ★ Approximately every 11 years the Sun's magnetic poles switch, causing a fluctuation in magnetic activity from low to high and to low again. This is called the **solar cycle**.
- ★ During **solar maximum,** the Sun's **magnetic fields** are very active and become entangled, causing huge bursts of energy in the form of **solar flares** and **coronal mass ejections (CMEs)**.
- ★ During **solar minimum**, a period when the Sun's magnetic fields are more stable, the likelihood of solar eruptions is very low.

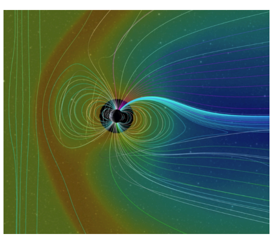
Featured NASA Missions: The [Solar Dynamics Observatory (SDO)]() is designed to help us understand the Sun's influence on Earth and near-Earth space by studying the solar atmosphere in many wavelengths simultaneously. The [Solar and Heliospheric Observatory (SOHO)]() is designed to study the Sun inside out, from its internal structure, to the extensive outer atmosphere, to the solar wind that it blows across the solar system. SOHO has revealed the first images ever of the Sun's convection zone — its turbulent upper layer of the interior — and of the structure of sunspots below the surface.

Explore: Modeling Magnetic Fields

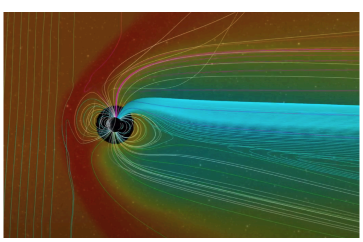
Overview of Activity 1 (25 Minutes)

In this activity, learners explore the properties of magnetism by using a compass to draw the magnetic field lines of a bar magnet. Learners then view an animation of a CME hitting Earth's magnetosphere, observing the shape of the magnetic field of Earth, which is the same shape as a bar magnet. Learners can transfer their knowledge of magnetic fields to magnetic fields on the Sun.

CME Animation/Model



Pre-CME



CME hitting Earth

Particle Density Key
Credit: NASA SVS / GSFC

Materials

- Handout_Modeling Magnetic Fields
- Compass
- Bar magnet
- Case of iron filings

Instructions

A. **Provide Context:** *A very important component of understanding* ***solar wind*** *and predicting* ***space weather*** *is understanding* ***magnetism****. Both Earth and the Sun have* ***magnetic fields****.*

A ***magnetosphere*** *is the region around a planet dominated by the planet's magnetic field. Earth's* ***magnetosphere*** *is very important to the habitability of Earth. The* ***magnetosphere*** *protects Earth from the* ***solar wind*** *and other harmful high-energy particles from the Sun. Without the* ***magnetosphere****, Earth's atmosphere would have been scrubbed away by the solar wind and life would not have been possible on Earth.* [Slide 8]

The Sun's magnetic field is constantly interacting with Earth's magnetic field. ***Space weather*** *describes the variations in the space environment between the Sun and Earth. In particular* ***space weather*** *describes the phenomena that impact systems and technologies in orbit and on Earth. When the* ***solar wind*** *intensifies* ***geomagnetic storms*** *can occur, which are disturbances in Earth's* ***magnetic field****. The severity of a* ***geomagnetic storm*** *is measured by how much Earth's* ***magnetosphere*** *is disturbed as a result of the* ***solar wind****.*

B. **Watch:** *This animation from NASA's Scientific Visualization Studio:* Comparative Magnetospheres: A

Educator Background: How does a compass work? Earth is a gigantic magnet. The small, metal needle in the compass aligns itself with Earth's **magnetic field**. **Magnetism** is a noncontact force, meaning that magnets can affect materials without touching them. We say that a magnet creates a **magnetic field**, or a region of influence in the space around the magnet. Bigger magnets have larger **magnetic fields** than smaller magnets do.

Educator Background: What happens when you put a compass near a magnet? When you place a compass near a magnet, the small, metal compass needle aligns with the **magnetic field** of the magnet. Even though Earth's **magnetic field** is gigantic, a magnet has a stronger influence on a compass needle than Earth's **magnetic field** does because of the magnet's proximity to the compass.

*Noteworthy Coronal Mass Ejection is a computer model made from real data collected during a **CME** that erupted from the Sun in 2006, launching particles Earthward. These storms can interfere with the electrical infrastructure and communications on Earth and in space, which is why scientists are interested in predicting them. While the 2006 **CME** was not the brightest or largest solar event observed, its impact on Earth was substantial, requiring some effort to protect satellites.*

*Scientists at NASA and other science agencies can predict **space weather** by learning more about the Sun.* [Slide 9]

*The **CME** explosion does not occur until 10 seconds into the movie.*

*As the **solar wind** strikes Earth's **magnetic field**, the **magnetic fields** carried by the **solar wind** bend and reconnect around Earth.*

Point out to learners that as the movie zooms out, from a 3D image to a 2D profile of the magnetic field, it shows the density of the **magnetic fields** carried by the **solar wind** coming from the Sun, which is on the left.

*The colors in the visualization shows the increased density of particles caused by the **CME**. This visualization effectively illustrates how Earth's **magnetic field** protects Earth from severe **solar storms**.*

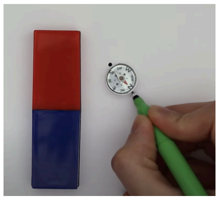
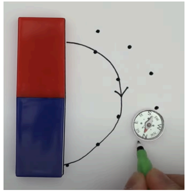
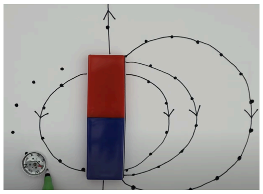
*The red shows the increased density of the particles coming from the Sun. The blue on the far side of Earth shows decreased density in the field as the energy is scattered and dissipated by Earth's **magnetic field**.*

C. **Experiment: Magnetic Fields**

Part 1: How does a compass work?

First, have learners experiment with just the compass by

Drawing Magnetic Fields

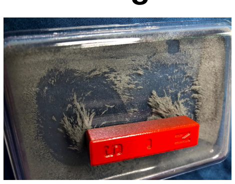
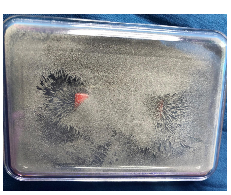




Credit: [VT Physics]

Educators Note: The compass in the video is a plotting compass. If you have a gyrocompass instead of a plotting compass, simply instruct learners to orient the magnet with the poles of the Earth before drawing the magnetic field.

Plotting Compass	Gyrocompass
	

Iron Filing Case

Credit: NASA/Christina Milotte

moving it around and changing its orientation, instructing them to keep the magnets away from the compass. Have learners share their observations. [Slide 10]

Make a prediction! What will happen when you put the compass near the magnet? Have learners experiment with the compass and the magnet and then have them share their observations.

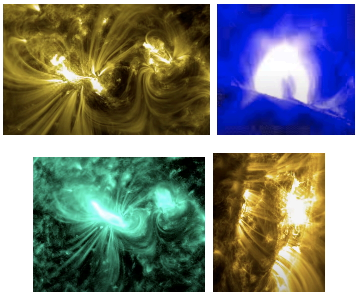
Part 2: What does a magnetic field look like?

Direct learners to page 49 of the NASA Helio Club Youth Guide or use the Handout_Modeling Magnetic Fields. Have learners follow the directions on how to use a compass to draw the magnetic field of the bar magnet. You can also show an instructional video to help guide learners. [Slide 11]

1. Trace one of the bar magnets on a piece of paper. (There is extra notebook paper in the NASA Helio Club Youth Guide).
2. Place the compass next to the magnet, near one of the magnet's poles.
3. On the paper, mark where the needle is pointing with a dot.
4. Move the compass so that the opposite end of the needle lines up with the dot.
5. Repeat Step 3 – mark where the needle is pointing with a dot.
6. Keep moving the compass, repeating Steps 3-4 until your compass is touching the magnet at the opposite pole.
7. Connect the dots.
8. Repeat Steps 2-7, starting at different points near the pole of the magnet, tracing the magnetic field lines.
9. Repeat Steps 2-8 on the other side of the magnet.

D. **Verify Results:** Remind learners that their drawing is a

Images from The Difference Between CMEs and Solar Flares Video



Credit: NASA SVS / GSFC

2D representation of the magnetic field around a magnet, but that the field lines go all the way around the magnet. We can verify the accuracy of our drawing by using the case of iron filings to see the magnetic field lines. Placing the magnet on top of the case, notice that the iron filings show a radiation pattern from each pole, like in the drawing. [Slide 12]

E. **Sharing Results:** Have learners watch the video again: The Difference Between CMEs and Solar Flares. Instruct learners to look for the shapes of the magnetic fields on the Sun during solar flares and CMEs. **Direct learners to page 49** of the NASA Helio Club Youth Guide to view images from the video. [Slide 13]

Allow time for learners to share their observations.

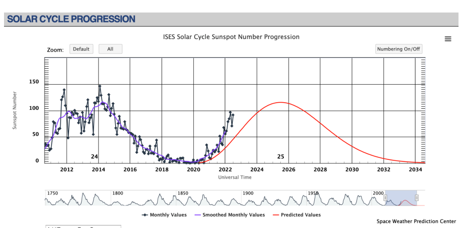
Activity 1 Major Concepts

- ★ Both Earth and the Sun have **magnetic fields**.
- ★ A **magnetosphere** is the region around a planet dominated by the planet's magnetic field.
- ★ Earth’s **magnetosphere** protects Earth from the **solar wind** and other harmful effects of the Sun.
- ★ The Sun’s magnetic field is constantly interacting with Earth’s magnetic field. **Space weathe**r describes the variations in the space environment between the Sun and Earth. In particular **space weather** describes the phenomena that impact systems and technologies in orbit and on Earth.
- ★ When the **solar wind** intensifies **geomagnetic storms** can occur, which are disturbances in Earth’s **magnetic field**. The severity of a **geomagnetic storm** is measured by how much Earth’s **magnetosphere** is disturbed as a result of the **solar wind**.

Explain: Predicting Space Weather

Overview of Activity 2 (25 Minutes)

In this activity, learners will analyze space-weather data from the National Oceanic and Atmospheric Administration (NOAA). Learners will compare two different types of data: sunspot data and measurements from magnetometers on Earth.



NOAA's Solar Cycle Sunspot Number Progression
Credit: NOAA

Use the slider on the graph to access older data.
Credit: NOAA

Materials

- Handout_NOAA Sunspot Data 1986-present

Instructions

A. **Provide Context:** *Scientists can predict geomagnetic storms in several ways.* [Slide 14]

*Scientists can monitor how active the Sun is during the **solar cycle** by counting **sunspots** and by using ground stations to monitor the changes in Earth's **magnetic field.***

***Sunspots** are dark, cooler regions on the Sun's visible surface caused by a concentration of magnetic field lines. Like **CMEs** and **solar flares**, **sunspots** are an indication of high solar activity.* [Slide 15]

*By monitoring the number of **sunspots**, we can determine the level of magnetic activity on the Sun and more accurately predict **space weather**. The more **sunspots**, the more solar eruptions a cycle is expected to unleash.*

B. **Analyzing Data: Direct learners to the Solar Cycle Progression Graph** on NOAA's Space Weather Prediction Webpage. [Slide 16]

*This graph shows the number of **sunspots** that have occurred over the last 11 years.*

- *Scroll your cursor over the graph to see the measured values.*
- *Use the slider on the timeline below the graph to change the amount of data that you can*

NOAA Sunspot Data 1986-present

Sunspot Data 1986-present

Solar Cycle	Year in Cycle	Year	Peak Sunspot #	Point in Cycle	Solar Cycle	Year in Cycle	Year	Peak Sunspot #	Point in Cycle
22	**1**	**1986**	**15**	**min**	**24**	**1**	**2008**	**7**	**min**
	2	1987	61			2	2009	13	
	3	1988	176			3	2010	93	
	4	**1989**	**212**	**max**		4	2011	93	
	5	1990	192			5	2012	98	
	6	1991	204			6	2013	108	
	7	1992	161			**7**	**2014**	**116**	**max**
	8	1993	102			8	2015	89	
	9	1994	53			9	2016	55	
	10	1995	36			10	2017	28	
23	**1**	**1996**	**13**	**min**		11	2018	14	
	2	1997	52		**25**	**1**	**2019**	**5**	**min**
	3	1998	102			2	2020	15	
	4	1999	164			3	2021	56	
	5	2000	175			4	2022	101	

*see, all the way back to 1755, when scientists started recording **sunspot** data.*

Currently, we are in Solar Cycle 25, which is the 25th cycle since 1755. Using the data from the past 250+ years, scientists can accurately predict how intense solar cycles will be and when maximum and minimum will occur.

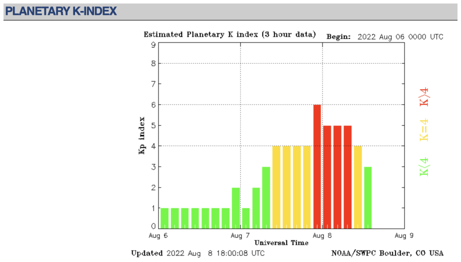
Direct learners to page 50 of the NASA Helio Club Youth Guide or use the Handout_NOAA Sunspot Data 1986-present. *This table shows the peak number of **sunspots** for each month from 1986-2022, with predicted data through 2029. This data was taken from the graph you just analyzed.* [Slide 17]

Instruct learners to examine the **sunspot** data from both the table and the graph and answer the following questions:

- *What do you notice about the differences between the solar cycles?*
- *Do you see patterns in the data?*
- *What do scientists think Solar Cycle 25 will look like?*

C. **Explain:** *You may have noticed that Solar Cycle 22 was 10 years, cycle 23 was 12 years, and cycle 24 was 11 years. Each **solar cycle** is roughly 11 years, but can vary based on the behavior of the **magnetic fields** on the Sun. You can also see from the 250+ years of data that there is a pattern of more-active and less-active cycles.*

*Because the Sun's poles are about as strong as they were at the same point in the last **solar cycle**, scientists predict that Solar Cycle 25 will play out in similar fashion to Solar Cycle 24. Solar Cycle 24 was a weak cycle, peaking at 116 **sunspots** (the average*



NOAA's Space Weather Dashboard KP Index Graph

is 179). Solar Cycle 25 is now underway and expected to peak with 115 ***sunspots*** *in July 2025.*

D. **Measuring Earth's Magnetic Field: Tell learners:** *In addition to counting sunspots to predict space weather, NOAA and NASA also use observatories all around the world to measure the disturbances in Earth's* ***magnetosphere***. [Slide 18]

Just like weather scientists on Earth use scales to quantify the severity of storms such as hurricanes, ***space weather*** *scientists use a scale to quantify the severity of* ***geomagnetic storms***. *This scale is called the* ***Kp-index***.

The ***Kp-index*** *is a nine-point scale that measures the level of disturbance in Earth's* ***magnetosphere.*** *The* ***Kp-index*** *is calculated using an average of measurements taken every three hours at 13 geomagnetic observatories around Earth.*

The higher the number is, the more severe the disturbance. If the ***KP-index*** *rises above 6 or 7, we may expect satellite blackouts and interference with communication and electrical systems on Earth.*

Direct learners to the NOAA Space Weather Kp-Index Data for the last three days. [Slide 19]

Analyze the graph:

- *When did the greatest "observed Kp" occur over the last three days?*
- *Was there a lot of geomagnetic activity over the last three days?*
- *What does this activity tell you about what is happening on the Sun?*
- *What would you predict the activity would be over the next three days?*

E. **Explain:** *The Carrington Event is a notable geomagnetic storm that occurred in 1859, caused by*

	both a solar flare and a CME. At a sustained Kp value of 9, NOAA predicts that a Carrington-like event today would cause worldwide disruptions in communications via telephone, radio, and TV, and cause electrical blackouts. [Slide 20]

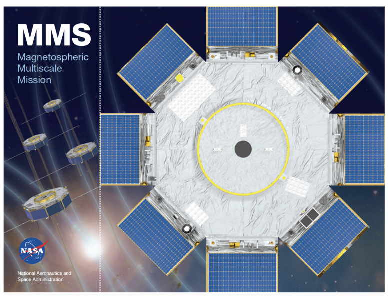
Activity 2 Major Concepts

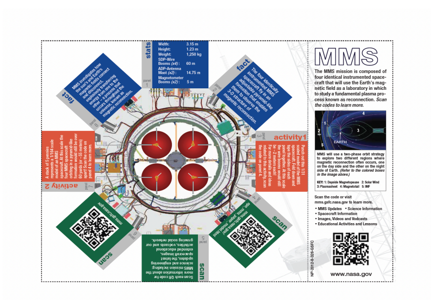
- ★ Scientists can monitor how active the Sun is during the **solar cycle** by counting **sunspots** and by using ground stations to monitor the changes in Earth's **magnetic field.**
- ★ **Sunspots** are dark, cooler regions on the Sun's visible surface caused by a concentration of magnetic field lines. Like **CMEs** and **solar flares**, **sunspots** are an indication of high solar storm activity.
- ★ Each **solar cycle** is roughly 11 years but can vary based on the behavior of the **magnetic fields** on the Sun.
- ★ The **Kp-index** is a nine-point scale that measures the level of disturbance in Earth's **magnetosphere.** The **Kp-index** is calculated using an average of measurements taken every three hours at 13 geomagnetic observatories around Earth.

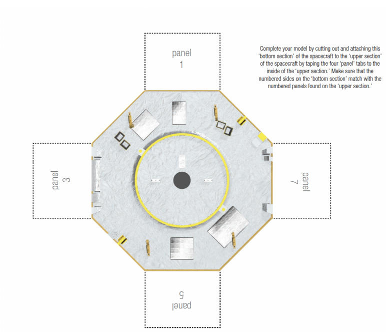
Extend: MMS Spacecraft Model

Overview of Activity 3 (25 Minutes)

This session closes with learners exploring more about NASA's MMS mission; learners will build a 2D model of the spacecraft.







MMS Paper Model
Credit: NASA GSFC

Materials

- Handout_MMS Model/Bookmark, print one sided
- (5) Pennies
- (8) Pieces of dry spaghetti
- Tape
- Scissors

Instructions

A. **Provide Context:** *The Sun's and Earth's **magnetic fields** connect and disconnect explosively, transferring energy from one to the other. This energy can create **space weather** and **geomagnetic storms**.*

*This process of connecting and disconnecting magnetic fields occurs throughout the universe and is known as **magnetic reconnection**.*

B. **Watch:** Video: NASA ScienceCasts: Earth's Magnetosphere. *This video gives an overview of Earth's **magnetosphere** and how NASA missions collect data on **space weather.*** [Slide 21]

Have learners consider the following questions:

- Why is Mars' atmosphere so thin?
- What does it mean that Earth's magnetosphere is permeable?
- How would you describe magnetic reconnection?

C. **Provide Context:** *One of the NASA missions that investigates the effects of **space weather** on Earth is NASA's Magnetospheric Multiscale (MMS) mission, which collects data on how the Sun's and Earth's **magnetic fields** connect and disconnect explosively, transferring energy into Earth's atmosphere.*

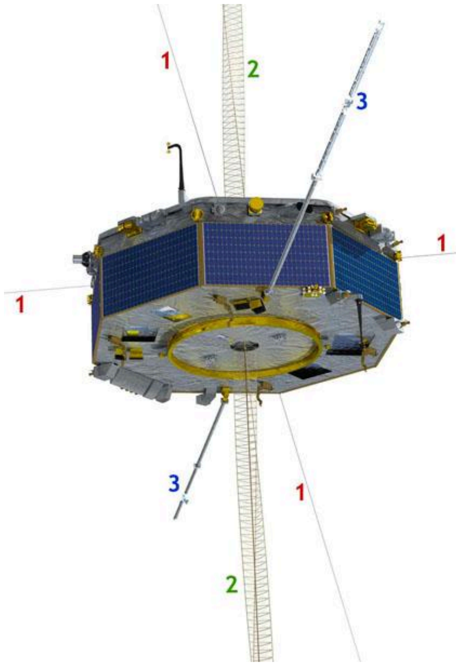
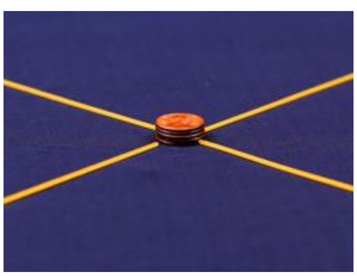
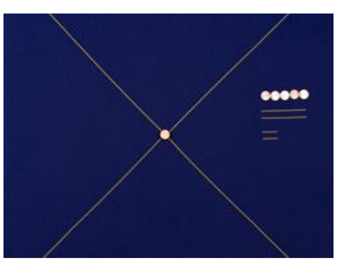


Diagram of MMS Instrument Booms

Credit: NASA GSFC

1. **SDP-Wire Booms**
2. **ADP-Antenna Masts**
3. **Magnetometer Booms**





5 pennies create a base for the model.
Credit: NASA GSFC

D. **Watch:** *How Will the 4 MMS Spacecraft Launch and Deploy? This video shows the deployment of the four identical spacecraft that make up NASA's MMS mission and the instruments on the spacecraft.* [Slide 22]

Have learners consider: Why are there four spacecraft and what shape is their formation in?

The ***Spin-plane Double Probe (SDP) instrument*** *and the* ***Axel Double Probe (ADP) instrument*** *work together to measure the 3D electric field, and the* ***Magnetometer instruments*** *measure the magnetic field.* [Slide 23]

Magnetic fields and electric fields are perpendicular to one another. The fields affect one another.

E. **Model: Direct learners to page 51** of their NASA Helio Club Youth Guide, or use the Handout_MMS Paper Model. Direct learners to cut out the paper model and the accompanying book mark, tape the front to the back, and follow the directions on panel 3. [Slide 24]

Have learners complete their models by cutting out and attaching the front and back of the model by taping the four 'panel' tabs. Each panel is numbered so you can match the front to the back.

Have learners follow the directions on panel 7 and stack and tape five pennies together to create a base for the model. Learners can also attach eight pieces of dried spaghetti to simulate the booms coming off of the spacecraft. [Slide 25]

Find more information about this activity at MMS Bookmark and Scale Model Activity.

F. **Explain:** *Earth's magnetosphere has different parts, as diagrammed on the bookmark that accompanies the model. The different parts are determined by how the* ***solar wind*** *interacts with the* ***magnetosphere.*** [Slide

	26] 1. ***Dayside Magnetopause:*** *The location in space where Earth's magnetic field balances the pressure of the solar wind. It is located at the edge of the magnetosphere.* 2. ***Solar Wind:*** *The plasma of charged particles coming out of the Sun in all directions at supersonic speeds.* 3. ***Plasma Sheet:*** *A sheet of plasma that extends down the magnetotail dividing the two lobes of Earth's magnetic field.* 4. ***Magnetotail:*** *The extreme extension of a magnetosphere, on the side of a planet opposite the Sun, shaped by the solar wind.* 5. **Interplanetary Magnetic Field (IMF)**: The solar magnetic field carried by the **solar wind** among the planets of the solar system.

Activity 3 Major Concepts

★ The process of connecting and disconnecting magnetic fields occurs throughout the universe and is known as **magnetic reconnection**. The Sun's and Earth's **magnetic fields** connect and disconnect explosively, transferring energy from one to the other. This energy can create **space weather** and **geomagnetic storms**.

★ The MMS mission has four identical spacecraft, flying in a tetrahedron formation, to capture three-dimensional data of Earth's **magnetic field**.

★ Earth's magnetic field has different parts, which is determined by how the **solar wind** interacts with the **magnetosphere.**

- The **dayside magnetopause** is the location in space where Earth's magnetic field balances the pressure of the **solar wind**. It is located at the edge of the magnetosphere.
- The **magnetotail** is the extreme extension of a **magnetosphere**, on the side of a planet opposite the Sun, shaped by the **solar wind**.

Featured NASA Missions

NASA's Magnetospheric Multiscale (MMS) mission orbits through near-Earth space to observe a little-understood process called magnetic reconnection. This process occurs in many places throughout the universe and powers a wide variety of events, including giant explosions on the Sun and auroras shimmering in the night sky.

The **NASA THEMIS and ARTEMIS** program studies how mass and energy move through the near-Earth space environment to determine the physical processes initiating auroras. THEMIS was launched in 2007. In 2010, two of its five spacecraft were repurposed as ARTEMIS and moved to a new location to study similar processes closer to the Moon. The **ARTEMIS Program** is the first step in the next era of human exploration. Together with commercial and international partners, NASA will establish a sustainable presence on the Moon to prepare for missions to Mars.

Evaluate: What did you learn about space weather?

Overview of Activity (15 Minutes)	Materials
At the end of the session, learners complete the KWL chart, adding what they learned to the L [Learn] column. Encourage learners to look through Session 4 in the Helio Youth Guide, and to review the activities and the observations they recorded during the activities, to help them summarize what they learned during the session.	• Handout_KWL_Session 4
	Instructions A. **Direct learners to page 48** in the NASA Helio Club Youth Guide, or print the Handout_KWL_Session 4 [Slide 27] B. Have learners complete the **L [Learn Column]** of the KWL chart. Emphasize to learners that they should also be correcting any misconceptions they had prior to the session, from the K [Know] column, and answering any questions from the W [Wonder] column, if they are able to.

Session 4 Major Concepts

- ★ The Sun is made of a superheated matter called **plasma**, which constantly flows outward from the Sun as the **solar wind**.
- ★ While the **solar wind** is constantly flowing from the Sun, sometimes it can intensify because of complex **magnetic fields** on the Sun, which cause solar eruptions that release enormous amounts of energy into the **heliosphere**.
- ★ Approximately every 11 years the Sun's magnetic poles switch, causing a fluctuation in magnetic activity from low to high and to low again. This is called the **solar cycle**.
- ★ During **solar maximum,** the Sun's **magnetic fields** are very active and become entangled, causing huge bursts of energy in the form of **solar flares** and **coronal mass ejections (CMEs)**.
- ★ During **solar minimum**, a period when the Sun's **magnetic fields** are more stable, the likelihood of solar eruptions is very low.
- ★ Both Earth and the Sun have **magnetic fields**.
- ★ A **magnetosphere** is the region around a planet dominated by the planet's magnetic field.
- ★ Earth's **magnetosphere** protects Earth from the **solar wind** and other harmful effects of the Sun.
- ★ **Space weathe**r describes the variations in the space environment between the Sun and Earth. In particular **space weather** describes the phenomena that impact systems and technologies in orbit and on Earth.
- ★ When the **solar wind** intensifies **geomagnetic storms** can occur, which are disturbances in Earth's **magnetic field**.
- ★ Scientists can monitor how active the Sun is during the **solar cycle** by counting **sunspots** and by using ground stations to monitor the changes in Earth's **magnetic field.**
- ★ The **Kp-index** is a nine-point scale that measures the level of disturbance in Earth's **magnetosphere.**
- ★ The process of connecting and disconnecting magnetic fields occurs throughout the universe and is known as **magnetic reconnection**.
- ★ The Sun's and Earth's **magnetic fields** connect and disconnect explosively, transferring energy from one to the other. This energy can create **space weather** and **geomagnetic storms**.
- ★ Earth's magnetic field has different parts, which is determined by how the **solar wind** interacts with the **magnetosphere.**

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