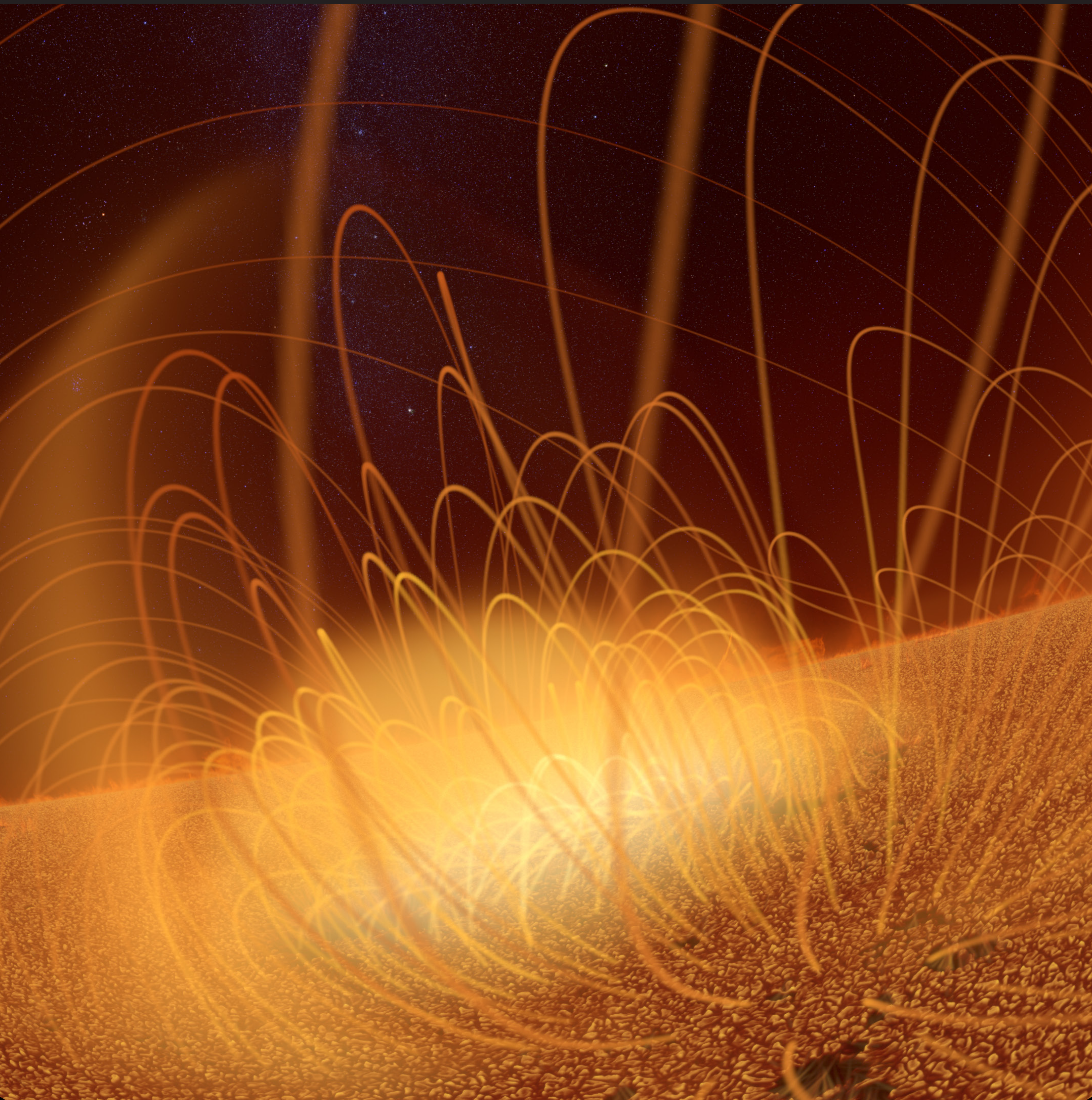
SOLAR SUPERSTORMS

EDUCATOR'S GUIDE



Overview

Solar storms are as common as the changing seasons on Earth. Much of the time the storms coming from the Sun are weak and have little to no effect on Earth. Sometimes these storms aren't even pointed at Earth and go towards other regions and planets in our solar system. These storms are often referred to by scientists as Coronal Mass Ejections or CMEs for short. It's important to remember that solar activity is driven by nuclear fusion at the Sun's core, allowing the Sun to shine bright and emit heat. We depend on the Sun for the very energy and light it emits. Life on Earth would have no chance if it weren't for the Sun's brightness and stability.

As much as we enjoy and take for granted the Sun's consistency, we should not be lulled into a false sense of security that the Sun can do no harm. Aside from getting a bad sunburn, our Sun has the potential to unleash massive eruptions that could effect many of the technologies at the heart of modern society. Scientists have been actively studying the Sun in detail going all the way back to the time of Galileo over 400 years ago. He did so by looking at our star with his newly developed telescope near sunset, when the atmosphere dims its bright light.

IMPORTANT TIP: DO NOT LOOK DIRECTLY AT THE SUN, ESPECIALLY THROUGH A TELESCOPE OR BINOCULARS.

Solar Superstorms takes us on a journey of exploration as we focus on one of the most powerful solar eruptions to hit Earth in recorded history. This storm is known as the Carrington Event in 1859. The show describes this observed event and the effect it had on the Earth and society back in 1859 and follows with an exploration of the latest scientific research being done to better understand and predict these eruptions in the future.

At the end of August 1859, people all over the world witnessed auroral lights as far south as the tropics, including Hawaii and Australia. Richard Carrington an amateur astronomer observed of a solar flare associated with solar superstorm. He saw a cluster of dark spots on the Sun that appeared to have patches of bright white light around them. Just an hour, he spotted a giant solar flare erupting from the Sun that would impact Earth in both beauty and destruction. The beauty came in the form of aurora so bright and colorful that one journalist reported being able to read a newspaper at night. The destruction was seen as telegraph communications around the world began to fail. Some telegraph operators even reported being shocked and paper catching fire. All of this was caused by the energy that solar flare pumped into the Earth's atmosphere. When a solar storm interacts with Earth atmosphere, we call it a geomagnetic storm.

Can you imagine what would happen today if such a storm hit Earth? Would you stay up late to see the aurora? What would happen to the satellites orbiting Earth, our phones, or TV's?

Education goals

National Science Standards

<u>Middle School (Grades 6-8)</u>

MS-PS1-4

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.

- Plasma is a state of matter that occurs when temperatures rise to extremes, stripping electrons away from atoms such that gas becomes ionized.

Crosscutting: Cause and Effect
Cause and effect relationships may be used to predict phenomena in natural or designed systems.

- Gas that is heated to become plasma in the Sun allows for the production of magnetic fields.

MS-PS2-3

Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

- Observations of the solar cycle allow scientists to determine the amount and strength of magnetic activity on Sun.
- Supercomputer models, based on observations of the Sun, allow scientists to deduce how magnetic fields are generated within the Sun, their change in strength over time, and how they manifest into sunspots, flares, and coronal mass ejections.
- **Activity: The Sun and Magnetic Fields** (pg 10)

Crosscutting: Cause and Effect
Cause and effect relationships may be used to predict phenomena in natural or designed systems.

- The Sun's activity can interact with and affect Earth's magnetic field, leading to aurora and possible damaging power outages.
- The solar cycle is correlated with the amount of magnetic activity on Sun and is observable through the amount of sunspots, flares, and coronal mass ejections.
- **Activity: Spot the Sunspots** (pg 17)

MS-PS4-3

Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.

Crosscutting: Influence of Science, Engineering, and Technology on Society and the Natural World
Technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigations.

- We can use spacecraft such as SOHOand SDO, as well as ground-based observatories such as SDO to measure and monitor the Sun's activity. Computational models of the Sun also increase our capacity to understand the Sun and how it can affect the Earth.

__High School (Grades 9-12)__
HS-PS4-2
Evaluate questions about the advantages of using a digital transmission and storage of information.

- Although digital storage of information is efficient and extremely useful, there are inherent risks to relying heavily on digital systems.

Crosscutting: Science on Society and the Natural World
Modern civilization depends on major technological systems.

- Given our dependency on global technological systems, the next major solar storm to hit Earth could have devastating effects if we are not prepared.

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.

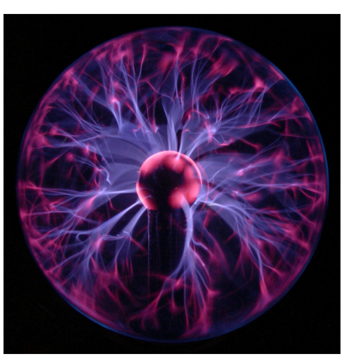
Based on computer simulations and observations of activity on the Sun's surface, we can deduce that the core of the Sun is heated to tens of millions of degrees, allowing fusion to take place. This produces energy in the form of light that then travels outward, taking a million years to travel outward before escaping the surface of the Sun.

Crosscutting: Scale, Proportion, and Quantity
The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.

- Solar activity ebbs and flows in a roughly 11-year cycle. During times of more solar activity, the number and strength of sunspots, solar flares, and coronal mass ejections increases. This increases the chances that Earth will be affected by the solar activity.

b. Main Questions:
- What is plasma?
- How can we learn about the Sun?
- What is the solar cycle?
- What is a solar storm?
- How do aurora form?
- What will happen if a solar storm strikes the Earth?
- Can we do anything to prepare for the next large solar storm?

What is plasma?



Plasma is one of the four states of matter (the other three being solid, liquid, and gas). When gas is heated to extreme temperatures or when a strong electromagnetic field is applied to a gas, the atoms and molecules can lose or gain extra electrons, creating charged particles called *ions*. This state of matter behaves differently from a gas and is thus called plasma. Lightning, fire, plasma globes, and neon lights are all examples of plasma found here on Earth. Although not entirely common on Earth, plasma is the most common state of ordinary matter in the universe. The Sun, all other stars in the universe, and much of the regions between stars and galaxies are composed of plasma.

How can we learn about the Sun?

We learn about the Sun from a combination of observations and computer simulations. Many of the observations inform the conditions that need to be met with computer simulations, and computer simulations can offer models of the Sun that we can use to predict new observations we should see from the Sun.

A slew of NOAA and NASA satellites observe the Sun at different wavelengths (predominantly visible light, ultraviolet light, X-ray light) to learn about different layers of the atmosphere and different physical processes that are happening within the upper layers of the Sun. [Note: Some of the colorful images you see of the Sun are false-colored images because the light that produced the images is a wavelength that the human eye cannot see.] Pulsations of the Sun's surface can tell us about the interior of the Sun in a similar way to how scientists can use the tremors of Earth's surface during an earthquake to learn about the interior of the Earth. Observations of sunspots can tell us about the Sun's magnetic activity and indicate the likelihood of solar storms.

Computer simulations of the Sun allow us to develop models for *how* the Sun operates: how it transfers heat and energy, how it develops magnetic fields, how sunspots and coronal mass ejections are formed. These models are currently being used to try to answer questions such as, "why does the solar cycle last approximately 11 years?" or, "why is the corona (outer-most layer) of the Sun so hot?" Accurate models can give us great predictive power, which is especially important when we're trying to monitor solar activity and how it could influence us here on Earth.

What is the solar cycle?

The solar cycle is a natural cycle of magnetic activity within the Sun. Magnetic activity is lowest during "solar minimum" and highest during "solar maximum." A complete solar cycle from minimum to maximum and back to minimum takes approximately 11 years. During solar maximum, the amount of flares, sunspots, and ejected material from the Sun increases. This is also the time when strong aurora or other consequences may manifest here on Earth. Scientists are still trying to learn what causes the 11-year solar cycle.

What is a solar storm?

A solar storm can refer to any large, rapid release of energy from the Sun's surface. Solar flares, coronal mass ejections, massive bursts of solar wind, or any other large explosions in the Sun's atmosphere can characterize a solar storm.

What will happen if a solar storm strikes the Earth?

Thankfully, the spinning, molten core of the Earth generates a protective magnetic field that guards us against weak solar storms. A weak solar storm directed at the Earth may produce aurora that are more visible at lower latitudes than normal. However, more powerful and energetic solar storms have the potential to cause much more significant effects: The charged particles that enter Earth's atmosphere from a large storm have the potential to disrupt normal function of the technologies on which modern society heavily depends. Major disruptions to the power grid and commercial airline communications, interference with high-frequency radio communications and GPS, and damage to satellites are all possible consequences of a large solar storm.

How do aurora form?

Auroral displays are associated with the solar wind, the continuous flow of electrically charged particles from the sun. When these particles reach the Earth's magnetic field, some get trapped. Many of these particles travel toward the Earth's magnetic poles. When the charged particles strike atoms and molecules in the atmosphere, energy is released. Some of this energy appears in the form of auroras. Auroras occur most frequently during solar maximum, the most intense phase of the 11-year solar or sunspot cycle. Electrons and protons released by solar storms add to the number of solar particles that interact with the Earth's atmosphere. This increased interaction produces extremely bright auroras.

Can we do anything to prepare for the next large solar storm?

As society's reliance on technological systems grows, so does our vulnerability to space weather. The ultimate goal in studying space weather is an ability to forecast events and conditions on the Sun and in near-Earth space that will produce potentially harmful societal and economic effects, and to do this adequately far in advance and with sufficient accuracy to allow preventive or mitigating actions to be taken. Actions we can take to reduce the damage of an oncoming solar storm, provided enough time to do so, include powering down electronic systems, grounding airplanes, and orienting spacecraft so as to minimize disruptions to their instruments.

Glossary

Aurora
Shimmering lights in the sky caused by charged particles from the Sun entering Earth's atmosphere. These are most commonly found near the north pole (*aurora borealis*, northern lights) and the south pole (*aurora australis*, southern lights), but can be seen at lower northern and southern latitudes during times of higher solar activity.

Charged Particles
Particles with an electric charge, such as protons, electrons, and ions.

Coronal Mass Ejection
A burst of charged particles from the Sun's outer layer (corona) that travel outward into space.

Geomagnetic Storm
A temporary disturbance of Earth's magnetosphere caused by charged particles from a coronal mass ejection.

Heliophysics
A branch of physics that studies the Sun and its influence on the surrounding space.

Ionosphere
A layer in Earth's atmosphere that contains a high concentration of ions and free electrons.

Magnetic Field
The region surrounding a magnetized body in which it can affect charged particles.

Magnetosphere
The region surrounding a planet in which charged particles are trapped by the planet's magnetic field.

Nuclear Fusion
The process in which two (or more) smaller nuclei slam together and make one larger nucleus. This is the process by which the Sun generates heavier elements in its core and produces energy in the form of light.

Plasma
A gas consisting of ions and electrons.

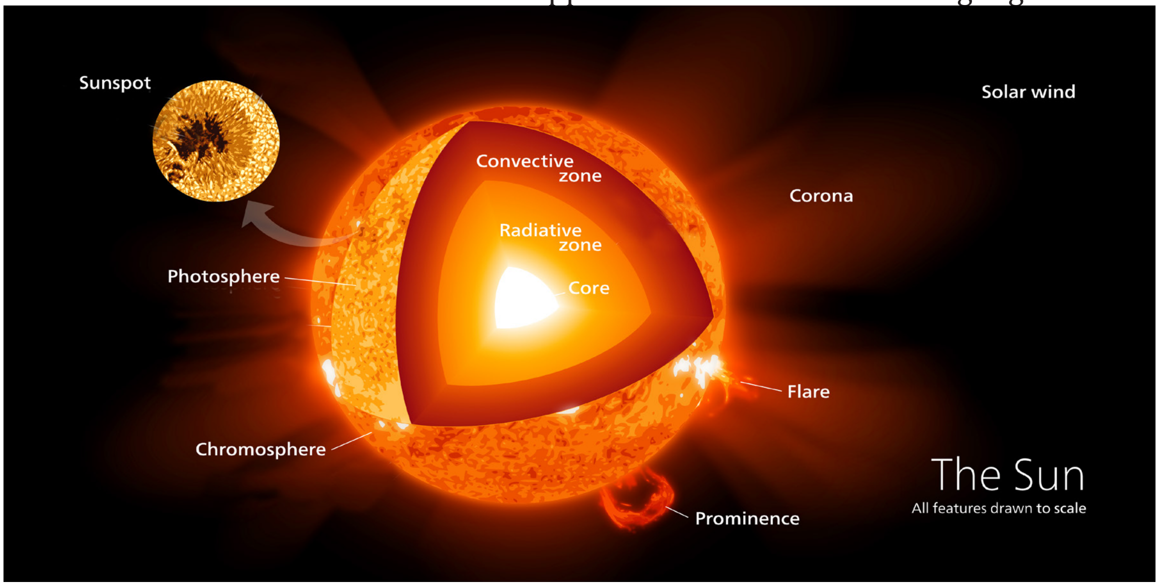
Prominence
A great loop or filament of hot gas that extends outward from the Sun's surface following magnetic field lines. Some prominences may break apart and give rise to coronal mass ejections.

Space Weather
Natural processes in space that can affect the near-Earth environment, satellites, and space travel.

Solar Flare
A huge and sudden release of energy on the solar surface, likely caused when energy stored in magnetic fields is suddenly released.

Solar Wind
A stream of charged particles ejected from the Sun.

Sunspots
Blotches on the surface of the Sun that appear darker than surrounding regions.



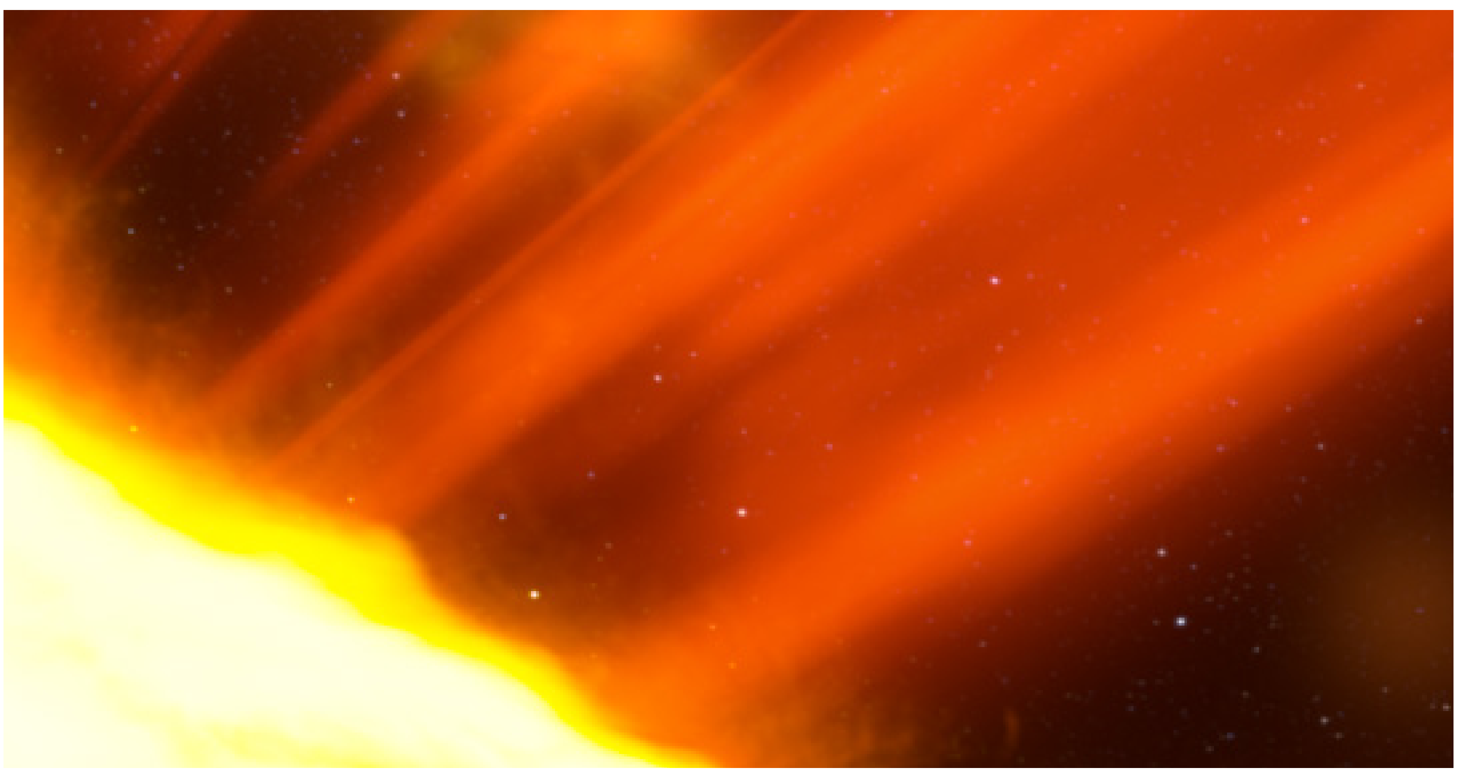
(Can we edit out the words “Penumbra”, “Umbra”, “Granule”, “Temperature minimum”, “Transition region”, and “Tachocline”?)

Inquiry based labs, experiments and demos

The Sun and Magnetic Fields
Credit: NASA Wavelength
http://nasawavelength.org/

Spot the Sunspots
Credit: Lawrence Hall of Science http://www.lawrencehallofscience.org/do_science_now/

For more recommended activities, check out the DIY Sun Science app:
http://www.lawrencehallofscience.org/do_science_now/diy_sun_science



The Sun and Magnetic Fields

Lesson and text adapted from "Live from the Aurora, Educator's Guide" http://stargazers.gsfc.nasa.gov/pdf/products/educator_guides/aurora_educators_guide.pdf.

Grades:

5-9

Objectives:

- Students will be able to map a magnetic field.
- Students will be able to explain that invisible fields surround magnets.
- Students will be able to explain that magnetic fields on the Sun are visible in Sunspots

Description:

Students will simulate solar magentic activity by using iron filings to map magnetic fields around a bar magnet. Students map the magnetic field surrounding two dipole magnets, both parallel and anti-parallel alignment. Students apply vector measurements to their field maps. Then students examine the field arrangement around complex arrangements of the dipole magnets.

Suggested Timing:

45 – 60 minutes.

Vocabulary:

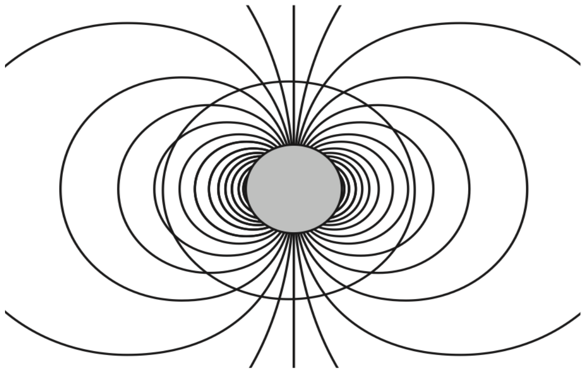
- Magnetic Force
- Orientation
- Field
- Dipole

Materials: (One per group)

- Large sheets of paper
- Two cow magnets (strong bar magnets)
- Iron Filings (http://www.teachersource.com/)
- Worksheet

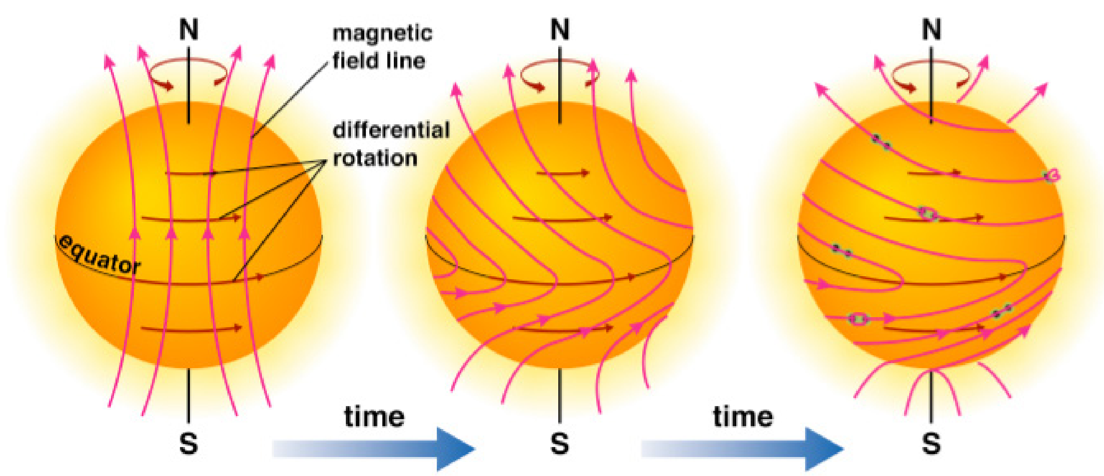
Background Information:

Humans have been aware of and made use of the magnetic field of Earth for the past 2 millennia. Mariners, following the example of the Chinese, used the magnetic properties of magnetite and magnetized metals to find their way relative to the fixed orientation of the compass needle in Earth's magnetic field. Today, we use magnets in a variety of ways, from floating fast spinning CDs in our computers, stereos and TVs, to magnetic resonance imaging, to sticking paper to our refrigerators. Magnetism is a noncontact force, meaning the magnet can affect materials across an intervening space. We do not have to be at the location of the source object to detect it. We say that a magnet creates a magnetic field or a region of influence in the space around the magnet. The bar magnet is the prime example of a dipole magnet. A spherical magnet in an otherwise empty region of space would have a magnetic field approximately modeled in the figure below.



While Earth's magnetic field looks similar to the one in the image above, the Sun's field is significantly more complex because the Sun is not a solid.

Material at the equator rotates faster than material at the poles, causing the magnetic field to stretch and twist. Over the course of the eleven-year Sunspot cycle the field becomes so twisted that parts of the field break through the Sun's atmosphere, carrying material with them.



From The Essential Cosmic Perspective, by Bennett et al.

The material above the Sun's surface appears as prominences. Sunspots, or the points where the magnetic field exits and enters the surface of the Sun have "north" and "south" poles. This is why they always appear in pairs.

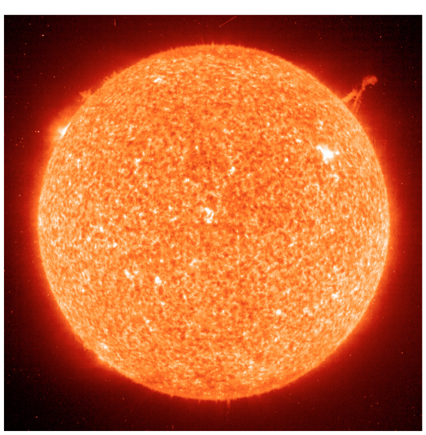


Image From: http://science.nasa.gov/ Image From: umbra.nascom.nasa.gov

Content:

Predict: (Engagement and assessing prior knowledge)

Ask: ***How do you know a magnet is a magnet?***

Where does magnetic force begin and end around a magnet?

Try to elicit these responses from students' previous experience with magnets.

- Magnets affect other magnets and metals.
- Magnetic influence or strength is not related to size of magnet.
- Magnetic influences extend through space, but get weaker with distance.
- Magnets have well differentiated ends or poles.
- There are two poles.
- Like poles repel; unlike poles attract.

Method: (Body of the lesson)

Hand out materials. Instruct students to position the magnets as show in each image, lay a sheet of paper over the top, and sprinkle iron filings on the sheet of paper. Show students how to pour the iron filings back into their container without spilling them. Tell them to use caution because they are very hard to clean up and will also stick to the magnets. Instruct them to draw the pattern of filings that they see, then carefully pour them back into their container before rearranging the magnets into the next configuration. Give students 20-30 minutes to complete the activity. Circulate, answering questions. Questions can be asked motivating students to think critically about the data and the data collection procedure. Some suggestions follow.

- What happens when the two magnets are aligned, positive to positive? Negative to negative?

- Can you tell which field line is from which magnet?

Show students the image attached to this lesson. Explain that these are Sunspots. In the first image students see a visible light image Sunspots.

Ask: Why do you think the Sunspot is darker than the surrounding area? Take a few answers then explain that the dark area is cooler than the surrounding bright areas.

Explain that second image is a MDI Magnetogram, an image of magnetic field polarity. The black spots are negative polarity while the white spots are positive polarity.

Live-It: (Assessment/application assignment)

Have students answer the following questions:

- What is the map representing?
- What is happening between the magnets?
- Suppose you were able to map the field in a plane 30 cm above the plane of the source. What sort of a map would you predict seeing? Can you use the map you have made to demonstrate your prediction is reasonable?
- How are the iron filings like Sunspots?

<u>Extension:</u>

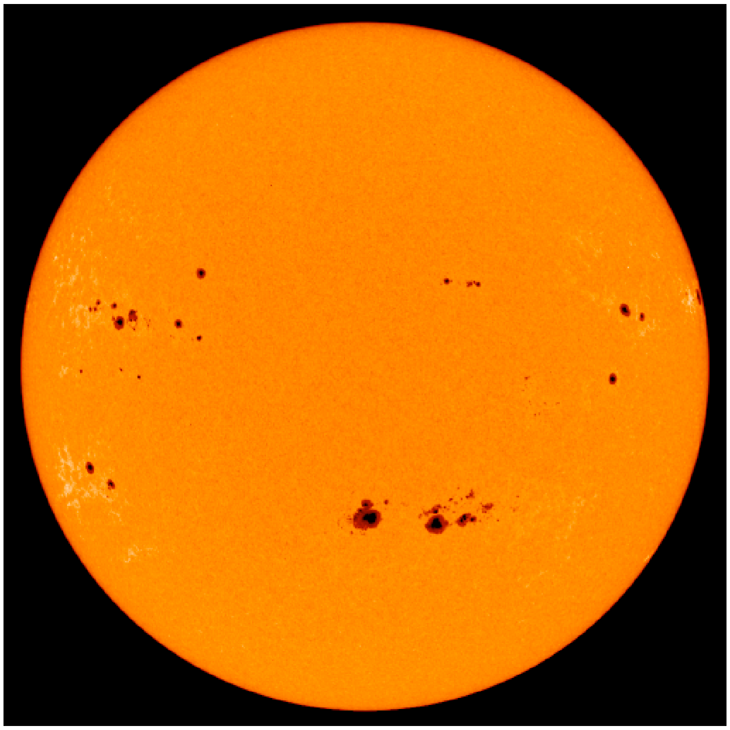
Students can research the Maunder Minimum, an unusually low time in the Sunspot cycle, and compare it to the current Sunspot cycle.

<u>Resources:</u>

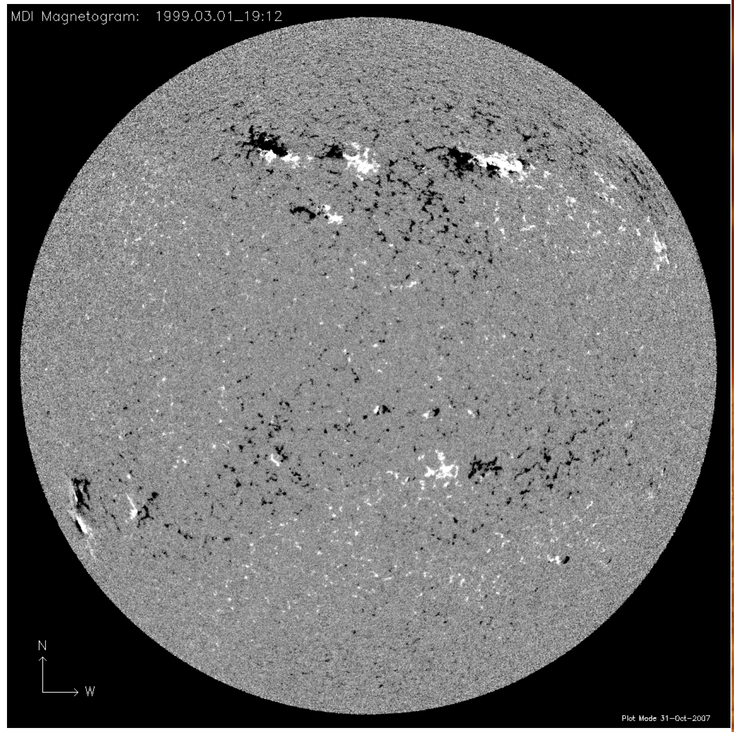
The Solar Dynamics Observatory: http://www.youtube.com/watch?v=PZEKINoI9aU

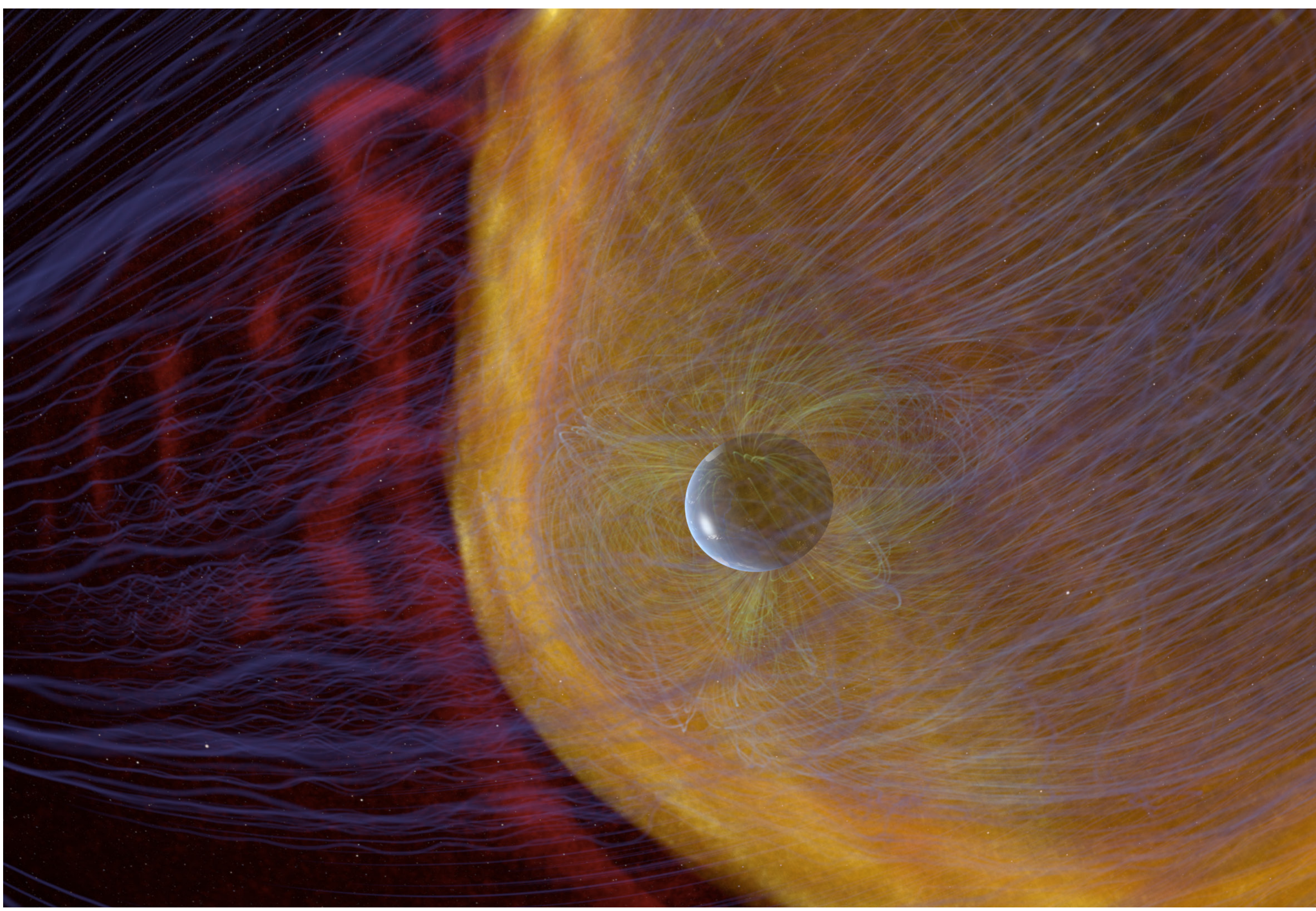
Little SDO Looks Inside the Sun's magnetic field: http://www.youtube.com/watch?v=mvtbPJM5o94

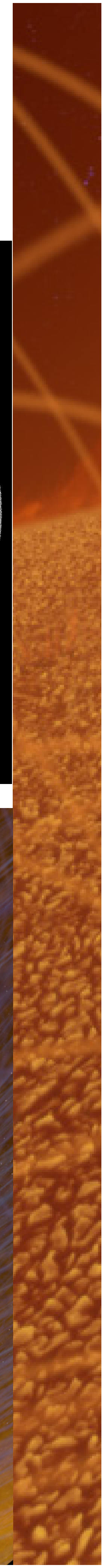
Intensitygram showing dark Sunspots



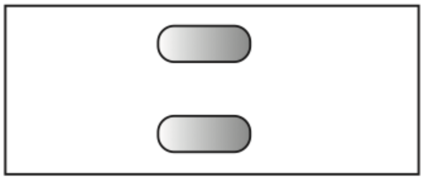
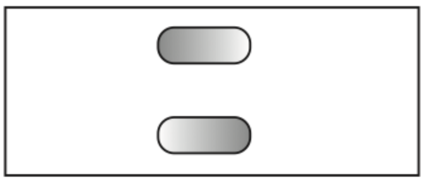
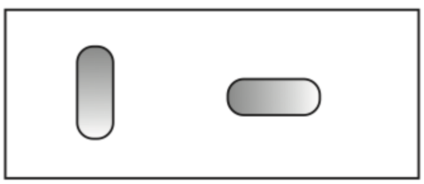
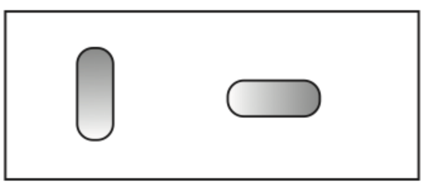
MDI Magnetogram showing Sunspot north (white) and south (black) poles.







The Sun and Magnetic Fields

	Magnet Alignment (Shaded from positive to negative)	Iron Filing Pattern
1		
2		
3		
4		
5		
6		

DIY SUN SCIENCE

Spot the Sunspots

Can you spot the sunspots?

Description

Use binoculars or a telescope to identify and track sunspots. You'll need a bright sunny day.

Age Level: 10 and up

Materials

- two sheets of bright white paper
- a book
- tape
- binoculars or a telescope
- tripod
- pencil
- piece of cardboard, roughly 30 cm x 30 cm
- scissors
- thick piece of paper, roughly 10 cm x 10 cm (optional)
- rubber bands (optional)

- Do not use binoculars whose larger, objective lenses are 50 mm or wider in diameter.
- Binoculars are usually described by numbers like 7 x 35; the larger number is the diameter in mm of the objective lenses.
- Some binoculars cannot be easily attached to a tripod.
- You might need to use rubber bands or tape to safely hold the binoculars on the tripod.

Time

Preparation: 5 minutes
Activity: 15 minutes
Cleanup: 5 minutes

Safety

Do not look directly at the sun with your eyes, through binoculars, or through a telescope! Do not leave binoculars or a telescope unattended, since the optics can be damaged by too much Sun exposure.

Step 1

If you're using binoculars, cover one of the objective (larger) lenses with either a lens cap or thick piece of folded paper (use tape, attached to the body of the binoculars, to hold the paper in position). If using a telescope, cover the finderscope the same way. This ensures that only a single image of the Sun is created. Next, tape one piece of paper to a book to make a stiff writing surface.

Step 2

If using binoculars, trace both of the larger, objective lenses in the middle of the piece of cardboard. Cut out the circles. Tape the cardboard onto the binoculars to create a shield around the binoculars.

Tip This cardboard shield will help block sunlight so it doesn't obscure the Sun's image coming through the binoculars.

Step 3

Place the binoculars or telescope on a tripod. Without looking at the Sun, point the binoculars or telescope toward the Sun. Hold the book/white paper about 8 cm behind the eyepiece. You should see a bright circle of light on the white paper. This feature is the disk of the Sun! Focus the binoculars or telescope to produce a crisp image.

Step 4

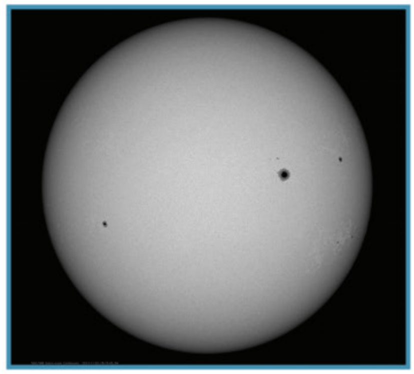
Experiment with moving the paper closer to or farther away from the binoculars or telescope. What happens to the brightness of the image? Sketch the disk of the Sun directly on the piece of paper, noting any dark spots. These are sunspots.

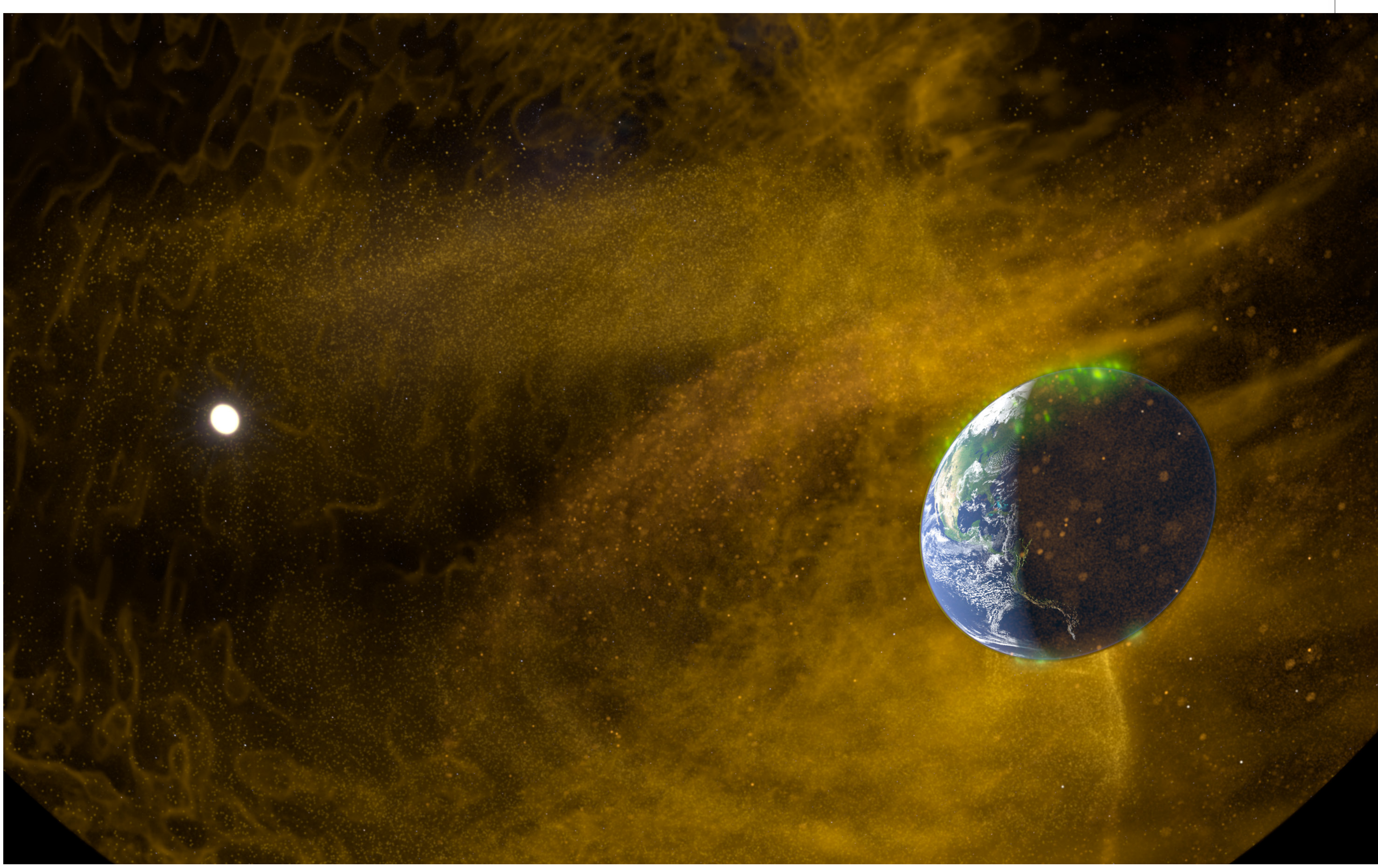
Tip Remember not to leave binoculars pointed at the Sun for too long!

Step 5

If you want to compare your sketch to NASA's Solar Dynamics Observatory satellite, go the the website below. How does this image compare to the sketch you made in the previous step?

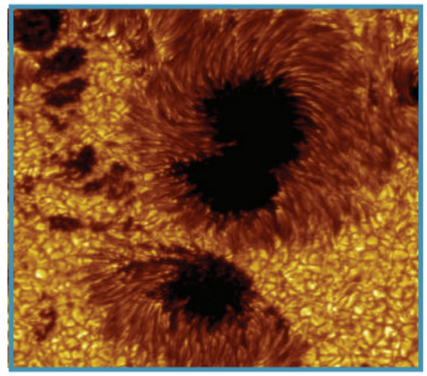
Website:
http://sdo.gsfc.nasa.gov/assets/img/latest/latest_512_HMII.jpg





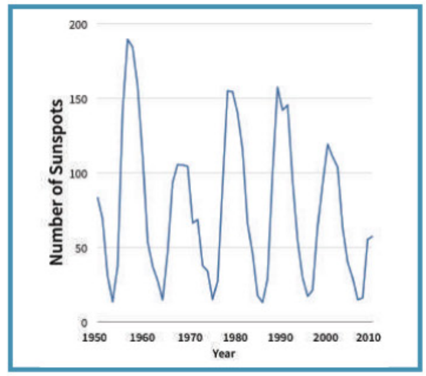
What's Going on?

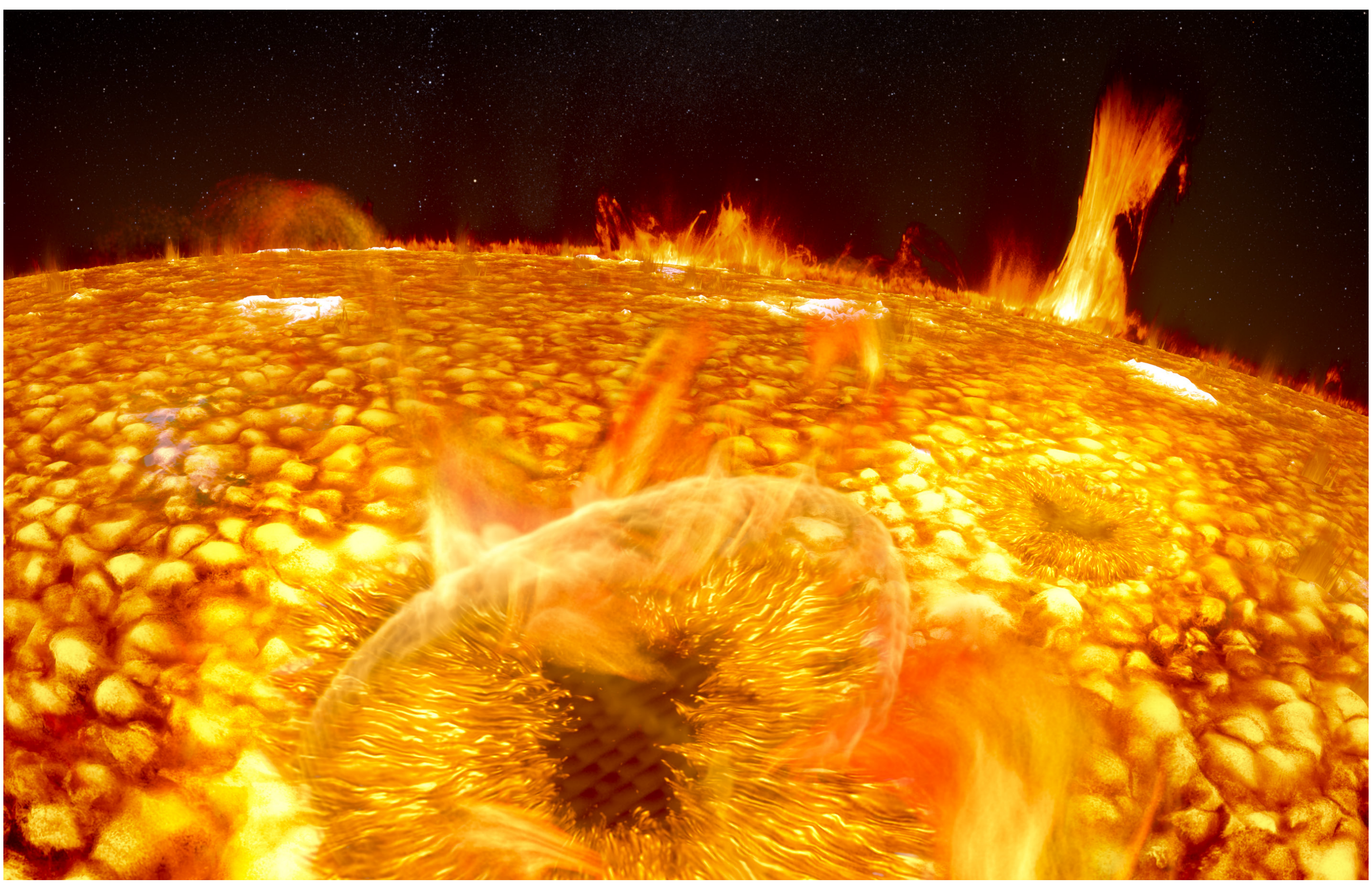
Sunspots are temporary dark spots that appear on the Sun's surface. They are caused by intense magnetic activity, and are **cooler than the areas of the Sun that surround them. Sunspots can be as small as 16 km across (the size of a big city) or** as large as 160,000 km across (about 13 times the size of Earth).

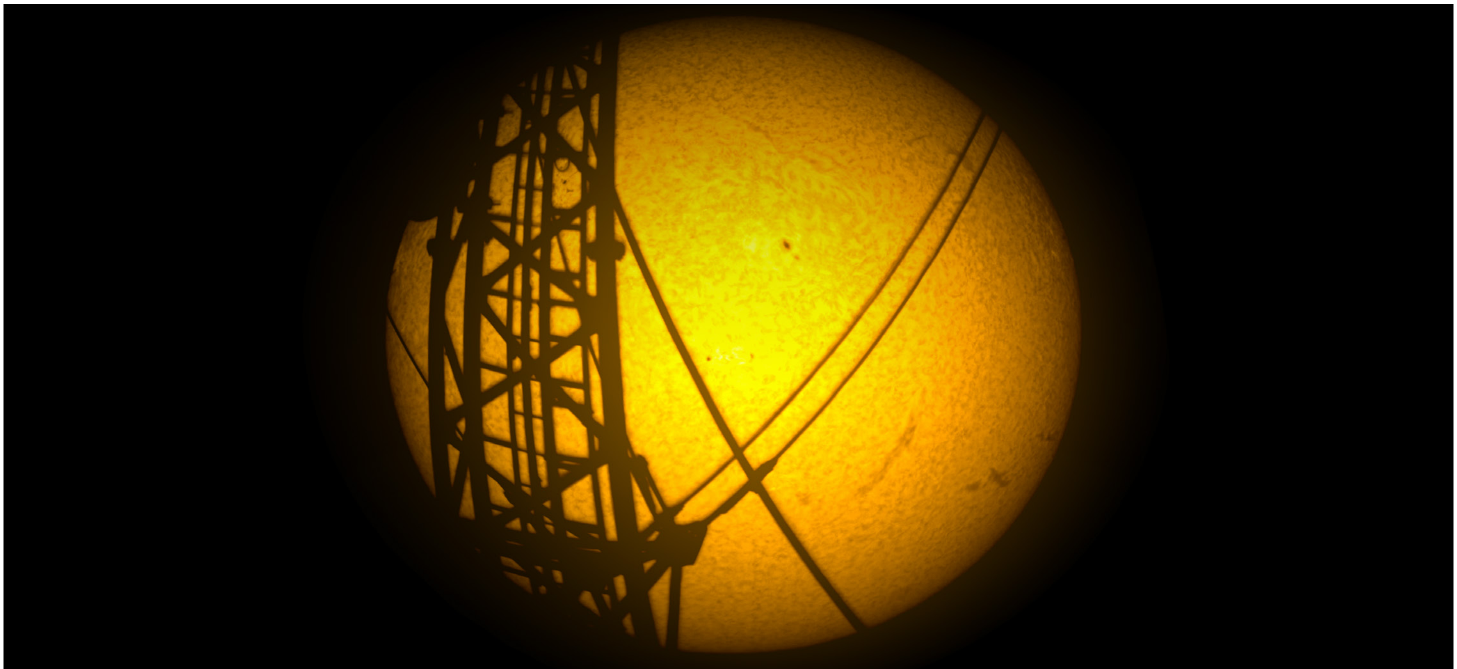


The sunspot cycle

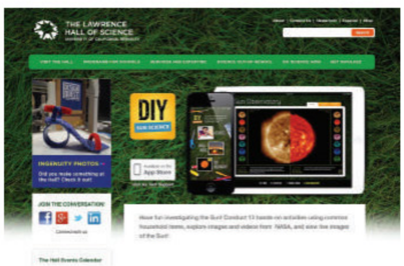
A sunspot can appear on the Sun's surface for a few days to a few weeks. Sunspot activity follows an 11-year solar cycle, where more sunspots appear during the Sun's "solar maximum" and fewer **sunspots appear during the Sun's "solar minimum."**







Learn More



For more info and other activities, visit:

LawrenceHallofScience.org/do_science_now/diy_sun_science

Credits

This project was supported by NASA under award number NNX10AE05G. Any opinions, findings, conclusions or recommendations expressed in this program are those of the author and do not reflect the views of NASA.

THE LAWRENCE HALL OF SCIENCE

The DIY Sun Science app allows families and educators to investigate and learn about the Sun at home, at school, or anywhere you go! The app features thirteen hands-on investigations, as well as images and videos.

Activity inspired by "Safely Viewing Sunspots," Space Science Lab, University of California, Berkeley. Image 7, NASA/SDO. Image 8, Göran Scharmer, Swedish 1-m Solar Telescope, Institute for Solar Physics.

Additional Resources:

The Lawrence Hall of Science

As a public science center in Berkeley, California, the Lawrence Hall of Science offers science activities not only at their center, but online as well. The website is a great resource for K-12 activities on the Sun.
http://www.lawrencehallofscience.org/

National Aeronautics and Space Administration

The NASA website is a great resource for information on satellites, space missions, recent space discoveries, and space activities for all ages.
http://www.nasa.gov/

Solar Dynamics Observatory

SDO is the NASA flagship spacecraft currently studying the Sun. The instruments on board provide ultra high resolution imaging of the Sun. The detail of the solar surface and the videos of flares and prominences are quite stunning.
http://sdo.gsfc.nasa.gov

SOlar Heliospheric Observatory

SOHO is a joint NASA and ESA spacecraft studying the Sun. There are a lot of fantastic images taken by SOHO from Coronal Mass Ejections to Sun quakes.
http://soho.esac.esa.int

Space Weather

This website is a great resource to help understand what is currently going on with the Sun. It also forecast space weather events and their impacts on earth. You will find current articles pointing out fun and interesting things to look at in the sky, from planets to meteor showers.
http://www.spaceweather.com

Space Weather Media Center

This is an online Flash-based interactive tool kit that provides access to illustrations, visualizations, videos and near-real time images of the Sun from a variety of NASA spacecraft missions.
http://sunearthday.gsfc.nasa.gov/spaceweather/#

Space Weather Prediction Center

The SWPC is part of the Nation Oceanic and Atmospheric Administration (NOAA). Their job is to study the Sun and its potential impacts on Earth. If you live and/or visit northern latitudes (above 50 degrees), this is a great resource for knowing when Aurora will light up the sky.
http://www.swpc.noaa.gov

Many of the resources and activities came from the following sources:

NASA
http://www.nasa.gov/

The Lawrence Hall of Science
http://www.lawrencehallofscience.org/

The Cosmic Perspective
J. Bennett, et al. *The Cosmic Perspective*. Addison-Wesley, 7th ed., 2013.

SPITZ

University of Colorado Boulder

FISKE PLANETARIUM BOULDER COLORADO