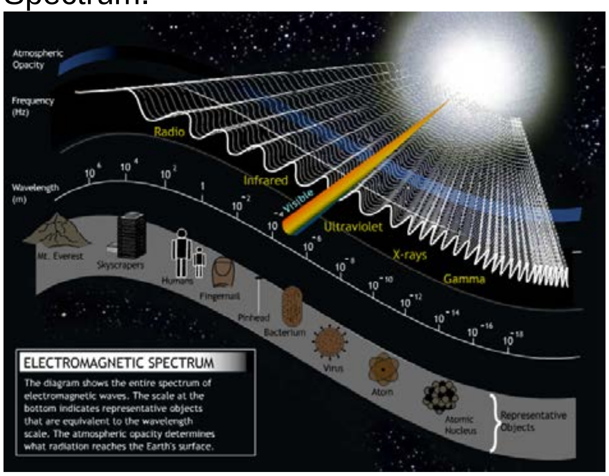
Module 2: Why do we study the Sun?

Activity A: The Sun & EM Spectrum

Overview

The Sun provides Earth with energy to enable and sustain life on our planet. This light energy is called electromagnetic radiation, which is a combination of perpendicular electric and magnetic fields. Electromagnetic radiation is divided into seven different wavebands according to the wavelength of energy. For example, a very long wavelength of electromagnetic radiation is in the "radio waves" waveband of the Electromagnetic (EM) Spectrum, and very short wavelength radiation is in the "gamma radiation" waveband of the EM Spectrum.



Images: NASA

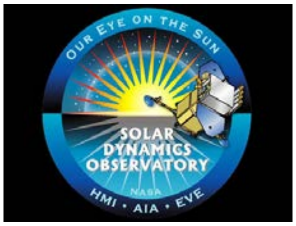
One section of electromagnetic radiation is called visible light because it is in the specific waveband that our eyes can see. Light energy (electromagnetic radiation) from the Sun is contained in "packets" called photons. Photons are released from the Sun and travel to Earth, and beyond, at the speed of light. The speed of light travels at approximately 186,000 miles/second or 300,000 km/s, which so far is the fastest known speed in the universe. If you could travel at the speed of light you'd be able to travel more than seven times around the equator of the Earth in one second - that's FAST!

Teacher Overview

The goal of Solar Module 2 is for student-led teams to develop a basic understanding of how and why scientists study the electromagnetic spectrum and magnetic fields of the Sun to gain a greater understanding of solar activity and space weather. The focus of Module 2A is to provide an authentic opportunity for students to learn about and apply concepts of the EM spectrum through the context of the Sun by utilizing SDO technology and data.

Radiant energy from the Sun is the main source of energy to the Earth and is measured as solar irradiance. The Total Solar Irradiance is the full output of light energy from the entire disk of the Sun, measured at the Earth's surface. The solar spectral irradiance is a measure of the brightness of the entire Sun at specific wavelengths of light.

Spectral irradiance variations are seen in many wavelengths – from Infrared (IR) and Visible, through the Ultraviolet (UV), to Extreme Ultraviolet (EUV) and X-ray radiation wavebands. Light of different wavelengths reaches different parts of the Earth and its atmosphere. Visible light and IR radiation reach Earth's surface, warming the troposphere and planet to livable conditions. UV light creates the ozone layer in the stratosphere, which then absorbs UV radiation. At the upper atmosphere, Ultraviolet light creates the thermosphere, which is ionized by light at the short wavelengths of EUV radiation and this region also completely absorbs EUV and X-ray radiation. Even minor changes in the Sun's energy output can have major impacts on Earth.



NASA'S Solar Dynamic Observatory (SDO) is enabling scientists to gain tremendous knowledge of the source of the Sun's energy and how that energy is stored and released by the corona and transition region (the region between the corona and chromosphere) of the Sun's atmosphere. Bursts of solar energy can affect our technology that relies on satellite communications such as cell phone service, weather forecasting, GPS, and ATMs.

- **AIA – Atmospheric Imaging Assembly**
- **EVE – Extreme Ultraviolet Variability Experiment**

There are three key instruments onboard SDO that are researching the Sun in amazing detail - AIA, EVE, and HMI. Two of these instruments, AIA and EVE, measure the EM radiation of the Sun. The main goal of SDO's AIA research is to greatly improve our understanding of the activity within the Sun's atmosphere that drives space weather and affects planets, especially Earth. A main objective of SDO's EVE research is to measure and better understand the extreme ultraviolet output from the Sun on different timescales - in seconds due to solar flares, in days due to the Sun's rotation, and in years due to the solar cycle. Also, EVE gives insight as to how the Sun's EUV output influences Earth's climate and near-Earth space environment. View these two video clips to learn how NASA's SDO is using the Electromagnetic Spectrum to increase our knowledge of the Sun at light-speed!

Team Goal

Your goal is to learn about the Electromagnetic Spectrum and understand how SDO uses the EM Spectrum to study and learn about the Sun in greater detail.

Objectives

Students will be able to:

- List and describe the wavelengths of the Electromagnetic (EM) Spectrum from the lowest frequency to the highest frequency (Radio Waves to Gamma Rays)
- Identify key EM wavelengths that are used in researching specific regions of the Sun.
- Understand that Visible Light (white light) is only one waveband of EM radiation that the Sun emits within the Electromagnetic Spectrum.

Essential Vocabulary

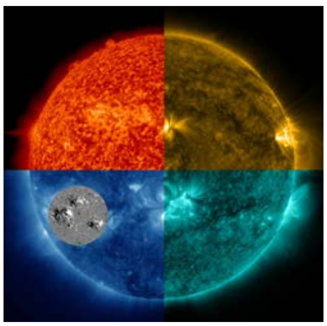
- Angstrom
- Electromagnetic Spectrum
- Electromagnetic Energy
- Frequency
- Heliosphere
- Kelvin
- Nanometer
- Radiant Energy/Radiation
- Solar Irradiance
- Spectral Irradiance
- Wavelength

Materials

- Computer with Internet access
- "Helioviewer Solar Exploration" data sheet(s)
- Pencil

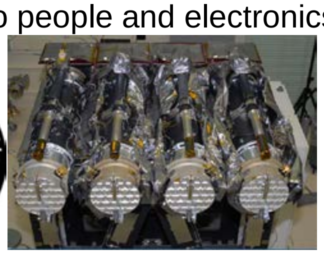
Engage & Explore!

<u>1. BUILD Knowledge:</u>
SDO EM Instruments



Images: NASA

Light of different wavelengths reaches different parts of the Earth's atmosphere. Visible light and infrared radiation reach Earth's surface, warming our planet to livable conditions. Most ultraviolet radiation wavelengths are absorbed at higher altitudes in our atmosphere. Extreme ultraviolet (EUV) and some X-ray radiation (wavelengths less than 120 nm) are absorbed by the upper atmosphere above 100 km (60 miles). Thankfully, EUV radiation is completely absorbed by Earth's atmosphere but it is very dangerous to people and electronics in space.



AIA: Lockheed Martin Solar Astrophysics Laboratory

EVE: University of Colorado Boulder
Laboratory for Atmospheric and Space Physics

Images: NASA

[SDO AIA Video]
[SDO EVE Video]

Module Lesson
Time: 2 block periods/4 class periods

Materials: per team
- Computer with Internet access
- "Helioviewer Solar Exploration" data sheet(s)
- Pencils

Teacher Prep:
- Bookmark Helioviewer website (http://helioviewer.org/) on computer(s)
- Make copies of "Helioviewer Solar Exploration" data sheets

Student Engage/Explore Activity
<u>1. BUILD Knowledge:</u>
SDO EM Instruments
Two of SDO's instruments, EVE (Extreme Ultraviolet Variability Experiment) and AIA (Atmospheric Imaging Assembly), work together to measure changes in the Sun's EUV spectral irradiance in order to understand what causes these changes. EUV is very dangerous to astronauts and electronics in space. Space weather can affect our technology that relies on satellite communications such as cell phone service, weather forecasting, GPS, and even ATMs. SDO is continually and accurately measuring changes in the Sun's solar irradiance, or photon output, to give us a greater understanding of solar variability and its impacts on Earth.

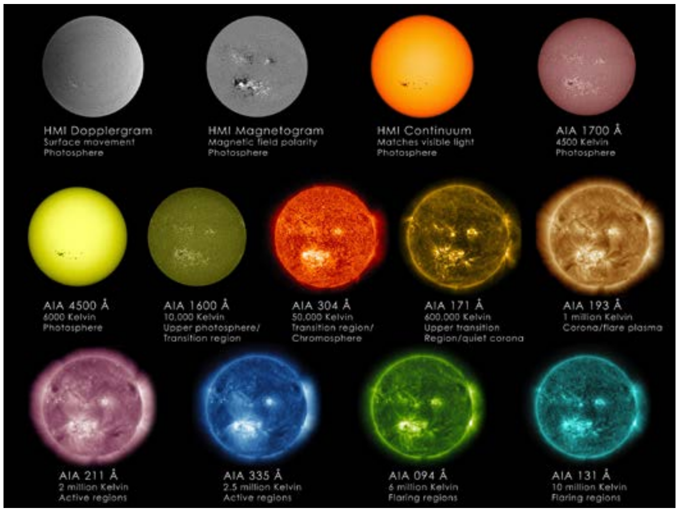


Image: NASA

SDO AIA EM Spectrum Wavelengths:
Measured in Angstroms Å (10^{-10} m, one ten-billionth of a meter)

- ☐ 094 (Soft X-ray)
- ☐ 131(EUV Light)
- ☐ 171 (EUV Light)
- ☐ 193 (EUV Light)
- ☐ 211 (EUV Light)
- ☐ 304 (EUV Light)
- ☐ 335 (EUV Light)
- ☐ 1600 (UV Light)
- ☐ 1700 (UV Light)
- ☐ 4500 (Visible Light)

Student Engage/Explore Activity
1. BUILD Knowledge (cont.):
SDO EM Instruments

First, student teams watch the NASA video clips to gain background knowledge of how two of three instruments on the Solar Dynamic Observatory (SDO) use the Electromagnetic Spectrum to study the Sun. The main goal of the AIA research is to greatly improve our understanding of the activity within the Sun's atmosphere (heliosphere) that drives space weather and thus affects Earth. A main objective of EVE is to measure and better understand the EUV output from the Sun on different timescales-in seconds due to solar flares, in days due to the Sun's rotation, and in years due to the solar cycle. Also, EVE gives insight as to how the Sun's EUV output influences Earth's climate and near-Earth space environment.

SDO AIA Video
SDO EVE Video

Student Engage & Explore Activities (cont.)

SDO Electromagnetic Spectrum Wavelengths
Measured in nanometers (nm=10^{-9} m) / Angstroms Å (Å =10^{-10} m, one ten-billionth of a meter)

SDO AIA Wavelength	EM Spectrum Waveband	Region of Solar Atmosphere Measured	Typical Temperature of Solar Region
450 nm = 4500Å	Visible Light (longer wavelength, lower frequency & energy)	Photosphere	5000 K
170 nm = 1700Å	UV Light	Temperature minimum, photosphere	5000 K
160 nm = 1600Å	UV Light	Transition region & upper photosphere	10^5 & 5000 K
33.5 nm = 335Å	EUV Light	Active region corona	2.5×10^6 K
30.4 nm = 304Å	EUV Light	Chromosphere & transition region	50,000 K
21.1 nm = 211Å	EUV Light	Active region corona	2×10^6 K
19.3 nm = 193Å	EUV Light	Corona & hot flare plasma	1.2×10^6 & 2×10^7 K
17.1 nm = 171Å	EUV Light	Quiet corona, upper transition region	6.3×10^5 K
13.1 nm = 131Å	EUV Light	Flaring regions	4×10^5, 10^7 & 1.6×10^7 K
9.4 nm = 94Å	Soft X-rays (shorter wavelength, higher frequency & energy)	Flaring regions	6.3×10^6 K

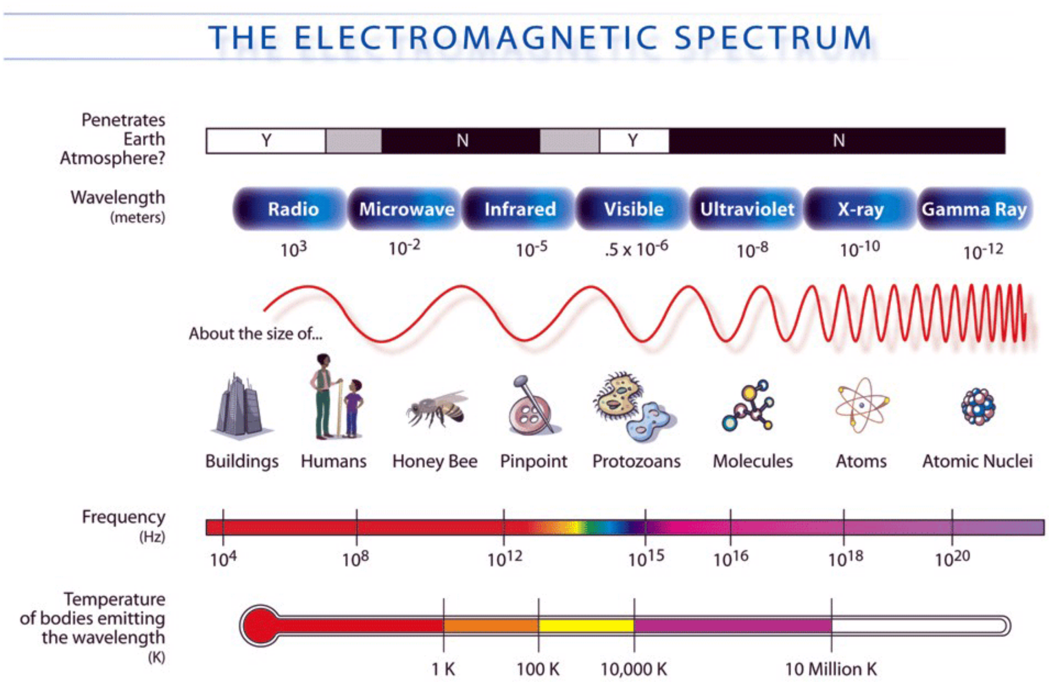
2. APPLY Learning:

EM Spectrum

How are the different wavelengths of the Electromagnetic Spectrum formed? As the temperature of an object increases its EM wavelength decreases, which means the hotter an object is, the shorter the wavelength of radiation it gives off. Take NASA's tour of the EM Spectrum by clicking the link below. As you take your tour, research and record details about the different wavelengths that make up the EM Spectrum on the "What's the Wavelength" interactive foldable:
EM Spectrum Tour

Now, reinforce your learning of the Sun and the Electromagnetic Spectrum by watching the NOVA Sun Lab video link below. As you watch the video, complete and check your answers on the "What's the Wavelength" interactive foldable for accuracy. Remember, this foldable is an artifact for your team's Module 4 SDO Exploration Museum 3-D Solar Exhibit!
The Sun & EM Spectrum Video

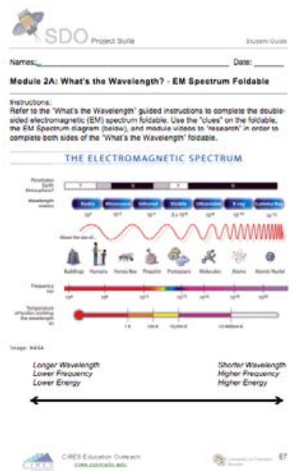
Image: NASA



Longer Wavelength
Lower Frequency
Lower Energy

Shorter Wavelength
Higher Frequency
Higher Energy

Student Engage & Explore Activities (cont.)
2. APPLY Learning:
EM Spectrum
Next, teams reinforce their understanding of the Sun and the Electromagnetic Spectrum by watching the NASA and NOVA video links below. Teams then complete a foldable representation of the EM Spectrum to reinforce their understanding of the different wavelengths that SDO uses research solar activity.
EM Spectrum Tour
The Sun & EM Spectrum Video


SDO Project Suite Student Guide

Names:______________________________ Date:______

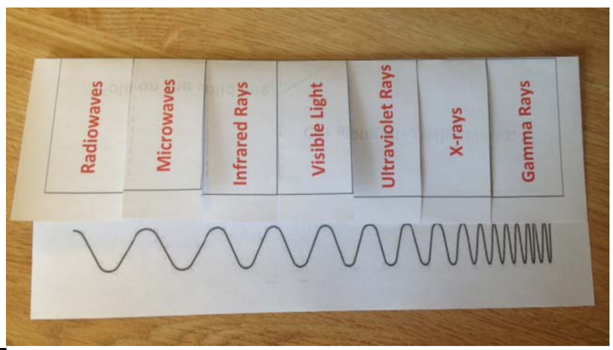
Module 2A: What's the Wavelength? - EM Spectrum Foldable

Instructions:
Refer to the "What's the Wavelength" guided instructions to complete the double-sided electromagnetic (EM) spectrum foldable. Use the "clues" on the foldable, the EM Spectrum diagram (below), and module videos to "research" in order to complete both sides of the "What's the Wavelength" foldable.

THE ELECTROMAGNETIC SPECTRUM

Longer Wavelength
Lower Frequency
Lower Energy

Shorter Wavelength
Higher Frequency
Higher Energy



Gamma rays have the shortest wavelengths, of less than 0.01 nanometers (about the size of an atomic nucleus). This is the highest frequency and most energetic region of the electromagnetic spectrum. Gamma rays can result from nuclear reactions taking place in objects such as pulsars, quasars, and black holes.
X-rays range in wavelength from 0.01 to 10 nanometers (about the size of an atom). They are generated, for example, by super-heated gas from exploding stars and quasars, where temperatures are near a million to ten million degrees.
Ultraviolet radiation has wavelengths of 10 to 310 nanometers (about the size of a virus). Young, hot stars produce a lot of ultraviolet light and bathe interstellar space with this energetic light.
Visible light covers the range of wavelengths from 400 to 700 nanometers (from the size of a molecule to a protozoan). The Sun emits most of its radiation in the visible range, which our eyes perceive as the colors of the rainbow. Our eyes are sensitive only to this small portion of the electromagnetic spectrum.
Infrared wavelengths span from 710 nanometers to 1 millimeter (from the width of a pinpoint to the size of small plant seeds). At a temperature of 37 degrees C, our bodies radiate with peak intensity near 900 nanometers.
Radio waves are longer than 1 millimeter. Since these are the longest waves, they have the lowest energy and are associated with the lowest temperatures. Radio wavelengths are found everywhere: in the background radiation of the universe, in interstellar clouds, and in the cool remnants of supernova explosions, to name a few. Radio stations use radio wavelengths of electromagnetic radiation to send signals that our radios then translate into sound. These wavelengths are typically a few feet long in the FM band and up to 300 yards or more in the AM band. Radio stations transmit electromagnetic radiation, not sound. The radio station encodes a pattern on the electromagnetic radiation it transmits, and then our radios receive the electromagnetic radiation, decode the pattern and translate the pattern into sound.

3. DEMONSTRATE Ability:

Helioviewer Solar Exploration!

The Sun's surface temperature is about 6000 ^{o}C and emits most of its radiation in wavelengths between 300 - 600 nanometers, which is in the Ultraviolet and Visible Light range. SDO takes a full-disk image of the Sun in 10 different EM wavelengths every 10 seconds and these images are 10 times clearer and sharper than HD. SDO then transmits this vast amount of information back to Earth, which is equivalent to downloading half a million iTunes songs everyday! Solar scientists around the world are very excited about the incredible amount of extremely detailed information that SDO provides, which you get to use first-hand in this module activity.

Helioviewer is an amazing, inter-active website that provides your team with access to high-tech, near real-time images and data of the Sun. Helioviewer is designed to let your team choose your own data sets, timeframe, and solar features to observe. For example, a team can track a 28-day cycle (one rotation) of the Sun to observe its sunspots and magnetic fields and download photos and a movie of the actual event! The SDO space project is collecting information on:

- Measurements of the Sun's irradiance (the Sun's energy output) over a broad range of EM Spectrum wavelengths that represent a wide range of energies (EVE)
- Images of the variation in radiance among the Sun's different magnetic features (AIA)
- An understanding of how the Sun's magnetic fields are created and change (AIA & HMI)
- Measurements of the origin of the Sun's energy (HMI)

Watch the tutorial video to learn how to use the amazing Helioviewer tool to view and analyze SDO data in various EM wavelengths (if you need more information, click on the user guide links below):

How to use the Helioviewer Tutorial
Helioviewer User Guide
Helioviewer User Guide printable version

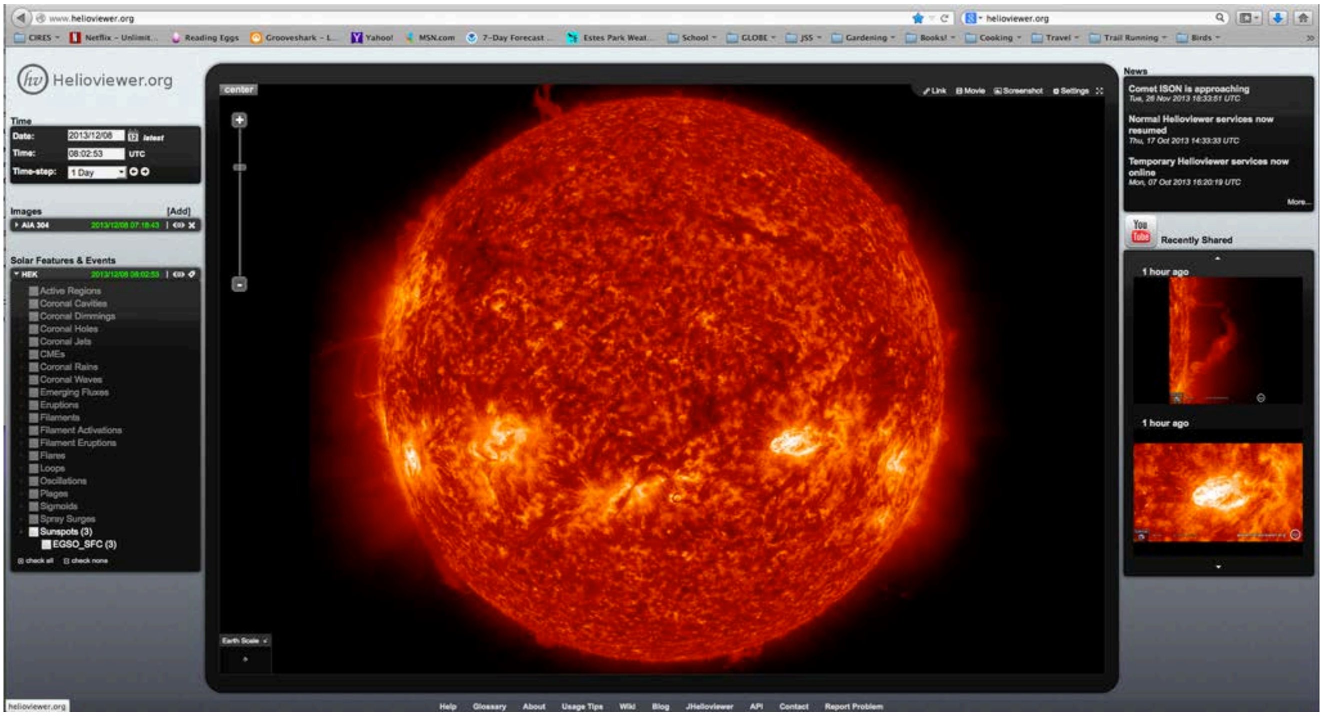


Image: Helioviewer.org

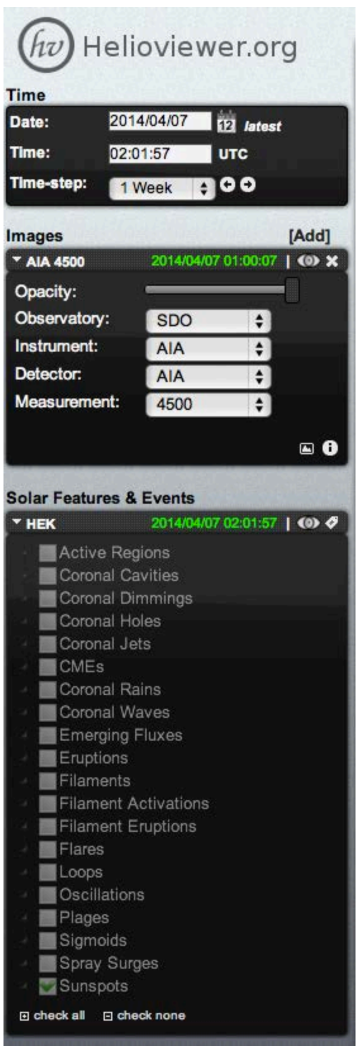
After your team views the Helioviewer tutorial, select your team's "Helioviewer Solar Exploration" topic. Each topic follows the same basic instructions for using the Helioviewer.org website selections (located on the left side of webpage):

1. "Time" box: Choose a start date, use the calendar to click a date (selecting a time is not necessary).
2. Choose the time-step (1-day, 1-week, or 28-days) that fits your team's topic choice.
3. "Images" box: Observatory: SDO
4. Instrument: AIA for EM Spectrum images or HMI for magnetism images
5. Detector: Select the same choice as #4 (AIA or HMI)
6. Measurement: Select the AIA wavelength number listed in the investigation instructions below, for HMI choose "magnetogram".

Helioviewer Solar Exploration Topics

Select one topic and follow its instructions. Complete the required information on the "SDO Helioviewer Solar Exploration Data Sheet" activity sheet.

A. Sunspot Sleuths Helioviewer Activity:
Use the visible light spectrum to identify and track the motion of sunspots on the Sun's surface for one week. Where are most sunspots located? Sunspots do not move but appear to do so due to the rotation of the Sun. Which direction does the Sun rotate? What changes, if any, do you observe in the size, shape, and number of sunspots over a one-week period? Enter these selections into the online Helioviewer fields and also write them on your team's Helioviewer Solar Exploration Data Sheet:

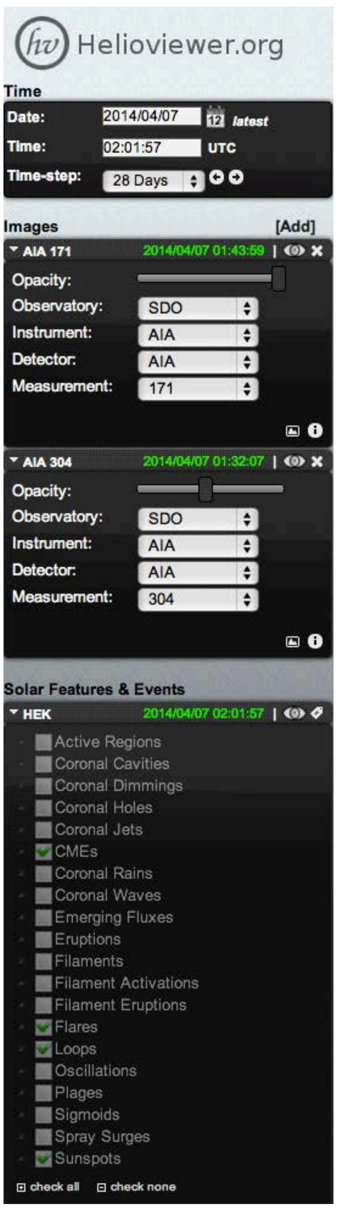


Images: Helioviewer.org

1. In the "Time" box, choose the Date: Select a start date from the calendar (make sure it is at least 7 days earlier than today's date).
2. Time-step: "1-week"
3. In the "Images" box choose Observatory: "SDO"
4. Instrument: "AIA"
5. Detector: "AIA"
6. Measurement: "4500"
7. In the "Solar Features & Events" box check only "Sunspots" (keep the "eye" and "tag" logo unchecked).
8. Next, make a photo gallery or movie. For a photo gallery, click on the "Screenshot" tab and choose "Full Viewport". Repeat these steps for six additional days. For a movie, click on the "Movie" tab and choose "Full Viewport". There will be a message indicating how long it will take to process the movie and a notice will pop up on screen when your SDO movie is ready to view.

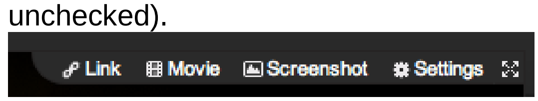
9. Download and save your images or movie for your team's Solar Module 4 Living Museum & 3-D Solar Exhibit!

B. [Solar Explosions Helioviewer Activity](#):
The Sun rotates once every 27 days along its equator, which is faster than the 31-day rotation at the Sun's poles. Create a movie of a "day" on the Sun. Describe any major events that you observe happening on the Sun's surface – CMEs (coronal mass ejections) or flares (these are the two causes of space weather on Earth), sunspots, loops, etc. Is there an ordered pattern in the occurrence of the solar features and events? Enter these selections into the online Helioviewer fields and also write them on your team's Helioviewer Solar Exploration Data Sheet:



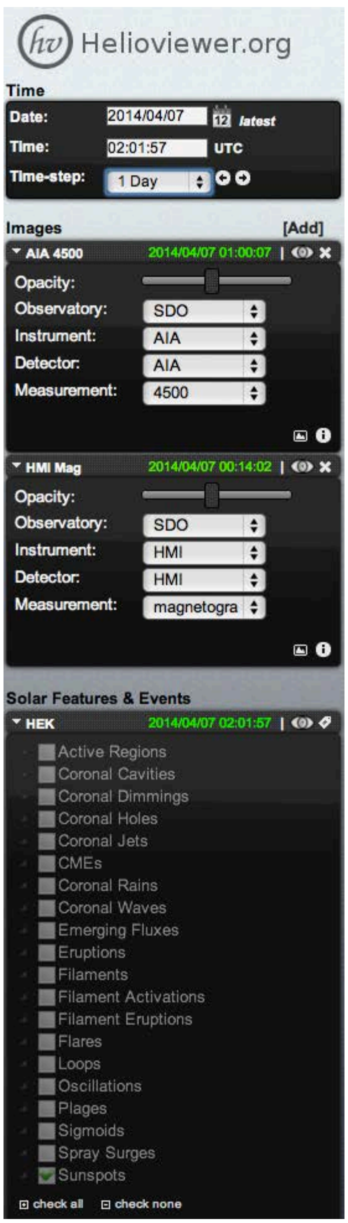
Images: Helioviewer.org

1. In the "Time" box choose the Date: Select a start date from the calendar (make sure it is at least 28 days earlier than today's date).
2. Time-step: "28-days"
3. In the "Images" box choose Observatory: "SDO"
4. Instrument: "AIA"
5. Detector: "AIA"
6. Measurement: "171"
7. Click the "Add" button at the top right to select another image to overlay and again select Observatory: "SDO", Instrument: "AIA", Detector: "AIA", Measurement: "304".
8. In the "Solar Features & Events" box, check up to four features & events "CMEs", "Flares", plus two other features & events of your choice (make sure the "eye" and "tag" logo are unchecked).



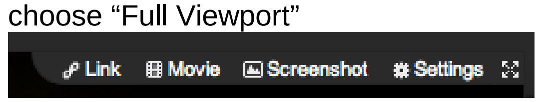
9. Click on the "Movie" tab and choose "Full Viewport". There will be a message indicating how long it will take to process the movie and a notice will pop up on screen when your SDO movie is ready to view.
10. Download and save your movie for your Solar Module 4 Living Museum & 3-D Solar Exhibit!

C. [Mag-light Mystery Helioviewer Activity](#):
Identify an SDO image of the Sun with multiple sunspot regions, then overlay the image with an HMI image (solar magnetic activity). What do you notice about the location of sunspots on the Sun's surface in relation to the locations on the Sun with high levels of magnetic activity? Enter these selections into the online Helioviewer fields and also write them on your team's Helioviewer Solar Exploration Data Sheet:



Images: Helioviewer.org

1. In the "Time" box choose the Date: select a start date from the calendar.
2. Time-step: "1-day"
3. In the "Images" box choose Observatory: "SDO"
4. Instrument: "AIA"
5. Detector: "AIA", Measurement:" 4500"
6. Click the "Add" button at the top right to select another image to overlay.
7. Again select Observatory: "SDO", Instrument: "HMI", Detector: "HMI", Measurement: "magnetogram".
8. In the "Solar Features & Events" box check only "Sunspots" (keep the "eye" and "tag" logo unchecked).
9. Then click on the "Screenshot" tab and choose "Full Viewport"



10. Download and save your images for your Solar Module 4 Living Museum & 3-D Solar Exhibit!
11. Repeat these steps for 6 more days. Once your team has chosen a topic, click on the link below to access the Helioviewer website to start your team's "Helioviewer Solar Exploration"! As a team, complete the online Helioviewer topic activity and data sheet together. Remember to save and download your Helioviewer images and/or movie for use in your Module 4 SDO Exploration Museum 3-D Solar Exhibit as an artifact!

Student Engage & Explore Activities (cont.)
<u>3. DEMONSTRATE Ability:</u>
Helioviewer Solar Exploration!

Helioviewer is an amazing, inter-active online tool that provides the public with access to high-tech technologies and incredible amounts of near real-time images and data of the Sun. Helioviewer is designed to let users choose and overlay their choice of data sets, timeframe, and length-scales. For example, a user can track a 28-day cycle (one rotation) of the Sun to observe its sunspots and magnetic fields and download photos and a movie of the actual event!

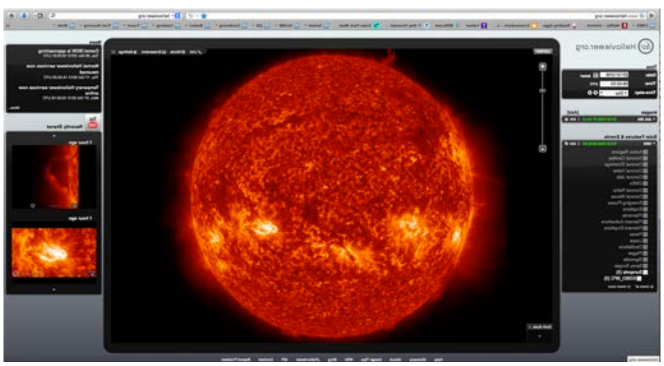
The SDO space project is collecting information on:

- Measurements of the Sun's irradiance (the Sun's energy output) over a broad range of EM Spectrum wavelengths that represent a wide range of energies (EVE)
- Images of the variation in radiance among the Sun's different magnetic features (AIA)
- An understanding of how the Sun's magnetic fields are created and change (AIA & HMI)
- Measurements of the origin of the Sun's energy (HMI)

Hand out copies of the "Helioviewer" data sheet to teams. Student teams then watch the "How to use the Helioviewer" tutorial video prior to starting their investigation. The accompanying user guide links provide online and printable support for teachers and students.

How to use the Helioviewer
Helioviewer User Guide
Helioviewer User Guide printable version


Names: Date:
Module 2A: SDO Helioviewer Solar Exploration Data Sheet



After teams watch the Helioviewer tutorial, they select their "Solar Exploration" topic, start their investigation, and complete the "Helioviewer" data sheet during the activity. Remind students to save and download their SDO images and/or movie for use in their Module 4 SDO Exploration Museum 3-D Solar Exhibit, as this is an essential artifact!

There are three "Helioviewer Solar Exploration" topics; student teams choose one of the topics to investigate

A) Sunspot Sleuths - observe sunspots for a previous 1-week period.
B) Solar Explosion - identify CMEs and Flares (the two main sources of Space Weather that affects Earth) for a previous 28-day period (this is approximately the amount of time it takes the Sun to rotate once on its axis).
C) Mag-light Mystery - investigate the relationship between sunspots and magnetism for a previous 1-day observation of the Sun (can be repeated)
Helioviewer Activity

Excellent effort exploring the EM Spectrum of the Sun!

Differentiation/Extension

- Solar Sun Catchers:
  Using transparent printer paper, print a range of color SDO EM Spectrum (AIA) images. Create a collage of the images and write a poem to creatively describe the science behind the scenes.
  SDO Suncatcher Images

- NASA Solar Math
  Grade Level 3-5, p. 5
  Grade Level 6-8, p. 38
  Grade Level 9-12, p. 73

Internet Resources

All About the Sun
Stanford Solar Center Colors and Motions of the Sun Video
What is Ultraviolet Light?
Space Weather Center: Solar Vision in EM Waves
NOVA Sun Lab Research Challenge
SDO Change Pairs Activity