The Sun

To solve problems, scientists ask scientific questions. They determine the best methods to answer the question, collect the data, and analyze it to draw evidence-based conclusions that answer the question. You will be practicing these steps in the **process of science** in this lab.

Learning objectives:

- Students will be able to analyze different wavelengths and sunspots to learn about the Sun.
- Students will be able to apply and analyze steps in the **process of science** (scientific literacy).
- Students will be able to calculate **unit conversions** (quantitative literacy).
- Students will be able to calculate **averages** (quantitative literacy).

Materials needed:

- Web access to Helioviewer (http://helioviewer.org)

Part 1: Navigating Helioviewer

You will use Helioviewer (http://helioviewer.org) to collect data in this lab. Helioviewer allows you to see current and past images of the Sun taken at different wavelengths by different spacecraft, such as the Solar Dynamics Observatory (SDO) spacecraft.

Do some brief independent research to learn about the electromagnetic spectrum and NASA's Solar Dynamics Observatory (SDO).

1. Why is it useful to look at the Sun in different wavelengths?

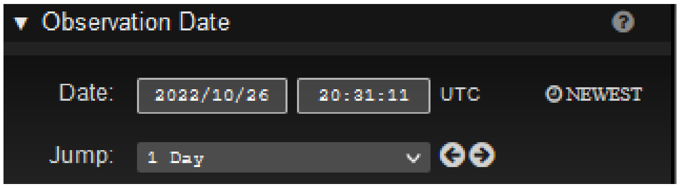
○ Different wavelengths convey information about different parts of the Sun and its layers.
○ Each wavelength represents the Sun's material at specific temperatures.
○ Features of the sun appear different in different wavelengths.
○ All of these are reasons to look at the Sun in different wavelengths.

Go to Helioviewer (http://helioviewer.org). To change setting options, click "Data Sources" on the left side, if the toolbars aren't already open.

Double check that the settings for the Observatory is SDO, Instrument is AIA, and Difference is No difference image. Click on the different choices for "Measurement" 

to change the wavelength of light you are looking at.

2. The wavelength 94 Å shows the Sun in what color? ____________________

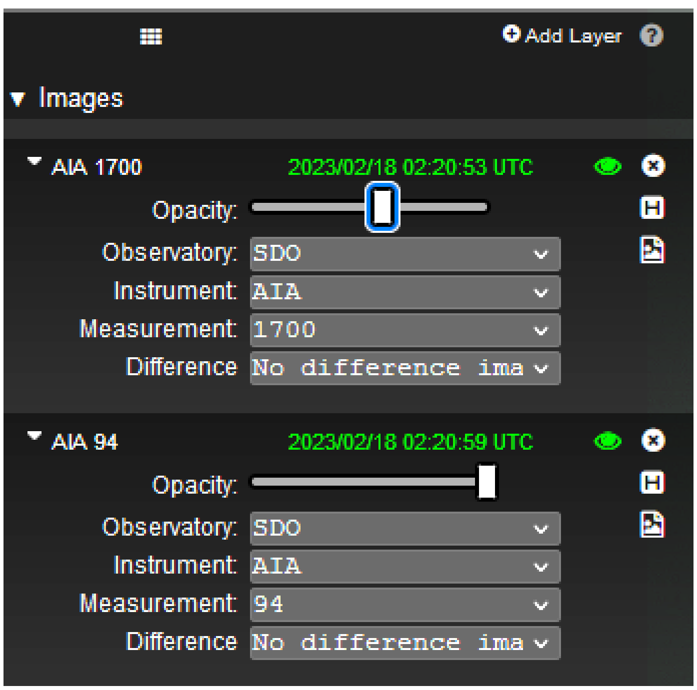


3. Use the “Observation Date” tool to change the date to October 26, 2022, and view the Sun at different wavelengths. What do you see at the wavelength 193 Å?

- ○ A heart on the Sun
- ○ Venus in front of the Sun
- ○ A featureless Sun, with no active regions
- ○ A smiling Sun
- ○ A pattern of sunspots that looks like the Big Dipper

In the Images Section, click the "Add Layer" 

button so that there are two “Images” panels. For the images, change the Measurement to 1,700 (top image) and 94 (bottom image), as shown below.



Slide the Opacity marker on the top image. This allows the top image to fully block the bottom image or to become transparent (clear), so you can see right through it to the image behind it. In this way, you can see either just the top 1,700 Å image, just the bottom 94 Å image, or a combination of the two. Moving the Opacity marker to the left makes the image more see-through.

Use the “Observation Date” tool to set the date to a significant date for you in 2011 or later (e.g. a birthday).

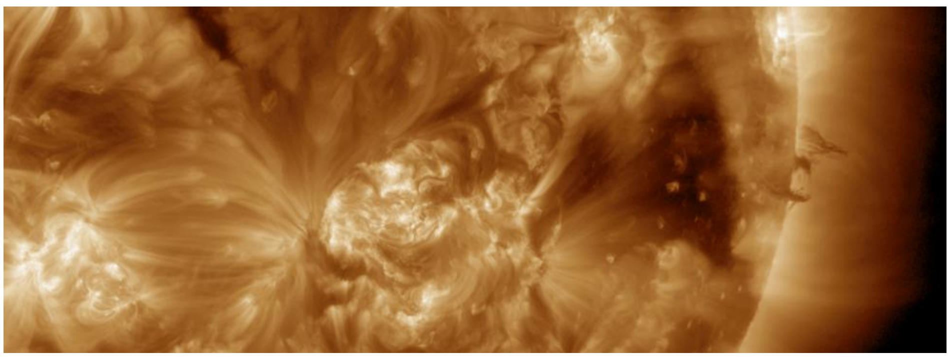
Adjust the Opacity marker for the top image to the far left, making the top image transparent (clear), so you can see active X-ray regions at 94 Å (bottom image).

Identify a bright feature (i.e., an active X-ray region). If you cannot find any bright features, look at a different date. Some years have very few active regions. Once you've found an active X-ray region, use the "Jump" arrow to increase the date by one day and then one more day.

4. How did the bright feature you identified in the image move as you moved forward in time?

○ To the left ○ To the top (up)
○ To the right ○ To the bottom (down) ○ It didn't move

Part 2: Analyzing data about the Sun



The Sun seen at a wavelength of 193 Å. (source: Helioviewer)

For the rest of this lab, you will look at images of the Sun in two wavelengths of light:

- 94 Angstroms (Å)
- 1,700 Angstroms (Å)

Short wavelengths of the electromagnetic spectrum, such as visible light, are usually measured with the units of nanometers (nm) or Angstroms (Å). 1 nanometer equals 10 Angstroms (Å).

Unit conversion is where we take the measurement in one set of units and change it to a different set of units. For example, if we measure distance in miles, we can **convert the units** to kilometers. The numbers change, but the actual distance does not.

5. What two wavelengths of light from the Sun will be used in this lab, in nanometers? **Convert the units**.

○ 0.94 nm and 17 nm ○ 94 nm and 1,700 nm
○ 9.4 nm and 170 nm ○ 940 nm and 17,000 nm

6. A flu virus is approximately 900 Angstroms in length (900 Å/virus). How many viruses would fit across the wavelength of 1,700 Å? **Convert the units to viruses**, recording your answer to one decimal place.

________________ viruses

7. If you want to see what the Sun looks like in X-ray wavelengths (or close to it), which wavelength would you observe?

○ 94 Angstroms (Å)
○ 1,700 Angstroms (Å)
○ Both of these show X-rays (or close to it)

8. If you want to see what the Sun looks like in visible light wavelengths (or close to it), which wavelength would you observe?

○ 94 Angstroms (Å)
○ 1,700 Angstroms (Å)
○ Both of these show visible light (or close to it)

9. Solar flares are about 11 million °F (6,300,000 °C) and much hotter than the surface of the Sun, which is about 10,000 °F (5,700 °C). Based on these relative temperatures and the electromagnetic spectrum, what SDO wavelengths would be useful to observe solar flares and sunspots on the Sun's surface?

○ Solar flares at 94 Å and sunspots at 1,700 Å
○ Solar flares at 1,700 Å and sunspots at 94 Å
○ Both wavelengths are good for both solar flares and sunspots
○ Both solar flares and sunspots at 94 Å
○ Both solar flares and sunspots at 1,700 Å

What is the relationship between features seen in 1,700 Å and features seen in 94 Å?

Consider the above scientific question about features on the Sun. Find sunspots (dark spots on the Sun's surface seen in the wavelength you previously determined) and active X-ray regions (bright areas seen in the wavelength you previously determined). Slide the Opacity marker so you can see how the features compare.

10. What is the relationship between the position of sunspots and active X-ray regions?

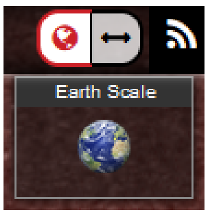
○ Sunspots are generally closer to the Sun's equator than the related active X-ray region.
○ Sunspots are generally closer to the Sun's poles than the related active X-ray region.
○ Sunspots and active X-ray regions generally overlap and are at similar positions.
○ There is no relationship between the position of sunspots and the position of active X-ray regions.

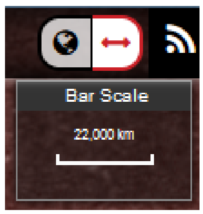
Active regions that result in solar flares are important for astronomers to monitor because they can hit Earth, any astronauts in space, and our spacecrafts, potentially disrupting our power, GPS, and cellphone systems.

Part 3: Collecting data about sunspots

What is the average size of sunspots?

Consider the above scientific question about sunspot size. Using Helioviewer, you will collect data to answer this question and use the information you gathered to critically think about the conclusion proposed below.





To measure the size of features on the Sun, there is a scale tool that can either show the size of the Earth or a scale bar measuring kilometers (km). You can move the scale by dragging it to different locations.

11. To measure the size of an average sunspot, which of these is NOT something you should consider?

- ○ Determine what to use for scale to measure the size
- ○ Make measurements near the center of the Sun because the curvature of the Sun distorts the appearance of the size near the edges
- ○ Know the temperature of a sunspot
- ○ Take multiple measurements to get an average
- ○ Learn to identify sunspots in the wavelengths they appear in

12 What part of the **process of science** did you just do when you made these decisions?

- ○ Ask a scientific question
- ○ Determine the methods to use
- ○ Make observations and collect data
- ○ Analyze data and develop conclusions
- ○ Share results and conclusions

Choose a day when the 1,700 Å image has at least 4 sunspots on it. Alternatively, find different sunspots in different weeks. Don't forget that you may need to adjust the Opacity marker to see the right wavelength. If you are having a hard time finding sunspots, you can go to the "Features and Events" panel beneath the "Images" panel. Scroll down to the bottom and check the box next to "Sunspots." This turns on an outline around each sunspot that astronomers have identified and named.

Use the Earth scale to measure 4 sunspots, and record your measurements in Data Table 1 below. Measure the sunspot sizes related to Earth's diameter (e.g. 0.5 Earths, 1 Earth, 2 Earths, 10 Earths, etc.). You will need to zoom in, and you may need to move forward and back in time so you can view the sunspots when they are near the center of the Sun.

Scientists calculate **averages** to get more accurate results by reducing differences that happen by chance and error in measurements. You will take multiple measurements and average them together. To calculate the average, add up your measurements, then divide by the total number of measurements.

Data Table 1

	Sunspot 1	**Sunspot 2**	**Sunspot 3**	**Sunspot 4**	**Average**
Size (Earth diameters)					

13. What part of the **process of science** did you do when you filled in Data Table 1?
- O Ask a scientific question
- O Determine the methods to use
- O Make observations and collect data
- O Analyze data and develop conclusions
- O Share results and conclusions

14. How did you calculate the **average** sunspot size?
- O I added together each of the 4 sunspot sizes.
- O I added together the highest and lowest size and divided by 2.
- O I added together 4 sizes and divided the total by 4, one for each measurement.
- O I added together each size in the table and divided by 6, one for each column in the table.

15. What is the **average** size of the sunspots you measured?
- O 0.1-0.5 Earth diameters
- O 1-3 Earth diameters
- O 5-8 Earth diameters
- O 10-15 Earth diameters

A fellow student proposes the following conclusion statement, "**An average sunspot is approximately 20,000 km in diameter**." Earth's diameter is 13,000 km, so you will need to **convert the units** to analyze the statement.

16. How would you modify the statement to make it more accurate with the data you collected?
- O The average sunspot is approximately 6,000 km in diameter.
- O The average sunspot is approximately 90,000 km in diameter.
- O The average sunspot is approximately 150,000 km in diameter.
- O I would not change anything because it is all accurate

17. Let's say there's a sunspot that is 16,800 km across. A professional truck driver can drive approximately 800 kilometers a day. 800 kilometers equals 1 truck day. How long would it take a truck driver to drive across the sunspot? **Convert the units**.

_____________ truck driver days

Part 4: Planning methods to answer a scientific question

❓ How many days does it take a sunspot near the Sun's equator to go around exactly once?

The methods section of a scientific study gives the specific step-by-step strategy used to collect data to answer a scientific question. You are asked the above scientific question about the timing of a sunspot's rotation. What methods would you use to collect data to answer the scientific question?

18. The first step is to become comfortable with Helioviewer and create a rough plan. Which of these decisions would you NOT need to make before you start collecting data to answer the scientific question?

○ Decide what wavelength of light to use in Helioviewer to see sunspots.
○ Decide whether to step forward by hours, days, or weeks by testing each one and watching the sunspots shift over time.
○ Decide how many sunspots must be visible at one time before you can collect data.
○ Decide to measure how long it takes for a sunspot to cross the side of the Sun facing Earth, and then multiply that length of time by two to account for the time to cross the other side of the Sun.

19. After making initial decisions on how to answer the question, it is time to create a table. What header would NOT go in the table?

○ Date the sunspot becomes visible on the left
○ Date the sunspot disappears around the curve of the Sun on the right
○ Number of sunspots visible on surface of Sun when the sunspot appears
○ Total number of days it takes the sunspot to move from left to right side of Sun

After figuring out the rough plan and creating a table, in what order would you complete the next four steps to collect relevant data? Here are the steps (out of order). Put the steps in order (Step 1, Step 2, etc.). One step will NOT be used.

- Adjust the calendar back to the date when the sunspot you chose appears on the left side of the Sun. Record the date in the table.
- Average together the date the sunspot appears and the date the sunspot disappears to predict how long most sunspots take.
- Advance forward one day at a time until the sunspot disappears on the right side of the Sun. Record the date in the table.
- Calculate the number of days it took the sunspot to move from left to right. Then, multiply the number of days by 2 to determine the time for one full rotation
- Find a sunspot that is near the equator to track and record in the table.

20. What is Step 1?

21. What is Step 2?

22. What is Step 3?

23. What is Step 4?

24. What part of the **process of science** did you just do to answer the preceding questions in Part 5?

- O Ask a scientific question
- O Determine the methods to use
- O Make observations and collect data
- O Analyze data and develop conclusions
- O Share results and conclusions

Test your methods by using them to collect data to answer the scientific question. Ideally, it would be best to make this measurement for many sunspots, record your data in a table, and take an average. However, to test your methods, complete these steps in the order you chose for just one sunspot. Be sure to check off each step as you complete it. Adjust your order if necessary.

25. How many days did you count for one sunspot to appear, cross the Sun, then disappear? Be sure to use your own count on Helioviewer.

- O 5-6 days
- O 7-9 days
- O 10-12 days
- O 13-15 days

26. Based on your data, roughly how long does it take sunspots near the Sun's equator to complete one full rotation?

O 1 day O 1 week O 1 month O 1 year

Part 5: Analyzing data about sunspot rotation

> ❓ **Do sunspots closer to the poles take the same amount of time to make one rotation as sunspots at the equator?**

A student decided to look at the number of days it took for sunspots in different locations to move across the Sun, from the left side to the right side on Helioviewer. They made 6 measurements for each location, resulting in the following Data Table 2. What conclusions can you make from the data related to the scientific question above about the rotation of sunspots at the equator?

Data Table 2

Distance from Equator	Sunspot (days)	Sunspot (days)	Sunspot (days)	Sunspot (days)	Sunspot (days)	Sunspot (days)
0° (equator)	14	14	13	14	12	13
30°	14	15	14	13	15	13
45°	14	16	15	16	15	14

To answer the scientific question, figure out what numbers in Data Table 2 you want to average together. Calculate the **average**, and add it to the table.

27. What numbers did you use to calculate the **average**?

- O I calculated the average for all the sunspots because this averages the largest number of sunspots for more accurate results.
- O I calculated the average for each row because this averages sunspots of the same distance from the equator together.
- O I calculated the average for each column because this averages the first measurements together, the second measurements together, etc.

28. What were the **averages** you calculated?

- O 14.1
- O 254
- O 13.3, 14, 15
- O 14, 14, 14
- O 80, 84, 90
- O 14, 15, 14, 14.3, 14, 13.3
- O 42, 45, 42, 43, 42, 40

29. Select the evidence-based conclusion that answers the scientific question regarding the rotation of sunspots.

- O Sunspots closer to the equator take more days to cross the Sun (slower than the poles).
- O Sunspots closer to the equator take fewer days to cross the Sun (faster than the poles).
- O Sunspots closer to the equator take the same number of days to cross the Sun.

30. What numerical data did you use to draw your evidence-based conclusion?

○ I looked for the highest number in each column and noticed that the top number in the column was mostly smaller than the bottom number in the column. For example, in 3 columns, the equator is 2 days shorter than at 45°.

○ I looked at the average for each row and compared them. For example, the equator is 13.3 days, and 45° was 15 days.

○ I looked at the first measurement for each location. For example, the equator is 14 days, and 45° is also 14 days.

○ I looked at the average for each column and compared them. For example, 3 of the 6 columns averaged 42, and they ranged from 40-45 days.

○ I looked at the average for all the measurements together. For example, the average was 14.1 days.

31. Think about the trend or pattern you identified, and predict how it will continue farther from the equator. If you see a sunspot at 60°, how long would take it to cross the Sun?

○ Less than 14 days ○ 14 days ○ 15 days ○ More than 15 days

Part 6: Determining how to answer scientific questions

Below are scientific questions (Questions A-E) that you will use to answer questions in Part 6.

- **Question A. “What was the largest sunspot this year?”**
- **Question B. "Which wavelengths are best for viewing sunspots?"**
- **Question C. "Do sunspots move closer or farther from the equator?"**
- **Question D. "When a sunspot appears and disappears, does the related active X-ray region also appear and disappear at the same time?"**
- **Question E. "How does the number of sunspots vary over the course of a year?"**

Read the following Methods Section that describes the plan to answer a scientific question:

1) First, make a table with a column for each month of the year, and a column labeled “number of sunspots”.
2) Second, set the calendar for the first of the month for each month in the table and count the sunspots. Record the number in the table.
3) Third, make a graph with the data, putting time on the horizontal axis and number of sunspots on the vertical axis.

32. Which of the scientific questions (Questions A-E above) is answerable using these methods?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

Read Data Table 3:

Data Table 3

Date sunspot appears	Date sunspot disappears	Date related active X-ray region appears	Date related active X-ray region disappears

33. Which of the scientific questions (A-E, above) needs a table like Data Table 3?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

Read this evidence-based conclusion statement:
"**Sunspots do not change their distance from the equator over their lifetime**."

34. Which of the scientific questions (A-E, above) is related to this conclusion?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

Part 7: Synthesizing the process of science

How does the number of sunspots vary over decades?

A student writes a research report after collecting data with Helioviewer to answer the above scientific question about the number of sunspots. The student asks you to read the report as a peer review to check for errors, an important step in science. Analyze the report and determine what is wrong with it.

Student's Research Report:
To determine how the number of sunspots varies over decades, I used Helioviewer to collect data for January 1 of each year for 18 years. I recorded these dates and the number of sunspots I counted in Data Table 4. The number of sunspots is high from 2012 through 2015 (4 years) and again in 2022 through 2026 (5 years), but there are no sunspots from 2017 through 2020 (4 years). Therefore, I conclude that the sunspots have a 4- or 5-year cycle of highs and lows.

Data Table 4

Date (Month, Day)	Number of Sunspots	Date (Month, Day)	Number of Sunspots	Date (Month, Day)	Number of Sunspots
Jan 1, 2009	0	Jan 1, 2015	5	Jan 1, 2021	1
Jan 1, 2010	0	Jan 1, 2016	1	Jan 1, 2022	2
Jan 1, 2011	0	Jan 1, 2017	0	Jan 1, 2023	8
Jan 1, 2012	3	Jan 1, 2018	0	Jan 1, 2024	1
Jan 1, 2013	3	Jan 1, 2019	0	Jan 1, 2025	7
Jan 1, 2014	1	Jan 1, 2020	0	Jan 1, 2026	3

35. Which part of the research report is the weakest because there is an error in the student's thought process?

- ○ Helioviewer cannot be used to collect data about the number of sunspots.
- ○ They did not collect relevant data to determine how the number of sunspots vary over the course of decades.
- ○ Data Table 4 does not have useful headings or record the relevant data.
- ○ They do not correctly summarize the years when the sunspot numbers are high and low.
- ○ Their conclusion of a 4-5 year cycle describes only half the cycle. A full cycle goes from one high to the next high.

36. Select **two** ways that you could fix the data collection to improve the methods used in this research report.

- ☐ I would include in Data Table 4 every day in January each year, not just January first.
- ☐ I would include in Data Table 4 the first date in all 12 months of the year, not just January.
- ☐ I would include a count for the active X-ray regions.
- ☐ I would include a column for several different wavelengths, not just the visible wavelength.
- ☐ I would include data that covers several decades, not just the most recent ones.

37. Does it make sense to calculate an **average** for the number of sunspots in Data Table 4 to answer the scientific question above?

- ○ Yes, it helps to reduce differences that happen by chance in measurements.
- ○ Yes, you add the counts together and divide by the total number of measurements.
- ○ No, the scientific question asks for change over time.
- ○ No, you cannot calculate averages when the measurements are so different.

38. Think about the trends or pattern you can identify in the student's data. It may help to sketch a graph if you are a visual learner. Using the trend, how do you predict the number of sunspots will change for the five years after they stop collecting data?

- ○ The number of sunspots will decrease.
- ○ The number of sunspots will increase.
- ○ The number of sunspots will stay the same.
- ○ There is not enough data to determine a trend.

A student brainstormed different ways they could communicate the key findings in Data Table 4:

- Option 1: Create a graph with bars or dots that compare the average number of sunspots for each of the columns of data.
- Option 2: Create a graph with bars or dots that show the number of sunspots for each year.
- Option 3: Create a journal of pictures that shows a year-by-year sequence of the number of sunspots.
- Option 4: Create a single picture of the Sun that shows every sunspot recorded each year.
- Option 5: Create a video that zooms in to show the details of one of the sunspots for each year.

39. How would you communicate the key findings in Data Table 3? Option #_______ (Include only one option, although there is more than one option that could be a good communication strategy)

Reflection

40. Which question in this lab connects to your personal experience? Consider the lab topic, math skills, and the process of science. You may also consider your lived experience or stories you've encountered. To earn credit, list the question number and explain how it relates in 2-3 sentences.