Intro College

Sunspot Science: Measuring the Frequency and Period of Sunspots

Inspired by *The Physics Teacher*'s

"Teaching Astronomy Using Tracker"

by Mario Belloni, Wolfgang Christian, and Douglas Brown

Description: This data analysis activity requires students to analyze NASA SOHO coronagraph images to make meaning of cyclical patterns in sunspots, using the terms "period" and "frequency". This resource was developed to supplement *Lecture-Tutorials for Introductory Astronomy*. It aims to promote understanding of the concepts of period and frequency in the context of sunspot cycles, while also supporting conceptual understandings presented in the inspiring article from *The Physics Teacher.* The inspiring article features an activity to use free web-based software to estimate the rotational period of the Sun.

This work is a modification on the resource developed by AAPT and Temple University, a project funded by the NASA Heliophysics Education Consortium (HEC) to support learning about space science in college-level physics and astronomy courses. Visit aapt.org/resources/SSEC to explore additional resources for use in large classroom settings.

Purpose: 1) Form a deeper understanding of frequency and period by exploring these properties in the context of a natural phenomenon occurring within our solar system.
2) Closely measure and interpret authentic data from the NASA-SOHO spacecraft to identify patterns and determine whether these patterns conform to existing scientific theory.

NGSS Connections: *Although this activity is intended for introductory college, it can be easily modified to be an interactive worksheet for high school students.* ***See Page 12 for detailed NGSS correlations.***

Performance expectation:

- Supports the understanding of frequency as a foundation for HS-PS4-1.

Disciplinary Core Ideas:

- Wave Properties: PS4.A; Instrumentation: PS4-C; The Universe and Its Stars: ESS1.A

Crosscutting Concepts:

- Patterns; Systems and System Models

Science and Engineering Practices:

- Analyzing and Interpreting Data

Materials:

- Computer and projector with internet access to YouTube:
  - Sunspot Time-Lapse February 2013: https://www.youtube.com/watch?v=NA961oOs2FY
  - 15 Years of Sun in 15 Minutes: https://www.youtube.com/watch?v=mi6FU_mejz8
  - Sunspot Time-Lapse (graph revealed at end): https://www.youtube.com/watch?v=ntMcdg7oZlE
  - Additional videos of sunspots can be found on the SOHO website, but they must be downloaded to play: https://sohowww.nascom.nasa.gov/bestofsoho/Movies/sunspots.html
- Printed student worksheets

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

Activities (in brief):

- Part 1: Students consider an analogy of waves in the ocean and changes in sunspots to better understand the concepts of period and frequency.
- Part 2: Students visit the SOHO website and sketch the day's sunspots. Then, students observe one or more YouTube videos showing sunspot time lapses across multiple days to apply the ideas of period and frequency to describe them.
- Part 3: Students analyze graphical data sets showing long-term sunspot data, and again apply the ideas of period and frequency to describe them.
- Part 4: Students analyze the maxima and minima of sunspots in data sets.
- Part 5: Students use their understanding of periodicity to extend and modify an original sunspot data set.
- Part 6: Students look for other sunspot cycles (beyond simple frequency), including solar surface area coverage.

Prior Conceptual Understandings Required

- None

Common Misconception:

Learners of all ages commonly believe that sunspots move along the sun's surface as a car moves along a highway. This is incorrect. What students perceive as sunspot "motion" is a combination of the sun's rotation (spin), Earth's axial tilt, and plane of the Earth's orbit around the Sun. Sunspots are dynamic phenomena in which turbulent processes take place in strong magnetic fields. They churn and roil, but individual sunspots actually don't move much laterally from their point of origin. The appearance of "movement" in the SOHO images results from changes in the frame of reference of Earth-to-Sun and the ecliptic plane—the imaginary plane containing the Earth's orbit around the sun. It's important to guide students in understanding that all forms of motion must be defined within a reference frame. The interactive simulations and video clips featured in the Sunspot Science Digi Kit will help dispel this misconception.

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

Lecture Tutorial: Measuring the Frequency and Period of Sunspots

Student Worksheet

Note to teacher: *Italicized commentary* are notes for teachers. Red statements show sample correct student responses. Highlighted yellow items are areas where students are likely to get "stumped."

Description: This data analysis activity requires students to analyze sunspots on NASA's SOHO coronagraph images to make meaning of cyclical patterns using the terms period and frequency. This resource is designed to supplement *Lecture-Tutorials for Introductory Astronomy* for lecture-style classrooms.

This activity requires use of the SOHO website to view images.

For question 5, we suggest the use of YouTube here:

- Sunspot Time-Lapse February 2013: https://www.youtube.com/watch?v=NA961oOs2FY
- 15 Years of Sun in 15 Minutes: https://www.youtube.com/watch?v=mi6FU_mejz8
- Sunspot Time-Lapse (graph revealed at end): https://www.youtube.com/watch?v=ntMcdg7oZlE

Additional videos of sunspots can be found on the SOHO website, but they must be downloaded to play: https://sohowww.nascom.nasa.gov/bestofsoho/Movies/sunspots.html

Prerequisite:

- None

Vocabulary: *Definitions courtesy of the ESA (European Space Agency) and the CESAR Project*

- Sunspot – Continuously changing dark "spot" that can be observed on the sun's surface. Sunspots appear darker than the surrounding areas because they are a cooler temperature than the neighboring gas. Sunspots are caused by the sun's strong, shifting magnetic fields.
- Photosphere – the apparent surface of the sun. Since the sun is made of gas, there is no solid surface. In observing the sun, there is a depth beyond which the density of the gas is so high, we cannot see through it. This region is the photosphere, which is seen as a disk through a filtered telescope. Sunspots are generated in the photosphere.
- Solar Cycle – A periodic phenomenon in which the sun alternates between a solar maximum when sunspots are much more frequent, and a solar minimum when sunspots are infrequent or nonexistent. In this activity, students will be calculating the solar cycle period.

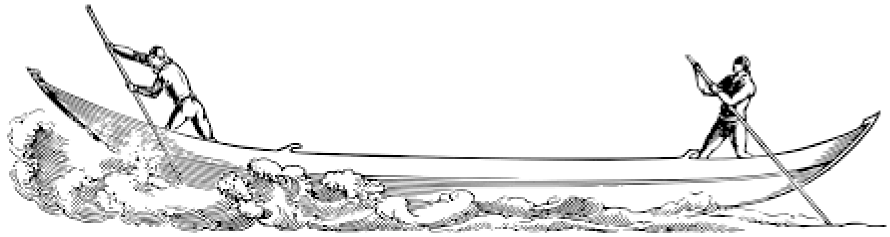
This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

Instructions:
In this activity, you will analyze various types of data associated with the periodic cycle of sunspots. Some of the data you will analyze was collected by scientists nearly 300 years ago!

Part 1: Define Frequency and Period

To better understand frequency and period, imagine the following scenario:

Envision yourself along with a classmate in a boat away from the beach. You are counting the wave crests that pass your boat during the span of 10 minutes. Your classmate is timing how long it takes between the arrival of one crest and the next.



1. In a brief paragraph, describe what is *different* about the measurements each of you is taking while in the boat.
   I am counting the number of wave crests during a span of time (my measurement will be unitless). My classmate is counting the number of seconds from crest to crest (my classmate's measurement will have units of seconds).

2. Scientists describe these two ways of measuring cyclical patterns in terms of the following:
   Period: The length of time for a cyclical pattern to repeat itself.
   Frequency: The number of cyclical repetitions in a pattern per unit of time.

   Based on the above definitions, which person in the boat is measuring the period? the frequency?
   I am measuring the frequency, because I am measuring the number of crests per every 10 minutes. My classmate is measuring the period, because s/he is measuring the time from one crest to the next.

3. While in the boat, a storm picks up, and the wave crests come more often. How will the period and frequency change?
   The period will be shorter, because there will be less time from crest to crest. The frequency will increase, because there will be more crests in the time span.

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

The terms **period** and **frequency** can be used for any kind of cyclical or “periodic” phenomenon.

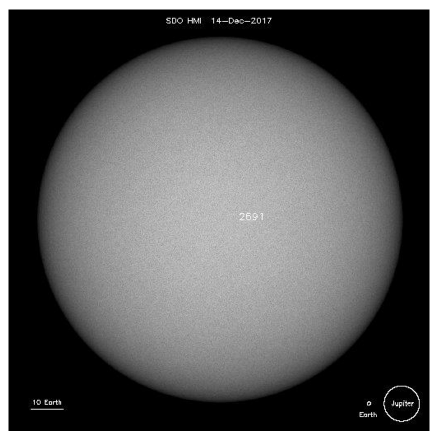
Sunspots drawn by Galileo, June 1612

Galileo Galilei observed and recorded sunspots in the 1600’s and noticed that the appearance of these dark splotches on the Sun came and went in a regular pattern.

Nowadays, sunspots can be observed by anyone through a telescope *using an approved solar filter*, and images are professionally captured by NASA’s SOHO (Solar and Heliophysics Observatory), a camera that has been placed in space. Dark spots on the Sun are produced by strong localized magnetic fields that cause the region to be cooler and appear darker than the surrounding area.

Credit: NASA

<u>Part 2: Single Observation</u>



4. Look at an image of the Sun today on SOHO’s site: https://sohowww.nascom.nasa.gov/sunspots/

   a) Sketch any sunspots on the image to the right. If there are no sunspots, click on “List of all available daily images” and find a day with clearly visible sunspots. Include the date below the image. (Hint: You might want to look at images from 2012.)
   Answers will vary. Teachers may need to guide students in understanding that we are entering a Solar Minimum in 2019-2020, a time period in which sunspot activity is at its lowest.

   b) How big are these sunspots? (Estimate based on the diameter of Earth and/or Jupiter).
   Answers will vary. Point out that the relative sizes of Earth and Jupiter can be found in the lower-right corner of the image.

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

5. Watch a sunspot time lapse video shown by your instructor. Or, see a variety of sunspot time lapses from SOHO here at the following links:

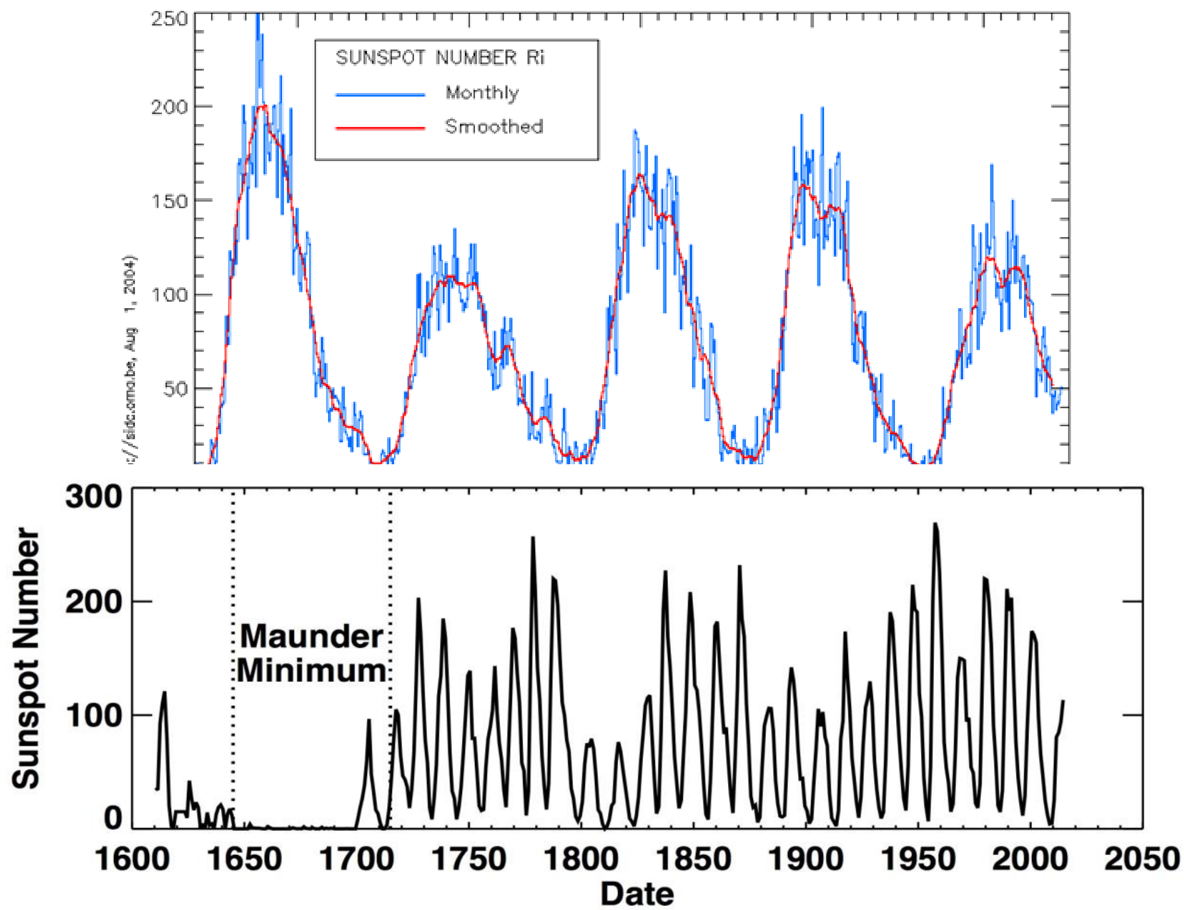
   Sunspot Time-Lapse February 2013: https://www.youtube.com/watch?v=NA961oOs2FY
   15 Years of Sun in 15 Minutes: https://www.youtube.com/watch?v=mi6FU_mejz8
   Sunspot Time-Lapse: https://www.youtube.com/watch?v=ntMcdg7oZlE

   Would it be appropriate to use the terms **period** and/or **frequency** when describing these images? Why or why not?
   Yes. Because the Sun spins, sunspots can be seen again and again. Sunspots can also appear and disappear. Because they are cyclical, they have a period and a frequency. *Students might notice that sunspots can appear/disappear, change in size, and change location. Because it might be hard to track a single sunspot on a full rotation, or because students might only consider the appearance of a single sunspot, they might struggle to understand that there are multiple cycles on the Sun. Remind students that a sunspot need not complete a full rotation in order to have a cyclic pattern.*

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

Part 3: Describe Sunspot Cycles in Terms of Period and Frequency (Long Period)

People have been making observations of the Sun for a really long time. When you plot the number of sunspots produced each month, you find an interesting pattern. Two graphs below display data across the past 50 years and the past three centuries.



6. What is similar and what is different about the two graphs above?
   What is similar between the two graphs is that the number of sunspots goes up and down throughout time, and that the peaks tend to reach about 250. What is different are the timescales--one spans about 50 years, and the other spans about 400 years.

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

7. What pattern or patterns do you notice about the number of sunspots produced as time goes by?
It seems as though the number of sunspots hits a low, increases, then decreases back to the low amount every 10-12 years. The maximum number of sunspots is not the same each time, though, and can range from about 100 to 250. Something unusual happened between about 1650 and 1700, when there were almost no sunspots at all.

8. Describe the changes in the number of sunspots**:**

   a) What is the **period** of sunspot cycles? (Explain how you calculated this).
   The period is one maximum every 10-12 years. I calculated this by looking at the date from the low point to the next low point. For example, using the top graph, there was a low point between 1976 and 1977, and then another low point in 1986 (a difference of 10 years). There was another between 1964 and 1965, which is about 11 or 12 years before the next peak.

   b) What is the **frequency** of sunspot cycles? (Explain how you calculated this).
   The frequency of sunspot cycles is about 1 crest every 10-12 years. *Because students previously considered counting the number of waves every 10 minutes, it might be hard for students to recognize that they can choose a variable unit of time to better represent one cycle.*

<u>Part 4: Maximum and Minimum</u>

9. Using the 1950-2005 graph, in what years do you see a solar maximum (the largest number of sunspots)?
1958, 1968, 1980, 1990, 2000

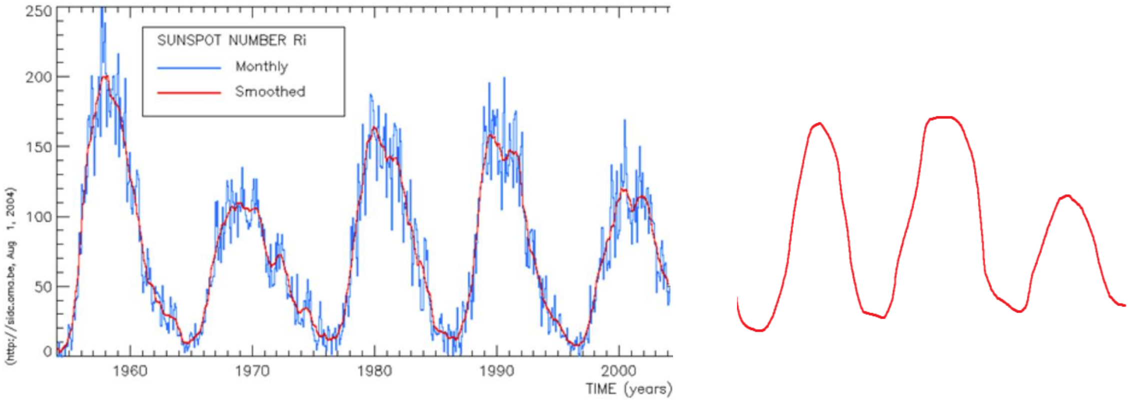
10. Using the 1950-2005 graph, in what years do you see a solar minimum (the smallest number of sunspots)?
1964-65, 1976-77, 1986-87, 1996-97

11. Is the number of sunspots observed at solar maximum the same from cycle to cycle? Explain how you know.
No. The peaks sometimes go up to about 100 or as far as 250.

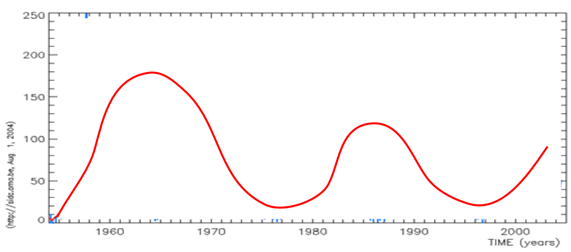
This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

Part 5: Extending the Sunspot Model

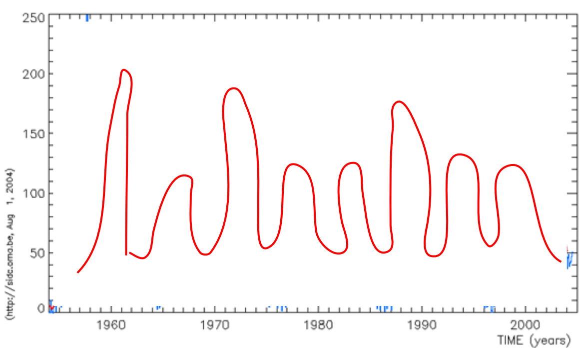
12. Predict: When do you expect the next solar maximum to be? Extend the graph into the gray area with a sketch.



13. Predict: What would the graph look like if it was to have a longer **period?**



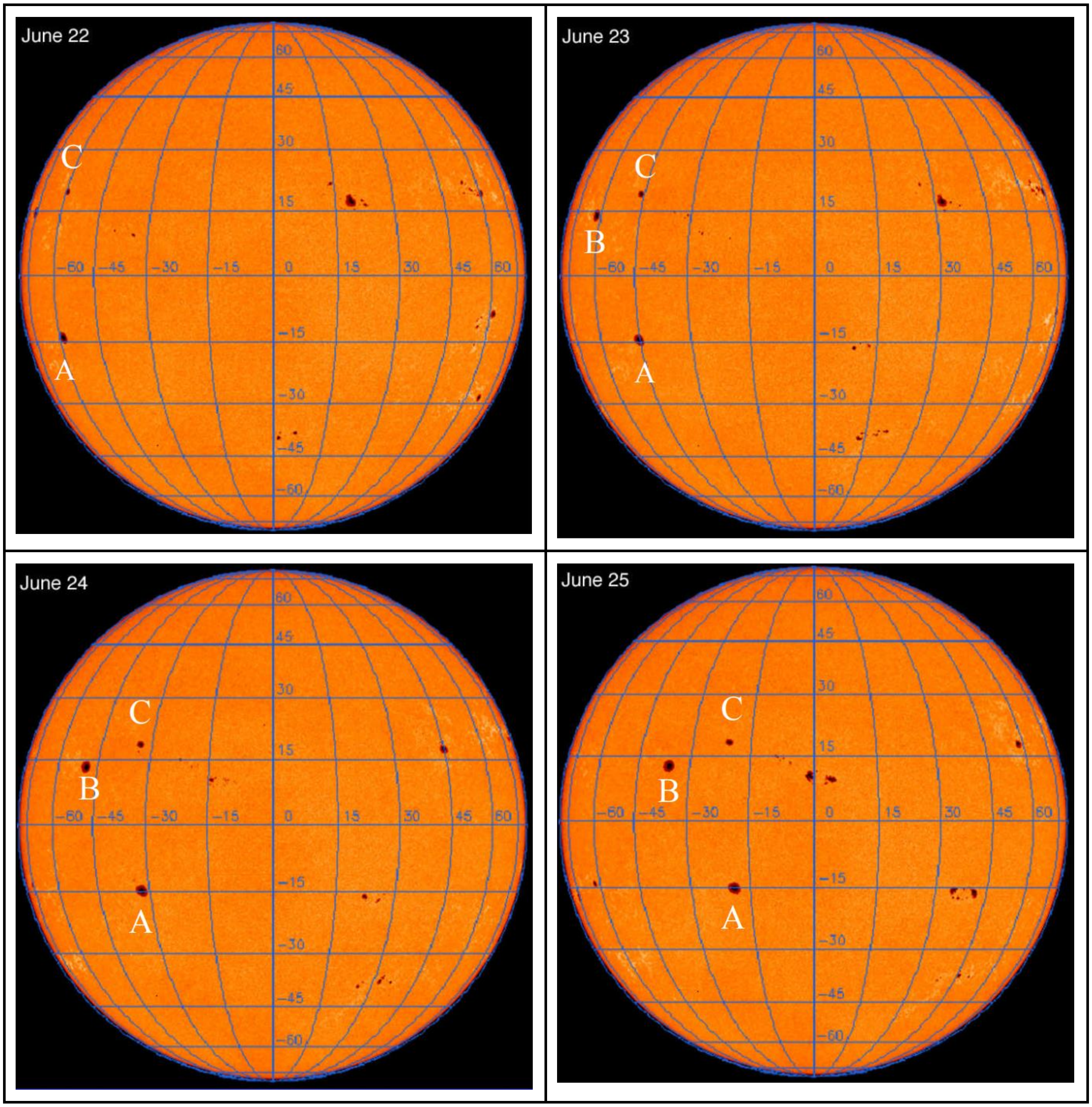
14. Predict: What would the graph look like if it was to have a longer **frequency?**



This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

Section 6: Additional Cycles

15. The Sun has cycles other than the number of sunspots. Look at the images below of the *location* of sunspots. What kinds of cycles do you notice? How might you measure or quantify these changes? (Write your answer at the top of the next page.)

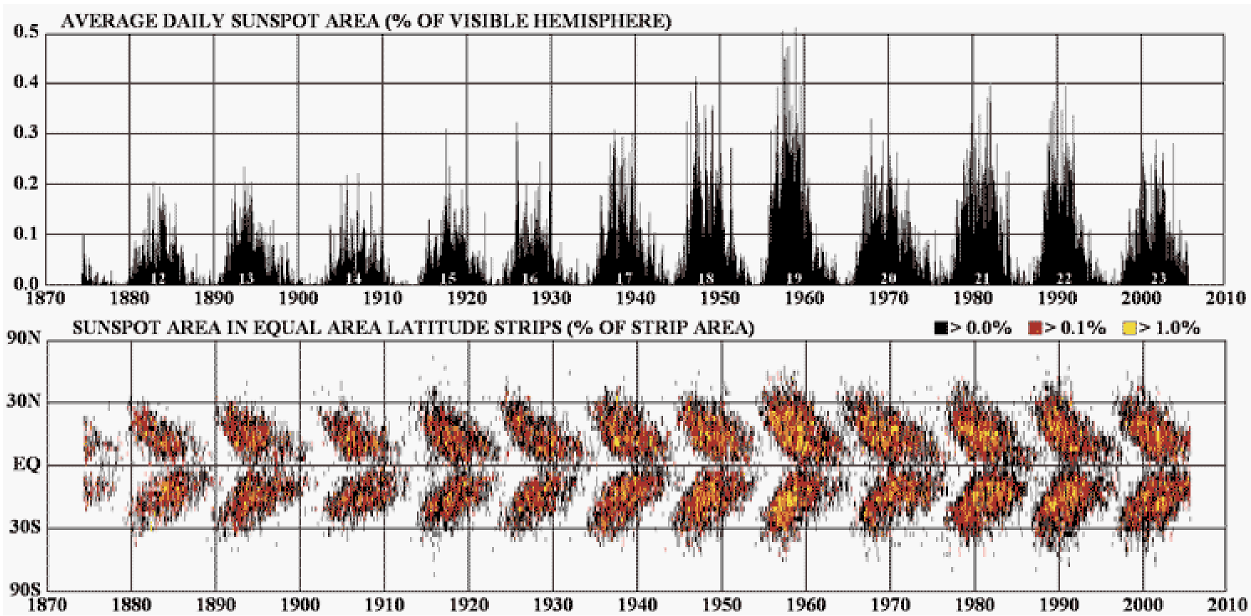


(answer #15 here)

We could use the grid to keep track of how sunspots move. Using the Cartesian coordinate system, we could list their x, y coordinates as time goes by.

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

16. The following are two additional graphs that demonstrate the surface area and location of sunspots over time. What patterns do you notice in *each* of the graphs below? Use the words **period** and **frequency** in your descriptions.



The average daily sunspot area changes periodically. The period of sunspot area cycles is about about 12 years, and the frequency is about one cycle every 12 years. It could also be said that there are a little more than 9 cycles every century. Sunspot area also seems to change in latitude, with most of the sunspots appearing between 30S and 30N. (They don't seem to form near the poles). As each cycle goes by, the sunspots seem to get closer and closer to the equator).

17. Think about coherence and continuity of patterns throughout scientific data. Where else in this class have we talked about periodic cycles in the physical world?
Answers will vary, but might include examples such as circular motion, pendula, etc.

See next page for NGSS Correlations

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

NGSS Standards

Performance Expectation: High School Physical Science-Waves

HS-PS4-1 Wave: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

Disciplinary Core Ideas: High School Physical Science - Waves

- **HS-PS4.A.1: Wave Properties -** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. *(Note to teachers: It will be important to guide students in understanding that wave properties are being presented within the context of authentic data on sunspots, which can be represented as wave patterns. However, real sunspots do not "move across" the surface as astronomers believed many years ago. Sunspots appear to be moving in solar images because of the sun's rotation (spin).*
- **HS-PS4.C.1: Instrumentation -** Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.

Disciplinary Core Ideas: High School Earth/Space Science

- **HS-ESS1.A.1-The Universe and Its Stars:** The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years. *(NOTE: Partial alignment only to the first segment of the DCI: "The star called the sun is changing.")*

Science and Engineering Practices

- **Analyzing and Interpreting Data, Grades 9-12:** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable claims or determine an optimal design solution.
- **Using Math and Computational Thinking, Grades 9-12:** Use mathematical representations of phenomena to describe explanations.

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

Crosscutting Concepts

- **Patterns, Grades 9-12:** Patterns in rates of change and other numerical relationships can provide information about natural systems.
- **Systems and System Models, Grades 9-12:** When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.
- **Scale, Proportion, and Quantity:** Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another.

This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Consortium to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.