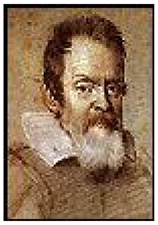


Are Those Sunspots Really on the Sun?

Summary of Activity:
Students will acquire solar images (or draw sunspots), and record coordinates of sunspots. They will calculate and plot their apparent movement and describe their shapes. They will determine whether sunspots are features on the surface of the Sun, or objects in orbit around it.

Grade Level: 5 - 12

Duration of Activity:

About 1 hour for preparation, 1/4 hour per day for 10-14 days if you choose to collect new data; at least 1-3 hours for analyzing data, answering questions and doing optional calculations.

Student Prerequisites:

1. Basic knowledge of the Sun and planets.
2. Concept of coordinates, longitude and latitude.
3. Measuring, plotting, basic geometric terms, i.e. "width-to-height ratio".
4. Optional - angular velocity (speed of rotation), vs. linear velocity, high school mathematics.

Preparation & Supplies Needed:

1. Sunspot Recording Worksheets. (http://solar-center.stanford.edu/solar-images/worksheet.html). Print out and make enough copies for *each day* of your observations.

2. Latitude/longitude grids. (http://solar-center.stanford.edu/solar-images/latlong.html). You may have to enlarge/shrink these with your computer or copier to make them match your solar disk images. And it will be easiest if you can copy them onto transparency paper.

3. Sunspot speed graphs. (http://solar-center.stanford.edu/sunspots/spotspd.html). Print these out or make copies for each person.

4. Computer & access to the internet. You will download an image of the Sun every day, for about 2 weeks (either intensitygrams or magnetograms).

5. Copier machine and transparency paper (recommended)

6. A basketball and a tennis ball (optional)

Introduction

When Galileo Galilei discovered sunspots, he had a problem. Here it was, 1612, and he had just pointed his new version of the Dutch tool called a "telescope" towards the heavens. Not only did he discover the moons of Jupiter, the "seas" and craters on our own Moon, and the phases of Venus, but he also found what he thought to be dark smudges on the Sun. How could this be? After all, the Catholic Church taught that the heavens were perfect. So there could not be imperfections, or spots, on the Sun. (Remember that it is dangerous to look directly at the Sun through binoculars or in any other way!)

The German astronomer Christoph Scheiner claimed the spots must be tiny undiscovered planets circling the Sun, which would occasionally pass in front of its disk. Try this experiment and see if Galileo was right!

Objectives:

Students will:

1. Observe sunspots and consider ways to determine whether they are on the Sun, or in orbit around the Sun (Galileo's dilemma).
2. Collect and record sunspot data (images) for 2 weeks, or use sample data provided.
3. Tabulate data and draw inferences from their numbers.
4. Answer questions, and participate in group discussion, before the activity and after.

Procedure

Please read the whole procedure, and complete the quiz and group discussion before you begin collecting data. Note that most (but not all!) sunspots appear in groups, so to make things simpler we will call them **sunspot groups**, even in cases when there may be just one sunspot.

Quiz

1. What are latitude and longitude lines? Can you show them on a solar coordinate grid ?

2. What is a magnetogram and what is an intensitygram?

3. Can you find a sunspot or sunspot group on both a magnetogram and an intensitygram?

Discussion

I. What do you suppose sunspots are? Do you think sunspots move?

II. From your own point of view, are sunspots features on the Sun itself, or objects in orbit around the Sun? How would you try to prove this? Discuss this in your group.

Collecting Data:

1. Decide on whether you want to use magnetograms or intensitygrams.

2. Go to SOHO daily images - (http://sohowww.nascom.nasa.gov/data/realtime-images.html). Magnetograms are labeled "MDI Magnetogram", and intensitygrams are "MDI Continuum".

3. Every day for 10-14 days, either print out a copy of the internet solar image, or sketch and label the image and sunspot groups you see. (If you have to sketch, try placing the latitude/longitude grid directly over the image on your screen to find exactly where to sketch your spots. Be careful to always have the image straight up and down.)
   Here are some examples of Galileo's sunspot drawings:
   http://galileo.rice.edu/sci/observations/sunspot_drawings.html

4. For each of the major sunspot group, record on your Sunspot Recording Worksheet:
   i. The name of each sunspot group. Make up any name you want, but make sure to keep track of which group has which name.
   ii. Where (i.e. at what latitude and longitude) the spot groups lie.
   iii. Note whether there were any observable changes in your sunspot groups (has the group changed size, shape, disappeared altogether?)

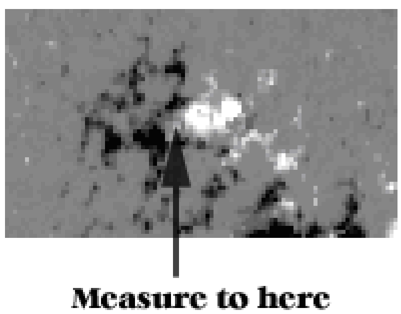
   You can see a sample completed data sheet here (http://solar-center.stanford.edu/images/sunworksheet.gif)

Hints:

- You'll need to track the sunspots for about 2 weeks. Start with images for the current day. If these aren't complete, start looking at images from previous days. If you don't have 2 weeks to spare, or if there are no substantial sunspots in the recent images (as is often the case during a solar minimum), you can look at images from earlier dates.

The easiest way to do this is to go to:
http://soi.stanford.edu/production/mag_gifs.html for magnetograms, and to:
http://soi.stanford.edu/production/int_gifs.html
for intensitygrams, and browse by clicking on the year and month of interest.
Another way to obtain archived images is to go to:
http://sohodata.nascom.nasa.gov/cgi-bin/data_query. Enter the start and end dates, and the type of image you want (don't worry about "Latest n images").
Alternatively, you can use these magnetograms in the examples:
(http://solar-center.stanford.edu/solar-images/teacher.html#examples)

- The label on each image indicates the time when it was taken (e.g. for "2009/02/03 22:29", the date is February 3rd, and the time is 22:29.) *Each day when you retrieve your images, try to get one from the same time as the day before.*
- Measure only the large blotches, and don't worry about the smaller dots or the spread-out areas which look like lace.
- When you measure the latitude and longitude, **measure to the center of the spot or spot group**. On the magnetograms, measure to the area right between the white and black portions:



Data Analysis

1. First, you're going to transfer your sunspot data onto the table for your Sunspot Speed Graph. Note that you will need to figure out the distance, in centimeters, traveled by the sunspot groups each day. You will then make a graph with the group's longitude on the horizontal axis, and its apparent speed in *centimeters per day* on the vertical axis.
(As an optional assignment, you can also record the group's speed in *degrees of longitude* per day, and plot it on a separate graph.)

2. Pick your best sunspot group, the one for which you have the most data. What you want to find is how far that group appeared to travel across the Sun's disk. Remember to measure to the **center** of the spot or spot group!

3. To figure out how far the sunspot group moved from the first to second day, subtract your measured distance (the one you measured on your sketch from the edge of the Sun) of the first day from the measured distance of the second day. (e.g. if your Day #1 = 3 cm and Day #2 = 4.5 cm., the distance would be 4.5-3 = 1.5 cm) Now, graph that point above the longitude measurement for the second day.

4. Figure out how far the group moved between each of the rest of your days, and place the points on the graph. (If you have a day missing, figure the distance the spot group moved in 2 days and use half that amount for each of the 2 days.)

5. Once your data is plotted, draw a line/curve between the points. To minimize recording errors, graph one or two more sunspot groups just as you did the first.

Questions

1. What can you say about the shapes of the sunspots? Do they remain constant?

2. Look at the shape of one sunspot as it appears on the edge (limb) of the Sun's image. What happens to its width-to-height ratio as it moves across the disk, and when it again approaches the limb on the other side? Why do you think that is?

3. Do sunspots *always* appear and disappear on the solar limb?

4. Look at your graph. Does the "movement" of sunspots across the disk (in centimeters per day) remain constant with longitude?

5. If the distances traveled, and hence the speeds, were different, in what areas of the Sun did they appear faster? In what areas did they appear slower?

6. Why do you think the spots appear to move at different speeds the way they do?

7. In your groups, discuss whether or not you think sunspots are features on the Sun's surface. Suppose that the spots are objects in orbit some significant distance away from the Sun. Would their speeds appear to change much as they went past the limb and then across the center of the solar disk?

If you have difficulty visualizing this, try a simple experiment. Draw a dot on a basketball, and rotate the ball around its axis, such that the dot appears to travel horizontally when you look at it from the side. While spinning the ball at a constant rate, observe the apparent changes in speed of the dot. Now, put the ball down on a table, and sit across the room. Have another person hold a tennis ball a few feet from the basketball and slowly move it in an orbiting motion around the basketball. Observe whether the speed of the tennis ball varies much while it passes in front of the basketball.

Then, check out this SOHO image of Mercury's transit across the solar disk!

Extra questions:

i. Does your sunspot speed graph in centimeters per day show angular or linear velocity?

ii. Does the *angular* velocity of the sunspots remain fairly constant? Why or why not?

Extra assignment:

If you were Galileo, how would you mathematically prove the spots are actually on the Sun?
(http://solar-center.stanford.edu/sunspots/gproof.html)