Name: ______________________

Section: ______________________

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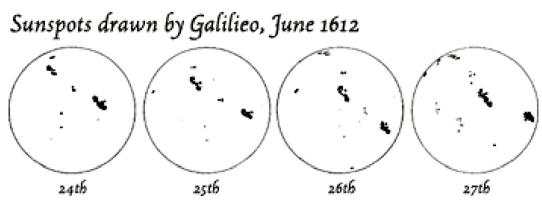
Prelab 7: Sunspots and Solar Rotation

The purpose of this lab is to determine the nature and rate of the sun's rotation by observing the movement of sunspots across the field of view of a CCD image. Before we begin, let's explore some of the terms and concepts that will be used during the lab:

Sunspots: Sunspots have been observed, if not understood, for centuries. Some of the earliest human records of sunspots date back to ancient Chinese drawings of the Sun at sunset, when the Sun was dim enough to make out small spots on the disk seen in the sky. Generally, the solar disk is too bright, and sunspots too small, to be seen with the naked eye, but sunspots are easily seen using a telescope and solar filters. Galileo Galilei, who pioneered the use of the telescope in astronomy, was one of the first to publish a series of observations of sunspots that he made with the telescope in 1613. Galileo was quick to recognize that the spots were markings on the visible surface of the Sun, and that they moved as the Sun rotated. Three of his sketches of sunspots, made on three consecutive days, can be seen below. The changing detailed appearance of the spots is not due to Galileo's imperfect drawing skills, but to the variability in appearance of the sunspots themselves. They grow and shrink in size, and spots last a few weeks at most before fading out. We now know that sunspots are areas of intense magnetic activity on the surface of the sun.



The motion of the spots affords us a way of measuring the rotation rate of the solar surface. Solar rotation is one of the principal factors affecting the roughly 11-year cycle of sunspot activity, solar flares, and other phenomena. In the 1860's Richard Christopher Carrington used sunspots to determine that the period of rotation of the Sun depends on latitude. Spots near the equator of the Sun go around every 25 days, while spots near latitude 45 go around once every 28 days. This *differential rotation* would not be possible if the Sun were a solid body. Determining the solar rotation rate from sunspots is easy in principle: you just need to record the time it takes for a spot to go once around the Sun, or perhaps some fraction of the distance around the Sun. In this lab, we will measure the rotation rate of the Sun with the help of images from the GONG solar telescope database.

1. (1 point) What is a sunspot?

2. (1 point) Why is it important to measure and record the latitude of a sunspot?

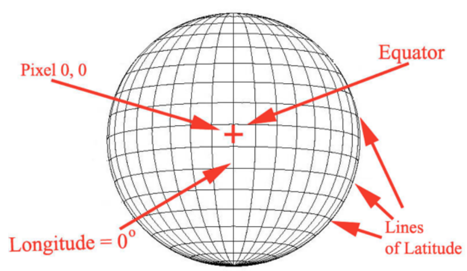
Sidereal and Synodic Periods The *Synodic Period* is the value of the sun's rotation as viewed from Earth. Remember, though, that the Earth is moving in its orbit around the sun, so the synodic period is NOT the sun's actual rotation rate! The actual rotation rate of the sun is called the *Sidereal Period*. This is the time it takes for one point on the sun's surface to rotate once with respect to the distant stars. The sidereal period is slightly shorter than the synodic period, as the sun has to turn slightly further to catch up with the orbital motion of the Earth. In this lab, you will measure the synodic rotation rate, then use this value to calculate the synodic and sidereal periods.

$$P_{Synodic} = \frac{360}{Slope}$$
$$P_{Sidereal} = \frac{P_{Synodic} \times (365.25)}{P_{Synodic} + (365.25)}$$

3. (2 points) If we measure a sunspot that has a slope of 18 degrees per day, what is the synodic period?

4. (2 points) For the same sunspot, what is the sidereal period?

Heliographic Coordinates: Heliographic coordinates are similar to longitude and latitude on Earth. The poles of the Sun are at +90 degrees (north) latitude and −90 degrees (south) latitude. The equator of the Sun is at 0 degrees latitude. The 0 degrees heliographic longitude line runs right down the middle of the solar disk as you see it, with positive lines of longitude to the right, and negative ones to the left). Unlike longitude lines on the Earth, heliographic longitude lines are not fixed to the surface of the Sun and do not rotate with the Sun! This lab will use heliographic coordinates, as illustrated below:



5. (2 points) Imagine a spot located to the left of the centerline of the Sun. Is its longitude positive or negative? What about a spot to the right?

6. (2 points) If you had a series of consecutive pictures taken over the course of several days, how would you expect the apparent latitude of a sunspot to change from one picture to the next? What about the apparent longitude (*hint: which one might slope downwards?*)?

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Lab 7: Sunspots and Solar Rotation

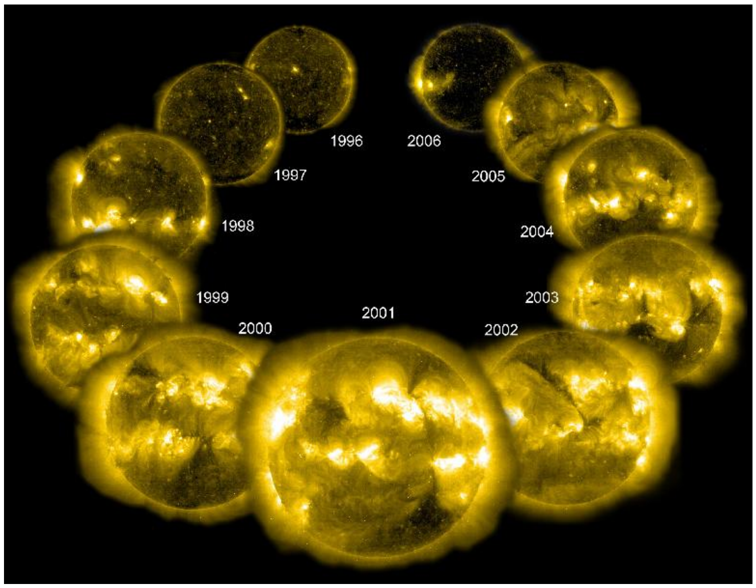

Figure 1: One complete (11-year) solar cycle, imaged by SOHO, shown here in extreme UV light.

1 Introduction

The purpose of this lab is to determine the nature and rate of the sun's rotation by observing the movement of sunspots across the field of view of a CCD image. This lab uses heliographic coordinates, which are illustrated below:

2 Instructions

1. For this lab, you will need a calculator.
2. A brief word on curve fitting (ie. fitting a line to a set of data points): A "linear fit" is characterized by the slope and the y-intercept, here called T-Zero (the x-value, or time, where the line crosses the zero point of the y-axis). The slope refers to how much the line is tilted. It is important to write down the entire T-Zero value.
3. The database for the CLEA Solar Rotation Lab consists of 368 images obtained at the GONG solar telescopes between January 1, 2002 and April 30, 2002. Although images are acquired once per minute while the Sun is up at each of the GONG solar telescopes (averaging a total of about 3600

images per day!), the database for this lab contains only three images per day. On average that's one image every 8 hours, which is more than sufficient to determine the rate of rotation of the Sun.

4. Open the CLEA lab entitled SOLAR ROTATION. Click on File, then Login. Enter the first name of each group member, then click ok, and click yes. Return to the File menu and click Run.

5. Load your sunspot images: Click File, Image Database, Image Directory, Load. Choose the file alist.txt to load images of the solar disk from the GONG network of solar telescopes. Images will appear similar to the one in Figure One. Now click File, Image Database, Select All. Click File, Image Database, Load Selected Images. Finally, click Images, Sort Image List.

6. If you'd like to see the images as a short movie, click Images, Animation, On. Once you are comfortable with the motion of the sunspots, you can turn the animation off.

7. Record your images' range of dates in the lab worksheet.

8. Now, we want to identify several sun spots on the disk of the sun, and record their positions over the next set of images. Begin with the image on 2002/1/13 and identify three (3) spots on the left hemisphere of the image. Pick larger spots close to the edge of the image, as you will be following these same three spots through each new frame. Click on each of the three sunspots you've chosen and fill in the spot ID box before clicking "record." Use something like 1, 2, 3 or A, B, C to identify the spots. When you are done with the image, click "Finished." **Make sure you keep track of these three spots and that you use the SAME spot ID's for the same spots in each image.** There is no way to correct labels after they've been recorded, so if you make a mistake, you will have to restart the lab.

9. **Repeat the recording procedure in the last step for EACH IMAGE in the list, until all three spots are identified in each image.** If a spot goes off the right side of the disk, label the point at the edge of the disk closest to where the spot went out of the picture, and continue labeling and recording the remaining spots. In the next image, your missing spot should reappear on the left. When your three spots are recorded in each of the images, you're ready to move on to analysis.

10. Click Analysis, Plot/Fit Data. A new window should pop up; there, click File, Dataset, Load Longitudinal Values. Load one spot ID at a time, and use the adjustment bars in the middle of the screen to match the straight line to the data points. **The straight line must pass directly through the data points, otherwise it is not "fit" correctly.** If you have a data point that does not seem to make sense (doesn' fit the line), ask your TA.

11. Record the spot ID, T-Zero (in Julian Days), Slope (in degrees per day, representing the average number of degrees per day a sunspot moves across the disc of the sun), and RMS on the lab worksheet. Your RMS value (the error measurement describing how well your observations fit the line) should be below 1.00 RMS degrees.

12. Continue loading the longitudinal values for each spot until you have fit and recorded each of your three spots. **Print** a plot of all sunspot longitudinal values and their best fits on the same page.

13. Click File, Dataset, Clear data. Load the latitudinal values as you did for the longitudinal ones. Record the Mean Latitude (in degrees) for each spot in the lab worksheet. You do NOT have to print the latitudinal values.

14. Complete the remaining questions and calculations on the lab worksheet.

Picture Credits: Prelab Galileo Drawings: http://earthobservatory.nasa.gov/Features/SolarMax/Images/sunspots.gif, Prelab Heliocentric Coordinates: CLEA Student Manual, Lab Solar Cycle: http://apod.nasa.gov/apod/ap071203.html. DISCLAIMER: This lab has been edited from the CLEA simulations and student manuals: Marschall, Laurence, Glenn Snyder, and Jeff Sudol. Project CLEA Software. Project CLEA. Gettysburg College, National Solar Observatory. Web. 15 July 2014. ¡ http://www3.gettysburg.edu/ marschal/clea/CLEAhome.html ¿.

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Lab 7 Worksheet: Sunspots and Solar Rotation

1. (1 point) Date Range of Solar Images:

2. (1 point) In the images, which way does the Sun rotate: left to right or right to left?

3. (1 point) On average, how many sunspots are on the disk of the sun?

4. (3 points)

Spot ID	T-Zero (JD)	Slope (deg/day)	RMS (deg)	Mean Latitude (deg)

5. (7 points) Using $P_{Synodic} = \frac{360}{Slope}$ and $P_{Sidereal} = \frac{P_{Synodic} \times (365.25)}{P_{Synodic} + (365.25)}$, fill in the following table:

Spot ID	Synodic Period (days)	Sidereal Period (days)
	Average of Sidereal Period	

6. (2 points) Why don't the sunspots move in a precise horizontal pattern across the disk of the sun?

7. (2 points) Why is there greater uncertainty in the measurement of a sunspot twoards the edge of the sun as opposed to the center? Think about the implications of heliographic coordinates...what happens when you project a 3D object onto a 2D piece of paper?

8. (3 points) Attach your plot with the three lines of best fit for longitudinal data (latitudinal data plots not needed). Make sure your lines of best fit are fitted correctly.