Astronomy 102 Lab: Solar Observing

Pre-Lab Assignment: In this lab, you will determine the rotation rate of the Sun, determine the speed of material ejected from the Sun in a coronal mass ejection, and use resources available on the internet to learn more about the visible Sun and the more active regions of the Sun which are not readily visible to the naked eye. When you look at the photosphere of the Sun, you will be able to see some structures, such as limb darkening, sunspots, and granulation. Answer the following questions before coming to lab.

A) What is meant by "limb darkening?"

B) What is a "sunspot?"

C) The units for velocity are miles per hour, based on distance (miles) divided by time (hours). Let's say you leave your house in your car and head for the interstate highway. At 9 AM you pass mile marker 84. When you pass mile marker 200, you note on your watch that it's 11:30 AM. What is the elapsed time in hours? What is the total distance traveled in this time frame? What is your average velocity during this time frame?

D) You have already done a lab on spectra, including emission and absorption lines. Given the graph below, which of these (emission or absorption line) is represented by the dip? What about the hump?
**Objective:** This activity will let you use images of the Sun taken from solar observatories to calculate the rotation period of the Sun. You will also measure the expansion rate of a coronal mass ejection and study other solar features and past solar activity.

**Background:** When the Sun is unusually active, the aurora borealis, or northern lights, can be visible in more of the continental U.S. including Champaign. You will use data from that time period, when there were many sunspots and large number of solar flares.

**Procedure:**

**A. The visible Sun:** You will find three images taken in white (visible) light on 2003/10/26, 10/27, and 10/28. These images are labeled with the date on which they were taken.

You will now use sunspot positions to track the rotation of the Sun. On the white light images, the sunspots are the dark splotches. Look at the three white light images and find three sunspot groups that appear on each image (each dot will be a group rather than a single spot). You will track the progress of these sunspots as the Sun rotates.

We will refer to the sunspot groups from left to right as sunspots "1," "2," and "3," respectively. The image we see of the Sun is a circle; if you measure horizontally across a circle, you will get the largest value at the equator and a value that approaches zero as you approach the poles. For each sunspot group, measure the distance across the disk of a horizontal line that passes through the group in centimeters. You only need to measure this on one image. Record the length of this line in the appropriate space below.

If you are having difficulty with this, please consult the example at the following address.  
http://natsci.parkland.edu/ast/101/labs/solarex.html

1. **Total horizontal distance across the image of the disk of the Sun for:**
   
   **a. Sunspot 1:**  
   **b. Sunspot 2:**  
   **c. Sunspot 3:**

   Locate each sunspot group on 10/26 and measure the distance from the center of it to the left edge of the image of the Sun. Fill in the appropriate spaces in the table below. Repeat the procedure for 10/27 and 10/28.

<table>
<thead>
<tr>
<th>Date</th>
<th>Sunspot 1</th>
<th>Sunspot 2</th>
<th>Sunspot 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

You will now use your data to determine the rotation rate of the Sun. Calculate the distance traveled by each sunspot group between the 10/26 image and the 10/27 image. Do this by taking the distance on 10/27 and subtracting the distance on 10/26 for each sunspot group.

Distance traveled from 10/26 to 10/27 for:

**3A. Sunspot 1:**  
**3B. Sunspot 2:**  
**3C. Sunspot 3:**

Calculate the distance traveled by each sunspot group between the 10/27 image and the 10/28 image.
Distance traveled from 10/27 to 10/28 for:

4A. Sunspot 1:  4B. Sunspot 2:  4C. Sunspot 3:

Calculate the average distance traveled by each sunspot group in one day. For example:

\[
\text{Average distance traveled by sunspot 1 in one day of time.}
\]

Average distance traveled in one day of time for:

5A. Sunspot 1:  5B. Sunspot 2:  5C. Sunspot 3:

To get the time for each sunspot group to cross the front of the Sun, take the total horizontal distance across the Sun for each group (Question 1) and divide it by the average distance traveled by the group in one day. For example, let’s say the total distance across the Sun for a sunspot is 10 cm. \( \text{(Your values will be different.}\) The average distance traveled by a sunspot in one day is 2.0 cm. Thus, the sunspot will take \( 10 \div 2.0 = 5 \) days to cross the front of the Sun.

Time to cross the front of the Sun for:

6A. Sunspot 1:  6B. Sunspot 2:  6C. Sunspot 3:

You have now calculated the time to cross the front of the Sun. The sunspot would require twice the time you calculated to go completely around the Sun. Multiply each of your answers above by two and find the average. This is the rotation period of the Sun.

7. Rotation period of the Sun:

The rotation period of the Sun near the equator is 25 days. Calculate a percent error for the rotation period you calculated.

\[
\% \text{ error} = \left| \frac{\text{accepted value} - \text{measured value}}{\text{accepted value}} \right| \times 100
\]

8. Percent error:

9. List some sources for the error in your rotation period determination. \( "\text{Human error" is not an acceptable answer. Explain how a person would cause such errors.}\)

Now, look at the magnetogram provided, which was measured by GONG. Compare the white light image on 10/27 with the magnetogram, including the locations of the sunspot groups.

10. Is there a correlation between sunspots in the white light image and structures on the magnetic field image? What does this tell you about the relationship between sunspots and the magnetic field?

B. Coronal mass ejections: Watch the video of a coronal mass ejection (CME). It can be found at this address. http://sohowww.nascom.nasa.gov/gallery/Movies/C3 00apr/C3 00apr.mov Look up the definition of a CME in your textbook or consult the Space Weather Phenomena page so you know what you are
looking at. You will see a central black circle that represents the Sun and a second white circle surrounding the first one; this is the disk the SOHO satellite uses to block out the Sun's brilliance.

11. Describe how a CME appears in the video in a few sentences.

Next we want to measure the speed of one of these ejections from the Sun. Please look at the images of a CME. We need to find the scale of these pictures first, which is like what you would find on a road map, where 1 cm would correspond to 10 miles. The white circle at the center of each image represents the disk of the Sun. The tick marks along the bottom of the image mark off units of the Sun's diameter.

Measure the diameter of the outer edge of the white circle in millimeters. The Sun's diameter is actually 1,400,000 kilometers. Plug your measured value into the following equation to calculate the scale of the photographs. Round your answer to three significant digits, such as 18,645 km rounded to 18,600 km.

\[
\text{Scale of the photos} = \frac{1,400,000 \text{ km}}{\text{your measured value in mm}} = \text{your calculated scale in km/mm}
\]

We'll follow the progression of the expanding bubble of material on the right side of the Sun. Select a feature that you can see in all five images, such as the extent of the bright structure or the inner edge of the dark loop shape. The spikes disappear over time so they shouldn't be used. Measure the position of the feature in each image and record the information in the table below. Since the Sun is much larger than a few millimeters across, you convert the position to km by multiplying by the scale factor you calculated in Question 12.

Calculate the change in position by subtracting between the current position and the previous position. The first line is blank, but second line should have the change between position 1 and position 2. Calculate the speed by dividing the change in position by the change in time.

13. Fill in the table below. Round your answers in this section to three significant digits.

<table>
<thead>
<tr>
<th>Time</th>
<th>Position (mm)</th>
<th>Position (km)</th>
<th>Change in Position (km)</th>
<th>Change in Time</th>
<th>Average Speed (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>08:36</td>
<td></td>
<td></td>
<td></td>
<td>1,860 seconds</td>
<td></td>
</tr>
<tr>
<td>09:27</td>
<td></td>
<td></td>
<td></td>
<td>3,060 seconds</td>
<td></td>
</tr>
<tr>
<td>10:25</td>
<td></td>
<td></td>
<td></td>
<td>3,480 seconds</td>
<td></td>
</tr>
<tr>
<td>11:23</td>
<td></td>
<td></td>
<td></td>
<td>3,480 seconds</td>
<td></td>
</tr>
</tbody>
</table>

14. Based on what you've learned, what two forces do you think are acting on the CME to make it act the way it does?

15A. Do you expect the CME to be accelerating, decelerating, or moving at a constant speed as it leaves the Sun?
15B. How well does that match the changes in velocity you calculated?
C. The Sun on the Web: Use the websites linked below to answer the following questions.

First, go to spaceweather.com. Look at the data in the left margin to see the most recent sunspot number.

16. Record the date and the sunspot number:

The sunspot number tells astronomers if we are around a solar maximum or a solar minimum. The sunspot cycle shows how the sunspot number varies over time. The length of the cycle is the average time between successive solar maxima. Use the plot of monthly averaged sunspot numbers since 1750 to estimate the length of the sunspot cycle. Since no cycle is the same, you will get a more accurate result by calculating the average length over several cycles. Pick two sunspot maxima that are far apart and note the cycle number listed below the peak. For example, the current cycle is "24."

17A. First maximum year:  
17B. Second maximum year:

17C. First cycle number:  
17D. Second cycle number:

Determine the time difference between the two sunspot maxima and the difference in cycle numbers. Find the average sunspot cycle length by dividing these two differences.

18A. Year difference:  
18B. Cycle difference:

18C. Average cycle length:

19. Is the sunspot number of the current cycle increasing, decreasing, or stable?

20. When is the solar maximum of cycle #25 going to occur?

21. What was the maximum sunspot number ever recorded?

More on the next page...
D. The spectrum of the solar wind: In the Spectra lab, we saw how you can use the spectrum of a glowing object (like a star) to determine its composition. The SOHO satellite has done that with the Sun. One of the instruments is the MTOF or "Mass, Time-of-Flight" spectrometer, which measures the elements in the solar wind. Look at the CELIAS MTOF page on the table.

Look at the spectrum in the graph. The atomic mass of each element is listed across the bottom and the abundance of each element in the solar wind is measured on the vertical axis. The sharpest peaks are the most abundant and the chemical symbols are listed at the top.

23. Which element is the most abundant in the solar wind?

24. Which four elements are the next four most abundant?

25. Are you looking at an absorption line spectrum or an emission line spectrum?