Sunspots and Solar Rotation

The Problem:

When Galileo first pointed his telescope at the Sun he found dark spots on its surface (But he also may have ruined his eyes - there are better ways to look at the Sun). Sunspots and phenomena related to them can affect the Earth in a number of ways. They can also be used to derive the rotation period of the sun.

The goal of this project is to track the movements of sunspots for several weeks to prove that the Sun rotates and to derive its period of rotation. Since this is 'real' data, this is also an excellent opportunity to study experimental errors.

Introduction

Since the time of Galileo there has been a continuous record of the appearance of the Sun – there are almost 400 years of sunspot data now available. From this data astronomers have determined the rotation period of the Sun, the nature of the solar cycle, the existence of differential rotation and possible influences of the solar cycle on terrestrial climate.

The basic observation is extremely simple. Any telescope can be arranged to project an image of the Sun onto a screen so that the positions of the spots can be indicated. With systematic observations from day to day, the movements of the spots caused by the solar rotation can easily be measured.

Galileo showed that the movement of the sunspots across the apparent disk of the Sun is just what we should expect to see if they are really rotating across a spherical surface, rather than a flat disk. If that is true, then it is necessary to set up a spherical coordinate system of solar latitude and longitude, analogous to the latitude and longitude system on the Earth. To measure the day-to-day positions of sunspots, this system of heliographic coordinates must be projected onto a flat surface to match the projection of sunspots onto the solar disk, as shown in Figures 1 and 2. For this exercise, it is convenient to measure heliographic longitude from the East edge (the East “limb”) of the Sun toward the West limb. Heliographic latitude can be measured North and South from the Sun’s Equator. The Sun also exhibits differential rotation, different rotation speeds at different latitudes.

As shown in Figures 1 and 2, two additional factors need to be taken into consideration. The heliographic coordinate system is based on the actual rotation axis of the Sun. But that axis does not line up with either the ecliptic (the orbit of the Earth) or with the Earth’s rotation axis, so two angles must be specified to describe the orientation of the heliographic coordinate system on the plane of the sky. The position angle, (P) represents the angle between the direction of North on the Earth and the projected north pole of the Sun (Figure 1).
The second angle, $B_0$, (which is also called the **heliographic latitude**) represents the angle between the solar equator and the ecliptic plane, as shown in Figure 2.

Although the direction of the Sun’s rotation axis is fixed in space, as the Earth goes around the Sun, the projection of the solar axis onto the plane of the sky changes continuously. Both the angles $P$
and $B_\phi$ change from day to day. In principle, both of these two angles can be found by observing enough sunspots, but it would take years of work to calculate accurately. Fortunately, this work has already been done, and both angles are tabulated for each day of the year in the *Astronomical Almanac*.

This lab assumes that the sunspot measurements have already been made, either by the class or by someone else. The sunspot positions have been sketched onto observation charts drawn to match a series of transparent overlays, drawn with heliographic coordinates projected through various values of the angle $B_\phi$. These overlays can be used to measure the heliographic coordinates of any sunspots visible on the chart.

**Available equipment:**


2. Observation charts with sunspot observations made by the class. Some supplemental solar images obtained from the Internet may be included to fill in gaps in the data.

3. Coordinate grid overlay pages for calculating the positions of the sunspots.

4. Graph paper to plot the longitudes of individual spots as a function of time.

**Experimental Procedure:**

For each sunspot that has been observed on more than one day, it will be possible to make a measurement of the solar rotation period. If several sunspots have been recorded it will be possible to make several independent measures of the rotation, and find the mean period and standard deviation.

*i. Measure the sunspot movements -*

To find out how fast the Sun is rotating proceed with the following steps:

- **a.** The first task is to go through the observation charts to identify each sunspot on every chart on which it appears.

- **b.** If it has not already been done, identify the East-West direction on each chart.

- **c.** Use the appropriate coordinate overlay grid to estimate the solar latitude and longitude of every major sunspot recorded on each observation page. Record these positions on the data page attached to this lab.

- **d.** Plot the positions of the sunspots on one of the "sunspot positions" graphs, with the time (in days) on one axis and longitude (in degrees) on the other. It is possible to fit almost two months of observations on a single graph, so divide the observing period into convenient time segments. If possible, use different symbols for sunspots at different latitudes.
e. Identify points that obviously correspond to a single sunspot observed on different days, and draw the best straight line through all the points. Do not “connect the dots.” The slope of this line will be the mean daily rotation of this sunspot. Dividing this number into 360 will give the period of rotation in days.

ii. Compute the period of solar rotation -

There should be a separate measurement of the solar rotation period for each “good” sunspot. Compute the average of the rotation periods from the individual sunspots and the standard deviation. If several groups measured the same set of solar images, it should be possible to compare the calculated rotation periods.

Analysis and Discussion

Discuss your experiment and the results and calculate your measurement errors. How well does your calculated period for solar rotation compare to the expected value? Do you see any evidence that suggests that the rotational period is a function of latitude, i.e. differential rotation? List any planets you might expect to exhibit differential rotation and explain your choices.