

Lab: Rotation period of the sun from sunspots

Introduction

The Sun rotates about an axis inclined by about 7° with respect to the axis of the solar system (the axis perpendicular to the ecliptic). The easiest way to see this is to observe the motion of sunspots across the face of the sun. Individual sunspots last for a month or so after formation, but do not travel far during their lives, and therefore can be taken as markers of solar rotation. Sunspots form at high latitudes and in small numbers when it's early in the 11-year solar cycle, and in greater numbers and at lower latitude as the cycle progresses. We happen to be just past a "solar maximum" in sunspot number and other signs of solar activity, this year.

In this experiment we will use observations of sunspots over a period of several days to measure the rotation period of the Sun. If its clear, we can use the Undergraduate Astronomy Lab's heliostat - that big set of motorized mirrors in the back room of B+L203 - for some of our data. We can also use the Astroscan which projects the sun onto the wall, or the cute little Sunspotter. But observations over several days need to be used to measure the rotation rate of the Sun, and we might not get clear weather during our scheduled lab periods anyway. Thus we will supplement our own data with images kindly provided on line, on a daily basis, by solar observatories in places where the sun nearly always shines. One such place is the C.E.K. Mees Solar Observatory, located on Haleakala, Maui, Hawaii. Look under White light images <http://www.solar.ifa.hawaii.edu/mees.html>. Another such place is Big Bear Solar Observatory (BBSO), on the Web at <http://www.bbso.njit.edu>. You will need to use their archive <ftp://ftp.bbso.njit.edu/pub/archive/> to find images from other days and times.

To measure the rotation period in a few days of observations, one must bear in mind that the solar image we see is a two-dimensional projection of a three-dimensional object, and that the rotation axis is not perfectly aligned in a cardinal direction. Equal distances on the projected image do not necessarily correspond to equal distances on the surface of the sun. We will need to *determine* the axis of solar rotation from the images. Furthermore, the sun's rotation period we get directly is a *synodic* period, measured from the moving Earth, and the rotation period we want is a *sidereal* period; that is, relative to the fixed stars.

Procedure

1. First we need to deal with how to obtain sidereal periods from synodic periods. Conceptually this may be made easier by considering planetary revolution rather than solar rotation. The synodic period of a planet other than Earth is the time interval between consecutive oppositions or conjunctions of Earth with that planet. *Opposition* means that Earth, planet and Sun lie along a line, with the Sun on one end. *Conjunction* means that they lie along a line with the Sun in the middle.

Show that the synodic period S and sidereal period P of an inferior planet (Mercury or Venus) are related by $\frac{1}{S} = \frac{1}{P} - \frac{1}{P_{\oplus}}$, and those of a superior planet (Mars - Pluto) by $\frac{1}{S} = \frac{1}{P_{\oplus}} - \frac{1}{P}$, where

P_{\oplus} is one sidereal year on Earth. Sunspots will behave like inferior planets.

- 2a. The instructors will have set up the heliostat or Astroscan, and projected the solar image onto a place where paper can be mounted. Draw a circle the same diameter as the solar image, on a

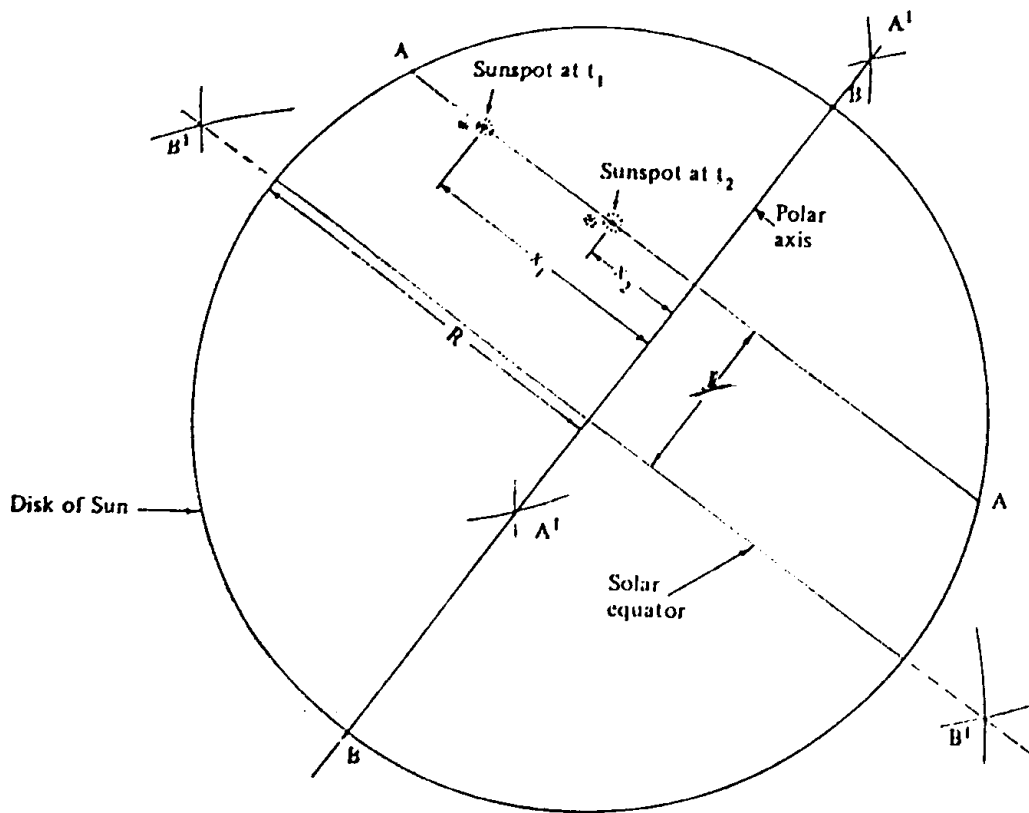


Figure 1: the sunspot diagram.

sheet of white paper, and mount the paper with the solar image inside your circle. Sketch whatever sunspots you can find onto the paper. Now unplug the heliostat drive and allow the solar image to drift across the paper. Sketch the direction of the drift in order to establish the east-west line. Note the time at which you made your sunspot sketches.

- 2b. For each of the next several days (or even today, if it's cloudy), obtain white-light images of the Sun from BBSO or any of the other solar observatories that offer on-line images. Print out a copy of each. In general your determination of the rotation period will be more accurate, the more data you have. You can work with the first and last images you acquire to determine the rotation rate; any images that you have in between will be useful in identification of which spots in the latest image correspond to which spots in the earliest image.
3. Choose a pair of observations of a sunspot (see Figure 1) and carefully rule a straight line through them (line AA in Figure 1).

For the next few steps, you will find a compass and a good metric ruler to be useful. Refer throughout to Figure 1.

4. Bisect AA. This is easily done with a compass. With the compass point at points A, and a constant leg spread, scribe arcs A' above and below AA. Connecting the intersection points of arcs A' leads to line BB, the perpendicular bisector of AA. Line BB is the projection of the sun's axis of rotation.

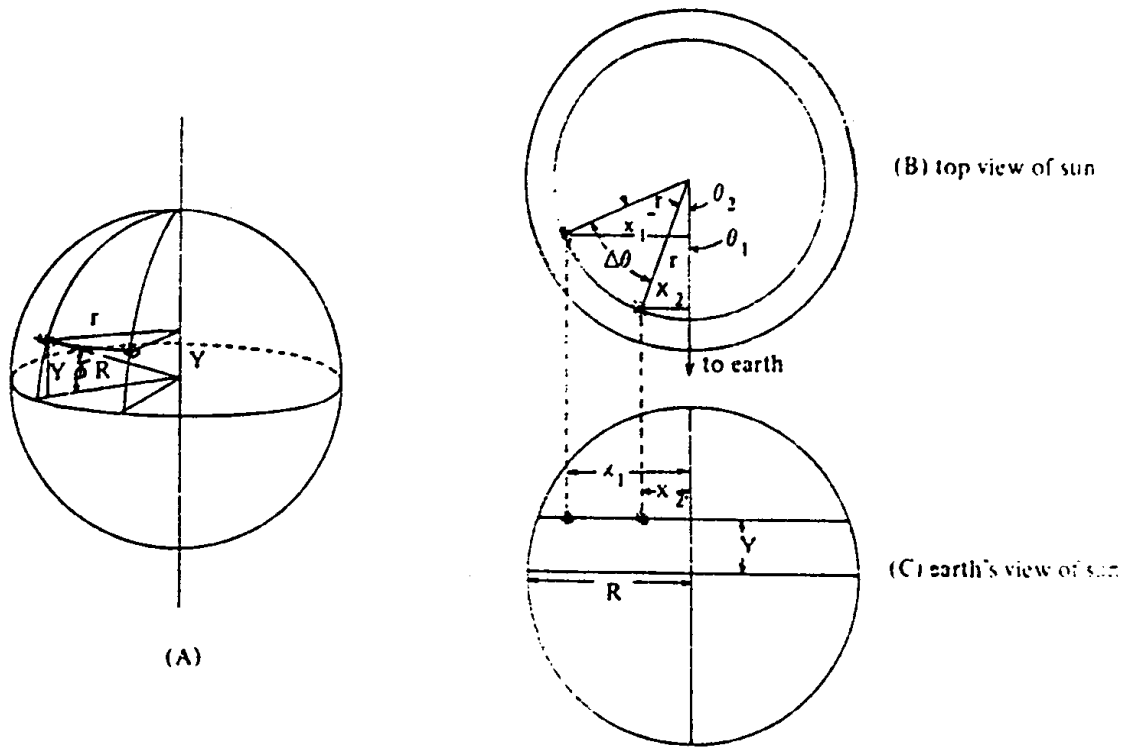


Figure 2: circumstances of solar observations.

5. Bisect line BB . This is done as in step 4. With the point of the compass at points B , scribe arcs B' . Connecting the intersections of the arcs leads to the perpendicular bisector of BB . This new line is the projected solar equator.
6. With your millimeter scale, measure the radius of the solar image (R), the distance from the equator to the two instances of a spot (Y), and the distance from the polar axis to each instance of the spot (X_1 and X_2). Measure X_1 and X_2 on an axis with an origin at the intersection of AA and the polar axis, so that their values are positive on one side of the polar axis, and negative on the other.
7. Determine the latitude of your sunspots:

$$\sin \varphi = \frac{Y}{R} ,$$

where φ is the latitude of the sunspot. That this is true can be seen easily in Figure 2A. The distance from each spot to the polar axis, along a radius perpendicular to this axis, is thus

$$r = \sqrt{R^2 - Y^2} ,$$

as can also be seen in Figure 2A.

8. Determine the angle θ between the rotational radius to each instance of the spot, and the line of sight to the polar axis (see Figure 2B), from

$$\sin \theta = \frac{X}{r} = \frac{X}{\sqrt{R^2 - Y^2}} .$$

Note that this angle will have the same algebraic sign as X .

9. Determine the change in angle $\Delta\theta$ of the sunspot during the time interval Δt between your observations,

$$\Delta\theta = |\theta_2 - \theta_1| ,$$

and thus obtain the synodic period of rotation S of the sun,

$$S = \frac{360^\circ}{\Delta\theta} \Delta t ,$$

and the sidereal period P (see step 1):

$$P = \frac{SP_\oplus}{S + P_\oplus} .$$

Express all of your periods and time intervals in days (1 day = 86400 sec). Note that your observation were probably not separated by an integer number of days!

10. Repeat the process (steps 6-9) for several more sunspots.
11. On the basis of all of your measurements, report your best estimate of the solar sidereal rotation period. Estimate the experimental uncertainty in your result, and discuss the origins of the uncertainty.
12. Compare your result to the period that an object would have in *orbit*, slightly above the Sun's surface. What does this tell you about the mechanical support of the Sun's surface against gravity.

