Solar Rotation
ASTR 101

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1 Objective

This report will demonstrate how observations of sunspots can be used to determine the rotational period of the Sun. It will explain how two dimensional pictures can be used to calculate three dimensional angles of rotation across the surface of the Sun.

2 Introduction

The Sun is the star located at the centre of our solar system which the Earth and all other planets orbit.

3 Equipment

The equipment used for this lab is as follows: a sheet of semi-transparent paper, a sheet of opaque paper, ruler, protractor and a drafting compass. Initial images of the Sun in the date range of 2012-Sept-27 to 2012-Oct-04 were provided by the instructor.

4 Procedure

Given photographs of the Sun taken at the same distance (the Sun appears to be the same size in all images), a sketch of each photograph was made on the sheet of semi-transparent paper. Each sketched was placed "on top" of the last, meaning that the same sheet of semi-transparent paper was used for

all 8 sketches and each sketch is simply done on top of the last. Each sketch represents a date in the range of 2012-Sept-27 to 2012-Oct-04. To ensure that the Sun's rotational angle was consistent across all 8 sketches, markings in four corners of the semi-transparent sheet were made to ensure proper alignment the it was moved from photograph to photograph. For each sketch, the only points of interest drawn were the outline of the Sun and an outline of each sunspot present in each photograph. Each sunspot was labelled with the data of the photograph. To see the time that the photograph was taken, see Table 1. These times will be used in future calculations.

Now that all major sunspots have been labelled on the semi-transparent paper, a single common sunspot was selected from each of the 8 sketches to ensure we are making the future calculations based on a single sunspots movements and not interchanging them. After this selection, a line is drawn from one edge of the Sun's outline to the other which best represents this particular sunspot's movement across the surface of the Sun. At this point, any sunspots that were not directly on the path of the newly drawn line, had perpendicular lines drawn from the newly formed line to the sunspot. This is to ease measurements to come.

Next, the sheet of opaque paper was taped onto the semi-transparent paper in a fashion such that an edge of the opaque paper follows the same path as the line drawn above. At this point, a measurement was taken of the line in question to determine its middle point in regards to the boundaries set by the Sun's outline. One the middle was determine, the drafting compass was set to this width and place at the middle location. From here a semi-circle was traced onto the opaque sheet of paper that began where the outline of the sun intersected with the horizontal line drawn above and continued around to the opposite side of the Sun's outline and intersection of the horizontal line. If this newly formed semi-circle was held at a 90° angle to the semi-transparent sheet of paper, the opaque sheet would represent the three dimensional space of the outline of the Sun.

With the opaque sheet of paper flat on the semi-transparent sheet, dotted lines were drawn from the 8 sunspot locations on the horizontal line to the perimeter of the newly traced semi-circle. These new locations are representative of the sunspots location in three dimensions. Now a solid line is drawn from the middle point of the horizontal line, determined earlier, to the new location of each sunspot along the perimeter of the new semi-circle. These lines represent the angle from the centre of the Sun to the sunspot.

Next, the angles between the lines for each sunspot to the centre of the Sun were determined. This was done by calculating each adjacent date's sunspot angle. This was accomplish using the protractor (i.e. The angle between 2012-Sept-27 and 2012-Sept-28 was measured). The results for these measurements can be seen in Table 2 column $\Delta \theta$ (degrees). Next, the times between photographs

were calculated from the given photographs. The date and time information from these photographs can be found in Table 1 The results for these calculations can be found in Table 2 column Δ T (days). Finally, the period change was calculated using the previous two figured obtained using the formula below. These calculations can be found in Table 2 column P (days).

5 Observations

All observations for this report were made on the day of 2012-Oct-15. All photographs of the Sun were made between the days of 2012-Sept-27 to 2012-Oct-04. As all calculations and measurements made inside of this report are based off of given data, weather conditions and time of time have not been reported as they hold no effect. For all observations and calculations made using both the semi-transparent sheet of paper and opaque sheet of paper, the drawn diagrams can be found as Figure 1 in the back of this lab report. These observations include sketches of all 8 Sun photographs, the horizontal path of sunspots, three dimensional projects of location and angle as well as the determined centre of the horizontal path of sunspot movements. Other rough calculations and simple tables can be found at the back of this lab report as well.

6 Tables and Measurements

Date	Time (days)
2012-Sept-27	27.11
2012-Sept-28	28.21
2012-Sept-29	29.21
2012-Sept-30	30.69
2012-Oct-01	1.10
2012-Oct-02	2.18
2012-Oct-03	3.74
2012-Oct-04	4.19

Table 1: Time of pre-existing measurements taken on their given days.

7 Calculations

To calculate the period of rotation, in days, for the Sun, Equation 1 was used to obtain the period from the change in time and the change in angle of the sunspot in between two adjacent photographs.

Date	Δ T (days)	$\Delta\ \theta$ (degrees)	P (days)
2012-Sept-27	-	-	-
2012-Sept-28	1.10	18°	22.0
2012-Sept-29	1.00	15°	24.0
2012-Sept-30	1.48	20.5°	26.0
2012-Oct-01	0.41	7°	21.1
2012-Oct-02	1.08	14°	27.8
2012-Oct-03	1.56	18.5°	30.4
2012-Oct-04	0.45	10°	16.2

Table 2: Measurements of sunspot movement over various time periods.

$$P = \frac{\Delta T * 360°}{\Delta\theta} \tag{1}$$

To calculate the uncertainty (U) of the measurements, Equation 2 was used by subtracting our second smallest period calculation from the second largest then dividing by two. The numbers used for this calculation can be found in Table 2 in column P (days). This calculation yields the result of 3.35 days.

$$U = \frac{27.8 - 21.1}{2} \tag{2}$$

To calculate the final result, which is the rotational period of the Sun, the previous periods calculated in Table 2 in column P (days), and summed and divided by total calculations as seen in Equation 3. This creates our final result (P_avg) as an average of all data calculated. This equation yields the result of 23.9 days.

$$P_{avg} = \frac{\sum P}{7} \tag{3}$$

To calculate the size of a sunspot (l_real), Equation 4 is used, where l is the measure size of a sunspot on our sketch, D is the measured size of the Sun of the sketch and D_real is the real size of the Sun. The assumed size of the sun is given inside of the lab manual as well as the size of the Earth for comparison. With the measured size of a sunspot being 3.5mm and the measured size of the Sun being 141mm, the result yields 34,565.6 km.

$$l_{real} = \frac{l * D_{real}}{D} \tag{4}$$

8   Questions

The following questions and answered are asked inside of lab 11, Solar Rotation, inside of the lab manual for ASTR101. The questions have been repeated for the reader.

Q. The accepted value of the observed rotation period of the sun is 27 days at the equator and 28 days at 30 degrees latitude. Compare your determination of the period with these values, giving your best estimate of the uncertainty in your determination.

A. As seen with Equations 32, the period of the Sun's rotation was found to be 23.9 days with an uncertainty of 3.35 days. Our estimate falls short of the generally accepted value of 27 days, however, if maximum positive uncertainty is applied, a result of 27.25 days is found and can be accepted. The large uncertainty here can be largely attributed to the inaccuracy of the hand drawn sketches.

Q. What are we assuming about sunspots, which is fundamental to determining the rotation of the Sun by this method? How might you investigate the validity of this assumption?

A. This report makes large use of the assumption that the sunspots observed are actually located on the surface of the Sun as opposed to being between our line of sight and the Sun's surface which was previously though by the likes of Aristotle [1]. This theory can be easily tested with the notion of parallax. If the sunspot was not on the surface be rather in front of the Sun, parallax should be detectable when viewed from different positions on the Earth or as the Earth orbits the Sun. Without the observation of parallax it should be determined that the sunspots are indeed on the surface of the Sun.

Q. In a paragraph describe how the sunspots change in size, shape and number over the few days of observation.

A. An easy conclusion to draw for the number of sunspots visible is that as the Sun rotates, sunspots approach the "horizon", edge of the Sun's outline", then disappear to the far side of the Sun. This causes the number of sunspots to change over time. This is also the root cause of the sunspots apparent change in shape and size. As the Sun rotates, the sunspots are viewed from different angles on Earth. Near the horizon they may appear as a thin tall line, but while viewed at the centre of the Sun, they may appear as a large circular blob. This explanation gives the sunspots their apparent transitions in size and shape.

Q. Assuming the diameter of the Sun is 1,392,500 km, how big is a sunspot? Compare it to the diameter of the Earth (12,765 km).

A. As seen with Equation 4, the size of a sunspot is 34,565.6 km. In comparison to the Earth which is 12,765 km, the sunspot is roughly 2.7 times larger than the Earth.

9   Conclusions / Discussions

This reports has shown how to calculate the period of the Sun's rotation using observed sunspots and their apparent motion over time. This report has also shown how two dimensional observations can be transformed to take three dimensional calculations.

10   Evaluation

I found this report to have interesting properties for my own celestial observations. I have recently started to observe planets with my Celestron Super C8 Plus telescope and have noticed slight variations in how the planet appears over time (especially with Mars). With the knowledge learned from this lab I will be able to carry out similar experiments in my own time with land features of planets in order to determine their own rotational periods. I would have liked to learn more about the internal structure of the Sun and possibly the causes of the nuclear furnace which heats us every day, or perhaps learn more about the sunspots themselves as opposed to just viewing them as a type of black box.

References

[1] Letter to the Editor: Sunspot observations by Theophrastus revisited