Student's guide

CESAR Science Case – Rotation period of the Sun and the sunspot activity

Name ______________________________ *Date* ______________________________

Introduction

As you may know, the Sun is a luminous globe among many, consisting of hot gas that provides our planet with heat and in consequence, the presence of life. This allows the planet to be a habitable celestial body. We also get days and nights thanks to the light that it is emitting. Without our Sun the Earth would be a cold and lifeless place.

The first observation of the Sun was made by Galileo Galilei. In many years, astronomers in his lifetime believed that the Sun was a perfect, flawless body. But Galileo changed that picture by saying that it has spots on its surface. He actually observed the Sun, not knowing that it was harmful for his eyes. That is why he became blind and that is why you should not look directly at the Sun, especially with a telescope. **Remember to always use a filter, or project it on a screen, when you look at the Sun.**

After his observations, many scientists have studied the Sun and learned more about it. Now, we know how big the sunspots are, the approximate date of the birth of the Sun or its structure from the core to the outer regions.

The sunspots are very useful to determine some properties of the Sun, and they are really big when you calculate the size of one of them and compare it with the size of Earth. The easiest way to know the rotation period is measuring the sunspots movement but also the sunspots tell us about how close is the Sun´s activity to a maximum or a minimum in the solar cycle.

The task of this laboratory is to use ESA images taken with the CESAR Solar Telescope to analyse the sunspots on the surface determining these properties.

Theoretical background

As mentioned, Galileo was the first person taking the study of our Sun in real consideration. He observed that although a spot took around two weeks to travel from one side of the Sun to the other one, its motion continually seemed much slower when it was close to the edge than when near the Suns center.

The effect that Galileo noticed is called foreshortening. Basically, a spot coming around the limb is actually traveling towards the observer. Since our eyes cannot see the 3-D effect that is happening, the spot seems to move slower across the disk. However, when it is in about 1/3 of the Sun, all the motion of it is crossways the disk. That is why it look as if is moving faster. Foreshortening would only outcome if the spot were on (or very close) the Sun's surface. A planet too would not give the impression to change its speed when moving across the disk of the Sun while orbiting.

How would this be described geometrically? Well, figure 1 below is basically how Galileo though when he faced this phenomena.

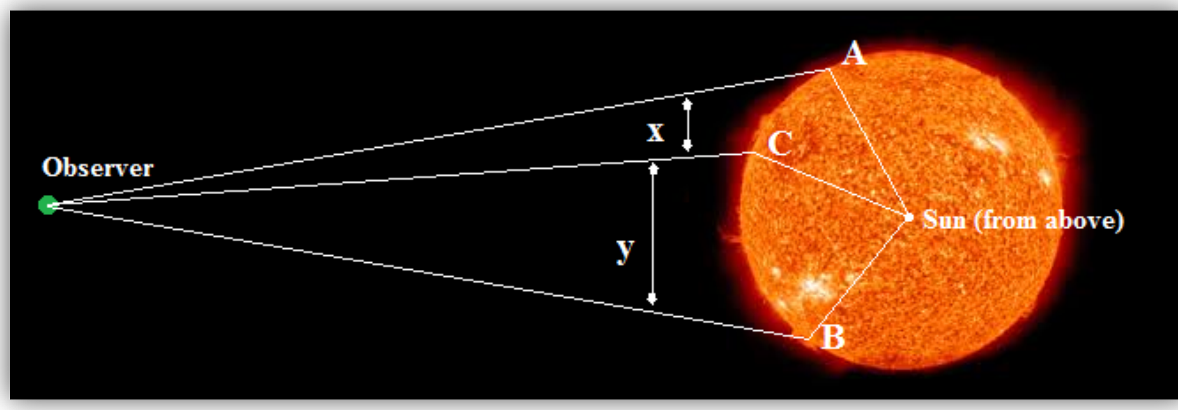

Figure 1: *The points A, B and C are different points on the surface of the Sun. X is the apparent short distance and Y is the apparent long distance. The figure is not in scale.* ***Credit****: CESAR*

The three points have equal distances apart from the Sun's surface. Assuming that the Sun is rotating at a constant speed, the letters are representing the positions of a sunspot at time intervals that are equal. From the observer's perspective, the spot moving from A to C only travels a short way; therefore it appears to move in a slower pace. On the other hand, the spot moving from C to B covers a great area, hence appears to move fast. This is also valid for a planet moving across the Sun.

About the sunspots, it is mentioned in the Booklet that sunspots appear in the **photosphere**, a layer of the Sun that could be considered as the "surface" of the Sun. Sunspots are disturbed by powerful magnetic activity, which prevents convection, thus decreasing its surface temperature in that area. These areas have a magnetic field that is about 2,000 times more powerful than the one Earth has, and much higher than anywhere else on the Sun.

Because of the strong magnetic field, the temperature decrease compared to the sunspot surroundings since the concentrated magnetic field stops the flow of new, hot gas from the Sun's internal to the surface. Even if the sunspots are still extremely hot and bright, they look darker since they have a cooler temperature than their surroundings. With cooler we mean a typical temperature around 3500 degrees Kelvin compared to the surrounding 6000 degrees Kelvin.

The Sun is not a static object; it has a very dynamic surface where the number of sunspots can range between 0-10 sunspots to 150 or even more. It has an 11-years cycle based on its activity that has been repeating since the first sunspot data were registered. While the Sun is on a maximum the number of sunspots and mass ejections increase. The reason for this cycle is not well known for now.

Material

1. CESAR Astronomical word list
2. CESAR Booklet
3. CESAR Formula sheet
4. CESAR Student's guide
5. CESAR images of the Sun
6. Matlab, Octave (optional)
7. The software for this Science Case
8. Paper, pencil, ruler, calculator, protractor

Laboratory description and purpose

In this laboratory you are going to observe and take images of the Sun with the CESAR Solar Telescope which is installed at ESAC, in Villafranca del Castillo (Spain). The purpose of this lab is to study the Sun and learn more about its characteristics, especially the sunspots.

Firstly you are going to track the spots during a time interval. It is only possible to track the spots by taking images of the Sun. It depends on your group that you may have used the CESAR Solar Telescope remotely for that or you have downloaded a preselected set of images to work with.

The target to you is to understand some patterns of the sunspots and do measurements to get its coordinates and the change in longitude of them. For the last thing you are going to use some programs and lastly you are going to plot a grid of the Sun with the degrees on it to easily determine the coordinates of any sunspot.

With the collected coordinates you are going to calculate the Sun's rotation period. For this it's necessary to understand the difference between the synodic rotation period and the sidereal rotation period.

Lastly, you will try to see if you can predict sunspot activities, in other words try to foresee what will happen in the next 11 years and what the actual status of the Sun is. For all of this you are going to look at old and new data that has to be plotted and get a good idea of the graph. Moreover you are going to determine the actual status of the Sun by calculating the Wolf number and using the correlation between the latitude of the sunspots and the solar activity.

In the end, you will need to answer some question just to see if you have grasped the whole concept of sunspot studies as they are very important for the correlation with the solar mass ejection.

Laboratory execution

Start by reading the Booklet to understand the theory. By doing this, the laboratory will become much more easier to execute since you will have less questions and more understanding.

If your group has access to the Solar Telescope it is supposed that you have already choose a date for the beginning of the observation, and decided in how many days it will conclude. In the end, a start date and a finish date should be picked. An observation period of 3-7 days is a good example. It may seem to be many days but you will get a better visualization of the movement of the sunspots.

Once the CESAR team has provided you the images of the Sun, it is time to start the measurements. You will need to write down the day and time the pictures you are using were taken and write down the position of the sunspots that appear on it. Follow your teacher instructions to calculate the heliographic coordinates of any sunspot.

Now you should have a table with the coordinates in degrees of the sunspots that you choose to measure. Two of three measurements is a good number. Try to measure sunspots of different regions in the Sun's surface.

As you have notice, the process is a bit complicated. There is a short way to determine the coordinates of any of the sunspots. It is based on superposing a grid of coordinates to your images of the Sun. For this, you have to rotate your given images the position angle of the solar rotation axis measured from the N-S direction (P). Using this method try to estimate the coordinates of other sunspots that you didn't measured and compare the values of your measurements with the grid.

You can also print out the images and use a transparent image of the template. Put the transparent sheet over the image and plot it.

Now you have the coordinates of some sunspots you have to measure the same sunspots in another image. That is the idea of a tracking, to see how the position of a sunspot changes while the time pass. You could choose to measure the same sunspots in any of the other images provided.

To determine the rotation period of the Sun, you have to right down the longitude values for each sunspot for each time. You have to calculate the variance of time that a sunspot takes to move one degree ($^{\Delta t}/_{\Delta L}$) and then using the formulas in the Formula Sheet calculate the sidereal rotation period of the Sun that should be close to 27d 6h 36'.

The next task for you is to calculate the size of any sunspot and compare it. How much bigger is the sunspot compared with the size of Earth? You can use the previous images to calculate this by a cross multiply but first you have to measure the size of the sunspot and the diameter of the Sun in pixels.

For the proportion that you have to do, take this values of the real diameter of the Earth and the Sun:

Average diameter of the Sun: 1.391.000 km
Diameter of Earth: 12.742 km

As always, the units should be the same. That is, if you want to use mm in the calculation instead of pixels, make sure that the Sun's diameter has the matching unit and vice versa.

Let us start with the last exercise which is about getting some information about the 11-years solar cycle and determine if we are close or far from a solar maximum. If we want to know where we are in that cycle, the easiest way to get a respond is to plot all data of solar activity registered up to now. For this you could access to: *http://solarscience.msfc.nasa.gov/greenwch/spot_num.txt*. This website is constantly updated with the newest observations of the Sun. The table below is the chosen data. Every record consists of the year, the month and monthly average sunspot number (SSN) which has been calculated for each year. The chosen data range from 1052 to 2011, which is 60 years of data. More years equals to more data and a better plot. When you plot the numbers, use a software (for example Matlab). Excel is also a good tool to get a scatter plot. Ask your teacher for which one to use, if these are not available.

Year	SSN		Year	SSN		Year	SSN		Year	SSN
1952	31.5		**1967**	93.8		**1982**	115.9		**1997**	21.5
1953	13.9		**1968**	105.9		**1983**	66.6		**1998**	64.3
1954	4.4		**1969**	105.5		**1984**	45.9		**1999**	93.3
1955	38.0		**1970**	104.5		**1985**	17.9		**2000**	119.0
1956	141.7		**1971**	66.6		**1986**	13.4		**2001**	110.9
1957	190.2		**1972**	68.9		**1987**	29.4		**2002**	104.0
1958	184.8		**1973**	38.0		**1988**	100.2		**2003**	63.7
1959	159.0		**1974**	34.5		**1989**	157.6		**2004**	40.4
1960	112.3		**1975**	15.5		**1990**	142.2		**2005**	29.8
1961	53.9		**1976**	12.6		**1991**	145.8		**2006**	15.2
1962	37.6		**1977**	27.5		**1992**	94.5		**2007**	7.5
1963	27.9		**1978**	92.5		**1993**	54.7		**2008**	2.9
1964	10.2		**1979**	155.4		**1994**	29.9		**2009**	3.1
1965	15.1		**1980**	154.6		**1995**	17.9		**2010**	16.5
1966	47.0		**1981**	140.4		**1996**	8.6		**2011**	55.6

By plotting these values (by hand or by a software), predict on the graph (if you do it by hand, draw a dotted line) what will happen in the next few years. When you plot the points you will notice that there are very clear maximums (peaks) and minimums (valleys).

Hopefully there is a method to estimate our current position in the 11-years solar cycle. It basically use the mean sunspot's latitudes. As it is explained in the Booklet, the sunspots moves from 35 to 5 degrees along the cycle. You have to use proportions to estimate where we are.

One more method is based on the number of sunspots. The more number of sunspots, the more solar activity and the closer to a maximum we are. The sunspot activity is measured with the Wolf number. So you have to calculate it and estimate if we are close to the maximum or minimum. The Wolf range of values is between 0-10 for minimum activity and 140-170 for the maximum.