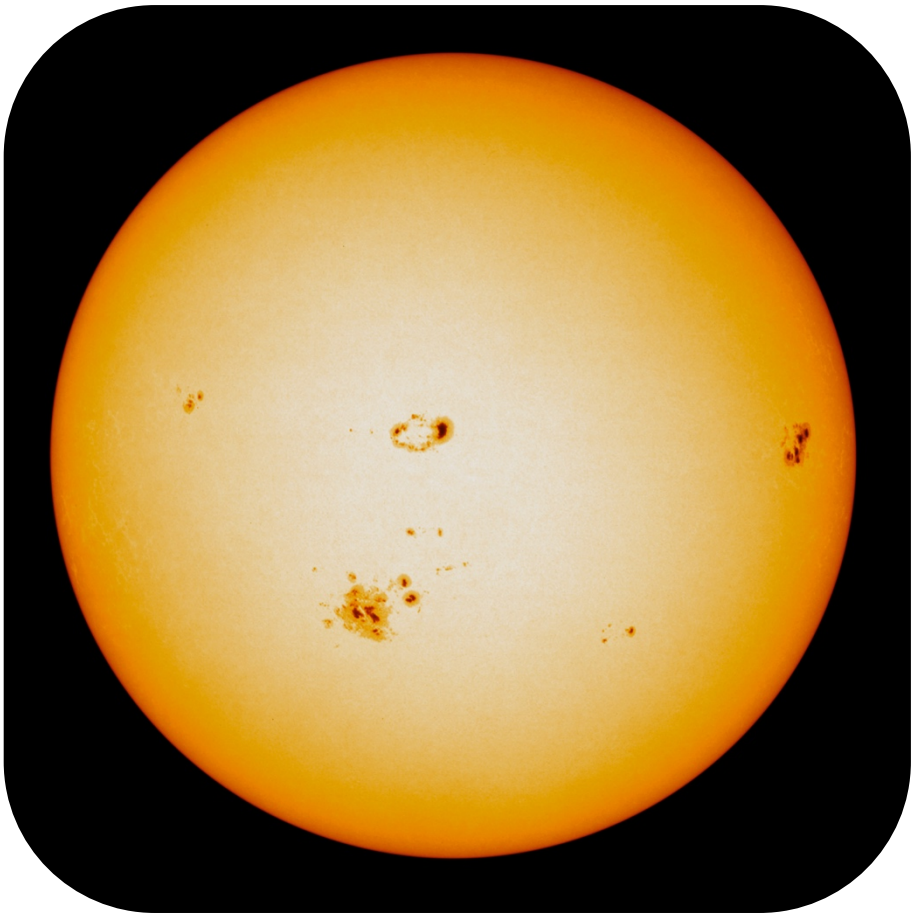
Sun’s differential rotation

Student’s Guide – Advanced Level

CESAR’s Science Case



Introduction

Unlike the Earth, the Sun is not a rigid body. As it's a non rigid body, different parts of the Sun may rotate at different speeds, and they actually do so.

In this laboratory you will study the differential rotation of the Sun by measuring the rotating speed of multiple sunspots. As the CESAR team at ESAC has a solar observatory constantly monitoring the Sun, there's no need to request observation time in the observatory, you can just use the database, and download the images that seem good to do the measurements successfully.

In this guide, all the equations are written down when needed and the sun-related essential background is provided. However, before further reading, you may want to take a look at "Sun" chapter from the CESAR's booklet, for more information about the topics treated in this laboratory.

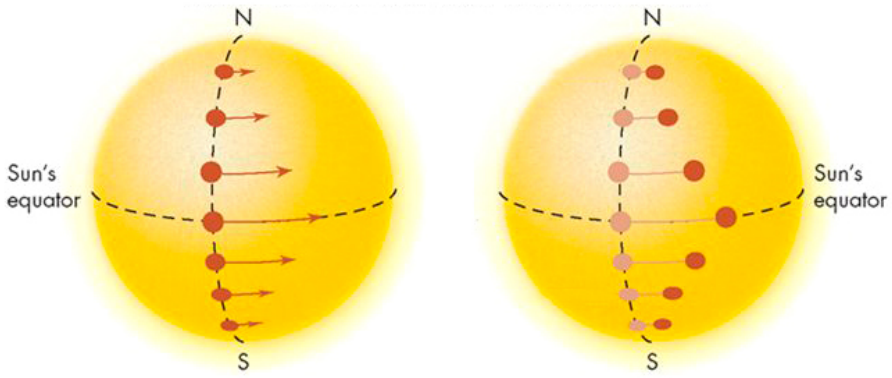
Material

What will you need?

- The Sun's differential rotation Student's Guide.
- CESAR's Booklet.
- Computer with Web Browser and Internet Connection.
- Access to CESAR web tools or an image processing program such as Gimp or Photoshop.
- Access to CESAR web tools or a data and graph program such as SciDavis or Origin.
- Computer with a spreadsheet program such as Excel or Numbers. Or access to GoogleDocs.
- Calculator (physical or online) for the math
- Paper and pen.

Background

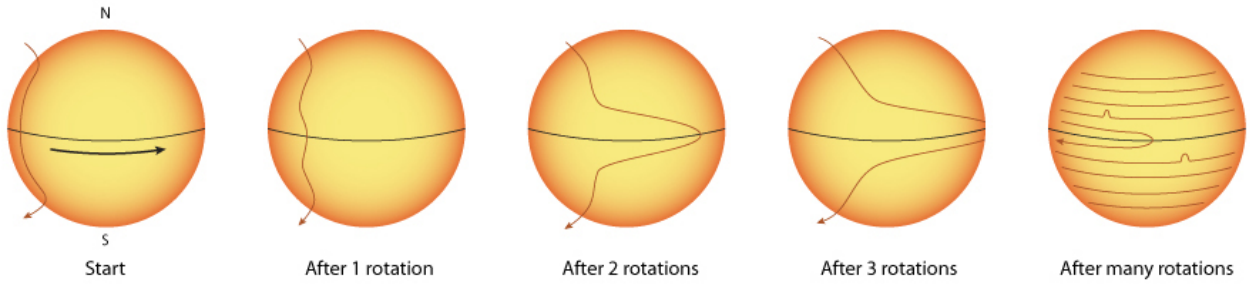
Unlike the Earth, the Sun is not a rigid body. This means that when studding the movement of the Sun, you can not consider it as a compact structure. The sun is actually a massive sphere of plasma, more similar to a huge ball of gas than to a rigid solid.



Credits: McGraw-Hill

Unlike in Earth, not every point of the Sun's surface rotates at the same speed. In the Earth every point in the surface rotates 360º each day, in the Earth a day last 24h in everyplace, because the whole Earth moves together. But as the Sun is not a rigid body, and no strong forces attach the plasma to the plasma near by, different places of the surface may rotate at different speeds. Nothing forces the Sun surface to move has a whole.

In fact, after many observations, it has been stated that sun poles rotate slower than the equator. Actually, in the Sun, the bigger the latitude is, the slower the surface rotates.



Credits: NASA / IBEX

Laboratory Execution

We are calculating the rotation speed of the Sun by measuring the speed of sunspots. Our point is to study the differential rotation of the Sun, that is, to measure the speed at different latitudes (as we expect the speed to change with latitude). So once we locate a sunspot, the first thing to do it's calculate its latitude. Then we'll calculate its speed and write it down in a data table.

Step 1 - Coordinates of a sunspot

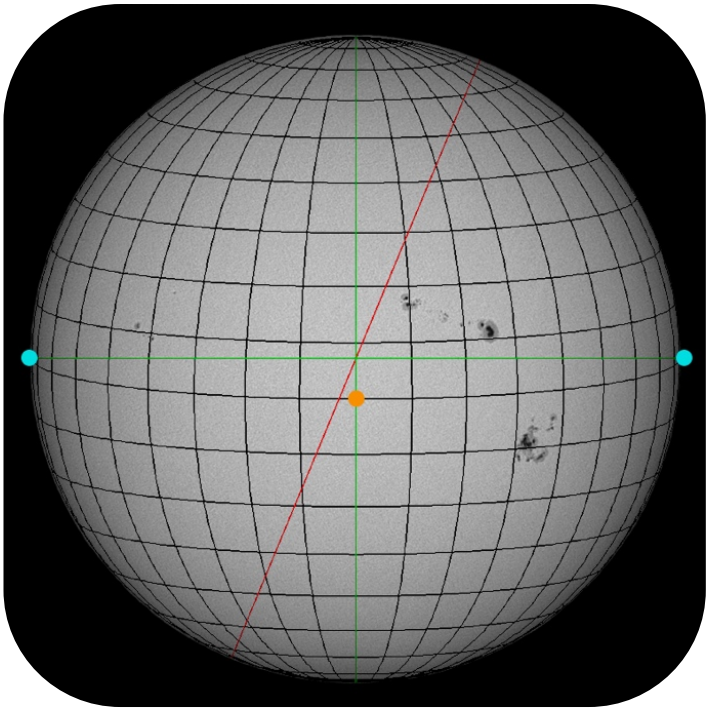
To obtain the latitude of a sunspot, you will select an image from the Sun (better if it has big sunspots close to the image's centre) and align it to a grid; then merge them together. This process may be done with CESAR's web tool or with an image processing program such as Gimp or Photoshop. The result should look similar to the image below. Note that the sun is not always at the same position, so **it is crucial that the pictures and the grid information have the same date and hour**.

If you are not using CESAR's web tool, you can download the grids from here:

bass2000.obspm.fr/ephem.php

, and sun images from here:

cesar.esa.int/sun_monitor/archive/helios/visible/



Credits: CESAR ESAC & BASS2000 LEISA

The equator's parallel is the one that, at the left and right edges of the previous image, touches the green horizontal line (at the turquoise spots). The prime meridian, is the green vertical line. This means that the 0º, 0º point is located at the orange-marked dot. (If you are not familiar with coordinates, take a look at the introduction of the CESAR Booklet's chapter "Earth Coordinates" for further information.) In the grid, each square is 10º X 10º, knowing this, you can easily determine the coordinates of a sunspot. In this example, there are big sunspots at 12º, 25º and at -9º, 32º. There are also smaller ones at 13º, 24º; 17º, 10º; 18º, 9º; -5º, 37º; -12º 35º; and many more. Now locate the sunspots in your own image and write down their coordinates.

Step 2 - Collecting data.

To measure the speed of a sunspot, we are looking at sun images from different days. Measuring how much the sunspot moved from its position in the first picture to where it appears in the second one, and dividing it by the time that passed between the pictures, will give us the average speed.

$$speed = {}^{distance}/_{time}$$

To do so, repeat step one for an other image taken a few days before or after the previous one (remember to use a new grid each time). Look at the same sunspot and write down the longitude at which its located now, you'll notice the spot has moved. Repeat the process and write down the longitude for a few different sunspots in a few different days, remember to always write day exact date and time of the image when you measure the coordinates of a sunspot. You should be able to fill in a data table like this one, where for each sunspot you must first determine its latitude and then its longitude in different days:

		Latitude	Longitude		
		Same for all days	Day 1	Day 2	Day 3
Sunspot 1	Date / Time	-			
	Degrees				
Sunspot 2	Date / Time	-			
	Degrees				
Sunspot 3	Date / Time	-			
	Degrees				

If you can only locate one sunspot in your image, then fill only the "Sunspot 1" part of the table. And then look for an other image to fill "Sunspot 2" and "Sunspot 3". It doesn't matter if each sunspot is from a different picture, actually, you are encouraged to look at a lot of pictures, so you can find sunspots that are located at different latitudes, that way your experiment will have more information.

However, once you choose a sunspot you must look at least at three images from that same sunspot taken at different days, before you look for a different one.

You are free to use the table above. But you may want to make one of your own to include more days and more sunspots, to make your experiment more precise. Since you are starting a new table, consider doing it in a spreadsheet program such as Numbers or Excel, that will considerably ease the calculus task that will come next.

Step 3 - Calculating speeds

Now that we have the data, lets calculate the speed of each sunspot. The formula it's easy:

$$speed = {}^{distance}/_{time}$$

The distance, measured in degrees, is just the difference in longitude between two days. So, for example, we may take the sunspot 1's longitude from day 2 in degrees minus the sunspot 1's longitude from day 1 in degrees.

Then we need the time interval, that is just the difference in time between the two dates of the images. So, for example, we may take the sunspot 1's date / time from day 2 in hours minus the sunspot 1's date / time from day 1 in hours.

Note that the time is to be expressed in hours, to express the date / time difference in hours you can use this formula

$$days\ difference\ \cdot 24h + hours\ difference + \frac{minutes\ difference}{60} + \frac{seconds\ difference}{60\ \cdot 60}$$

Once you have the time difference in hours and the distance in degrees use the speed formula and you will obtain the speed of that sunspot in degrees/day.

We already have the rotation speed of the sunspot. But you may have noticed that we've only used day one and two data. You may repeat this procedure for days two and three. If you do so, you will have two speed values for the same spot, or even more if you took data for more than three days. This is often done in science to increase accuracy. Once you've got all the speed values for one sunspot, you must obtain the average. The result is a more accurate value for the speed of that sunspot.

Still, we've only used data from one sunspot, once you have an accurate value for sunspot 1's speed, you may repeat the whole procedure for all the sunspots you located.

As it was said before, the task of calculating the speeds is much easier if you had the table in a spreadsheet and you only have to write the operations once.

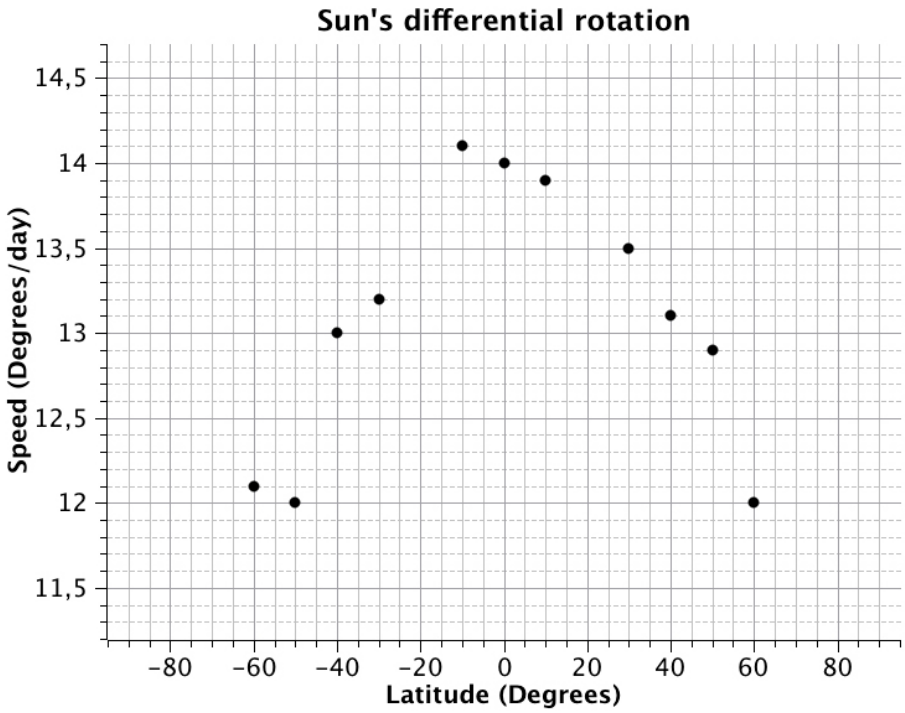
Step 4 - Presenting the results

By now, you should already have accurate values of the rotating speed for several sunspots. But the speed of sunspots one, two and three means nothing to other astrophysics. To present a study of the differential rotation, you must present the speed value in terms of the latitude. For example, you may fill the following table. Make sure to order the sunspots from the lowest to the highest latitude.

Latitude (Degrees)	Speed (Degrees/Day)

Now, the values have a scientific meaning. Still, you should never present a data table alone, because it gives no information unless you are using the data somehow. The data must always be accompanied by a visual representation. For doing so, move this table to a data and graph program such as SciDavis or Origin. (If you are not familiar with this programs, take a look at the CESAR Booklet's chapter "SciDavis" for further information.)

Once you have the data in the program, plot the speed as a function of latitude. It should look like this:



This is the correct way of representing results in science. If you have taken enough measures,

And that's it, you've calculated the sun rotation speed at different latitudes!

Conclusions

In this laboratory you have studied Sun's differential rotation. You've calculated Sun's rotation speed at different latitudes. For doing so you tracked the movement of different sunspots at different latitudes and calculated their speed by examining time-separated pictures.

When doing science, it's always a good idea to check your results before publishing them. As you know from the images in the background section, the sun's rotation speed is higher in the equator (at low latitudes) than closer to the poles (higher latitudes). Does this agree with your calculations? Have you obtained lower velocities for higher latitudes?

If you do have obtain a consistent value, try to use it somehow, for example: Examine your data and roughly predict how fast a sunspot at 15º would rotate.