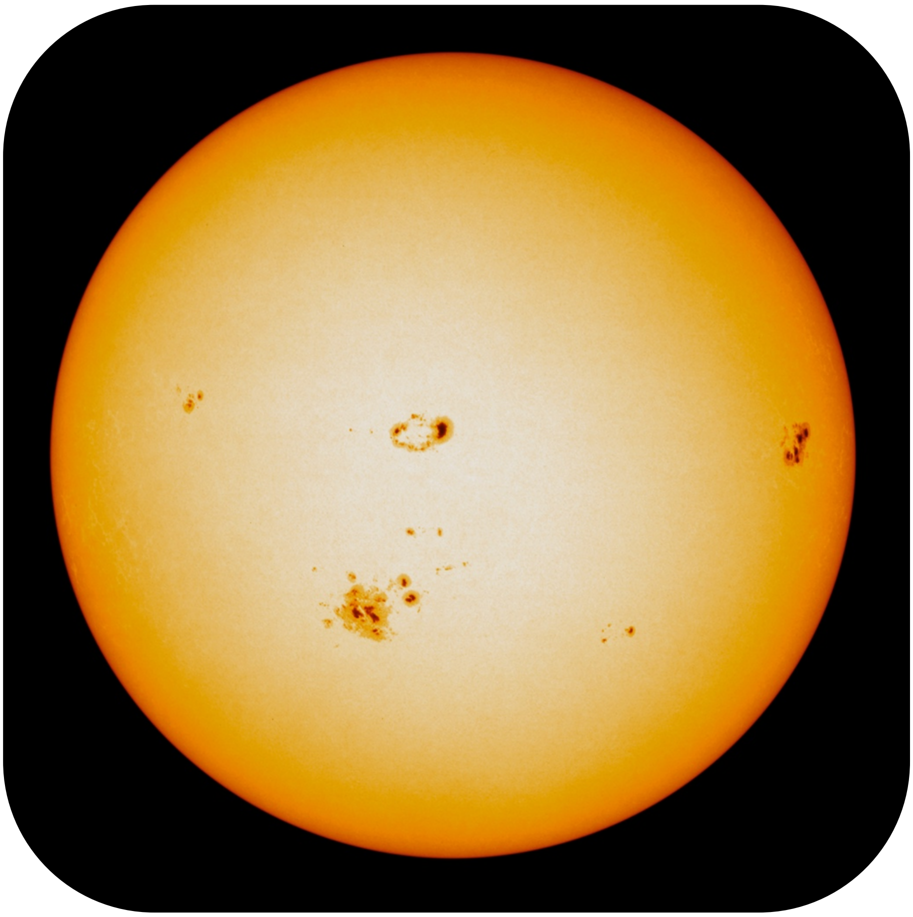
Sun's differential rotation

Student's Guide – Intermediate 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 (CESO) constantly monitoring the Sun, there's no need to request observation time in the observatory, you can just use the on-line 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

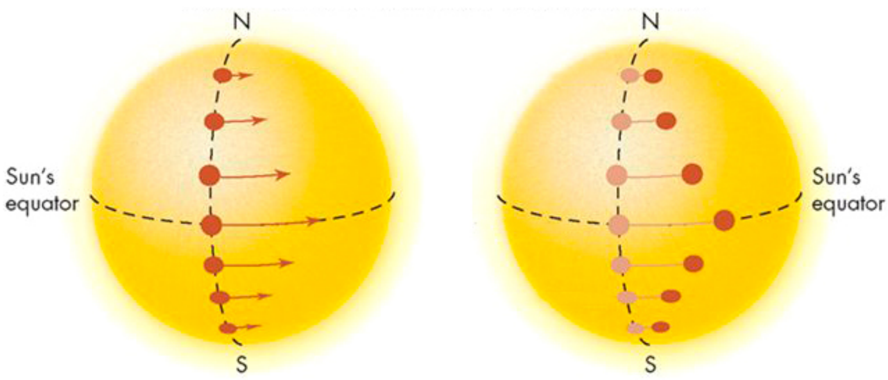
What will you need?

- The Sun's differential rotation Student's Guide.
- CESAR's Booklet.
- Comp
- uter with Web Browser and Internet Connection.
- Access to CESAR web tools.
- Calculator (physical or online such as wolframalpha.com) and paper and pen.
    - Or a spreadsheet program such as Excel or Numbers, or access to GoogleDocs.

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 solid rigid structure.

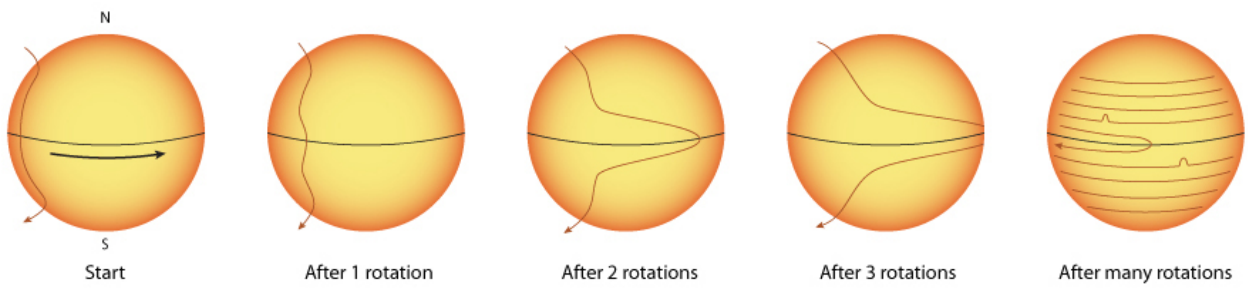
This is no different to soil and water. Soil is a solid structure, but water is not. You may have water moving at different speeds than the water near by, like a sea current. That's because water is not a rigid body, water is not attached to anything and it's free to move anywhere. Same thing happens with the plasma in the sun.



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, but more like water, **nothing forces the Sun surface to move has a whole. The plasma located in different places of the surface may rotate at different speeds, that is what we call differential rotation.**

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**. And that is what we are checking with this laboratory.



Credits: NASA / IBEX

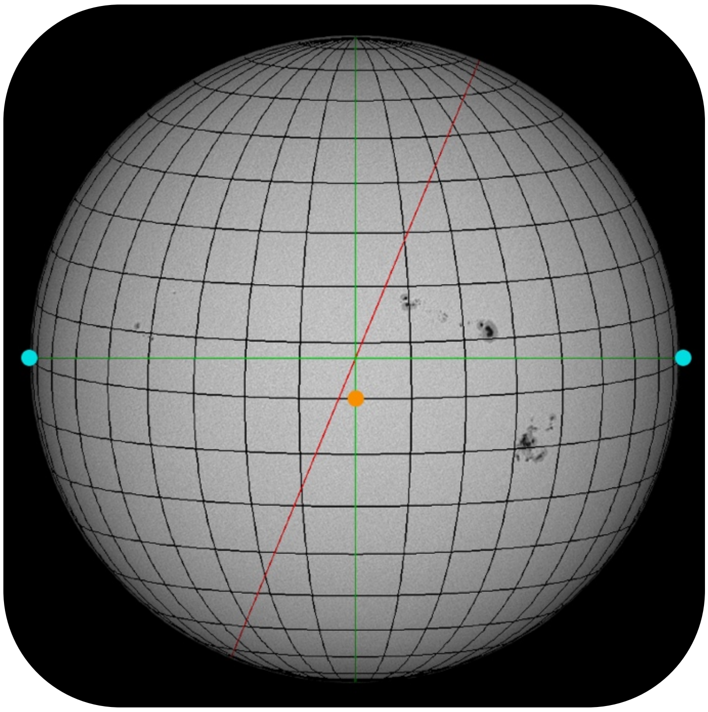
Laboratory Execution

We are calculating the rotation speed of the Sun by measuring the speed of sunspots in Sun's surface. Our point is to study the differential rotation of the Sun, so we'll have to locate one sunspot close to the equator and an other one as far away as possible. Once we locate them, we'll calculate their speeds (which is also the rotation speed of the Sun) and check if they really are different.

In the CESAR web tool, the equator line is the horizontal one marked in a different colour. You must use the displayed calendar to look through different days until you find a picture that has a sunspot at the equator. Once you got it, go through the steps to measure its speed. Then you will have to find a second sunspot, further away from the equator. Use the calendar again, go through a few months, choose a sunspot as far away as possible and go through the steps again.

Step 1 - Coordinates of a sunspot

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**. To obtain the latitude of a sunspot, you will align your image to a grid with Sun's parallels and meridians and then merge them together. This process is automatically done by CESAR's web tool.



Credits: CESAR ESAC & BASS2000 LEISA

If you are not familiar with coordinates, take a look at the introduction of the CESAR Booklet's chapter "Earth Coordinates" for further information, as Earth and Sun coordinates are basically the same. The equator and the prime meridian are the lines marked in a different colour, 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 sunspot in your own image and write down its 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.

To do so, repeat step one for an other image taken a few days before or after the previous one. Look at the same sunspot and write down the longitude at which its located now (latitude will not change), you'll notice the spot has moved. Remember to always write the exact date and time of the image when you measure the coordinates of a sunspot.

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. Then we need the time interval, that is just the difference in time between the two dates of the images expressed in days. To express the date / time difference in days you can use this formula

$$days\ difference + \frac{hours\ difference}{24\ h/day} + \frac{minutes\ difference}{24\ h/day\ \cdot 60\ min/h}$$

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

And that's it, you've calculated the sun's rotation speed at this latitude!

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, lets go one step further: The following graph shows a theoretically predicted value for the Sun's rotation speed as function of the latitude. Try to understand the graph. Then, represent the values you have obtained. How good do they match the curve? If your points don't precisely match the curve, discuss whether the points or the curve are misplaced and why. Looking at your data, would you be confident to aver that the prediction is correct or incorrect? Why?