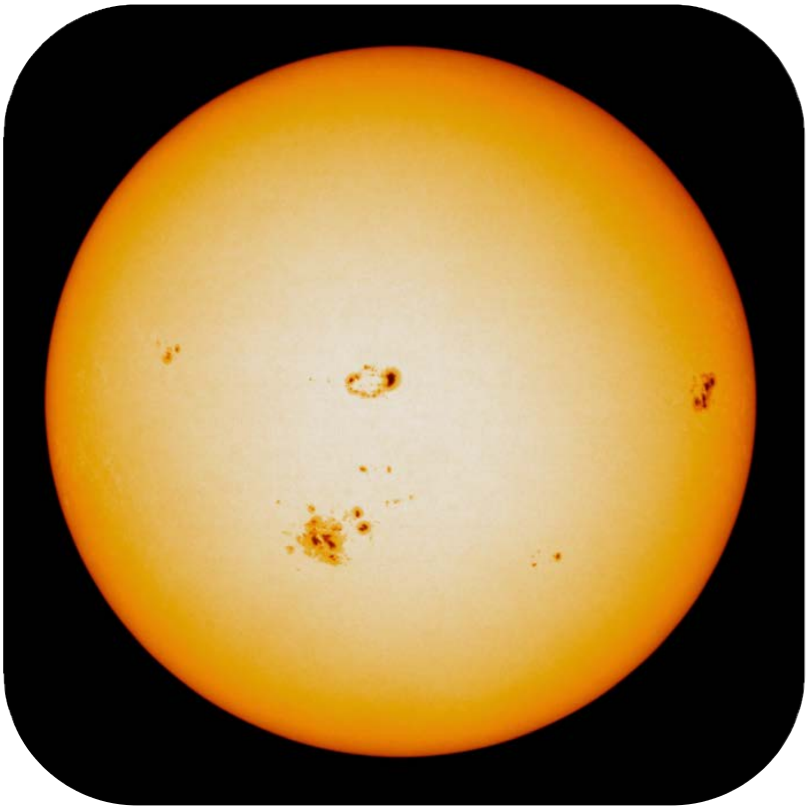
CESAR Science Case

Tracking sunspots

Using sunspots to calculate the rotation of the Sun

Student Guide



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Background

The Sun, our closest star, is a ball of hot gas or "*plasma*" that is mostly made out of hydrogen and helium. The temperature at the surface of the Sun is about 5500ºC (5800 K). Just like the Earth, the Sun rotates. However, unlike the Earth, the Sun is not a solid body, this means that the gas that forms its surface does not move as one piece, and therefore does not move at the same speed. This phenomenon, called ***differential rotation***, can be observed simply by tracking the movement of sunspots on the Sun surface over several days.

WARNING –Never look at the Sun directly as it can cause serious damage to your eyes.

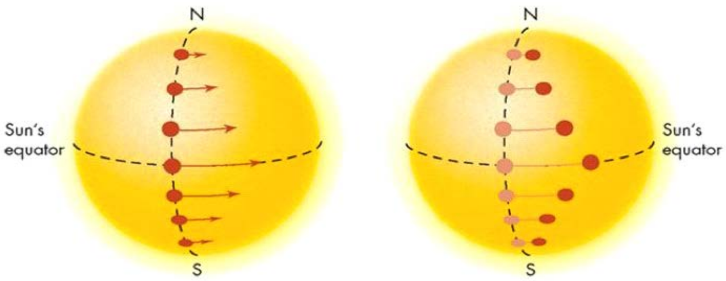


Figure 1: The gas at the surface of the Sun does not move at the same speed as the Sun rotates. Credit: McGraw-Hill

Sunspots are seen as dark patches on the surface of the Sun. They appear darker than the rest of the Sun's surface (known as the photosphere) because they are about 1000 K cooler. Sunspots can vary in size, from those that are comparable to the size of the Earth, to the largest that are about the size of Jupiter (Figure 2). Looking closer at one of them you can differentiate the umbra and the penumbra region (Figure 2).

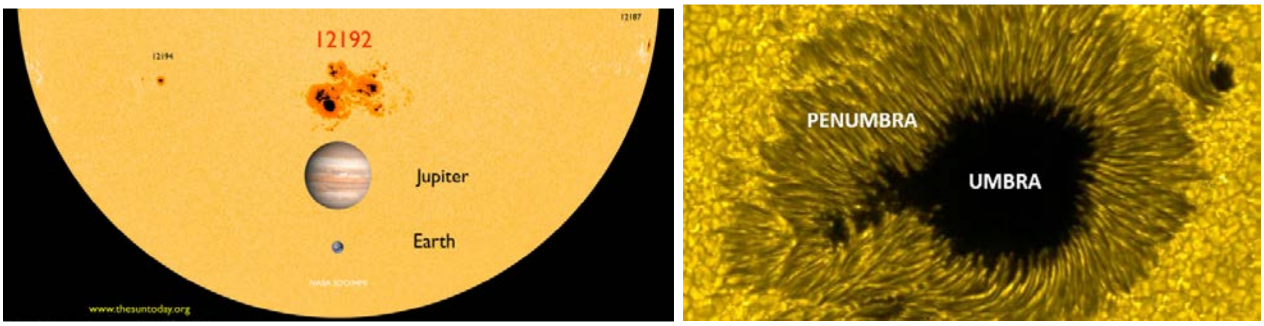


Figure 2: Sunspot size comparison (left). Sunspot components (right).
Credit: Dra. Anik De Groof presentation, Dr. Benjamin Montesinos)

The Earth has a magnetic field that resembles a bar magnet (Figure 3). Just like the Earth, the Sun has a magnetic field, and sunspots occur because of the effect the Sun's differential rotation has on it.

Figure 3: Similarity between the Earth's magnetic field (left) and a bar magnet (right).
Credit: NASA, Dra. Anik De Groof presentation from ESA/SOLO Team.

Over time, as the Sun rotates, its differential rotation causes the magnetic field lines become twisted and tangled, as shown in Figure 4. These tangles in the field lines can produce localised magnetic fields that poke up through the surface of the Sun forming a sunspot.

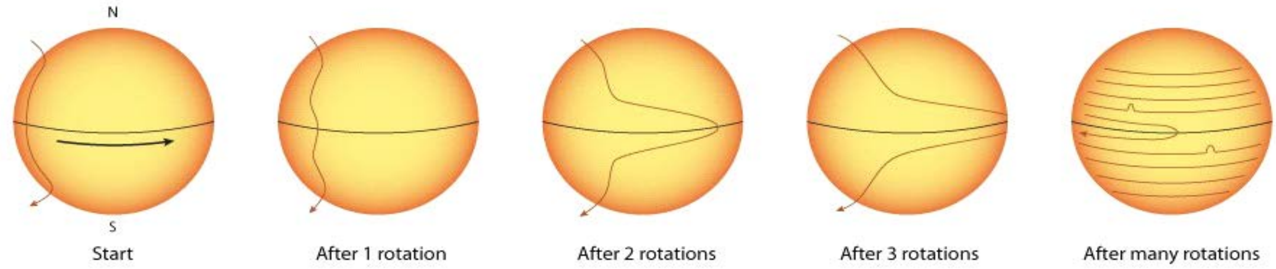


Figure 4: How the Sun's differential rotation builds over several days. Credit: NASA/IBEX.

Sunspots often appear in pairs, so where one sunspot is created as field lines rise through the surface, a second one appears where they fall back down.

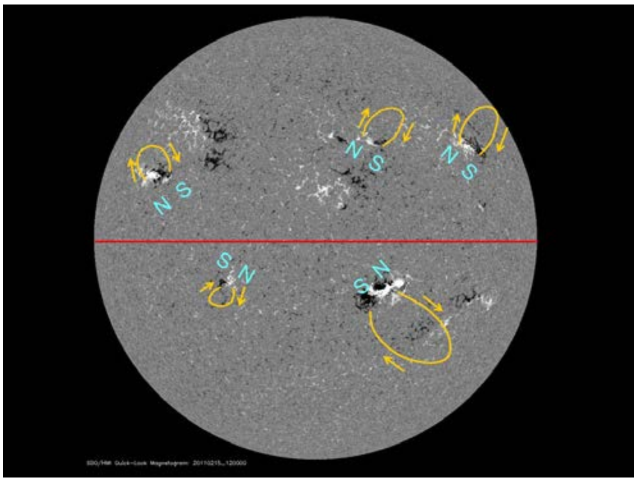


Figure 5: Sunspot pairs. Credit:Benjamin Montesinos presentation.

Activity 1: Getting to know the Sun

The Sun is ‘our’ star, the source of light and energy, and thus life on Earth. It is a very ordinary star: not particularly big or small, old or young, but much closer to us than all others.

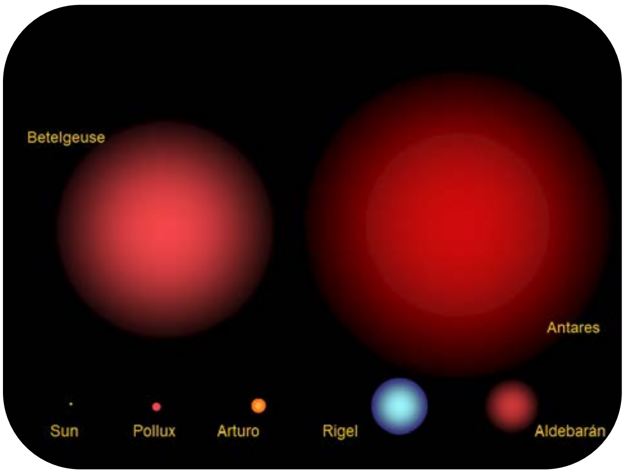


Figure 6: Size comparison stars. Credit: Dr.Benjamin Montesinos presentation.

The Sun, as are most stars, is made up of hot gases and has several layers. The surface of the Sun is called the **photosphere.** Beneath the photosphere is a **convective zone** and a **radiative zone**. Then at the very centre of the Sun is the core, where nuclear reactions take place. Above the photosphere, are the **chromosphere** and the **corona**.

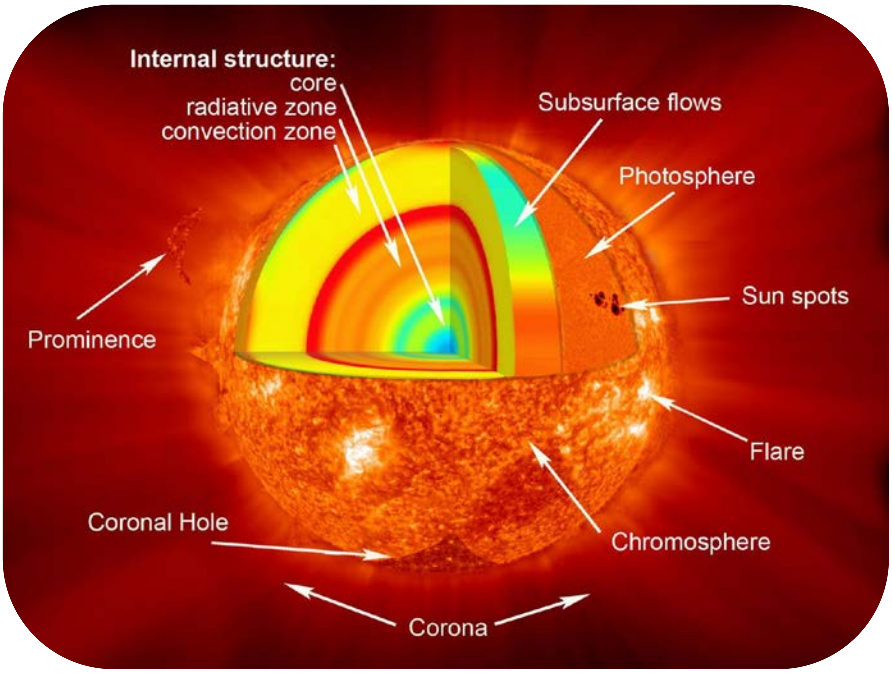


Figure 7: The regions of the Sun. Credit: NASA/ESA SOHO.

Answer the following questions using the background information.

What gases make up the Sun?

In what part of the Sun are sunspots are seen? Draw a sketch.

Opposite to the Sun, the Earth is a rocky planet. You are given some properties of the Sun and Earth in Table 1. Compare these two celestial objects and complete the last column.

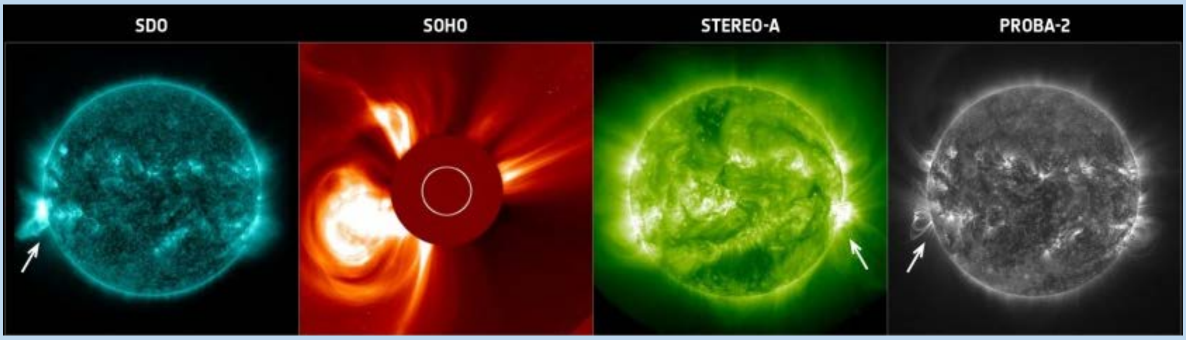
Property	Sun Value	Earth value	Sun/Earth comparison
Radius (km)	~ 700 000	6400	
Mass (kg)	~ 2×10^{30}	~ 6×10^{24}	
Average density (kg/m^3)	1400	1217	
Surface temperature (ºC)	~ 6073	17	
Age (years)	4 600 000 000	4 540 000 000	

Table 1: Properties of the Sun and the Earth.

Activity 2: The colours of the Sun

Did you know?

The Sun is constantly being observed by many space telescopes. Examples of such telescopes, are ESA's PROBA-2 **mission** and the ESA/NASA SOHO observatory. A new spacecraft, ESA's Solar Orbit will soon join this fleet and is scheduled for launched in 2020. These space telescopes provide a wealth of data about the Sun. The branch of physics that studies the Sun is known as ***Heliophysics***.



Sun observed in UV. Credit: kiri2ll.livejournal.com.

What do you see?

Looking at the Extreme Ultraviolet images of the Sun above can you see any sunspots (dark spots)?

Many telescopes on the ground also study the Sun in detail. For this and the next activities you will be using real images taken by the CESAR Education Solar Observatory (CESO[1]) that is located at the European Space Astronomy Centre in Spain.

[1] CESO websites: http://cesar.esa.int/index.php?Section=Observatories_ESAC_Sun, http://cesar.esa.int/index.php?Section=Live_Sun

Find out what the Sun looks like today by clicking this link:
http://cesar.esa.int/index.php?Section=Live_Sun

What do you see?

Looking at the image of the Sun labelled 'Visible' can you see any sunspots (dark spots)?

Objects at different temperatures emit different types of light. If sunspots are at a temperature of 4500ºC (4800 K), what type of light should be use to study them (X-rays, visible light, infrared, etc)? Tip: Use Figure 8 to help.

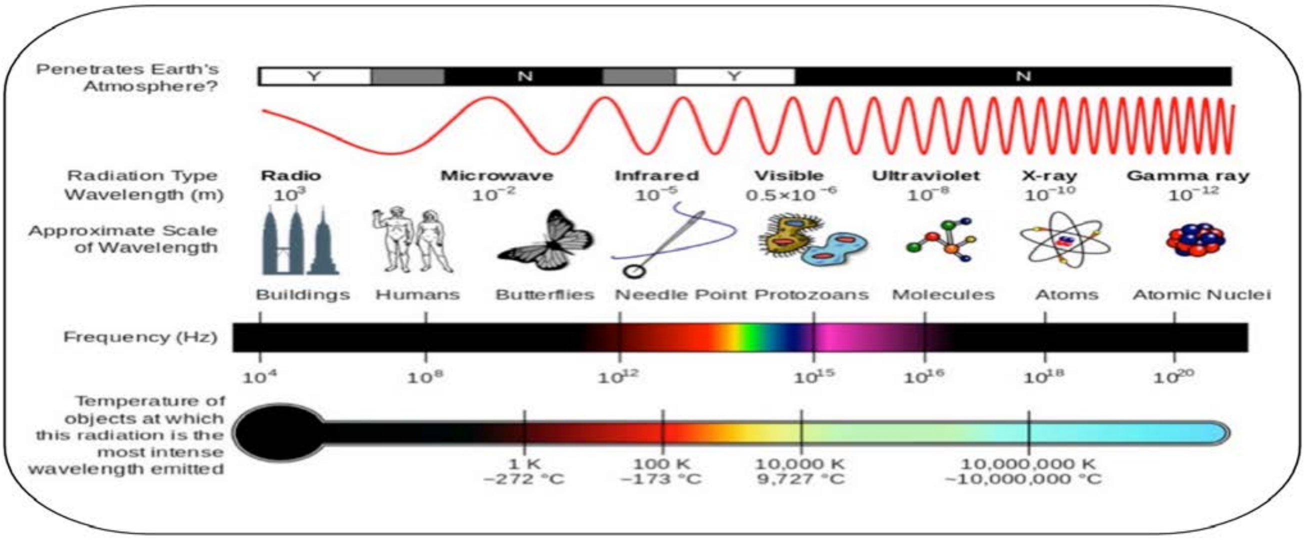


Figure 8: Properties of the electromagnetic spectrum. Credit: Wikimedia Commons. http://cesar.esa.int/upload/201711/electromagnetic_spectrum_booklet_wboxes.pdf

Activity 3: Calculate the rotation period of the Sun

In this activity you will be using images of sunspots moving across the Sun to calculate its rotation period. You will access these images and make your measurements using an online web tool.

The rotational period of an object is the time that it takes to spin around, or rotate, once. For example, the rotation period of the Earth is about 1 day. In the case of the Sun, we can deduce this value by measuring how long it takes a sunspot to move across part of the Sun's surface; or the number of degrees it covers, knowing that a complete rotation is 360 degrees.

Hypothesis

How long do you think it takes the Sun to complete a full rotation (to spin around once)?

In what direction do you think sunspots move across the surface of the Sun?

a. North to South
b. South to North
c. East to West
d. West to East
e. Other. Draw a sketch to illustrate your answer.

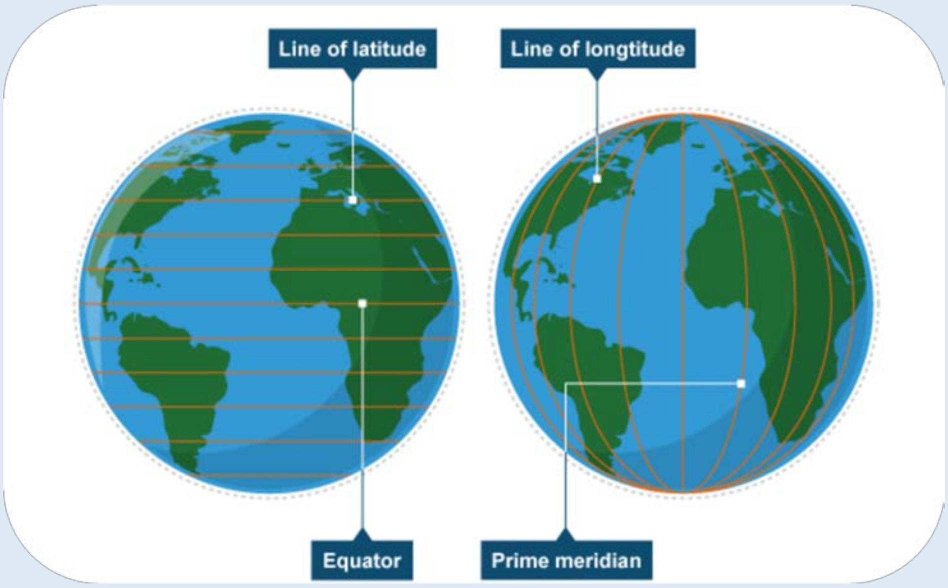
Do you expect sunspots to move at the same speed on different parts of the Sun's surface?
Tip: check Figure 1.

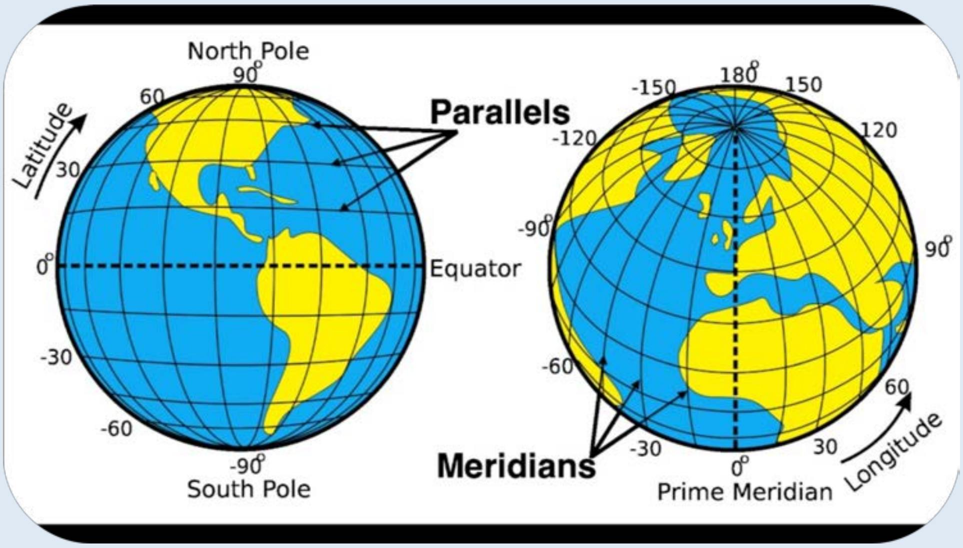
If yes, at what speed do you think they move?

If no, where do you think they would move the fastest? Why?

Did you know?

The coordinates of latitude and longitude are used to measure positions on the Earth. The equator is the reference line for the latitude, being positive to the north and negative to the south. The longitude increase from west to east, considering zero longitude at the primer meridian which is the Greenwich meridian. Both coordinates are given in degrees.





Definition of Longitude and Latitude.
Credit: https://www.bbc.com/bitesize/guides/ztqtyrd/revision/1 (top), http://nishalspace.com (bottom).

Did you know?

A pixel is the smallest element in an image. It gives a lot of useful information about the object being photographed. If one square is 40 pixels wide it is smaller than another square that is 80 pixels wide. It is immediately possible to see that the second one is twice the size of the first one. So, if for example, the size of the first square is known to be 2 metres, the size of the second square must then be 4 metres!

Investigation

To calculate the rotation period of the Sun you will access images from CESAR Education Solar Observatory (CESO) via an online web tool. The web tool will lead you through the different steps needed to make the calculation.

To access the web tool, go to: http:/cesar.esa.int/tools/14.differential_rotation

Step 1: Explore the image database

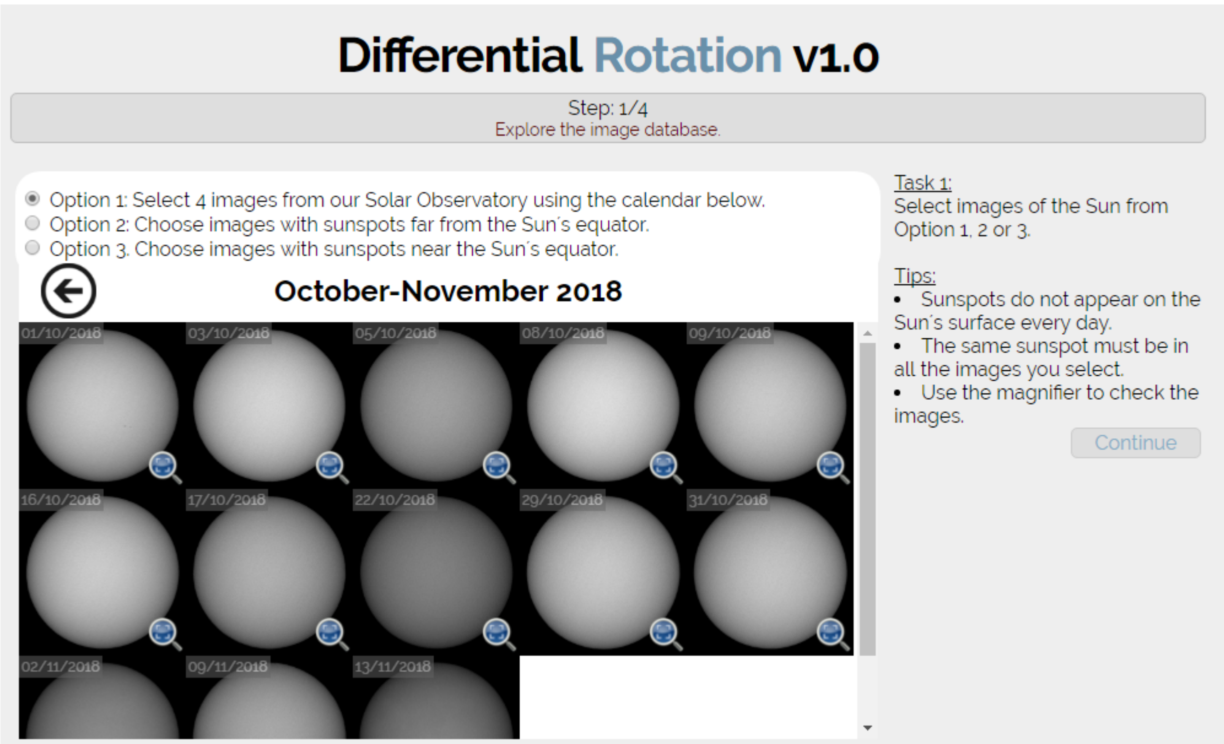


Figure 9: Step 1 of the Tracking sunspots web tool.

From your observations, does the sunspot move in a particular direction?
Draw a sketch to explain your answer.

If so, does it move in longitude or in latitude?

Which option did you choose to select your images? Why?

Step 2: Get the coordinates of the sunspot

In this step you will find out the coordinates (longitude and latitude) of the sunspot for each image.

The web tool automatically transforms plane coordinates (*x* and *y* in pixels) to spherical coordinates with the centre of the Sun as reference. For this conversion it is necessary to know how many pixels are needed to make up the Sun's radius.

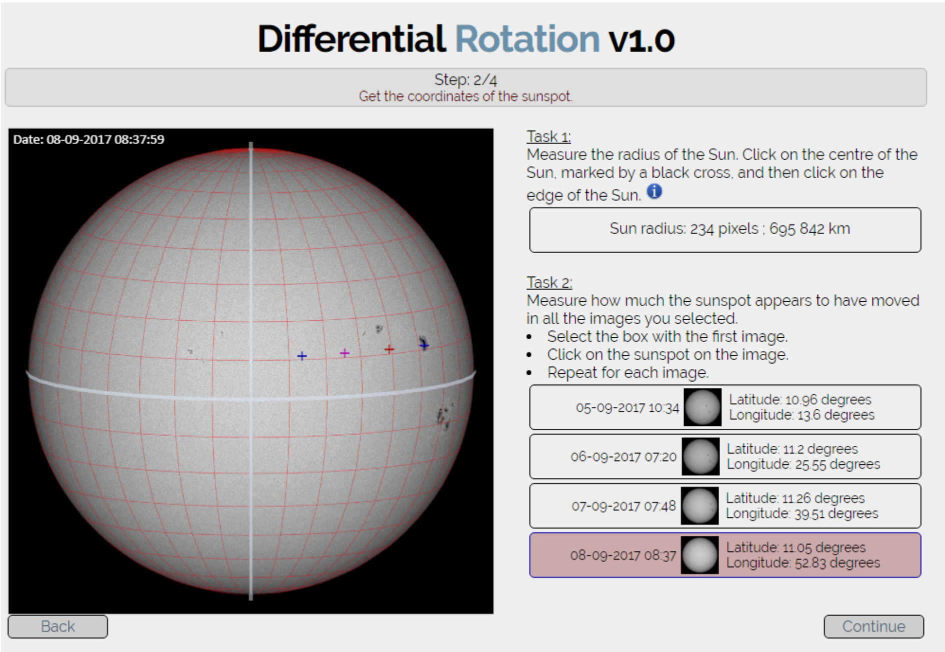


Figure 10: Step 2 of the Tracking sunspots web tool.

After measuring the Sun radius, by tracking the sunspot in each of the images selected you will get the information about the sunspot date, latitude and longitude. Note down these values in Table 2, as they will be used afterwards for your investigation.

Image number	Image date (DD-MM-YYYY hh:mm)	Sunspot latitude (degrees)	Sunspot longitude (degrees)
1			
2			
3			
4			

Table 2: Your measurements of the position of the sunspot for each image and the time the image was taken.

Step 3: Calculate the Sun rotation period (for a sunspot)

This step provides information about the coordinates (longitude and latitude) of the sunspot and the date and time that each image was taken (Table 2).

The movement of the sunspot in longitude from one image to the next and the time over which the sunspot moved (the difference in the time between two consecutive images) are needed to calculate the rotation period of the Sun.

In the web tool you will calculate the difference in longitude and the difference in time between two images. If you selected more than 2 images you will have more than one result for the Sun's rotation period. The mean of these values can be calculated to obtain the final result. You will also calculate the mean latitude of the sunspot (which should not change much), this will give you the rotation period for a particular latitude of the Sun.

The time needed for this calculation is in days. An example calculation of converting the time units follows (also see Table 3):

- **Image 1**: Date: 05-09-2017 10:34, Latitude: 10.96º , Longitude: 13.6º
- **Image 2:** Date: 06-09-2017 07:20, Latitude: 11.2º , Longitude: 25.55º

Image number	Image date (DD-MM-YYYY hh:mm)	Sunspot latitude (degrees)	Sunspot longitude (degrees)
1	05-09-2017 10:34	10.96º	13.6º
2	06-09-2017 07:20	11.2º	25.55º

Table 3: Example table of measurements of the position of the sunspot for each image and the time the image was taken.

Convert minutes into hours:

Image 2, taken at 07:20, so 20 minutes/60 = 0.33 hours.

Image 1, taken at 10:34, so 34 minutes/60 = 0.57 hours

Subtract time of Image 2 from time of image 1:

07.33 -10.57 = -3.24 hours, so -3.24/24 = -0.135 days

Next look at the dates the images were taken. They were taken 1 day apart. So, the time difference between the images is:

1 - 0.135 = 0.865 days

Difference between longitude values: 25.55º - 13.6º = 11.95º

Calculate the time difference and longitude difference for your set of images, input the results of your calculations directly into the web tool.

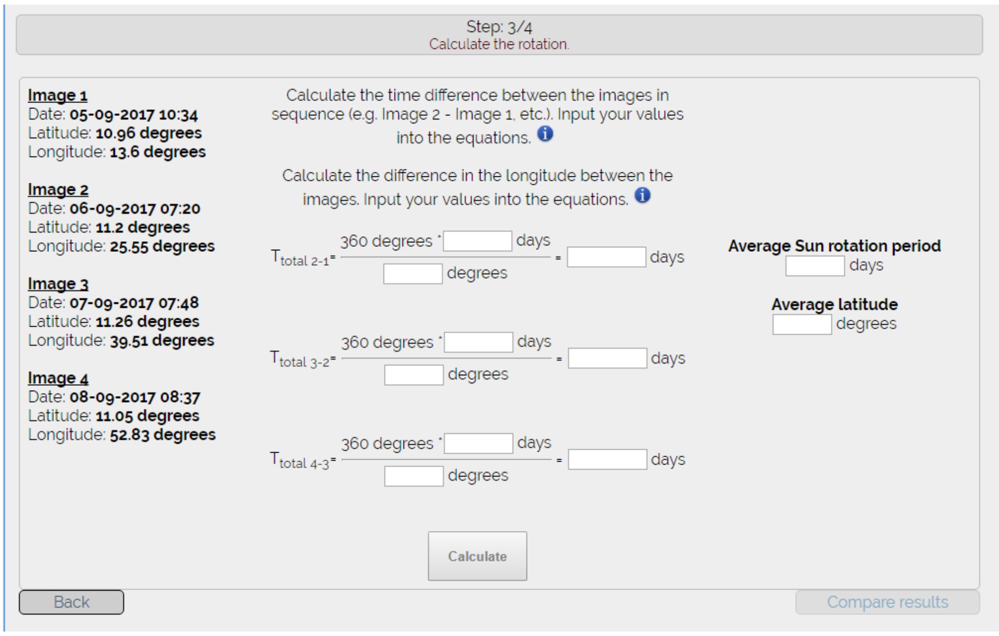


Figure 11: Step 3 of the Tracking sunspots web tool.

Record your results for the average latitude of the sunspot in your images and average rotation period of the Sun in Table 4.

	Average sunspot latitude	Average Sun rotation period
1		
2		
3		

Table 4: Your results for the rotation period of the Sun and latitude of the sunspot.

Try repeating the calculation of the Sun's rotation period with another set of images that have a sunspot at the same latitude and then calculate an average value. Use Table 5 to record your measurements of the position of the sunspot and the time the images were taken. Add the final results for average latitude and rotation period to Table 4.

Image number	Image date (DD-MM-YYYY hh:mm)	Sunspot latitude (degrees)	Sunspot longitude (degrees)
1			
2			
3			
4			

Table 5: Your measurements of the position of the sunspot for each image and the time the image was taken (second set of images).

Step 4: Compare the Sun's rotation period with those of other Solar System bodies.

Your result for the average rotation period and average latitude is displayed in Step 4 of the web tool. You can then compare the rotation period of the Sun with the rotation period of other Solar System objects.

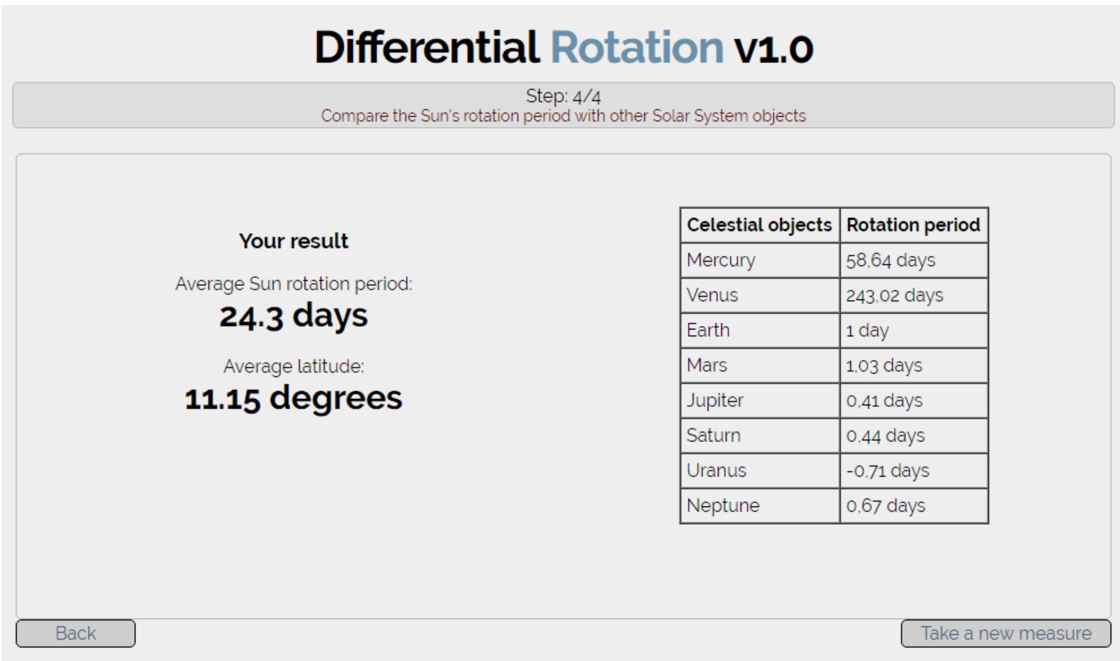


Figure 12: Step 4 of the Tracking sunspots web tool.

Did you expect the Sun to rotate faster or slower than the Moon? And compared to Earth?

Conclusions

Are your values of the Sun’s rotation period what you expected? Compare your results with those from other groups, are they similar? If not, what could be the reasons for the differences?

Are the values of the Sun’s rotation period exactly the same when calculated with a different pair of images? Did you expect this? Why?

How do you calculate the average of a measurement? Do you think that scientists do it often?

Activity 4: The Sun's rotation period at different latitudes

Repeat Activity 3 using another set of images. If you have already done your calculations using images with sunspots close to the equator, select another set of images with sunspots closer to the poles of the Sun and vice versa.

Image number	Image date (DD-MM-YYYY hh:mm)	Latitude of sunspot (degrees)	Longitude of sunspot (degrees)
1			
2			
3			
4			

Table 6: Your measurements of the position of the sunspot for each image and the time the image was taken.

Record your results in Table 7.

Option	Average sunspot latitude	Average Sun rotation period
1		
2		
3		

Table 7: Your results for the rotation period of the Sun using sunspots at different latitudes.

Does the Sun rotate faster depending on:

a) the hemisphere, b) the date, c) the position in latitude? Explain your answers.

Does the Sun rotate faster closer to its equator or closer to its poles (in other words where is the value of the rotation period smallest)?

Links

…about Sun

☐CESAR Booklet: *The Sun structure, The Magnetic Sun*

…about stars

CESAR Booklet: *Stellar evolution*

…about the electromagnetic spectrum and ESA missions

CESAR Booklet: *The electromagnetic spectrum:*
http://cesar.esa.int/upload/201711/electromagnetic_spectrum_booklet_wboxes.pdf

Science@ESA: *The full spectrum* (video):
http://sci.esa.int/education/44685-science-esa-episode-1-the-full-spectrum/

Science@ESA: *Exploring the infrared universe* (video):
http://sci.esa.int/education/44698-science-esa-episode-3-exploring-the-infrared-universe/

References:

www.windows2universe.org/sun/activity/sunspot_history.html

www.nasa.gov/mission_pages/stereo/mission/index.html