EXPERIMENTAL DETERMINATION OF THE SOLAR ROTATION PERIOD FOR SUNSPOTS

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1. Experimental determination of the solar rotation period for sunspots

1.1. Sunspots’ history

The changes in the position of the Sun spots observed by Galileo\(^1\) in 1612 during three consecutive days showed that the surface of the Sun rotates on itself. This fact provides a method to determine its rotation period\(^2\)\(^3\)\(^4\) (Picture 1) and it will only be necessary to measure the time it takes for a stain to give an entire cycle, or the time it takes to travel a known fraction of the distance.

![Picture 1. Galileo’s drawings\(^1\) of sunspots. June 9th, 10th, and 11th, 1912.](image)

The determined value from the images of the Sun taken from the Earth is called “the Synodic Rotation Period”. This is the apparent period of rotation of the Sun seen from the Earth, but is not the real period of rotation of the Sun. We must keep in mind that as the Sun rotates, the Earth orbits the Sun from West to East. The real period of rotation of the Sun, known as the period of sidereal rotation, is the time it takes from a fixed point of the Sun to turn as far as the distant stars are concerned. As a point of the Sun rotates 360 degrees with respect to the stars, the Earth moves ahead of its orbit. The Sun will have to spin a little faster to catch the Earth. Therefore, the synodic period is slightly longer than the sidereal one. Luckily, we can correct this added time, if we know the time the Earth takes to orbit the Sun (approximately once every 365.25 days). If \(P\) is the sidereal rotation period in days (this is the value we want to determine), and \(S\) is the synodic period rotation period in days (this is the value it has measured), then:

\[
P = \frac{(S \times 365.25)}{(S + 365.25)}
\]

(equation 1)\(^5\). Synodic period.
1.2. Objectives

- Observe using a telescope the evolution of sunspots from recorded photographs over a long period of time.
- Determine the spots’ trajectory.
- Make an estimate of the periods of Synodal and Sidereal rotation of the Sun with a technology that is available to everyone.

1.3. Observation

The observation of the Sun can be done with any telescope by placing a filter on the lens to protect the eye of the observer. The observation can also be made more safely by collecting the image on a screen that is placed behind the eyepiece. Another way to do this is to attach a camera to the primary focus of the telescope. If you don’t take photos are not taken, the spots must be drawn and the date and time of the observation must be noted down.

We started this practice during the month of March 2020 and, as we were at the beginning of the pandemic and in a state of alarm, we had to take the images provided by NASA’s SOHO satellite. On July 7, when the state of alarm was raised, we made an observation of the Sun (pictures 4 and 5) with the MEADE LX90GPS telescope (with the Canon EOS 1000D camera attached) and a sunscreen to prevent damage our vision.

Pictures 2 and 3. MEADE LX90GPS telescopes, Canon EOS1000D camera and solar filter.
We started this practice during the month of March 2020 and, as we were at the beginning of the pandemic and in an alarm state, we had to take the images provided by NASA’s SOHO satellite. On July 7, when the alarm state was raised, we made an observation of the Sun (Pictures 4 and 5) with the MEADE LX90GPS telescope (with the Canon EOS 1000D camera attached) and a solar filter to avoid damaging our vision (pictures 2 and 3).

Pictures 4 and 5. Photographs of the Sun taken on July 7th 2020 showing minimum solar activity.

The fact that in images 4 and 5 we don’t observe any spots in the solar photosphere, indicates that currently the solar activity is minimal, or what is the same, we are at the
end of the cycle or at the beginning of a new cycle. According to NASA, the 25th Solar Cycle was due to begin in April 2020, with a 6-month margin of error.

On November 14, 2020, after the SOHO satellite showed a new spot on the Sun indicating the start of the 25th solar cycle, we went to the “Maria Rúbies High School observatory” in Lleida, where we made an observation of the Sun with the MEADE LX200 EMC telescope (with the Canon EOS 4000D camera attached) and a sunscreen so as not to damage our vision.

Picture 7. MEADE LX200 EMC telescope with solar filter.

Picture 8. Photograph of the Sun taken on November 14, 2020, showing the beginning of the 25th Solar Cycle.
In Picture 8, we can see that there is a sunspot Northwest of the Sun. This spot represents the beginning of the 25th Solar Cycle, so solar activity has begun.

We also used a Solarscope, which is a device for observing the Sun and its solar activity. To do this, its lens must be orientated towards the Sun and the screen will reflect the surface of the Sun (photosphere) with its solar activity (if it’s any) (Picture 9).

![Observation of the solar photosphere through a Solarscope.](image)

Picture 9. Observation of the solar photosphere through a Solarscope.

![Solarscope screen on which the solar photosphere is reflected. Image taken on November 14th 2020.](image)

Picture 10. Solarscope screen on which the solar photosphere is reflected. Image taken on November 14th 2020.
In picture 10, we can see a small sunspot, which is the same as in picture 8, in the Southwestern part of the Sun.

Another option is to take the daily images sent by the SOHO satellite [6][7], a mission of the American and European space agencies.

The differences between the spots will be observed [8]. There can be seen same isolated groups of spots, large or small ones, either with nucleus or with nucleus and penumbra.

When choosing the spots to draw and analyze, it is advisable to choose the rather large spots because they are the ones that are the longest period and we practically make sure that we will find them again in the following days of observation.

1.4. Tools

- Tracker Program [9]
- Video clip of the movement of sunspots between the days 03/27/2001 and 04/01/2001: spotfull.mpg [10]

1.5. Experiment description

We will assume that the Sun is a perfect sphere that rotates like a rigid solid at a constant angular velocity. With this assumption, the sunspots will also move at a constant speed. According to that model, determining the period of rotation of the Sun (T) is equivalent to measuring the time a stain takes to make a complete turn around the Sun.

The movement of a spot seen from the Earth is a straight path, while if we could observe it from the pole it would be circular (in green). (Picture 11)
The average linear velocity \( v \) of motion of the sunspots parallel to the solar equator will be determined. To do this, it will be necessary to know the evolution of the position \( d \) of each of the spots over time \( t \) from the analysis of two consecutive images:

\[
v = \frac{d}{t}
\]

Equation 2. Average linear velocity.

The distance travelled by the stain in a period \( T \) is equivalent to the length of the circumference \( L \).

\[
L = \pi D, \text{ being, } D, \text{ the diameter.}
\]

Equation 3. Length of the circumference.

The period will be time the sunspot takes for a spin, that is to say:

\[
T = \frac{L}{v}
\]

Equation 4. Period.
1.6. Process

- Open the video clip “spotfull.mpg” with the program Tracker, and select the frame number 25 corresponding to the 17:36 h (UT) of the day 27/03/2001. (Picture 13).
- Calibrate the "measurement stick" by assigning the value of 1,393,000 km, which is the length of the solar equator. (Picture 14).


- Select a spot, number it, and write down the date and time (UT) when the photo was taken. (Picture 15).

Picture 15. Numbered sunspot.
• Locate the origin of the coordinate system in the center of the spot. (Picture 16).

![Picture 16. Coordinate system in the center of the observed spot.]

• Advance the video clip to another frame (in our case to the frame 400 corresponding to 17:36 h (UT) on 01/04/2001), and measures the distance (d) traveled by the stain in these 4 days (120 h). (Picture 17).

![Picture 17. Measurement of the distance (d) traveled by the stain) in 120 hours.]
Measure the diameter, D, of the circumference described by the stain. In the case of the selected spot, \( D = 1,229 \times 10^6 \text{ km} \). (Picture 18).

![Image](image.png)

**Picture 18.** Measurement of the diameter of the circumference traversed by the observed spot (D).

### 1.7. Obtained results, analysis and discussion

<table>
<thead>
<tr>
<th>Sunspot number</th>
<th>( d \times 10^5 ) (km)</th>
<th>t (h)</th>
<th>( v = \frac{d}{t} \times 10^5 ) (km/h)</th>
<th>D ( \times 10^6 ) (km)</th>
<th>( L = \pi D \times 10^6 ) (km)</th>
<th>( T = \frac{L}{v} ) (h)</th>
<th>T (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>7,09</td>
<td>120</td>
<td>5,91</td>
<td>1,30</td>
<td>4,08</td>
<td>690</td>
<td>28,8</td>
</tr>
<tr>
<td>02</td>
<td>7,40</td>
<td>120</td>
<td>6,16</td>
<td>1,388</td>
<td>4,36</td>
<td>708</td>
<td>29,4</td>
</tr>
<tr>
<td>03</td>
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<td>120</td>
<td>6,64</td>
<td>1,393</td>
<td>4,38</td>
<td>659</td>
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<td>04</td>
<td>6,67</td>
<td>120</td>
<td>5,56</td>
<td>1,258</td>
<td>3,95</td>
<td>710</td>
<td>29,6</td>
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<tr>
<td>05</td>
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<td>120</td>
<td>5,73</td>
<td>1,399</td>
<td>4,39</td>
<td>766</td>
<td>31,9</td>
</tr>
</tbody>
</table>

Table 1. Data taken from the spotfull.mpg video analysis.
Spots 1 and 4 have similar (north) latitude, and spots 2, 3, and 5 move almost along the equator of the Sun (latitude 0). With the determined values we cannot conclude that there is a significant difference in the synodic period between the two groups of spots as stated by the international scientific community. That is to say, we are not in a position to say that the synodic period depends on the latitude of the spot. What we will do, then, is make an estimate calculus of the synodic period by making the arithmetic mean of the 5 values determined.

The mean value of the synodic period (S) is 29.4 days, and the mean deviation of the determinations is 0.98 days. Thus, we can express the result as:

\[ S = (29.4 \pm 1.0) \text{ days} \]

If we compare this result with the real value of the synodic period at the equator (27.3 days), there is a difference of 2.1 days, equivalent to a relative error of 8%.

We will calculate the sidereal period (P) from equation 1.

\[
P = \frac{(S \times 365.25)}{(S + 365.25)} \text{ (days)}
\]

<table>
<thead>
<tr>
<th>S (days)</th>
<th>( P = \frac{(S \times 365.25)}{(S + 365.25)} ) (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.8</td>
<td>26.7</td>
</tr>
<tr>
<td>29.4</td>
<td>27.2</td>
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</tr>
<tr>
<td>29.6</td>
<td>25.4</td>
</tr>
<tr>
<td>31.9</td>
<td>29.3</td>
</tr>
<tr>
<td></td>
<td><strong>27.2</strong></td>
</tr>
</tbody>
</table>

Table 2. Sidereal period.

The average value of the sidereal period is 27.2 days with an average deviation of 0.94 days.

We will express the result as:

\[ P = (27.2 \pm 1) \text{ days} \]
1.8. Conclusions

- The first goal has not been achieved for two reasons: This research began in mid-March, just when the state of alarm was declared for COVID-19 and classes were suspended; Thus, we were unable to make an observation with the school telescope. On the other hand, the activity of the Sun for a few months was minimal and no sunspots were observed. Despite of this, research has continued using ancient images of the Sun provided by the SOHO satellite. After doing the practice, we made two observations of the solar photosphere on July 7 and November 14, 2020: The first one was at a stage of minimal solar activity, and the second one was at the beginning of a solar cycle where there was a sunspot.

- It is observed that the movement of the spots is rectilinear with a direction parallel to the equator.

- It has been possible to estimate experimentally the synodic period of the Sun. Its value is:

  $$S = (29,4 \pm 1,0) \text{ dies}$$

- The sidereal period has been calculated from the synodic period. Its value is:

  $$P = (27,2 \pm 1) \text{ dies}$$

- We didn’t find any significant difference in the synodic period depending on the latitude of the sunspots.

- The free video analysis software "Tracker" is an excellent tool for a kinematic study of the movement of sunspot.
1.9. Bibliography


