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Lab 3 Solar Rotation

Objective

The objective of this lab was to determine the Sun's rotation period by tracking the movement of a sunspot over an eight-day period using Photoshop for image analysis. I measured angular displacement, calculated daily angle differences, and used these measurements to compute the synodic rotation period of the Sun. The main takeaways include understanding the methodology for observing solar rotation and the significance of precise data analysis in astronomy studies.

Introduction

The sun, which is the nearest star to us, rotates about the axial line; this motion has an important impact on solar activity such as the solar magnetic field, sunspots, and solar flares. Sunspots are relatively cooler and darker patches on the photosphere of the sun and are due to the strong concentration of magnetic field interference with convection. When seeking to explain the gross physical features of the sun's sharply defined solar rotational axis, it is noteworthy that the sun contains a pattern of features that can be followed as they rotate around the sun.

In this lab, we choose a specific sunspot and measure its angular displacement as it rotates across the sun's surface over a span of eight days. This method is considered acceptable, scientifically, because it gives astronomers a rotation period of the Sun which is important in studying the Sun’s dynamics and interaction of space weather with the Earth.

In the development of astronomy, sunspot studies also played an important role. As an example, in the middle of the 17th century, astronomer Galileo Galilei was able to demonstrate the rotation of the Sun by observing sunspots, which was in conflict with geocentric views of the universe.

However, in order to help outline our observations, we had to make a few relevant assumptions.

Uniform Rotation: We assumed the Sun rotates uniformly, neglecting its known differential rotation where different latitudes rotate at different rates.
Stable Sunspot: We assumed the sunspot remained consistent in size and shape over the observation period.
Negligible Earth's Motion: For initial calculations, we did not account for Earth's orbital motion around the Sun, focusing on the synodic rotation period.
These assumptions allowed us to focus on measuring the sunspot's movement accurately and applying mathematical calculations to determine the Sun's rotation period.

Procedure

1. **Setup and Preliminary Steps**
   - Open the solar surface images in Adobe Photoshop. Ensure each image is aligned consistently for accurate measurements.
   - Overlay the second page as a projection to serve as a reference for the sunspot positions.
2. **Drawing Ellipses and Lines for Reference**
   - Use the Ellipse Tool to draw ellipses around each sunspot location. This helps in visually tracking the movement across images.
   - Overlay lines from the reference points to each sunspot using the Line Tool. This aids in ensuring the consistency of measurements and verifying the angles drawn.
   - Adjust the transparency of the overlay if needed
3. **Measuring Angles with Photoshop Ruler**
   - Select the Ruler Tool from the toolbar, which can be found under the Eyedropper tool.
   - For each image, use the ruler to measure the angular position of the sunspot. Click and drag from a fixed center point to the sunspot position to determine the angle and record it.
4. **Calculating Angle Differences**
   - Compute the change in angle ($\Delta\theta$) between consecutive images. Subtract the angle of the previous day from the current day's angle to get the difference and record it in the table.
5. **Data Analysis**
   - Calculate the average change in angle ($\Delta\theta$) using the recorded differences.
   - Determine the standard deviation of the angle differences to represent the uncertainty in your measurements. Express your average change in angle with this uncertainty as $\Delta\theta \pm \sigma$.
6. **Calculating Synodic Rotation Period**
   - Use the average angle change ($\Delta\theta$) to calculate the Sun's rotation period (P) using the formula:
   - Document the calculated period, including its uncertainty, using the propagated uncertainty formula for the period.

Observations/Data Collection

Measuring the Angles of rotation

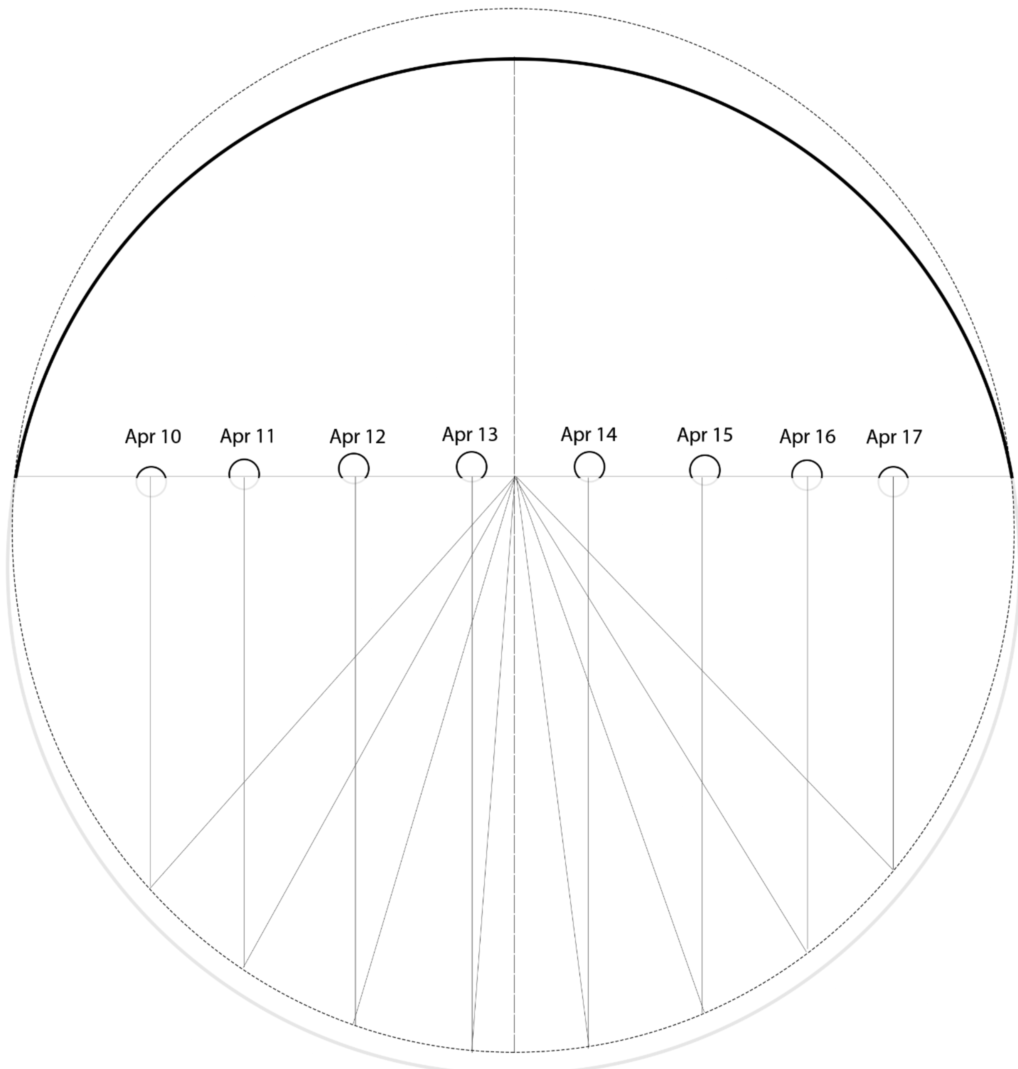

Table 1: Angular displacements of a sunspot.

Date Observed	**Measured Angle (°)**	**Change in Angle θ (°)**	**Squared Differences of Change in Angle**
10-Apr	**48.5**	**NA**	**NA**
11-Apr	**61.0**	**12.5**	**0.09**
12-Apr	**73.5**	**12.5**	**0.09**
13-Apr	**85.7**	**12.2**	**0**
14-Apr	**97.4**	**11.7**	**0.25**
15-Apr	**109.6**	**12.2**	**0**
16-Apr	**121.4**	**11.8**	**0.16**
17-Apr	**133.9**	**12.5**	**0.09**

Mean of Change in Angle (Average): $\frac{12.5+12.5+12.2+11.7+12.2+11.8+12.5}{7} = 12.2°$

Sum of Squared Differences of Change in Angle:

$(12.5 - 12.2)^2 = (0.3)^2 = 0.09 \qquad (11.7 - 12.2)^2 = (-0.5)^2 = 0.25$

$(12.5 - 12.2)^2 = (0.3)^2 = 0.09 \qquad (12.2 - 12.2)^2 = (0)^2 = 0$

$(12.2 - 12.2)^2 = (0)^2 = 0 \qquad (11.8 - 12.2)^2 = (-0.4)^2 = 0.16$

$Sum = 0.09 + 0.09 + 0 + 0.25 + 0 + 0.16 + 0.09 = 0.68$

$Variance = \frac{0.68}{7} \approx 0.097$	$Standard\ Deviation\ (Uncertainty) = \sqrt{0.097} = 0.312 \approx 0.31°$

Average Δθ: $\Delta\theta_{Mean}$ = 12.2°

Standard Deviation (Uncertainty): $\sigma_{\Delta\theta}$ = 0.311°

Calculate the Synodic Rotation Period (P): $P = \frac{360°}{\Delta\theta_{Mean}} = \frac{360°}{12.2°/day} = 29.508\ days$

So, the synodic rotation period of the Sun is approximately 29.51 days.
Calculate the Uncertainty in Period (ΔP):

$\frac{\Delta P}{P} = \frac{\sigma_{\Delta\theta}}{\Delta\theta_{Mean}} = \frac{0.31°}{12.2°} = 0.0255$

$\Delta P = P \times \frac{\Delta P}{P} = P \times 0.0255 = 29.508 \times 0.0255 = 0.07525 \approx 0.075\ days$

So, Period of Rotation with Uncertainty: P = 29.51 ± 0.75 days

All Calculations were done in Excel, the sheet can be found here.

Analysis

1. Add 1° to the average/mean of change in angle to correct for Earth's Motion:

   $$\Delta\theta_{corrected} = \Delta\theta_{mean} + 1° = 12.2° + 1° = 13.2°\ per\ day$$

   $$P_{sidereal} = \frac{360°}{\Delta\theta_{corrected}} = \frac{360°}{13.2°/day} = 27.2727...$$

   $$P_{sidereal} \approx 27.27\ days$$

   The sidereal rotation period of the Sun is approximately 27.27 days.

2. Equation Relating Uncertainty in period to uncertainty in the angle measurement:

   $$\frac{\Delta P}{P_{sidereal}} = \frac{\sigma_{\Delta\theta}}{\Delta\theta_{corrected}} \rightarrow \frac{\Delta P}{P_{sidereal}} = \frac{0.31°}{13.2°} = 0.0235$$

   $$\Delta P = P_{sidereal} \times \frac{\Delta P}{P_{sidereal}} = 27.27\ days \times 0.0235 = 0.641\ days$$

   $$P_{sidereal} = 27.27 \pm 0.64\ days$$

   The sidereal rotation period of the Sun is approximately 27.27 ± 0.64 days.

3. $$\frac{Photo\ diameter\ of\ sunspot\ (cm)}{Photo\ diameter\ of\ Sun\ (cm)} = \frac{Real\ diameter\ of\ sunspot\ (km)}{Real\ diameter\ of\ Sun\ (km)}$$

   Measured Diameter of Sun (using Measure in GIMP): 15.8 cm

   Measured Diameter of Sun-Spot (using Measure in GIMP): 0.5cm

   $$Real\ Diameter\ of\ sunspot = Real\ diameter\ of\ Sun \times \frac{Photo\ diameter\ of\ sunspot}{Photo\ diameter\ of\ Sun}$$

   $$Real\ Diameter\ of\ sunspot = 1,392,000\ km \times \frac{0.5\ cm}{15.8\ cm} = 44,050\ km$$

   The real diameter of the sunspot is 44,050 km.

4. $$Ratio = \frac{Real\ Diameter\ of\ sunspot}{Diameter\ of\ Earth} = \frac{44{,}050\ km}{12{,}756\ km} = 3.4532 \approx 3.5\ Earths$$

   Number of Earths ≈ 3.5

   The sunspot's diameter is approximately 3.5 times that of Earth's diameter.

5. **Considerations:**

   <u>If the Sunspot Were Something Passing Between Us and the Sun:</u>

   a. Appearance:

      i. It would move across the Sun's disk in a straight line, possibly at a different speed than the Sun's rotation.

      ii. The sunspot might not follow the Sun's rotational path and could show a lack of parallax with solar features.

b. Observation:
   i. The sunspot would transit the Sun without exhibiting limb darkening or curvature consistent with the Sun's surface.

If the Sunspot Were on the Surface but Not Fixed in Position:

a. Appearance:
   i. The sunspot might change latitude (move north or south) over time.
   ii. It could change shape, size, or intensity.
b. Observation:
   i. In the diagrams, the sunspot would display inconsistent movement not matching the Sun's rotational period.
   ii. There might be irregularities in its path or unexpected accelerations/decelerations.

How to Check the Assumption:

Fixed Sunspot:
   i. Should move steadily across the Sun's disk due to the Sun's rotation.
   ii. Maintains a consistent speed and direction relative to the Sun's equator.
   iii. Observation: In your diagrams, the sunspot's progression should match the calculated rotational period.

Compare Relative Positions:

c. Relative to Other Features:
   i. If multiple sunspots are present, checking if they maintain their relative positions.
      Observation: Consistent spacing and movement suggest they are fixed on the surface.
d. Examining changes over time:
   i. Shape and Size Stability - Minimal changes indicate fixed features.
      Observation: Significant changes could imply active solar regions or transient phenomena.

Summary:

By comparing our diagrams over multiple days we can observe:

If the sunspot moves consistently with the Sun's rotation and maintains its relative position and shape, it supports the assumption that the sunspot is fixed to the solar surface.

If the sunspot's motion deviates from the expected path, or if it changes dramatically in size or shape, this could indicate that the sunspot is not fixed or is influenced by other solar activities.

Discussion

In this experiment, our goal was to measure the synodic and sidereal rotation of the Sun based on the apparent motion caused by the displacement of a sunspot over a time frame of 8 days. Our calculations yielded a synodic period of 29.51 ± 0.75 days and a sidereal period of 27.27 ± 0.64 days. These results provide valuable insights into solar rotation and align with our understanding of the Sun's behavior.

Assumptions Made

Sunspots are Fixed to the Solar Surface: It was assumed that the sunspot which was tracked did not migrate from its place on the surface of the Sun and rotated together with it. This made it possible for us to state that only the rotations of the Sun were responsible for the apparent motion of the sunspot as there was no additional rotating motion of the sunspot itself.

Sun's Rotation is Uniform: The Sun is considered as a body in constant rotation. Its differences in rotation are ignored in this work because we shall consider the sun as a solid object and its differential rotation will be disregarded. Such a neglect was important for making our calculations, however it does not give the realistic picture of the rotation of the Sun since it is not constant but dependent on the position of the latitude.

Negligible Effects of Solar Activities: Effects of solar activities such as flares or magnetic disturbances on the sunspot growth and deformation are also ignored when sunspots are observed. The same criterion applies in this case, that for the duration of the observation sunspot.

Comparison with Accepted Values

The accepted sidereal rotation period at the solar equator is 24.47 days (“Solar Project”). Our calculated sidereal period is 27.27 ± 0.64 days. To determine if our measurement is consistent with the accepted value, we will compare the two considering the uncertainty:

Difference between measured and accepted values:

Difference = 27.27 days - 24.47 days = 2.8 days

Combined Uncertainty: $\sqrt{(0.64\ days)^2 + (0\ days)^2} = 0.64\ days$

As the difference (2.77 days) is greater than our uncertainty (0.64 days), our measurement does not agree with the accepted equatorial value within the uncertainty range.

However, the Sun exhibits differential rotation, meaning it rotates faster at the equator and slower at higher latitudes. At approximately 26 degrees latitude, the typical sidereal rotation period is around 27 days, which closely matches our calculated value. Considering this, our measurement is consistent with the expected rotation period at the latitude where our sunspot likely resided.

Effect of Assumptions on Results

Assumption of Uniform Rotation: In this case, we assumed the Sun to be a rotating body of uniform shape with no consideration for the Sun's differential rotation. This assumption could also introduce bias within the results in comparing them to the measured equatorial rotational period. Since our calculated period aligns with the rotation period at mid-latitudes, it suggests our sunspot was located away from the equator, and the uniform rotation assumption partially holds at that latitude.

Sunspot Fixed on the Solar Surface: If the sunspot was drifting independently (for example, because of some force of the solar magnetic field) this would alter our calculated rotation periods. The data of the sunspots used in this instance corresponded with the rotation of the Solar system, in support of our assumption.

Improving Data Collection and Assumptions

To enhance the accuracy of our results:

Account for Differential Rotation: Incorporate the Sun's differential rotation into our calculations by determining the latitude of the sunspot. Measuring the sunspot's latitude would allow us to use latitude-specific rotation rates, reducing discrepancies with accepted values.

Extended Observation Period: Observing the sunspot over a longer period could improve the precision of the average daily angular displacement and reduce uncertainty.

Multiple Sunspots Analysis: Tracking multiple sunspots at different latitudes could provide a more comprehensive understanding of solar rotation and verify the differential rotation effect.

Impact of Differential Rotation

Given the Sun's differential rotation:

Sunspot at Different Latitudes: If our sunspot were located closer to the equator, we would expect a faster rotation period (around 24.5 days sidereal). Conversely, a sunspot near the poles would yield a slower rotation period (>30 days). Our calculated sidereal period of 27.27 days suggests the sunspot was at an intermediate latitude, consistent with the typical rotation period at around 26 degrees latitude.

Consistency with Differential Rotation: Our estimate aligns with the understanding that the Sun rotates more slowly at higher latitudes. This consistency supports our findings and indicates that our sunspot's position influenced the observed rotation period.

Historical Significance of Sunspot Observations

The observation of sunspots played a pivotal role in challenging the Ptolemaic Greek cosmology, which posited a perfect, unchanging celestial realm. Sunspots demonstrated that the Sun, considered a perfect celestial body, had blemishes and underwent changes over time. This contradicted the long-held belief of immutable heavenly bodies.

Changing Perception of Our Place in the Universe

The discovery of sunspots contributed to a paradigm shift in humankind's understanding of the universe:

Imperfection of Celestial Bodies: Accepting that the sun was blemished destroyed the belief in celestial spheres that were perfect and projected that the laws of nature functioned both in the earth and the sky.

Advancement of Heliocentric Theory: Investigation of sun-spots resolved the issue of rotation of other heavenly bodies supporting the heliocentric model of Copernicus and shoved the earth further away from the center of the universe.

Scientific Inquiry into the Cosmos: Sunspots also commanded a different approach to practically try and study astronomy, casting the roots of astrophysics that changed the conception that the universe was stagnant rather than an active one that operated and could be active.

Conclusion

Our experiment successfully determined the Sun's synodic and sidereal rotation periods by tracking a sunspot's movement. While our sidereal period did not match the equatorial rotation rate, it was consistent with the expected period at intermediate latitudes, demonstrating the Sun's differential rotation. The main assumptions made allowed us to simplify complex solar dynamics for our calculations, though acknowledging and accounting for these assumptions could improve future measurements. The historical context of sunspot observations highlights their significance in transforming our understanding of the universe and our place within it.

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