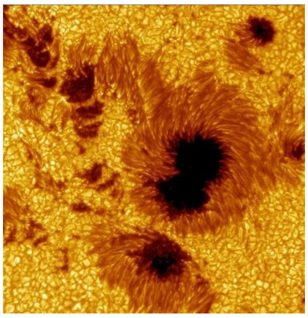
Determination of the period of differential rotation of the Sun



Does the sun rotate as a whole?

Metadata

General Info

Title: **Determination of the period of differential rotation of the Sun**

Short description: Based on spectroheliograms provided by the Geophysical and Astronomical Observatory of the University of Coimbra, and using the Tracker (freeware), we ask three questions about the Sun:

- Is it the spherical sun?
- If it rotates, how long does it take to go around?
- Does it rotate like a rigid body?

Students will have to transform the sequence of images into data, which will assume a graphic representation and, after that, they must achieve the proper mathematical function that will be adjusted. Finally, students must exploring its physical meaning of this behavior and understand why it happens.

Keywords: light curves, variable star, brightness; supernova, asteroids, exoplanets; reporting research, photometry

Educational Context

Context: Students will learn how to use Tracker, digital video analysis software, to track the variation of sunspot position and calculate the period of rotation of the Sun. Further analysis will show that the Sun does not rotate like a rigid body: it exhibits differential rotation. Students can present their work to the class and discuss how it compares to the most accurate results astronomers have.

Age: 16-18 years old (High school)

Prerequisites: Computer knowledge at the user level to install and use the indicated software. Knowledge about Kinematics (uniform circular motion) Functions (graphical representation of functions) and Astronomy (Sun behavior, Sunspots and solar magnetic fields)

Lv. Of difficulty: 4/5

Duration: (8 hrs max)

Educational Objective

Cognitive Objectives: Project-based learning to reinforce physics and mathematics concepts.

Affective: Promoting group working and collaboration

Psychomotor: Development of skills of observation and precision and visual dexterity.

Subject Domain

Big Ideas of Science : The Solar System is a very small part of one of millions of galaxies in the Universe.

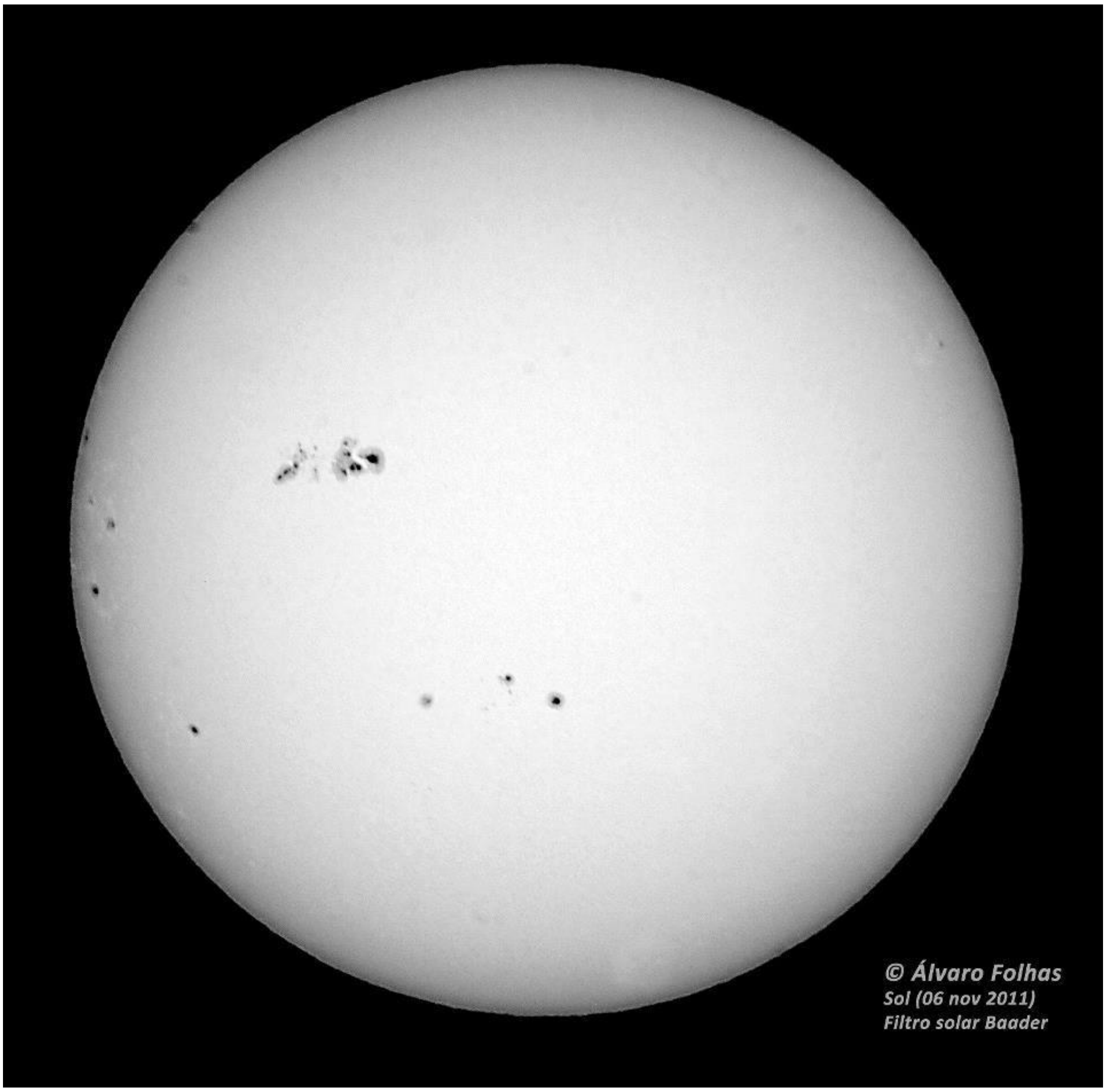
Subject Domain: Astronomy, Physics, Mathematics, ICT.

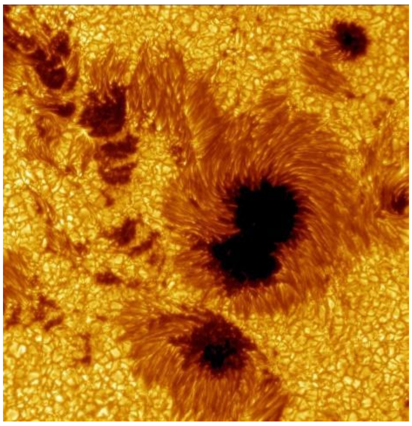
Physics and Astronomy: Characterization of the solar rotational motion.Mathematics and ICT: Data collection and processing of information and its graphical representation

Orienting & Asking Questions

The Sun is our closest star and the one that determines all life on Earth. But the Sun is a star in permanent activity and one way to observe this solar activity is through sunspots and their behavior.

Sunspots are areas that appear dark on the surface of the Sun. They appear dark because they are cooler (about 3000K) than other parts of the Sun's surface which temperature is about 5800K.





The reason of Sunspots are cooler than the surroundings is because the magnetic field in the sunspot is stronger and inhibits convection, preventing the hot gas from deeper inside the sun to come to the surface. Since the transfer of energy by convection is less efficient in the sunspot, these are not as hot as the surroundings.(SideImage: *Sunspots taken with the Swedish Solar Telescope. [SST/Royal Swedish Academy of Sciences]*

Two different zones may be detected in a sunspot: the dark centre, called the umbra, and the lighter border, the penumbra.
The appearance of groups of sunspots observed on different days, appears in different positions indicating a movement of the solar surface. The presence and amount of visible sunspots on the surface of the Sun varies in a regular cycle of about 11 years, called the Solar Cycle.

Hypothesis Generation and Design

You can find out a lot about our Sun by exploring the behavior of sunspots present in images of the sun (Spectroheliograms). In this demonstrator we will use spectroheliograms provided by the Geophysical and Astronomical Observatory of the University of Coimbra - OGAUC (available in an attached folder). Thus, based on these spectroheliograms and using Tracker (freeware), we ask three questions about the Sun:

- **Is it the spherical sun?**
- **If it rotates, how long does it take to go around?**
- **Does it rotate like a rigid body?**

Students will have to transform the sequence of images into data, which will assume a graphic representation and, after that, they must achieve the proper mathematical function that will be adjusted. Finally, students must exploring its physical meaning of this behavior and understand why it happens.

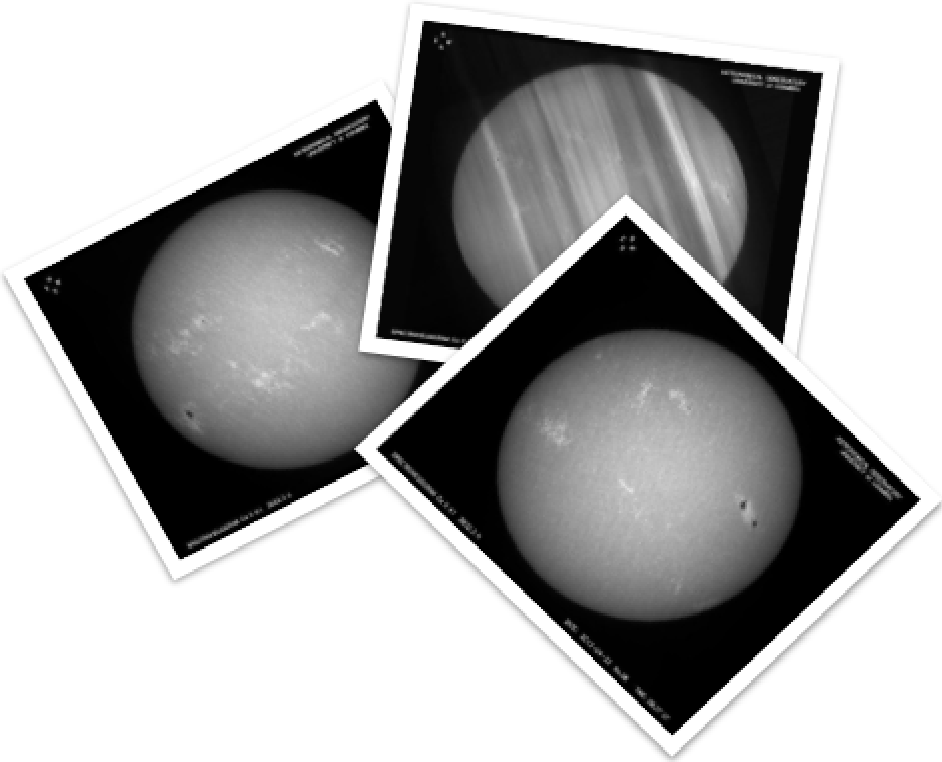
Students will learn how to use Tracker, digital video analysis software, to track the variation of sunspot position and calculate the period of rotation of the Sun. Further analysis will show that the Sun does not rotate like a rigid body: it exhibits differential rotation. Students can present their work to the class and discuss how it compares to the most accurate results astronomers have

Planning and Investigation

Plan Investigation

The strategy of making determinations of different groups of sunspots, with the class organized into working groups.Thus, each group seeks to determine the period of solar rotation as a function of the movement of a group of sunspots (at a certain solar latitude) over time. To do so, students will use the daily spectroheliograms from 12th February 2011 to 17th March 2011, provided by the

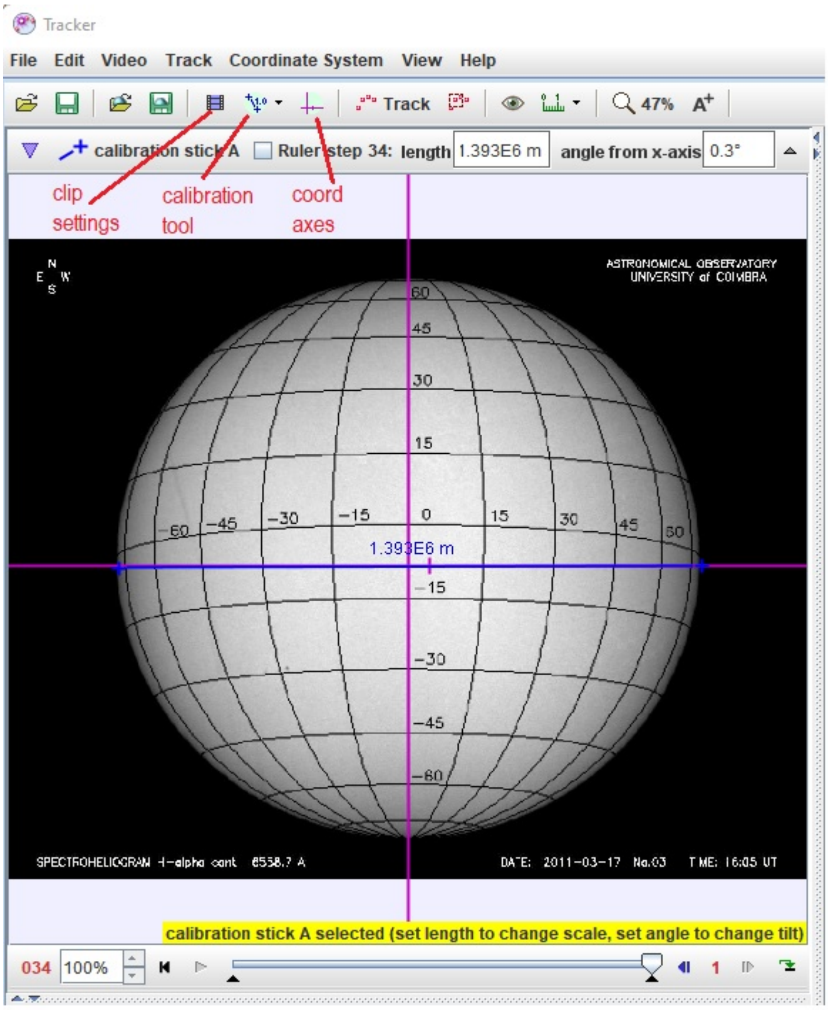
Geophysical and Astronomical Observatory of the University of Coimbra (OGAUC). ordered chronologically.
For weather reasons, it was not possible to acquire images on all days of this period. Thus, I created "dummy images" to fill in the gaps resulting from the missing days (in order to have one image per day and thus maintain the temporal periodicity of the set), which were duly marked not to be used in the data acquisition. This resulted in 35 spectroheliograms for the 35 days considered.



This study uses Tracker as a digital video analysis tool. Once the determination is made, the results of the different working groups are gathered, which will be analyzed in order to draw conclusions on the questions initially raised.
If I have all the images of the sun and present them sequentially, I will have something similar to a video. There we can see its behavior and extract information by digital video analysis.

Tracker:

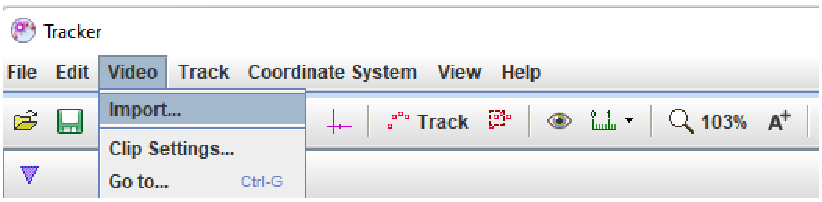
Tracker is a digital video analysis software (developed by Douglas Brown) that allows marking the different positions of an object over time, according to a reference and a measurement scale, using the time base of the video itself. In this way we obtain a table of positions versus time.



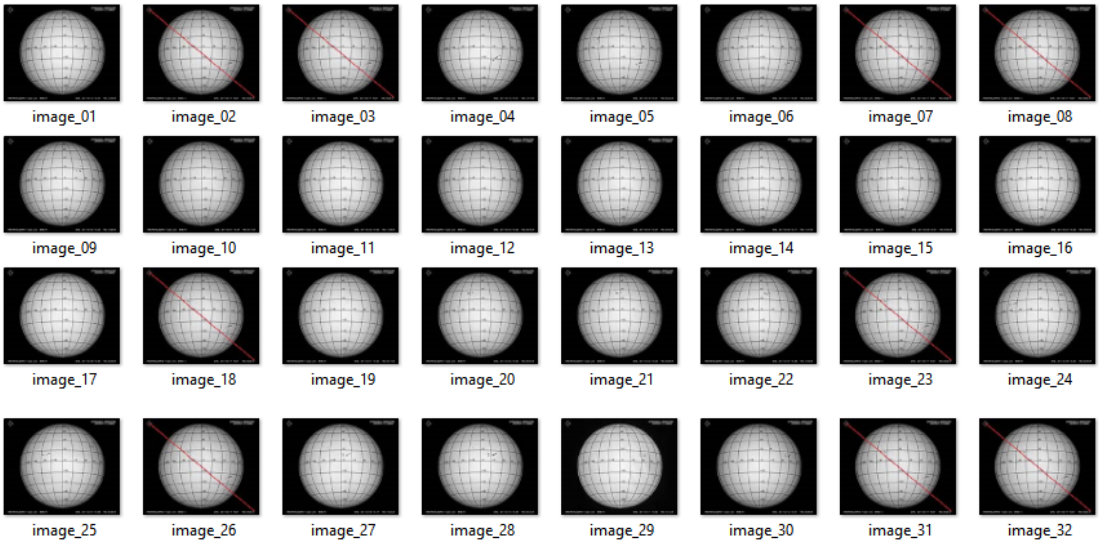
Procedures

1. Download and install the program Tracker (from Open Source Physics website https://www.compadre.org/osp/webdocs/Tools.cfm?t=Tracker). Download, the set of images of the Sun provided by OGAUC.

2. Open the program Tracker and load the entire set of images into it. To do that, from Tracker's Menu, select **Video** **Import**... and navigate to the spetroheliograms directory and open the (image) file "image_01.jpg" corresponding to the spectroheliogram of 12th Feb 2011 (12h36).

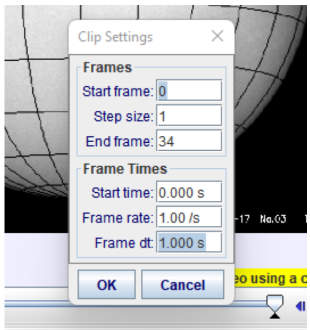


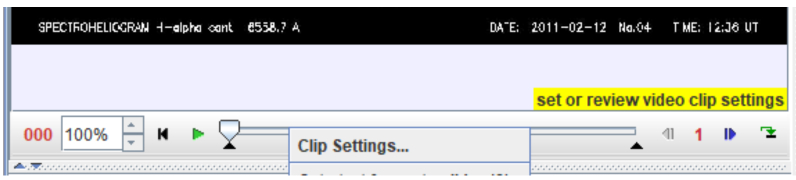
All the files in the set are sequentially numbered and Tracker will load them all. Press the **green play** button, to check that all the images have been loaded. At this point, we must have a video of the rotation of the Sun.



Note: Image sequence numbering must have a fixed format. For example, selecting the first image in a sequence numbered image_01.jpg to image_25.jpg it will open all the 25 images, but if the sequence is numbered image_1.jpg to image_14.jpg then only the first 9 images, from 1 to 9, will be opened.

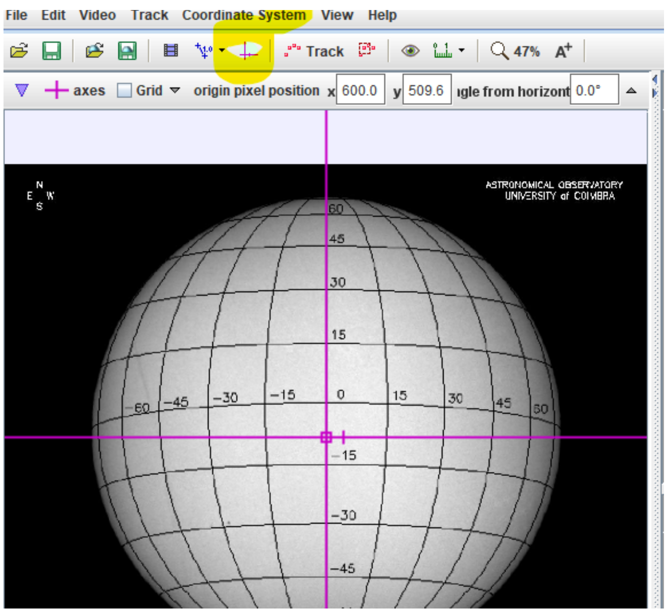
3. Set the time **Δt** between frames to 1 second. **Right click** on the video, or on the video control slider, and select the **Clip Settings** menu item. Set the **Frame duration** to **1s**.



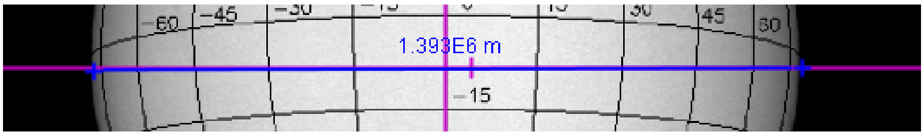


Note that this the time in between images is actually 1 day.

4. Set the origin of the coordinate system. Select the show coordinate axes icon (yellow mark), to overlay the axes referential on the images. Drag and set the coordinate axes to the center of the Sun such that the coordinate cross is centered on the Sun's image.



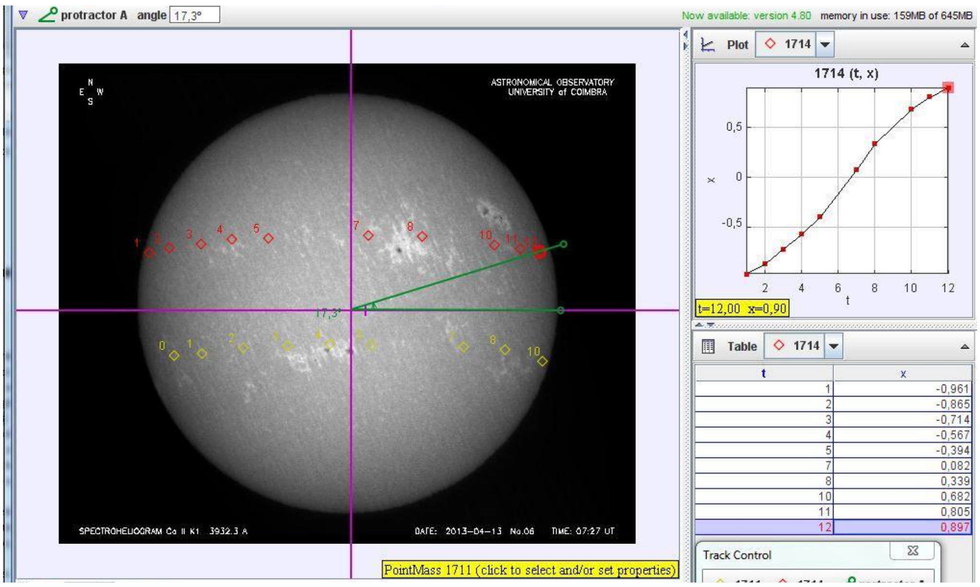
5. Set the scale of image. Click on the **calibration tools icon**, and add a new calibration stick. Drag each of the ends of the stick to one edge of the Sun near, if not on top of, the coordinate axes. This will give the length of this calibration stick as the diameter of the Sun. Double-click on the number and set to 2 (as in 2 solar radii if you want to work in radii) or 1392700 (if you prefer work in km).



6. Choose a sunspot/group of sunspots and track its position over time. To do that select on menu bar the icon **Track New Point Mass**. By default, the Track Control window will call this new track mass A. You can right-click on the **mass A** field and change its name to sunspot A. Find a sunspot easy to track that maintains its shape across the Sun. You may also want to right-click in the video to **Zoom In** or **Zoom Out** to aide your view of the sunspot. **Shift-click** on a sunspot to begin tracking your sunspot. Tracker will step forward to the next image so that you can continue tracking the position of that sunspot for the entire sequence marking it on each frame, with the exception of dummy frames (jump them). You may start or stop tracking at any frame, so you do not need to choose a sunspot that is visible at the start of the image sequence.

Perform Investigation

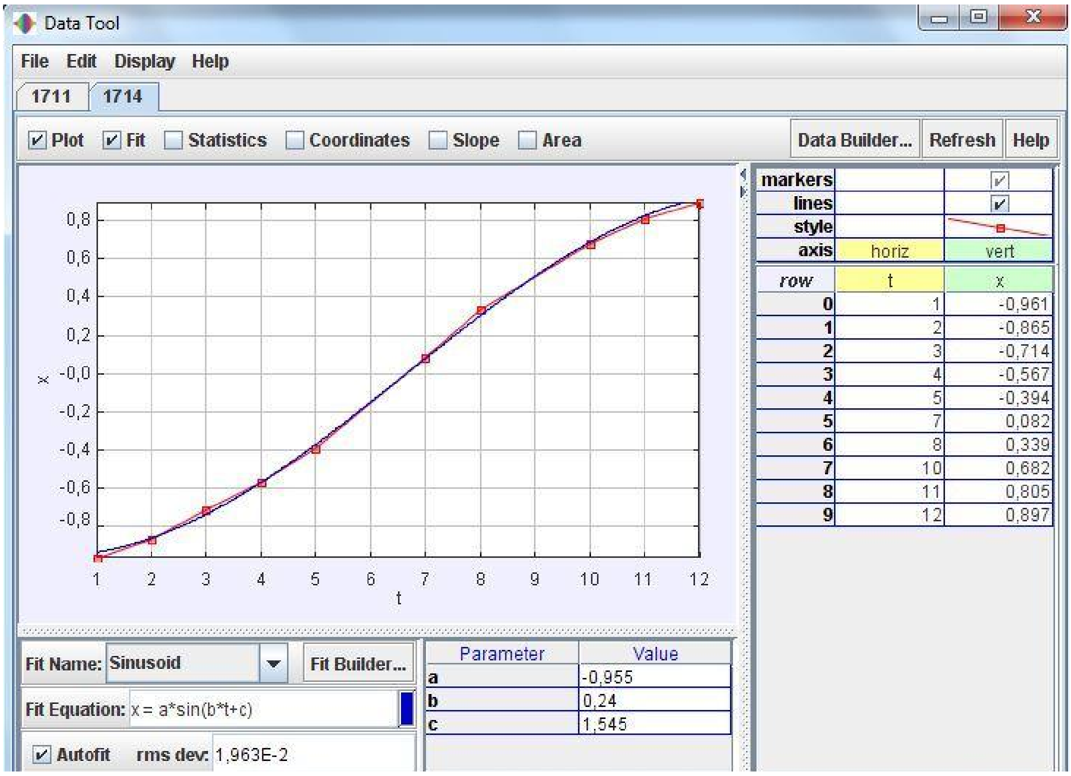
7. Each mark we make on the position of the choosen sunspot on each frame Tracker assign it.This results in a table of position and time values, and the respective graph, where you can see the **sinusoidal shape** of the function defined by the experimental points. If we down have a grid over the images the Tracker also has a very useful tool for our process - the Protractor- with which we can estimate the angle that defines the solar latitude, in this case 17.3º.



Analysis & Interpretation

Analysis and interpretation : Gather result from data

8. **Right-click** on the graph (x vs t) and select "**Analyze**…" Tracker's built-in data tool will open. Check the box for fit and select the sinusoidal fit in the fit name drop down. The fit equation is: **x = a*sin(b*t+c)**. Check Autofit box to run the fit algorithm. If the data and the fit are right on top of each other, go to next step (step 9). Otherwise, click on the value cells of the table of a, b, and c values. A small pair of up/down buttons will appear. Adjust the "a" parameter so that the sin curve's amplitude matches your data. Adjust the "c" parameter so that the sin curve crosses x=0 at the middle of the graph. Now adjust the "b" parameter which changes the frequency of the sine curve so that the curve closely resembles your data. Now check the Autofit box. Your fit curve should now overlap your data.



9. **Calculate the angular speed, ω.** We are only interested in the b value from the sinusoidal fit, which is the angular speed of the sunspot, ω.

Thus, we obtained by sinusoidal regression (generic expression x= A sin (ω.t)), the value of 0.24rad/day, for the angular velocity value ω (parameter b).

Knowing that $\omega = 2\pi/T \Leftrightarrow T = 2\pi/\omega = 2\pi/0.24 = 26.18$ days

We have thus determined the value of the period T of solar rotation of the spots under analysis, at the solar latitude of 17.3º.

Conclusion & Evaluation

Conclude and communicate result/explanation

Now that you have found the answers to the problem, carry out some research that will help you to better understand the reasons of the behavior of the sun. Prepare a written work/electronic presentation about your object of analysis in order to present it to the class with your results.

Present your results to the class and record a table with the Rotation Period and the respective solar latitude of the sunspots. Discuss the results and verify how the period varies with solar latitude, describing and concluding if the Sun behaves as a rigid body or, if not, where it has the highest angular velocity.

Compare your result with the data about the differential rotation of the Sun presented on literature. Search for the work of Carrington (1863) of this subject.

Evaluation/Reflection

About the importance of this little project for you, rate from 1- very poor to 5-Very good each topic:

- The interest that this activity represented for you.
- The knowledge acquired/reinforced
- the skills you worked

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