UNIVERSITY COLLEGE LONDON University Of London Observatory

PHAS1510 – Certificate in Astronomy 1213.01

PHAS1510-10: Tracking Sunspots

Modified from an original document from the Remote Access Astronomy Project, University of California. Original authors were Jatila van der Veen and Philip Lubin. Used with permission.

Name:___________________________________

An experienced student should aim to complete this practical in 1 session. Before attempting the exercise, you should read Chapter 18 of Universe.

1 Objectives

The aims of this practical are to calculate the rotational period of the Sun from the daily movement of sunspots on the solar surface and to get a feeling for just how active the Sun really is.

2 Items required

You will need:

- A set of sequential images showing the full disk of the Sun.
- A copy of the ImageJ image viewing software.
- A calculator or a copy of the Excel spreadsheet designed for this exercise.(Before running the program you should ensure that the MS-Windows default printer on the desktop of the ULO computer you are using is set to the 'ULO-NWcolourprinter'. Ask a demonstrator to make the change for you if you are unsure how to do this.)

The ImageJ software, suitable images and the spreadsheet are available on the Certificate's Web site.

If you are logged in on a ULO Windows PC, then the spreadsheet may be opened by clicking on the `Tracking Sunspots (Diploma)` shortcut on the Windows desktop. You can save your work at any time on your `H:` drive `(Homes on Uno)`. The spreadsheet is also located on the `Public` drive at

`P:\COURSES\CERTIFICATE\10_sunspots\sunspots-calc_final.xls`

If you wish to work on this at home, email yourself a copy of the spreadsheet. ImageJ is available on the Certificate's Web site as a download. *N.B. Please hand-in a printed copy of all your spreadsheet data and spreadsheet calculations along with your completed experiment script for marking.*

3 Introduction

Recorded observations of sunspots date back 2000 years to ancient Chinese observers; Indian astronomers also recorded observations of sunspots, and there are references to them by Greek observers from around 400 BC. In western history, Galileo was among the first observers to look at the Sun through a telescope, in 1610, and observe "dark spots" on its face.

3.1 Observational Characteristics

In ordinary visible light sunspots appear dark compared to the rest of the solar surface because they are cooler than the surrounding regions - "only" about 4000 K, while the average temperature of the photosphere (solar surface) is 5780 K. The reason why sunspots are cooler than the rest of the Sun's surface has to do with the complicated interactions between the solar magnetic field and convecting ionised gases in the outer layers of the Sun.

3.2 Heat transport in the Sun

The Sun is made mostly of ionised hydrogen. In the core, where the thermonuclear reactions that make the Sun "shine" are taking place, the temperature is millions of degrees Kelvin. Heat is carried away from the core to the outer layers by the slow process of radiative transport. It takes energy hundreds of thousands of years to travel from the interior of the Sun to the outer layers because the radiation can't flow rapidly outward – it "bounces around" in the interior. Within the upper 100,000 km of the Sun, however, heat is transported to the surface more rapidly by convection.

3.3 Magnetic fields in the Sun

The strong magnetic fields of sunspots keep the hot, ionised gases from reaching the surface and releasing their heat directly below the sunspots; this is what causes sunspots to be somewhat cooler than the rest of the Sun's surface and appear dark in comparison[1].

The Sun as a whole has a weak magnetic field, similar to that of the Earth, with the magnetic field lines emerging at the north pole and re-entering at the south. The overall intensity of the solar magnetic field is about 1 Gauss - the same as that of the Earth.
(1 Gauss = 10^{-4} Tesla = 10^{-4} Newton/Amp-metre.)

In sunspots, however, the local magnetic field can be several thousand times stronger. We know this is so because of the splitting of the lines in the absorption spectra of sunspots. This effect, called the Zeeman effect after the Dutch physicist who discovered it in 1886, was first observed for sunspots by George Ellery Hale in 1908, at the Mount Wilson Observatory.

3.4 Rotation rates of the Sun and formation of sunspots

The Sun behaves like a fluid. While the terrestrial planets are solid and rotate as rigid bodies, the Sun rotates faster at its equator than at its poles. As a result, the north-south magnetic field lines get stretched out in an east-west direction, at lower latitudes, wrapping up and eventually pinching off and forming intense localised fields. Sunspots tend to form in pairs, one a north magnetic pole where the local field lines emerge from the surface, and the other a south pole where the local field lines plunge back into the solar surface. Sunspots are often accompanied by towering arcs of ionised gas that follow these local field lines.

[1] If you could isolate sunspots they would appear far brighter than the full Moon, but somewhat red.

One way that astronomers have deduced the variable rotation rate of the Sun is by observing the motion of sunspots at different latitudes. (Another way is by observing the *Doppler shift* of spectral lines in the photosphere at various latitudes.)

3.5 Observing the Sun

You cannot safely observe the Sun directly in visible light! However you can observe sunspots with a small telescope if you project the image of the Sun onto a screen. If there are any sunspots, they will appear as dark spots on the solar disk. Other ways to observe the Sun are with special filters or digital cameras that are sensitive at X-ray or other wavelengths.

4 About the images

The images you will use in this activity were taken through a special "white light" filter. This filter reduces the intensity of light passing though the telescope by reflecting the majority of radiation away. Only a tiny fraction of the incident radiation is transmitted, passing through the telescope and onto the camera.

The white light filter used is similar to the one that can be fitted on the Meade telescopes at ULO. (You may have an opportunity to use these telescopes to observe the Sun.)

The images show the yellow disk of the Sun, speckled with brownish sunspot groups. If you look closely at these sunspot groups, you can make out some of the structure. Surrounding some of the groups are "plages". These appear as white irregular patches and are hot, disturbed gas. They usually precede the formation of sunspots and persist even after the sunspots have disappeared. You can see plages on some of the images provided.

5 Calculating the average speeds of sunspots.

On a PC running Windows, run ImageJ by double-clicking the icon. To complete this exercise, you will need a selection of images of the Sun taken over sequential days. Suitable images taken by the Mees White Light Telescope (MWLT) at the C.E.K. Mees Solar Observatory in Hawai'i are available in ImageJ under `File/Open Samples`. The date of each observation is given in the menu. All images were taken at 17:05 UT. ULO staff have scaled each image to be the same size and have rotated them so that the N-S line is vertical in each image.

Bring up each image, one at a time, onto the screen. The sunspot groups should be obvious. You can zoom-in by selecting the magnifying glass tool and left-clicking on the image and zoom-out by right-clicking. You can measure coördinates using the cross–hair tool. You can scroll around the image while using either tool by holding the space-bar down.

Choose a sunspot and observe how it moves across the solar disk as time progresses. You should ensure that your chosen sunspot is clearly visible in each image.

If you want more information about your chosen sunspot's group, try looking in the archive section of spaceweather.com[2]. You are going to determine the Sun's period of rotation by measuring the position of your sunspot as the Sun revolves.

ImageJ is able to display coördinates using both the top left and bottom left hand corners of the image as the origin. *Check that the origin is in the bottom left hand of the image.* If this is not the case, go to the `Analyze\Set Measurements...` menu and tick the `Invert Y Coordinates` check–box.

[2]http://spaceweather.com/archive.php

For the calculations that we are about to do, we must define the centre of the Sun's face as our origin. The position of your chosen sunspot must then be found relative to this zero point. The `sunspots-calc_final.xls` spreadsheet provided for this exercise is able to do this automatically.

For each image note the date and record the x and y coördinates of the same spot as it appears in each image. Enter this information in Table 1 on page 4 and then copy the x and y coördinates into the appropriate columns of the `sunspots-calc_final.xls` spreadsheet.

Image Name	Date	Time (UT)	x coördinate	y coördinate
sun-170603-1705.jpg	17/06/03	17:05		
sun-180603-1705.jpg	18/06/03	17:05		
sun-190603-1705.jpg	19/06/03	17:05		
sun-200603-1705.jpg	20/06/03	17:05		
sun-210603-1705.jpg	21/06/03	17:05		
sun-220603-1705.jpg	22/06/03	17:05		
sun-230603-1705.jpg	23/06/03	17:05		
sun-240603-1705.jpg	24/06/03	17:05		
sun-250603-1705.jpg	25/06/03	17:05		

Table 1: Enter your raw data in this table.

5.1 Translating from flat images to the real Sun.

Now comes the tricky part: we have pictures that are a projection of a round object onto a flat plane. When we observe the motion of a feature going around the sphere of the Sun *on a flat image* we may get the wrong idea about how fast the feature is moving. It will seem to us, from our point of view, that when a particular sunspot is near the edge of the Sun in our image it moves more slowly than when it is closer to the centre of the Sun *in our particular field of view.*

So, we have to translate the motion we observe on the flat image to what is really happening on the spherical surface of the Sun.

On a flat plane, like our picture, we find it most convenient to express the position of a point in terms of its x and y (Cartesian) coördinates. A sphere is 3-dimensional, so we have to add a third axis, z. Because our image of the Sun is a projection of 3 dimensions onto 2, we can translate what we observe in 2 dimensions back to 3 dimensional "reality" by using a bit of simple trigonometry.

We translate the motion we observe in 2 dimensions to motion on a sphere in terms of R, the radius of the sphere, and two angles: θ, the angle from north to south, and ϕ, the angle from east to west. Omitting the derivation (you can look that up yourself if you are interested!) we can find θ and ϕ from our x and y measurements using Equations 1 and 2 [3].

$$\phi = \tan^{-1}\left(\frac{x}{\sqrt{R^2 - x^2 - y^2}}\right) \tag{1}$$

$$\theta = \cos^{-1}\left(\frac{y}{r}\right) \tag{2}$$

Here R is the radius of the whole Sun, and r is the projection of the vector $\overline{R}$ onto the $x - z$ plane, and is given in Equation 3.

$$r = \sqrt{R^2 - y^2} \tag{3}$$

5.2 Calculations

The spreadsheet provided does most of these calculations for you, but you should work through this section to understand what it is doing, and fill in the appropriate values where indicated. Be sure to include the units of all your answers, and to quote them to a suitable accuracy.

1. Find the radius of the Sun in pixels by measuring the diameter of the Sun on two or three of the images and dividing by two. What is the average value of R that you have measured? (This value is required in the spreadsheet for the calculations.)

   $R =$

   ____

2. What is the mean change in ϕ each day?

   $\overline{\Delta\,\phi} =$

   ____

   This angle represents the number of degrees per day by which your sunspot has moved.

[3] $\tan^{-1}$ and $\cos^{-1}$ are inverse trigonometric functions. For example, if $\cos(\pi) = -1$ then $\cos^{-1}(-1) = \pi$.

3. Convert your average change in ϕ into the rotation period using Equation 4:

$$\text{Solar Rotation Period} = \frac{360^\circ}{\Delta\phi} \tag{4}$$

Solar Rotation Period =

If you came out with an answer in the neighbourhood of 25 to 28 days, you are correct!

Questions

Sunspot activity

4. Sunspot region 365 can be found at approximately (52,357) on 17/06/03. Comment on how the region appears to change as time progresses.

Solar scale

5. Given that the radius of the Earth is 6378 km, and the radius of the Sun is 6.96×10^5km, about how many times larger than the Earth's diameter is the diameter of sunspot region 365?

   Hint: To get a good estimate for this, you should use choose an image in which the sunspot group is approximately in the centre of the Sun.

Measurement errors

6. About how many pixels, on average, did you find that a sunspot moved in a day?

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7. What would you estimate your error in picking the same point on the sunspot in each image is; $\pm$ how many pixels?

8. What percent of the daily change in position of a sunspot is your error in picking the same point on that sunspot?

9. How do you think your errors in measuring the coördinates of the sunspot in each image affected your estimates of the rotation rates?

6 References

- Lubin, P. and van der Veen, J. *Tracking Sunspots*, Remote Access Astronomy Project, University of California at Santa Barbra.

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