NUCLIO
Núcleo Interactivo de Astronomia

Sun4All

EU-HOU
Hands-On Universe, Europe
Bringing frontline interactive astronomy to the classroom

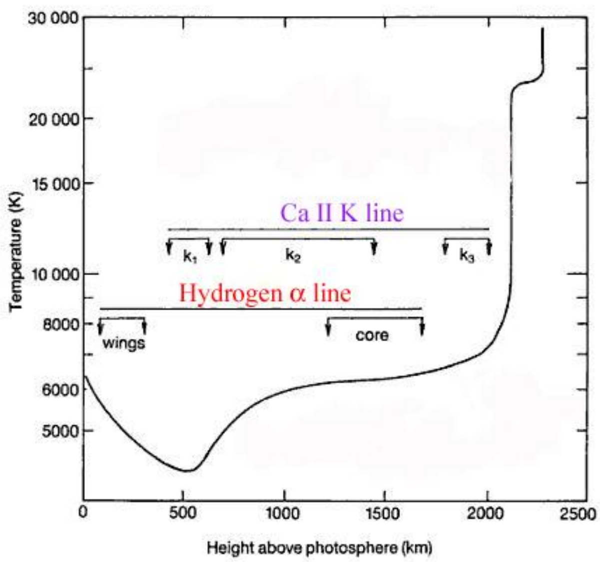
This exercise is based on images taken with the spectroheliograph located in Astronomical Observatory of the University of Coimbra (Portugal). The archives of Coimbra observations is accessible through this Web page:
http://www.astro.mat.uc.pt/novo/observatorio/site/arquivo.html

How to start:

1. Images taken with different filters (i.e. different wavelengths) allow us to look at different depths in the Sun atmosphere and highlight different characteristics. Using SalsaJ, open the images:
    images_Sun4All/Sun1_1600.jpg
    images_Sun4All/Sun2_4500.jpg
    images_Sun4All/Sun3_0335.jpg
   and put them in a stack using "Image/Stack/Images to stack". The three images are taken at the same time at a wavelength of, respectively, 1600 A, 4500 A and 335 A, by the Solar Dynamic Observatory (http://sdo.gsfc.nasa.gov/data/). Click on "Image/Stack/Animation Options" and choose e.g. "1" for "speed". You can launch (resp. stop) the animation with "Image/Stack/Start Animation" (resp. Stop Animation).

2. The first two images show the photosphere. At the center of the image, you can see a dark spot: it is called a sunspot, a colder zone in the Sun photosphere.
   The third image, showing the corona (the most external part of the Sun atmosphere) allows you to see the magnetic lines originating the sunspot.

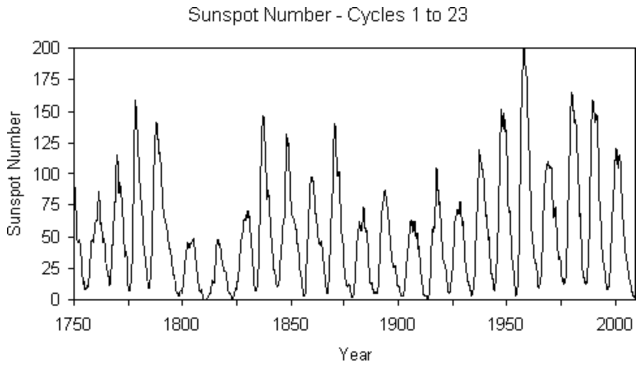
3. In the following, you will use images taken with the Calcium lines (K1v and K3) and hydrogen line (Ha) at different epochs. K1v filter images enable to study the photosphere, while the K3 and Ha filters are used to observe the chromosphere.



Graph showing the height above the photosphere of the Ca II K and Hα line (Vernazza et al., 1981)

Counting sunspots in a time sequence

In 1844, Heinrich Schwabe conjectured about the existence of a sunspot cycle: that is, the number of sunspots should change periodically. In fact, counting of the sunspots over several years reveals maxima and minima, regularly spaced in periods of approximately 11 years.

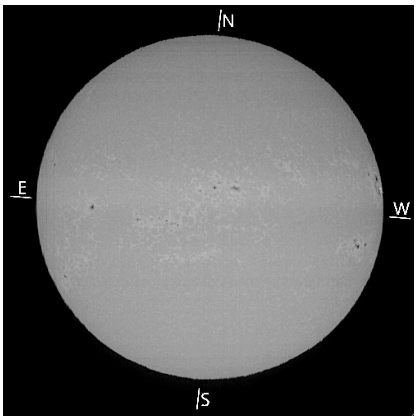


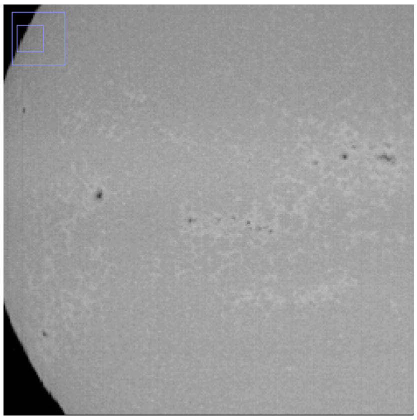
Solar cycles from sunspots number (http://www.ips.gov.au/Educational/2/3/1)

1. In this exercise, we will count sunspots on 7 images of the Sun (images_Sun4All/ Sol_K1V_*.jpg) taken between 1994 and 2006 to show the evolution of solar activity during the 23rd (and last, until now) solar cycle.

2. In the SalsaJ toolbar, click on File/Open. Open the file:
   images_Sun4All/Sol_K1V_010113.jpg.

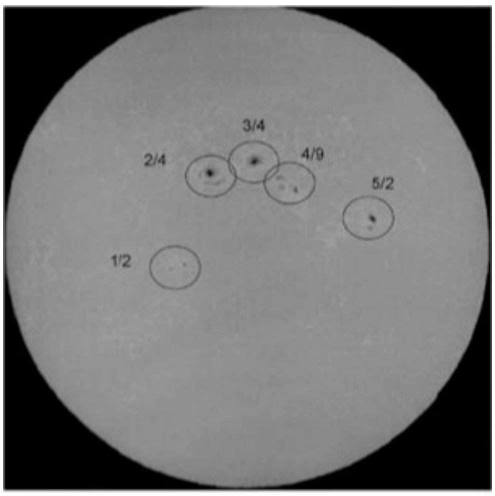
3. In order to get a better view of the image, it is convenient to invert the Look Up Table (LUT, correspondence between colours and intensity). Click on Image/LookUp Tables/Grays invert.





The sun in K1v on 27/12/2001 *Zoom on some group of sunspots*

4. We will use a counting criterion and technique based on **Wolf's index**, established in 1849 by the Swiss astronomer Johann Rudolf Wolf (1816 – 1893).
   Wolf's index is represented by **R** and is calculated by the formula **R= 10 g + s**, where **g** is the number of observed groups of sunspots and **s** is the total number of single sunspots of all groups.



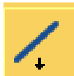
5. On the figure on the right hand side, there is an example to help with the counting method. Five groups (therefore g=5) were identified and in each group a different number of sunspots was identified (on the figure, the group number/number of sunspots in the group is shown inside an ellipse). So, we have a total

number of 21 sunspots (thus s=21). We can easily calculate R=71.

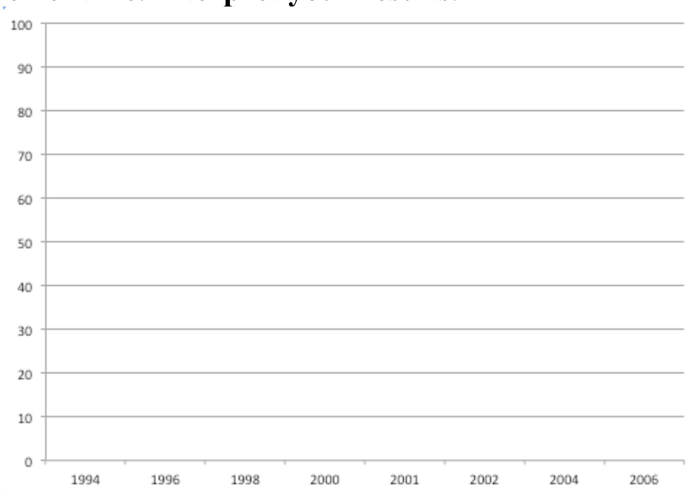
6. Now close the image and use “Plugins/Macro/Sun4All: Solar cycle with sunspot counting” in order to open some images taken in the period 1994-2006 and perform the inversion as described above. Start counting the sunspots and groups and fill up the table below.

Image	Nb. of groups **g**	Nb. of spots **s**	Wolf’s Index **R = 10 g + s**
Sol_K1V_940126.jpg			
Sol_K1V_960109.jpg			
Sol_K1V_980125.jpg			
Sol_K1V_000118.jpg			
Sol_K1V_010113.jpg			
Sol_K1V_020126.jpg			
Sol_K1V_040122.jpg			
Sol_K1V_060126.jpg			

Note : sometimes the difference between single sunspots and groups is not always clear. You can use the  tool to zoom the image, then use the  tool to select a group of sunspots and start counting the spots in the group.

To highlight single sunspots, you should use the  (segment) tool, drawing a segment across some sunspots of a certain group of sunspots. Select the “Plot Profile” option of the “Analyse” menu. It will draw the Plot Profile, which provides information on the intensity of the points of the image covered by the segment. If a certain maximum is considerably superior to others immediately before and after, it is almost certainly corresponding to a sunspot in the image.

7. Now plot (on the grid below or in an Excel spread sheet, for example) the Wolf’s index as a function of time. **Interpret your results.**



To proceed to the next step, we can now close all the image windows with Plugins/Macros/Close All images windows.

Solar rotation

The solar rotation is differential; this means that the its period varies from about 24 days for the equator, to for instance 31.5 days near latitudes ±70°. We can estimate this period with some of our data.

1. Open the four following files:
   images_Sun4All/ Sol_K1V_921121.jpg,
   Sol_K1V_921122.jpg,
   Sol_K1V_921123.jpg,
   Sol_K1V_921124.jpg.

2. As before, invert the LUT table (with Image/LookUp Tables/Grays invert).

3. Stack the images with Image/Stacks/Images to stack.

4. Start the animation with Image/Stacks/Start Animation. It is possible to zoom and recentre the stack on a particular area of the Sun. Click on the image to stop the animation or Image/Stacks/Stop Animation.

5. Optional Operations:

   Save the file in avi format with File/Save as/AVI…. Make sure you add the extension (avi): "Filename.avi" and choose the folder where to save it.

   In order to enhance the visible sunspots in the image, it is possible to apply some changes, both in colour, brightness and contrast. In the "Lookup Tables" of the "Image" menu you can choose one of the available options to change the colour of the image or of the previous stack. For instance, the "Fire" LUT gives nice results. To enhance the spots, invert the LUT using Image/Lookup Tables/Edit LUT and click on invert. Using the  (brightness and contrast) tool and changing its parameters, you can enhance the sunspots.

6. Open images Sol_K1V_921121_withgrid.fits and Sol_K1V_921124_withgrid.fits. Those are simply the first and last images of the previous collection, on which we have superimposed a grid showing the meridians (-80, -60°… +40°, +60°, +80°).

7. As before, invert the LUT table (with Image/LookUp Tables/Grays invert).

8. Consult on http://www.astro.mat.uc.pt/novo/observatorio/site/arquivo.html the exact date and time of the images.

9. Estimate the displacement in longitude of one sunspot during this interval. For example, you may choose the sunspot located on the –40° meridian, and closest to the equator.

10. Estimate the solar rotation period for this latitude.

Computing the real size of prominence

1. Open the following file: images_Sun4All/Sol_K3_990909.jpg

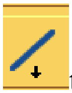
2. Invert the Lookup Table with Image/LookUp Tables/Grays invert or Image/Lookup Tables/Edit LUT and click on invert.

3. Pass the mouse on the “Rectangular selection” button and click with CTRL + the right button to select “Oval selection”: the icon is then changed from a rectangle to an oval.

4. Click on Oval selection to adjust an oval to the limb of the Sun.

5. Determine the area of the Solar disc with Analyse/Measure. A results window appears providing the value of the area.

6. Zoom in the image using the  tool and locate the prominence you will be working on using the  tool.

7. Draw a segment connecting the two extremes (the beginning and the end) of the prominence, using the  tool.

8. Determine the length of the drawn segment with Analyse/Measure.

9. Using the area of the solar disc previously measured in pixels, and the height in pixels of the prominence represented in the image, determine the range of the prominence as a function of the Sun radius.

10. Knowing that the radius of the Sun is 690,000 km, calculate the real range of the prominence (in km).

11. Proceed in similar way to determine the maximum height reached by the prominence (in km).

12. Now comment the sentence "…the astronomers thus became aware of their gigantism..." (referred to the solar prominences). Complementary data: Earth’s diameter d = 12,800 km.

Estimating the speed of ejection

We will now outline the procedure to calculate the speed of the ejection $\mathbf{V_0}$ of the prominence present in the studied image (images_Sun4All/Sol_K3_990909.jpg), using the data calculated in the previous section.

Assumptions defining the framework of the problem:

- We consider that the material of the arch is subjected only to his "solar weight", that means the gravitational attraction of the Sun (thus, we neglect any other force, including magnetic forces).
- We will admit that the solar referential is Galilean. Hence, we will neglect all effects due to his rotation.
- It is supposed that the picture corresponds to an arch in a plan perpendicular to the direction of aiming.

Data:
- mass of the Sun **Ms** = $1,99*10^{30}$ kg
- Gravitational constant **G** = $6,67*10^{-11}$ I.S.U.

One possible procedure:
From the assumptions formulated above, our problem is equivalent to the study of the movement of a mass **m,** regarded as specific, in the field of uniform gravity of the Sun. In this case the movement is parabolic. Using the data measured above of the range of the "shooting" and the maximum height reached by the prominence, it is possible to find the firing angle (between the initial speed $\mathbf{V_o}$ and the local “horizontal line”) as well as the value of initial speed $\mathbf{V_o}$.

An example of detailed progression:

1. Calculate the value of gravity **g** on the surface of the Sun, starting from the Newton’s law of universal gravitation.

2. On the image, the matter is ejected from the surface of the Sun, from point **O**, with a speed $\mathbf{V_o}$, forming an angle $\boldsymbol{\alpha}$ with the horizontal line, at the date **t=0**. A dynamical analysis (assessment of the forces, and application of the Newton’s second law) of the movement of a material point **P**, pertaining to the arch and of mass **m**, show that:
   $\mathbf{x(t)} = V_o.\cos(\alpha).t$
   $\mathbf{y(t)} = - 1/2\ g.t2 + V_o.\sin(\alpha).t$

3. By eliminating the time t, find the equation of the trajectory:
   $\mathbf{y(x)} = - (\ g / 2.V_o^2.\cos^2(\alpha)\ )\ x^2 + \tan(\alpha)\ x$

4. The range of the shooting corresponds to the x-coordinate x_p (different of 0) such as $\mathbf{y(x_p)=0}$. Determine the literal expression of $\mathbf{x_p}$ according to α, g, V_o.

5. Determine in the same way the literal expression of maximum height reached $\mathbf{y_s= y(x_p/2)}$.

6. Then find that : $\mathbf{y_s/x_p} = 1/4 \tan(\alpha)$

Numerical applications:

1. Calculate the value of $\boldsymbol{\alpha}$ in radians, then in degrees.
2. Using the data calculated in the previous session, **calculate the value of $\mathbf{V_o}$**.

Typical velocities of prominences are around 200km/s.