SOL PARA TODOS

GUIDEBOOK

SUN FOR ALL

INDEX

0. Abstract Summary and goals of the project

This document presents a set of activities to be developed within the aim of the project "Sun for all", funded by Ciência Viva (2005 117/ 18). The goal of this project is the promotion of science in general and astronomy in particular, among students.

The project is based on an asset of over 30000 images of the Sun (spectroheliograms) that are kept at the Astronomical Observatory of the University of Coimbra, as result of a work of over 80 years of daily solar observations, started in 1926.

Presently there are about 15000 digitised images available to the general public due to another project, also funded by "Ciência Viva", which was developed from 2002 to 2004.

The solar observations collection has an enormous scientific value and this project makes this collection available in digital way via WWW to Portuguese and foreign students, as well as a set of activities that enables them to use the images, thus introducing them to the scientific method, having the Sun and its atmosphere as background.

1. Introduction

The Sun is the nearest star to the Earth. Our planet is, therefore, dependent from this star since its formation. This dependency isn't just because of the yearly Earth translation movement around the Sun. It is much more than that. The Sun is the Earth's main source of heat and light, essential to all the life it holds. The phenomena that occur (occurred or will occur) inside the Sun and on its surface cause impact on Earth's surface.

It is not always easy to understand or measure this impact and, in many cases it is equally complex to establish cause-effect relations. It all depends on the phenomenon and its intensity. However, there are confirmed results, which show the Sun-Earth interaction. On image 1, two diagrams are compared: the red line represents the temperature variation on the surface of Earth since 1855 up to 2000; the blue one represents the solar irradiation value received on Earth during the same period of time.
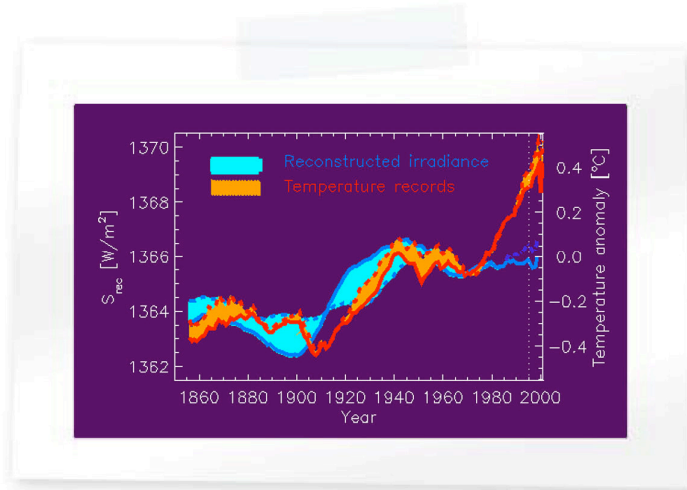

Figure 1: Solar irradiation and temperature variation since 1855 up to 2000
(source: http://www.mps.mpg.de/projects/sun-climate/resu_body.html)

As you can see, there is a clear correlation between the two diagrams until 1980 and since then, the two graphs diverge. This divergence, giving way to an anomalous temperature raise, can be explained by phenomena as the greenhouse effect, an actual problem with decisive importance for the Planet's future.

The solar surface irradiation is one of the measurable impacts of the Sun on Earth. It is especially regulated by what happens on the Sun's atmosphere. There are several phenomena that flow from the solar atmosphere, such as prominences or sunspots - Figure 2.
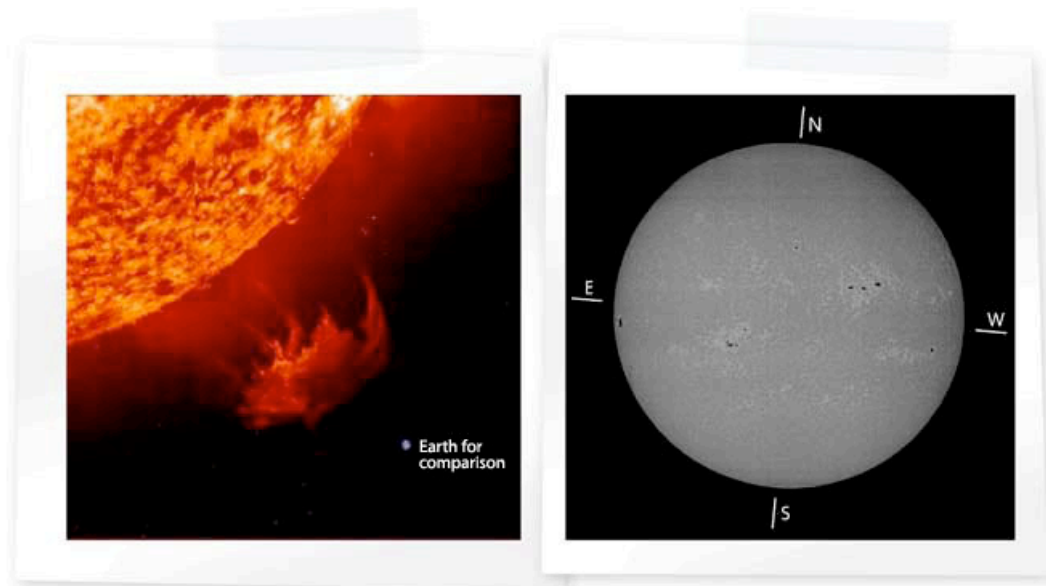

Figure 2: The left image shows a prominence and also the comparison between its size and the size of the Earth. On the right, sunspots can be observed, identified as the darker zones on the Sun's surface.
(source: SoHo, ESA and the Astronomical Observatory of the University of Coimbra)

In figure 3, two curves are compared: the solid line represents the average change of temperature on Earth's surface from 1856 up to 2000; the dashed line represents the number of observed sunspots during the same period of time.

Again, as it could be observed by the irradiation phenomenon, a divergence is detected around 1980.
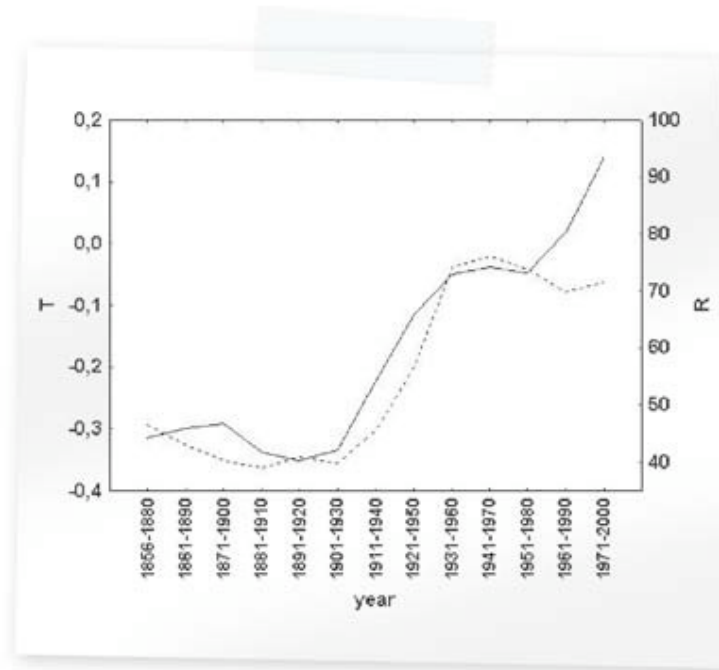
Figure 3: Temperature versus number of sunspots from 1856 up to 2000
(unknown source)

But the Sun-Earth interaction can be observed in different ways besides the ones related to the climate. Solar flares, being extremely energetic, can interfere with daily life. On the 30th of October of 2003, a solar "storm" damaged North American's power-station systems, causing a 9 hour blackout in many Canadian cities. On the "Space Weather" web site (http://www.solarstorms.org/SRefStorms.html) one can find a journalistic register of many solar storms that occurred between 1859 and 2003, many of them responsible for material damages. Therefore, studying the Sun, besides being interesting itself, presents an important tool to understand much of what happens on our Planet's surface. Specifically, studying the Sun through the analysis of solar activity, which turns out to be the key theme of this particular project and the activities proposed below.

The majority of these activities are mainly focused on sunspots. In the next chapter a privileged space is given to this issue. The other manifestations of solar activity such as prominences and faculae will also be part of the proposed activities.

2. Solar activity: sunspots, faculae, flares…

Some historians state that it might have been Anaxagoras, in 467 BC, that firstly reported a sunspot observation. However, the first identified drawing of a sunspot dates from 1128 and was done by a Worcester's monk (in Great Britain) – Figure 4.

Figure 4: Historical drawing of a sunspot
(source: http://www.parhelio.com/articulos/artichistoria.html)

But only by using the telescope was it possible to start a regular and systematic counting of sunspots. Indeed, at the beginning of the seventeenth century, the drawing of sunspots was part of the observations done by Galileo Galilei with the help of a lunette, along with the discovery of the four biggest Jupiter satellites and the identification of the phases of Venus.

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 – Figure 5.
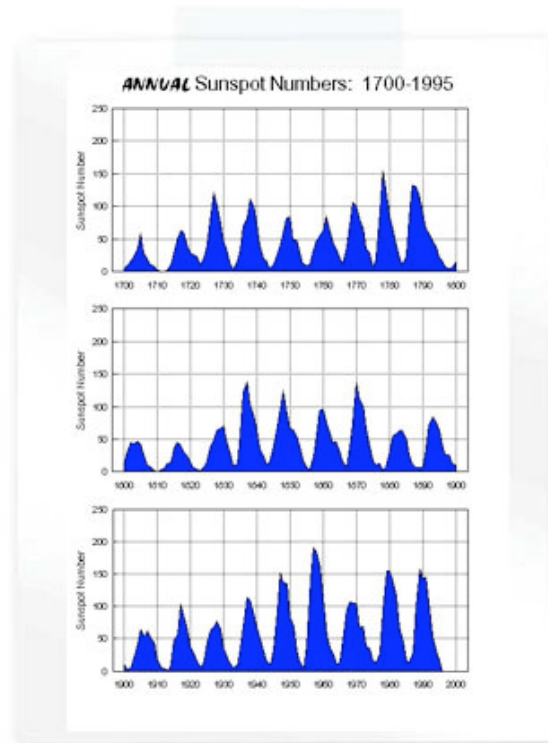
Figure 5: Variations on the number of sunspots between 1700 and 1995 and the solar cycle of 11 years.
(source: http://www.windows.ucar.edu/tour/link=/sun/activity/solar_cycle.html).

Understanding the cause of this periodicity or even explaining the reason why sunspots are formed are less obvious aspects than the detection and counting of these spots. Remember that the Sun is an approximately spherical body, essentially made of gas and plasma. Its atmosphere has three layers: the photosphere, the chromosphere and the corona. Figure 6 illustrates the location of these three regions.
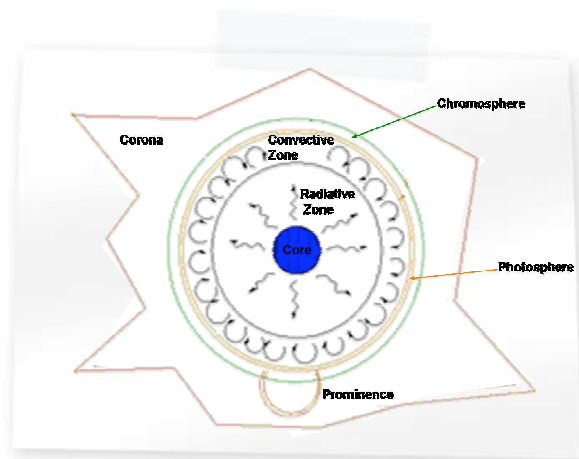

Figure 6: Diagram representing the Sun's internal and external structure: the photosphere, the chromosphere and the corona.
(source: http://www.windows.ucar.edu/tour/link=/sun/activity/solar_cycle.html)

The photosphere can be identified as the Sun's surface, with a temperature of about 5770[1] Kelvin (0° C = 273 K). Sunspots are formed within this. But how? The Sun holds a magnetic field, resulting from the combination of gas rising and sinking movements, which occur near the solar surface (the convection zone) and the Sun's rotation. The magnetic field generated in the interior rises up to the surface, creating spots – Figure 7.
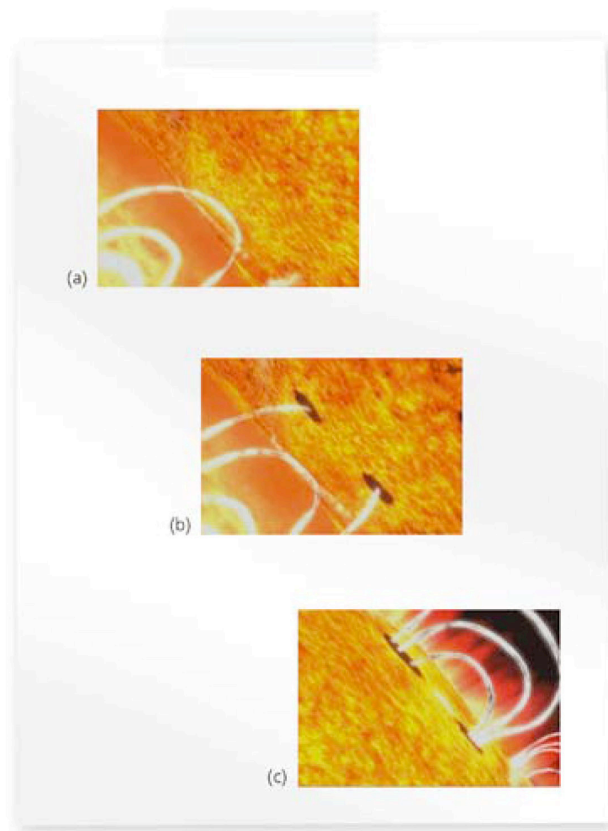

Figure 7: The magnetic field is generated in the interior of the Sun (a), then rises to the surface (b), and the magnetic field lines, intercepting the surface, create sunspots (c)
(source: http://sohowww.estec.esa.nl/gallery/Movies/10th/SunspotsForm.mpg, watch the film for a better understanding of the phenomenon).

The sunspots are darker than the surrounding photosphere, reflecting a difference between their temperature (about 3000 K) and the surrounding surface temperature (5770 K). On the other hand two different zones may be detected in a sunspot: the umbra (darker centre) and the penumbra (less darker border) – Figure 8.

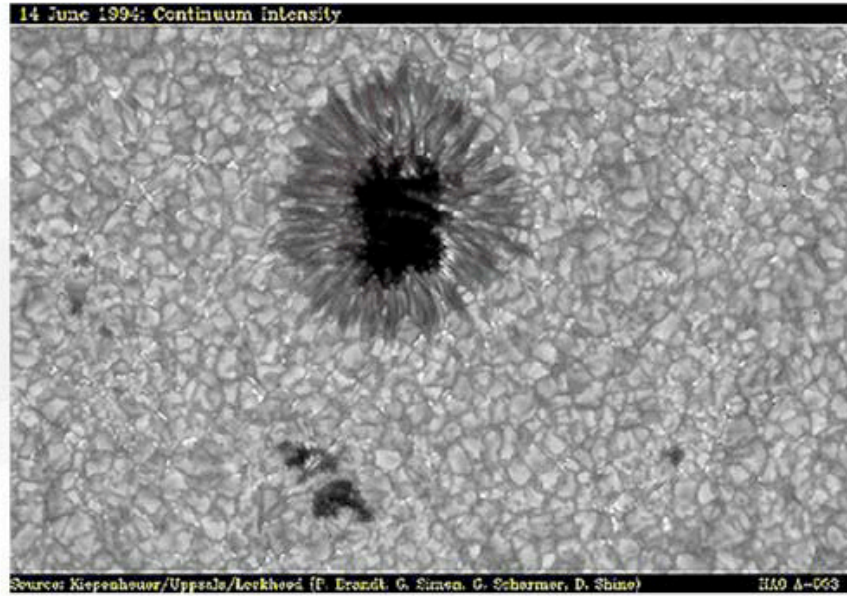[1] 0º=273 K

Figure 8: Detail of a sunspot: umbra and penumbra.
(source: http://web.hao.ucar.edu/public/slides/slide3.html)

Regarding the aforesaid, the sunspot's analysis is a very important aspect of the study of the phenomena occurring on the surface of Sun. Therefore, the activities here proposed will be particularly dedicated to sunspots and the kind of information that can be gathered from their analysis.

The photos that we will be working on are obtained through spectroscopy, in other words, through an analysis of the solar spectrum.

Some of the chemical elements on the solar atmosphere are not in their original state. This means that some electrons were "ripped out" from the atoms as consequence of high temperatures. This phenomenon, known as ionization, originates darker areas in the solar spectrum, which correspond to the radiation absorbed by the chemical element in exchange of one or more electrons. Figures 9 presents the spectrum band centred on the Hα line.
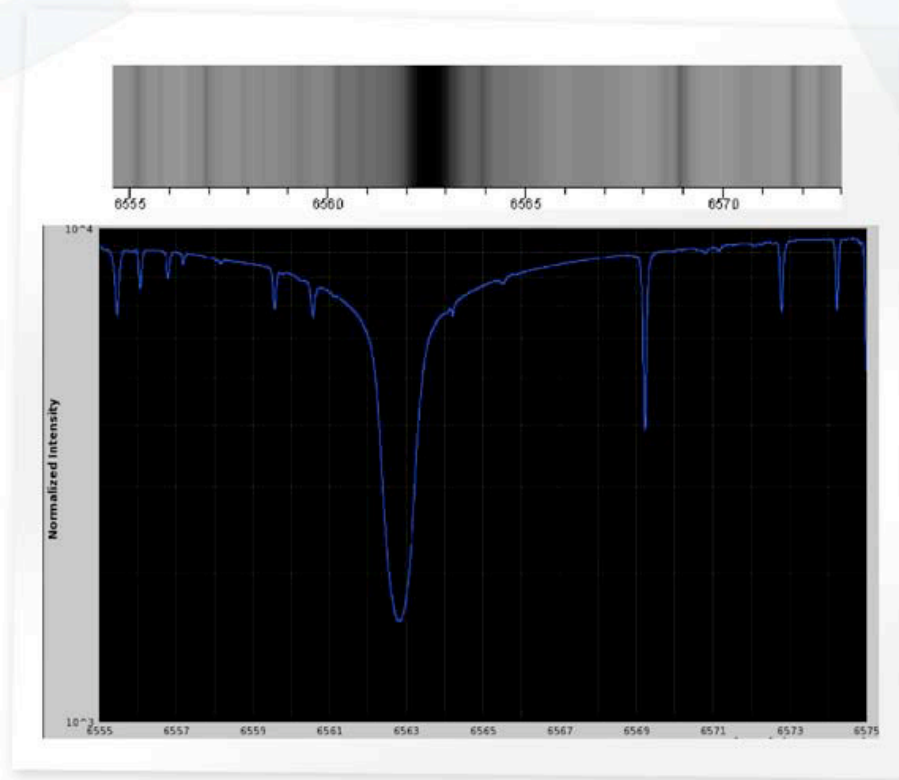
Figure 9 (a) and (b): Solar spectrum next to the hydrogen line (Hα): sharper line at 6563 Å: (a) spectrum and absorption lines; (b) change rate of radiation intensity depending on the wavelength.
(sources: (a) http://www.astrosurf.com/rondi/obs/shg/spectre/intro.htm# (b)and Paris Observatory: http://bass2000.obspm.fr/commun/pageac_ang.htm)

On other hand there is another crucially important spectral line for this work, since it gives out information about the photosphere and the chromosphere: the ionized line of Calcium (Ca II), detected between 3900 and 4000 Å. In particular, the K line of Ca II shows up at 3934 Å. The K3 line corresponds to the centre of the Ca II stripe and K1-v corresponds to one of the "wings", in this case is the inferior length K3 line – Figure 10.
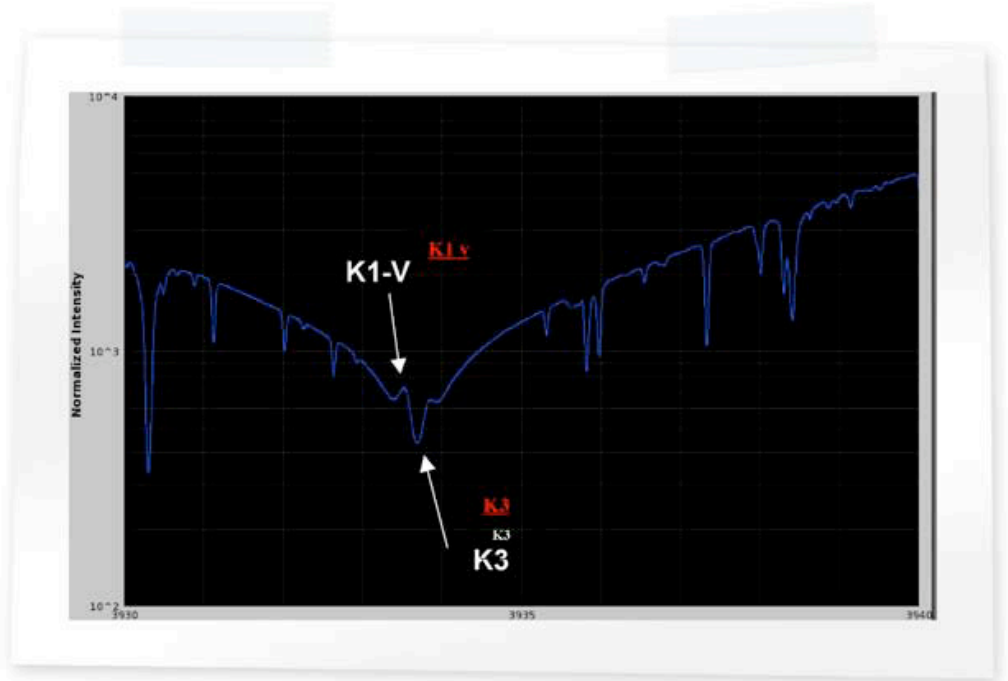
Figure 10: Solar spectrum: change rate of intensity depending on the wave-length next to the CaII K line. (source: Paris Observatory: http://bass2000.obspm.fr/commun/pageac_ang.htm)

It's worth pointing out that the interest of getting simultaneous (or almost simultaneous) images in different spectral lines has to do with the fact that, through them and its complementarity, it is possible to better understand the solar atmosphere. Indeed, the several lines that compose the solar spectrum are emitted in different layers of the Sun's atmosphere, at different temperatures – Figure 11.
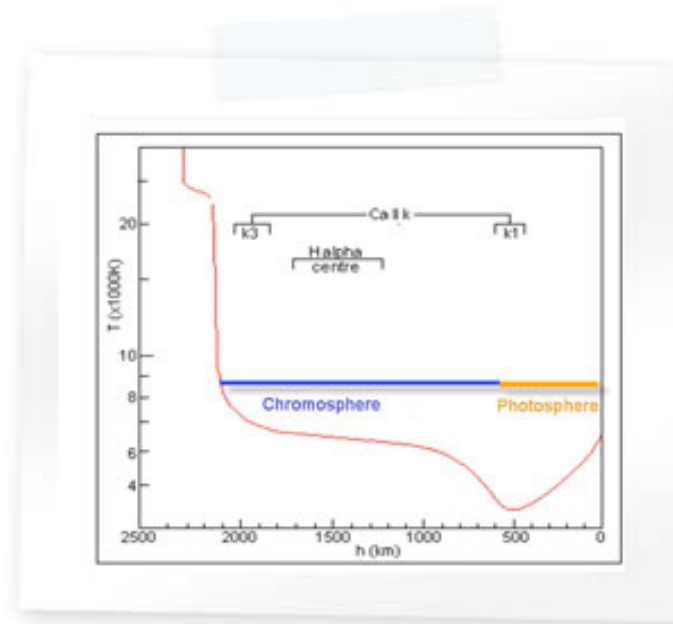

Figure 11: Temperature change rate in the solar atmosphere (0 km corresponds to the bottom of the photosphere) and the corresponding place where lines are formed: lines K3 and Hα are formed in the chromosphere while K1-v is formed in the photosphere.
(source: adapted from *J. Vernazza, E.Avrett and R.Loeser, Astrophys. J. Suppl, 45, 635 – 1981*)

As we can see, the Hα and K3 lines are formed in the chromosphere and K1-v line is formed in the photosphere. Thus, the sunspots are easily seen on K1-v line and prominences and filaments are seen in K3 and Hα lines – Figure 12 (a) and (b).

A filament is a prominence while observed in a faculae region - brighter and (contrarily to the sunspots) hotter than the surrounding areas, which are often associated to sunspots – Figure 12 (b)
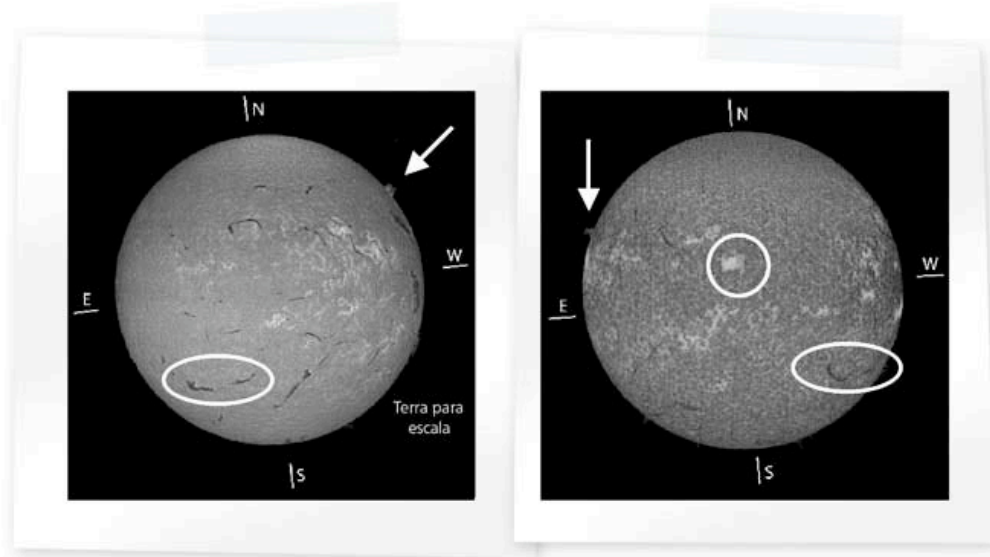

Figure 12 (a) and (b): Hα and K3. Prominences (arrows), filaments (ellipses) and faculae region (circumference)
(source: Astronomical Observatory of the University of Coimbra)

3. Eighty years of dedication to Solar observations in Coimbra [2]

At the end of the first decade of the twentieth century, Francisco Miranda da Costa Lobo (1864 – 1945), astronomer and professor at the University of Coimbra (figure 13) started the necessary studies to install an instrument in this University that would allow the acquisition of images of the Sun through the use of spectroscopy. The history of the installation of this device is described by Costa Lobo himself in "Astronomy in Portugal at the present time", a communication that he made as the inaugural speech of the Conference of Spanish Association for the progress of Sciences in 1926.

At the end of the 9th decade of the nineteenth century, the famous French astronomer Deslandres installed the spectroheliograph at the Paris-Meudon Observatory. This device enables the acquisition of images of sunspots and solar prominences.

Figure 13: Francisco da Costa Lobo
(Museum of the Astronomical Observatory of the University of Coimbra).

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[2] Text based on "Notes about the History of Astronomy in Portugal", J. Fernandes, Theme of the month of the Astronomer site, November 2002 (http://www.portaldoastronomo.pt/tema8.php)

Similar devices are also installed a little around all Europe and the United States. The study of the Sun, especially of its outside layers, was popular back then. Thus Costa Lobo reports that, in 1907, he visited the main European Observatories with the "purpose of getting the installation of a spectroheliograph for the study of the Sun on the Astronomical Observatory of Coimbra".

There were many difficulties that Costa Lobo had to overcome, but he always could count on Deslandre's cooperation. Deslandres offered pieces for the device and the French astronomer d'Azambuja, a Portuguese descendent, took part on the definitive installation of the spectroheliograph, in 1925. In July that year, the second General Meeting of International Astronomic Union in Cambridge registers that "Coimbra, Portugal, has installed a spectroheliograph and plans to add direct photography and spectroscopic work" (1925, Transactions IAU).

On the 1st January 1926, Francisco da Costa Lobo, with the useful cooperation of his son Gurmesindo, began the daily registration of solar images in K1-v and K3 lines: the spectroheliograms.

Thus begins an observational work, whose protocol principles and bases have been preserved until now, allowing the gathering of the aforementioned image assets. To this fact a team of dedicated observers have contributed a lot. They guarantee that the Sun observations are done on weekdays, weekends and holidays.

At the present time (and since 1968) the spectroheliograph is installed at the Astronomical Observatory of the University of Coimbra, in Santa Clara – Figure 14.

Figure 14: Spectroheliograph building, celostate and cupola
(source: Astronomical Observatory of University of Coimbra)

Despite of being faithful to the original observation principles and motivations, there have been important improvements on the spectroheliograph throughout the years. For example, the images on Hα line, obtained in the eighties, which made it possible to obtain three spectroheliograms in three different lines: K1-v, K3 and Hα - Figure 15.

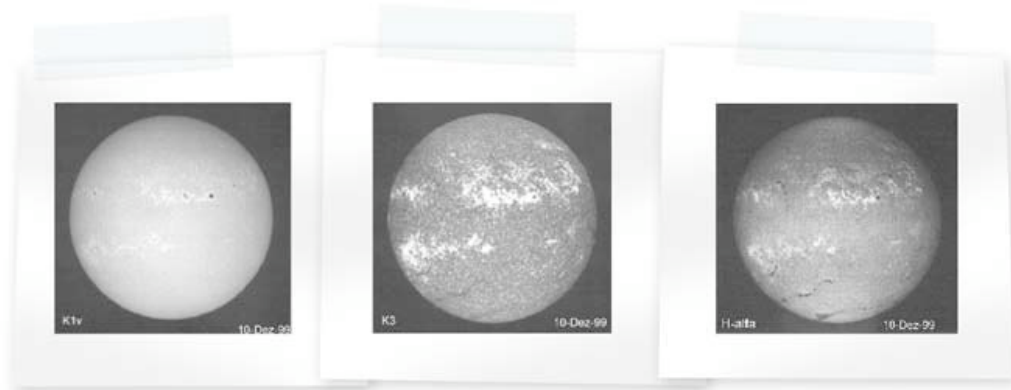**Figure 15**: Images taken on the Calcium lines (K1-v and K3) and hydrogen line (Hα) on the 10th December 1999.
(Source: Astronomical Observatory of the University of Coimbra)

In the present century it was possible to install a CCD[3] camera for the acquisition of digital Sun images[4], being the photographic film system definitively replaced on March 2007.

The spectroheliograms have been used throughout the last decades on scientific and research work. In this project we will use this kind of solar observations for learning activities of Junior High Schools and High Schools

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[3] CCD – *Charged Couple Device*.
[4] For further information consult the article "Eighteenth Anniversary of Solar Physics at Coimbra" Mouradian & Garcia, in "The Physics of Chromospheric Plasma", ASPCS, Vol. 368, 2007, Ed. Heinzel, Dorotovic and Rutten, p.3.

4. Functional aspects to carry out the activities

The activities are based on interaction between students and the spectroheliograms' database, available on the official Website of the Astronomical Observatory of the University of Coimbra. Its access is free and may be gained through the "Sun for All" project's Webpage (www.mat.uc.pt/sun4all) or through the Department of Mathematics Webpage by following the steps:

1. Enter the U.C. Mathematics Department Website – www.mat.uc.pt
2. Select "Observatório Astronómico"
3. Select "Observatório Astronómico da Universidade de Coimbra"
4. On the upper menu of the Observatory's Web page there is an option called "CENTRO DE DADOS". In this option select "Arquivo Obs. Solares"
5. On the left side you will find the following menu:

Figure 16: Research menu of the solar observations archive.

This menu allows you to choose a period of time from ("De") month (MM) and year (AAAA) until ("a") month (MM) and year (AAAA). On this menu you can also select the type of line on "Tipo de Risca". Three options are available here:

- K1-v filter - if you want to observe the photosphere;
- K3 or Halpha filter - if you want to observe the chromosphere.

Then you choose "K1-v" (if you want to observe the photosphere) or choose "Halpha" or "K3" (to observe the chromosphere).

When you validate this option, spectroheliograms within the choosen period of time will appear on the right side (see figure 17).

Figure 17: On this example 17 images were obtained with a filter centred on K1-V line in January 2001.

To take a closer look at the spectroheliogram for a fixed day, previously chosen, all you need is to select the correspondent image. Figure 18 shows the result of this procedure, if the 30th January 2001 spectroheliogram was chosen.
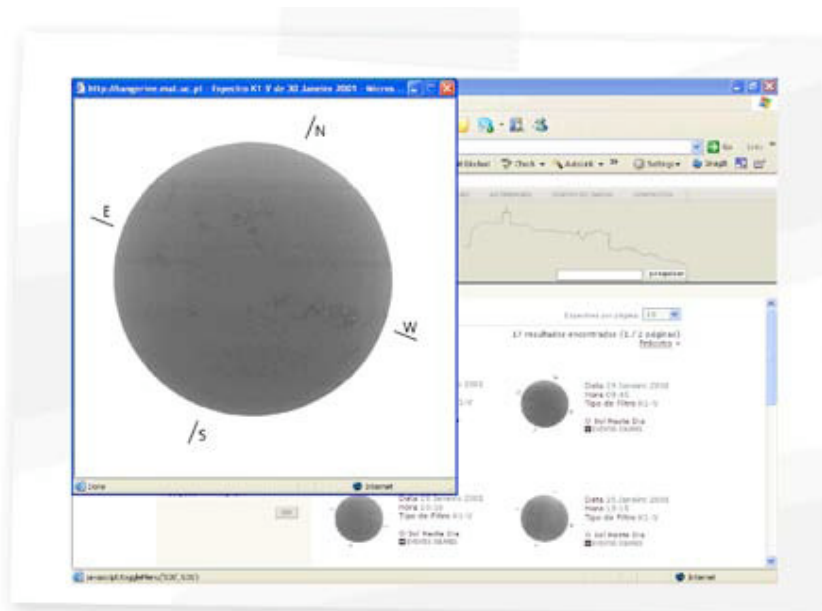

Figure 18: Spectroheliogram of the 30th January of 2001.

Notice that the image shows up as a negative photo. All database images are represented this way, because the digitisation process was based on the original photographic films (therefore negatives). This fact has no influence at all in the accomplishment of the activities. Nevertheless, those who want to use positive images instead, only need to use software that allows to invert the colours. For example, the program "Paint", a standard application of Windows operating system, makes this operation possible (see appendix 2).

Figure 19 compares two images of the same spectroheliogram: the original (on the left) and after colour inversion (on the right).
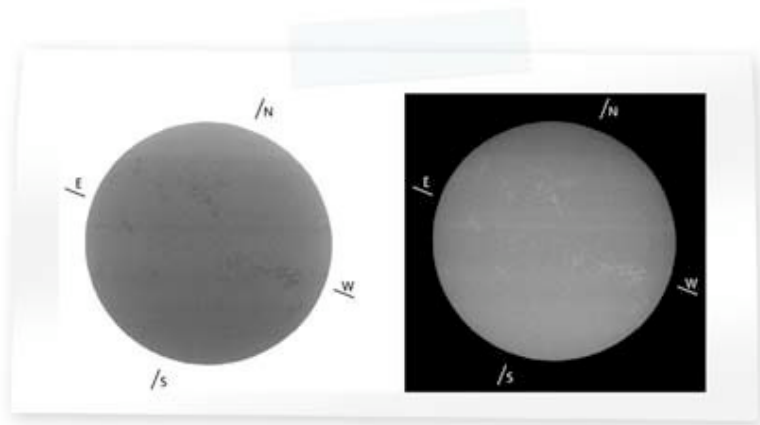

Figure 19: spectroheliogram of the 31st January 2001: negative and positive.

On figure 17 you can notice there are no images of the 26th and the 27th January 2001. This is because of the fact that, during those days, the weather conditions didn't allow solar observations.

North-South (N/S) and East-West (E/W) directions are indicated on some images. These indications have to do with the Sun orientations, in other words, solar North and South. However some images have no such orientations. In these cases the North-South direction should be considered as coincidental with the screen's vertical.

For the activities described on the next item, besides the mentioned software, needed to invert colours, it is also necessary to know how to use a spreadsheet, as Excel for example. Therefore, in some activities you can find Excel files already prepared to help with the accomplishment of the proposed tasks. On appendix 3 we show an example of how Excel's spreadsheet is used.

One of the main aspects of the suggested activities has to do with sunspots counting. In the paragraphs below we present 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

$$R= 10g + s,$$

where "g" is the number of observed groups of sunspots and "s" is the total number of single sunspots of all groups. For the single sunspots you take the umbra as the counting reference. However, the distinction between single sunspots and sunspots groups isn't always obvious – Figure 20.

Figure 20: Sunspots group observed by Soho Satellite.
(source: http://apod.nasa.gov/apod/ap010411.html)

On figure 21 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). In the group number one, 2 sunspots were identified; in the second group, 4 sunspots were identified; in group three, 4 sunspots; in the fourth group, 9 were identified and in the fifth and last group, 2 sunspots. So, we have a total number of 21 sunspots. Thus s=21. Therefore R=71.
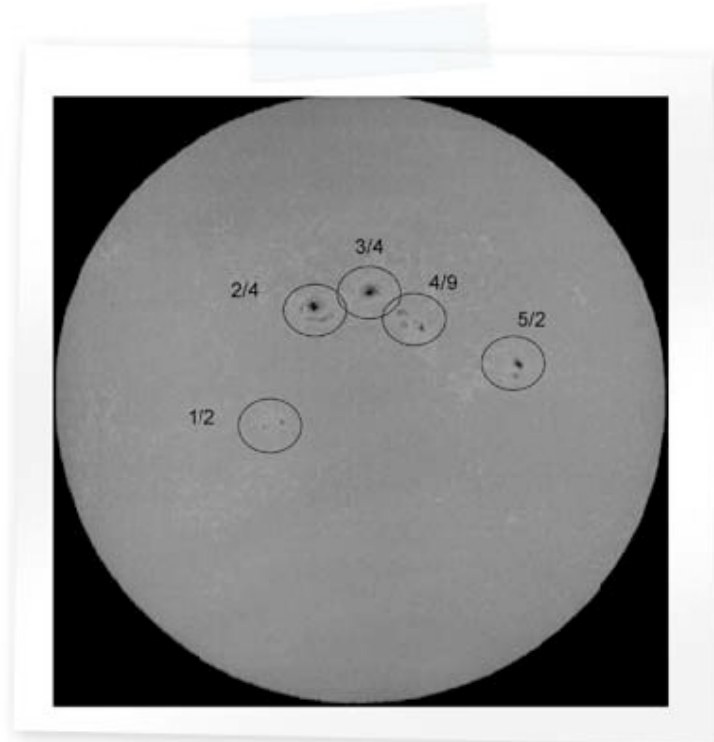

Figure 21: Calculating Wolf's index on the example case: g=5, s=21 and R=71
(Source: Dorotovic, private communication)