EDUCATIONAL ACTIVITY
Calculation of Solar Activity. Wolf number

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1.- Instrumentation

The activity will be performed using digital images of the solar photosphere obtained with a telescope. The European project GLORIA offers a solar telescope to society (see ref 3-3). It is also possible to use other ground-based telescopes such as the GONG project (ref 3-2) or even images taken from space (ref 3-1).

2.- Record of sunspots activity

Warning: You should never look at the sun with the naked eye. It is very dangerous. Observations must be performed using a safe method (see ref 7).

The spots come from the east of the solar disk and proceed towards the west. They appear confined between latitudes 5° and 40° (north and south). The lifetime of sunspots can vary from a few days to a few weeks. The apparent displacement of spots around the disc is due to the rotation of the Sun, although some may show small motions. A spot never crosses the equator of the Sun, it always stays in one of the two hemispheres, north or south.

3.- The Wolf Number

In 1848 the Swiss astronomer Rudolf Wolf introduced a method for registering solar activity by counting the number of visible sunspots, known as the number or index of Wolf or Zurich (also known worldwide as the International Sunspot Number).

Although qualitative (there are other methods to supplement or replace the Wolf index, such as calculating the extent of the spots or the McIntosh classification ref 8) it has the virtue that Wolf extended it until the first telescopic observations of Galileo and has remained uninterrupted until today, and therefore it has been used in the solar activity records in the last 400 years.

Before estimating the solar activity using the Wolf number, it is necessary to know some definitions to obtain the proper activity index.

Groups of spots: Set of spots (with penumbra) and pores, or individual pores, close together and jointly evolving. For your calculation assume the Zürich classification (see section 4).
**Foci**: It is called foci both spots and individual pores. For example, if in a spot we distinguish two umbras, then we have 2 foci.

**Unipolar Group**: A spot or a compact group of spots with a maximum heliographic distance between the ends not exceeding 3º.

**Bipolar Group**: Two spots or a group of several spots extending east-west with a heliographic distance of 3º.

The Wolf number (W or R) is obtained from the following expression:

\[ R = k (10G + s) \]

**k** is a statistical correction factor applied by the international coordinating center (ref5) which coordinates and analyses the observations. It takes into account the atmospheric conditions and the type of instrument used for the observation (for example: telescope, binoculars) it is usually lower than 1. For this activity we can use \( k = 1 \).

**G** represents the number of visible groups. An isolated pore counts as a focus and as a group. **s** the number of total foci of all the spots, as it was explained before.

The minimum activity or smallest Wolf number is 0 (the solar surface should be completely clean), then going to 11 since one group on the solar disk with a single focus would be \( G = 1, f = 1 \), therefore, \( R = 11 \). From 11, you can follow the consecutive values of natural numbers (12, 13, 14, etc.). We can roughly calculate the number of individual spots on the solar surface if we divide the number of Wolf or *sunspot number* by 15. Figures 2 and 3 are examples of calculating the number of Wolf.
Figure 2. Calculating the number of Wolf for an image of the solar photosphere obtained by the GONG Telescope (NSO, USA) installed at the Observatorio del Teide (IAC). The official number (Relative Sunspot Number) given by SIDC (see ref 5) for selected day was 87.
Figure 3. Calculating the number of Wolf for an image of the solar photosphere obtained by the TAD telescope installed at the Observatorio del Teide (IAC). The official number (Relative Sunspot Number) given by SIDC (see ref 5) for selected day was 23.

4.- Zürich Classification

Counting the number of groups to calculate the number of Wolf is based on the Zürich classification of sunspots.

The spots usually appear in groups. Ideally one group consists of two spots with opposite magnetic polarity, extended in the direction of the parallel, with multiple smaller spots and pores in between. Following the classification of Zürich, a well developed spot goes through all types: A, B, C, D, E, F, G, H, J, ending finally in A, but this rarely happens. Type F spots are infrequent and spots usually evolve from type E to G. Many groups only reach type D and most end as type A, B and C.
The duration of a group can be a few hours for a pore, to several months for the most evolved groups.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Evolution</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>Unipolar, Pores or small group of pores without penumbra.</td>
<td>One or more pores arise very close together. In any area of the solar surface between 5° and 40°</td>
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<tr>
<td>B</td>
<td>Bipolar. Larger group of pores without penumbra generally with an east-west formation.</td>
<td>One or more pores arise east or west of the previous group (bipolar system). The number of pores increases around where the first and second pores appeared.</td>
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<tr>
<td>C</td>
<td>Bipolar. Spot with penumbra with a group of pores.</td>
<td>Some of the pores at the ends of the group initiate the formation of the penumbra. The most western pore often becomes a spot (head spot).</td>
</tr>
<tr>
<td>D</td>
<td>Bipolar. Two or more spots with pores between them. The extent of the group is below 10° heliographic.</td>
<td>One or more spots form at the opposite end where the first formed. New pores are formed between the two spots and pores can also form inside the spots.</td>
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<tr>
<td>E</td>
<td>Bipolar. Groups of spots and intermediate pores. The extent of the group is between 10° and 15° heliographic.</td>
<td>Spots form in the intermediate zone and the extent of group increases. New spots can form at the ends of the group. The extension is at least 10°. A new system may appear at the same latitude in the opposite hemisphere.</td>
</tr>
<tr>
<td>F</td>
<td>Bipolar. Group of spots and intermediate pores. Spots are extensive and complex. The extent of the group is above 15° heliographic.</td>
<td>The group continues growing irregularly. Projections of pores and bright bridges appear. The spots are irregular and rapidly changing in shape. Bipolarity is lost and multipolarity emerges. This is the maximum. The extent of the group is of at least 15°.</td>
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<tr>
<td>G</td>
<td>Bipolar. Group decaying with spots on the ends without intermediate pores. The extent of the group is below 10° heliographic.</td>
<td>The dissolution of the group begins. Intermediate pores and spots disappear, the spots at the ends become rounded and bipolarity returns. The extent of the group is about 10°.</td>
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<tr>
<td>H</td>
<td>Unipolar. Spot with a penumbra bigger than 2.5° heliographic.</td>
<td>Pores and spots from one end disappear, the bipolarity disappears and one or more spots with or without pores remain clustered in one area. The extent of the group is greater than</td>
</tr>
<tr>
<td></td>
<td>2.5°.</td>
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<tr>
<td>J</td>
<td>Unipolar. A spot with a penumbra smaller than 2.5° heliographic.</td>
<td>One small spot or two, usually without pores in its proximity with an extent less than 2.5°.</td>
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</tbody>
</table>

**Difficulties.** Some difficulties could arise while discriminating between two (not apparent) completely different types of groups, for example, a type C with type H. Observing the evolution of the group may determine their classification. However it does not affect the calculation of the Wolf number.

Sometimes the differences from one type and another (D and E, E and F, F and G, H and J) can only be set by the extent of length of the group, we recommend using a template that shows the meridians and parallels of the Sun to determine the size of the groups which may be conflicting.

It can also be difficult to find out whether a set of spots or foci corresponds to one group or two. To find this out their magnetic polarities should be measured, but experience and observation on successive days will help with your decision.

**5.- References**

**ref 1** - SOHO Observatory ([http://sohowww.nascom.nasa.gov](http://sohowww.nascom.nasa.gov))

**ref 2** - GONG Telescopes Network ([http://gong.nso.edu/](http://gong.nso.edu/))

**ref 3** - Images of the Sun (photosphere) from internet.
   1. From the Space (SOHO satellite) [http://sohowww.nascom.nasa.gov/data/realtime/hmi_igr/1024/latest.jpg](http://sohowww.nascom.nasa.gov/data/realtime/hmi_igr/1024/latest.jpg)
   2. From a network of ground Telescopes (GONG) [http://gong2.nso.edu/dailyimages/](http://gong2.nso.edu/dailyimages/)
   3. Images of the Sun (photosphere) through a robotic Solar telescope - TAD - (Teide Observatory, IAC) from the GLORIA project [http://users.gloria-project.eu](http://users.gloria-project.eu) (Solar Experiment)

**ref 4** - Images of Great Celestial Shows [http://www.tierrayestrellas.com](http://www.tierrayestrellas.com)


**ref 8** - The MacIntosh classification [http://www.astrogea.org/divulgacio/sol_mcintosh.htm](http://www.astrogea.org/divulgacio/sol_mcintosh.htm)