# SolarLab – Didactic unit


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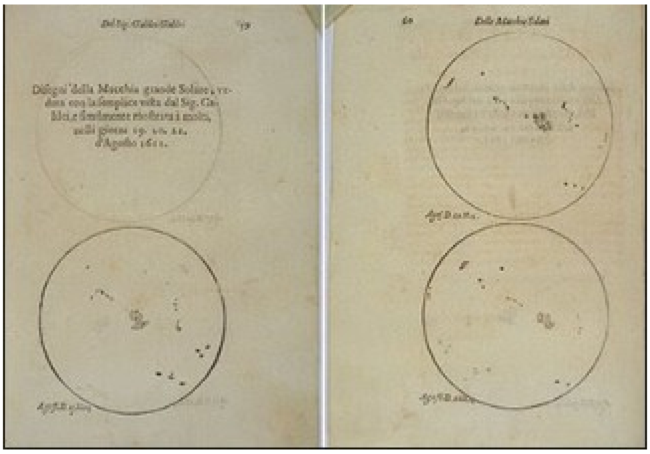
# 3. Obtaining the Wolf number

## Introduction. Solar activity

The Sun may seem like a static object, resting in the center of the Solar System while the planets orbit around it. But this is not the case. Our star is constantly undergoing processes of change that release large amounts of energy. In fact, the stability of its appearance and luminosity is due to a balance of forces that are in constant conflict.

The processes that occur on the surface and in the atmosphere of the Sun, which produce solar wind, flares, and coronal mass ejections, are sometimes more intense and frequent. We refer to this intensity as solar activity.

We quantify solar activity through its radio wave emissions. But if we want to know how the Sun has evolved in the 400 years we have been studying it, we must find a simple and visual way to measure it.



Galileo's representation of sunspots in 1610

In this activity, we will look for a way to relate sunspots to solar activity. We will quantify it with a number called the Wolf number (named after the Swiss astronomer who first used it in 1848).

## Prior hypothesis. Wolf number

In order to find a number that relates sunspots to solar activity, we must find which characteristic of sunspots provides us with the most information. Sunspots are distributed in groups, sometimes simple and sometimes more complex. We are going to consider three possibilities, playing with the number of sunspots and the number of groups. Here we propose three, although we invite you to let the students come up with their own.

1. **The number of spots**. Each and every individual pore significantly affects solar activity, regardless of its size or position. If they are in groups, they have a slightly greater effect than if they are separated.

2. **The average number of spots in each group.** The more complex the clusters are, the more activity they indicate, so activity could be inferred from the number of pores in each group.
3. **The number of groups**. The occurrence of a group, even if it is only a single pore, indicates intense solar activity. Groups with more spots will have slightly more activity.

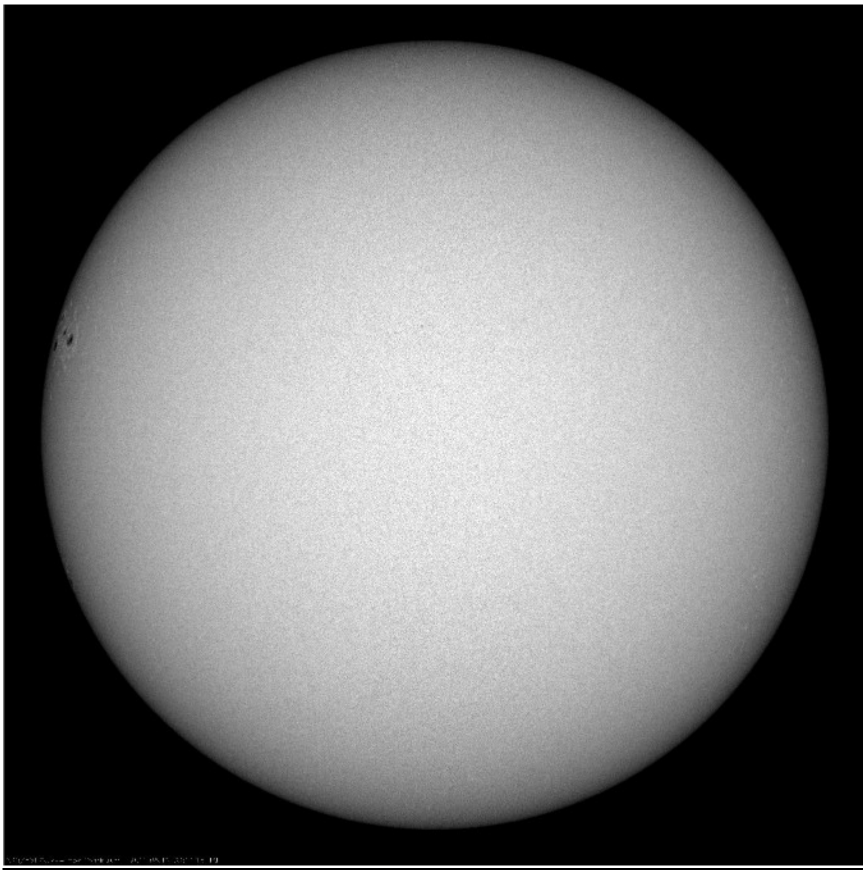
Only one of the three statements is correct. We can find out which one it is by testing them with real images and data from the Sun. To follow the steps of the scientific method, we start with an observation from which we form a hypothesis, and then we test or refute it with experimental data.

## Observation

Let's analyse some images of the Sun taken by NASA's SDO space observatory. For each day, a black and white photograph taken with the HMI-Intensitygram filter is shown, in which sunspots can be clearly seen alongside another, yellow image showing the ultraviolet emission observed with the AIA 171 Å filter. This image serves as a qualitative sample of solar activity. It is recommended to compare the images with the values given in a table at the end: the number of spots or foci (F), the number of groups (G) and the average number of spots in each group (Avg).

**Image 1**

Date: 16-08-2011



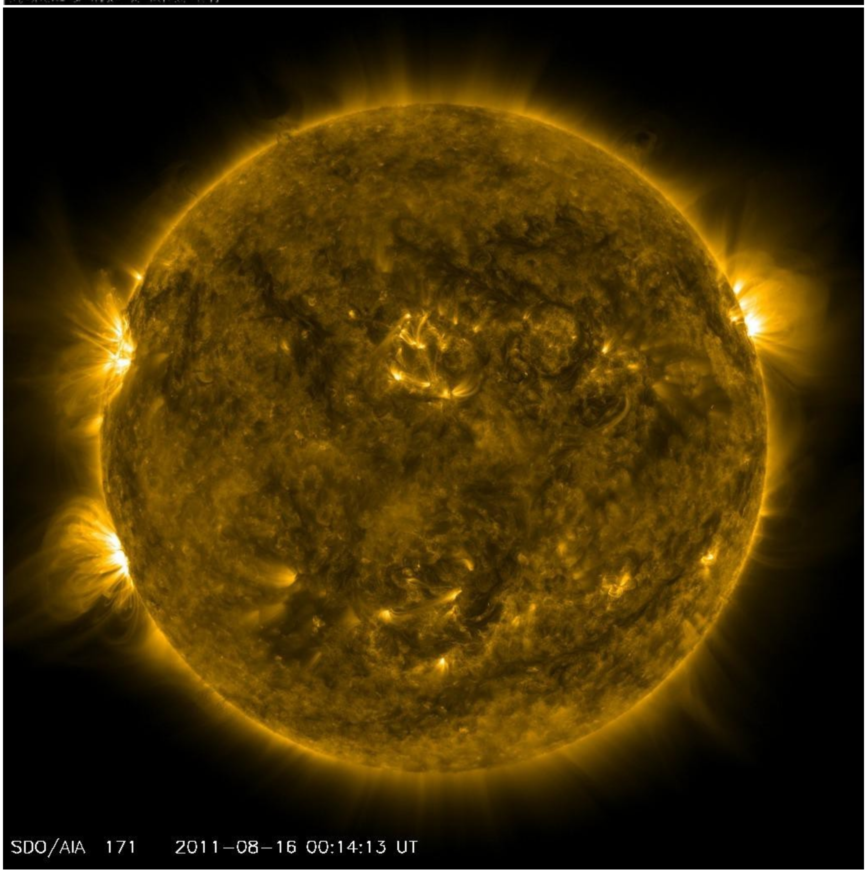
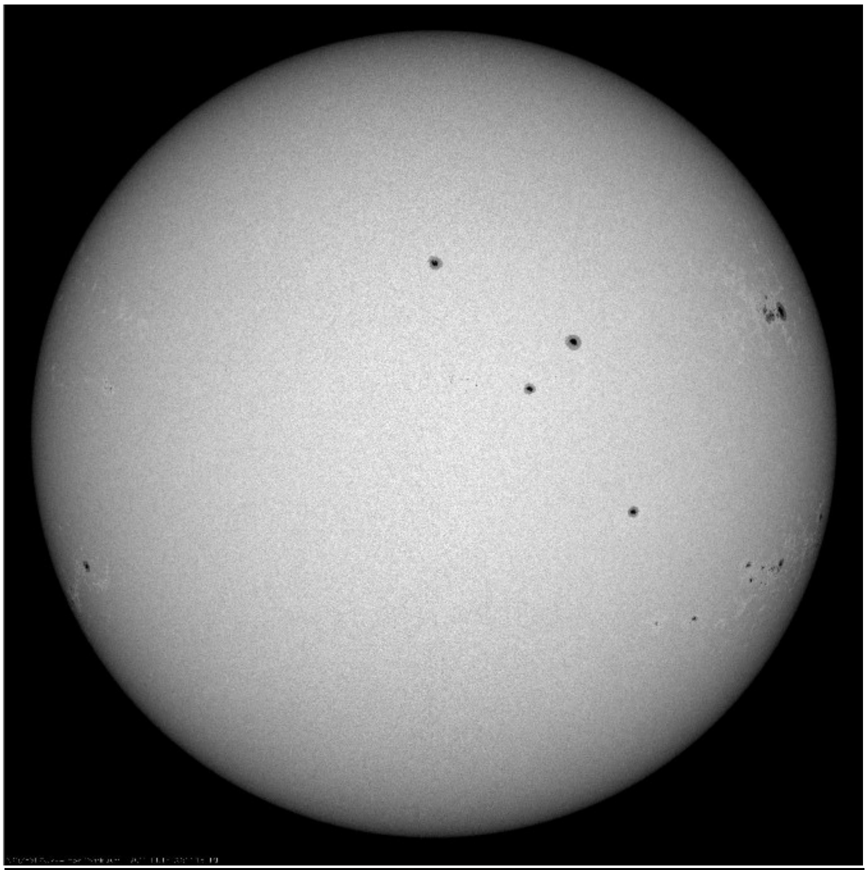


**Image 2**

Date: 14-11-2011



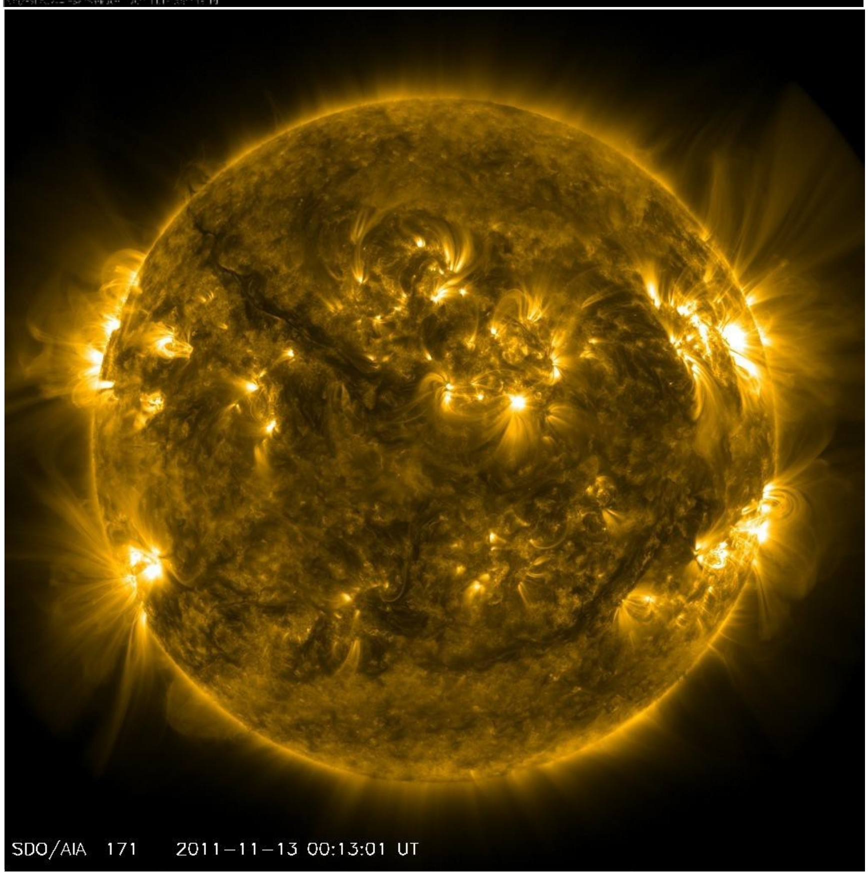
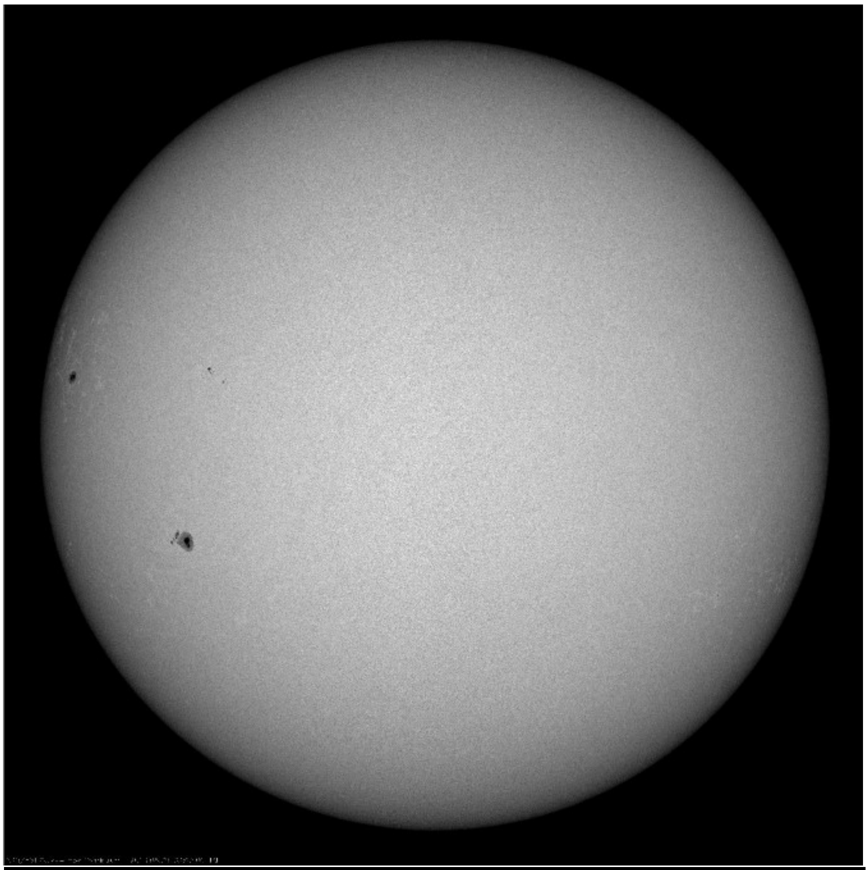


**Image 3**

Date: 28-08-2013



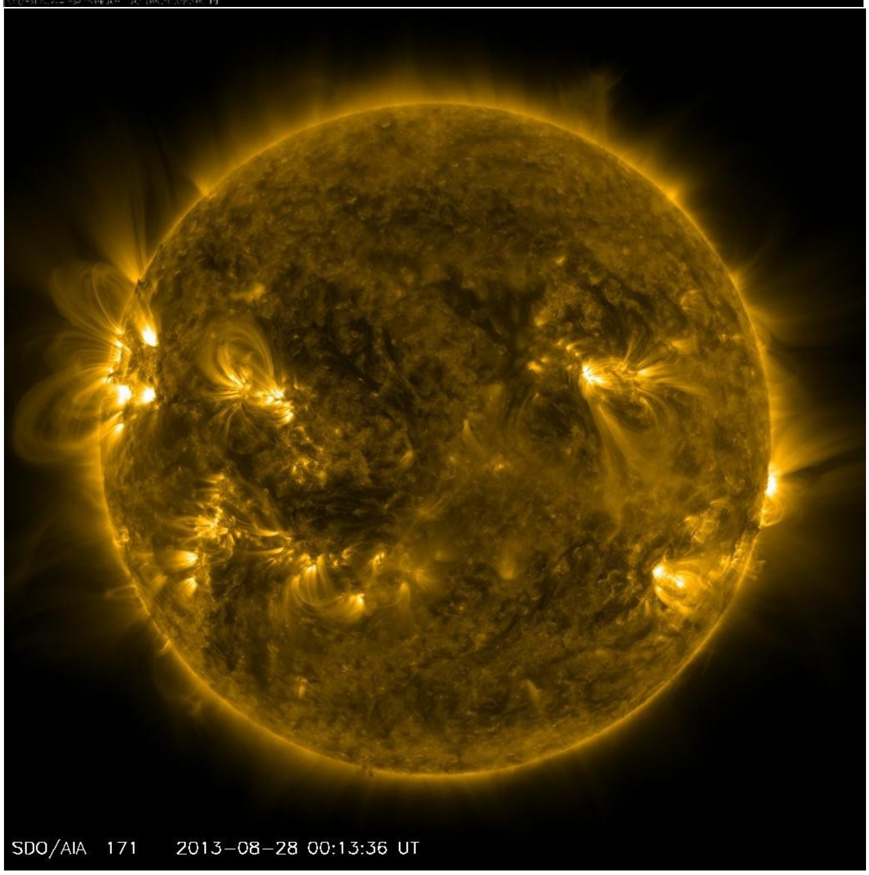


**Image 4**

Date: 23-04-2011

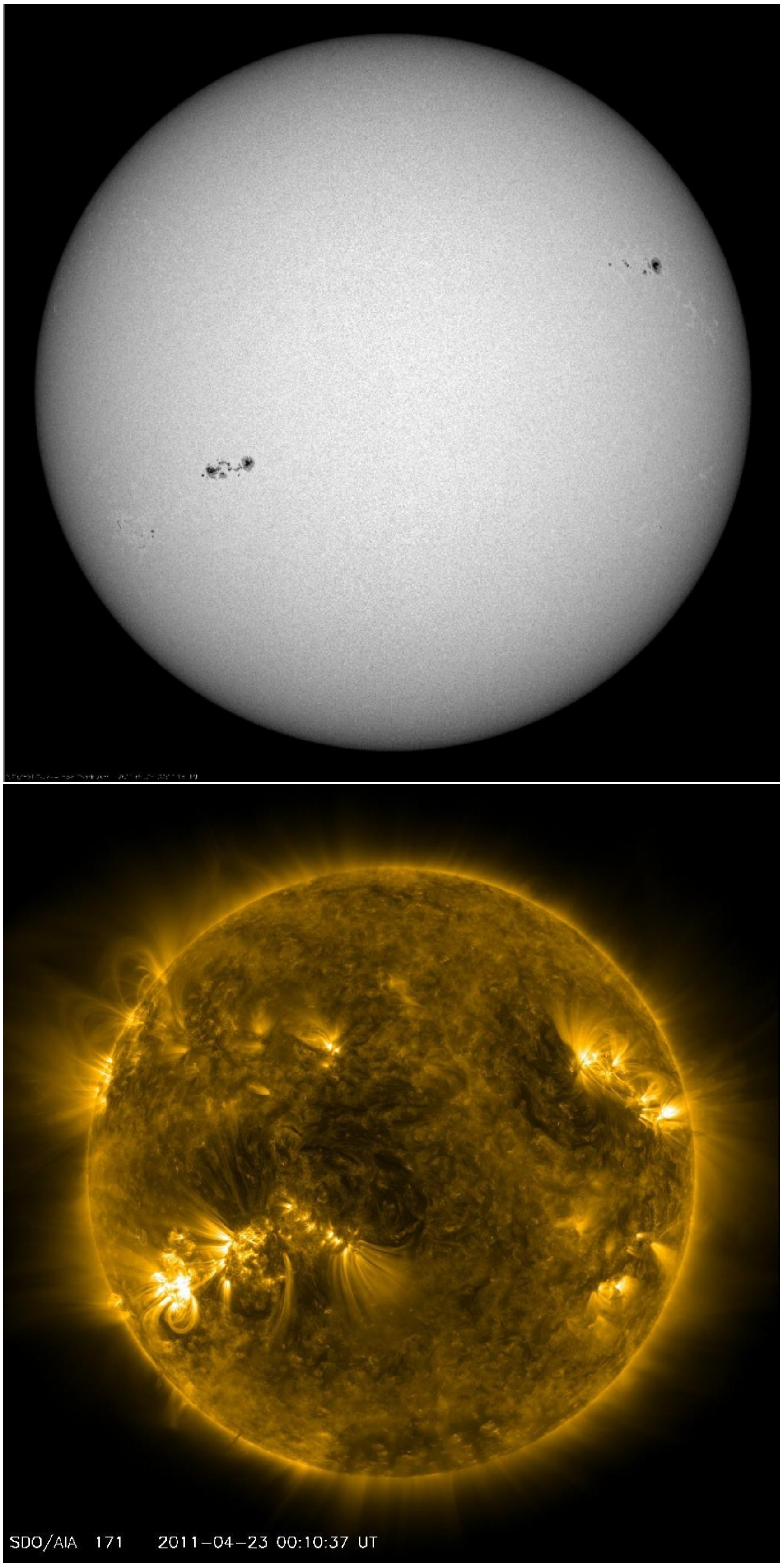
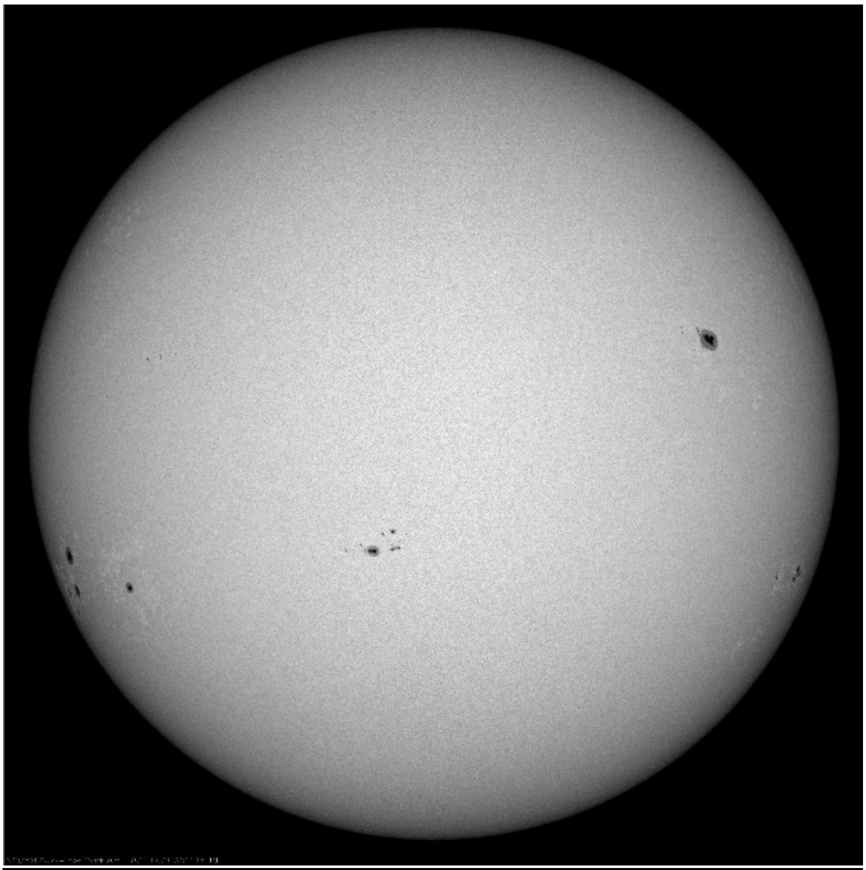


**Image 5**

Date: 29-12-2011



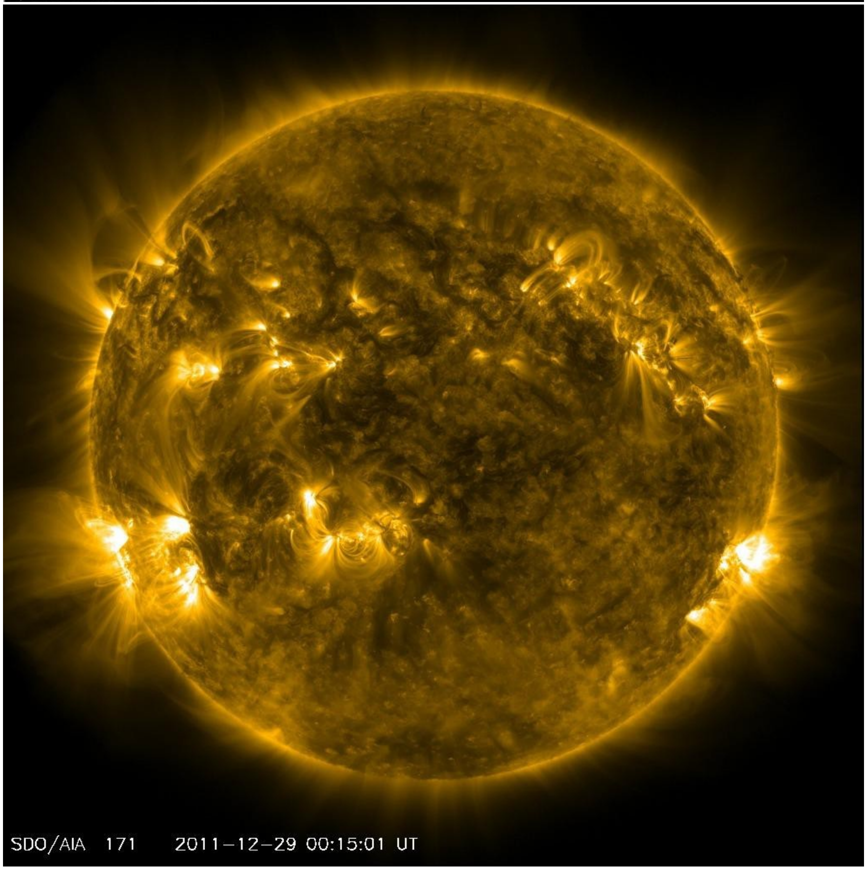
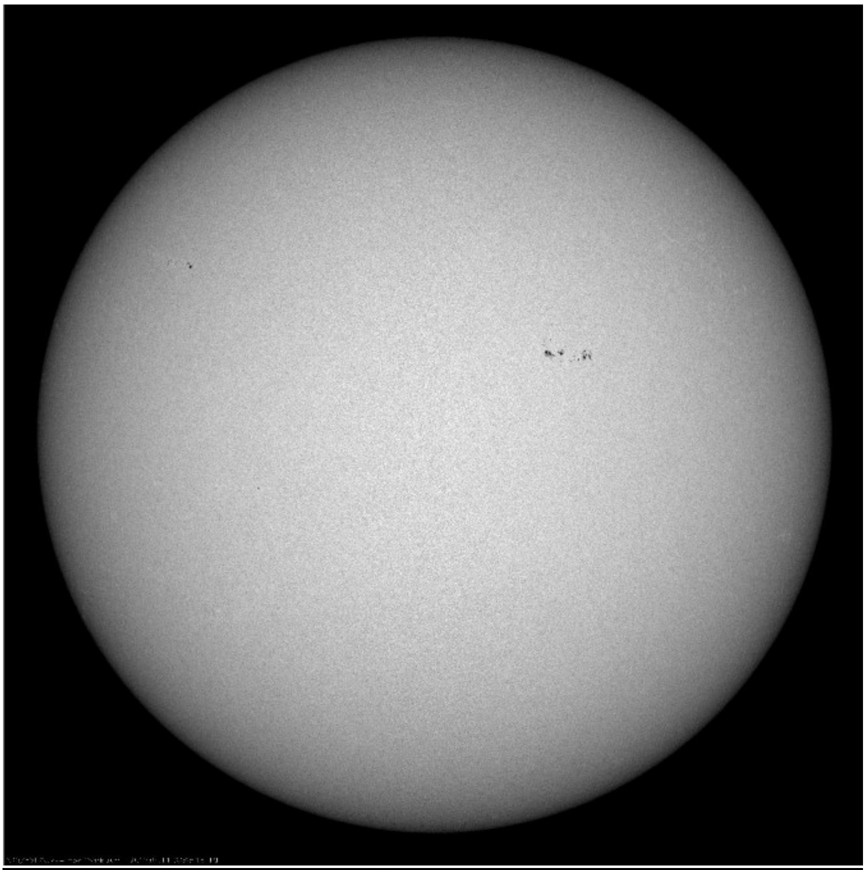
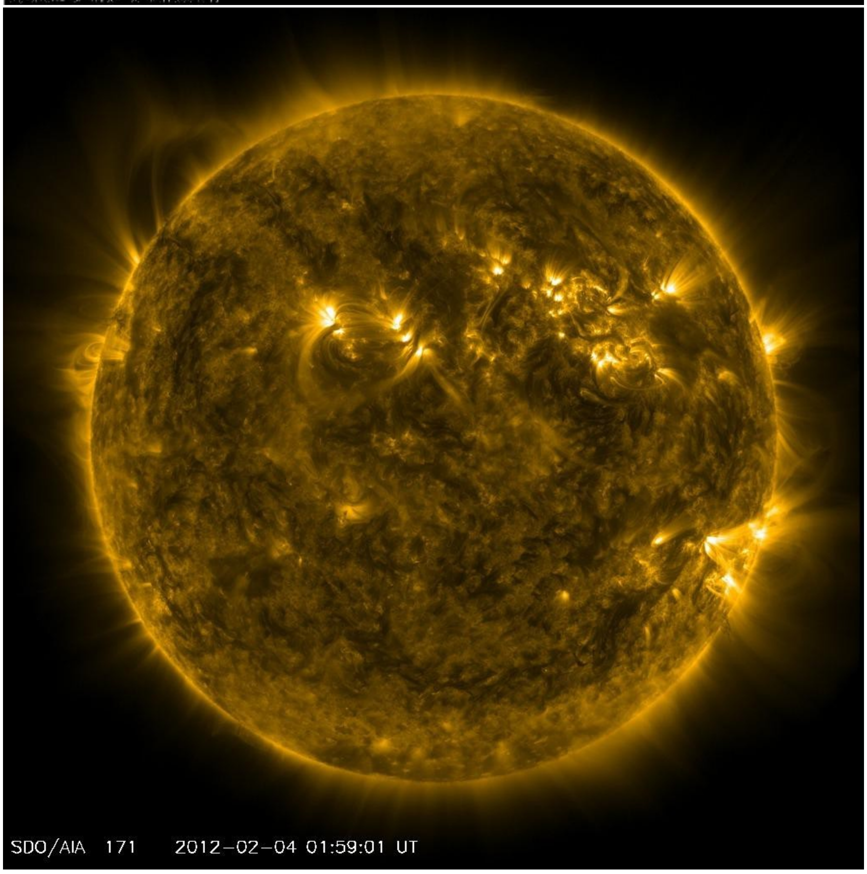


**Image 6**

Date: 14-04-2012





## Hypothesis statement

Based on your observation of the images, you are now ready to choose one of the three options regarding how sunspots affect solar activity. However, the hypothesis of an experiment must be formulated in such a way that it can be tested. A good way to achieve this is to quantify it numerically.

Let's translate each of the three proposed hypotheses into mathematical equations. We will need several quantifiable values:

$W_1$, $W_2$ and $W_3$ are the Wolf numbers corresponding to each hypothesis.

*F* indicates the total number of individual spots or foci on the solar surface.

*G* is the number of groups into which the spots are distributed.

1. **The number of spots.** Spots are ten times more important than groups.

$$W_1 = 10 \cdot F + G$$

2. **The distribution of spots.** The important factor is the average number of spots contained in each group.

$$W_2 = \frac{F}{G}$$

3. **The number of groups**. Groups are ten times more important than individual spots.

$$W_3 = 10 \cdot G + F$$

Based on your observations of the two images, which ones do you think correspond to days of greater activity? Counting the number of spots and groups for each day, which Wolf number value would be most appropriate for quantifying activity? To count spots and groups correctly, practice is necessary. When in doubt, pores that are very light or small are not taken into account when counting spots. If several spots merge into one large spot, it is considered a single spot.

## Experimental data: solar activity

We now have a quantification of our hypothesis. What we need next is actual data from the Sun that will allow us to compare our observations with real activity.

The best indicator of solar activity is the intensity of X-rays. Fortunately, the atmosphere acts as a filter for this type of radiation, which would otherwise make life impossible. However, this emission is always accompanied by radio waves with a frequency of 2800 *MHz* (the waves we receive on our FM radios are between 88 and 108 *Hz*). These waves do reach Earth and their intensity can be measured. The greater the solar activity, the more intense the waves received.

The following table shows the *F2800* radiation intensity for each of the images, given in solar flux units, or sfu (1 sfu = $10^{-22}$ W/m$^2$/Hz). The *G* and *F* values are also given for verification purposes. Sometimes the counting of spots is somewhat subjective. It doesn't matter if the values obtained do not match exactly those given in the table, as this is already taken into account in scientific studies.

| | ***F2800 (sfu)*** | ***F*** | ***G*** |
|---|---|---|---|
| **Image 1** | 93 | 8 | 1 |
| **Image 2** | 161 | 35 | 12 |
| **Image 3** | 108 | 13 | 3 |
| **Image 4** | 119 | 43 | 4 |
| **Image 5** | 147 | 55 | 8 |
| **Image 6** | 98 | 19 | 2 |

## Data analysis

We now want to see if there is a relationship between solar activity (*F2800*) and the Wolf number we have proposed ($W_1$, $W_2$ or $W_3$). This is normally done using a statistical value called the linear correlation coefficient. For this exercise, we are going to use a more intuitive method, simply answering the question: does my *W* value increase each time *F2800* increases?

You can check this using the following table. Arrange the data from the images in order from lowest to highest solar activity and observe the behaviour of *W*. You can compare this with the values obtained by your classmates.

A quick way to see this and show the results to other people is to make a graph. You can do this to see the shape of the number *W* (*x*-axis) against *F2800* (*y*-axis) in each of the three cases.

What is the correct equation for obtaining the Wolf number?

| **Image num.** | **F2800** | $W_1$ | $W_2$ | $W_3$ |
|---|---|---|---|---|
| | | | | |
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## Aplication

Now you know a simple way to indicate solar activity by counting sunspots. Many amateur astronomers around the world send reports with the data they obtain to solar observatories to facilitate monitoring. You can also do a daily count with the H-alpha telescope and send it to the I.A.C. where we will keep a record of all the students' projects.

Sometimes it is difficult to tell whether spots belong to one group or two. To find out for sure, it is best to wait a few days and see how they develop.

**Observation sheet**

| Date and time | F | G | W | Comments |
|---|---|---|---|---|
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## Links

Citizen science project integrated into Zooniverse, contributing to science by classifying sunspots

http://www.sunspotter.org/

Data from the Royal Observatory of Belgium on Wolf numbers over time and other data on solar activity

http://sidc.oma.be/html/sunspot.html

http://sidc.oma.be/products/mobu/

Data from the Greenwich Observatory since the 18th century

http://solarscience.msfc.nasa.gov/greenwch.shtml