"Percorsi per le Competenze Trasversali e l'Orientamento" (a.k.a. PCTO):

DETERMINING THE SOLAR ROTATION PERIOD: AN EXPERIMENT IN SUNSPOT OBSERVATION

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ABSTRACT

The purpose of this report is to review and discuss our experience conducting a simple experiment aimed to measure the rotation period of the Sun. We describe here the steps we have taken to do so, starting with the observation of sunspots.

Sunspots are areas of the solar photosphere affected by intense magnetic activity. They have a lower temperature (about 3700 K) than the surrounding area (about 5700 K). These factors make them noticeably dark, therefore allowing us to collect data by means of observation, as we have done.

As it is known, the Sun rotates on its axis and, being part of the photosphere, sunspots also move in a circular motion. Using "JHelioviewer"[1], a visualization software for solar images, we observed their motion for 13 days and then made a two-dimensional map of the sunspots' positions. Having done so, we calculated the angular frequency and subsequently found the rotation period of the Sun.

|| Keywords: Sun: Sunspots; Sun: Rotation period.

INTRODUCTION

Countless studies have been done on the sun's rotation that have made it possible to measure the solar rotation period, but all of them have employed complex and expensive instrumentation to not everyone has access. What we hope to accomplish is to suggest a different approach, which requires nothing more than a certain degree of mathematical competence. Given the requirements, this experiment could potentially benefit the public understanding of science because it can be easily replicated in schools or any other non-scientific context.

The following is a list of required materials:

-Software:JHelioviewer:
-Software:Excel
- Images of the sunspots taken by the SDO[2] (Solar Dynamic Observatory) through HMI[3] (Helioseismic and Magnetic Imager) once a day for 13 consecutive days.

In order to understand everything that will follow, some knowledge of the sunspot phenomenon is required.

Sunspots were first observed in 1610 by Galileo Galilei[4], who thoroughly described them in his book titled "Istoria e dimostrazioni intorno alle macchie solari". His initial hypothesis suggested that clouds hovering the Sun's surface could cause dark spots to appear. Because their periodic disappearance hinted at the fact that the Sun had to rotate at a constant speed on its own axis, this marked the beginning of an intense crysis of the Ptolemaic system and the Aristotelian concept of aethereal perfection.

Today we know that sunspots are caused by a heightened magnetic activity which inhibits the conduction of plasma. This in turn causes a drop in temperature, resulting in a darker colour compared to the surrounding areas of the photosphere and less energy being emitted. Sunspots can come in pairs or clusters and have irregular shapes. The first scientist to measure the solar rotation period through sunspots was the astronomer Johannes Fabricius[5]: in 1611 he published his own work independently from Galileo. In 1630 physicist Christoph Scheiner[6], while observing sunspots himself, measured the rotation period and noticed how it would decrease as the latitude of the sunspots increased. Solar rotation is therefore differential.

Because the Sun is not a solid body, plasma (and therefore the photosphere right above it) travels at different speeds depending on its location: slower near the equatorial line and faster at the polar regions.

We employed the visualization software "JHelioviewer" (developed by ESA JHelioviewer Team and based on the JPEG 2000 compression standard) to conduct our observations: among the many telescopes and spacecraft whose images it collects, we have chosen to use those of NASA mission Solar Dynamics Observatory (SDO).

OBSERVATIONS AND ANALYSIS OF DATA

Through SDO HDMI Continuum's database, we have observed the circular motion of three sunspots. For each one, we measured their longitude (φ), and latitude (θ), along with their displacement over time (**t**). We repeated this operation once every day, for a total of 13 days. JHelioviewer automatically measures the latitude and longitude by pointing the cursor over the desired sunspot. We chose sunspots which weren't too close to the equatorial line nor to the polar regions (between 20° and 30°). The latitudes of the 3 are as follows:

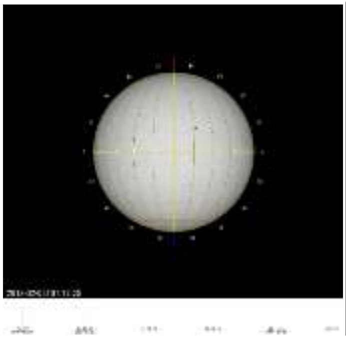


FIG.1: Latitude=15°; observed from 28/01/2013 to 9/02/2013 Julian date: 2456320.81255-2456322.81255

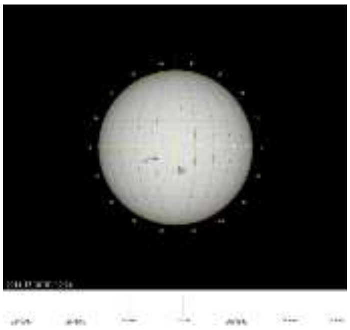


FIG. 2: Latitude=23.5°; observed from 17/03/2015 to 28/03/2015 Julian date: 2457098.81255-2457109.81255

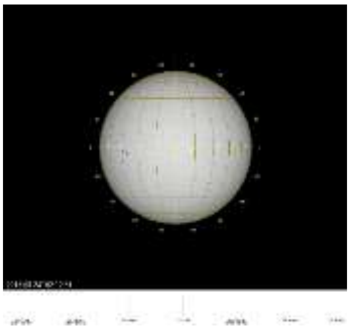


FIG. 3: Latitude=30°; observed from 11/12/2014 to 23/12/2014 Julian date: 2457002.81255-2457014.81255

An issue came up regarding the interpretation of this data: although we are looking at the Sun as a two-dimensional representation (FIG 4), it is obviously a sphere This causes sunspots closer to the edge of the disk to appear as if they travel a shorter distance than those closer to the centre. To amend that, we decided to find the trajectory of each sunspot. We drew a chord parallel to the sun's diameter over the images which approximately passes through each position the sunspot has been in. Having done that, we marked the semi-circle whose diameter is the aforementioned line. Then, for each position, we've drawn a line perpendicular to the diameter: their intersection with the semi-circle shows the sunspot's actual locations (FIG. 5). This procedure has been repeated for each sunspot.

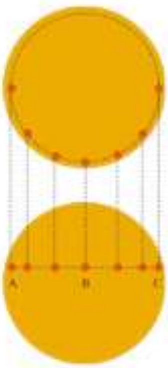


FIG. 4

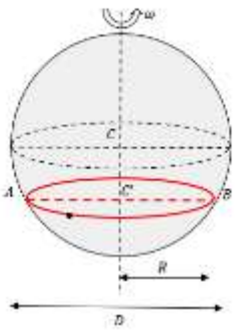


Fig. 5

What we are describing when observing the circular motion's projection on the diameter can be considered simple harmonic motion. (FIG. 6). If AB= diameter, β = arc angle, x our longitude φ and R= radius, then, using trigonometry, we can write the following:

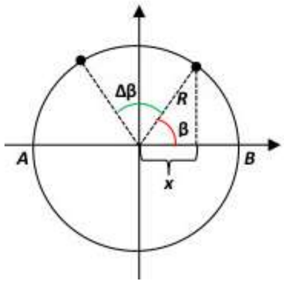


FIG.6

$$x = R\cos\beta$$
$$x = R\cos(\omega t + \alpha)$$

$\omega = \beta/t$ being the sunspots' angular velocity and the phase constant.

$$x / R = cos(\omega t + \alpha)$$
$$arccos(x / R) = \omega t + \alpha$$

If

$$y = arccos(x / R)$$

then

$$y = \omega t + \alpha$$

We are looking at a function whose graph is a straight line with a ω slope. (FIG. 7):

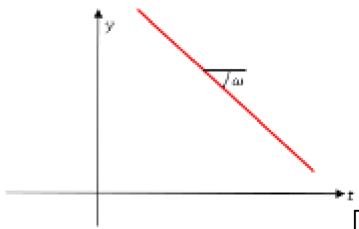


FIG. 7

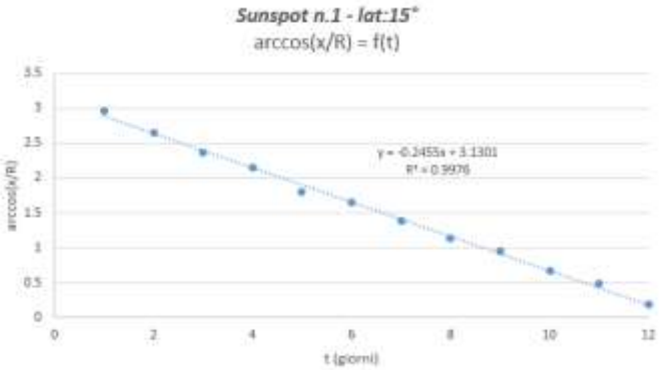
When considering circular motion, its period is always defined as T=2 π/ω. This equation is exactly what we need to calculate the period of rotation.

ω (rad/days)	T = 2π/ω (days)
0.2455	25.59342

Radius of sunspot's Trajectory
R (cm)
6

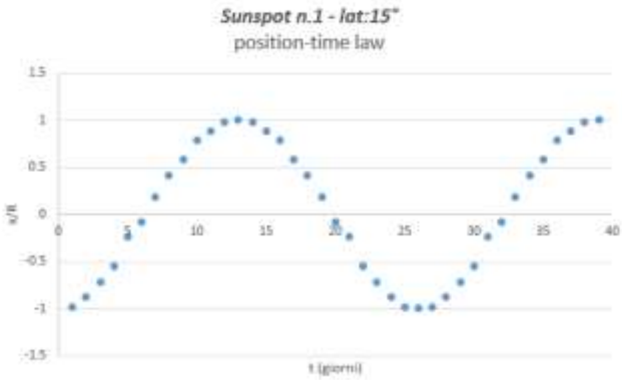
Here are the data tables.

First Sunspot:

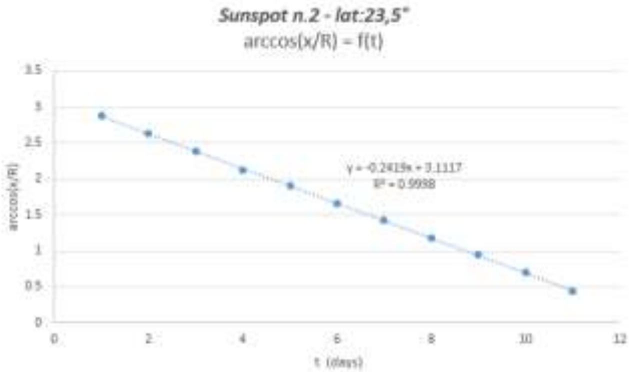


t (days)	x (cm)	arccos(x/R)
1	-5.9	2.958763937
2	-5.3	2.653722747
3	-4.3	2.369807283
4	-3.3	2.153160565
5	-1.4	1.806300564
6	-0.5	1.654226413
7	1.1	1.386420136
8	2.5	1.141020895
9	3.5	0.947969741
10	4.7	0.670785993
11	5.3	0.487869906
12	5.9	0.182828717

We used Excel to draw position-time graphs, being wise to the fact that our time of observation is far too short to show the sinusoidal wave typical of harmonic motion.
Our section of sinusoidal graph reaches its peak at 13 days, therefore mirroring the data for the next 13 days will give the desired wave.



Second Sunspot:

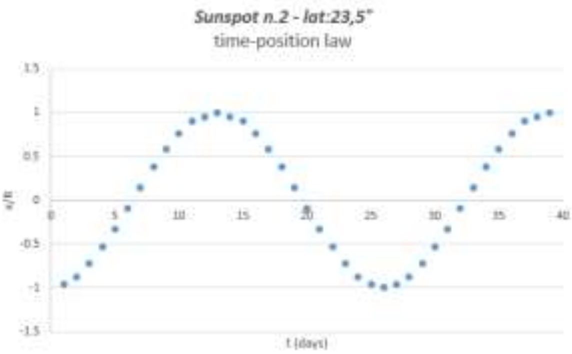


t (days)	x (cm)	arccos(x/R)
1	-5.9	2.958763937
2	-5.3	2.653722747
3	-4.3	2.369807283
4	-3.3	2.153160565
5	-1.4	1.806300564
6	-0.5	1.654226413
7	1.1	1.386420136
8	2.5	1.141020895
9	3.5	0.947969741
10	4.7	0.670785993
11	5.3	0.487869906
12	5.9	0.182828717

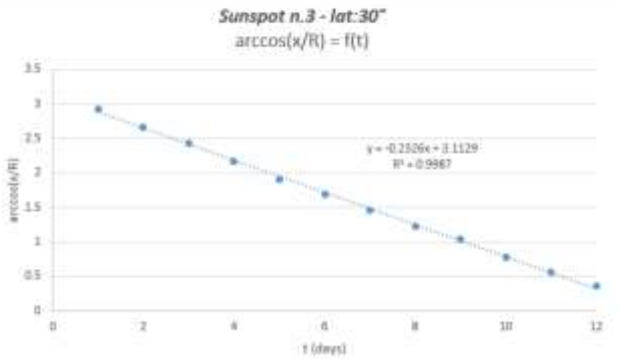
ω (rad/days)	T = 2π/ω (days)
0.2455	25.59342

Radius of sunspot's Trajectory

R (cm)
5.5



Third Sunspot:

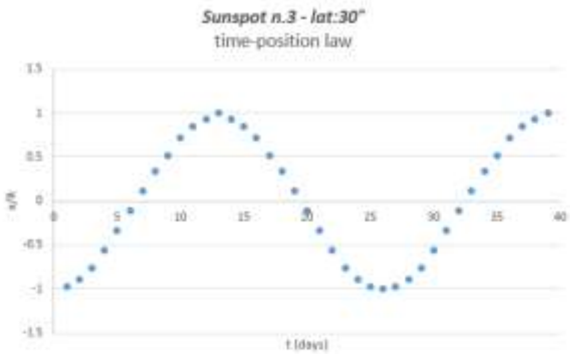


t (days)	x (cm)	arccos(x/R)
1	-4.4	2.930381773
2	-4	2.665710404
3	-3.4	2.427298099
4	-2.5	2.159827297
5	-1.5	1.910633236
6	-0.5	1.682137341
7	0.5	1.459455312
8	1.5	1.230959417
9	2.3	1.034319313
10	3.2	0.779719029
11	3.8	0.565269184
12	4.2	0.367208021

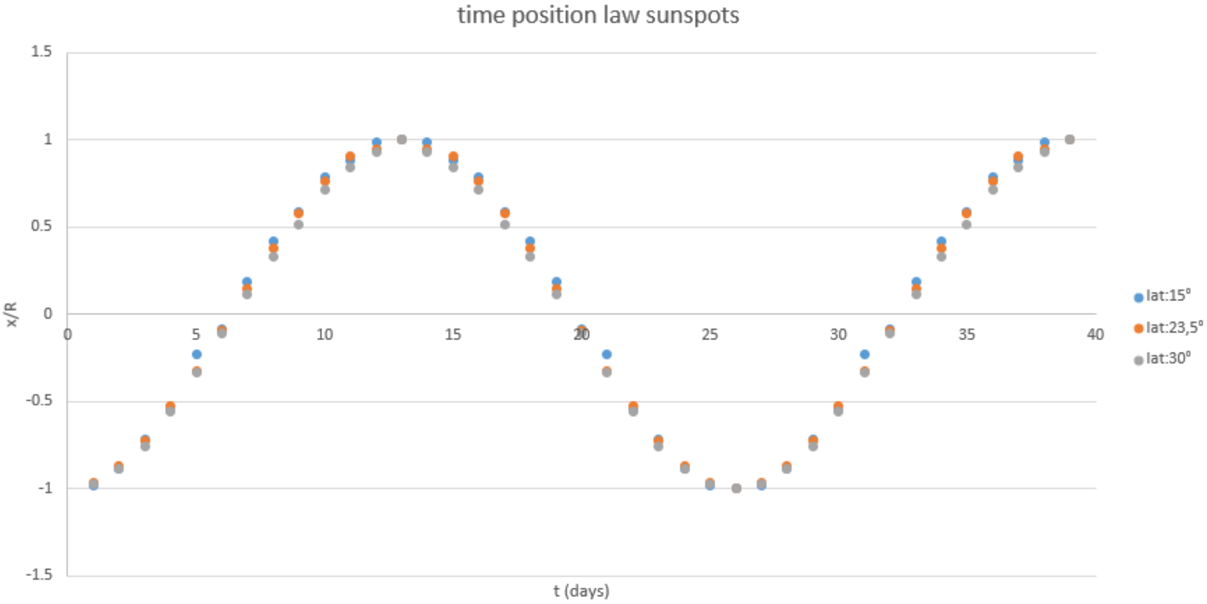
ω (rad/days)	T = 2π/ω (days)
0.2419	25.97431

Radius of sunspot's Trajectory

R (cm)
4.5



Below is a position-time graph of all three sunspots combined:



t (days)	*lat:15°*	*lat:23,5°*	*lat:30°*
1	-0.98333	-0.96364	-0.97778
2	-0.88333	-0.87273	-0.88889
3	-0.71667	-0.72727	-0.75556
4	-0.55	-0.52727	-0.55556
5	-0.23333	-0.32727	-0.33333
6	-0.08333	-0.09091	-0.11111
7	0.18333	0.14545	0.11111
8	0.41667	0.38182	0.33333
9	0.58333	0.58182	0.51111
10	0.78333	0.76364	0.71111
11	0.88333	0.90909	0.84444
12	0.98333	0.94545	0.93333
13	1	1	1
14	0.98333	0.94545	0.93333
15	0.88333	0.90909	0.84444
16	0.78333	0.76364	0.71111
17	0.58333	0.58182	0.51111
18	0.41667	0.38182	0.33333
19	0.18333	0.14545	0.11111
20	-0.08333	-0.09091	-0.11111
21	-0.23333	-0.32727	-0.33333
22	-0.55	-0.52727	-0.55556
23	-0.71667	-0.72727	-0.75556
24	-0.88333	-0.87273	-0.88889
25	-0.98333	-0.96364	-0.97778
26	-1	-1	-1
27	-0.98333	-0.96364	-0.97778
28	-0.88333	-0.87273	-0.88889
29	-0.71667	-0.72727	-0.75556
30	-0.55	-0.52727	-0.55556
31	-0.23333	-0.32727	-0.33333
32	-0.08333	-0.09091	-0.11111
33	0.18333	0.14545	0.11111
34	0.41667	0.38182	0.33333
35	0.58333	0.58182	0.51111
36	0.78333	0.76364	0.71111
37	0.88333	0.90909	0.84444
38	0.98333	0.94545	0.93333
39	1	1	1

RESULTS AND DISCUSSION

The experiments have yielded the following results:

Sunspot at φ =15°:	T= 25.5934 days
Sunspot at φ=23.5°:	T= 25.97343 days
Sunspot at φ =30°:	T= 27.0128 days

We have found that the sun's rotation period isn't constant, but instead differential, because it varies with latitude (more specifically, it increases as *φ* increases)

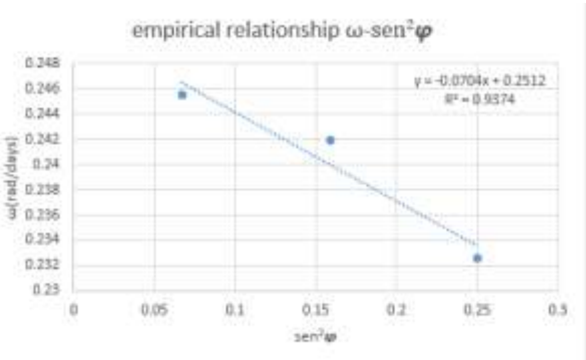
This empirical relationship is called *differential rotation law,* and it is usually written as follows[7]:

$$\omega(\lambda) = A + Bsin^2\lambda$$

Where λ is the heliographic latitude and A, B are parameters of the solar rotation, which we know to be differential.

Using Excel, we can use the *method of least squares to* make a linear interpolation of our data. The resulting equation describes the variation of the angular velocity (and therefore of the synodic period)

Using the values in the table, we calculated each constant:



$\varphi(°)$	Sen$^2\varphi$	$\omega(\frac{rad}{days})$
15	0.066987	0.2455
23.5	0.159001	0.2419
30	0.25	0.2326

$$A = 0.2512\frac{rad}{day}$$

$$B = -0.0704\frac{rad}{day}$$

However, our method has limitations. Firstly, our measurements will have an error which is dependent on images' resolution from Jhelioviewer. In addition to this, what we have measured is actually the synodic rotation period: it is only the *apparent* rotation period as seen from Earth, influenced by the rotation of the Earth around the Sun (from west to east) and the Sun's own on its axis. This means that the *actual* rotation period, known as sidereal period, is slightly shorter than its synodic counterpart.

Moreover, our approach can be improved: for example, the observation of additional sunspots, especially when taken at latitudes which make them easier to be scrutinized, could be beneficial. Another complication stems from the time of observation: right now, the Sun is going through a period of decreased activity, as opposed to a decade ago. Lastly, the smallest variation in the measurements of the sunspots' coordinates might yield wildly inaccurate results.

CONCLUSIONS

Our main focus was to suggest an easier but effective approach in order to measure the Sun's rotation period employing images taken from SDO's database from JHelioviewer and then using some basic notions of dynamics. Considering its simplicity and the reasonable results we obtained, we can state that our endeavour was successful.

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See_also:
The_spinning_sun:
http://www.mso.anu.edu.au/~jerjen/researchprojects/spinningsun/spinningsun.html

C. Isabel Ribeiro; Sunspots on a rotating Sun (articolo da cui abbiamo preso spunto per l'esperienza):
https://www.scienceinschool.org/content/sunspots-rotating-sun

Convertitore in data Giuliana:
http://www.onlineconversion.com/julian_date.htm

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