



ASTROEDU

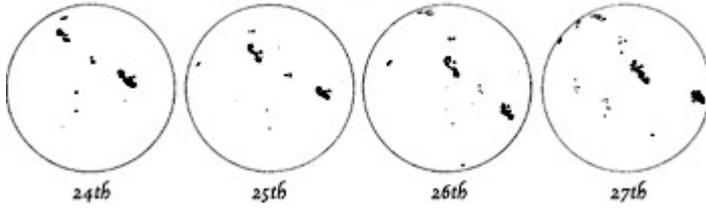
Peer-reviewed Astronomy Education Activities

Is the Sun rotating? Follow the sunspots!

**The Earth rotates on its axis, giving us
night and day - but what about other
celestial objects like the Sun?**

Philippe Kobel, GalileoMobile; María Dasí Espuig, GalileoMobile; Deborah Scherrer,
Stanford Solar Center

Sunspots drawn by Galileo, June 1612



 AGE 12 - 19	 LEVEL Middle School, Secondary
 TIME 1h	 GROUP Group
 SUPERVISED No	 COST PER STUDENT Low Cost
 LOCATION Small Indoor Setting (e.g. classroom)	

CORE SKILLS

Planning and carrying out investigations, Analysing and interpreting data

TYPE(S) OF LEARNING ACTIVITY

Structured-inquiry learning

KEYWORDS

Sun - rotation - Sunspot - Galileo



SUMMARY

The Earth rotates on its axis, giving us night and day – but what about other celestial objects like the Sun? In this activity students will use real satellite images of the Sun (Solar Dynamics Observatory, SDO) to discover that the Sun also rotates about its own axis! For this they will use a technique used for the first time by Galileo Galilei himself, and still used by astronomers to this day: following the displacement of sunspots. Observing Galileo’s drawings, students will make hypotheses about the nature and motion of sunspots. To test their hypotheses and provide evidence for the rotation of the Sun, they will use a set of 27 consecutive daily SDO images from the 25th November to the 20th December 2014, containing a large number of sunspots. Students will make crude estimates of the rotation period of the Sun (without calculations) by following different sunspots. They will finally discuss and compare their findings.

This activity is part of the [GalileoMobile Handbook of activities](#) and was tested during our expeditions in India and Uganda.



GOALS

This activity gives students the chance to find out that even a star like the Sun rotates, inviting them to picture a Universe where motion and rotation are ubiquitous. They will do this by:

- Reproducing Galileo’s historical experiment (with modern data)
 - Making hypotheses about sunspots and question their nature
 - Finding evidence in favor of the hypothesis that the Sun rotates, thereby causing the apparent motion of sunspots on its surface
-



LEARNING OBJECTIVES

Factual/conceptual content :

- Justify that the Sun is a rotating celestial body based on observational evidence.
- Define the rotation period of an object.

Science process skills :

- Propose alternative hypotheses for a phenomenon; discriminate between them based on careful data examination.

Attitudes :

- Recognize the Sun as a constantly changing and dynamic celestial object on the basis of observable surface features and its rotating motion.
-



EVALUATION

Besides the live in-class discussions, we propose, e.g., the following alternatives to evaluate how students have understood the scientific methodology behind this inquiry-based activity.

Each group could make a:

- Road map on a A3 page (poster) summarizing the different steps of their investigation, including illustrations.
- Lab report.

The first option presents the advantage of being doable in class and fosters more interaction within student groups.

To test whether the attitude of students has changes between before and after the activity, we propose to make them draw the Sun before and after the activity and write a sentence on their drawings about “What I think about the Sun/ How I see the Sun”.



MATERIALS

Paper version

Ideally, students will perform the activity in pairs. Thus, for each pair provide one set of:

- printed drawings of sunspots by Galileo Galilei in folder [see attachments]
- printed set of images of the Sun by Solar Dynamics Observatory (SDO) in folder [see attachments]

Print the Sun images one-side only (two images per page), so that students can easily spread the dataset on the table.

Electronic version

This activity can also be done on computers either by opening daily images of the Sun on the [Solar Monitor website](#) , or opening the images in PNG format.

- All the images in PNG format and in JPG format are in the attachments > SDO images.zip.

If you want to show an animated movie of the rotation of the Sun based on the dataset you are using, you will need (see Conclusion part in the Description of the activity):

- [SalsaJ software](#)
- Alternatively, you can use the movie provided in the “Movies” folder. It was compiled using SalsaJ.

About the SDO dataset chosen for this activity

The image set we provide was directly downloaded from the [Solar Monitor website](#). This dataset was close in time to the solar maximum of 2013 and carefully chosen to display a large number of sunspots, allowing students to look at different sunspots to analyse and compare their results.

Feel free to choose any other set of images from this website, provided you select enough consecutive days to cover, at least, one solar rotation.

Telescope version

It is possible to follow the motion of sunspots during consecutive days by using a method called “projection”, namely projecting the image of the Sun using a solarscope or a telescope and a screen (see [AAS page on eye-safety](#)). This method presents the advantage for students to “feel” the time scale of solar rotation. However, depending on when the activity is performed with respect to the solar cycle, there could be no sunspots at all or only a few, which may not provide enough data for students to test their hypotheses.



BACKGROUND INFORMATION

Teachers should be aware of Galileo’s dilemma about the nature of sunspots, the later discovered magnetic nature of sunspots as well as the differential (non-rigid) rotation of the Sun.

Here we provide a brief overview of the structure of the Sun, Galileo’s historical observations, the nature of sunspots, the non-rigid rotation of the Sun and an introduction to the satellite mission that produced the data used in this activity. At the end of each subsection, we provided links where teachers can read more about these topics.

The composition of the Sun

The Sun is a giant gaseous ball composed of mostly hydrogen and helium. Due to the extremely high temperatures in the Sun, the electrons can detach from their atom’s nuclei and are free to move. This state of matter is called “plasma”. Since the Sun’s matter is charged, it can interact with magnetic fields.

The Sun can be divided into 5 layers: the core, the radiative zone, the convective zone, the photosphere, and the atmosphere. The core is the innermost layer and it is the place where energy is produced by nuclear fusion (~ 15 million °C). The radiative zone extends from the core to about 70% of the solar radius and here the energy is transported mainly through radiation (photons are emitted, absorbed and re-emitted continuously). In the next layer, the convective zone, energy is transported by convection (upward movement of hot matter and downward movement of cold matter, similar to the boiling of a soup). The photosphere, at ~ 6000 °C, sits right above the convective zone. Since it is the layer from which most of the light comes, we call it the solar surface, although we would not be able to stand on it.

Beyond the photosphere we find the solar atmosphere, which is composed of two other layers: the chromosphere and the corona. The chromosphere is a thin reddish gaseous layer immediately above the surface. The corona is the Sun’s very thin plasma atmosphere, extending millions of kilometres into space.

Visit [NASA Solar Science website](#) for more information.

Galileo's sunspot observations

In 1612 Galileo Galilei pointed a telescope at the Sun. He was one of the first to do this, preceded by Thomas Harriott and Johannes Fabricius. Galileo knew that if he looked directly through the telescope, he could burn his eye. Instead, he projected the image on a screen to make careful drawings. In Galileo's time people believed that the Sun was a still, perfectly immaculate object. To his great surprise, he saw dark spots on the Sun. He was very intrigued by the nature of these spots, and therefore he observed and drew them on a daily basis to study them.

Visit [Rice University Galileo website](#) for more information.

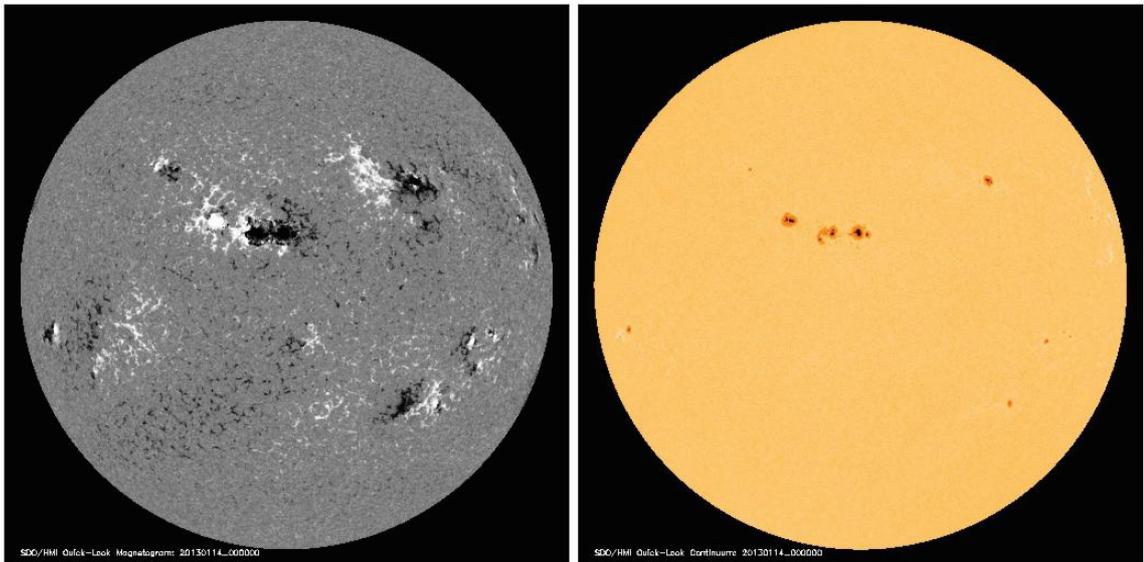
The magnetic nature of sunspots

The nature of sunspots remained an enigma until 1905, when the astronomer George Ellery Hale detected intense magnetic fields within these dark regions. Using a spectroheliograph he found that a certain property of the light (polarisation) emitted by the Sun was altered in a way that is specifically caused by magnetic fields. Today, satellites like Solar Dynamics Observatory (SDO) are equipped with special instruments to detect the location of magnetic fields on the Sun and infer their intensity. Figure 1 shows two images of the same day, obtained by SDO: a visible-light image of the whole solar disc and a map of the orientation and intensity of the magnetic fields present on the solar disc (magnetogram).

Sunspots are seen in the photosphere as dark features in contrast to the rest of the solar surface, because the matter within them is about 2000 °C cooler than their surroundings at ~ 6000 °C. The intense magnetic fields are responsible for this cooling. Since magnetic fields produce pressure, plasma inside sunspots is forced out to maintain pressure equilibrium between the sunspot (gas pressure plus magnetic pressure) and the surrounding plasma (gas pressure). Therefore the plasma inside the sunspot is less dense and a little cooler (if we compare the inside and outside of a sunspot at the same geometrical depth).

Sunspots usually clump together in groups and have lifetimes between several days and weeks. Sunspots are dynamic and evolve together with the magnetic field: they appear, change, disappear. Their number varies periodically with time together with the amount of magnetic field of the Sun, following the so-called 11-year sunspot cycle: every 11 years, the sunspot number and the amount of magnetic field reach a maximum (called "solar maximum"), followed by a minimum with barely no spots on the Sun. The dataset proposed in this activity is chosen close to the solar maximum, in order to display a large number of sunspots.

Sunspots are found in patches like storms on Earth, and are usually located in bands in both the northern and southern hemispheres. The bands that sunspots form in, move from mid latitudes to almost the equator throughout the 11-year sunspot cycle. Note that individual sunspots do not drift much in latitude since they only exist for a few weeks - just the latitudes where new spots form move towards the equator.



Visit [Solar Center website](#) for more information on solar magnetograms.

Visit [Solar Dynamics Observatory website](#) for more information on visible light images of the Sun.

The rotation of the Sun

Like the Earth, the Sun has a north pole and a south pole, and rotates around its axis. As seen from the Earth the Sun rotates about its axis once every about 27 days. The Sun's equator is almost in the plane of the Earth's orbit, and the Sun's north pole is in the same direction as the Earth's north pole. Seen from above the solar north pole, the Sun rotates counter-clockwise. Most modern images of the Sun are oriented so that the solar north is up and therefore features on the Sun's surface appear to move from left to right as the Sun rotates. Note that Galileo's drawings of sunspots (Fig. 2) are not oriented this way.

The non-rigid rotation of the Sun

Rigid objects do not change shape (i.e. they are non-deformable). Therefore, when rigid objects spin every part rotates at the same rhythm. This means that every part of the object takes the same amount of time to complete a turn. This is called rigid rotation. This is the reason why every spot on Earth takes 24 hours to complete a turn.

In non-rigid objects, i.e. deformable objects, rotation is different in different parts of the object. This is the case of the Sun, since it is made up of a gaseous matter called plasma. Like the Earth, the Sun has a North pole and a South pole, and rotates around its axis. However, the Sun's plasma near the equator completes a full turn in a little less than 27 days, whereas plasma near the poles can complete a full turn in as much as 35 days. This means that plasma can rotate at different speeds, depending on the latitude they are at: i.e. faster at the equator than at the poles. This is called differential rotation.

If you measure the Earth's rotation by measuring winds or the motion of clouds, you will find that the rotation of the Earth's atmosphere also varies with latitude. This is because the Earth's atmosphere is a gas and not a solid. As seen from space, the atmosphere rotates in less than 24 hours at mid latitudes and in more than 24 hours near the equator. We call this the "Westerlies" and "Trade winds" respectively. Differential rotation is not a unique aspect of the Sun; it is common for rotating bodies such as other stars and gaseous planets to have different rotation rates at different latitudes.

Visit [Swinburn University Cosmos website](#) for more information.

The Solar Dynamics Observatory

The Solar Dynamics Observatory (SDO) is a satellite mission from NASA. It was launched into an orbit around the Earth in 2010 and it has been observing the Sun since then. SDO's main goal is to study the solar atmosphere to understand better the relationship between the solar magnetic fields and energetic, short-term phenomena such as solar flares and coronal mass ejections.

Visit [Solar Dynamics Observatory website](#) for more information.

For more information about the solar cycle, see the [NASA Solar Science website](#) and [YouTube video](#)



FULL ACTIVITY DESCRIPTION

Ask students :

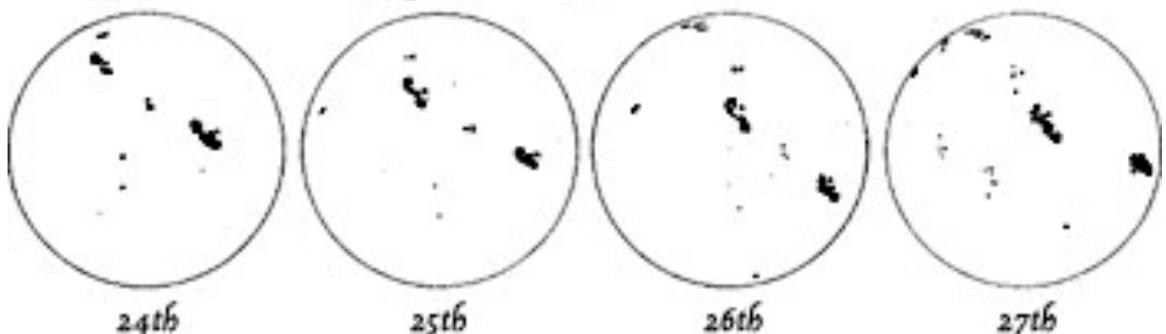
Do you think the Sun is rotating on its axis, like the Earth, or is it quietly at rest?

Tell the story of Galileo's first observation of the Sun.

Galileo Galilei was one of the first astronomers to point a telescope to the Sun, in 1612 (preceded by Thomas Harriott and Johannes Fabricius). In Galileo's epoch, people believed that the Sun was a still, perfectly immaculate object! To his great surprise, he observed spots on the Sun, and made the drawings shown in Fig. 2. He was very confused by the nature of these spots...

- Group students in pairs
- Distribute to the class copies of Galileo's drawings to examine (file "Galileo drawings.pdf" in folder « Material to print »).
- What happens to the spots from one day to the next?
- If you have a digital projector/beamer, you can project the movie "Galileo drawings" provided in the folder "Movies"

Sunspots drawn by Galileo, June 1612



Formulating hypotheses

A hypothesis is a guessed explanation of a phenomenon. In our case, the phenomenon is the sunspots and their apparent displacement across the Sun.

Ask the students to come up with several hypotheses about the sunspots and the causes of their apparent motion. Guide them to the following ones:

Are sunspots:

- **H1** small bodies or planets that orbit around the Sun (obstructing part of its light when passing in front of it)?
- **H2** clouds in the gaseous atmosphere of the Sun, that move because of atmospheric motions (currents)?
- **H3** features on the Sun's surface, that move because the Sun itself is rotating?

Help students realize that H1 and H2 do not imply that the Sun is rotating, as planets or clouds could move independently.

Note about H3: Students might think that the displacement of spots is due to the rotation of the Earth (about its axis), from which we observe the Sun. We can rule out this effect by performing the following experiment. Have the students turn slowly on themselves while focusing on a distant fixed object, like the blackboard or your nose. As they turn, they will realise that the object will not change position with respect to its surroundings; just as the Earth's rotation does not cause the spots to move on the Sun.

Although the Earth's revolution has an effect (see Discussion in Part 3), its period is too slow (365 days) to account for the much faster motion of the spots (see Galileo's drawings, over only 3 days!).

Testing hypotheses based on observations

To test their hypotheses, students will need to examine the Sun in greater detail and over more days. We will use a set of images of the Sun taken in December 2014 by a satellite called Solar Dynamics Observatory (SDO) from NASA.

- Ask the students how they think they could test their hypotheses if they had more images.
- Tell them that they will have in their hands a large set of images from a modern satellite, the Solar Dynamics Observatory (SDO), which observes the Sun everyday, including today! If you can, show them today's image of the Sun from SDO on the [Solar Monitor website](#)
- Give each student pair a printed set of SDO images (in folder "Material to print").
If you perform the activity electronically, students can directly browse through the images online or open them in PNG format.
- Give students some time to examine the images and ask them to search for evidence to discriminate between their hypotheses.

You can give some hints by asking questions like:

- In which direction are the spots moving? Is it the case for all of them?
- Do they seem to move randomly or together?
- Do they seem to move at the same rate?

Ask students to share their observations and arguments together and list them on the blackboard. Guide them towards the following:

- H1 could seem reasonable at first, because small planets orbiting the Sun could have orbits lying in a similar plane and thus, their apparent motion would be in the same direction. However, planets do not revolve around (orbit) the Sun at the same speed (closer ones to the Sun move faster), so, if sunspots were planet-like objects, we should observe some spots overtake others. Furthermore, H1 is also unlikely because the spots in the images appear to change shape (even in Galileo's drawings) and sometimes disappear.
- H2 is unlikely because if the spots were clouds moving due to Earth-like atmospheric currents, we would expect more random motions.
- The most likely hypothesis is thus H3: the Sun rotates and the spots are features on its surface.

We emphasized the words “most likely”, as students should become aware that in science, we can never prove a hypothesis, be 100% sure about it. All we can do is gain more evidence...

You can ask the students:

To gain more evidence, we'd like to “see the Sun rotate”, which is difficult in still images. But what could we do to animate all the electronic images ?

In front of students, you can quickly compile all the SDO images in a movie. This allows students to see and “feel” the rotation of the Sun. Use the free software SalsaJ and follow the steps listed here (see [How to create an animation with several images](#))

- For best results, use the images in JPG format in the folder “SDO images”, as these do not have latitude lines.
- You can also use directly the movie “Movie from dataset” provided in the folder “Movies”, which was compiled in SalsaJ.

Note that, even with the movie, we cannot strictly rule out the H2 hypothesis. Spots could indeed be clouds moving due to circulatory atmospheric currents running parallel to the equator as in Jupiter, for instance. *Without information about the magnetic field or surface temperature*, it is impossible to know more precisely the nature of sunspots (which is magnetic, as shown in Fig. 1) and thus discriminate between those hypotheses.

Estimating the rotation period of the Sun

This part of the activity is about stimulating the creativity of the students and leading them to an intuitive understanding of the process of measuring a rotation period. For a more rigorous calculation of the Sun's rotation period using kinematics, visit the sister activity [Measure the Sun's rotation period](#).

- Now that the students are confident that the Sun rotates, tell them that the next step is to determine how much time it takes the Sun to make a full rotation. This time interval is called the rotation period, which is an intrinsic property of all rotating objects.
- Challenge the teams to come up with their own methods to estimate the rotation period (in terrestrial days) based on the SDO images.
- Ask different groups to explain their method to the class and list their results on the blackboard.

Mostly, students will follow one spot moving across nearly the entire visible disk (or half of it). Since this motion corresponds to only half of the full turn around the

Sun, they have to multiply the number of days it took by 2 to obtain the number of days it would take for a full turn (respectively by 4 if they followed a spot motion across half the visible disk, which is a quarter turn). Their results might vary between 24 to 32 days.

Lead a class discussion about the reasons of the discrepancy between results.

This discussion should make the students aware that their method only gives crude estimates. They might, for instance, forget to take into account the time the spot took from the very left edge (where the spot is invisible) to its first visible position (or from the last visible position to the very right edge), and this “missing time” is hard to estimate.

Finally, explain the gaseous (i.e. non-rigid) nature of the Sun to the students and the possibility that all spots might not rotate exactly at the same speed.

Conclusions

Ask the students to reflect on their discovery and share their questions in class:

- What did they learn about the Cosmos today?
- What do they think about other celestial objects, planets, stars?

To show that rotating celestial bodies are common, you can also show videos from YouTube showing rotation of planets in the Solar system (see these videos of [Mars rotation](#), or [Jupiter rotation](#)).

Lead them to a view of a restless Cosmos where motion is natural and ubiquitous.

(This ubiquitous rotating motion in the Cosmos actually adds further evidence for the hypothesis of the rotating Sun, H3)

- To test whether their perception of the Sun as a constantly changing and dynamic object has indeed changed after the activity, you can ask them to “draw the Sun as they see it”, write what they think about it, legend it etc...
- Since they’ll certainly ask about the precise nature of sunspots, you can tell them that these are cooler regions of the Sun appearing darker in contrast to the rest of the surface. It is only since 1905 that we know that sunspots act like huge magnets, exerting deflecting forces on the currents of hot matter (see Background information).



CURRICULUM

This activity fits in the framework of a science curriculum in that it illustrates the inquisitive nature of science. By promoting the view of a Cosmos in natural motion, this activity is also a suitable introductory activity in the first chapters of a Physics course, when introducing Motion. Based on the idea that motion is natural, as opposed to rest, students are better prepared to grasp Newton’s laws of motion.



ADDITIONAL INFORMATION

Additional links for more information about the Sun are included in the section “Background information”.



CONCLUSION

At the end of this activity students have discovered that the Sun, like the Earth, rotates about its own axis. To do this they examined drawings by Galileo Galilei and a larger dataset of modern satellite images of the Sun.

CITATION

Kobel, P.; Espuig, M. D.,; Scherrer, D., 2021, *Is the Sun rotating? Follow the sunspots!*, [astroEDU](#),

ACKNOWLEDGEMENT

We particularly thank Eva Ntornousi for her insightful review of the activity, as well as all the collaborators, teachers and students who participated in the activity and provided feedback.
