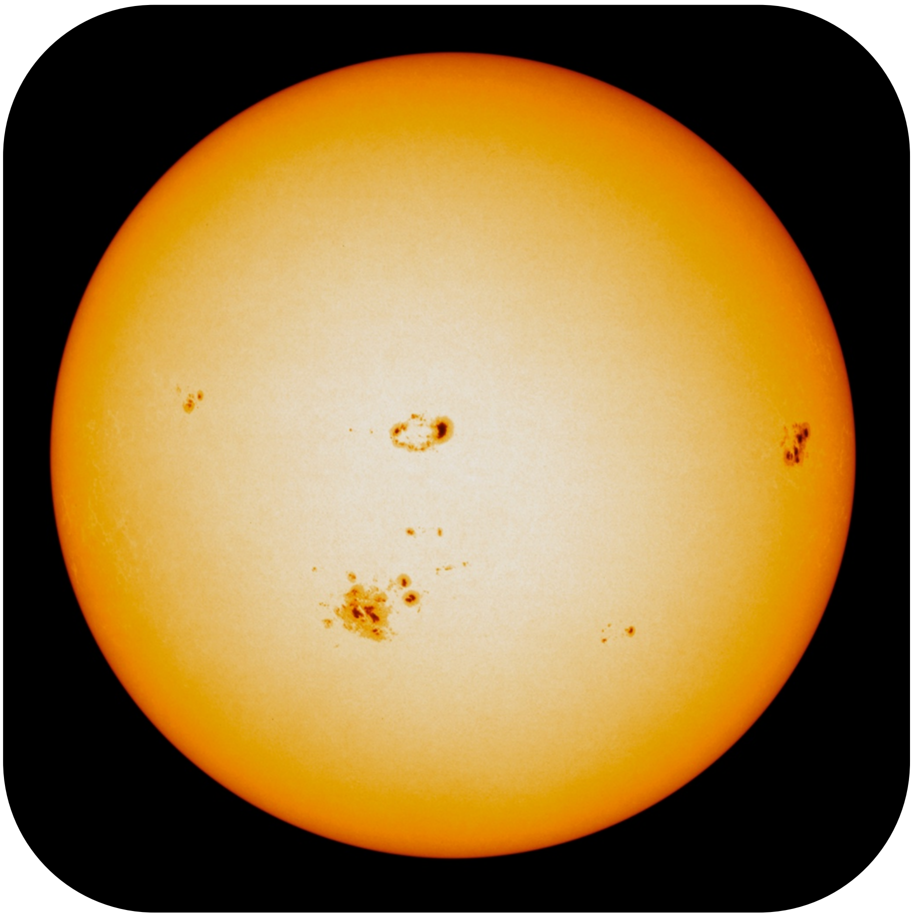
Sun's differential rotation

Teacher's Guide - Intermediate Level

CESAR's Science Case



Introduction

This is the teacher's guide for "Sun's differential rotation" CESAR's Science Case. Note that **this guide does not contain full instructions** to successfully develop the science case, those can be found at the student's guide. This guide includes information about the learning purposes of the activity as well as about the material and background needed for it, so that the teacher may decide **weather this laboratory is suitable** for his class or not. This guide is also meant to **help the teacher trough organising the activity**, providing tips and keys for each step, as well as the **solutions** to the case's calculations and the quiz.

In this science case the students are to **calculate the Sun's differential rotation** using images from CESO (CESAR's ESAC Solar Observatory). For this task, they must collect data from astronomical images and use some basic physics and mathematics. By the end of this laboratory, students will be able to:

- Explain how the Sun moves and how that movement is different to Earth's.
- Understand what differential rotation is.
- Easily work with coordinates.
- Calculate velocities by tracking targets in time-separated images.
- Represent, discuss and analyse scientific results.

By completing this science case, students will find out how astronomical pictures can be used to obtain valuable data, also they will realise how challenging is to obtain reliable data to confirm scientific theories.

Material

What will they need?

- The Sun's differential rotation Student's Guide.
- CESAR's Booklet.
- Computer with Web Browser and Internet Connection.
- CESAR web tools.
- Calculator (physical or online such as wolframalpha.com) and paper and pen.
    - Or a spreadsheet program such as Open Office, Google Docs, Excel or Numbers.

There are no needed chapters from the booklet, however "Sun" is recommended to get more knowledge about the topics treated in this laboratory, and the introduction in "Earth Coordinates" may came in handy if students don't have the basic knowledge about standard coordinate systems.

Background

To follow the intermediate level guide, student's must have a math basis. Knowledge about basic operations, degrees and unit conversions is recommended. Also they must know how to represent a point in a graph. Nothing harder than that will be done, but students should be conformable with those concepts.

Although all the Sun-related essential background is provided in the student's guide, it might be useful if those concepts among some others (like what sunspots or solar flares are) were explained in a lesson previous to the laboratory execution day. In that way they will learn more about our star, and they will have time to settle the knowledge before doing the exercise. In case you decide to do so, you'll find in the "Sun" booklet and in the "Sun's differential rotation Student's Guide" all the information necessary for that lesson. Also, as said before, **the introduction in "Earth Coordinates" may also be useful if the students don't have basic knowledge about standard coordinate systems.**

If you want to consider a math free laboratory, check the basic level guide. On the other hand, note there's also an advanced level if you consider that the student's guide for the intermediate level is way to easy.

Laboratory Execution

Once student's have the background knowledge and the needed material, all they ought to do is read their guide and follow the steps. This task is suitable both for doing it alone or in small groups.

If they make no mistake, they should obtain about 14.5 degrees/day for the equator speed and a slightly smaller speed for the spot closer to the poles (never less than 9 degrees/day). Also they should be able to place some points in the upper centre of the graph.

Just in case they do commit some mistake, in the following paragraphs are every step's solutions along with common mistakes that may help you identify their error:

Finding a sunspot at 0° latitude should be easy, but students will realise that there's no way to find sunspots at high latitudes, and they will have to accept that they can only have data in a narrow spectrum of latitudes. They should try to find a sunspot as close to the poles as possible, but they probably wont find a sunspot over ±30° latitude.

Step 1 - Coordinates of a sunspot

There's no difficulty in this step, just **check that students do know how to use coordinates.**

Step 2 - Collecting data

Check that students do know what latitude and longitude is, so they don't get confused in this step.

What we actually want to do, is select two images, separated by one or more days, so that in one of them the sunspot is at the left, and in the other one in the right.

The difference in longitude for a sunspot in two images separated by one day should be about 14º, and around 14º more for each extra day of difference.

Sunspots rarely move in latitude, if students note a change in latitude, they are most probably looking at a different sunspot.

Step 3 - Calculating speeds

If they make no mistake, they should obtain about 14.5 degrees/day for the equator speed and a slightly smaller speed for the spot closer to the poles (never less than 9 degrees/day). If they don't, check that the distance and time values make sense and are expressed in degrees and days.

However, a lot of precision is needed to detect the differential rotation, even if they do get lower velocities for higher latitudes **the difference should be small** (never more than 6 degrees/day). So if after revising the process they still don't get a better result, they are good to go as long as all the values are between 12.5 and 16.5 degrees/day.

Let's give a few examples to clear the error tolerance: If they get 17 degrees/day for the equator and 16 degrees/day for a bigger latitude, the result is good, because they got a value close to 14.5 degrees/day for the equator speed and a slightly smaller speed for the spot closer to the poles (that wasn't smaller than 9 degrees/day), which was the desired result. Also if they get 12 degrees/day for the equator and 11 degrees/day for a bigger latitude, the result is good too, because they got a value close to 14.5 degrees/day for the equator speed and a slightly smaller speed for the spot closer to the poles (that wasn't smaller than 9 degrees/day), which was the desired result. In this two cases the main requisite was achieved so the result is considered good. Now: If they get 15 degrees/day for the equator and 16 degrees/day for a bigger latitude, the result is not good, because even if they did get a value close to 14.5 degrees/day for the equator speed they did not get a slightly smaller speed for the spot closer to the poles, which was the desired result. Still, as the two values are between 12.5 and 16.5 degrees/day, if you found no mistake in the process, they are good to go. However, if they get 12 degrees/day for the equator and 13 degrees/day for a bigger latitude, the result is neither good, because even if they did get a value close to 14.5 degrees/day for the equator speed they did not get a slightly smaller speed for the spot closer to the poles, which was the desired result. And as the two values are neither between 12.5 and 16.5 degrees/day, they are not good to go; there must be a big mistake somewhere.

Conclusions

You will note that at the end of the student's guide, there is a conclusions paragraph where some questions are asked. It's a good idea to let students do the conclusions part on their own, and then organise a class discussion and talk about the results. The following paragraphs treat all the questions they are asked to answer, and will help you guide the debate to its purpose.

1. Try to understand the graph.

The graph shows the Sun's differential rotation. It represents the rotation speed as function of the heliographic latitude. At 0° latitude, near the equator, the rotation speed is about 15 degrees/day. At latitude 90° or -90°, near the poles, the rotation speed is about 9.5 degrees/day. The graph is symmetric, the speed equally decreases from 15 degrees/day to 9.5 degrees/day if moving towards the north or the south pole.

2. Then, represent the values you have obtained. How good do they match the curve?

Students should be able to place some points in the upper centre of the graph, however they probably wont match the curve.

3. If your points don't precisely match the curve, discuss whether the points or the curve are misplaced and why.

The curve may actually be misplaced, it is just a prediction and it may not be very precise. Still, the shape of the curve matches what we know about Sun's differential rotation, indicating it's probably correct. The placed points, are only two. If the one at higher latitude has a faster speed, then the points do not match what we know about Sun's differential rotation, indicating they are probably incorrect. (There's also the unlikely possibility that our knowledge is wrong.) Even if the points agree with our knowledge, they have a big error, because of this error, it's more likely that they are the misplaced ones. The reason for this error is that the latitude and longitude measurements weren't precise enough, we would need images with higher resolutions and way more precise grids to get better measurements.

4. Looking at your data, would you be confident to aver that the prediction is correct or incorrect? Why?

The class should not be able to neither confirm nor deny the prediction. There main three reasons are the error in each measurement, the low quantity of points, and the lack of data near the poles. Still, students should be proud, in science, is very common to obtain this kind of result. The fact that the points are placed somewhere near the predicted curve is already a great result. If a scientist obtains this result he would never say that the experiment was a failure, he actually would be encouraged by the results and would design a new experiment to get more and more precise measurements and keep trying to prove the prediction.

Even if the student's guide ends up here, the activity may continue with the quiz. Although this quiz can be used as a qualifiable exam, it is not only meant to be so. Even if the students have successfully calculated some velocities, if they don't fully understand the whole procedure, the quiz questions may make them doubt (some of them might be really tricky). Besides than examining them, it is a good idea to give them some time to do the test by their own, and then group them for discussing their answers. It is likely that they have different answers for some of the questions, and **by discussing them, they will achieve a much better comprehension of the whole process** they used. In the last pages of this guide, all the questions from the quiz are answered. For each question the correct answer is provided, and just in case it's not clear why, it's also indicated why the others are wrong. Finally, for each question there is one possible answer that makes no sense, if one of this answers is given, you can be sure the student is randomly answering.

Once you finish the activity, please, do consider giving us some feedback at:

cesar.esa.int/index.php?Section=Contact

Quiz

The correct answers for the quiz are **c b a d c a b d c c**.

The no sense answers for each question are **b c d a b c c b d a**.

In case of doubt, the discussion of each question follows next:

1. Unlike the Earth, the Sun is not a rigid body. This means that

- ☐ when studding its movement, you can not consider the Earth as a compact structure.
- ☐ the Sun is about to turn into a compact structure by eating planet Earth.
- ☐ the Sun is not forced to move as a whole.
- ☐ when studding the movement of the Sun, you can consider it as a compact structure.

You do can consider the Earth as a compact structure, so answer **a** is not correct. You can not consider the Sun as a compact structure, so answer **d** is not correct. The Sun not being a rigid body means, among some other things, that it is not forced to move as a whole.

2. Unlike Earth's, the Sun's surface

- ☐ is made of water, with sea currents that are free to move anywhere.
- ☐ rotates at higher speeds in lower latitudes.
- ☐ is made of plasma that will turn into soil after a few years.
- ☐ moves faster in the poles and slower in the equator.

Sun's surface is made of plasma that rotates faster in the equator (at lower latitudes) and slower at the poles.

3. The Sun's rotation speed is different at different latitudes, this means that if two sunspots appear

- ☐ at the same longitude, they will be at different longitudes after a few days.
- ☐ at the same latitude, they will be at the same longitude after a few days.
- ☐ at the same longitude, they will be at the same longitude after a few days.
- ☐ at the same time, they will fuse into a bigger sunspot capable of great things.

The first three answers sound similar, but only the first one is correct. If two sunspots appear at the same latitude, they would be in the same parallel, and if they are in the same parallel there is no way they have the same longitude unless they are in the exact same place, which makes no sense, so answer **b** is not correct. If two sunspots appear at the same longitude, one of them would be closer to the equator and will move faster, so they wouldn't be at the same longitude after a few days. Look at the first image in the background section of the student's guide, all the sunspots appear at the same longitude but they end up with different ones, as said in answer **a**.

4. We can calculate the rotation speed of the Sun by measuring the speed of sunspots because

- ☐ sunspots want to help us and they whisper the Sun's differential rotation.
- ☐ sunspots are located at the Sun's surface, that moves as a whole.
- ☐ sunspots move like sea currents as they are free to move anywhere.
- ☐ sunspots are located at the Sun's surface, whose speed we want to measure.

Sunspots do not move like sea currents, and the Sun surface does not move as a whole; the only correct is **d**.

5. The Sun rotates

- ☐ clockwise, like the Earth does.
- ☐ so fast that it is flat.
- ☐ counter-clockwise, like the Earth does.
- ☐ faster in the poles.

With the North orientated upwards, the Sun rotates counter-clockwise. Check the movement of the sunspots when you choose images of the same feature with a few days of difference, the sunspot moves to the right (counter clock-wise as seen from above).

6. You wrote down the latitude of each sunspot to

- ☐ check the speed of the Sun at different latitudes.
- ☐ measure how much the latitude changes after a few days.
- ☐ measure the latitude of the Sun as seen by a radiotelescope.
- ☐ subtract it from the latitude of the same sunspot after a few days, and divide it by time.

The Sun rotation has different speeds in different latitudes, we wrote down the latitude of each sunspot to measure the different speeds of the Sun at different latitudes. The latitude of a Sunspot does not change over time, the longitude does. Answers b and d would be correct if we where talking about longitude.

7. You wrote down the longitude of each sunspot to

- ☐ check the speed of the Sun at different longitudes.
- ☐ measure how much the longitude changes after a few days.
- ☐ measure the longitude of the Sun as seen by a new radiotelescope.
- ☐ check if the longitude remains stable.

Now we do are talking about longitude, so answer **b** is correct.

8. To calculate the speed of a sunspot you

- ☐ divided time by distance.
- ☐ used a chronometer.
- ☐ looked at, at least, three different sunspots.
- ☐ tracked the sunspot in time-spaced images.

To calculated the speed of a sunspot the distance was divided by time, not the other way round. To calculated the speed of a sunspot we looked only at that single sunspot in different images spaced over time.

9. We say that the Sun has differential rotation because

- ☐ two sunspots in the equator don't necessarily have to rotate at the same speed.
- ☐ the plasma is differential and it does actually rotate.
- ☐ the plasma located at different distances from the poles may rotate at different speeds.
- ☐ the student's guide says so, and the students guide knows more than anyone.

Two sunspots in the equator do rotate at the same speed, the differential rotation is the different speeds of Sun's surface at different distances to the equator.

10. The Sun's differential rotation graph, where the rotation speed was represented as function of

- ☐ the heliographic longitude, showed that we are not alone in the Universe.
- ☐ the heliographic longitude, showed that the Sun rotates faster in the equator.
- ☐ the heliographic latitude, showed that the rotation speed is symmetric to the equator.
- ☐ the heliographic latitude, showed that the Sun rotates faster in the poles.

In the graph the rotation speed was represented as function of the heliographic latitude. And again, the Sun surface rotates faster in the equator (at lower latitudes) and slower at the poles.