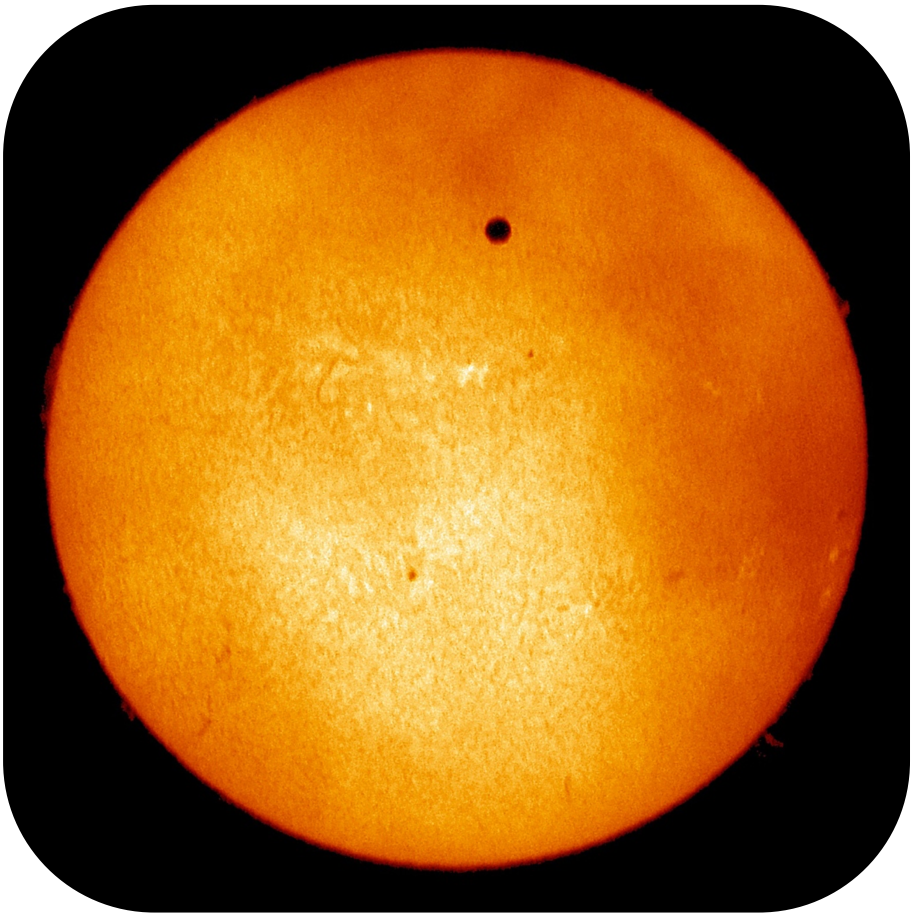
The Venus-Sun distance

Teacher's Guide – Intermediate Level

CESAR's Science Case



Introduction

This is the teacher's guide for "The Venus-Sun distance" 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 Venus-Sun distance** using images from a Venus transit. For this they must use mathematics along with parallax relations. By the end of this laboratory, students will be able to:

- Explain what a transit is.
- Expose the main parallax concepts.
- Use parallax for measuring astronomical distances.

By completing this laboratory, students will find out how astronomical pictures can be used to obtain valuable data, also they will find a real scientific use for proportionality (basic proportionality theorem / Thales' theorem / intercept theorem).

Material

What will they need?

- The Venus-Sun distance Student's Guide.
- CESAR's Booklet.
- Computer with Web Browser and Internet Connection.
- Google Earth or similar program to look for coordinates. (Optional)
- Access to CESAR web tools.
- Calculator (physical or online such as wolframalpha.com) and paper and pen.
    - Or a spreadsheet program such as Excel or Numbers, or access to GoogleDocs.

The needed chapter from the booklet is **"Parallax Effect"**, but "The Sun" and "Transits and Eclipses" chapters can be of use for further information.

Background

To follow the intermediate level guide, student's must have a math basis. Knowledge about basic operations, unit conversions and solving easy equations is recommended. However, all the math is easily explained step by step in the intermediate level guide. 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.

In case you decide to go on with the intermediate level, note **that before reading the student's guide** and actually starting the laboratory, students must acquire **general knowledge about parallax and parallax proportionality relations**. Those things are explained in the CESAR Booklet, in "Parallax Effect" chapter. Although in their guide's introduction, students are encouraged to read this chapter before they keep reading, it might be more useful if those concepts were explained in a lesson previous to the laboratory execution day. In that way they'll have time to settle the knowledge before doing the exercise, and the booklet will only be used as a reference document. In case you decide to do so, you'll find in the booklet all the information necessary for that lesson.

Also, as said before, further chapters from the booklet can be read to expand the knowledge acquired in this activity and for better understanding the experiment: Sunspots are used in the first step of the laboratory execution although there's no explanation regarding them. By reading or explaining to them the "Sun" chapter, they will understand what sunspots are. Also as in this laboratory they'll be using images from a Venus transit, a brief explanation of what a transit is, is given in their guide. But the "Transits and Eclipses" chapter is much more detailed and will ease the the task of picturing the situation of the experiment and also expand their knowledge about this phenomenon.

Once they, at least, have understood "Parallax Effect" chapter, they will be ready for the laboratory execution.

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, the final result for the **Venus-Sun distance should be around 0.72 au**. Usually the measurements are not done with absolute precision, and also the method described in this guide uses several approximations that slightly modify the result, so values between 0.62 au and 0.82 au are good enough. In the final question the Venus-Sun distance is about 115,200,000,000 m; if the Venus-Sun distance in au wasn't precise, we should expect a similar vagueness in this calculation.

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.

Step 1

Make sure not to align the images looking at Venus, just align the sunspots. After merging the images, if the two Venuses superpose a little, everything is probably right.

There is not only one correct value for the $\overline{A'B'}$ distance measured in pixels, the value depends on what image you use and how you make the measurement. What is important is the relation between that distance and the sun radius measured in the same image. But that's is done in step three.

Step 2

In step three it will show up if step one was done properly. Again there is not only one correct value for the Sun radius measured in pixels, but whatever the value is, it should be around 25 times bigger than the $\overline{A'B'}$ distance measured in step one. That means that $\overline{A'B'}\ [R_S] \sim \frac{1}{25} \sim 0.04$.

Common mistake is to measure the Sun diameter instead of the radius.

The Sun radius in meters is 695,700,000 m.

Using those two values, $\overline{A'B'}\ [m]$ should be around 27,828,000.

Step 3

The coordinates for Canberra are 35º 18' S, 149º 9' E, and for Svalbard 78º 13' N, 15º 38' E. Similar values are alright as the specific position of the observatories is not specified.

Introducing this values into the CESAR web tool should approximately give 12,340,000 m as the value for the $\overline{AB}$ distance.

Step 4

Just a single operation is to be done here. Using the values obtained before, $\overline{VS}\ = 0.69\ au$ which was the expected value.

Conclusions

One au is about 150 billion meters, then the Venus-Sun distance is about 108,000,000,000 m. You may discuss with your class the convenience of using au instead of meters when expressing astronomical distances.

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 obtained the Venus-Sun distance, 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 is completely absurd, if one of this answers is given, you can be sure the student is randomly answering.

Quiz

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

The absurd answers for each question are d c a b d c b d d b.

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

1. Back in the 16th century, astronomers

- ☐ discovered the astronomical unit, usually just named au.
- ☐ set the Earth-Sun distance as reference unit.
- ☐ were not able to measure distances.
- ☐ travelled to Venus after visiting the Sun.

All first three answers might look correct. But if you give it a second thought, first one is not. Astronomers did not discover the astronomical unit, a unit is not something inherent to the universe, hence a unit can not be discovered, nonetheless a unit may be set as reference for measuring. Answer c is not correct either, astronomers do were able to measure distances, they just were not able to measure astronomical distances in meters. So answer b is the only one left.

2. The Parallax relation we used involves

- ☐ four different astronomy constant values.
- ☐ the Venus-Sun distance and the Venus-Earth distance.
- ☐ a Venus satellite and two Sun prominences
- ☐ the distance between an observer and the apparent position of Venus as seen by him.

Answers a b and d could seem correct. Four values do are involved on the relation, but $\overline{A'B'}$ and $\overline{AB}$ are not really astronomy constant values. So answer a is not correct. Answer d is not correct either because the distance between an observer and the apparent position of Venus as seen by him would be $\overline{AA'}$ or $\overline{BB'}$ and neither of those appears in the equation. Son answer b must be the only right one again.

3. Besides de parallax relation, we also used a relation obtained from

- ☐ the Venus Express mission.
- ☐ the Venus transit data.
- ☐ the geometry of the transit.
- ☐ the Venus transit photographs.

The other relation we used, the one that is mentioned in the question three, is $\overline{EV} = 1 - \overline{VS}$. When we obtained this relation we hadn't look at he images or at the data yet. We obtained it only by examining the geometry of the situation.

4. We need images from two different observatories because

- ☐ Earth rotation will eventually provoke dawn, and Venus will no longer be visible.
- ☐ one observatory must be launched in a Sun rocket to Venus.
- ☐ having two observatories is necessary for getting accurate images.
- ☐ only with two different lines of sight parallax effect occurs.

It is true that Earth rotation will eventually provoke dawn, and Venus will no longer be visible. But that's not the reason for having two observatories. The reason is that only with two different observatories you can observe Venus from two different lines of sight, and only in that situation you can study the parallax effect. If we had only one observatory, there would be no parallax effect, we could had never draw proportional triangles nor use the parallax relation, as this relation includes the distance between the two observatories.

5. We chose two images taken at the exact same time because

- ☐ if not, Venus would be in a different position when each picture was taken.
- ☐ Canberra images were named using UTC, but Svalbard ones where named using UTC+2.
- ☐ that way the two pictures will be exactly the same.
- ☐ if not, Venus and the Sun would fall apart.

Again, it is true that Canberra images were named using UTC, and that Svalbard ones where named using UTC+2, but that's not a reason at all. Also if you think about it the two pictures will never be exactly the same even if they were taken at the same time because Venus is seen in different positions from each place. The actual reason for choosing two images taken at the exact same time is that Venus is orbiting the Sun, during the transit it moves and crosses the sun disk. If we had chosen two images from different times Venus would be in a different position when each picture was taken. Why is it important that Venus is in the same position when each picture is taken?

Because if not the $\overline{A'B'}$ distance would seem two be larger than what it actually is. If we had merge two images taken at different times, one of the Venuses would be far away from the other because during the time that passed between the two pictures, it would have moved.

6. The distance that was measured in pixels in the merged image was

- ☐ the distance between the two observatories.
- ☐ the distance between the two Venus' shadows.
- ☐ the distance between the apparent position of the Sun while it absorbs Venus.
- ☐ the distance between the apparent position of Venus as seen from two different places.

The distance measured in pixels was the one measured in the sun image, that was, between the two Venuses. This means both b and d answers may be correct. But the two images of Venus are not shadows, if you think about it you can not project a shadow in the sun, the Venuses look as shadows because we are looking at the half of the planet that is at night, so its completely dark. But they are not shadows, what is seen in each image is the actual Venus, so d is the only correct answer.

7. During a Venus transit,

- ☐ Venus hides part of the Sun surface.
- ☐ Venus explodes and the reappears when the transit is over.
- ☐ the Earth is between Venus and the Sun.
- ☐ the Sun is between Venus and the Earth.

Nothing to ad in this one.

8. After doing the calculations, the Venus-Sun distance is obtained in au because

- ☐ back in the 16th century the au was set as a reference unit for measuring distances in space.
- ☐ while developing the (eq. I) we set the Earth-Sun distance equal to one.
- ☐ the au is still the appropriate unit to express distances between solar system objects.
- ☐ someone from Venus told the Sun to do it that way.

Answers a and c would be correct if we were talking about why the Venus-Sun distance is expressed in au. But actually, we are talking about why is **obtained** in au. To answer this, we should take a look at where the equation we are using to calculate the Venus-Sun distance came from.

We started with this two equations:

$$\frac{\overline{A'B'}}{\overline{VS}} = \frac{\overline{AB}}{\overline{EV}} \qquad \overline{EV} = 1 - \overline{VS}$$

All the values here must be expressed in au, because only in au the Earth-Sun distance is 1. (Remember that the 1 in the right side equation is the Earth-Sun distance, as it was explained in the Student's guide). If we hadn't set the Earth-Sun distance equal to one, we could use any other unit, but because we did, we now can only use au. So in the equation we used, that was obtained from those two, the distances (including the Venus-Sun distance we obtain) are also expressed in au.

$$\frac{\overline{A'B'}}{\overline{VS}} = \frac{\overline{AB}}{1 - \overline{VS}} \quad \rightarrow \quad \overline{VS} = \frac{1}{1 + \frac{\overline{AB}}{\overline{A'B'}}}$$

(Note that we didn't change the but $\overline{A'B'}$ and $\overline{AB}$ values from meters to au because as one is divided by the other units will disappear as long as they are the same for both.)

9. Parallax effect was useful because thanks to the fact that Venus is

- ☐ in two places at the same time, we can draw proportional triangles and use proportionality.
- ☐ seen in two different positions, we can draw proportional triangles and use proportionality.
- ☐ seen in two different positions from the same place, we can use proportionality.
- ☐ a green planet, we can draw proportional triangles and use proportionality.

First three answers may sound similar, but Venus is not actually in two different places at the same time, it is just seen in two different positions from two different places. Son only answer b is correct.

10. Proportionality was useful because it helped us find

- ☐ the distance between A and B.
- ☐ a shiny treasure.
- ☐ the distance between A' and B'.
- ☐ the parallax relation.

The parallax relation from the booklet is no different that the basic proportionality theorem / Thales' theorem / intercept theorem.