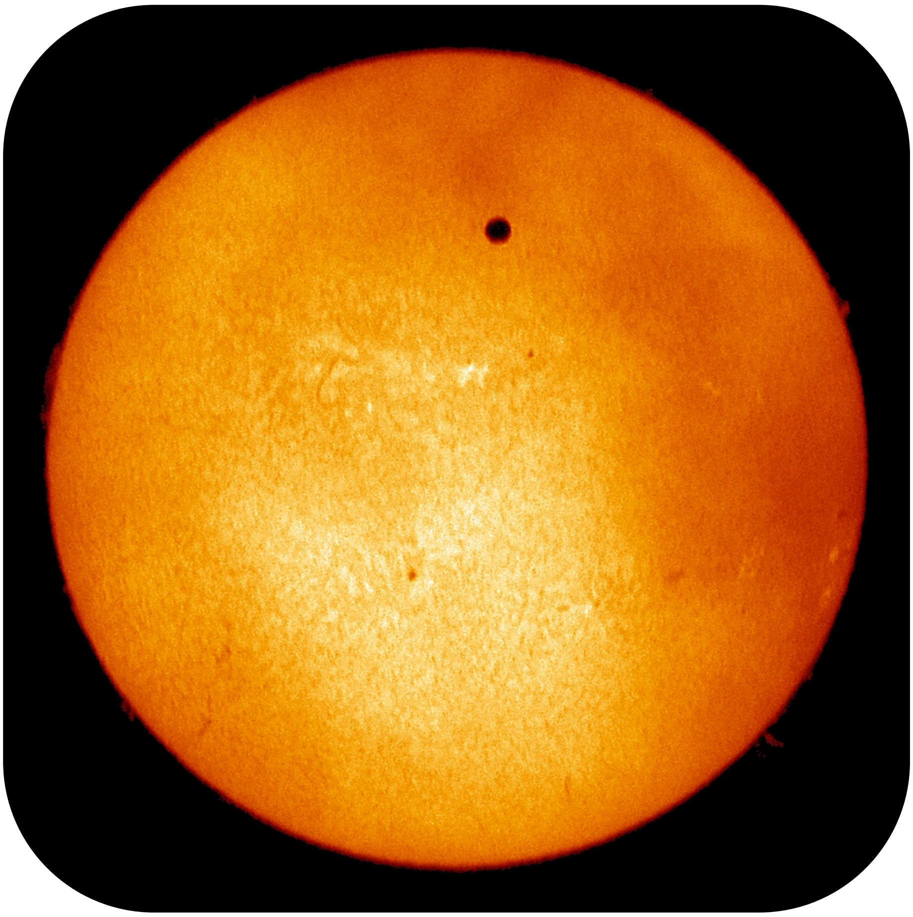
The Venus-Sun distance

Student's Guide – Intermediate Level

CESAR's Science Case



Introduction

In everyday life we measure distances in units such as meters; that is, we take a meter as reference and express distances as multiples of this reference. Back in the 16th century, astronomers were not able to measure the distances between solar system objects in meters, that's why they took the Earth-Sun distance as reference, and measure other distances as multiples of it. When used for measuring, the Earth-Sun distance is called an astronomical unit, or usually just au. **It's the object of this laboratory to use Venus transit data for measuring, in astronomical units, the distance between Venus and the Sun.**

Before you keep reading, **you're highly encouraged to take a look at the CESAR Booklet** and read "Parallax Effect" chapter, as most of the formulas and knowledge you'll need to successfully complete our task are extensively treated there. That way you may even find by yourself a manner to achieve our goal. However, in this guide, all the equations are written down when needed. Also, you may read "The Sun" and "Transits and Eclipses" chapters for further information.

Material

What will you need?

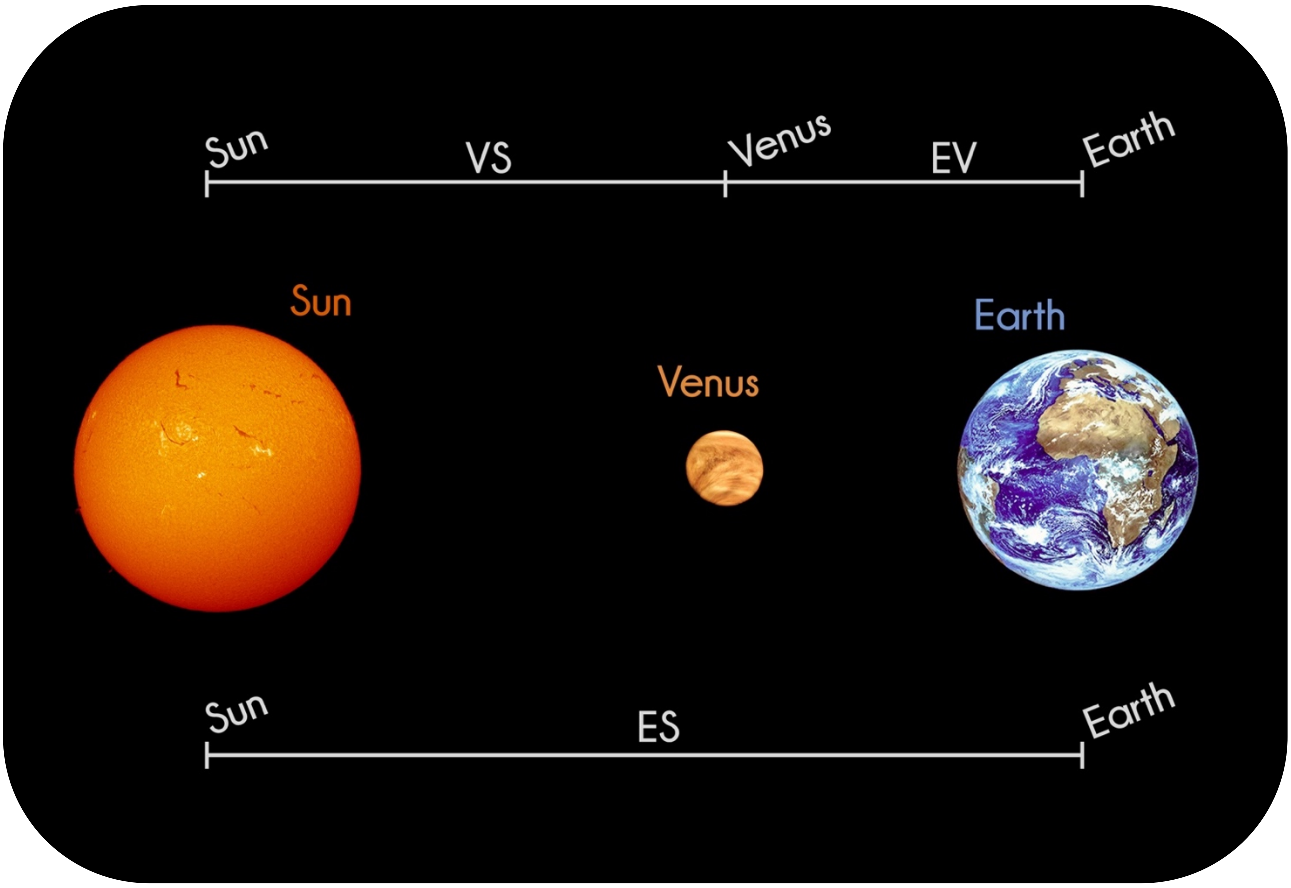
- The Venus-Sun distance Student's Guide.
- CESAR's Booklet.
- Computer with Web Browser and Internet Connection.
- Google Earth or similar program to look for coordinates. (Optional)
- Access to CESAR web tools.
- Calculator (physical or online such as wolframalpha.com) and paper and pen.
    - Or a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

Background

Step 1

To measure the Venus-Sun distance we are going to use images from a transit. A transit, is the astronomical phenomenon of one celestial body appearing to move across the surface of a different celestial body, and hence hiding a part of it. We are particularly interested in a Venus transit; which is Venus appearing to move across the Sun surface seen from somewhere in Earth. Such an event does not happen every day, so instead of requesting observation time in a solar observatory for the next transit, we'll use images from the last one, that occurred in June 2012.

As you may know from reading the Booklet, we can use parallax to measure astronomical distances, to do so let's first study the geometry of our case: During a Venus transit, we would expect to see the Sun, Venus and the Earth as in the image below. An astronomer in Earth would see Venus crossing the Sun disk.



We can deduce from the picture, that during the transit, the total distance between the Earth and the Sun, $\overline{ES}$, is the sum of the distance between the Earth and Venus, $\overline{EV}$, plus the distance between Venus and the Sun, $\overline{VS}$.

Mathematically, we can express this by writing

$$\overline{ES} = \overline{EV} + \overline{VS}$$

But as you may remember from the introduction, the Earth-Sun distance is just 1 au, so

$$1 = \overline{EV} + \overline{VS}$$

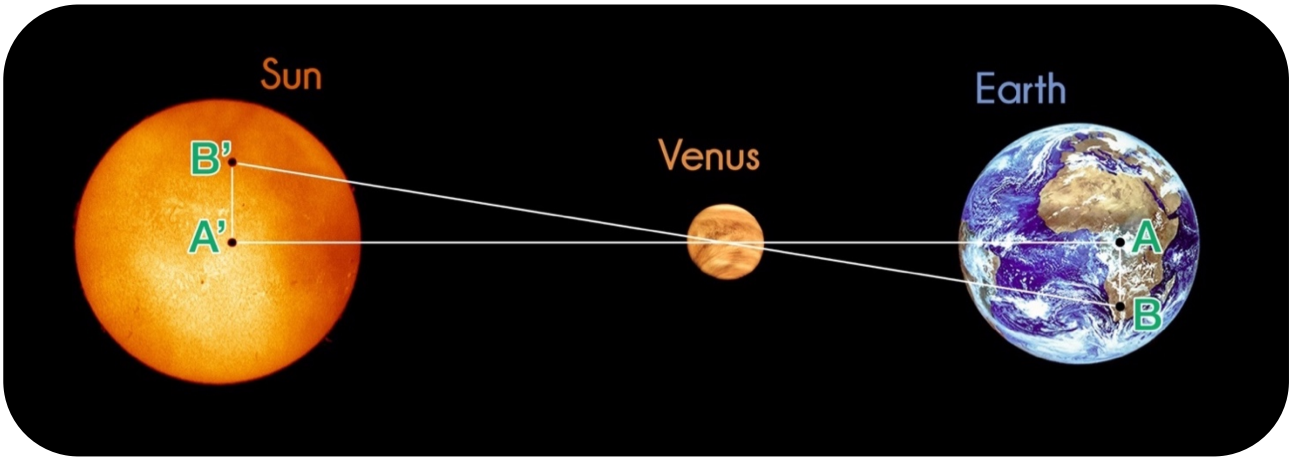
Knowing this, we can easily express the Earth-Venus distance as

$$\overline{EV} = 1 - \overline{VS}$$

We will need this for the next step.

Step 2

As in the Booklet, lets say there are two astronomers in Earth, A and B, that are taking pictures of the transit. The situation would look similar to the picture below, where A' and B' are the positions in which the astronomers A and B would see Venus crossing the Sun.



You already know that because the triangles in the picture are proportional to each other, the distance between A and B, $\overline{AB}$; and the distance between A' and B', $\overline{A'B'}$; are related by the equation

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

Now it's time to remember the first step, where we found that

$$\overline{EV} = 1 - \overline{VS}$$

, if we put this information into the relation, we obtain

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

which is a relation between $\overline{VS}$ (the Venus-Sun distance that we are trying to calculate), and two other quantities: $\overline{AB}$ and $\overline{A'B'}$.

In that equation, $\overline{VS}$ is hard to obtain, so lets do some easy to follow math to make it simpler.

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

$$\rightarrow \quad \overline{VS} \cdot \frac{\overline{AB}}{\overline{A'B'}} + \overline{VS} = 1 \quad \rightarrow \quad \overline{VS} \cdot \left(\frac{\overline{AB}}{\overline{A'B'}} + 1\right) = 1 \quad \rightarrow \quad \overline{VS} = \frac{1}{1 + \frac{\overline{AB}}{\overline{A'B'}}}$$

The result of this math is a simple formula to calculate $\overline{VS}$ out of the two quantities $\overline{AB}$ and $\overline{A'B'}$.

So if we somehow measure $\overline{AB}$, and we get $\overline{A'B'}$ out of the transit data, we'll be able to use that last equation to finally calculate the Venus-Sun distance.

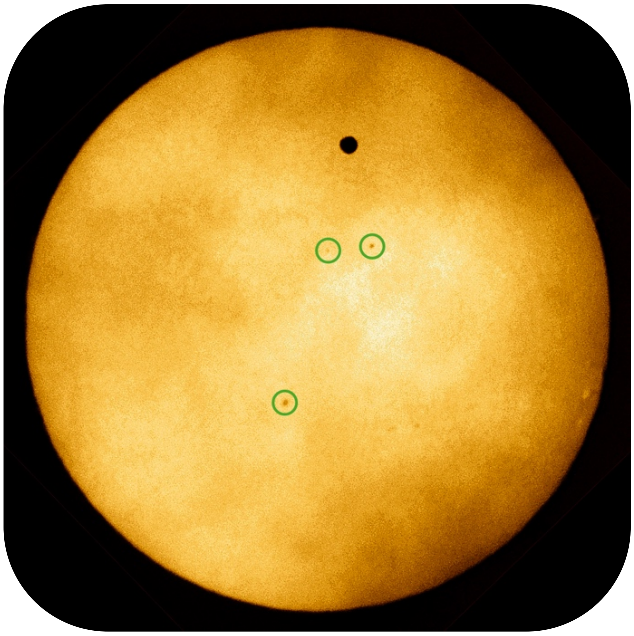
We'll call this last equation (eq. I).

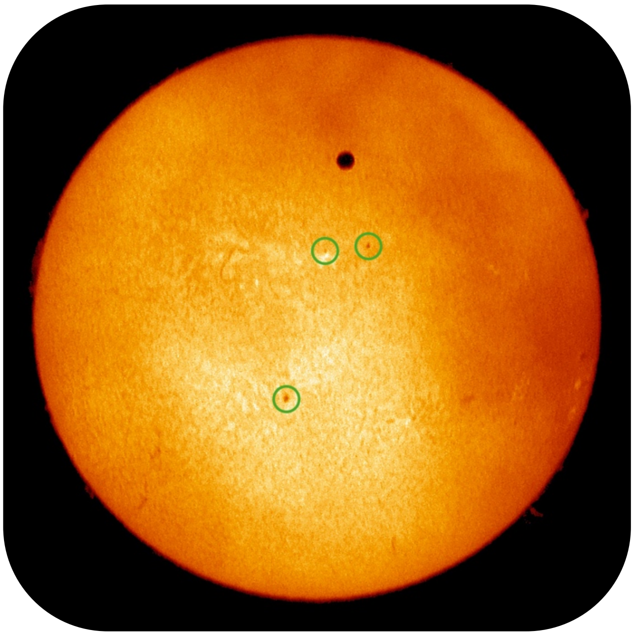
Laboratory Execution

Step 1

To get $\overline{A'B'}$, we first need images from the transit taken from two different observatories in Earth, the ones we called A and B. As we explained before, better than waiting for the next transit, is to use data from the last one. In the CESAR web tool, you can find Sun images taken during the 2012 June transit by CESAR team, both from Canberra (Australia) and Svalbard (Norway).

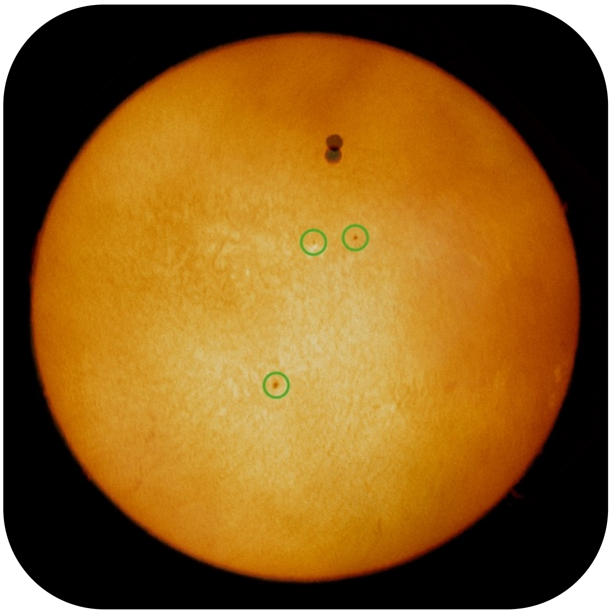
You will see that in any image you choose there is one black circle in the Sun disk, that would be Venus. You should also note some smaller black dots, those are sunspots.

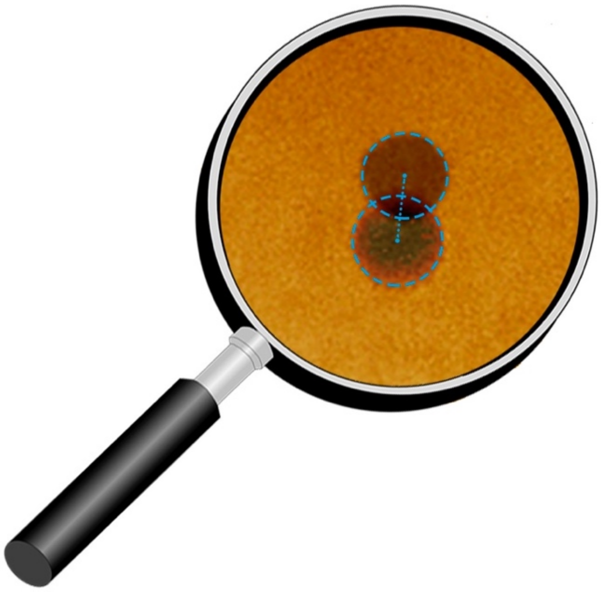




Once you access the images, you must measure the distance between A' and B'. But of course, A' and B' are the position in which Venus is seen from the two different observatories, so the spots A' and B' are in different images. To measure the distance, we should first **merge those two images in one**, so that we have a final image in which we do can **see both points at the same time**.

Before merging them you may have to **align the images**, so that the sun is in the exact same position in both. The best way to align the images is by checking the position of the sunspots (those green circled). Just let one image be fixed as reference, and move, flip, resize and rotate the other one until the sunspots in both of them are in the exact same position. After merging them, you should get something like the image below, where the sunspots from both original images are in the same position, and the two images of Venus are visible.





It's a standard procedure in science to align astronomy images to a standard reference. You may choose one picture from the SOHO (SOlar and Heliospheric Observatory) whose images are aligned to the Sun's North, and use it to align yours. Make sure to choose an image that was taken at the same time as the other two. Then set it fixed (as this is the standard reference) and move the other two together to align them to the SOHO one, using the same procedure as before.

Now that we have an aligned image where we can measure the distance, we may wonder between which two points exactly we should measure, choosing one random point in each A' and B' Venus images would be way too imprecise. Instead we can **find the centre** of Venus in both A' and B' and **measure, in pixels, the distance** between the two centres $\overline{A'B'}$, as shown in the magnifying glass image.

Step 2

In (eq. I), $\overline{AB}$ is divided by $\overline{A'B'}$, but since we did the $\overline{A'B'}$ measurement in a digital image, the value of the distance is expressed in pixels $\overline{A'B'}\ [pix]$, so a **unit conversion must be made**. To change it into meters we may first express it as a multiple of the Sun radius R_S, that is, measure in the image the Sun radius in pixels too $R_S\ [pix]$, and calculate the relation

$$\overline{A'B'}\ [R_S] = \frac{\overline{A'B'}\ [pix]}{R_S\ [pix]}$$

which is just $\overline{A'B'}$ expressed using R_S as a unit or reference. Then, if you look in the web for the value of the Sun radius $R_S\ [m]$ in meters, you can obtain $\overline{A'B'}\ [m]$ in meters too just by doing

$$\overline{A'B'}\ [m] = \overline{A'B'}\ [R_S] \cdot R_S[m]$$

Step 3

We now know $\overline{A'B'}$, one of the two quantities needed for (eq. I). Let's obtain the second one, $\overline{AB}$:

To obtain $\overline{AB}$, we'll use the coordinates from the two observatories A and B along with a useful web tool. The coordinates from Canberra and Svalbard can be obtained using Google Earth or any similar program. (If you don't have access to such as program, the coordinates could also be found on the web). Once you've got the coordinates, you may use the tool provided in the CESAR webpage to calculate the distance between those two coordinates. Now we also know the $\overline{AB}$ distance (make sure it's in meters).

Step 4

Since now we have all the needed quantities, **we'll use (eq. I)** to obtain the Venus-Sun distance.

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

And that is it!

Conclusions

In this laboratory you have obtained the Venus-Sun distance out of Venus transit data, only by using one simple parallax relation. To use that relation, you have previously calculated:

- $\overline{A'B'}$ out of the transit images, for which you used trigonometry and unit conversions, and you needed to look for the Sun radius value.
- $\overline{AB}$ out of the coordinates of A and B, for which you used a web tool.

Once you have found the Venus-Sun distance, it's a good idea to check it with some previous known data, for example: We know that the Earth is 1 au away from the Sun, and we know that Venus is closer to the Sun that Earth. Also, Mercury is 0.39 au from the Sun, and Venus must be further away. Does this agree with your calculations?

If you do have obtain a consistent value, try to use it somehow, for example: If an au is about 150 billion meters, how far away (in meters) is Venus from the Sun.