Student's guide
CESAR Science Case – The Venus transit and the Earth-Sun distance

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Introduction

A transit happens when a body passes, or transits, in front of its parent star. This happens often in our Solar system, but those transits that we can observe are solar eclipses. From the Earth we can only observe the Venus transits and Mercury transits. The other planets are behind the Earth, making it impossible for us to observe as it crosses the disk of the Sun.

The Venus transit is a rare one that happens in pairs with eight years apart. The recent one that happened in 2012 is the second of that pair. Once we have a pair, the next ones will be expected after either 105 or 121 years. This is due to the orbits of Venus and the Earth; they are not in the same plane. If their orbits were exactly in the same plane, or ecliptic plane, we would see a transit every time the two planets were in line with the Sun. This happens approximately once every two years. When this takes place, in nearly every alignment between the Sun, Venus and the Earth, Venus is in the sky either under or over the disk of the Sun.

The transits can be very useful for calculations. In the year 1716, the astronomer Edmund Halley proposed a method using a Venus transit to measure the Solar system. This method is the effect of parallax. More about is can be found below. *The task of this laboratory is to use ESA data while considering this effect and then calculating the Earth-Sun distance, also called one astronomical unit* (AU).

Theoretical background

The effect of parallax is something that is very common. For example, see what happened if you reach out your arm and look at one finger with one eye, and then closing that eye and looking with the other one; you will see a displacement difference. This also happens when we look at celestial objects from different locations. It is because of this that the transit looks somewhat changed for two observers at different places on Earth. This does of course not mean that Venus is simultaneously moving across the Sun's disk and then entering it again. Also, observed at the same moment, the position of Venus in front of the Sun is not quite the same.

These effects allow at least three ways to find the distance of the Sun from observations of the transit. The first is to photograph the Sun at the same moment from two observing points and measure the displacement of Venus due to parallax, the second is based on measure the lengths of the paths to get the value of the parallax, also from two observing sites and the third method is based on timing the start and end of the transits. Whichever you choose can help you during your calculations, which is the purpose of this lab.
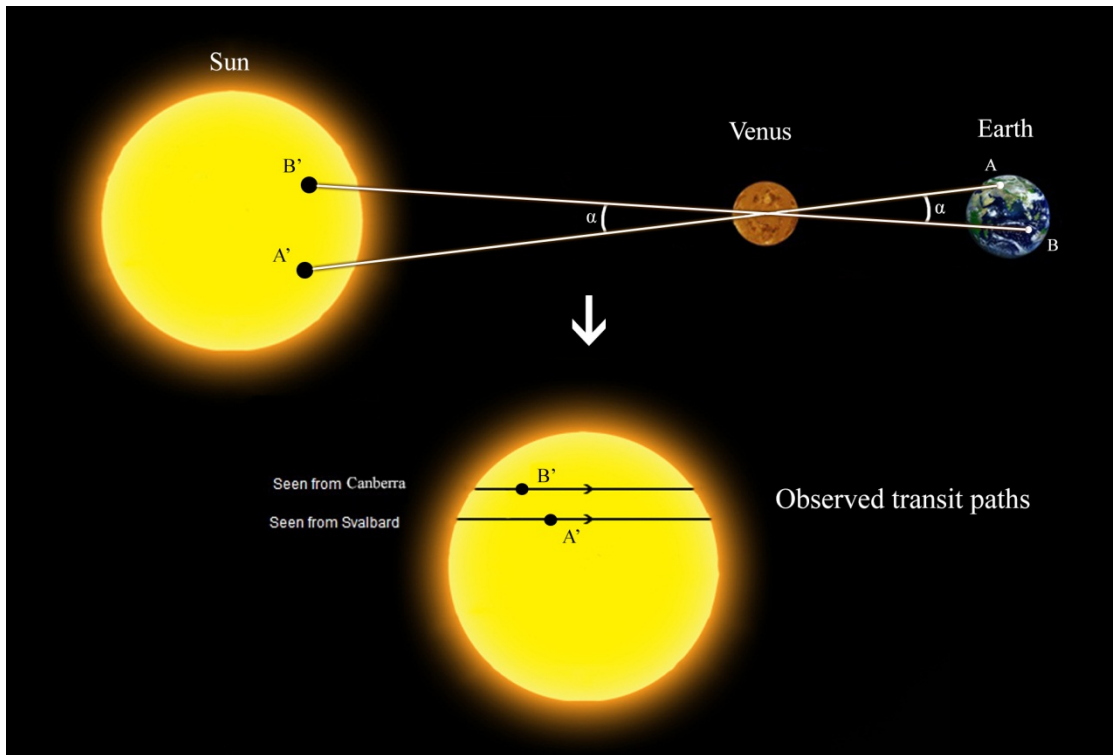
Figure 1: Here, we see two observers at the different locations A and B. An observer in the northern hemisphere at the location A would see Venus' disk at point A'. The other observer B located in the southern hemisphere would see Venus on the Sun at the location B'. If we compare these observations, the angle α separating A' and B' can be calculated. We already know the size of the Earth and the positions of the observers, so this can help us find the distance AB, and AB is the base of isosceles triangle ABV (V is Venus). From the base length and the angle α, we can calculate the triangle's size and then find the distance to Venus. Note that the figure is not in scale.   *Credit: CESAR*
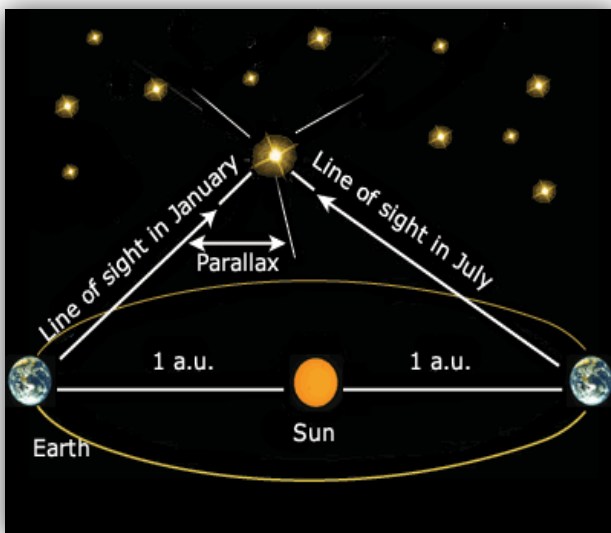

Since the Earth's orbit is an ellipse and not a complete circle, the distance between the Sun and Earth differs. The planet is on the opposite sides of the Sun six months apart. This leads to a visible change in the relative position of the stars during the year. The nearer stars seem to move relative to more distant stars.

Figure 2: Here, we can see the parallax effect related to stars instead. It works as the same way as it was mentioned earlier and thanks to this, we can calculate the distances to neighbouring stars as well.

Credit: ESA.int

Since Venus is having an orbit around the Sun, it is good to mention Kepler's three laws of motion. They are very useful for calculations related to planetary motion and the laws can increase one's knowledge about these natural movement. Below are brief explanations of the three laws:

i.   The planets have an elliptical shaped orbit, with the center of the Sun being positioned at one focus. This is called **The Law of Ellipses**. You can describe a focus as one of the two inner points that help us to determine the form of an ellipse. The distance between one focus and back to the second one is always the same, no matter where on the ellipse.
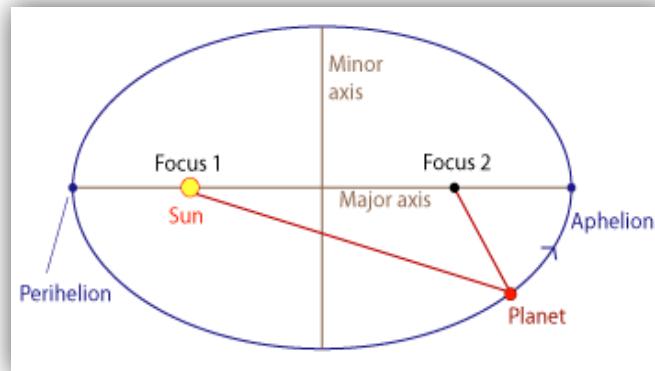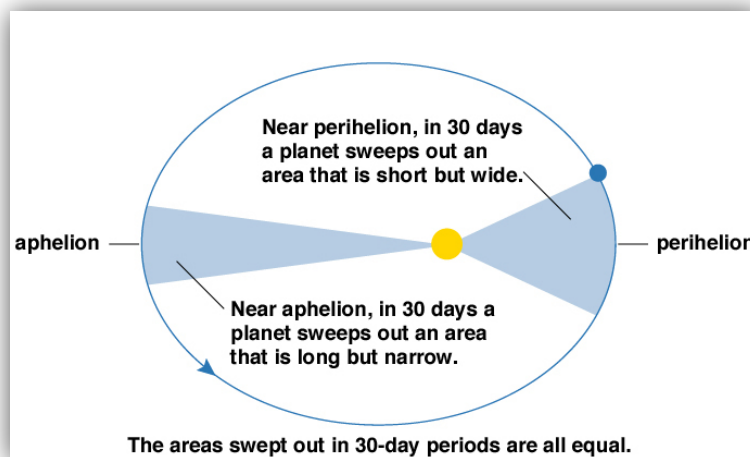

Credit: *University of Washington*

ii. An imagined line drawn from the center of the Sun to the center of a planet will sweep out equivalent areas in equal time intervals. This is named **The Law of Equal Areas**. That is, the orbital speed of a planet changes and it depends on its distance from the Sun. The Sun's gravity (or gravitational pull) is stronger when a planet is closer to the Sun and it will move faster at that point. When the distance increases between them, the Sun's gravitational pull becomes weaker and the planet will move slower in its orbit.
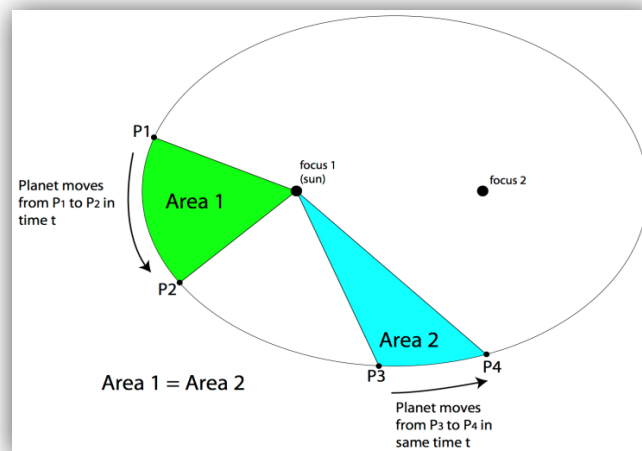
Credit: *A Plus Physics*

iii. The relation of the squares of the periods of any two planets is equivalent to the relation of the cubes of their average distances from the Sun, also called the **Law of Harmonies**. That is, if you take 30 days and square it for each planet, and then divide it by the cube of its distance to the Sun, the number that you will get will be the same for all planets.

Near perihelion, in 30 days a planet sweeps out an area that is short but wide.

aphelion ———

perihelion

Near aphelion, in 30 days a planet sweeps out an area that is long but narrow.

The areas swept out in 30-day periods are all equal.

Credit: Oswego State University of New York, Addison Wesley.

Material

1. CESAR Astronomical word list
2. CESAR Booklet
3. CESAR Formula sheet
4. CESAR Student's guide
5. ESA Venus transit photos
6. The software for this Science Case
7. Calculator, paper, ruler, eraser

Laboratory description and purpose

During this laboratory, the task for you is to calculate the distance from the Earth to the Sun by using data from the last Venus transit through three different methods. This event occurred between the 5th and 6th of June 2012. During this event, two ESA teams took pictures of it from two different observing points; one in Svalbard (Norway) and one in Canberra (Australia). The data is in the form of photos, but also time and dates that they were taken, which may be useful for you.

The purpose of this laboratory is to understand how a transit can be useful for distance calculations. By understanding the parallax effect and physical laws, together with good knowledge in geometry, this can be achieved.

You also need to use an image processing program while doing this laboratory, since it gives valuable information that is necessary to manage the task. In the end, with the right calculations etc., and estimation of the Astronomical Unit (AU) should be done. Ask your teacher which program you are going to use, or go to the CESAR Website for this Science Case and use the program that we provide.

Laboratory execution

You have access to photos of the Venus transit that you need to use for all of the three methods. As mentioned, the two locations are Svalbard and Canberra. All the photos are named as:

position_filter_year_month_day_hour_minute_second_number.jpg

As you may have noticed, the sunspots seem to be on different place on every picture, depending on which one you are picking as a reference picture. Here is one of the tasks of the laboratory. To be able to calculate the astronomical unit, the sunspots need to be aligned so that they are exactly on the same point on each photo. You can get an accurate alignment depending on what tools you choose to use. Try to get it as correct as possible! Once it's done, you have to go to the SOHO website and their data archive. The link to the page is http://sohodata.nascom.nasa.gov/cgi-bin/data_query. Choose the date of the transit and save an image from the website. Then, compare that image in order to see the sunspots of the ESA team on the same place as the SOHO image. Afterwards you should have your images aligned.

For the first method you have to take a pair of images; be sure that you pick two pictures, one picture from Canberra and one from Svalbard at almost the same time. Your teacher will know where to find the folders. Align the pair of images using the SOHO image as reference. Then you have to take some measurements on your image. Follow your teacher instructions for this. When all the necessary measurements had been done, you should calculate the linear distance between the observers to be able to calculate the value of an AU using some trigonometric formulas that your teacher will explain to you.

Tip: use software, like for example GIMP or Photoshop (if your school/university has a licence). It is also possible to project the picture on a wall and do the measurement with a ruler. Even Power Point is a good tool to use. Have in thought that using triangles is a great way to go. It is, as mentioned, your choice how to precede the experiment, as long as you understand what you are doing.

For the second method not only one pair of images have to be aligned with the SOHO reference image. You have to search for a set of five images taken from Canberra, align them and finally superpose them in a single one. Also you have to choose five images taken from Svalbard and make the same process to finally get two pictures. On each picture you have to measure the length of a line that crosses the Sun's disk through the centres of Venus's disks. With that distance and using some trigonometric formulas you could estimate the value of an AU too.

Finally for the third method you need to choose four images of the transit for each location. One image at the moment when Venus starts entering the solar disk, other at the moment when Venus completely enters the solar disk, and another similar images for the moment when Venus goes outside the solar disk. You have to be careful when decide which image represent each of the four situations, try to be precise. The values that you are going to use are the times when the pictures were taken. You have to determinate the duration of the transit from the two locations to determinate the AU value. Note that there is no images for the moment when Venus enters inside the Sun's disk from Svalbard so you could take that it occur at 0h 22'

At the end of each method, you should have an equation. By putting required data, you should get an approximate value of the distance. Note that it does not have to be a value that is exactly as the AU (149 597 871 km). A value close to it is just as good. The purpose with this laboratory is to learn how to get this value, or one that is close to it. By more accurate measurements, this can of course be accomplished.