SOLARSCOPE		Level
Worksheet « Venus Transit» WS 7	**Calculation of** **Astronomical Unity** (during Venus transit: 8 juin 2004)	All level

Astronomical Unit evaluation starting from the Venus transit observation.

-Teaching proposals:

The proposals exposed below relate to clubs, Personal Works, Discover Routes and other interdisciplinary structures: indeed, neither the Venus transit, neither astronomy, nor the measurement of distances in the solar system appear in programs schools.

The Venus transit of June 8, 2004 offers the possibility to animate the end of the school year by giving a beautiful opportunity to visit an observatory. (Attention: candidates will be numerous!) Even more: it can be pretext to create an astronomy club within the establishment in order to carry out the projection of the event in the schoolyard, by using for example the solarscope which allows to observe the transit and sunspots safety, even with young children.

However, it would be more interesting that pupils measure distance Ground-Sun starting from their own observations: play being then to compare their result with this already known size with the best precision. Even younger pupils can take part of this event: such a success would set off without any doubt in some case a real passion for scientific and historical studies.

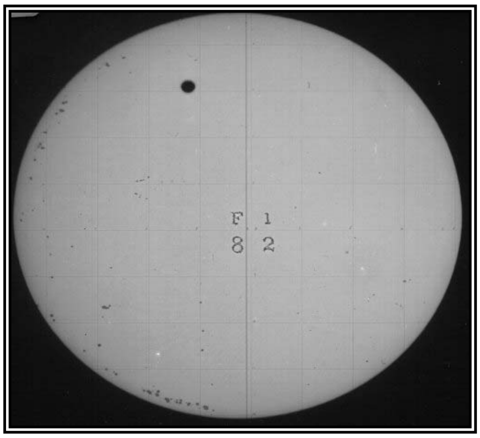
-Venus transit:

Tuesday June 8, 2004, between approximately 5.30 and 11.15 am (in universal time), Venus will cross the solar disc. Such a phenomenon occurs only every 122 years, by pair of two 8 years separate passages. The last passage took place on December 6, 1882. This phenomenon hasn't been seen in the twentieth century. The twenty first will see two of them: in 2004 visible from Japan in Azores to the Antarctic in Kerguelen, therefore in any part of Eurasia, a second and last in 2012 visible mainly around the Pacific. Also, the scarcity of the event will involve a strong mediatization, equivalent to a total Sun eclipse like August 11, 1999.

-What is going to be observed?:

Passages or transits in front of the Sun are comparable to eclipses, but the total disappearing of the Sun passing in the shadow of the other is not observed. They are caused by a planet located between the orbit of the Earth and Sun, this means Mercury or Venus, and observed from Earth under an angle much smaller than the Moon or Sun. Indeed, when the night sky is looked at, planets (we observed Mars this summer!) appear to us like a size not very different than stars. When Venus or Mercury intervenes between the Sun and us, that forms on the solar disc a small round spot, with contrario of sunspots with irregular contours. Without instrument, the phenomenon passes unnoticed because the luminosity's fall is negligible. These passages thus remained unknown until their discovery by Johannes Képler (1571-1630) in the XVII century, this discovery has been made by calculations and not by observation. With the Solarscope, an image of the Sun around 122 mm in diameter will be observed, on which a black spot of 3,7 mm will move during almost 6 hours following a trajectory which will be a function of the observation place. On the last 7 May, 2003 the Mercure planet as passed in front of the Sun, phenomenon less spectacular and more frequent than the Venus passage. Mercury made a very small visible spot on the solar disc (with the help of an instrument): 13 seconds of arc*, to compare to the 1900 seconds of the solar diameter is 1/50 th of the solar diameter... very small! Venus represents 58 seconds of arc, approximately 1/30 th of the solar diameter at the time of its passage, Mercure formed a visible image of 0.8 mm on the Solarscope's screen.

* 1 degree of angle represents 60 minutes of arc and 3600 seconds of arc



Photography (rare) of the last Venus Transit in 1882.

- Aspect excpected of the solar disc during the Venus passage. No alive person has the experience of a such observation since the Venus passages reproduce only every 122 years per couple of two separated 8 years.

-Why is it important to observe this transit?

The average distance from the Earth to Sun, or half large axis of the terrestrial orbit is so important that "Astronomical Unit" is given (or A.U.) because it is unit surveying of the solar system and entire univers. 1 A.U. = 149 597 870 km.

For a while, the value of the A.U. has been unknowing. Tycho Brahé's observations (1546-1601), exploited by Johannnes Kepler within the Copernic's heliocentrism, made it possible to connect orbit dimensions eachothers starting from revolution periods observed (third Kepler's law: cubes of the ellipse large axis are in the ratio of squares of periods). But all of these observations relating only to angular measurements, this means on the locating of directions but without in-depth scale, did not make it possible to know the A.U. value, therefore the distance Ground-Sun.

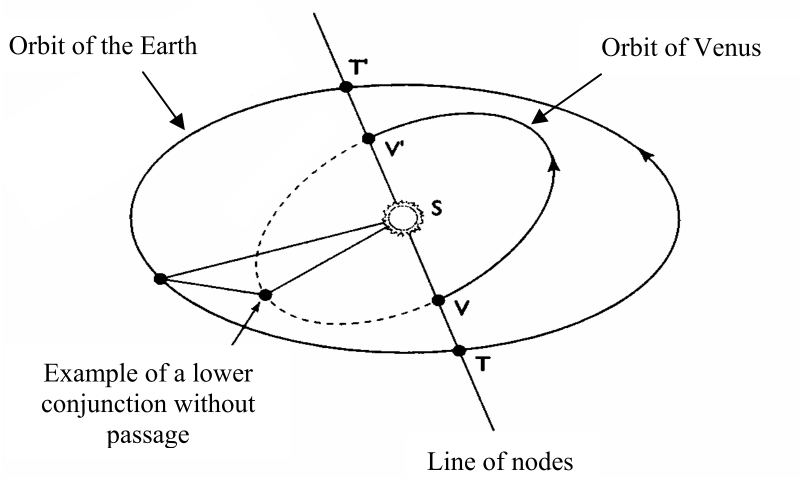
This one is from now well-known (radar measurements), but the next Venus passage (June 8, 2004) is the occasion to revive one of large and first moments of the international scientific co-operation by inviting the various observers to exchange their results to reach by themselves the Astronmoical Unit value. As follows:

"alone I observe not more than a rare phenomenon, if I exchange with other people, I measure the Univers".

Why is this phenomenon so rare?

If the orbit Earth's plan was the same as Venus or Mercury's, there would be a transit with each one of their lower conjunctions (see figure hereafter). However, nothing of the kind, their plans being tilted compared to the ecliptic: so the alignment takes place only when the Earth and one of these planets are simultaneously on the line of nodes, cas illustrated for Venus below :

1The synodical period of Mercury is approximately 116 days and 584 days for Venus. But passages are rarer: in one century, there were at maximum thirteen of Mercury and two of Venus.



-What is going to be measured?

It is important to know that the distance Earth-Sun obtained since observations will not be a high precision (leave that to astronomers!). But, the fact to know how to calculate this distance from exchanges between various observers, having dreaded the method and its approximations is essential.

The problem is extremely complex if it must be treated in all of its rigour. There is an exact solution, on the site of the IMCCE and written by Mr. Rocher, where passionatelies interested in astronomy can look into. The studied movement is only a prospect effect with movement: I am with a friend, in a train in full speed and we look a car thrue the window which goes in the same direction like us (less quickly). But it becomes complicated, because it's a prospect effect in a train with two floors and the passengers (my friend and myself) are sitted on swivelling seats on a floor and in a different coaches... But back to our planets.

When Venus, passing between the Earth and Sun, is projected on the solar disc, it is close to the Earth so that two observers do not see the same disposition. This prospect effect, known also as "parallax effect" in the astronomers language, was proposed in 1716 by the English astronomist Edmund Halley to measure the distance from Earth to Sun. Edmund Halley (1656-1742) is famous for announced the return of the comet which has from now its name.

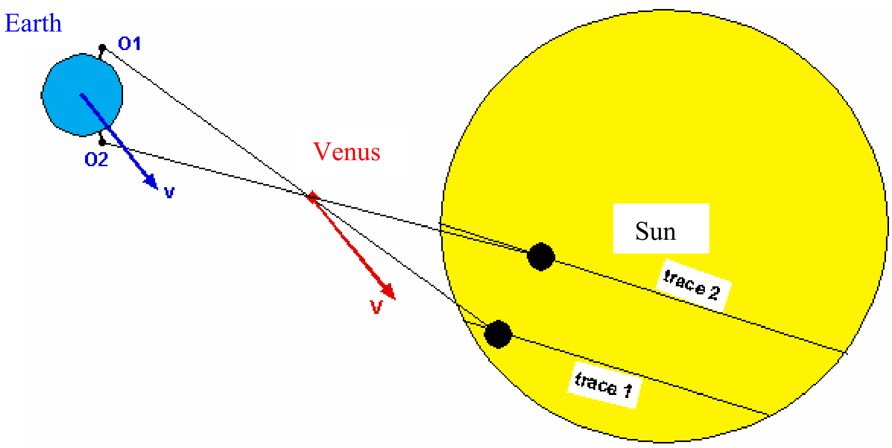


Figure 1 Observers O1 and O2 do not see the Venus planet being projected at the same place on the solar disc. This prospect effect will allow the measurement of the distance from the Earth to Sun.

The aim is to raise with the precision of a few seconds of time moments of the interior contacts, i.e. moments 2 and 3 on the figure below.

Thus, each observer will note these moments with the precision of the second, although the perception of the real time is dubious because of the black drop phenomenon discovered by the observers during passages of 1761 and 1769, confirmed by the observations of 1872 and 1884. If need be, the observer will describe the successive aspects that he will observe by noting his comments. A dated photographic view will surely improve the reliability of a such observation, but the written or recorded comments can be interesting for the result interpretations.

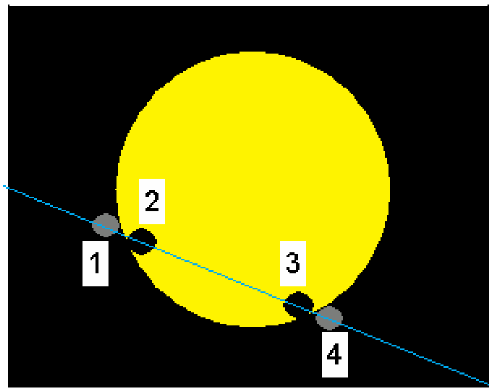


Figure 2: 1 and 4 are external contacts; they are not datable with precision². They will be able to be dated if a serie of dated and recorded images in the vicinity of these transitions is used. 2 and 3 are internal contacts, observable, but a delicate precise dating due to the phenomenon of the "black drop". Venus image apparent is slightly deformed at the time when this one is in contact with the solar disc.

-Calculation of the A.U.

There are two methods to calculate the A.U.

Joseph-Nicolas Delisle's method (1688-1768)

t is the date of one of the contacts that you observed and *t'* is given, for this same contact, by another distant observer. *t* and *t'* will be different. The prospect effect which involves this difference will enable you to calculate the distance *a* from the Earth to Sun at the passage time, provided that you know your position and your correspondent's (latitude λ and longitude ϕ, λ' and ϕ' for your correspondent's). The prospect effect which would be simple to express for observers which would be on Earth without diurnal rotation, becomes complicated due to this rotation. The calculation detail which establishes formulas which will follow is not necessary to the method application. The justification will be found in the appendix for those who would wish to go further in geometrical-kinematics comprehension of the passage.

² "For the entrance, as soon as Venus is perceived on the solar disc, the contact is already exceeded. For the exit, better can be done because the disappearance evolution is followed whereas for the entrance, the start of the phenomenon is not exactly located for its observation."

With the help of some approximations which did not change the precision of the result more seriously than inherent uncertainties to the measurement of *t* and *t'*, the contribution can be separated from the apparent displacement of the Venus center seen from the Earth center (or geocentric) of the position effect on the terrestrial sphere. For two cited observers i and j, the difference of the dates for the same passage induce to the A.U. value according to the formula:

$$UA = \frac{R_T}{t_j - t_i} \frac{1}{a/b - 1} \left\{ A\left[\cos\phi_j \cos\lambda_j - \cos\phi_i \cos\lambda_i\right] + B\left[\cos\phi_j \sin\lambda_j - \cos\phi_i \sin\lambda_i\right] + C\left[\sin\phi_j - \sin\phi_i\right] \right\}$$

tj and *ti* are the dates noted by each observer and co-ordinates of each one are affected of index corresponding. *a* and *b* are not known, but the ratio *a*/*b* = 1,382 results from the third Kepler's law in the approximation of circular orbits (*a/b*=1,398 if ellipticities of the orbits and the orientation of the large axes compared to the line of nodes are taken into considaration). Finally *RT* = 6364 km is the average radius of the Earth.

Constants *A, B* and *C* are given by the relative position of planets at the moment of the considered contact. Calculation looks complicated, but does not require the knowledge of *a*; only of the ratio of the orbit rays and angular velocities of planets on their orbit whose relative slope is known. *A, B* and *C* are given below (in million seconds of time) for the passage of June 8, 2004:

	Contact 1	contact 2	contact 3	contact 4
A	3,624	3,699	1,810	1,544
B	0,062	-0,343	-1,926	-2,155
C	1,635	1,901	-3,230	-2,964