A Unique European Educational Programme – Venus Transit 2004

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1. Introduction

Astronomy of rare astronomical events such as the total solar eclipse, the Venus transit, comets, supernova explosions attract attention of millions of people in the world, especially if young people are targeted. Therefore, such events can be used as a bridge between science and public. With the help of astronomy we could increase the interest of young people in science, make them familiar with scientific methods of examining the world and involve them in international projects. During the last 10 years we were lucky to have opportunity to observe the Hale-Bopp comet in 1997, the total solar eclipse in 1999 and the Venus transit in 2004.

Figure 1: Left: Venus on the solar disk, June 8 2004 Right: Venus Transit attracted attention of millions of people on all continents.

In general young people like discussing about universe and some natural phenomena linked to the sky. Also astronomical instruments could be a source of great interest. For example, watching how the cupola opens and how the mechanism works and of course observing celestial objects will find enthusiastic response.

2. Description of the project

We will focus on the educational meaning of the last astronomical event called the Venus Transit which occurred on June 8 2004. The event lasted about 6 hours and was visible from Europe, Africa and Asia. The international project showed that collaboration between scientific centres, universities and schools is very fruitful. The most important participants were schools since in this way the broadest and the youngest public could be reached. Good response with the public was due to the campaign in media and among the teachers and to the well prepared websites with all information regarding the event at different levels and in many European languages.

The main goals of the project VT-2004 (e.g. [1]) were to increase the interest in science among young people, to establish a closer contact between students scientists and scientific organizations, to explain the scientific methods of examining the world, to involve young people in an international project with the website to exchange information between participants, to show them a method for preparing a scientific experiment and measurements with scientific value, to give them knowledge of the historical background closely related to the measurement of the Solar System (methods, distances, motions of the celestial bodies, exoplanets …) and to perform and participate in the real time measurements of the Earth-Sun distance. The astronomical unit (AU) was to be measured in the same way as it had been done in the past. The main difference was that in the previous centuries the measurements were done by scientists who needed several years to get the results. The advantage of modern communications and advanced technology enabled immediate calculation of the AU at the Paris Observatory where all the data were sent via internet.

3. Determining the astronomical unit (AU)

The Earth-Sun distance known as the astronomical unit AU is the base unit in measuring the distances in the universe and cannot be measured directly. Historically it has been determined with triangulation or the parallax method by measuring angles from two different places on the Earth. The solar diurnal parallax β_d is the angle at which the Earth's radius R is seen from the Sun

$$\beta_d = \frac{R}{AU} \; . \qquad (1)$$

The method of the parallax allows us to measure only distances to objects that are close to Earth, since the baseline cannot be greater then the Earth's radius. Using this method for determining the solar parallax is not practical during a normal day, when only the Sun is visible, since the parallax is too small to be measured with sufficient precision without another marker in the sky.

Venus and Mars can help as position markers in the sky. One possibility to calculate the Earth-Sun distance is to determine the solar parallax by finding the Venus's parallax during Venus Transit. The method has historical meaning and makes an interesting exercise in the classroom with more able pupils. The scientists at the Paris observatory organized the worldwide observation of the last Venus transit for the on-line determination of AU.

- ***In the classroom***

To explain the idea in the secondary school, we use a simple model where we assume that the Sun, Venus and Earth are in the same plane, that Venus and Earth orbits are circular and that two places on Earth are on the same meridian (have the same longitude). The mathematics is much more difficult if we use two observations taken from two places with different longitudes.

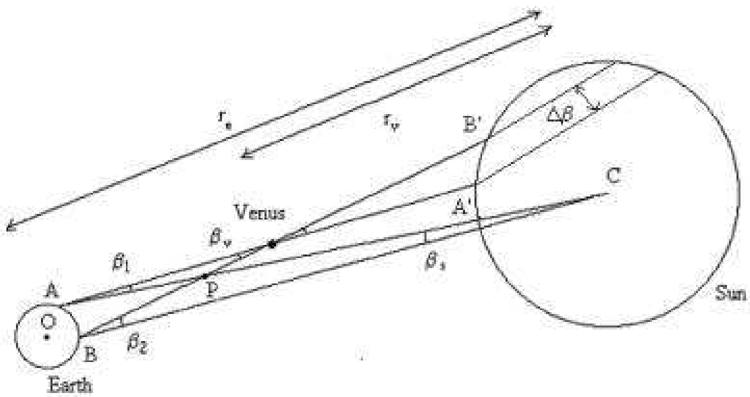

Figure 2: Determination of the Earth-Sun distance from parallax method.

Consider the plane that is defined by tree points: the centre of the Earth (O), the centre of the Sun (C) and the centre of Venus (V_{enus}) (e.g. Fig. 2). Two observers situated at two different places on the Earth at points A and B (on the same meridian, but at different latitudes) see Venus as a small dot projected on the solar disk at points A' and B'. Let r_e be the Earth-Sun distance and r_V be the Venus-Sun distance. Consider the angle $\beta_s = \angle ACB$:

$$\beta_s = \frac{AB_\perp}{r_e}, \tag{2}$$

where $AB_\perp$ is the distance between two observers on the Earth perpendicular toward the Sun, and the angle $\beta_V = \angle AV_{enus}B$:

$$\beta_V = \frac{AB_\perp}{r_e - r_V}. \tag{3}$$

If we observe the movement of Venus and draw its path during the whole transit, we observe that it is a straight line. The two observers from places A and B will draw two parallel lines. The separation of the two lines - the parallax displacement is: $\Delta\beta = \beta_2 - \beta_1$ (e.g. Fig.2). Considering the two triangles APV_{enus} and BPC, we note that they share a common angle at P, therefore it follows that $\beta_1 + \beta_V = \beta_2 + \beta_s$, so that we get using Eqs. 2, 3:

$$\Delta\beta = \beta_V - \beta_s = \frac{AB_\perp}{r_e} \cdot \frac{r_V}{r_e} \cdot \frac{1}{(1 - \frac{r_V}{r_e})} = \frac{AB_\perp}{r_e} \cdot \frac{1}{(\frac{r_e}{r_V} - 1)} \tag{4}$$

Using Eq. 4 and the third Kepler's law $(\frac{r_e}{r_V})^3 = (\frac{t_e}{t_V})^2$, where t_e and t_V are the revolution periods of the Earth (365.25 days) and of Venus (224.7 days); one finds

$$\Delta\beta = 2{,}61453 \frac{AB_\perp}{r_e} \tag{5}$$

Finally, the Earth-Sun distance can be calculated as

$$r_e = 2{,}61453 \cdot \frac{AB_\perp}{\Delta\beta} \tag{6}$$

So, the Earth-Sun distance is proportional to the distance $AB_\perp$ between two observers on the Earth perpendicular toward the Sun and inversely proportional with the parallax $\Delta\beta$.

The distance $AB_\perp$ can be deduced from the latitudes of the two observing places; since Vardö and Papeete are almost exactly on opposing meridians, they are on the same great circle, note however that while the transit started at 20:15 and ended after local midnight at 2:35 at Vardö (the Sun did not set at Vardö!) it was observed from 8:15 until 14:35 at Papeete [e.g. Fig. 3]:

$$AB_\perp = 2R\sin\left(\frac{180^0 - \Phi_1 - \Phi_2}{2}\right) \cdot \cos\left(\frac{180^0 - \Phi_1 + \Phi_2}{2} - \delta\right) \ , \tag{7}$$

where R is the radius of Earth, Φ_1 and Φ_2 are the latitudes of both places and δ is the declination of the Sun. Observations of 1769 from Vardö (Lapland) and Papeete (Tahiti) with latitudes $\Phi_1 = 70^0 21'$ N and $\Phi_2 = 17^0 32'$ S were done with the baseline $AB_\perp$ for R = 6378 km, and $\delta = 22^0 26'$:

$$AB_\perp = 10470 \ km . \tag{8}$$

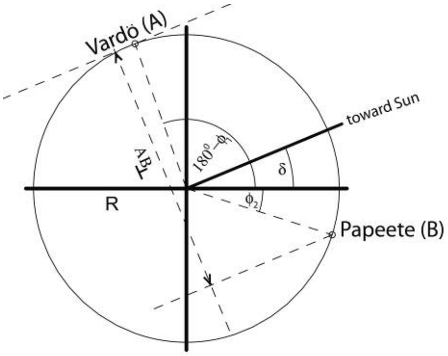

Figure 3: Finding the distance $AB_\perp$ between Vardö and Papeete situated in different hemispheres and on opposing meridians.

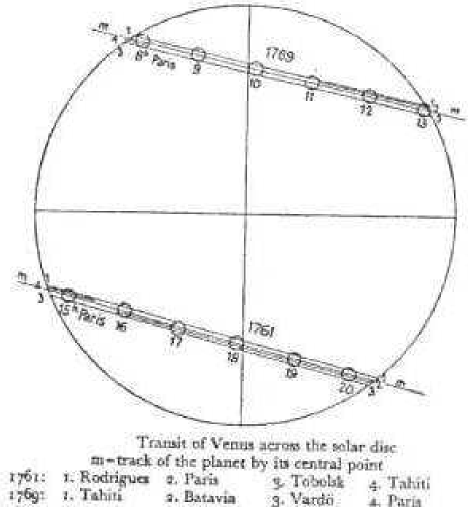

Figure 4: Observations of data from 1761 and 1769.

The solar parallax between those two places can be read off the data showing in Fig. 4 as follows. We note that $\Delta\beta$ is the angle between the two tracers of the transit path projected on the solar disk. Thus (e.g. Fig. 2)

$$\Delta\beta = \frac{A'B'_{\perp}}{r_e}, \tag{9}$$

and also

$$\Delta\beta = \frac{A'B'_{\perp}}{2R_S} \cdot \frac{2R_S}{r_e}. \tag{10}$$

The ratio $\frac{A'B'_{\perp}}{2R_S}$ can be read off the Fig. 4 and $\frac{2R_S}{r_e}$ is the angular diameter of the Sun ($30'$). Finally, we calculate from Eqs. 6, 8, 10 that the distance from the Earth to the Sun is

$$r_e = 145 \cdot 10^6 \ km, \tag{11}$$

which differs from the true value for $4{,}6 \cdot 10^6$ km.

- The On-Line Calculation of the Astronomical Unit

It happened for the first time in history that it had been attempted to ensure the real time calculation of the value of AU from all measurements that came in. However, this was not done in the way as astronomers did in the past by selecting optimally located sites.

The measurement of the AU by observing the contacts of Venus is a measure based on the measurement of time of contacts, not of distance, and this time is different for all observers. The real time calculation of the AU from the observed time was done by the function F that connects the time of contacts, the position of the observer, the AU, the diameter of the Sun and Venus, the equatorial radius of the Earth and the flatness of our planet, as well as the spatial position of the centers of Venus and the Sun at any time. Using this method it is possible to calculate the AU for each contact timing observation received from exact position of the observer as an independent measurement, since nowadays we already know the exact values of other parameters in function F. The algorithm was the following: the first measurement received was averaged with the second one and so on until the n-th observation was averaged with all the (n-1)-th measurements.

One of the problems doing this was how to make sure that bad observation would not corrupt the average computed value. Any observation far from the theoretical value because of low accuracy or the geographical location may have the result in an infinitely large value of the AU. Therefore good measurements must be accurate enough and its site must fulfil two criteria – the parallax must be as large as possible in be as far away as possible from the intersection of the penumbra and the terrestrial ellipsoid. The system was partially constrained in the way that it tried to keep the triangle the Sun, the observing site and the centre of the Earth as finite triangle. This meant the advantage of having a finite solution of the calculated AU for all permitted values.

The distribution of the calculated values of the AU [e.g. Fig. 5] was nearly Gaussian. It was further improved when obviously false values were rejected from the database. The average of the calculated AU was determined as $\overline{a} = \frac{\sum_{i=1}^{N} n_i \cdot a_i}{N}$, where a_i is the calculated AU for each observation, n_i the number of observers with a_i and N the number of observations. The standard deviation was found by dividing the Gaussian dispersion σ by the square root of the number of observations. The final result for the value of the AU based on 4367 observed timings of all four contacts was determined as:

1 AU = 149 529 684 km ± 55059 km,

which differs from the true value of the AU by 68 186 km. This topic is discussed in a more detailed way in [1].

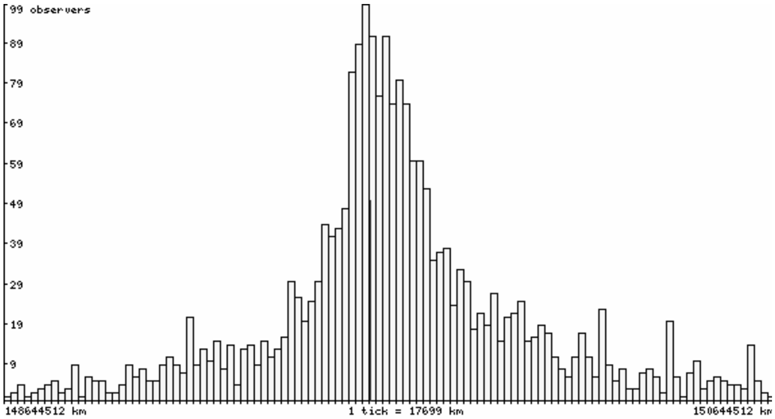

Figure 5: Distribution of the calculated value of the AU using all timings in the database.

4. Conclusion and outlook

The measured value of astronomical unit was the best of all times in the terms of accuracy. It is a remarkable achievement considering the fact that most measurements were made by amateur observers in Europe and shows how important the technological progress was in the last century. The success was so good because accurate timing was available, because geographic locations were more accurate. Better optics, digital image recording and advanced image processing software were also importantly added to the success.

As the Venus transit project was so successful it would be good to use already established networks. In order to keep it alive it would be sensible to organize a new annual public educational program EUROPEAN ASTRONOMY DAY aimed at the broad public in general and the schools in particular, since celestial events are usually very rare and some of them even unpredictable. It would have the same basic goal, namely to transform curiosity into knowledge and to increase the interest in science and in the way it works, emphasizing the relations between science and society.

One possible suggestion for the European astronomy day could be the measurement of the circumference of the Earth using Eratosthenes method which also requires a geographical distance as it was the case in VT-2004 project. The main idea is to shift the accent from the celestial event too much wider spectrum of possible activities, aimed at different target groups. Main activities would include setting-up a central website with background information, overall program of the event and all related links as well as opportunities for contact between participant, solar observations during daytime (sunspots or other activity), evening and night observations of selected dark-sky objects, exhibitions to emphasize the universality of astronomy, competitions at different levels with interesting prizes to stimulate active participation, related media activities and accompanying cultural activities (concerts, readings, art shows …).

In time this could lead to wide popularisation of astronomy, physics and science in general. It only takes some effort from the involved personal, especially teachers, and it would need a secure long term funding.

References

[1] www.vt-2004.org