Transit of Mercury Vs Transit of Venus

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1. Abstract

This project is about a live observation of the transit of Mercury on 9th May 2016. This transit period is estimated from the captured images by means of an obscure camera. To do so we need to know first the distance between the Earth and the Sun.

After having calculated it the 2016 transit of Mercury has been compared with the transit of Venus on 9th June 2004, which had already been studied by former students of our high school. The relationship between the radii of both planets has been experimentally determined by means of a photo program.

Finally, we have proceeded to calculate again the transit period of Mercury by means of a different method, using the third Kepler's law. We have used the transit period of Venus, calculated by former students in 2004, to work it out.

2. Introduction

The exciting world of Astrophysics is barely known by people, not by the deposited interest, but by the lack of resources to be able to enjoy it, like for example having a good telescope, and also the lack of information. In this research project we will try to capture the world in a simple way and on the other hand we aim to report it in our High School.

We wanted to bring this astronomical event to the educational community of our High School. We assemble our telescope at school, however, due to weather conditions nothing could be seen anything, so we looked at it on the internet. The transit was observed simultaneously from a telescope in London and through the retransmission of the European program STARS4ALL, with the collaboration of the IAC and sky-live.tv. We put the relay at school so other students could also watch the event and know what a transit is.

3. Objetives

1. Show the transit of Mercury on May 9th, 2016 to the educational community at “Institut Guindàvols” in Lleida.

2. Know the relative positions of the Earth, Mercury and the Sun when a transit is produced.

3. Make an experimental estimation of the distance from the Earth to the Sun.

4. Compare the transit of Mercury on May 9th, 2016 with the Venus transit on June 8th, 2004.

5. Make an estimation of the period of translation of mercury assimilating the movement of Mercury to a uniform circular motion.

6. Experimentally determine the relation between the radius of Mercury and Venus.

4. Marco theoretical

What is a transit?

It is an astronomical phenomenon[1] consisting in the passage of one planet ahead of another one with respect to the Sun, covering it completely or partially from the point of view of the observer.

In the case of the Earth there are only two possible transits, the Mercury and Venus, ones since they are the unique planets of the solar system that have an innermost orbit to the Earth.

The transit situation is not the same from any site, but it depends on the distance of the Earth and the Sun and also influences the position of the observer (image 1). That is to say that the shadow of Mercury will change depending on the place that we look at it.

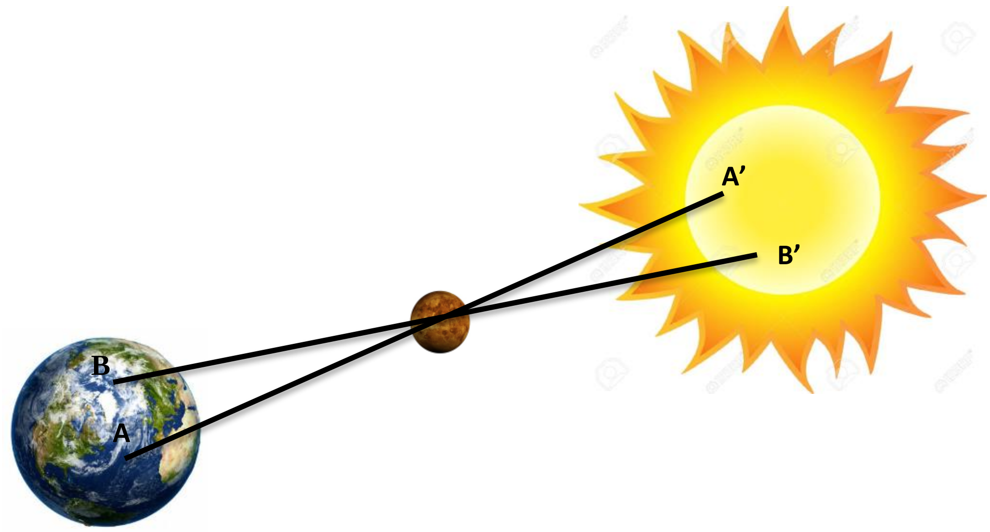


Image 1: Position of the transit of Mercury.

If Mercury and the Earth orbitted in the same plane, we would see a transit whenever Mercury was lower, i.e. on the same celestial conjunction, and as its Synodic period (the time that it takes to turn its orbit) is on average of 116 days, there would be a transit three times a year.

However, the transit will only occur when the orbital planes of Earth and Mercury agree on the line of nodes (which is one of the two points where an inclined orbit crosses the plane of reference) (Image 2).
This event only happens twice a year, between 8 and 9 may or 10 and 11 November. If an inferior conjunction occurs in any of these dates, there will be a transit. This occurs as average 13 times per century in intervals of 3, 7, 10, 13 years.

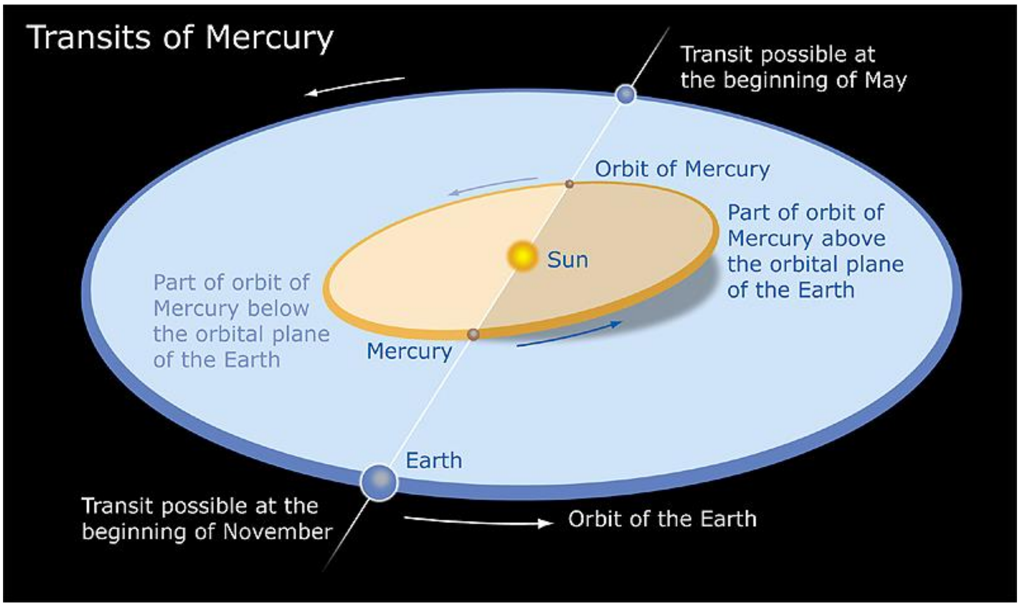


Image 2: Positions to happen a transit.

Mercury[2]

Mercury Is the planet of the Solar System which is closest to the Sun and the smallest one. Its orbit is inside the Earth and it hasn't got any satellites. Its translation period is of 88 days and its period of rotation of 59 days.

It has a surface similar to the Moon since it has different craters caused by meteorites. It is studied since the time of the Babylonians until present day. In recent years several proves such as 'Mariner 10', "MESSENGER" or the "BepiColombo" have been launched to study it in depth.

Image 3: The planet studied, Mercury.

5. Experimental design

4.1 Experiment 1: Experimental estimation of the distance from the Earth to the Sun.

4.1.1 Description of the experiment:

This experiment consists in projecting the image of the Sun on the screen of an obscure camera and measure the size of the image (D2) and the distance from the screen to the hole (L2). As we have the information about the measure of the diameter of the Sun (D1), we can know the distance from the Earth to the Sun (L1) using Thales' theorem (image 4).

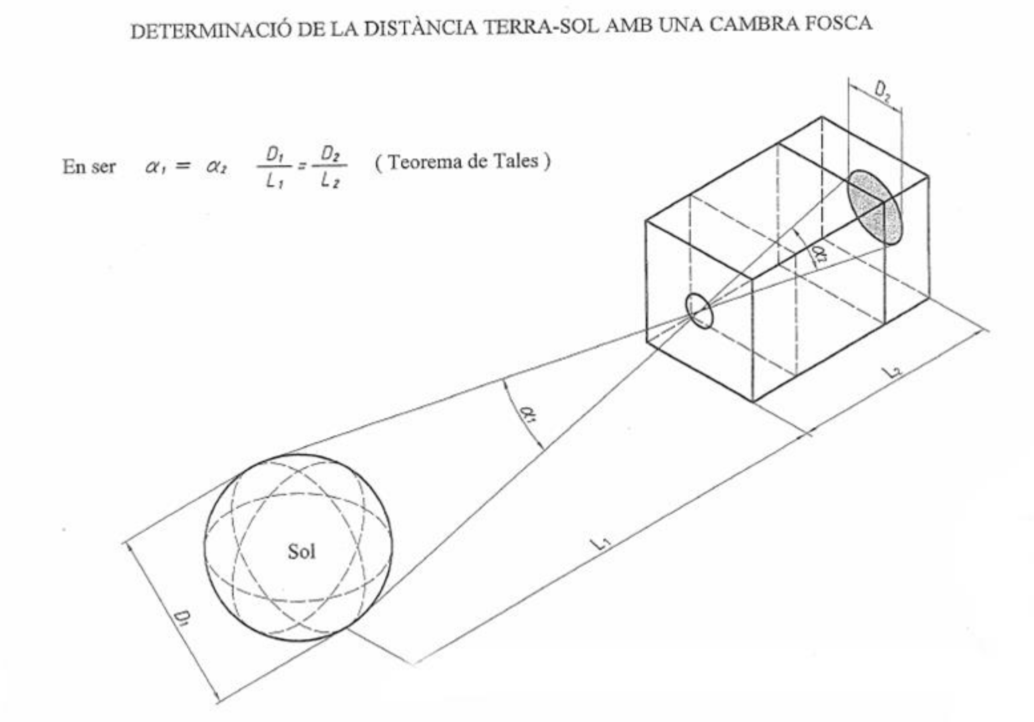


Image 4: Representation of the experiment.

4.1.2 Procedure

1- To build an obscure camera (Image 5)

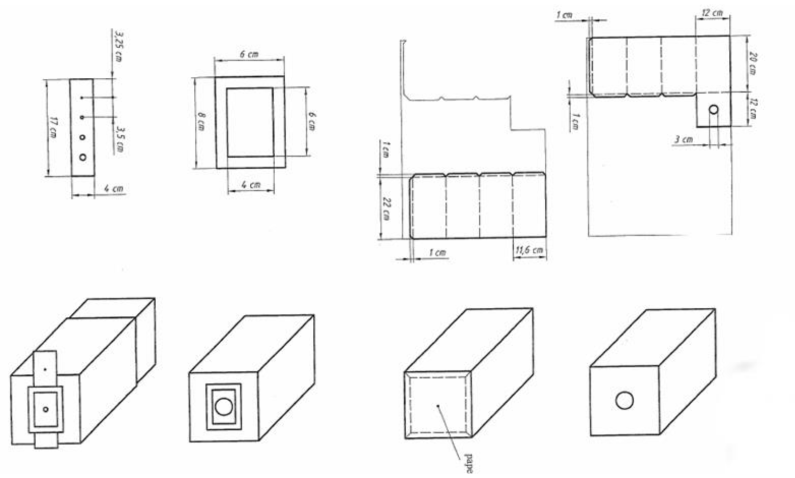


Image 5: built an obscure camera.

2- Attach the obscure camera to the support and place one of the small holes in the strip built. We face it to the Sun and measure the diameter of the projection of the Sun on the screen of the obscure camera with a gauge (image 6).

Image 6: measure of the diameter of the projection of the Sun on the screen.

3- Measure the length of the obscure camera (L_2) with a tape measure.

4- Calculate the distance from the Earth to the Sun using the formula derived from Tales Theorem:

$$\frac{D_1}{L_1} = \frac{D_2}{L_2} \rightarrow \boxed{L_1 = \frac{L_2 \times D_1}{D_2}}$$

4.1.3 Materials

Obscure camera: - black cardboard - Scissors - Glue - Translucent paper	Tripod / Support
	Vernier caliper (precision 0'1 mm)
	Tape measure (1 mm Precision)

4.1.4 Assembly design

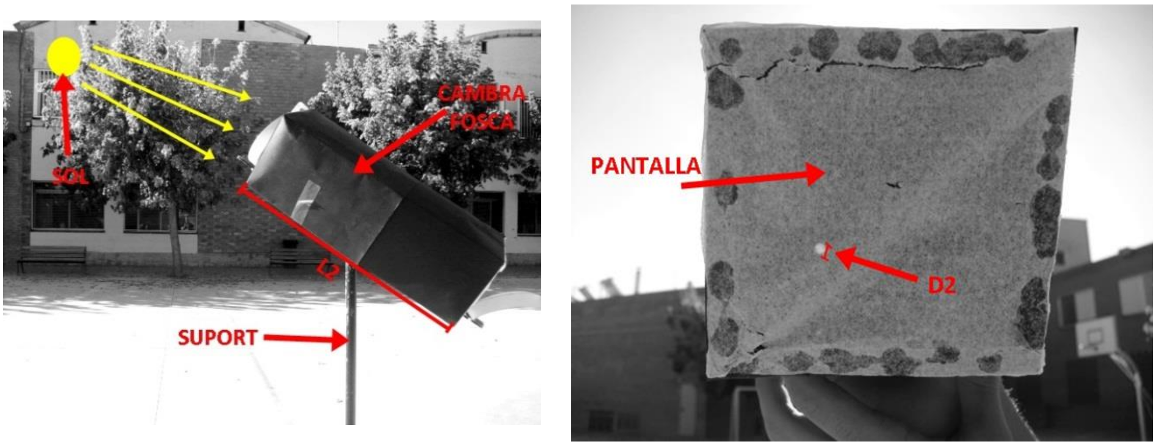


Image 7 and 8: assembly schemes.

4.1.4 Results. Analysis and discussion.

The results of the various measures are as follows:

Measure	L_2/mm	D_2/mm	$L_1=\frac{L_2 \times D_2}{D_1}$/km
1	361	4,1	1'2x10^8
2	359	3,4	1'4x10 ^{8}
3	360	3,3	1'5 x10^8
4	356	3,5	1'4x10^8
5	370	3,5	1'4x10^8

Making the overage of the results we will have a more successful outcome:

Measure	L_1/km	Ea=$\lvert L_1 - \overline{L_1} \rvert$/km
1	1'2x10^8	0'2 x10^8
2	1'4x10 ^{8}	0
3	1'5 x10^8	0'1 x10^8
4	1'4x10^8	0
5	1'4x10^8	0
	$\overline{L_1} = \frac{\sum L_1}{5}$ **= 1'4 x10^8 km**	**Ea max=0'2 x10^8 km**

The end result is as follows:

$$(\overline{L_1} \pm \text{Ea max}) \Rightarrow (1'4 \pm 0'2) \text{x} 10^8 \text{ km}$$

Finally, we will compare the value with the real value:

L real= 1'5x10^8 km

L_1 =1'4x10^8 km

$$Er= \frac{|L_1 - L_r|}{L_r} \text{x}100 = \frac{|(1{,}4-1{,}5)\times 10^8|}{1{,}5\times 10^8} \text{x}100 = \frac{0{,}1}{1{,}5} \text{x}100 = 6{,}7\%$$

The relative error is the 6,7%, therefore a very successful outcome.

4.2 Experiment 2: Experimental estimation of the translation period of Mercury

4.2.1 Description of the experiment

In this experiment we will make an estimation of the translation period of Mercury by catches of screen, made by us, of the transit of this year observed from the telescope at "Queen Mary University of London Observatory". The initial idea was to make our own photographs with our telescope, but due to the weather conditions no photograph could be done. From the images of the transit the distance travelled by Mercury on the solar disk will be determined. This is done by comparing the lengths of the segments to the path of Mercury on the solar disk with the length of the diameter of the Sun. The actual distance traveled by mercury is obtained by assuming that the diameter of the Sun is 1400.000 km.
The graphic treatment of the images of the transit has been done with the photo editing program "Gimp[3].
Knowing the distance travelled by Mercury on the solar disk, and the distance from the Earth to the Sun the angular displacement of Mercury ($\Delta\theta$) can be determined.

If we know the time (Δt) that the displacement of Mercury has talon, and if we assimilate its movement to a uniform circular motion (despite the fact that its orbit is very eccentric), we can make an estimation of the translation period (T) from the expression:

$$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T} \rightarrow T = \frac{2\pi \cdot \Delta t}{\Delta\theta} \text{ (Expression 1)}$$

4.2.2 Materials

- Program "Gimp 2"
- Program "Microsoft Word 2010"
- Telescope MEADE LX90 GPS.
- Camera Canon EOS 1000D attached to the telescope.
- Solar filter.

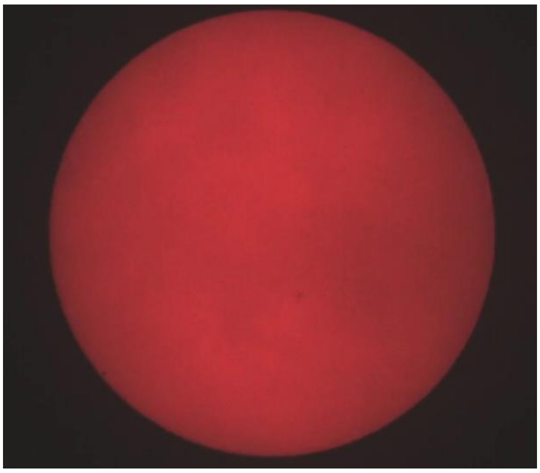
Imagen 9:
Telescope MEADE LX90 GPS solar filter and camera Canon EOS 1000D attached to the telescope. (05-09-2016).

4.2.3 Procedure

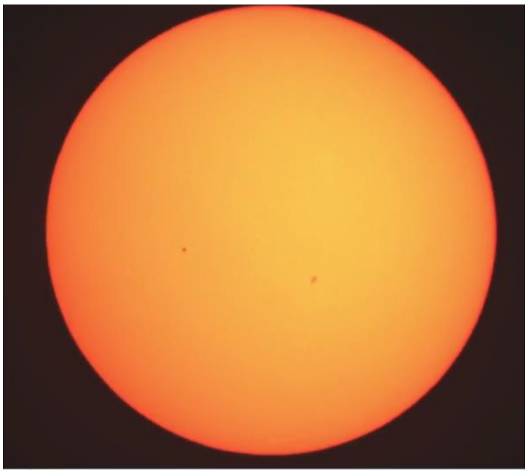
In order to estimate Mercury's translation period, the following approximation will be made: Mercury's orbit is assumed to be circular and we will assimilate its motion around the Sun into a uniform circular motion.

1- We have done photographs of the transit of Mercury of May 9th, 2016, as well as the time from the respective outlet:

11:19 UT

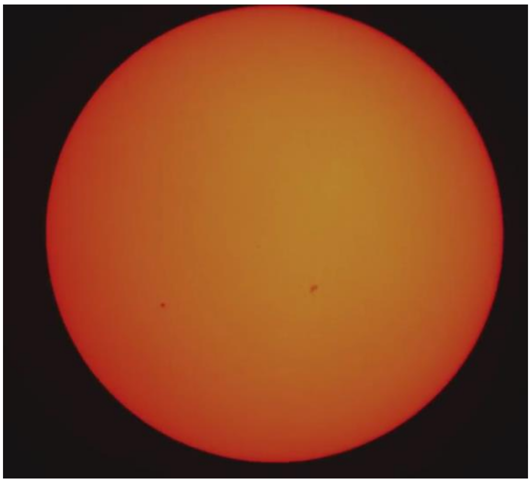


11:32 UT



13:04 UT

13:47 UT



14:07 UT

2- The overlap of these 5 images with "Microsoft Word" allows tracing the path of Mercury on the solar disk (image 10). This can be done by cutting the images, and then sticking them one on top of the other to make more layers. Finally, modifying its transparency is achieved that all black spots (Mercury) appear on the solar disk.

Image 10: different positions of the transit of Mercury.

3- Drawing a line that passes through the different positions of Mercury, we obtain its trajectory on the solar disk (image 11).

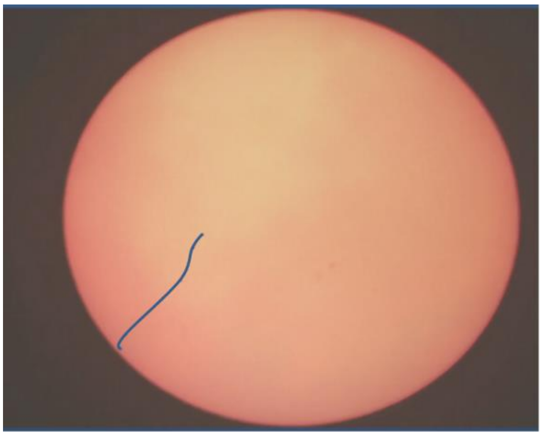


Image 11: Path of Mercury on the solar disk between 11:19 and 14:07 (UT).

4- To estimate the distance traveled by Mercury on the solar disk (image 12) during transit we will assume that the path is straight (yellow line). The parallel diameter to the path of Mercury will be drawn (green line) and the lengths of these lines will be compared. The measurement of each length will be expressed in pixels. To know the actual distance travelled by Mercury on the solar disk, it is necessary to know the equivalence between pixels and kilometers.

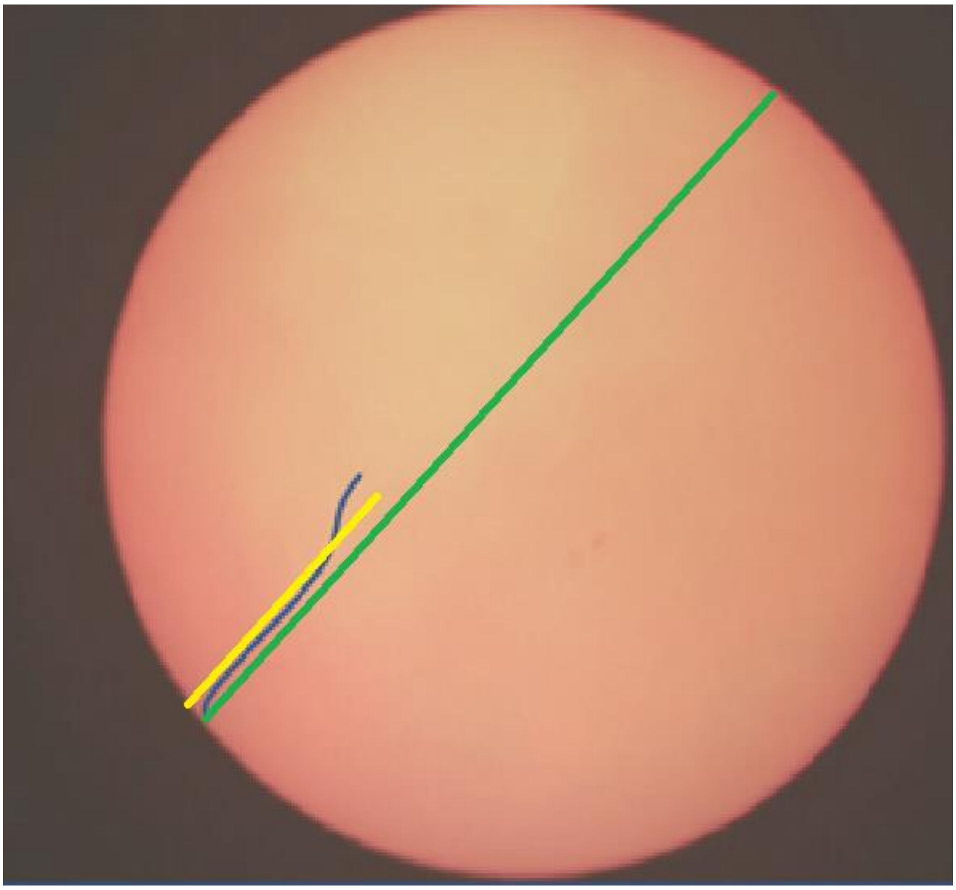


Image 12:
Mercury trajectory (blue line)
Mercury trajectory adjusted to a straight line (yellow line)
Diameter of the Sun (green line).

If we know that the diameter of the Sun (D_r) is $1{,}4 \times 10^6 km$ and that equals 533,77 pixels in our photograph, then the distance travelled by Mercury (X pixels) will be:

$$X\ pixels \times \frac{1{,}4 \times 10^6 km}{533{,}77\ pixels} = Z\ km$$

5- We have determined that the distance from the Earth to the Sun (D_{s-t}) is $1{,}4 \times 10^8 km$, and we know that the diameter of the Sun (D_r) is $1{,}4 \times 10^6 km$. Therefore knowing the length of the path that describes the transit of Mercury (L_r), we know the angular displacement of Mercury (Δθ) using expression 2.

$$\tan\frac{\Delta\theta}{2} = \frac{L_r/2}{D_{s-t}} \qquad \text{(Expression 2)}$$

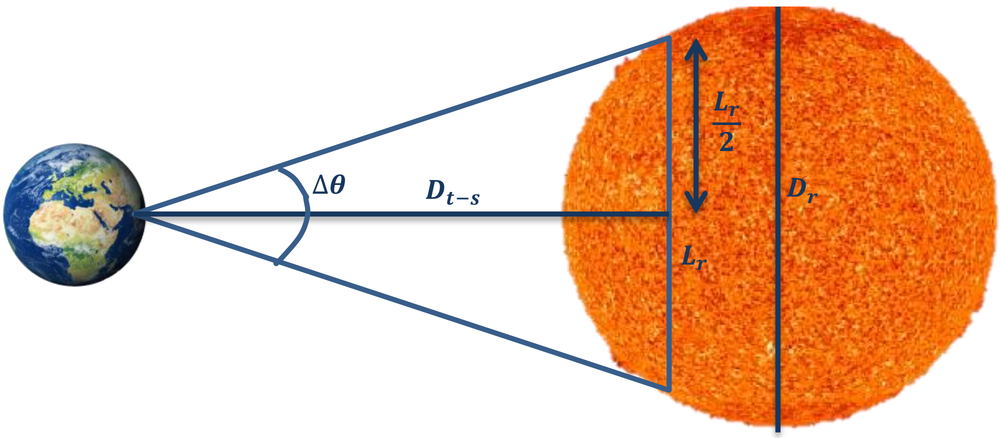


Image 13: displacement of Mercury (Δθ) during the transit.

7- Knowing the angular displacement of Mercury (Δθ) and the elapsed time (Δt) we will determine the translation period using the formula of angular velocity of uniform circular motion:

$$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T} \rightarrow T = \frac{2\pi \cdot \Delta t}{\Delta\theta}$$

4.2.4 Results obtained. Analysis and discussion.

We have obtained that the diameter of the Sun of our photograph is of 666 pixels and the length of the line drawn by Mercury during the last transit is 177 pixels, therefore:

$$176{,}98\ pixels \times \frac{1{,}4 \times 10^6 km}{533{,}77\ pixels} = 464192\ km$$

Subsequently we have calculated the angular displacement of Mercury using the value of the distance of the Earth to the Sun (D_{s-t}) previously calculated:

$$tan\frac{\Delta\theta}{2} = \frac{L_r/2}{D_{s-t}} = \frac{464192/2}{1{,}4 \cdot 10^8 km} = 1{,}66 \cdot 10^{-3} \rightarrow$$

$$\tan^{-1} 1{,}66 \cdot 10^{-3} = 1{,}66 \cdot 10^{-3} rad \rightarrow \Delta\theta = 2 \cdot 1{,}66 \cdot 10^{-3} = 3{,}32 \cdot 10^{-3}\ rad$$

The time elapsed between 11:19 and 14:07 is 2h 48 min (**10080s**)

From expression 1:

$$T = \frac{2\pi \cdot \Delta t}{\Delta\theta} = \frac{2\pi \cdot 10080}{3{,}32 \cdot 10^{-3}} = 19076659s$$

$$19076659s \times \frac{1\ h}{3600s} \times \frac{1\ dia}{24h} = \mathbf{220{,}79\ days}$$

This result differs greatly from the period of the actual translation (88 days) by the fact of having assumed that his movement described a circular motion uniform rather than following an elliptical path. And also we did not consider the rotation of Mercury, so it is not always in the same position. This approach works in the case of Venus, but not for Mercury.

4.3 Experiment 3: Experimental determination of the relationship between the Mercury and Venus radius.

4.3.1 Description of the experiment

In this experiment an estimate of the ratio of the Mercury and Venus radii will be made. For this we will compare a photograph of the Mercury transit of May 9th, 2016 with a photo of the transit of Venus of June 8th, 2004 taken by students of this High school. This is achieved by overlapping both images making them part of the same circumference. In this way we will obtain the apparent sizes of Mercury and Venus in a single photo.

4.3.2 Materials

- Program "Gimp 2"
- Photographs of the transits of Mercury (2016) and Venus (2004).
- Program "Microsoft Word 2010"

4.3.3 Procedure

We will use a photo of Venus made on June 8th, 2004 by former students of high school (image 14) and an image of Mercury performed on May 9th, 2016 by Josep Masalles (image 15), because due to the weather we could not take our own photos.

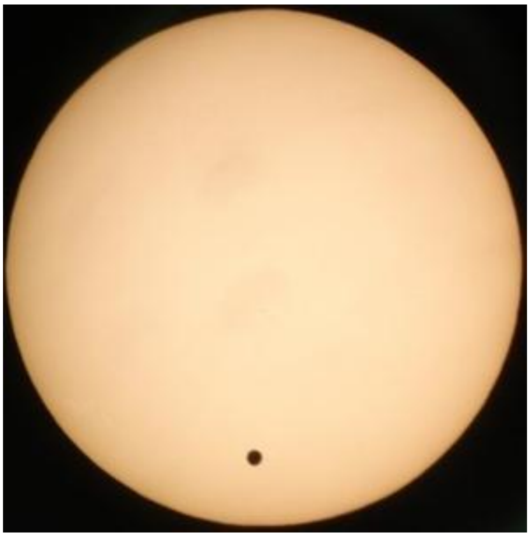


Image 14:
Transit of Venus (06-08-2004). Image by former students of high school: K Wierzchos, A Agraz, and O. Puértolas.

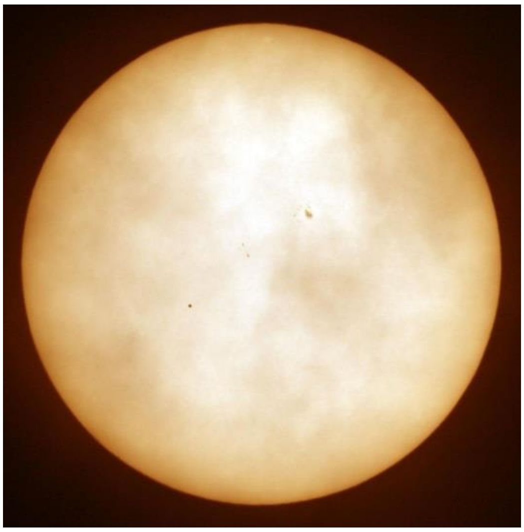


Image 15:
Transit of Mercury (05-09--2016). (Josep Masalles)

1- With "Microsoft Word" we will open the photo of the transit of Mercury and paste the one of Venus above, so that they form part of the same circumference (image 16).

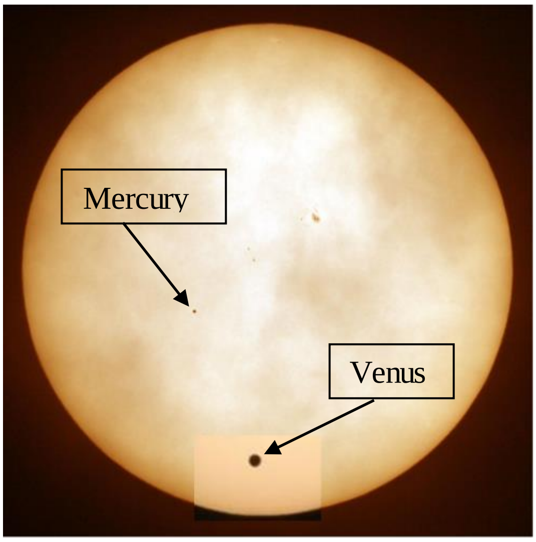


Image 16: Mercury and Venus in the same solar disk.

2- With the program "Gimp" we will measure the diameter of both planets in pixels (Figure 17).

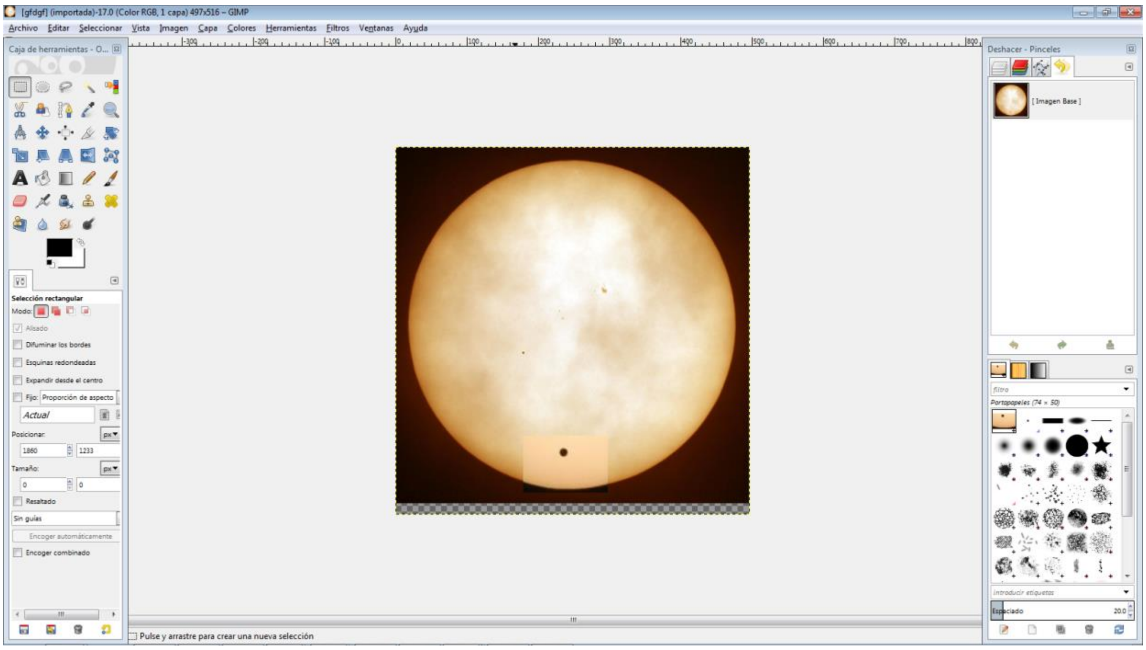


Image 17: Count the number of pixels of the diameter of the planets with the program "Gimp".

3- The last step will be to consider that the apparent dimensions of Venus and Mercury depend on the distance to which they are with respect to the Earth.

As a consequence of the straight-line propagation of light, it can be shown that the ratio of the radius of the planets (RV/RM) is directly proportional to the product of the ratio of apparent radii (RV'/RM') and from the relation of the distances of the planets to the Earth (equation 3)

$$\boldsymbol{\frac{R_V}{R_M} = \frac{R'_V}{R'_M} \times \frac{d_{TV}}{d_{TM}} \begin{cases} d_{TV} = distance\ Earth - Venus \\ d_{TM} = distance\ Earth - Mercury \end{cases}}$$

(Equation 3)

4.3.4 Results. Analysis and discussion.

The results obtained are:

$$Apparent\ diameters\ (pixels) \begin{cases} Venus: 21 \\ Mercury: 4 \end{cases}$$

Knowing that:

$$Distance\ from\ Earth\ to \begin{cases} Venus: 41{,}4 \cdot 10^6 \text{ km} \\ Mercury: 91{,}7 \cdot 10^6 \text{ km} \end{cases}$$

Then using the formula mentioned above (formula 1) we will be able to calculate experimentally the relation existing between the radius of Mercury and Venus:

$$\frac{R_V}{R_M} = \frac{R'_V}{R'_M} \times \frac{d_{TV}}{d_{TM}} = \frac{21}{4} \times \frac{41{,}4 \cdot 10^6}{91{,}7 \cdot 10^6} = \mathbf{2{,}37}$$

The value accepted by the international scientific community is: 2,48

Therefore, the relative error is: $Er = \frac{|L_1 - L_r|}{L_r} x100 = \frac{|2{,}37 - 2{,}48|}{2{,}48} x100 = 4{,}44\%$

The most important origin of this error is to suppose that the orbits of the planets (Earth, Mercury and Venus) are circular.

4.4 Experiment 4: Experimental determination of the translation period of Mercury from the translation period of Venus

Kepler's third law allows us to determine the period of Mercury if we know the period of Venus[4] (determined in 2004 by former students of our high school following the transit of Venus) and the middle radii of the orbits of the two planets. The value found in 2004 was **221,2 days.**
The average distance from Venus to the Sun (d_{vs}) is $108{,}2 \cdot 10^6 km$, and the one of Mercury to the Sun (d_{Ms}) $7{,}9 \cdot 10^6 km$

$$\frac{T_v^2}{T_m^2} = \frac{d_{vs}^3}{d_{Ms}^3}$$

Kepler's third law

Then: $T_m = \sqrt{\frac{d_{ms}^3 \times T_v^2}{d_{vs}^3}} = \sqrt{\frac{(57{,}9 \cdot 10^6)^3 \times 221{,}2^2}{(108{,}2 \cdot 10^6)^3}} = \mathbf{86,6\ days}$

Therefore the relative error:

Er= $\frac{|T_1 - T_r|}{T_r}$ x100 = $\frac{|(86{,}6-88)|}{88}$ x100 = **1,6%**

6. Conclusions

1- Due to bad weather conditions, the educational community of Guindàvols High school was unable to observe Mercury's transit through the telescope. However, it was possible to be observed by the students of 1st year of High school through internet.

2- The distance from the Earth to the Sun has been determined experimentally. The value found is 1.4 ·108. The relative error is 6.7%.

3- No satisfactory results have been found in the determination of the translational period of Mercury due to the approximation of considering its circular orbit.

4- Comparing the transit of Mercury (09-05-2016) with the transit of Venus (08-06-2004) has been able to determine that the radius of Venus is 2.37 times greater than that of Mercury, with a relative error of 4.4%.

5- From the translation period of Venus determined by former students of our high school in 2004 has been able to determine the translation period of Mercury using Kepler's third law. The value obtained is 86.6 days, with a relative error of 1.6%.

7. Thanks

To Josep Masalles: for sharing his photograph of the transit of Mercury.

To Rosa Borrell: for the correction of the English version.

8. References

1. “Transit de mercuri 9 de maig de 2016”. “Activitats”

   Link: foradorbita@planetari.cat - www.planetari.cat

2. Mercury. Wikipedia.

   Limk: https://es.wikipedia.org/wiki/Mercurio_(planeta)

3. Gimp program.

   Limk: http://gimp.es/

4. K. Wierzchos, A. Agraz y O.Puértolas. 8 de junio. A observar se ha dicho!”.

   Link: http://www.xtec.cat/~acosiall/venus/

Images:

- Image 2: positions to allow a transit.
  Enlace: http://www.astroasheville.org/wp-content/uploads/2016/01/nodes-image.jpg
- Image 3: Mercury.
  Link: http://esoterismomagico.com/wp-content/uploads/2015/01/mercurio.jpg
- Image 15: image shared by Josep Masalles Román. Taken at 15 h 14 min the UT 09.05.2016 at Vilanova i la Geltrú, Catalonia.