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THE SUN,
KING OF THE SKY

From Galileo to Halley

Glad to meet you, my name is Peter Le Fur. I'am a physics teacher in an engineers school, called ISEN, in Toulon, in the south of France. My pupils are 18 to 20 years old.

I train teachers of the Nice education authority to do astronomy with their pupils. I am a member of the CLEA committee for bringing together teachers and astronomers.

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First chapter

AT THE BEGINNING OF XVIITH CENTURY

Henri IV, king of France

Shakespeare

This story begin in the early XVIIth century, when Shakespeare was writing and Henri IV was king of France.

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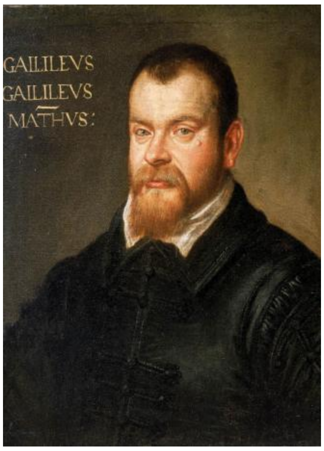
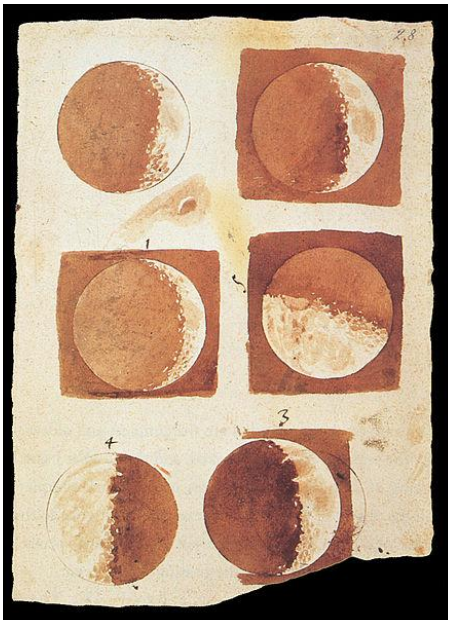
Moon , watercoloured by Galileo Galilei (1610)

in « Sidereus nuncius » published in march 1610





It's well known that Galileo Galilei observed the medicean stars (in fact, Jupiter's moons) on january 1610.

His drawings and watercolours constitute the first still life nature of celestial objects, observed through a telescope.

He published these pictures in the "Starry Messenger".

Thus, science began with a kind of "international" publication written in Latin at the dawn of XVIIth century.

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From http://www.museogalileo.it/en/explore/galileoportal.html

Harriot, Galileo and Scheiner observing Sun

But Galileo didn't forget the most important object of our earthly sky: the Sun, our star.

To study it, he had to develop a particular method of observation, because he might have damaged his eyes by looking at the sun through a telescope.

OBSERVING SUN IS DANGEROUS.

Don't forget, Galileo was blind at the end of his life...Look at this film from www.imss.fi.it

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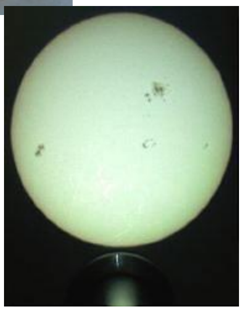
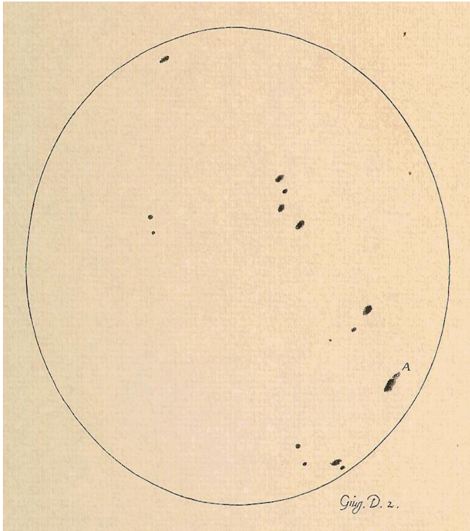
On 2nd june 1613/ 2011 with pupils



- Galileo’s drawing of the sun:



Galileo's drawing looks like a modern abstract painting. We can give it a title:"black spots in a circle“.

Nowadays, same observations could easily be done with pupils or students from six years old to twenty.

By projection (solarscope) there are no risks.

At this time, only a few scientists could observe the sunspots. but a scientific competition already existed: Father Scheiner, a Jesuit, said he was the first observer of sunspots, before Galileo. He was right (Harriot's drawings for except).

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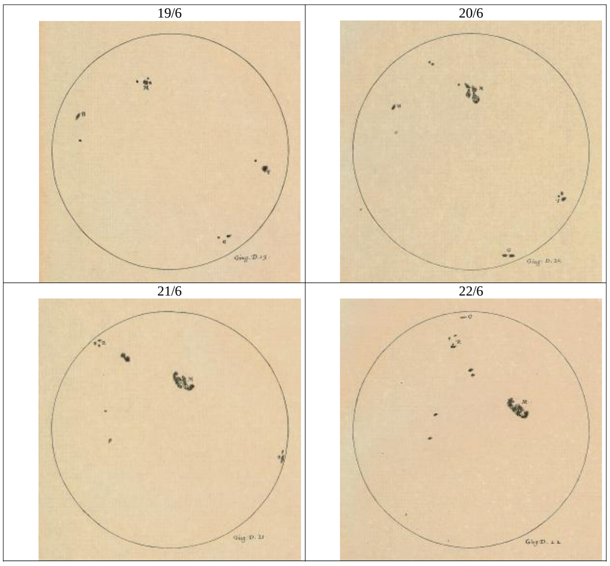
Continuous observations from june 1613 to july 1613.

-> Place your tracing paper on the first drawing (19th june) .

-> tick off the center of a spot, choosen at random.

-> Try to track it day after day by moving your paper from a picture to the following.

-> **Be careful : Don't rotate your tracing paper, slide it straight.**



What are these spots ? Do they appear anywhere, at anytime ?

Are they long-lived objects ?

Galileo looked for answers to these numerous questions... and to others.

Now you'll try to be new Galileos, like students. you have tools in your hands: a pen, a set of observations and tracing paper.

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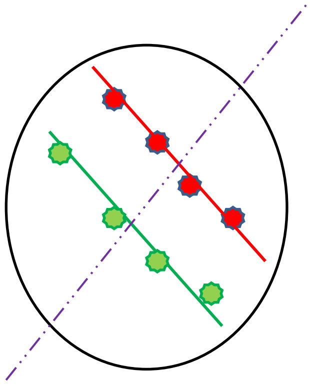


Following spots during few days

Who is right ? Galileo or Scheiner ? What evidence ?

What are you discovering ?

A spot could be followed during few days; its trajectory describes a straight line.

It can be a few days old.

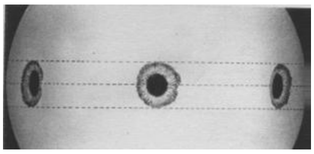
But we don't know if the shape changes are physical events or bad drawing effects.

Test another spot.

Father Scheiner thought that the sun’s surface was clean but some little planets, revolving round the sun, pass in front of the solar disk, between the photosphere and the observer.

Galileo thought that sun spots are physical events on the sun. So their movements show the rotation of the sun, and definite a polar axis you can draw.

Perspective effect on sun

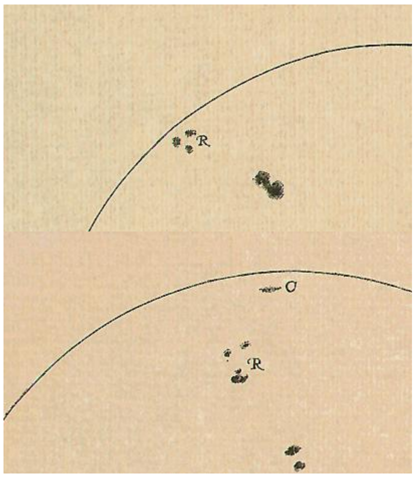


Umbra, penumbra and faculae

the film (the film.MPG)

p1

- Distortion of sunspots group near limb:



Look at these details of Galileo's drawing: The shape of the group of spots changes when it moves away from the limb (circular edge between shiny sun surface and black sky). It widens out.

Near the limb, spots are not circular but elliptic.

Today whe can take films or pictures with a little telescope protected by a reflecting “mylar” screen, placed in front of the mirror. So we observe the elliptic shape of sun spots due to perspective effects. Notice the center of spot is lower than edges. And the atmospheric turbulences blurs the images.

So Galileo discovered the evidence of his hypothesis about the nature of sunspots. The rotating sun carries black points. Too bad Scheiner.

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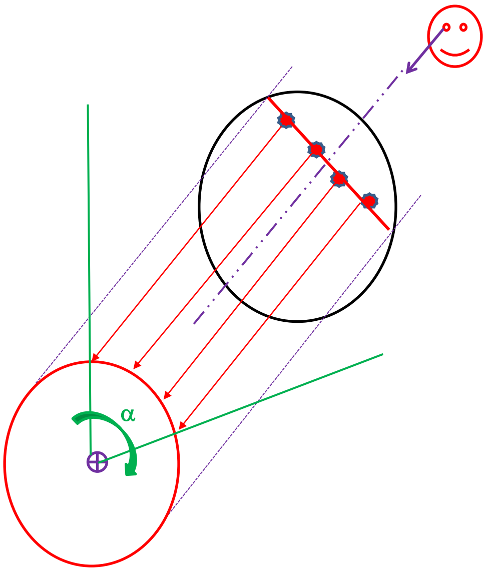

The period of rotation is: T=Δt (days) 360/α(°)=27.2days

What can we measure with such observations ?

The period of rotation.

Look at the sun from the north pole. Project the great circle of constant latitude (its diameter is less than that of the sun's).Track the sun spot day after day.

Measure the rotating angle alpha(°) swept by the spot during a few days (here 3) called delta t. Calculate the period.

Delta t multiplied by 360° divided by alpha. This period is related to the referential of Earth and sun. You must corrected this value to obtain the period related to the referential of sun and stars.

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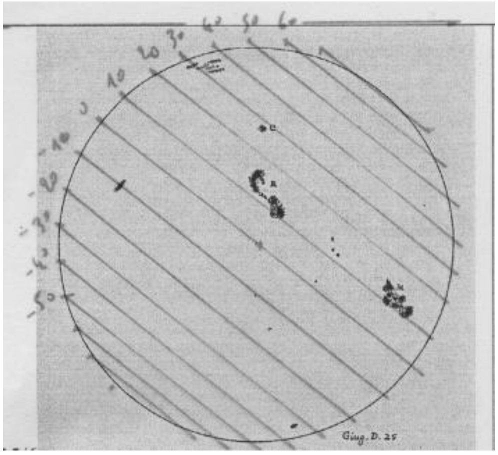

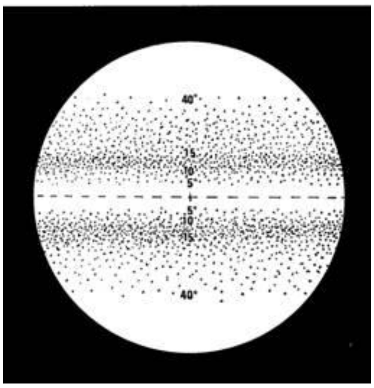

Statistical distribution of spots in latitude

-10<Lat<10	**2**
10<Lat<30	16
30<Lat<50	4

latitude	25th june	26th june				Mean
lat :-70° to -50°	0	0				0
lat :-50° to -30°	1	1				1
lat :-30° to -10°	1	11				6
lat :-10° to 10°	2	2				2
lat :10° to 30°	16	26				21
lat :30° to 50°	4	1				2,5
lat :50° to 70°	0	0				0

Are Galileo's discoveries finished ?

No!

So students discoveries continue by using Galileo's drawings, the spread sheet EXCEL and a printed transparent paper.

Calculate the mean and conclude:

Many more sunspots lie in areas of between 10°->50° latitude. You discover "Royal zones"

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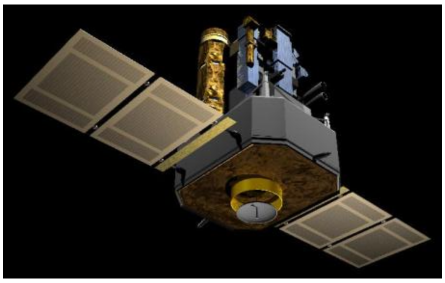
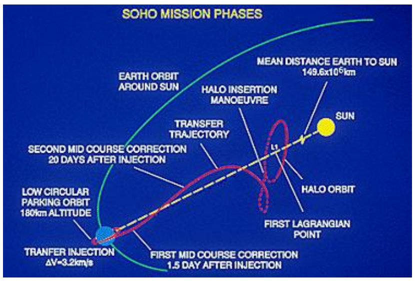
1610/2010

- Galileo’s movie ssm_fast.mov Soho’s movie MagnetoC.mov





Look: 4 centuries separate these Galileo's pictures from the film taken by Solar and Heliospheric observatory (SOHO).

In orbit since 1996 round Lagrange point L1, where solar attraction is cancelled by that of the earth (and inertial force). It observes Sun continuously.

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Old Galileo visited by Viviani, his pupil.

(Tito Lessi 1892)

Nowadays, eyes and hands have disappeared from the professional astronomical toolbox.

At that time, Galileo's work looked like the activity of the painter: they perceived up the reality with their physical senses and translated it into a comprehensive picture of the world.

Galileo questioned Universe like Le Caravage sounded out his model's soul.

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Second chapter

AT DAWN OF XVIIITH CENTURY

Louis XIV, king of France

Leibniz

The second part of this story begin in the early XVIIIth century, when Liebniz was calculating and Louis XIV was king of France.

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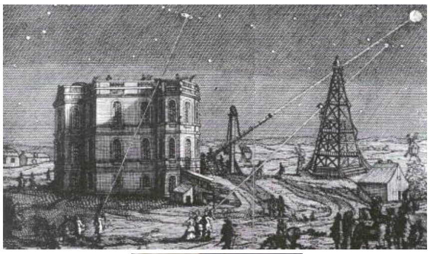
The observatory of Paris, founded by Louis XIV (1667), gave results about solar activity.



Louis XIV's astronomers discovered the speed of light (Römer). They measured Earth (Picard) and began to measure the solar system (Cassini and Richer).

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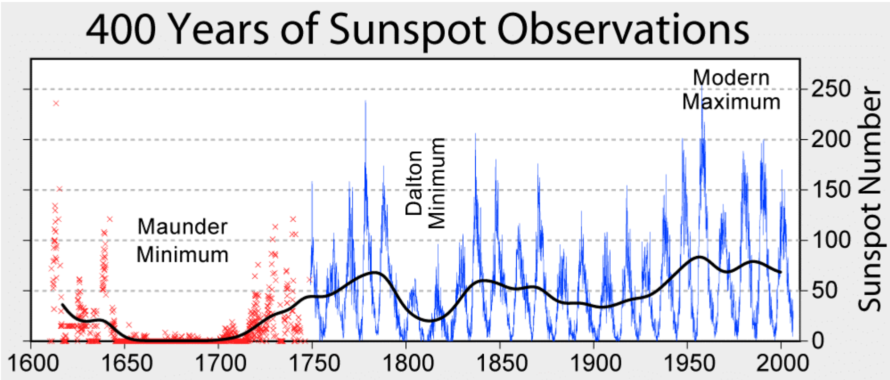
Activity of Sun
was very low during « sun king » reign !



SOHO_EITbig07_cycle.mov

Look at these "activity curve": in the y axis the number of sun spots is plotted, over time; dates are written in the X axis.

Two surprises await us:

-> the nb of spots is a periodic function of time (with T=11.6years). See the SOHO animation (1996->2007) which describes a complete solar cycle. High activity corresponds to many spots visible on sun disks and low one to no spots.

->during about fifty years (1650->1700) almost no spots were observed. There was no activity of sun during the "Sun king" Louis XIV's reign! It's called "Maunder minimum".

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Lully composed « Isis », indirect witness of the cold weather in the second half part of XVIIth century.

Scientists still discuss relationship between weather and solar activity.

Listen to this short piece of Lully's opera called Isis -1667-The name of this extract is "aria of trembling people": they sing "mortels frissons". It could translated as "mortal shivers".

At this time, the weather was particularly cold in winter. Then, western europe was subject to icy winters, bad harvests and even worse, famines.

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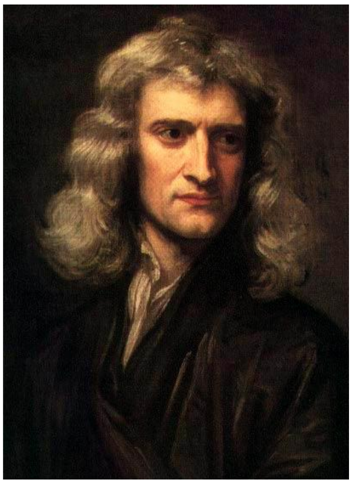
The king of scientists: Newton



- New expression of the 3rd Kepler's law:

$$T^2/a^3 = 4\pi^2/ GM_{sun}$$

T: period of planet
a: « radius » of the circular planetary orbit

->measurement of a and G.

->knowledge of M_{sun}

But today it's a European meeting, so, i must forget my patriotic point of vue and tell you about two great British scientists of the end of XVIIth and beginning of XVIIIth.:Newton and Halley.

At first, look at this portrait of Newton who discovered the driving force of the solar system: gravitation. He published his work “The Principia" in 1687.

His wellknown gravitation formula gives a new expression of the Kepler's third law - on the right side of slide. In fact he never knew the value of "universal gravitation constant" called G; it was measured about 100 years later by Cavendish (1798).

Morever, the accuracy of measurements of the radius a (half great axis of elliptic orbit) was very poor. Only a scaled map of solar system was well known.

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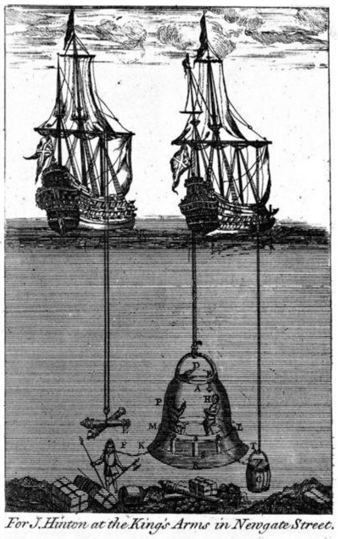
Halley and the Venus transit



His friend Halley who persuaded Newton to publish Principia was a great astronomer and a famous adventurer. Look at his research about sub marine suite !

A very good observer, he found a method to determinate "a" of the earth with accuracy. Nowadays, a of the earth is called astronomical unit. He wanted to apply the "parallax method" in using the venus's transit in front of the sun.

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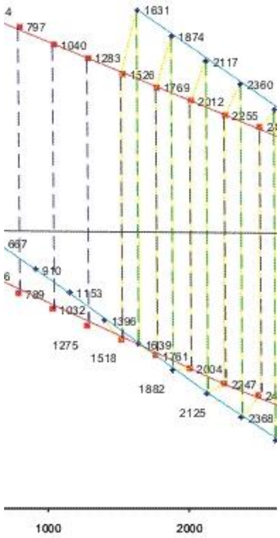
Adventure of sciences: transit of Venus



What's a transit of venus ?

look at this very old film from the net. The pictures where taken by David Todd from the Lick observatory, California, in 1882. Venus marks out a straight path in front of the sun during about six hours.

But these phenomena are rare: the nearby diagram shows the dates of the transit.

But Halley died in 1742, before the next transit of 1761.The periodicity is 111 years followed by 8 years and so on.

Notice that a transit took place the 8^{th} june 2004. Next one is predicted on june 6^{th} 2012 . After we will wait for 2117 ! Too late for us (a thought to Halley).

We can see next transit in Europe and show it to students, with a telescope using the projection method.

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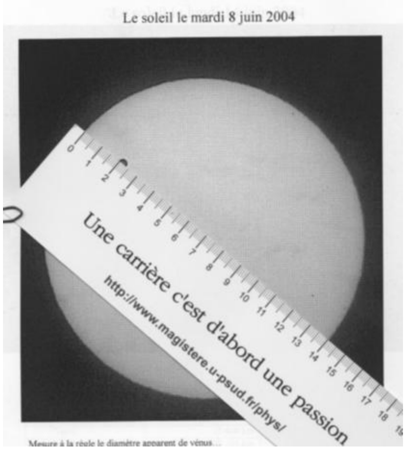
A research for pupils

- 7H50 UT 8th may Te 100



- Diameters of Sun and planets: (wikipedia)

Soleil	$139\ 10^4$ km
Terre	$1.24\ 10^4$ km
Venus	$1.21\ 10^4$ km

- Draw Venus-circle at the scale of the picture, if sun is 139 mm diameter.
- Compare with the actual diameter of venus on picture. Conclude .
- Venus why are you too BIG ?

Work done with eleven years old pupils-primary school.

This is a picture of the Sun with Venus in 2004. Now we know the sizes of these astronomical objects. See spread sheet. On this picture the diameter of sun is 139 mm. What is Venus's diameter ? draw the circle which were Venus.

Compare with the actual diameter on picture.

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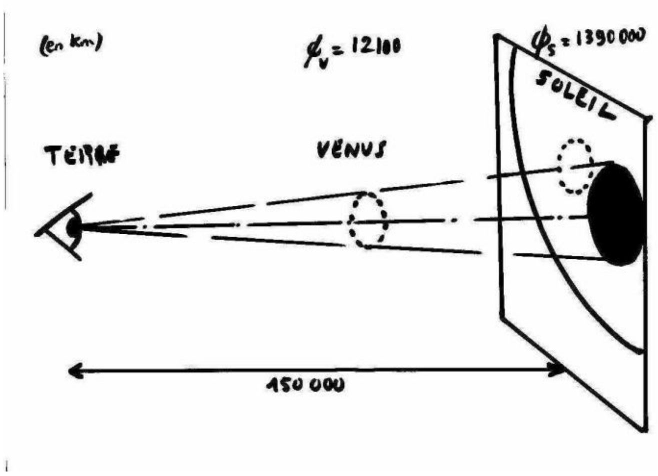
Cardboard experiment



Look at this cardboard experiment. The closer Venus is to Earth, the bigger it will appear.

With a tape measure, determinate the distance Sun-Venus, if you know the distance of Earth Sun.

Venus-Sun are far from 110 Mkm, apart.

But its only a task with pupil. What about Halley's method to know the distance of Earth-Sun ?

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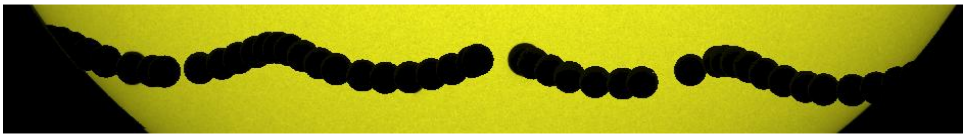
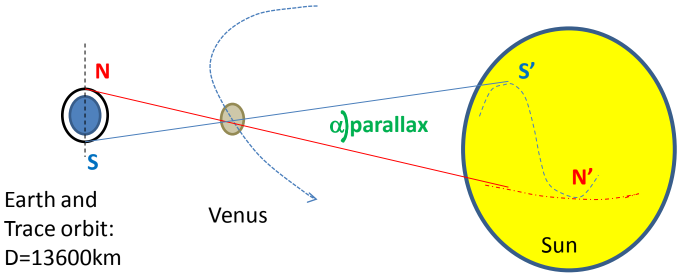
Halley’s method updated by « Trace »



- Trace describe a polar orbit , 600 km high.
- Measure the angle of parallax α=1’.



But in fact Halley didn't know the real sizes of objects, so what did his method consist in ?

To discover it, look at this recent picture take by a polar satellite named Trace.

Why does the trajectory represent a sinus ?

When Trace follows its orbit, it goes through north pole N and south one S. So Venus seems to balance from N' to S'.

We can measure alpha called "parallax angle". Venus is one minute arc wide.

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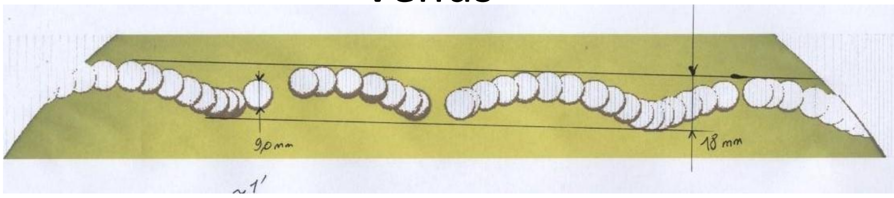
Calculate the distance from Earth to Venus



- EV=D(orbit of trace)/α(rad)
- EV(km)=13600cos(23°)/2.91 10^{-4}
- **EV(km)=43.2 10^{6} km**

- Mean value: 41.2 10^{6} km
- 3ème Loi de Képler donne ES=149.6 Mkm, VS=108.2 Mkm

The angle of parallax has the same size as Venus's apparent diameter.

Take care, the orbit of Trace is leaning on the ecliptic plane (like earth axis): 23°.

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The end of this story

Halley died before this result.

At this time, observing the transit of Venus from a lot of differents points on earth was a true and fantastic adventure. Think about Le Gentil de la Galaisière.

But it's a too long story for today.

Don't forget: look at the sun with your pupils or students on june 6^{th} 2012.

It will not be the end of the world, but for some of young people, it will be the beginning of a great passion, blending science and beauty, the marvelous beauty of the sky.