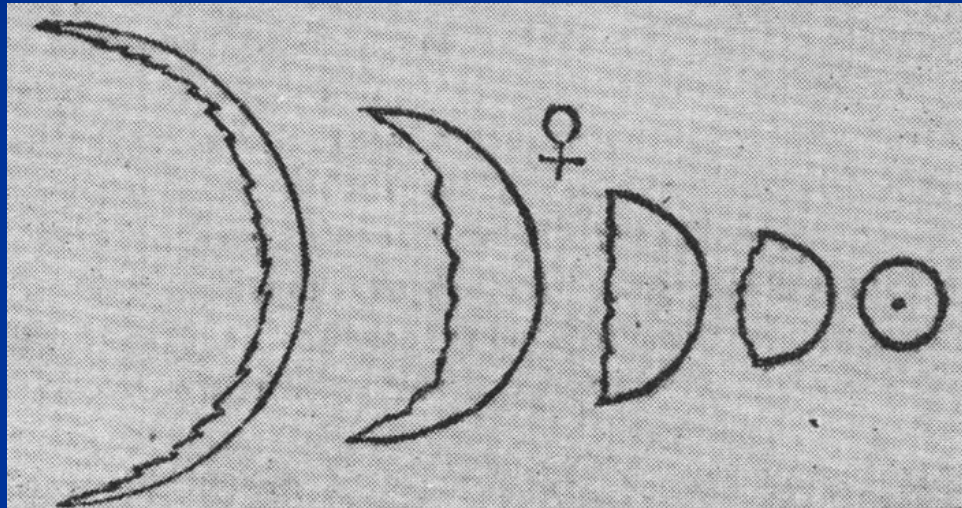
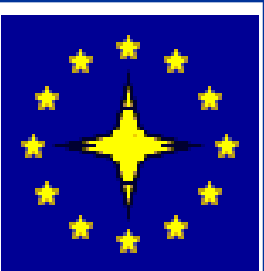


# Galileo and the phases of Venus

charles-henri.eyraud@inrp.fr



Madrid, 27 november 2009: Adventures in teaching astronomy  
EAAE-IAU Course on Astronomy Education



# Bibliography « Galileo and Venus »

## Letters and books of Galileo

- *11 december 1610 to Giuliano de Medicis, OGG X 483*
  - *1th january 1611 to Giuliano de Medici, (OGG XI, 11-12*
  - *30 december 1610 to Benedetto Castelli, (answer to his letter of 22 august 1610) OGG X, 502-504*
  - *30 december 1610 to Cristoforo Clavius , OGG X 499-502*
  - *12 february 1611 to Paolo Sarpi,, OGG XI, 46-50*
  - *The essayer, 1623*
  - *Dialogue concerning the two chief world systems 1632, OGG VII, 350-..., 366)*
- OGG=Opere di Galileo Galilei, ed nazionale, ed by A. Favaro

## Articles

- *Phases of Venus in 1610. O. Gingerich. Journal for the History of Astronomy, XV, 1984: 209-210.*
- *The appearances of Venus and Mars in 1610, William Peters, JHA, XV 1984*
- *Galileo, Kepler and phases of Venus, Stillman Drake, JHA, XV, 1984*
- *Galileo and the discovery of the phases of Venus, Paolo Palmieri. JHA XXXII 2001: 109-129.*
- *Cahiers Clairaut n°5 et 28 (revue du Comité de Liaison Enseignants Astronomes)*

## Letter to Castelli, Florence. 30 December 1610 (See Proceedings)

### *Read the letters of Galileo and make Drawings*

...Know then that about three months ago I began to observe Venus with the instrument, and I saw it round in shape and very small; it went daily growing in bulk and keeping the same rotundity until finally, coming to a very great distance from the Sun, it commenced to lose rotundity from the eastern side, and in a few days was reduced to a half-circle. In that shape it stayed many days, but always growing in size; now it begins to become sickle-shaped; and as long as it is seen evenings it will go on thinning its little horns until they vanish. But then returning [in the] mornings, it will be seen with horns thin and still turned away from the Sun; it will go on growing toward a half-circle until maximum elongation. Then it will remain semicircular for some days, though diminishing in bulk; then from the semi-circle it will pass to ail round in a few days, and will be seen that way for many months, both as morning and [then as] evening star, all round but very small in size.

# Letter 11 december 1610

to Giuliano de Medici, Praha

*"Haec immatura a me iam frustra leguntur o, y"*

*In vain I'm looking at these things immature o, y.*

Kepler suggested the solution

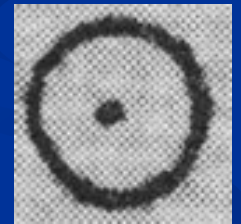
**MACULA RUFA IN IOVE EST GYRATUR MATHEM, ECC.**

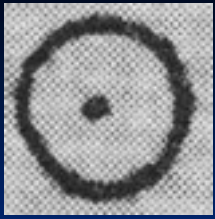
There is a red spot on Jupiter, revolves mathematically, etc.

# Letter 30 december 1610

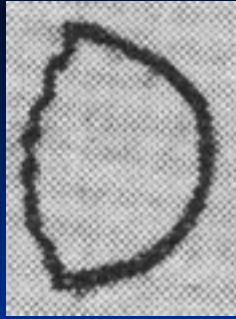
to Castelli , Florence,

".... I began to observe Venus, who, in the evening, was perfectly round, and very small ..."





1



2



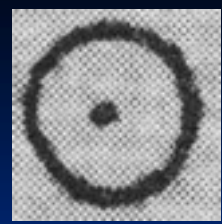
3

1-.... perfectly circular. With such a figure is maintained for many days, but increases substantially in size.

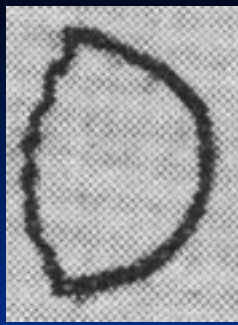
2- Approaching the same elongation it commenced to lose retundity from the eastern side,

3- and in a few days was reduced with to a half-circle. In that shape it stayed many days but always growing in size.





1



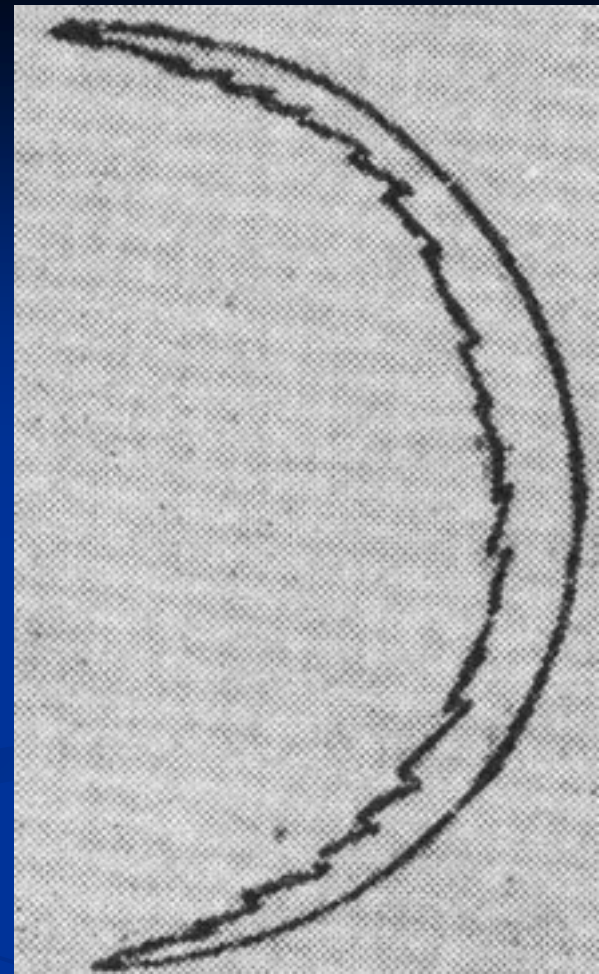
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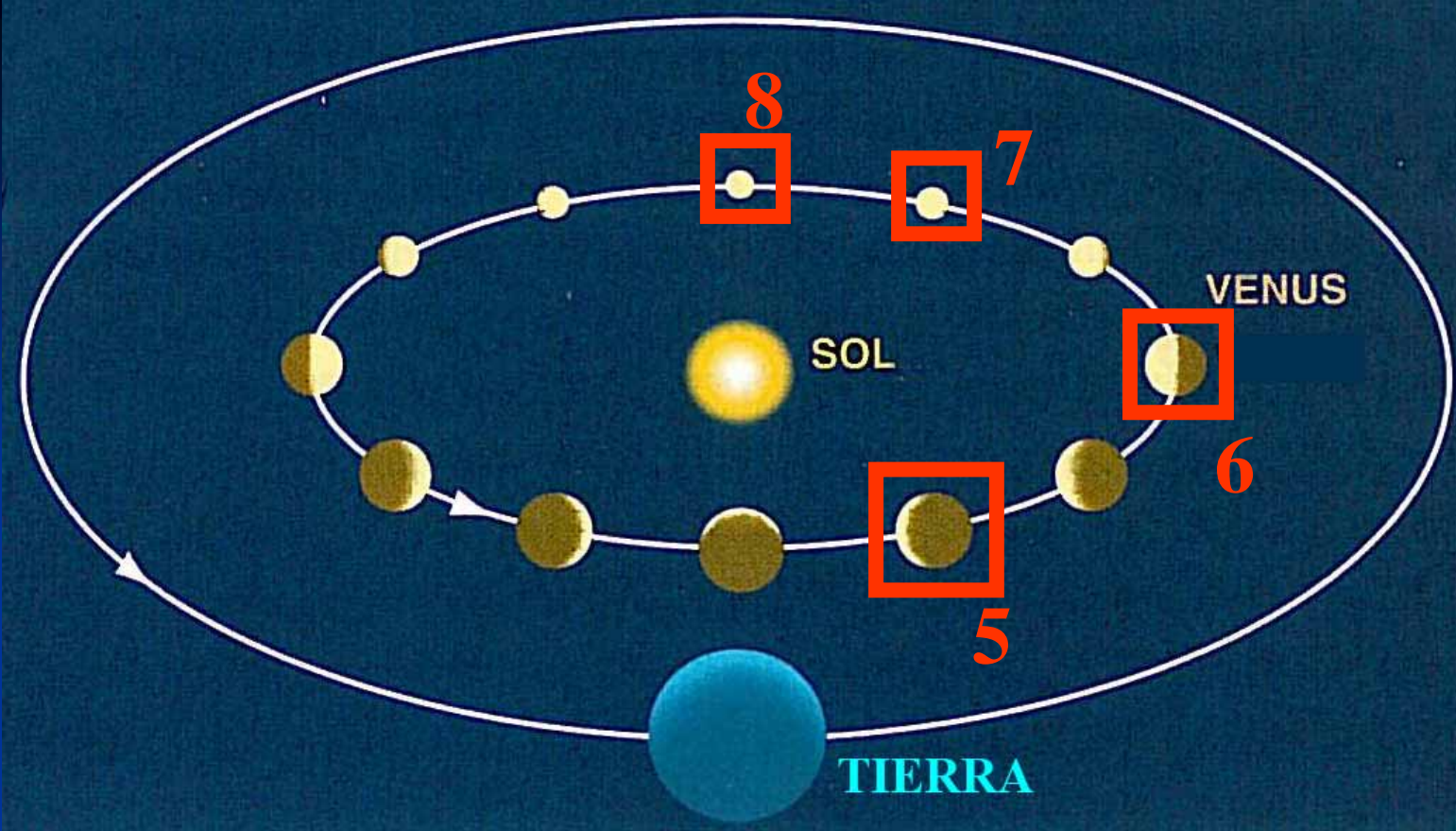
3



4



4-now it begins to become sickle-shaped; and as long as it is seen evenings it will go on thinning its little horns until they vanish.



5- But then returning in the mornings, it will be seen with horns thin and still turned away from the sun;

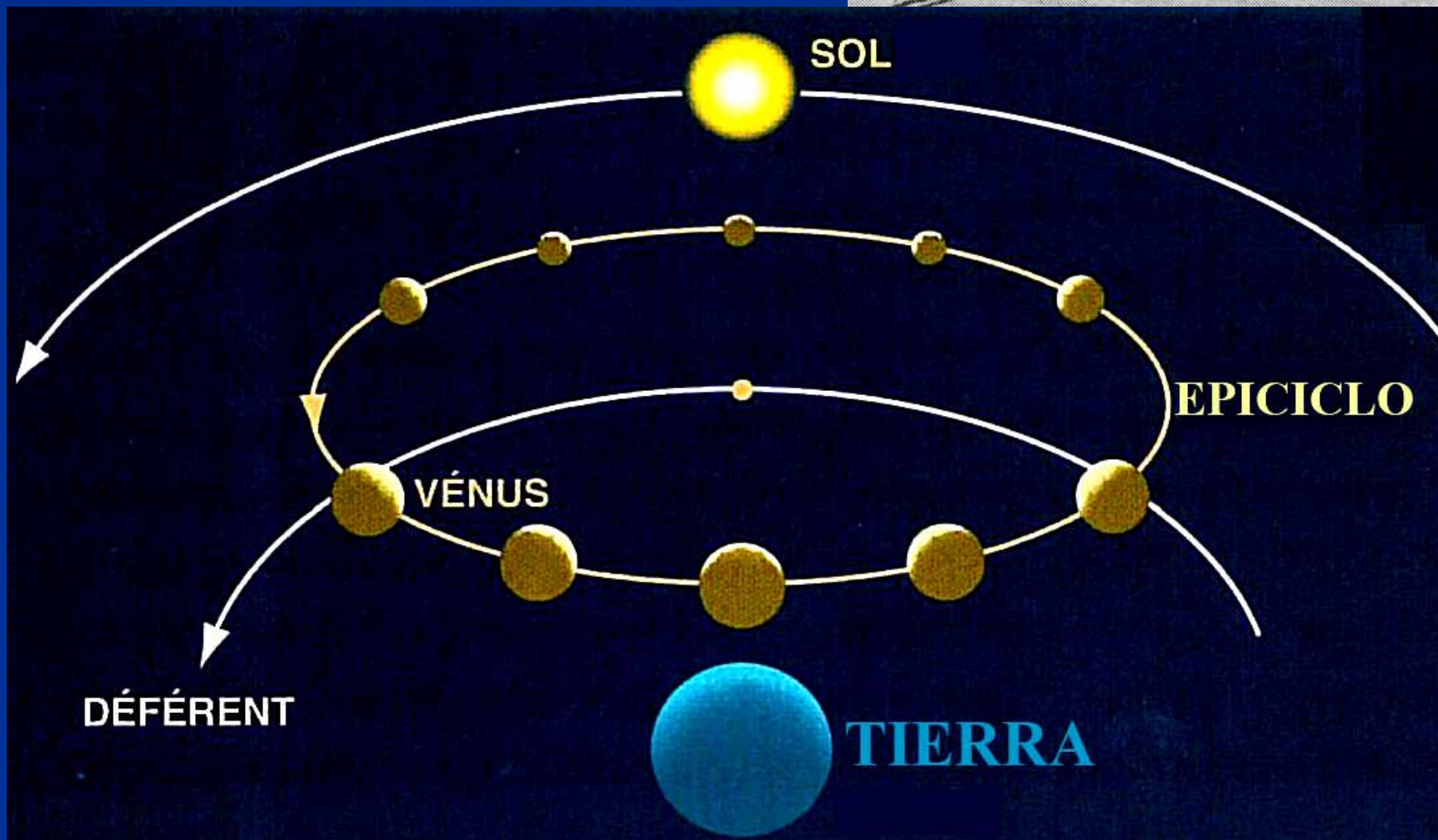
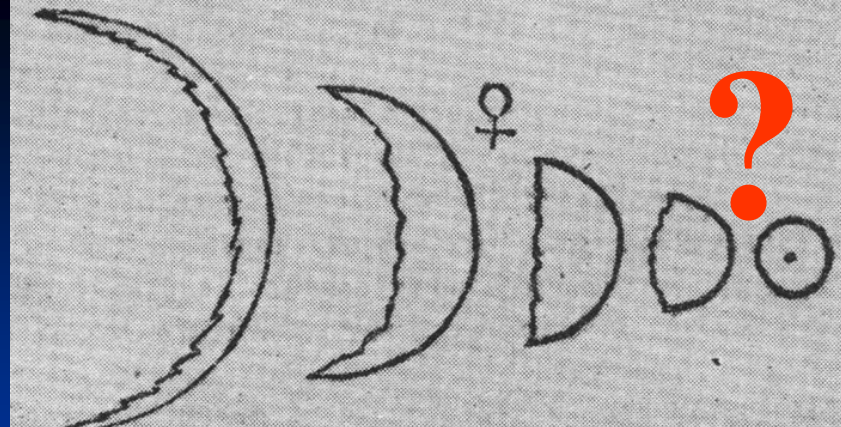
6- It will go on growing toward a half-circle diminishing in bulk;

7- then from semicircle it will pass to ail round in a few days, and will be see that way for many months

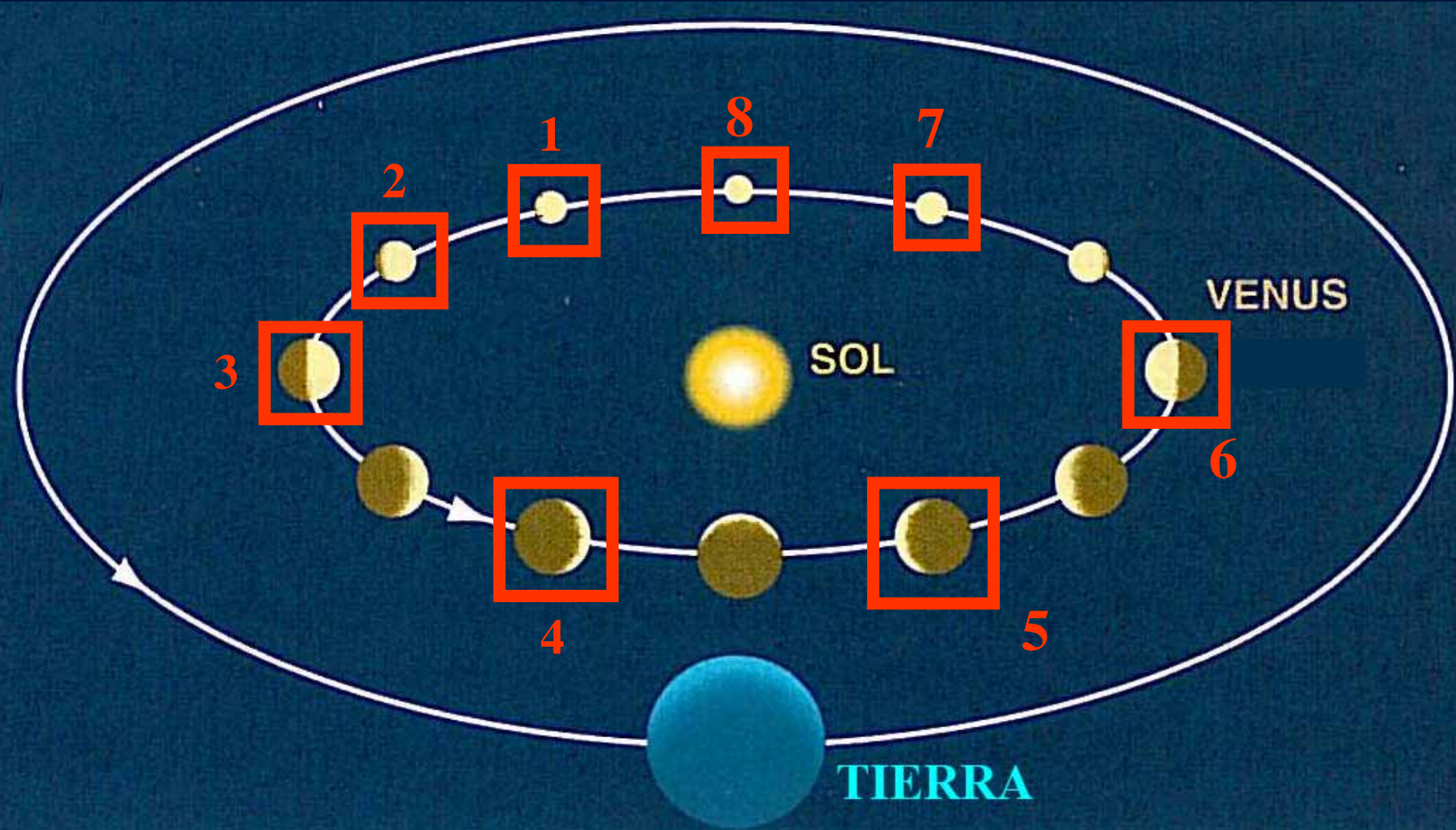
8- removing approximately three months it will be invisible



# Ptolemy's model



# Galileo's conclusion



- The planets are all dark in nature
- Necessarily Venus revolves around the sun



# Venus, Letter 16 June 1612

So, the sentence I sent :

*Haec immatura a me iam frustra leguntur o. y.,*  
(In vain I'm looking at these things immature o y.)

means:

*Cynthiae figuras aemulatur mater amorum,*

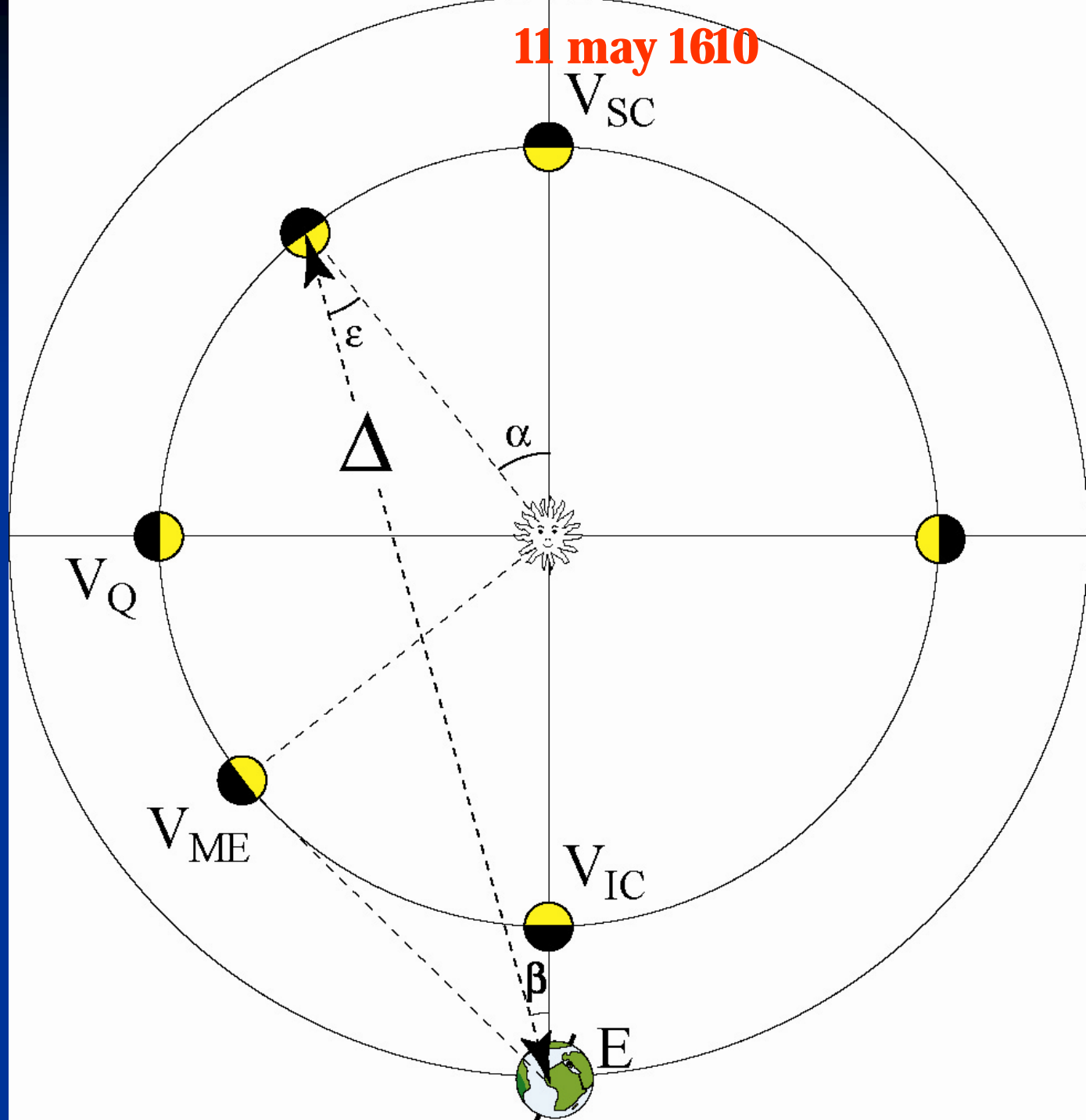
Venus imitates the phases of the moon

# Periods of Venus, dates of quadrature and conjunctions

- The synodic period of Venus is 584 days
- The superior conjunction occurred on 11 May 1610.
- Calculate the date of the quadrature, of the inferior conjunction and of the next superior conjunction, supposing the motions of the Earth and Venus are circular and uniform.



Periods of  
Venus:  
quadrature  
conjunctions



# Periods of Venus, dates of quadrature and conjunctions

- 1) Quadrature ( $\alpha=90^\circ$ ) 11 may 1610+146 days : 4 october 1610
  - Inferior conjunction ( $\alpha=180^\circ$ ) 11 may 1610+292 days : 28 february 1611
  - Superior conjunction ( $\alpha=360^\circ$ ) 11 may 1610+584 days : 11 may 1611+219=16 december 1611
  - In fact the real dates are a bit different
    - 11 may 1610 superior conjunction
    - 26 february 1611 inferior conjunction
    - 11 december 1611 superior conjunction
- because the Earth and Venus don't move with a circular uniform motion

# Sidereal period of Venus : $T_{\text{Venus}}$

- angular velocities :  $\omega$

$$\omega_{\text{syn Venus}} = \omega_{\text{Venus}} - \omega_{\text{Earth}}$$

- $\omega_{\text{Venus}} = \omega_{\text{syn Venus}} + \omega_{\text{Earth}} = 2\pi/584 + 2\pi/365.25 = 2\pi/T_{\text{Venus}}$

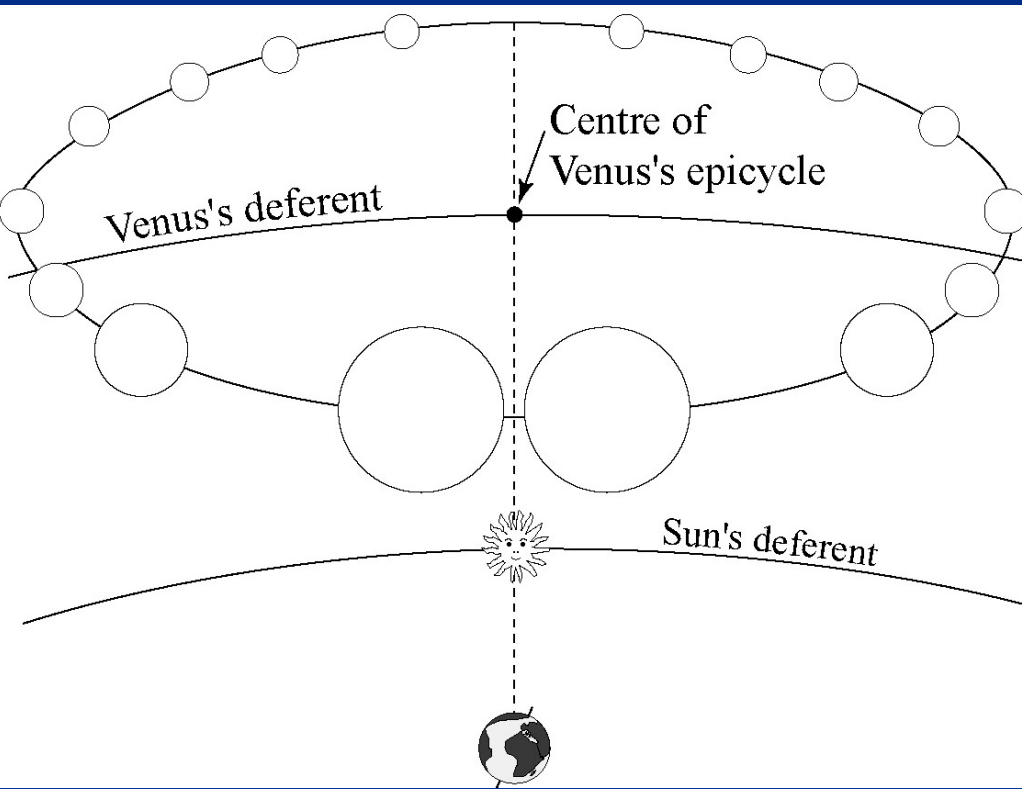
- $T_{\text{Venus}} = 365.25 * 584 / (584 + 365.25) = 224.7$  jours

# Phases on Venus in geo and heliocentric models

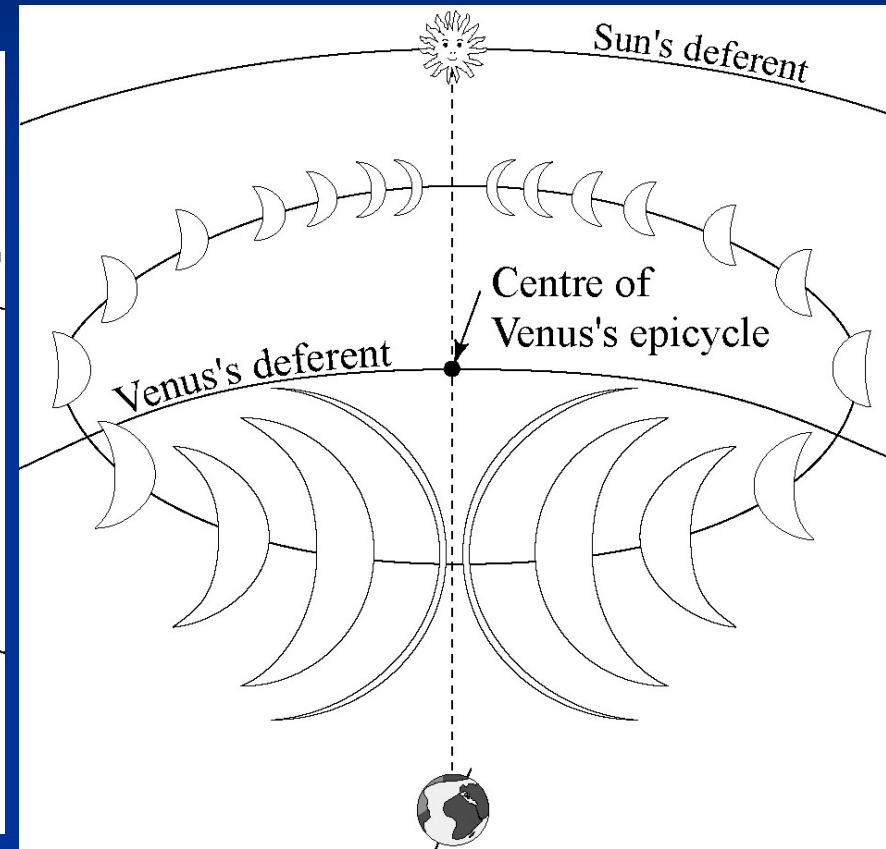
- 1) Determine the phases of Venus in geocentric models, where the Earth is at the center of the universe and planets orbit around (Venus “above” or “below” the sun)
  - Pseudo-Aristoteles model : Earth (center)-Moon-Sun-Mercury-Venus-Mars-Jupiter-Saturne
  - Ptolemeo’s model : Earth (center)-Moon-Mercury-Venus-Sun-Mars-Jupiter-Saturne
  
- 2) Determine the phases of Venus in the heliocentric model, where planets orbit around the sun.
  - Copernican system : Sun (center)-Mercury-Venus-Earth-Mars-Jupiter-Saturne



# Phases on Venus in geocentric models

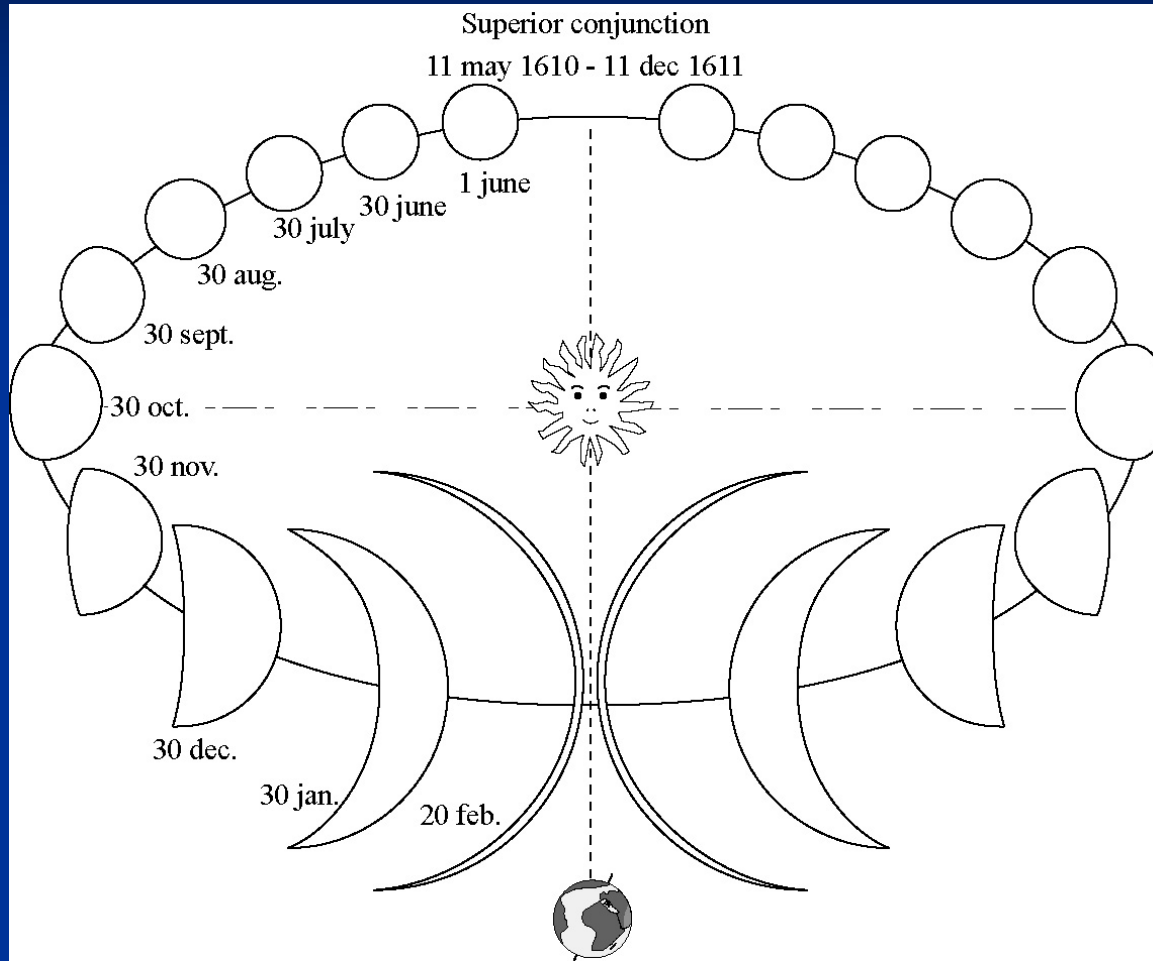


Pseudo-Aristoteles model

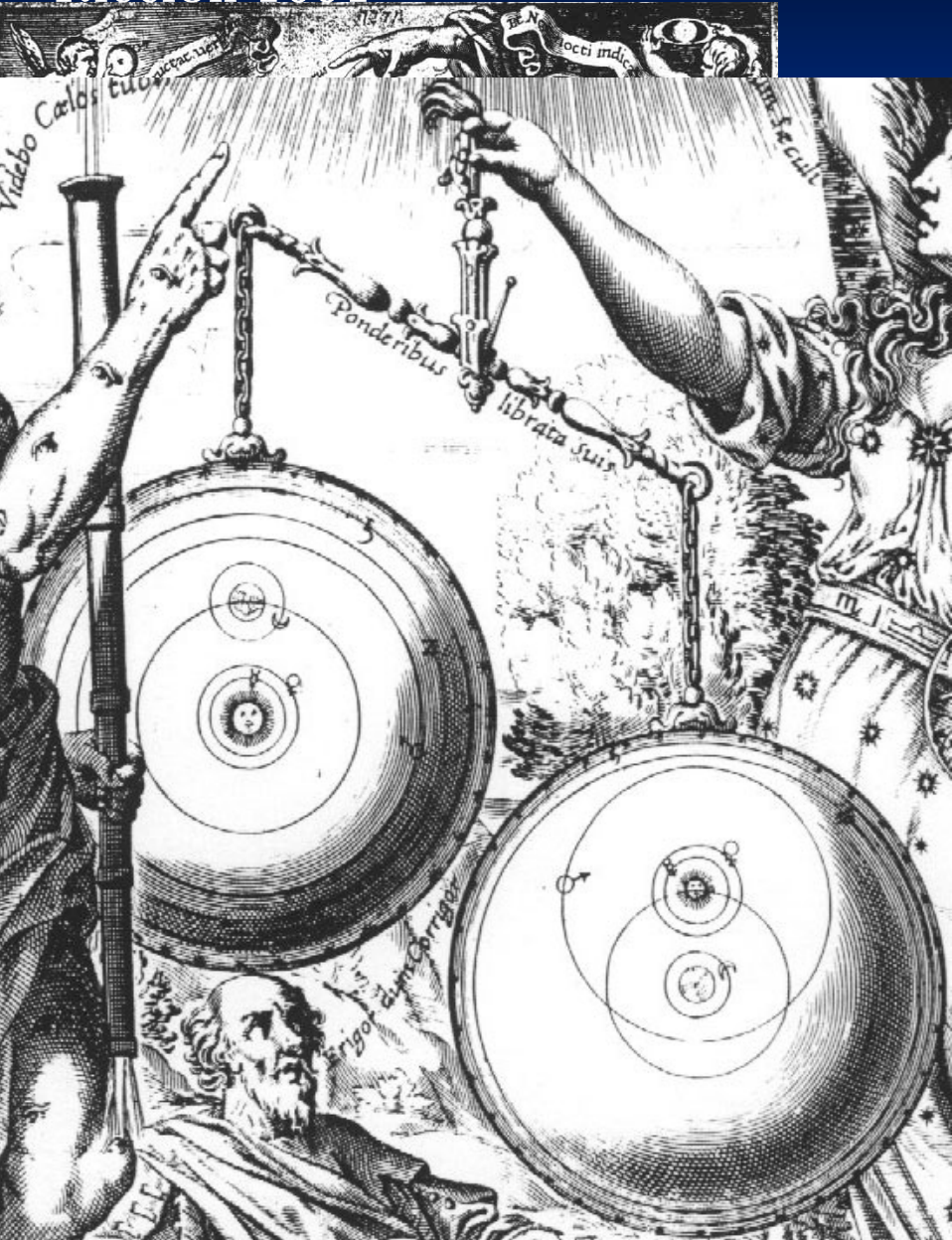


Ptolemy's model

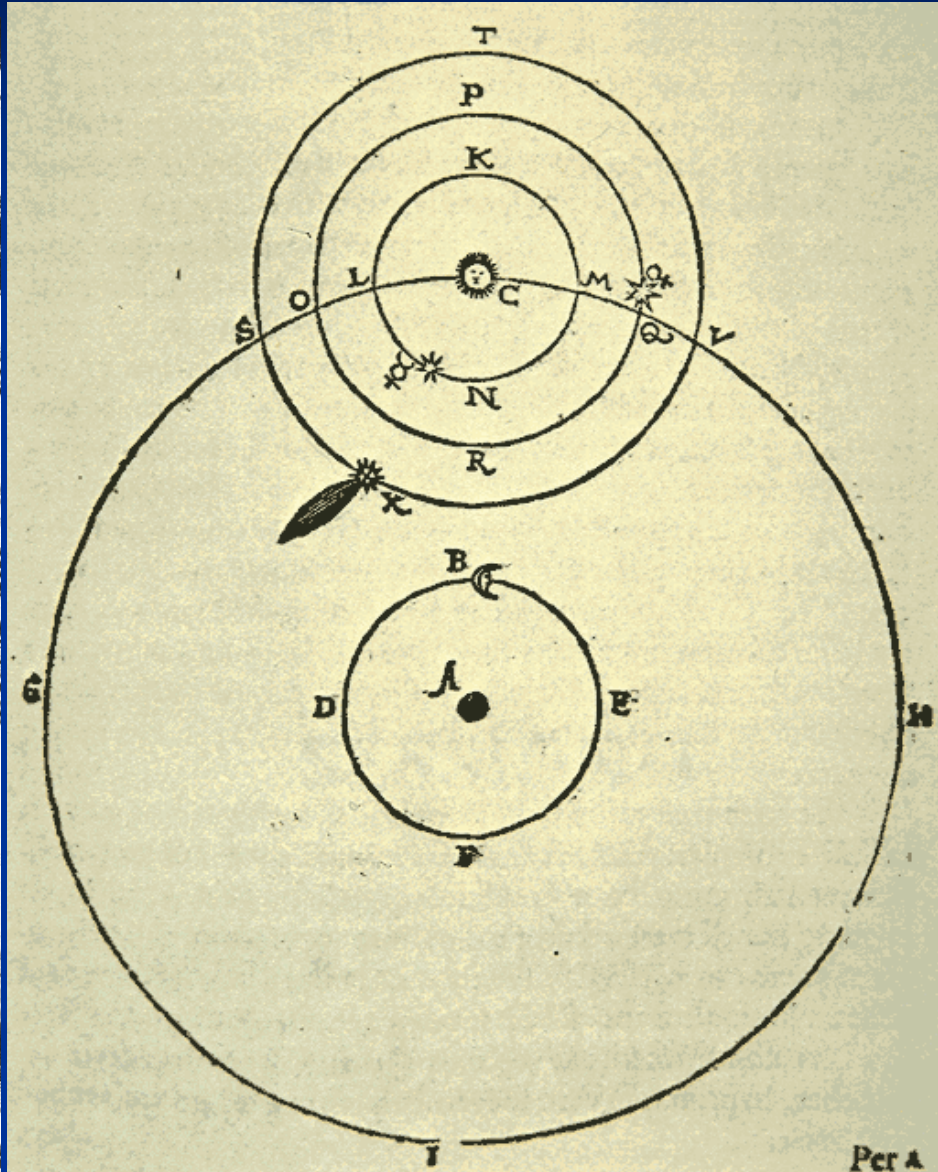
# Phases on Venus in the heliocentric model



Almagestum novum  
Riccioli 1651



# Tychonic model





# Distances Venus-Earth and angular diameters

- Data : Venus's diameter : 12 100km  
Jupiter's diameter 143 000km  
Earth-Sun = 1 a.u.= 150 000Mkm  
Venus-Sun = 0.723 a.u.      Jupiter-Sun=5.2 a.u.
- **Maximum elongation**  
What is the date of the greatest elongation of Venus (angle  $\beta$ )  
Why is the elongation not equal to  $0^\circ$  at the inferior conjunction ( $8^\circ$  in 1610)?
- **Distances**  
-Calculate the distances  $D$  Earth-Venus and the apparent diameters of Venus at the conjunctions VSC and VIC and at the greatest elongation VME  
-Compare to the apparent diameter of Jupiter at the opposition



# Maximum elongation

$$\text{TVS} = 90^\circ$$

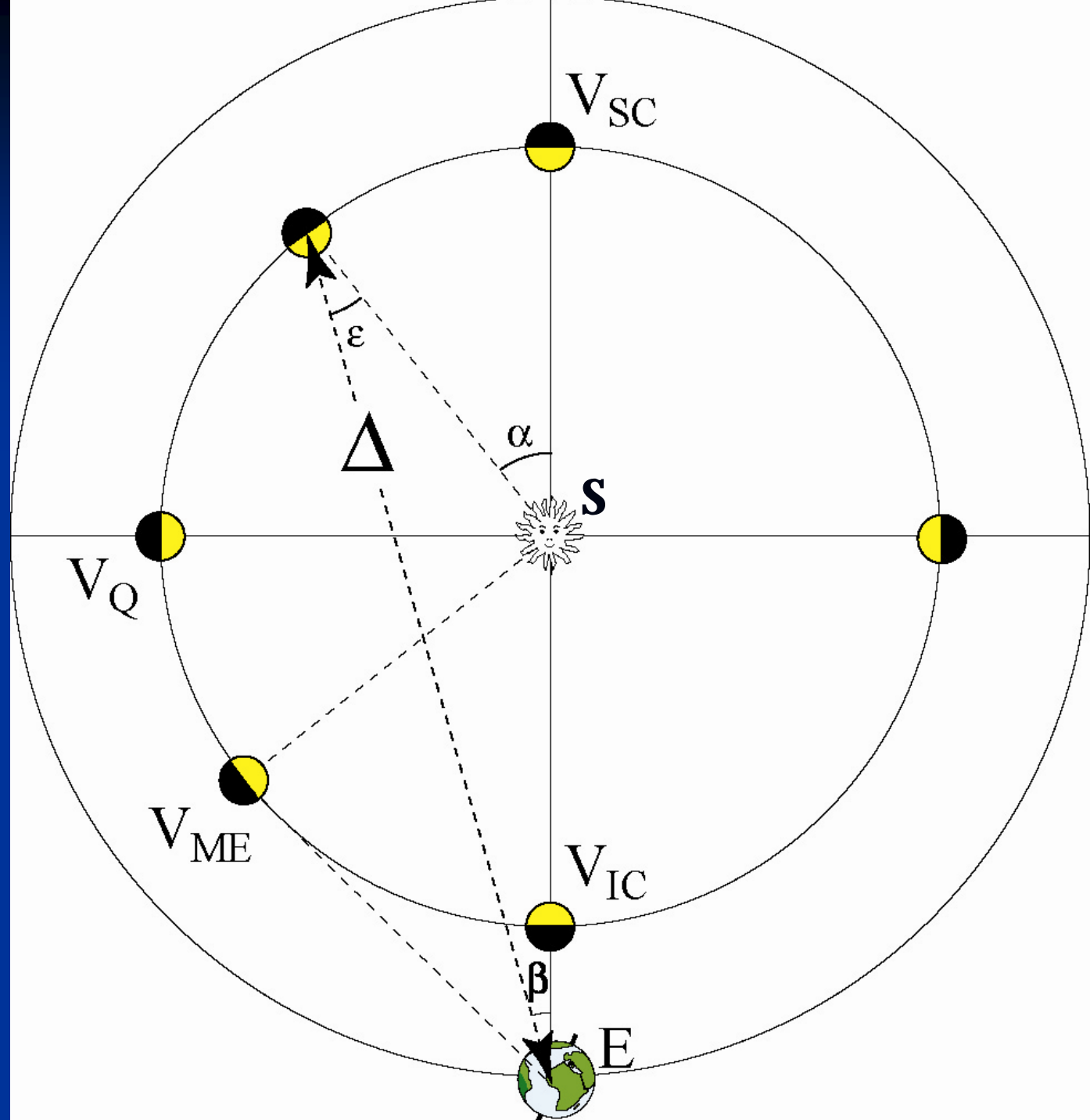
$\Delta = \dots$

$\beta =$

$\alpha =$

$t =$

Date =



# Maximum elongation

$$TVS=90^\circ$$

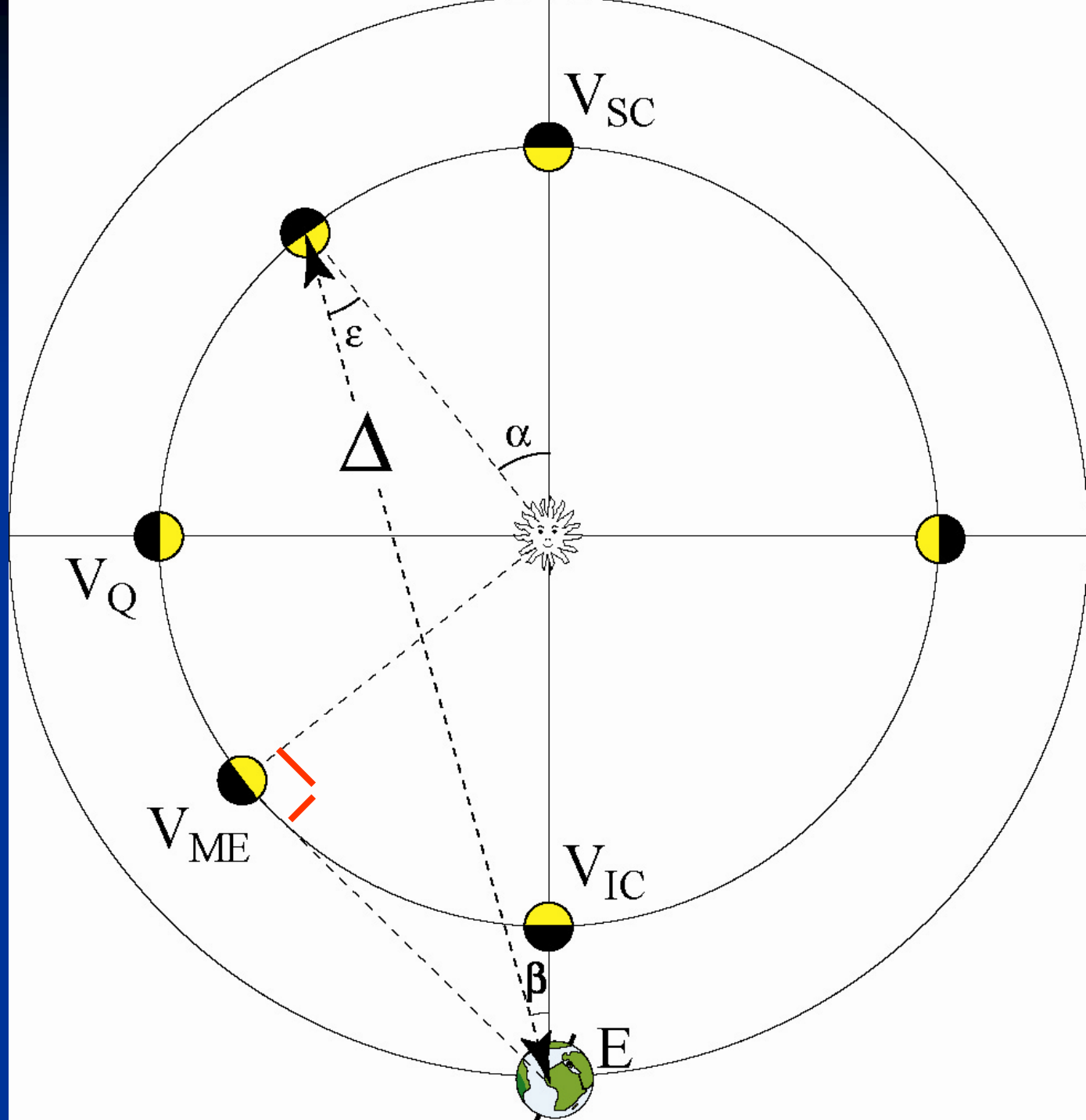
$$\Delta=0.69\text{a.u.}$$

$$\beta=46.33^\circ$$

$$\alpha=136.33^\circ$$

t=221 days

18 december



# Elongations and distances

Date of the greatest elongation : 18 december

- The real greatest elongation occurred on 16 december 1610. Our model is a 2D model for a 3D phenomenon, and the real motions are neither circular nor uniform.
- Elongation= $8^\circ$  on inferior conjunction because Venus and Earth don't orbit on the same plane. The elongation is  $0^\circ$  only when a transit occurs (ecliptic latitude of Venus= $0^\circ$ )

# Elongations and distances

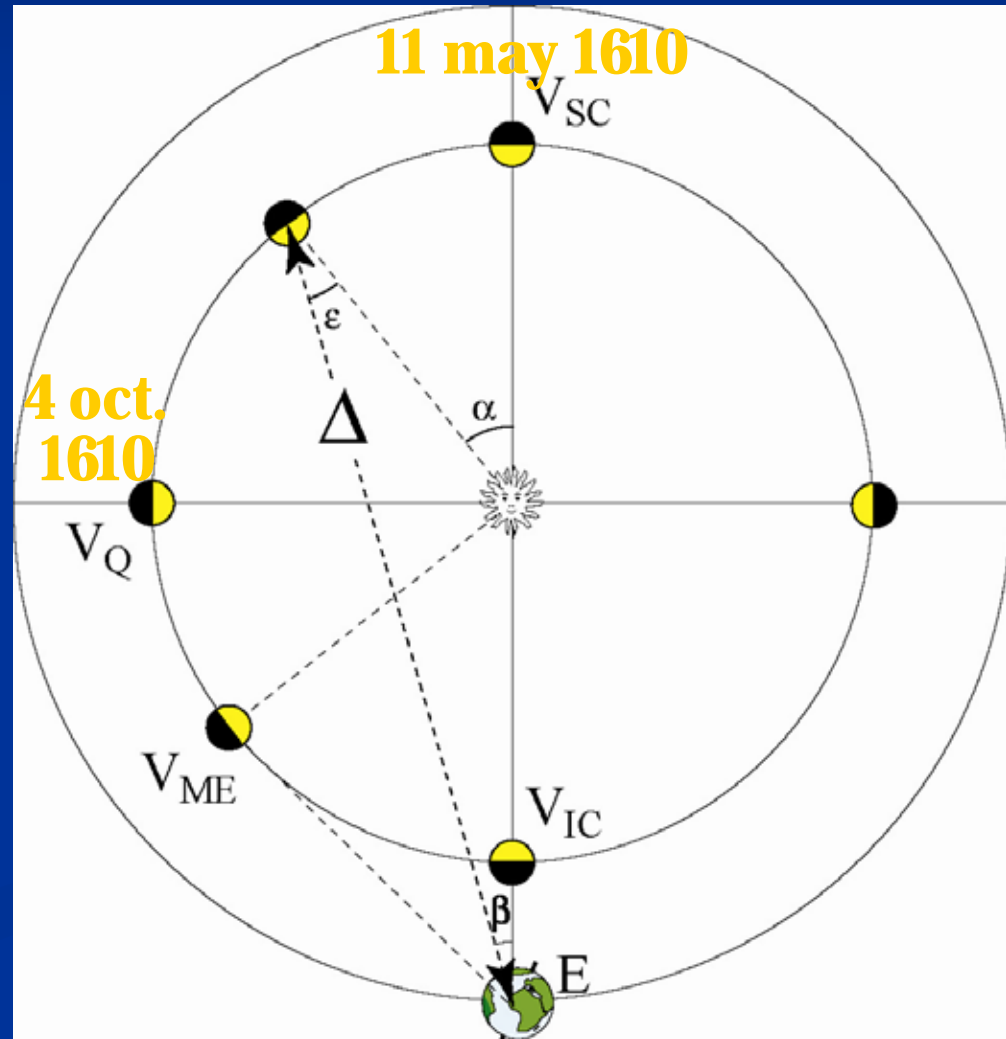
	Sup. conjunction	Max elongation	Inf. conjunction	Jupiter opp.
Distances	1.723	0.69	0.277	4.2
Ang. (" of arc)	9.7"	24.1"	60.1"	46.8"



# Drawing of the terminator

Calculate the phase (angle  $\varepsilon$ ) of Venus on 15 september 1610

Draw the phase



# Drawing of the terminator

15 september = 127 days after sup. conj.

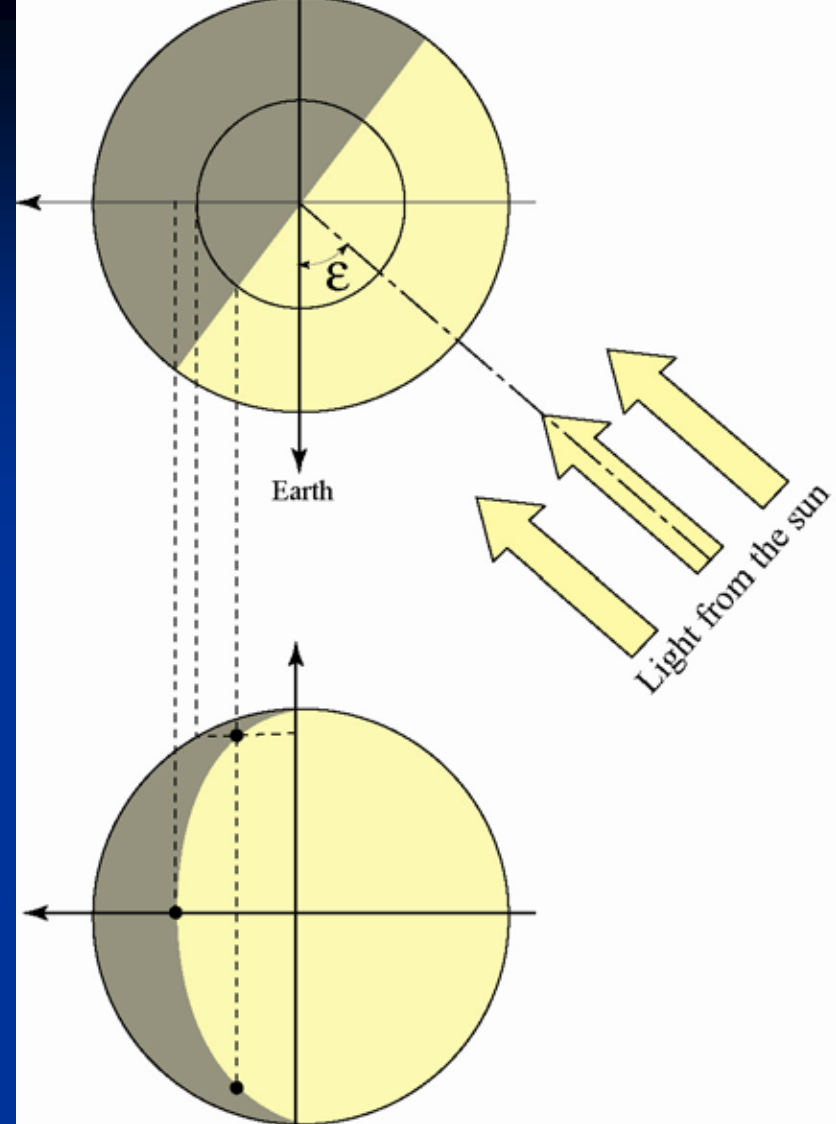
$$\alpha = 127 * 360 / 584 = 78.3^\circ$$

$$\Delta^2 = SE^2 + SV^2 - 2SE * SV \cos(TSV) = 1.314 \text{ a.u.}$$

$$\sin \epsilon / ES = \sin(180 - \alpha) / \Delta$$

Phase angle  $\epsilon = 49^\circ$

We can draw the phase



# Annexe

