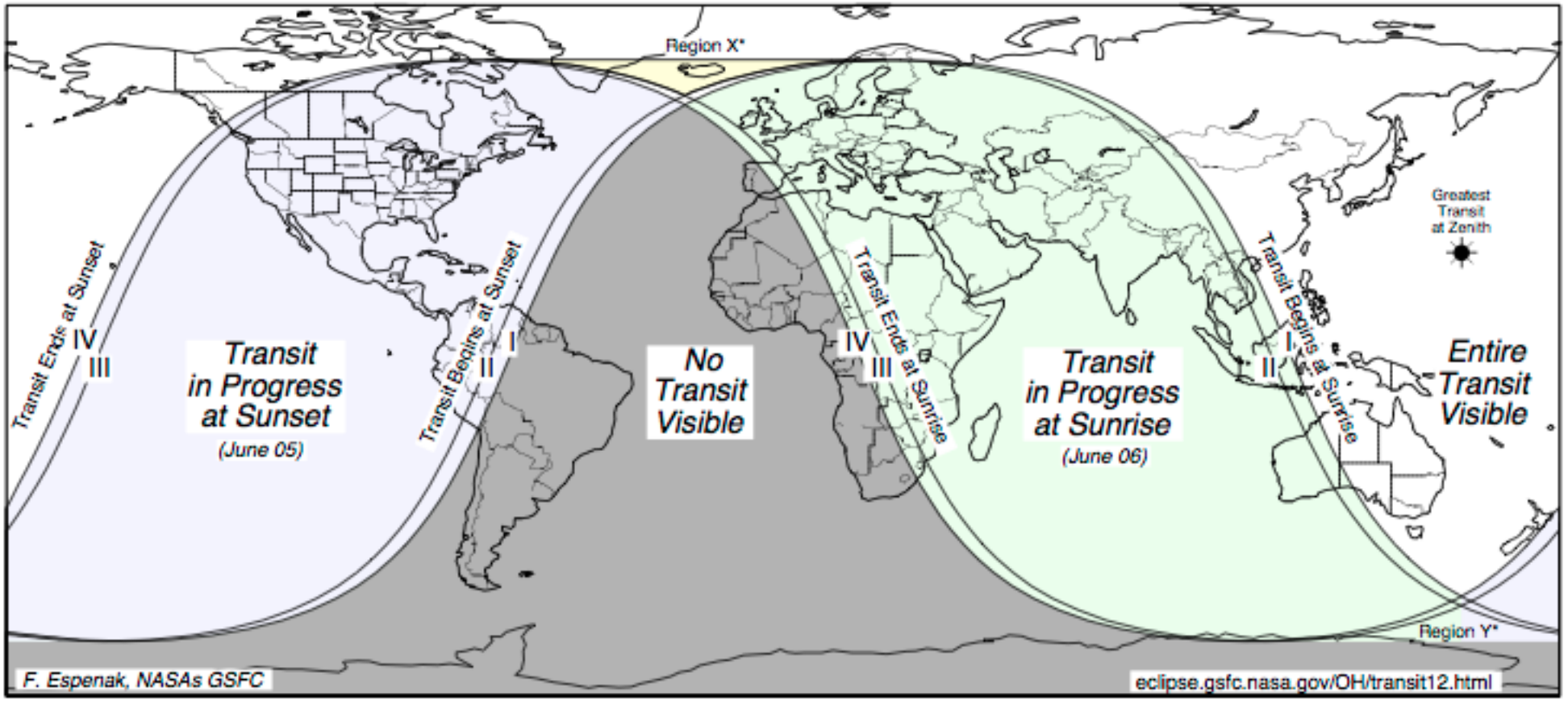

Venus in sole visa
Davor Krajnović

Global Visibility of the Transit of Venus of 2012 June 05/06



- Venus starts exiting the Sun disk (3rd contact): 06:37:40.7 am (CEST)
- All finished (4th contact): 06:55:10.1 (CEST)
- Sunrise: 05:15

Astronomical Almanac 2012

What is a Transit?

- Transit:
  - occurs when a body appears to move across the face of another body
  - The apparent size of the transiting body is SMALLER that the background object
- Occultation
  - Same as transit, but the body that transits occupies the most of the background body (or completely hides it)
  - The apparent size of the transiting body is LARGER that the background object
- Eclipse
  - When a body (partially) disappears during an occultation
  - Solar eclipse: Moon occults the Sun
  - Moon eclipse: Earth occults the Moon (Moon in the shadow of Earth)

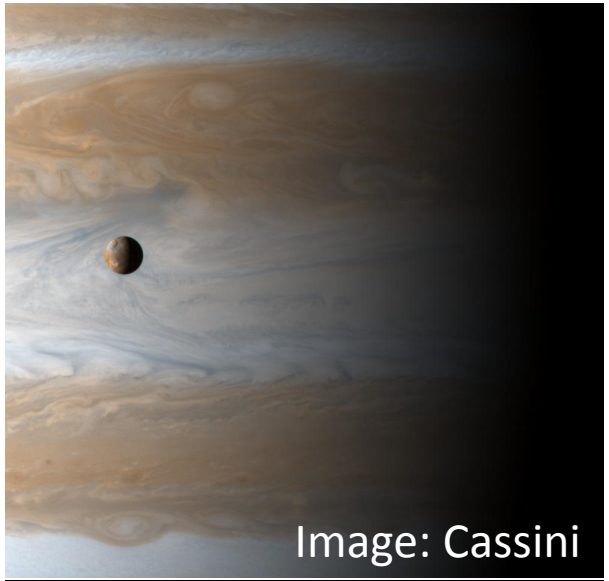
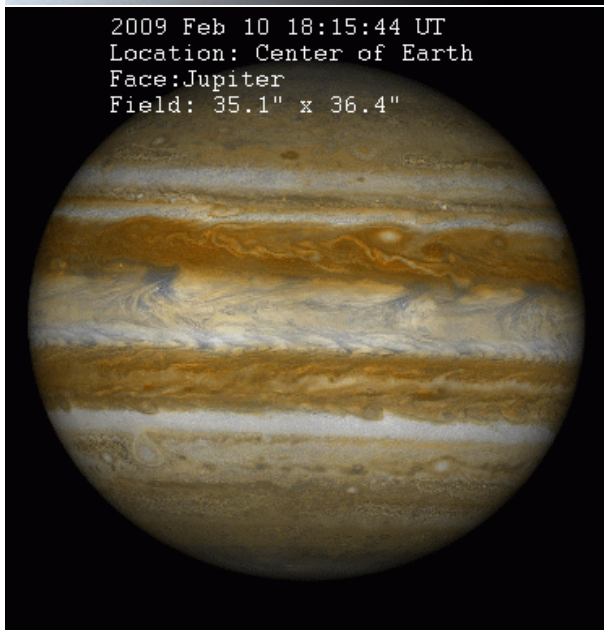


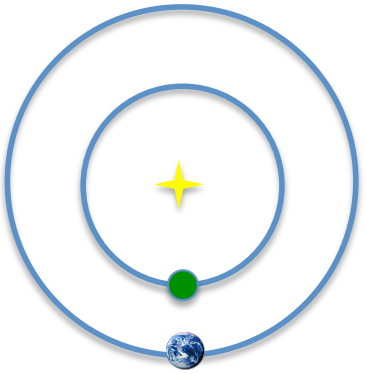
Image: Cassini



Source: wikipedia

Why isn't Venus in transit every year?

- Orbits of Earth and Venus!
  - Venus year: 224.7 days
  - Earth year: 365.256 days
  - 13 Venus years = 8 Earth years

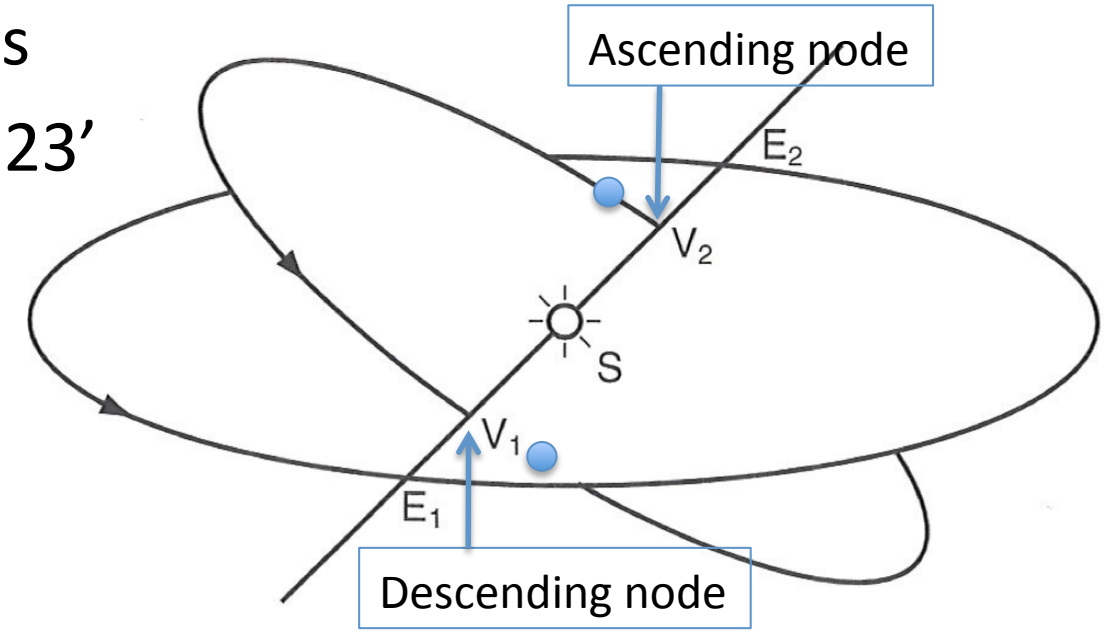


Inferior conjunction

- Synodic period = 583.9169 days
  - 5 x Synodic period = 2919.58 days
  - 8 x Earth year = 2922.05 days
  - Every 8 years Venus and Earth occupy nearly the same position in space (relative to fixed stars)
  - Difference: 2.46 days
  - ➔ every 8 years Venus is 22' further on its orbit

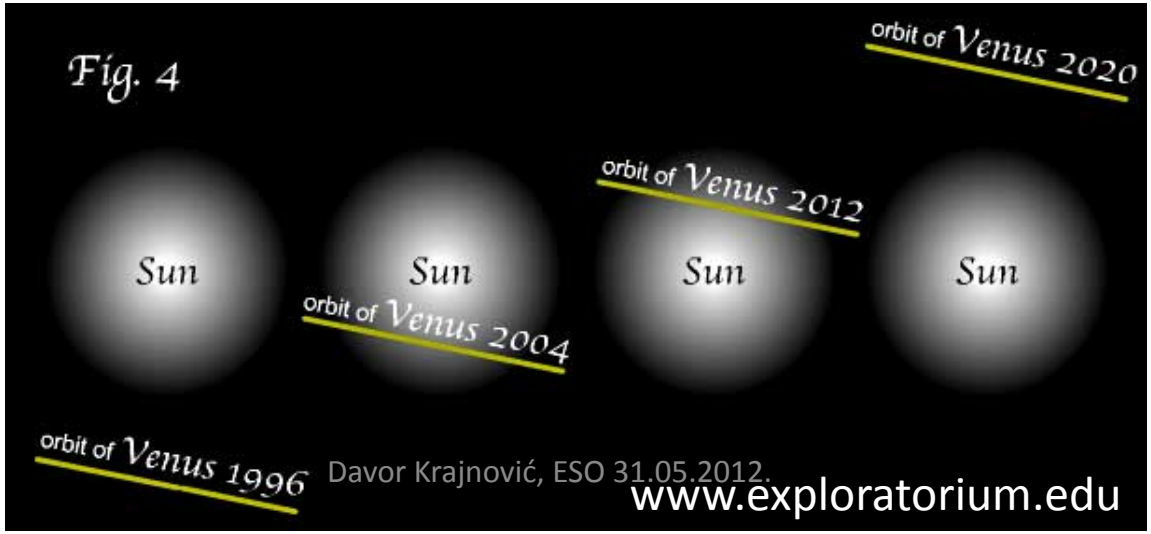
Why isn't Venus in transit every year?

- Transit occurs when Earth crosses the line of nodes at the same time as Venus
- Tilt of Venus orbit = 3° 23' wrt ecliptic
- Venus is
  - around 8 Dec at its ascending node
  - around 7 Jun at its descending node
- Venus is faster than Earth ➔ every 8 years Venus is 22' higher or lower in its orbit



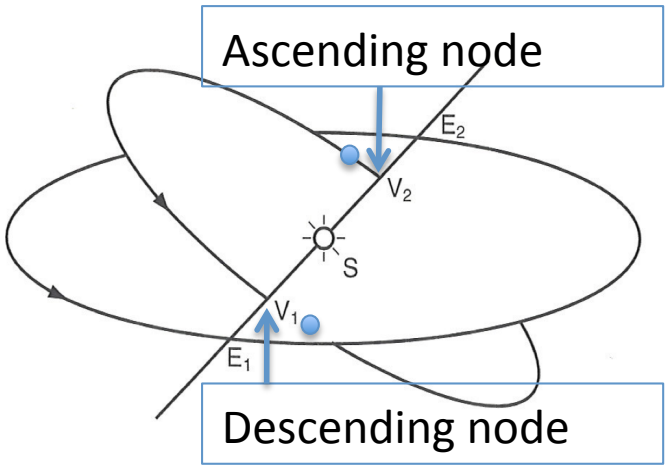
Will it happen?

- Assume that we see Venus in the middle of the Sun disc today
- Sun disc is 32’ in diameters
- In 8 years Venus will be 22’ above (or below) the point we see it today ➔ it will miss the Sun!!
- If it is closer to Solar limb ➔ it will cross it again!!
- Venus transit happen in pairs of 8 years (3x8 not possible!)



Complex, but periodic

- Earth's & Venus' paths are not circles, but ellipses
  - Speed changes a as function of position on the orbit
  - Distance to Sun (Sun's apparent size) changes
  - Gravitational influence of other planets…
- The present schedule:



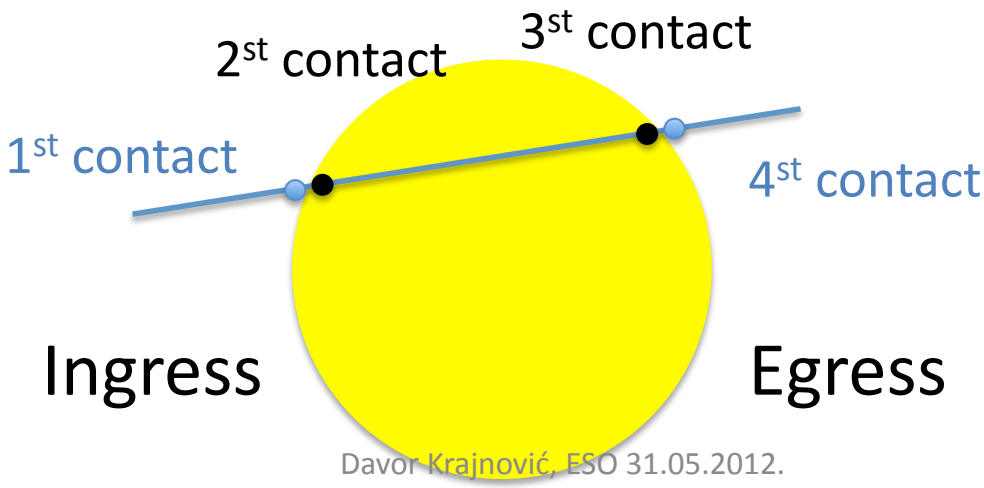
A	A		D	D		A	A		D	D		A
8		121.5		8	105.5		8	121.5		8	105.5	

243 243

Some other features

- Venus goes from East to West across the Sun
- June and December transits are not fixed to a date
  - Retrograde motion of Venus' line of nodes
  - Retrograde motion of Earth rotation axis (precession of the equinoxes)
  - ➔ 29.8" per year
  - during 243 period ➔ delay of ~2 days

7.12.1631	6.6.1761	9.12.1874	8.6.2004	11.12.2117	11.6.2247
4.12.1639	3.6.1769	6.12.1882	6.6.2012	8.12.2125	9.6.2255

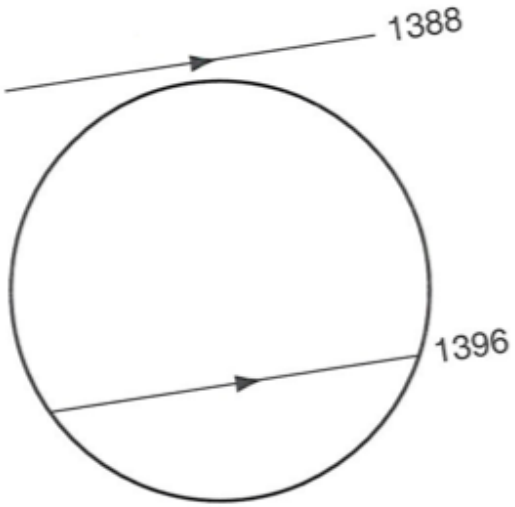


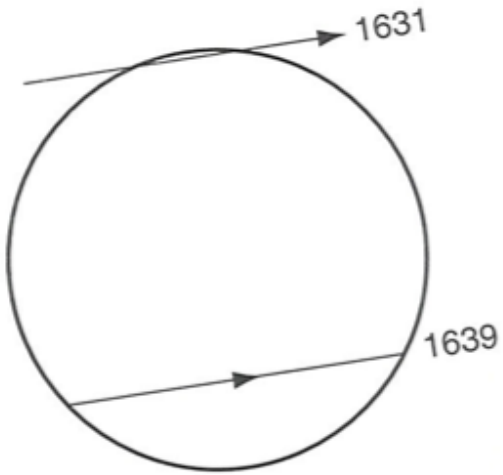
Transit of June 8, 2004

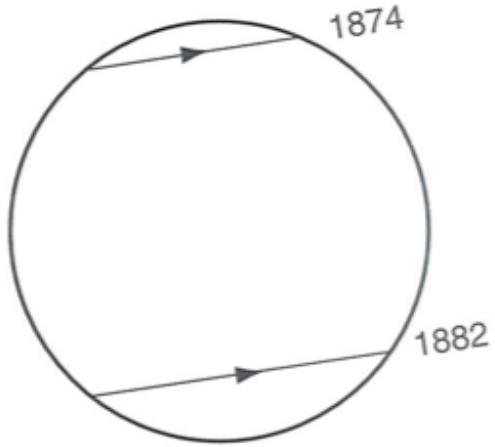
Davor Krajnović, ESO 31.05.2012.

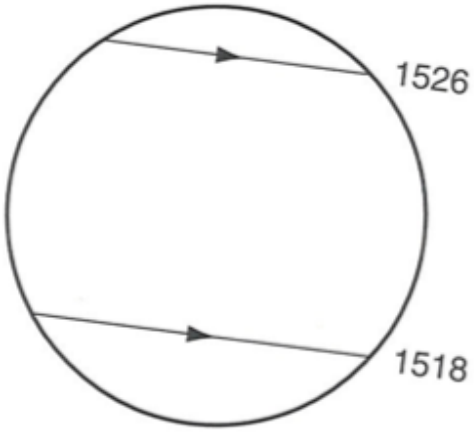
Portugal, movie by ESAC

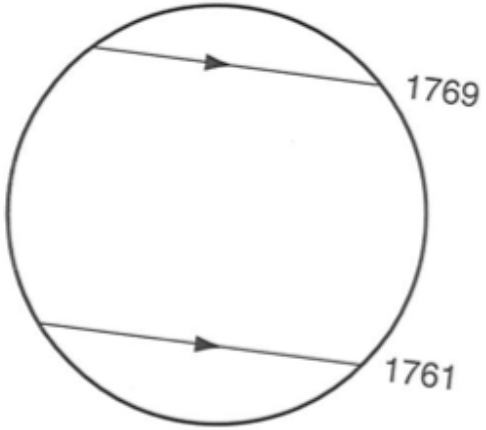
Past transits

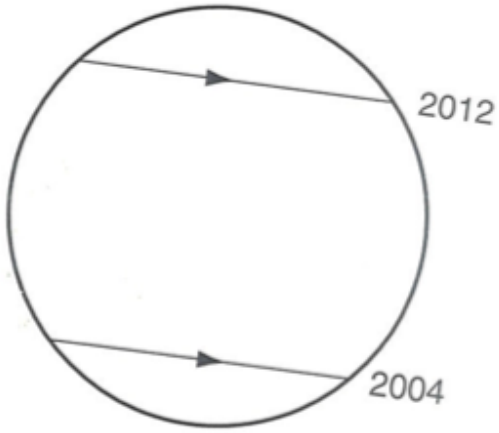








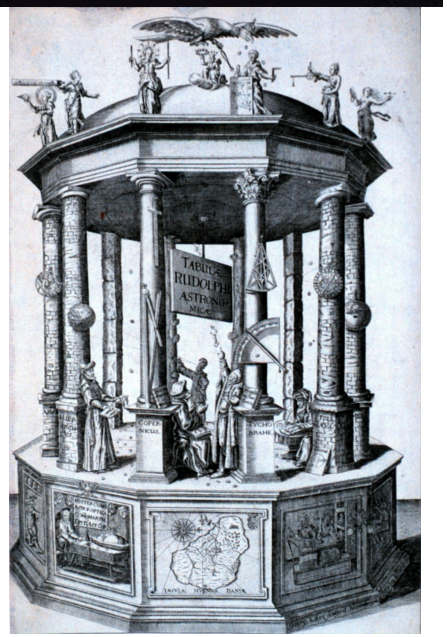




Meeus (1989), Maor (2000)

The prediction

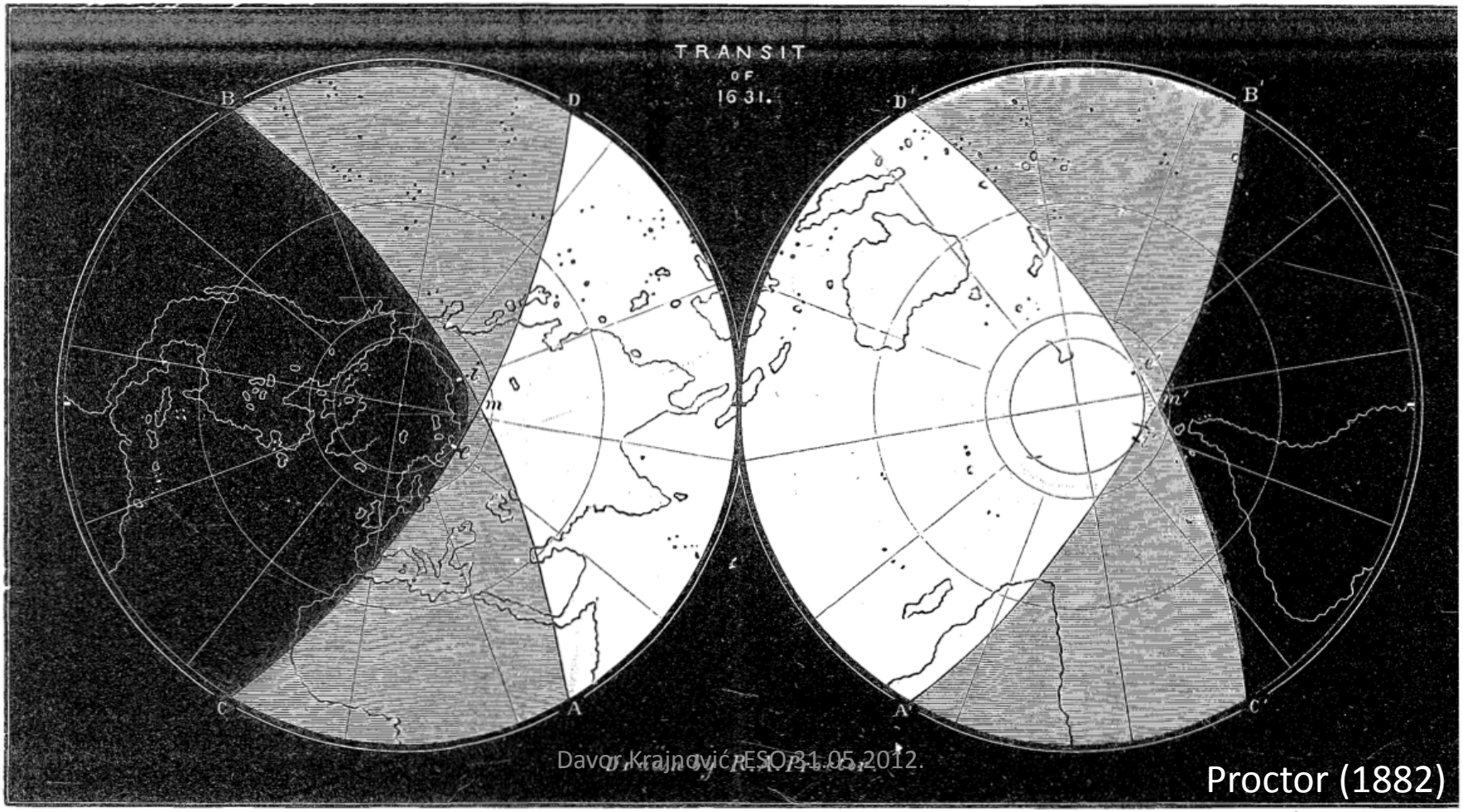
- Johannes Kepler (1571 – 1630): "Rudolphine tables", 1627
  - Astronomical rules for finding Sun, Moon, planets
  - 1000 star coordinates (Brache's observations)
  - Tables of logarithms
  - Geographical coordinates of major cities
- Two predictions:
  - Transit of Mercury: 7.11.1631
  - Transit of Venus: 6.12.1631



Front cover

The first attempt on Venus

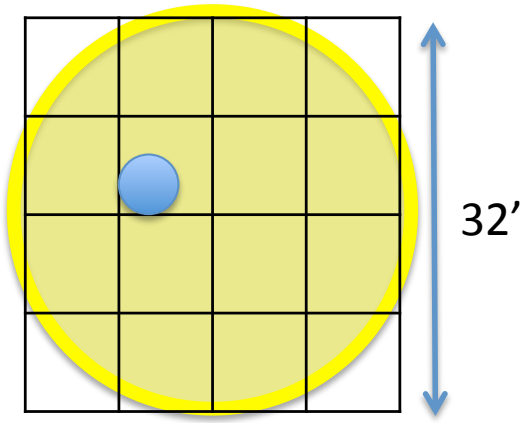
- Kepler predicted it would not be seen in Europe and issued a call “to mariner and learned men of the New World”



Proctor (1882)

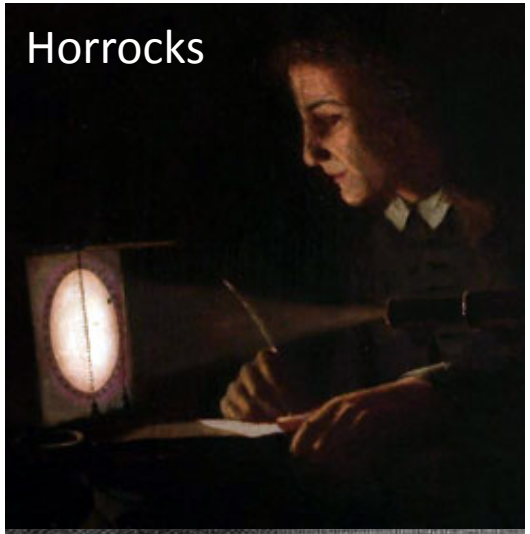
The first sighting of a transit

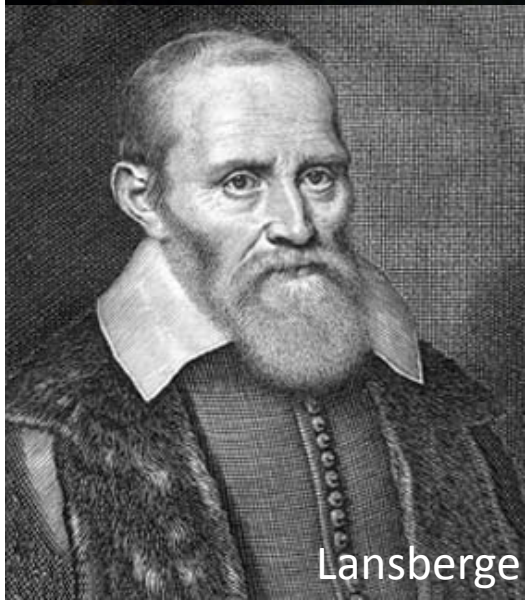
- 1631 transit of Venus is not recorded to be seen, but it was attempted
- Pierre Gassendi (1592-1655)
  - prepared for the transit of Venus, but it was cloudy from 4-6.12 and clear on 7.12 (too late)
  - "successfully" observed transit of Mercury in 1631
  - Through clouds: saw a dot on Sun, clouds came and went, the dot moved!!
  - measured apparent size of Mercury: 20"
  - Attempted to measure times of ingress and egress, but no good clocks available (used position of the Sun)



Unexpected second chance!

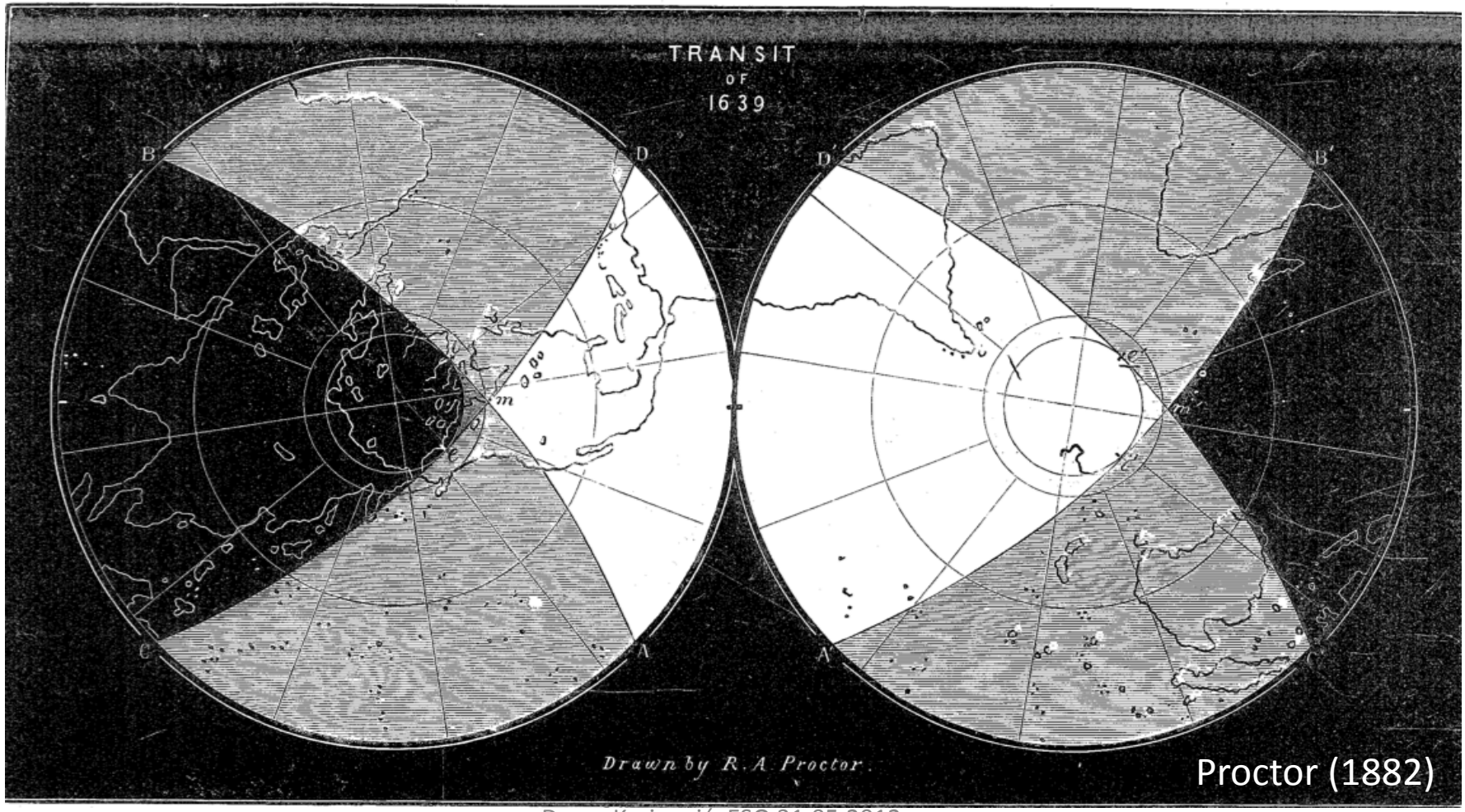
- Jeremiah Horrocks (1618-1641)
  - expert in Keplers theory of elliptical orbits (calculated the correct orbit of the Moon)
  - examined Rudolphine tables and calculated* that another transit will happen on 04.12.1639.
  - Confirmed using Lansberge tables (actually much worse than Rudolphine tables)





* Apparently it took him 3 years to calculate this, completed a month before the transit!

Visibility of the 1639 transit



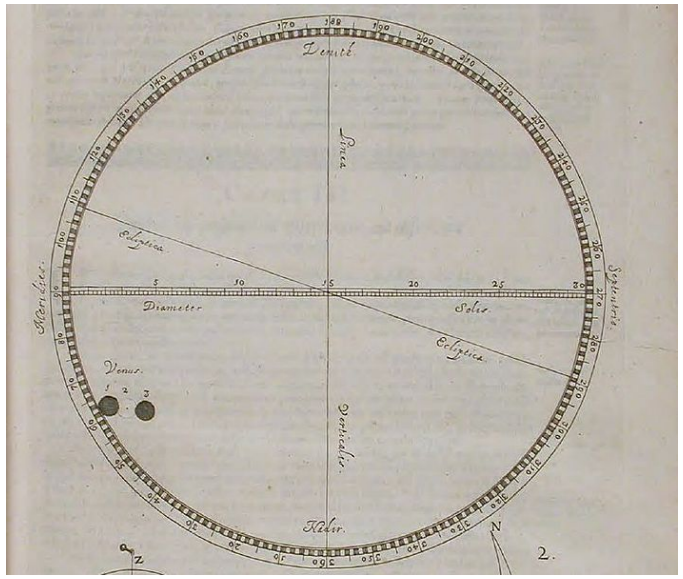
Proctor (1882)

Venus - ho!

- Horrocks' prediction: Venus transits on 04.12.1639
- Stared observing on 03.12.
- December 4, Sunday, Much Hoole
  - Observed since 10:00, cloudy
  - At 13:00 interrupted by "business of the highest importance"
  - Resumed observations at 15:15
    - No clouds at all
    - Venus on the Sun disc!
  - Sun set at 15:50
- Science:
  - Venus apparent size: ~1' (much smaller than thought)
  - Confirmation of Kepler laws
- Died just after completing "*Venus in Sole Visa*"
- Publication of the results in 1662 by Johannes Hevelius as an Appendix to his book: "*Mercurius in Sole Visus Gedani*"

Carr House where Horrocks observed (?) the 1639 transit

What Horrocks saw (by Hevelius)

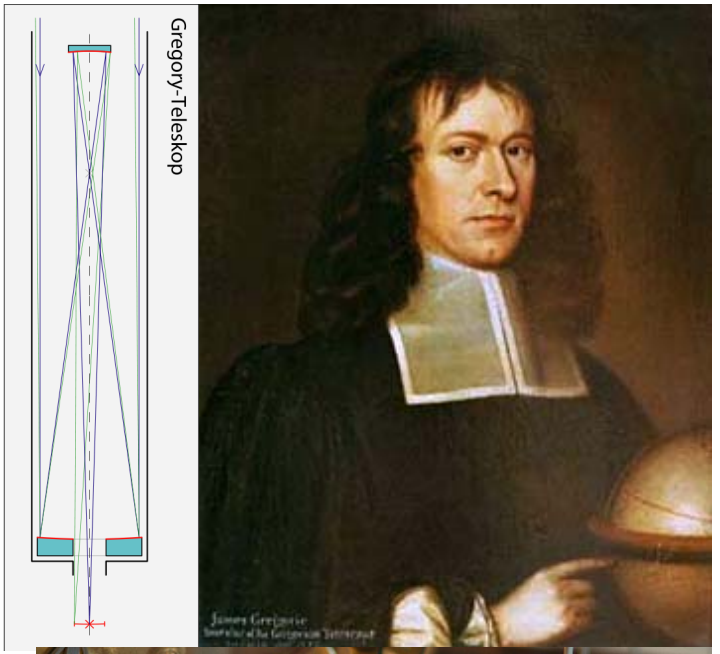


Only two men saw it!

- William Crabtree (1610-1644)
- December 4, Sunday, Manchester
  - Cloudy
  - 15:35 clouds disperse, Venus in sight!
  - Awestruck; recorded only a few observations

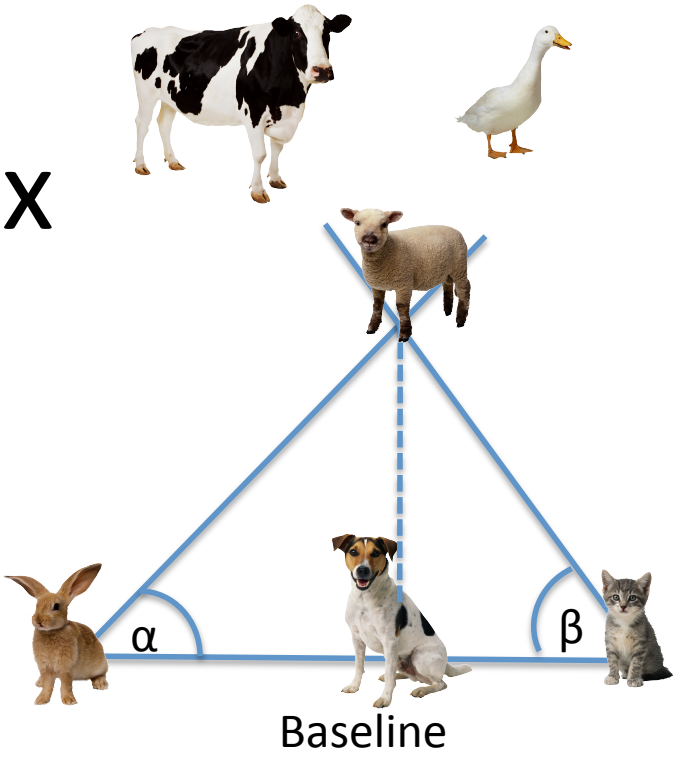
The measure of the Universe

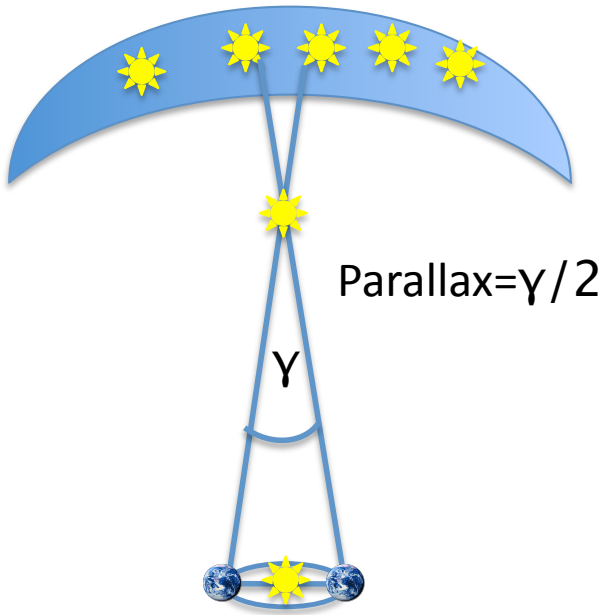
- James Gregory (1638-1675)
- Optica Promota (1663)
  - suggested that transits of Venus or Mercury could be used to determine the **parallax of the Sun**
  - The Holly Grail of astronomy (and cosmology) – **DISTANCE**
  - Period squared is proportional to distance cubed: $P^2 \sim a^3$ (Kepler, 1616): $P^2_{Earth}/a^3_{Earth} = P^2_{planet}/a^3_{planet}$



The method of parallax

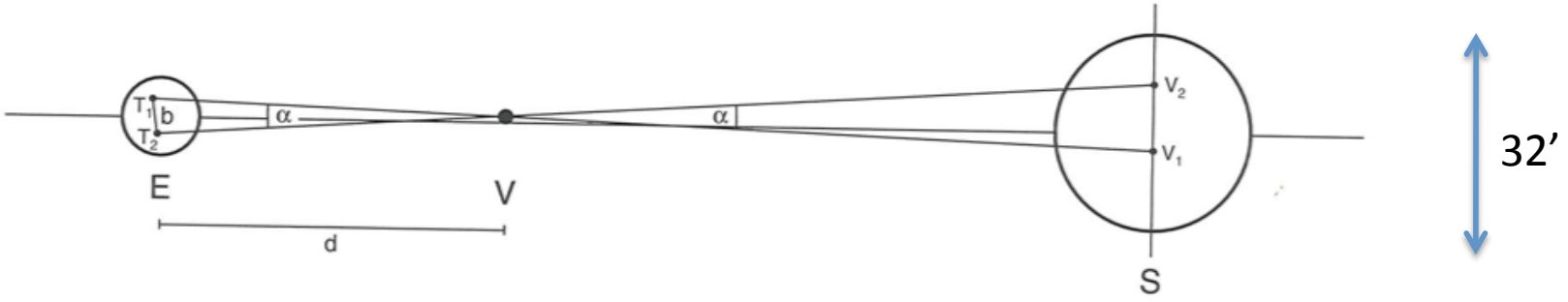
- Used to measure the distance, from knowing angles in a triangle
- In astronomy: parallax = distance
- 1 parsec = distance to a star whose annual parallax is 1”
- Better accuracy for longer base line
- Hipparchus used Istanbul - Alexandria distance (~1000 km) to measure the parallax of the Moon
- Diameter of the Earth’s orbit: parallax of stars (Bessel 1838 – 61 Cygni – 0.28”)
- Diameter of Earth ~ 12000km
  - long enough to get the **parallax of the Sun** (or the distance Earth-Sun)
  - but can’t see background!
  - can we use something else?





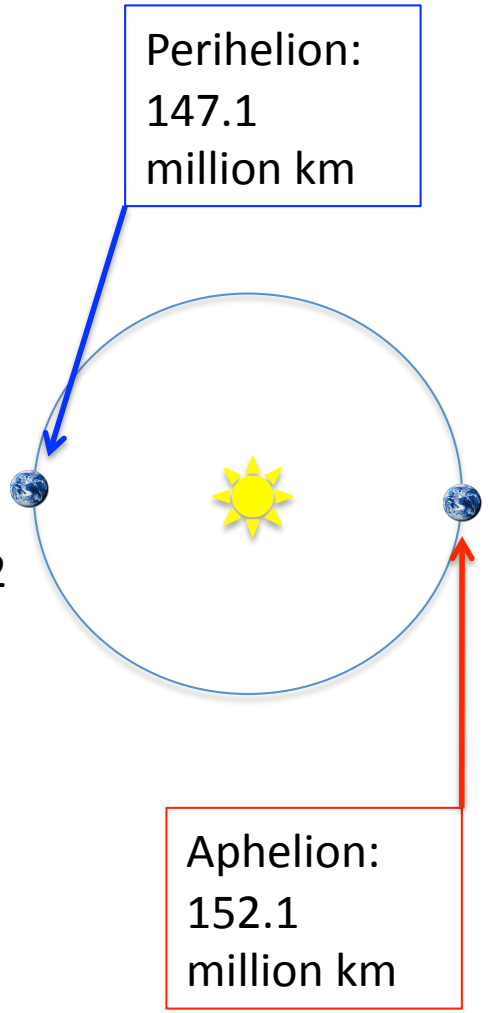
Solar parallax via parallax of Venus

- Send one astronomer to a place T_1
- Send another astronomer to a place T_2
- Let them measure the respective positions of Venus on the solar disc V_1 and V_2
- Compare with the diameter of the Sun to get α (knowing b) ➔ d
- From d and Kepler's 3rd law: distance to the Sun: **astronomical unit**
- Simple but:
  - Simultaneous observations needed!
  - Hm…. XVIII century



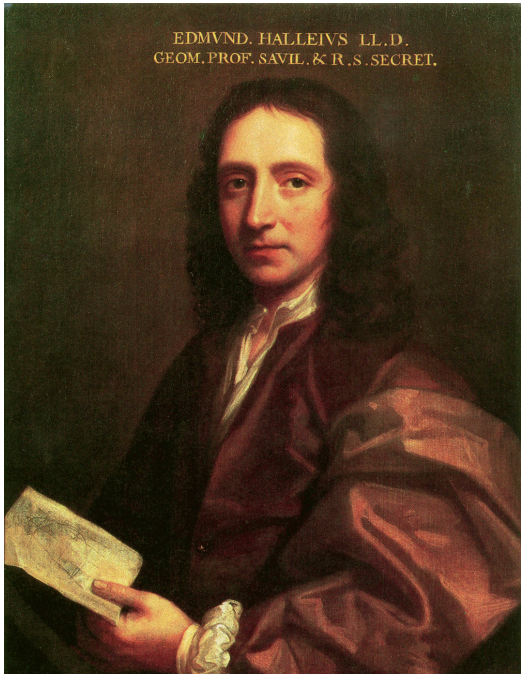
Astronomical Unit

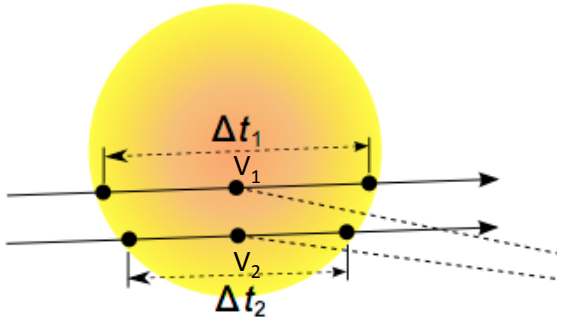
- Originally defined as the length of the semi-major axis of the Earth's elliptical orbit around the Sun
- Today (IAU 1976 Grenoble): "The astronomical unit of length is that length (AU) for which the Gaussian gravitational constant (k) takes the value k=0.017 202 098 95 when the units of measurement are – the astronomical units of length, mass and time."
- k = √(GM), in the system where **mass** is in solar masses, **time** in mean solar day, and **length** is an AU.
- Alternatively: radius of a circular orbit around the Sun of a mass-less particle moving at an angular frequency of 0.017 202 098 95 radians per day, or a period of 365.2568983 days (known as a Gaussian year)
- Equivalent to 149 597 870 km
- Radar measurements or telemetry from space probes (to inner planets)
- **1 AU = 149 597 870.691 ± 0.03 km**
- Solar parallax: **8.794148** seconds of arc



Halley's method

- Edmond Halley (1656-1742)
  - Fellow of the Royal Society, Savillian Professor of Geometry, Astronomer Royal, Captain of the Royal Navy…
- Proposed a new method
  - *Methodus Singularis Qua Solis Parallaxis Sive Distantia a Terra, ope Veneris intra Solem Consipiciendoe, Tuto Determinari Poterit: Proposita Coram Regia Societate ab Edm. Halleio J.U.D. Ejusdem Societatis Secretario*, Phil. Trans., Vol. 29, 454, 1714-1716.
  - Instead of angle, let's measure the **duration** of the passage
  - Send astronomers to T_1 and T_2
  - Let them measure the durations of transit Δt_1 & Δt_2
  - Different durations ➔ different path lengths
  - Circle geometry ➔ angular distance between V_1 and V_2 = Venus Parallax
- Halley estimated accuracy of 1 sec or 1/500 for the distance





Delisle's improvement

- Joseph Nicolas Delisle (1688 – 1768)
- Improvement (1743):
  - (only) record the timing of the ingress and/or egress (t_{1i}, t_{2i}), (t_{1e}, t_{2e})
  - $t_{1i} - t_{2i} \sim \Delta t_1 - \Delta t_2$
  - easier to measure (less dependant on weather) + partial sites also included
- Halley: call for action
- Delisle: spiritus movens:
  - Mobilised and prepared the scientific community
  - Produced the Mappemonde for 1761 transit

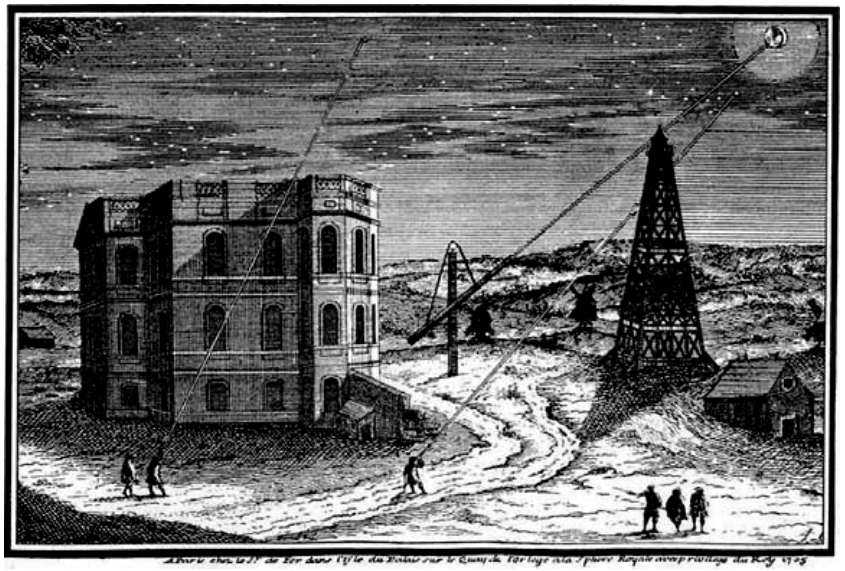
An astronomical challenge

- Challenges:
  - **Longitudes** are not well known and difficult to determine
  - **Clocks** are only partially good time keepers
  - **Travelling** is very expensive and very long
  - Only 1 previous transit recorded!
- Results can be achieved only via organised scientific expeditions
- Role for the learned societies

H4 – Harrison Chronometer 1759.
Affordable chronometers from 1783.

Change of World

- Many things happen in 120 years
- Science became a respectable occupation (for those who could afford it)
- Scientists considered as useful people
- Paris Observatory (1667)
- Greenwich Observatory (1675)
- Leopoldina (1652)
- Royal society (1660)
- Académie des Sciences (1666)
- The Republic of Letters
- The spirit of the Enlightenment
  - There is interest (to spend money) for understanding natural phenomena
  - There is a conviction the natural world can be explained



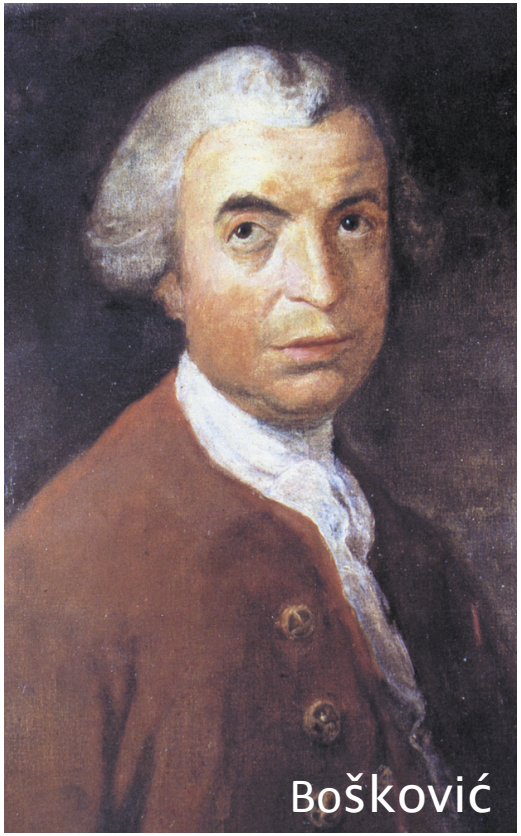
Paris (above) and Greenwich (bellow) Observatories

The French

- Local observations:
  - Paris Observatory – Maraldi
  - Palais du Luxembourg –Lalande
  - Observatoire de l'Ecole Militaire – Jeaurat
  - Observatoire de la marine - Messier
  - Hote de Cluny – Lemonnier/La Condamine + Louis XV
- Académie des Sciences – several expeditions
  - Chappe d'Auteroche – Tobolsk
  - Pingré– Rodrigues Island
  - Le Gentil de la Galaisiere – Indian Ocean
  - Cassini de Thury – Vianna, Austria

The British

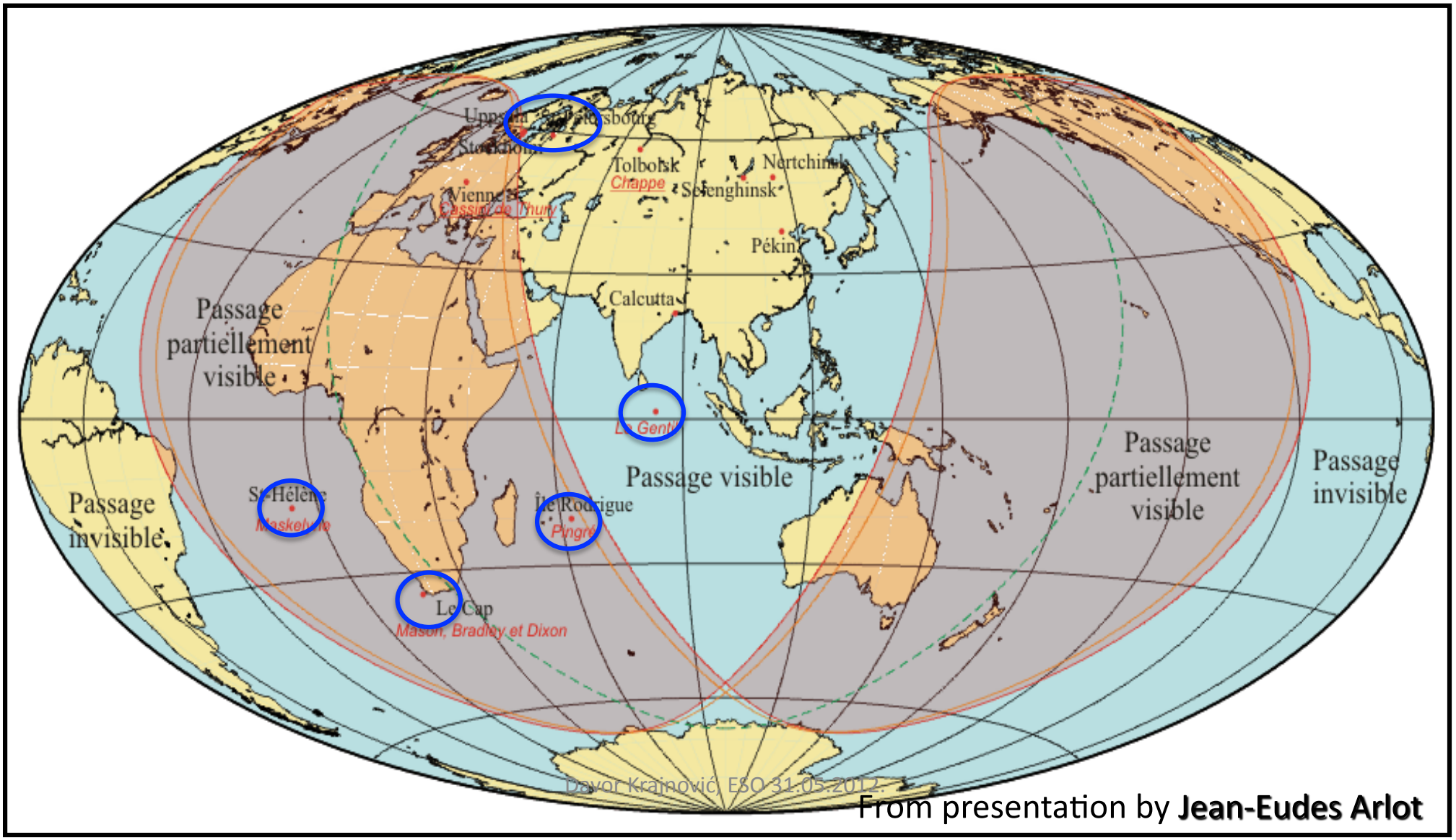
- Hm…. Not really prepared
- On June 19. 1760 a paper was read by a visiting Jesuit (a Croatian!) at the Royal Society: R. Boscovich, *De Proximo Veneris Transitu* (Phil. Trans. 1759, 51, 865)
- His points why should RS organise expeditions:
  - (Measurement of the solar parallax)
  - Its famous member (Halley) devised the method
  - England is the best in making astronomical instruments
  - English astronomers always made significant discoveries
  - French are preparing several expeditions and English shouldn't be left behind!
- He brought the Delisle's Mappemonde
- Action:
  - Nevil Maskelyne – St. Helena
  - Charles Mason & Jeremiah Dixon – Sumatra
  - Several local observations


Bošković

The seven years war (1756-1763)

- Global conflict between Britain and France

Observations of 1761



From presentation by **Jean-Eudes Arlot**

Pingré

- Alexandre – Gui Pingré (1711-1796)
  - Rodrigues Island
  - Rain and clouds, windy
  - No useful observations!
  - While on Rodrigues: island twice sacked by British
  - On the way home: attacked and captured by a British warship which dropped him off in Lisbon
  - His conclusion: "*Liquor gives us the necessary strength for determining the distance of the Earth from the Sun.*"

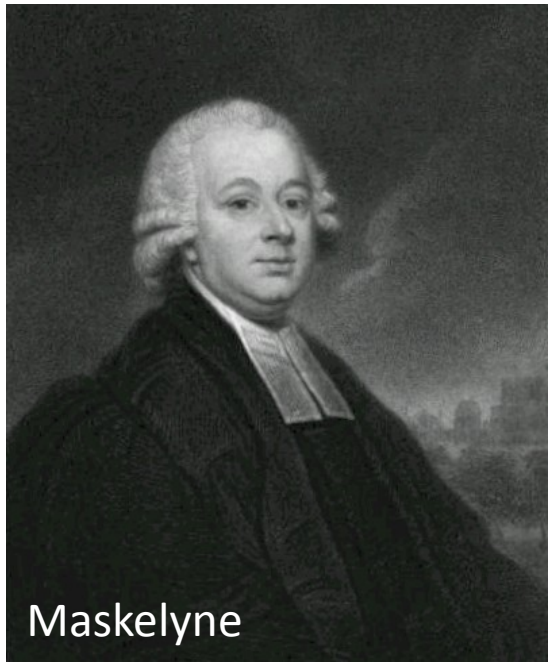
Le Gentil

- Guillaume-Joseph-Hyacinthe-Jean-Baptise Gentil de la Galaisière (1725- 1792)
- Pondicherry, India
- Slow passage due to no wind on frigate *La Sylphide*
- Reached India on 24.05
- News: Pondicherry fallen to British
- Captain turned the frigate around
- Observed on the boat:
  - Clear skies
  - And a shaky boat….
- Not demoralised: decided to stay in the Indian Ocean and wait for the next transit!
- Studied local flora and fauna
- Stay tuned….

Maskelyne & Mason

- Nevil Maskelyne (1732 – 1811)
  - Future Astronomer Royal
  - St. Helena
  - Cloudy
  - Useful study of sea currents and tides

- Charles Mason (1730-1787)
  - Destination: Sumatra
  - Left Portsmouth on *HMS Sea Horse*
  - Attacked by a French frigate in the Channel
  - Returned and refused to go again!
  - Forced to leave again
  - Went as far as Cape of Good Hope (Sumatra fallen to French)
  - Good weather ➔ the only successful observations in the south!

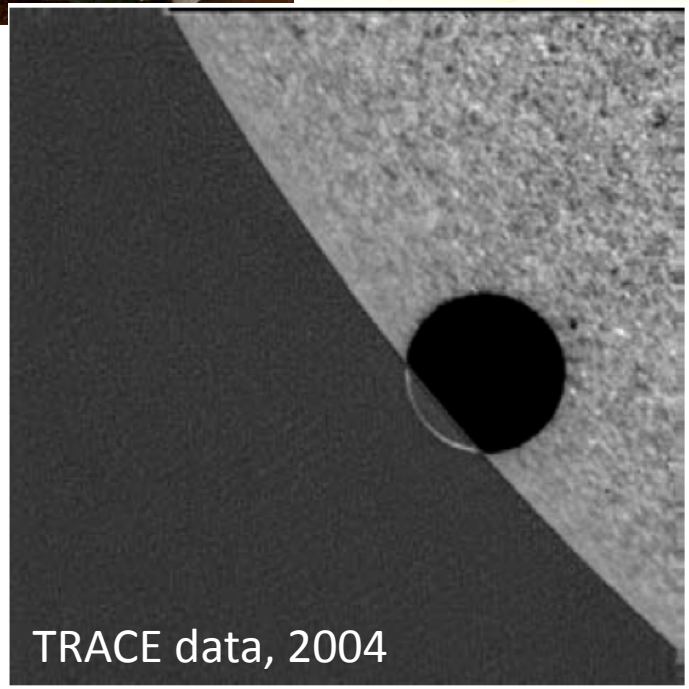

Maskelyne

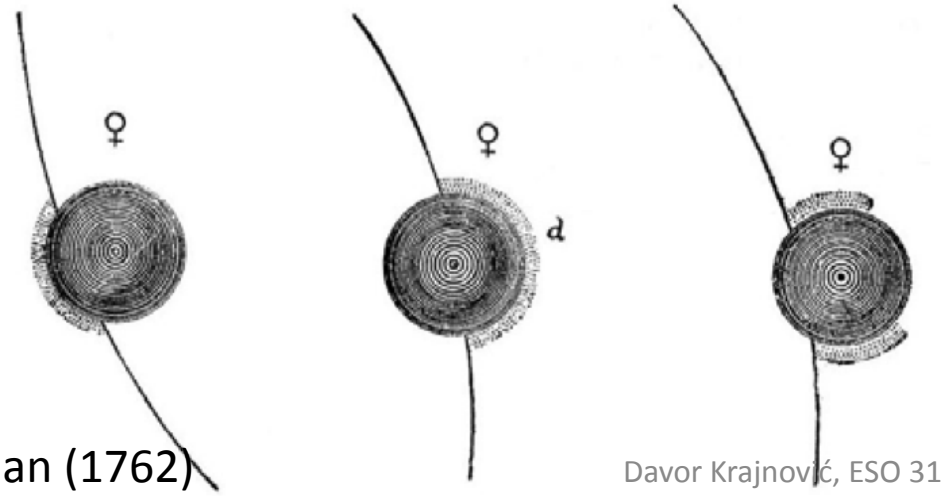
Lomonosov & Bergman

- Mikhail Vasilyevich Lomonosov (1711- 1765)
  - St. Petersburg
- Tober Olof Bergman (1735- 1784)
  - Uppsala
- Discovery of Venus Atmosphere
  - Lomonosov (1761a,b)
  - Bergman (1762, Phil.Trans. 52, 227)


Lomonosov


Bergman


TRACE data, 2004


Bergman (1762)

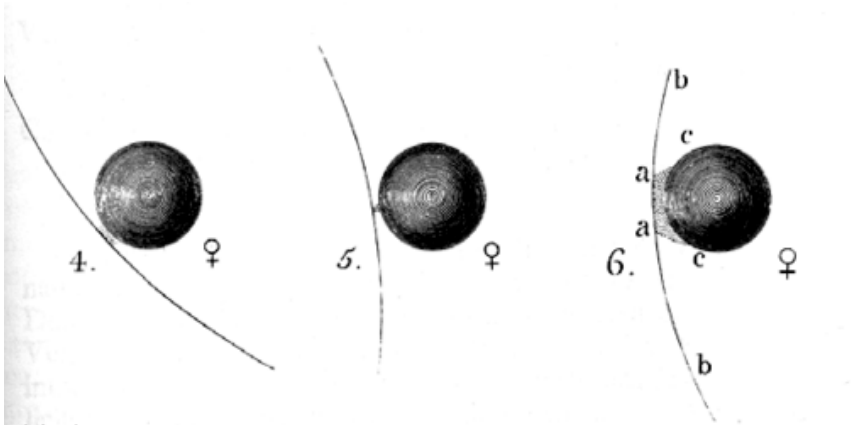
Results of 1761

- 120 observers at 62 separate locations
- Estimates for Solar parallax:
  - 8.5” – 10.5”
  - Or 1 AU = 125 100 000 - 154 600 000 km
  - (Halley expected an error of ~300 000 km)
- Overall disappointing
- Bad weather and inexperienced of astronomers
- **Not precise longitudes**
- **The black drop effect!**
- The second chance is only 8 years away and now astronomer will be prepared!!

1 AU TODAY:
8.794148”
149 597 870 km

The black drop effect

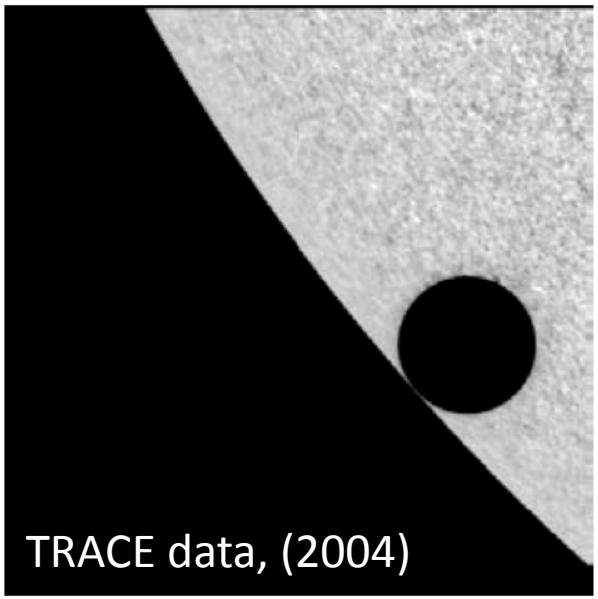
- Halley's and Delisle's methods dependant on precise measurement of entry and exist of Venus
- Observers expected a sudden separation of Venus and Sun's limb, but
- Venus' trailing edge seemed to linger on
- Instead of 1-2 sec timing accuracy, observers were not able to decide when is Venus in the disc of Sun to 10 sec or more!

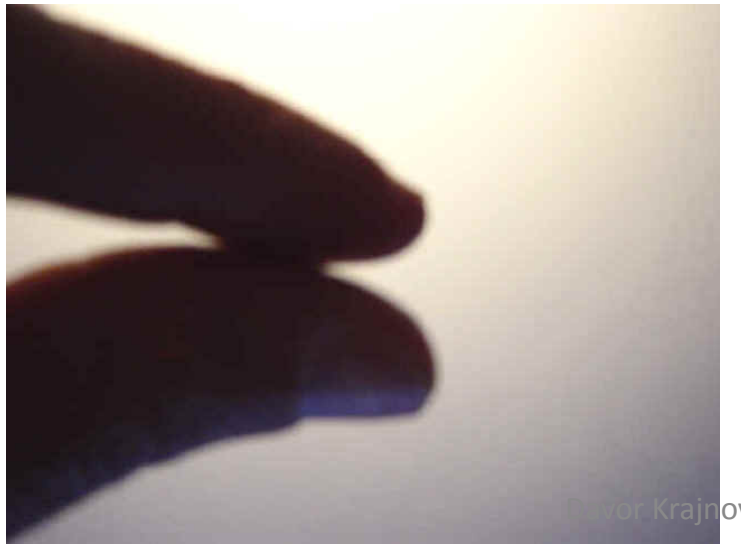


Bergman (1762)

The black drop explained

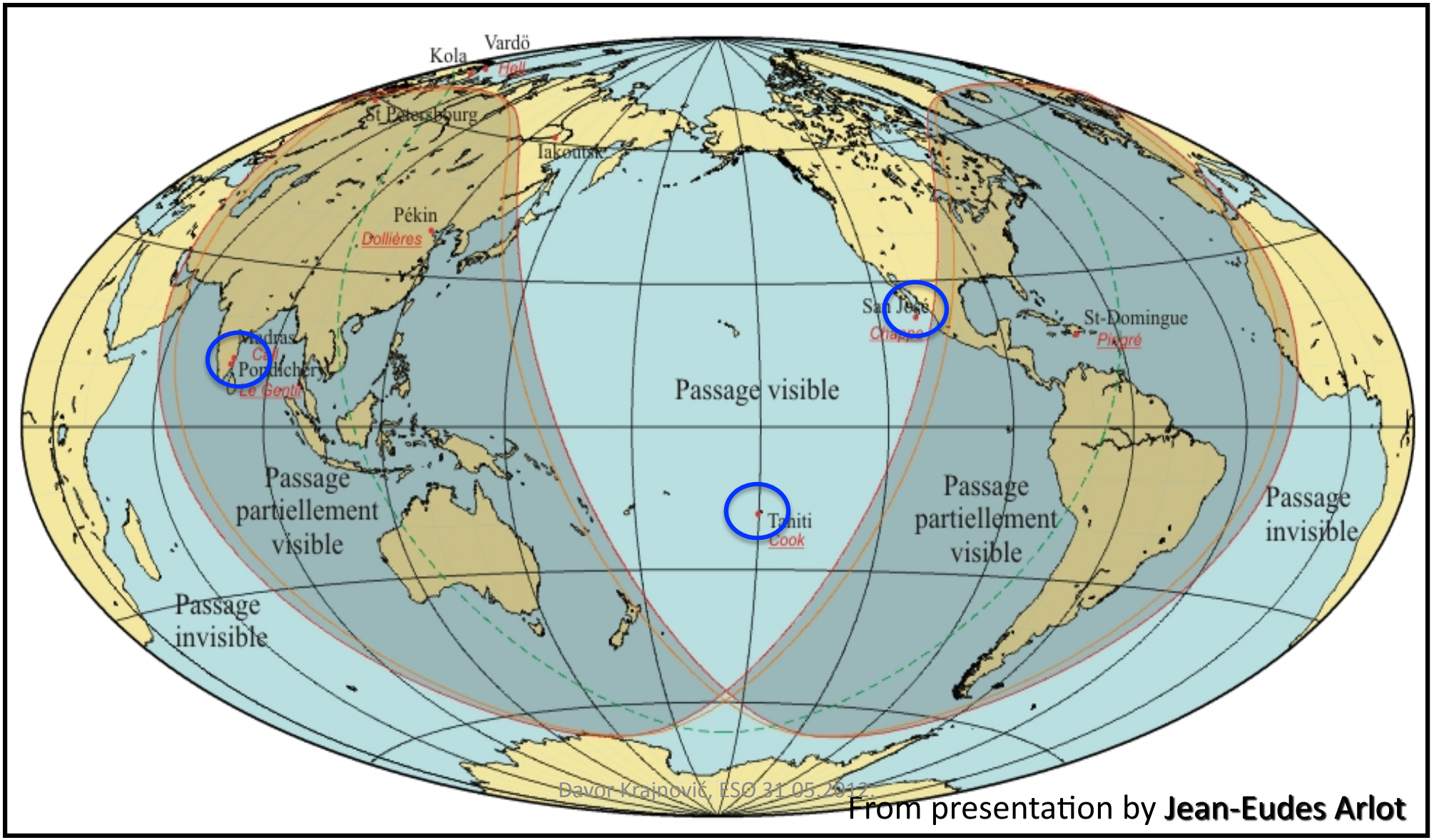
- Combination of:
  - (Venus atmosphere)
  - Earth atmosphere
  - Optical effect of a bright background
  - Instrumental effects !!!
- Once a pest, today a prize (but not seen often!)


TRACE data, (2004)



Swedish, 1m Solar Telescope, La Palma

Voyages of 1769



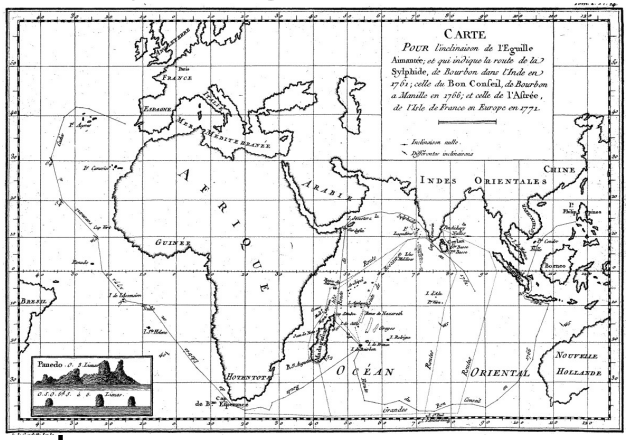
From presentation by **Jean-Eudes Arlot**

d'Auteroche

- Abbé Jean-Baptiste Chappe d'Auteroche (1728-1769)
  - Solomon Islands (then under Spain)
  - Not allowed➔ sent to Mexico (boat to Veracruz, overland to southern tip of Baja California
  - Jose del Cabo (16.05.1769)
  - Great weather, one of the most precise measurements
  - Before departure: epidemic broke in the village
    - Most of the inhabitants died
    - Only one survivor of the expedition: geographer M.Pauly – brought back the data
  - *"Voyage en Californie, pour l'observation du passage de Vénus sur le disque du soleil",* published by Cassini de Thury

Le Gentil – record for astronomical persistence

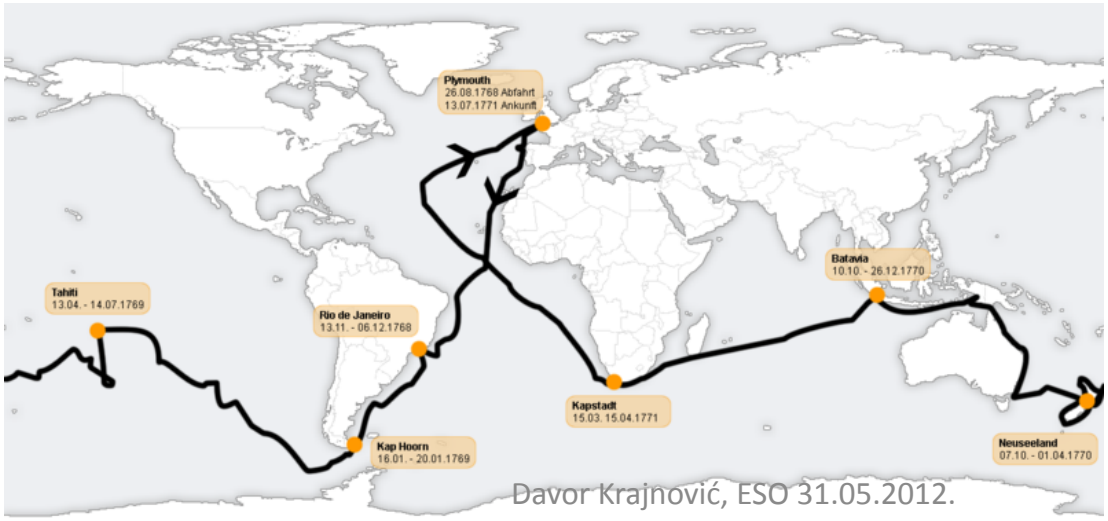
- Stayed on Mauritius, travelled around the Indian ocean exploring wildlife and natural history
- Decided to go to Manila, Philippines
- Academy sent him back to Pondicherry
- (This time) British offered assistance (+ a telescope)
- On the day of transit: cloudy (in Manila sunny!)
- Mild nervous breakdown…

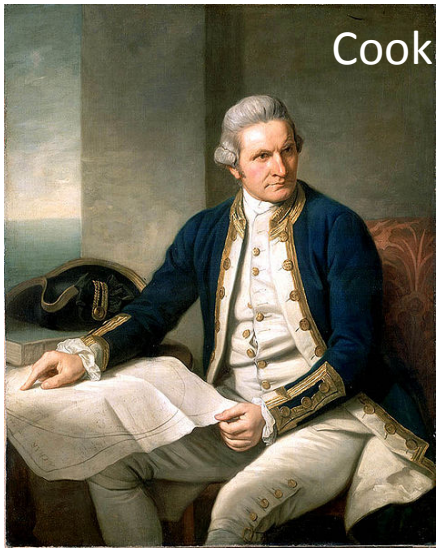


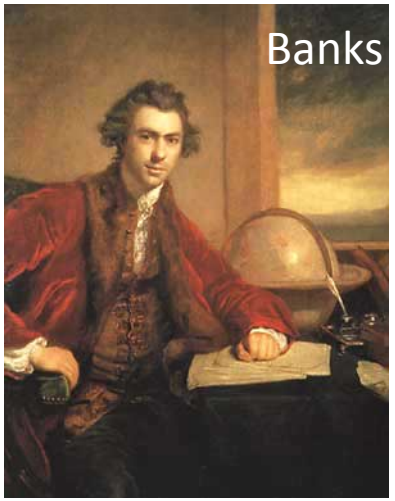
- Return home delayed due to dysentery and a shipwreck
- Upon return home:
  - Assumed dead by his family: estate plundered and divided
  - Academy “retired” him (as he must have neglected his duties for some personal benefit)
  - After a lengthy legal fight (and intervention by the King) got his property back
  - Got married and had a daughter
  - Published: *Voyage dans les mers de l'Inde, fait par ordre du Roi, à l'occasion du passage de Vénus, sur le disque du Soleil, le 6 juni 1761 & le 3 du même mois 1769,* (1779, 1781)

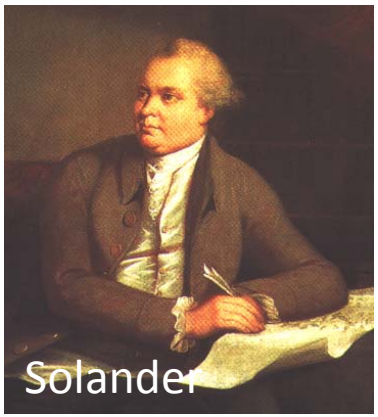
Cook

- Transit best visible from the South seas
- Uncharted (unknown) regions
- Interest in combining the astronomical and exploratory expeditions under the RN
- Lieutenant James Cook (1728 – 1779) and HMS Endeavour (built for coal trade)
- Scientists:
  - Joseph Banks, Esq (future President of the RS)
  - Charles Green, astronomer (1735 – 1771)
  - Daniel Solander, botanist (1733 – 1782)









Cook's Venus Transit

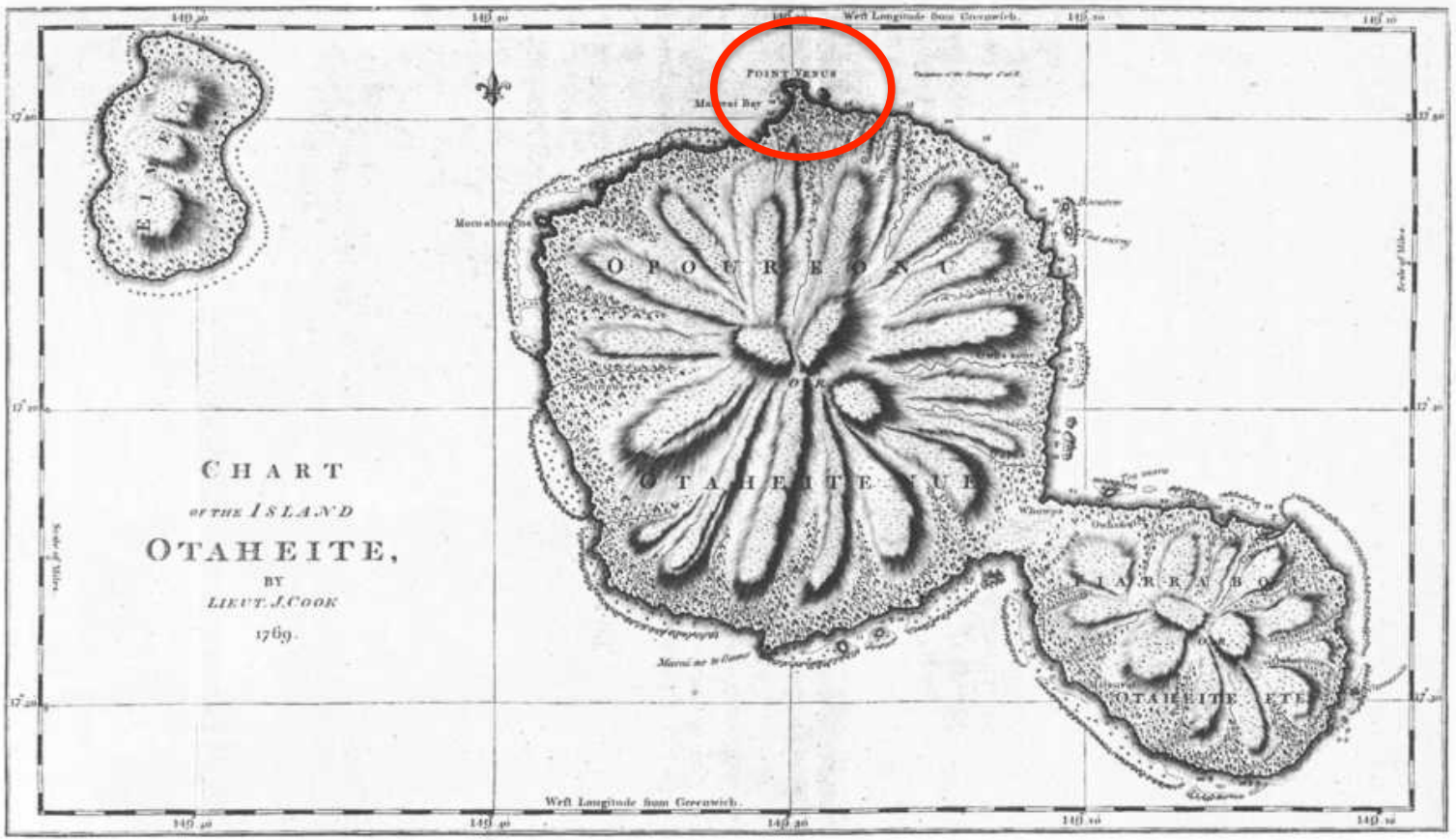
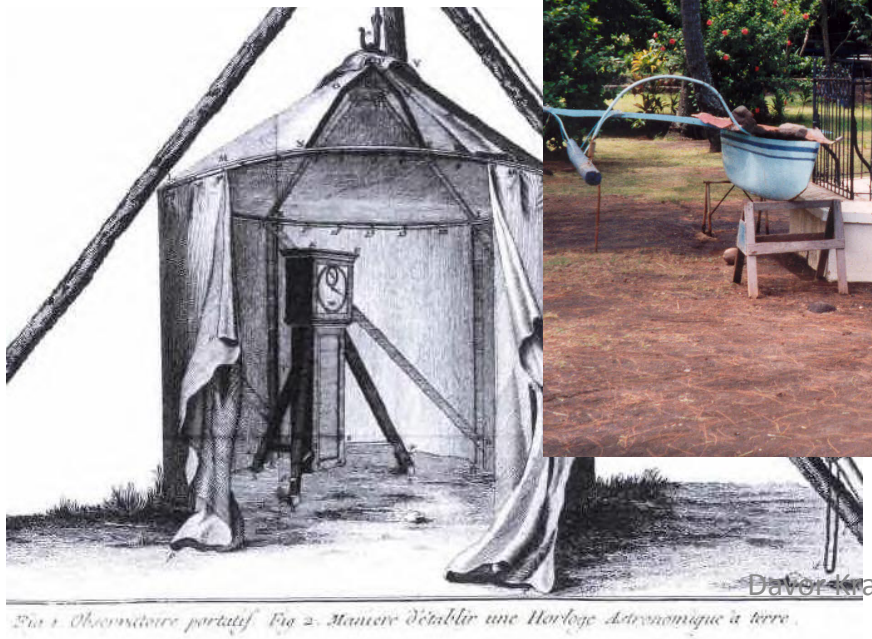
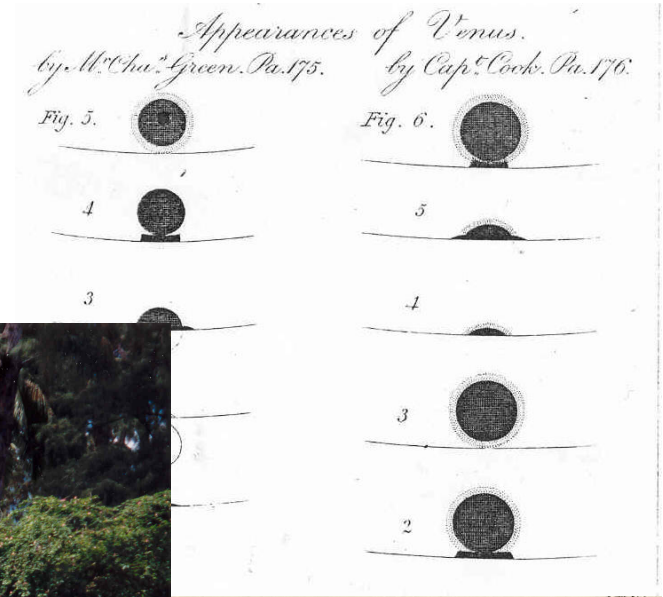


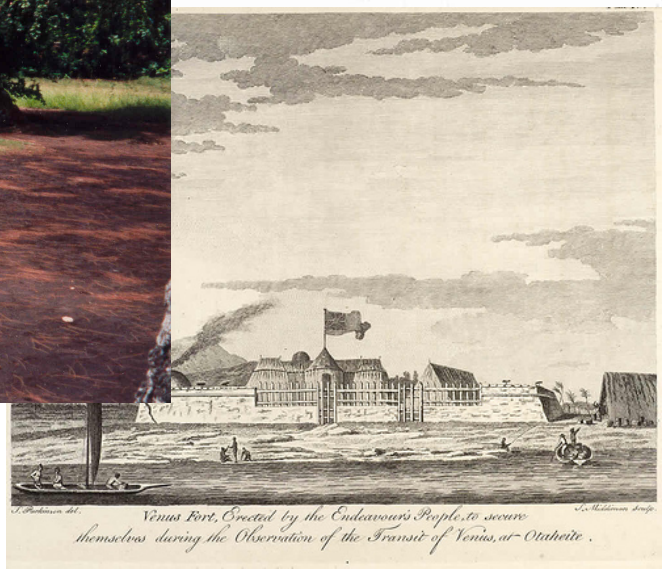
Fig. 4. Cook's chart of Tahiti, showing Matavai Bay and Point Venus (reproduced from Hawkesworth)

Cook's Venus Transit

- Tahiti - the only place in Pacific with known longitude and latitude
- Fort Venus
- Small trouble with natives
  - Stolen quadr reassembled
- Clear skies and







Results of 1769

- 138 observers at 63 locations
- Better results than in 1761:
  - Solar parallax: 8.43” – 8.80”
  - AU = 149 300 000 – 153 900 000 km
- But not as expected
  - Black drop (timing issue)
  - Uncertain longitudes
- RS escape goat: Charles Green (died during voyage)

1 AU TODAY:
8.794148”
149 597 870 km

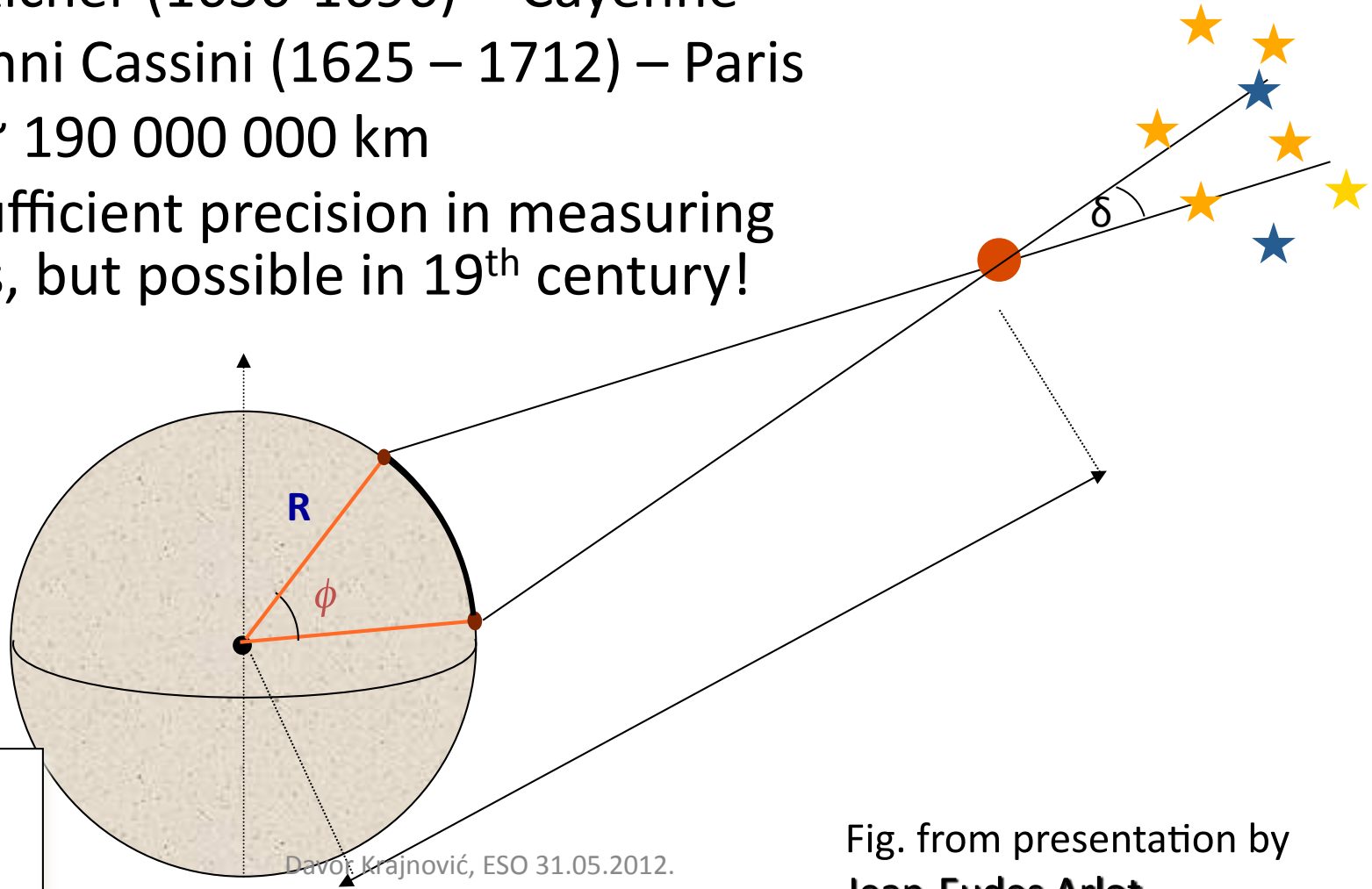
105.5 years later

- The world changes again
  - Industrial revolution
  - Faster and safer travels
  - Good time keepers
  - Determining longitude not a very big deal
  - Photography (daguerreotypes)
  - Lots of past experience
  - New nations (USA, Germany…) willing to prove themselves
- But is it necessary?
  - Precision in astronomy reached new levels: sub-arcsecond (e.g. Bessel in 1838 determined parallax of 61 Cyg of 0.28”)
  - AU from the parallax of Mars

Fig. from presentation by **Jean-Eudes Arlot**

Parallax of Mars

- Attempted before
  - Jean Richer (1630-1696) - Cayenne
  - Giovanni Cassini (1625 – 1712) – Paris
  - 1 AU ~ 190 000 000 km
  - Not sufficient precision in measuring angles, but possible in 19th century!

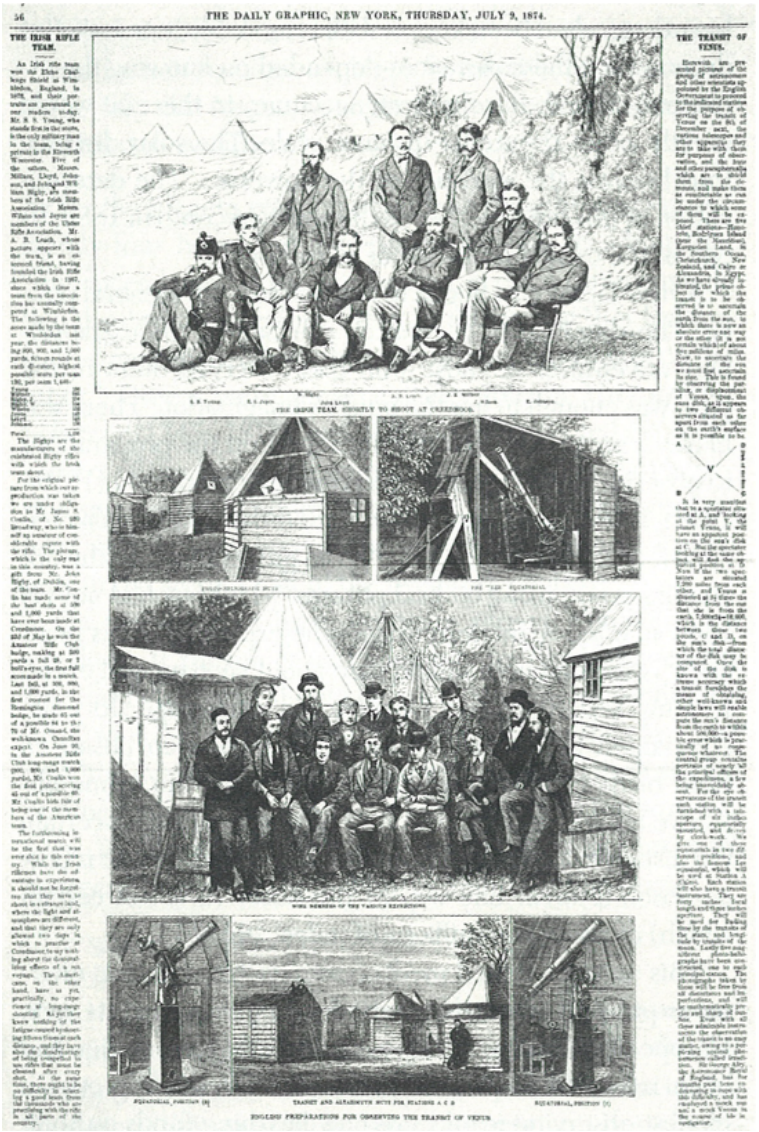


$$2R\sin\frac{\phi}{2} = D\,\delta$$

Fig. from presentation by **Jean-Eudes Arlot**

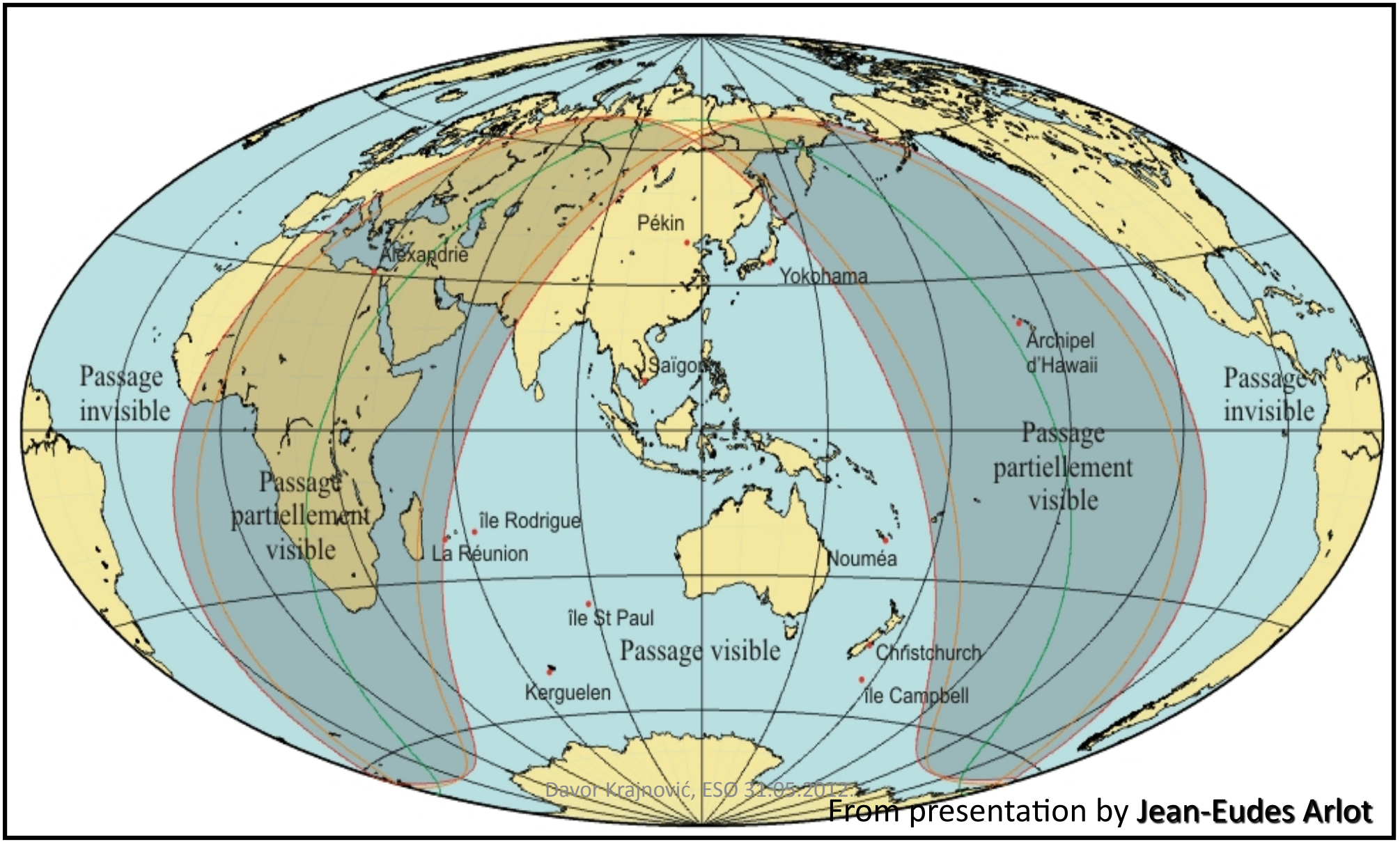
No problem with money

- Venus transit still very attractive
- Media coverage
  - Rarity of the event + adventures of 18th century
  - All newspapers report on the progress of expeditions
- General public
  - Governments “happy” to spend money
  - US Congress (1874):
    - Approves $50 000 (today: $1.25 million)
    - Final sum: $175 000 (today: $4.375 million)
  - US Congress (1882)
    - Approves $85 000 at start (even though some astronomer were against, including S. Newcomb – see later)
  - World wide (1874): > $1 000 000 (today: 25 million)



Daily Graphic on Irish Expedition of 1874 (From Maor 2000)

Voyages of 1874



From presentation by **Jean-Eudes Arlot**

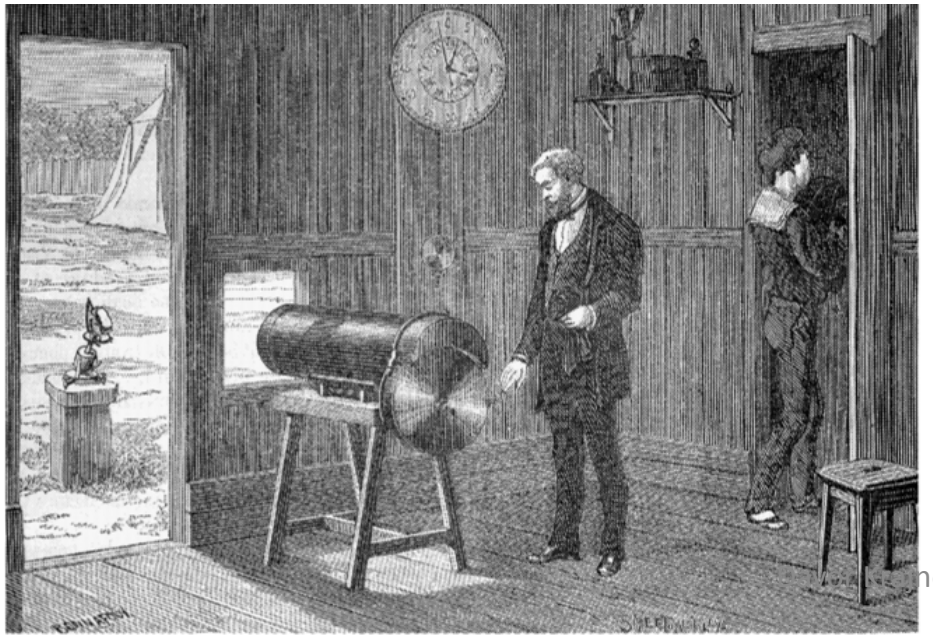
Expeditions

- French 1872: 2 north, 2 south
- British 1872: several
- *Conference internationale du passage de Venus* (1881) – Paris
  - Call for cooperation in selection of locations
  - Discussion of technical details (i.e. photography)
- British 1884: 16 teams at 6 locations
- France 1884: (at least) 8 locations
- Many, many other countries

New technology

- Jules Janssen (1824-1907)
  - Observing in Japan
  - ‘revolver photographique’
  - Technology spin off: cinema


M. Janssen, membre de l'Académie des sciences.



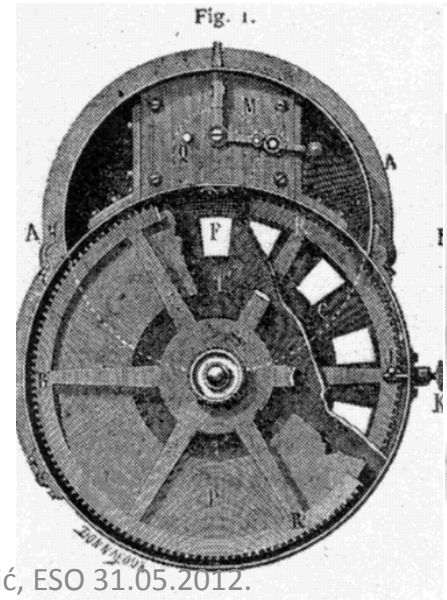
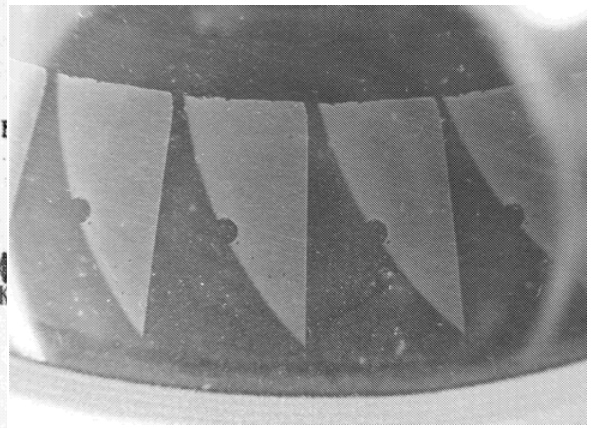
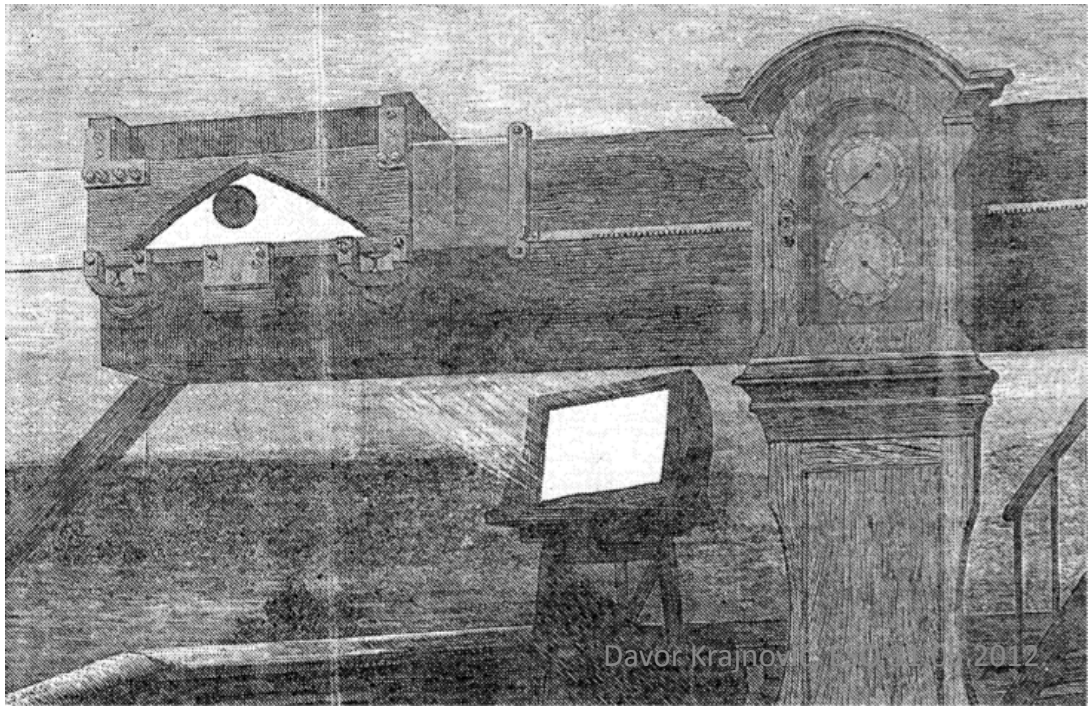


Fig. 1.



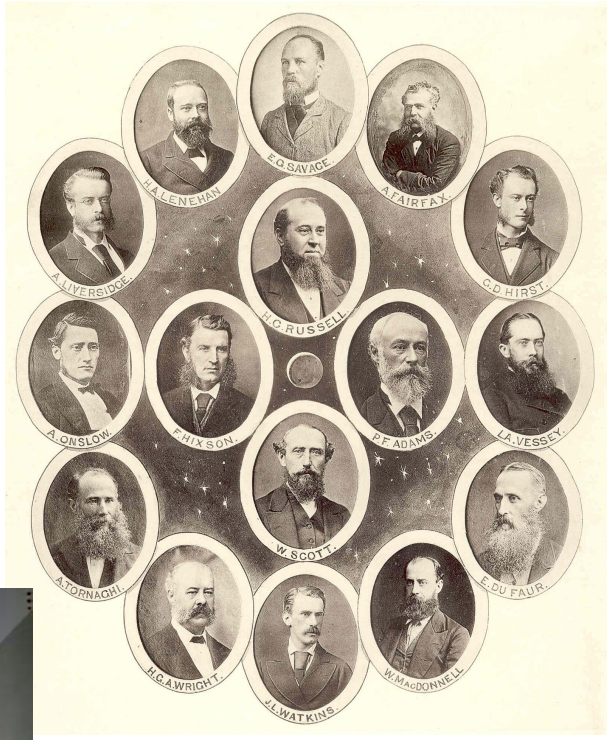
New approach

- George Biddell Airy (1801-1892)
  - Astronomer Royal
- Practicing for the Venus transit
  - Done by other nations as well
  - Systematic preparations of large team of scientists and support staff



New homecoming

- Commemorating medallions
- Photographs
- Paintings

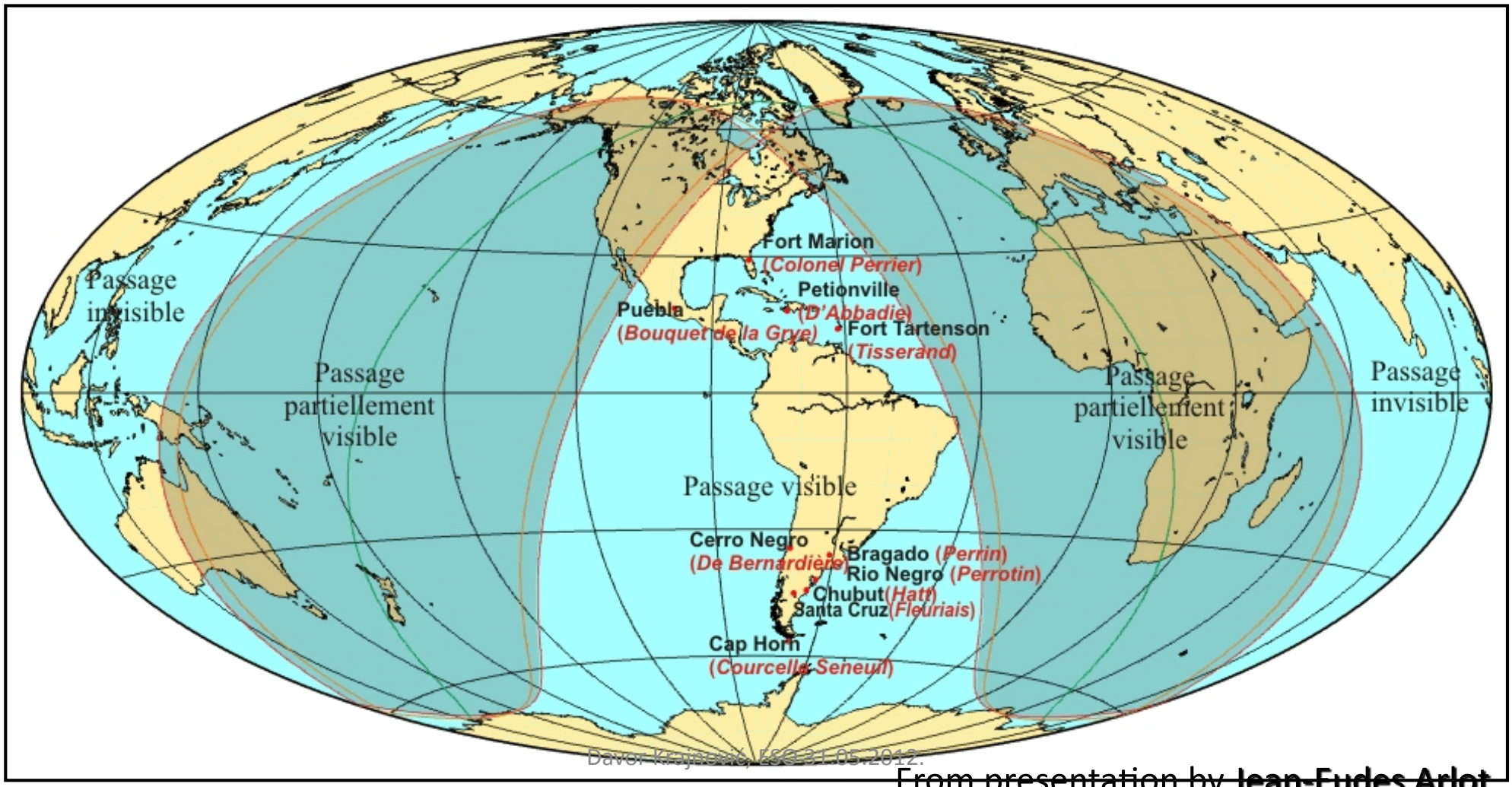


Members of an Australian expedition

Medallion commemorating 1874 and 1882 transits

Dupin: Transit of Venus for Paris Observatory

Voyages of 1882

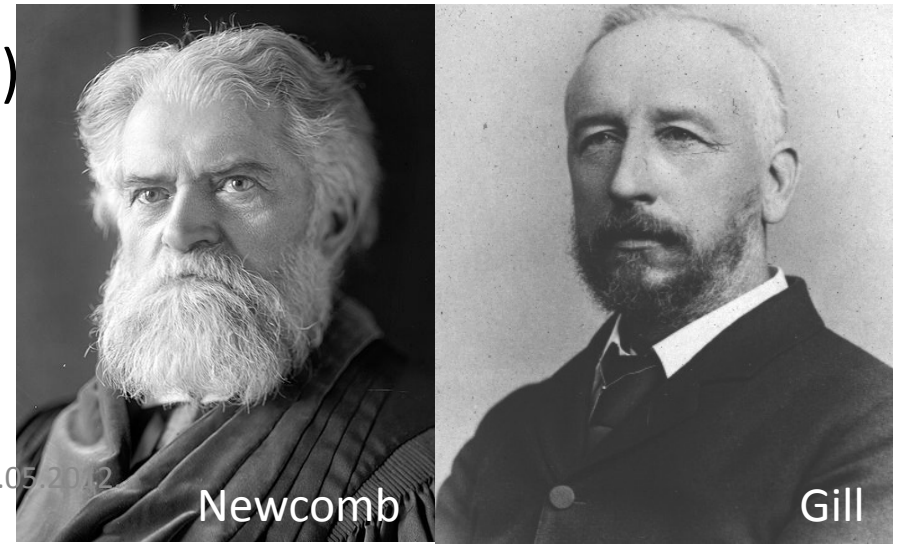


From presentation by **Jean-Eudes Arlot**

Results of XIX centruy

- Anticlimax
- Solar Parallax: 8.79” – 8.88”
- AU = 147 960 000 – 149 480 00 km
- Simon Newcomb
  - Used data from both 18th and 19th century
  - 8.79” ± 0.05” (18th century)
  - 8.79” ± 0.02” (18+19th century)
  - Reached Halley’s estimate
- David Gill
  - Sollar parallax from Mars
  - 8.78” ± 0.01”

1 AU TODAY:
8.794148”
149 597 870 km



Summary of AU measurements

Epoch	AU [km]	Error [km]	Diff to today AU	who
1st BC	78 540 000	Unknown	71 057 900	Posidonius*
2nd – 16th	7 206 000	Unknown	140 958 000	Ptolomy*
17th	94 000 000	Unknown	55 597 870	Horrocks
1761	138 540 000	14 400 000	11 057 870	Pingré & Short
1761 & 1769	151 000 000	1 500 000	1 402 130	Lalande&Pingré
1761 & 1769	149 670 000	850 000	72 130	Newcomb
1874 & 1882	149 670 000	330 000	72 130	Newcomb
1931	149 675 000	17 000	77 136	Spencer Jones^
2004	149 608 708	11 835	10 838	VT-2004

- * estimates based on uncertain assumptions
- ^ parallax of Eros

Resources

- Big thanks to our Librarians: Uta and Silvia!
- Eli Maor: "*June 8, 2004: Venus in Transit*", 2000, Princeton, PUP
- Richard Proctor: "*Transits of Venus*", 1882, London, Longmans, Green & Co.
- Harry Woolf: "*The Transits of Venus, A study of Eighteenth-century Science*", 1959, Princeton, PUP
- Harm Habing, "Kosmos", 2009, Diemen, Veen Magazines
- Papers
  - Proceedings of the IAU – Volume 2004, Issue IAUC 196
  - IAU Resolutions 1976
  - Launay & Hingley, 2005, JHA, 36, 57
- Wikipedia
- www.transitofvenus.org (+ F. Espenak)
- www.exploratorium.edu
- www.eso.org/public/outreach/eduoff/vt-2004/
- www.endeavourvoyages.com.au/

The last in our lives

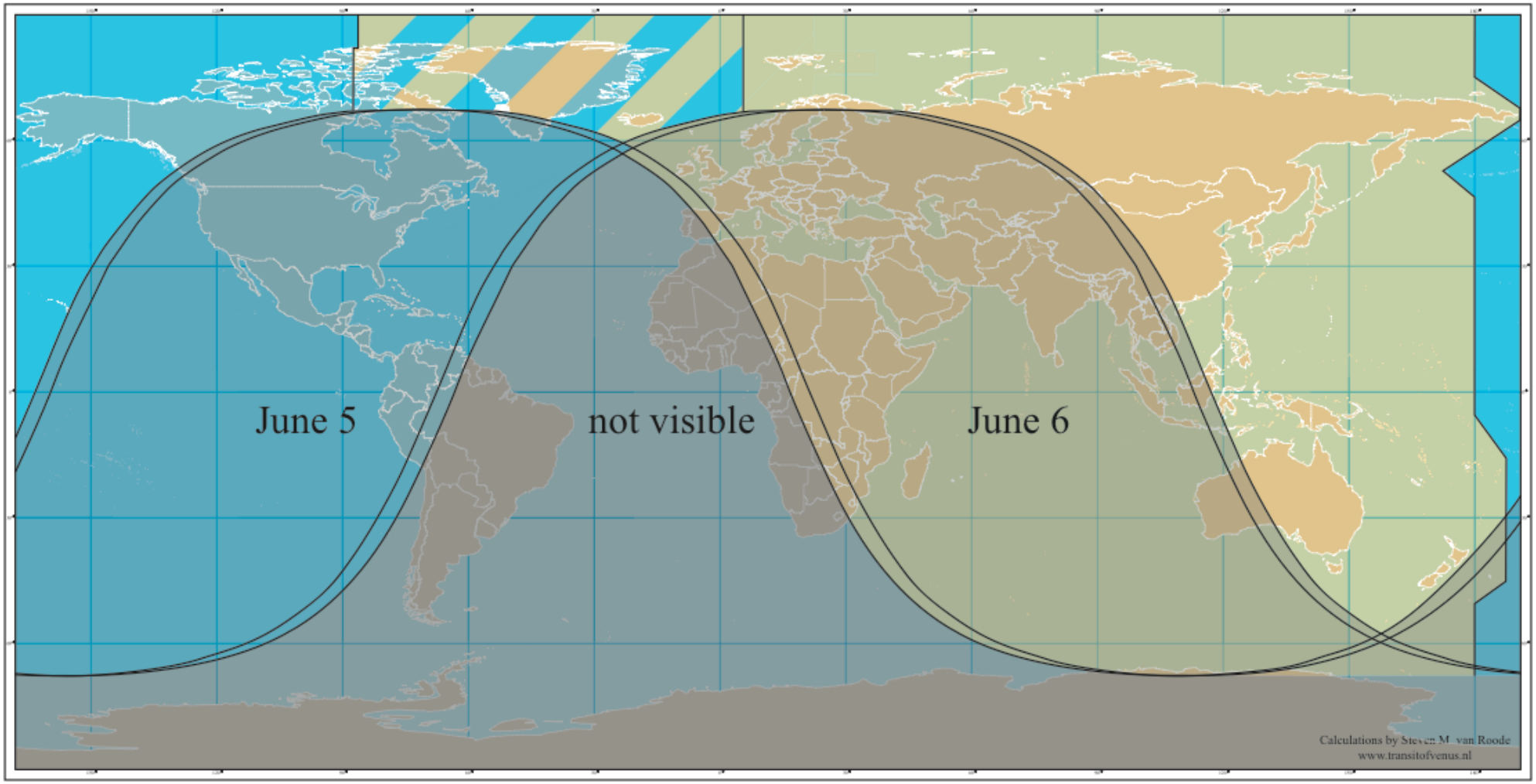
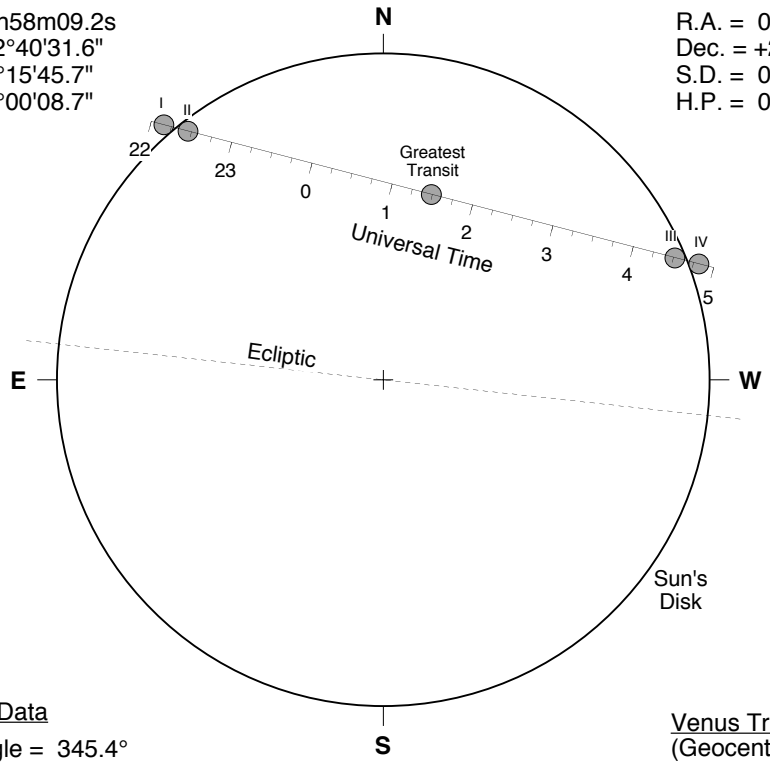


FIGURE 2

Transit of Venus of 2012 June 05/06

Greatest Transit = 01:29:36.3 UT J.D. = 2456084.562225



Sun at Greatest Transit
(Geocentric Coordinates)

R.A. = 04h58m09.2s
Dec. = +22°40'31.6"
S.D. = 00°15'45.7"
H.P. = 00°00'08.7"

Venus at Greatest Transit
(Geocentric Coordinates)

R.A. = 04h57m58.8s
Dec. = +22°49'25.9"
S.D. = 00°00'28.9"
H.P. = 00°00'30.5"

Geocentric Data

Position Angle = 345.4°
Separation = 554.4"
Duration = 06h40m

Ephemeris Data

Eph. = VSOP87
ΔT = 66.7 s

F. Espenak, NASAs GSFC - 2011 Jun
eclipse.gsfc.nasa.gov/OH/transit12.html

Venus Transit Contacts
(Geocentric Coordinates)

I	= 22:09:38 UT
II	= 22:27:34 UT
Greatest	= 01:29:36 UT
III	= 04:31:39 UT
IV	= 04:49:35 UT