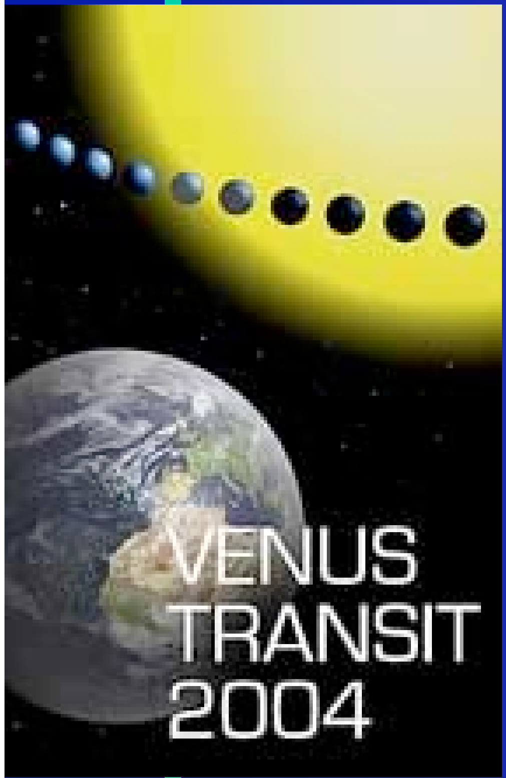
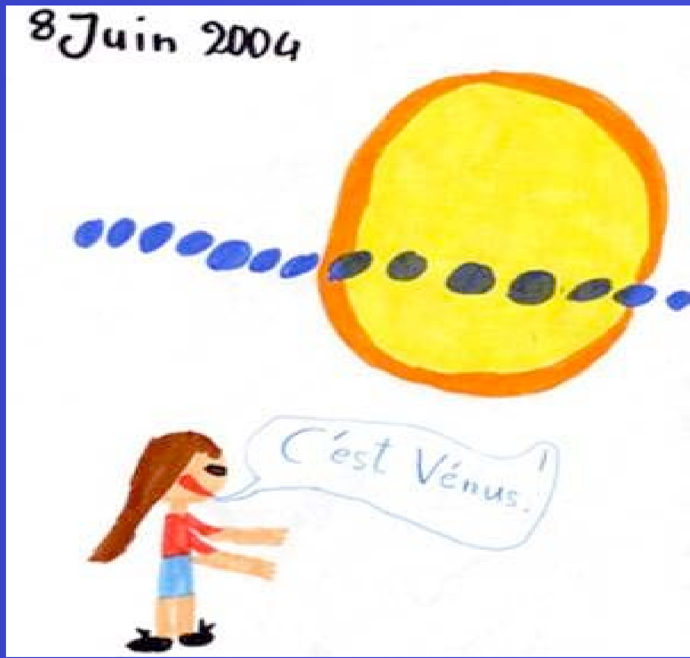
The VT-2004 observing campaign and the Astronomical Unit



Jean-Eudes Arlot
Directeur de recherche du CNRS

Patrick Rocher
Astronome à l'IMCCE

William Thuillot
Astronome à l'IMCCE

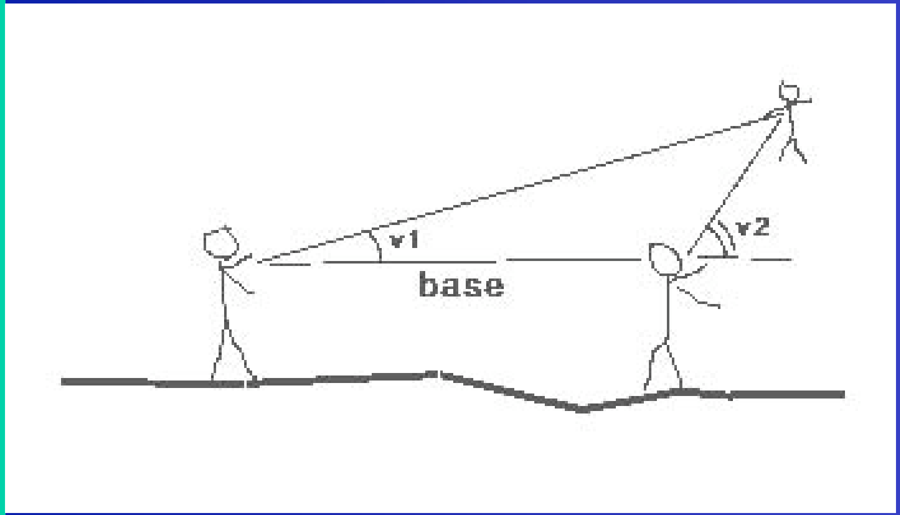


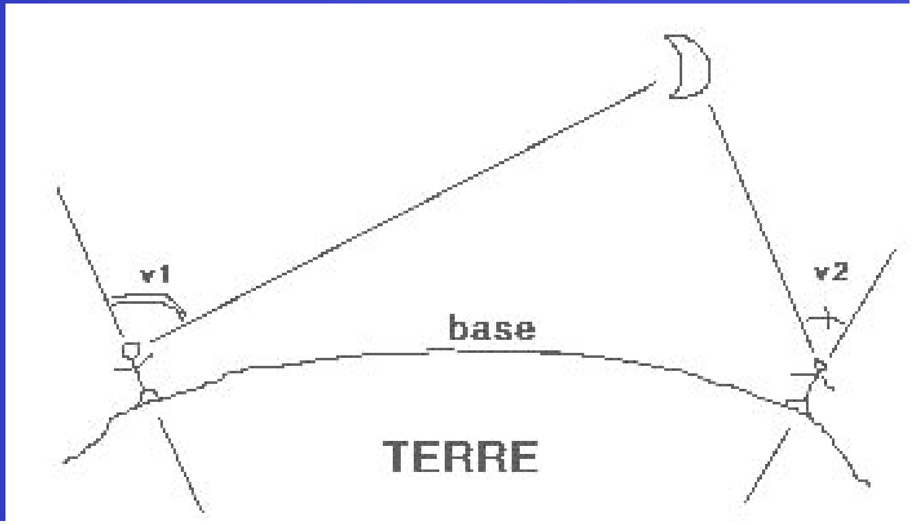
Venus in the sky

The measure of the distances

Parallax or triangulation

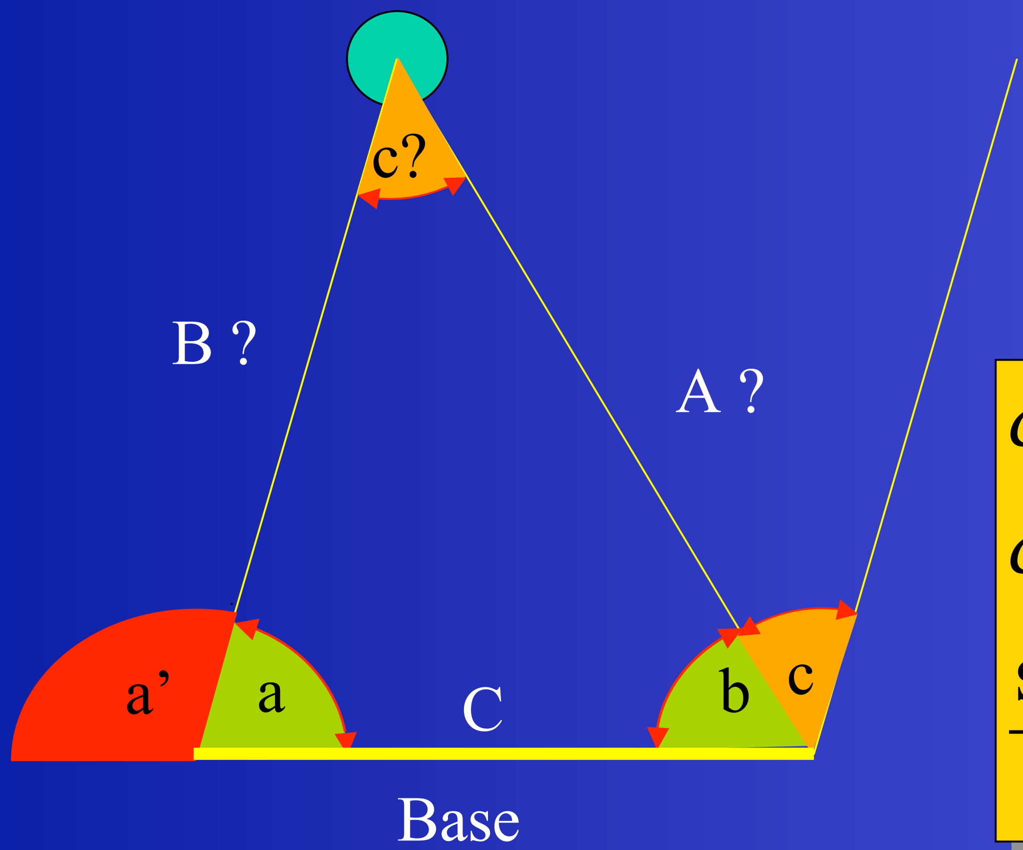
Or how to measure a distance without going there…





Resolving a triangle

The triangulation



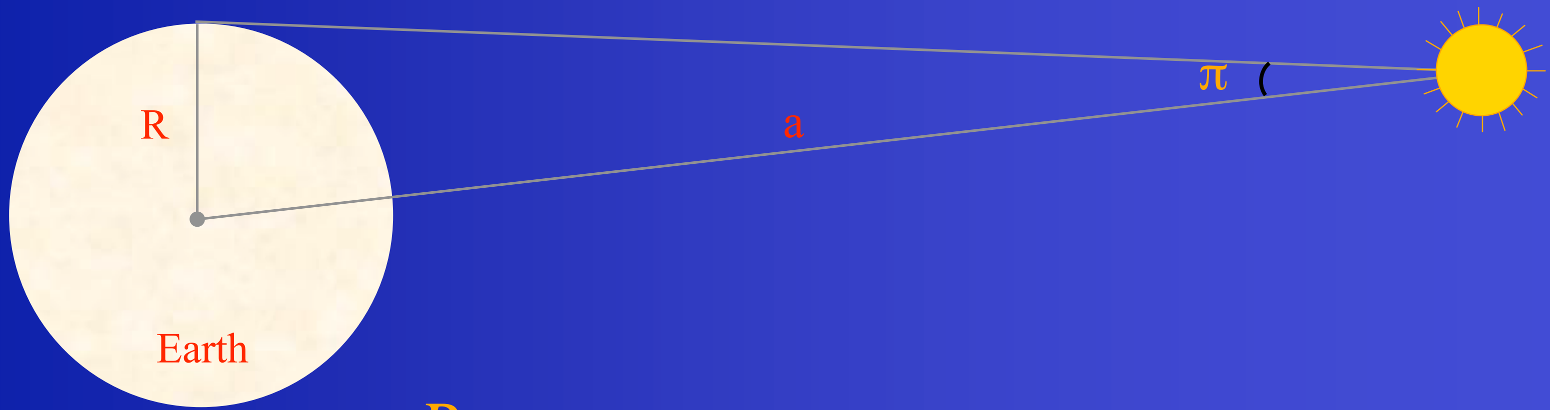
$$c = 180° - (a + b)$$

$$c = a' - b$$

$$\frac{\sin c}{C} = \frac{\sin b}{B} = \frac{\sin a}{A}$$

Definition: the solar mean horizontal parallax

- astronomers measure only angles from the Earth



$$\sin \pi_0 \approx \frac{R}{a} \quad \equiv \text{ parallaxe horizontale moyenne}$$

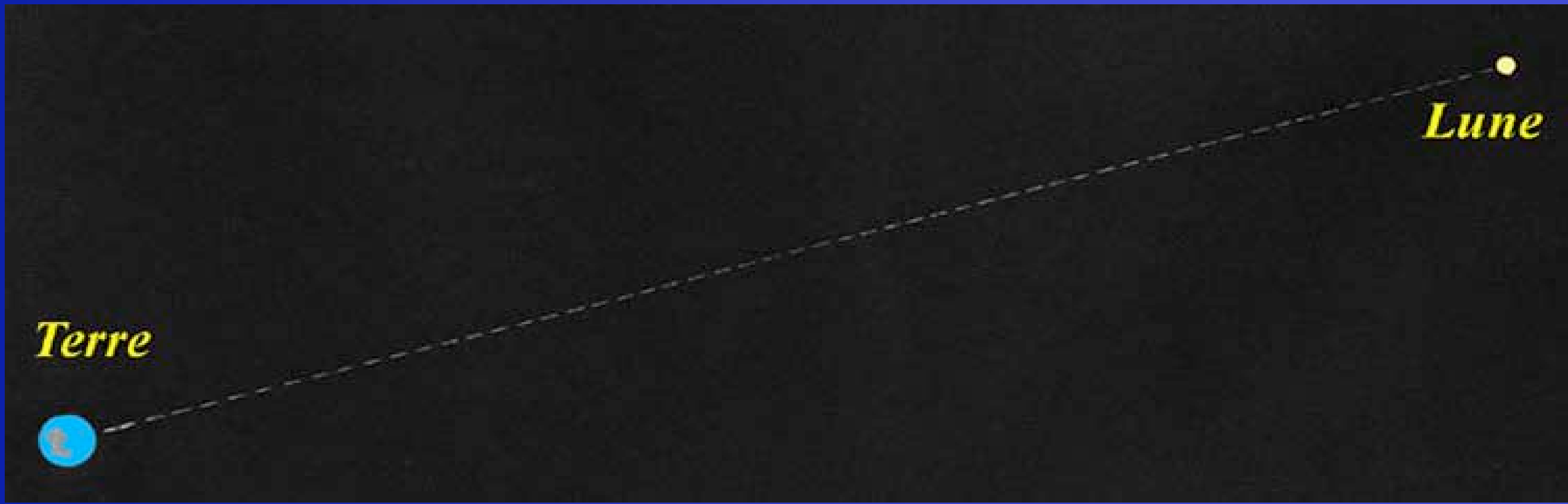
The knowledge of the horizontal parallax of a planet is equivalent to the knowledge of its distance to the Earth

The parallax of the Sun is a fundamental question in the Keplerian astronomy

The parallax

The method of the parallax allows to measure distance to objects close to the Earth.

The Sun is too far: only Venus and Mars are accessible.



Earth and Moon at scale: how to measure the parallax?

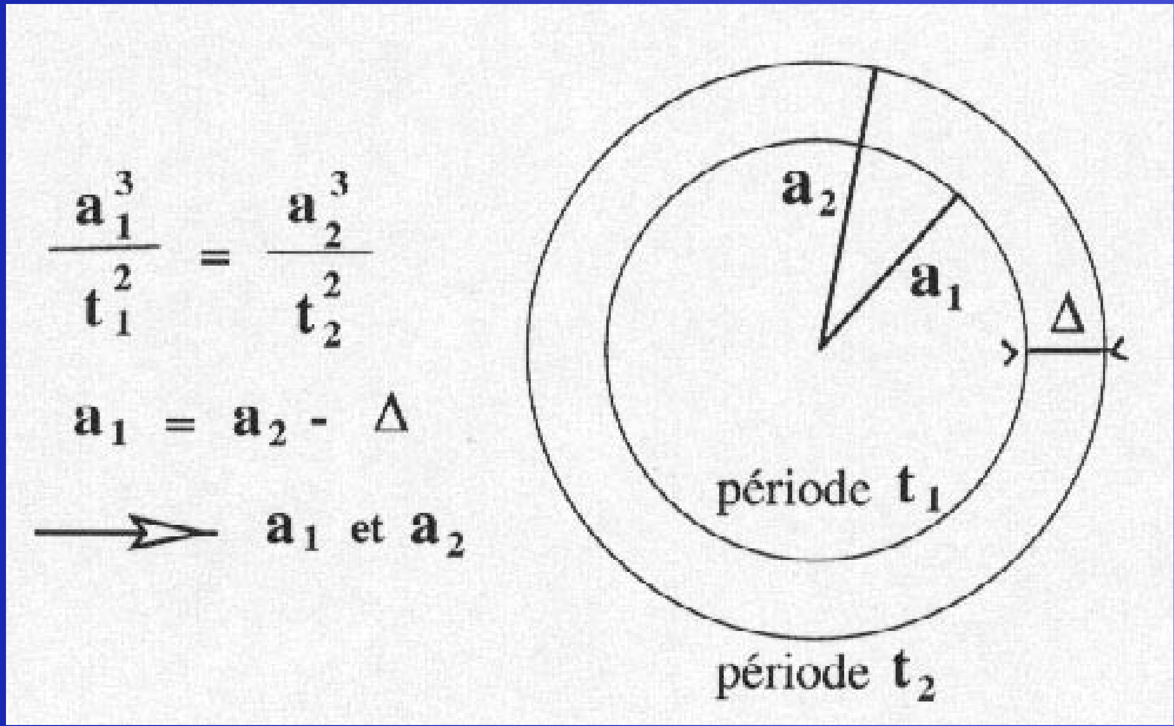
Kepler will provide a way to measure the solar system

Third law:

•a^3/t^2 is a constant for all the planets
where **a** is the semi major axis of the orbit
and **t** the duration of a revolution around the Sun

Kepler (1571-1630)

So, the knowledge of only ONE distance between two planets leads to the knowledge of all distances in the solar system



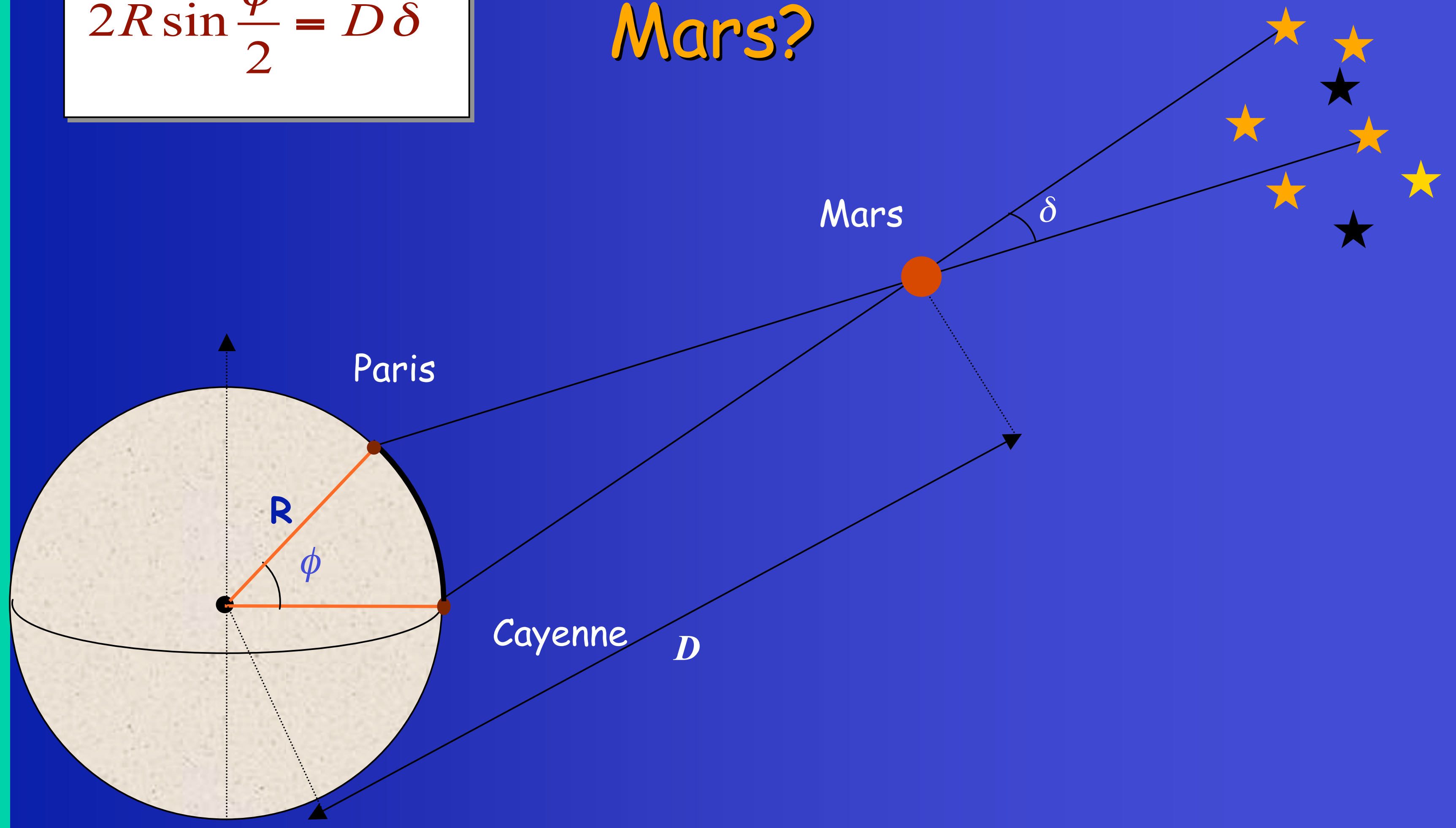
La troisième loi de Képler nous donne toutes les distances dans le système solaire à partir de la mesure d'une seule.

Il ne nous reste plus qu'à mesurer une distance dans le système solaire…

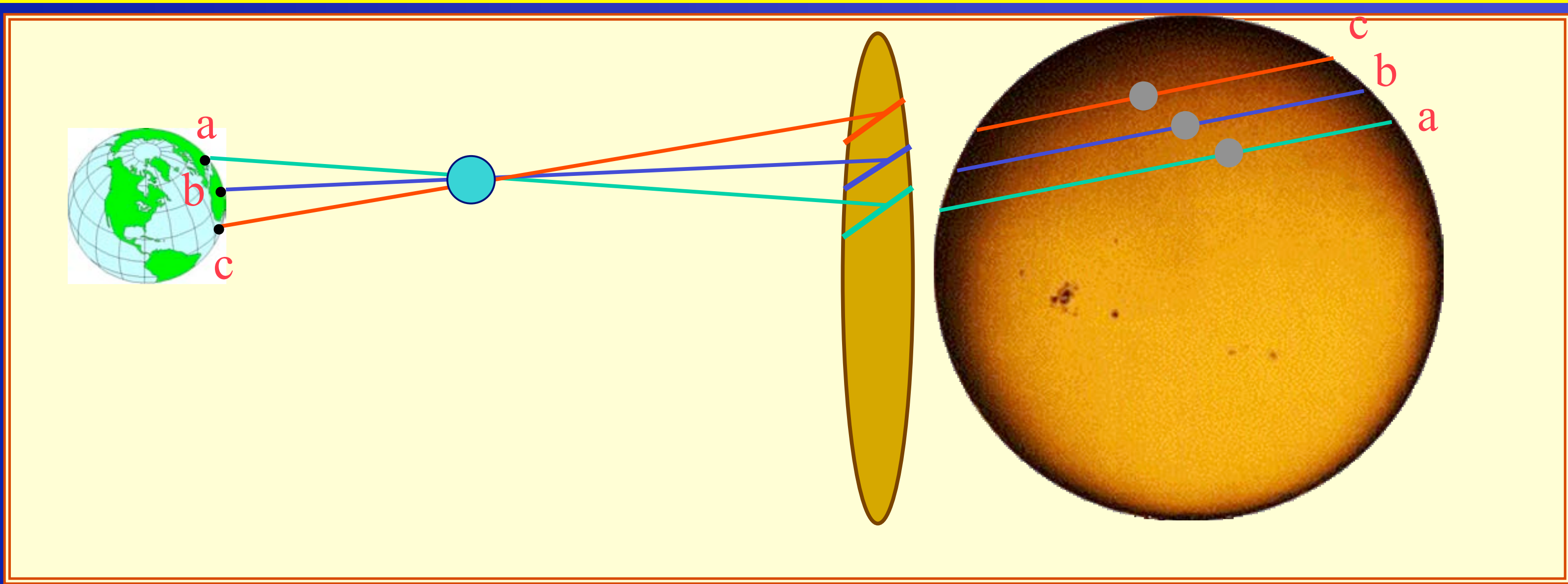
First method: the parallax of Mars

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

Mars?



Halley's method: the parallax of Venus

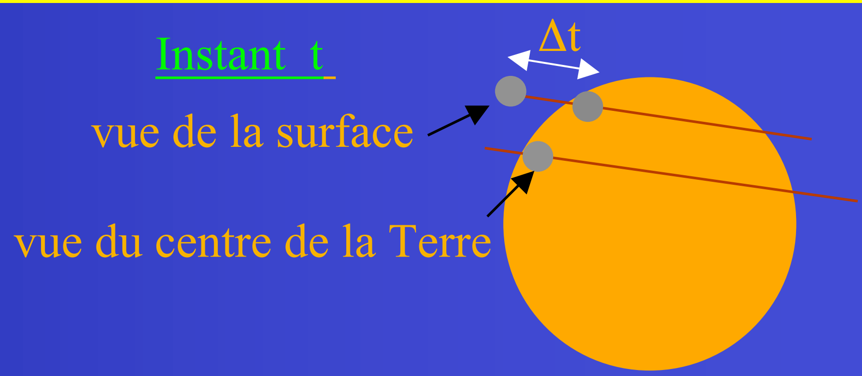


- The parallax of Venus is deduced from the relative positions of two apparent paths of Venus on the Sun during a transit
- The measure of an angle is replaced by the measure of a duration

or Venus?

Delisle's method: observing only the contacts between Venus and the Sun

Contacts instead of the duration



Advantages relatively to duration

Less problems due to meteorological conditions

More possible sites of observations (partial transit only)

Disadvantages

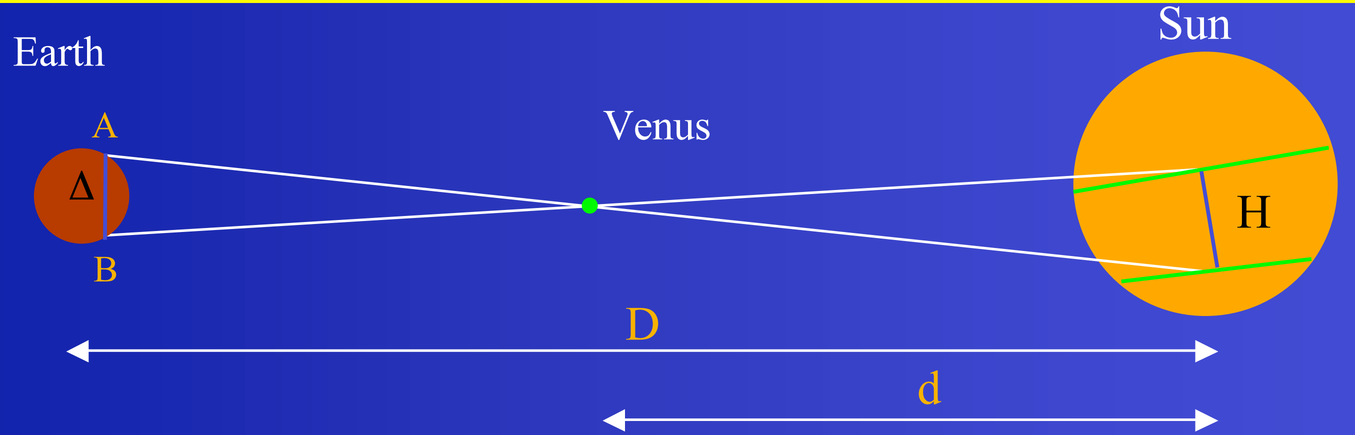
Observing an event instead of a duration

- ➔ need of accurate clocks

Comparing observations from different sites

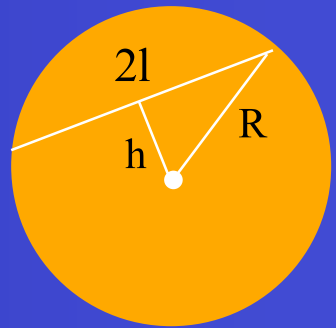
- ➔ need of a good knowledge of the longitude !

The principle of the parallax of Venus – and the Sun -



Approximative calculation:

1. $H/\Delta = d/(D-d) \sim 2.5$ ➔ H in km



2. $h^2 = R^2 - l^2$

- For two close chords :

3. $\delta h = \delta l * l/h$ and $\delta l = V\delta t$: angular data

- The Sun is not at the infinite and the third Kepler's law provides d/(D-d)

H is known as a length and an angle ➔ Parallax

First observations: the XVIIth century


P. Gassendi
1592 - 1655

The first use of the transits will be to demonstrate the reality of Kepler's laws.

For the first time Gassendi observes in Paris in 1631 a transit of Mercury.

He wrote to Wilhelm Schickard, professor at Tübingen :

"Le rusé Mercure voulait passer sans être aperçu, il était entré plutôt qu'on ne s'y attendait, mais il n'a pu s'échapper sans être découvert, je l'ai trouvé et je l'ai vu; ce qui n'était arrivé à personne avant moi, le 7 novembre 1631, le matin".

The first observation of a transit of Venus is due to: J. Horrocks (1619-1641)

- The Kepler's laws seem to modelize very well the solar system
- The distance Earth-Sun is evaluated to 94 millions km
- Horrocks was lucky since the transit of 1631 was only observable a few minutes before sunset…

The XVIIIth century: an international challenge

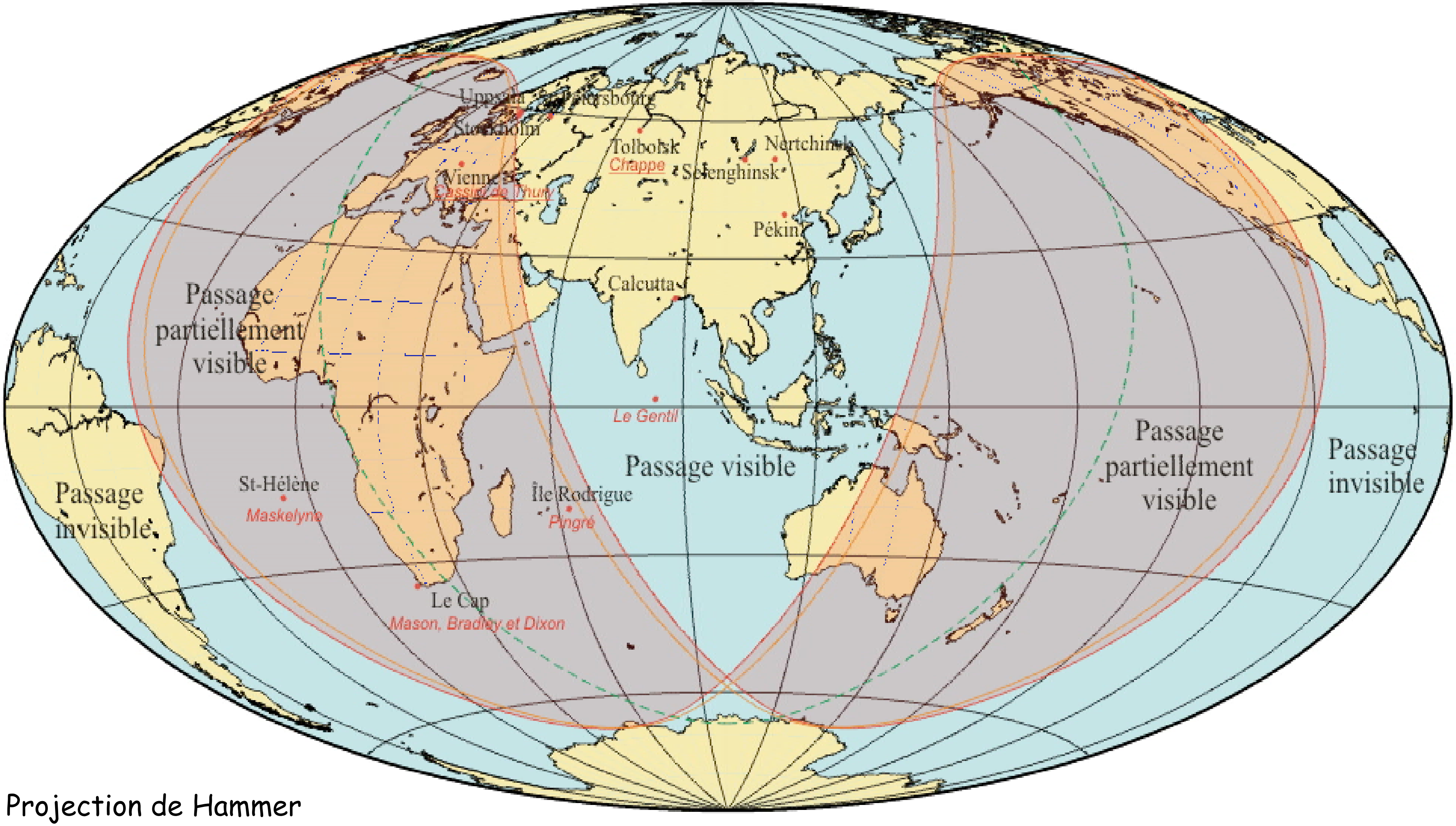
Now, the goal is to measure the solar system with accuracy

All nations will contribute, mainly France and England

But:

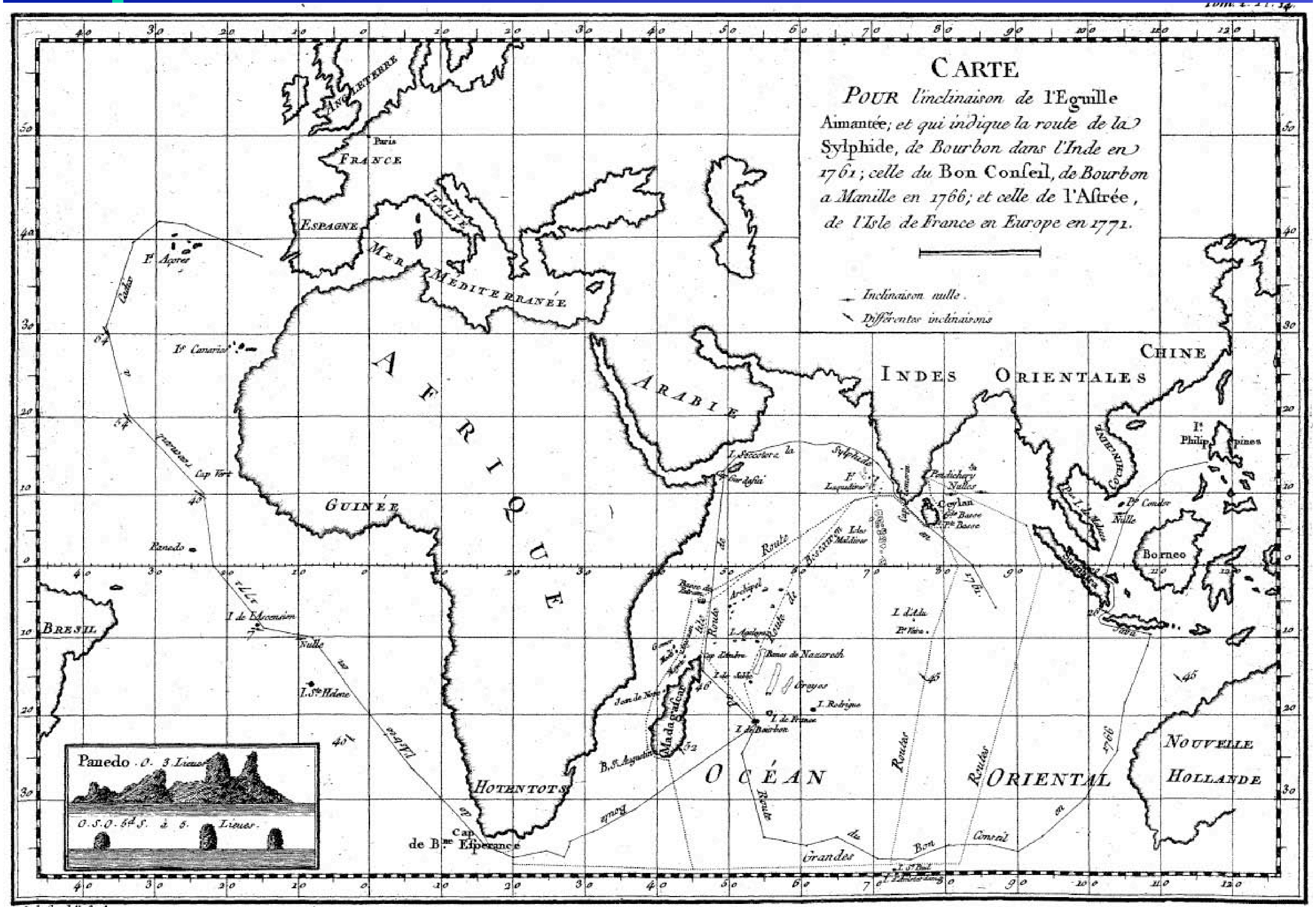
- Longitudes are not sufficiently known.
- Clocks are not good timekeepers.
- Traveling is long and expensive
- Nobody has never seen a transit.

And on June 6, 1761, observing the transit needs to go far from Europe



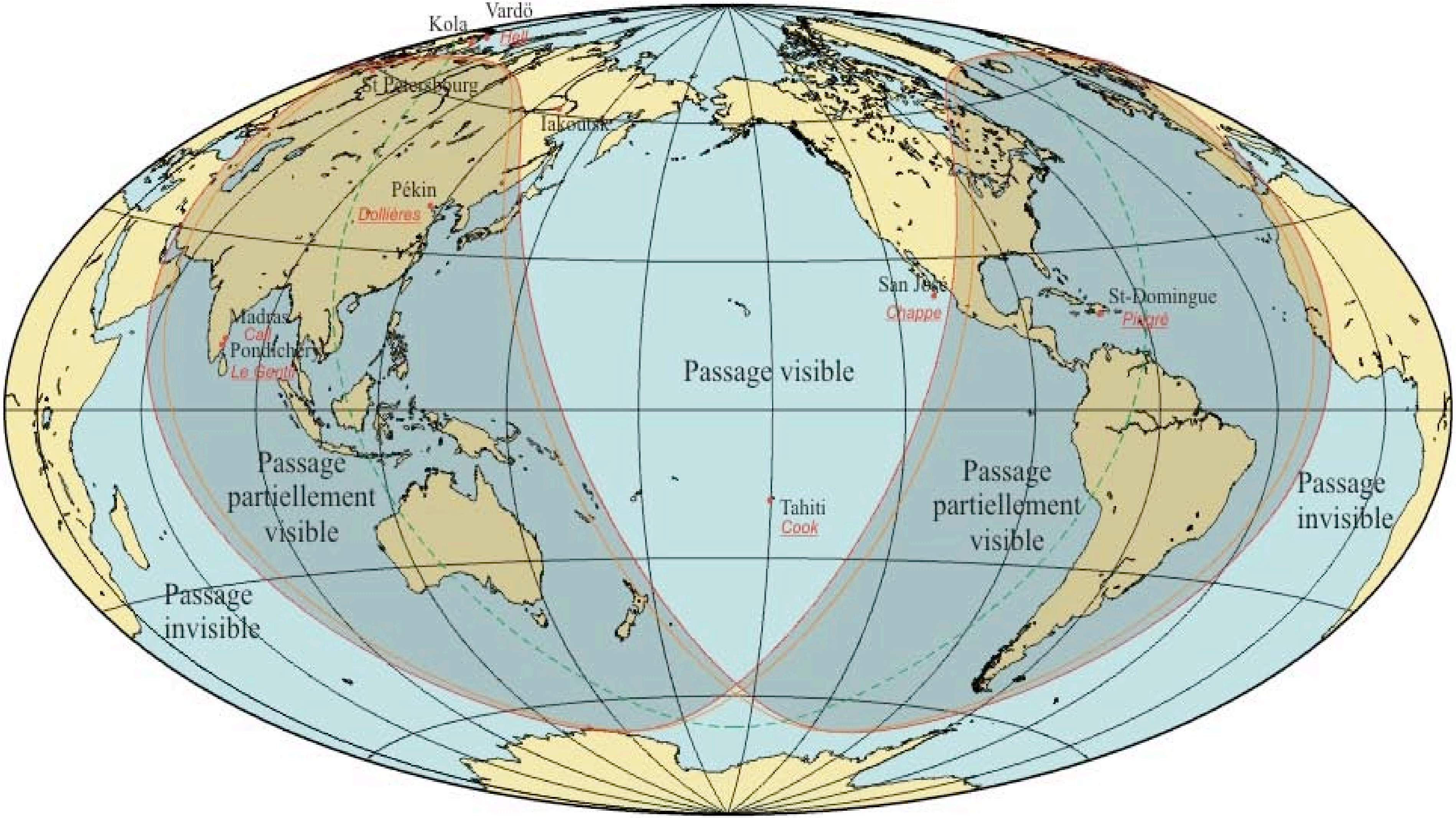
Projection de Hammer

The long voyage of Le Gentil



The « seven years » war (1756-1763) did not help astronomers

Long voyages also for the transit of 1769



The transit of 1769: Cook in Tahiti

« Cape Venus »

What results for the AU ?

- Bad results in 1761 due to the inexperience of the astronomers

8.5" < P < 10.5"

125.1 Mkm < AU < 154.6 Mkm

bad longitudes and black drop

- Good results in 1769

8,43" < P < 8,80"

149.3 Mkm< AU < 155.9 Mkm

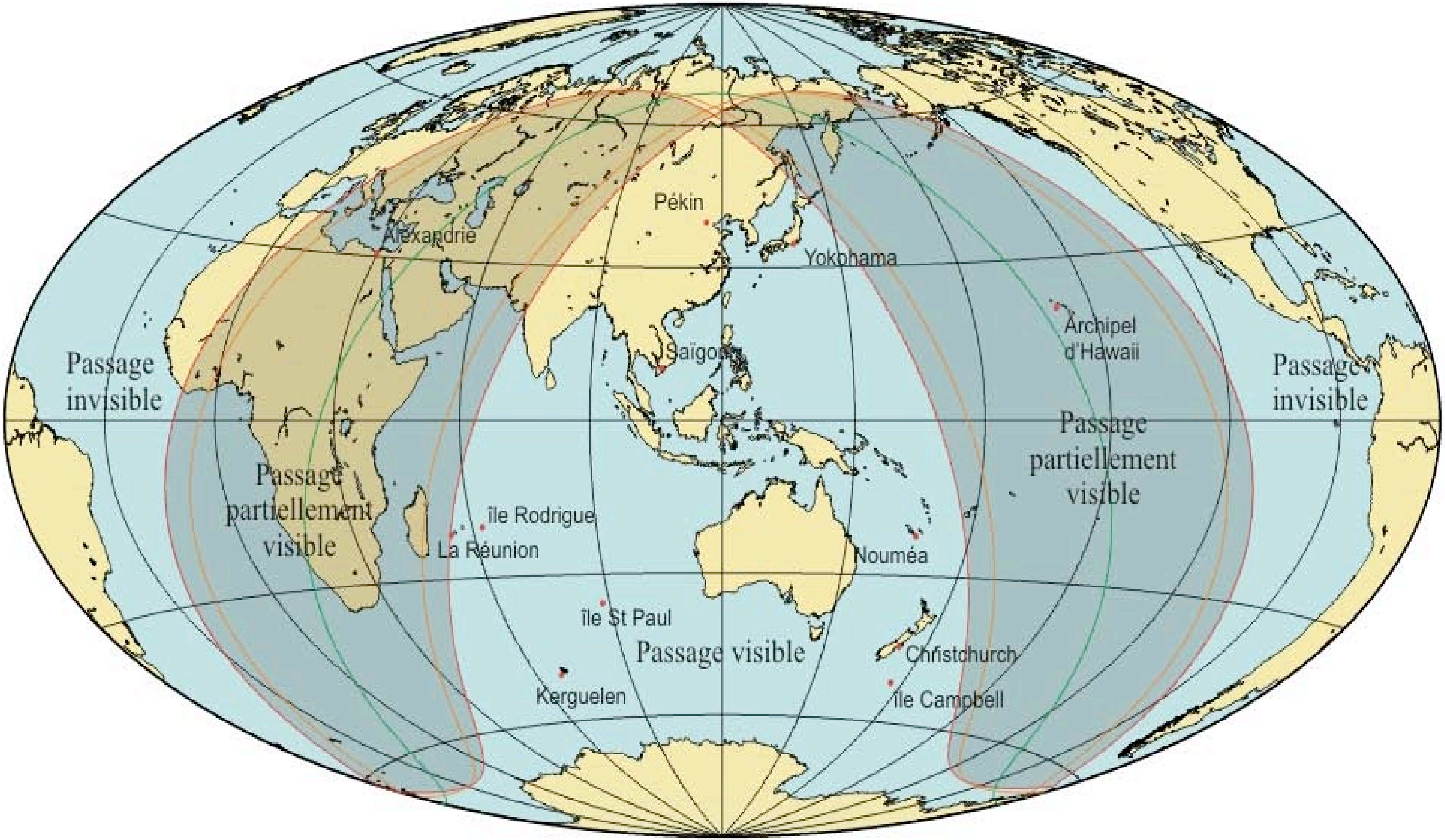
- Remember « true » AU = 149.597870 Mkm

New challenges after the war of 1870: the triumph of science and technics

- Good longitudes thanks to the telegraph
- Good time keepers
- Faster travels
- A new method: recording images thanks to daguerreotypes
- Astronomers have the written experience of the past observations

- However, the transits of Venus are no more useful

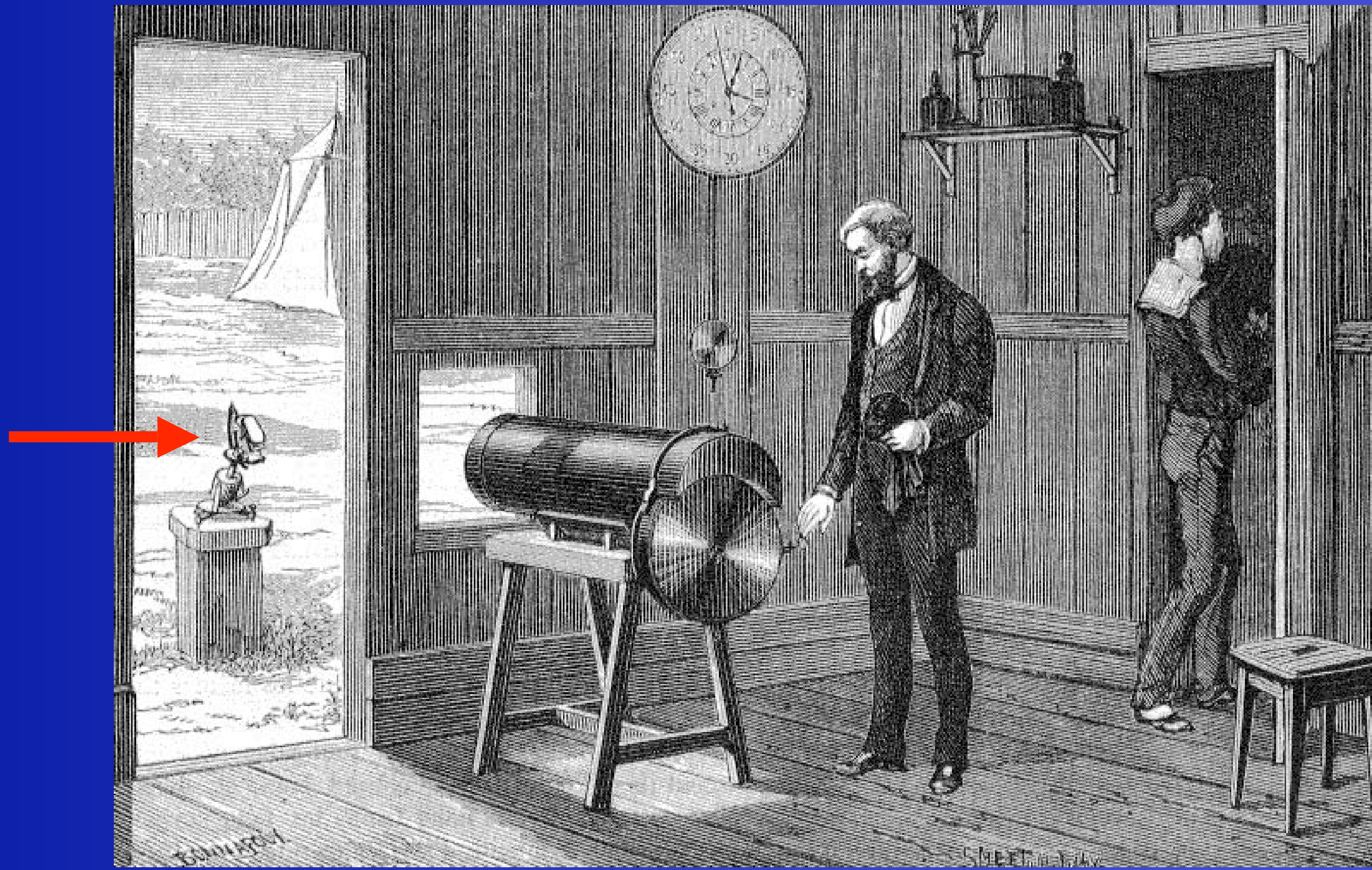
Le passage du 9 décembre 1874



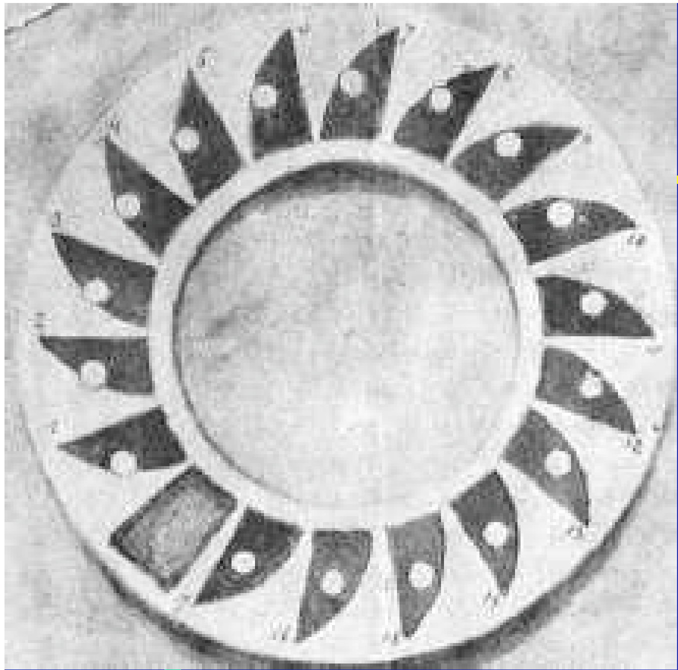
The daguerreotype of Mouchez at Saint-Paul

•124 daguerreotype plates corresponding to 443 exposures, and 47 photographic plates corresponding to 142 exposures

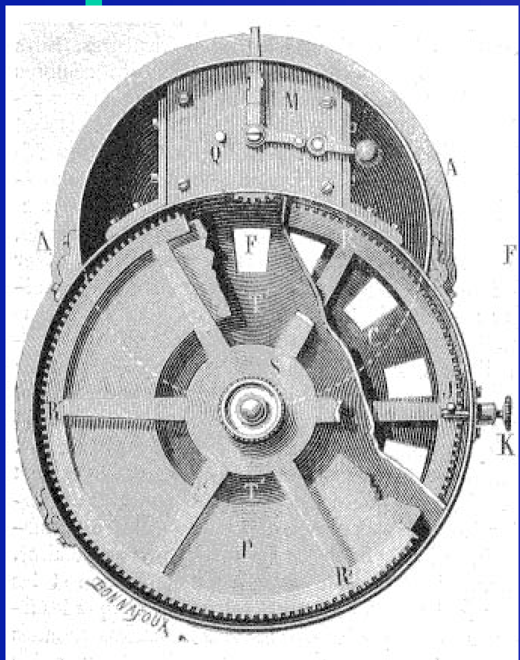
Janssen invents the photographic revolver



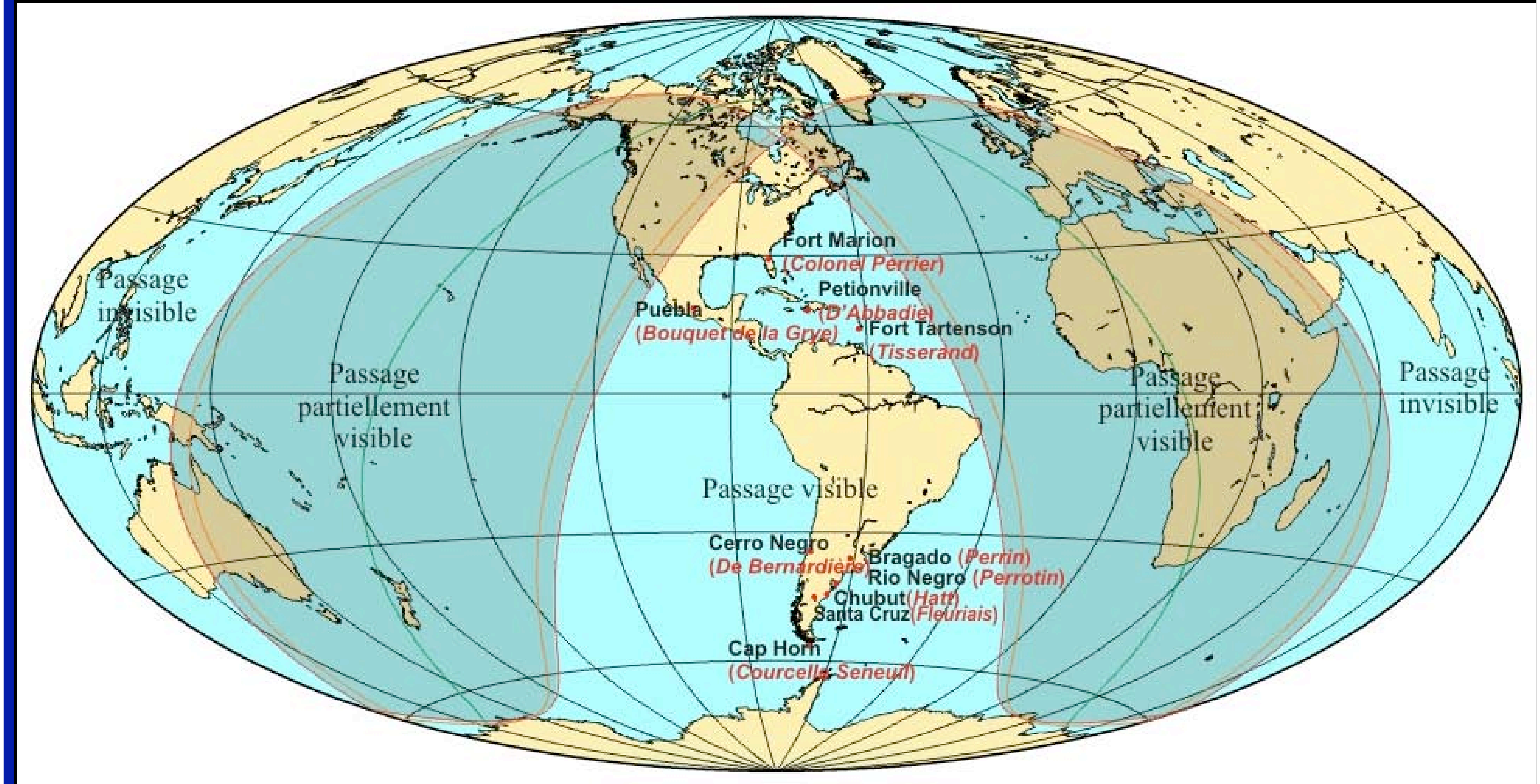
and Foucault invents the siderostat



Observation of 1882 in Japan
by Janssen



Le passage du 6 décembre 1882



On sait que désormais le passage de Vénus ne sera plus suffisant

What results for the AU ?

- Newcomb used the observations of the XVIIIth century and shows that with the longitudes corrections, the results of 1761-69 are the same than those of 1874-81!

$$8.790'' < P < 8.880$$

$$147.960 \text{ Mkm} < AU < 149.480 \text{ Mkm}$$

- Remember « true » AU = 149.597870 Mkm

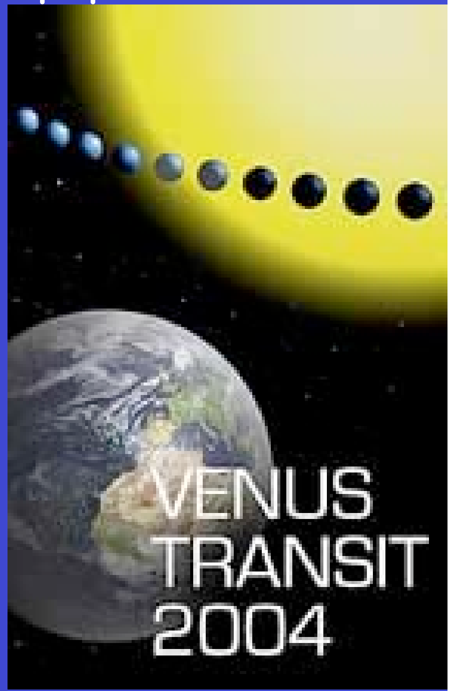
A new challenge:
showing how works an international scientific programme:
the European project VT-2004

- Making the measure of the AU as during the past centuries
- Replacing the astronomers by general public, amateurs, pupils and students
- Using Internet to avoid long travels

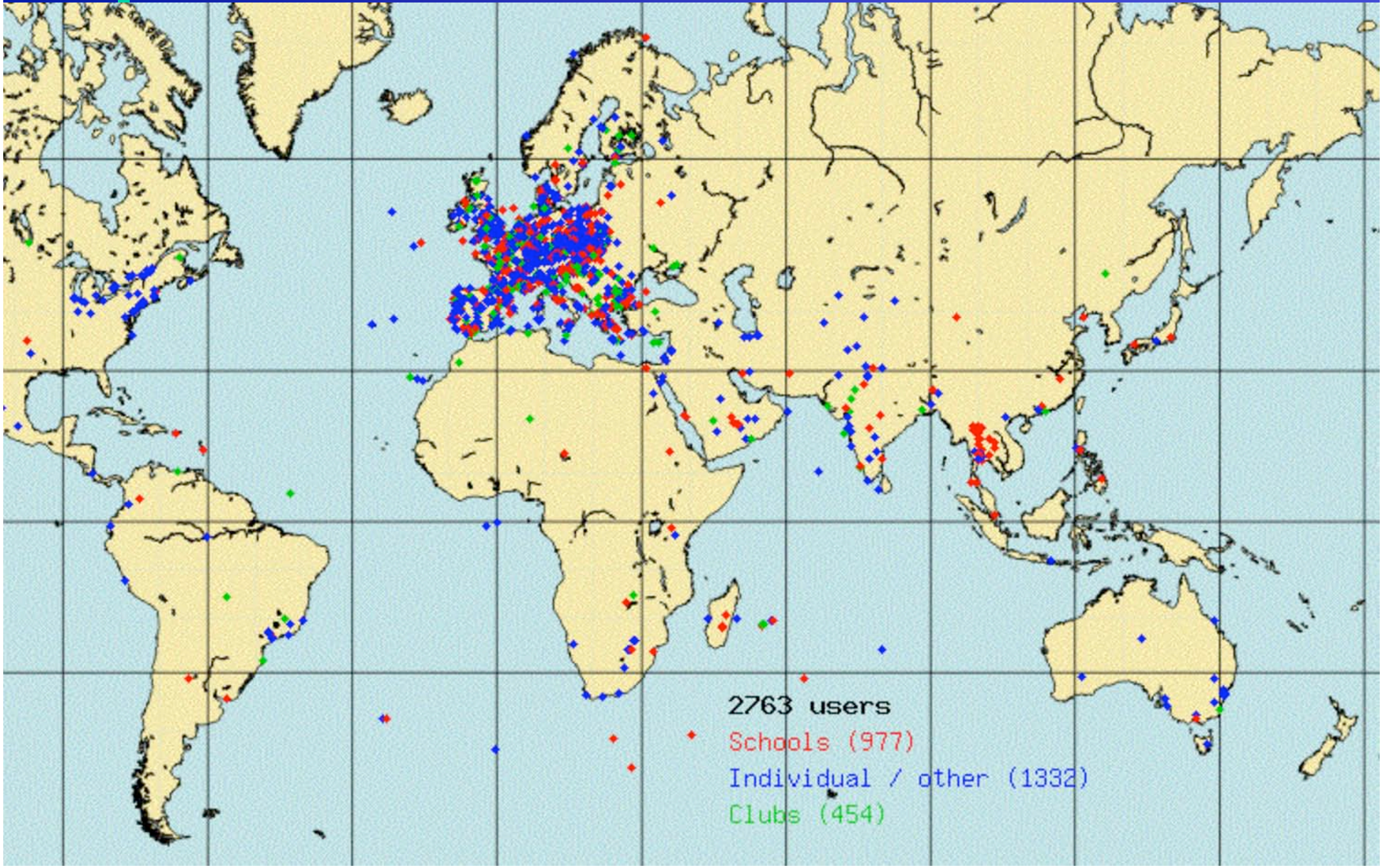
- Sending all the measures to a center of calculation

in Paris which will determinate the value of the AU

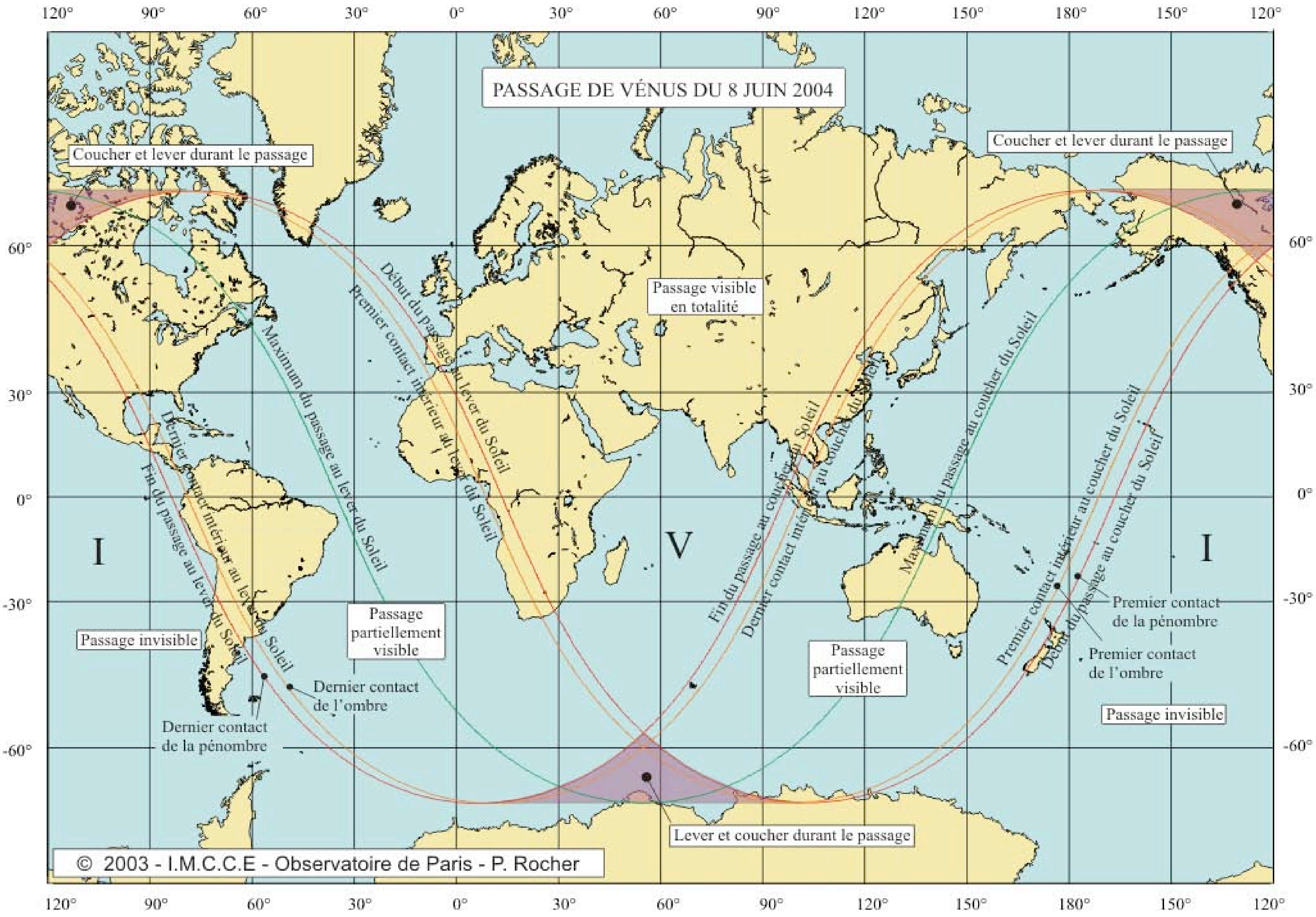
http://vt2004.imcce.fr

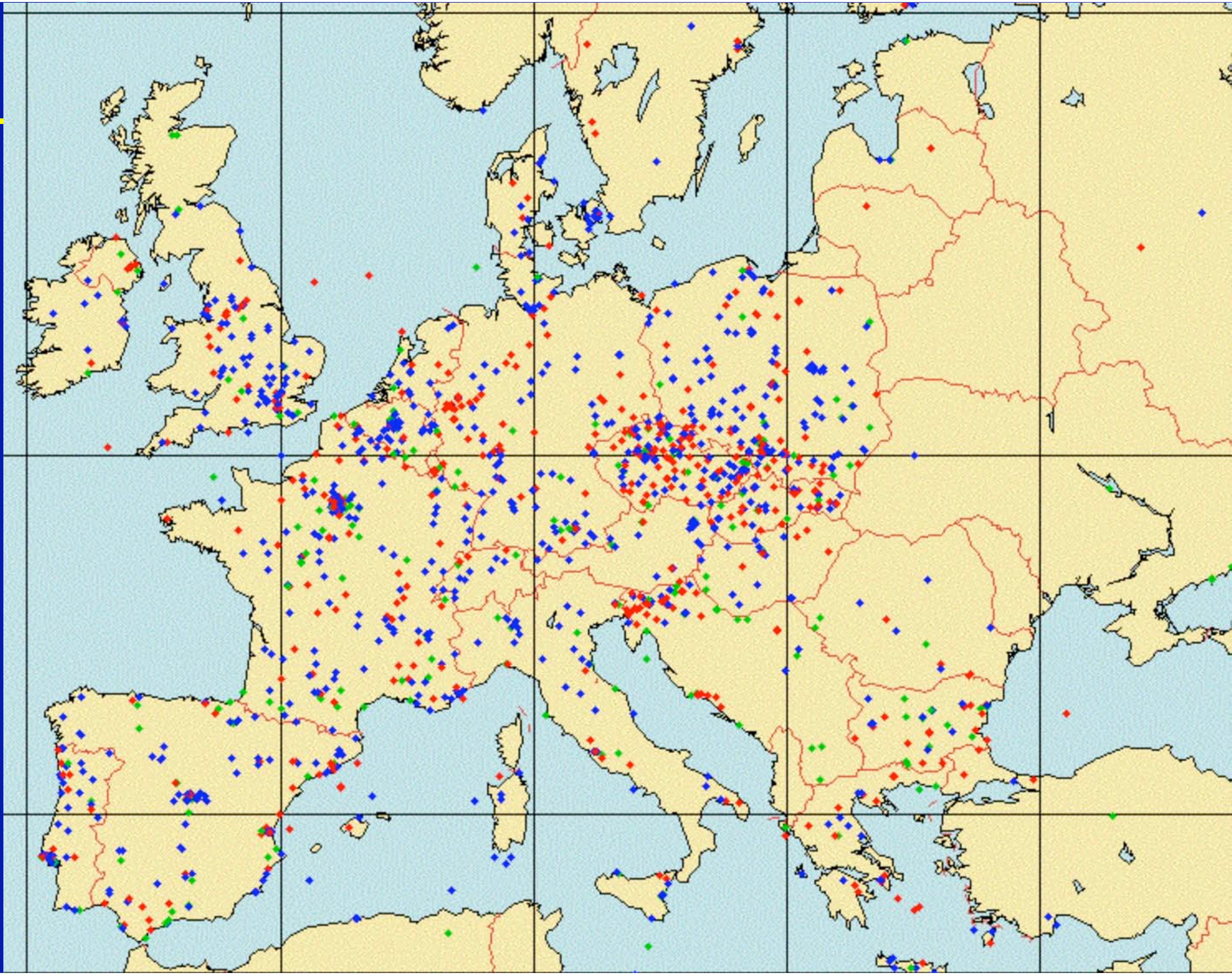


The international network of the VT-2004 program



Where the transit was observable





The timings received from 1500 observers

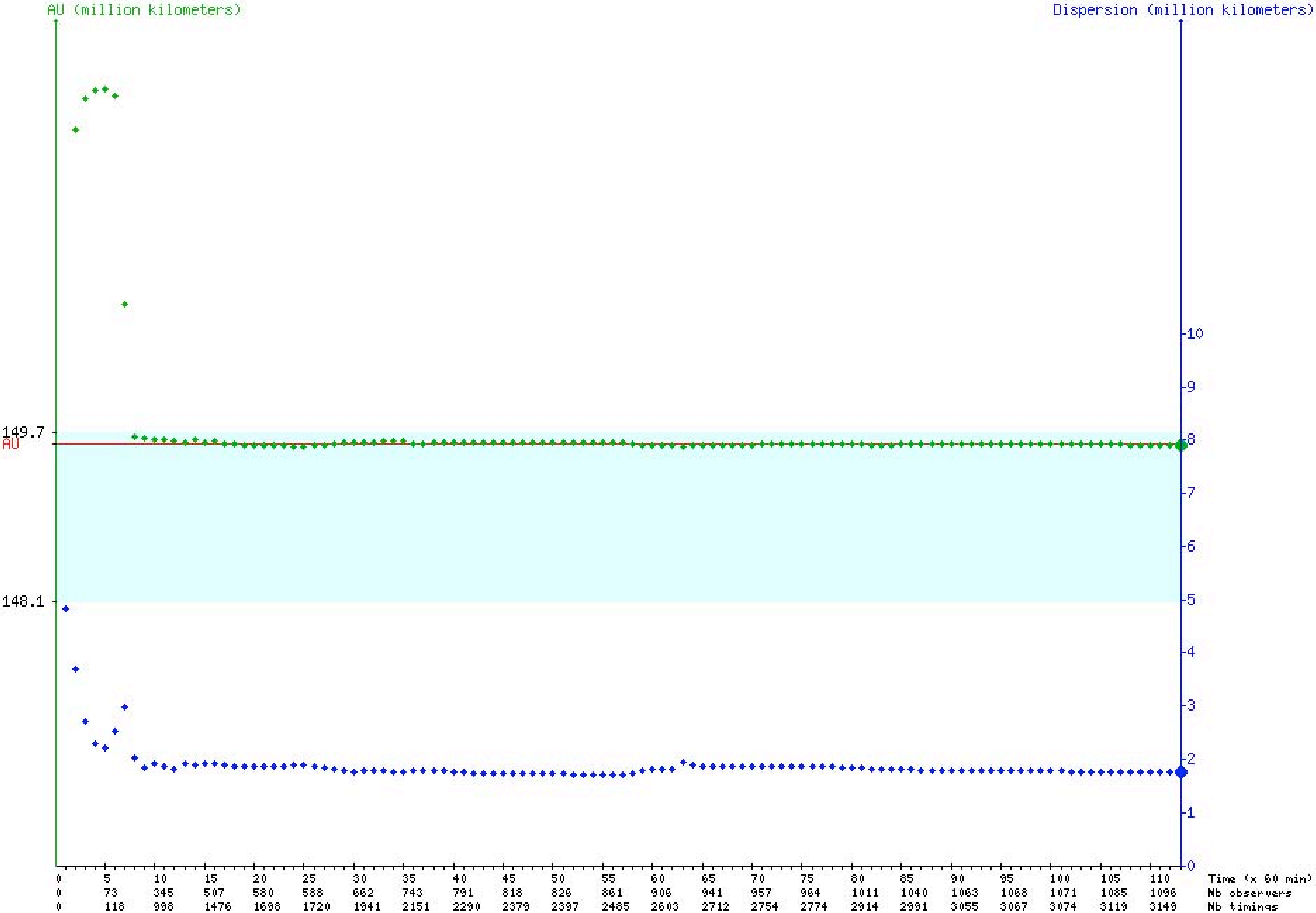
	T1	T2	T3	T4	all
Europe	676	1105	1297	1137	4215
Africa	8	14	21	20	63
Americas	3	3	30	27	63
Asia	35	59	60	32	186
Australia	9	14	0	0	23
all	731	1195	1408	1216	4550

Number of timings received

Dt = T(observed) – T(predicted)

1066 observations : |DT| < 8s
583 observations : |DT| < 4s

First, calculating the AU in real time



The calculation of the AU in real time

An average was made during the arriving of the data on June 8, 2004:
this has never been made before and mixed all observations

- On June 18
- Registered: 2228
- Observers: 1440
- Contacts observed: 4367
- AU calculated = 149529684 km
- Diff. to AU = 68186 km

- On July 10
- Registered: 2534
- Observers: 1510
- Contacts observed: 4509
- AU calculated = 149534170 km
- Diff. to AU = 63700 km

Since all the timings were used, we introduced a constraint: the Sun may not be at the infinite...
This improved each individual determination of the AU but did not change the final average.

Attention, the observers sent timings and not values of the AU!

Second, the linearized calculation with selected data

- For each observation:

What should be the AU to minimize the difference between the observed value and the theoretical one?

(no constraint but selected data after iteration)

- The final value of the AU using the best data :

(583 observations)

149 608 708 km

- Diff. to the « true » AU = 10 838 km
- Standard error: 11 835 km

- *This method is the best since we did not choose neither the sites of observation, nor the precision of the data*

Third, trying to make Delisle's calculation

- Delisle's method needs to associate pairs of observations to calculate the parallax
- Unfortunately the observers were not well-situated
- The result is:

with 4386 pairs, (1066 observations)

AU= 149 840 958 km +/- 310 577 km

diff. to « true » AU: 243 088 km

Fourth, trying the Halley's method

- We need observations of the duration from well-situated observers:

Only 10 pairs may be associated using the Halley's criteria and unfortunately none having a sufficient accuracy to get a value of the AU

Quelques remarques sur les résultats obtenus le 8 juin 2004

- Nous avons travaillé en temps réel alors que Delisle a attendu de recevoir toutes les mesures pour faire ces calculs
- ➔ utilisation d'un algorithme de calcul convergent

- Nos observateurs étaient disposés n'importe où alors que Halley avait défini des zones optimales pour placer les observateurs
- ➔ les bonnes mesures ne donnent pas toujours les meilleurs résultats

- Les observateurs ne mesuraient pas une distance mais un temps
- ➔ on devait donc calculer une UA pour chaque observation puis faire la moyenne de toutes les données successivement

Comparer les différents calculs de l'UA

- XVIIème siècle:

Horrocks, UA= 94 000 000 km, diff. à l'UA : 55 597 870 km

- au XVIIIème siècle :

- Pingré et Short, 1761, UA= 138 540 000 km +/- 14 400 000 km, diff. à l'UA 11 057 870 km

- Lalande et Pingré, 1761 & 1769, UA= 151 217 000 km +/- 1 512 000 km, diff. : 1 619 130 km

- Newcomb, 1890, UA= 149 668 378 km +/- 825 000 km, diff. à l'UA : 70 508 km

- au XIXème siècle :

- Newcomb, 1890, UA= 149 668 378 km +/- 330 000 km , écart à l'UA 70 508 km

- Au XXIème siècle:

-Delisle: UA= 149 840 958 km +/- 310 577 km, écart à l'UA 243 088 km

-Temps réel:UA = 149 529 684 km +/- 55 059 km ; écart à la « vraie » UA : 68 186 km

-Observations sélectionnées: UA = 149 608 708 km +/- 11 835 km

Comparing the calculated AU

- XVIIème siècle:

Horrocks, UA= 94 000 000 km, diff. à l'UA : 55 597 870 km

- au XVIIIème siècle :

- Pingré et Short, 1761, UA= 138 540 000 km +/- 14 400 000 km, diff. à l'UA 11 057 870 km
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- Au XXIème siècle:

-Delisle: UA= 149 840 958 km +/- 310 577 km, écart à l'UA 243 088 km

-Temps réel:UA = 149 529 684 km +/- 55 059 km ; écart à la « vraie » UA : 68 186 km

-Observations sélectionnées: UA = 149 608 708 km +/- 11 835 km

Comparison between determinations of AU

Epoch	AU in km	Estimated error	Diff. to « true » AU	method
XVIIth	94 000 000	unknown	55 597 870	Horrocks
XVIIIth: 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	recalculated by Newcomb
XIXth: 1874 & 1882	149 670 000	330 000	72 130	Newcomb
XXIth: 2004	149 608 708	11 835	10 838	VT-2004

Conclusions

- Before the XVIIIth century, the AU was strongly underestimated
- The XVIIIth century determined an accurate AU
- The XIXth century improved the value only because the longitudes were better known
- The XXIth century provided a very accurate value in spite of the inexperience of the observers because:
  - GPS provided good longitudes
  - UTC was available everywhere
  - The optics of the telescopes minimized the black drop
  - The CCD receptors allowed to record the event and to determine accurate timings

The educational project for next years:

-Make a database with the timings and images made on June 8, 2004

-Provide the tools for the analysis of images

-Make possible the virtual observation of a transit

-Calculate the AU thanks to the database

Rendez-vous in 2012