Le temps-fréquence à l'Observatoire Géodésique Fondamental de Calern

- CNRS - GéoAzur - OCA – UNICA

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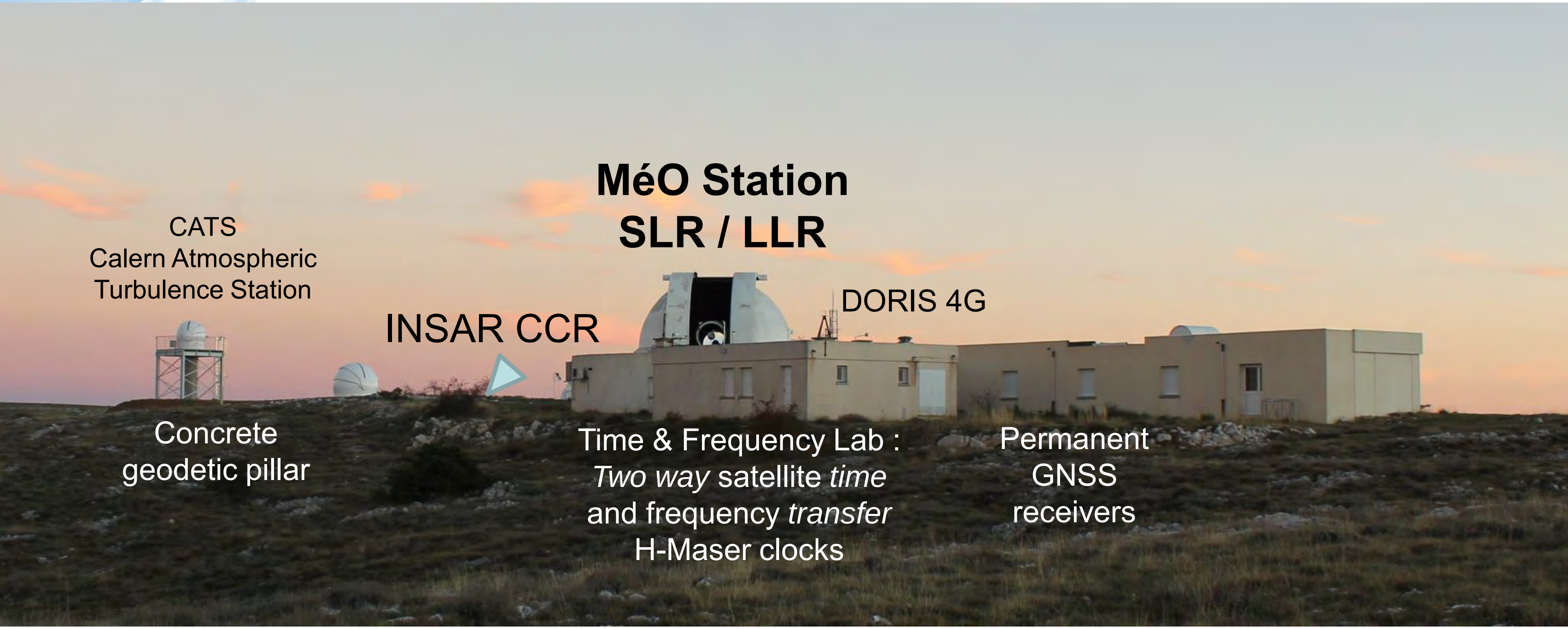
Observatoire de la Cote d'Azur
Calern Site

- Site inaugurated in 1974
- Calcerous plate of 20 km² in the Grasse hinterland
  - Altitude : 1270m. longitude 6,9230°E ; latitude 43,750° N
  - Good compromise between accessibility (20 km of Grasse) and astronomical quality

A MULTI-TECHNIC OBSERVATORY



MéO pour « Métrologie Optique »

Wettzell Fundamental Geodetic Observatory (Germany)

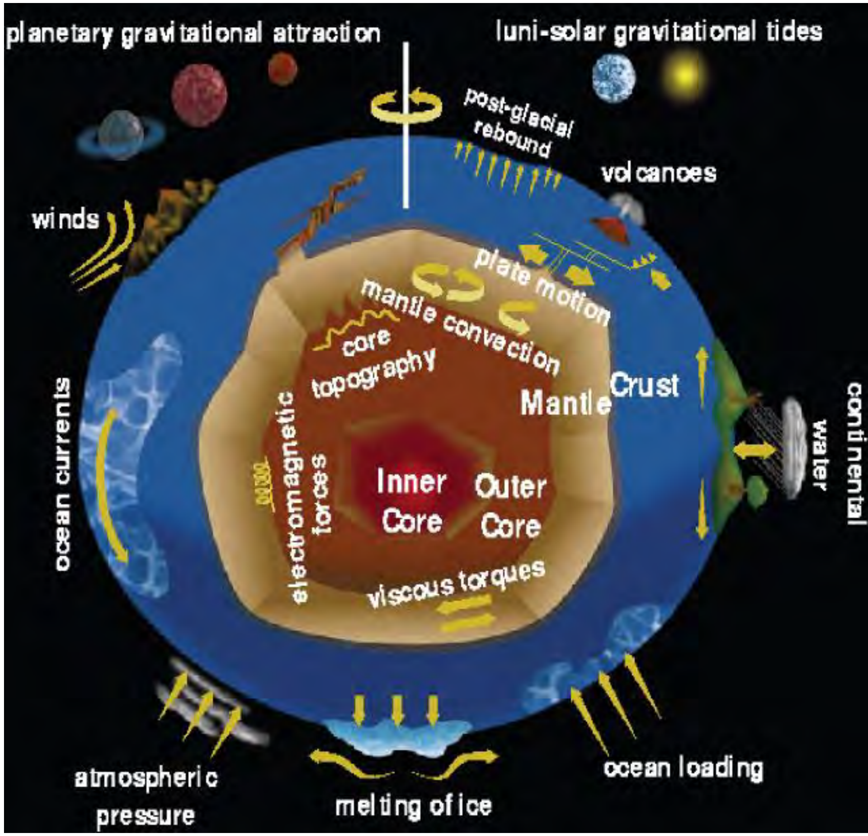
- Two SLR stations
- A 20 m radio telescope for intercontinental VLBI measurements (RTW)
- A twin system consisting of two 13 m radio telescopes, also for VLBI measurements (TTW-1 and TTW-2)
- Several Multi-GNSS receivers
- A beacon for the French Doppler system DORIS

- Several atomic clocks and hydrogen masers and a fibre-optic time distribution system with delay compensation
- A ring laser in an underground observatory for monitoring the Earth's rotation
- A superconducting gravimeter
- A complementary measuring equipment for ground and atmosphere monitoring (seismometer, tiltmeter, hydrological sensors, climate station, water vapour radiometer, temperature profiler, cloud detector)

Scientific challenges in spatial geodesy

- Held by the International Association of Geodesy (IAG)
  - Development of few multi-technic Observatories **GGOS** (Global Geodetic Observing System) with homogeneous network on Earth
  - Coordinate and link data from different instruments (ITRF)
  - **Millimetric accuracy and precision**

- What should be improved ?
  - Improvement of the metrological performances of SLR station
  - Automatic operation
  - New station in the South hemisphere

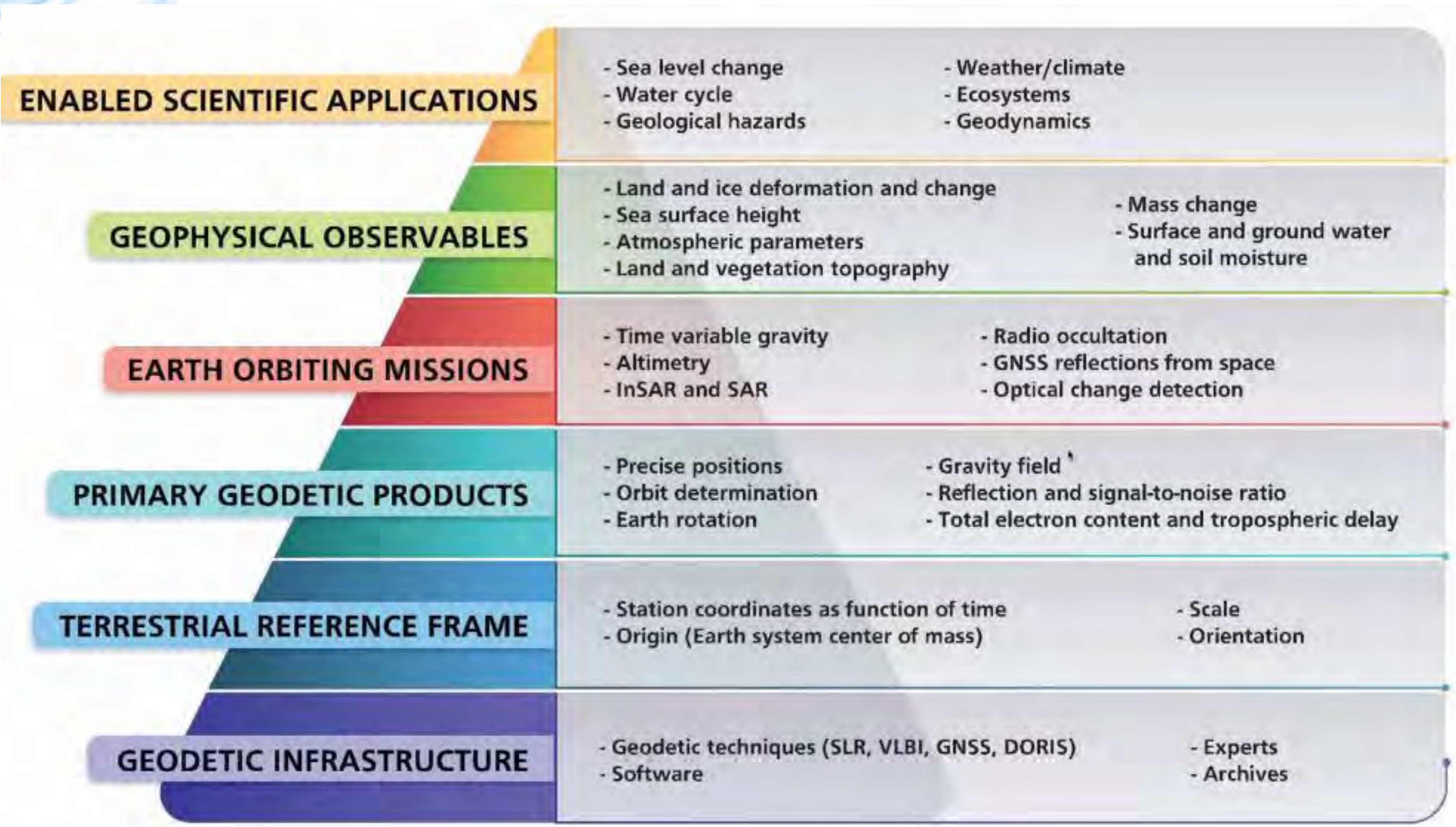


Technics contribution:

Table 2.1: Applications of space geodetic techniques, adopted version based on: Rothacher (2003).

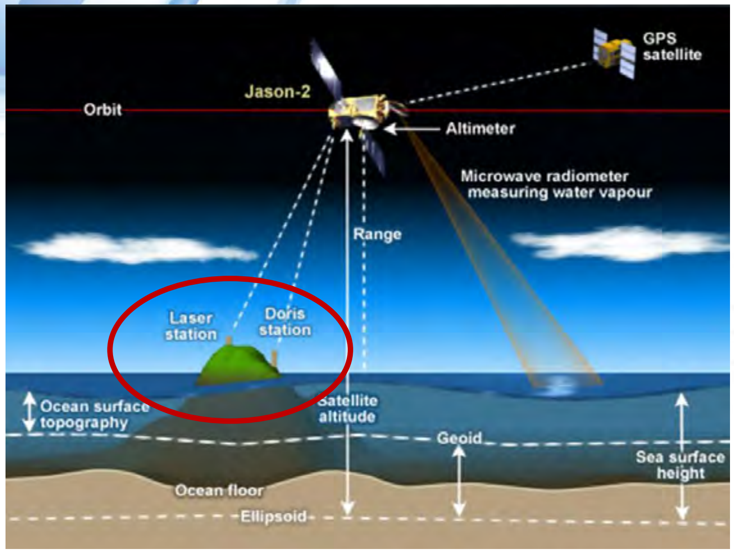
Parameter type	VLBI	GNSS	DORIS	SLR	LLR	Altimetry, InSAR	Gravity missions
Quasar coordinates	XXX						
Nutation	XXX	X		X	XX		
Polar Motion	XX	XXX	X	XX	X		
UT1-UTC	XXX				XX		
Length-of-Day	XX	XXX	XX	XXX	X		
Sub-daily ERPs	XXX	XXX	XX	XX			
ERP Ocean Tide Ampl.	XX	XX	XX	XX		XXX	XX
Station coordinates	XXX	XXX	XXX	XXX	XX	X	
Gravitational const.		X	X	XXX	XX		
Geocenter		XX	XX	XXX	X	X	X
Gravity Field		XX	XX	XXX	X	X	XXX
Orbits		XXX	XXX	XXX	XXX	XX	XX
Ionosphere	XX	XXX	XX			XX	XX
Troposphere	XX	XXX	XX	X	X	XX	
Timing	XX	XXX	X	XXX		X	

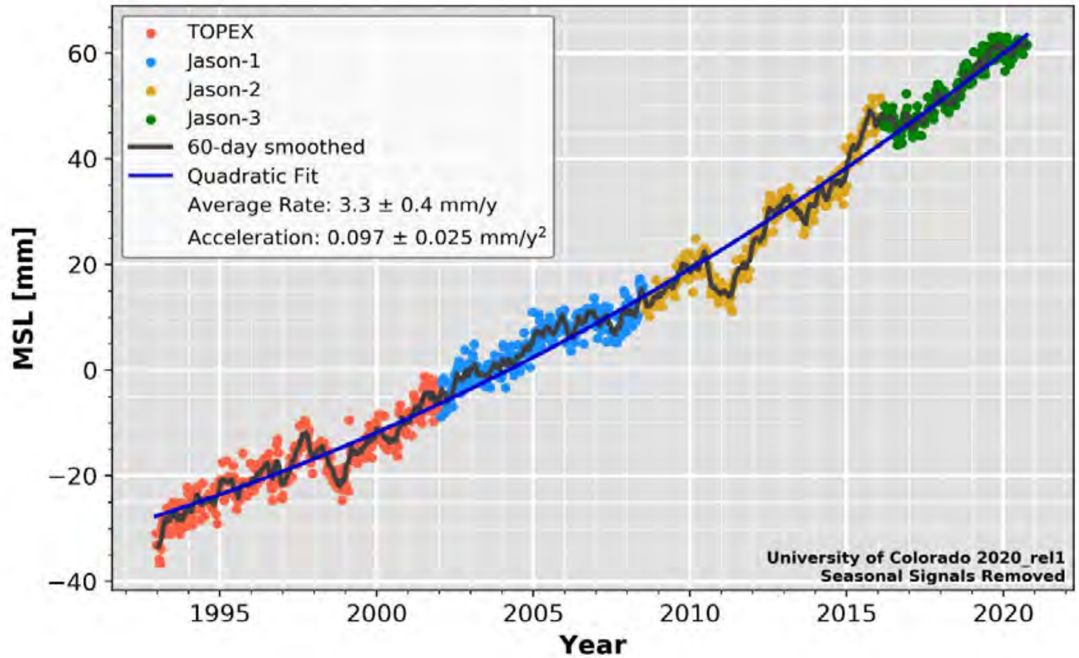
Spatial geodesy



National Academies: Evolving the Geodetic Infrastructure to Meet New Scientific Needs

Exemple: Le niveau moyen des mers



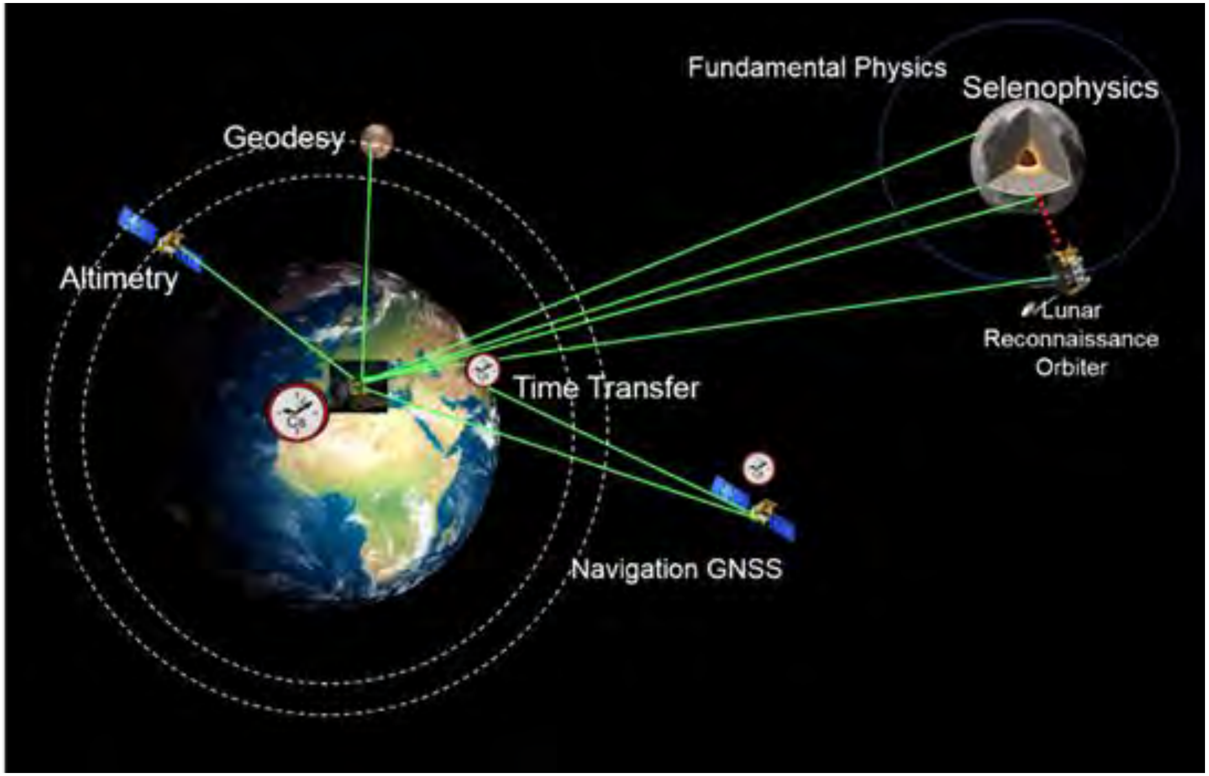


La géodésie spatiale permet la surveillance du MSL grâce à un cadre de référence terrestre précis (ITRF 2014- ITRF 2020), un suivi précis (SLR, GNSS, DORIS) des satellites d'altimètrie, la détermination quotidienne de l'EOP (UT1 par VLBI), des variations de gravité dans le temps déterminées par GRACE et GRACE-FO et le suivi SLR des satellites géodésiques pour déterminer les paramètres du géoïde (C20 et C30).

Beckley, B.D et al. (2021): "Integrated Multi-Mission Ocean Altimeter Data for Climate Research complete time series Version 5.0", (https://doi.org/10.5067/ALTTS-TJA50).

https://podaac.jpl.nasa.gov/dataset/MERGED_TP_J1_OSTM_OST_ALL_V50

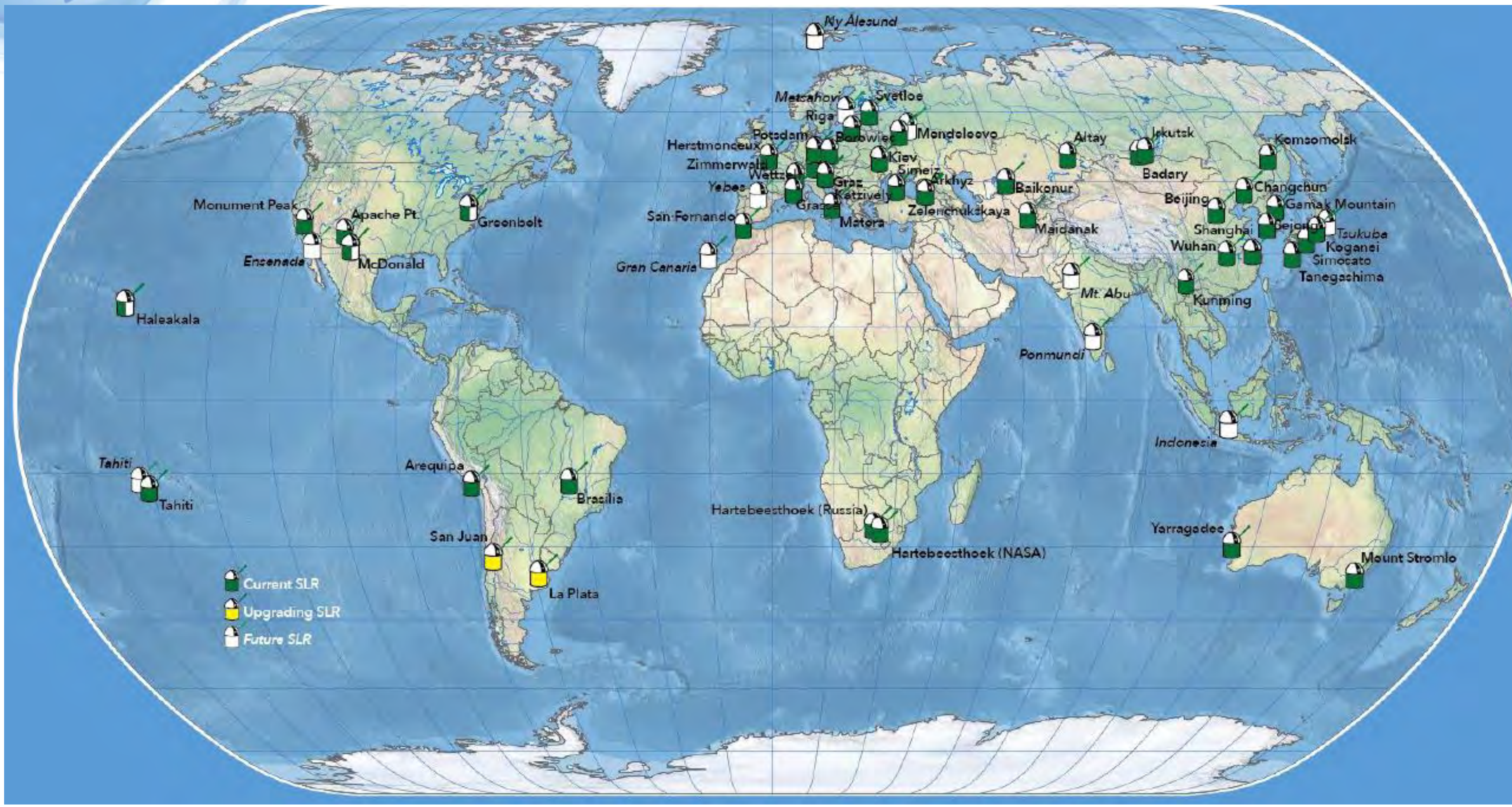
Laser link to probe Earth & the close universe



<u>Liens métrologiques précis :</u>

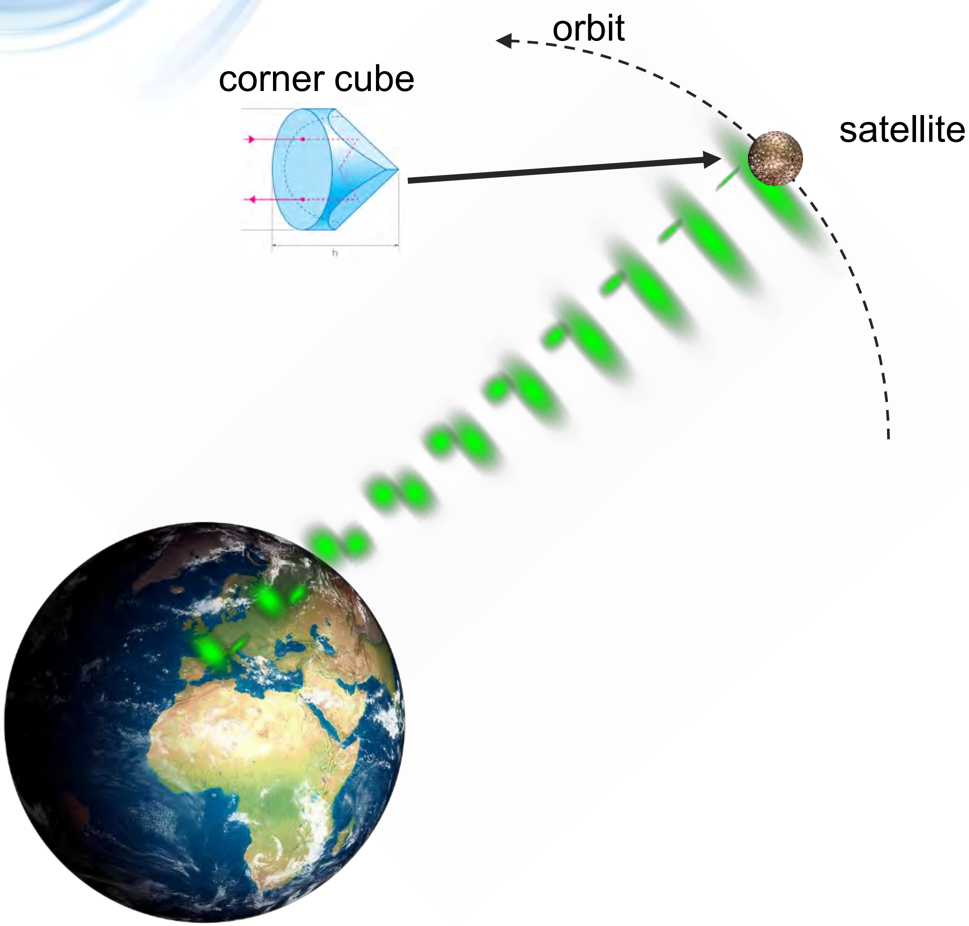
- Confronter les modèles relativistes d'éphémérides aux observations
  - Information sur les forces internes et externes des corps
- Références absolues de temps, d'espace, d'orientation
  - Tâche traditionnelle de l'astronomie (EOP-ITRF)
- Tests de la physique fondamentale
  - Red shift gravitationnel, Lense–Thirring, Isotropie de la vitesse de la lumière...

International Laser Ranging Service



- 40 SLR stations

Satellite Laser Ranging principle



- Measurement of the time of flight of laser pulses:

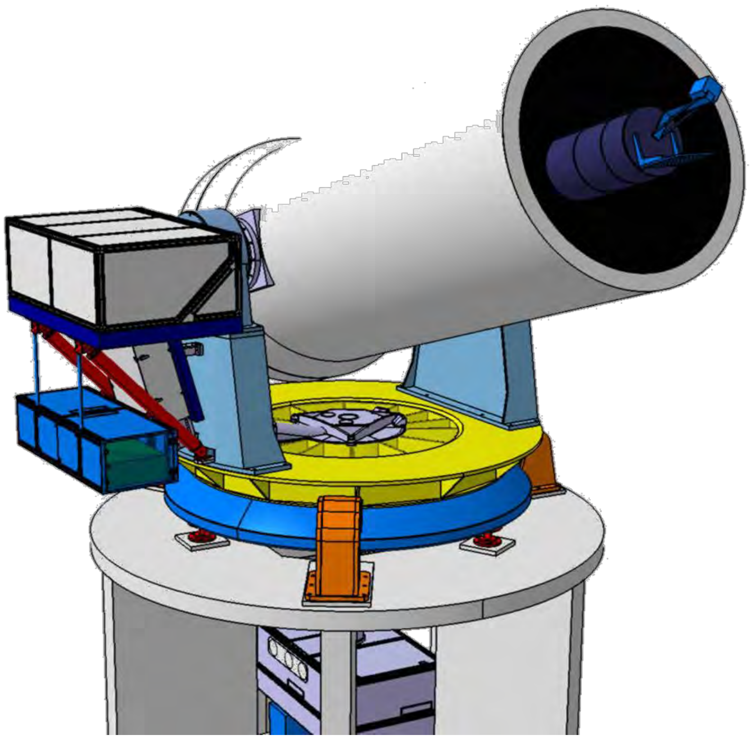
$$D = \frac{c.(t_{arrival} - t_{departure})}{2}$$

- The observable is time.
- D is a pseudorange
- Reference points:
  - Ground : the cross of the telescope axes
  - Space : the center of mass of the satellite

Measured distance: [300km – 420 000 km]
Accuracy ~10 mm
Precision ~ 10 mm

MeO (Métrologie Optique)

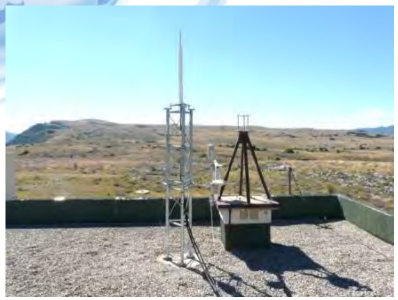
- Ritchey Chretien optical configuration
  - Primary Mirror: Parabolic 1540 mm
  - Nasmyth table (fold mirror)
- Encoders
  - Linearity: 1 arcsec
  - Repeatability error < 0.1 arcsec rms
  - Absolute accuracy < 2 arcsec rms
- Motorization
  - Direct drive Etel motors
  - Torque: 10000 Nm
  - Speed: 5°/s
  - Time constant: 0.1s



Time & Frequency lab (SNO « Horloges »)

- Active H-Maser (T4 science) (contribute to TAF)
- TWTFT system
- 3 GPS
- T-F Electronics (µphase stepper, 10MHz and PPS distrib,…)
- Event Timers
- Passive H-Maser (T4 science)

Common time scale for the technics



DORIS 4G

LLR + SLR

GNSS (CNES + IGN)

OCA Time scale

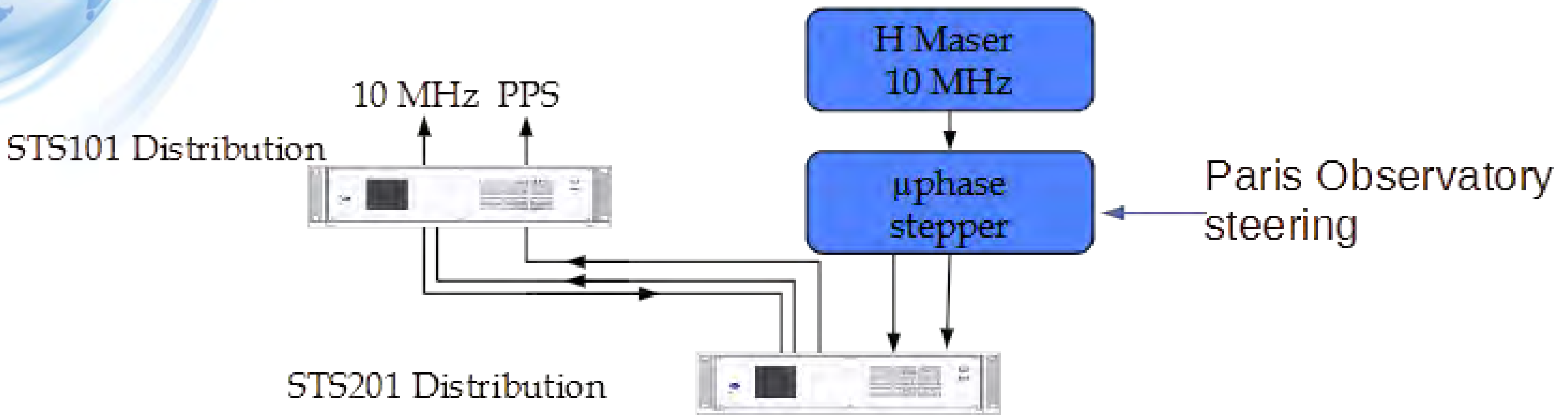
Clocks active + passive H-Maser + microphase stepper for steering

TWSTFT

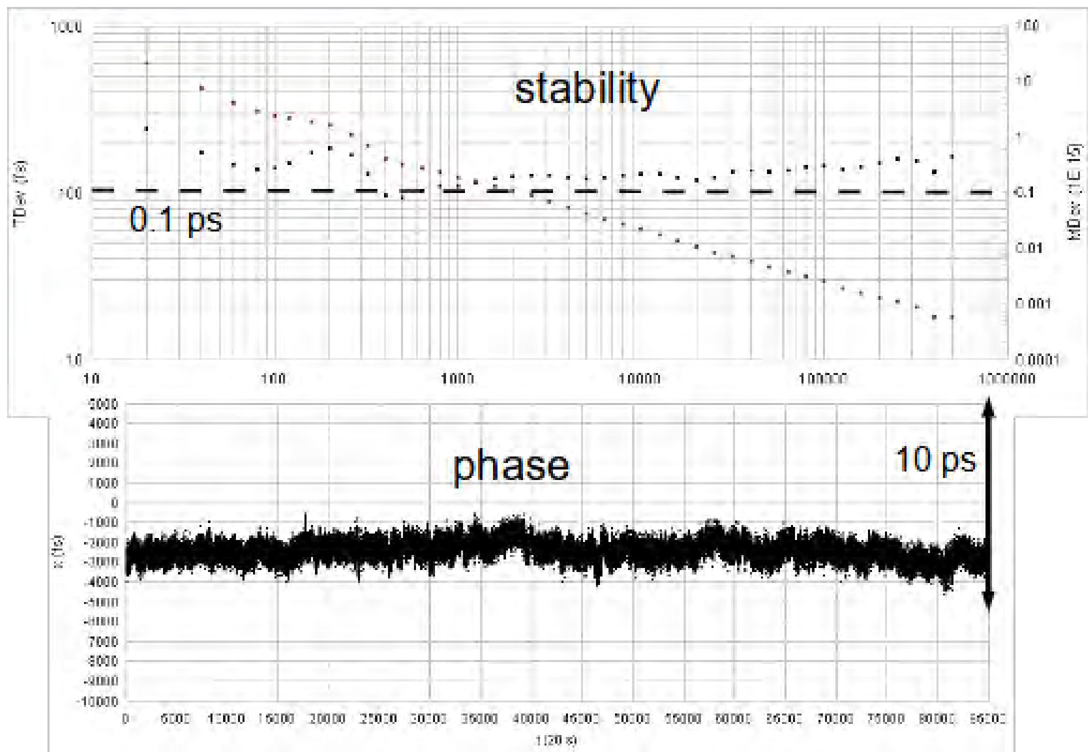
PolarX5TR +GTR50

TAF via OP-SYRTE

Internal distribution to SLR/LLR detection



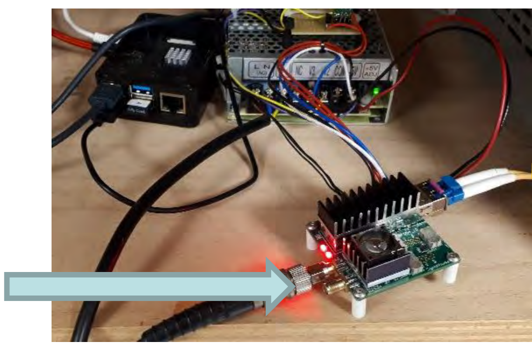
- STS distribution from CNES-T2L2 experiment
- In operation for SLR/LLR but not for the other geodetic techniques at the moment



Fibered Distribution System : STS 416

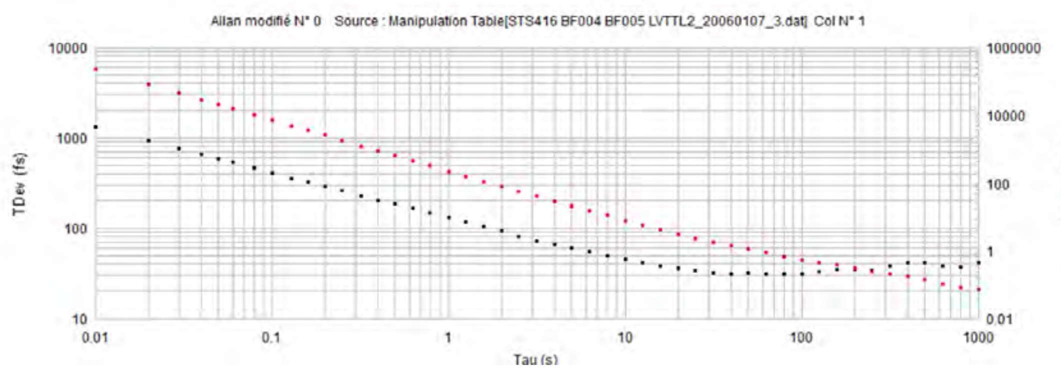
- Système de distribution fibré via module SFP en développement pour 10 Mhz et PPS

Input Signal single ou P/N pair



Fiber RX/TX pair

Output Signal single ou P/N pair

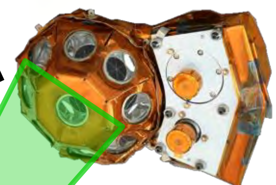


SigmaWorks
etienne.samain@sigmaworks.fr

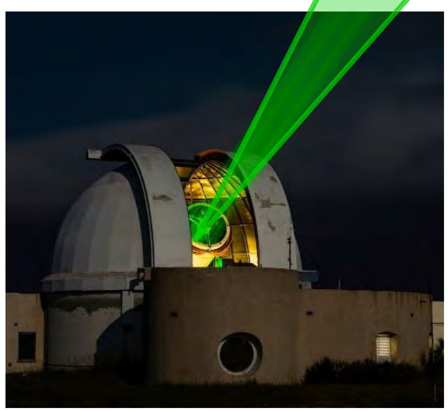
Le transfert de temps laser par satellite 2009-2017

Satellite
Jason 2

Mission T2L2



Active Laser Retro-Reflector
-Photodiode
-Event Timer
-Clock !

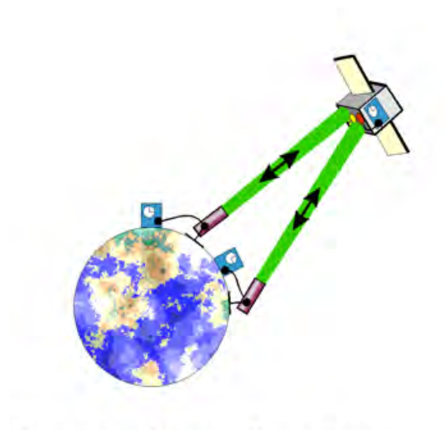


3 laser events recorded:

2 events in the ground time scale -> TOF
+
1 event in the space time scale
=
Time transfert from ground to space !

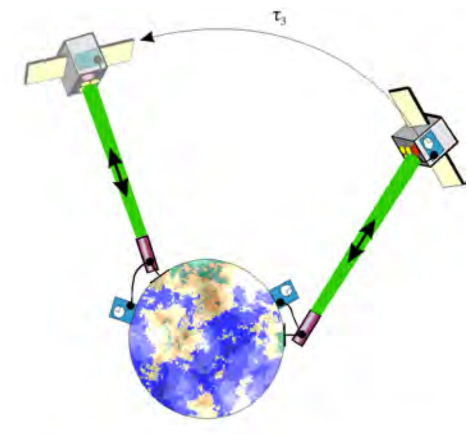
Le transfert de temps laser par satellite 2009-2017

- Deux possibilités



Common View

No noise added from the onboard oscillator



Non common View

Noise added from the onboard oscillator when the satellite is not visible by any station

Ground to ground time transfer in common view European campaign

Direct comparison between GPS CV & T2L2

For the two time transfer techniques GPS CV and T2L2, two independent relative calibration campaigns were undertaken with the same travel calibration equipment

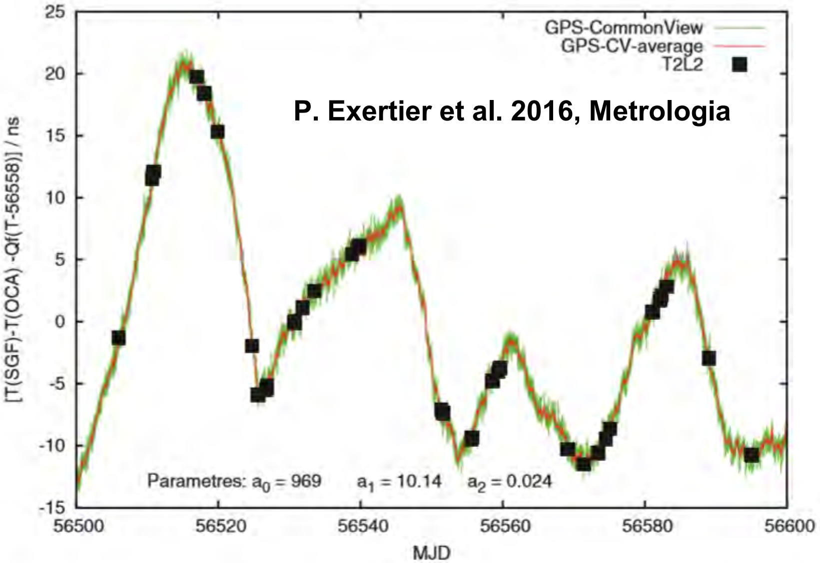
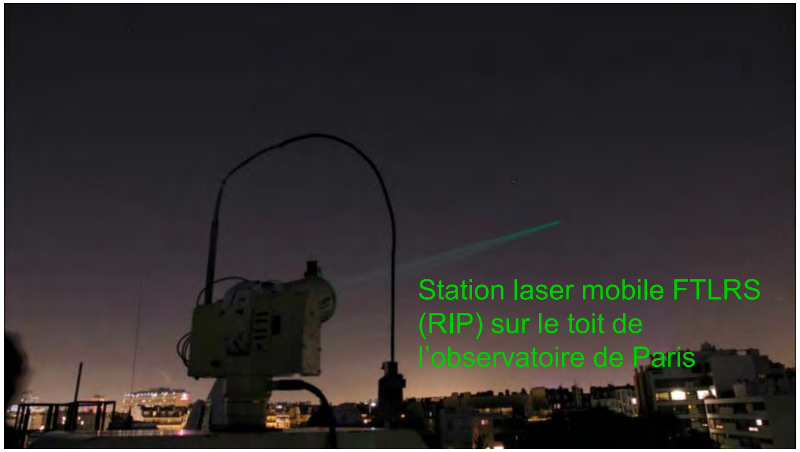


Figure 3. Time differences between time scale reference points in OCA and in SGF with a quadratic fit removed: green continuous noisy line is for GPS CV, red smoothed continuous line is for GPS CV filtered by a moving average over 13 samples, and blue squares are for T2L2.

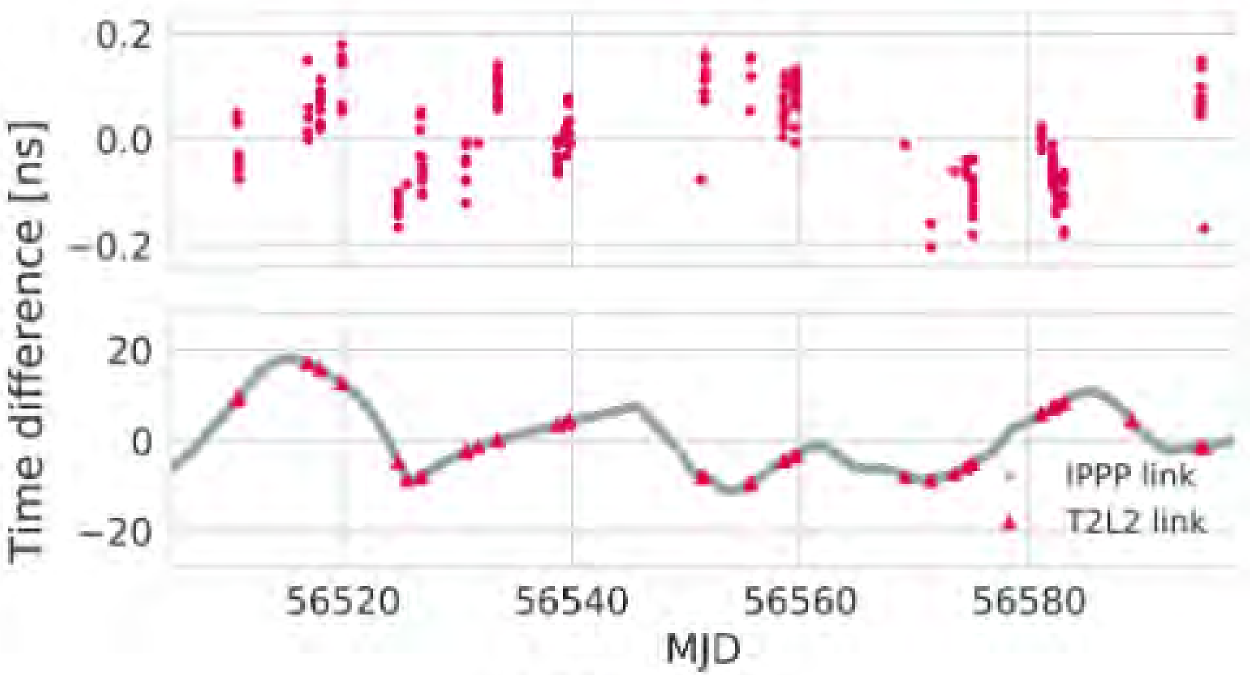


Time differences between GPS CV and T2L2 are no greater than 240 ps, with a standard deviation below 500 ps, mostly due to GPS CV.

Ground to ground time transfer in common view In European campaign

Comparison between IPPP GPS & T2L2

J. Leute et al. 2018



(a) SGF / OCA

Difference between IPPP and T2L2 link

Time difference after an identical quadratic fit has been removed.

Agreement between two independent space-based time transfer techniques:

- IPPP based on GPS carrier-phase observations
- T2L2 based on laser ranging

=> standard deviation below 100 ps for baselines on which T2L2 can operate in CV.

Le transfert de temps laser par satellite

- Synchroniser les échelles de temps des stations du réseau ILRS

Table 10
Huge time biases per period (MJD) and main phase jumps (unit in μs).

Station	Dates	Time bias	Jump
7090	56296–	−1.0	
	56786–	+1.2	−1.2
	56834–	+1.0	−1.0

Différence entre la position de la station vue par les lageos de Wettzell avec et sans correction du biais en temps

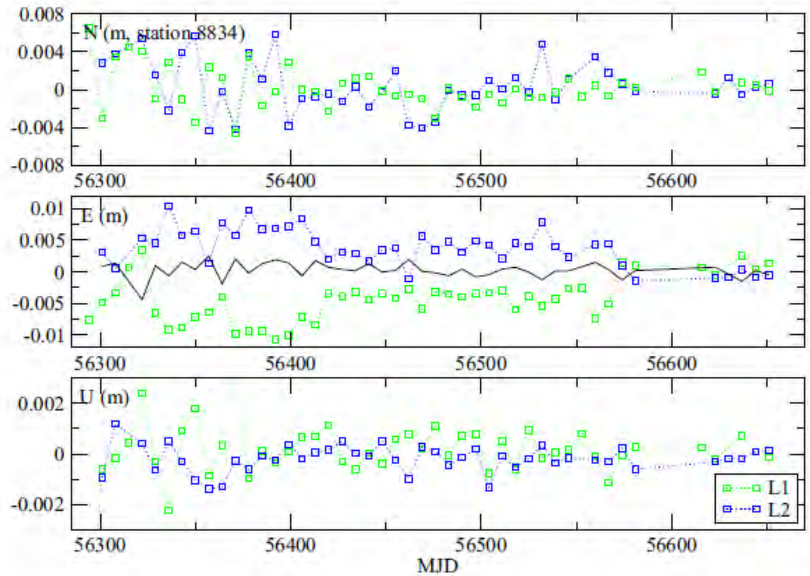
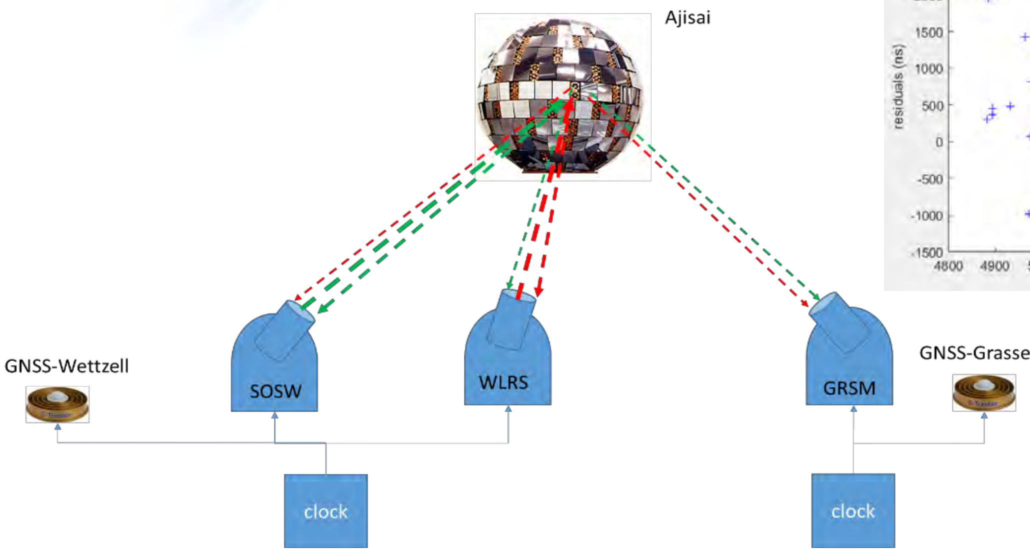
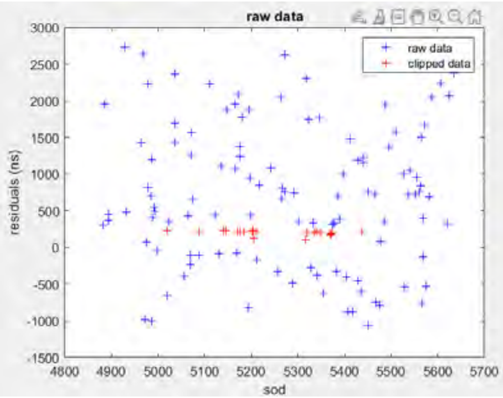


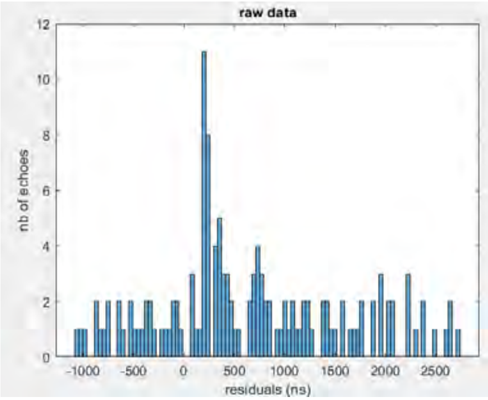
Fig. 11. Differences between standard (weekly) and TB-applied coordinate solutions (north, east, up; station Wettzell) from LAGEOS (L1) and LAGEOS-2 (L2); in black, the east component is the combination from both satellites (in mm).

Pierre Exertier, A. Belli, J.M. Lemoine, Time biases in laser ranging observations: A concerning issue of Space Geodesy, Advances in Space Research,Volume 60, Issue 5, 2017,Pages 948-968,

Le transfert de temps laser par satellite aujourd'hui

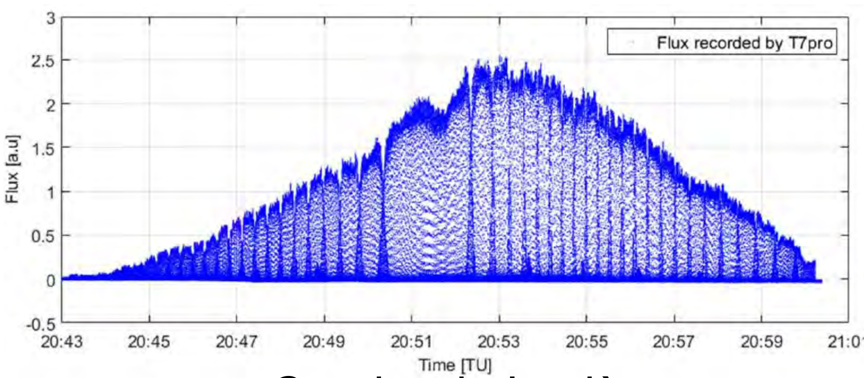






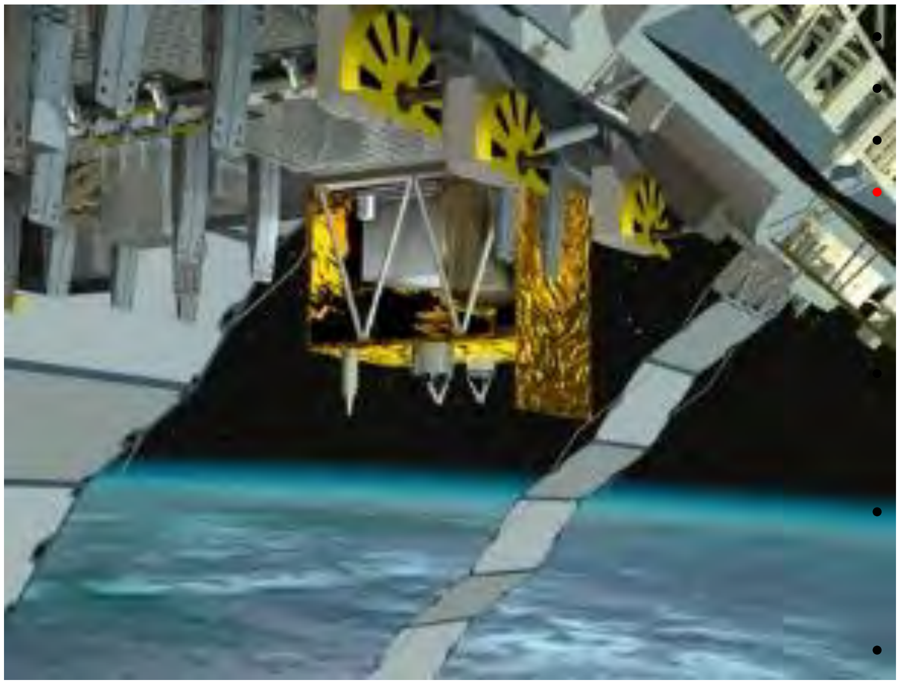
Ecoute IR Wettzell sur Ajisaï juin 2023 : σ = 3.102 ns, Nb of echoes =14

- Transfert de temps par réflexion diffuse sur le satellite Ajisaï
  - European collab: Wettzell, Hertsmonceux
  - Intégration du laser haute cadence en phase finale
- Thèse Carlo Calatroni (started 2023)
  - Modèle de rotation d'Ajisaï : Par quel miroir est passé le photon observé ?



Courbe de lumière

ACES – PHARAO – ELT onboard ISS (2025)



- PHARAO : a cold atom cesium clock
- ACES: Space Hydrogen Maser
- MWL: A microwave time transfer system
- ELT : A laser link : comparison of distant clocks, both space-to-ground and ground-to-ground, to frequency uncertainty levels well below 1 x 10^{-16} after a few days of integration time.
- Because of the high stability of the ACES clock signal, non-common view comparisons of clocks across intercontinental distances will be possible with ELT.
- The optical link also finds interesting applications in the distribution of the ACES time reference and in the synchronization of geodetic observatories.
- Combined with MWL performance, ELT will contribute to the characterization and cross-comparison of two different time transfer and ranging systems (study of atmospheric propagation delays and for the construction of mapping functions at three different wavelengths).

Upgrade laser : Télémétrie Haute Cadence

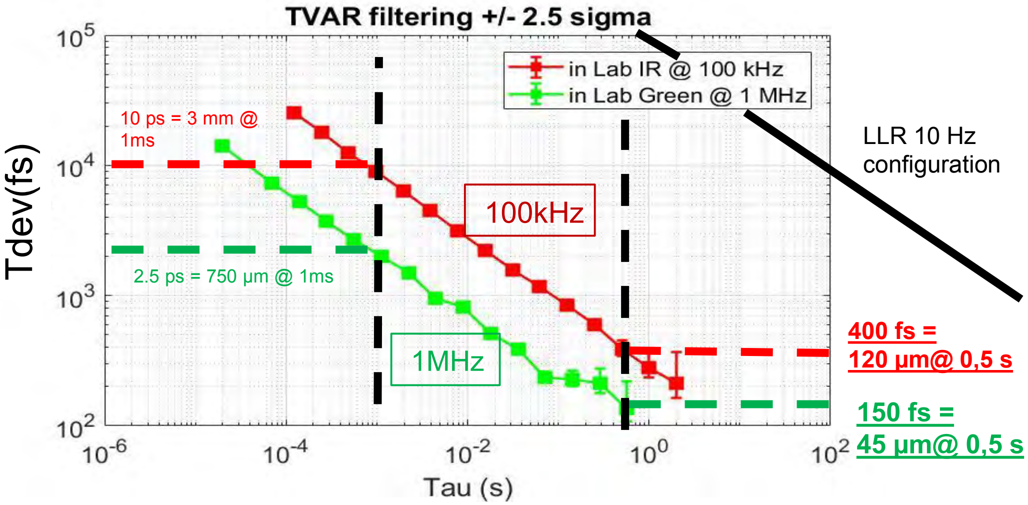
New laser in 2020 : 100W 10ps FWHM @400kHz

New SPAD in 2015 for 532nm (@1MHz) & 1064nm (@100kHz)

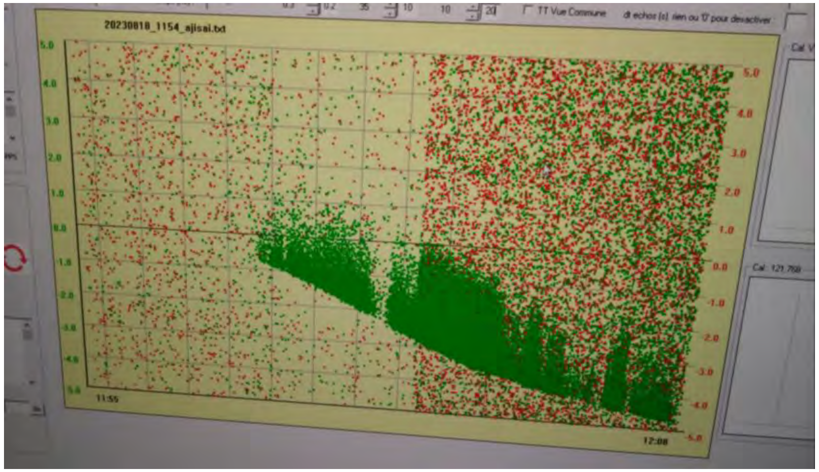
Aperture sharing in 2021

High count rate event timer (SigmaWorks)

Performances on ground



Ajiaï @ 1kHz and 10kHz



With the support of

GRAM Gravitation Références Astronomie Métrologie

cnes

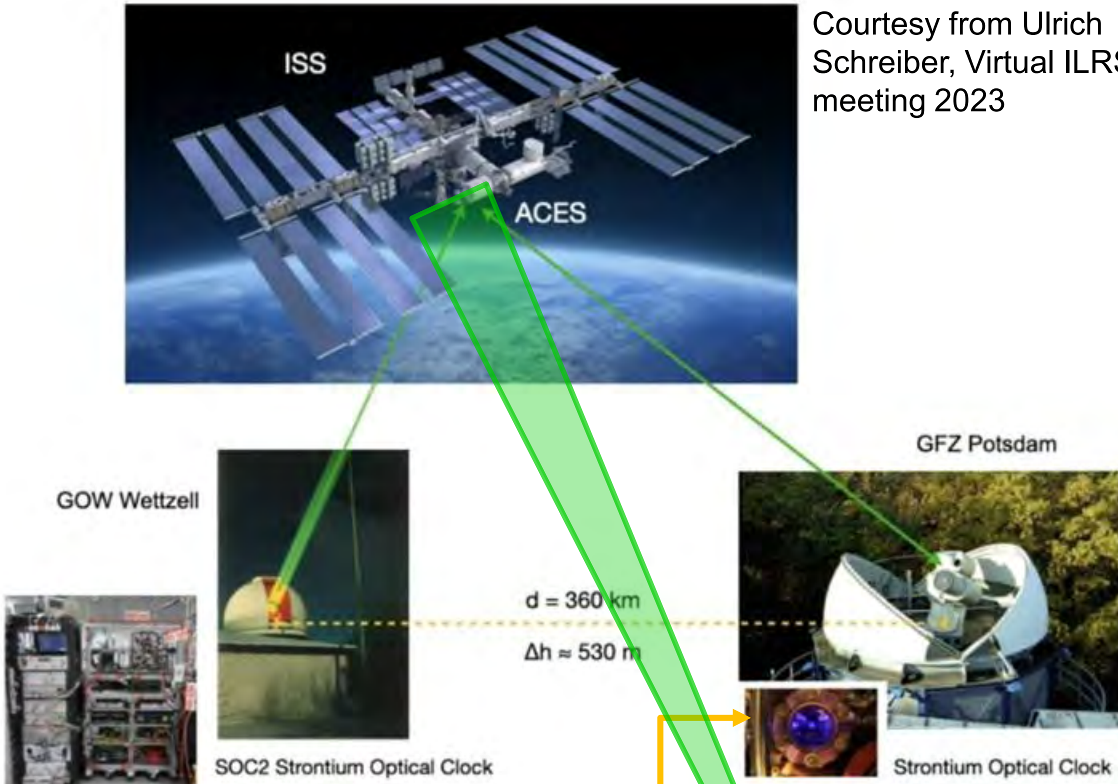
FIRST TF

Extended comparison capabilities

The Refimeve signal (ultra stable optical frequency through the fiber network) **should arrived at OCA-Calern in 1-2 years**

We have a co-fund from Refimeve for the acquisition of a comb (120k€) and are looking for a second co-fund

Refimeve + ACES



Courtesy from Ulrich Schreiber, Virtual ILRS meeting 2023

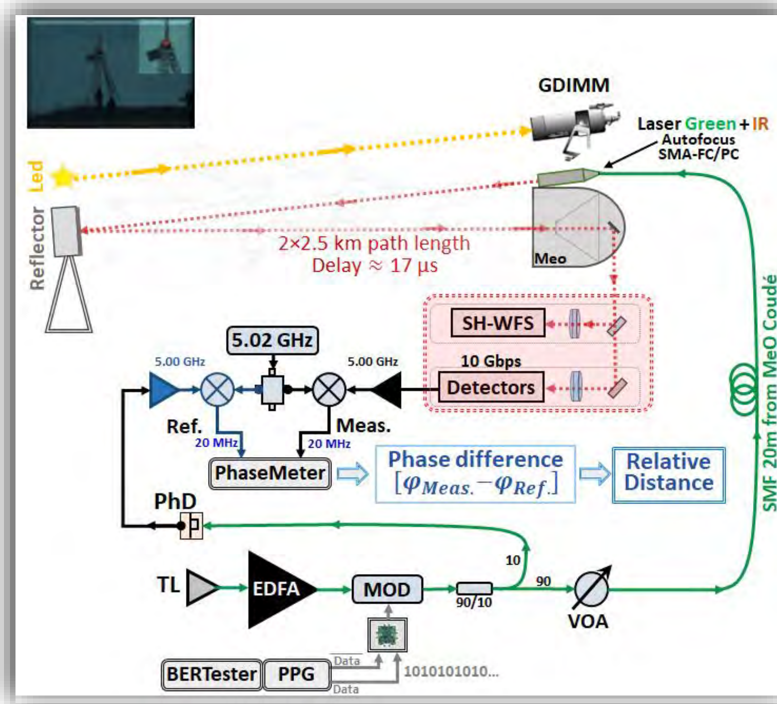
With Refimeve link and/or?
- **Sr optical clock comparison with ACES using a fiber link between Brunswick and OP-**
- **OCA comparison between TWSTFT and mobile MWL**

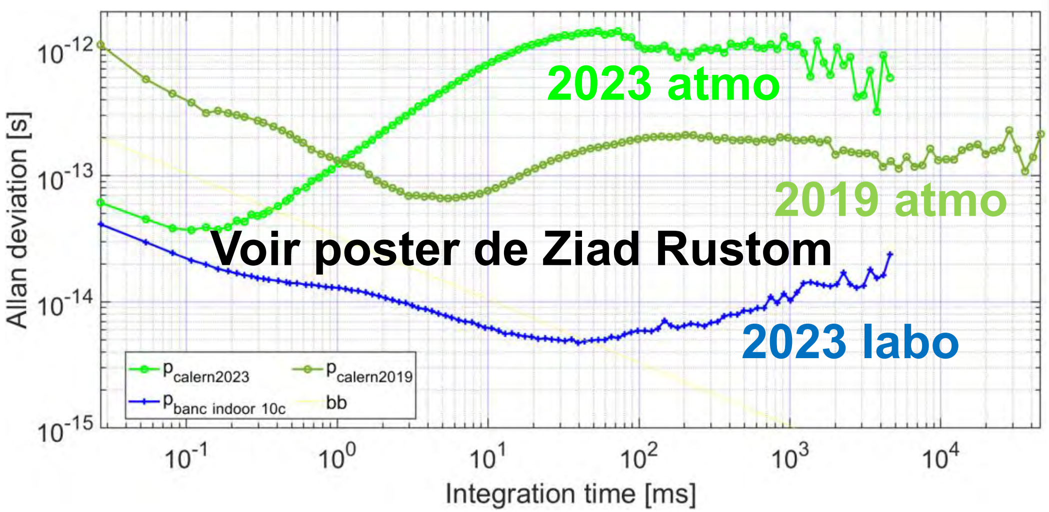
Fiber link between Brunswick and Postdam

+ mobile clock installed @OCA ?

Ground to ground experiment @ 10 Gbit/s

➢ Telecom detection → Time Transfer / Ranging by LaserComm link





- ❑ Atmospheric turbulence effect:
  - + High speed Telecom detection,
    - → SNR, BER measurement
  - + Laser Ranging Measurement - Phase
    - High Speed > 10 kSps
- ❑ Understanding SHWFS data
  - → model for Deformable Mirror

Conclusion

- Un Observatoire Géodésique fondamental est un observatoire regroupant plusieurs techniques de géodésie spatiale:
  - rattachées spatialement (rattachement topo)
  - partageant une échelle de temps commune
  - en comparaison constante !
- Le temps-fréquence est partout dans un observatoire géodésique:
  - Il est source de synchronisation et de référence pour les techniques d’observation
  - Il est l’observable de techniques d’observation
  - Il fait partie des produits de la Géodésie (UT1, ITRF,…)
- R&D interne active pour le transfert de temps par lien laser pour la Géodésie
  - Haute cadence SLR
  - MétroCom

Fin