Observatoire géodésique multi-techniques de Calern

Novembre 2023

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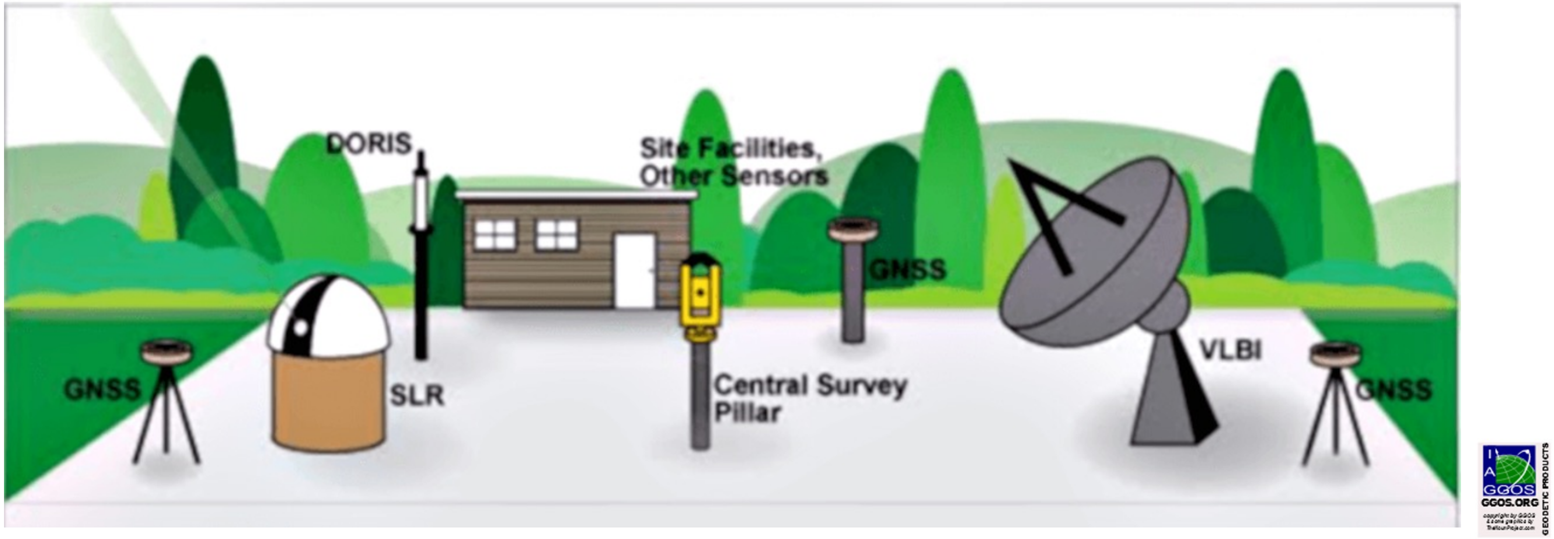
UNIVERSITÉ CÔTE D'AZUR
Observatoire de la CÔTE d'AZUR
cnrs INSU Observer & comprendre
IRD Institut de Recherche pour le Développement

C'est quoi un observatoire géodésique multi-techniques ?

Un site accueillant plusieurs techniques de géodésie spatiale co-localisées.

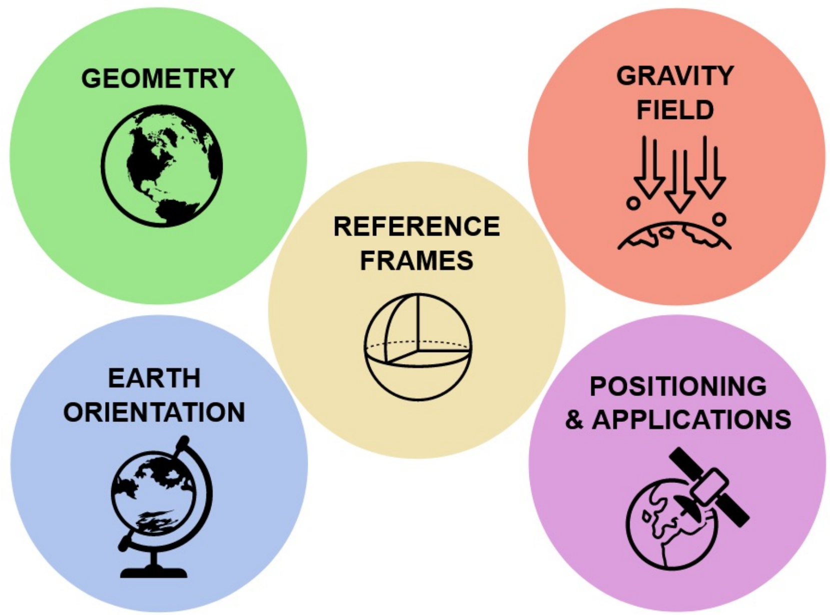


- GNSS – Global Navigation Satellite Systems
- SLR – Satellite Laser Ranging
- VLBI – Very Long Baseline Interferometry
- DORIS – Doppler Orbitography and Radiopositioning Integrated by Satellite

A quoi sert un observatoire géodésique multi-techniques ?

Geometry

- Surface Deformation Models
- Ocean Topography Models
- Sea Level Change
- Digital Elevation Model
- Ice Sheets & Glaciers – Variations
- Station Positions & Variations
- Tide Gauge Records
- Sea Surface Heights



Gravity Field

- Global Gravity Field – Models
- Gravity Field – Temporal Variations
- Terrestrial Gravity Data
- Regional / Local Geoid Models
- Ice Sheets & Glaciers – Variations
- Height Systems

Earth Orientation

- Earth Orientation Parameters

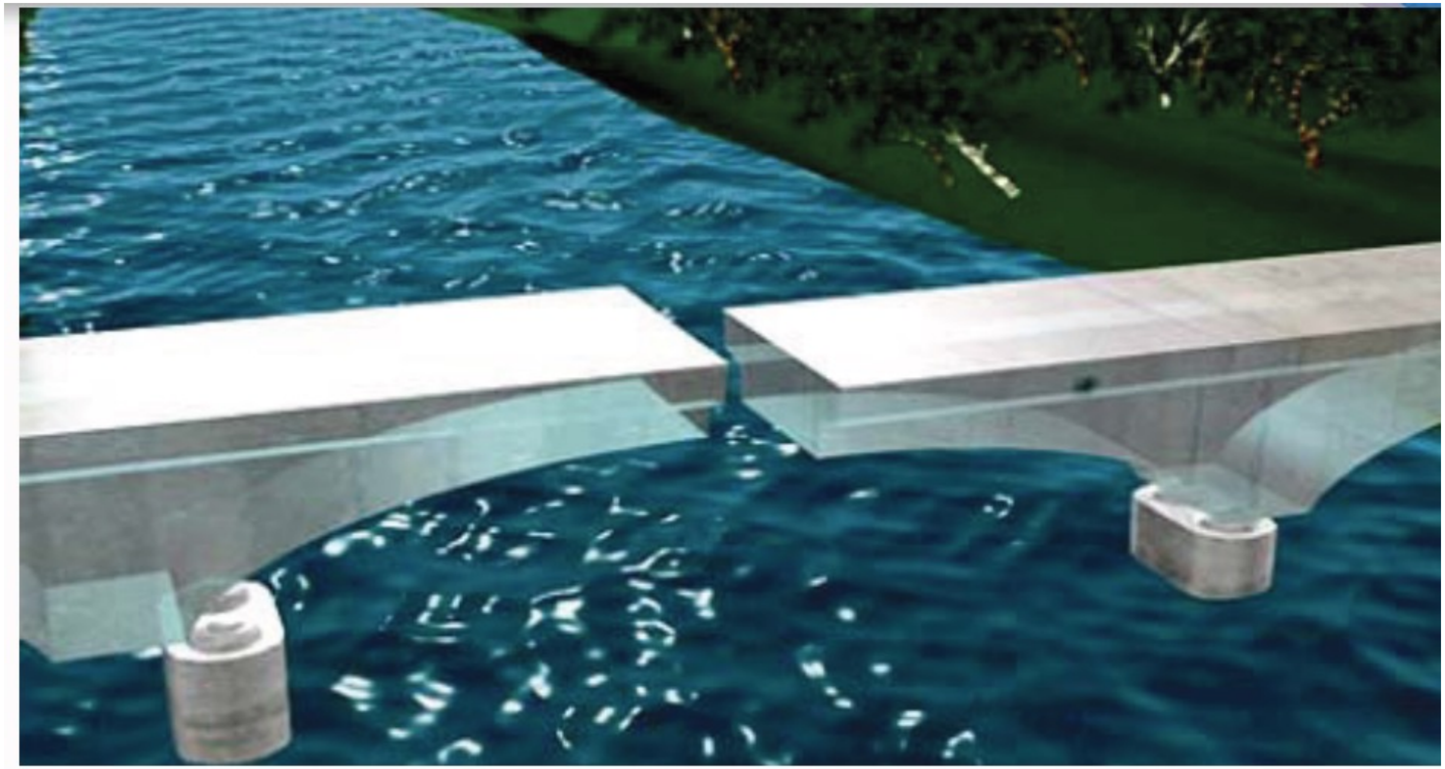
Reference Frames

- Height Reference Frame
- Celestial Reference Frame
- Gravity Reference Frame
- Terrestrial Reference Frame

Positioning & Applications

- Thermosphere
- Ionosphere
- Lower Neutral Atmosphere
- Atmospheric Products
- GNSS Satellite Orbits and Clocks

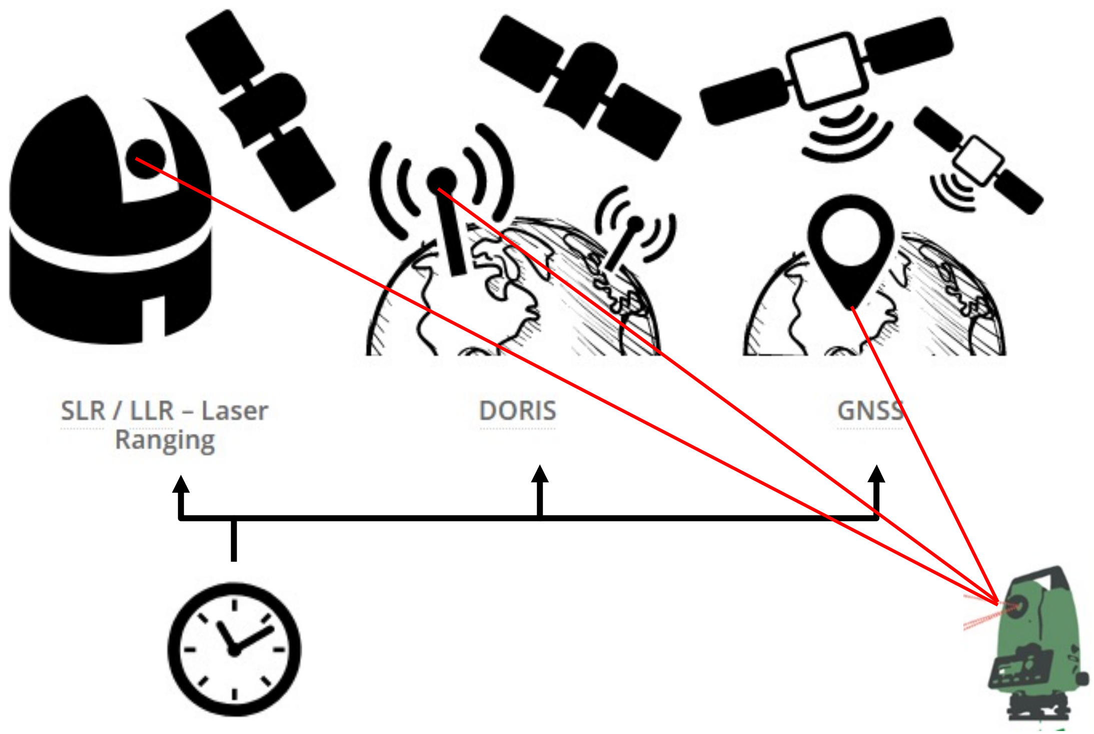
Concrètement, à quoi ça sert ?



Design error at bridge construction in Laufenburg (2003): During the construction of the bridge across the Rhine river in Laufenburg, a control showed that a height difference of 54 centimeters exists between the bridge built from the Swiss side and the roadway of the German side. Reason of the error is the fact that the horizons of the German and Swiss side are based on different reference frames. Germany refers to the sea level of the North Sea, Switzerland to the Mediterranean.

Courtesy of Hermann Drewes / DGFI

Sommaire



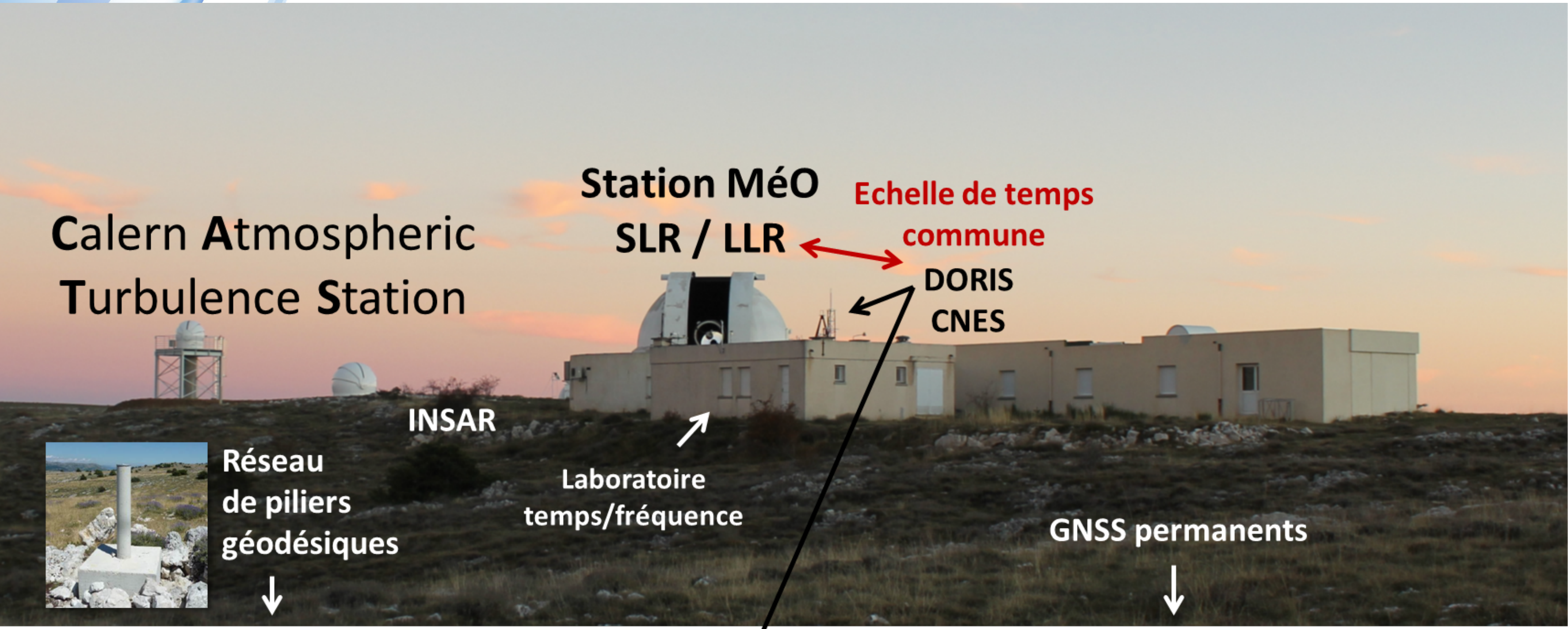
1. Présentation de l'Observatoire Géodésique multi-techniques du plateau de Calern
2. Co-localisation et suivi de la croisée des axes du télescope (collaboration IGN-ENSG)
3. Distribution de l'échelle de temps locale et comparaison
4. Amélioration de la métrologie SLR/LLR

1. Observatoire de la Cote d'Azur
Site de Calern

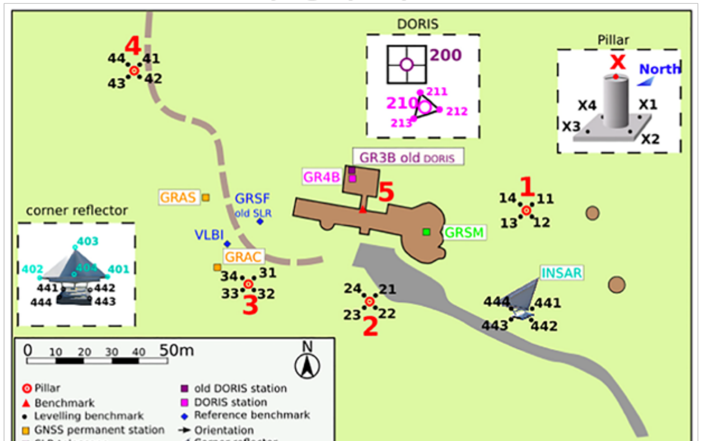
- Site inauguré en 1974

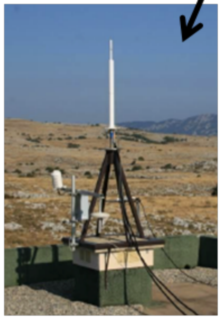
  Astrométrie & plateforme de développement pour de nouveaux instruments
- Plateau calcaire de 20 km² dans l'arrière pays Grassois
  - Altitude : 1270m. longitude 6,9230°E ; latitude 43,750° N
  - Compromis entre accessibilité (20 km de Grasse) et qualité astronomique

1. Un Observatoire Géodésique multi techniques



Rattachements topographiques – IGN





Réseau permanent 2020

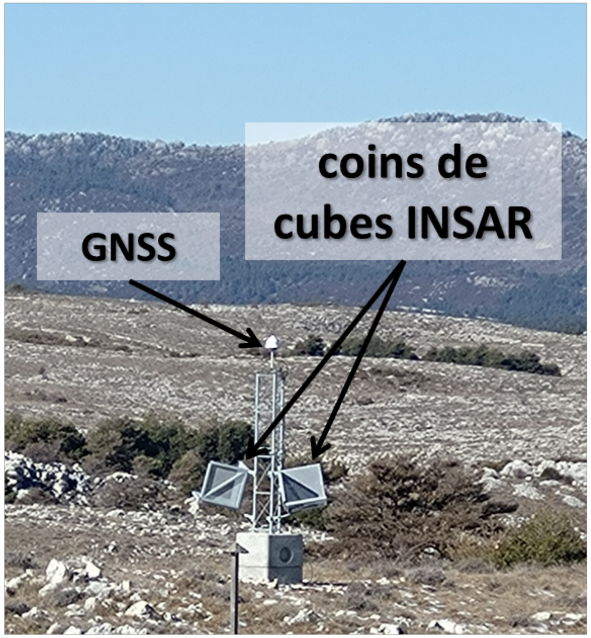
Collaboration IGN-ENSG-Geoazur

GNSS / INSAR

Coins de cube : recommandation GGOS
Obs. géodésique multi-technique

- Réflecteur de référence pour Sentinel-1
- Rattachement IGN/ITRF + suivi mouvement vertical →
- Données Sentinel libres d'accès

- Étude mécanique sur l'installation de coins de cubes INSAR sur des mâts accueillant des antennes GNSS établies →
- Etude de l'impact des coins de cubes INSAR (et de leur design) sur le GNSS



- Deux réflecteurs → inclinaison topographique

Collilieux et al. (2022)

2. Rattachement topographiques pour le suivi des points de référence des techniques de géodésie spatiale

Collaboration IGN-ENSG-Geoazur

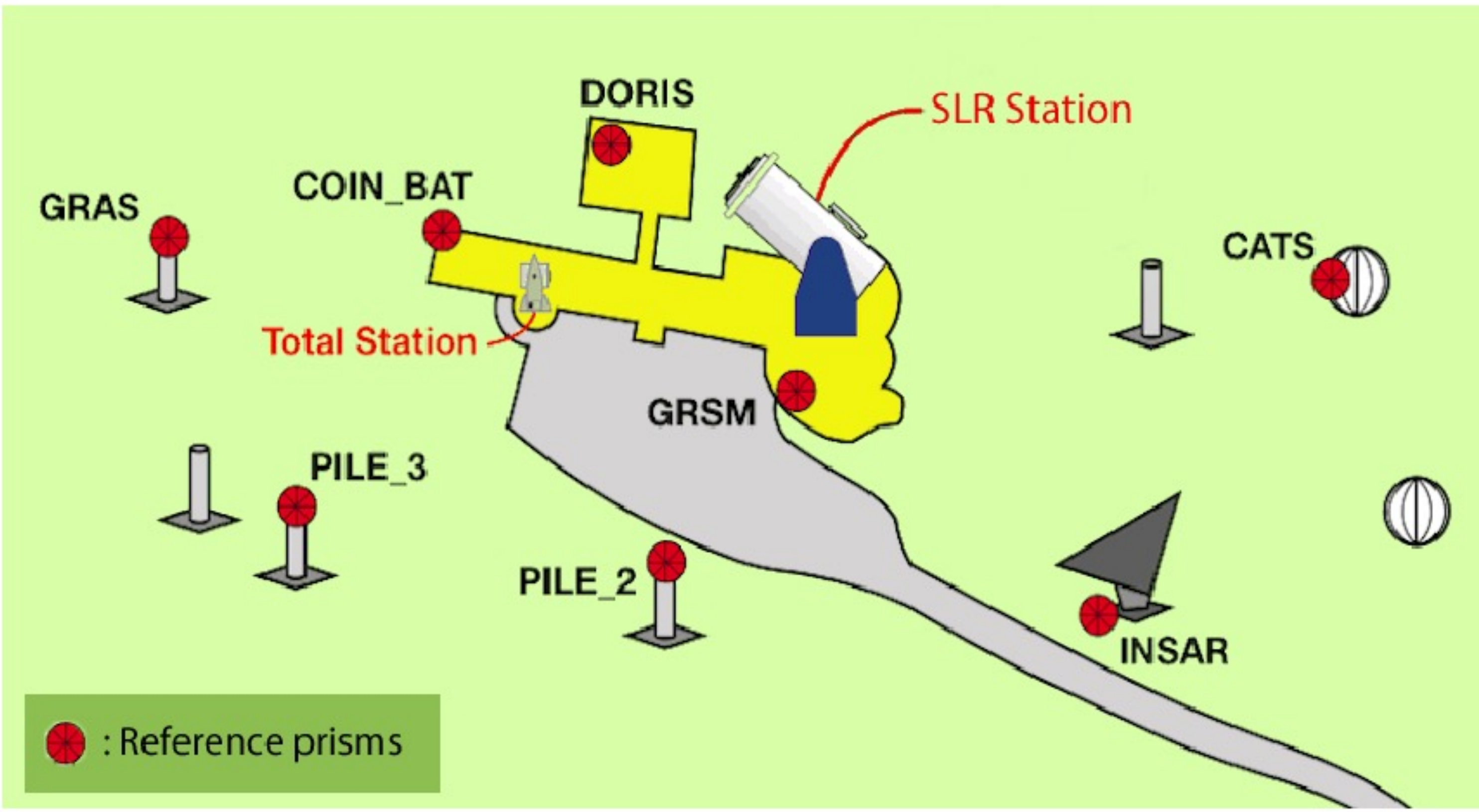


Fig.1 *Overview of the Grasse co-location site configuration during a local tie survey.*

Barneoud et al., REFAG 22

2. Rattachement topographiques pour le suivi des points de référence des techniques de géodésie spatiale

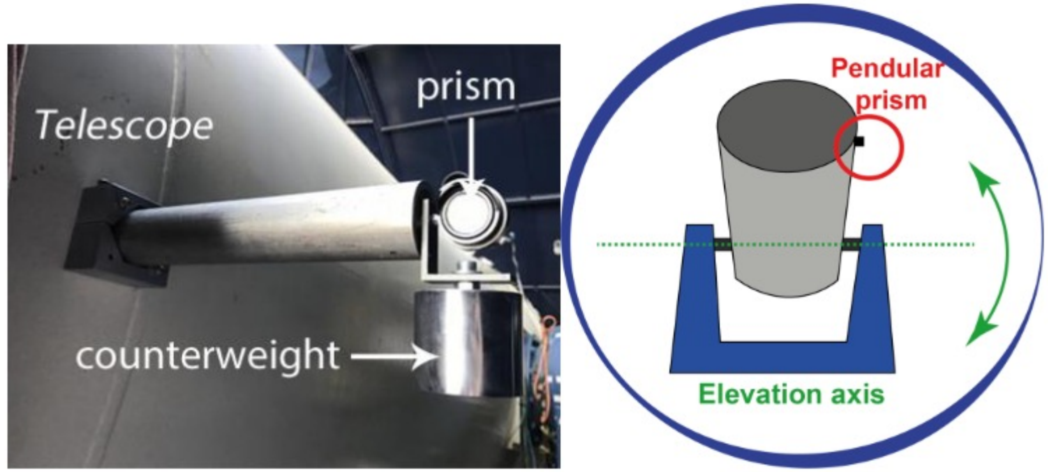


Fig. 3 *Setup of a pendular prism on the telescope (left) and global view during rotation along the elevation axis (right).*

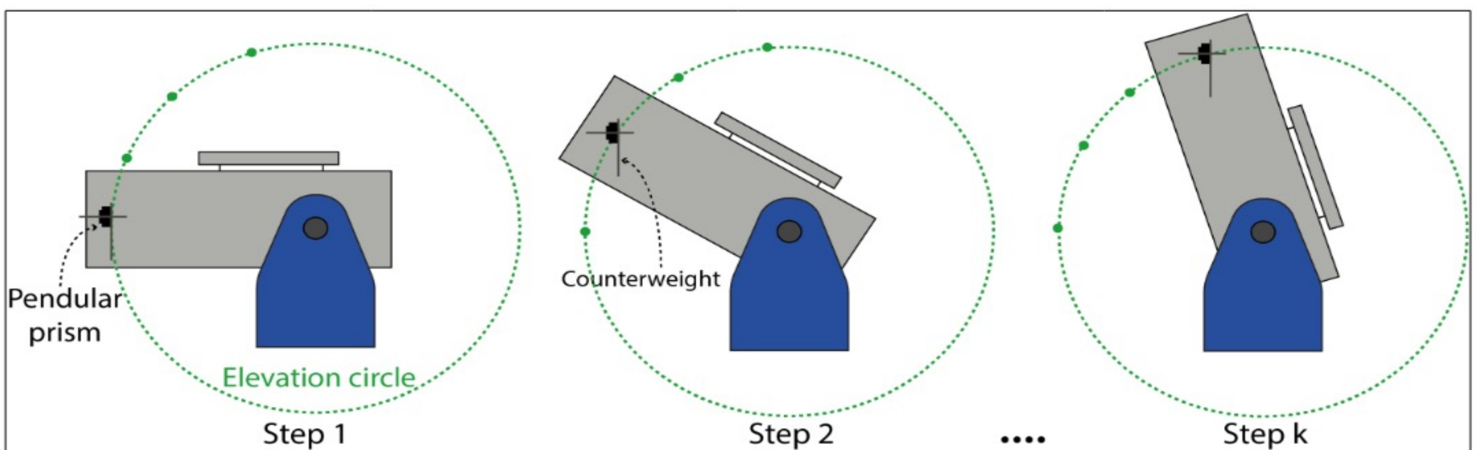
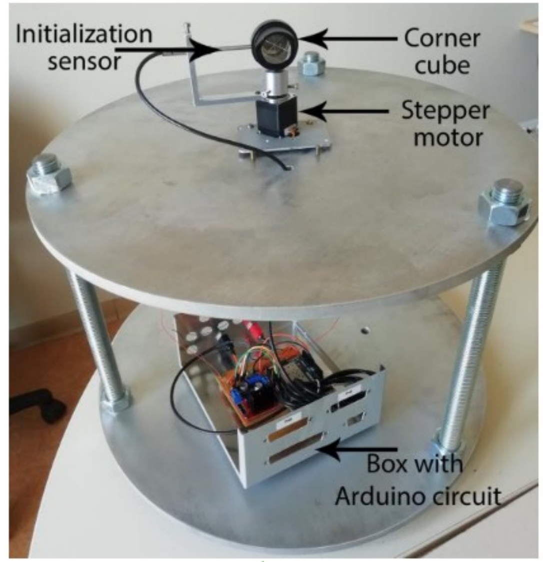
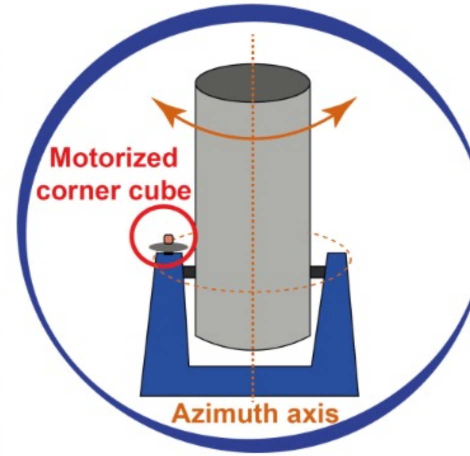


Fig. 4 *Steps of elevation circle measurements. Thanks to counterweights, the pendular prism always faces the total station.*

2. Rattachement topographiques pour le suivi des points de référence des techniques de géodésie spatiale





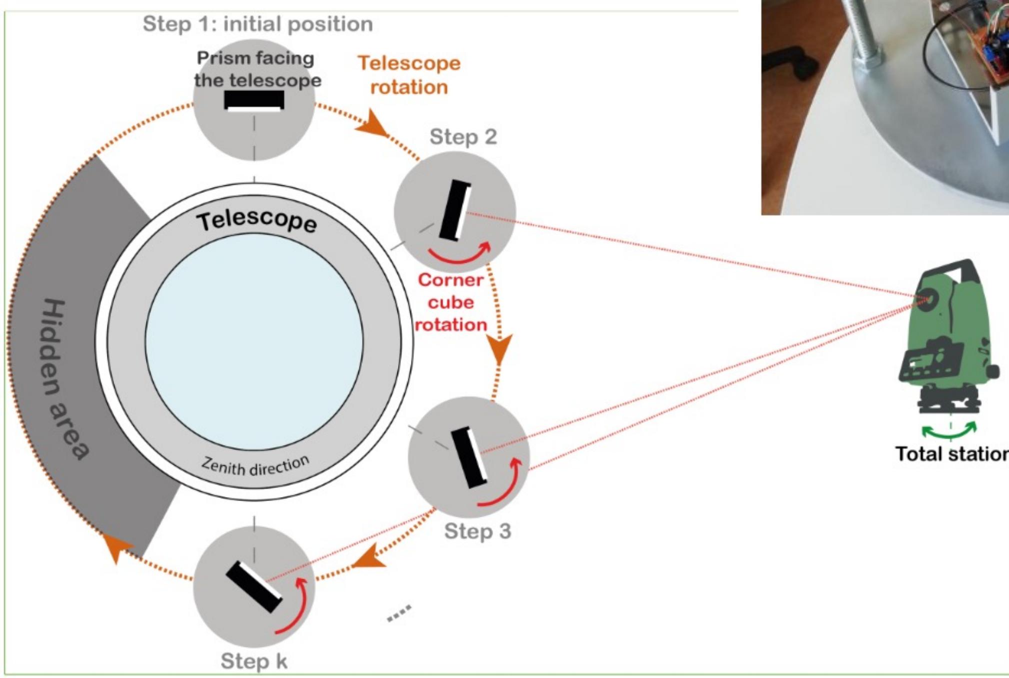


***Fig. 6** Steps of azimuth circle measurements. With stepper motor, the corner cube is always visible from the total station after telescope rotation. The telescope is pointed upwards, in the zenith direction (top view, four steps shown).*

2. Rattachement topographiques pour le suivi des points de référence des techniques de géodésie spatiale

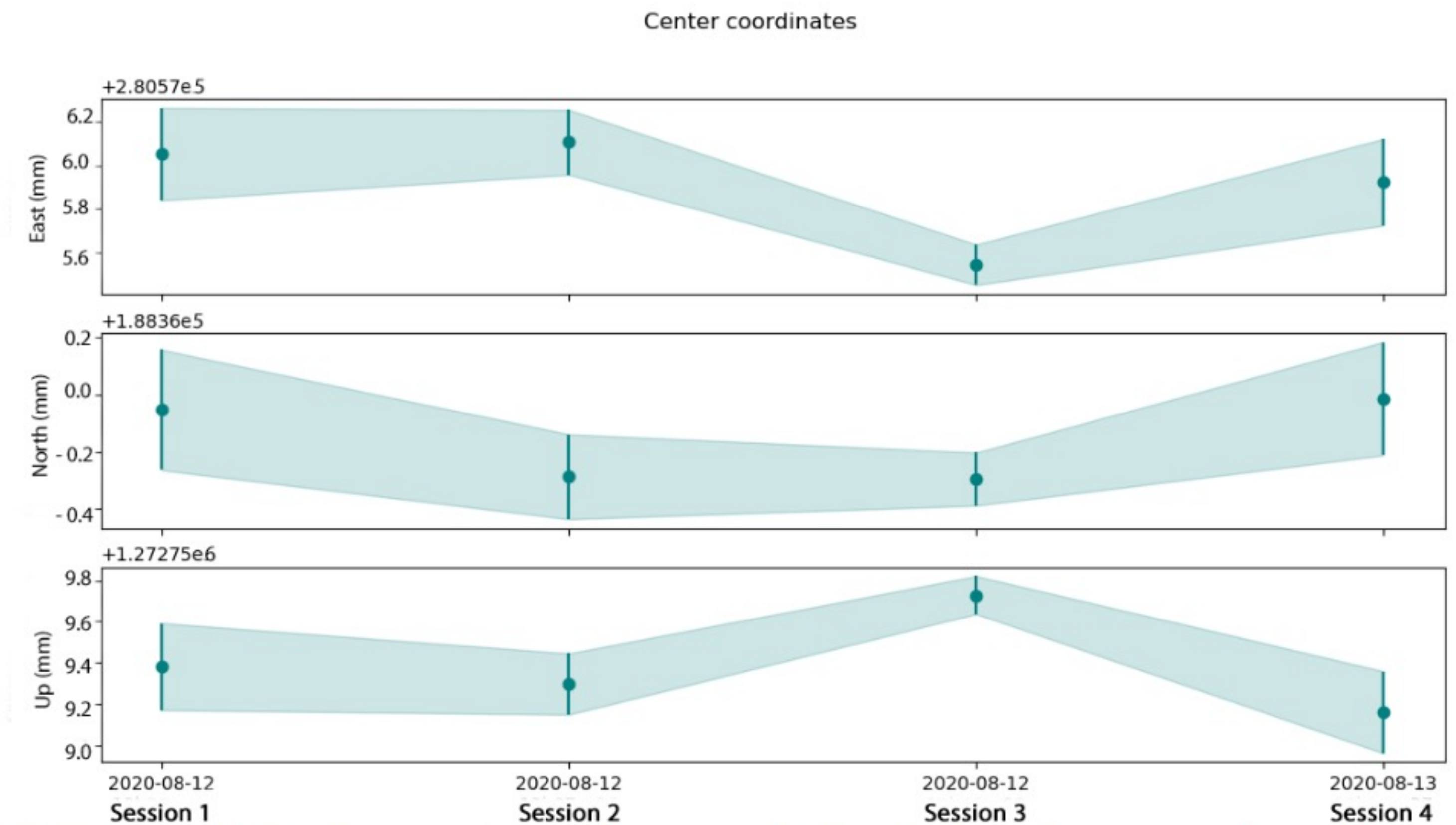


Fig.8 Computed SLR reference point coordinates provided in a local coordinate system during different measurement sessions.

Barneoud et al., REFAG 22

Suivi du point de référence de la station laser avec une incertitude inférieure au mm.

2. Rattachement topographiques pour le suivi des points de référence des techniques de géodésie spatiale

- Intégration d’un nouveau tachéomètre de l’IGN pour offrir des données de géodésie spatiale co-localisées au sol

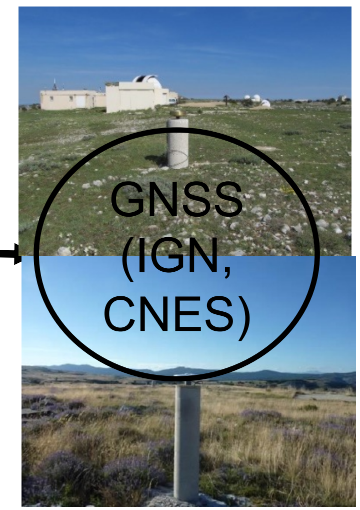
3. Distribution de l'échelle de temps locale et comparaisons

Active H-maser (2008)

2x microphase stepper

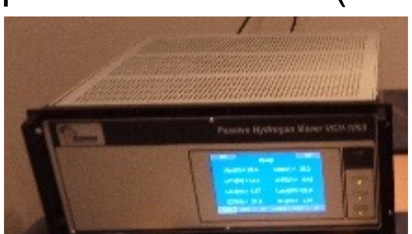
OCA Time scale

Clock active H-Maser + microphase stepper for steering ; Means of comparison : TWSTFT, GNSS (PolaRXTR)



TAF
via OP-
SYRTE

passive H-maser (2020)



PolarX5TR
+GTR50

TWSTFT

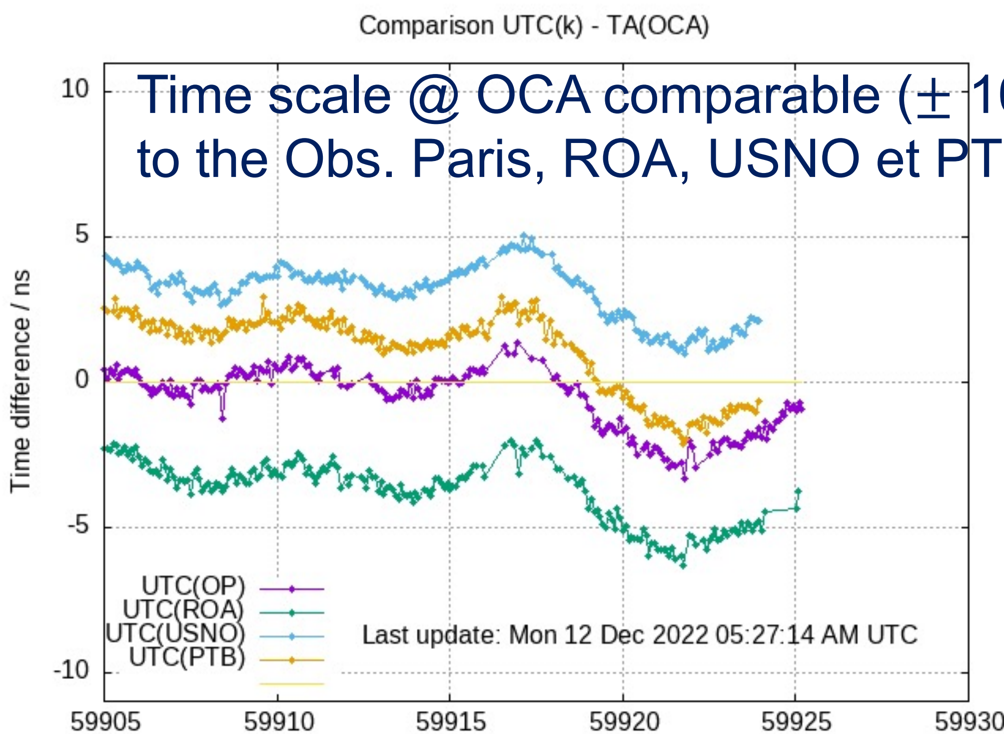
3. Distribution de l'échelle de temps locale et comparaisons

- **Active H-Maser (2008) => 15 years !**

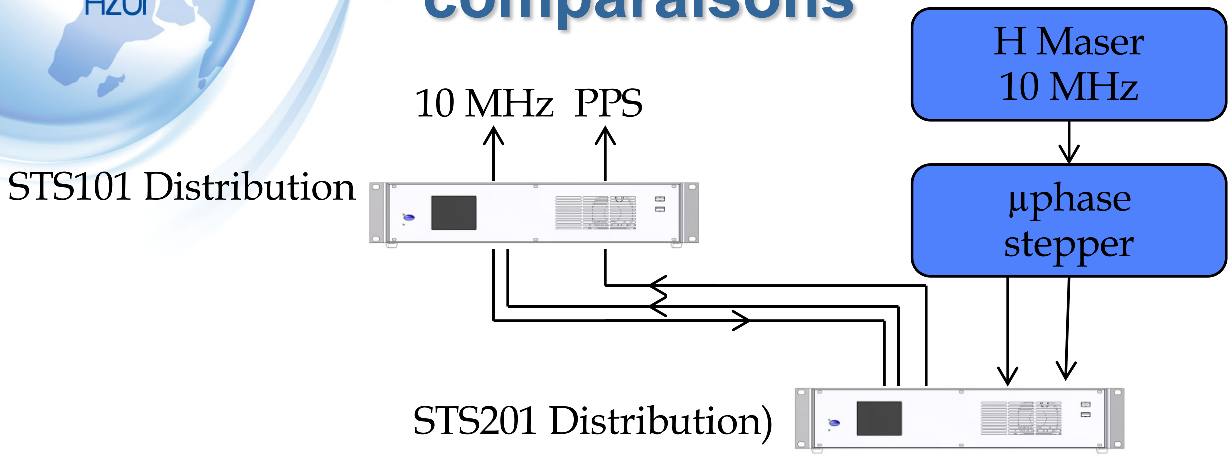
=> We are looking for support for a new one => ~500 k€ !!

Common time scale with all the geodetic technics (DORIS, GNSS, SLR)

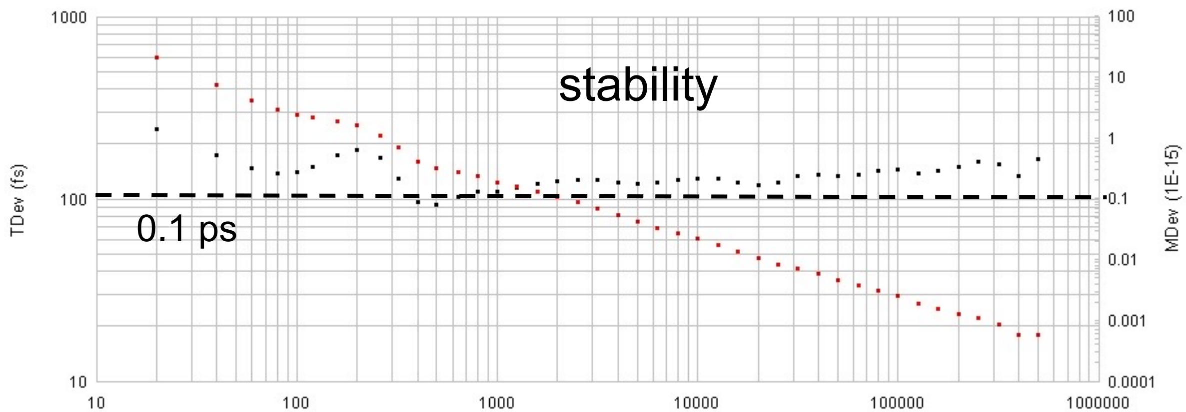
Time scale @ OCA comparable (± 10 ns) to the Obs. Paris, ROA, USNO et PTB

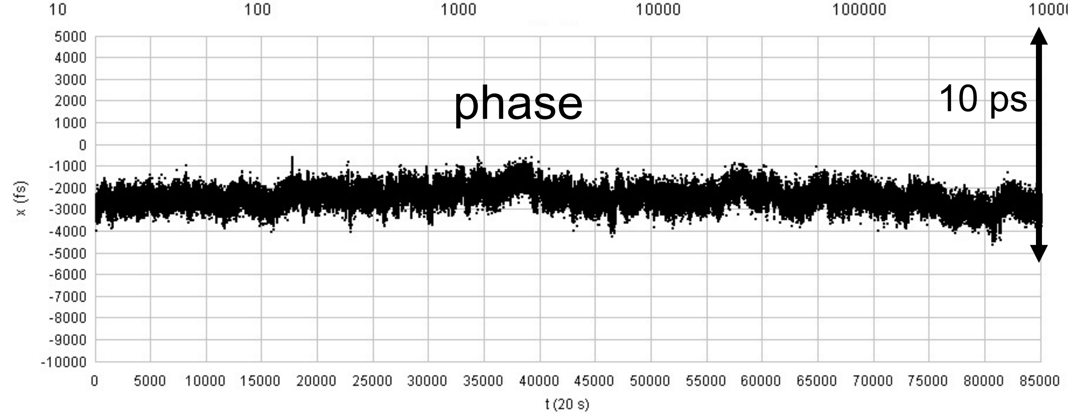


3. Distribution de l'échelle de temps locale et comparaisons



- STS distribution from CNES-T2L2 experiment
- In operation for SLR but not for the other geodetic tecnics





3. Distribution de l'échelle de temps locale et comparaisons

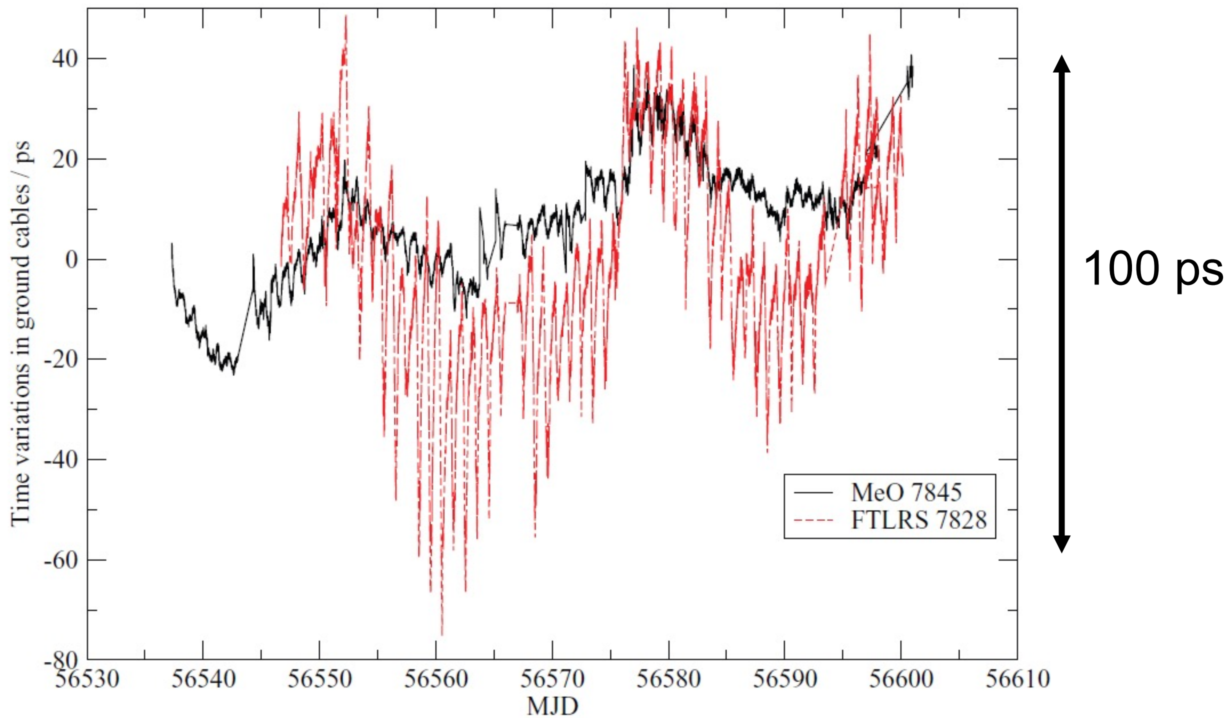


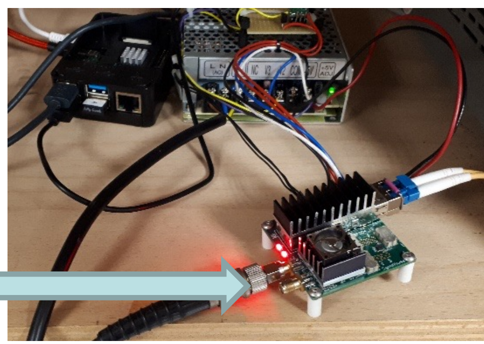
Figure 1. Monitoring of the time variations (in ps) of signals in ground cables from the SLR station to the local clock distribution reference point at OP (in red: FTLRS 7828) and in OCA (in black: MeO 7845), based on Sigma Time STS time signal generators. The correlation between plots is almost certainly due to similar weather conditions despite the distance between both stations.

Exertier et al., metrologia, 2017

3. Distribution de l'échelle de temps locale et comparaisons

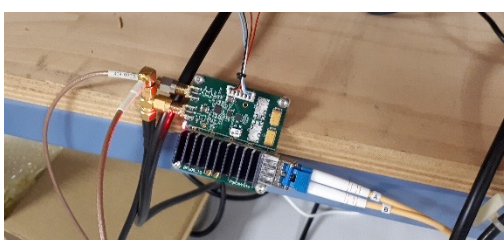
Evolution vers un système fibré basé sur des SFP en collaboration avec SigmaWorks

Input Signal single ou P/N pair



Fiber RX/TX pair

Output Signal single ou P/N pair



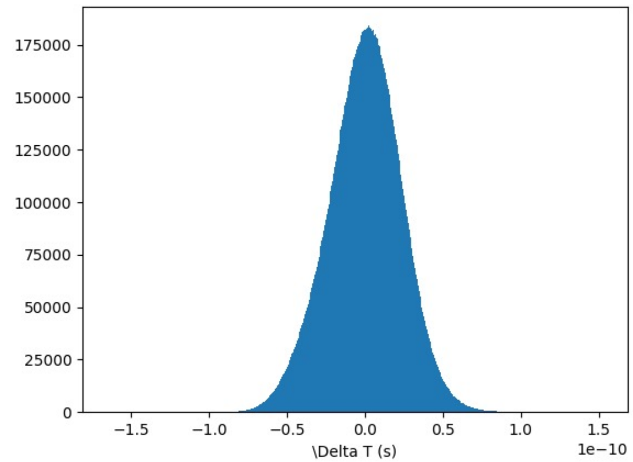
SigmaWorks

etienne.samain@sigmaworks.fr

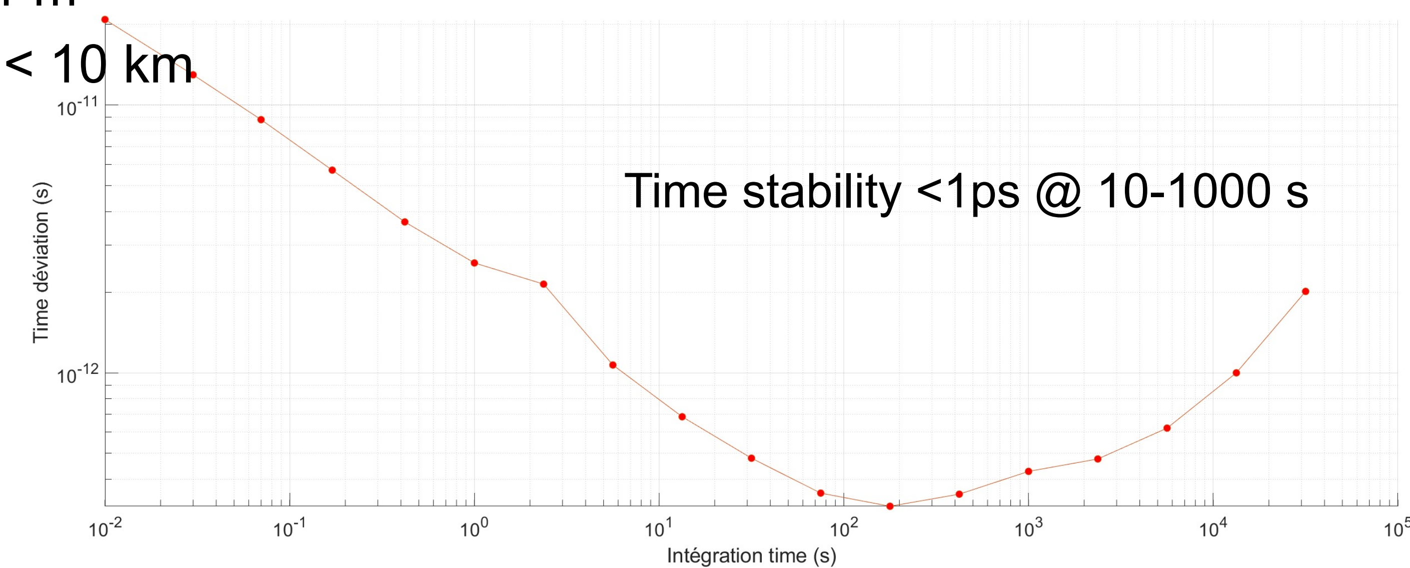
3. Distribution de l'échelle de temps locale et comparaisons

- Cadence des signaux max : 5 MHz
- Incertitude : < 5 ps RMS
- Stabilité : < 10 ps @ 1000 s
- Déclenchement sur front de monté
- Durée des pulses : quelques dizaines de ns
- Nombre de canal : 1
- Distance min : 1 m
- Distance max : < 10 km

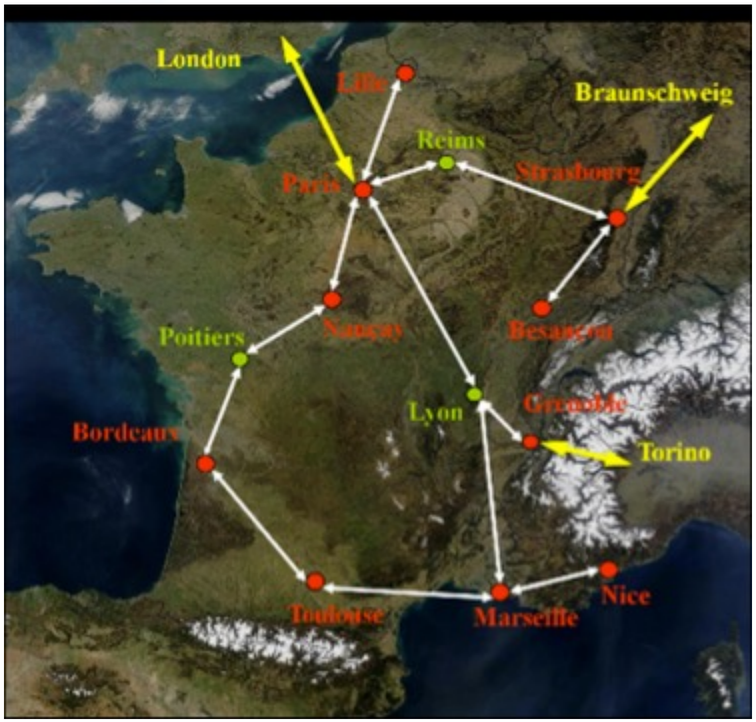
Standart deviation ~23ps RMS



Time stability <1ps @ 10-1000 s



Perspectives with the arrival of Refimeve at OCA-Calern

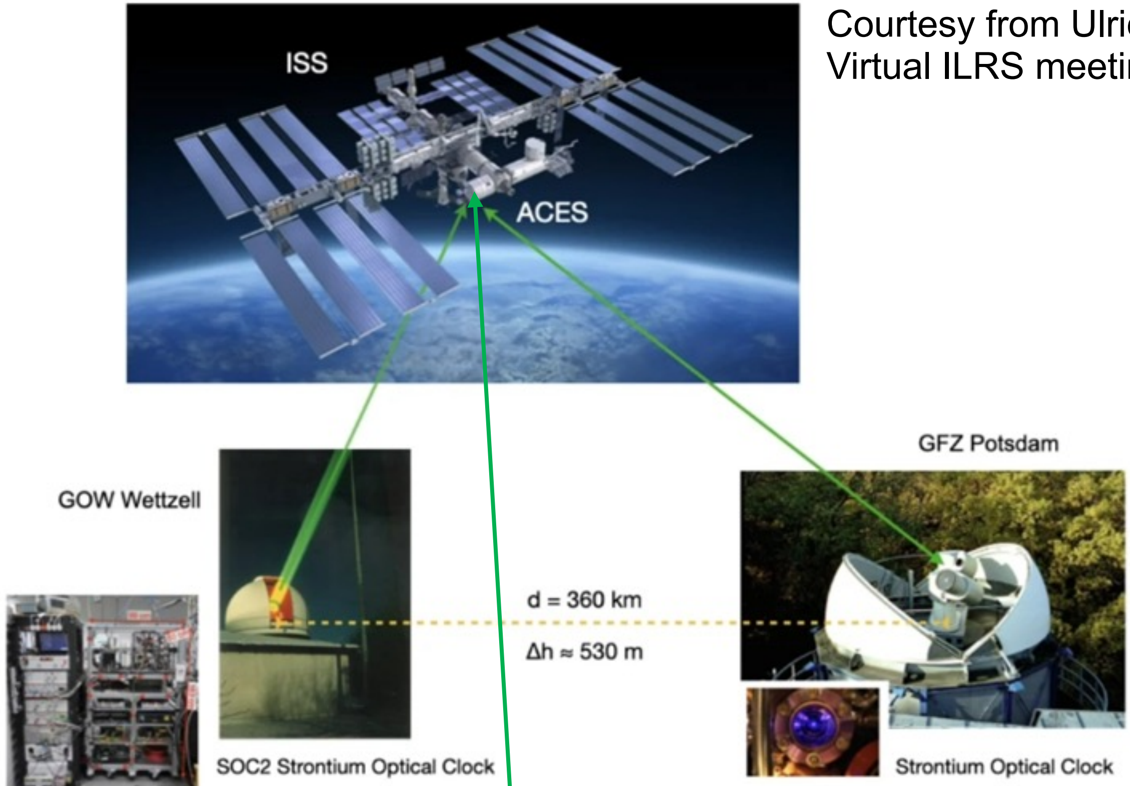


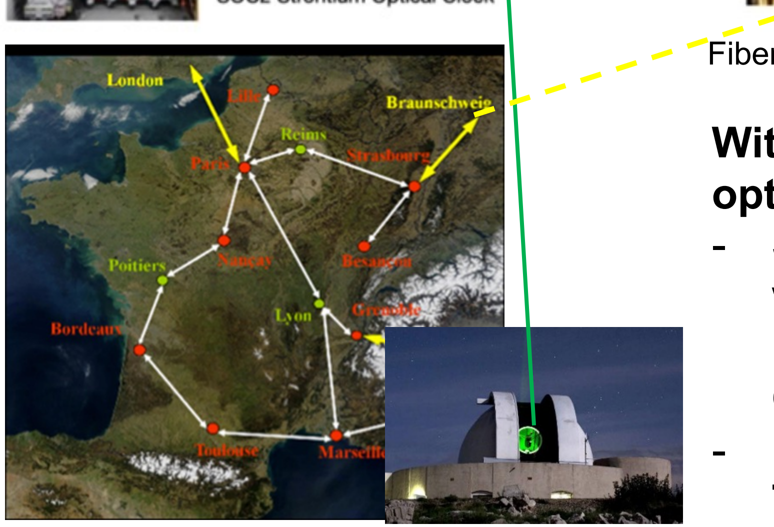
The Refimeve signal (ultra stable optical frequency through the fiber network) **should arrived at OCA-Calern in 1-2 years**

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

Possible idea ?

Courtesy from Ulrich Schreiber, Virtual ILRS meeting 2023





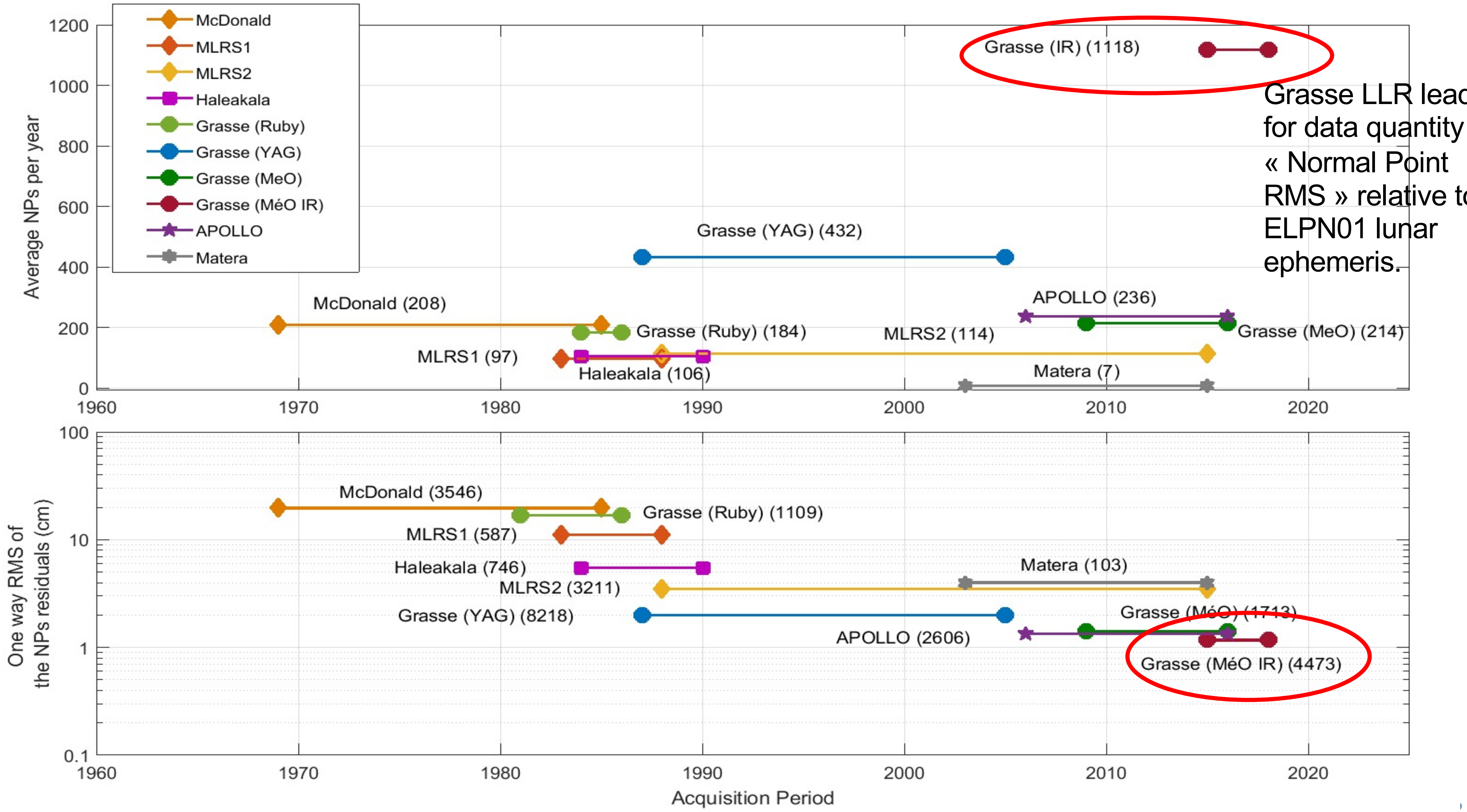
Fiber link between Braunschweig and Postdam

With Refimeve link and/or mobile optical clock installed @OCA ?

- **Sr optical clock comparison with ACES and with a fiber link between Braunschweig-OP-OCA**
- **comparison between TWSTFT and mobile MWL**

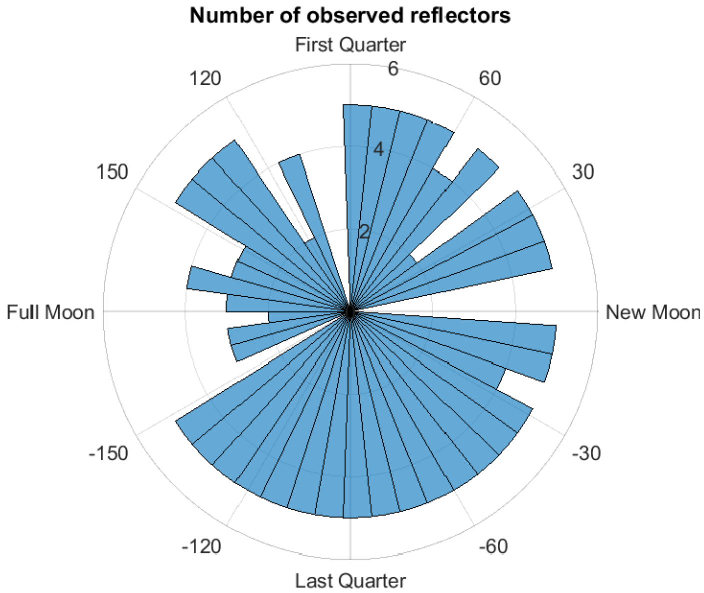
4. Amélioration de la métrologie SLR/LLR

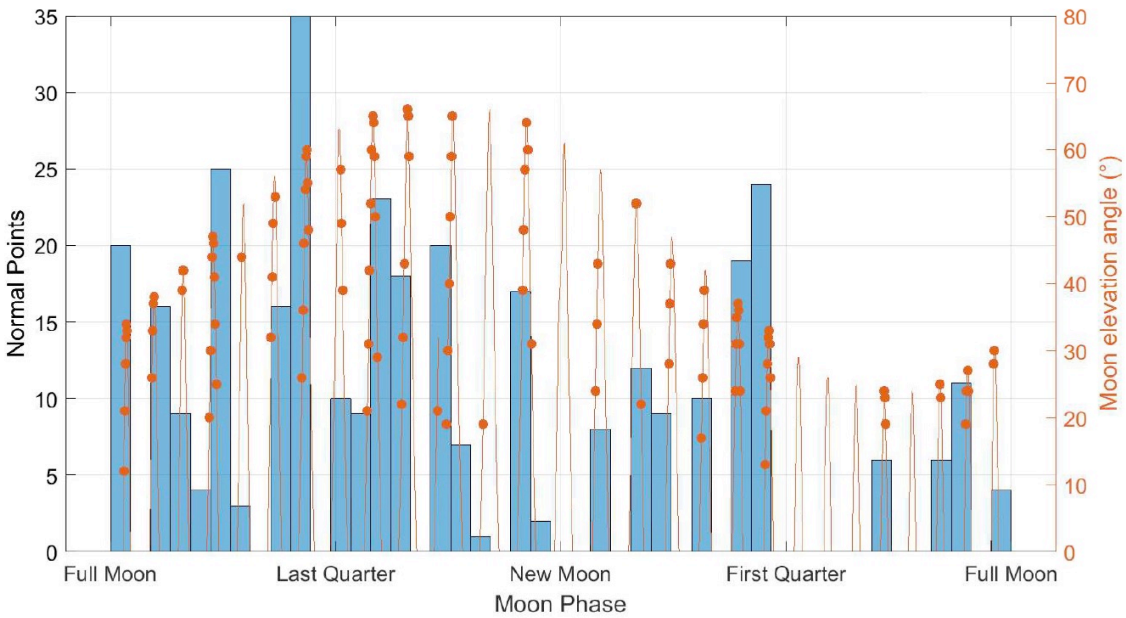
Installation photodétection IR en 2015



Grasse LLR leadi
for data quantity a
« Normal Point
RMS » relative to
ELPN01 lunar
ephemeris.

4. Amélioration de la métrologie SLR/LLR





- Observation at any point of the lunar cycle
- First full and continuous cycle observation in 2018
- Link Budget greatly improved thanks to IR and new optical tuning of the MéO telescope : multi-photon return from the Moon !!

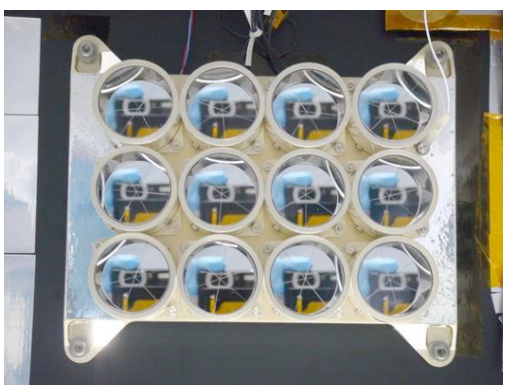
4. Amélioration de la métrologie SLR/LLR

Interplanetary links with spatial probes

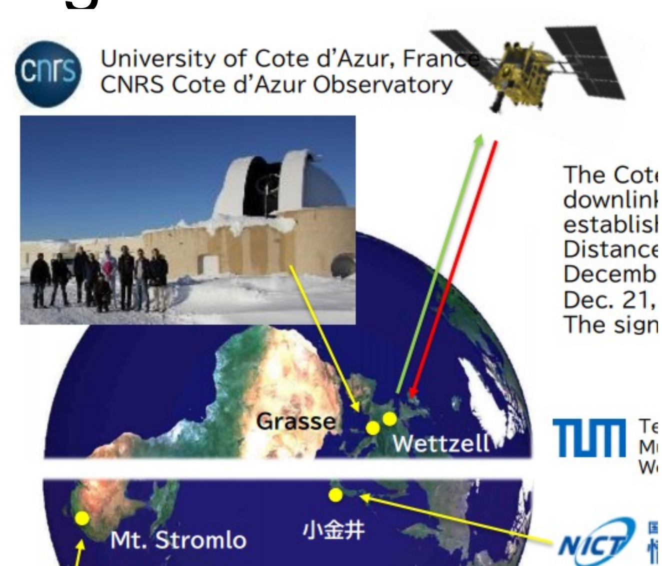
Grasse-MéO is the only one station in the world to have succeeded on:

- Lunar Reconnaissance Orbiter LRO-NASA-> 2 ways ranging
- Hayabusa2 – 2 x one-way ranging at 6.5 Mkm

Same as Apollo XI and XIV



12 solid corner cubes, 31.7mm diameter
•Materials Suprasil cubes, Al frame
•Mass 650.25g
•Volume: 15 x 18 x 5 cm3
•Operating temperature range : -150 to +30°C
 Thermally isolated from spacecraft
•Tested for 14-g vibration
•Optical characteristics:
•90°dihedral angle (unspoiled)
•Total internal reflection (bk uncoated)
•AR coating on top surface

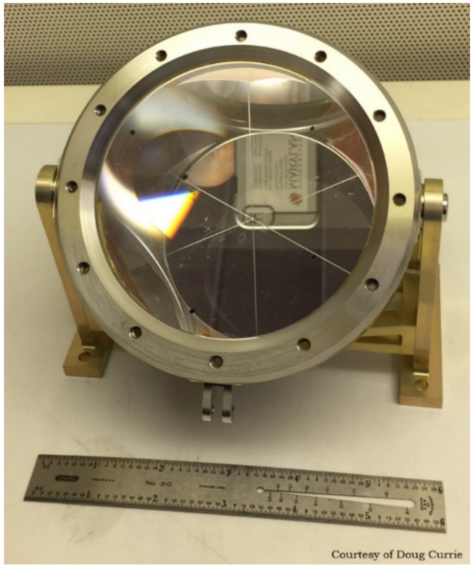


4. Amélioration de la métrologie SLR/LLR

Perspectives for LLR

Next Generation RetroReflector:

mono corner-cube instead of panel
=> Ranging Accuracy Improved by a factor of 100



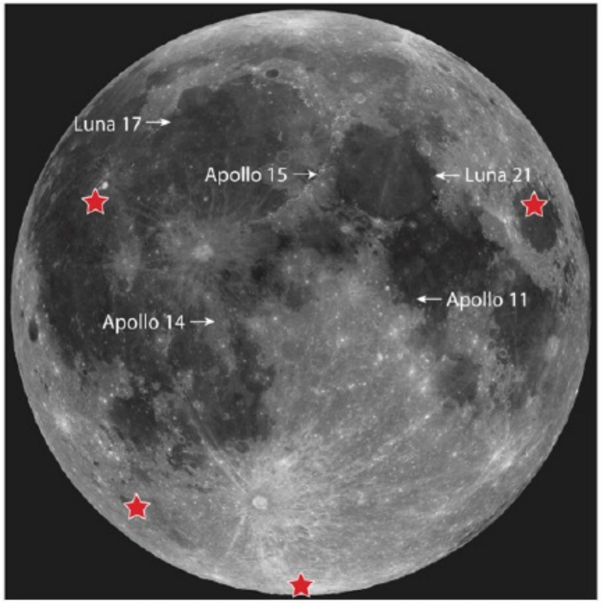


Figure 1: Existing LRA locations (labelled by mission) and possible locations (star) for future retroreflector deployment.

Vishnu Viswanathan et al., Extending Science from Lunar Laser Ranging, White paper,

4. Amélioration de la métrologie SLR/LLR

Old LLR laser : Quantel/BMI

Seeder :
Nd:YAG pumped by flash, Mode-locking AOM + SESAM, 10Hz, 150 ps FWHM, 1 mJ/pulse @ 1064nm

Amplification : Nd:YAG pumped by flash (Φ 7mm, Φ 9mm, Φ 12mm) = 300 mJ/pulse @ 1064 nm, 10Hz

4. Amélioration de la métrologie SLR/LLR

Reception of a Coherent HyperRapid laser in 2020

With the support of GRAM (Gravitation Références Astronomie Métrologie), cnes, FIRST TF

New laser for ACES-ELT

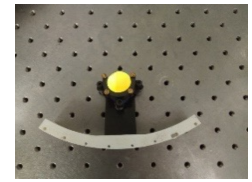
10 ps FWHM ; 50 W @532 nm @400 kHz =>125 mW @1kHz ; Adjustable pulse repetition rate between 1Hz to 4 MHz

	Specification	Measurement
Beam Quality Parameter M^2	≤ 1.3	1.11
Beam divergence, full angle (mrad)	≤ 1	0.72
Beam diameter, 1 m in front of laser (mm)	N/A	2.4
Beam circularity, 1 m in front of laser (%)	≥ 85	97.9
Average power (W)	100W	101.0
Average power stability over 8 hours, within +/- 1°C, RMS 1σ (%)	≤ 1%	0.48
Pulse energy max (µJ)	250µJ	252
Pulse-to-pulse energy stability over 1000 pulses, RMS 1σ (%)	≤2%	0.90
Pulse length, IR (ps)	≤ 15	10.3
Central Wavelength @ 1064 nm [nm]	1064	1064.1
Spectral Emission bandwidth @ 1064 nm	N/A	205pm
Temperature max Power 1064nm	N/A	42.5

New instrumentation for high count rate telemetry

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

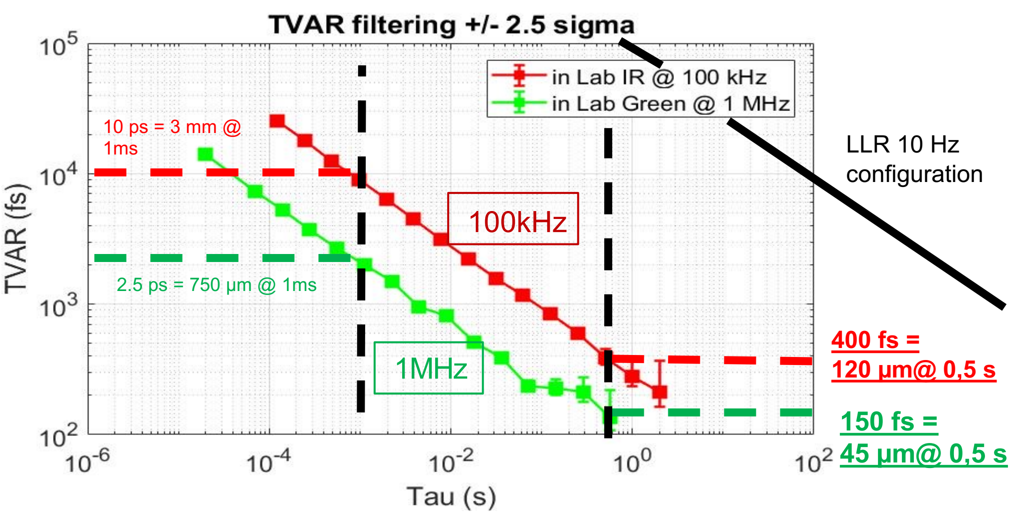
New SPAD in 2015 for 532nm (@1MHz) & 1064nm (@100kHz)



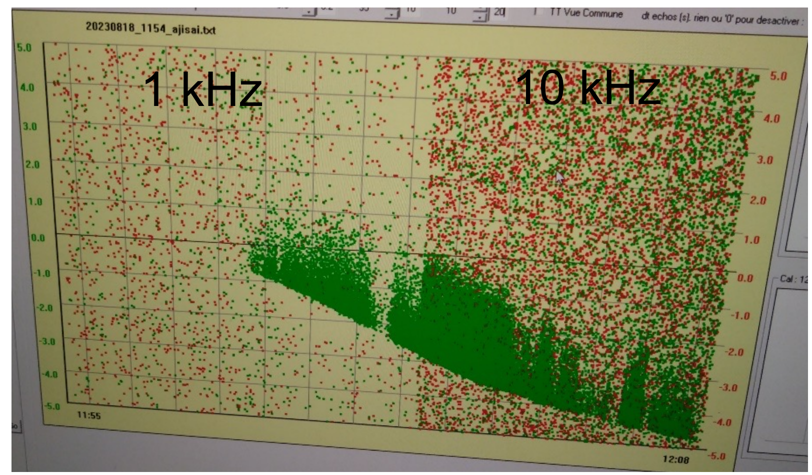
Aperture sharing in 2021

High count rate event timer (SigmaWorks)

Performances on ground



Example of data on Ajisai



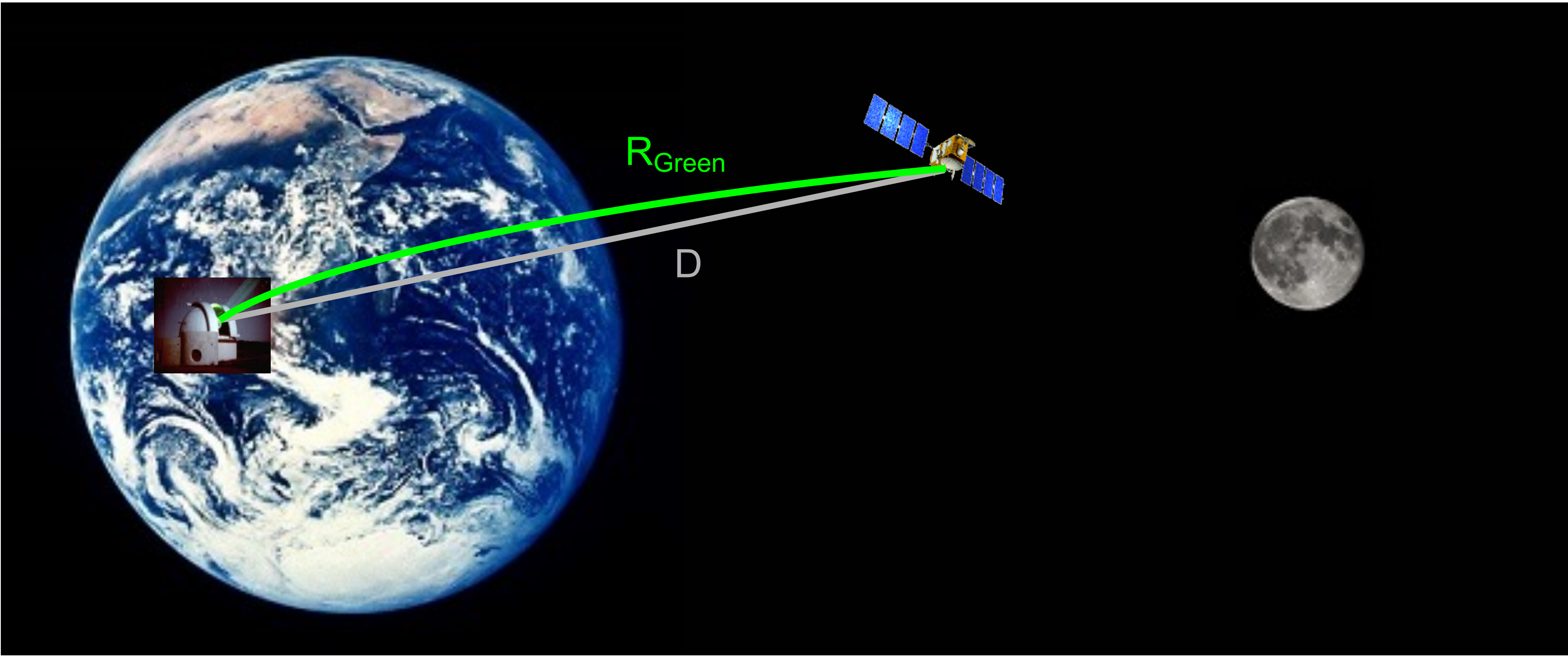
With the support of

4. Amélioration de la métrologie SLR/LLR
Accuracy for SLR

Currently:

$2D = R_{Green}$ with $R_{Green} = \dfrac{(t_{return} - tstart).c_0}{n(\lambda, T, Pv, Pa, CO_2)}$

Unknown parameter
=> uncertainty at the cm level



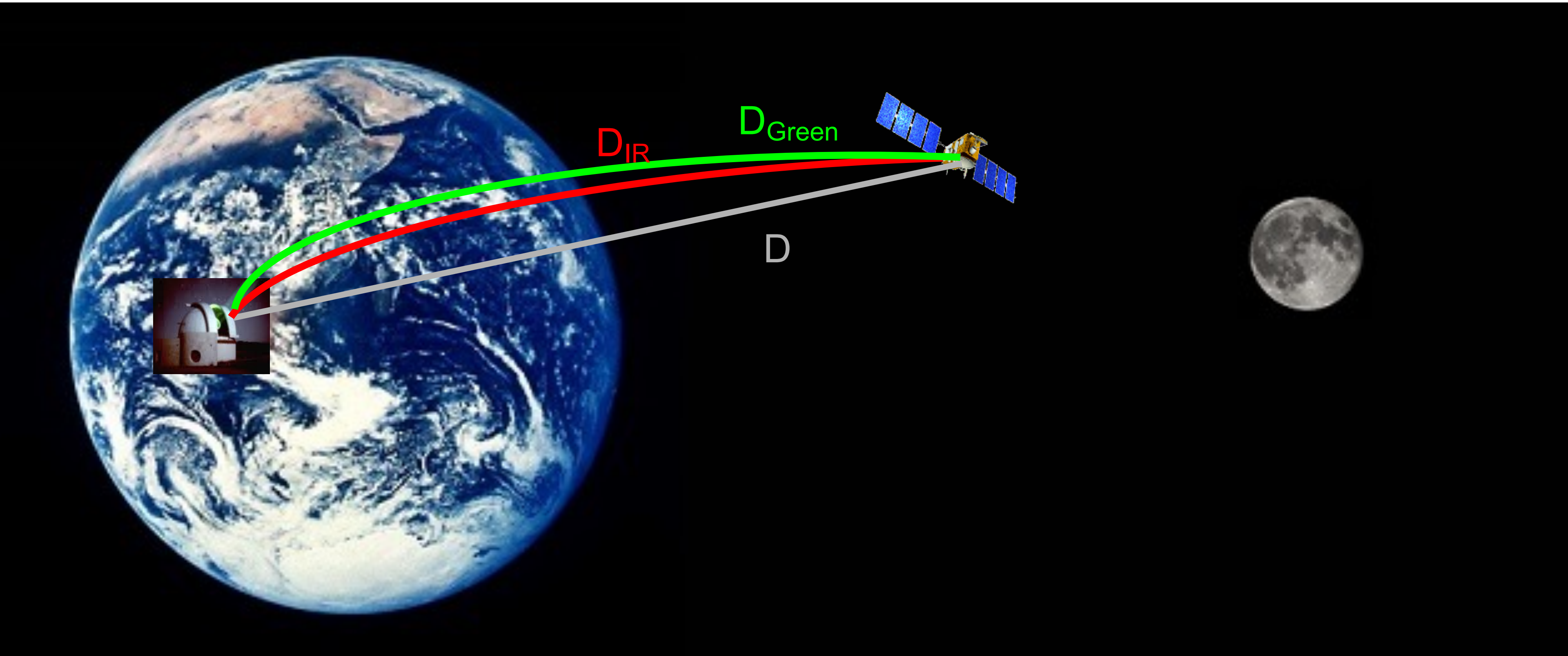
Our motivation:

2 colors measurement at the mm level

$$D = D_{Green} + A\,(D_{Green} - D_{IR})$$

=>

Requires an high improvement of the time-of-flight measurement on the both wavelength.



Geometre project: Task 2.3

Objectives :

Compare the Arpent long range distance meter developed by LNE-CNAM (sub-mm accuracy) to the new two-colour SLR setup at GRSM and to the tie done by IGN

2587.402 meters

Close corner cube

Distant corner cube

ARPENT laser telemeter in front of the GRSM telescope

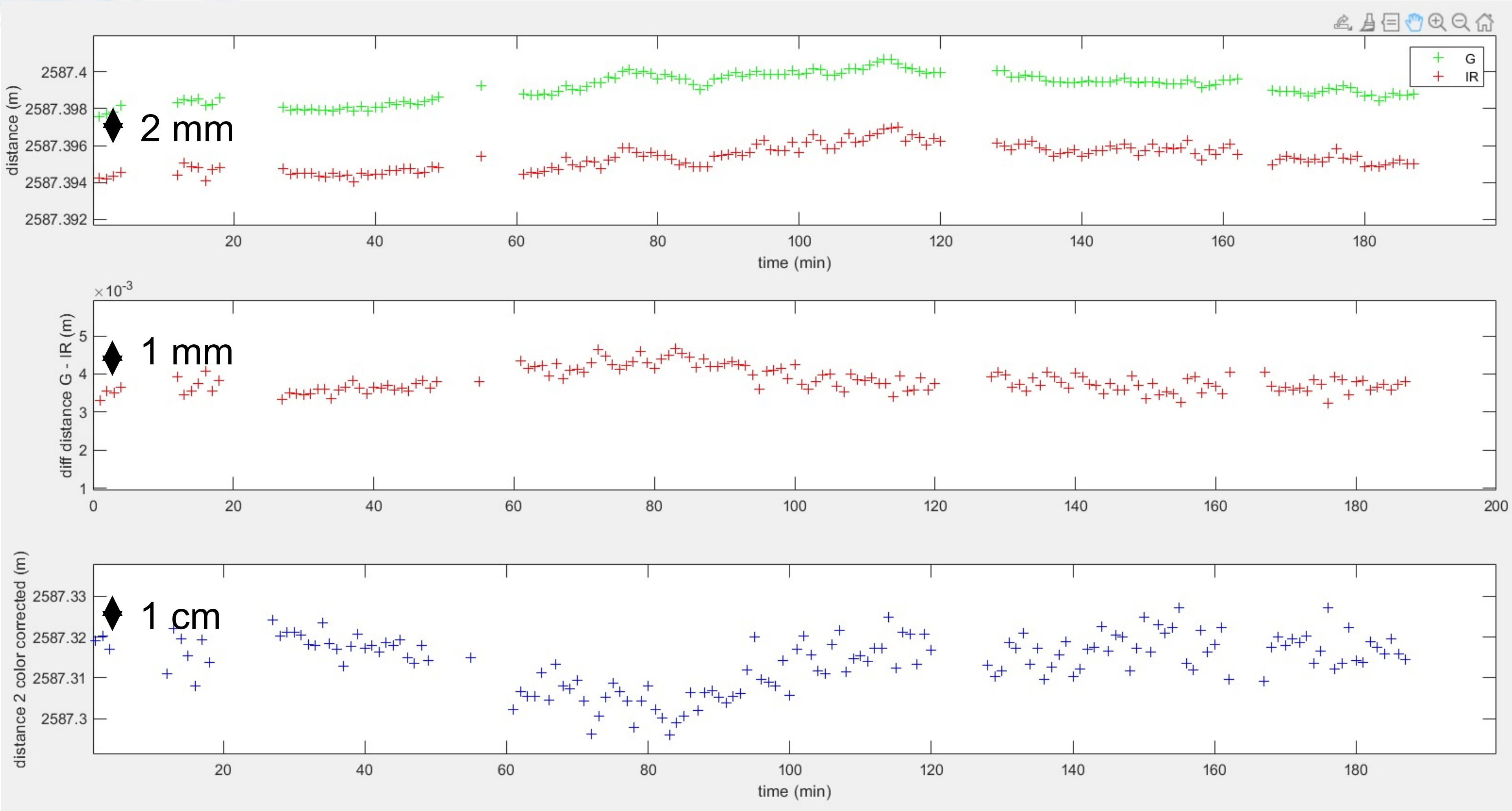
2 experiments in september 2022:

1) Relative distance measurement between two corner cubes with 2 different 2-colour instruments

2) Displacement over 1 cm and back with mm steps

Geometre project

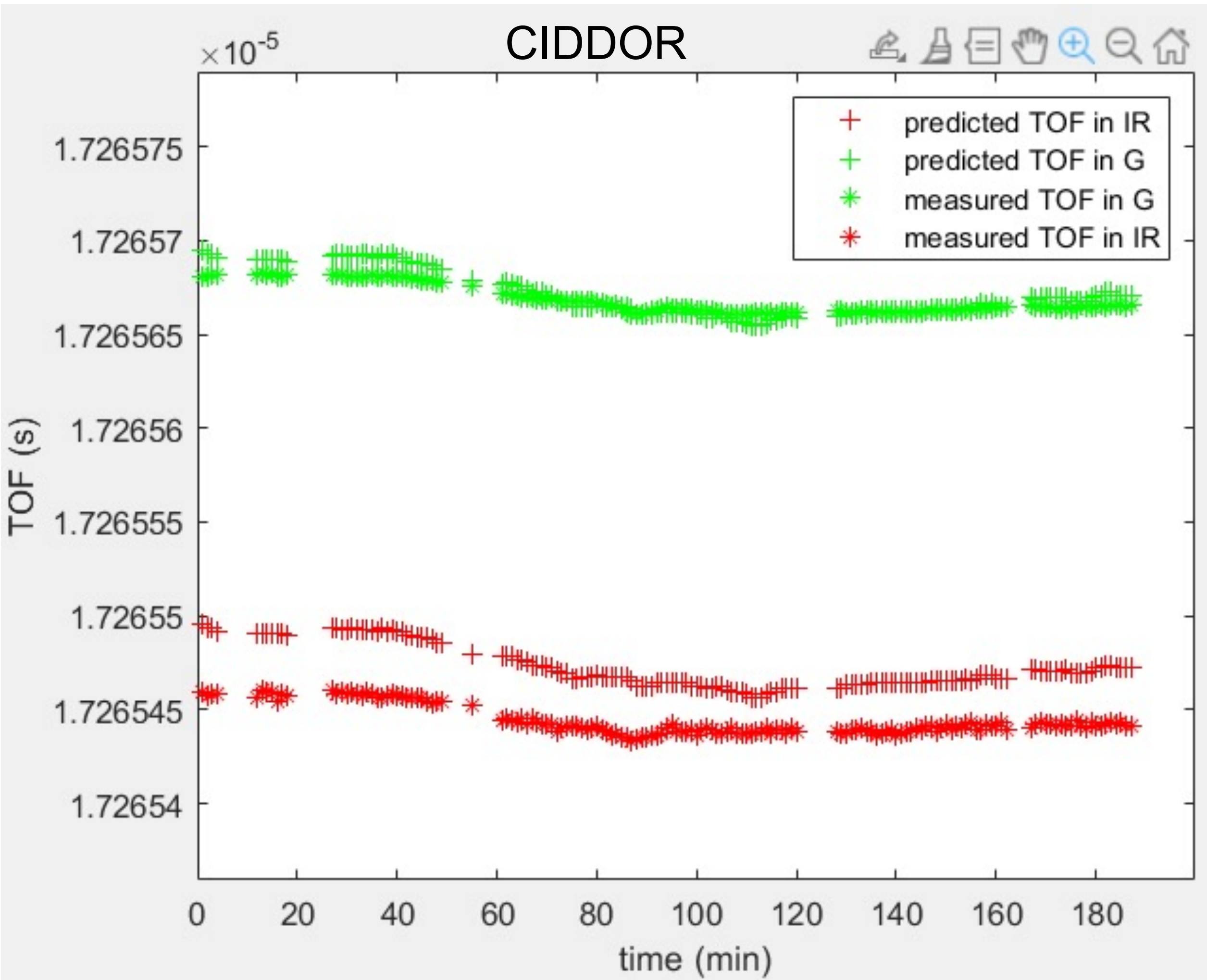
2-colour computation with CIDDOR, for day 22nd september



Geometre project

Comparison between measured & predicted TOF for day 22nd september

Predicted TOF computed with D=2587.3996 m



Good concordance between measured & predicted TOF in G

Bias between measured & predicted TOF in IR

Geometre project

Day 22nd september, with CIDDOR

Sampling (1 min)	A (Ciddor)	Distance_G	Distance_IR	D_2color
Mean (m)	-22.18	2587.3992	2587.3954	**2587.314**
Std (m)	15E-3	0.7E-3	0.7E-3	**6.6E-3**

In G, concordance with CNAM&IGN @ 0.4 mm

In IR, concordance with CNAM&IGN @ 4.2 mm
Bias with one mirror found

2color @ 10 kHz doesn't reach accuracy at mm level.

We hope to be close to the mm accuracy by operating at 400 kHz (2024)

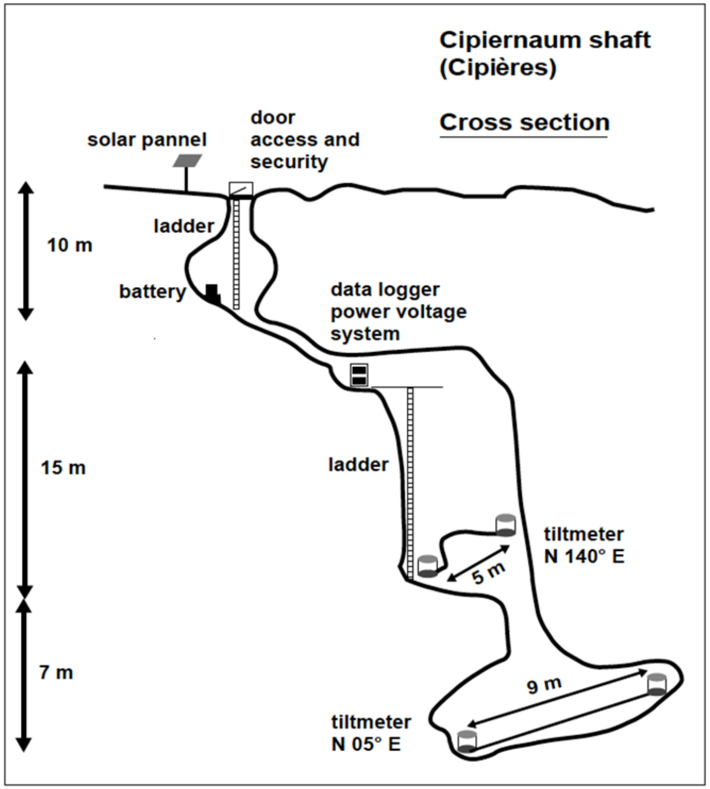
CONCLUSION

1) l'Observatoire multi-techniques de Calern présente un certain nombre d'avantages
   - 3 des 4 techniques de géodésie spatiale rattachées et partageant une même échelle de temps
   - Tirs laser sur la Lune => EOP + lien ITRF-ICRF
   - Amélioration métrologique du SLR vers le mm

2) Sans soutien financier aux infrastructures sol => qualité métrologique des données ne sera pas atteinte ! Le financement sous forme de projet ne permet pas de répondre aux besoins d'infrastructures (exemple horloge H-MASER =500k€ ; Laser-Lune-TT = entre 500 k€ et 2,5M€) => impossible à financer par les ANR, APR-CNES, R&T, CSAA-INSU


Thanks for your attention

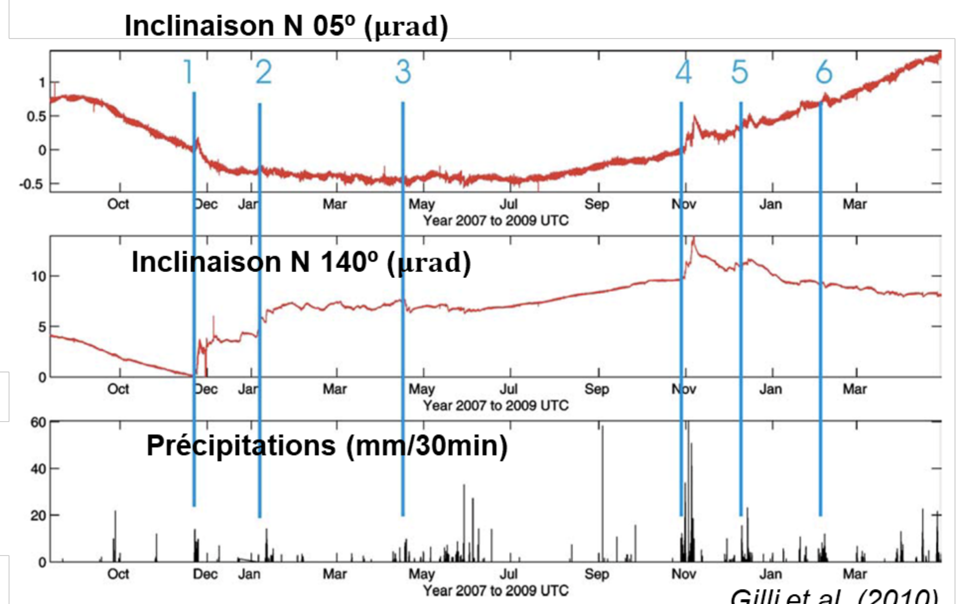
Remise en fonction de l'inclinomètre longue base de cipiernaum



En fonction entre 2007 et 2009

- ✓ lien entre déformation et flux hydriques au niveau du plateau de Calern
- ✓ signal induit par composante hydrologique profonde et superficielle

En cours de remise en fonctionnement



Gilli et al. (2010)