Les liens optiques sol-espace de la station laser de l'Observatoire de Calern.

AG First TF- 6 Novembre 2020

CNRS - GéoAzur - OCA – UNS
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OBSERVATOIRE DE LA COTE D'AZUR
CALERN SITE

- Site inaugurated in 1974

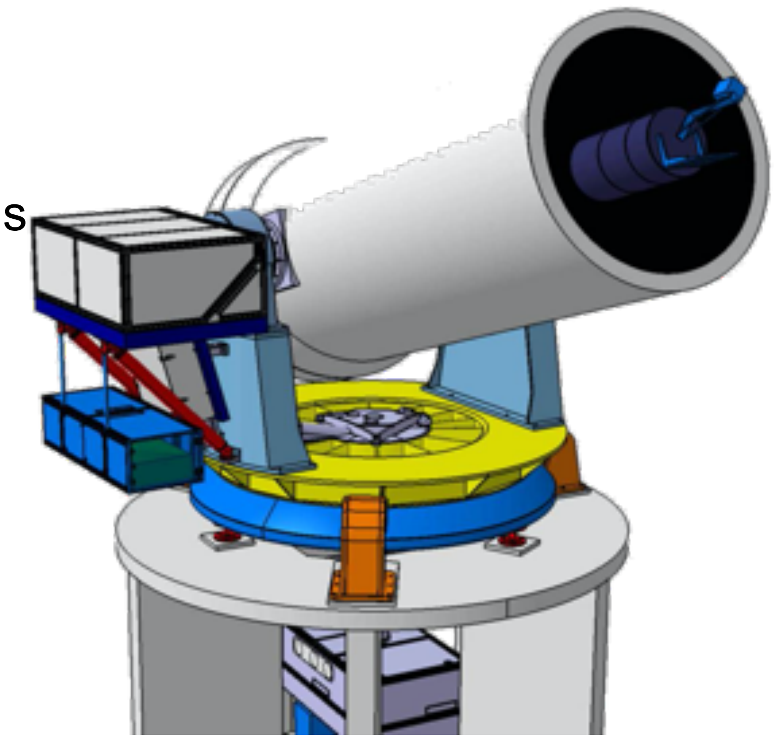
- Calcerous plate of 20 km² in the Grasse hinterland
  - Altitude : 1270m. longitude 6,9230°E ; latitude 43,750° N
  - Good compromise between accessibility (20 km of Grasse) and astronomical quality

Activités

- Service d'observation: Lune et Satellites
- R&D Métrologie Laser:
  - Télémétrie Haute cadence
  - Mesure de distance par liens télécoms en espace libre
  - R&D automatisation
- Collaborations extérieures:
  - Ecole polytechnique de Milan
  - ANR I2C (W. Guerin Laboratoire Inphini) : Interférométrie d'intensité stellaire
  - ONERA Com. Optique et Observation satellite avec OA
  - Optique atmosphérique - Laboratoire Lagrange
  - SigmaWorks (Etienne Samain)

MeO (Métrologie Optique)

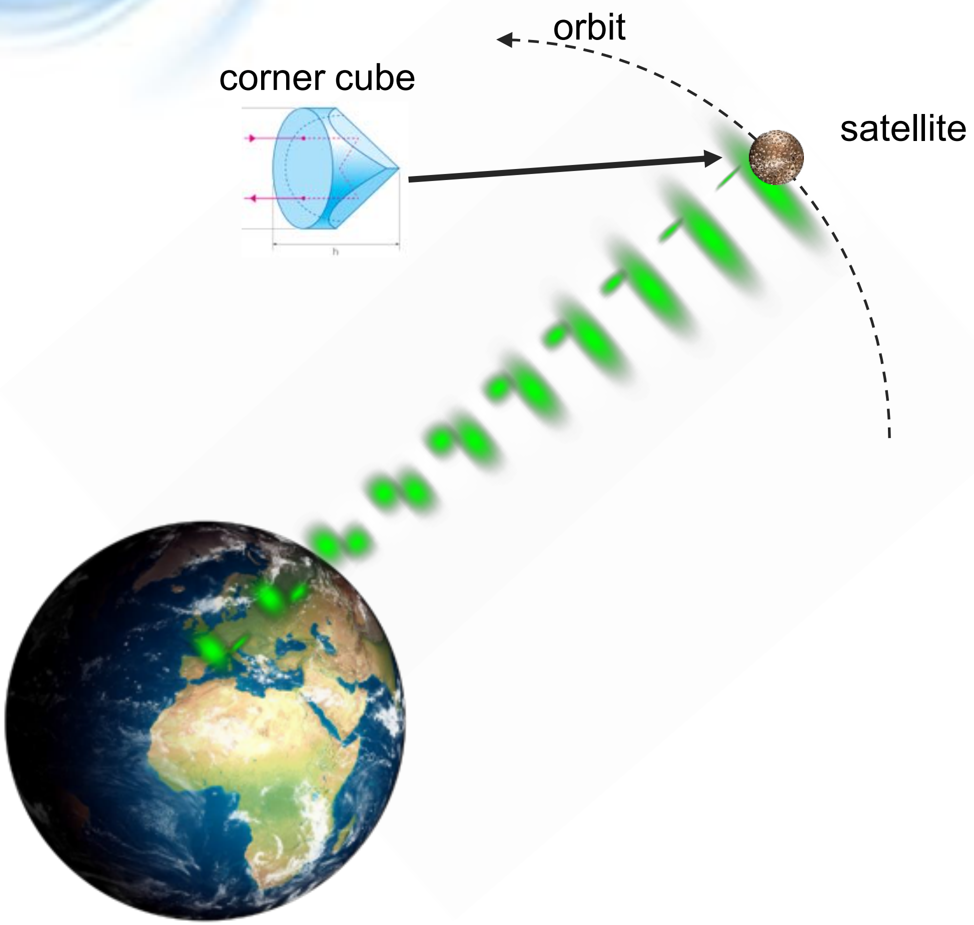
- Ritchey Chretien optical configuration
  - Primary Mirror: Parabolic 1540 mm
  - Nasmyth table (fold mirror)
- Encoders
  - Linearity: 1 arcsec
  - Repeatability error < 0.1 arcsec rms
  - Absolute accuracy < 2 arcsec rms
- Motorization
  - Direct drive Etel motors
  - Torque: 10000 Nm
  - Speed: 5°/s
  - 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
- ~~Caesium clocks~~ Passive H-Maser (T4 science)

Satellite Laser Ranging principle



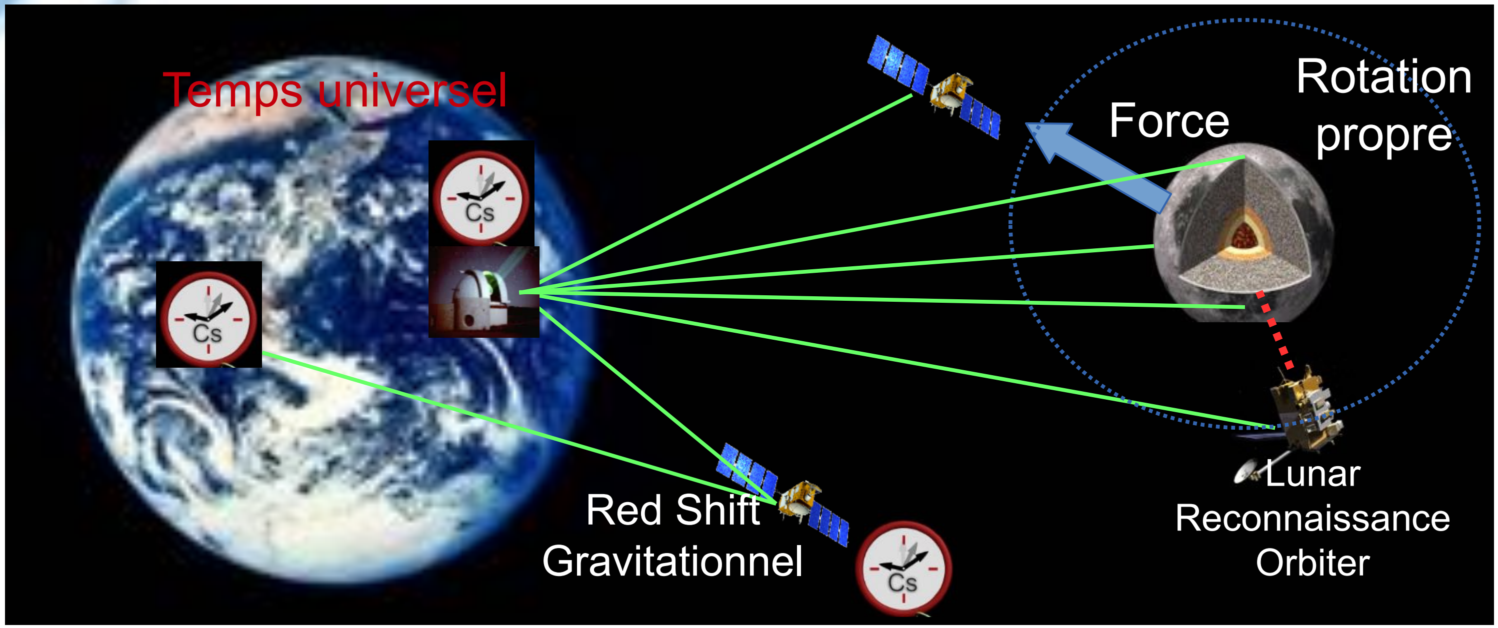
- Measurement of the time of flight of laser pulses:

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

- 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

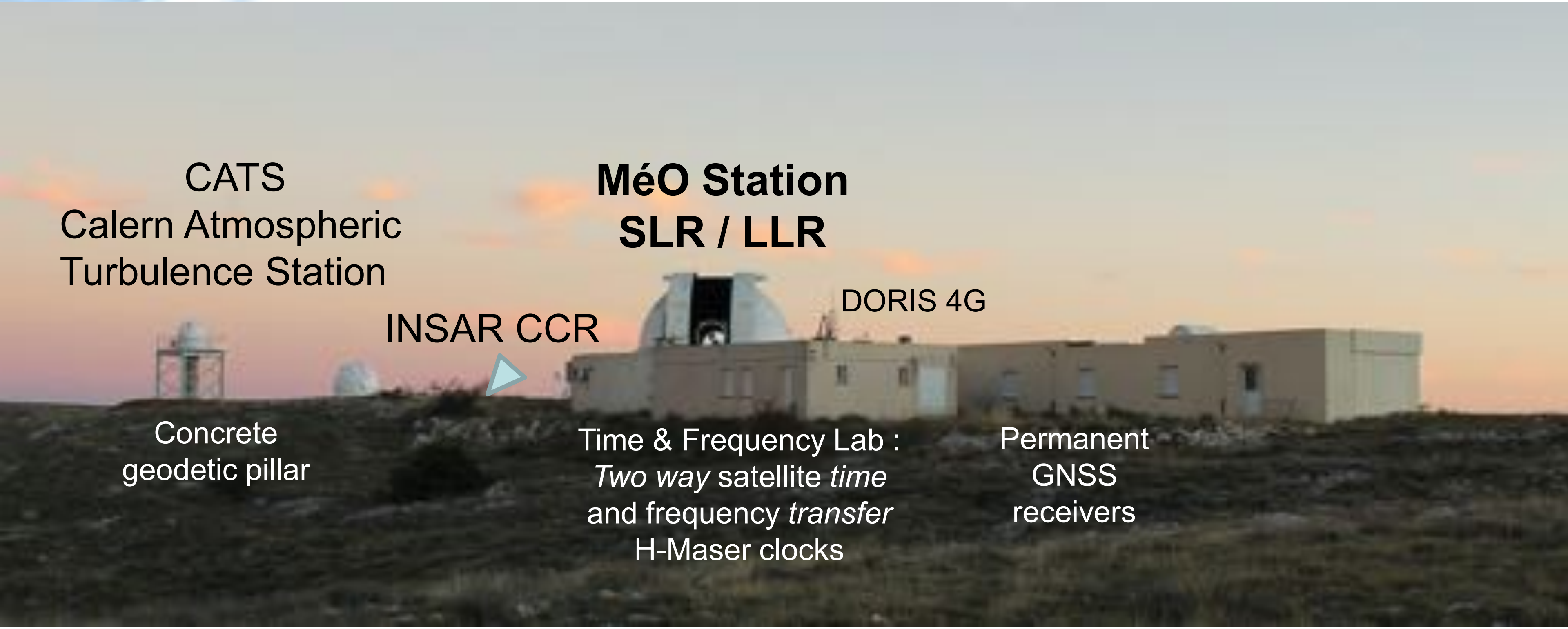
Laser link to probe the close universe



<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...

A MULTI-TECHNIC OBSERVATORY



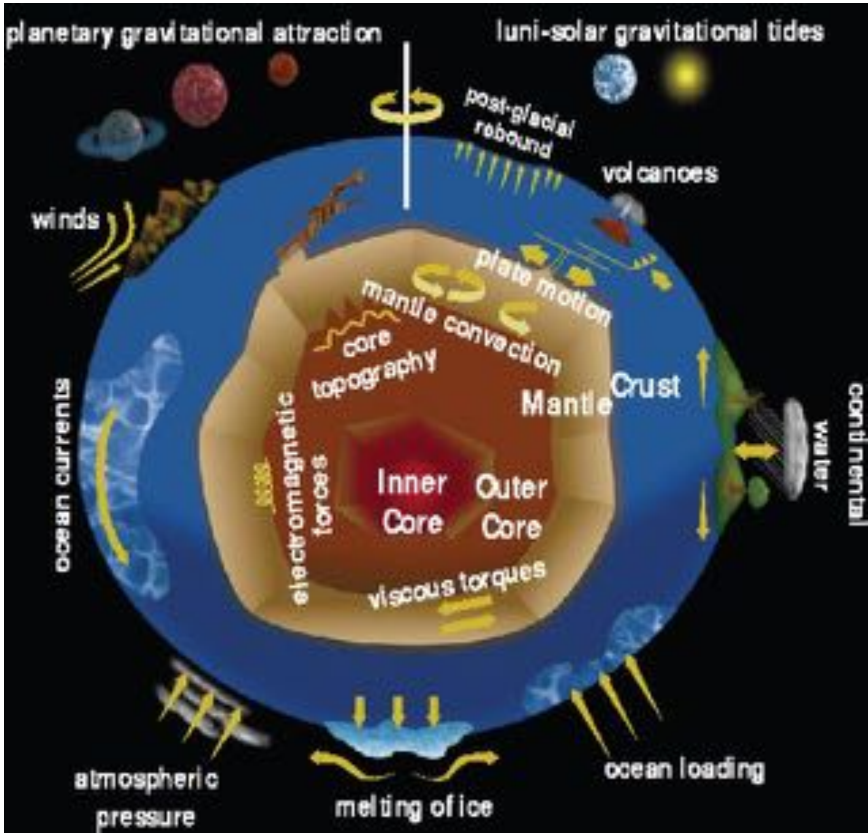
Technics for geodetic observatory

	Product	VLBI	SLR	GNSS	DORIS
Earth rotation	length of day	XXX	X	XXX	
	movement of pole	XXX	XX	XXX	X
	nutation	XXX		X	
	UT1	XXX			
Terrestrial frame	coverage homogeneity	X	X	XX	XXX
	center of mass		XXX	X	X
	center of figure	XX			
	tectonic movements	XXX	XX	XXX	XXX
	densification		X	XXX	XX
Celestrial frame		XXX			
Gravity field	high wavelengths (statistical)		XXX	XX	X
	short wavelengths (statistical)		XX	XXX	XX
	temporal variations		XX	X	

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

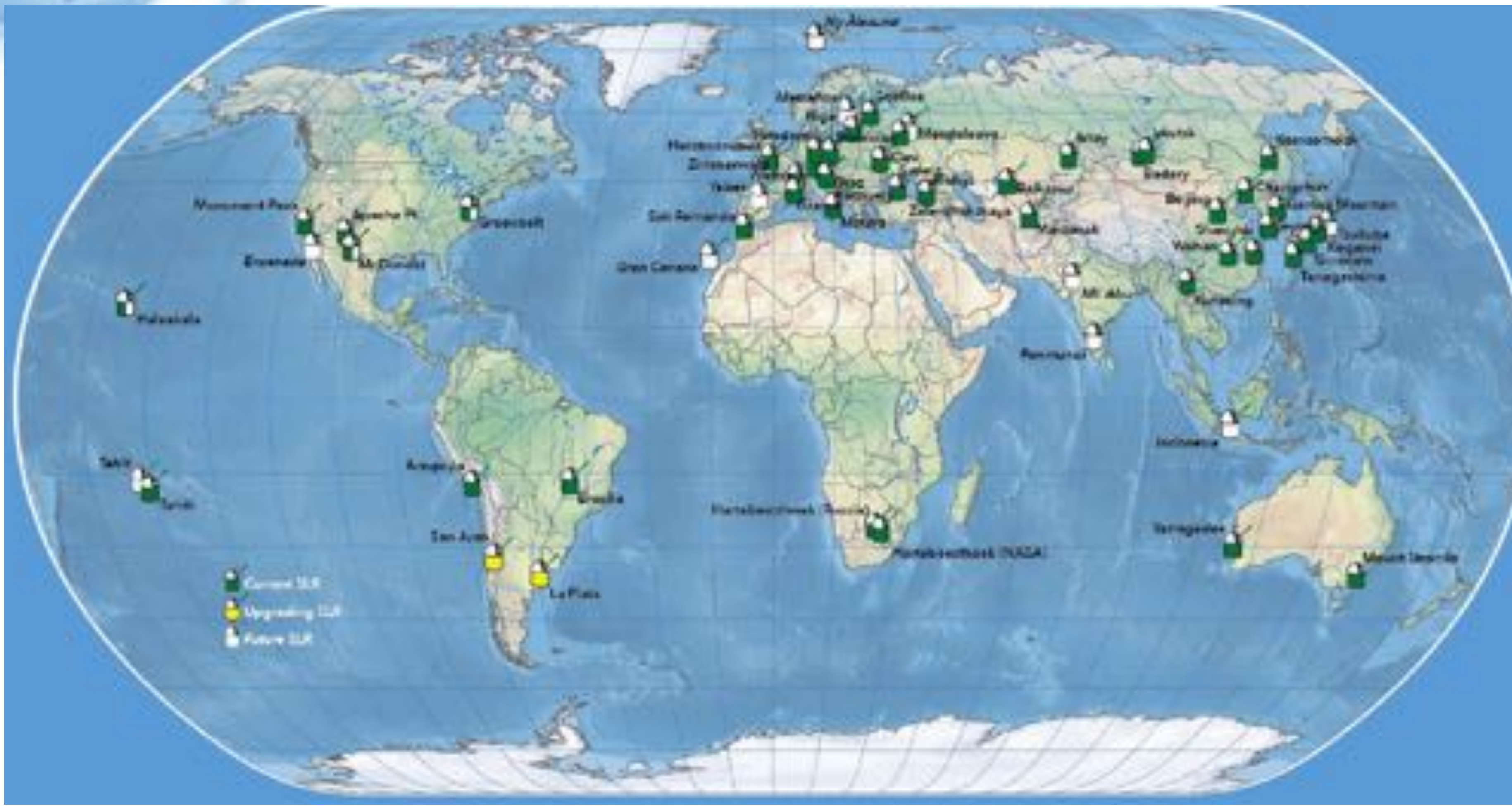


Service National d'Observation

- 11 observateurs
- 1 observateur de jour / 2 observateurs de nuit
- 5 jours / 7 avec des exceptions pour les campagnes
- 2019 :
  - 2858 passages satellite
  - 1246 Npts sur la Lune

Responsable SNO / Pôle R&D: Julien Chabé
Responsable Pôle Observatoire MéO: Clément Courde

International Laser Ranging Service



- 40 SLR stations

Lunar Laser Ranging

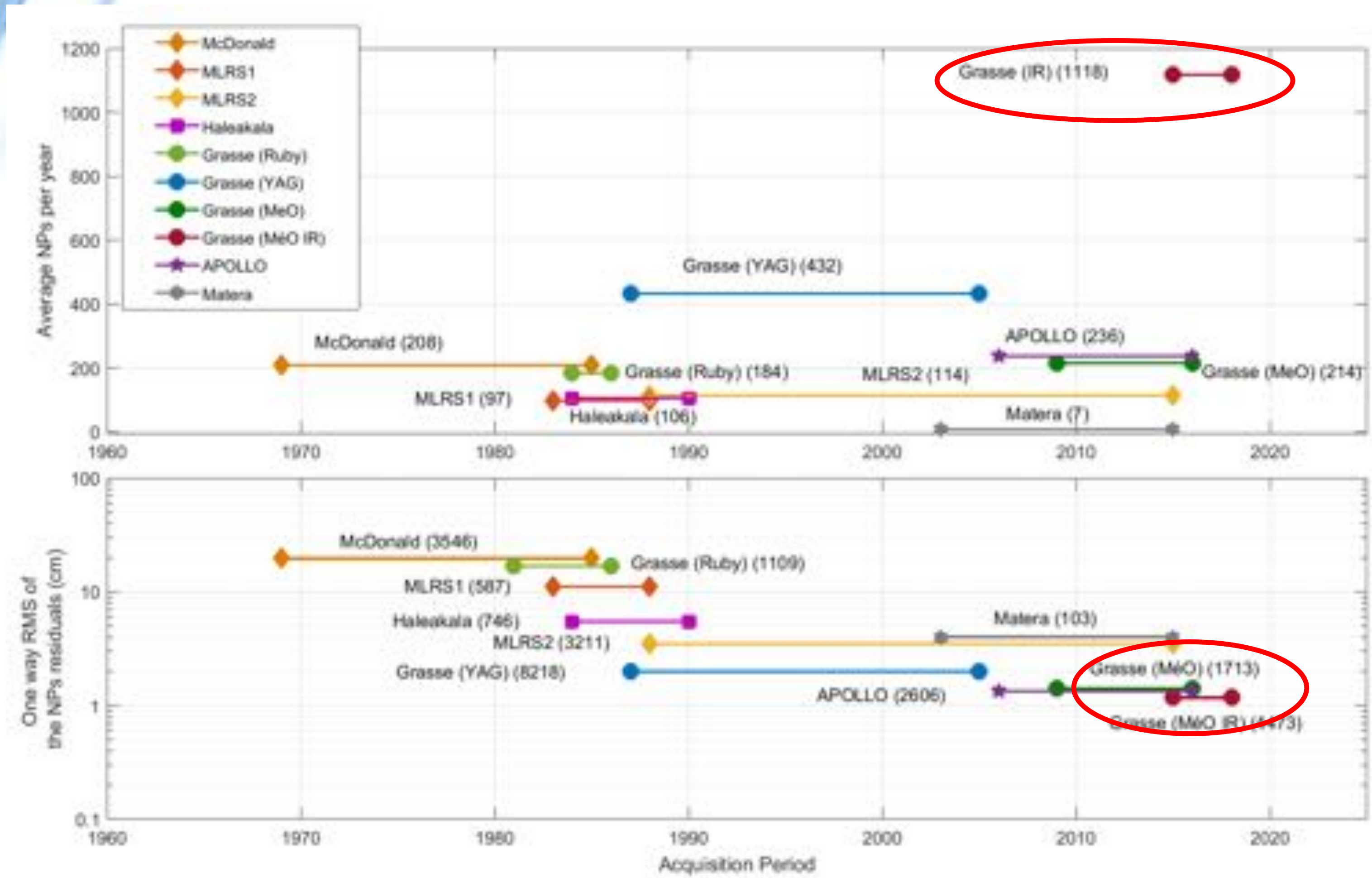
- Only few stations perform lunar laser ranging at cm level.

The target is at ~ 380 000km

Specs :

- 100ps laser pulse width, 250mJ (green) & 300mJ (IR) laser pulse @ 10Hz
- Hydrogen maser clock for timing

Lunar Laser Ranging performances



- Grasse LLR leading for data quantity and « Normal Point RMS » relative to ELPN01 lunar ephemeris.

Scientific outcomes from LLR data

- Selenophysics
  - **Moon core radius**
  - Viswanathan, V., Rambaux, N., Fienga, A., Laskar, J., & Gastineau, M. (2019). Observational constraint on the radius and oblateness of the lunar core-mantle boundary. *Geophysical Research Letters*, 46, 7295– 7303. https://doi.org/10.1029/2019GL082677

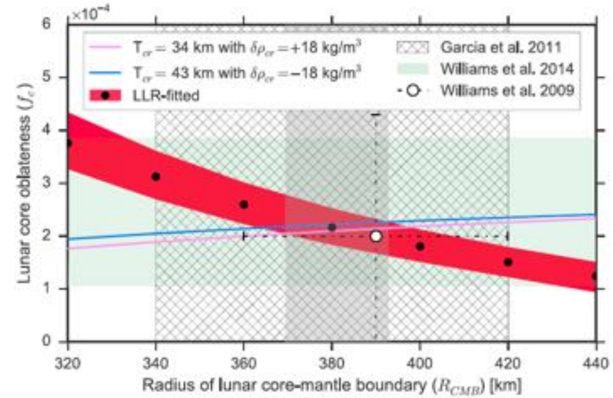
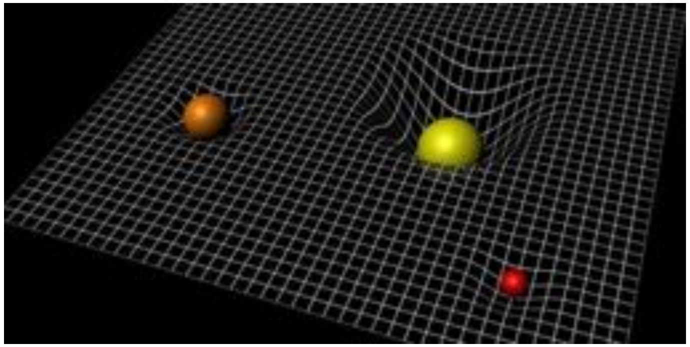


Figure 1. The lunar laser ranging (LLR)-fitted value of the lunar core oblateness f_c (in black dots with region of uncertainty in red) intersects the theoretical hydrostatic values of f_c (solid lines in violet and blue corresponding to models with two different lunar crustal thicknesses (34 and 43 km) with ±18 kg/m³ crustal density variations, respectively) at a

- Fundamental Physics
  - **Lorentz Symmetry Violations from Matter-Gravity Couplings with Lunar Laser Ranging**
  - A. Bourgoin, A. Hees, S. Bouquillon, C. Le Poncin-Lafitte, G. Francou, and M. C. Angonin, Phys. Rev. Lett. 117, 241301 (2016).
  - A. Bourgoin, C. Le Poncin-Lafitte, A. Hees, S. Bouquillon, G. Francou, and M.-C. Angonin, Phys. Rev. Lett. 119, 201102 (2017).



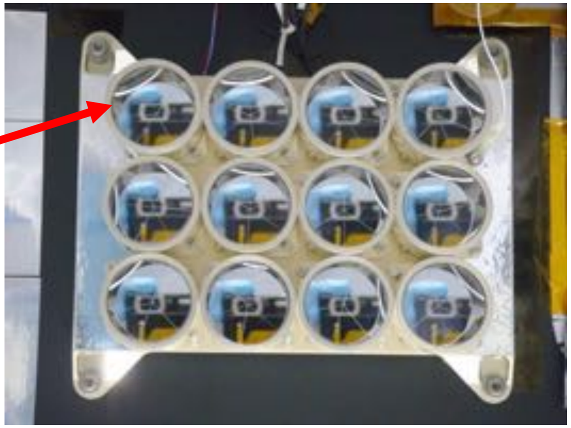
- Ephemeris:
  - Pavlov, D. Role of lunar laser ranging in realization of terrestrial, lunar, and ephemeris reference frames. *J Geod* **94,** 5 (2020). https://doi.org/10.1007/s00190-019-01333-y
  - *The new lunar ephemeris INPOP17a and its application to fundamental physics* V Viswanathan, A Fienga, O Minazzoli, et al. Monthly Notices of the Royal Astronomical Society 476 (2) 1877 (2018)

Lunar Laser Ranging performances : LRO

- Lunar reconnaissance Orbiter **entered lunar orbit on June 23, 2009**
- Any laser ranging facility has never been able to range it (even Apollo Observatory and its 3.5 meter telescope)

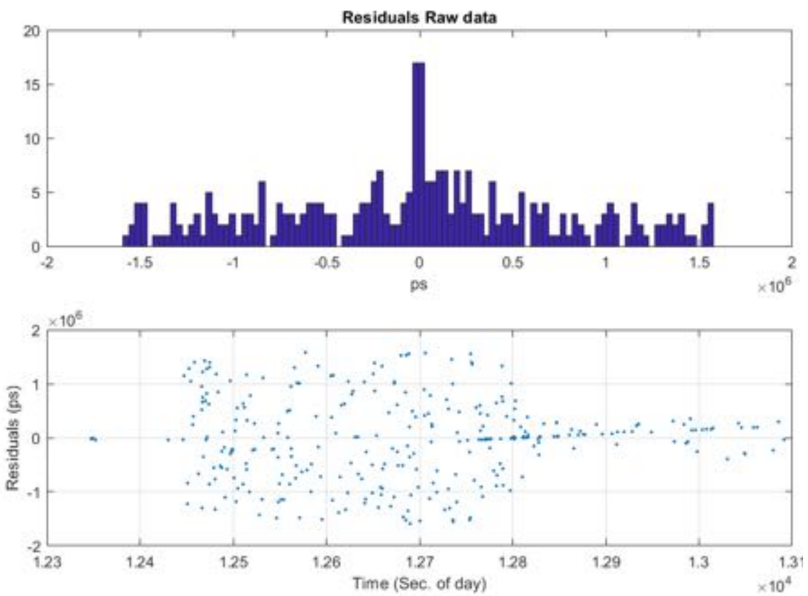
12 solid corner cubes, 31.7mm diameter
•Materials Suprasil cubes, Al frame
•Mass 650.25g
•Volume: 15 x 18 x 5 cm3
•Operating temperature range : -150 to +30°C
Thermally isolated from spacecraft
•Tested for 14-g vibration
•Optical characteristics:
•90°dihedral angle (unspoiled)
•Total internal reflection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

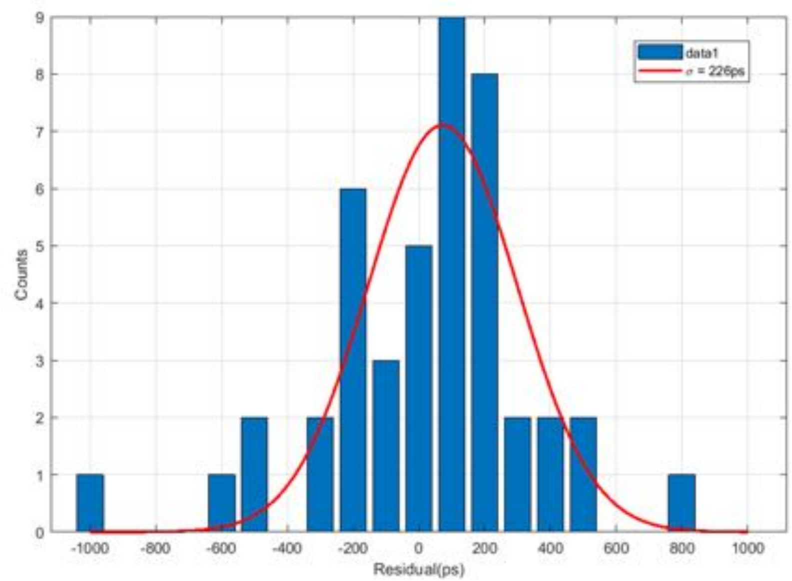
Same as Apollo XI and XIV



Lunar Laser Ranging performances : LRO

- First results on Sept. 4th 2018 from MéO LLR (2 successful passes)
- Two others success on Aug. 23rd and 24th 2019
- Example of data:

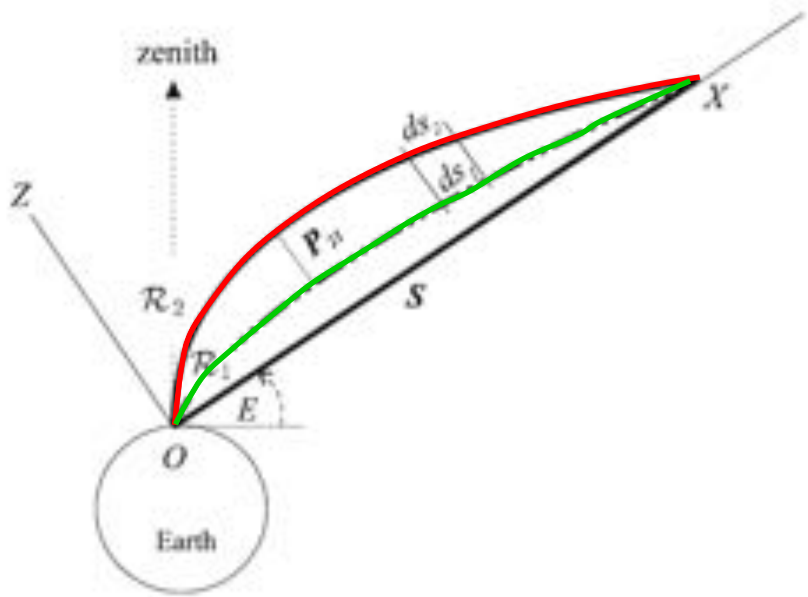




- Not enough passes to conclude on the reflectors performances as many parameters can affect the return rate (Sun illumination, laser incident angle)
- **Mazarico, E., Sun, X., Torre, J. *et al.* First two-way laser ranging to a lunar orbiter: infrared observations from the Grasse station to LRO's retro-reflector array. *Earth Planets Space* 72, 113 (2020). https://doi.org/10.1186/s40623-020-01243-w**

R&D activities

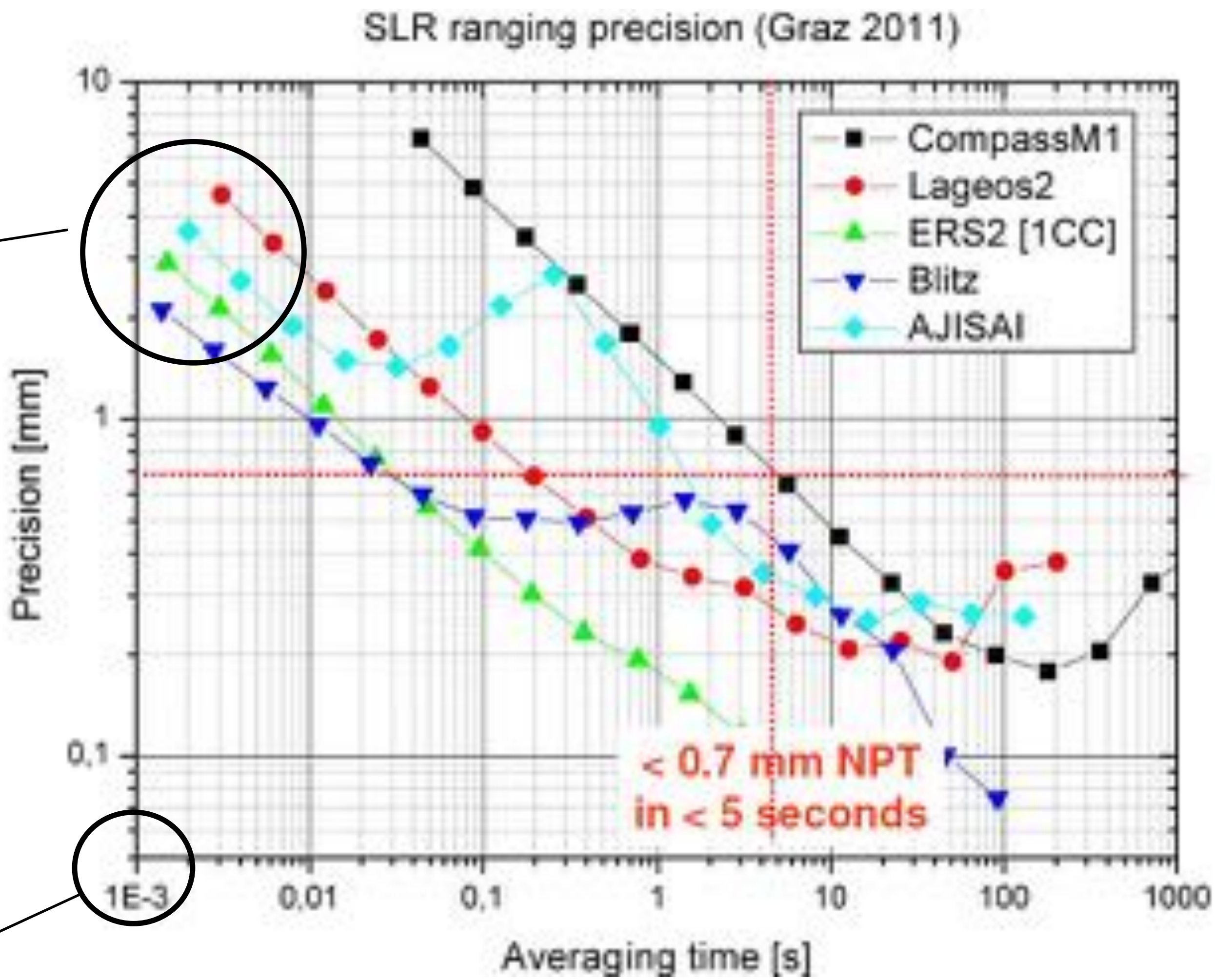
R&D : Improve accuracy in SLR



- A simultaneous 2 color ranging measurement can eliminate uncertainty on the refraction index
- But you need to <u>perform sub-millimetric ranging at both wavelength !</u>
- <u>High rate laser ranging</u>

R&D : 2 colors / High Rate

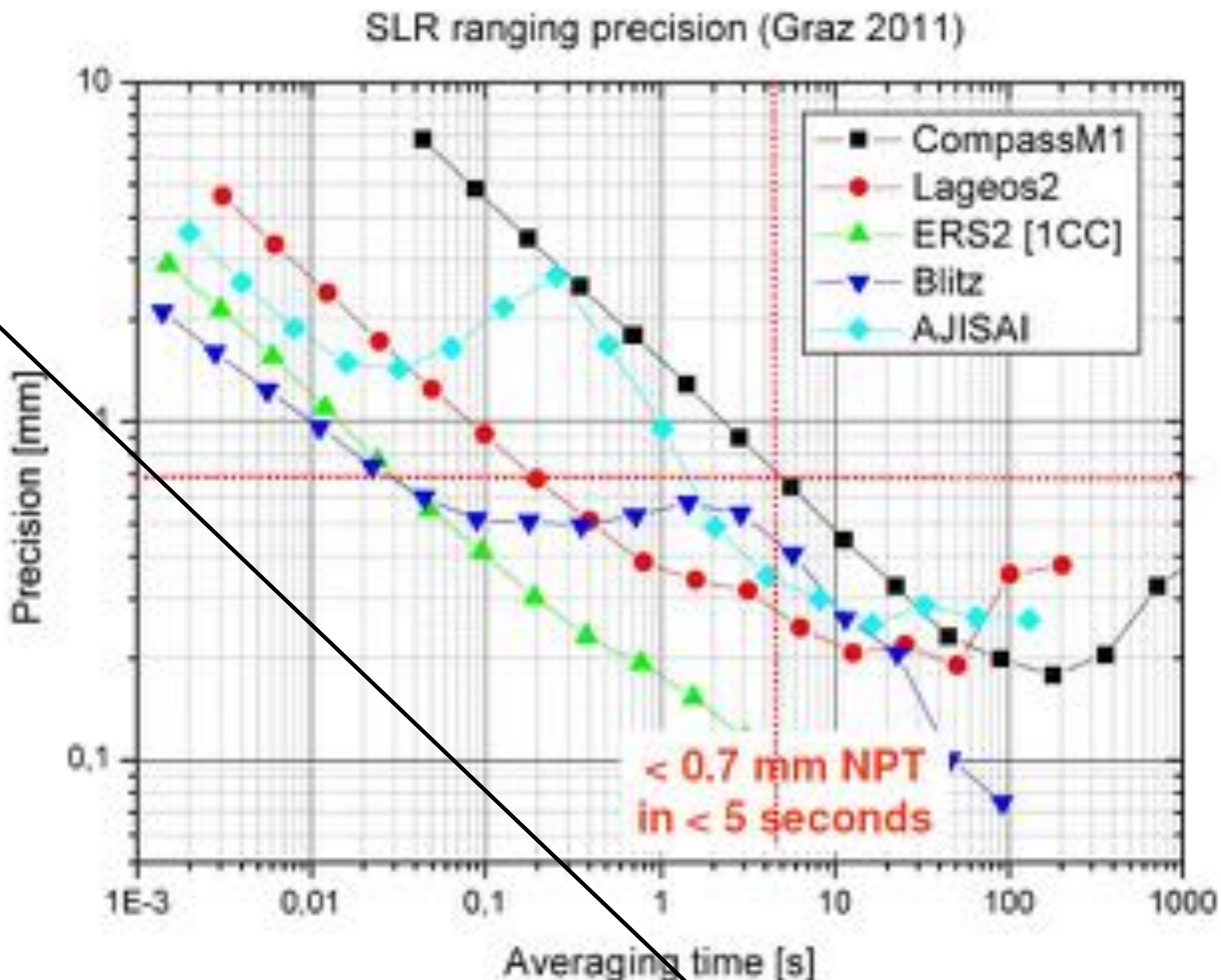
Limitations :
- Timing jitter des SPAD
- Dispersion atmosphérique
- Cibles multi coin de cubes



Limitations :
- Énergie par impulsion des laser
- Rétrodiffusion de l'atmosphère

Metrological performances in SLR

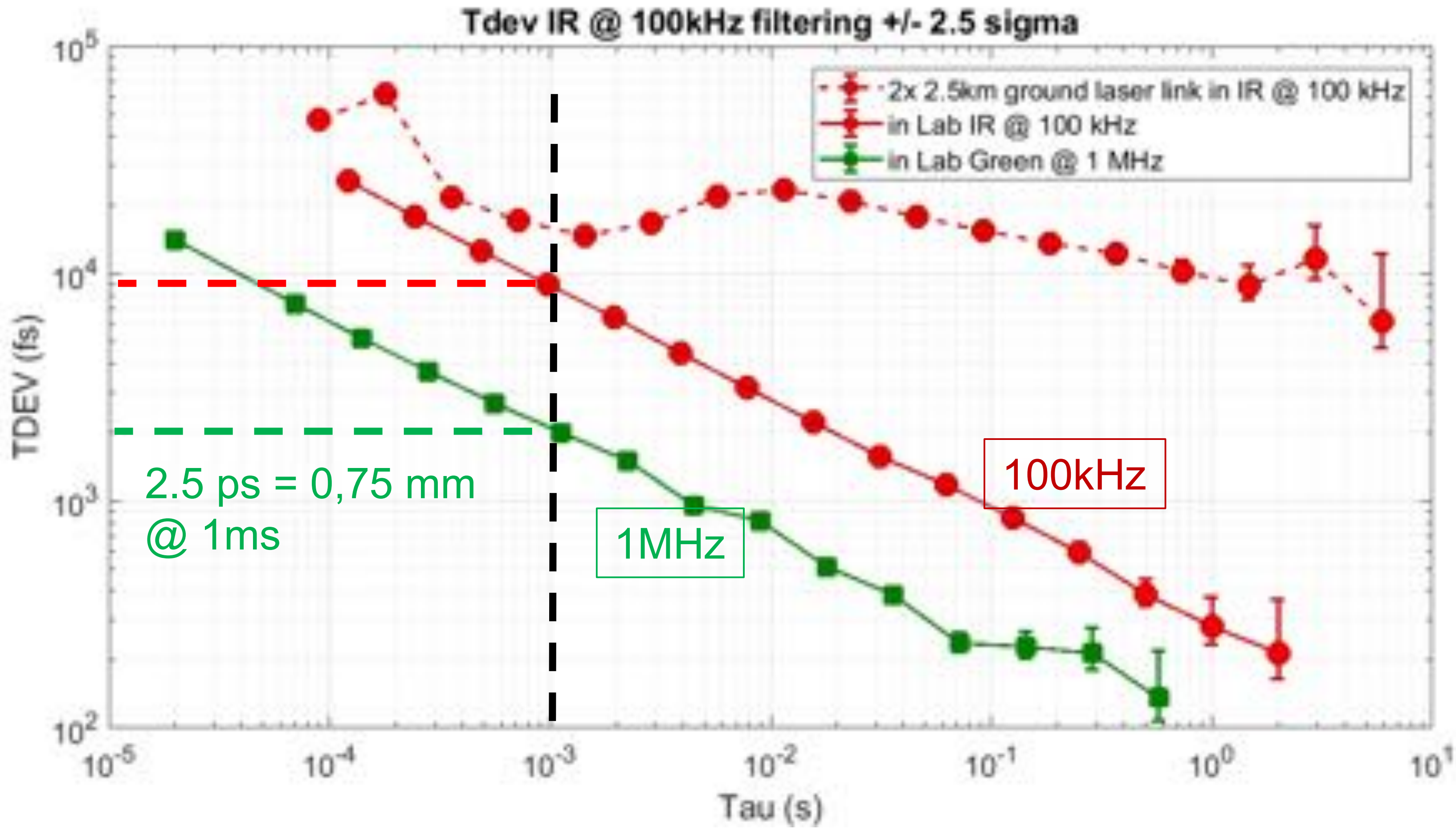
Objectif visé en télémétrie haute cadence



Développement de deux détecteurs simple-photon en collaboration avec l'école Polytechnique de Milan :

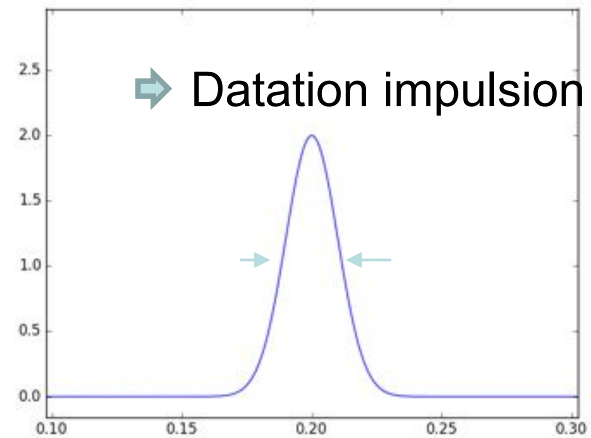
Taux de mesure simple-photon = 1 MHz @532 nm et 100 kHz@ 1064 nm

First results TVDEV SPAD (green) @ 1MHz

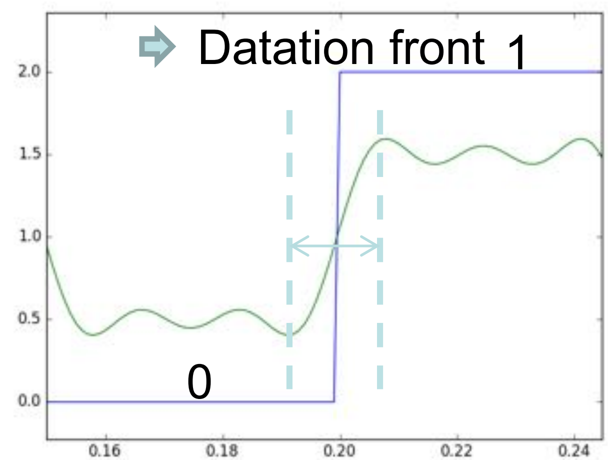


R&D : Laser Com for Ranging ?

- <u>Classical laser ranging</u>
  - Laser pulse ~10 à 100 ps width
  - Single photon detection (SPAD)
  - Rate 10Hz à 2kHz
  - Precision : 10 ps (intégration de ~ 100 mesures)

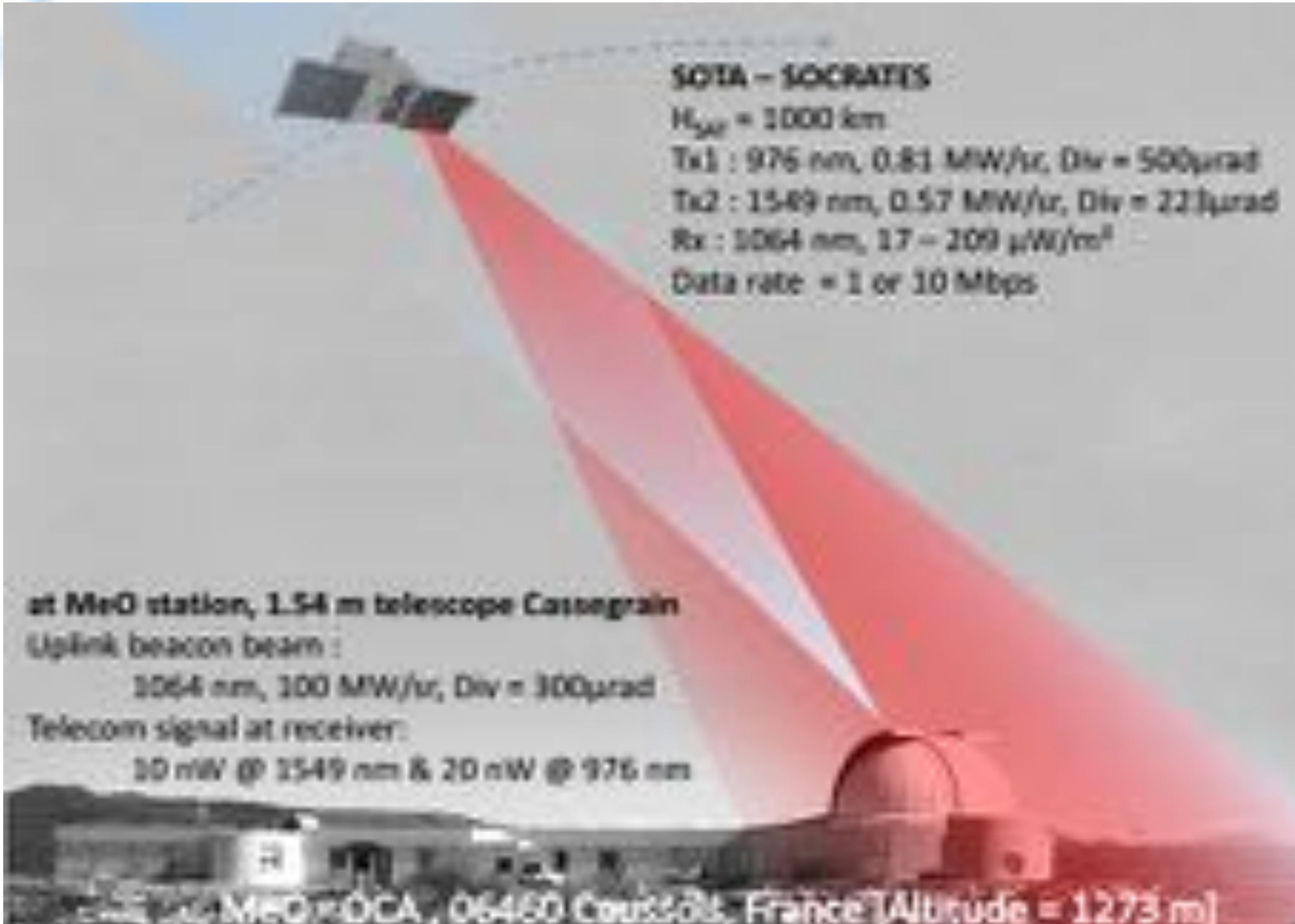


- <u>Laser ranging by Optical com @ 1 to 10 Gbit</u>
  - Continuous laser Amplitude Modulation (Bits)
  - Rate~ telecom rate
  - Multiphoton detection
  - Precision ~ ps Thousand to millions of measurement !

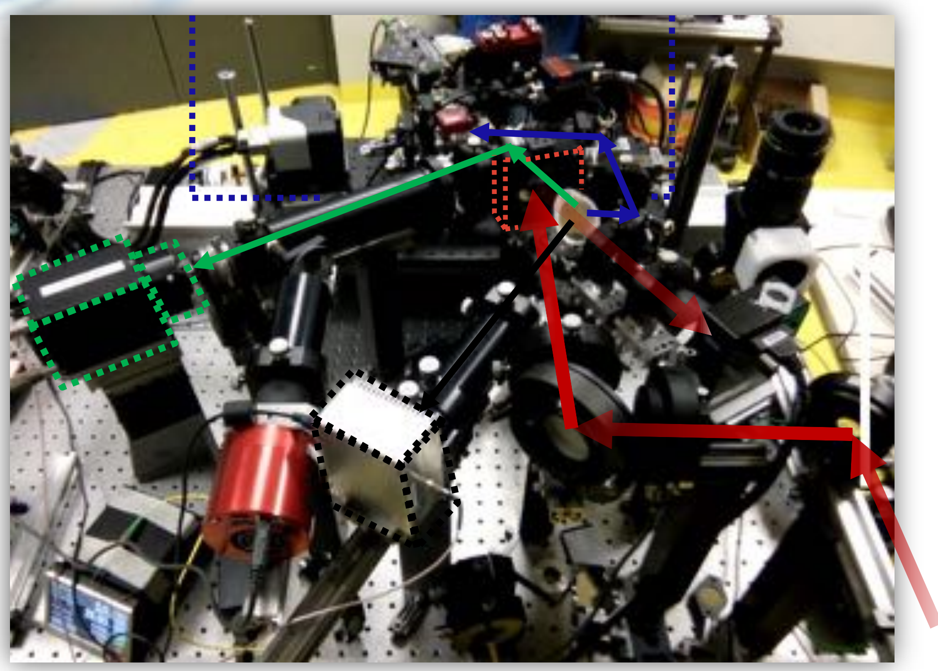


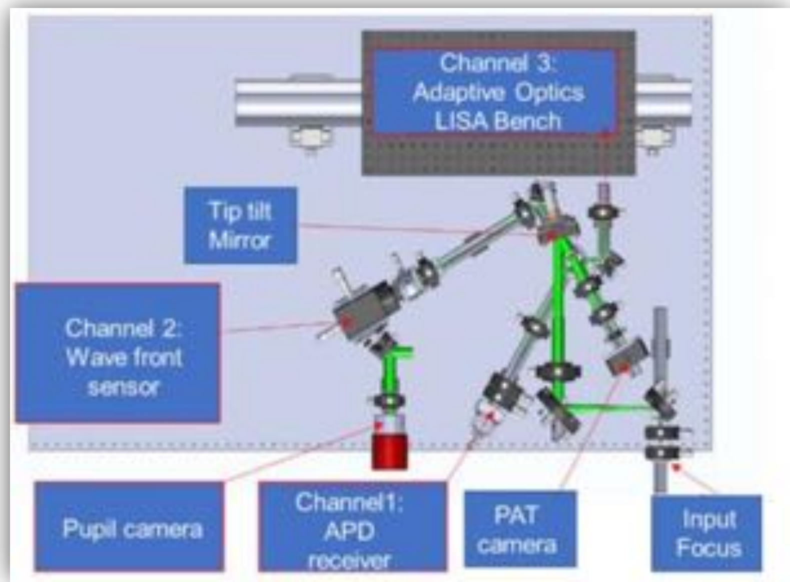
DOMINO – SOTA Experiment

NICT National Institute of Information and Communications Technology



Laser Com Downlink Analysis Bench

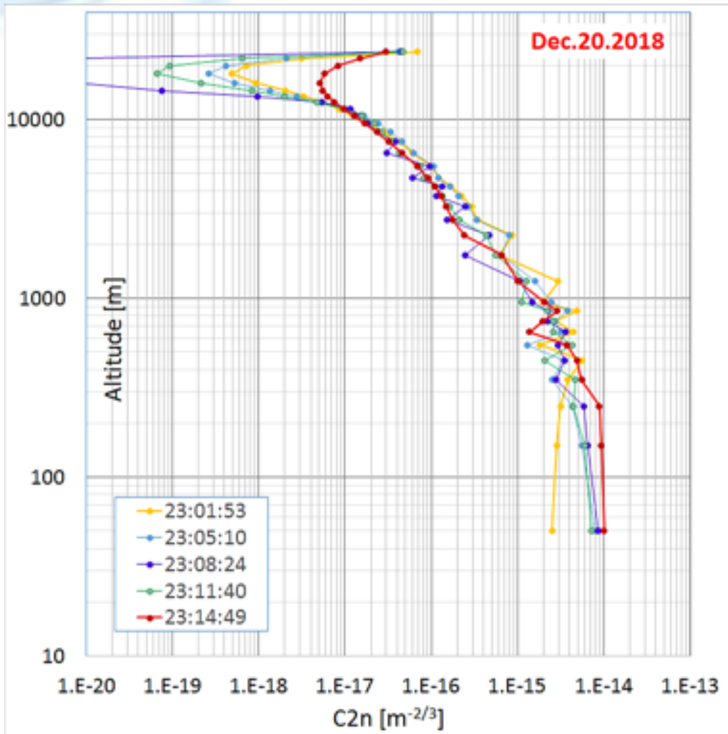


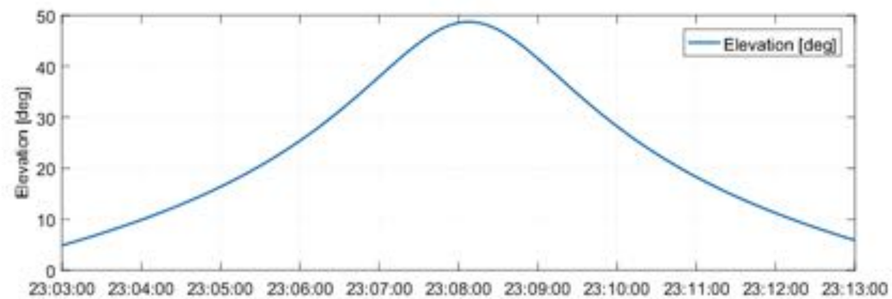


- ❑ 90% Triangle Beam splitter ➔ 3 sub-aperture channels (40cm)
  - 1. Telecom APD detector
  - 2. WaveFront sensor (high speed IR camera)
  - 3. LISA ONERA (Adaptive Optic → fiber coupling)
- ❑ 10% Fine tracking by TipTilt mirror + camera → Pupil stabilization

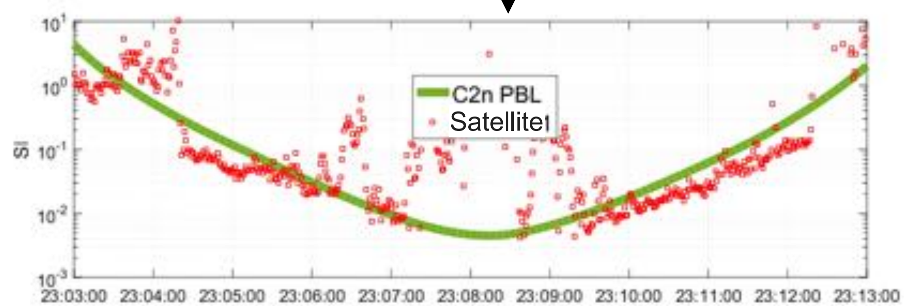
Characterization of the transmission channel

PBL : Profil altimétrique de la turbulence : Modélisation de la scintillation





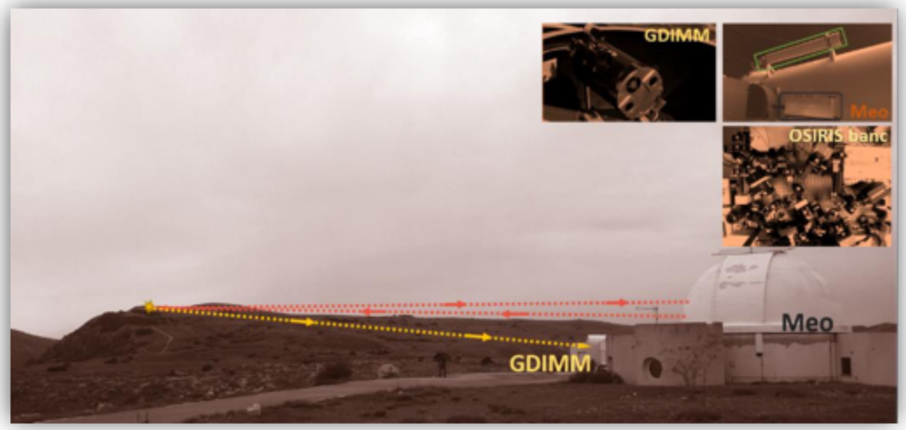
$$\sigma_I^2 = 17D^{-7/3}(cos\xi)^{-3}\int_0^H h^2 C_n^2(h)dh$$

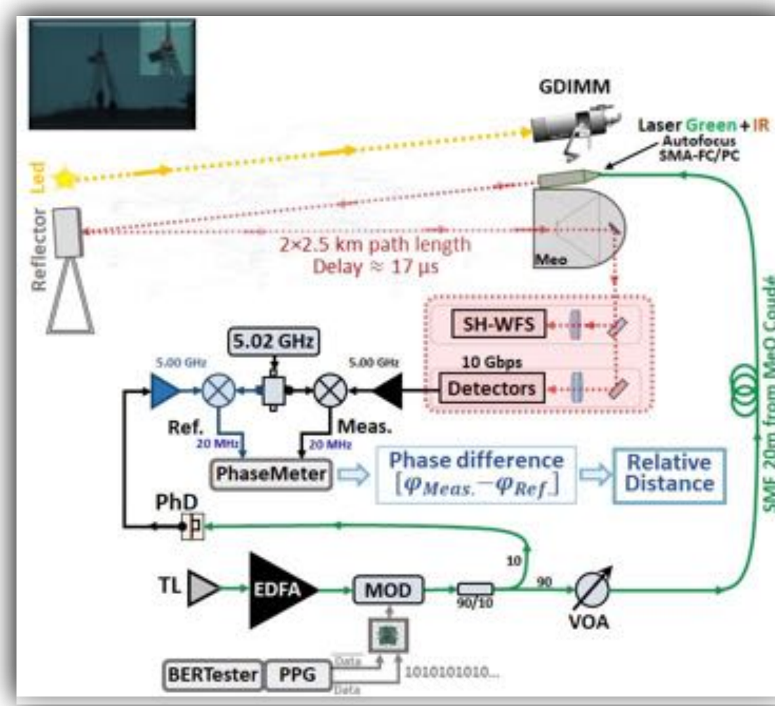


Station CATS

Ground to ground experiment @ 10 Gbit

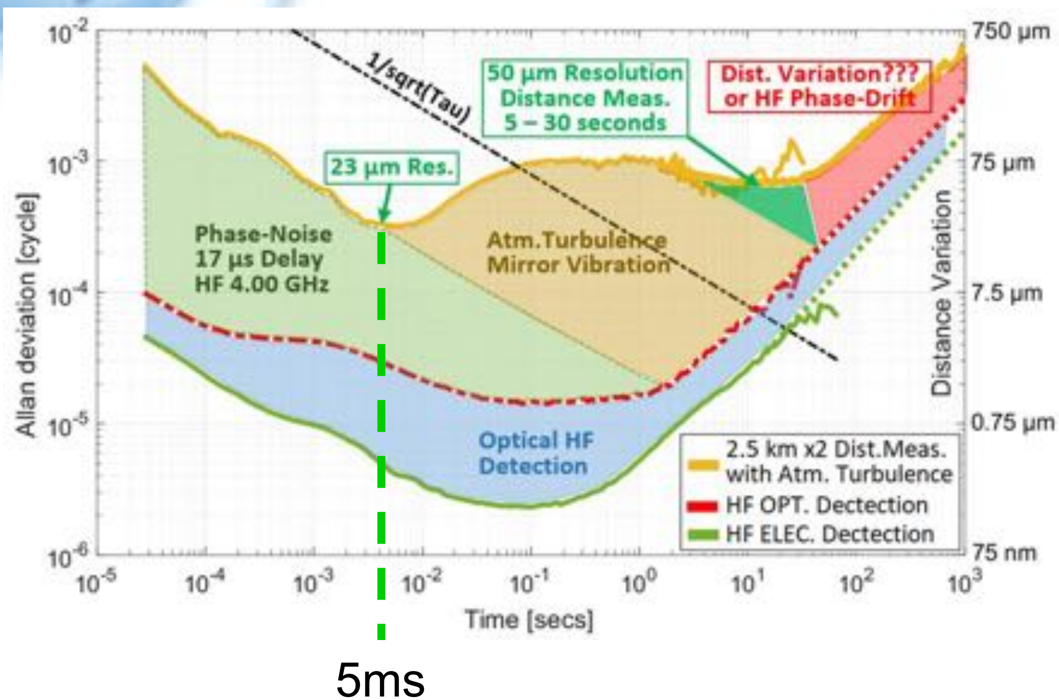
➢ Telecom detection → Time Transfer / Ranging by LaserComm link

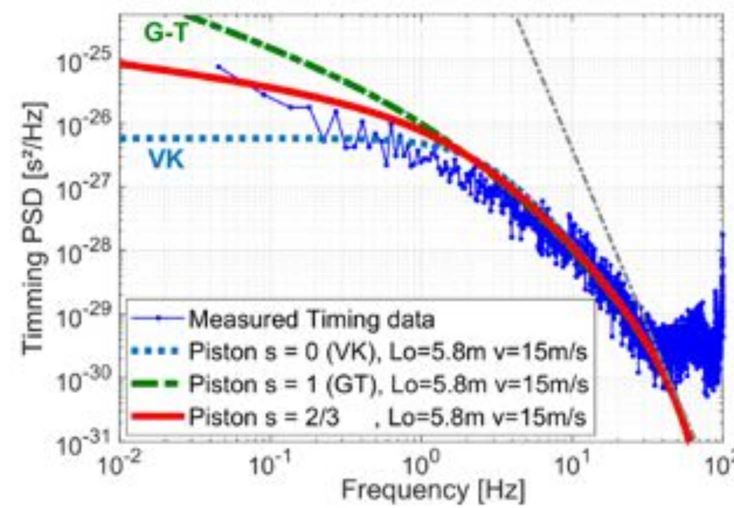




- ❑ Atmospheric turbulence effect:
  - + High speed Telecom detection,
    - → SNR, BER measurement
  - + Laser Ranging Measurement - Phase
    - High Speed > 10 kSps
- ❑ Understanding SHWFS data
  - → model for Deformable Mirror

Ranging results @ 10 Gbps





- **23 µm (at 5 ms)** means a measurement sensitivity of < 100 fs on timing jitter measurement over free space laser link
- Similar timing jitter measurement by the DIMM instrument
- Model for timing jitter power spectral density

Conclusion

- MéO Laser Ranging facility is very active (SNO):
  - Best station for Lunar Laser Ranging
- Active R&D to improve laser ranging:
  - Use telecoms systems as new ranging / time transfert systems
  - High Rate SLR to meet **GGOS** (Global Geodetic Observing System): **Millimetric accuracy and precision**

Maintenance 2019: primary mirror recoating

Actions de diffusion des connaissances

Nuit « Coupoles ouvertes » 2019…

Anniversaire des 50 ans d'Apollo 11

Tirs sur comète…

Merci de votre attention