Télémétrie laser haute cadence sur cibles passives pour le transfert de temps sol-sol

AG Labex First TF
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Clément COURDE[1], Julien CHABE[1], Grégoire MARTINOT-LAGARDE[1], Duy-Hà PHUNG[1], Mourad AIMAR[1], Nicolas MAURICE[1], Hervé MARIEY[1], Nils RAYMOND[1], Julien SCARIOT[1], Hervé VIOT[1], Gilles METRIS[1], Michel ABGRALL[2], Daniele ROVERA[2]

[1] Université Côte d'Azur, CNRS, Observatoire de la Côte d'Azur, IRD, Géoazur

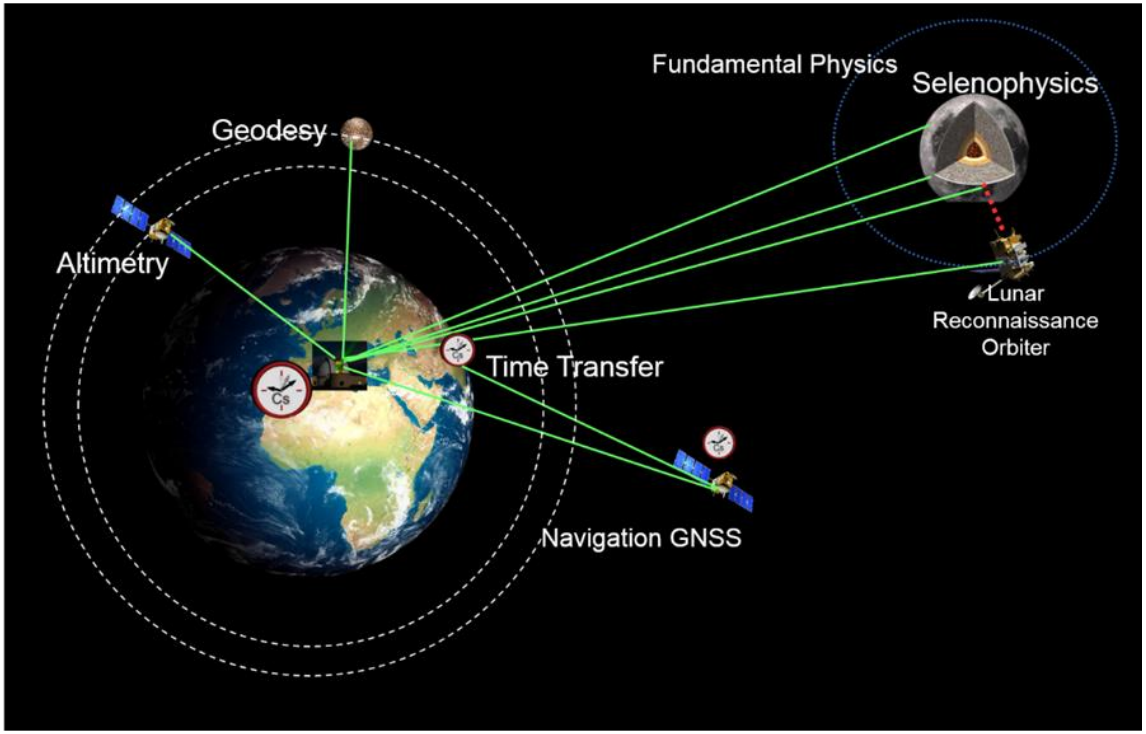
[2] SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, LNE

Context

Ground-Space Laser links for probing the close universe

Precise metrological links between space bodies (<cm et ps):

- Relativistic ephemeris versus Observations
- Information on forces acting on the bodies (external and internal)
- Reference frame for space (geodesy) and Time
- This a traditional task for astronomers (ITRF, UTC, BIPM...)
- Fundamental physics testing (Gravitational red-shift, Lense–Thirring, …)



SLR Principle vs Time transfer

Measurement of the time of flight of laser pulses

On ground

Event timer

$\Delta T = date_{return} - date_{start}$

$$D = \frac{c.\Delta T}{2}$$

In space

Passive Retro-Reflector

⇨ High stability clock is required

Required accuracy on the date: 100 ns / UTC
Required accuracy on the clock frequency: better than $\sim 10^{-11}$

Measured distance:
[400km – 400 000 km]
Accuracy < 10 mm
Precision ~ mm

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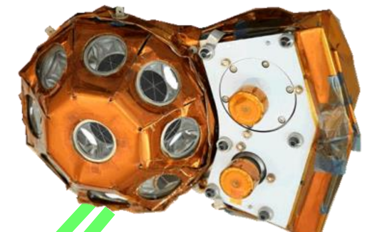
In space

Active Retro-Reflector



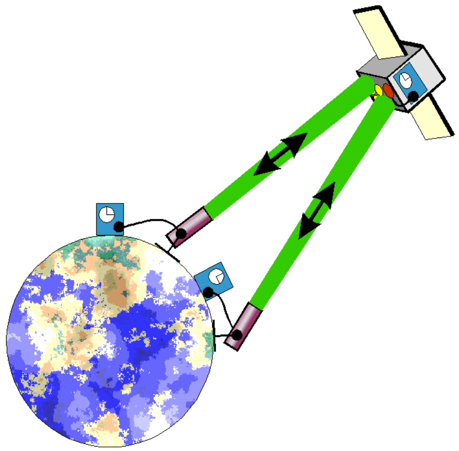
Event timer

$date_{board}$

the relative time lag between on-board and ground time :

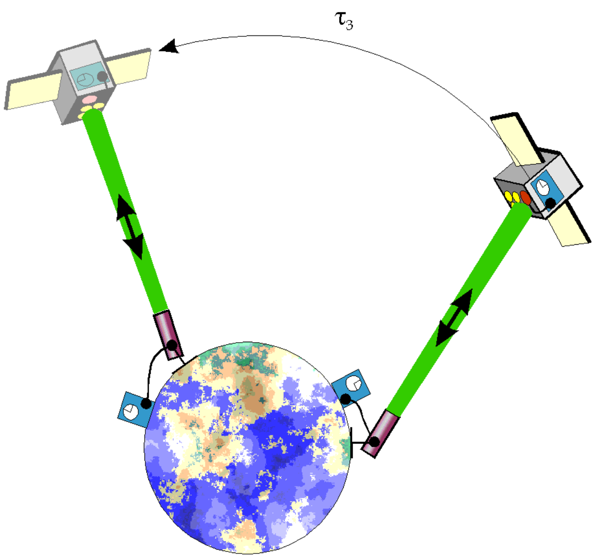
$$\chi = \frac{date_{start} + dateret_{urn}}{2} - datebo_{ard} + corr$$

Common view and non common view
Ground to ground time transfer



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

Space missions

T2L2 results

10 ps stability @ 1000 s for Ground-Space & Ground-Ground time transfer

Uncertainty at 150 ps E. Samain et al., 2015, Metrologia

Agreement between T2L2 and GPS-CV better than 240 ps
P. Exertier et al. 2016, Metrologia

Agreement between T2L2 and IPPP in common view with a standard deviation below 100 ps J. Leute et al. 2018

Impact of the SAA on the USO frequency behaviour
A. Belli et al., Advanced in spaces research, 2015

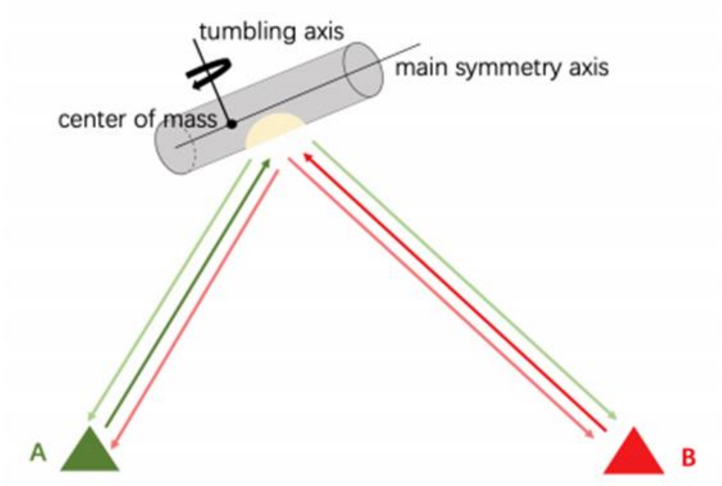
Agreement between T2L2 and GPS PPP in non common view at 1 ns level
E. Samain et al., 2018, *IEEE transactions on ultrasonics, ferroelectrics, and frequency control*

Shutdown in 2014

Perspectives : ACES with MWL & ELT : 2024 ?

And in the meantime ?

Time transfer by laser links thanks to diffuse reflections



Liu, T., Eckl, J. J., Steindorfer, M., Wang, P., & Schreiber, K. U. (2021). Accurate ground to ground laser time transfer by diffuse reflections from tumbling space debris objects. *Metrologia*

Each station performs two-way ranging to the rocket body. In addition to that, each station performs one-way detection of the laser pulses from another stations.

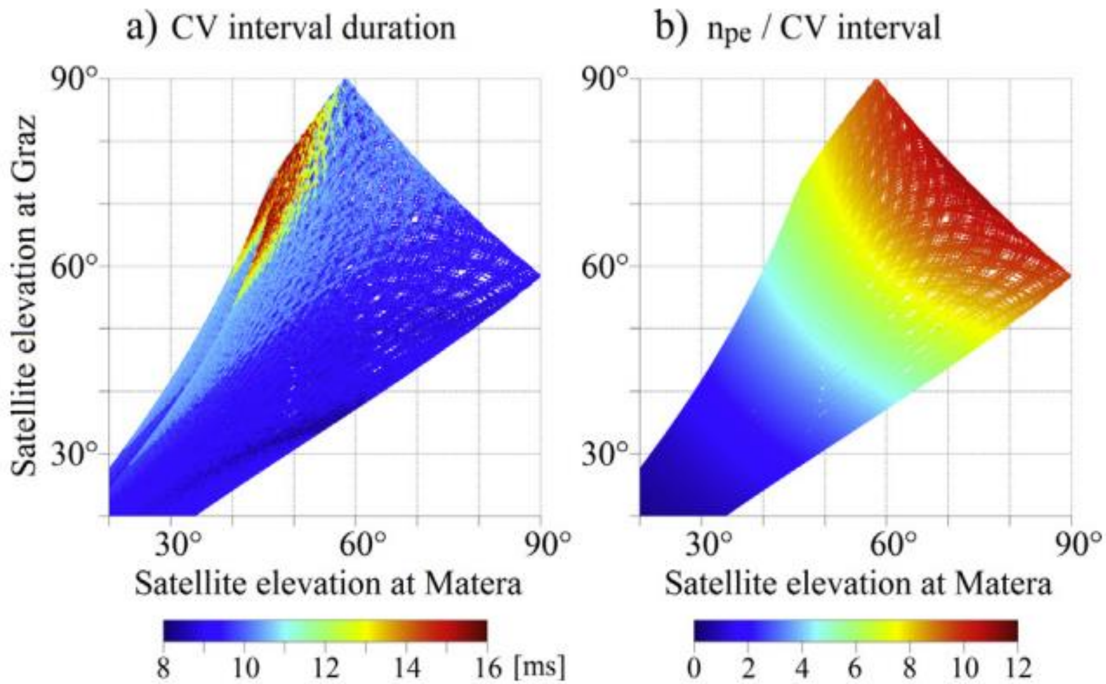
The use of two distinct wavelengths allows to satisfy the single-photon level of the detection.

Time transfer demonstration on a rocket body between Wettzell and Graz with 1 σ statistical uncertainty of 3 ns.

Advantage : a long term and fully passive space segment

Limitations : works only for common view, needs of a better target model

Time transfer by laser links thanks to diffuse & specular reflections



Kucharski, D., et al. . (2019). Hypertemporal photometric measurement of spaceborne mi specular reflectivity for Laser Time Transfer link model. Advances in Space Research, 64(4), 957-963.

Ajisai can be used as a well modelled target which allow to exploit both diffuse & specular reflections thanks to its **mirrors & corner cubes.**

Due to the **rotation of Ajisai**, the simulation study indicates that the Common View between two distant stations is possible **874** times per pass with **time slot** duration **of 9.15 ms** in mean, in **single-photon** mode.

=> High Count Rate laser ranging required

Works in progress at Geoazur-MeO

High repetition rate SPAD

Collaboration in 2014 with

And with the support of the

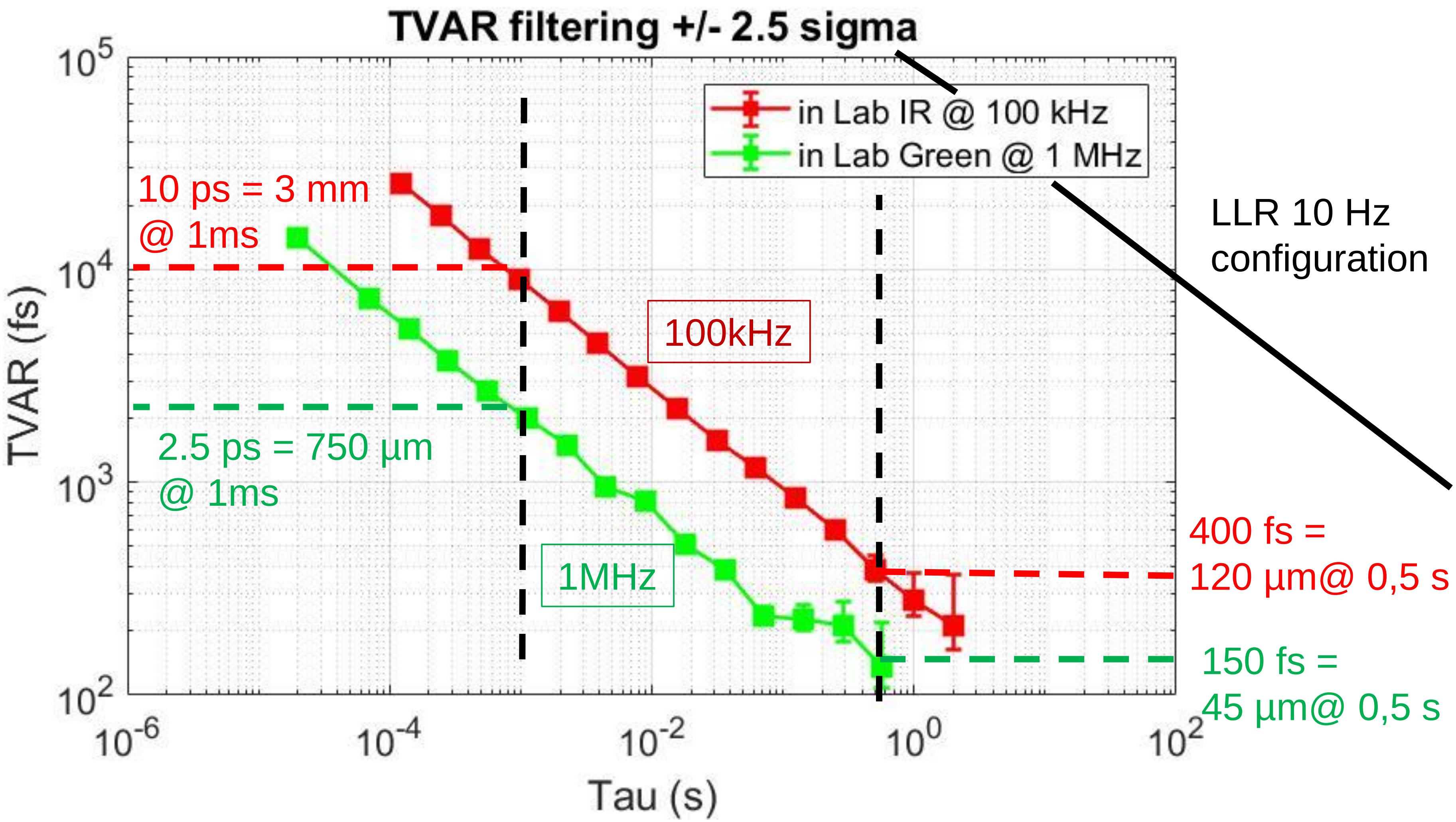
Development of two high repetition rate SPAD detections

Si-SPAD	
Active area diameter	100 µm
Max repetition rate	1 MHz
Timing jitter	33 ps FWHM
DCR @ 7 V	74 Hz
Quantum efficiency	53% @ 532 nm

InGaAs-SPAD	
Active area diameter	50 µm
Max repetition rate	100 kHz
Timing jitter	76 ps FWHM
DCR @ 7 V	200 kHz
Quantum efficiency	47% @ 1064 nm

Works in progress at Geoazur-MéO

Calibration on corner cube



Works in progress at Geoazur-MeO

Reception of a Coherent HyperRapid laser in 2020

With the support of GRAM, cnes, FIRST TF

10 ps FWHM

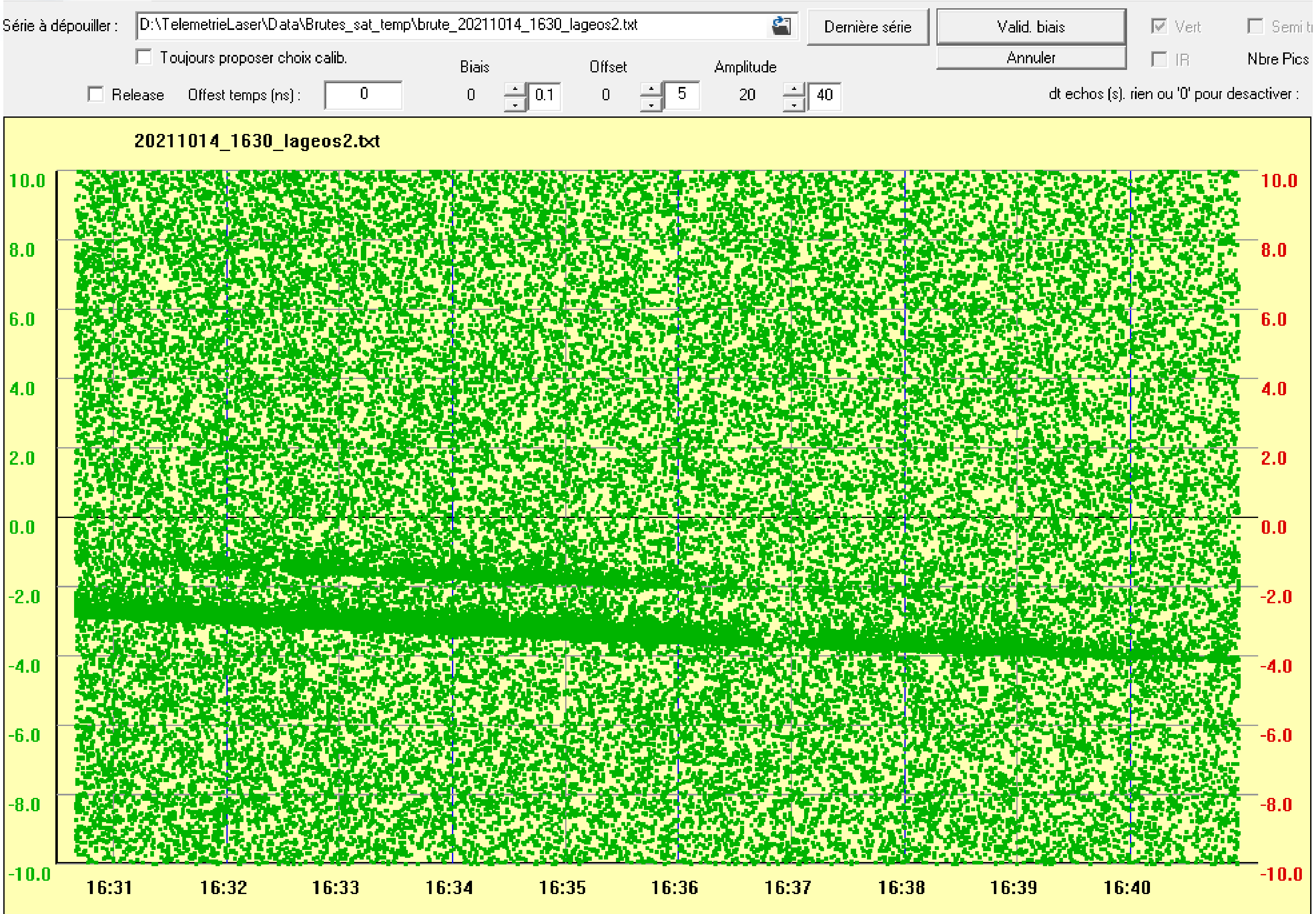
100 W

Adjustable pulse repetition rate between 400 kHz 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

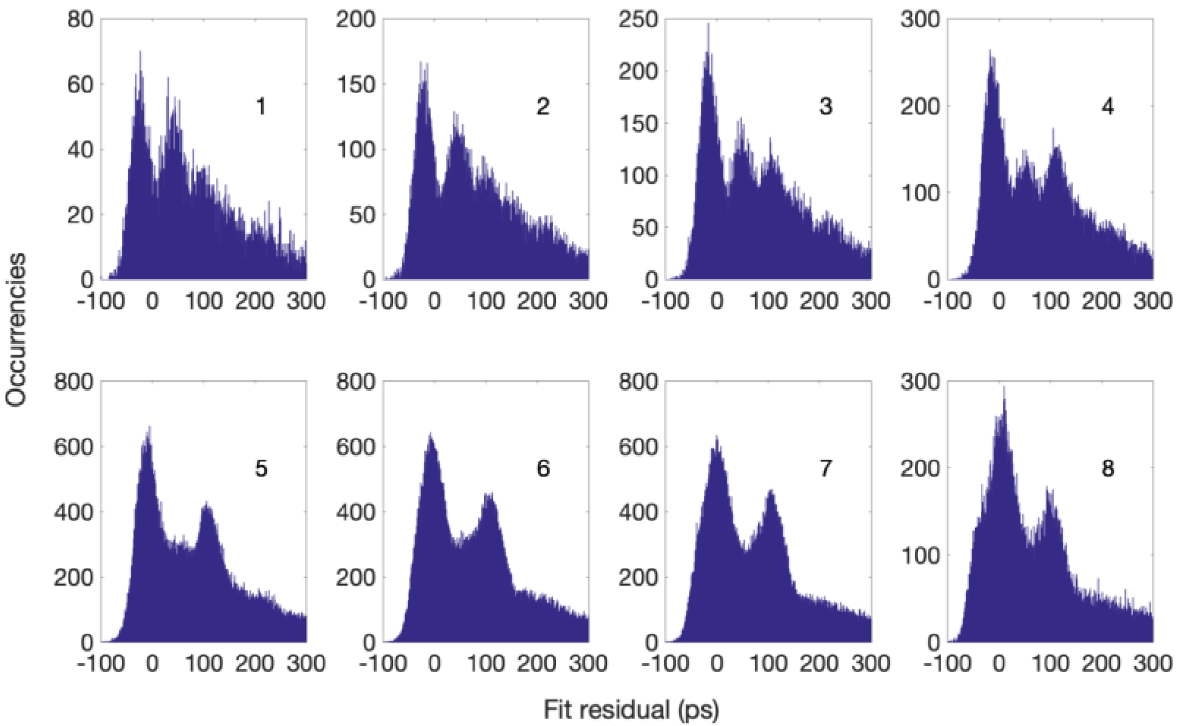
Works in progress at Geoazur-MéO

First measurements on Ajisai, Lares, Lageos, Galileo during night/day light @ 4kHz



Works in progress at Geoazur-MéO

A lot of information in the return structure thanks to high count rate laser ranging



Prelaunch Optical Characterization of the Lager Geodynamic Satellite (LAGEOS 2)

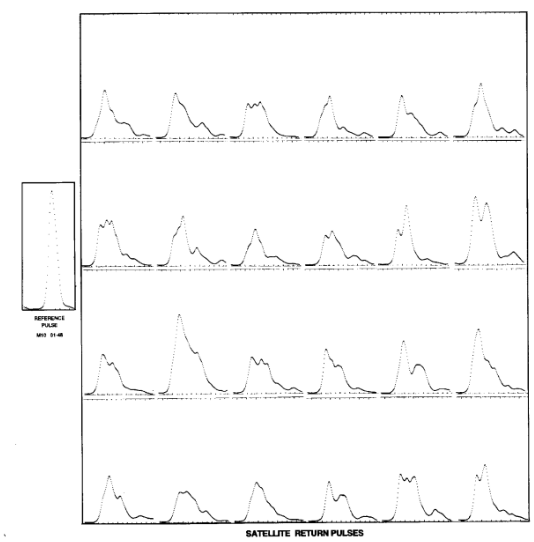
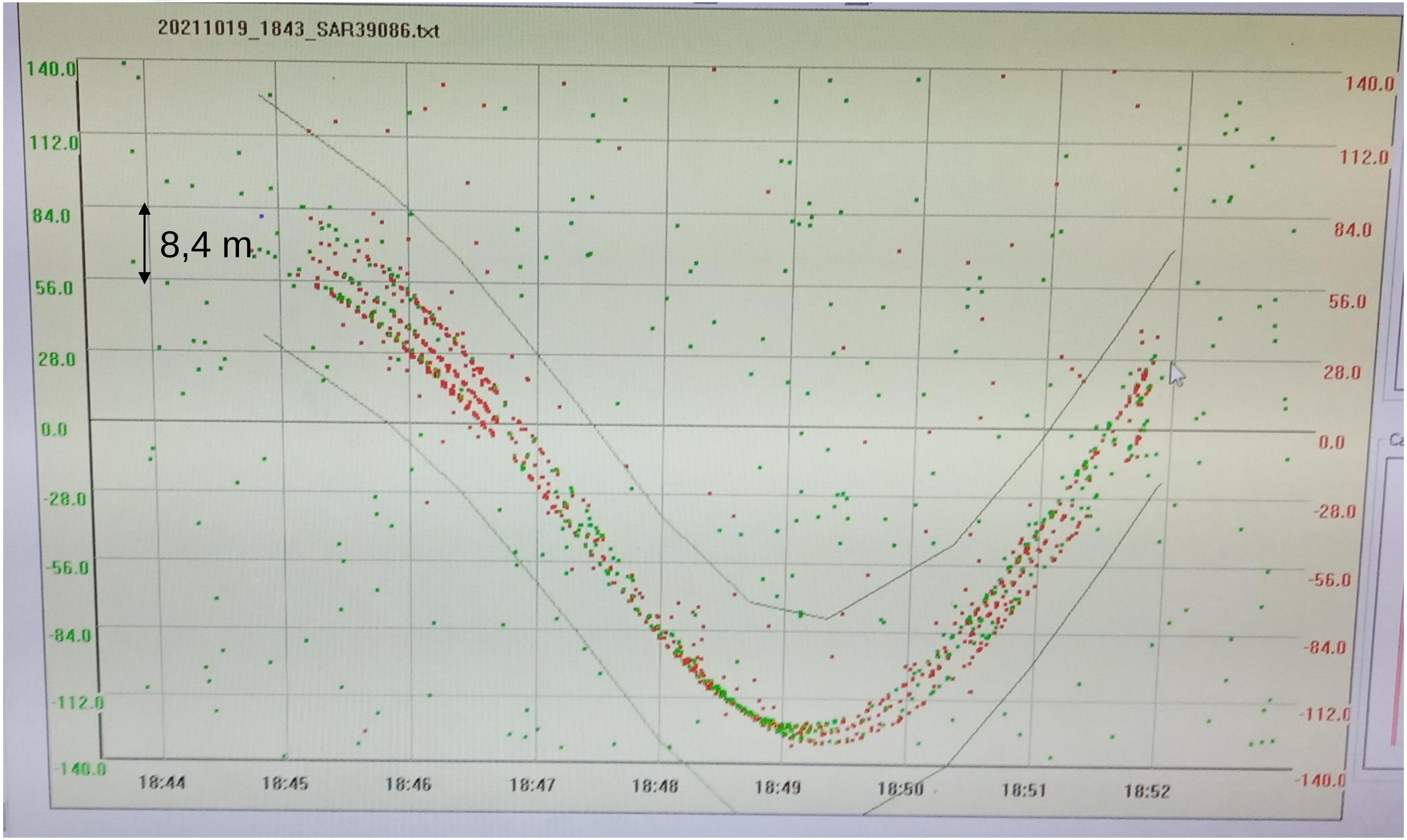


Figure 4.4.2.1-8. Reference and random orientation satellite returns using annulus.

From D Dequal et al., ILRS workshop 2019, 100 kHz on Lageos

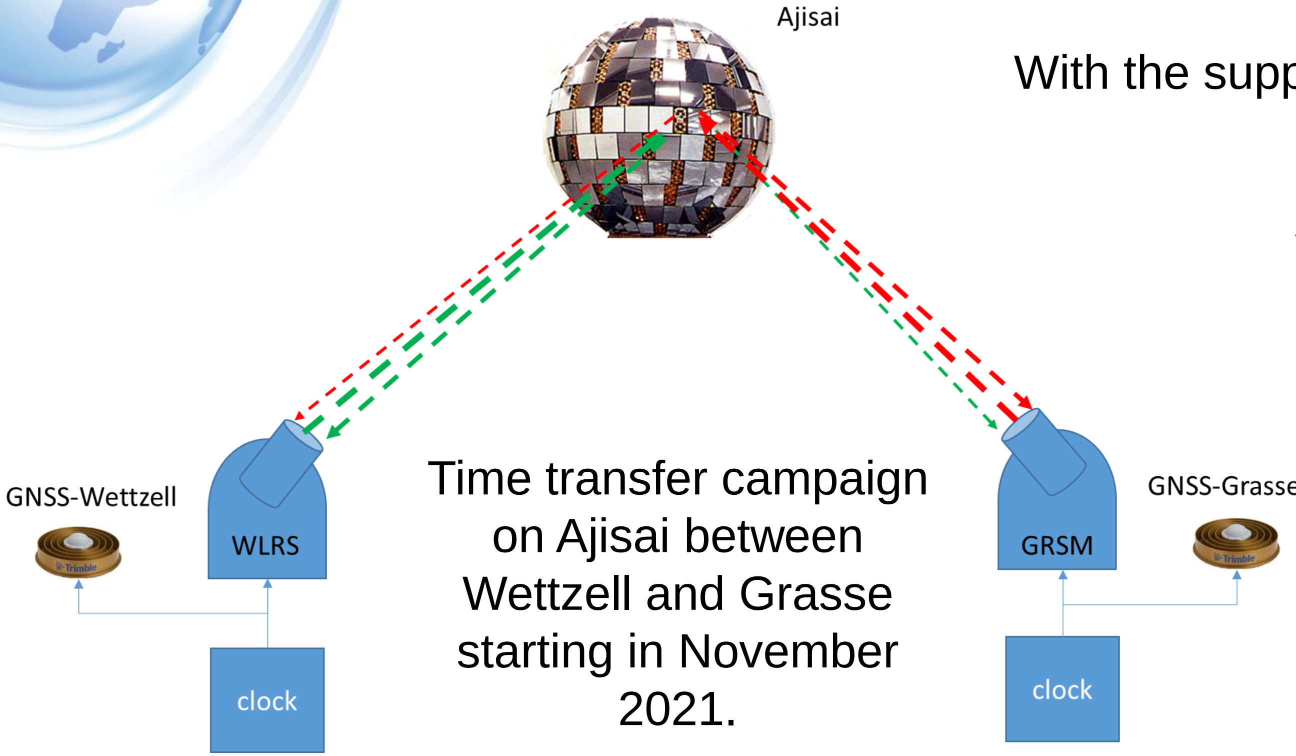
Works in progress at Geoazur-MéO

Attitude determination of space debris and satellites
R&T CNES



Time transfer by laser links on Ajisai between Wettzell and Grasse

With the support of FIRST TF



Time transfer campaign on Ajisai between Wettzell and Grasse starting in November 2021.

Works done :

- Implementation of ND wheels for independant attenuation of each detection channel
- Implementation of independant gating on the two detection channels
- Implementation of the new prediction calculation
- Lock-in of the rotating mirror on the time scale and synchronization of the LLR firing date

Schedule :

- Calibration of the GNSS links with the support of OP-SYRTE Nov 21
- Calibration of the laser links Nov 2021
- Common view observations with Wettzell firing in infrared and Grasse in green with the LLR lasers Nov 2021
- Common view observations with Wettzell firing in infrared and Grasse in green with the high count rate lasers 2022

Thanks for your attention