Agenzia
Spaziale
Italiana

Lunar/Satellite Laser Ranging (LLR/SLR) a Matera

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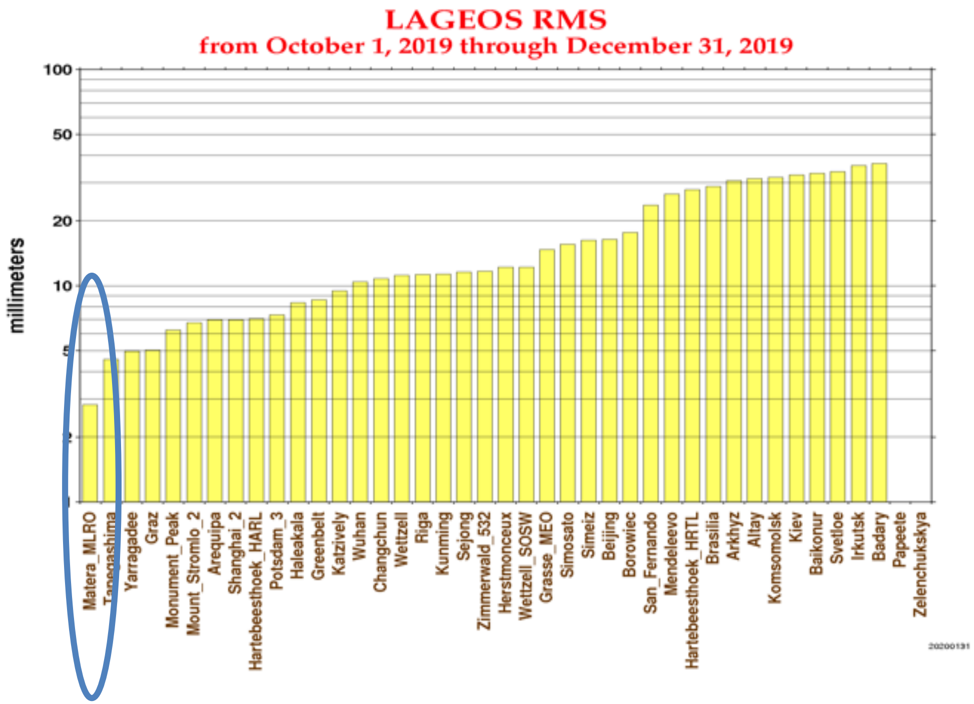
12/11/2020 – **Workshop sulla Gravitazione Sperimentale – INFN CSN2**

Outlook

1. Satellite Laser Ranging
    - System overview
    - Recent results
    - Future perspectives
2. Lunar Laser Ranging
    - System overview
    - Recent results
    - Future perspectives
3. Debris Laser Ranging
    - First tests and perspectives

SLR: MLRO in the ILRS Network



Matera Laser Ranging Observatory is one of the reference station of the ILRS network:

- Record in single shot precision (LAGEOS)
- 24/7 operation with high up-time
- Negligible pointing bias* (<0.02 mm azi./ele.)
- Very small day-night effect* (0-2 mm LAGEOS)
- Small long-term orbit residuals* (1-3 mm LAGEOS)

Data quality & quantity

* *https://ilrs.dgfi.tum.de/quality/weekly_biases/stations/*

Test of very high repetition rate laser

Test of the Ekspla Atrlantic 60 for SLR

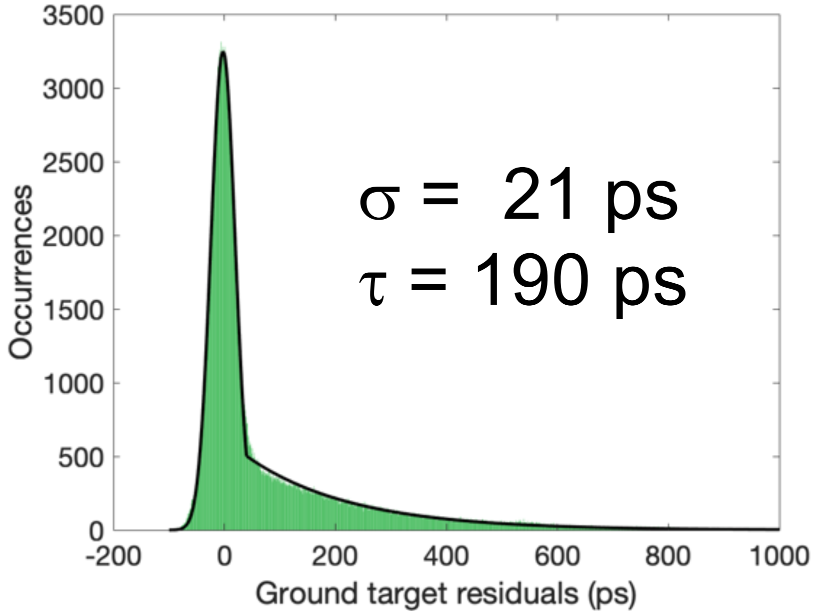
Parallel operation of two systems in interleaved mode

MLRO standard configuration	
Rep. rate	10 Hz
Pulse energy	100 mJ
Pulse width	50 ps
Detection technology	MCP-PMT (analog)

Ekspla configuration	
Rep. rate	100 kHz
Pulse energy	100 µJ
Pulse width	9 ps
Detection technology	SPAD (Geiger)

Ground target…

Reference Target at 95 m



σ = 21 ps

τ = 190 ps

Typical detector shape:

Gaussian peak (σ_{det}) + exponential tail (τ)

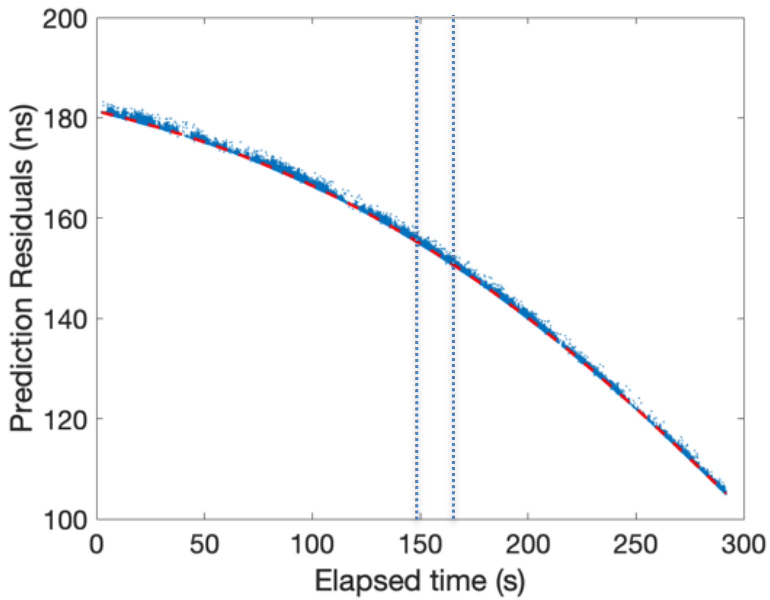
$$f(t) = Ae^{-\frac{(t-t_0)^2}{2\sigma^2}} \Theta(t_1 - t) + Be^{-\frac{t-t_1}{\tau}} \Theta(t - t_1)$$

$$\sigma_{theory} = \sqrt{\sigma_{det}^2 + \sigma_{ele}^2 + \sigma_{laser}^2} = 20\, ps$$

17 ps   10 ps   3.8 ps

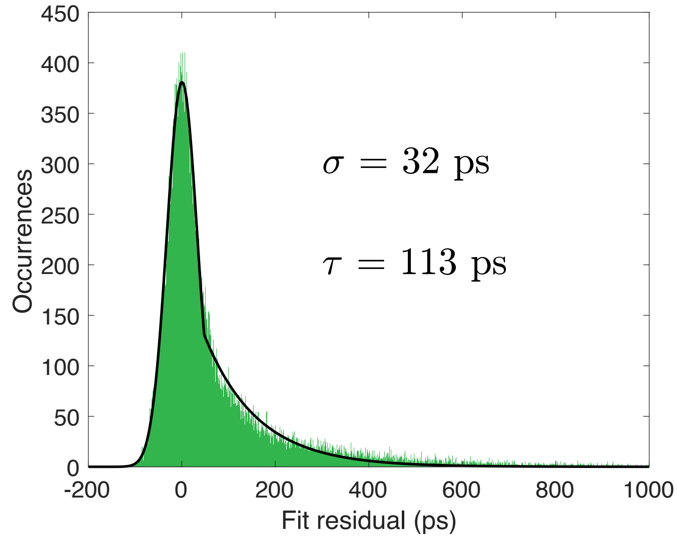
… and satellite (LARES)

Polynomial fit on PR => fit residuals (FR)



Iterative 2.5 sigma clipping

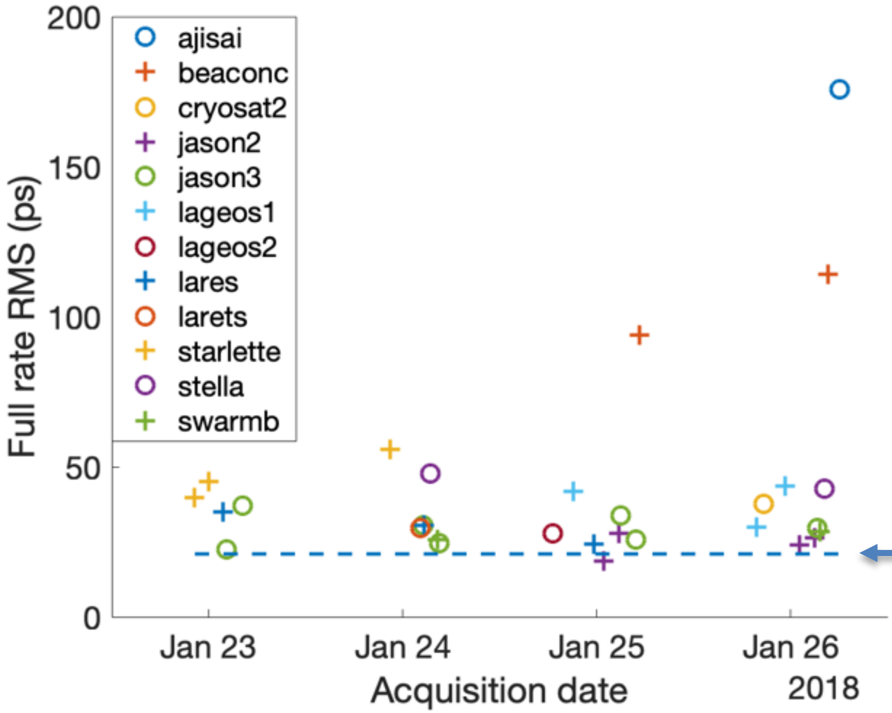
Returns in 15 s (SNPI)



https://ilrs.cddis.eosdis.nasa.gov/data_and_products/data/npt/npt_algorithm.html

5 nights analysis of full rate jitter

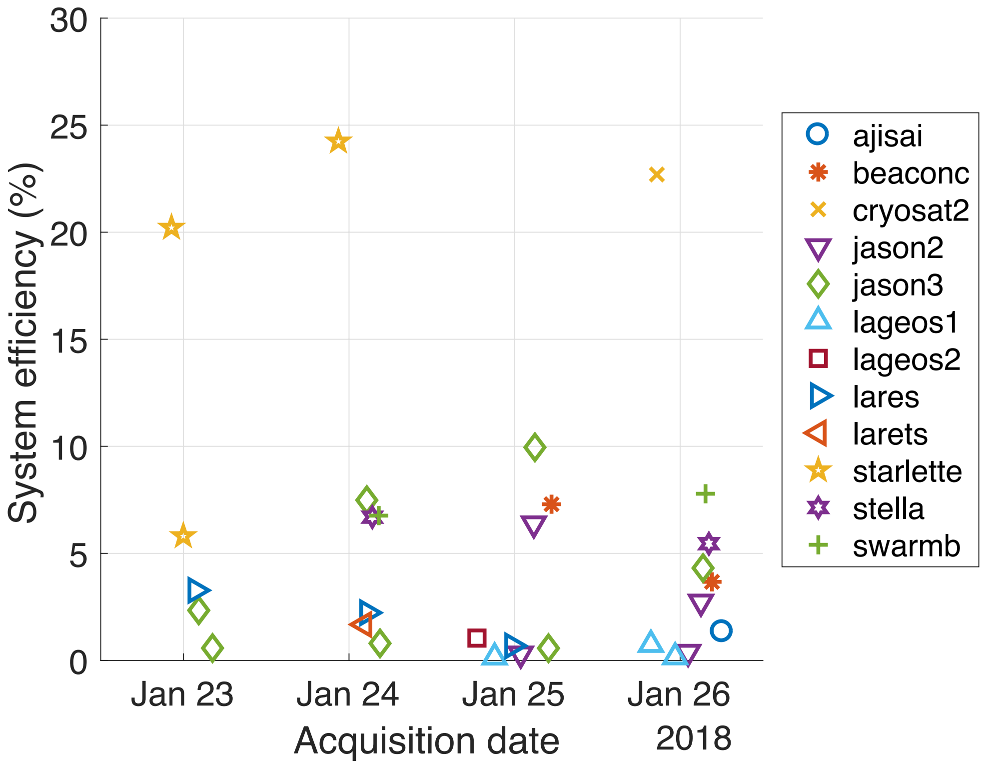
σ_{FR} often limited by satellite signature



Average σ_{FR} for all normal point intervals in a pass

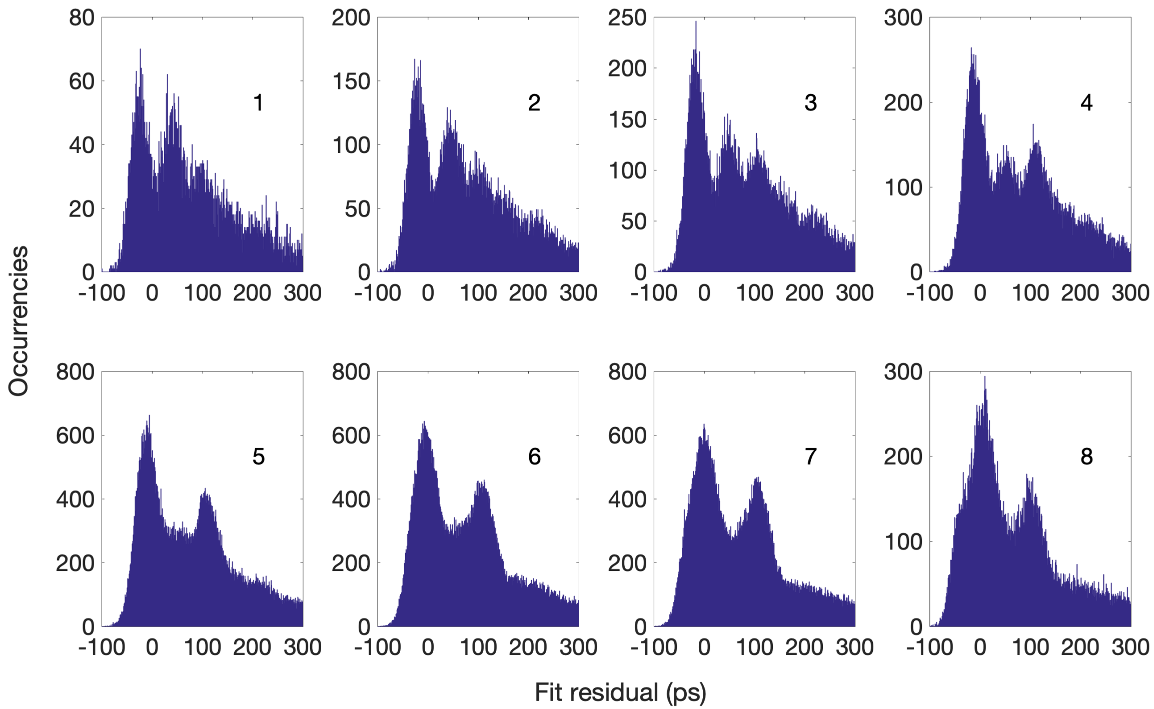
21 ps limit

Unprecedented statistics!



- ≈ 20 ps single shot jitter
- 100 kHz transmission rate
- 1-10 kHz detection rate (unbiased)

Possible error on mean center of mass correction



Lageos 2 pass 24^{th} Jan.

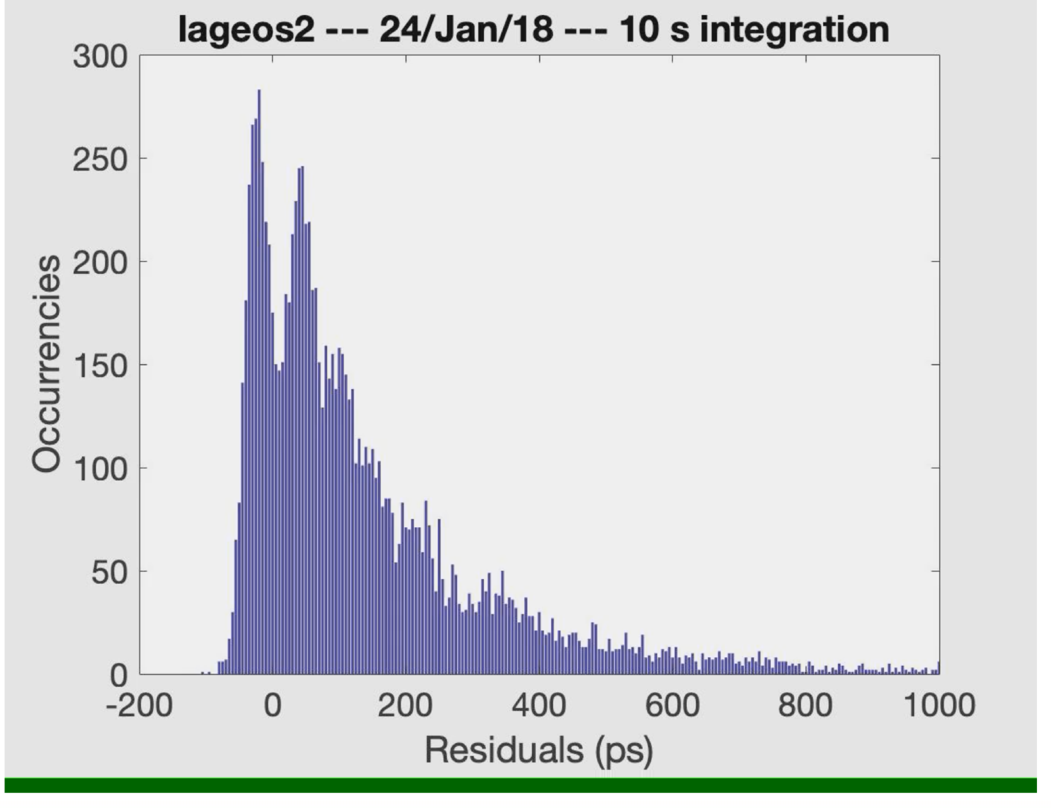
One histogram per NP

Lageos are not spinning, average approximation on PDF does not hold

This might introduce systematics on analysis

D.Dequal et al., "100 kHz satellite laser ranging demonstration at Matera Laser Ranging Observatory " Under review at Journal of Geodesy

A lot of information in return structure!



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

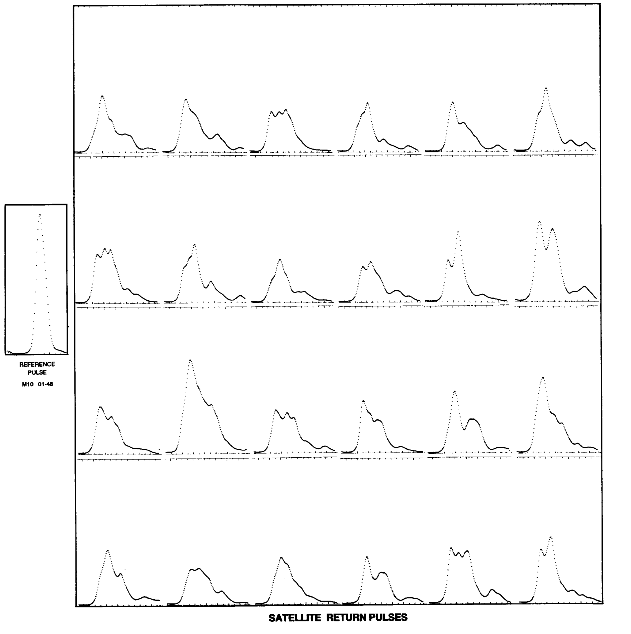


Figure 4.4.2.1-8. Reference and random orientation satellite returns using annulus.

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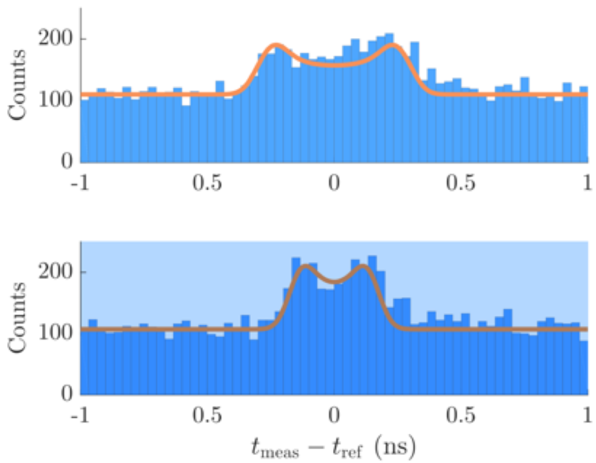
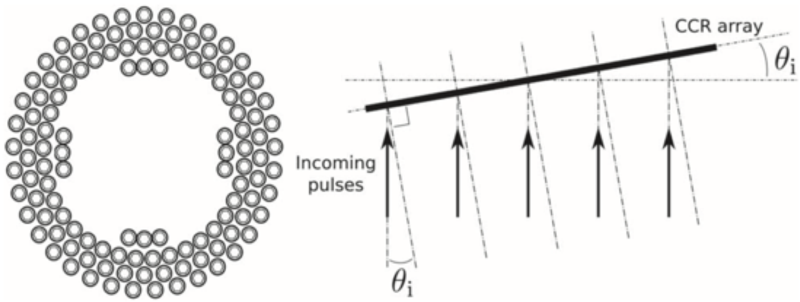
SLR for passive detection of satellite attitude



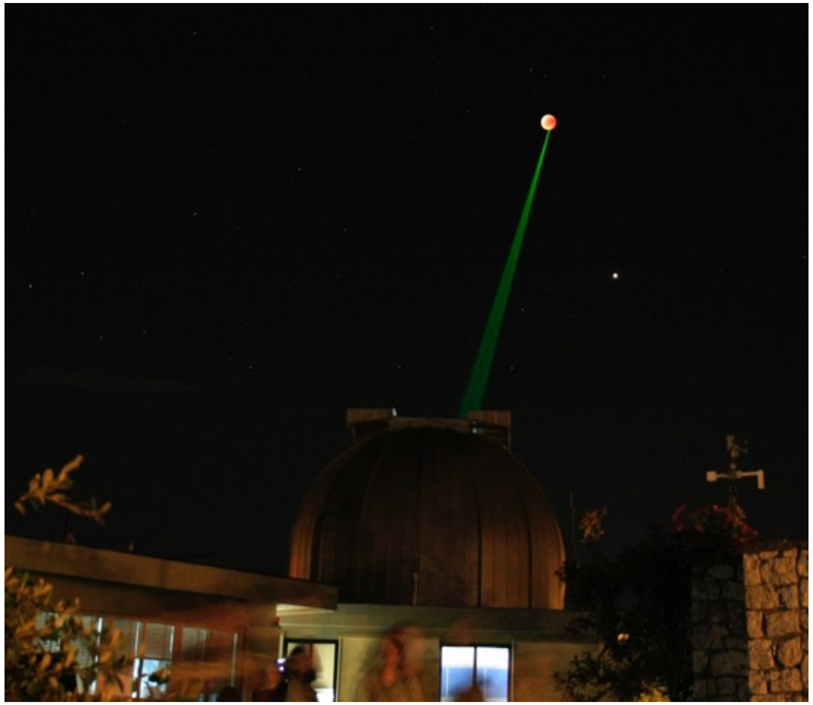
Glonass attitude determination

kHz / MHz SLR can be used to monitor the attitude of passive objects



L.Calderaro et al., «Towards quantum communication from global navigation satellite system »
Quantum Sci. Technol. 4 (2019) 015012
See also:
G. Kirckner et al., «Laser Ranging to Nano-Satellites in LEO Orbits: Plans, Issues, Simulations»
Conference: 18th International Workshop on Laser Ranging

Lunar Laser Ranging



Recent history:

2017 First results after long stop

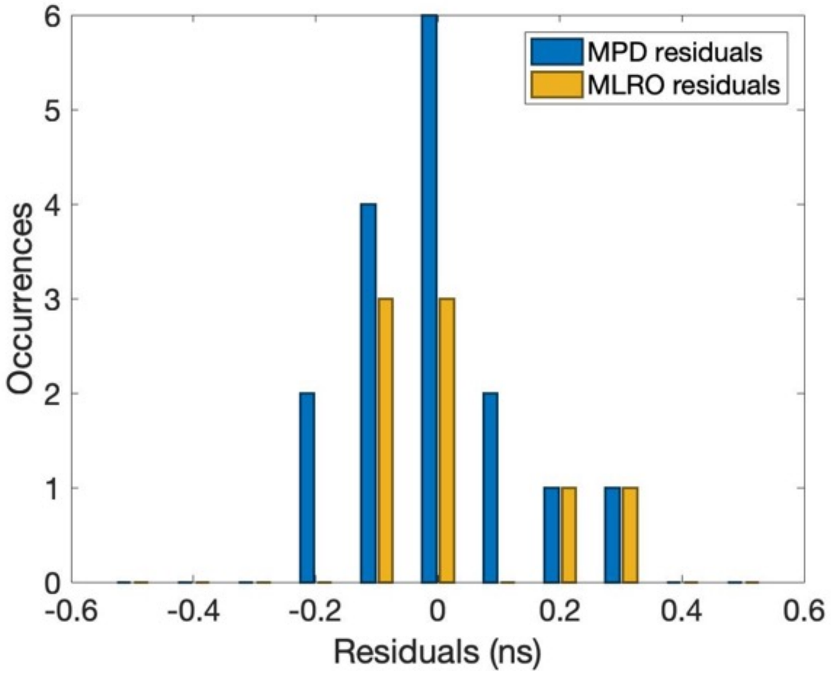
2018 Detector change (Photek to Hamamatsu)

2019 Primary recoating

Average detection 80 mHz on Apollo 15 (2019)

SPAD test on LLR

Apollo 15 returns (5 min)

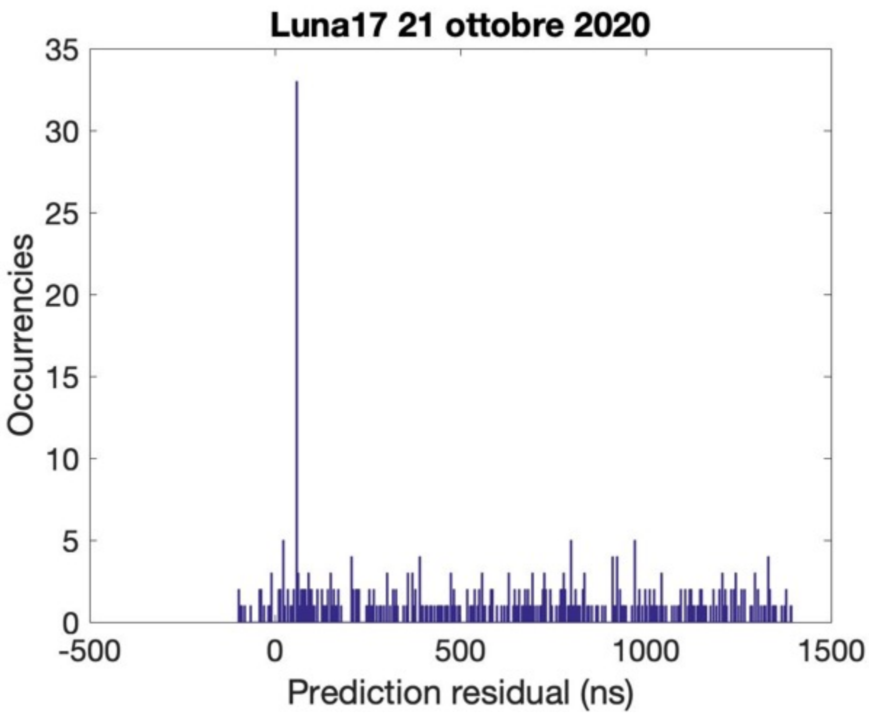


Test with Micro Photon Device SPAD in parallel with MLRO

- MPD std= 0.12 ns, MLRO std= 0.14 ns
- MPD/MLRO return ratio= 2.00

Optical setup not optimal, x4 attenuation due to BS. New setup under development

Finding Lunokhod 1



"Lost" rover found in 2010, but never tracked by MLRO

Analysis showed ≈ 7μs offset

After debug, offset reduced to 400 ns

First successful detection from MLRO!

MLRO is now operative on all lunar targets!

MLRO Upgrade

A 2-years plan to upgrade MLRO has just started

- New SW for DAQ, control and analysis
- New HW for DAQ and moving optical elements
- New Laser:
    - 100 Hz (x10 w.r.t. current)
    - 200 mJ (x2 w.r.t. current)
- New detector

Space Debris activity

February 2020 support to Deimos Space for space debris acquisition campaign:

- Optical tracking: ok
- Cooperative target: detected
- Non cooperative target: NOT detected

August 2020: test with PMT single photon detector:

- Non cooperative target: NOT detected

Next step: test with MPD detector in LLR seup

Conclusions

- MLRO successfully tested SLR @100 kHz
- Possible follow up for attitude determination
- Future upgrade for 100 Hz system, LR2Galileo

- LLR fully operative on all lunar targets
- New line for SPAD detector testing
- New laser for x20 increase in return rate

- SDLR working for cooperative debris.
- Work ongoing for non-cooperative debris


Thank you for your attention