Instituto Geográfico Nacional
Centro Nacional de Información Geográfica

LARES-2 centre of mass corrections

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Gobierno de España · Ministerio de Transportes, Movilidad y Agenda Urbana · Instituto Geográfico Nacional
YEBES
BGS British Geological Survey

Introduction

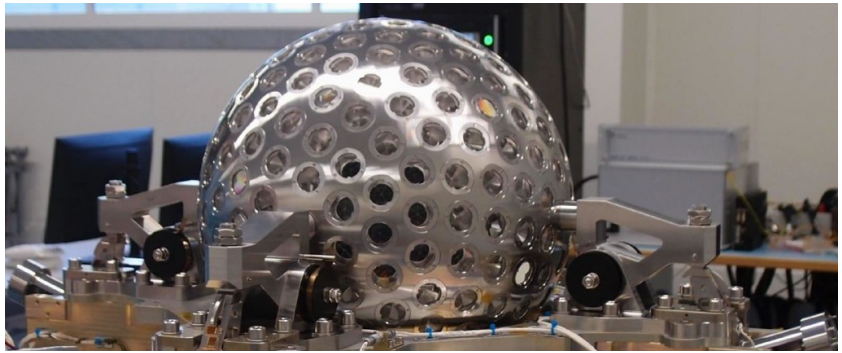
LARES-2 is the latest addition to the family of spherical geodetic satellites.

Designed for best accuracy and precision.

Promising results reported by several groups.

So far, the default centre of mass correction (CoM) provided by the mission has been used.

We report our results for station-specific CoM values for LARES-2.



(ASI)

CoM computation

The methods employed are those devised and followed previously (LAGEOS, LARES, Starlette, etc)

Two parts:

1) Determination of satellite's **optical response**
2) Derivation of **CoM corrections** for each station

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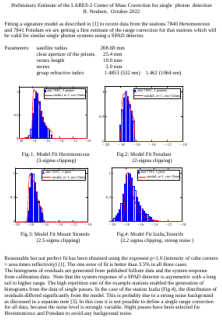
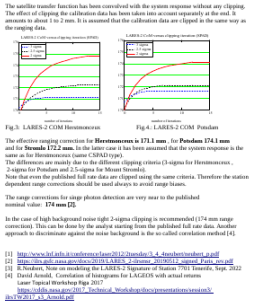
Preliminary computations already reported by Reinhart Neubert, following the same fundamental methods.





Neubert. Preliminary estimate of the LARES-2 center of mass correction for single photon detection. *Tech. Note,* 2022

Rodríguez, Appleby, Otsubo. Upgraded modelling for the determination of centre of mass corrections of geodetic SLR satellites. *J Ged,* 2019

Otsubo et al. Center of mass corrections for sub-cm precision laser-ranging satellites: Starlette, Stella and LARES. *J Geod,* 2014

CoM computation I. Optical response

We seek to work out the **shape** of the retroreflected laser pulses.

We simplify the problem to make it tractable, modelling the **average** optical behaviour of the satellite:

- Ignore polarisation effects
- Do not model retroreflector dihedral angle offsets
- Do not model thermal effects
- Do not consider velocity aberration
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We do **not ignore** these effects: they are included **empirically.**

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We do take into account:

- Characteristics of CCRs
- CCR positions in the satellite
- CCR recess and visibility
- Reflection losses
- Laser wavelength

We **thank** the LARES-2 mission for providing the information required for the refined computation presented here (I. Ciufolini and C. Paris).

CoM computation I. Optical response

The empirical fit determines the single free parameter of the model.

The input data are ~5M single-photon observations of LARES-2 (*)

- Passes flattened with orbit + polynomial
- Rejection of problematic passes (few observations, low S/N, deficient flattening...)
- Histogram accumulation → average LARES-2 distribution

(*) Massive acknowledgment to the **Herstmonceux** crew for their unremitting provision of world-class data.

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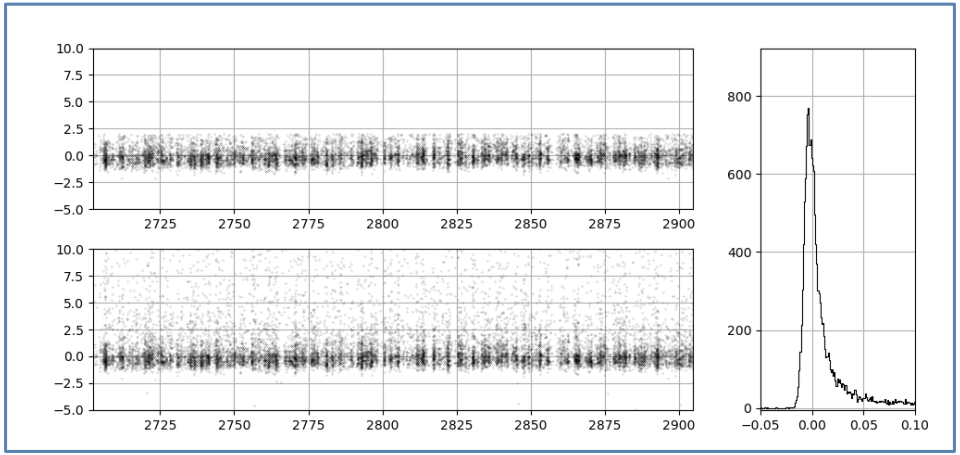

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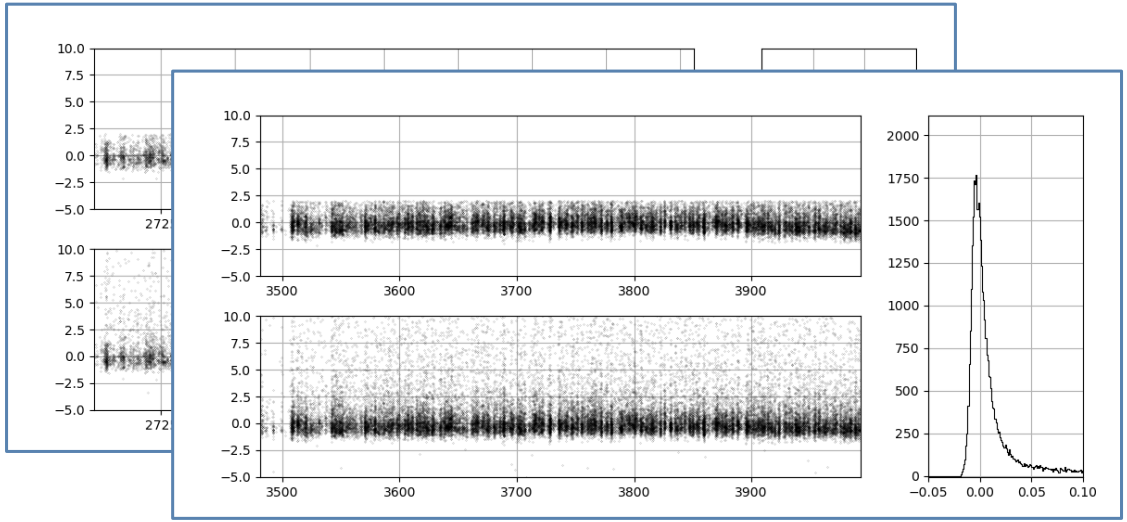

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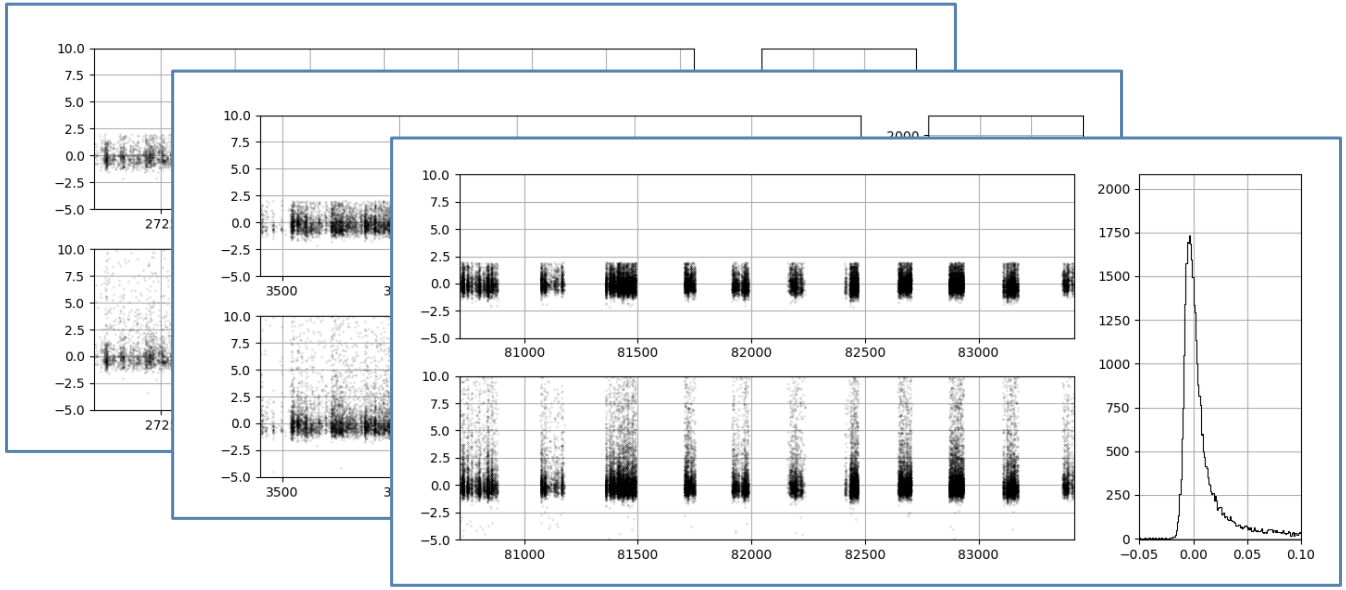

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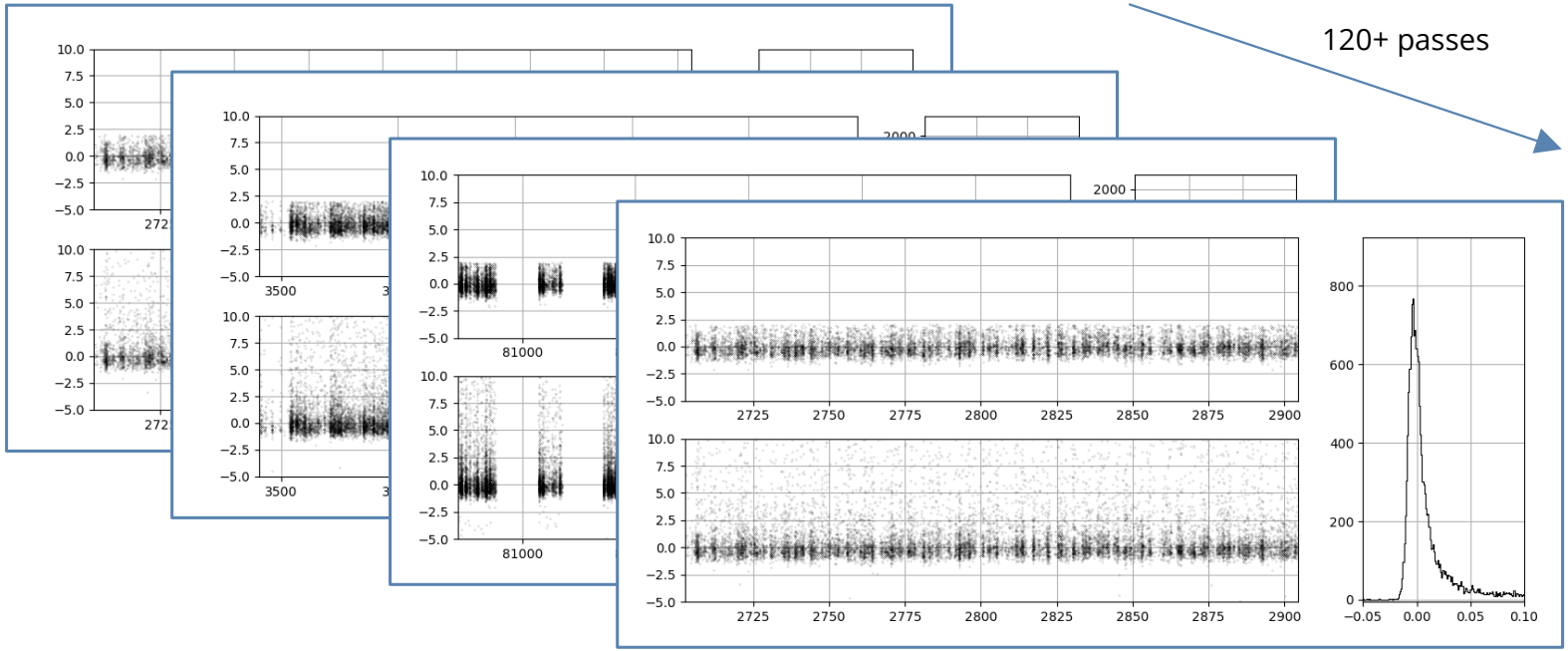

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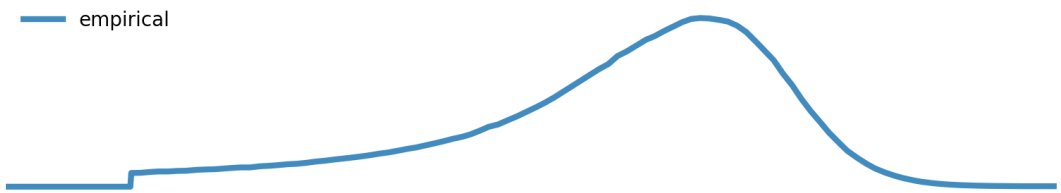

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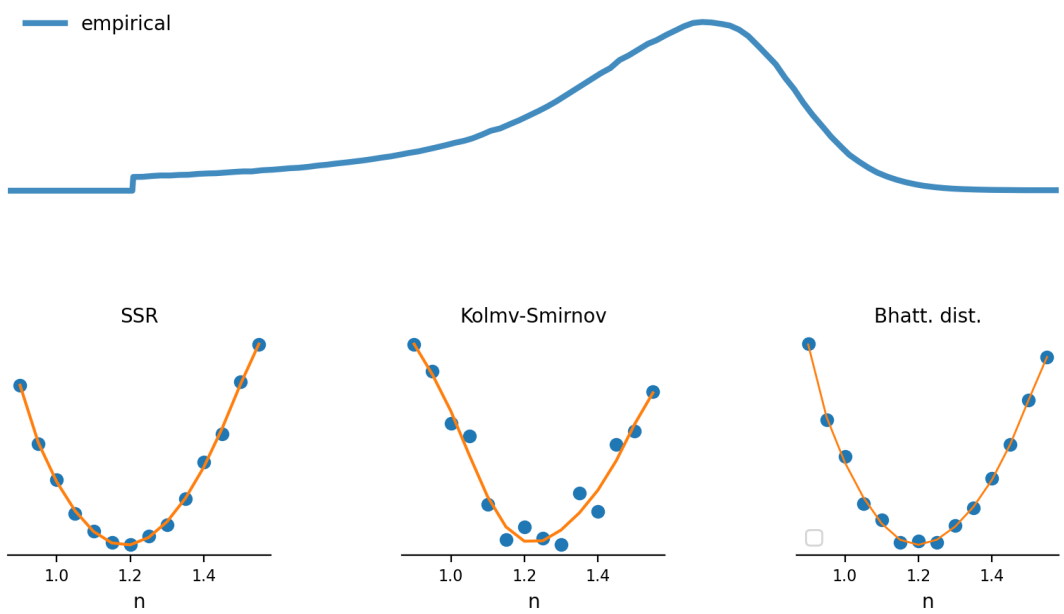

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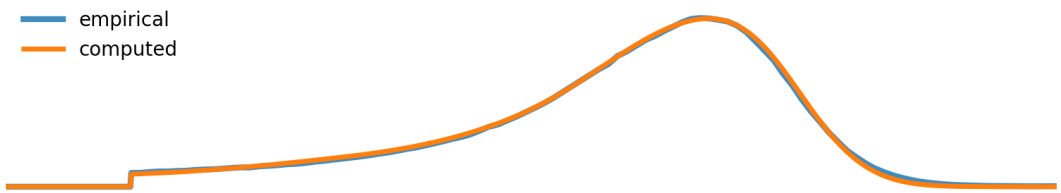

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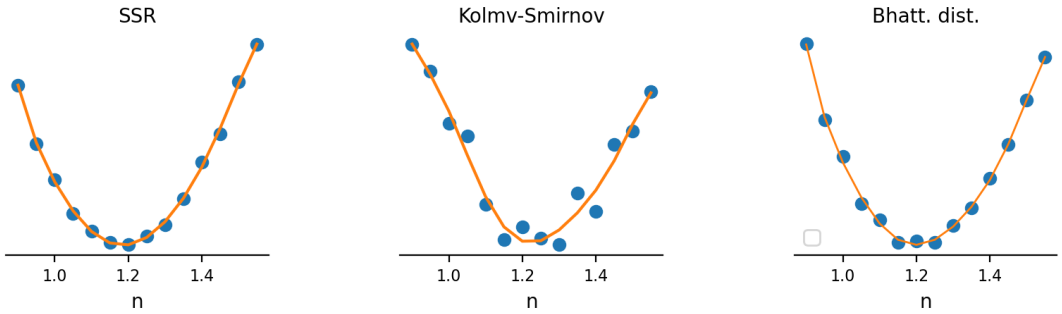

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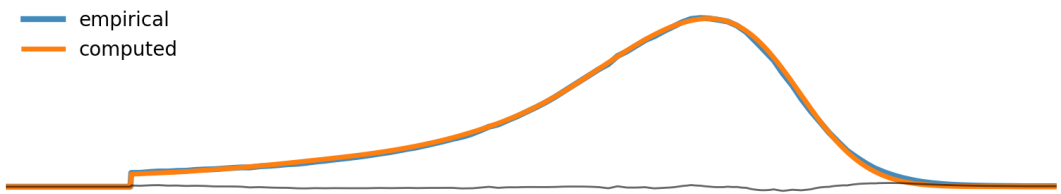

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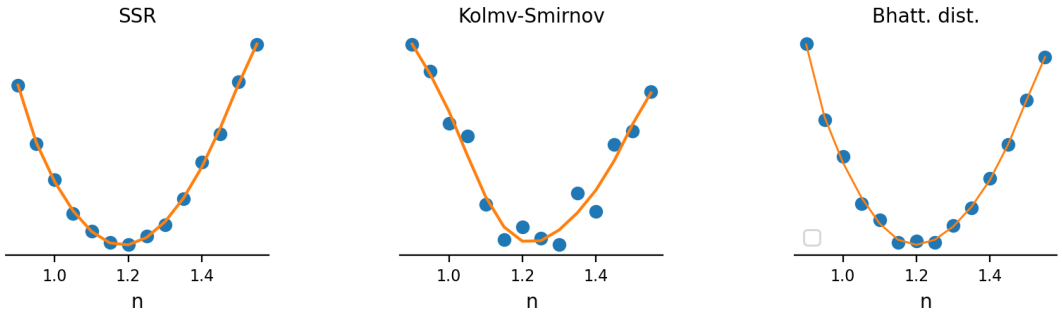

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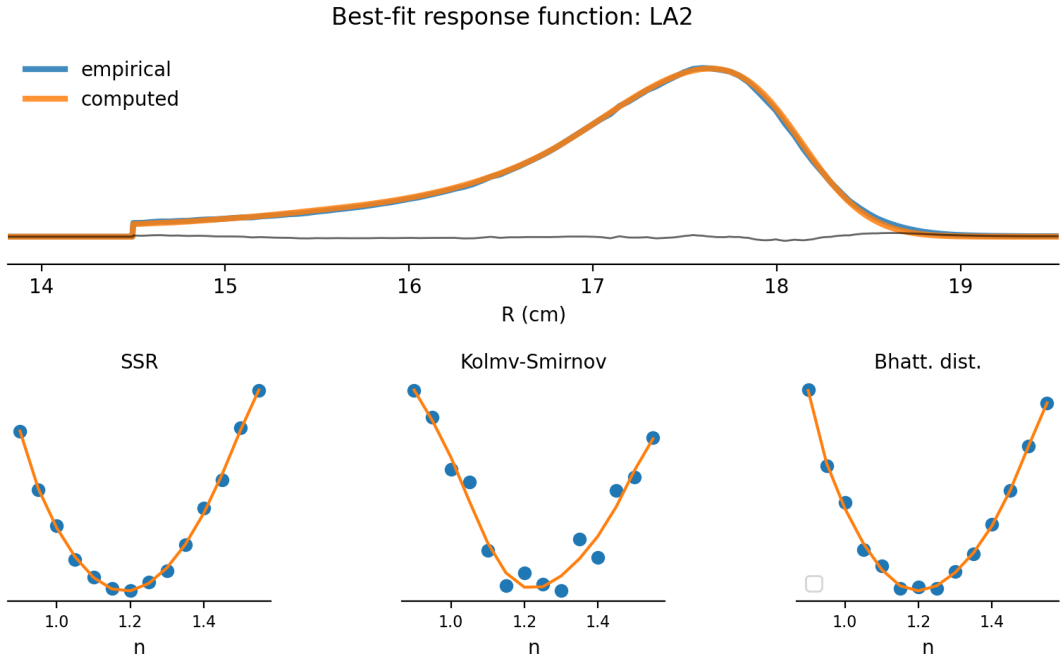

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CoM computation I. Optical response

LAGEOS
600 mm
426 CCRs

LARES
364 mm
92 CCRs

LARES-2
424 mm
303 CCRs

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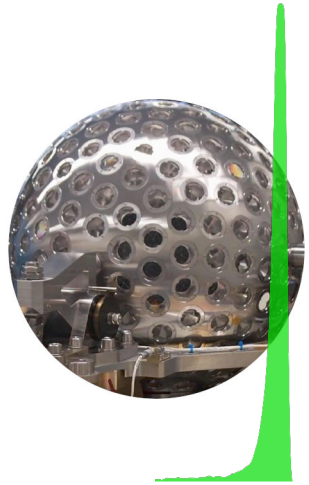

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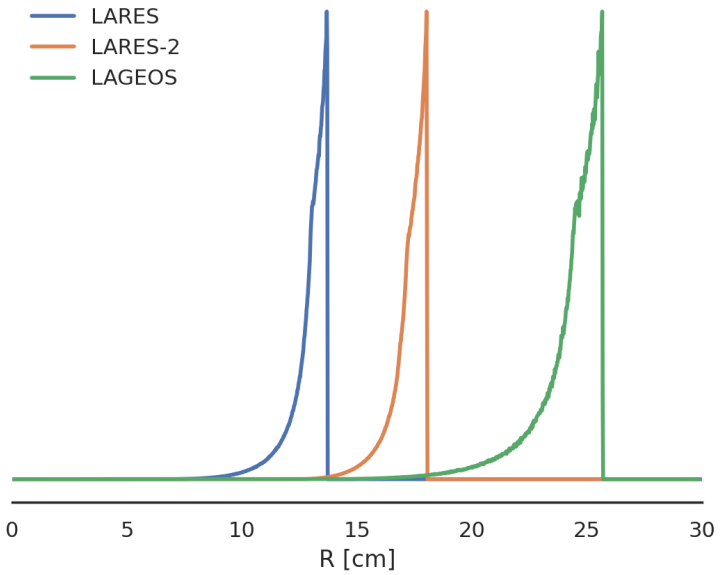

Computed optical responses

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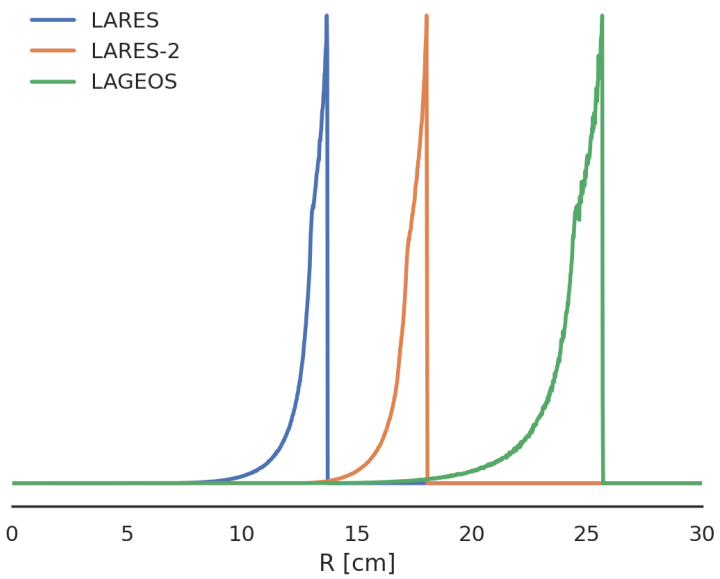

Computed optical responses

Thanks to its design, the target signature effects of LARES-2 are smaller than both LARES and LAGEOS.

The spreads of LARES and LARES-2 distributions are similar

- Improved precision over LAGEOS

The packing of CCRs is much more dense than LARES

- Reduced variability of the laser returns

We expect a superior performance from LARES-2.

Arnold. Thermo-optical design of a geodetic satellite for one millimeter accuracy. *Adv Space Res,* 2020
Ciufolini et al. The LARES 2 satellite, general relativity and fundamental physics. *Eur. Phys. J. C,* 2023

CoM computation II. Derivation of CoM values

Satellite **optical** behaviour → **CoM** values

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Things to consider:

- Station hardware
- Mode of operation (single/multi/mixed-photon)
- Data reduction details

Difficulties:

- Heterogenous network
- Uncertain/imprecise information on HW used
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We model the stations trying to make the best use of the information available.

Two cases:

- Single-photon
- Multi-photon

Mean return rates from NP data used to account for mixed modes of operation.

No ground truth to compare against.

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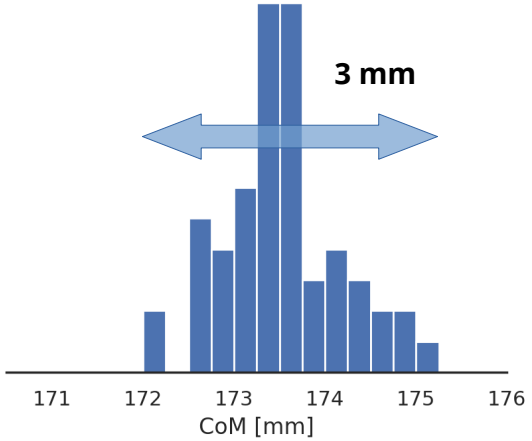
We obtain a narrow range of CoM values for LARES-2 (very good news)



LARES-2

```
Min: 172.0 mm
Max: 175.0 mm
Avg: 173.5 mm
```

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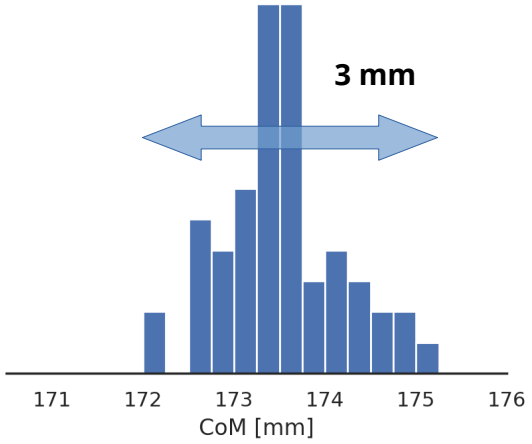

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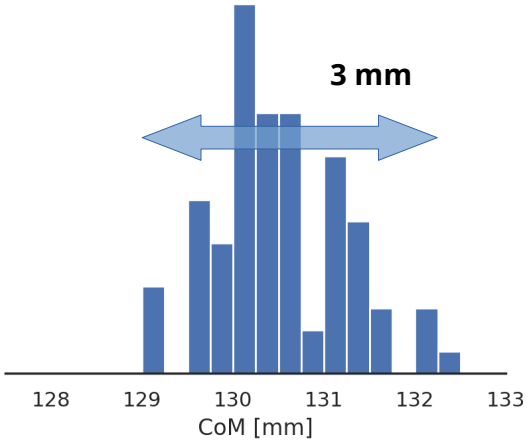
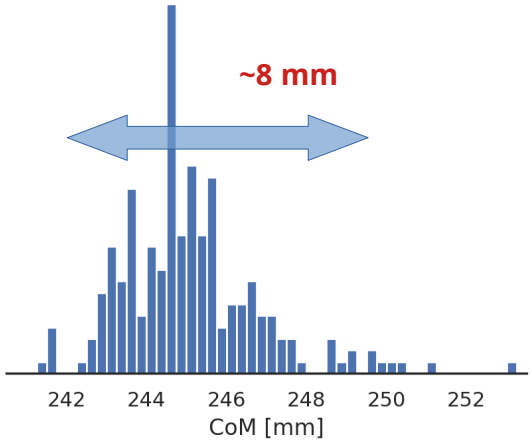


LARES

Min: 129.0 mm
Max: 132.3 mm
Avg: 130.5 mm



LAGEOS

Min: 241.4 mm
Max: 253.1 mm
Avg: 245.0 mm

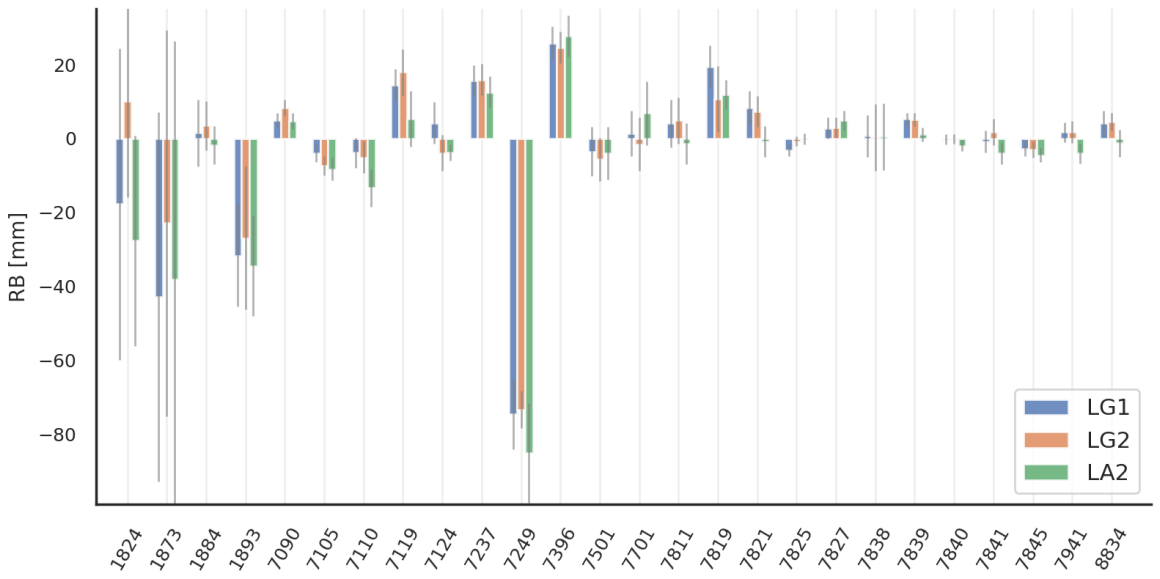
Testing

No independent means to test the results. Geodetic solutions is the best we can do.

Analysis period: Aug 2022 – Sep 2023
34 stations in total

Coordinates + RB solved for

avg # weeks / sta LAGEOS : 32
avg # weeks / sta LAGEOS-2: 28
avg # weeks / sta LARES-2 : 25



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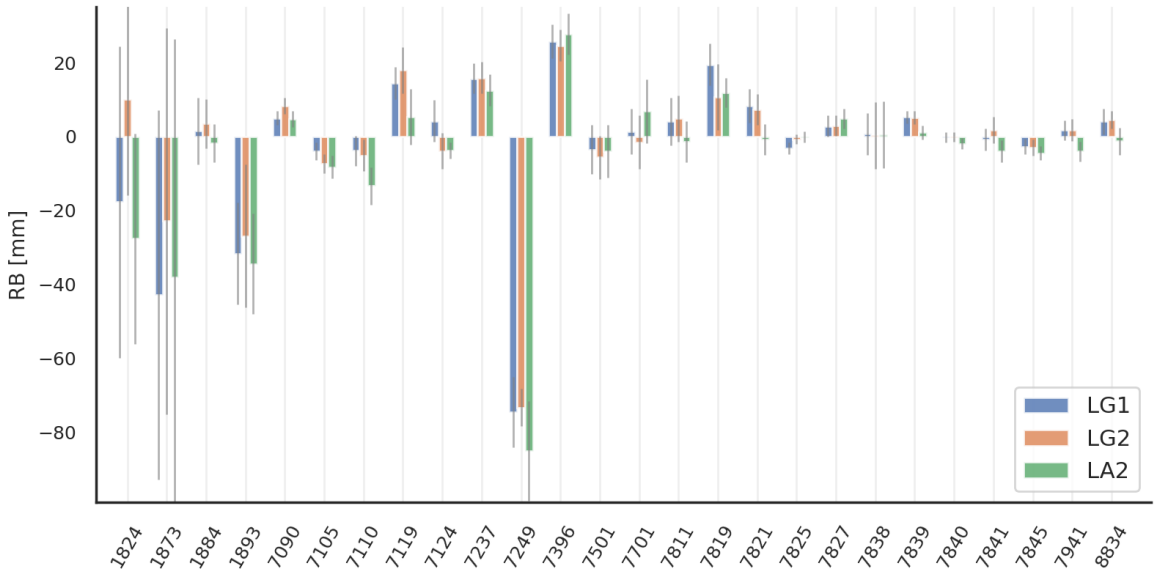
Stations **NOT** tracking LARES-2:
1874, 1888, 1889, 1890, 1891, 7394, 7503



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Many stations show large systematic errors that can not be explained by CoM mismodelling.

Average range biases

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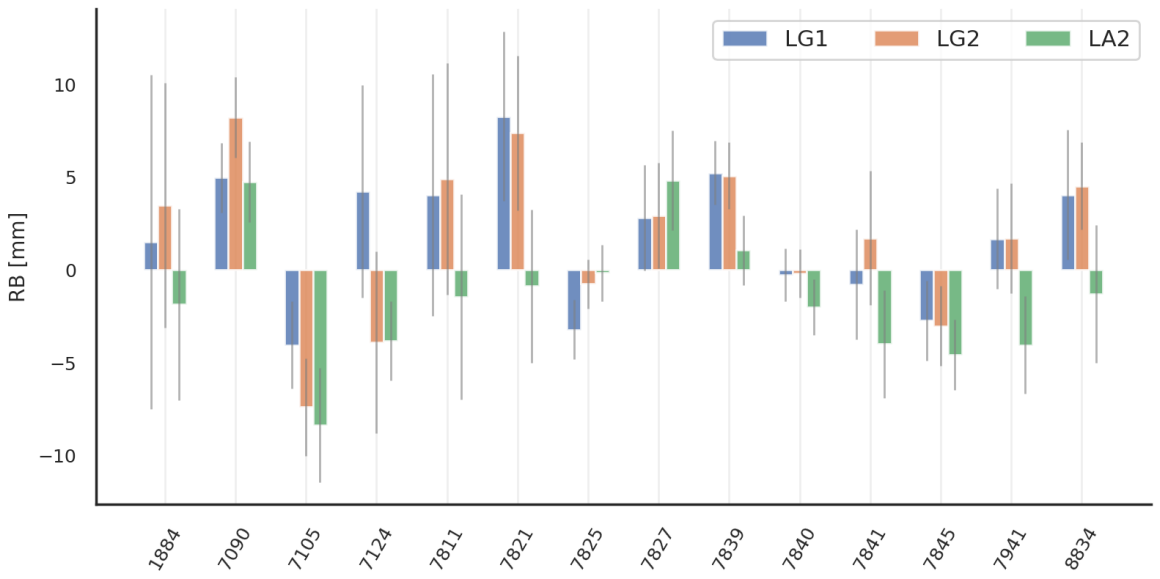
Restricting analysis to stations with:

- Average LA2 RB ≤ 10 mm
- Std error LA2 RB ≤ 6 mm

14 stations left



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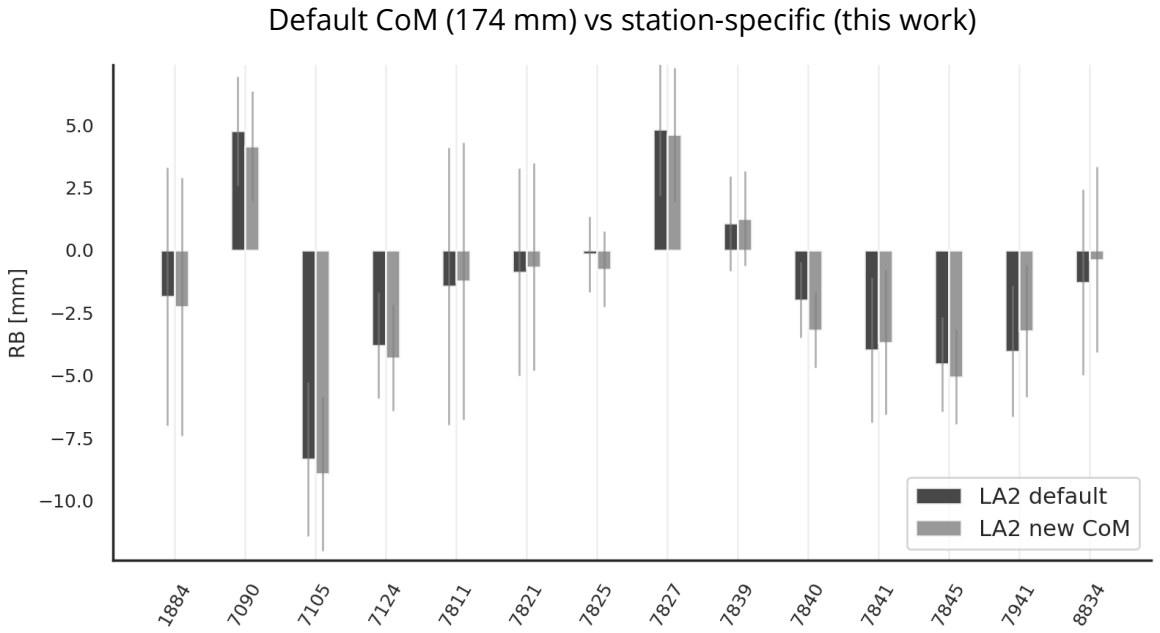
Results with default vs new CoM show only *slight* changes in RB:

- 50% better, 50% worse
- Uncertainties of geodetic results **>** CoM differences



Conclusions

Following known methods, we find that:

- Advantageous optical behaviour of LARES-2
- The range of CoM values is smaller than LAGEOS by ×3
- The mission-provided default CoM value is very close to the mean of our results
- We can not prove an improvement when station specific corrections are applied (yet?)
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The global performance of the ILRS network should be improved

- We still see systematic errors at levels of centimetres
- We still see many stations with unstable behaviour
- Less than 50% of the network with a minimum of productivity/quality/stability

Testing and improving our models, and identifying error sources requires fixing these problems.

Thank you