Instituto Geográfico Nacional
CENTRO NACIONAL DE INFORMACIÓN GEOGRÁFICA

LARES-2 centre of mass corrections

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INSTITUTO GEOGRÁFICO NACIONAL

YEBES

British Geological Survey

Introduction

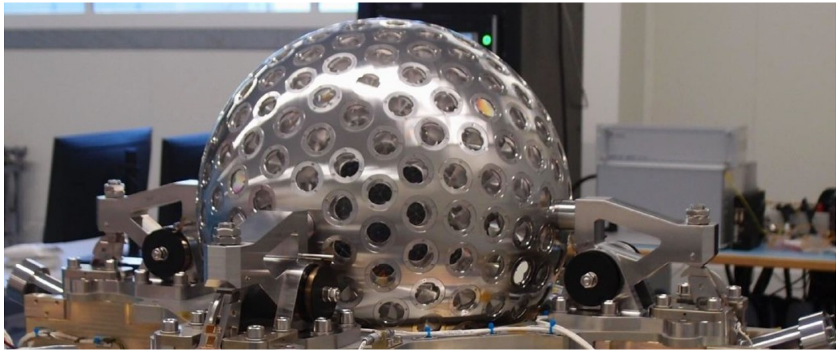
LARES-2 is the latest addition to the family of spherical geodetic satellites.

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)

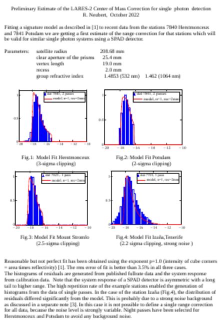
CoM computation

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

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



Preliminary Estimate of the LARES-2 Center of Mass Correction for single photon detection
R. Neubert, October 2022

Fitting a signature model as described in [1] to recent data from the stations 7840 Herstmonceux and 7841 Potsdam we are getting a first estimate of the range correction for that stations which will be valid for similar single photon systems using a SPAD detector.

Parameters:	satellite radius	208.68 mm
	clear aperture of the prisms	25.4 mm
	vertex length	19.0 mm
	recess	2.0 mm
	group refractive index	1.4853 (532 nm) 1.462 (1064 nm)

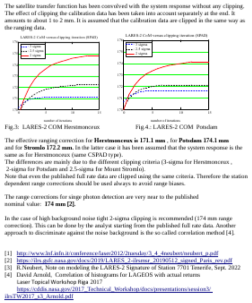
Fig.1: Model Fit Herstmonceux (3-sigma clipping)

Fig.2: Model Fit Potsdam (2-sigma clipping)

Fig.3: Model Fit Mount Stromlo (2.5-sigma clipping)

Fig.4: Model Fit Izaña,Tenerife (2.2 sigma clipping, strong noise)

Reasonable but not perfect fit has been obtained using the exponent p=1.0 (intensity of cube corners = area times reflectivity) [1]. The rms error of fit is better than 3.5% in all three cases.
The histograms of residuals are generated from published fullrate data and the system response from calibration data. Note that the system response of a SPAD detector is asymmetric with a long tail to higher range. The high repetition rate of the example stations enabled the generation of histograms from the data of single passes. In the case of the station Izaña (Fig.4), the distribution of residuals differed significantly from the model. This is probably due to a strong noise background as discussed in a separate note [3]. In this case it is not possible to define a single range correction for all data, because the noise level is strongly variable. Night passes have been selected for Herstmonceux and Potsdam to avoid any background noise.



The satellite transfer function has been convolved with the system response without any clipping. The effect of clipping the calibration data has been taken into account separately at the end. It amounts to about 1 to 2 mm. It is assumed that the calibration data are clipped in the same way as the ranging data.

Fig.3: LARES-2 COM Herstmonceux

Fig.4.: LARES-2 COM Potsdam

The effective ranging correction for **Herstmonceux is 171.1 mm** , for **Potsdam 174.1 mm** and for **Stromlo 172.2 mm.** In the latter case it has been assumed that the system response is the same as for Herstmonceux (same CSPAD type).
The differences are mainly due to the different clipping criteria (3-sigma for Herstmonceux , 2-sigma for Potsdam and 2.5-sigma for Mount Stromlo).
Note that even the published full rate data are clipped using the same criteria. Therefore the station dependent range corrections should be used always to avoid range biases.

The range corrections for singe photon detection are very near to the published nominal value: **174 mm [2].**

In the case of high background noise tight 2-sigma clipping is recommended (174 mm range correction). This can be done by the analyst starting from the published full rate data. Another approach to discriminate against the noise background is the so called correlation method [4].

[1] http://www.lnf.infn.it/conference/laser2012/2tuesday/3_4_4neubert/neubert_p.pdf
[2] https://ilrs.gsfc.nasa.gov/docs/2019/LARES_2-ilrsmsr_20190512_signed_Paris_rev.pdf
[3] R.Neubert, Note on modeling the LARES-2 Signature of Station 7701 Tenerife, Sept. 2022
[4] David Arnold, Correlation of histograms for LAGEOS with actual returns
Laser Topical Workshop Riga 2017
https://cddis.nasa.gov/2017_Technical_Workshop/docs/presentations/session3/ilrsTW2017_s3_Arnold.pdf

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
- Do not compute diffraction patterns

We do **not ignore** these effects: they are included **empirically.**

From the physical characteristics of the retroreflectors and the satellite, we model its optical behaviour using geometrical optics.

The model is fitted to empirical data to determine the best match.

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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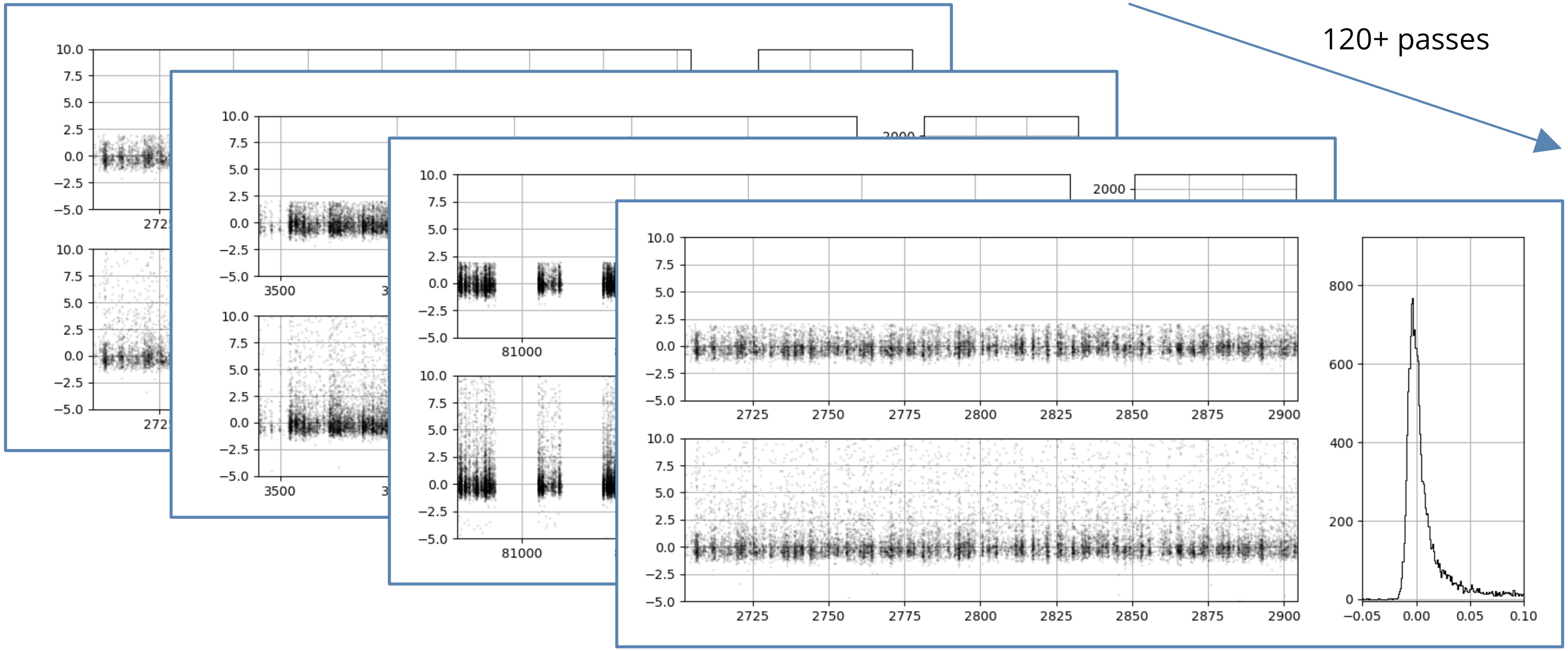

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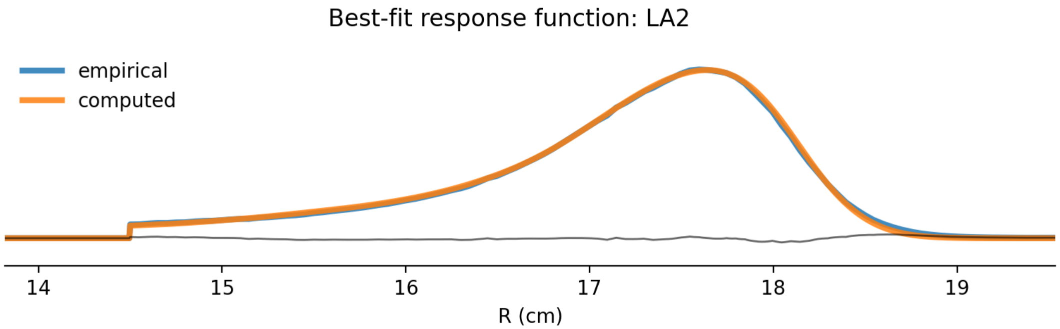
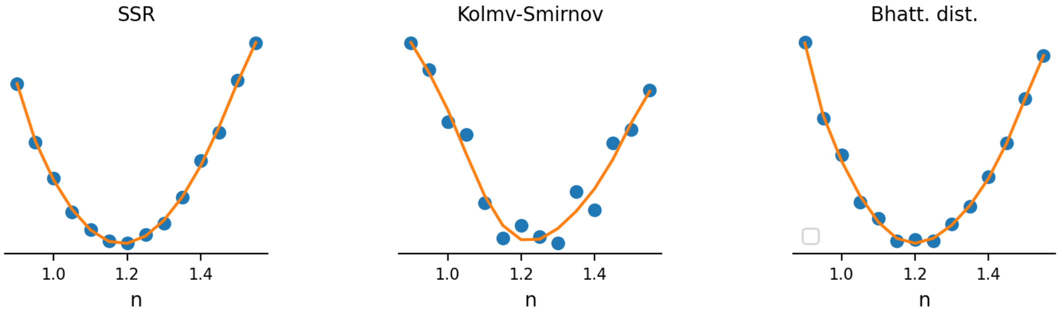
CoM computation I. Optical response

The fitted model reproduces the empirical data very well:



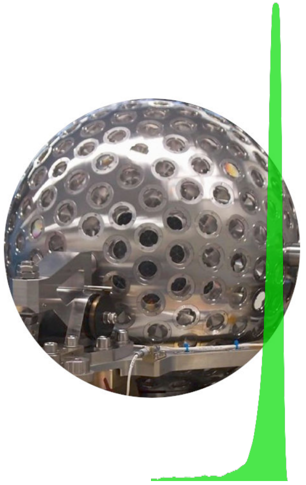
Different metrics to assess the similarity of the distributions (empirical vs model)



CoM computation I. Optical response

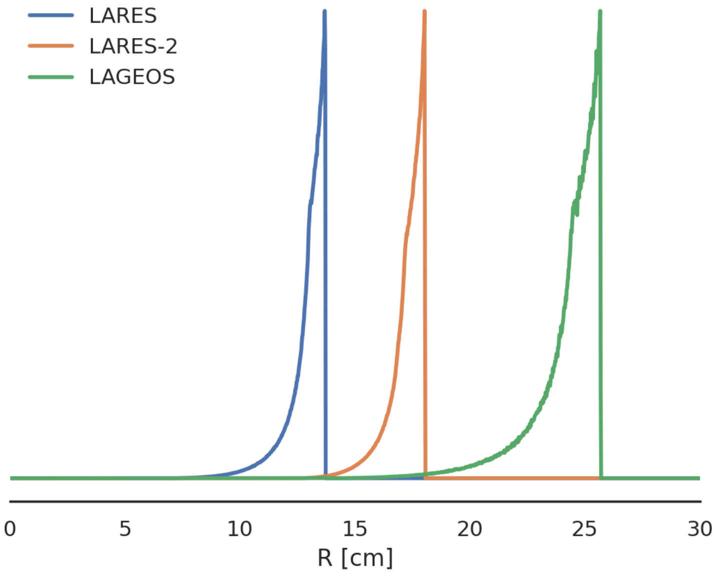
LAGEOS
600 mm
426 CCRs

LARES
364 mm
92 CCRs



LARES-2
424 mm
303 CCRs

CoM computation I. Optical response



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

Things to consider:

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

Difficulties:

- Heterogenous network
- Uncertain/imprecise information on HW used
- Uncertain/undefined mode of operation
- Unclear reduction/calibration details
- Instabilities and changes at the stations
- Tricky modelling for multi-photon/mixed-mode

We model the stations trying to make the best use of the information available.

Two cases:

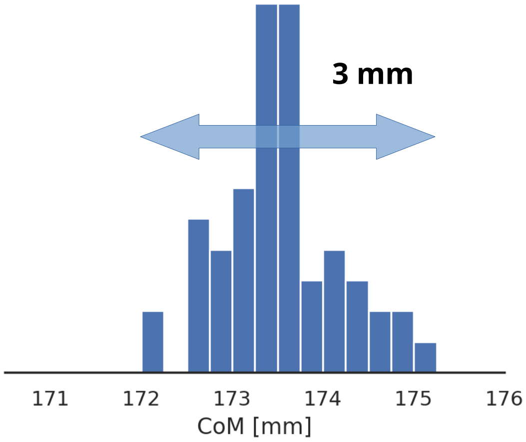
- Single-photon
- Multi-photon

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

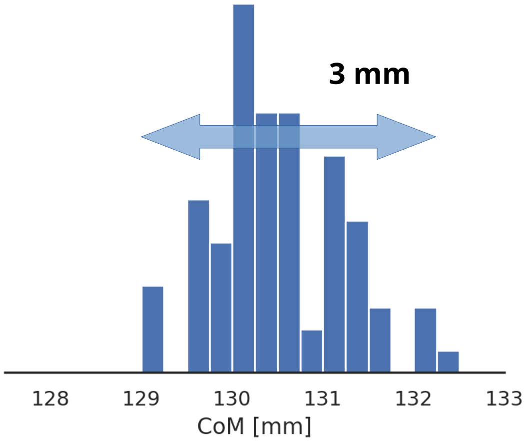
No ground truth to compare against.

CoM computation II. Derivation of CoM values

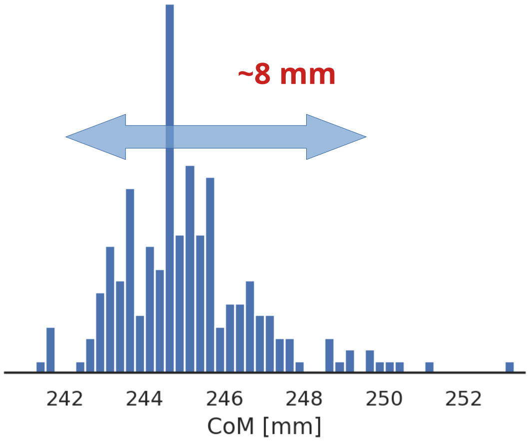
We obtain a narrow range of CoM values for LARES-2 (very good news)



LARES-2
Min: 172.0 mm
Max: 175.0 mm
Avg: 173.5 mm



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

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

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

Average range biases

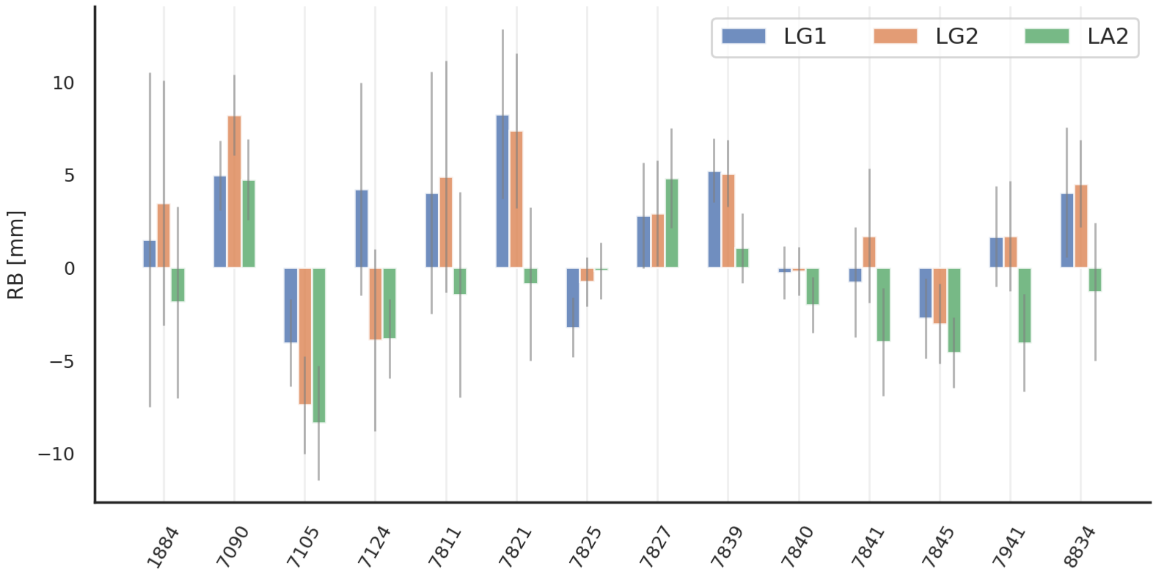
Testing

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

Restricting analysis to stations with:

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

14 stations left



Average range biases

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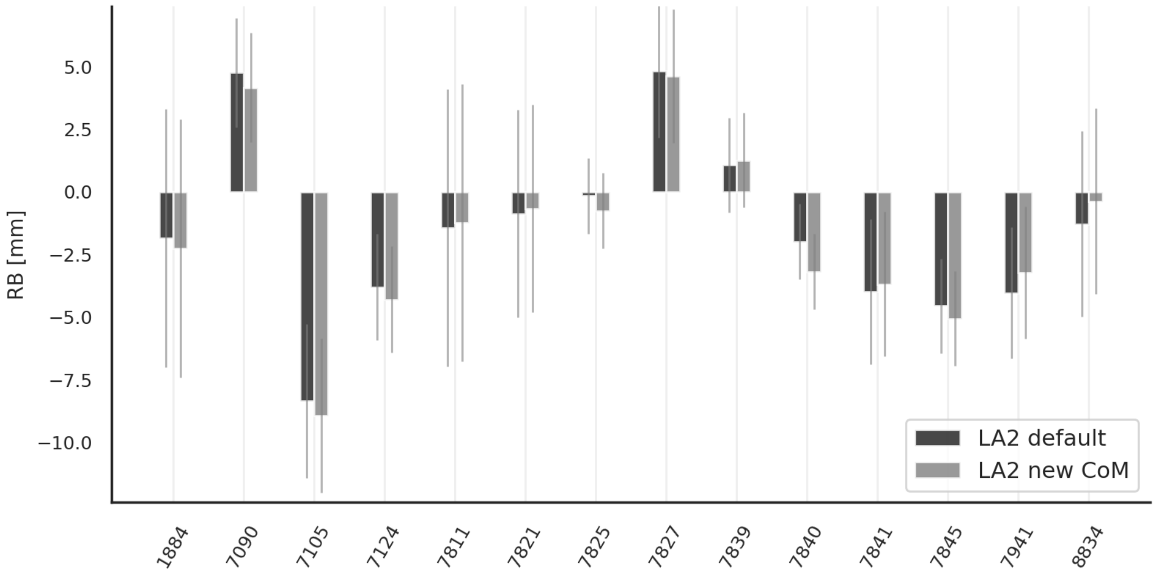
14 stations left

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

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

Default CoM (174 mm) vs station-specific (this work)



Average range biases

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?)
- The performance afforded by the satellite is beyond the precision of the technique over 1 year

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