Genesis Science Workshop

3rd -4th April 2025

Matera, Italy

Working Group 5 (SLR) Session

Working Group 5

SLR WG

GENESIS ESA Science meeting

3-4 April 2025

Agenda

[11h30 - 11h35] **Introduction**

[11h35 - 11h45] **Laser Range Correction – Simone Dell’Agnello**

[11h45 - 12h30] **Discussion**

GENESIS Mission Objectives

Contribute to improve ITRF accuracy and stability by providing in-orbit colocation and necessary combined processing for the four space-based geodetic techniques that contribute to its realization. The goal is to contribute to the achievement of the Geodetic Global Observing System (GGOS) objectives for the ITRF realisation, aiming for a parameter **accuracy of 1 mm and a stability of 0.1 mm/year**, in order to provide significant scientific benefits in Earth modelling, and to support a wide range of societal applications (as endorsed by the United Nation resolution A/RES/69/266).

Targets:

Accuracy: 1 mm

Stability: 0.1 mm per year

Contribute to improve the link between the ITRF and the ICRF, thanks to the increased consistency of the Earth Orientation Parameters (EOP). In particular, this mission shall allow for the first time a link between the orbit reference frame, ITRF and ICRF.

WG5: Where are we now ?

Main topic in 2024: the Optical Cross Section (OCS) of GENESIS

=> the LRR OCS requirement value has been officially increased from $3Mm^2$ to $6Mm^2$

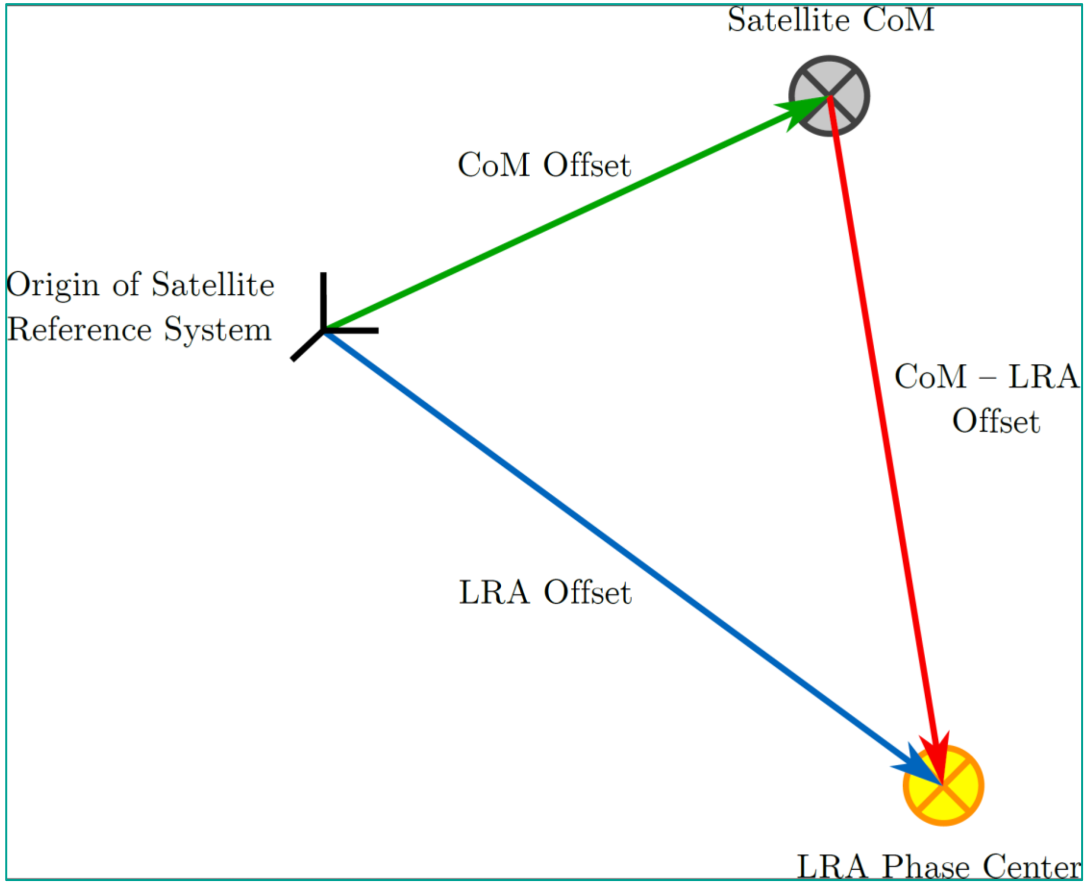
New subject in 2025 :

position vector knowledge & the range correction

Measuring the Laser ranging correction with level of accuracy required by Genesis

- Measure/calibrate the optical center of the LRR
  - w.r.t. the center of mass of the LRR
  - w.r.t. the other technics
  - w.r.t. the center of mass of the satellite after all the integration
- Important:
  - Origin of the SRF must be known better than 1mm
  - Satellite CoM must be known better than 1mm
  - LRA optical phase center must be known better than 1mm

  → All points should be calibrated on the fully mounted/equipped satellite, preferably with electronic devices switched on!



Zeitlhöfler, 2019

(Optical) Laser Range Correction (LaRCo): accuracy benchmarks as input for Genesis

Spheres, hemi/sphere, spherical caps/domes like: LAGEOS, LARES-2, Genesis, …

Please give feedback in particular to the following slide

Genesis Science Workshop, April 03-04 2025, Matera, IT

INFN – Frascati National Labs (INFN-LNF)
S. Dell'Agnello for the SCF_Lab Research Group
(simone.dellagnell0@lnf.infn.it)
Via E. Fermi 54, Frascati (Rome), 00044 – Italy

Extreme 1α (optical) challenges for the Genesis LRR

- OCS of 6 Msqm has been approved by ESA and industrial consortium.
- We held LRR KO. LRR SRR (System Reqs. Review) after Genesis meeting in Matera. **We ask for ILRS feedback on the following:**
- Requested accuracy of calculated (purely optical) laser range correction is:
- **1.0 mm (3D, 2-sigma) equivalent to 0.5 mm (3D, 1-sigma), that is to say at 1 standard deviation (1-std), to be compared to:**
  - **5 mm @1-std for LAGEOS** (source: David Arnold)
  - **2 mm @1-std for LARES-2** (source: LARES-2 mission support req. form)
  - **Quoting definitive numbers is hard, like the LAGEOS OCS (7 to 15 Msqm)**
  - **Genesis must be better than x10 LAGEOS @1-STD**
  - **Genesis must be better than x4 LARES-2 @1-STD**
  - **Very challenging/critical, who knows/wants to compute @0.5mm 1σ?**
- Compare requested laser ranging accuracy to accuracies of atmosph. corrections:
  - **For 10º / 15º / 20º elevations, accuracies are 5 mm / 2 mm / 1 mm**
  - See Journal of Geodesy (2019) 93:1853–1866 https://doi.org/10.1007/s00190-019-01287
    - **Authors: these 1 / 2 / 5 millimeters are @1-STD / 1-sigma.**
  - **ILRS requested x2 OCS increase for low elevations, where limit is 2-5 mm.**

Extreme 1α (optical) challenges for the Genesis LRR

- Requested accuracy of calculated (purely optical) laser range correction is:
- **0.5 mm @1-sigma for Genesis, to be compared to**

  5 mm @1-sigma for LAGEOS (source: David Arnold)

  2 mm @1-sigma for LARES-2 (source: LARES-2 mission support req. form)
  - **Who has better definitive numbers for LAG / LS2 ?**
  - **Very challenging/critical, who knows/wants to compute @0.5mm 1σ ?**

- Compare requested laser ranging accuracy to accuracies of atmosph. corrections:
- **10/15/20^{o} elevations, accuracies 5/2/1 mm at 1-sigma**
  - **ILRS requested x2 OCS increase for low elevations, where limit is 2-5 mm.**

- **Why 0.5 mm if there is (at least) another limitation of 2-5 mm?**
- **Other multi-mm limitations (at stations, for ex.)?**
- **Final (optics plus mechanics …) accuracy goal of LaRCo is 1 mm.**
- **Achievable with optics [0.5-1.0] mm $\oplus$ mech/else [0.0-0.5] mm:**
  - **0.75 $\oplus$ 0.25 = 0.8 mm, 0.8 $\oplus$ 0.3 = 0.85 mm, 0.9 $\oplus$ 0.4 < 1 mm, …**
  - **Numerically, optical LaRCo accuracy can be relaxed keeping final goal.**

LaRCo (<u>La</u>ser <u>R</u>ange <u>Co</u>rrection), a facility?

For hemi/spheres, spherical caps/domes like: LAGEOS, LARES-2, Genesis, EO mission, …

Goal: Service to ESA, ILRS and SLR science community.

<u>Expert consultants / collaborators</u>: Pippo Bianco, Toshi Otsubo …
<u>ILRS feedback / endorsement (or not)</u>: useful to inform ESA.

ILRS NESC WG meeting, 13-03-2025

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S. Dell'Agnello for the SCF_Lab Research Group
(simone.dellagnell0@lnf.infn.it)
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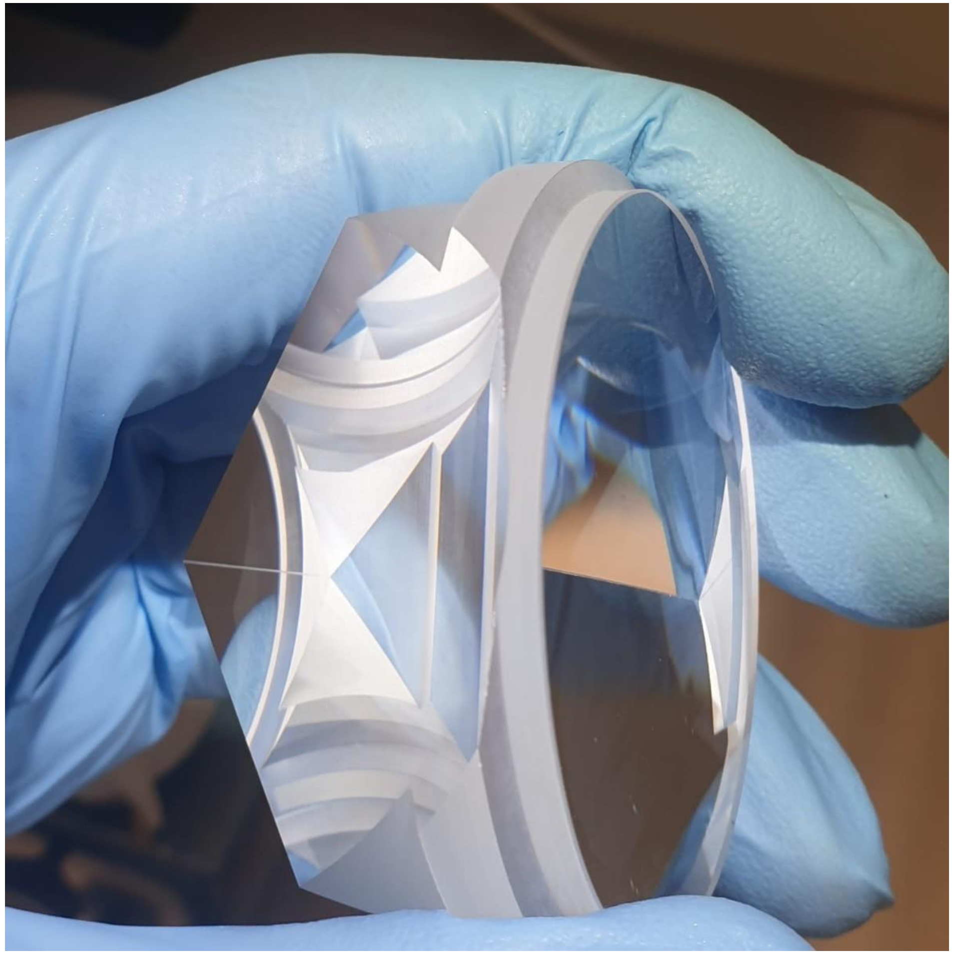
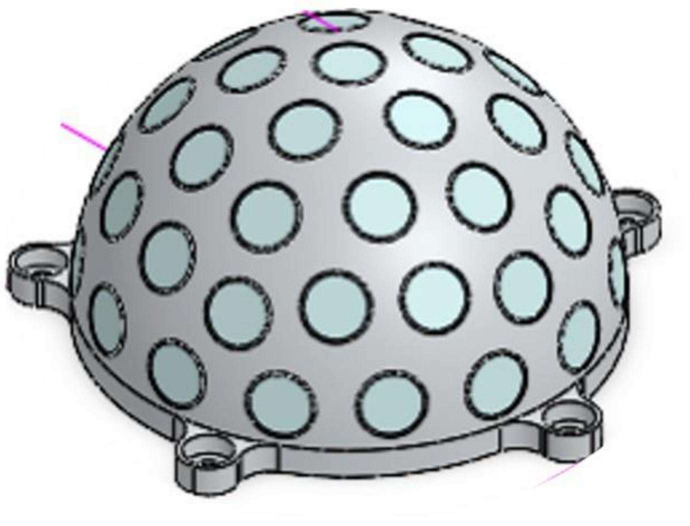
Cube Corner laser Retroreflectors (CCRs)



For flat Laser RetroReflectors (LRRs), for example GNSS LRRs, we know what range correction we are supposed to measure for normal laser incidence, and this can be used as a calibration of the LaRCo facility.

On the other hand, it will be interesting to verify how the GNSS LRR range correction changes vs laser incidence angle.

State-of-Art SLR Geometrodynamics



The GENESIS mission will contribute to a highly improved International Terrestrial Reference Frame (ITRF) with an accuracy of 1 mm and a long-term stability of 0.1 mm/year. The ITRF is the foundation for all space and ground-based observations in navigation and Earth sciences – monitoring the terrestrial environment and setting it within a set framework for mapping changes over time.

LARES-2 (LAser RElativity Satellite): 2022, ASI
LAGEOS-2 (LAser GEOdynamics Satellite): 1994, ASI

ASI's LARES-2 LRR made by INFN-Frascati & INFN-Padova launched on 13 July 2022 by ESA

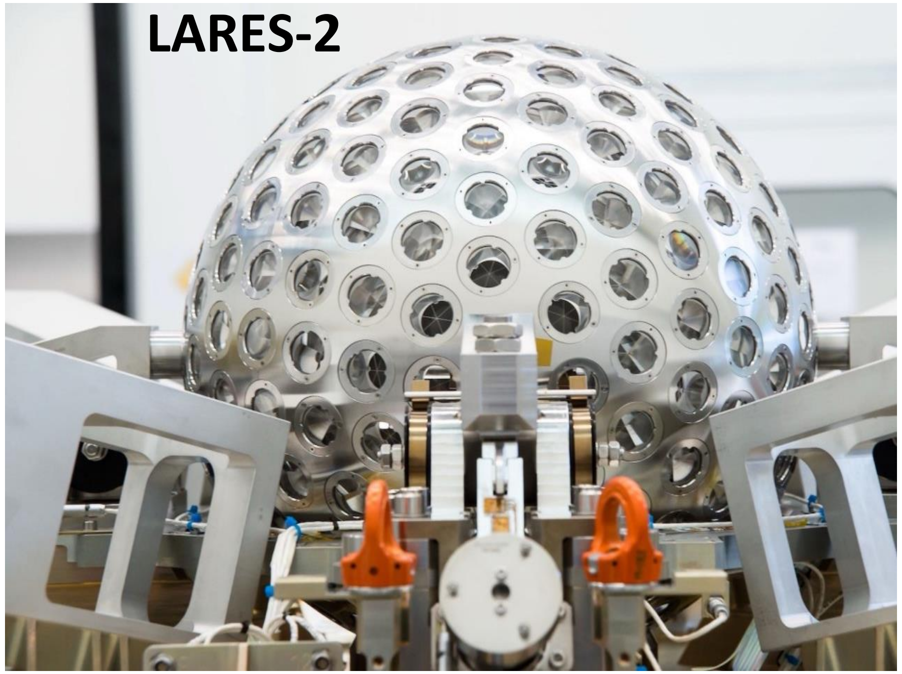
with the qualification flight of Vega C. 303 CCRs/sphere, 42cm diameter, 300 kg.

OHB-I, Milan: HDRM mechanism, quadrupod interfaces with Vega C.

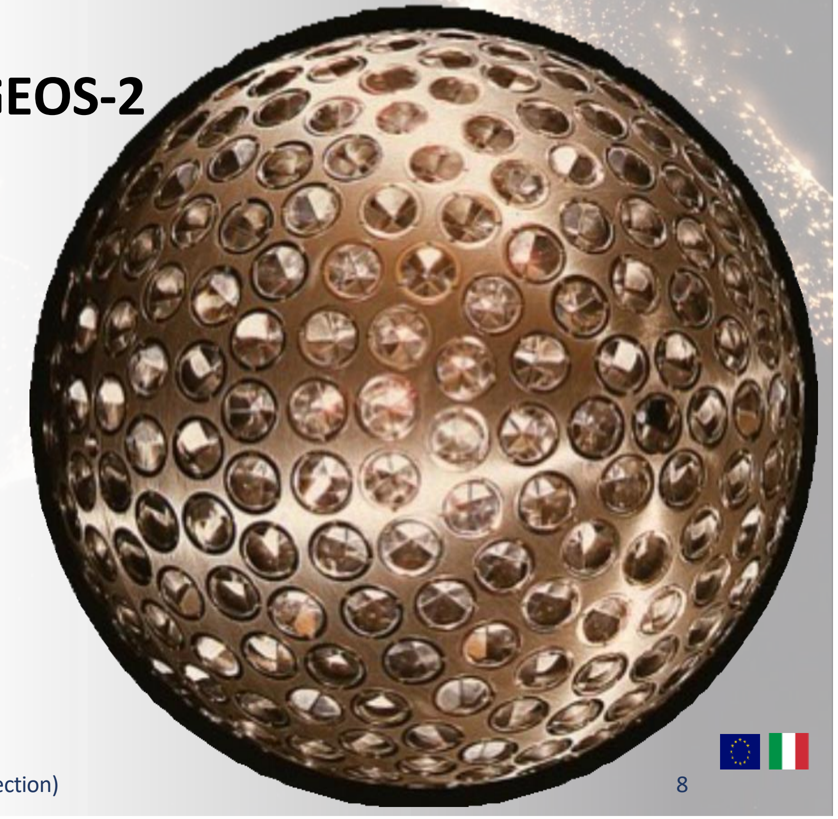
Best LRR, so far (**calculated 2 mm 1-STD/sigma** accuracy of laser range correction).

Premiere point-like test mass for General Relativity and Space Geodesy.

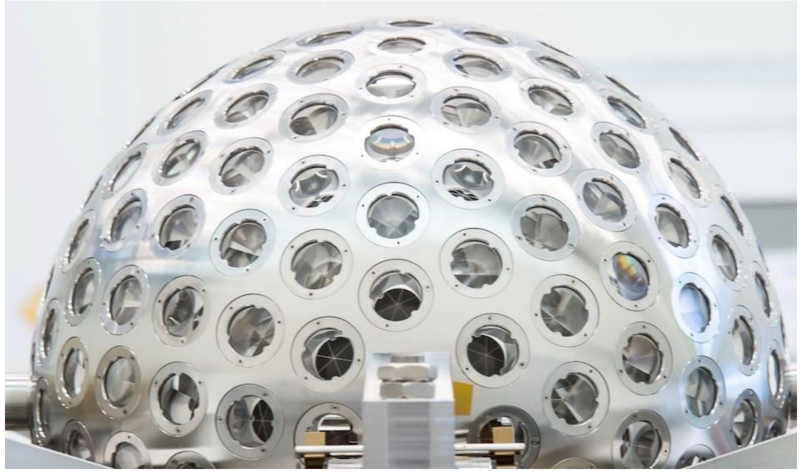
LARES-2



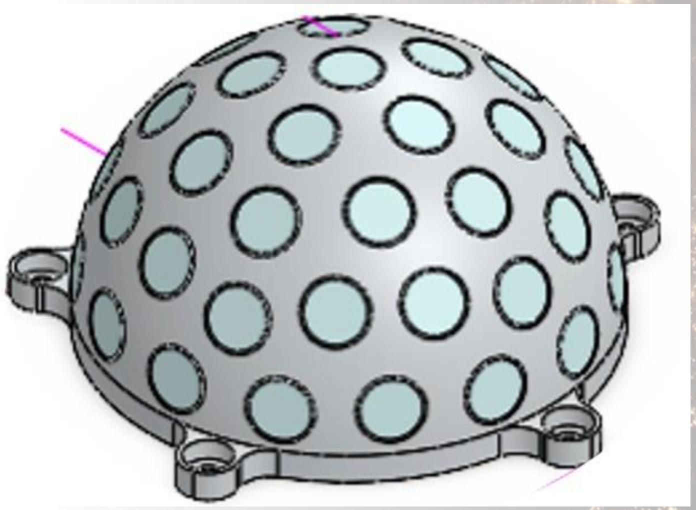
LAGEOS-2



LARES-2
(~6000 km)



Genesis
(~6000 km)
Just notional drawing



GNSS
(~20000 km)
Flat LRRs

ASI EO mission
(~600 km)
Spherical LRRs but smaller than Genesis LRR

LaRCo = Laser Range Correction

- Service facility to measure in the lab the laser range correction.
- Sort of ultimate laser ranging calibration, relating geometrical centers of LRR hemi/spheres, spherical domes to the measured laser time-of-flight (ToF), **and reach/break the barrier of 1 mm of laser range accuracy.**
- **But for Genesis the optical barrier is actually at 0.5 mm at 1-STD / 1-sigma.**
- Measurement done twice in 60 years of laser ranging, for LAGEOS-1/2 in ~1974/1994. Now only calculated.
- At INFN-Frascati we have a suited Clean Room, the SCF_lab2, co-funded by ASI & INFN, with a massive optical granite table, suitable for heavy 'cannon-ball' type of stand-alone satellites, like LAGEOS-1/2 and LARES-1/2).

Ideas for implementation of LaRCo

- Direct involvement of the ILRS stations / SLR analysis Community !

We think that, in addition to the ILRS endorsement, an appropriate direct form of involvement in the project of some *representative, voluntary* ILRS *'partner'* stations would be crucial, not only useful. The range correction is FOR ILRS stations + SLR analysts. We also believe that this involvement in the project needs to be built together, getting feedback from stations' operators, analysts and taking time to discuss critical technical and programmatic details of the project. ILRS cannot get funding, but the single stations may and do get national, European funding, some also ESA funding. We foresee specific and focussed purchased support services not for ILRS as an organization (not possible), but for some *partner* ILRS stations and for some *partner* SLR analysts.

Ideas for implementation of LaRCo

- Facility instrumentation:
  - ➢ Technique of detection of the return signal?
    - Single photon, Multi photon; CFD? ...
  - ➢ What detector?
    - Streak camera, MC PMT, C-SPAD … What other detector or detector combinations (for start time) to measure the ToF?
  - ➢ What laser WL / repetition rate?
    - 532, 1064 nm / kHz ?
  - ➢ Laser pulse width and / or polarization type
  - ➢ Do all of the above categories map directly into separate corrections to be delivered to the funding agency / ILRS?
  - ➢ Flat LRRs: check range correction vs laser incidence angle
  - ➢ Clock options, …
- HW procurement and verification/validation
  - ➢ Share work (and associated funding) with *partner* stations
  - ➢ More sharing to be decided together. And come to Frascati, please.

Ideas for implementation of LaRCo

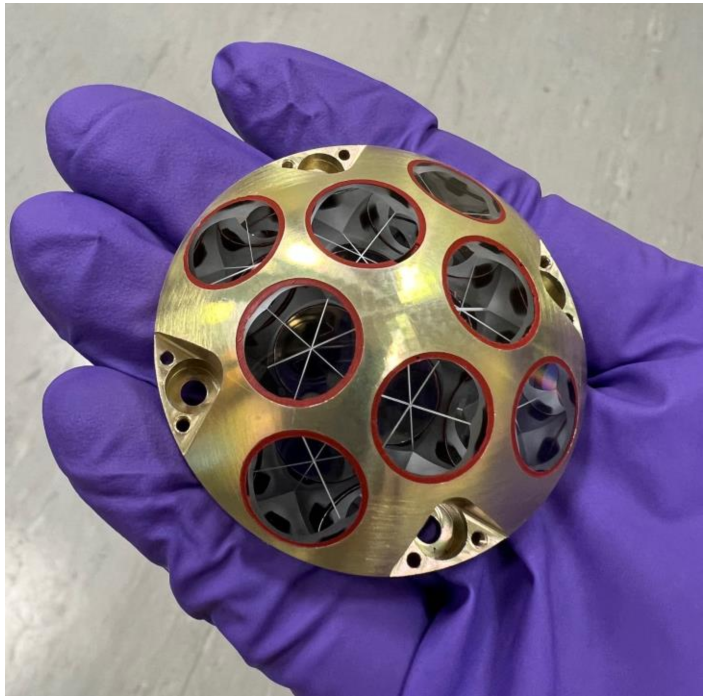
- Execution of the measurements:
  - Ask personnel of *partner* stations (representing detection techniques and/or detectors and/or laser characteristics of the previous points) to participate in the range correction measurements.
  - Participating means travel to Frascati, work there together, even in the preparation and then analysis of the results (this also remotely).
  - This will be TBD weeks of work for 1-2 people, which needs to be supported financially with LaRCo funding (if/when approved). It would be not only fair to the *partnering* stations, but also pragmatically effective.

Optical LRR design of Genesis: support material

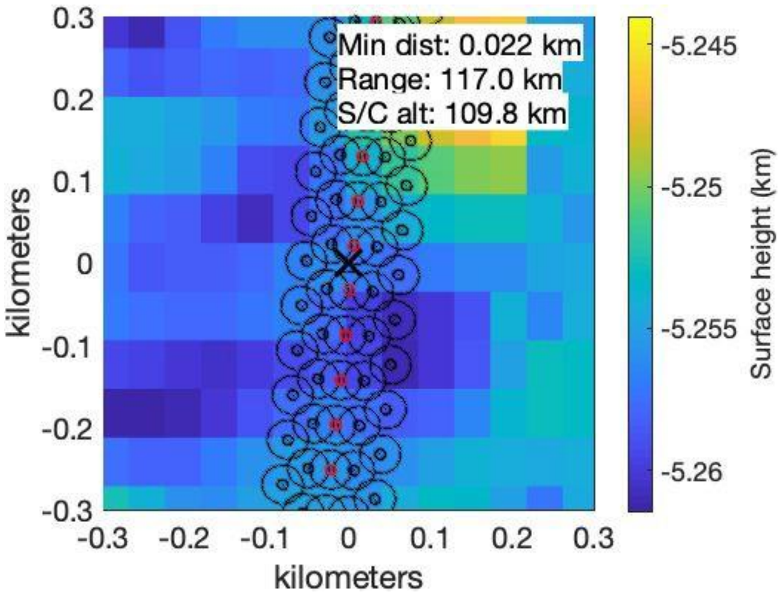
- Chosen spherical geometry (like LAGEOS / LARES-2) and 0.5inch coated, COTS (non-Suprasil 1/33) CCRs (3x and 2x finer discretization of LAG/LS2) have significant positive heritage. Range correction accuracy of 0.5mm @1σ: critical !!
  - 0.5 inch UNcoated CCRs perform worse (see next slides), so would violate OCS req.
  - Thermal degradation of the OCS not a limitation for this small CCR diameter.
- LARES-2 optics / geometry violates Genesis requirements of OCS (6Msqm), range correction (0.5mm @1σ), Volume; maybe violate Mass.
- LAGEOS optics / geometry violates range correction, V, M.
- G2G uncoated optics / flat geometry violates range correction, FOV badly ($\leq 17^o$).
- G2G coated optics / flat geometry violates range correction anyway. Plus:
  - G2G coated 1.3inch CCRs subject to large thermal degradations of OCS, of factor up to x$(1.3/0.5)^3$ ~ 18 larger degradation than 0.5inch coated CCRs chosen for Genesis. We measured this thermal degradation (x8.3) in the lab for the coated 1.1inch GLONASS CCRs in 2011 and scaling it (this x0.83) to 1.3inch CCRs one finds:
    - Violates OCS, more severely at increasing laser incidence angles in the FOV (semi-cone) ~10^o to 30^o
- Using Suprasil 1/311 will increase (about): OCS x20%, CCR cost x5, lead time x5
  - Which is the reason why Suprasil 1/311 has been avoided for LARES-2 and G2G.

TRL=9 Italian coated ½-inch CCRs on CNSA Chang'e-6 lander
Observation by laser altimeter LOLA on NASA orbiter LRO

1st observation on 31-07-2024 (landing in June 2024)



Chang'E-6: 2024-213-23:53:50, inc. angle: 20.79°
Lunar time: Day
Return received



Coated and uncoated ½-inch CCRs on lunar landers: observations by laser altimeter LOLA on NASA-LRO

LRR (Laser RetroReflector)	Total Attempts	Total Successes	Success Rate	Day/Night Success Rate
Apollo 11	11	9	82%	Day: 67% Night: 100%
Apollo 14	20	16	80%	Day: 78% Night: 82%
Apollo 15	10	3	30%	Day: 33% Night: 28%
Chandrayaan-3 lander **micro-LRR, uncoated CCRs**	96	15	**16%**	Day: 24% Night: 10%
SLIM lander **micro-LRR, uncoated CCRs**	13	3	**23%**	Day: 100% Night: 0%
Chang'E-6 lander **micro-LRR, coated CCRs**	**25**	**7**	**28%**	Day: 60% Night: 0%
IM-1 lander **micro-LRR, uncoated CCRs**	16	0	**0%**	Day: 0% Night: 0%

De: David Edmund Smith smithde@mit.edu
Objet: Ranging to small reflectors
Date: 15 mars 2025 à 17:45
À: Simone Dell'Agnello (LNF) simone.dellagnello@lnf.infn.it

Hi Simone: Hope all is well with you.

We presented a poster at the LPSC meeting in Houston last week on ranging results to the small reflector arrays and to the large Apollo arrays. The poster is attached.

We only show the number of observations of Chang'E 6 but this coming week I expect we will see if we can derive an independent position of the lander. The analysis is led by Erwan Mazarico and Gael Cascioli. They chose to estimate the 3-D position of each landing site as well as the s/c position, which I think was a little ambitious, considering the amount of data. Personally, I would have just estimated just the height or the array above the surface since we probably know the location of the reflector array from imaging to a meter or two and uncertainty in the position of LRO (according to Greg Neumann) remains the largest error source. I have always hoped we would be able to detect the radial tidal effect at each site.

Kopal Jha produces the ranging data files for archiving the LOLA and Radio Science data in the PDS at the Geosciences Node at Washington Univ. and says that you can find the range data to the small reflectors in the LOLA altimetry data files (we are not doing altimetry at the present time so the files should be really small). Also, these files get updated when the orbits are improved, although the range measurements would not be expected to change. Finally, you can arrange for all the altimetry/ranging data to be delivered to you automatically and routinely every month. But note, Kopal only uploads LOLA data to the PDS every 3 months per the agreement of LRO with NASA.

Simone, I hope you find the poster interesting and useful. The benefit of the coating on your array is clear in the percent success.

Best wishes,
Dave

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