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LaRRI: LASER RETRO-REFLECTOR FOR INSIGHT MARS LANDER

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ABSTRACT

There are laser retroreflectors on the Moon and no laser retroreflectors on Mars. Here we describe the design, construction, qualification and imminent deployment of next-generation, optimized laser retroreflectors on the Moon and on Mars (where they will be the first ones). These instruments are positioned by time-of-flight measurements of short laser pulses, the so-called 'laser ranging' technique. Since 1969 Lunar Laser Ranging (LLR) to Apollo/Lunokhod laser retro-reflector (CCR) arrays supplied accurate tests of General Relativity (GR) and new gravitational physics: possible changes of the gravitational constant Gdot/G, weak and strong equivalence principle, gravitational self-energy (Parametrized Post Newtonian parameter beta), geodetic precession, inverse-square force-law; it can also constraint gravitomagnetism. During 2017, INFN-LNF"s team carried out the final activities of manufacturing, qualification of space flight and integration of LaRRI on the NASA – JPL's spacecraft InSight which is schedule to fly to Mars in 2018.

Keywords: *general relativity, laser retro reflector, lunar laser ranging.*

I. INTRODUCTION

Overview: LaRRI is a pocket size, yet fully functional, array of metal back-coated Cube Corner Retroreflectors installed on the top desk of InSight. Corner Retroreflectors is a set of three mutually perpendicular reflective surfaces, placed to form the corner of a cube, work as a retroreflector. The three corresponding normal vectors of the corner's sides form a basis (x, y, z) in which to represent the direction of an arbitrary incoming ray, [a, b, c]. When the ray reflects from the first side, say x, the ray's x-component, a, is reversed to $-a$, while the y- and z-components are unchanged. Therefore, as the ray reflects first from side x then side y and finally from side z the ray direction goes from [a, b, c] to [$-a$, b, c] to [$-a$, $-b$, c] to [$-a$, $-b$, $-c$] and it leaves the corner with all three components of its direction exactly reversed.

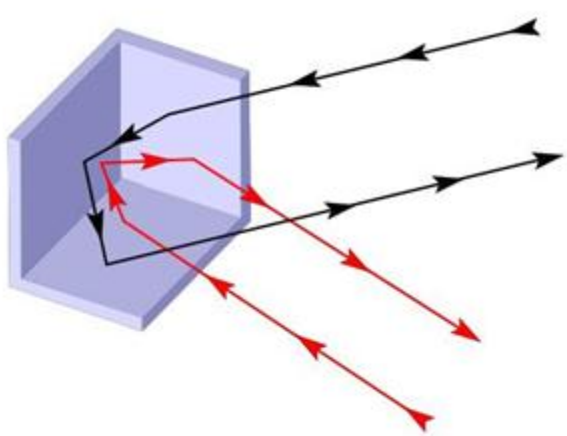

Figure1: working of Cube Corner RetroReflector

Scientific goals:

- Be the stepping stone of the Mars Geophysical Network.
- Provide accurate definition of Mars Meridian.
- Support Mars atmosphere lidar observations from orbit.

Exploration and technology goals:-

- Georeference the InSight landing sight.
- Support future lidar-based landing next to InSight.
- Be a precursor for the next generation of laser reflectors.

II. LARRI ASSEMBLY

LaRRI's design and manufacturing began just after the integration of INRRI on the ExoMars EDM ESA space craft.

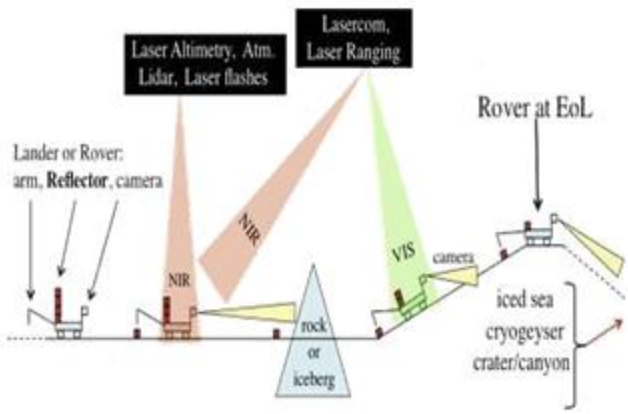

Figure2: INRRI/LaRRI assambly

In the following figures, we show a particular of the metal coated back faces of the CCRs before fixing to aluminum frame and the retro reflection at work through the front face of the CCR.

LaRRI microreflector was assembled fixing eight CCRs to an aluminium alloy frame using a space qualified silicon rubber for the bonding.

Concerning the Mars, our main goals are lunar exploration, geodesy and precision tests of General Relativity (GR) and new gravitational physics, continuing and extending up to a factor 100 the reach of Apollo and Lunokhod laser retroreflectors. We developed a large (54 mm optical diameter), single retroreflector (Mars Laser Instrumentation for General relativity High accuracy Tests).

CCRs thermal relaxation times:
The measurement was performed at three different fixed temperatures of the support aluminum structure: 280K, 300K, 310K.

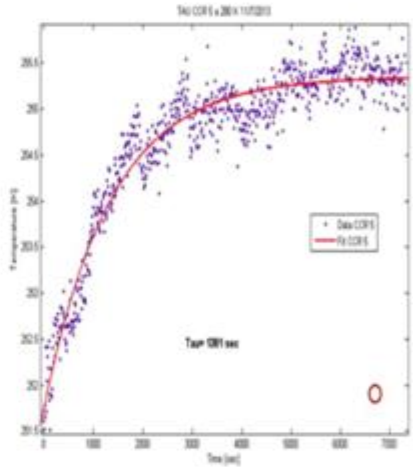

Figure3: CCRs thermal characteristics with different temperature

We report the analysis of the seven CCRs in the center, easier to measure.

	T1=280K[SEC]	T2=300K[SEC]	T1=310K[SEC]
CCR1	1518±156	1973±58	1313±157
CCR2	1555±233	1595±28	1355±208
CCR3	1340±2	1632±29	1635±398
CCR4	1437±32	1893±33	1379±325
CCR5	1531±101	1719±31	1784±500
CCR6	1425±61	1925±28	1548±292
CCR7	1423±63	1732±35	1535±428

LaRRI microreflector will be the second array of CCRs deployed on Mars, and, evenytually, the first operational one. LaRRI CCRs have got the same technical specifications as INRRI CCRs. We show, as an example, two measured FFDPs (For Field Diffraction Pattern) and average intensities of one of LaRRI's CCRs taken before and after the space qualification compaign.

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Figure4: Naked CCR CCRs Optical characterisation

Before starting Sun ON phase, with vacuum pulling and LN2 flowing in cryostat systems, first FFDP, named 000, is acquired; it will serve as a baseline steady-state optical condition. Then, for the rest of the Sun ON phase, no optical interrogation is performed, in order not to affect the thermal stimulation of the assembly.
During Sun OFF phase, FFDPs are shot with the following frequencies:

- 1 FFDP every 2 minutes for 60 minutes.
- 1 FFDP every 4 minutes for 60 minutes
- 1 FFDP every 10 minutes for 120 minutes
- 1 FFDP every 30 minutes until the end of the phase

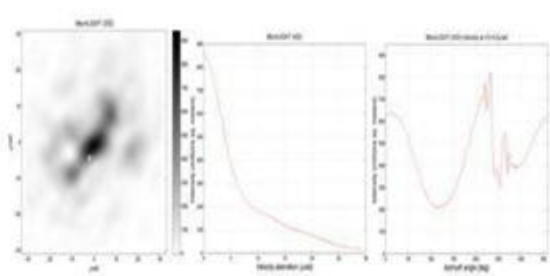

Figure5: Starting from right: 1) FFDP, 2) intensity vs velocity aberration, 3) intensity vs azimuth angle at range 4.0-4.5 µrad, all taken before Sun ON phase.

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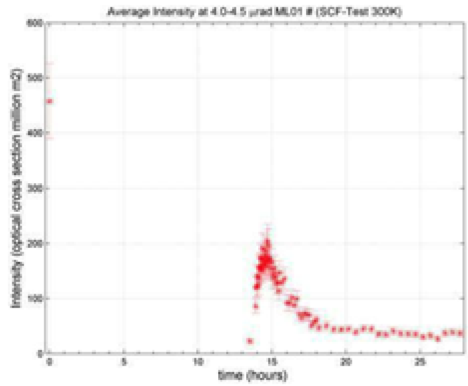

Figure6: Average intensity vs time at range 4.0-4.5 μrad during the SCF-Test with housing at 300 K

III. CONCLUSIONS

The results shows that MoonLIGHT-2 can provide a mm-accuracy during lunar night. This is because the SUN-ON phase FFDPs are in good agreement with the simulations as shown by the longer CCR and the reduced thermal gradient. Further analysis will be done in order to ensure the operatively phase not only during lunar night but also during lunar day time.

LaRRI will be the first operational micro-reflector on MARs. A like its precursor INRRI, LaRRI was designed, manufactured and space qualified by INFN-LNF, in order to meet its integration on board InSight.SCF_Lab has now space qualified micro-reflector devices for both ESA and NASA Mars surface mission.

Data analysis and simulation:
The Planetary Ephemeris Program (PEP)

- Determine the positions and velocities of the centers of mass of the Sun, plan-ets, Pluto, and Earth-Moon barycenter by integrating their equations of motion Integrate the equations of motion for the Moon, Moon rotation and Earth (but not Earth rotation)
- Determine the asteroid positions from an elliptic approximation (rather than from integrated equations of motion)
- Calculate the displacement of the lunar reflector with respect to the center of mass of the Moon
- Calculate the displacement of the ranging station with respect to the center of mass of the Earth
- Treat photon propagation e↵ects
- PEP also allows us to find a constant bias term for any specified span of data.

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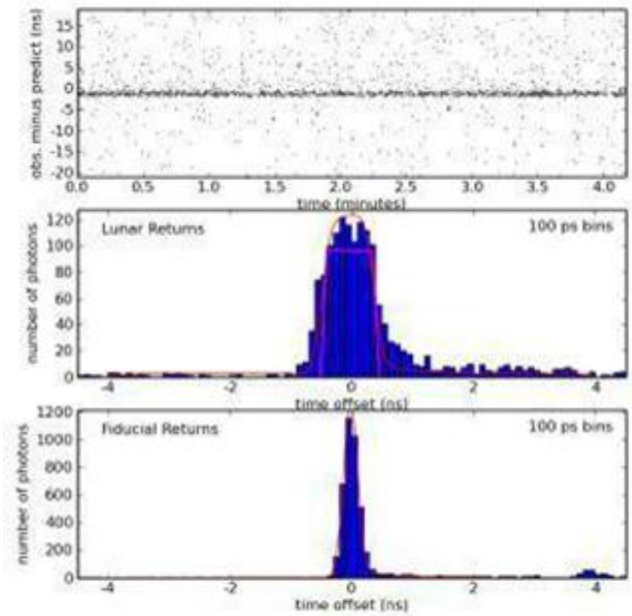

Figure 7: In the plot, the top panel shows a 40 ns window of observed round trip time minus the predicted range. Background noise and detector dark current appear as scattered dots, while the lunar return is in the middle. The middle panel shows a histogram of the lunar returns, while the bottom panel shows the local "fiducial" CCR return, fitted by the red Gaussian. The Lunar return is additionally spread by the tilted reflector array modeled by the superimposed magenta trapezoidal shape.

IV. FUTURE PROSPECTS

INRRI: We are currently simulating the INRRI performance with the Exo-Mars EDM mission. With this simulations we want:

Geo-referencing of Mars surface using a preliminary version of a future Mars Geo/physics Network based on INRRI; Using INRRI to measure GR parameters along with LLR measurements.

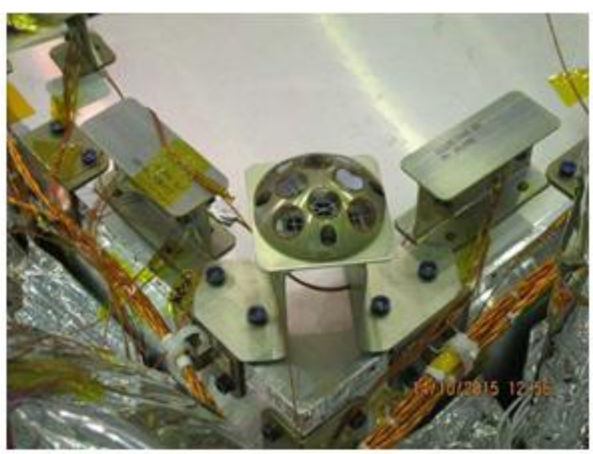

Figure 8: INRRI integrated on ExoMars EDM

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