# Testing and physics analysis of old (Lunokhod) and new (MoonLIGHT) lunar laser retroreflectors

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## Abstract

Since its foundation, one of the most important objective of the INFN's SCF_Lab (Satellite/lunar/GNSS laser ranging/altimetry and cube/microsat Characterization Facilities Laboratory) has been the development, design, manufacturing, and qualification for space flight of an 'innovative' LRA (Laser Retroreflector Array) of CCRs (Cube Corner Retroreflectors) especially intended for laser ranging operations in the Earth-Moon system; in fact, the innovation is the use of a single, large retroreflector for lunar laser ranging from MLRO (Matera Laser Ranging Observatory) for precision tests of general relativity. The SCF_Lab Team, with support by ASI, is reaching the aforementioned goal, and is going to fly to the Moon its MoonLIGHT (Moon Laser Instrumentation for General relativity High-accuracy Tests), after about 50 years from the last deployment of devices of the same kind on our natural satellite [1, 2]. MoonLIGHT is a LRA, which makes use of a single CCR; it has got a unique and original design, aimed at compensating for the detrimental effect of lunar librations on the precision of lunar laser ranging 'shots' and their respective observational products, the so-called normal points [3, 4]. This paper describes INFN's unprecedented payload, its target use, and its space qualification process (which is currently ongoing) for TeamIndus and Moon Express 1 missions to the Moon, which are both scheduled for 2019. As a figure of merit, MoonLIGHT's thermal and optical behaviours will be compared to those of the one of the very few remaining Lunokhod CCRs, cut and polished in France about 50 years ago.

## 1. Introduction

Since 1969, LLR (Lunar Laser Ranging) to the Apollo (and Lunokhod) CCRs has provided almost all significant tests of GR (General Relativity). However, the Apollo LRA geometry contributed only a negligible fraction of the laser ranging error budget back in the 1970s. Today, due to the increase of the performances of laser ranging systems, and because of lunar librations, the lunar laser ranging error budget is basically CCR dominated.

In fact, the major issue affecting Apollo LRAs is the lunar longitudinal librations, resulting from the eccentricity of the lunar orbit around the Earth: due to this natural phenomenon, one corner of the Apollo arrays is farther away from Earth than the opposite corner by several centimetres, thus broadening the pulse retroreflected to Earth. Consequently, the precision of the experimental tests of gravitational theories is limited.

INFN-UMD's MoonLIGHT instrument is a new-generation LLR payload made of a single, large CCR unaffected by librations (Figure 1 and Figure 2). Thanks to this new design, MoonLIGHT can increase the precision of high-accuracy tests of GR up to a factor 100, compared to the Apollo (and Lunokhod) CCRs.

Whilst Apollo CCRs suffer from librations, Lunokhod LRAs have widely experienced extreme variations of the retroreflected OCS (Optical Cross Section), due to a thermally unfortunate mounting system (Figure 3).

Thanks to the present paper, and for the first time to our knowledge, part of a contemporary measurement campaign on one of the last surviving Lunokhod CCRs on Earth is presented. In fact, we have quantitatively estimated the optical performance variations of the CCR caused by a change in its temperature.

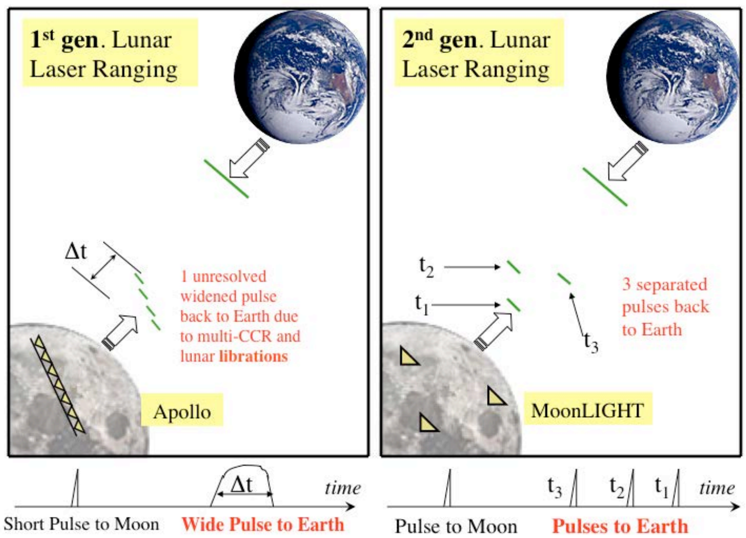


Figure 1 - Comparison between 1st and 2nd generation lunar LRAs. The librations affect the arrays (left panel), whereas single CCRs are unaffected (right panel). Reflected pulses are thus shortened (right panel).

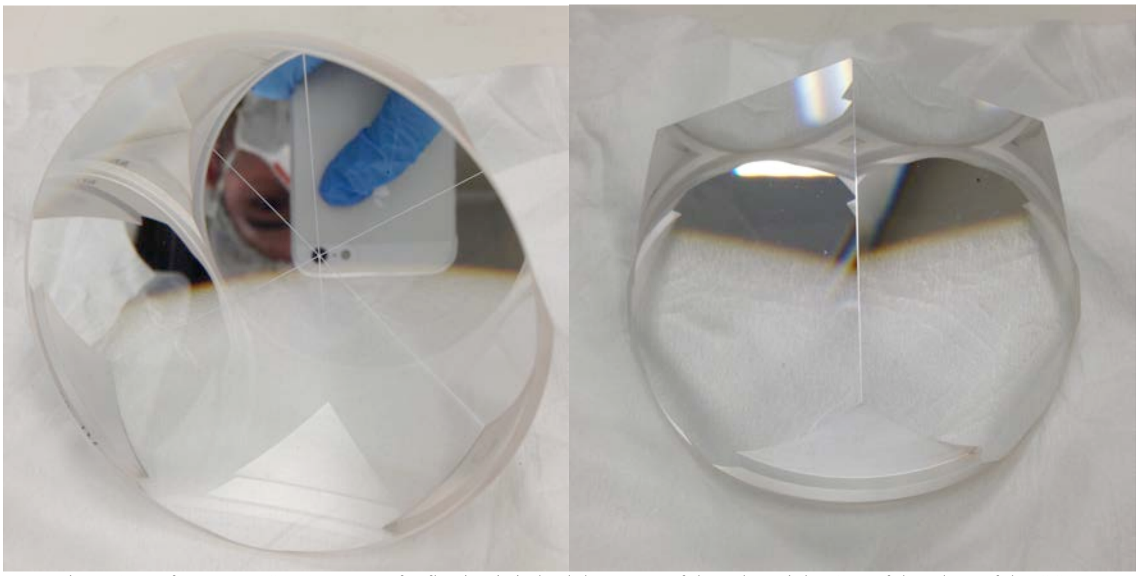
Figure 2 - Left: MoonLIGHT's centre of reflection is indeed the vertex of the cube. Right: One of the edges of the CCR.


Figure 3 - Lunokhod CCR in its storage enclosure (front view).

## 2. Materials and Methods

### 2.1 Materials

The FFDP (Far Field Diffraction Pattern) diagnostics was performed on the Lunokhod CCR, following the usual SCF_Lab-developed procedure [5]. Even after tens of years of ‘wrong’ storage (Figure 3), the CCR showed a nominal retroreflecting power (Figure 4) at $T_{initial}$ = 21.8 ˚C.

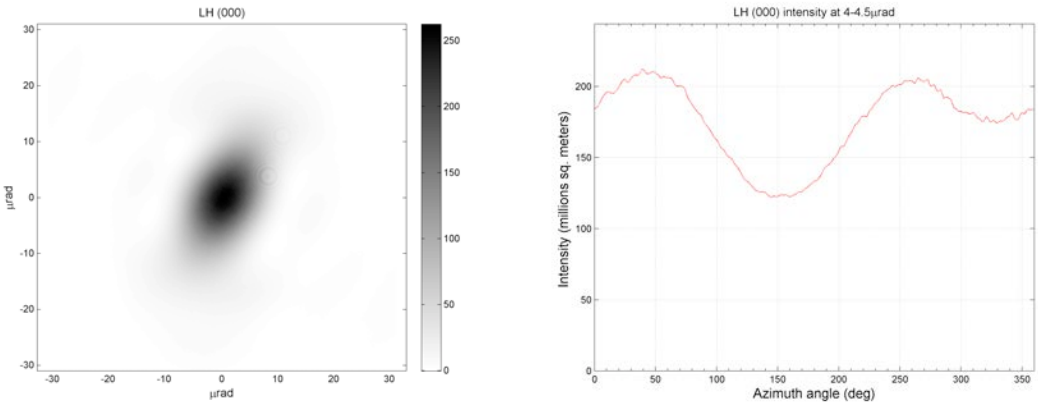


Figure 4 - Left: Lunokhod’s FFDP. Right: Lunokhod’s intensity at the operational VA (Velocity Aberration).

We took advantage of the endowment of the SCF_Lab, namely, the optical bench, a DC power supply, and a thermocouple thermometer.

### 2.2 Methods

DC power supply heated up the CCR pumping 10 W for 20 min through heater tape resistor. After 20 min, $T_{MAX}$ = 80.0 ˚C; power supply was switched off, and first cooling FFDP was acquired. Thereafter, 4 more FFDPs were acquired. At the end of the test, temperature of the CCR was back at $T_{initial}$ = 21.8 ˚C (Figure 5).

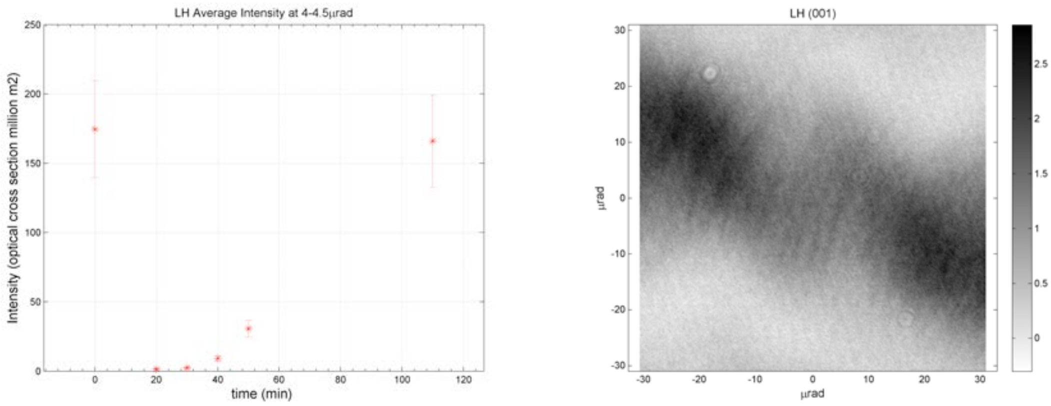


Figure 5 - Left: The evolution of the average intensity at the operational VA is followed during the test. Right: Lunokhod's FFDP when the storage enclosure (Figure 3) is a $T_{MAX}$ = 80.0 °C. The FFDP is disrupted by the increased temperature, and the extreme thermal gradients within the body of the CCR itself. A 'disastrous' factor 200 worsening of optical performance of the Lunokhod CCR appears w.r.t. Figure 4.

## 3. Results and Discussion

INFN-UMD's 'large' single-CCR space-qualified retroreflector payload is ready for hot and cold lunar environments, awaiting for installation on board next lunar landers, as per continuous interactions with all the relevant stakeholders (Figure 6).

Comparison with Lunokhod coated cube, which has approximately the same dimensions and weight of MoonLIGHT, and whose measured optical performances worsen spanning over two orders of magnitude as the temperature increases, further showed the goodness of selecting MoonLIGHT / NGLR (Next-Generation Lunar Retroreflector) uncoated cubes for next-generation lunar laser ranging.

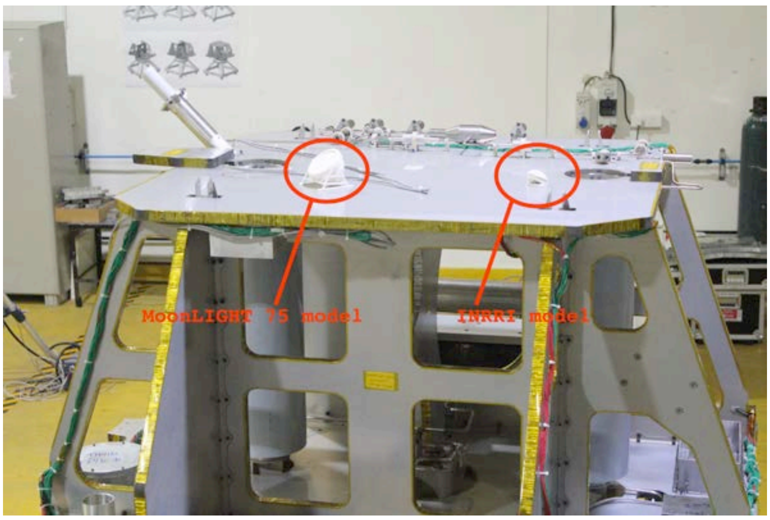


Figure 6 - Clearance assessment at TeamIndus integration site on the actual qualification model of the lander. Mounting schemes are purely indicative, and may not resemble the actual flight configurations.

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