FIRST LASER RANGING RESULTS FROM THE LUNAR RECONNAISSANCE ORBITER TO THE MINIATURE LASER RETROREFLECTOR ARRAY ON CHANDRAYAAN-3.

X. Sun[1], D. R. Cremons[1], D. E. Smith[2], G. A. Neumann[1], D. Mao[3], M. K. Barker[1], E. Mazarico[1], G. Cascioli[4], S. Bertone[5], H. Tomio[2], J. W. Head III[6], M. S. Robinson[7], O. Aharonson[8], M. T. Zuber[2], N. E. Petro[1], P. Veeramuthuvel[9], G. Senthil Kumar[9], and S. Megala[9] [1]NASA Goddard Space Flight Center, Code 698, Greenbelt, MD 20771, USA, xiaoli.sun-1@nasa.gov; [2]Massachusetts Institute of Technology, Cambridge, MA, USA; [3]Hexagon US Federal, Chantilly, VA, USA; [4]University of Maryland, Baltimore County, MD, USA; [5]University of Maryland, College Park, MD, USA; [7]Brown University, Providence, RI, USA; [7]Arizona State University, Tempe, AZ, USA; [8]Weizmann Institute of Science, Rehovot, Israel; [9]Indian Space Research Organisation, Bangalore, India.

Introduction: A laser range measurement from the Lunar Reconnaissance Orbiter (LRO) to the Chandrayaan-3 lunar lander has been accomplished. The Lunar Orbiter Laser Altimeter (LOLA) on LRO has successfully detected the signal reflected by the miniature laser retroreflector array (LRA) on Chandrayaan-3 of the Indian Space Research Organisation (ISRO).

LRA on Chandrayaan-3: Laser retroreflectors are commonly used on Earth-orbiting spacecraft for ground based Satellite Laser Ranging. NASA has recently used miniature laser retroreflector arrays, here referred to as LRA, on landers and rovers on the lunar surface as fiducial markers at landing sites [1-2]. Each LRA consists of eight corner-cube retroreflectors on a hemispherical support structure which is 5.1 cm diameter at the base and 1.7 cm high. Each retroreflector has three mirror surfaces perpendicular to each other. It reflects laser light like a mirror which is always aimed back at the incoming light source. The distribution of retroreflectors in the array enables laser ranging from any direction ±60° from its optical axis. The reflected laser light is orders of magnitude stronger than from the lunar surface and other objects [3]. Thus, they can be uniquely detected by orbiting or landing spacecraft equipped with lidars. The LRAs are passive optical instruments and will remain functional on lunar surface for many decades, similar to the Laser Ranging Retro-Reflectors (LRRR) deployed by the Apollo astronauts.

NASA provided the LRA for Chandrayaan-3 under an international agreement. Figure 1 shows a photograph of the Chandrayaan-3 lander with the LRA.

Chandrayaan-3 successfully landed by the Manzinus crater close to the lunar south pole on August 23, 2023. It completed all its planned surface activities in September 2023 and can be safely ranged by LOLA since then.

LOLA and LRA Targeting: LOLA is one of the six operating science instruments on LRO and the only lidar in lunar orbit at present. LOLA has topographically mapped the Moon since LRO launch in June 2009 [4-5]. It has five laser beams and five independent receiver channels. Each beam forms a spot which is about 10 m wide on the surface from a range of 100 km.

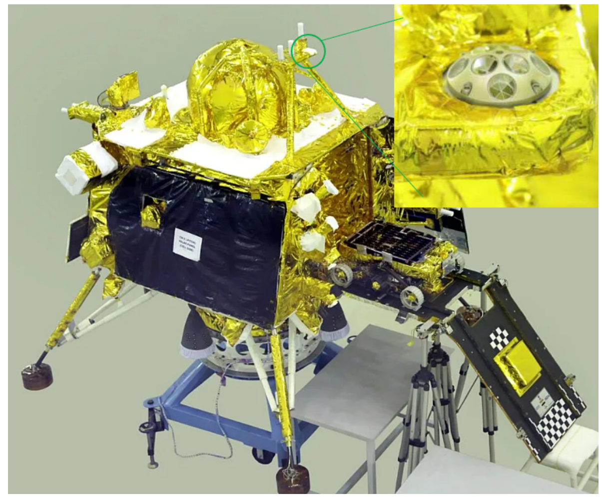

Figure 1. Chandrayaan-3 lander and the LRA. The size of the LRA is 5.1-cm diameter at the base and 1.7-cm heigh. It weighs 20±1 g.

It is technologically challenging for LOLA to detect returns from the LRA. The LOLA beam pointing is controlled by the LRO spacecraft. The spacecraft has to roll to point the LOLA boresight to the expected LRA position. The pointing has to be within 0.01° of the target in real time for one of the five laser beams to hit the LRA. There is only one laser pulse which can hit the LRA from each pass. Due to the 28-Hz laser pulse rate and gaps between the five laser footprints, LOLA laser beams could miss the LRA on any single pass. Therefore, it requires multiple passes for the LOLA laser to hit an LRA. The slews must also be planned around other spacecraft activities.

Furthermore, the LOLA lasers and the detectors have degraded after 14 years in lunar orbit. The laser beam has broadened spatially with side lobes [6], which reduces the intensity of the laser light and the strength of the return signals. Meanwhuile, the detector threshold has to be set relatively high to reduce the chances of false detection due to intrinsic detector noise and solar background noise.

Results: In preparation for ranging to Chandrayaan-3, we first conducted a series of laser ranging attempts to the much larger Apollo LRRR which were already on the lunar surface [7]. We successfully ranged to the two LRRRs from the Apollo 11 and Apollo 14 missions multiple times. These larger retroreflector arrays produced orders of magnitude stronger return signals from known geolocations which helped us to verify the spacecraft target pointing capability and quality of geolocations of laser footprints after orbit reconstruction [7]. Ranging to these larger LRRRs also helped us to optimize LOLA instrument settings for LRA measurements. The results showed that the spacecraft is capable of precisely pointing the LOLA laser beams onto a given target point on the lunar surface. The spacecraft timing accuracy is sufficient to determine which laser pulse hits the retroreflectors. With our LRO orbit reconstruction, we can geolocate the LRAs to within a few tens of meters from ~100 km orbital altitude. We continued to range to these large Apollo LRRRs in between ranging to the LRA on Chandrayaan-3 as a near-concurrent verification of spacecraft targeting accuracy and LOLA receiver operation.

We have made eight attempts of ranging to the LRA on Chandrayaan-3 from September 2023 to the present. We obtained one unambiguous detection of the LRA during the LRO targetting slew on December 12, 2023, 20:00 UTC. The observation was during lunar nighttime at the Chandrayaan-3 landing site. LRO was ascending to the east of Chandrayaan-3 and LOLA was pointed 20° from nadir direction. The laser beam incidence angle was 20.04° with respect to the LRA optical axis, assuming that the lander was perfectly upright.

The range measured from LRO to the LRA was 94,503.40 m. The range uncertainty was expected to be 0.20 m or better based on the LOLA performance at similar received signal level. The received laser pulse energy was lower than 0.13 fJ/pulse based on the LOLA pulse energy monitor but higher than the 0.08 fJ/pulse detection threshold. The LRA location was 69.3724° S latitude and 32.3207° E longitude, based on the initial orbit solution by the LRO Flight Dynamics team. The LRA location from this LOLA detection is within 0.001° of the Chandrayaan-3 location released by ISRO https://www.isro.gov.in/chandrayaan3_gallery.html. We are currently updating the LRO orbit solution, which is expected to give a more accurate and precise LRA location.

The LOLA detector thresholds were set to twice the nominal values for altimetry measurements. Based on the on-board noise monitors, the rate of false detections due to noise was about 0.17 per second at this threshold setting around the time of this measurement. The LOLA receiver range window over which an LRA return could be detected was 133 μs for the laser pulse. Therefore, the probability of a false detection for the LRA should be less than 2.3×10^{-5}. Considering the close agreement between the geolocations from LOLA and ISRO, we are certain that the signal return was from the LRA on Chandrayaan-3.

We plan to continue ranging to the Chandrayaan-3 LRA at every opportunity in the coming months, at different incidence angles and spacecraft altitudes. The results will help us to obtain a more precise and accurate solution of the LRA position in the lunar geodetic frame.

Conclusion: We successfully ranged from LOLA to the LRA on Chandrayaan-3 lander on lunar surface. The measurement result verifies the design and deployment of the LRA, validates the concept of using miniature LRAs as fiducial points on planetary surfaces, and paves the way for future lidars to range to a network of LRAs on the lunar surface. Lase ranging to LRAs distributed spatially on the lunar surface will provide measurements to improved understanding of the Moon's dynamics and internal structure.

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