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Probing General Relativity and New Physics with Lunar Laser Ranging

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Over the past 40 years, Lunar Laser Ranging (LLR) to the Apollo Cube Corner Retroreflector (CCR) Arrays have supplied almost all the significant tests of General Relativity. LLR can evaluate the PPN (Post Newtonian Parameters), addressing this way both the possible changes in the gravitational constant and the self-energy properties of the gravitational field. In addition, the LLR has provided significant information on the composition and origin of the moon. This is the only Apollo experiment that is still in operation. Initially the Apollo LLR Arrays contributed a negligible fraction of the ranging error budget. Over the decades, the ranging capabilities of the ground stations have improved by more than two orders of magnitude. Now, because of the lunar librations, the existing Apollo retroreflector arrays contribute a significant fraction of the limiting errors in the range measurements.

We built a new experimental apparatus (the "Satellite/lunar laser ranging Characterization Facility", SCF) and created a new test procedure (the SCF-Test) to characterize and model the detailed thermal behavior and the optical performance of cube corner laser retroreflectors in space for industrial and scientific applications. Our key experimental innovation is the concurrent measurement and modeling of the optical Far Field Diffraction Pattern (FFDP) and the temperature distribution of the SLR retroreflector payload under thermal conditions produced with a close-match solar simulator. The apparatus includes infrared cameras for non-invasive thermometry, thermal control and real-time movement of the payload to experimentally simulate satellite orientation on orbit with respect to both solar illumination and laser interrogation beams. These unique capabilities provide experimental validation of the space segment for SLR and Lunar Laser Ranging (LLR).The primary goal of these innovative tools is to provide critical design and diagnostic capabilities for Satellites Laser Ranging (SLR) to Galileo and other GNSS (Global Navigation Satellite System) constellations. Implementation of new retroreflector designs being studied will help to improve GNSS orbits, which will then increase the accuracy, stability, and distribution of the International Terrestrial Reference Frame (ITRF), to provide better definition of the geocenter (origin) and the scale (length unit).

The SCF is also actively used to develop, validate and optimize 2nd generation LLR arrays for precision gravity and lunar science measurements to be performed with robotic missions of the International Lunar Network in which NASA and ASI participate (ILN). The capability will allow us to optimize the design of GNSS laser retroreflector payloads to maximize ranging efficiency, to improve signal-to-noise conditions in daylight and to provide pre-launch validation of retroreflector performance under laboratory-simulated space conditions.

For the MAGIA lunar orbiter Phase A study funded by ASI, we studied fundamental physics and absolute positioning metrology experiments, to improve test of the gravitational redshift in the Earth–Moon system predicted by General Relativity and a precursor test of our 2nd generation LLR payload, developed by the Univ. of Maryland (PI) and INFN-LNF (Co-PI).

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