A Lunar Laser Ranging RetroReflector Array for the 21st Century.

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Introduction: The Apollo Lunar Laser Ranging Arrays (LLRRAs) [1], [2] have been responsible for a very large body of science, ranging from Geophysics and Lunar Physics to General Relativity [3]. However, after being in successful operation for 40 years, the ground stations have improved in ranging accuracy by a factor of more than 100. Therefore, the LLRRAs now limit the accuracy of the overall measurement. A new approach will be presented that improves the accuracy that may be obtained from the Lunar Array by a factor of 100 to 1000. Deployment of this Lunar Laser Ranging Retroreflector Array for the 21st Centaury (LLRRA-21) will support improved measurements today and will support the improvements in ground station arranging capability for the next forty years. Our approach with the LLRRA-21 has a limiting accuracy for the lunar portion of the system which is between 0.03 and 0.001 mm. The basic physics of the approach will be presented as well as the challenges, the thermal modeling and optical modeling and thermal vacuum testing to support the approach as well as the proposed method of deployment.

Background: In the late 1960's and early 1970's, we deployed there retroreflector arrays on the lunar surface. These consisted of a flat array of 1.5" cube corner reflectors, 100 for Apollo 11 and 17 and 300 for Apollo 15. These arrays were pointed back at the earth. The major issues at that time were ground station capabilities. Initial accuracies were at the 15 cm level. Over the decades the station hardware, the software processing and the knowledge of the earth's atmosphere have improved to the level of a few mm with the APOLLO station at Apache Point. We have now reached the point that the lunar installation is the major source of uncertainty. This is due to the lunar librations tilting the arrays. When tilted w.r.t. the direction to the earth, a very short laser pulse is spread. As a result a very short laser pulse cannot be used to obtain an accuracy commensurate with the laser pulse length. Thus, after forty years, the ground stations have improved by a factor of about 100 and our 1969 system has reached the limit of accuracy. The objective of the presentation is to describe a new version of the retroreflector array that will provide a lunar emplacement with a potential accuracy that is many orders of magnitude better than the existing arrays. This will both provide short term gains and will provide a system that will allow the future improvement of the ground stations (shorter lasers, better timing), better knowledge of the atmosphere and better knowledge of the variations in the earth tides and ocean loading. There are also future concepts that would bypass these problems.

Scientific Rational:

In discussing the scientific rational, we will address the future accuracy, that is, under the assumption that the ground station component of the accuracy will improve the manner of the past decades.

Relativistic Effects: Time Delay: The curvature of space is affected by the sun earth and moon. The accuracy of LLRRA-21 should for the first time allow the measurement of the effect of the moon. Nordtveldt Effect: LLRRA-21 should improve this measure of the failure of the equivalence principle by several orders of magnitude. [4] Lorenz violations [5]: LLRRA-21 should improve this by 2 or 3 orders of magnitude

Lunar Effects: Lunar Core: The size and nature of the lunar core will be evaluated with a new accuracy. It may also allow the separation of effect of the core and effects of higher order terms in the gravity field. Lunar Tides [6]: The earth raises tides of a few centimeters. This results in a determination of the lunar Love number with a 10% accuracy [6]. LLRRA-21 should allow a greatly improved evaluation of these quantits.LLRRA-21 should be able to detect free librations induced by the impact of medium sized meteorites. This can provide a probabilistic assessment of the danger from larger meteorites.

Earth Effects: A variety of effects on the earth that have been addressed with LLRRA can be greatly improved by the operation of LLRRA-21. Although small, the effects of post-glacial rebound may be detectable [7] In particular, the effects of ocean loading and understanding the variation in the ocean loading will be an important project.

Technical Description of the Approach: The problem wit the current LLRRA is basically that one cannot time the return obtained from each CCR in the array. This is because they are separated by centimeters so the return pulses are separated by picoseconds. We could correct this by removing the CCRs from the current mounting and spreading them out with sufficient separation that the ground station could distinguish each return. The problem with this approach is two-fold. First the astronaut would spend too much time deploying one hundred packages and, second, the return from each 38 mm CCR would be too weak. The LLRRA 21 approaches this by enlarging the individual CCRs to an input diameter of 100 mm and to use only five arrays. To reduce the effect of the diurnal expansion of the regolith, each CCR will be anchored to the regolith about one meter below the surface, where the temperature variation is negligible. To further reduce this effect, a thermal blanket of MLI will be spread about the each CCR. Details of the emplacements and the link budget will be presented.

Concept Evaluation: In this section, we consider and address the primary challenges in the project. We describe the challenge, discuss the simulations and then describe the testing that is planned.

Challenges: The two most significant challenges are the thermal performance of the CCR and the stability of the emplacement on the lunar surface.

From a thermal point of view, the CCR must retain sufficient optical quality so that the retro-reflected beam will provide the concentration of light back at the ground station. The CCR must retain this performance in spite of the effects of the solar radiation that is absorbed within the CCR and then radiating to space. Other heat sources are the conduction from the mounting tabs and the radiation from the mounting structure that enters the back face. All of these distort the optical performance as the heat exits the front face.

Concerning the stability of the emplacement, during solar day, the regolith is hated and then expands. Without attention, the CCR would rise and fall a good part of a millimeter from lunar night to lunar day due the thermal expansion of the regolith.

Thermal and Optical Simulation: The thermal behavior of the CCR and its mounting under solar illumination has been simulated using Thermal Desktop of C&R. This indicates that by careful engineering the thermal issues can be addressed in a manner that preserves the required optical performance. These results will be presented.

In addition, the behavior of the lunar environment has been simulated. This allows the consideration of both our solution to the motion of the regolith and the impact during the lunar cycle of the environment on the CCR package.

Thermal Vacuum Testing: The thermal issues for the CCR have been addressed in simulation. However, to further validate the program, we have fabricated a 100 mm CCR of fused silica, with full flight qualifications. This will be tested in the Space Climatic Facility, the thermal vacuum chamber developed at the Laboratories Nuclear Fisca / INFN at Frascati Italy [7]. This will subject the CCR and it's mounting to full solar illumination and then valuate the optical performance with an interferometer and the thermal performance with an infrared camera.

Conclusion: The Apollo Lunar Laser Ranging Retroreflector Arrays have provided benchmarks on the lunar surface for the past forty years. Implantation of our Lunar Laser Ranging Retroreflector Array for the 21st Century on the next Lunar Landing by NASA should provide benchmark to support ground station and analysis improvements for the next forty years. Thus we may expect a continuing flow of scientific results in General Relativity, Lunar Physics, Earth Physics, with discoveries and improvements comparable with the discoveries provided by the LLRRAs.

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