The University of Maryland led the team that provided NASA with Lunar Laser Ranging Retroreflector Arrays (LLRRAs) for the Apollo Missions. In the past 40 years, Lunar Laser Ranging have proven to be the definitive tests of General Relativity and the understanding of the interior structure of the moon. However, over the past four decades, ground station technology has improved by a factor of over 200, such that the Apollo lunar arrays are now a significant contributor to the ranging errors.

Currently, the University of Maryland leads a program to design and validate LLRRAs that are composed of single 100 mm solid CCRs (a.k.a. LLRRA-21) to be carried to the moon. These are expected to improve the accuracy that will be supported by the lunar emplacement by at least two orders of magnitude and should support ranging down to the tens of microns level.

This effort is a collaboration of the University of Maryland with the Frascati National Laboratory (LNF) of the Institute for Nuclear Physics (INFN) of Italy. This joint effort is addressing the design, analysis, thermal and optical simulation, fabrication and thermal vacuum testing of our concept for the lunar array.

Current LLRRA-21 Design concept

The figure on the left illustrates the current design concept. The thermal shields, shown in gold, isolate the CCR from the “pocket” or “housing.” This reduces the radiative transfer between the pocket and the CCR. The inner face of the shield is silver coated and shaped like the CCR. This reflects most of the solar radiation that passes through the CCR and enters the housing. On the right is the image of the package that has been used in the thermal vacuum chamber tests. Attached to the front of the housing is the Dust/Sun Shade that is discussed in more detail in Poster 302. This improves the thermal behavior to maintain the signal level and protect the CCR from lofted dust and secondary ejecta.

Current Package Parameters

- CCR and Housing Weight: < 1.5 kg
- Deployment Mechanism Weight: 1 kg
- Power: 0 watts
- Communication Requirement: > 40 years
- Lifetime: > 40 years
- TRL: 6.5

Current Signal Loss Background

The Apollo Lunar Laser Ranging Station has determined that the Apollo arrays have a greatly reduced return signal. This is a factor of ten for a full lunation and a further factor of ten for several thousand years. Thus, we can say that the direct impact of the micrometeorites is not the source of the Apollo degradation and for LLRRA-21 with a shielding factor of about 200, that this will definitely not be a limiting factor for the lifetime.

There are three candidates for this effect:

1. Damage to the Front Face of the CCR due to Primary Impacts by Micrometeorites
2. Secondary Ejecta Landing on CCR due to Micrometeorite Impacts in Regolith
3. Electrically Charged Dust that has been “Lofted” by Electric Fields

1) is Addressed in Poster 430, 2) and/or 3) Currently Seems to Be the Best Candidates

LLRRA-21 Science Objectives

Lunar Science

Without Lunar Laser Ranging (LLR) we would not know of the existence, size nor shape of the liquid core. Thus much of our knowledge of the interior of the moon is the product of the forty years of Lunar Laser Ranging to the Apollo arrays. Thus we seek to further parameterize the liquid core, search for an inner solid core, obtain better knowledge of the Love numbers and address other effects related to the librations and the Q of the lunar motion.

General Relativity

Most of the most accurate tests of GR are currently derived from LLR to the Apollo arrays. We expect to improve the current accuracy of these tests by up to a factor of 100. This will address the validity of General Relativity at a new level of accuracy, especially as one confronts the possible temporal and spatial variation of G.

Issues for Micrometeorite Impact Hypothesis

To Address the Dust Impact Hypothesis, We must Consider:

1) Effect of the Micrometeorite Impacts on the Signal Level
   a. Effect of an Impact on the Front Face of the CCR
   b. Energy of Micrometeorite Required for Damage
2) Number of Micrometeorites with above Damage Level
3) For the LLRRA-21 Design
   a. Shielding Factor
   b. Resultant Expected Lifetime

Effect of Micrometeorite Impacts on SiO2

In order to determine the effect of micrometeorites impacting the fused silica glass of the CCR, we need to be able to impact the CCR with dust (micrometeorites) which have velocities of kilometers/second. In order to accomplish this, we have collaborated with the CCLDAS group at the University of Colorado. The CCLDAS “Dust Accelerator” which accomplishes these requirements has been developed and recently brought on-line. A schematic of the Dust Accelerator which achieves this difficult feat is shown in the figure below.

Schematic of Dust Accelerator

With the 200 mm Dust/Sun Shade and assuming an isotropic angular distribution of the micrometeorites we would not get the signal loss seen on the Apollo arrays for several thousand years. Thus we can say that the direct impact of the micrometeorites is not the source of the Apollo degradation and for LLRRA-21 with a shielding factor of about 200, that this will definitely not be a limiting factor for the lifetime.

With respect to the dust effect candidates 2) and/or 3), the shielding of the CCR by the Dust/Sun Shadre assures the reduction this effect by more than a factor of 100.

Summary and Conclusions

With the 200 mm Dust/Sun Shade and assuming an isotropic angular distribution of the micrometeorites we would not get the signal loss seen on the Apollo arrays for several thousand years. Thus we can say that the direct impact of the micrometeorites is not the source of the Apollo degradation and for LLRRA-21 with a shielding factor of about 200, that this will definitely not be a limiting factor for the lifetime.

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SEM Images of Damage

A sampling of SEM images showing effect of impacts. The dimensions are typically 3 to 5 microns for the full diameters.

Energy Requirement for Damage

Most of the thousands of impacts produced no damage. So in order to define the energy required to produce damage, we address the measurement of mass and velocity obtained by the detectors on the beam path of the Dust Accelerator.

Schematic of Dust Accelerator

Various estimates exist concerning the number of micrometeorite impacts per square centimeter that we might expect on the lunar surface. To the right are some measurements of the flux of such very small micrometeorites.

Expected Frequency of Impacts

Various estimates exist concerning the number of micrometeorite impacts per square centimeter that we might expect on the lunar surface. To the right are some measurements of the flux of such very small micrometeorites.