

Early Ranging Results to NGLR-1 and Validation of the NGLR Project Objectives

On March 2nd, 2025, the Blue Ghost lander of the Firefly Aerospace successfully landed on the Moon and successfully deployed NGLR-1¹. On March 3rd the Lunar Laser Ranging Observatory (LLRO) in Grasse, France obtained more than 1,000 individual range measurements to NGLR-1*. On March 4th, LLRO in Wettzell, Germany, and the Grasse LLRO obtained more range measurements. On 20 March, the LLRO at Apache Point, US obtained additional range measurements⁵. Similar range measurements are continuously being made and expect to be accomplished over the next 50 years.

Thus, NGLR-1 has demonstrated a Technology Readiness Level (TRL) of 9.

Objectives of the Next Generation Lunar Retroreflector Project

Greatly Reduced Dispersion Demonstrated

The accuracy of a given set of range measurements has an inverse linear dependence on the dispersion or scattering in the values of the residuals. The measurements performed during the first month after deployment by the Wettzell, Germany and Apache Point, USA, LLROs demonstrated an improvement in the dispersion due to the NGLR-1 range measurements of a factor of 17 with respect to those of the Apollo 15 retroreflector array. The Wettzell LLRO demonstrated a normal point precision of 0.79 and 1.14 millimeters. Thus NGLR-1 will support further improved precision of the range measurements as the LLROs increase their capabilities in the future.

Target Cross-Section Determination

The objective of our NGLR project has been to achieve a Cross-Section (C-S) approximately equal to the C-S of the Apollo 11 retroreflector array.

The preliminary range measurement data from the LLRO in Grasse, France has been analyzed to determine the C-S of NGLR-1 as compared to the C-S of the Apollo 11 retroreflector array (A11). The **C-S of NGLR-1 is 100%+/- 18%⁺** of the C-S of A11 when calibrated with the C-S of A15/3. Further, the **C-S of NGLR-1 is 65%+/- 17%** of the C-S of A11 when calibrated with the average of the C-Ss of A11&A14.

These calibrations of the C-S are based on **1,239 Individual Range Measurements (IRMs)** to NGLR-1 combined into 19 Normal Point Interval (NPIs) on 3 March and on **2,146 IRMs** to NGLR-1 on 4 March combined into 36 NPIs.

The LLROs are currently transmitting linear polarization with an undetermined orientation angle rather than the design polarization of the NGLR-1. Assuming this polarization angle is random as the hour angle changes, a theoretical correction would result in estimates of the cross-section of 180%+/- 32% % of the C-S of A11 when calibrated with the C-S of A15/3. Further, the C-S of NGLR-1 is 117%+/- 31% of the C-S of A11 when calibrated with the average of the C-Ss of A11&A14.

This is the start of the kind of time series that has been analyzed for the Apollo retroreflector arrays and that have provided the Apollo science described above. With the deployment of three NGLRs, this will lead to gains in the accuracy of the scientific results by more than order of magnitude¹.

Multi-Decade Lifetime

A very long lifetime of the operation of the NGLRs is crucial to the improvement in the science results to be achieved by the deployment of three NGLRs. The NGLRs must have lifetimes similar to the Apollo retroreflector arrays. To address this requirement, the design decisions for the NGLRs has been based upon the design decisions that were made for the CCRs used in the Apollo retroreflector arrays. The latter have demonstrated successful operation for the past 50 years.

Science Accomplishments Based on LLR

The current retroreflector arrays have produced some of the best science results in lunar physics (i.e., the discovery of the liquid core of the Moon and dissipation in the mantle²), lunar navigation (i.e., the primary tie points for both selenodetic reference frames), astrophysics (i.e., demonstrated negligible change in Big G³) and tests of General Relativity (i.e., provided the best results for the Weak Equivalence Principle, and is the only technique that demonstrates that gravitational energy falls at the same rate as baryonic matter⁴). This has only been possible due to the very long data series based on the continuous LLR to the Apollo Retroreflector Arrays (ARAs) for more than 50 years. The accuracy of these science results depends quadratically or linearly with the length of the data series.

Given the major improvement in the dispersion of the NGLRs compared to the dispersion found in the Apollo Retroreflector Arrays are expected the precision of the science results are expected to improve by a factor of ten or greater, depending upon the capabilities that are developed by the Earth-based Lunar Laser Ranging Observatories (LLROs)⁵.

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References

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* Data has been received from Clement Courde of the French LLRO via Stephen Merkowitz of NASA/GSFC

Data has been received from Johann Eckl of the German LLRO

\$ Data has been received from Nicholas Colmenares of the NASA/GSFC

+ All listing of uncertainties in the cross-section are one sigma uncertainties.