First observation of Apollo Laser Retroreflectors with the Lunar Reconnaissance Orbiter Camera and NASA's Moon Trek software.

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Introduction: The Lunar Laser Ranging (LLR) investigations have provided time high-precision measurements of geodesy, dynamics and distance of the Earth-Moon system, and inferences about lunar interior and gravitational physics. LLR studies are supported by a total of five passive Laser Retroreflectors (LRR) placed on the Moon surface by the past missions Apollo 11 (A11), Apollo 14 (A14), Apollo 15 (A15; Fig. 1) and Luna 17 and Luna 21 [1]. The detection of their positions is decisive to improve the measurement accuracy and the data from alternative instrumentations contributed to their analysis. The Lunar Reconnaissance Orbiter Camera (LROC) has operated by using the Standardized Lunar Coordinate System as reference system and has acquired images of the Moon surface that are data applicable to LLR planning and research. Various LROC images present nominal lighting conditions reflected off an LRR. These specular reflections of light are called solar glints and define measurements of higher precision of the LRR position. The identification of glints visible in LROC images enables researchers to record these measurements. NASA and INFN-LNF (Frascati National Labs) have collaboratively developed an LLR tool to support glint identification. The tool is available by using the Moon Trek which is the web based interactive visualization and analysis portal for lunar science and exploration, provided by the NASA's Solar System Treks Project [2, 3]. This research highlights the first observation of the LRR seen in images acquired by NASA's LROC by the identification of a total of 95 candidate glints of A11, A14, and A15 in LROC data by means of Moon Trek portal.

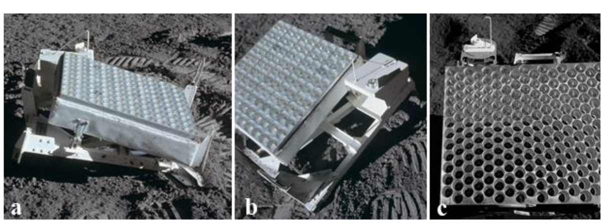

Figure 1: Lunar Retroreflectors arrays. a) Apollo 11, b) Apollo 14; and c) Apollo 15 array as placed on the Moon (NASA credits).

Data and Methods: The LLR tool of Moon Trek allows to investigate the images, to compute geometric calculations, and contributes to the Laser ranging research and the planning of future missions that involve ranging activities, such as future retroreflector deployments. In this work, this tool has been utilized for the glint identification. It is based on SPICE computations and is used to search for nominal conditions to catch a solar glint off of a retroreflector, to search for time intervals in which a reflector can be seen from a ground station on Earth, and to search in Planetary Data System (PDS) database for images with these conditions. The LLR tool allows us to find time intervals when spacecraft positioning is able to catch a solar glint reflected off a retroreflector according to the setting of the angles of LROC image acquisition, i.e., the incidence and phase angles. These angles represent key parameters for the glint detection. The incidence angle is the angle between the light incident on a surface/object (the LRR in this case) and the line perpendicular to the surface/object at the point of incidence, called the normal. The phase angle is the angle between the light incident onto an observed object (the LRR in this case) and the light reflected from the object (caught by the spacecraft). These have been set in the Moon Trek's LLR tool to identify solar glints and the results have been subdivided into two categories according to the incidence and phase angles above or below 30°. This analysis has then been accompanied by the search for LROC images available in PDS that have solar glint off the LRRs. The identification of solar glints reflected off an LRR array in the grayscale images could be confusing for several factors that bias the detection. The lunar surface shows albedo variations due to a wide variety of craters and morphologies that densely occur. The glints off an LRR are well defined features often circular and very white (close to 255 in RGB), similar to noise points that occur in raw images, or white points surrounded by a black boundary. Figure 2 shows an example of glint detection of the A11 LRR.

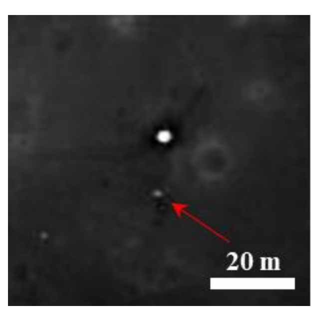

Figure 2: Apollo 11 LRR (pointed out by the red arrow), LROC ID: M109080308R

We identified optimal candidates of LROC images that present solar glints off A11, A14, and A15 retroreflectors. A total of 95 LROC images with candidate glints have been identified out of more than 200 images analyzed over a period of 10 years, from 2009 to 2019.

Additionally, we have investigated the presence of potential ‘false’ glints, on Apollo 12 (A12) and Apollo 16 (A16). The false glints can be due to the mission instrumentation, although they are not equipped with LRRs. We identified a total of 26 LROC images with false glints of A12 and A16, out of more than 300 images investigated. Table 1 shows the candidate glints of A11, A14, and A15 and the A12, A16 false glints identified, above and over the 30° of the incidence and phase angles.

	A11	A14	A15	A12	A16
n. Glints ≤ 30°	17	23	12	12	2
n. Glints > 30°	11	21	11	9	3
Tot	28	44	23	21	5
Tot	95			26	

Table 1: Candidate glints of A11, A14, and A15 and false glints of A12, A16 recognized in the LROC images. the results are subdivided into glints above 30° of incidence and phase angles and glints over 30° incidence and phase angles.

Statistical analysis has been performed to compare the result of the false glints with those of the candidate glints recognized in A11, A14, and A15. The calculation for the statistical confidence is based on the [4, 5] methods, and has enabled us to estimate the probabilistic interval of expected false glints for three arrays with 5%-95% probability. By means of Poisson distribution, the total expected false glints in the A11 + A14 + A15 candidate glints are among 17 – 61 (5% – 95% probability). This basic Poisson analysis uses the raw counts of glints found in the five samples, so far without any attempt to correct for possible, necessary relative normalizations among the sample.

Discussion and Conclusions: This research analysis represents, to our knowledge, the first observation of the LRR of A11, A14, and A15 identified from lunar orbit by LROC. The preliminary Poisson statistical analysis requires further investigation to understand and quantify the relative normalizations of the counts of the samples of candidate and false LRR glints, in order to be able (with the knowledge of these normalizations) to determine the statistical significance of this observation in a way quantitatively accurate.

Acknowledgments: Moon Trek portal is available at https://trek.nasa.gov/moon and is part of the Solar System Trek Project at https://trek.nasa.gov. Results of this work derive from LROC data can be found in the PDS archive (http://wms.lroc.asu.edu/lroc/search).

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