LROC candidate images with solar glints off Lunar Laser Retroreflectors: A dedicated tool of NASA's Moon Trek

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1 Introduction

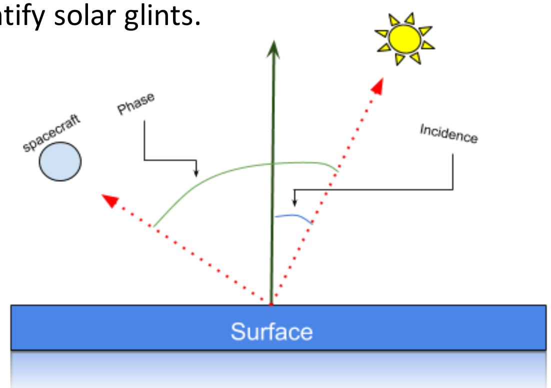
The Lunar Laser Ranging (LLR) investigations have provided high-precision time measurements of geodesy, dynamics and distance of the Earth-Moon system, and inferences about lunar interior and gravitational physics. LLR studies are supported by a total of five passive Laser Retro-Reflectors (LRR) placed on the lunar surface through the past Apollo-11, -14, -15 and Luna-17 and -21 missions [1]. The detection of their positions is crucial to improve the measurement accuracy and the data from alternative instrumentation that contributed to their analysis. The Lunar Reconnaissance Orbiter Camera (LROC) operated by using the Standardized Lunar Coordinate System as reference system, has acquired images of the lunar surface that represent data applicable to LLR planning and research. Several LROC images show nominal lighting conditions and solar glints reflected off an LRR. Their detection plays an important role in LRR analysis. Glint identification has been performed by using the LLR tool that allows us to investigate the image data, and to compute geometric calculations and LLR analyses. The identification of candidate images with solar glints through time allows researchers to record these measurements. NASA and INFN-LNF (National Laboratories of Frascati) have collaboratively developed an LLR tool to support glint identification. The tool can be accessed by using Moon Trek (https://trek.nasa.gov/moon) which is one of the web based interactive visualization and analysis portals provided by the NASA's Solar System Trek (https://trek.nasa.gov) project [2, 3]. The tool facilitates current ranging studies as well as planning future missions that involve ranging activities such as future retroreflector deployments. This analysis is accompanied by the search for LROC images available in Planetary Data System (PDS) that have solar glinted off the LRR. Using Moon Trek, it is possible to identify LROC images with solar glint off the LRR and to recognize optimal LROC candidates. This research allows us to identify good examples of LROC images that show solar glints. The identification of solar glints off LRR will allow us to find previous observations that might be incorrect and to measure the LRR position in the Standardized Lunar Coordinate System of LROC images [4].

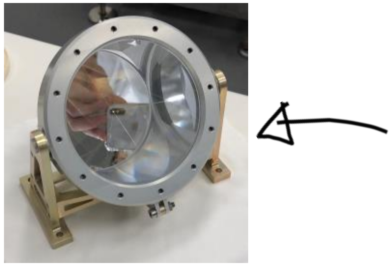
2 Solar Glints

Glints represent specular reflections of light that define higher-precision measurement of LRR position. The tool with SPICE computations is provided to search for nominal conditions to catch a solar glint off a retroreflector, to search for time intervals in which a reflector can be seen from a ground station on Earth, and to search in PDS database for images with these conditions. Moon Trek's LLR tool allows us to find time intervals when spacecraft positioning was able to catch a solar glint reflected off a retroreflector by setting the maximum incidence and phase angles.

3 Incidence and Phase angles

Incidence and phase 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), as shown in the image. These have been set in the Moon Trek's LLR tool to identify solar glints.



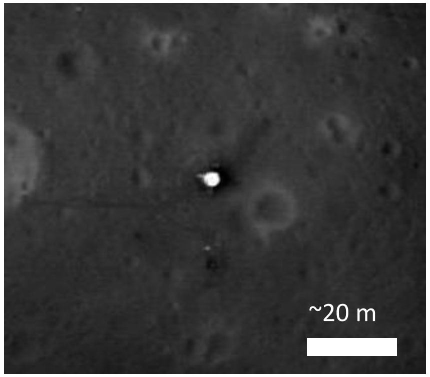


Diameter = 100 mm

Next-gen LRR model (a single, large laser retroreflector as a substitute of retroreflector arrays). [1, 3]

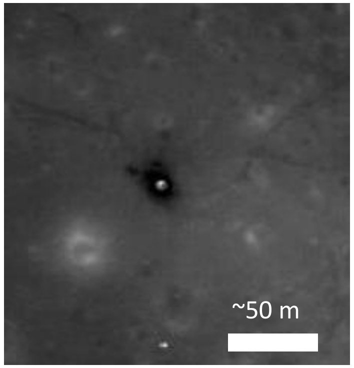
4 Detection

The identification of solar glints reflected off an LRR 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. This is their manifestation when the detection is performed at the local scale. When the scale is larger and the detection is performed at the regional scale, these features occur as white points surrounded by a black boundary (due to their shadow). The following images show examples of this scale-detection difference.



Apollo 11 LRR

LROC ID: M111443315R



Apollo 14 LRR

LROC ID: M1193183104RE

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5 LROC Images

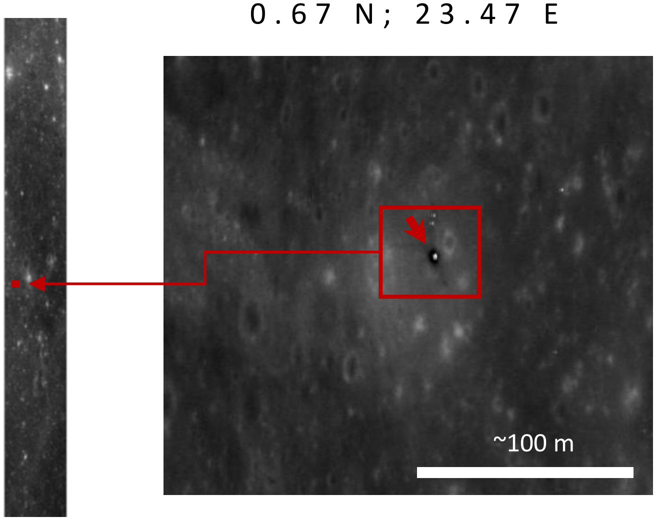
LROC images containing Apollo 12 LRR with glints, max incidence (I) and phase (P) angles < 30°. "Line" and "Sample" represent the coordinates where the LRRs are located in the image.

Mission	LROC	Date	I angle	P angle	Line	Sample
Apollo 11	M1116365580LE	2013 - 02	14,7	26,58	26406	4929
Apollo 11	M1116372683LE	2013 - 02	15,68	7,25	26585	4502
Apollo 11	M1116379787RE	2013 - 02	16,83	12,58	15332 ?	3466
Apollo 11	M1118716779R	2013 -03	13,86	11,66	27340	548
Apollo 11	M1118723881R	2013 - 03	12,89	6,47	27341	296
Apollo 11	M1118730984L	2013 - 03	11,75	28,36	26367	4837 ?
Apollo 11	M1134046721R	2013 – 09	7,26	6,12	7020	2478
Apollo 11	M1149338748R	2014 – 03	13,1	18,55	24326	735
Apollo 11	M1177606647L	2015 - 02	16,21	17,95	15779	1411
Apollo 11	M1192915976L	2015 – 07	18,06	19,78	26367	4837
Apollo 11	M1254093845L	2017 – 07	9.5	11.21	25125	1997
Apollo 11	M109080308R	2009 – 10	2.19	16.24	22906	1909
Apollo 11	M111443315R	2009 – 10	26.24	27.17	24284	830
Apollo 11	M139755141R	2010 - 09	8.77	7.65	2539	4084
Apollo 11	M170409762L	2011 - 09	13.96	15.63	28782	627
Apollo 11	M188071231R	2012 - 04	17.71	15.53	25350	3882
Apollo 11	M188085530R	2012 - 04	15.85	14.68	31547	1680
Apollo 14	M1116642521RE	2013 - 02	13.63	9.72	23995	3915
Apollo 14	M1162576153RE	2014 - 08	16.65	15.52	25439	2106
Apollo 14	M1164931338L	2014 - 09	10.97	12.67	30014	1332
Apollo 14	M1193183104RE	2015 - 08	14.89	13.78	28668	3381
Apollo 14	M1241423438RE	2017 - 02	21.05	20.07	14753	532
Apollo 15	M1149488705LE	2014 - 03	26,96	27,86	46493	2631
Apollo 15	M1147133190RE	2014 - 02	29,19	28,49	26992	2933
Apollo 15	M1118859327RE	2013 - 03	28,23	26,26	28772	421
Apollo 15	M1164788447LE	2014 - 09	28,52	29,12	24880	2193
Apollo 15	M1180101581LE	2015 - 03	27,98	28,89	22756	424
Apollo 15	M1193041966RE	2015 - 08	31,23	27,96	21177	4182
Apollo 15	M1312994367LE	2019 - 05	32,68	28,97	25888	4030
Apollo 15	M109215691RE	2009 - 10	27,56	27,99	23359	1147
Apollo 15	M126901141RE	2010 - 04	37,12	25,03	1358	2764
Apollo 15	M170538271RE	2011 - 09	30,21	29,67	35320	1704
Apollo 15	M185862938RE	2012 - 03	26,71	26,17	26756	3161
Apollo 15	M188200393RE	2012 - 04	31,30	25,97	22905	837

5 LROC Images examples

APOLLO 11

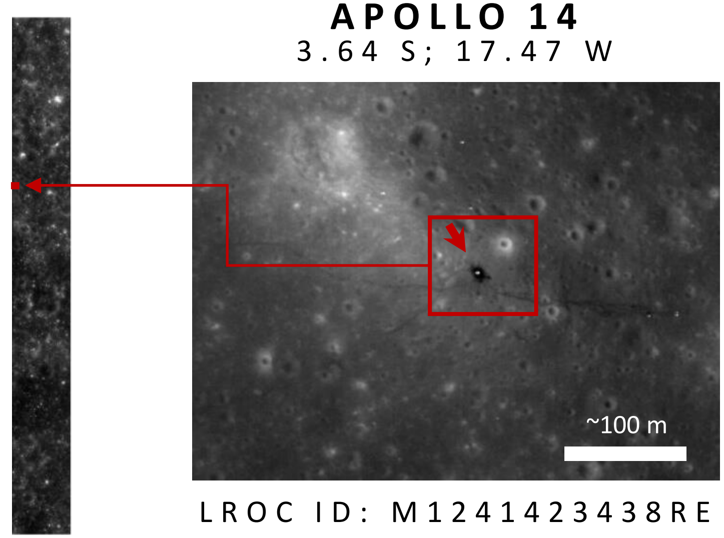
0.67 N; 23.47 E



LROC ID: M188085530R

APOLLO 14

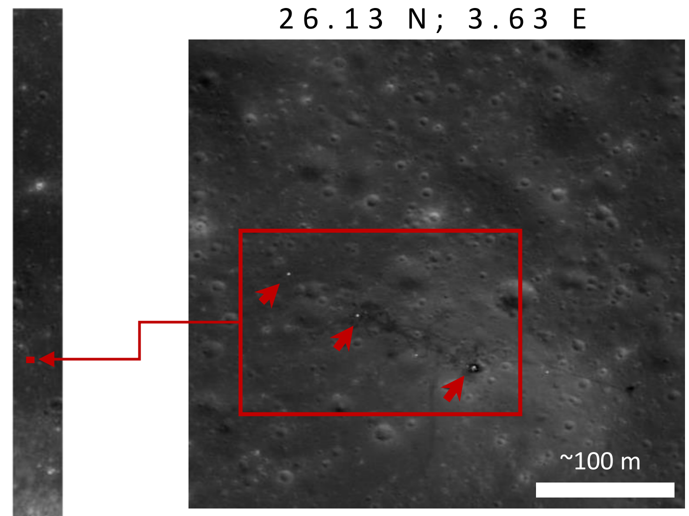
3.64 S; 17.47 W



LROC ID: M1241423438RE

APOLLO 15

26.13 N; 3.63 E



LROC ID: M170538271RE

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6 Conclusions

A total of 34 glints off LRR from Apollo-11, -14, and -15 have been detected.
Apollo-11 shows results with lower incidence and phase angles (I angle=7.26 and P angle= 6.12) and are the best candidates for nominal lighting conditions.
On the other hand, Apollo-14 and Apollo-15 results are shown in LROC images acquired with higher incidence and phase angles (up to 30 for both the angles).

7 Further investigation

Further investigation will be performed to detect potential Apollo-12 and Apollo-16 ‘false’ glints. No LRR was deployed by Apollo-12 and Apollo-16 missions and therefore they should not show glints. However, it is possible that false features similar to solar glints can be detected from Apollo-12 and -16, by cancelling the detection of Apollo-11, -14 and -15 solar glints. In this way, the investigation of LROC images where Apollo-12 and -16 are located has been started. This investigation concerns LROC images acquired in the same period in which glints have been detected in Apollo-11, -14 and -15. Currently, the research is still ongoing and provided negative results, i.e. no ‘false’ glints have been detected in LROC images of Apollo-12 and -16.
Further investigation also concerns the comparison between the obtained measurements and the ephemeris calculations obtained from LLR data in the Standardized Lunar Coordinate System of LROC images.

References

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[4] GSFC, "A Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter and Lunar Datasets,“ Greenbelt, Maryland 2008