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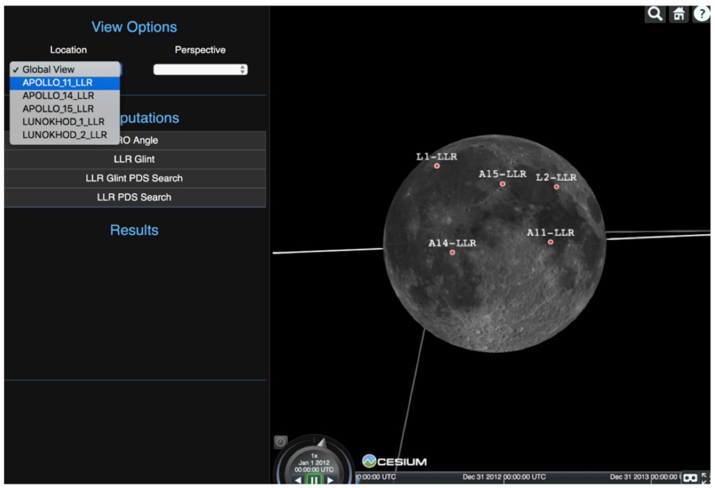
Applications and Planning for Lunar Laser Retroreflector Studies



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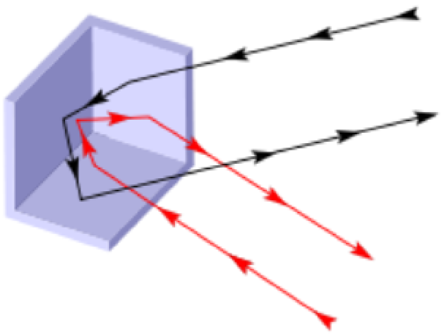
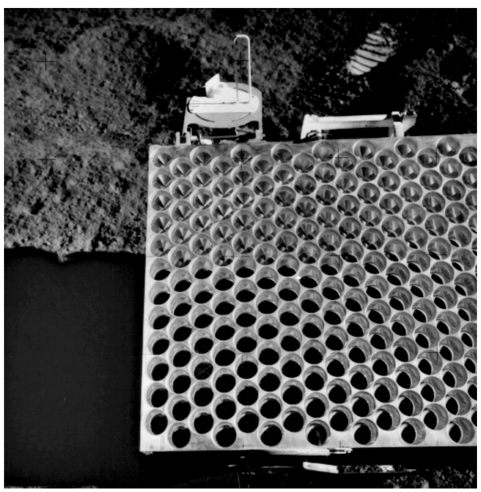
Introduction

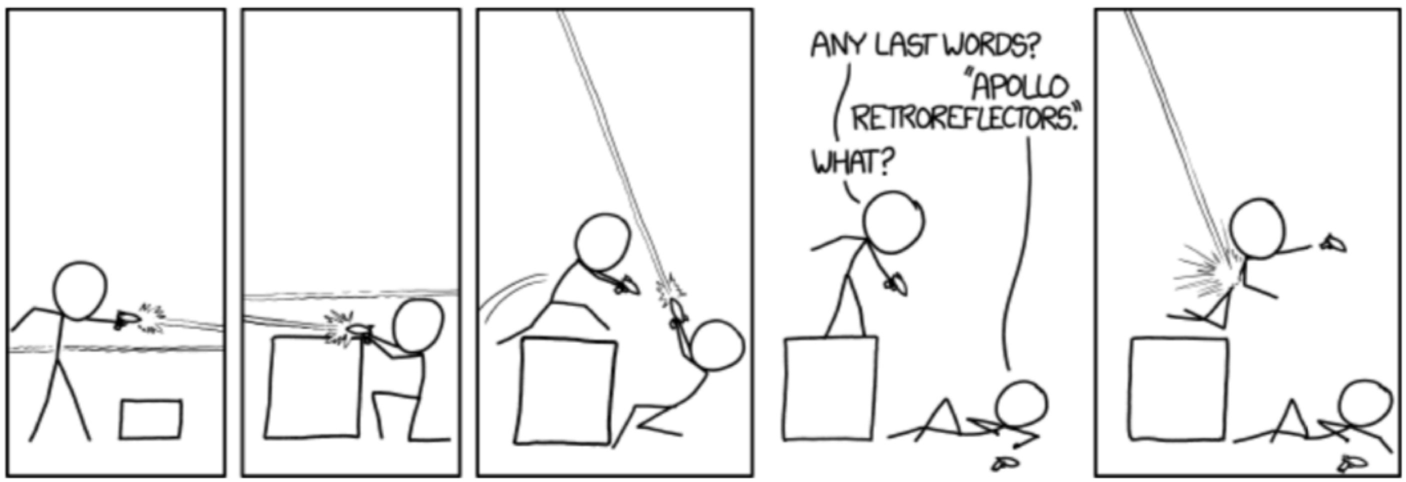
NASA is collaborating with INFN-LNF and UMCP on the development of a tool targeted to facilitate Lunar Laser Retro-Reflector (LRR) and Lunar Laser Ranging (LLR) studies and mission planning. The tool called LRR/LLR Geometry Calculator will allow mission planners and researchers to find, visualize, and analyze images taken by the Lunar Reconnaissance Orbiter (LRO) – and possibly other orbiters – that are applicable to LRR/LLR planning and research using NASA's Solar System Treks Project's Moon Trek online data visualization and analysis portal.

Overview of Lunar Laser Retroreflectors



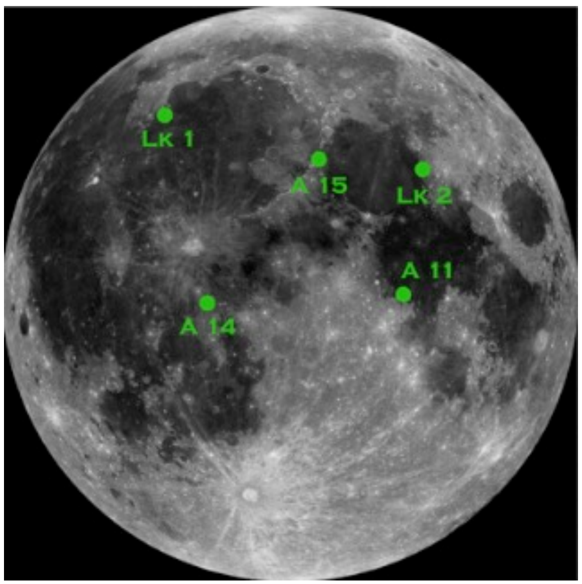
Basic design of single CCR (Cube Corner Retroreflector)
and of LRR (array of CCRs).
Basic working principle of "retro"-reflection

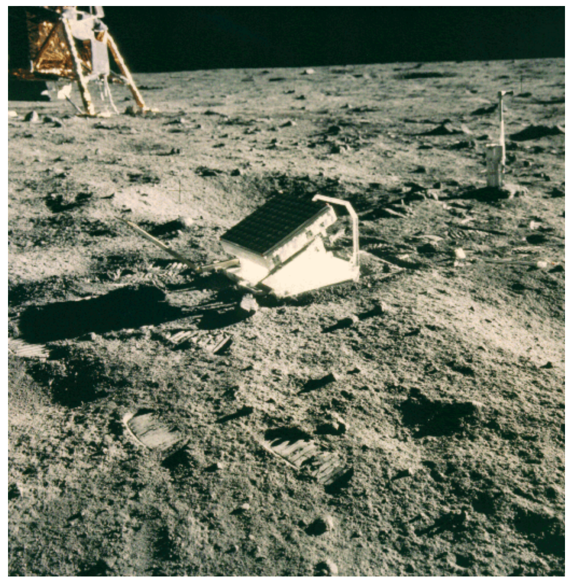




Overview of Lunar Laser Retroreflectors

History: Five passive LRRs were installed on the Moon, three by the landing crews of Apollo 11, 14, 15 and other two mounted on the Lunokhod 1 and 2 rovers.





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Lunar Laser Ranging (LRR) Overview

- LLR analysis provides high-precision measurements of ranges between observatories on Earth and LRRs on the Moon surface.
- LLR measures metrically the dynamics of the Earth-Moon system, including: improved knowledge of the Moon's orbit; rate at which the Moon is receding from Earth (now ~3.8 centimeters/year); variations in the rotation of the Moon
- LLR has become an essential technique to study <u>surface geodesy, geophysics, physics</u>
- It has been a key tool in studies of the lunar interior, providing evidence for solid-body tides and a fluid core
- It is especially important for testing General Relativity and new gravitational physics: possible changes of the gravitational constant *Gdot/G*, weak and strong equivalence principle, gravitational self-energy (PPN parameter β), geodetic precession, inverse-square force-law, constraints on gravitomagnetism, spacetime torsion, non-minimally coupled gravity, …
- LLR measurements from Earth resulted in the relative positions of the arrays accurate a centimeter level. LRR are core lunar ground control points of the ULCN = Unified Lunar Control Network (maintained by the USGS)

LLR and LRR Challenges

- The limited number of points provided by the few retroreflectors on the lunar surface constrains the general accessibility of the LRR reference frame.
- The restricted selenographical range of the existing LLR network means tidal librations are poorly constrained.
- In 1969 CCR arrays contributed a negligible fraction of LLR error. Since laser stations improved by >100, now, because of lunar librations and of their multi-CCR structure, current arrays dominate the error.
- Magnitude of the laser return signal has decreased by a factor ten (w.r.t. expected expected/initial laser return)
  - In fact, during lunar night, the return signal strength is about 10%
  - However, for the limited period around full moon, the signal level drops to about 1%
  - Deposit of lunar dust on the front faces of the CCRs is the most likely candidate
    - Other causes postulated: darkening due to UV and/or particle exposure, micrometeorite bombardment or change in the thermal coating due to dust, UV and or particle exposure.

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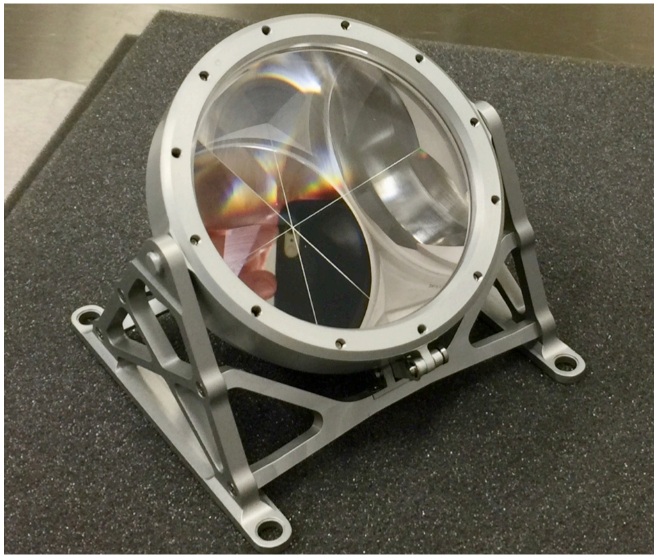
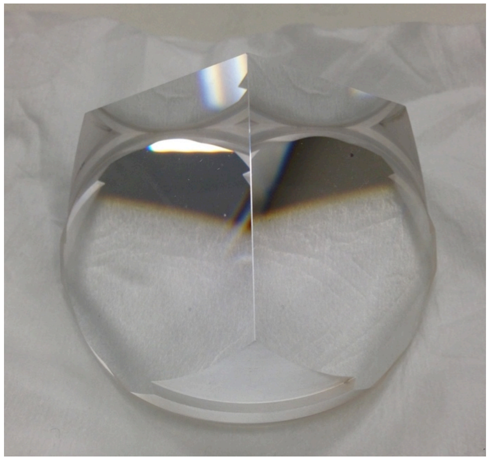
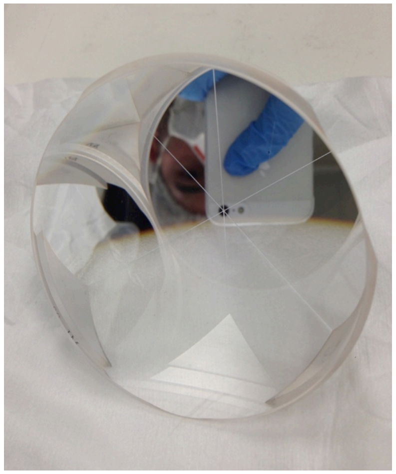
Next-Generation LRRs

Next-gen LRR model: a single, large (100 mm optical aperture) laser retroreflector in place of retroreflector arrays)







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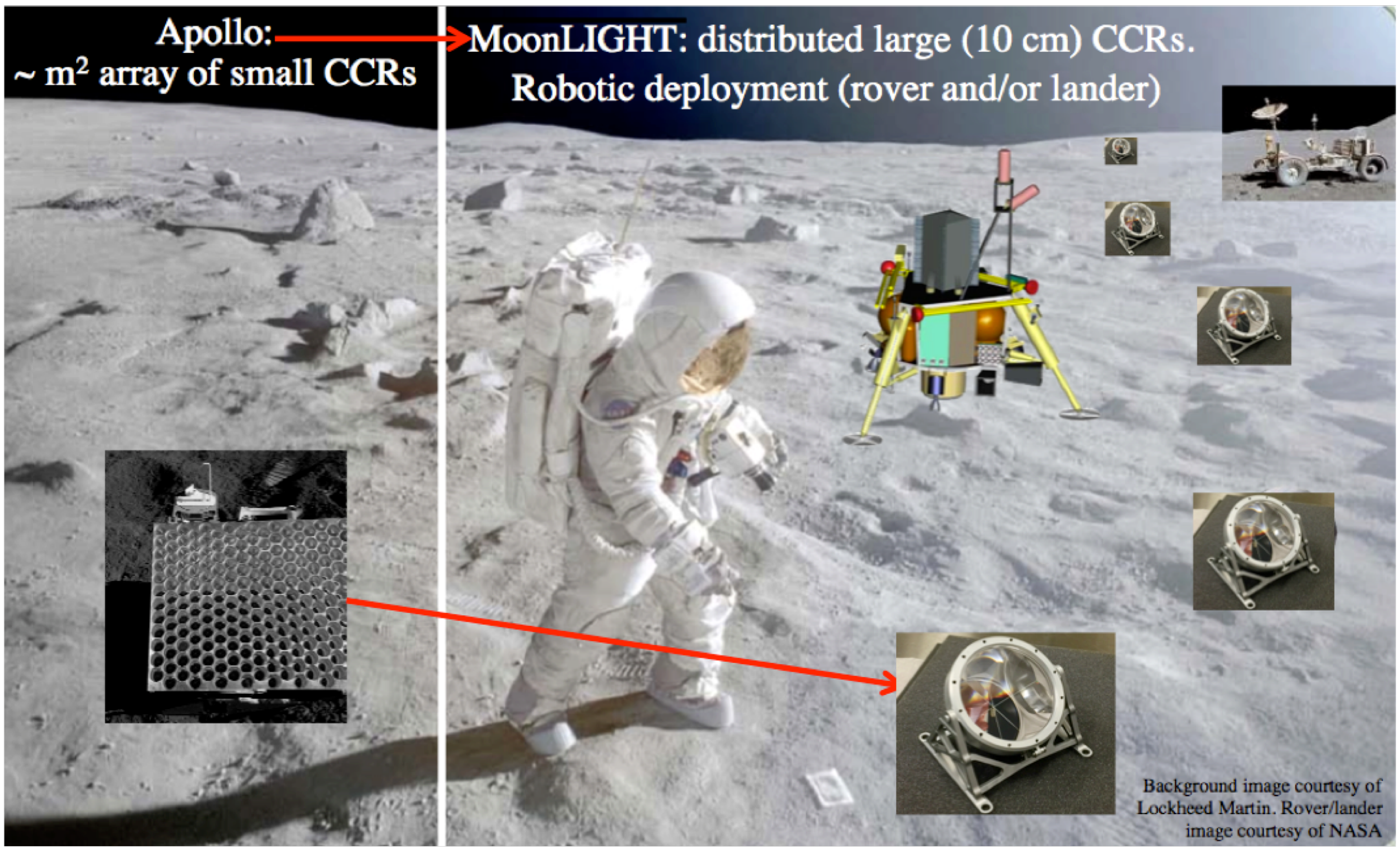
Next-Gen LRRs



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Next-Gen LRRs

Researchers at INFN-LNF and at UMCP are building and proposing to NASA, ESA, ASI (and other space stakeholders) next generation LRRs targeting a number of opportunities to return to the Moon. These include NASA's Commercial Lunar Payload Services (CLPS), Lunar Surface Instrument and Technology Payload (LSITP) Announcements of Opportunities, responses to three ESA Request for Information (RFIs).

A network of improved reflectors with improved coverage across the lunar surface will improve the knowledge of the lunar interior, the realization of the lunar reference frame (→ ULCS) and the accuracy of several tests of general relativity.

Especially when deployed as a **Lunar Geophysical Network (LGN)** in combination with other geophysical instruments, like seismometers and heat flow probes

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NASA Solar System Treks Project (SSTP)

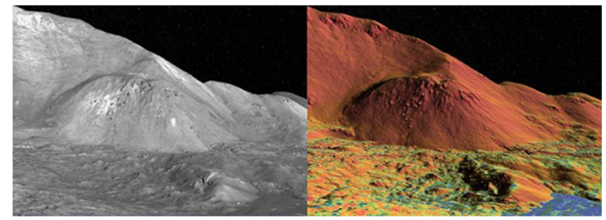
- An integral project within NASA's Solar System Exploration Research Virtual Institute (SSERVI), managed out of the SSERVI Central Office, and with software development and operations at JPL

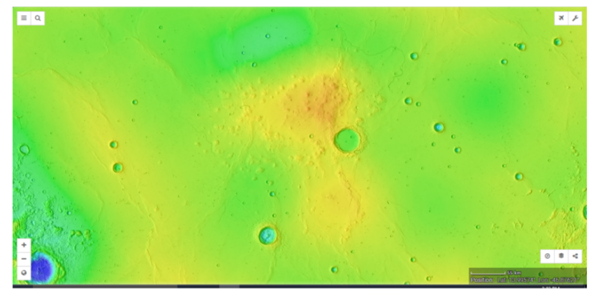
- A family of interactive web-based tools, data, and technology for exploration
  - Portals for a growing number of planetary bodies including the Moon, Mars, Vesta, moons of Saturn
  - Mission Planning, Scientific Research, Public Outreach/STEM
  - Online, browser-based web portals; nothing to install

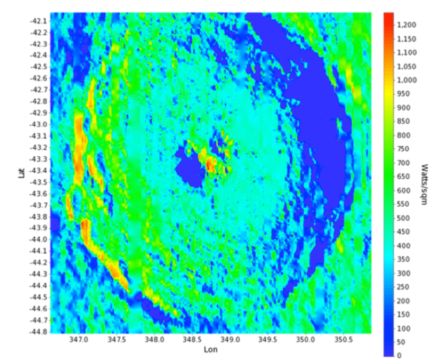
- Supporting NASA missions and NASA collaborations with partnering agencies
  - Currently supporting lunar & Mars landing sites selection, Cassini science, Dawn outreach
  - Supporting NASA partnerships with JAXA, ESA, KARI, INFN, IRAP

- Visualization of data products from many instruments aboard many missions
  - 2D & 3D viewing, interactive fly-overs, virtual reality path viewing, 3D printing of terrain

- SSTP's Moon Trek portal offers data from past and current lunar missions and features a powerful set of analysis tools such as rock and crater detection, lighting, and slope analysis.







Moon Trek's LRR/LLR Geometry Calculator

In collaboration with investigators from INFN-LNF and UMCP, the SSTP team is currently developing the LRR/LLR Geometry Calculator will support planning for future LLR deployment and LLR research on lunar cartography, lunar interior and precision tests of general relativity. It will be used to predict relative geometries between Earth laser stations, LLRs, LRO (and similar future orbiters) and to identify NAC images showing reflections of the Sun or lasers off of LLRs.

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Moon Trek's LRR/LLR Geometry Calculator

The tool is to provide answers to six key questions:

1) When an LRR is visible from a ground laser station, so that station could shine its laser and hit the LRR? For a newly-deployed next-generation LRR, this means it must be correctly aligned to Earth. An LRR is *correctly aligned* to Earth when the normal to its retro-reflecting surface is pointed along the Earth line of sight from the LRR lunar location *averaged* over the full cycle of the lunar libration pattern.

2) When were LRO cameras pointing at the LRR?

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Moon Trek's LRR/LLR Geometry Calculator

3) When could the Sun's Fresnel reflection from a LRR be seen in a LRO image? The photometric observation of Fresnel solar glints from single retroreflector surfaces has been proven with the LAGEOS satellites. Here we look for Fresnel solar glints from 100 reflectors (Apollo 11, 14) or 300 reflectors (Apollo 15).

4) Which LRO images are available in the Planetary Data System (PDS) that have the LRR in view?

Moon Trek's LRR/LLR Geometry Calculator

5) Are there any LRO images available in the PDS that have the solar glint off the LRR?

6) Are there any LRO images are available in the PDS that have the Fresnel reflection from the LLR ground station?

The answers to these questions will eventually allow Moon Trek users to find, access, visualize and analyze LRO NAC images that can greatly facilitate existing LLR research and future LLR planning and studies.

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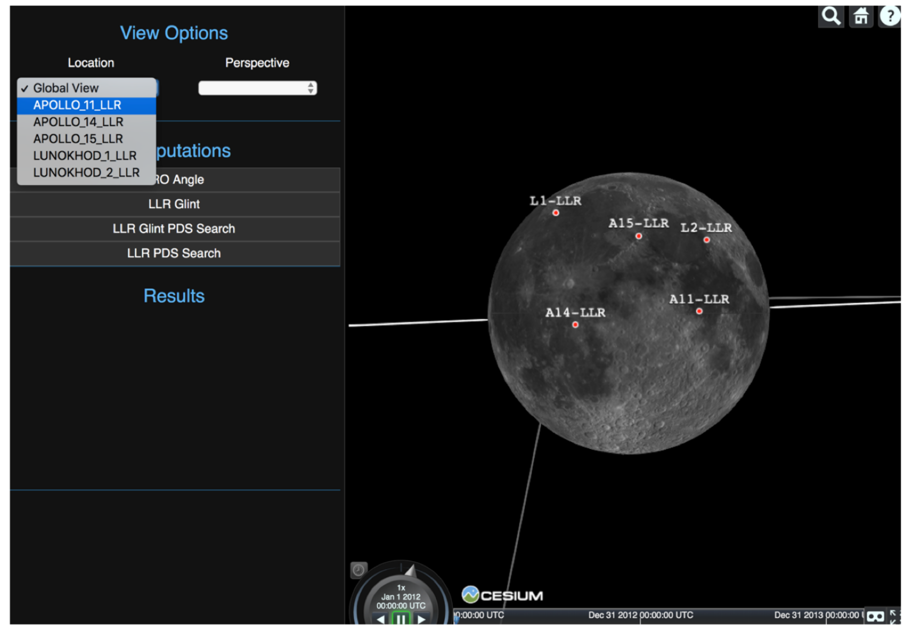
Moon Trek's LRR/LLR Geometry Calculator

The SSTP team is developing a standalone prototype comprising services using web-based APIs to compute geometries between a point on Earth, LRO, Sun, and one of 5 LRR sites on the Moon.



Moon Trek's LRR/LLR Geometry Calculator

The prototype was designed to be scalable and configurable allowing users to specify six parameters:

1) Observatory – Discrete set of stations on Earth
2) LRR – Discrete set of LRRs
3) LRO-MIN-DEC – Minimum declination (deg) of LRO
4) SUN-MIN-DEC – Minimum declination (deg) of the Sun
5) STARTTIME – Start time of search window (ISO 8601)
6) END-TIME – End time of search.

Using the knowledge of LRO orbits, data from NASA's observational geometry system SPICE, and the specified parameter values, the final prototype will provide answers to all six questions.

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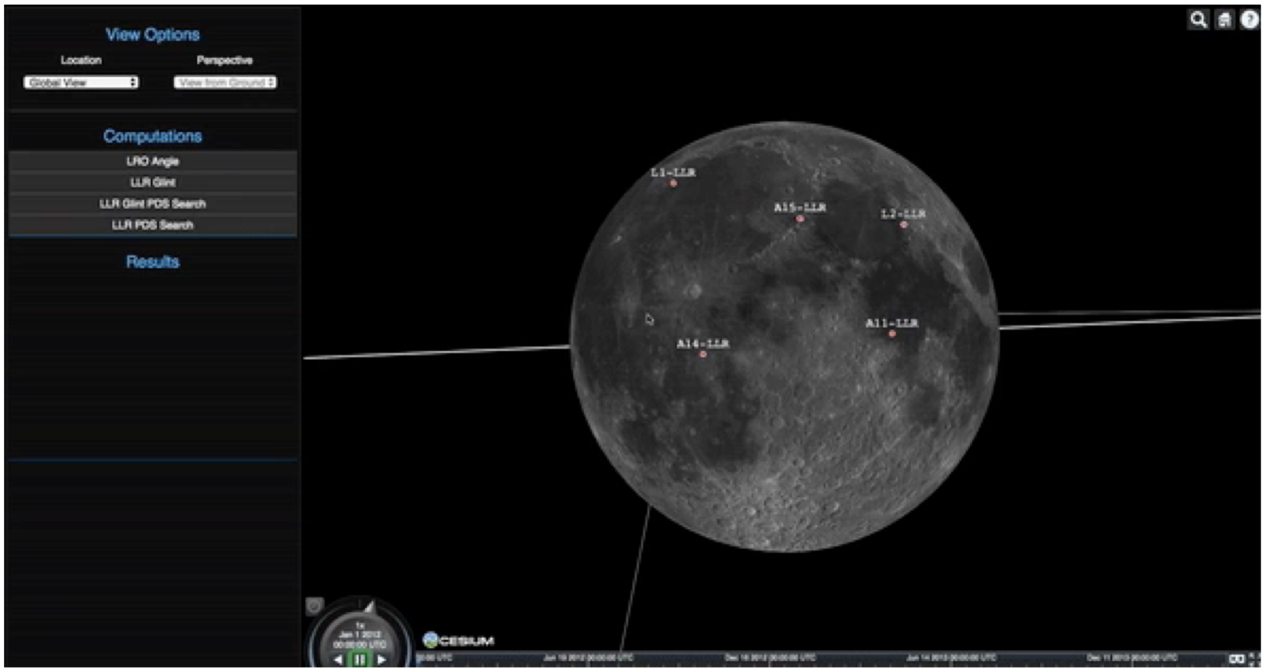
LLR Glint PDS Search

To find time intervals and accompanying images that have nominal lighting conditions and spacecraft positioning to catch a solar glint reflected off of a retroreflector



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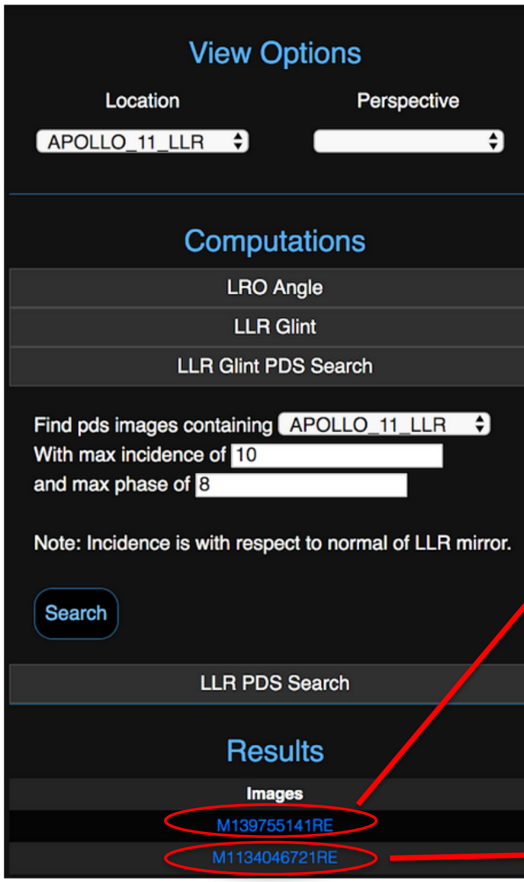
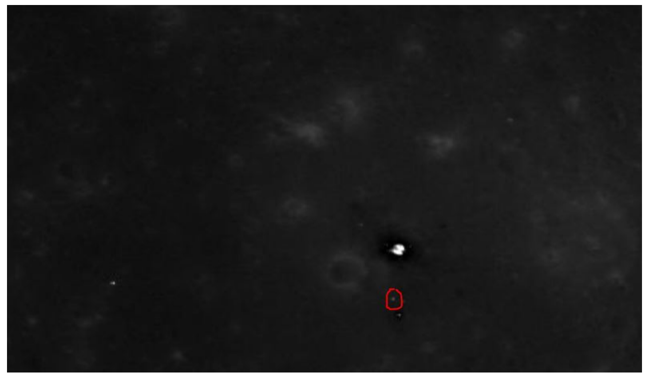
LLR Glint PDS Search Results





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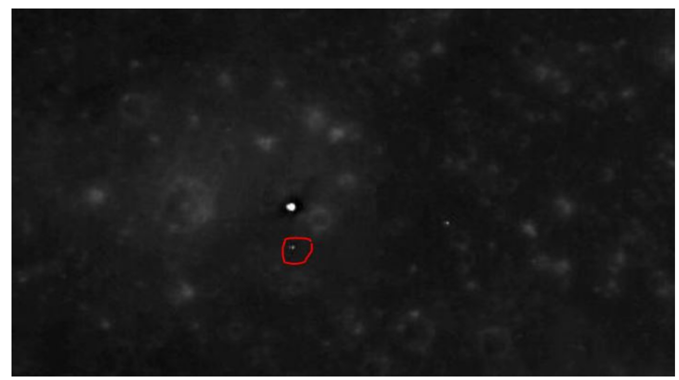

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Future Work

- The next iteration of the prototype and its results will help validate the correctness of calculation and the answers.
- The results will be used to retrieve the LRO NAC images, which in turn will be map projected.
- Integrate prototype into Moon Trek, adding a user interface for users to specify required parameters and execute the web services via Moon Trek's backend infrastructure.
- Upon completion of the calculation, users will be able to select and view the resulted images on Moon Trek in 2D and in 3D.
- Invite lunar community will to conduct beta testing and provide feedback.

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Acknowledgements

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The activity is also part of the INFN Affiliation to NASA-SSERVI, of INFN's research program named "MoonLIGHT" and of the joint research activities of INFN-LNF and the ASI-Matera Laser Ranging Observatory (MLRO). The latter is one of the three currently active LLR stations, together with APOLLO (Apache Point Observatory Lunar-Laser ranging Operation) in USA and Grasse in France.

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Thank You

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