The Contributions of ILRS Laser Ranging to the Lunar Reconnaissance Orbiter Mission

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Abstract

Laser Ranging (LR) to the Lunar Reconnaissance Orbiter (LRO) was active from June 2009 to September 2014 using a one-way (uplink only) technique where the ground stations fired their lasers at LRO and recorded the fire times, and the spacecraft altimeter, the Lunar Orbiter Laser Altimeter (LOLA), measured the receive events, telemetering them down in the S-band data stream. Ten ILRS stations participated in this operation, generating over 4000 hours of successful LR data. LR data was used to calibrate the spacecraft clock and to improve the orbital accuracy in the radial direction over just S-Band tracking data alone. In addition, the data was used to demonstrate that LR data alone can provide good orbital solutions when used with high-resolution gravity models. The poster presented how the LR data was used and its importance to LRO/LOLA, as well as discussed the on-going passive LR to LOLA experiment.

Laser Ranging to LRO

The Laser Ranging capability was added to the LRO Mission after LOLA had been selected [Smith2010] as an instrument on the spacecraft. It was determined that an "uplink only" LR would be feasible within budget by utilizing capabilities provided by the LOLA instrument. The addition of LR to LRO was a coordinated effort by the LOLA Science Team, the LOLA Instrument team, the NASA Satellite Laser Ranging (SLR) group and the LRO Mission [Zuber2010].

A subnetwork of ten ILRS stations around the world participated in laser ranging to the Lunar Reconnaissance Orbiter. Since ranging to LRO introduced some potential risks to the LOLA instrument, this was classified as "restricted satellite tracking." The restrictions involved both a maximum laser energy density from the station on LRO and a maximum laser fire rate. Stations were chosen by the LOLA Instrument Scientist in consultation with the NASA SLR group after a Call for Participation was issued. A Letter of Agreement between the LRO Mission and each participating station was signed by both parties. The international effort was coordinated by the Laser Ranging group at NASA's Goddard Space Flight Center (GSFC).

Predictions were provided by the Goddard Flight Dynamics Facility and placed on the Crustal Dynamics Data Information System (CDDIS) [Noll2010] for availability for the participating stations. Schedules were generated by the NASA GSFC SLR group for all stations. Initially laser ranging was limited to only one station at a time. As the Mission progressed, it was determined that the LOLA instrument could handle multiple stations ranging at the same time, so this restriction was removed for most situations.

LOLA's onboard flight software performed signal processing on both the lunar returns as well as the light coming from the Earth. Using the LOLA real-time housekeeping data, a website was generated and maintained by the LOLA Instrument Team to report in near real-time LOLA's signal processing of the incoming Earth light. With this information the ground stations could determine if they were successfully hitting LRO. Each week the global data was reviewed by both a member of the LOLA Instrument Team and the LOLA Science Team. The number of minutes of laser ranging data from each station was determined, and a report was provided back to the stations.

Figure 1 shows a map of the ten participating ILRS stations as of the September 2014. More details on each of the participating stations, including their ranging characteristics, and the amount of successful LR data they contributed, can be found in [McGarry2013].

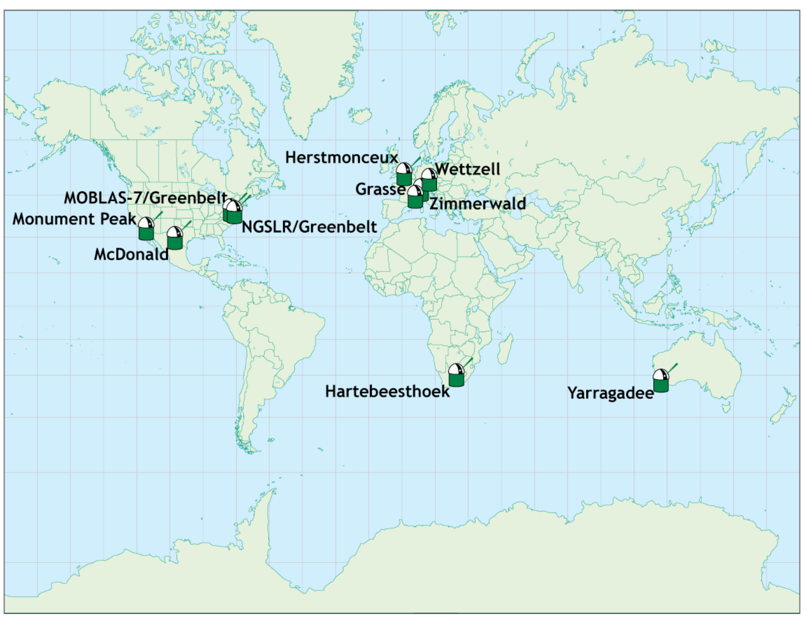

Figure 1: The ILRS stations that participated in LRO-LR as of September 2014

Contributions of LR to the LRO Mission

LR was added to LRO for use in characterizing the LRO onboard ultra stable oscillator (USO). Through laser ranging the ground station clocks were used to determine the drift and aging of the

USO. The primary ground station for LRO-LR was NASA's Next Generation Satellite Laser Ranging (NGSLR) system, which used a hydrogen maser to provide a very stable ground clock with frequency stable to ~ 1 part in 10^{15} in terms of flicker floor. The USO time precision derived from the LR data was shown in [Mao2016] to be < 0.015 ms, which far exceeded the Mission requirement of 3 ms. The calculated drift and aging of the onboard USO was then used to correct the LOLA timing measurements.

The LOLA receive times were combined by the LOLA Science Team with the ground station fire times to produce ranges. The LR normal point ranges were accurate to about 5 to 10 cm. These range measurements were used in the reconstruction of the LRO orbit, as an accurate orbit is essential in converting the LOLA altimetric ranges to accurate terrain heights. The LRO orbit determination process showed that LR alone could produce an accurate LRO orbit when using a high-resolution GRAIL gravity model. It was also shown in [Mao2016] that combining LR and S-band data yielded great improvement from S-band only results in the radial direction. [Bauer2016] also demonstrated the capability of using LR data in determining the LRO orbit while also describing the issues associated with one-way ranging data.

Summary of LRO-LR Accomplishments

In addition to its contribution to the LRO Mission, Laser Ranging to LRO accomplished a number of important ground breaking milestones, including:

- Enabling a new range measurement capability using existing SLR infrastructures, complementing and potentially replacing RF tracking in the future.
- Demonstrating operational laser ranging to a target orbiting a body other than Earth over a five year period.
- Showing that the ILRS Network can be coordinated to provide close to 24 hour coverage for laser ranging to targets beyond the Earth's orbit.
- Proving that simultaneous ranging from multiple ground stations to LRO was possible for much of the tracking, enabling the comparison of ground clocks, and setting the stage for future planetary spacecraft orbit determination from multiple SLR stations.
- Developing and demonstrating a successful method for providing tracking feedback to ground stations for 1-way uplink ranging (real-time website from instrument housekeeping data).
- Providing the opportunity to test new space technologies and mission concepts using established SLR infrastructures. These included laser communications [Sun2013a] and time transfer [Sun2013b], [Bauer2017] experiments.

Conclusion

Laser Ranging to LRO was a ground breaking endeavor which demonstrated that laser transponders could be used operationally to track objects orbiting a body other than Earth. It also showed that the Satellite Laser Ranging stations of the ILRS could support transponder ranging and could do it consistently and accurately for over five years. The data from LR not only provided the characterization of the onboard oscillator required by the Mission, but also supported the orbital reconstruction and demonstrated that LR data alone could be used to provide good orbits.

Acknowledgments

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