Laser Ranging to the Lunar Reconnaissance Orbiter: a Global Network Effort

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Abstract

The Lunar Reconnaissance Orbiter (LRO) will launch in early 2009 carrying multiple instruments for lunar study including the NASA Goddard Space Flight Center built Lunar Orbiter Laser Altimeter (LOLA). Also part of the mission will be the Laser Ranging (LR) instrument, which consists of a 2 cm aperture receive telescope mounted on the High Gain Antenna and a fiber optic bundle from this aperture to one of the LOLA detectors. Laser Ranging to LRO is an uplink-only measurement where ground stations time-tag their laser fires and LOLA measures the receive times to better than 10 centimeter precision with sub-centimeter resolution. This information will be used to improve the orbital knowledge which in turn will support the lunar gravity model development.

While NASA's Next Generation Laser Ranging System (NGSLR) is the primary ground station for LR, multiple International Laser Ranging Service (ILRS) stations will also be supporting this historic mission, providing much better coverage than a single station could provide. Data from all of the participating ILRS stations will be sent to the LOLA Science Operations Center (SOC) where ground fire events will be matched with LOLA events and ranges produced. Coordination of the global effort will be at the Goddard Space Flight Center, where predictions and schedules will be created, data archived (CDDIS), and an LR science product generated (LOLA SOC).

Introduction

This paper provides the status of the preparations for global LR support, and gives an overview of the scheduling, data-transfer, and real-time LR website feedback from the spacecraft.

LOLA's Earth Range Measurement

LOLA uses one of its five detectors to measure events coming from Earth. The Earth Window is the time when the detector is gated on, and this occurs in the first 8 milliseconds of every one of LOLA's 28 hz cycles. LOLA does not fire its lunar laser until approximately 9 milliseconds into the 28 hz cycle to avoid any collision between Lunar and Earth events.

LOLA's 28 hz cycle is synchronized to the raw spacecraft Mission Elapsed Time (MET). When the MET second rolls over, the spacecraft 1 pps signal is sent and LOLA's first 28hz cycle begins. The LRO Mission Operations Center (MOC) keeps track of the relationship between MET and UTC. At launch the knowledge will be better than +- 3 millseconds. This information should improve by several orders of magnitude shortly into the data-taking part of the mission.

The LOLA LR measurement is made with a single-stop timer. Because of the large field of view of the LR telescope (30 milliradians), the noise power can be 5 nanoWatts or greater when the High Gain Antenna is pointed to a fully sunlit Earth. The onboard software will increase the threshold to compensate for this high noise power but it cannot reduce it completely. For high noise situations ground station laser pulses that arrive early in LOLA's Earth Window will have a higher probability of being detected than those arriving later in the window.

The LOLA onboard software performs signal processing on the LR events at one second intervals using Poisson statistics to determine the ground pulses from noise. The software should be able to recognize signals from stations firing synchronously at rates of 7 hz or greater. The LOLA energy monitor should also register when ground system pulses are detected in the Earth Window.

Participating Stations

NGSLR will be the primary LRO laser ranging station and will fire at LRO every opportunity that the Moon is above 20 degrees elevation at the station, LRO is on the near side of the Moon, there is no local precipitation, and the LRO Go/No-Go flag is set for "go". NGSLR fires synchronously to LOLA at 28 hz, meaning that NGSLR uses the MOC supplied UTC to MET conversion, takes into account the range to the spacecraft, and only fires its laser when the resultant pulse would arrive at the spacecraft when the LOLA Earth Window is open.

McDonald Laser Ranging Station (MLRS), operated by the University of Texas at Austin under a contract with NASA, will also participate in LRO-LR. MLRS will fire asynchronously at their normal 10 hz rate which will ensure a minimum of 2 events per second in the LOLA Earth Window. MLRS will fire at LRO in a non-interference basis with SLR operations.

Other NASA associated stations that may provide support are MOBLAS-5 in Australia and MOBLAS-6 in South Africa. A modification to the MOBLAS systems to more precisely time the fires is being worked. The timing will be done with a separate computer and timing card so as not to interfere with SLR operations. The MOBLAS systems will fire asynchronously at 5 hz which will ensure a minimum of 1 event per second in the LOLA Earth Window.

Proposals have been received from Zimmerwald in Switzerland, Herstmonceux in Great Britain, Mount Stromlo in Australia, and Wettzell in Germany. All have been accepted for participation and two have formally signed agreements with the LRO project. All of the stations are expected to try synchronous ranging to LRO. Most of the stations have to operate in a configuration different from SLR in order to prevent possible damage to the LOLA detector. Agreed upon configurations will be listed in all of the formal Agreements.

Table 1. Participating stations and their characteristics. LRO-LR requirements are for an energy density of 1 to 10 femtoJoules per square centimeters at the spacecraft. Stations marked with an asterisk (*) do not yet have a final configuration agreed upon for ranging to LRO.

	Synch to LOLA?	**Firerate (Hz)**	**# / sec in LOLA window**	**Expected energy at LRO (fJ per sqcm)**
NGLSR	Yes	28	28	2 to 5
MLRS*	No	10	2 to 4	1 to 10+
Zimmerwald	Yes	28	28	1 to 3
Herstmonceux	Yes	7 or 14	7 or 14	1 to 3
Wettzell*	Maybe	7 or 10	2 to 7	1 to 10+
Mt Stromlo*	Yes	28	28	1 to 10+
MOBLAS	No	5	1 to 2	1 to 3

Station Scheduling

Each week an LR schedule will be generated which will give the requested firing times for each of the participating stations. Each system will decide which of the times they can support. Stations are requested not to fire at LRO outside of the scheduled times.

Initially only one station will be scheduled at any given time. This will allow the LOLA Science Team to work individually with each system's data and will also allow each system to test out the LR website feedback from LOLA (discussed later in this paper).

Eventually two or more stations may be scheduled during overlapping periods. Since LOLA is a single stop system, only the first event in the Earth Window will register and therefore multiple 28 hz stations would be competing for the same single stop in each window.

Data Products and Flow

LRO predictions will be generated by the NASA Goddard Space Flight Center Flight Dynamics Facility (FDF). These predictions are in the ILRS standard Consolidated Prediction Format (CPF). LRO will be in a polar orbit at approximately 50 km above the surface of the Moon. The predictions give the rectangular coordinates of the spacecraft's location from the center of the Earth in an Earth rotating coordinate system. The accuracy of these predictions will be better than 4 km (3D, 3 sigma). Predictions will be updated daily and will span a 10 day period of time. Only organizations that have signed Agreements with the LRO Project will be given access to the predictions.

The normal satellite CPF software as found on the ILRS website (Ricklefs 2006) can be used to generate pointing angles and range from the predictions. The LRO predictions as supplied are already point-ahead predictions, so the on-site software should not attempt to correct these predictions to make them point-ahead.

LRO fire times, weather information, and ancillary data from all stations will be sent into the LRO project in the new ILRS Consolidated Ranging Data Format (CRD) with the exception of the MOBLAS systems which will use an internal Transponder Data Format (iTDF). The CRD format can be found on the ILRS website (Ricklefs 2008). NGSLR will format its data in both iTDF and CRD formats. All LRO ground station data will be sent through Honeywell at Goddard Corporate Park where it will be grouped together and placed on CDDIS (Noll 2007). The LOLA SOC will pick up the ground system fires and match those with the LOLA event times to form one-way ranges to LRO. These one-way ranges will be placed back on CDDIS where they will be available to all of the participating organizations.

The information to convert UTC to MET and back is contained in the SCLK files. One file contains piecewise continuous linear functions relating the spacecraft UT to UTC. A second file contains an offset between spacecraft UT and the raw spacecraft MET. These files are only needed for stations that will fire synchronously to LOLA. After launch the information in the SCLK files is expected to change very infrequently.

Similar to ICESat, LRO-LR will have a Go/No-Go file that the LRO mission will use to control the firing of the ground stations (Gurtner 2005). The Go/No-Go flag is expected to be turned to "nogo" only during calibrations, maneuvers or emergencies, or any time that the High Gain Antenna is not facing Earth.

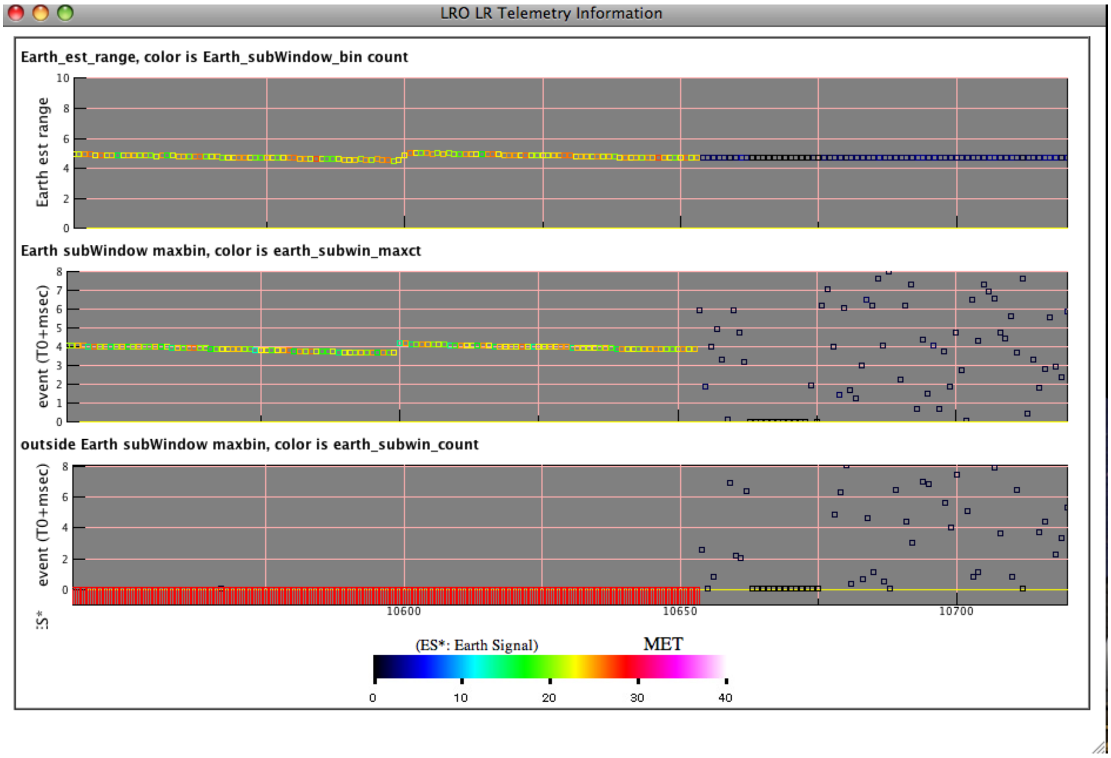

Figure 1. LRO-LR website displaying LOLA one second signal processing information of Earth Window data. The vertical axis is the Earth Window in milliseconds. The horizon axis is elapsed time in seconds. The dots in the top window represent LOLA's estimated location of the ground signal in the window. The color of each dot shows the number of receive events in that estimate. The middle window gives similar information but with a different signal processing which can pick up weak results from ground stations. The lower window attempts to capture receive events from a second ground station. Also shown in the lower window is the signal flag (red mark if LOLA believes LR signal is present). Real-time data flows from right to left. The left half of this plot shows LR signal events as seen by LOLA. The signal stops about half way through this plot and from then on the plot contains only noise.

Feedback to Stations

The LOLA signal processing and energy monitor information will be sent down in the LOLA House-Keeping (HK) packets in real-time. The HK packets will flow to the LOLA SOC where the relevant information will be displayed to a website as shown in Figure 1 (Torrence 2009). This information should be less than 30 seconds stale. The ground stations can make use of this website to determine if their pulses are being detected at LOLA. Synchronous stations, especially those with 28 hz fires, should be able to use the signal processing information, while all stations can make use of the energy information.

This website will also display the data received from each station over the past week so that each station can determine if all of its data is getting to the LOLA SOC.

Summary and Acknowledgements

LRO-LR laser ground stations will not only be supporting LRO and lunar science, but they will be taking some of the ILRS's first steps into planetary laser ranging. The LRO-LR Team and the LOLA Science Team would like to thank all of the ground stations who are participating in this mission.

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The launch is currently scheduled for late May 2009 with LR operations expected to start about a month later.

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