Laser Ranging to the Lunar Reconnaissance Orbiter

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http://lrolr.gsfc.nasa.gov

LRO-LR (JM,TZ):  9/21/2009
Lunar Reconnaissance Orbiter (LRO) – Laser Ranging (LR) Overview

Sub-network of ILRS will support LRO for one-way laser ranging

- Transmit 532 nm laser pulses at <= 28Hz to LRO
- Time stamp departure times at ground station
- Event arrival times recorded by LOLA
- Compute relative 1-way range to LRO from the two pieces of data

LRO Mission Includes:
- LOLA, laser altimeter
- LROC, camera
- LAMP, Lyman alpha telescope
- LEND, neutron detector
- DIVINER, thermal radiometer
- CRATER, cosmic ray detector
- mini-RF, radar tech demo

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LOLA is a 5-beam laser altimeter that operates at 28 Hz and acquires 140 measurements/s of
- altimetry
- surface roughness
- surface reflectance
and 180 measurements/s of derivable surface slopes with baselines of 25 to 50 m.

Profiles 10 to 12 m apart

50 m

5-m diameter observation area (red)

20-m FOV (green)

10 to 12 m apart

D. Smith & M. Zuber
One LOLA Detector does both Earth and Lunar

- Two range windows in one detector: 8 msec earth and up to 5 msec lunar.

- Range to LRO changes ~ 5-10 ms over an hour’s visibility.

- Need to either synchronize the ground laser fires to LOLA to ensure pulses land in every Earth Window, or fire asynchronously to LOLA (eg 10Hz).

![Diagram showing LOLA laser fire periods](image)
LR Objectives and Instrumentation

- Objective of LR is to enable the spacecraft to achieve its precision orbit determination (OD) requirement. The OD supports the generation of an accurate topographic model from LOLA’s measurements.

- Designed to measure centimeter-level orbit perturbations over a few seconds of flying time and meter-level perturbations from pole to pole.

- Flight Instrument:
  - 3.81 cm diameter aperture mounted on High Gain Antenna
  - Fiber optic bundle carries the light to the LOLA detector #1
  - LR FOV is ~ 1.7 deg (earth diameter is ~2 deg as viewed from moon)
  - 532 nm bandpass filter with 0.3 nm FWHM
  - Ultrastable OCXO oscillator: Symmetricom 9500 (2x10-12 over 1 hour)
  - Onboard software controls threshold setting using detector noise counts.
Primary Ground System: NASA’s Next Generation Satellite Laser Ranging System (NGSLR)

- 50 mJ Northrop Grumman laser (532.2 nm wavelength, 6 ns pulsewidth).
- Software controlled laser triggers - producing 28 Hz laser fires that arrive at LRO when the LOLA Earth Window is open.
- 55 microradian laser beam divergence (~20 km spot at moon).
- Aircraft avoidance radar (FAA regulations for non-eyesafe lasers).
- Honeywell Event Timer (ET) with 30 picosecond accuracy.
- Symmetricom Cesium oscillator (CS-4310) provides 10 Mhz time base for ET.
- TrueTime XL-DC GPS steered Rubidium provides station timekeeping.
- Arcsecond precision tracking mount, pointing accurate to a few arcseconds.
Participating Stations from the International Laser Ranging Service (ILRS)


- Also ranging to LRO:
  - McDonald Laser Ranging System (MLRS): Texas
  - Herstmonceux: Great Britain
  - Zimmerwald: Switzerland
  - MOBLAS-7: Maryland

- Working toward ranging to LRO:
  - Wettzell: Germany
  - Hartebeesthoek: South Africa
  - Yarragadee: Australia
  - Monument Peak: California
## Ground Station Characteristics

- Station fire rate and probable events per second in LOLA Earth Window with system configurations:

<table>
<thead>
<tr>
<th>Station</th>
<th>Synch?</th>
<th>FireRate</th>
<th>Events/second in Earth Window</th>
<th>Energy per pulse at LRO fJ/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGSLR</td>
<td>YES</td>
<td>28Hz</td>
<td>28</td>
<td>2 to 5</td>
</tr>
<tr>
<td>MLRS</td>
<td>NO</td>
<td>10Hz</td>
<td>2 to 4</td>
<td>4 to 10</td>
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<tr>
<td>Zimmerwald</td>
<td>YES</td>
<td>14Hz</td>
<td>14</td>
<td>2 to 10</td>
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<tr>
<td>Herstmonceux</td>
<td>YES</td>
<td>14Hz</td>
<td>14</td>
<td>1 to 3</td>
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<tr>
<td>Hartebeesthoek</td>
<td>NO</td>
<td>10 Hz</td>
<td>2 to 4</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Yarragadee</td>
<td>NO</td>
<td>10 Hz</td>
<td>2 to 4</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Monument Peak</td>
<td>NO</td>
<td>10 Hz</td>
<td>2 to 4</td>
<td>1 to 2</td>
</tr>
<tr>
<td>MOBLAS-7</td>
<td>NO</td>
<td>10 Hz</td>
<td>2 to 4</td>
<td>1 to 2</td>
</tr>
</tbody>
</table>

- Requirement: between 1 – 10 femtoJoules per square centimeter at LRO and between 1 and 28 events per second in LOLA Earth Window.
Data Products for LRO-LR

- Predictions (CPFs) generated by GSFC Flight Dynamics Facility (FDF):
  - Accuracy < 4 km (3D, 3 sigma)

- SCLK file relates spacecraft time (MET) to UTC for synchronous firing.

- Go/NoGo file. Set to NoGo to stop all stations from firing within 5 mins.

- Fire times recorded at each station:
  - Accuracy to UTC < 100 ns
  - Relative fire time error RMS < 200 ps (over 10 sec)

- Real-time feedback from spacecraft:
  - LOLA flight software performs signal processing on LR events
  - Results come down in LOLA housekeeping and are displayed on website
  - Latency is between 10 to 30 seconds
  - Stations use website to determine if they are hitting LRO
Real-time Telemetry Website
Preliminary Results from First 3 Months

- RMS of individual ranges is ~0.8 ns, (~24 cm), after removal of outliers. Calibration will improve these numbers. (Analysis by Greg Neumann).

- Precision of 2-way altimetry is 12 cm.

- Have collected over 44 hours of laser ranging data at LRO.

- One-way LR link is strong from NGSLR. Can range through thin clouds.

Sky on a night of successful ranging to LRO.

Thin clouds, high humidity as seen from camera on NGSLR mount.
Preliminary Performance Analysis

- Black line shows a time-of-flight residual of 200 ns wrt prediction.
- Residuals from a 4th-degree polynomial fit shown in red, 5-s normal points in blue
On-orbit Calibration of LOLA from NASA’s 1.2 m Telescope


Has supported many experiments including in 2005:
- 2-way ranging to Mercury Laser Altimeter (MLA) on MESSENGER (24 Mkm), and
- 1-way ranging to Mars Orbiter Laser Altimeter (MOLA) on MGS (orbiting Mars at 80 Mkm).

Very Preliminary Analysis of Sep 13 Scan
Plot of LOLA received events on scan location

LOLA receiver captures laser pulses from ground

Spacecraft scan is black line

Neumann (GSFC)
Very Preliminary Analysis Sep 13 Scan
Plot of ground received events on LRO scan location

Ground receiver captures laser pulses from LOLA

5 laser spots can be seen:
Goddard Geophysical and Astronomical Observatory (GGAO)
Birthplace of Satellite Laser Ranging in early 1960s

- Located ~ 3 miles from GSFC on Springfield Road (in middle of BARC).
- Home to NASA SLR, VLBI, GNSS and DORIS:
  - 1.2 meter telescope,
  - NGSLR,
  - MOBLAS-7,
  - VLBI MV3,
  - and numerous other facilities and experiments.

Part of this afternoon’s tour

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