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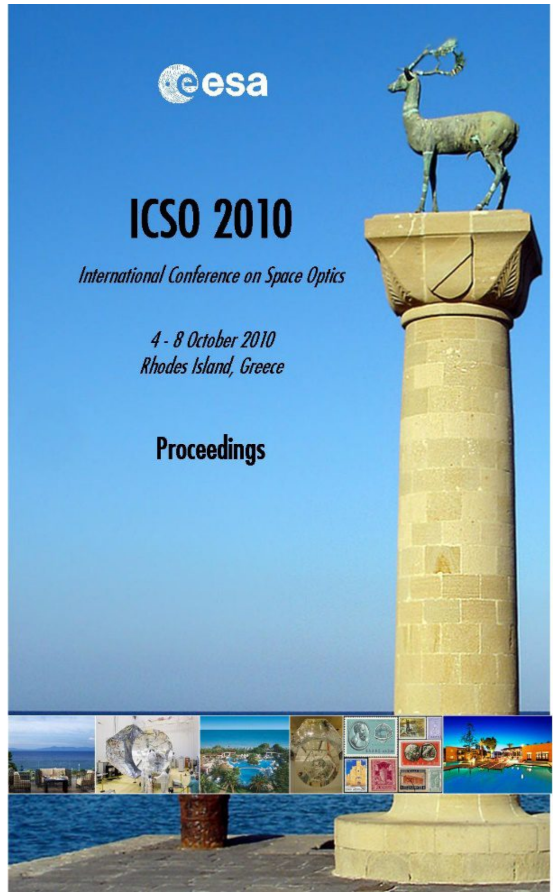

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THE LUNAR ORBITER LASER ALTIMETER (LOLA) ON NASA'S LUNAR RECONNAISSANCE ORBITER (LRO) MISSION

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INTRODUCTION

The Lunar Orbiter Laser Altimeter (LOLA) instrument [1-3] on NASA's Lunar Reconnaissance Orbiter (LRO) mission, launched on June 18th, 2009, from Kennedy Space Center, Florida, will provide a precise global lunar topographic map using laser altimetry. LOLA will assist in the selection of landing sites on the Moon for future robotic and human exploration missions and will attempt to detect the presence of water ice on or near the surface, which is one of the objectives of NASA's Exploration Program.

Our present knowledge of the topography of the Moon is inadequate for determining safe landing areas for NASA's future lunar exploration missions. Only those locations, surveyed by the Apollo missions, are known with enough detail. Knowledge of the position and characteristics of the topographic features on the scale of a lunar lander are crucial for selecting safe landing sites. Our present knowledge of the rest of the lunar surface is at approximately 1 km kilometer level and in many areas, such as the lunar far side, is on the order of many kilometers. LOLA aims to rectify that and provide a precise map of the lunar surface on both the far and near side of the moon.

LOLA uses short (6 ns) pulses from a single laser through a Diffractive Optical Element (DOE) to produce a five-beam pattern that illuminates the lunar surface. For each beam, LOLA measures the time of flight (range), pulse spreading (surface roughness), and transmit/return energy (surface reflectance). LOLA will produce a high-resolution global topographic model and global geodetic framework that enables precise targeting, safe landing, and surface mobility to carry out exploratory activities. In addition, it will characterize the polar illumination environment, and image permanently shadowed regions of the lunar surface to identify possible locations of surface ice crystals in shadowed polar craters.

INSTRUMENT DESCRIPTION

The LOLA instrument was designed, integrated and tested at the Goddard Space Flight Center, in Greenbelt, Maryland. LOLA is a heritage design from previous GSFC altimeters. The LOLA instrument configuration is shown in fig. 1 and the key instrument parameters are shown in Table 1.

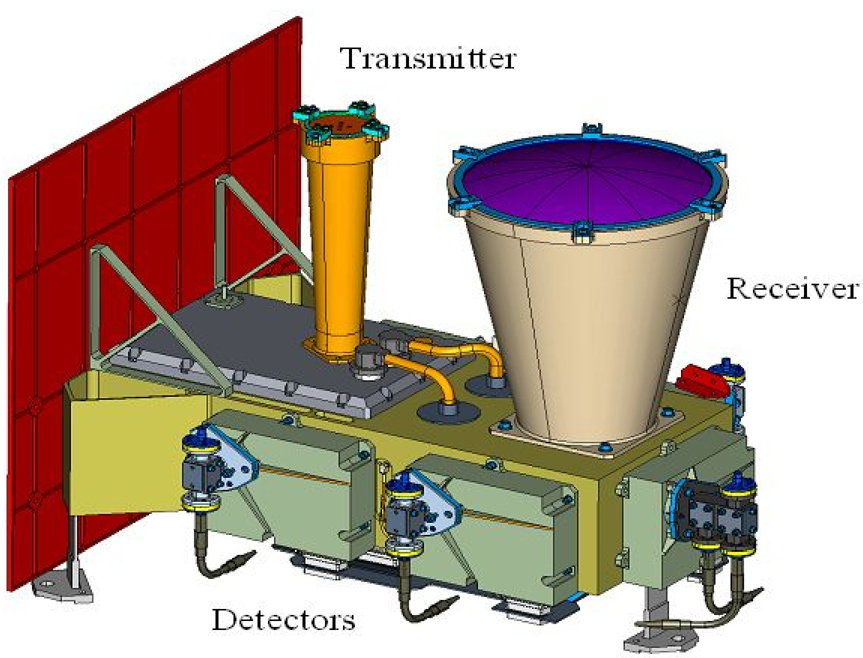

Fig. 1 LOLA Instrument Diagram

Table 1 LOLA Instrument Parameters

Parameter	*Value*
Laser Wavelength	1064.3 nm
Pulse Energy	2.7 mJ
Pulse Width	6 ns
Pulse Rate	28 Hz
Beam Divergence	100 μrad
Beam Separation	500 μrad
Receiver Aperture Diameter	0.14 m
Receiver Field of View	400 μrad
Receiver Bandpass Filter	0.8 nm
Detector quantum efficiency	40%
Timing Resolution	0.5 ns
Instrument Mass	12.6 kg
Instrument Power	34 W

A functional block diagram is shown in Figure 2. LOLA uses a Q-switched Nd:YAG laser at 1064 nm and avalanche photo diodes (APD) to measure the time of flight (TOF) to the lunar surface from a nominal 50 km orbit. The transmitted laser beam is split in five different beams by a diffractive optical element (DOE) with 0.5 mrad spacing. The receiver telescope focuses the reflected beams into a fiber optic array, placed at the focal plane of the telescope. The array consists of five fibers and each fiber in the array is aligned with a laser spot on the ground. The fibers direct the reflected beams into five detectors. The detector electronics amplify the signal and then compare it against a pre-set threshold. The output of the comparators is then time stamped relative to the spacecraft mission elapsed time (MET) using a set of time-to-digital converters (TDCs) with a 0.5 ns resolution. Both the rising and falling edges of the output of the comparators are recorded. Onboard algorithms filter out the false alarms and select the most likely ground echoes. A range gate limits the number of false alarms by detecting pulses arriving only within the expected time interval (the approximate range to the surface). A noise counter records the numbers of threshold crossings at the output of each comparator and a detection threshold level is adjusted automatically such that the average number of false alarm pulses within the range gate interval is maintained at a predetermined value. The signal-processing algorithm adjusts the receiver gain and maintains the range window centered on the lunar surface return. The transmitted pulse is also time stamped and the TOF to the lunar surface can be determined. LOLA uses an ultra-stable oven controlled crystal oscillator as a clock. The oscillator is carried on the LRO spacecraft and its timing signal is distributed to LOLA and other instruments.

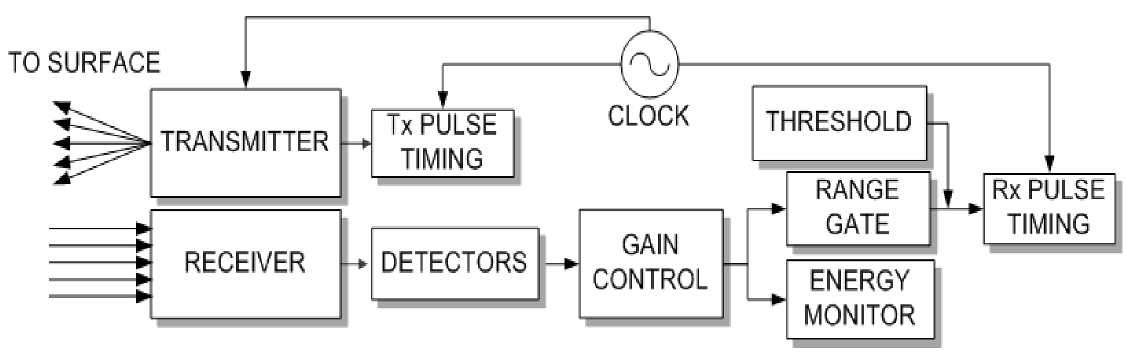

Fig. 2 LOLA Instrument functional block diagram

The LRO spacecraft also carries a unique laser ranging system for precise orbit determination. The laser ranging system consists of a 30 mm aperture optical receiver mounted on the LRO spacecraft high gain antenna used for communications and data transmitting. The receiver is pointed to a ground (earth) based laser satellite ranging station that sends a 532 nm laser pulse to LRO. The receiver focuses the incoming 532 nm beam into a fiber bundle and the laser pulses are then directed onto one of the five LOLA detectors modified to accommodate both 532 and 1064 signals. The timing of the ground-based laser is adjustable and is intended to arrive at LOLA well before the lunar returns.

LOLA Transmitter

The LOLA transmitter consists of two virtually identical, diode pumped, Q-switched Nd:YAG oscillators operating at 1064.4 nm. The diode pump lasers are derated to increase their lifetime. The laser beams are combined with polarizing optics and only one laser is operating at a time; the other one is redundant. The laser repetition rate is 28 ± 0.1 Hz, the energy per pulse at ambient temperature is ~ 2.7 mJ for laser 1 and ~ 3.2 mJ for laser 2. The pulse width is approximately 5 ns. The output of the laser is directed through a ×18 beam expander and then through a diffractive optical element that produces five beams separated by 500 ± 20 µrad. The laser beam prior to the beam expander has a divergence of 1.8 mrad. After the beam expander and the diffractive optical element, each beam has a 100 ± 10 µrad divergence and approximately the same energy although some variation in the energy between beams is expected due to imperfections in the diffractive optical element. The LOLA laser is designed to operate in vacuum but a significant amount of the sub-system and system testing was done in air. The laser cavity was integrated in a clean room and two filters in the laser housing are designed to prevent particulate and molecular contamination of the laser topics prior to launch.

The 5-laser beam pattern is clocked at 26o relative to the spacecraft velocity vector. From the nominal orbit of 50 km, each laser spot is approximately 5 m in diameter on the ground and the field of view (FOV) is 20 m. The five spot pattern will allow LOLA to measure both the slope and the roughness of the lunar surface. The five beam spot pattern on the ground (including the field of view) relative to the spacecraft velocity vector is shown in Figure 3.

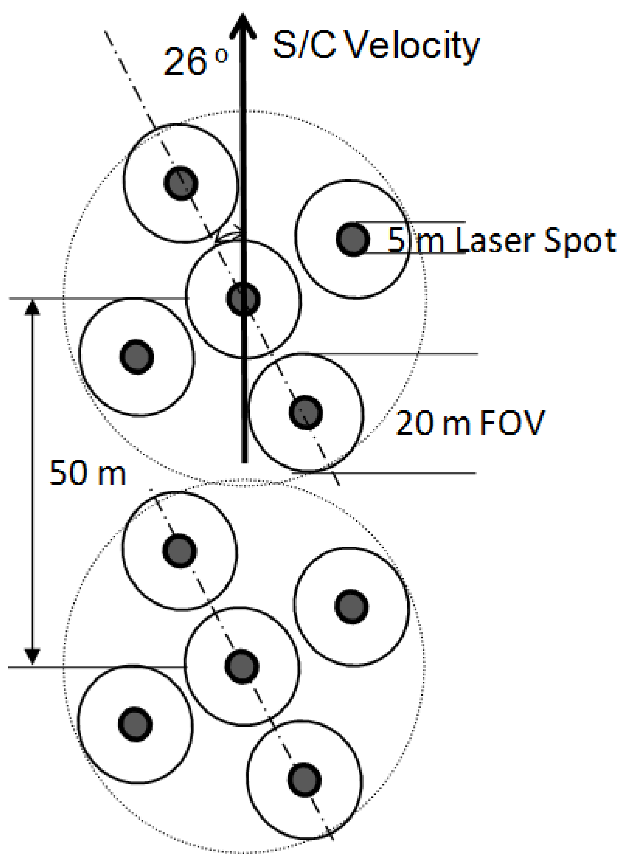

Fig. 3 LOLA Spot Pattern

A small kick-off mirror placed inside the laser box directs a small fraction of the laser power onto a silicon detector. The detector monitors the energy of the transmitted laser pulse and it is also used as a fire acquisition signal that turns off the drive to the pump diode lasers. In addition, the outgoing (transmit) pulse is time tagged and provides timing information for the time of flight measurement. The time tags of the transmit pulse serve as the "start" pulse timing for the TOF calculation.

LOLA Receiver

The LOLA receiver consists of a 14 cm clear aperture refractive telescope that focuses the received photons on to a fiber optic bundle. The effective focal length of the telescope is 500 mm. The design and materials of the telescope were chosen to minimize the thermal fluctuations expected on orbit. Since LOLA is not an imaging system, the objective is not to maintain a high image quality but to collect the maximum number of photons with the fewest possible losses and to minimize the background radiation. The telescope assembly includes a dielectric fold mirror, which lets all radiation other than 1064 nm pass through and reflects the laser radiation on the fiber optic bundle. This minimizes the amount of background solar radiation incident on the detectors. The fiber bundle consists of five identical fibers. Each fiber in the bundle directs the reflected energy into the aft-optics assembly for each detector. The aft optics consists of collimating and focusing optics to collimate the output of the fiber and send it on to the detector. A 0.8 nm bandpass filter angle-tuned to the laser wavelength is also included in the optical train to minimize the background solar radiation. The aft optics assemblies for detectors (channels) 2-5 are identical. Detector 1 houses the laser ranging aft optics. The aft-optics assembly mounts directly on a flange that is an integral part of the detector housing assembly. The housing assembly or detector plate includes the detector and all the associated electronics. The aft optics assembly includes a separate test port with an FC connector. The test port is intended for calibration purposes during instrument integration and testing. Signals from optical test sources can be injected into the test port and exercise the signal processing algorithms and electronics of the instrument. It is also possible to back-illuminate the detectors through the test port and monitor the field of view (FOV) and boresight alignment during the integration process.

RESULTS

The LOLA laser has been performing nominally since launch. The total accumulated laser shot counts is ~ 350 million (298 million in orbit) from Laser 1 and 283 million (260 million in orbit) from Laser 2 and there has been no indication of laser degradation on orbit.

The LOLA range measurement precision is 10 cm standard deviation based on the ground test results but difficult to verify on orbit due to the lunar surface roughness. However, the laser ranging measurements provide a measure of the altimetry accuracy. Fig. 4 shows an example of the LR measurement from one LRO orbit averaged over 5 seconds. The measurement precision is shown to be 9 cm (one standard deviation).

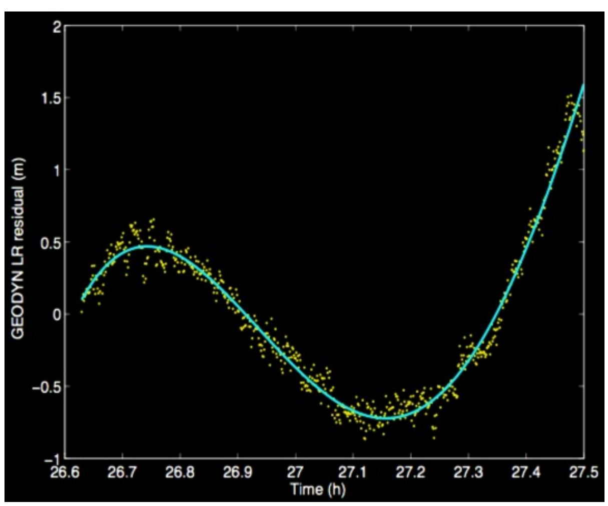

Fig. 4. Sample one-way laser ranging data from GGAO to LRO

Finally, a topographic map of the near side of the moon has been generated using one billion LOLA measurements (Fig. 5) at a spatial resolution of 20 meters along track and 0.1^{o} ground track spacing (4.5 km track spacing at equator and <200 m 5^{o} to the pole).

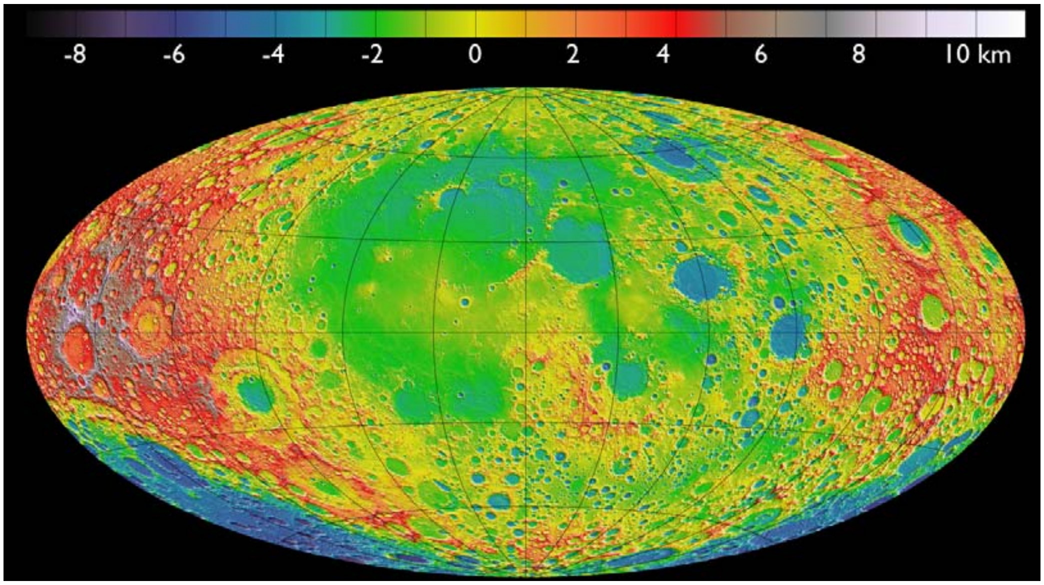

Fig. 5. Lunar topographic map with the first 1 billion LOLA measurements,

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