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Summary of the results from the lunar orbiter laser altimeter after seven years in lunar orbit

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ABSTRACT

In June 2009 the Lunar Reconnaissance Orbiter (LRO) spacecraft was launched to the Moon. The payload consists of 7 science instruments selected to characterize sites for future robotic and human missions. Among them, the Lunar Orbiter Laser Altimeter (LOLA) was designed to obtain altimetry, surface roughness, and reflectance measurements. The primary phase of lunar exploration lasted one year, following a 3-month commissioning phase. On completion of its exploration objectives, the LRO mission transitioned to a science mission. After 7 years in lunar orbit, the LOLA instrument continues to map the lunar surface. The LOLA dataset is one of the foundational datasets acquired by the various LRO instruments. LOLA provided a high-accuracy global geodetic reference frame to which past, present and future lunar observations can be referenced. It also obtained high-resolution and accurate global topography that were used to determine regions in permanent shadow at the lunar poles. LOLA further contributed to the study of polar volatiles through its unique measurement of surface brightness at zero phase, which revealed anomalies in several polar craters that may indicate the presence of water ice. In this paper, we describe the many LOLA accomplishments to date and its contribution to lunar and planetary science.

1. Introduction

The Lunar Reconnaissance Orbiter (LRO; Chin et al., 2007) was launched to the Moon on June 18, 2009 at 5:32 p.m. EDT (Vondrak et al., 2010). The purpose of the LRO mission was to obtain data about the Moon that will enable the future safe return of humans to the lunar surface, and to identify and characterize

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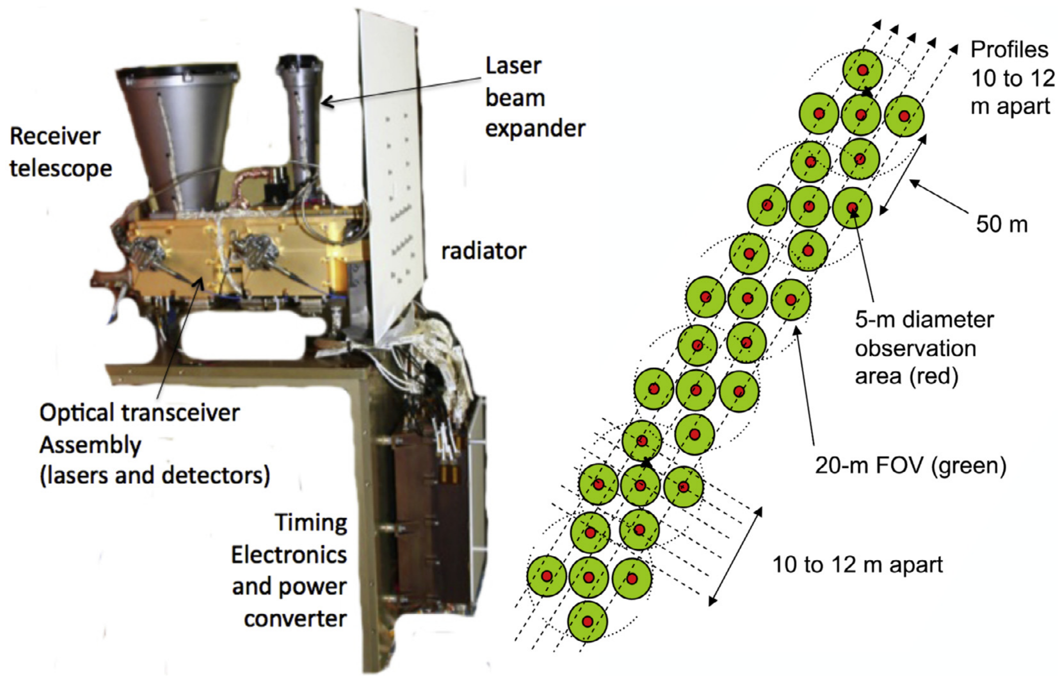

Fig. 1. The LOLA instrument (left) and the pattern of spots on the lunar surface (right). The red center spots are the areas illuminated by the laser and the green circles represent the fields of view of the corresponding detectors. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

scientifically interesting landing site locations. These goals formed the basis of the selection of the instrument suite and the initial spacecraft orbit. The Lunar Orbiter Laser Altimeter (LOLA; Smith et al., 2010) is one of the seven instruments onboard LRO, and was designed to acquire substantial topographic measurements in order to provide accurate relief information and a geodetic reference frame for all high-resolution datasets acquired by the spacecraft.

LOLA uses short pulses from a solid-state laser through a Diffractive Optical Element (DOE) to produce a five-beam pattern that illuminates the lunar surface (Smith et al., 2010). LOLA makes four types of measurements: the range between the spacecraft and the surface, the energy of the laser pulse reflected from the surface, the width of the return laser pulse, and the solar radiation reflected from the lunar surface. From these basic measurements, several scientific datasets are derived, including the topography, the albedo at the wavelength of the laser (1064.4 ± 0.1 nm; Smith et al., 2010), the roughness of the lunar surface within the footprint of each laser spot, and the 1064-nm reflectance of sunlight from the lunar surface.

In addition, LOLA enabled a Laser Ranging (LR) investigation (Zuber et al., 2010) by which laser pulses from Earth-based satellite laser ranging stations to LRO provided one-way range measurement. A small optical receiver mounted on the Earth-pointed high-gain antenna received the 532-nm pulses, which were passed to LOLA for precise timing via a fiber optic cable. This experiment provided additional tracking for LRO and enabled, for the first time, routine laser tracking of a spacecraft in lunar orbit.

LRO was placed in its commissioning, near-polar, eccentric orbit with low periapsis (~30-km altitude near the south pole) on June 27, 2009. Three months later, on September 27, the spacecraft entered its 50-km, near-circular mapping orbit, where it completed a one-year exploration mission for landing site characterization, and then started its science-driven mission. On December 11, 2011, the spacecraft was placed back in a near-frozen orbit (near constant periapse altitude and location) and altitude range of 30 km to 200 km to save fuel and extend the lifetime of the mission. In the spring of 2015, the orbit periapsis was lowered to 20–40 km.

Table 1
Instrument parameters and performance since start of operations, July 3, 2009, until March 1, 2016.

LOLA operation, 2009–2016	
Number of altimeter observations	6807,309,472
Number of laser firings	4000,021,600
Initial laser output (mJ)	2.5
Laser pulse rate (Hz)	28
Laser pulse width (ns)	5

2. The LOLA instrument

The LOLA instrument, shown in Fig. 1, is a laser ranging device that splits a pulsed laser beam into five output beams via a Diffractive Optical Element (DOE), has a single receiver telescope, and a detector for each of the beams. The LOLA ground pattern provides 5 profiles spaced approximately 12 m apart cross-track with measurements separated by 57 m along-track for each profile (from the average 50 km altitude). Fig. 1 shows the ground pattern of observations. Each beam provides a measurement of the round-trip time of flight (range), pulse spreading (surface roughness), and transmit/return energy (surface reflectance at the laser wavelength). The laser pulse energy, the receiver aperture size, and the spacecraft altitude limit the range precision to about 10 cm for a flat surface. As a consequence of its two-dimensional spot pattern, the instrument provides an unambiguous determination of both along-track and cross-track slopes along the spacecraft ground track (Fig. 2). LOLA has operated nearly continuously (exceptions discussed later) since July 3, 2009 (Table 1).

Laser altimetry from orbit requires the position and attitude of the spacecraft, and the altimeter's laser beam pointing with respect to the spacecraft coordinate system. To that end, several experiments were conducted to measure post-launch instrument