Introduction to special section on Results of the Lunar Reconnaissance Orbiter Mission

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[1] Since 2009 the Lunar Reconnaissance Orbiter (LRO) has made comprehensive measurements of the Moon and its environment. The seven LRO instruments use a variety of primarily remote sensing techniques to obtain a unique set of observations. The analyses of the LRO data sets have overturned previous beliefs and deepened our appreciation of the complex nature of our nearest neighbor. This introduction to the special section describes the LRO mission and summarizes some of the science results in the papers that follow.

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1. Introduction

[2] The Lunar Reconnaissance Orbiter (LRO), launched on June 18, 2009, carries seven instruments that make comprehensive remote sensing observations of the Moon and measurements of the lunar radiation environment. These measurements provide new information regarding the physical properties of the lunar surface, the lunar environment, and the distribution of volatiles and other resources. Scientific interpretation of these observations improves our understanding of the geologic history of the Moon, its current state, and what its history can tell us about the evolution of the Solar System. This issue contains papers reporting some of the initial science results of the LRO mission.

[3] LRO was initially conceived, funded, and implemented by NASA's Exploration Systems Mission Directorate as an Exploration Mission with the goal of seeking safe and attractive landing sites for future robotic missions and the return of humans to the Moon. In addition, LRO objectives included the search for surface resources and the measurement of the lunar radiation environment. After spacecraft commissioning in lunar orbit, the Exploration Mission began on September 15, 2009 and was completed on 15 September 2010 when operational responsibility for LRO was transferred to NASA's Science Mission Directorate for a two-year Science Mission with a new set of focused science goals. Upon successful completion of the Science Mission, LRO began an Extended Science Mission that is scheduled to continue until September 2014.

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2. LRO Measurements

[4] The LRO instruments use a variety of techniques to obtain a unique set of observations of the Moon and its environment. These instruments, which were previously described in detail [*Vondrak et al.*, 2010], are as follows:

[5] *Lunar Orbiter Laser Altimeter* (*LOLA*). Principal Investigator (PI), David Smith (NASA Goddard Space Flight Center, Greenbelt, MD): a system that splits a single laser pulse into five laser spots at 28 times per second to measure topography, slopes and roughness.

[6] *Lunar Reconnaissance Orbiter Camera* (*LROC*). PI, Mark Robinson (Arizona State University, Tempe, Arizona): consisting of two narrow-angle cameras with a spatial resolution of 50 cm from an altitude of 50 km and an ultraviolet/visible wide-angle camera for global imaging in seven color bands with 100 m resolution.

[7] *Lunar Exploration Neutron Detector* (*LEND).* PI, Igor Mitrofanov (Institute for Space Research, and Federal Space Agency, Moscow): neutron albedo measurements in three energy bands for detection of subsurface hydrogen.

[8] *Diviner Lunar Radiometer Experiment* (*Diviner*). PI, David Paige (University of California, Los Angeles, California): a nine-channel infrared radiometer to measure thermal state, rock abundance, and regolith composition.

[9] *Lyman-Alpha Mapping Project* (*LAMP*). PI, Kurt Retherford (Southwest Research Institute, Boulder, Colorado): a far ultraviolet imaging spectrometer to measure water frost in permanently shadowed regions and the components of the lunar exosphere.

[10] *Cosmic Ray Telescope for the Effects of Radiation* (*CRaTER*). PI, Harlan Spence (University of New Hampshire, Durham, New Hampshire): an energetic particle detector system to measure galactic cosmic rays and solar energetic particle events.

[11] *Mini Radio-Frequency Technology Demonstration* (*Mini-RF*). PI, Ben Bussey (Applied Physics Laboratory, Laurel, Maryland): a synthetic aperture radar to measure regolith properties and search for subsurface ice.

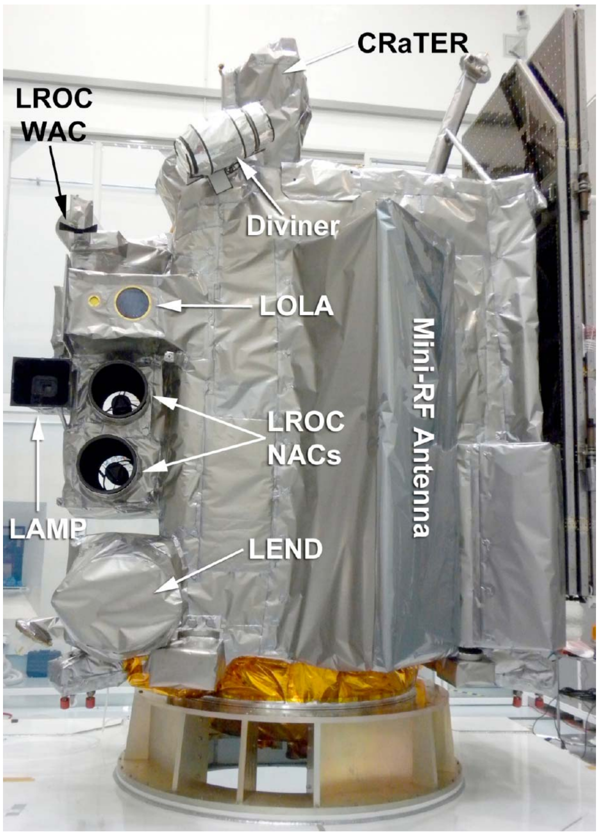

Figure 1. The fully assembled LRO spacecraft before launch.

[12] The locations of the instruments on the LRO spacecraft are shown in Figure 1.

3. LRO Operations

[13] LRO is a 3-axis stabilized spacecraft that is generally pointed in a nadir direction to allow continuous mapping of the lunar surface by the remote sensing instruments. The spacecraft is able to slew for instrument calibrations and specialized measurements, such as exospheric measurements and stereo imaging. Off-nadir operations were often more complex during the Science Mission than during the Exploration Mission, which was generally devoted to nadir observations. Spacecraft and mission operations are at the Mission Operations Center at the Goddard Space Flight Center and the instrument operations are led by Science Operation Centers at the seven instrument institutions, which are also responsible for instrument data processing and deliveries to the Planetary Data System (PDS).

[14] To provide a substantial capability to adjust its orbit, nearly half of the LRO spacecraft mass at launch was hydrazine fuel. The evolution of the LRO mission orbit is shown in Figure 2. LRO was initially placed during its commissioning phase into a 30 km × 200 km quasi-stable polar orbit with periselene over the south pole, an orbit that is fuel efficient to maintain. On September 15, 2009 it was moved to a quasi-circular mapping orbit that was maintained at 50 km mean altitude with monthly station-keeping propulsive maneuvers. In August and November of 2011 the periselene was lowered to 21 km in order to obtain high resolution imaging of the Apollo landing sites and other locations of high scientific interest. With diminishing fuel, on December 11, 2011 the LRO spacecraft was returned to the 30 km × 200 km quasi-stable polar orbit, which can be maintained for at least six years with the existing fuel reserves.

4. Data Access

[15] An important capability for LRO is the very high downlink data rate, which is enabled by both the proximity of the Moon to the Earth and the use of a dedicated Ka band telemetry ground station at White Sands, NM. The LRO data are added to the Planetary Data System (PDS) at three-month intervals, with a latency of no more than six months. These deliveries include not only raw and calibrated data, but also higher-level data products, such as maps of

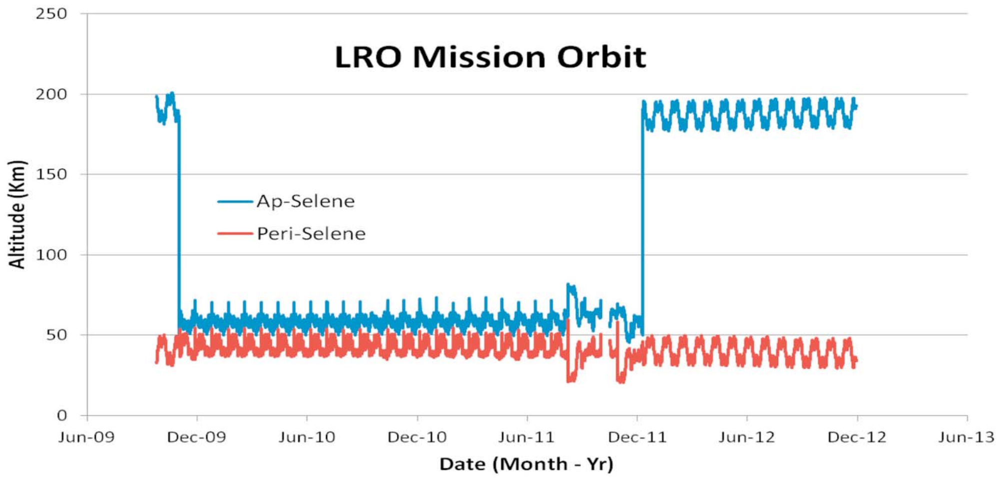

Figure 2. The evolution of LRO's orbit around the Moon. The elliptical orbit (30 × 200 km) was used during commissioning. For the Exploration Mission and much of the Science Mission the orbit was 50 km quasi-circular, with short excursions to lower altitudes. In December 2012 LRO was returned to the commissioning orbit.

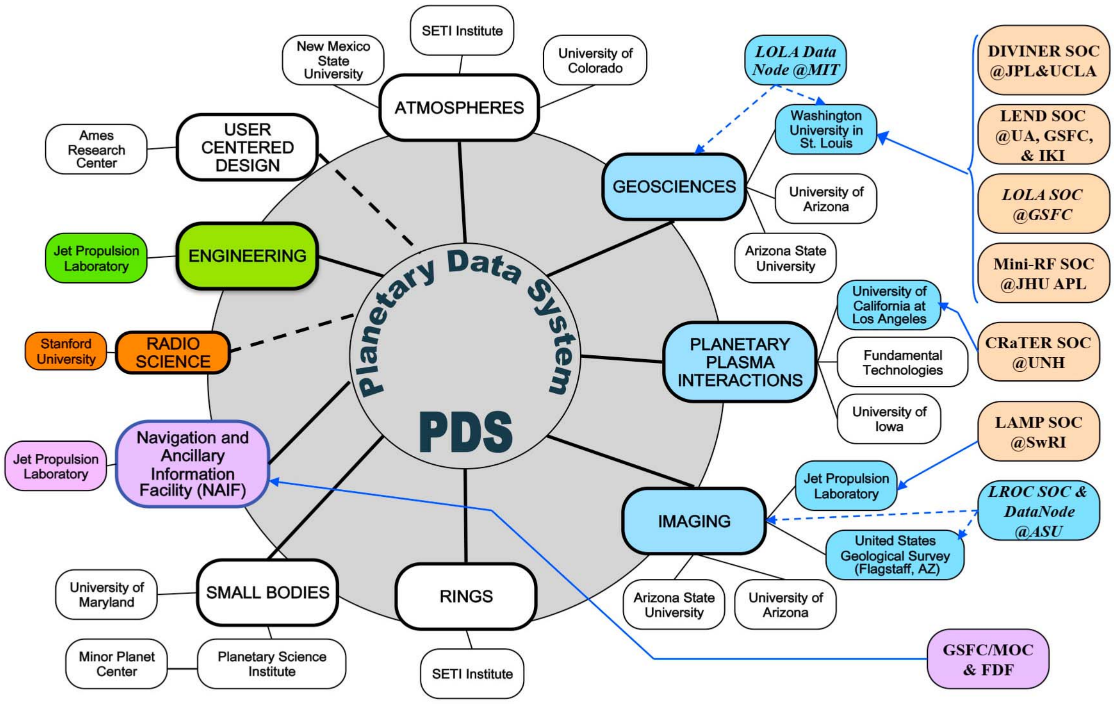

Figure 3. The LRO instrument data archive architecture, showing the relationship of each instrument Science Operation Center (SOC) to the PDS Nodes and Data Nodes.

geophysical quantities. Figure 3 shows the LRO instrument data archive architecture and the relationship of each instrument Science Operation Center (SOC) to the PDS Nodes and Data Nodes. As of September 15, 2012 more than 350 Terabytes of LRO measurements have been made available for use by scientists and the public.

5. Summary of LRO Science Objectives and Accomplishments

[16] The science objectives for the LRO Science Mission addressed five specific themes. These themes and some of the science results described in this special issue are:

[17] 1. *The bombardment history of the Moon*.

Developed an improved understanding of the ancient impactor populations that affected all the planets in the inner Solar System, through analysis of global high-resolution topography.

Improved the age dating of landforms by using crater counts from the new high-resolution images with Sun angles and illumination geometry optimized for morphology.

[18] 2. *Lunar geologic processes*.

Discovered the global population of small-scale, relatively young compressional structures that show the Moon is in a general state of relatively recent contraction.

Characterized volcanic complexes, such as Ina, which appear to result from inflated lava flows.

[19] 3. *The processes that have shaped the global lunar regolith*.

Determined the global distribution of regolith surface temperature and rock abundance.

Discovered that impact melt occurs as pools in lunar craters as small as 170 m, and that rough subsurface melt may extend beyond the visible surface melt.

[20] 4. *Characterization of the volatiles on the Moon with emphasis on the polar regions*.

Discovered significant subsurface hydrogen deposits in sunlit areas as well as in some, but not all, permanently shadowed regions.

Measured surprising amounts of several volatiles (e.g. CO, H_2, and Hg) in the gaseous cloud released from Cabeus by the LCROSS impact.

[22] 5. *The Moon's interaction with its external space environment*.

Measured galactic cosmic ray interactions with the Moon during a period with the largest space age cosmic ray intensities.

Created the first cosmic ray albedo proton map of the Moon.

[23] These results and many others are described in the papers in this issue. These analyses of the rich data sets collected during the first three years of LRO operations are being used to overturn previous beliefs and to deepen our appreciation of the complex nature of our nearest neighbor. The brief summary presented here demonstrates the extraordinarily abundant scientific yield from the continued observations by LRO.

[24] **Acknowledgements.** LRO accomplishments are the result of the LRO Science Team that developed the LRO instruments and analyzes the observations, as well as the LRO Project at Goddard Space Flight Center that developed and operates the LRO spacecraft. I am grateful for valuable discussions with John Keller and Noah Petro.

References

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