THE LUNAR RECONNAISSANCE ORBITER CORNERSTONE MISSION: A FOCUSED AND SYNERGISTIC STUDY OF FUNDAMENTAL SOLAR SYSTEM PROCESSES AT THE MOON.

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Introduction: The Lunar Reconnaissance Orbiter mission (LRO) is in the first year of a two-year extension, running through September 2018, to study the fundamental processes recorded on the Moon. LRO's instruments are measuring processes that operate not only at the Moon but also generally throughout the Solar System, especially on bodies without a significant atmosphere. This "Cornerstone Mission" (CM) employs all seven LRO instruments (including the return of Mini-RF to operational status) in a mission-wide approach to constrain science questions. This synergistic approach allows processes to be constrained at distinct spatial (both lateral and vertical) and temporal scales. These processes are divided into three distinct eras of lunar history.

Contemporary Processes: LRO has been at the Moon for over 7 years, making it NASA's longest duration lunar and airless body orbital mission. This unprecedented baseline of observations enables fundamentally new science, especially in observations of subtle changes to the lunar surface and its environment.

Evolutionary Processes: LRO will look to the recent geologic past to study processes taking place within the interior and their reflection on the surface, such as those that provide evidence of the Moon's recent volcanism, and the evolution of the regolith.

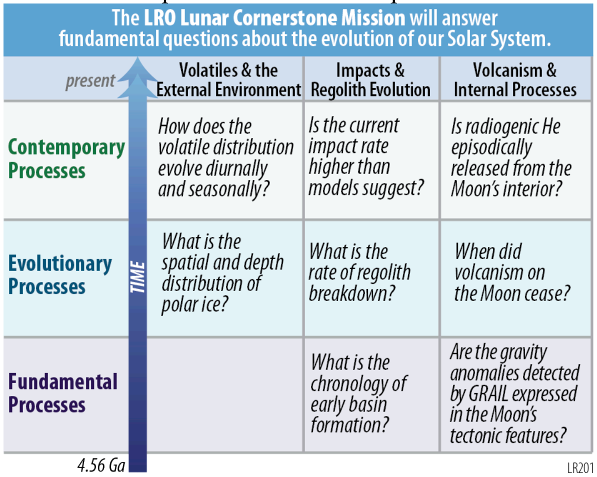
Fundamental Processes: Reaching farther back in time, LRO will employ new observations to determine the relative timing and duration of basin-forming impacts during the proposed period of Late Heavy Bombardment, the formation and evolution of the early crust, and the styles of early volcanism.

Science Focus During the CM: The LRO science teams identified three science themes for the CM, which build on Decadal-relevant science questions: 1) Volatiles and the Space Environment, 2) Volcanism and Interior Processes, and Impacts and 3) Regolith Evolution. A few examples of the science questions we will address during the CM are illustrated in Figure 1.

New Modes of Instrument Operations and Campaigns: As part of the senior review process, the LRO instruments developed new modes of operations or data collection campaigns. These new modes and campaigns offer fundamentally new measurements and capabilities to the mission. Over the two years of the CM, these new modes and campaigns will be employed in a cadence, typically dependent on beta-angle, orbital altitude, and meteor shower activity.

LAMP's New Mode: LAMP has established a new mode of sensitive dayside operations by opening a failsafe door. This device is intended as a one-time event to guard against a possible failure of the main aperture door. To limit the flux of dayside signal to a comparable level for nightside observations, the aperture door includes a pinhole with 0.13% throughput compared with the door-open nightside mode. Opening the failsafe mechanism expands the throughput from the 0.13% pinhole aperture to 10.7%, providing an up to 80x increase in dayside count rates. LAMP dayside measurements in this mode will assist the detection of surface hydration.

Mini-RF X-Band Measurements: While the Mini-RF instrument did not operate during ESM2, the team continued the analysis of bistatic observations collected during ESM1. Those data provide direct evidence for wavelength-scale deposits of water ice (10s of cm) within the upper meter of the floor of Cabeus crater [1]. On the basis of this positive result, a new mode of bistatic operation is proposed for the CM that utilizes the Goldstone deep space communications complex 34 meter antenna DSS-13 in concert with the Mini-RF receiver to observe the Moon at X-band wavelengths (4.2cm). DSS-13 will provide additional operational capability than is possible with the Arecibo Observatory and the X-band data collected will provide important information on the vertical distribution of potential water ice deposits.



The LRO Lunar Cornerstone Mission will answer fundamental questions about the evolution of our Solar System.

	Volatiles & the External Environment	Impacts & Regolith Evolution	Volcanism & Internal Processes
Contemporary Processes	How does the volatile distribution evolve diurnally and seasonally?	Is the current impact rate higher than models suggest?	Is radiogenic He episodically released from the Moon's interior?
Evolutionary Processes	What is the spatial and depth distribution of polar ice?	What is the rate of regolith breakdown?	When did volcanism on the Moon cease?
Fundamental Processes		What is the chronology of early basin formation?	Are the gravity anomalies detected by GRAIL expressed in the Moon's tectonic features?

Figure 1. During LRO's CM, the LRO science team a will address a number of science questions directly related to fundamental Solar System science, which cover processes that have acted over billions of years.

PDS Data Deliveries: LRO will continue to deliver data to the PDS at a three-month cadence. Currently over 700 Tb of data has been delivered to the

PDS, the largest data volume of any NASA Planetary Science Division mission. A number of higher level data products are in the PDS archive, including mosaics, topographic products, and derived products (*e.g.*, rock abundance from Diviner [2], local slope [3]). These products are available on the LRO PDS archive [4] and on individual teams websites [e.g., 5, 6].

LRO's Orbit Enables Fundamental New Science: LRO has maximized its science return by employing a quasi-stable orbit for more than 5 years, which has minimized fuel consumption. In this configuration, which has LRO with a low periapsis over the southern hemisphere (Figure 2), enables focused investigations on the region surrounding the South Pole [e.g., 7, 8].

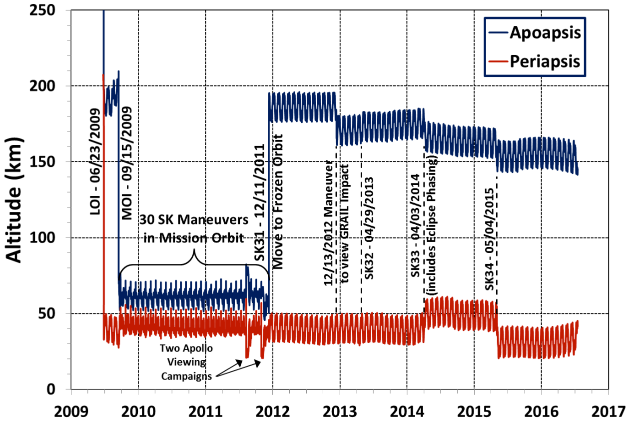


Figure 2. Plot showing the evolution of the LRO orbit since arriving at the Moon in 2009. Since late 2011 LRO has been in a quasi-stable elliptical orbit that allows for a significant reduction in fuel consumption. In this orbit configuration, LRO has made a station-keeping maneuver each year except in 2016.

This quasi-stable orbit also enables a long duration mission, allowing for studies of surface changes that necessitate an extended baseline. An example of such observations are the identification of newly formed impact craters and surface splotches [9]. This discovery offers, for the first time, the opportunity to characterize the current crater production rate and the rate at which the uppermost portion of the regolith is churned.

Scientific Productivity: Recently, a three volume special issue of Icarus has been published featuring manuscripts from each of the instruments as well as from outside the LRO teams [10-12]. These special issues are the largest produced by Icarus, and illustrate the continuing contributions to lunar and planetary science by the LRO teams.

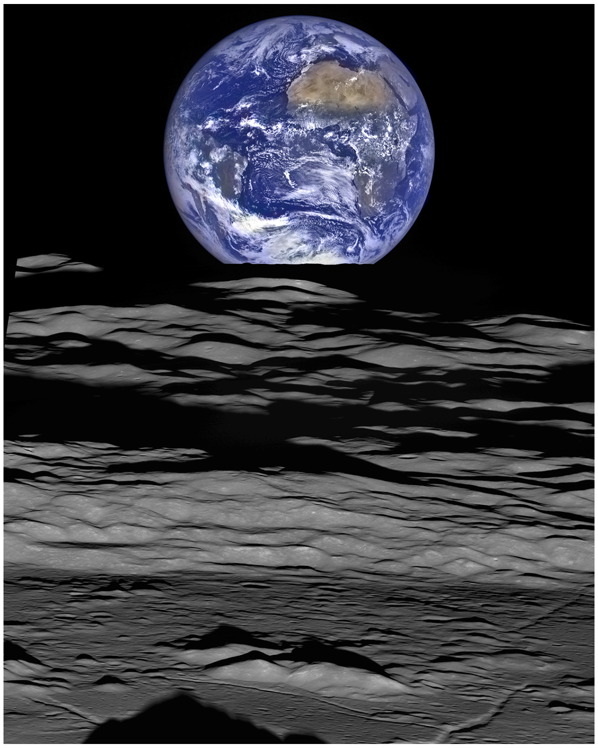


Figure 3. Image of the Earth setting over the limb of the Moon (Compton Crater is in the foreground), illustrating the close connection between the Moon and the Earth. LROC NAC image M1199291564L with WAC color for the Earth.

Conclusions: LRO remains a highly productive, scientifically compelling mission [12]. During its Cornerstone Mission LRO will continue to advance the leading edge of lunar and Solar System science (Figure 3). The LRO mission looks forward to many more years of providing critical data for the revolution in our understanding of the Moon, and by association the Solar System.

References: [1] Patterson, G. W., et al., (2017) *Icarus*, 283, 2-19. [2] Bandfield, J. L., et al., (2011) *J. Geophys. Res.*, 116, E00H02. [3] Rosenburg, M. A., et al., (2011) *Journal of Geophysical Research*, 116, E02001. [4] LRO PDS Archive, (http://pds-geosciences.wustl.edu/missions/lro/). [5] LROC RDR Page, (http://wms.lroc.asu.edu/lroc/rdr_product_select - _ui-id-1). [6] Lunar Reconnaissance Orbiter: Lunar Orbiter LASER Altimeter (LOLA) PDS Node, (http://imbrium.mit.edu). [7] Sanin, A. B., et al., (2017) *Icarus*, 283, 20-30. [8] Hayne, P. O., et al., (2015) *Icarus*, 255, 58-69. [9] Speyerer, E. J., et al., (2016) *Nature*, 538, 215-218. [10] Keller, J. W., et al., (2016) *Icarus*, 273, 1. [11] Keller, J. W., et al., (2016) *Icarus*, 273, 2-24. [12] Petro, N. E., et al., (2017) *Icarus*, 283, 1.