THE LUNAR RECONNAISSANCE ORBITER: REVOLUTIONIZING OUR UNDERSTANDING OF THE DYNAMICS OF PLANETS AND THE ROLE OF VOLATILES IN THE SOLAR SYSTEM. N. E. Petro and J. W. Keller, NASA Goddard Space Flight Center, Solar System Exploration Division (Noah.E.Petro@nasa.gov; John.W.Keller@nasa.gov)

Introduction: The LRO mission, currently in an extended mission phase, is producing a remotely sensed dataset that is unrivaled in planetary science. With an ever-increasing baseline of measurements the LRO data has revealed the Moon's surface and environment to be dynamic, with new craters and distal ejecta, variations in volatiles at and near the surface, a variable exosphere, and a surface that responds to variations in the flux of radiation from the Sun. Taken together the LRO dataset has significant value in forming how we understand airless bodies work in the Solar System and how planets evolve.

LRO is currently in an extended mission phase and the LRO science team is currently preparing to propose a new two-year mission phase to start in October 2016. During the LRO extended mission, the instruments continue to operate with no significant degradation, while we seek new and innovative ways to operate the spacecraft in order to conserve manpower, funds, and spacecraft resources. One way LRO has conserved fuel is through the use of an eccentric orbit (Figure 1) that requires a modest amount of fuel to maintain per year (~2 kg per year). In this orbit, at the current rate of fuel consumption, LRO could operate for at least 6 more years. Additional methods to conserve fuel are being explored that could extend the lifetime of LRO much further.

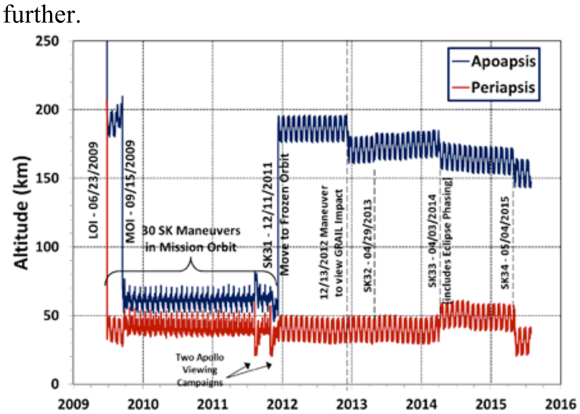

Figure 1. Evolution of the LRO orbit since arriving at the Moon in June 2009. Since November 2011 LRO has been in a "quasi-frozen" orbit that requires yearly burns to maintain.

In the six plus years of LRO operations all seven LRO instruments have made a number of paradigm-shifting discoveries. We list several examples here.

Geologically Young volcanism: LRO NAC images of irregular mare patches (IMPS), typified by the Ina D feature (Figure 2), have been used to determine model ages of the volcanic features. The crater size frequency distributions of these features suggest that the IMPs are 100 million years old or less [1]. This young age significantly extends the duration of volcanism on the Moon and implies that the lunar interior has been hot enough to support small-scale volcanism for much longer than previously believed.

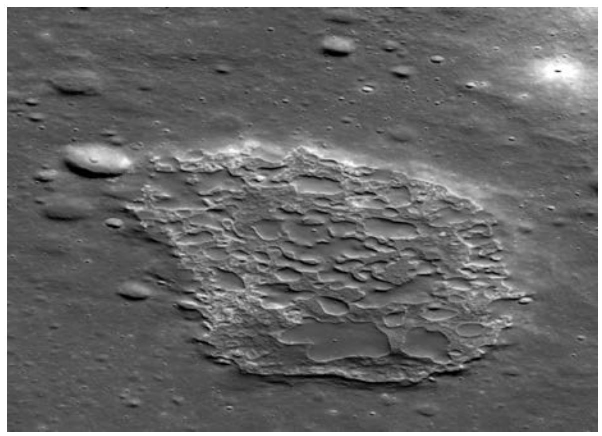

Figure 2. LROC NAC oblique view of Ina D, which is 2 km wide and roughly 50 m deep. LROC image M1108203502.

Time variable surface frost: A joint investigation between the LOLA and Diviner teams is measuring the surface properties of areas near the lunar South Pole that are illuminated for short periods of time during the lunar day. Using Diviner temperature measurements, areas that are cold for much of the lunar day and heat up briefly when illuminated are currently being measured by LOLA [2, 3]. LOLA active laser measurements are converted to albedo [4] (Figure 3) and appear to show a change in reflectance between day and night in these areas, with the surfaces being higher in reflectance at night. This variation suggests that a surface frost is formed at night when ice may be stable at the surface.

Volatiles At and Near the Surface: One of LRO's initial goals was to identify the distribution and abundance of volatiles in polar regions. With the discovery of broadly distributed volatiles in the form of hydroxyls LRO's search for volatiles expanded beyond the areas near the poles in permanent shadow.

Results from both the LEND and LAMP instruments show that not only are there volatiles at and near the surface well beyond polar craters, but that the abundance appears to vary as a function of time of lunar day [5, 6]. Both LEND and LAMP have shown that not all permanently shadowed craters are created equally, that across three large PSR regions in the South Pole (Faustini, Shoemaker, and Haworth) the amount of surface water ice is variable [7].

Additionally, an integration of LEND data with LOLA topography has shown that there are geophysical constraints on the distribution of hydrogen, specifically pole-facing crater walls appear to be enhanced in hydrogen relative to equator-facing walls [8]. Such studies were not possible before the availability of both high spatial resolution neutron and topographic data.

Figure 3. LOLA derived reflectance at 1064-nm of the near (top left), far (top right), northern (bottom left), and southern (bottom right) hemispheres.

Radiation Interactions with the Lunar Surface: The CRaTER instrument has proven to be remarkably flexible, making detailed measurements of the radiation environment at the Moon, in the form of both solar radiation and Galactic Cosmic Rays. In addition to measuring radiation directly radiated from the Sun, CRaTER measures radiation reflected and emitted from the lunar surface [9]. The measure of lunar protons, and the proton albedo of the Moon is revealing surprising heterogeneity in the lunar surface with an, as of yet, unexplained source. Additionally, preliminary analysis of polar data from CRaTER suggests that there is a signature of thick hydrogen deposits at the poles, including areas that are illuminated, in agreement with results from LEND [10].

Constraining the LRO-era Cratering Rate: Repeat imaging by the LROC NAC has revealed a number of LRO-era impact craters [11] (Figure 4). As the LRO mission continues, the temporal baseline expands enabling the identification of additional new craters that better constrains the flux of small objects in the inner solar system. Additionally, the expression and extent of ejecta (both continuous and distal) offers a unique opportunity to directly study the effects cratering.

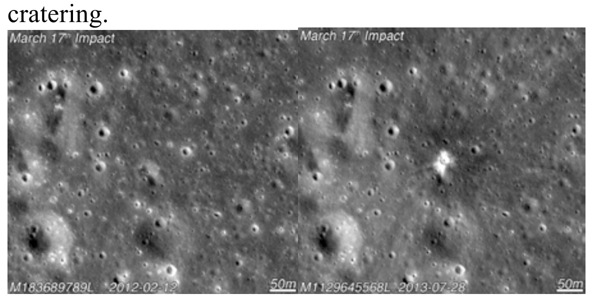

Figure 4. Temporal pair of LROC NAC images, showing the 18 m diameter crater that formed on March 17, 2013 [11].

Future Prospects for LRO: The LRO instrument suite has experienced no significant degradation in performance over the past two years, and fuel has been conserved in LRO's elliptical orbit (Figure 1). The LRO Project is currently formulating a proposal for the next NASA Planetary Science Senior Review (in early 2016). Such a proposal would fund LRO for two years starting in October 2016. A new mission to the Dynamic Moon with LRO would continue the high-paced discoveries the LRO science teams have made, and contribute in fundamental ways to our understanding of the entire Solar System. Using the 2011 Decadal Survey [12] as a guide, we will make significant contributions to our understanding of the geologic past (and present) of the dynamic Moon.

References: [1] Braden, S. E., et al., (2014) *Nature Geosci*, 7, 787-791. [2] Lemelin, M., et al., (2014) *AGU Fall Meeting Abstracts*, 13, 3832. [3] Lucey, P. G., et al., (2014) *LPI Contributions*, 1820, 3015. [4] Lucey, P. G., et al., (2014) *Journal of Geophysical Research (Planets)*, 119, 1665-1679. [5] Hendrix, A. R., et al., (2012) *Journal of Geophysical Research: Planets*, 117, E12001. [6] Livengood, T. A., et al., (2015) *Icarus*, 255, 100-115. [7] Hayne, P. O., et al., (2015) *Icarus*, 255, 58-69. [8] McClanahan, T. P., et al., (2015) *Icarus*, 255, 88-99. [9] Wilson, J. K., et al., (2012) *J. Geophys. Res.*, [10] Schwadron, N., (2015), *These proceedings*,Abst. [11] Robinson, M. S., et al., (2015) *Icarus*, 252, 229-235. [12] Planetary Science Decadal Survey, (2011) *Vision and Voyages for Planetary Science in the Decade 2013-2022*, 400 p.