PRELIMINARY RESULTS ON THE STRUCTURE OF LUNAR HIGHLAND CRUST FROM GRAIL GRAVITY AND LOLA ALTIMETRY. Maria T. Zuber[1], David E. Smith[1], Sami W. Asmar[2], Alexander S. Konopliv[2], Frank G. Lemoine[3], H. Jay Melosh[4], Gregory A. Neumann[3], Roger J. Phillips[5], Sean C. Solomon[6], Michael M. Watkins[2], Mark A. Wieczorek[7], James G. Williams[2], James W. Head III[8], Erwan Mazarico[1], Mark H. Torrence[9], [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02129-4307, USA (mtz@mit.edu); [2]Jet Propulsion Laboratory, Pasadena, CA 91109-8099, USA; [3]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA; [4]Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, USA; [5]Planetary Science Directorate, Southwest Research Institute, Boulder, CO 80302, USA; [6]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; [7]Institut de Physique du Globe de Paris, 94100 Saint Maur des Fossés, France; [8]Department of Geological Sciences, Brown University, Providence, RI 02912, USA; [9]SGT, Inc., Greenbelt, MD 20770, USA.

Introduction: The lunar crust is the product of early melting and preserves the surficial and shallow subsurface record of the Moon's post-accretional evolution. Deciphering this record requires an understanding of crustal composition, volume, structure and physical state [*e.g.,* 1]. Substantial advances in our geophysical understanding of the lunar crust are now possible due to recent and ongoing acquisition of high-resolution topography and gravity data sets from the Lunar Orbiter Laser Altimeter (LOLA) [2] and Gravity Recovery and Interior Laboratory (GRAIL) mission [3].

LOLA Altimetry: LOLA [2], a payload instrument on NASA's Lunar Reconnaissance Orbiter mission [4], has been operating nearly continuously in lunar orbit since 13 July 2009. LOLA is a multi-beam laser altimeter that operates at a wavelength of 1064.4 nm with a 28-Hz pulse repetition rate. The instrument's configuration and sampling strategy produce five parallel profiles along LRO's sub-spacecraft ground track. Surface spots are 5 m in diameter, profiles are 10-12 m apart, and observations along each profile are separated by ~56 m, determined by the laser pulse repetition rate and spacecraft velocity. At this point in the LRO extended mission, LOLA has collected over 5×10^9 valid measurements of elevation with a ranging precision of 10 cm and radial accuracy of <1 m. The along-track resolution is ~20 m, and average cross-track resolution is <1 km at the equator and decreases poleward.

A recent LOLA topographic model is shown in Fig. 1. LOLA altimetry has been used to assemble a precise global model of lunar topography. The global grid currently in the NASA Planetary Data System (PDS) is LDEM_512, with a pixel size in latitude of 59.225 m. A spherical harmonic expansion of the gridded data to degree and order 720 (spatial block size 7.5 km) has permitted refinement of fundamental parameters of the lunar shape [5], as well as studies of global bombardment [6] and local studies of landform evolution [7].

GRAIL Gravity: GRAIL [3] is the lunar analog of the very successful GRACE [8] twin-spacecraft terrestrial gravity recovery mission that continues to map Earth's gravity field since its launch in 2007. GRAIL was implemented with a science payload derived from GRACE and a spacecraft adapted from the Lockheed Martin Experimental Small Satellite-11 (XSS-11) mission, launched in 2005.

GRAIL has two primary objectives: to determine the structure of the lunar interior, from crust to core; and to advance understanding of the thermal evolution of the Moon. In addition, as a secondary objective, GRAIL observations will be used to extend knowledge gained on the internal structure and thermal evolution of the Moon to other terrestrial planets.

From the mapping orbit, GRAIL acquires high-precision range-rate measurements of the distance change between the two spacecraft using a Lunar Gravity Ranging System (LGRS) [9], built by the Jet Propulsion Laboratory. The LGRS consists of dual Ka-band (32 GHz) transmitters and microwave antennae that measure the inter-satellite distance change, and S-band (2 GHz) Time Transfer Systems that are used to correlate time between the spacecraft. Ultra-Stable Oscillators (USOs), built by The Johns Hopkins University Applied Physics Laboratory, drive both the Ka-band and S-band systems. Also referenced to the same USO is an X-band (8 GHz) beacon from each spacecraft to ground stations, independent of the telecommunications system, for precise Doppler and monitoring the payload's performance. The spacecraft-to-spacecraft range-rate data provide a direct measure of lunar gravity that leads to a high-spatial-resolution, high-accuracy global gravity field.

GRAIL began collecting data on 1 March 2012 and has completed two of three month-long mapping cycles in the primary mission. In these first two mapping cycles more than 99.99% of the acquired observations were successfully received by the Deep Space Network [10]. Preliminary gravity models reveal low noise levels to the shortest wavelengths resolved thus far, indicating that additional signal exists at even shorter wavelengths than the nominal planned field (degree and order 180) in at least some regions of the Moon. There is a high correlation of gravity with topography to much higher high degrees and orders than with any previous gravity model [*e.g.,* 11- 13].

Shallow Interior Structure of the Moon: Understanding the role of the highland crust in the thermal evolution of the Moon [*cf.* 14, 15] requires global models of crustal thickness as well as the effective elastic thickness of the lithosphere, both of which are derived from a combination of global, high-resolution gravity and topography data. The volume of the crust provides an important constraint on the extent of melting of the magma ocean, and its distribution forms the basis for models of crustal evolution. Variations in crustal thickness may reflect spatial variations in melting and/or re-distribution by impact at a range of scales. The effective elastic thickness yields the thermal structure in the shallow Moon at the time of surface or subsurface loading. Such analysis is particularly valuable in reconstructing the thermal state of the Moon during and subsequent to the late heavy bombardment of the lunar crust. Estimation of physical properties such as density [16], porosity [17] and the extent of crustal brecciation [18] and intrusive magmatism [19] is also possible and underway.

Topography and gravity maps in the vicinity of Tycho crater, shown in Fig. 2, underscore the promise of advancing understanding of lunar crustal structure.

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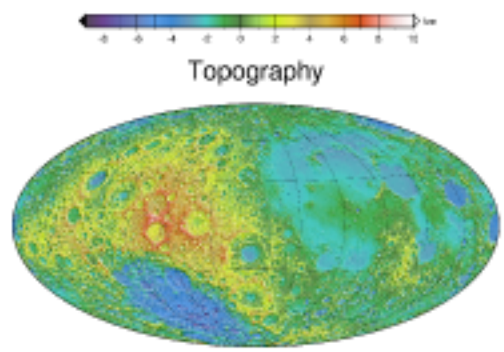

Figure 1. Hammer equal-area projection of LOLA topography [5]. The central longitude is 270°E; nearside is on the right and the farside is on the left.

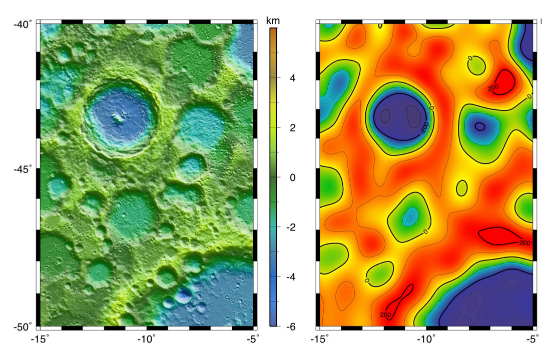

Figure 2. LOLA topography (left) and preliminary GRAIL gravity field (right) for the 86-km-diameter Tycho crater. In both panels Tycho is the prominent structure at upper left. In the GRAIL map reds correspond to mass excesses and blues to mass deficits. Here LOLA topography has a spatial resolution of 0.24 km and GRAIL gravity has a spatial resolution of 18 km.