GRAVITY RECOVERY AND INTERIOR LABORATORY (GRAIL): ANALYSIS STATUS AND IMPLICATIONS FOR UNDERSTANDING THE ROLE OF IMPACTS IN LUNAR AND PLANETARY EVOLUTION.

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Introduction: The Gravity Recovery and Interior Laboratory (GRAIL) [1], NASA's eleventh Discovery mission, successfully executed its Primary Mission (PM) in lunar orbit between March 1, 2012, and May 29, 2012. GRAIL's Extended Mission (XM) initiated on August 30, 2012, and its endgame was successfully completed on December 14, 2012. High-resolution models of the lunar gravity field, combined with topography from the Lunar Orbiter Laser Altimeter [2], are enabling geophysical analyses that elucidate the role of large impacts on the evolution of the Moon, and by extension, other terrestrial planets.

Primary and Extended Missions: GRAIL launched on September 10, 2012, and the dual spacecraft executed independent low-energy trajectories to the Moon via the EL-1 Lagrange point, inserting into lunar orbit on December 31, 2011, and January 1, 2012. After a series of maneuvers to decrease orbital periods and align the spacecraft into ranging configuration, the PM initiated on March 1, 2012. Initial analysis led to a spherical harmonic model of the gravitational field to degree and order 420 (spatial block size = 13 km), named GL0420A [3], that is improved in spatial resolution by a factor of 3-4 and in quality by three to more than five orders of magnitude in comparison with previous lunar gravity models from the Lunar Prospector (LP) [4] and Kaguya [5] missions. Subsequent analysis of the PM observations has enabled the production of independent spherical harmonic models by science team members at the Jet Propulsion Laboratory (JPL) [6] and Goddard Space Flight Center (GSFC) [7], both to degree and order 660 (spatial block size = 8.3 km).

GRAIL's XM average altitude was 23 km, less than half the average altitude of the PM. Because of the low orbital altitude, XM operations were far more complex than in the PM [8]. Unlike the PM, which featured only one thrust maneuver to change the mutual drift rate of the spacecraft over three months of mapping, the XM required three maneuvers a week to maintain the mapping altitude [9]. The quality of the data coupled with the low mapping altitude in the XM dictated that much higher resolution gravitational fields were possible in comparison to that originally envisioned. Current gravity fields produced at JPL and GSFC are to degree and order 780 (spatial block size = 7 km) and 900 (spatial block size = 6 km), the latter a factor of two improved spatial resolution compared to GL0420A [3].

At spherical harmonic degrees <60 (spatial block size = 91 km) corresponding to spatial scales of major lunar basins, the GRAIL models are now improved by as much as 10^6 over LP and Kaguya. Gravity and topography are highly coherent at degrees >100 (spatial block size = 55 km), interpreted to be a consequence of significant impact-related fracturing of the upper lunar crust and regolith re-distribution [3]. High coherence extends to increasingly small spatial scales as the lunar gravity field resolution is increased.

Additional aspects of GRAIL modeling bear directly on the role of impacts. Results show that the Moon's crustal density is less than previously thought and porosity is higher [10]. As for the high coherence, these observations are also interpreted to be a consequence of impact-related brecciation of the lunar crust. The lowest densities and highest porosities occur in association with ejecta blankets of major impact basins [10]. Modeling of basin formation and subsequent relaxation, compared to present-day gravitational signatures of mare and non-mare basins, have revealed the processes that contribute to the formation of lunar mascons [11].

These and other ongoing studies of GRAIL, LOLA and other remote sensing data sets in concert with laboratory analyses of lunar samples are collectively providing quantitative insight into the effect of impacts on the lunar crust and upper mantle and their contribution to lunar evolution.

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