EPSC Abstracts
Vol. 12, EPSC2018-575, 2018
European Planetary Science Congress 2018

Reviewing the contribution of GRAIL to lunar science and planetary missions

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Abstract

The GRAIL Discovery mission to the Moon in 2011 provided an unprecedentedly accurate gravity field model for the Moon. The goal of the mission was to provide insight into the structure of the Moon from its interior to the surface but it also made significant contributions to lunar spacecraft operations for all future lunar missions to the Moon. We discuss the science and the broader contributions from this mission that completed its objectives in December 2012 when the spacecraft impacted the lunar surface.

1. Introduction

GRAIL was a mission designed to measure the gravity field of the Moon with both high accuracy and high resolution. The measurement goal was to obtain the gravity at resolutions that would enable interpretation of the crust at fractions of its thickness, estimated at the time of launch to be about 45 km. To obtain a surface resolution of less than 10 km required the spacecraft to orbit the Moon at less than 20 km, an altitude that was considered dangerous at that time without an accurate gravity field model. Thus, the operational plan for GRAIL was to initially fly at about 50 km altitude, obtain a good gravity model, lower the orbit to near 20 km, further improve the gravity model and if successful, lower the orbit to nearer 10 km altitude. With the range of lunar topography reaching about 18 km the spacecraft could be expected to be only a few km above the surface during parts of its orbit [1-3].

2. Science

The science accomplishments of GRAIL [4-7] include (1) the discovery of very high correlation (0.98) of gravity and topography at crustal wavelengths between 100 to 20 km, (2) the crustal thickness to be only 35 km, (3) the mean crustal density of ~2550 kg m^{-3}, (4) the tidal Love number, k2 measured to better than 1% along with its monthly periodicity, (5) the k3 tide was detected, and (6) the Q of the Moon determined to be 41±4 at the monthly frequency.

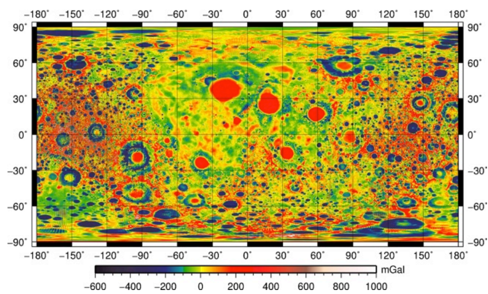

Figure 1: Free-air gravity of the Moon from GRAIL. Full uniform resolution spherical harmonic models were obtained out to degree & order 1200 with special fields with higher resolutions over certain areas to degree and order 1800.

3. Mission Operations

The significant improvement in our knowledge of the gravity field of the Moon by GRAIL enabled the re-analysis of the orbits of past and present lunar orbiting spacecraft, most notably the Lunar Reconnaissance Orbiter (LRO). LRO had been launched 2 years earlier than GRAIL to identify and locate future landing sites. The improvement of the accuracy of the orbit of LRO and the spacecraft's position by GRAIL increased the value of nearly all the instrument datasets but particularly the geodetic instruments, the laser altimeter and the camera.

The laser altimeter data provided very high resolution shape and topography of the Moon and the camera was able to image sites of strategic value and provide accurate positional knowledge of features at the few meter level.

Operationally, the improvement in the gravity field required less frequent orbital predictions for LRO and less tracking of the LRO spacecraft by the microwave network of Doppler tracking stations while exceeding the requirements of the mission.

The GRAIL gravity model was also used to re-determine the orbits of previous lunar missions, including Prospector, and subsequently the LADEE mission that studied dust concentrations down to about 20 km altitude in the lunar equatorial region.

4. Future Mission Applications

GRAIL was a dual spacecraft system in which the 2 spacecraft tracked each other to provide the gravity field data. Both spacecraft were launched together, separated shortly after, and each travelled independently to the Moon. This launch and mission architecture has now been considered for other planet gravity missions, including Mars, Venus, Europa, and even the Sun. However, at none of these potential destinations will it likely be possible to get the equivalent surface resolution that was obtained at the Moon due to the inability to fly close within a few 10's of km of the surface due, principally, to the present of an atmosphere that limits lifetime. Thus the GRAIL gravity model is likely to remain the most precise high resolution field of any planetary body for some time.

Acknowledgements

The GRAIL Science team gratefully acknowledge the leadership of the Jet Propulsion Laboratory who managed the GRAIL mission and also built the Ka-band inter-satellite ranging system that provided the data for measuring the lunar gravity.

References

[1] Zuber, M.T., Smith, D.E., Lehman, D.H., Hoffmann, T. L., Asmar, S.W., Watkins, M. M.: Gravity Recovery and Interior Laboratory (GRAIL): Mapping the Lunar Interior from Crust to Core, *Space Science Reviews* Journal, DOI 10.1007/s11214-012-9952-7

[2] Asmar, S.W. et al.: The Scientific Measurement System of the Gravity Recovery and Interior Laboratory (GRAIL) Mission, *Space Science Reviews* Journal, DOI 10.1007/s11214-013-9962-0

[3] Klipstein, W.M., et al.: The Lunar Gravity Ranging System for the Gravity Recovery and Interior Laboratory (GRAIL) Mission: *Space Science Reviews* Journal, DOI 10.1007/s11214-013-9973-x *Space Science Reviews* Journal, DOI 10.1007/s11214-013-9962-0

[4] Zuber, M.T., et al.; Gravity field of the Moon from the Gravity Recovery and Interior Laboratory (GRAIL) mission, *Science, 339,* doi: 10.1126/science.1231507, 2013.

[5] Wieczorek, M.A. et al.: The crust of the Moon, as seen by GRAIL, *Science, 340,* doi: 10.1126/science.1235768, 2013.

[6] Melosh, H.J., et al.: The origin of lunar mascon basins, *Science, 339,* doi: 10.1126/science.1231530, 2013.

[7] Williams, J.G., et al,: *J. Geophys. Res. Planets, 119*, 1546-1578