Gravity Recovery and Interior Laboratory: From satellite-to-satellite ranging to high-resolution gravity of the Moon

Maria T. Zuber and David E. Smith
Massachusetts Institute of technology
Cambridge, MA 02139

The Gravity Recovery and Interior Laboratory (GRAIL) mission was designed to obtain the gravity field of the Moon to unprecedented accuracy and resolution driven by the desire to better understand the Moon from "crust to core". The broad scale of the science - deep interior to the crust - drove the both the accuracy, the spatial resolution, and the altitude from which the measurements would be made; all at levels not accomplished before at the Moon or any planet.

A driving desire of the mission was to "see" inside the crust and that implied a surface and depth resolution of 30 km or less, equal to 1 degree of latitude on the Moon, and degree and order 180 in spherical harmonics. To get a resolution of 30 km meant having a near circular orbit that was, on average, 50 km in altitude. The precision at this resolution would need to be 0.1 mGal, or 1 micron/sec^2, which set a maximum for the total error. The only way to obtain this quality measurement was a satellite-to-satellite tracking system operating at 50 km above the lunar surface, an approach that had been demonstrated around Earth by the GRACE mission but from a much higher altitude.

This was the basic concept for GRAIL. But because of the need to sense the gravity field of the deep interior, which implied estimating the tidal gravity field and the lowest degree 2 terms of the static gravity field, the stability of the measurement implied an accuracy similar to the precision and for a mission life as long as possible. A very detailed simulation of the mission performed at JPL guided the mission to its final design. This showed that a 3-month mission could provide both the short wavelength and the long wavelength gravity data, with the accuracy required, to meet the objectives of the mission.

The challenge of launching 2 spacecraft to the Moon on one vehicle had not been demonstrated before, although we knew it could be accomplished it would place considerable constraints on the two spacecraft. Lockheed Martin provided the two spacecraft which were launched on a Delta 2 in Sept 2011. The spacecraft entered lunar orbit on Dec 31, 2011 and Jan 1, 2012 and after a period of orbit refinement and commissioning began science operations in early March 2012 for period of 3 months. The measurements met the performance objectives of the mission and because the operations had consumed less fuel than anticipated an extended mission was approved from Sept through November 2012. For the extended mission the average altitude of the spacecraft was lowered to 23 km and for the final weeks in December 2012 lowered to about 12 km, providing unprecedented resolution of 5 km for the lunar crust , equivalent to spherical harmonic degree and order 900, approximately 5x greater than originally planned. The two spacecraft impacted the moon on Dec 17, 2012.