Modeling the Vapor Release from the GRAIL Impacts on the Moon. D. M. Hurley[1], K. D. Retherford[2], T. K. Greathouse[2], G. R. Gladstone[2], S. A. Stern[3], M. H. Versteeg[2], M. W. Davis[2], J. Wm. Parker[3], D. E. Kaufmann[3], P. D. Feldman[4], W. R. Pryor[5], A. R. Hendrix[6] [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, dana.hurley@jhuapl.edu; [2]Southwest Research Institute, San Antonio, TX; [3]Southwest Research Institute, Boulder, CO; [4]Johns Hopkins University, Baltimore, MD 21218; [5]Central Arizona College, Coolidge, AZ; [6]Planetary Science Institute, Los Angeles, CA

Introduction: On 17 December 2012, the two GRAIL spacecraft ended their mission by impacting the lunar surface. The GRAIL spacecraft both hit the Moon on the nightside at 75.6° N lat. and 333.2°E lon. separated in time by about 30 seconds. The impacts were coordinated with the Lunar Reconnaissance Orbiter (LRO) such that instruments onboard LRO could observe the impact. The orbit of LRO was adjusted such that it flew past the impact site 11 seconds after the impact of the second GRAIL probe, 41 seconds after the first probe. As LRO passed on its near-terminator orbit, it rolled from its normally nadir viewing to 67° off of nadir so that it could observe the gaseous plume of material as it rose up from the dark nightside into sunlight at about 37 km altitude above the impact site.

The Lyman Alpha Mapping Project (LAMP) far ultra-violet imaging spectrograph onboard LRO observed the impact of the Lunar Crater Observation and Sensing Satellite (LCROSS) in October 2009. LCROSS impacted into the permanently shadowed Cabeus crater. LAMP detected emissions from 1800-1900 Å attricuted to elemental mercury (1845Å), calcium (1883Å), and magnesium (1828Å) [1]. It also detected molecular bands from H_2 and CO in the 1300-1700 Å region [1]. The LCROSS impact was at a higher velocity than the GRAIL impacts [2]. The effects of the incident impactor energy on the evolution of the plume can be studied by comparing the LAMP observations of the GRAIL and LCROSS plumes. Also, it is interesting to compare the constituents of the plumes to determine what the relative volatile composition is of the permanently shadowed Cabeus compared to the high latitude target for GRAIL.

Model: We have developed a Monte Carlo model that simulates the evolution of a gas released from the surface of the Moon[3]. It assumes a collisionless evolution of a gas under the influence of lunar gravity. A set of 100,000 particles are simulated with a distribution of initial velocities representative of the expanding vapor plume. The particles are released simultaneously from the impact point with a two component velocity. One velocity component is a bulk velocity directed radially outward from the impact site at a constant magntitude. The second velocity component has a magnitude drawn from a thermal distribution at a specified temperature and a random direction. The code solves the equation of motion using a fourth order Runge Kutta scheme and follows the particles in time until they either become photoionized, reencounter the lunar surface, or exit the gravitational influence of the Moon at the boundary of the Hill Sphere.

The vapor plume from the LCROSS impact can be modeled by a radial expansion at 3.7 km/s and a temperature of 1000 K [4]. For the GRAIL impacts, the incident energy was lower than the LCROSS impact. Therefore, we use a lower bulk velocity of 2.5 km/s in these initial simulations.

Results: Figure 1 shows the model plumes of a release of 1 mole of Hg at 11 seconds after impact (top) and 41 seconds after impact (bottom) from LAMP's perspective. However, LAMP cannot see material that is not illuminated by sunlight. None of the Hg released from the second impact and traveling at velocities up to 2.5 km/s had time to reach sunlight when LAMP passed the impact site. The model predicts that about 52% of the Hg released from the first impact is in sunlight when LAMP passes the impact site. Figure 2 shows the Hg plume at 41 seconds after impact accounting for the portion that is in sunlight, and converting the column density into brightness using the g-factor.

We also show the modeled hydrogen plume. Unlike Hg, the light weight of H results in the thermal velocity to be comparable to the bulk velocity. The resulting plume is morphologically different. Figures 3 and 4 show the same as Figures 1 and 2, but for the release of a mole of H at 2.5 km/s bulk velocity and 200 K.

Discussion: LAMP observations of the GRAIL impact show the evolution of the vapor plume produced by the first GRAIL impact. Our model predicts that the plume gasses from the second impact were still in shadow when LRO passed the impact site. For heavier elements, the vapor cloud appears as a spherical shell. However, the increasing importance of the thermal velocity for lighter elements make the H cloud brightest near the core. Also, the vapor cloud is larger for the lighter elements than for the heavier elements at any given time.

References: [1] Gladstone G. R. et al. (2010) *Science 330*, 472. [2] Colaprete A. et al. (2010) *Science*

330, 463. [3] Hurley, D. M. (2011) *JGR 116*, E10007. [4] Hurley, D. M. et al. (2012) *JGR 117*, E00H07.

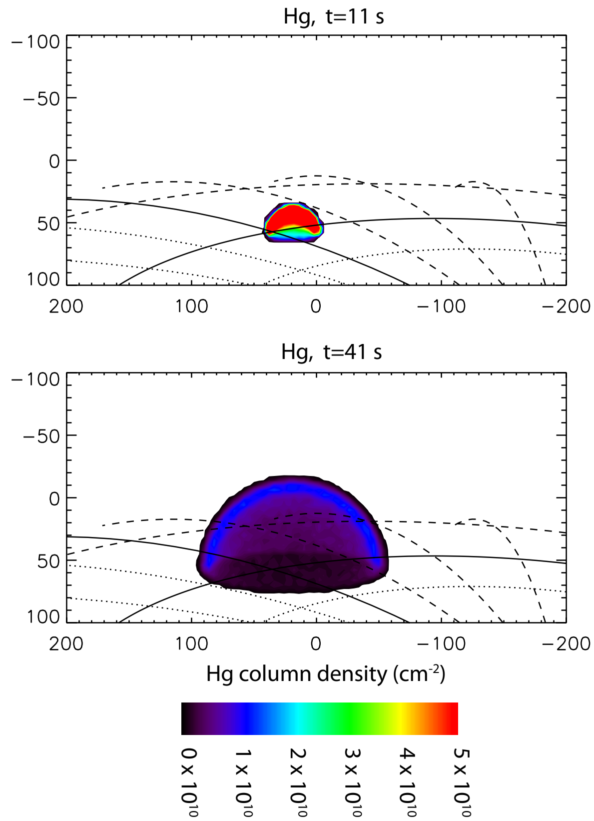

Figure 1. The modeled column density from LAMP's perspective of 1 mole of Hg released at 2.5 km/s and 200 K 11 s (top) and 41 s (bottom) after impact.

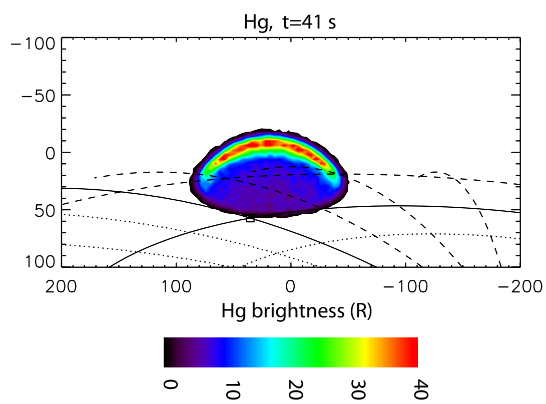

Figure 2. The modeled brightness of illuminated Hg at the time that LAMP passed the GRAIL impact site.

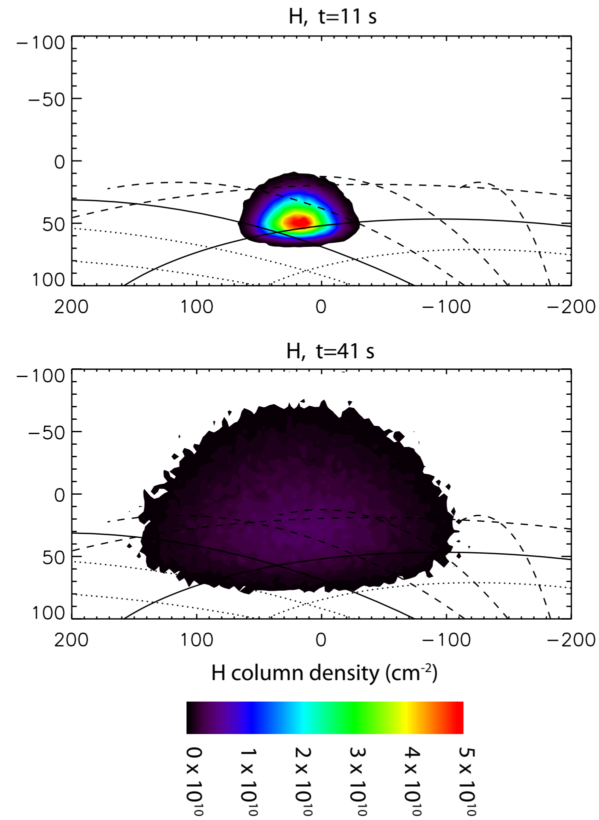

Figure 3. The modeled column density from LAMP's perspective of 1 mole of H released at 2.5 km/s and 200 K 11 s (top) and 41 s (bottom) after impact.

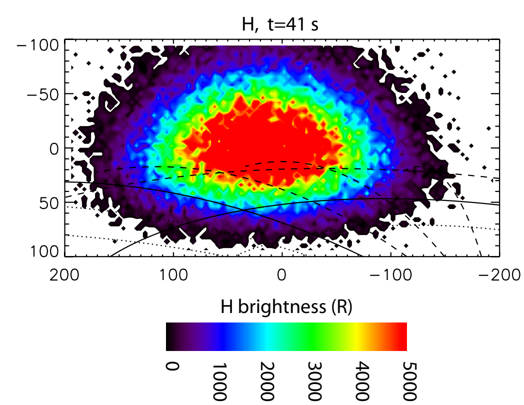

Figure 4. The modeled brightness of illuminated H at the time that LAMP passed the GRAIL impact site.