COMPARING LAMP DATA TO MODELS OF THE LCROSS VAPOR PLUME.
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Introduction: In the coldest regions of the Moon where direct sunlight never shines, volatiles may be frozen within the lunar regolith for billions of years [1]. The permanent shadow that produces the cold temperature necessary to trap volatiles also makes them difficult to detect. The Lunar Crater Observation and Sensing Satellite (LCROSS) experiment attempted to reveal the composition of those volatiles by lofting material out of permanently shaded Cabeus crater into the sunlight where it might be spectroscopically analyzed. The Lyman Alpha Mapping Project (LAMP) onboard the Lunar Reconnaissance Orbiter (LRO) was watching. We model of the evolution of the gases [2,3,4] that LAMP observed after the LCROSS impact and compare the models to LAMP data.

Observations: LRO's orbit was adjusted such that it flew past the LCROSS site 90 seconds after impact [5]. LAMP was pointed at the limb, perpendicular to the trajectory of LRO as the motion of LRO carried the spacecraft past the LCROSS impact site. In this configuration, the observed signal in the field of view evolved due to both the changing view from the spacecraft and the evolution of the gas cloud. LAMP observed strong emissions off of the lunar limb in the southern hemisphere immediately following the LCROSS impact in the wavelength range of 180-190 nm [5]. Additional weaker emissions were observed between 130-170 nm (see Fig. 1).

Mercury, Calcium, and Magnesium: Gladstone et al. [5] attribute the emissions observed by LAMP from 180-190 nm to elemental mercury (184.5 nm), calcium (188.3 nm), and magnesium (182.8 nm) (Fig. 1). Owing to the high oscillator strength of the mercury line, mercury comprises about 77% of the counts, although the estimated density of mercury from the spectrum is only 10% of the total Mg, Ca, and Hg column [5]. We start to model the observations by simulating only the mercury. Mercury is heavy, which is helpful in distinguishing thermal properties and non-thermal properties.

In Fig. 2, we show the model output for the line-of-sight column density of the heavy element mercury (seen from the LRO perspective) for a release temperature of 1000 K superimposed over an assumed blast velocity of 0, 2, 3, 4, or 5 km/s. We compare to the Hg light curve from LAMP to determine the blast velocity from the LCROSS impact. The peak is observed 40-44 seconds after impact. For the model runs, the peak occurs at 38 s for a 4 km/s blast velocity and at 46 s for a 3 km/s blast velocity. Thus the blast velocity we infer is ~3.5 km/s from the linear fit to the peak time as a function of velocity. A purely thermal expansion is ruled out.

We explored the parameter space of blast velocity, temperature, and relative abundance of Hg, Mg, and Ca. Performing regressions, we present the results as a function of temperature and blast velocity in Fig. 3. We find that χ^2 is most strongly influenced by the blast velocity, followed by relative abundance and temperature. The favored blast velocity is ~4.0 km/s depending on the temperature and abundance of species used in the simulations.

Next, we use these results to reproduce the LAMP light curve. Shown in Fig. 4 (blue line) is the combined light curve for the 3.7 km/s at 1500 K model prediction for the mixture of 9.8% Hg, 25.5% Mg, and 64.7% Ca. However, the observed count rate (orange hash marks) falls off much faster than the model can reproduce. The material causing the excess modeled count rate from t=50-80 s is model material that was ejected at an extremely low angle to the horizon, i.e., <20°. Adding some anisotropy in the release direction allows for the observed fall off. It is reasonable to find that the isotropic simulations produce more material released at angles close to the horizontal than there would have been in reality, or that would have made it past intervening obstructions. An example case for an anisotropic blast wave is shown in Fig. 4 (dashed line).

Diatomic Hydrogen and Carbon Monoxide: Besides mercury, LAMP also detected the fluorescence spectrum of H_2 gas as it looked over the limb toward the impact site in the two minutes after the LCROSS Centaur impact [5]. Incorporating fluorescence of CO into the spectrum provided an excellent fit to the data in the wavelength range 130-170 nm (Fig. 1).

Performing the same parametric study as for the 180-190 nm light curve, we show in Fig. 5 that for H_2 and CO, an adequate χ^2 spans a broader range of temperatures and blast velocity. [5] found that the column density of H_2 comprises 77% of the combined column. In Figure 5, white lines show the percentage of H_2 that produces the best fit as a function of temperature and velocity. For low temperatures and low velocity, the best fit comes from an entirely hydrogen gas cloud. Trending toward the upward right corner of high velocity and high temperature, increasingly greater fraction of CO is required to produce the best fit. The 75% and 80% contours are plotted in orange to display the H_2 abundance inferred from the LAMP data. The combined light curve for H_2/CO at 1000 K and 3 km/s is shown with the LAMP data in Fig. 4.

Conclusions: The minimum χ^2 for the H_2/CO simulations show a strong blast velocity dependence for v > 4 km/s. Because of the small mass of H_2, an H_2 dominated plume produces a good fit at lower blast velocity than the 3.5-4 km/s that is consistent with a CO dominated plume and the Mg/Ca/Hg plume.

The minimum χ^2 for the Mg/Ca/Hg simulations is largely temperature independent. However, the composition that provides the best fit varies as a function of temperature.

The simulations have revealed that LAMP observations are only sensitive to particles ejected at angles close to the horizontal (< 35°). The rapid decline in counts after the peak indicates that less material was ejected <20° than in an isotropic distribution, or that the material ejected <20° from the horizontal was obstructed by intervening landforms.

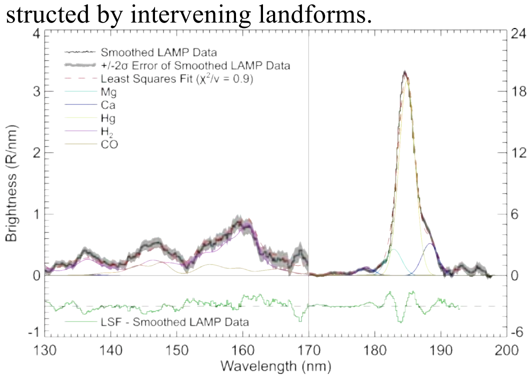

Figure 1. (From [5]) Observed emissions from LAMP by wavelength during 30-60 s after impact.

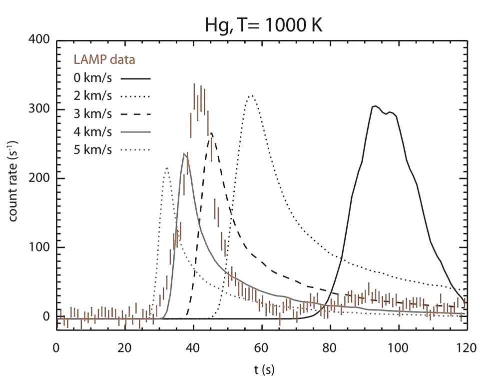

Figure 2. Time series for mercury emissions as would be observed by LAMP for different non-thermal blast simulations as well as LAMP data.

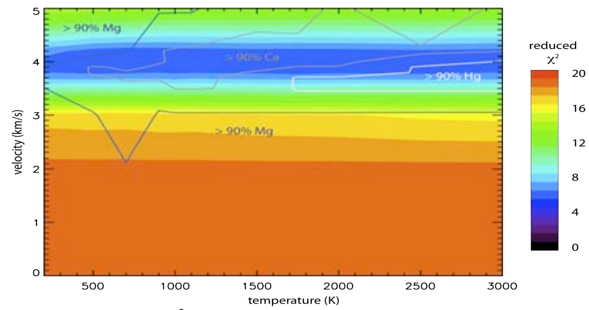

Figure 3. The χ^2 of the model fits to the LAMP data as a function of initial temperature and blast velocity. Contours showing which species dominates the composition to produce the best fit are superimposed.

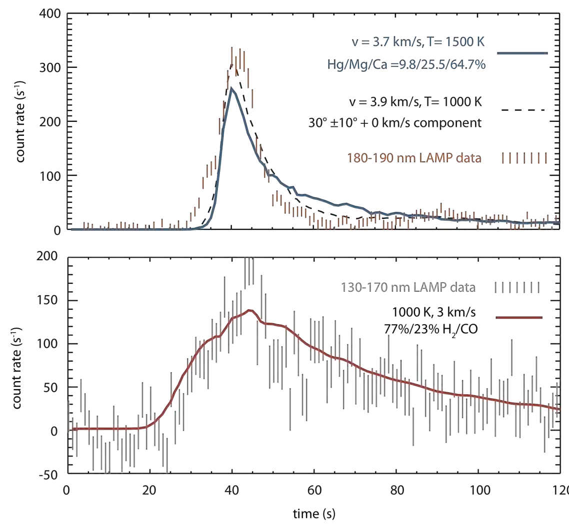

Figure 4. Simulated light curves are compared to LAMP observations for 180-190 nm (top) and 130-170 nm (bottom).

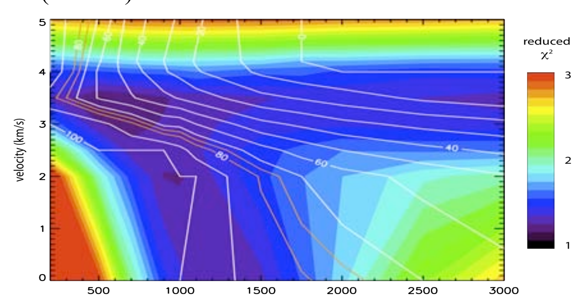

Figure 5. The χ^2 best fit as a function of temperature and blast velocity for simulations of H_2 and CO. Superposed are contours of % H_2 producing the best fit.

References: [1] Watson K. et al. (1961) *JGR 66,* 3033. [2] Crider D. H. and Vondrak R. R. (2000) *JGR 105*, 26773. [3] Killen R. M. et al. (2010) *GRL 37*, L23201. [4] Hurley, submitted to JGR. [5] Gladstone G. R. et al. (2010) *Science 330*, 472.