**LCROSS IMPACT: DUST AND GAS DYNAMICS.**

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**Introduction:** Data from NASA's Clementine mission may indicate the presence of water ice in permanently shaded craters – "cold traps" – in the lunar polar regions. The results from the Lunar Prospector (LP) mission appear to provide an even stronger case that there exists water near both poles [1,2]. While the existence of such deposits has long been theorized and discussed, these supporting finds offer no guarantee, as the interpretation of the mission data remains somewhat contentious [3,4]. A more direct method of detection would be needed to substantiate the observations.

In 2006, NASA developed a small lunar mission to make use of the 1000 kg extra payload available on the Lunar Reconnaisance Orbiter's launch vehicle and the Lunar Crater Observation and Sensing Satellite (LCROSS, NASA Ames) was chosen. LCROSS will follow the upper stage of the launch vehicle as it crashes into a cold trap searching for direct evidence of water in the ejected material. As described below, we model the mass and temperature distributions of lofted regolith grains and the water and OH vapor evolved from those grains as seen from Earth and from LCROSS after impact.

Our model of the LCROSS impact contains improvements in the physical representation since our LP studies [5]. In particular, we model how vapor is released from the soil and what effects the initial debris spray assumptions have on the results. We have also improved the modeling of the terrain to accommodate viewing geometries and illumination.

Ignoring the heating effects of the impact as a conservative approximation (initial particle temperature equal to local surface temperature), we here concentrate on the sun-warmed dust grains as the $H_2O$ source and break the problem into the following pieces: We first model the motions of the grains. We then model each grain's temperature as it cools (in shadow) or warms (in sunlight). Warm grains effuse a spray of $H_2O$ molecules that, in turn, may photodissociate into OH radicals and together these two species move ballistically and scatter off the surface until they are lost.

**Plume Model:** We assume that the scattered regolith grains are of uniform size and material. From Kring's studies of lunar samples [6], we chose a representative particle size of 70 µm, emissivity of 0.5 and a density of 3100 kg/m$^3$. The specific heat of lunar samples over the present temperature range of interest is well fit by a linear variation with temperature. Temperature is computed individually for each grain depending on the illumination it is exposed to and its gray body emission ($\varepsilon\sigma T^4$ ). We assume that the grains are made of 1% water ice by mass and this ice does not alter the base thermal or optical properties. Our most important results are for water and OH column densities and these would simply scale linearly with the assumed initial water mass fraction of the grains.

The surface temperature model assumes the sunlit surface is in radiative equilibrium; day side temperatures are approximated by a cosine$^{1/4}$ law, the night side is at 120 K and the floors of the several craters modeled (and therefore the ejecta, initially) are at 90 K. Both $H_2O$ and OH molecules can be lost, either temporarily or permanently, by condensation on a cool or cold surface depending on the local residence time.

Permanently shadowed craters are identified from radar and photograph data [3,4]. Craters are modeled as open-topped cylinders of shadow extending some height above the surface of the Moon, in this case 2km. The height to sunlight directly above the impact point is assumed to be the height of shadow over the entire permanently shadowed region. The height of this shadow is calculated taking into account the sub-solar longitude and latitude at the time of the impact.

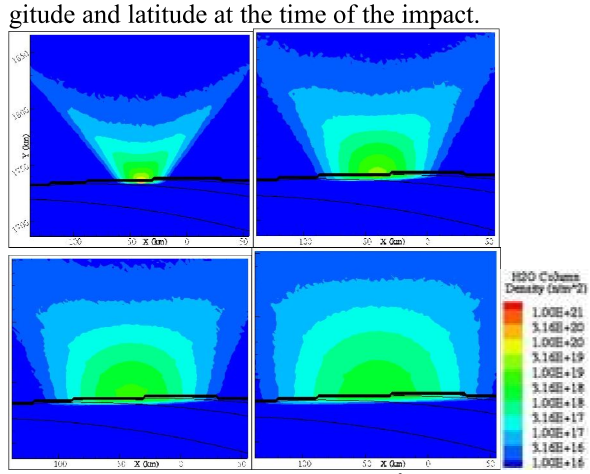


***Figure 1:*** *$H_2O$ column density (n/m$^2$). Clockwise from top left: 25, 50,(legend), 75, and 100 s after impact.*

Current estimates suggest that the lead vehicle will displace ~$10^6$ kg of soil and produce a crater final radius of about 11m (Don Korycansky, private communication). Using these estimates, we adopted the empirical model of Cintala, Berthoud, and Horz (CBH) [7] to assign initial velocities to the grains in our simulation. In this model, a particle's speed depends on its radial location within the crater, with particles initially near the center moving the fastest. All particles are assumed to be ejected at a 45° angle to the surface, producing the familiar "inverted lampshade" ejecta distribution.

Once the initial conditions are set, the particles are moved in one second time-steps nearly as described in Goldstein *et al.* [8]. Important physical effects in, and features of the model include: A surface temperature dependent mean residence time for particles falling to the lunar surface [9]. Molecules in sunlight may photodissociate to OH+H (time scale $8.3\times10^4$ s) or photoionize (time scale $2.45\times10^6$ s). Ions are assumed lost. OH on the surface behaves exactly as $H_2O$ (chemical interactions ignored). Sunlit OH molecules fluoresce at 3085 Å. The plume is modeled as optically thin and collisionless. Results are viewed from above the local pole and from the Earth using simple planar projections.

**Results:** The impact point is chosen to be inside a crater at 88.3°N, 48°W. Figure 1 shows a time series of the $H_2O$ simulation as seen from Earth; the impact site is just below the limb on the near side. Of the $10^6$ kg of soil presumed to be displaced by the impact, only ~19,000 kg of that ever rises high enough to be exposed to sunlight. A cloud of ~180 kg water vapor is sublimated of which 0.33 kg OH is produced after five minutes. The OH component of the plume shows a similar evolution in Figure 2.

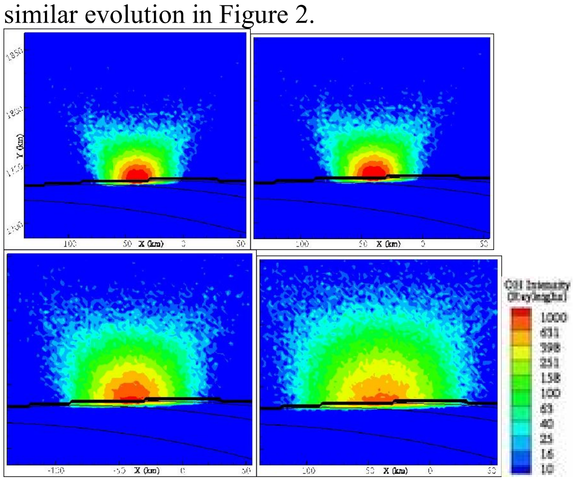


***Figure 2:*** *OH Intensity (Rayleighs) Time Series. Similar arrangement as Figure 1.*

Figure 3 presents the expected dust grain column density of an impact near the South Pole for comparison. Notice how it differs from the water molecule plume shape because the grains follow a ballistic trajectory from the impact point whereas the molecules receive randomized velocities when they are sublimated from the moving grains. By the end of a minute, the grains have reached a radiative equilibrium temperature of about 270 K.

Simulations are now being run to aid in the planning for telescopic observations regarding exposure times, and at what altitude the spectrograph slit should be focused to ensure the best signal. Figure 4 shows some results regarding slit altitude above the surface. In this example for observers planning to use Keck's NIRSPEC, peak signal strength dies off quickly as slit altitude increases, but this effect must be balanced with avoiding glare from the bright lunar surface.

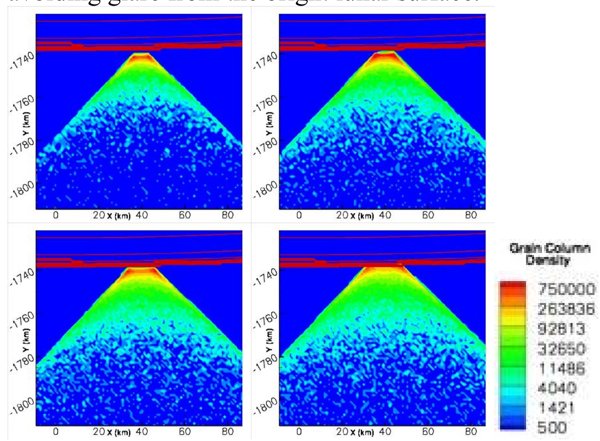


***Figure 3:*** *Grain column density (n/m$^2$) time series.*

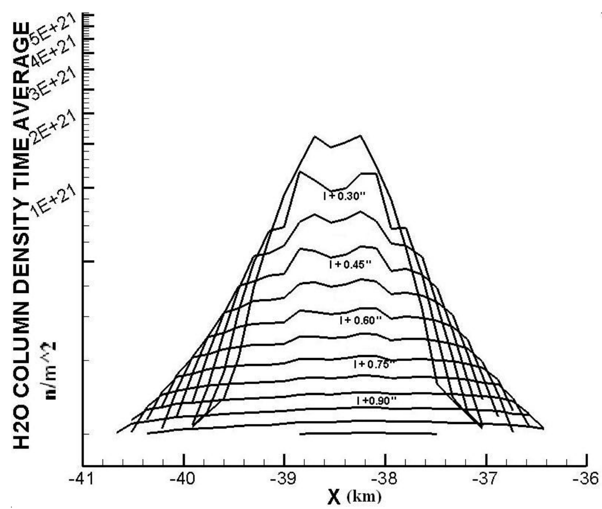


***Figure 4:*** *Slit position optimization chart. Lines show column density along the slit's length if aligned the indicated number of arcseconds above the impact.*

**References:** [1] Feldman, W. C. *et al*. 1998. *Science*, **281**, 1496--1500. [2] Lawrence, D. J., *et al*., 2006. *J. Geophys. Res*. vol. 111, E08001. [3] Campbell, B. A., and Campbell, D. B., 2006a. *Icarus* vol. 180, pp. 1-7. [4] Campbell, D. B., Campbell, B. A., Carter, L. M., Margot, J.-L., and Stacy, N, J., 2006b. *Nature*, vol. 443, pp. 835-837. [5] Goldstein, D. B., R. S. Nerem, E. S. Barker, J. V. Austin, A. Binder, and W. Feldman, 1999. *Geophys. Res. Let*., **26**, pp.1653-1656. [6] Kring, 2006. Powerpoint presentation. [7] Cintala, Berthoud, Horz, 1999. *Meteoritics and Planetary Science*, Vol 34, pp. 605-623. [8] Goldstein, D., B., Stern, S. A., Crider, D. H., Gladstone, G. R., Durda, D., D., Asphaug, E., Larignon, B., Varghese, P. L., and Trafton, L. M. *RGD* 2007. [9] Sandford, S. A. and Allamandola, L. J. 1990. *Icarus*, **87**.