Exploring Lunar Sediment and Water Ice through Modelling the LCROSS Debris Plume

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Abstract. In 2009, the Lunar CRater Observation and Sensing Satellite (LCROSS) mission impacted a Centaur rocket into Cabeus crater, a permanently shadowed crater near the lunar south pole. Spectra of the resulting impact plume taken by the shepherding spacecraft included water ice absorption bands, confirming the presence of water ice within the permanently shadowed crater[1]. Ground-based observations of the plume provided the opportunity to model the shape and temporal evolution of the plume lightcurve, and therefore to characterize the concentration and stratification of water ice within the crater[23].

Using the kinetics experimentally measured at the NASA Vertical Gun Range[4], we developed an N-Body debris plume simulation with a fixed initial velocity and angle distribution. We used a vertically stratified lunar sediment composition as our only variable in order to match the plume lightcurve. The observations are a time series of images taken with the Astrophysical Research Consortium 3.5 meter telescope at Apache Point Observatory using the Agile high speed optical imaging camera. We generated synthetic lightcurves from a family of five stratified lunar sediment models, composed of at least two of the four physically motivated layers: a layer of surface 'dirty ice', a mixing layer with a decreasing ice concentration with depth, a layer of pure regolith, and a layer of bedrock.

We found that the models that best fit the observed plume light curve included layers of surface ice, regolith, and bedrock; that the mixing regions did not change the minimum χ^2 statistic; and that the best fit boundaries between the layers are consistent across the models, despite this consistency not being a condition imposed on the models. We found that the surface ice layer extends down to 2.5 meters, and the bedrock layer begins at 4 meters below the surface. We determined that our best fit model contains surface ice, regolith, and bedrock, with no mixing region. From the vertical composition profile, we determine that our best fit model is consistent with a water ice mass of $1.7\pm\times10^{12}$ kg within the entirety of Cabeus crater and a water ice concentration of 6.9±1.3%, assuming a water ice albedo of 0.8 and a regolith density of 3000 kilograms per cubic meter. This value for mass concentration agrees within the error bars with the results from Colaprete et al. 2010 and Strycker et al. 2013, at 5.4 ± 1.4% and 6.3 ± 1.6%.

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[3] Luchsinger et al., 2019, Lunar and Planetary Science Conference Proceedings, 50, 3035.
[4] Hermalyn et al., 2012, Icarus, 218,654-665