Collisional Processes and Parameters Influencing the Delivery of Volatiles to Lunar Cold Traps after a Comet Impact

PREM, P., ARTEMIEVA, N.A., STEWART, B.D., GOLDSTEIN, D.B., VARGHESE, P.L., TRAFTON, L.M.

Over the years, several missions have recorded radar and spectral signatures that suggest the presence of water (and other volatiles) in cold, permanently shadowed craters near the lunar poles. We investigate comet impacts as a mechanism for the delivery of these volatiles. Our objective is to use impact simulations to constrain the amount of water that comets could have contributed to the lunar volatile inventory, and to understand the governing transport processes and how impact parameters influence volatile fallout. Our approach is to apply the SOVA hydrocode and the Direct Simulation Monte Carlo (DSMC) method to model several different impact scenarios and the subsequent migration of impact-delivered water to polar cold traps.

Upon impact, a comet vaporizes, generating a high-energy plume of vapor that expands into the near-vacuum of the lunar exosphere. Although much of this vapor escapes shortly after impact, a significant portion remains gravitationally bound, giving rise to a collisionally thick, transient, atmosphere that surrounds the Moon for days to months after impact. Within hours, vapor begins to fall back to the lunar surface. Molecules landing on the cold lunar night side largely remain frozen there until sunrise. However, shorter residence times on the warm day side support a relatively dense day side atmosphere, driven by global pressure gradients and sustained by the fallback of cold, rarefied vapor from greater altitudes. Over time, more vapor diffuses from the day side to the night side, where it condenses onto the night side surface. Meanwhile, the convergence of streamlines antipodal to the point of impact results in a shock that channels water to the surface at the antipode. This flow-field, with its shocks and pressure-driven winds, presents a picture of post-impact volatile transport that is qualitatively quite different from prior models of largely collisionless transport through ballistic hops. Only over months, as water is lost to photodestruction and condensation on the night side, do the gas dynamic processes transition to the collisionless limit, with the antipodal shock vanishing as the atmosphere becomes more and more rarefied. Sublimation of night side deposits at sunrise sustains a localized flow field at the dawn terminator, until ultimately, all the water initially retained is lost or captured. We track the accumulation of water ice in cold traps throughout these events.

In order to estimate the amount of water ultimately retained, we quantify the influence of various impact parameters on the fraction of cometary water captured in cold traps. The SOVA-DSMC approach allows us to model oblique impacts, with fewer simplifications. Here, we compare results from three impact simulations: a baseline case, together with a second and third at a different impact angle and a different impact speed, respectively. In both the more vertical and lower speed impacts, a greater fraction of water remains gravitationally bound to the Moon. The angle of impact also affects the geometry of the initial expansion plume: more oblique impacts result in a more pronounced downrange focusing of the vapor plume, leading to a more asymmetric fallback.