The Fuzzy Snow Line: Ice Stability on Airless Bodies Enhanced by Regolith and Roughness

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Condensed volatiles are key tracers of past and present conditions on planetary surfaces. Recent discoveries of volatile reservoirs from Mercury to the main asteroid belt show a wide distribution and some unexplained differences among these bodies. For example, vast ice sheets at the poles of Mercury contrast with a more patchwork assemblage on the Moon. Here, we present observations and a new model that attempts to explain some of the key features and wide distribution of condensed volatiles on airless bodies in the inner solar system.

On bodies without atmospheres, volatile stability is controlled by surface temperature, which is strongly dependent on insolation. Illumination is determined by topography at a range of spatial scales. In the subsurface, volatiles are protected by a thermally insulating regolith layer, which also acts as a barrier to vapor diffusion. Thus, the presence of regolith and surface roughness increases volatile stability. Observations by spacecraft – notably Lunar Reconnaissance Orbiter (Moon), MESSENGER (Mercury), and Dawn (Vesta & Ceres) – bear out the importance of these effects.

We use models of shadow geometries, temperatures, and statistical topography to evaluate the contribution of small-scale topography to the cold trap area. Our "micro cold trap" model, provides quantitative estimates for the cold-trapping potential of Mercury, the Moon and the dwarf planet Ceres. In both places, micro cold traps may provide a previously unknown volatile reservoir. On the Moon, we estimate the cold-trapping area of < 1 km shadows accounts for 10's of percent of the total cold-trapping area. On Mercury, this contribution is less significant, due to its proximity to the Sun. Inside the micro cold traps > 1 m, water and other volatiles may be more accessible to future robotic and human missions to the Moon and beyond. Mapping the "fuzzy snow line" therefore has implications for both planetary science and exploration.