68th International Astronautical Congress 2017

Paper ID: 39182
oral
student

SPACE EXPLORATION SYMPOSIUM (A3)
Interactive Presentations (IP)

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# MICRO-COLD TRAPS HARBOR SUBSTANTIAL SURFICIAL WATER-ICE DEPOSITS ON MERCURY: IMPLICATIONS FOR FUTURE ROBOTIC AND HUMAN EXPLORATION OF THE MOON

**Abstract**

The Mercury Laser Altimeter onboard the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft measured the surface reflectance, Rs, at zero phase angle across the northern hemisphere of Mercury at a wavelength of 1064 nm. The surface reflectance within permanently shadowed regions (PSRs) is anomalously higher or lower than the average reflectance of Mercury (Neumann et al., 2013). Reflectance anomalies correlate with areas that thermal models predict are capable of hosting stable water ice (Paige et al., 2013). Low-reflectance surfaces are suggested to be composed of organic-rich volatiles that insulate water ice in the near subsurface (Paige et al., 2013), and a high-reflectance deposit is indicative of surficial water ice. Recent work mapping Rs near Mercury's north pole demonstrated there was an increase in Rs northward of 85°N when the contribution of permanently shadowed craters $> 7$ km was masked (Neumann et al., 2017), suggesting that water ice is sequestered in micro-cold traps in spatial areas $< 7$ km in diameter.

Here we document the presence of micro-cold traps that exhibit a collocation of Rs enhancements, radar-bright material (Harmon et al., 2011), permanent shadow (Deutsch et al., 2016), and biannual maximum temperatures $< 100$ K (Paige et al., 2013). We also map Rs and density of energy returns in Chesterton, Tolkien, Tryggvadóttir, and Kandinsky craters. These four permanently shadowed craters host extensive radar-bright deposits. However, empirical measurements of Rs were not previously possible due to limited off-nadir observations. We calculate a mean Rs value of $> 0.3$ for each crater, suggestive of surficial water ice. Interestingly, the surrounding inter-crater terrain is also enhanced ($0.25 < \text{Rs} < 0.30$), suggesting it also hosts water ice. We suggest that micro-cold traps sequester a substantial proportion of the total cold-trapped volatiles at Mercury's surface and subsurface. This documentation was not previously possible due to the footprint limitations of Earth-based observations and MESSENGER-derived products.

Given that the Moon has similar surface roughness features and small impact craters as Mercury, it is possible that such terrain also harbors significant water ice. These micro-cold traps must be considered in future exploration of lunar PSRs and in the development of *in-situ* resource utilization infrastructure. Volatile-rich inter-crater terrain may offer solar power and communications benefits in comparison to the depths of permanently shadowed craters in future missions. The smaller scale PSRs at the poles of the Moon are excellent candidates for the search for water ice.