The World of Minerals
By Vivien Gornitz

Ice on Mercury and the Moon

At first glance, Mercury and the Moon seem like unlikely places to search for ice. Ancient craters of all sizes densely pock the surface of both celestial bodies. Mercury, the planet closest to the Sun, alternately bakes and freezes in temperatures that range from daytime highs of 427°C (800°F) to nighttime lows of -173°C (-280°F), around the equator. Similarly, the Moon undergoes extreme temperature swings from daytime highs of 127°C (260°F), plunging to -173°C (-280°F) at night, near the equator. Neither body, unlike Mars, possesses an atmosphere that could trap some escaping heat, nor shows any signs of past water activity. Yet theoretical calculations suggest that water-ice could survive for extended periods of time in permanently-shadowed craters near the poles on both bodies. The neutron spectrometer on board the Mercury MESSENGER spacecraft detected strong hydrogen signals near its north pole, hinting at the presence of water ice there (Fig. 1). Furthermore, MESSENGER's NIR (near-infrared) spectrometer sighted brighter than average areas near the mercurian poles, also suggestive of near-surface ice deposits. Meanwhile, on the Moon, orbiting spacecraft also picked up signs of exposed ice near the lunar south pole. The Moon Mineralogy Mapper M^3 instrument on the Chandrayaan-1 spacecraft, covering a wavelength range between 0.46–2.98 micrometers, µm, detected reflectance absorption minima, centered around 1.3 µm, 1.5 µm, and 2.0 µm, characteristic of water-ice. The Lunar Crater Observation Sensing Satellite (LCROSS) discovered several percent water-ice (by mass) within the upper couple of meters of some craters. Perpetually-dark, cold ice-bearing pixels were tightly clustered within a small region surrounding the Moon's south pole, whereas icy pixels were more diffusely scattered across a broader region at the lunar north pole.

A new study furthers strengthens the case for substantial polar ice deposits on these two celestial bodies by a detailed examination of the crater morphology on Mercury and the Moon. The depth of a simple, bowl-shaped crater formed by the impact of a colliding body is proportional to its diameter, for smaller craters within a given size range[1]. Over 2,000 simple mercurian craters, 2.5 to 15 km (1.6-9.3 mi) across, lying between 75°N -88° N latitude, were examined. (Only Mercury's north pole was studied due to MESSENGER's skewed orbit that yielded much less detailed images of its south pole). Data from over 11,000 lunar craters were collected in the same size range, between 60° to 90°N and S.

On both the north pole of Mercury and the south pole of the Moon, there is a consistent decrease in the normal crater depth to diameter ratio for craters nearer the poles; in other words, the craters become shallower than expected, heading toward the poles. The shallowing is attributed to partial filling of the crater by water ice. On Mercury, the maximum ice-filling thickness is ~ 50 meters (164 ft); the average is closer to 15 meters (49 ft). Craters in the south polar region of the Moon show a similar degree of shallowing (i.e., icy infilling). Shallower craters lie in regions that remain in permanent shadow and that also stay cold enough to keep water ice frozen for lengthy periods. Curiously, the lunar north pole does not show this morphological trend. Researchers are still puzzled as to why. Perhaps northern hemisphere ice

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[1] This relationship becomes more complex for larger craters, whose interior can be later modified by various processes including isostatic rebound, impact melting, impact breccia infilling, volcanism, sediment deposition, or erosion.

deposits are too thin to affect the crater depth, or once-thicker ice deposits were melted by the heat generated by major ancient impacts, such as the one that created the nearby giant Mare Imbrium basin.

Where did the ice come from? The ice may have been deposited as the result of large comet impacts and subsequent burial under rubble or ejecta from neighboring craters. Over time, erosion wore away some of the covering debris, re-exposing the ice. The process may have recurred several times, allowing a significant amount of ice to accumulate over time. Estimates of crater ice thicknesses range from an average of 10-15 m (33-49 ft) up to a maximum of 50 m (164 ft) near Mercury's north pole. Deposits in cold-trap craters around the Moon's south pole also reach similar thicknesses: an average of ~ 10 m (33 ft) up to a maximum of 50 m (164 ft). The Moon's south polar ice deposits could become an essential water resource for astronauts staying at some future lunar space station.

Further reading

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Mercury (planet). Wikipedia. https://en.wikipedia.org/wiki/Mercury_(planet) Last modified 8/11/2019 (accessed 8/12/2019).

Rubanenko, L., Venkatraman, J., and Paige, D.A., 2019. Thick ice deposits in shallow simple craters on the Moon and Mercury. *Nature Geoscience* 12:597-601.

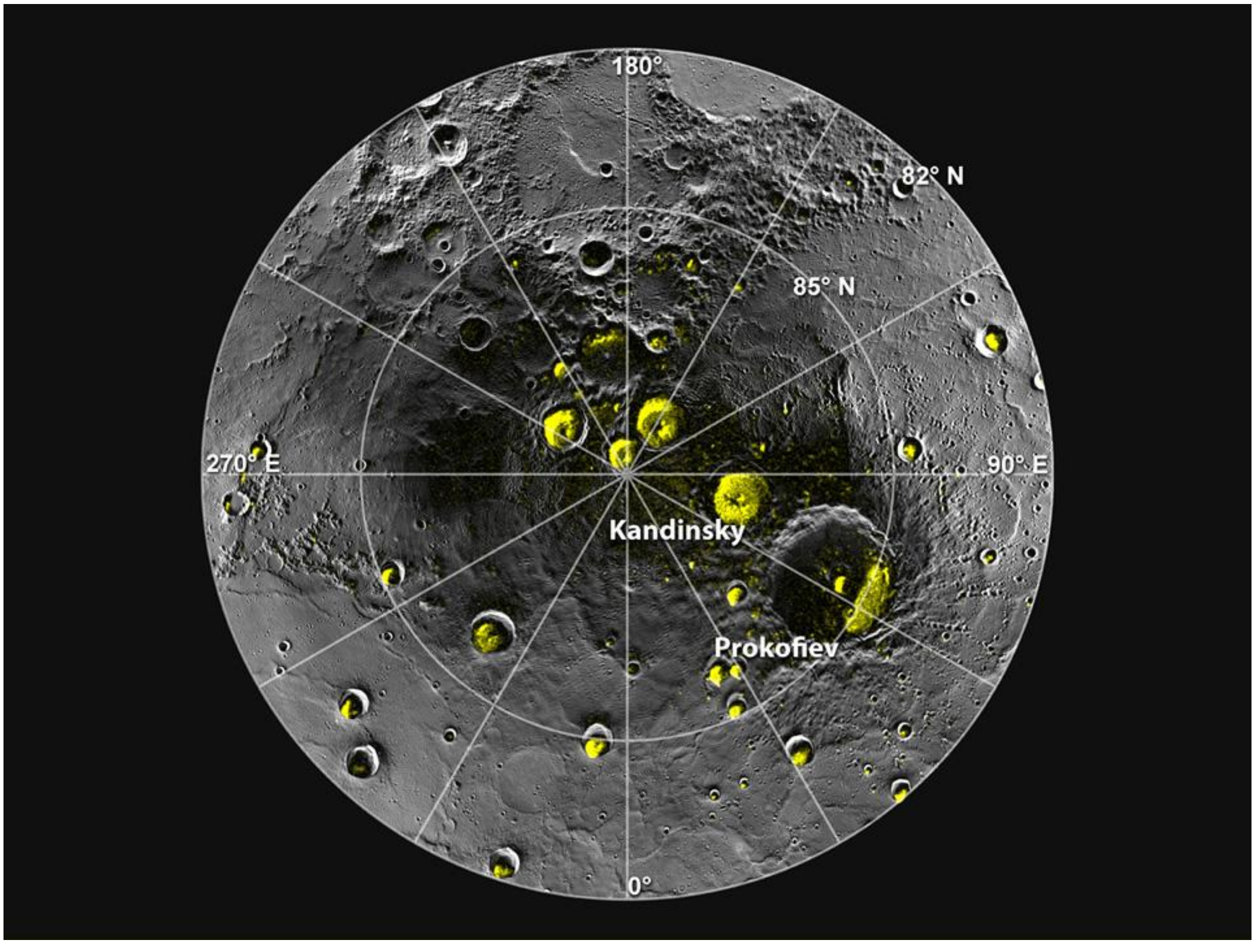

Figure 1. Detection of water-ice in craters near Mercury's north pole by MESSENGER spacecraft in 2011. Craters marked in yellow contain water-ice and lie in permanent shadow. Farther from the pole, ice deposits are concentrated on north-facing crater walls. (Photo credit: NASA/John Hopkins applied Physics Laboratory/Arecibo Observatory).

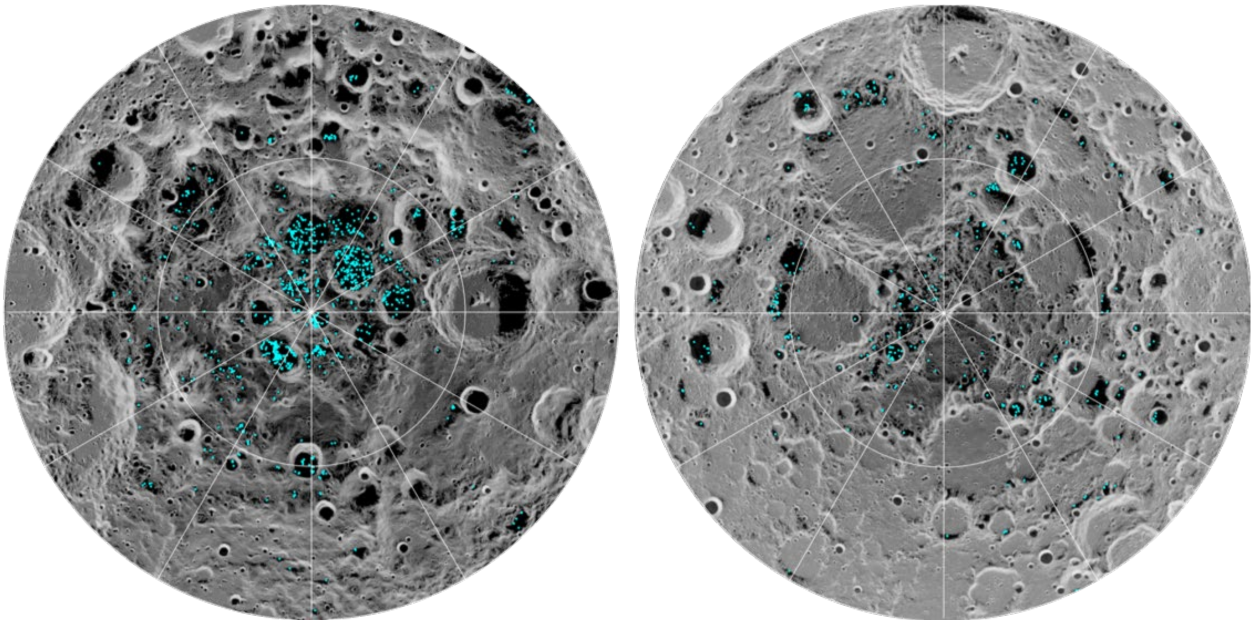

Figure 2. Distribution of water-ice on the Moon. South pole deposits (left); north pole deposits (right), as detected by NASA's Moon Mineralogy Mapper instrument. Darker shades represent colder areas, while lighter shades are warmer. Note the much tighter clustering of ice-rich craters near the Moon's south pole. (Credit: NASA).