WHAT ICE ON CERES MIGHT TELL US ABOUT ICE ON THE MOON.

N. Schorghofer[1], E. Mazarico[2], P. Pokorny[2,3], T.H. Prettyman[1], N. Yamashita[1], [1]Planetary Science Institute, Tucson, AZ; Albuquerque, NM; Honolulu, HI; [2]Goddard Space Flight Center, Greenbelt, MD, USA, [3]The Catholic University of America, Washington, DC, USA.

Introduction: Earth's Moon and planet Mercury both have polar cold traps that, theoretically, should harbor ice deposits [1], but only on Mercury have massive water ice deposits been observed. Ceres is a large ice-rich body in the asteroid belt that also has permanently shadowed regions (PSRs). Observations at Ceres by the Dawn spacecraft (2015-2018) may provide several lessons that are relevant for ice on the Moon: First, some permanently shadowed craters on Ceres contain putative water ice deposits [2,3,4], which suggests cold-trapping operates on large airless bodies. Second, ice is still very close to the surface on Ceres globally [5]; even billions of years of impact bombardment did not devolatilize the top meter of its surface. Third, the surface of Ceres is nearly completely ice-free [6,7], which implies that ice-free surfaces do not exclude the presence of significant concentrations of water ice in the shallow subsurface.

The temperature in lunar cold traps is comparable to the "annual" mean temperature at the polar regions of Ceres (~120 K) [8]. Impact speeds are lower on Ceres than on the Moon.

Near-surface ice and devolatization by impacts: The surface of Ceres is nearly completely ice-free. Only a few tiny patches of exposed ice have been identified spectroscopically [6,7], whereas Ceres' well-known bright spots mostly consist of salts. All observed H_2O exposures occur in fresh craters near rim shadows [6]. In contrast, Gamma Ray and Neutron Detector (GRaND) measurements at Ceres revealed that water ice still resides within about 1 m of the surface at polar and mid-latitudes [5].

Ceres, which formed ice-rich, was bombarded by smaller bodies in the asteroid belt throughout its history. Apparently, these impacts did not remove all of the ice near its surface. In fact, impacts can stir up ice from greater depth; the ejecta of the young (~20 Myr) Occator crater have a higher bulk H-concentration than the surrounding area [9]. According to one-dimensional models of the combined effect of impact mixing and sublimation, impact mixing results in a vertical gradient in ice concentration [10,11,12]. When H_2O is delivered from above, instead of being sourced from depth, impact-induced ejecta can lead to the burial of the ice and thus protect a fraction of the ice from destructive processes on the very surface [13].

Cold-trapping in permanently shadowed regions: The axis tilt of Ceres is currently 4°, but oscillates between 2° and 20° with a period of 24 kyr. Hundreds of craters are currently perennially shadowed [2,4], and at maximum axis tilt, only a handful of truly permanently shadowed regions remain [3]. The latter group mostly corresponds to the current PSRs that contain bright deposits that most likely consist of water ice. Mercury likewise shows a relation between ice deposits and PSRs (Fig. 1). This strengthens the case that cold trapping also takes place on the Moon, where relatively little exposed ice has been detected through spectroscopic and albedo measurements [e.g. 15], but significant volumes of ice may be present in the subsurface [16,17].

Acknowledgments: TREX SSERVI, NASA ISFM.

References: [1] J.R. Arnold, *JGR 84*, 5659 (1979) [2] T. Platz et al., *Nat. Astr. 1*, 7 (2016) [3] A. Ermakov et al., *GRL 44*, 2652 (2017) [4] N. Schorghofer et al., *GRL 43*, 6783 (2016) [5] T.H. Prettyman et al., *Science 355*, 55 (2017) [6] J.-Ph. Combe et al., *Icarus 318*, 22 (2019) [7] H. Sizemore et al., *JGR 124*, 1650 (2019) [8] P.O. Hayne & O. Aharonson, *JGR 120*, 1567 (2015) [9] T.H. Prettyman et al., *LPSC 50*, #1356 (2019) [10] N. Schorghofer, *Icarus 276*, 88 (2016) [11] N. Schorghofer et al., *LSPC 51*, #1794 (2020) [12] E. Costello et al., *JGR 125*, E006172 (2020) [13] D.M. Hurley et al., *GRL 39*, L09203 (2012) [14] N. Chabot et al., *Geology 42*, 1051 (2014) [15] S. Li et al., *PNAS 115*, 8907 (2018) [16] A. Colaprete et al., *Science 330*, 463 (2010) [17] L. Rubanenko et al., *Nat. Geosci. 12*, 597 (2019).

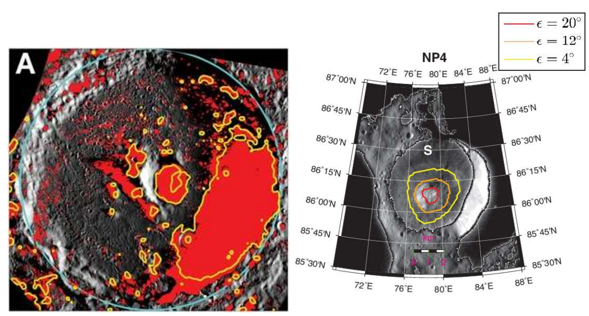

Figure 1: Left (from Ref. [14]): High-reflectance surface within Prokofiev crater on Mercury; the radar-bright region (yellow contour) is located within a PSR (red). Right panel (from Ref. [3]): Bilwis crater on Ceres with a bright crater floor deposit. Colored contours are boundaries of PSRs at various values of the axis tilt ε. No comparable relations between ice deposits and PSRs have been found on the Moon.