DARK SURFACE DEPOSITS IN THE NORTH POLAR REGION OF MERCURY: EVIDENCE FOR WIDESPREAD SMALL-SCALE VOLATILE COLD TRAPS. David A. Paige[1], Paul. O. Hayne[2], Matthew A. Siegler[2], David E. Smith[3], Maria T. Zuber[3], Gregory A. Neumann[4], Erwan M. Mazarico[3], Brett W. Denevi[5], Sean C. Solomon[6,7]. [1]Department of Earth, Planetary and Space Sciences, UCLA, Los Angeles, CA 90095, dap@moon.ucla.edu; [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; [3]Department of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139; [4]NASA Goddard Space Flight Center, Greenbelt, MD 20771; [5]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723; [6]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964; Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015.

Introduction: The MESSENGER Mercury Laser Altimeter (MLA) instrument has acquired normal reflectance measurements of the north polar region of Mercury at a wavelength of 1064 nm for more than two Earth years [1]. A subset of these data have previously revealed the presence of dark deposits in regions of permanent shadow where water ice is predicted to be thermally stable at near-surface depths, and the presence of bright deposits in regions of permanent shadow where water ice is predicted to be thermally stable at the surface [2, 3]. In this study, we examine the newly processed MLA reflectance data in conjunction with high-spatial-resolution thermal model results derived from MLA topography to better define the distribution of volatiles.

MLA Reflectance Data: A spatially interpolated MLA normal reflectance map of the north polar region is shown in Figure 1 with the mapped boundaries of the smooth plains deposits superimposed [4]. The MLA data were selected to exclude data acquired at high emission and long slant ranges and then calibrated using a procedure to remove temporal drifts. The resulting map shows broad regions of high reflectance that correspond well with the mapped boundaries of the smooth plains. At latitudes northward of 70°N, dark deposits on the north-facing interior rims of impact craters are clearly evident. These are hypothesized to be organic-rich sublimation lags overlying thermally stable radar-bright deposits of water ice [3]. MLA obtained only limited off-nadir observations poleward of 84°N because of the inclination of the MESSENGER orbit. However, in the densely sampled region from 75°N to 84°N, a gradual poleward darkening is evident in the MLA albedo map. The darkening appears to be pervasive down to the limit of the binned spatial resolution (0.5 km).

Thermal Model Correlations: A digital elevation model of the north polar region was generated from the latest MLA topography at 0.5 km spatial resolution and a three-dimensional ray-tracing thermal model calculation performed to calculate surface and subsurface temperatures [3,5]. The resulting annual maximum surface temperatures and annual average surface temperatures were then compared with the non-interpolated MLA reflectance observations using a bin size of 0.5 km. Figure 2 shows a cross plot of MLA reflectance and thermal model calculated annual average subsurface temperatures (T_{avg}) for the region from 84°N to 75°N and for a pixel size of 0.5 km.

Surface Water Ice: The annual average temperature plot shows a distinct increase in reflectivity with decreasing temperature for T_{avg} < 80 K, which corresponds to an increase in albedo for annual maximum temperature T_{max} < 100 K. This trend has been interpreted as evidence for the presence of increasing fractional surface coverage of bright water ice, which is stable to sublimation to vacuum for timescales of billions of years at temperatures less than 100 K [3].

Pure Dark Deposits: The annual average temperature plot shows that regions with T_{avg} ~ 100 K have uniformly low reflectivity. These areas are interpreted to be completely covered with "pure" dark surface deposits overlying thermally stable subsurface water ice.

Mixed Dark Deposits: In the range 100 K < T_{avg} < 290 K, we note a linear increase in reflectivity with temperature. We attribute this trend to the presence of a decreasing fraction of exposed dark surface material within each pixel with increasing temperature. For the Moon, it has been proposed that small impact craters [6] and other surface roughness features [7] may serve as "micro cold traps" that may contain thermally stable surface and subsurface deposits of water ice and other volatiles. For Mercury, we suggest that the presence of dark surface material "marks" the locations of small-scale volatile cold traps that are mixed at spatial scales below those that can be resolved by MLA and Earth-based radar measurements. In this latitude range on Mercury, the extent to which these cold traps contain subsurface water ice is not certain.

Darkening by Space Weathering: For T_{max} > 500 K and T_{avg} > 290 K, MLA reflectivity decreases with increasing temperature. Pending further analysis, we tentatively attribute this trend to darkening due to space weathering. It has been proposed that the rates of soil darkening due to a range of space weathering processes on Mercury increase with increasing temperature [8,9]. This phenomenon has not been positively identified on the Moon, but at the lunar equator

where T_{max} < 400 K and T_{avg} < 220 K, temperatures may be too low to allow a potential thermal space weathering component to be apparent..

Cold Trap Areas: If the observed poleward darkening is due to the presence of sub-resolution dark deposits, then the total area of these deposits can be estimated. Given the strong correlation between annual average temperature and reflectance, we have used the thermal model results to estimate approximately the fractional dark area within each pixel where surface or subsurface ice is not calculated to be thermally stable by assuming that the fractional dark area grows linearly from 0% for T_{avg} = 290 K to 100% for T_{avg} = 100 K. The results of this procedure imply that fully 22% of the area poleward of 70°N is covered by dark material in micro-scale cold traps. For comparison, at spatial scales of greater than 0.5 km, the thermal model predicts that only 4% surface area poleward of 70°N contains thermally stable subsurface water ice deposits, and only 0.5% of the area poleward of 70°N contains thermally stable surface water ice. We plan more detailed thermal models that explicitly include the effects of small-scale roughness to more accurately assess the extent of Mercury's polar cold traps and the implications for volatiles.

References: [1] Neumann, G. A. et al. (2013) *AGU Fall Meeting*, abstract P13A-1737. [2] Neumann, G. A. et al. (2013) *Science* 339, 296-300. [3] Paige, D. A. et al. (2013) *Science* 339, 300-303. [4] Denevi, B. W. et al. (2013) *JGR Planets* 118, 891-907. [5] Paige, D. A. et al. (2013) *AGU Fall Meeting*, abstract P11A-03. [6] Bussey, D. B. J. et al. (2003) *Geophys. Res. Lett.* 30, 1278. [7] Hayne, P. O. (2013). *BAAS* 45 (9), abstract 107.3. [8] Cintala, M. J. (1992) *JGR* 97, 924-973. [9] Domingue, D. L. (2014) *LPS* 45, this mtg.

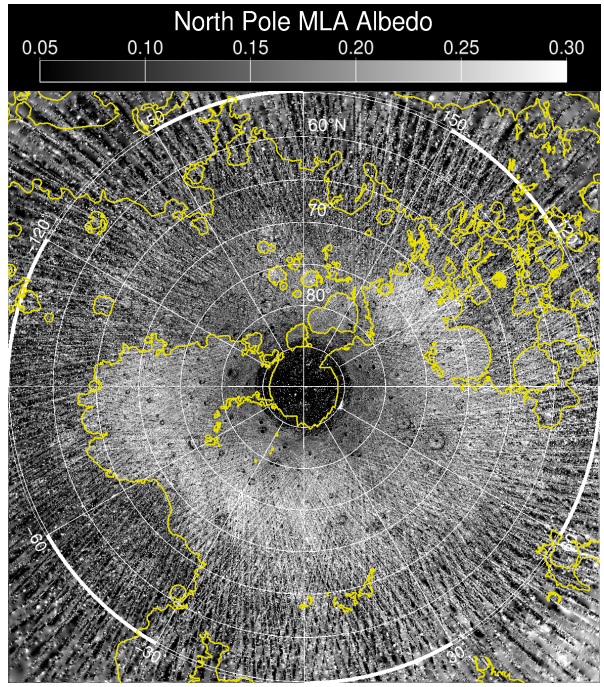

Fig. 1. Map of normal reflectance at 1064 nm in the north polar region of Mercury. The mapped boundary of the northern smooth plains [4] is shown in yellow.

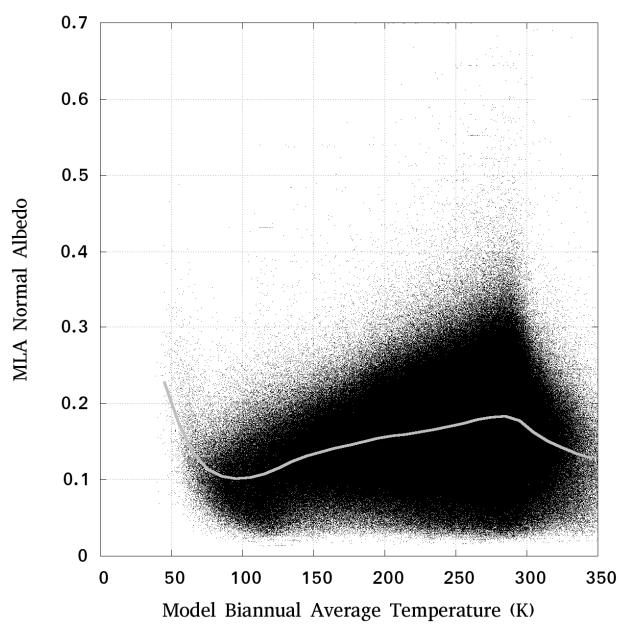

Fig. 2. MLA reflectance versus calculated annual maximum average subsurface temperature for all MLA measurement locations from 84°N to 75°N. The gray line shows the average MLA albedo as a function of temperature.