IMAGING INSIDE MERCURY'S PERMANENTLY SHADOWED CRATERS: FIRST IMAGES FROM MESSENGER.

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Introduction: Multiple lines of evidence support the presence of water ice within regions of permanent shadow near Mercury's poles: Earth-based radar observations show high radar reflectivities and inverted circular polarization ratios in such areas [e.g., 1], spacecraft images indicate that these areas do not receive direct sunlight [e.g., 2], neutron spectrometry is consistent with the presence of a hydrogen-rich material in the north polar region [3], measurements of surface reflectance at near-infrared wavelengths reveal anomalous dark and bright deposits in these same areas [4], and thermal models indicate that such areas are conducive to the presence of water ice [5]. Taken together, there is compelling evidence for water ice near the poles of the Solar System's innermost planet.

Images acquired by the SELENE Terrain Camera [6] and the Lunar Reconnaissance Orbiter Camera [7] have revealed details of shadowed surfaces on the Moon that are weakly illuminated by sunlight scattered from nearby terrain. Inspired by this success, the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) team recently targeted the shadowed regions near Mercury's north pole for imaging with the Mercury Dual Imaging System (MDIS) [8]. Here we present the first MESSENGER images that successfully resolve the surface within Mercury's permanently shadowed, ice-bearing craters.

Imaging Details: MDIS is composed of two cameras: a Wide-angle Camera (WAC) and a Narrow-angle Camera (NAC). MESSENGER's highly eccentric orbit has its periapsis over Mercury's north polar region. This region was therefore the focus of the first attempts to image in Mercury's permanently shadowed areas, because the shadowed areas fill a larger portion of the camera fields of view.

With its smaller field of view (1.5°), the NAC was used to acquire images for which the entire scene was within a region of shadow. However, the long exposure time required to produce a signal above the background level also resulted in considerable image smear due to the spacecraft's motion. These NAC images do not clearly show any details of the permanently shadowed surface, though there is the potential that more sophisticated analysis may ultimately yield interpretable images.

With the larger WAC field-of-view (10.5°) and MESSENGER's orbit, it is not possible for any permanently shadowed region on Mercury to fill a WAC scene. Unlike the NAC, the WAC is equipped with a filter wheel, which includes a broadband clear filter (central wavelength 700 nm, bandwidth 600 nm [8]). This broadband filter is regularly used to image stars for calibration purposes but is not typically used to image Mercury's sunlit surface, as the signal would be too high. However, WAC broadband filter images with exposures of 10 ms reveal surface details within areas of permanent shadow when those areas are located on the edge of the WAC charge-coupled device (CCD) that is read out first. When the frame is oriented such that permanently shadowed areas are not located at the readout edge of the CCD, the signal is typically dominated by frame-transfer smear from sunlit pixels.

The first successful MDIS images to reveal surface details inside permanently shadowed areas are 10 ms WAC broadband filter images of Chesterton crater. Additional images of other permanently shadowed craters are planned for acquisition prior to March 2013, and, if successful, these images will also be presented.

Imaging Results for Chesterton Crater: Chesterton is a 37-km-diameter crater located at 88.4° N, 225.5° E, that hosts a sizable radar-bright deposit (**Figure 1**). Recent thermal models indicate that the maximum surface temperature within regions of Chesterton are <100 K, and similar to results for the craters Kandinsky and Prokofiev, water ice could be cold-trapped at the surface [5]. No reflectance measurements by MESSENGER's Mercury Laser Altimeter (MLA) have been reported to date for the interior of Chesterton, but portions of the interiors of Kandinsky and Prokofiev show high reflectance (at 1064 nm), interpreted to be the result of surface water ice [4]. Hence, water ice may also be present on portions of the surface within Chesterton.

WAC broadband filter imaging results for Chesterton are shown in **Figure 2**. The permanently shadowed surface within Chesterton is marked with small craters, and Chesterton shows a central peak structure, as is expected for a crater of its diameter. The central peak correlates with a dark region in the Arecibo radar image, consistent with the central peak potentially being sunlit at some point during the Mercury solar day. The region shown in the WAC broadband filter image largely corresponds with bright areas in the Arecibo radar image, though no clear albedo variations on

Chesterton's floor can be identified in the broadband filter WAC image.

These first WAC broadband filter images are highly encouraging. Such images may provide constraints on the age of the surface and hence the timing and mechanism of water ice emplacement on Mercury. Insight into the nature and composition of the surface may also be possible, from an examination of the morphology of any fill and small craters on the shadowed terrain and determination of the reflectance properties of the surface. In particular, if some of Mercury's polar deposits consist of exposed surface ice ringed by much darker organic-rich sublimation lag deposits [5], the large variations in relative albedo, as seen at 1064 nm wavelength, may be resolvable in future MDIS images.

These images of Chesterton were obtained as exploratory images, but with their proven success there are many compelling reasons to develop a dedicated imaging campaign to acquire such images of all of Mercury's permanently shadowed, radar-bright, ice-bearing craters. Such a campaign could be achieved during a second extended mission for MESSENGER.

References: [1] Harmon J. K. et al. (2011) *Icarus, 211*, 37-50. [2] Chabot N. L. et al. (2013) *JGR, 118*, doi:10.1029/2012JE004172. [3] Lawrence D. J. et al. (2013) *Science*, 10.1126/science.1229953. [4] Neumann G. A. et al. (2013) *Science,* 10.1126/science.1229764. [5] Paige D. A. et al. (2013) *Science*, 10.1126/science.1231106. [6] Haruyama J. et al. (2008) *Science, 322*, 938-939. [7] Speyerer E. J. and Robinson M. S. (2013) *Icarus, 222*, 122-136. [8] Hawkins S. E. III et al. (2007) *Space Sci. Rev., 131*, 247-338.

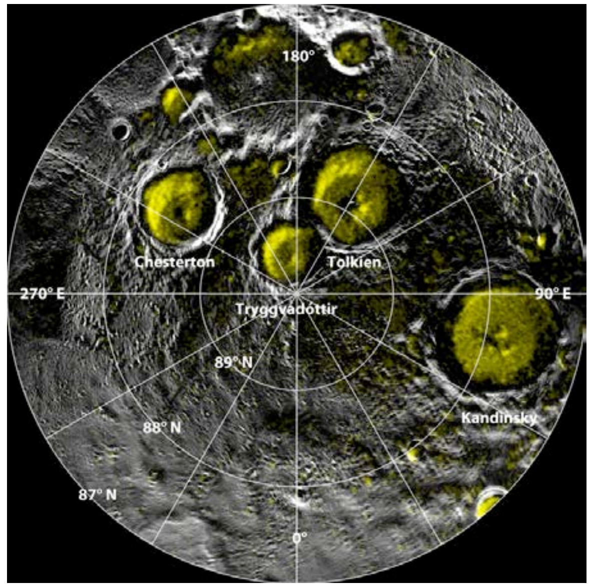

Figure 1. Mercury's north polar region, with Arecibo radar image in yellow [1] over a mosaic created by averaging MDIS images. Chesterton has a diameter of 37 km.

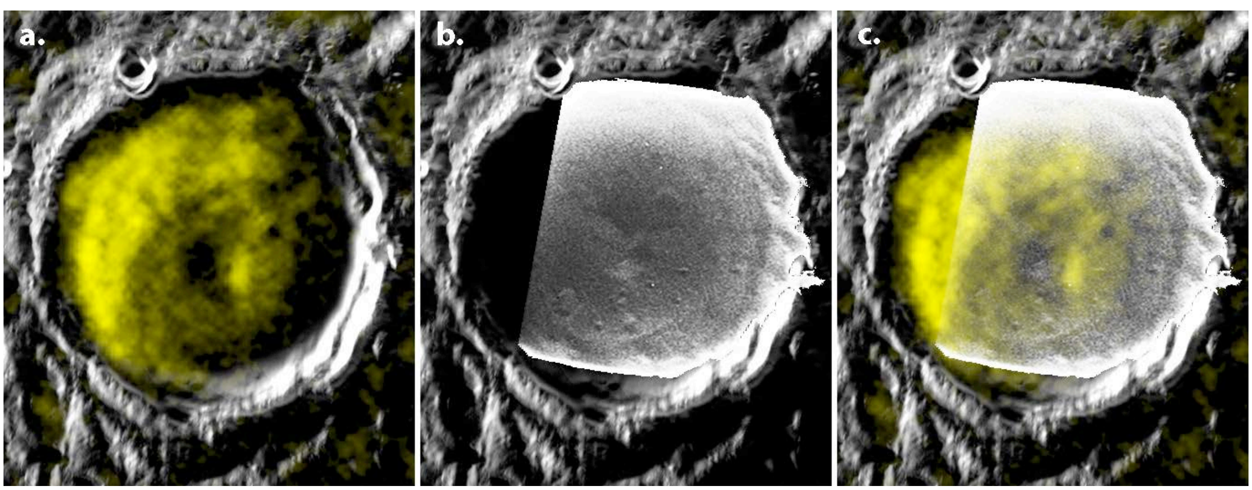

Figure 2. Average MDIS mosaic of Chesterton crater (37 km diameter) with: (**a)** Arecibo radar image in yellow [1]; (**b)** WAC broadband-filter, 10-ms-exposure image overlain, showing details of the permanently shadowed surface within the crater; (**c)** both radar (yellow) and WAC broadband filter images. The WAC broadband filter image was acquired at 185 m/pixel, and the image has been trimmed to exclude pixels exterior to Chesterton or compromised by sunlit portions of the image. The Arecibo radar image was obtained with a range resolution of 1.5 km.