IMMATURE CRATERS MATURE FASTER ON MERCURY THAN ON THE MOON.

Sarah E. Braden[1], Mark. S. Robinson[1], Brett W. Denevi[2], and Sean C. Solomon[3], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 858281; [2]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723; [3]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015.

Introduction: New Mercury Dual Imaging System (MDIS) and Lunar Reconnaissance Orbiter Camera (LROC) observations enable tests of hypotheses on space weathering effects on Mercury and the Moon.

The continuous ejecta and rays of young craters have been exposed to space weathering for less time than most other surface units. The high reflectance of young craters is a result of the excavation from depth of relatively immature material and its deposition onto the surrounding mature terrain [1]. Rays of this type are known as immaturity rays, in contrast to rays visible because of compositional differences [1]. Space weathering reduces an immaturity ray's reflectance, so over time the reflectance of ray material approaches that of surrounding mature material [1]. Space weathering encompasses multiple processes that affect the surface of an airless body, including sputtering, irradiation, implantation from solar wind particles, and bombardment by meteoroids and micrometeoroids. The optical effects of space weathering are known to decrease overall reflectance, suppress absorption features, and redden spectra [2-6]. Another process affecting the life span of maturity rays is gardening where impacts mix and overturn the regolith [7,8].

Previous studies identified key differences between the environments on Mercury and the Moon, and led to the hypothesis that on Mercury the rate of soil maturation is faster and reaches a more advanced state [9,10]. Mercury has a flux of impactors 5.5 times that of the Moon and impacts occur at higher velocities on average [9]. As a result, a given impactor encountering Mercury is expected to produce 14 times more melt and 20 times more vapor than on the Moon [9]. Mercury, unlike the Moon, has a magnetic field that partially protects its surface from charged particles, such that the solar wind flux at the surface is typically less than in the lunar environment despite the difference in solar distance [11]. Exceptions are demonstrated cases of moderate and extreme magnetic tail loading when the dayside surface is exposed to the solar wind [12]. The increased flux and velocity of micrometeoroids as well as the magnetic field's partial protection of the surface result in the prediction that melting and vaporization due to micrometeoroids will dominate space weathering on Mercury [5]. Whereas micrometeoroids and solar wind both alter the optical properties of the regolith, micrometeoroid bombardment also overturns (mixes) the regolith [7,8]. With increased micrometeoroid bombardment on Mercury [5,9], rates of regolith mixing should also increase. In Mercury's environment the contrast of young crater rays should decrease faster than on the Moon due to both optical maturity effects and regolith mixing.

Investigating compositional differences between Mercury and the Moon through comparison of ultraviolet to near-infrared reflectance is complicated by differences in the relative efficiency of optical maturation due to different space weathering environments [13]. Measuring the reflectance of immature materials at similar wavelengths addresses this issue and also provides a first-order constraint for models of Mercury's composition.

Data: Mosaics from the MDIS wide-angle camera (WAC), its narrow-angle camera (NAC), and the LROC WAC enable a detailed comparison of reflectance on the two bodies. The normalized reflectances of immature ejecta blankets were measured from mosaics with comparable wavelengths: the LRO 566 nm (FWHM=20 nm) mosaic and the MDIS 560 nm (FWHM=5 nm) mosaic. Images comprising the two mosaics were corrected to 30° phase angle (incidence angle $i = 30°$, emission angle $e = 0°$) [14,15]. To minimize the effect of photometric correction errors due to shadowing, only images with incidence angles below 45° for areas between 40°S and 40°N latitude were considered on each body.

Methods: *Craters with distinct rays or diffuse halos.* We classified young craters with high-reflectance ejecta into two groups: distinct rays and diffuse halos. A distinct-rayed crater has clearly defined rays, and the boundary between a ray and the surrounding mature material is discrete. Diffuse-halo craters have high-reflectance ejecta surrounding the crater, with no distinct rays (Fig.1).

Number of craters per unit area. Crater populations were measured using LROC and MDIS reflectance mosaics as well as mosaics optimized for morphological observations. A series of criteria for defining Eratosthenian (lunar) and Mansurian (mercurian) craters was developed, on the basis of previous work [16-18]. An Eratosthenian or Mansurian crater is defined by: (1) a sharp, well-defined rim, (2) no high-reflectance rays or continuous ejecta, (3) morphological evidence of an ejecta blanket, (4) a rim crest only slightly degraded. We avoided secondary craters by limiting our study to craters ≥10 km in diameter and excluding craters in clusters or linear crater chains.

Reflectance of immature materials. Measurements of normalized (photometrically corrected) reflectance were obtained by averaging a group of pixels (at least 5×5 pixels) over a uniform area of the high-reflectance continuous ejecta blanket. Sun-facing slopes were avoided while collecting the reflectance values. Known compositional rays on the Moon were excluded from the analysis.

Results: The classification of distinct-rayed or diffuse-halo craters yielded the following numbers. For lunar craters in the highlands with high-reflectance ejecta (*n*=287), 35% had distinct rays, 60% had diffuse halos, and 5% were intermediate cases. For mercurian craters with high-reflectance ejecta (n=129), 19% had distinct rays, 75% had diffuse halos, and 6% were intermediate cases. The percentage of craters with distinct rays out of the total population is lower on Mercury than the Moon, which indicates that sharp rays remain perceptible on the lunar surface for a longer time. Although optical maturity effects from both solar wind sputtering and micrometeoroid bombardment contribute to the degradation of distinct rays, regolith mixing due to the increased micrometeoroid bombardment on Mercury [5,9] may account for the lower percentage of mercurian distinct-rayed craters observed. Factors such as possible differences between Mercury and the Moon in the general thickness of the ejecta forming the rays could complicate our interpretation of the data.

If space weathering is more efficient on Mercury than on the Moon, then immaturity rays will also decrease in reflectance faster, eventually fading to the reflectance of the surrounding mature material. As a result, high reflectance-ejecta craters per unit area on the Moon should be greater than on Mercury, since the immature material on the Moon remains visible over longer timescales. Our measurements show that there are ~2 times more lunar immature craters per unit area than on Mercury. To further investigate this result, we compared the rayed crater population to the next youngest population of craters, those with sharp rims but no high-reflectance rays, commonly known as the Eratosthenian (lunar) and the Mansurian (mercurian) crater populations. The ratio of rayed craters to Mansurian craters (Mercury) per unit area is 0.09 ± 0.01, and the ratio of rayed craters to Eratosthenian (Moon) craters per unit area is 0.22 ± 0.03. The lower ratio of mercurian rayed craters to Mansurian craters per unit area is consistent with the idea that on Mercury, craters with high-reflectance rays mature faster, lose their rays, and therefore transition into the Mansurian crater population faster than they would if they were on the Moon. Our observations support the assertion that the rayed crater population on Mercury is overall younger than the rayed crater population on the Moon, as previously suggested [13].

Reflectance of immature materials. Observations of the reflectance of immature materials from 200 m/px data allow for the detection of small (<3-km-diameter) craters, which are more likely to be young craters. The most immature (highest reflectance) lunar and mercurian materials measured have reflectances of 0.29 and 0.14, respectively. The average normalized reflectance for immature lunar material is 0.15 (±0.02, *n*=287) and for immature mercurian material is 0.08 (±0.01, *n*=403). Average immature lunar material is ~2 times higher in reflectance than immature mercurian material, likely indicating a compositional difference, which agrees with previous results [13].

Conclusions: The lower percentage of distinct-rayed craters on Mercury, and the lower ratio of mercurian rayed craters to Mansurian craters per unit area, compared with those ratios for the Moon, is consistent with more efficient space weathering on Mercury than on the Moon, with indications of increased micrometeoroid bombardment playing a significant role.

References: [1] Hawke, B.R., et al. (2004) *Icarus*, 170, 1-16. [2] McCord, T.B. and Adams, J.B. (1973) *Moon*, 7, 453-474. [3] Pieters, C.M., et al. (1993) *J. Geophys. Res.*, 98, 20817-20824. [4] Fischer, E.M. and Pieters, C.M. (1994) *Icarus*, 111, 475-488. [5] Hapke, B. (2001) *J. Geophys. Res.*, 106, 10039-10074. [6] Noble, S.K., et al., (2001) *Meteorit. Planet. Sci.*, 36, 31-42. [7] McGetchin, T.R., et al. (1973) *Earth Planet. Sci. Lett.*, 20, 226-236. [8] Gault, D.E., et al. (1974) *Proc. Lunar Sci. Conf. 5th*, 2365-2386. [9] Cintala, M.J. (1992) J. *Geophys. Res.*, 97, 947-973. [10] Noble, S.K. and Pieters, C.M. (2003) *Solar Syst. Res.*, 37, 31-35. [11] Killen, R.M., et al. (2001) *J. Geophys. Res.*, 106, 20509-20525. [12] Slavin, J.A., et al. (2010) Science, 329, 665-668. [13] Denevi, B.W. and Robinson, M.S. (2008) *Icarus*, 197, 239-246. [14] Sato, H., et al. (2011) *Lunar Planet. Sci.*, 42, 1974. [15] Domingue, D.L., et al. (2011) *Planet. Space Sci.*, 59, 1873-1887. [16] Wilhelms, D.E. (1987) *U.S. Geological Survey Professional Paper* 1348. [17] McEwen, A.S., et al. (1997) *J. Geophys. Res.*, 102, 9231-9242. [18] Grier, J.A., et al. (2001) *J. Geophys. Res.*, 106, 32847-32862.

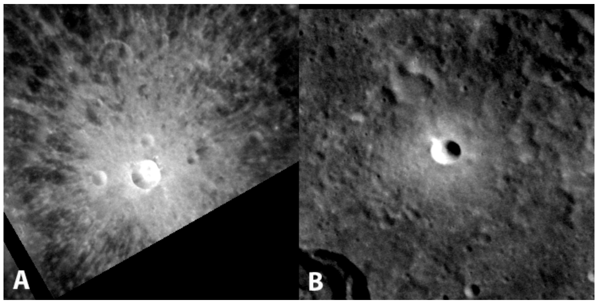

Figure 1: Examples of fresh craters on Mercury. (A) A distinct-rayed crater 6.8 km in diameter (10.97°N, 13.90°E); average reflectance is 0.14 at 560 nm. (B) A diffuse-halo crater 6.0 km in diameter (30.79°S, 278.94°E); average reflectance is 0.10 at 560 nm. (A) is relatively younger than (B), on the basis of the contrast and average reflectance of the rays.