REVISED AGE CONSTRAINTS FOR MERCURY'S KUIPERIAN AND MANSURIAN SYSTEMS. Maria E. Banks[1,2], Zhiyong Xiao[3,4], Sarah E. Braden[5], Simone Marchi[6] Clark R. Chapman[7], Nadine G. Barlow[8], and Caleb I. Fassett[9], [1]Planetary Science Institute, Tucson, AZ, USA, banks@psi.edu, [2]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC, USA, [3]School of Earth Sciences, China University of Geosciences, Wuhan, Hubei, P. R. China, [4]Centre for Earth Evolution and Dynamics, University of Oslo, Oslo, Norway, [5]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA, [6]NASA Lunar Science Institute, Southwest Research Institute, Boulder, CO, USA, [7]Department of Space Studies, Southwest Research Institute, Boulder, CO, USA, [8]Northern Arizona University, Flagstaff, AZ, USA, [9]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA, USA.

Introduction: The absolute time scale for the stratigraphic systems of Mercury was initially inferred from that of the Moon [1,2]. On the basis of morphologically distinct basin and crater deposits observed in Mariner 10 data, [1] subdivided Mercury's surface units into five time-stratigraphic systems: (oldest to youngest) pre-Tolstojan, Tolstojan, Calorian, Mansurian, and Kuiperian. The duration and onset of corresponding periods in the stratigraphic sequences on Mercury and the Moon are not necessarily the same, although they have generally been assumed to be broadly similar in past work. For example, [1] suggested an onset of the Mansurian system at ~3.5-3.0 Ga and that of the Kuiperian at about1 Ga.

The recent crater model production function (MPF) and inner solar system chronology of [3] incorporates current knowledge of impact populations. Using this MPF, [4] found the oldest pre-Tolstojan surfaces of Mercury to be about 4.0–4.1 Ga, and that widespread smooth volcanic plains were emplaced by ~3.6–3.8 Ga during the Calorian [1]. Here we focus on age constraints for the Kuiperian and Mansurian systems. High-resolution and multi-band image data obtained by the MErcury Surface, Space ENviroment, GEochemistry, and Ranging (MESSENGER) spacecraft were used to catalog impact craters interpreted to be Mansurian and Kuiperian in age [5–7]. The densities of these crater populations are used to estimate new limits for the age boundaries of these systems.

Data and Method: The Mansurian and Kuiperian are defined by the craters Mansur and Kuiper. Craters that have formed since the onset of the Mansurian are defined as morphologically fresh and are characterized by crisp morphologies with well-preserved rims, few or no superposed craters, continuous ejecta with radial lineaments, and well-defined secondary craters [1,8–9]. Kuiperian craters have bright ray systems. Mansurian craters retain fresh morphologies, but their associated ray systems no longer display a reflectance contrast with the local surrounding surface [1]. This study utilizes a dataset of Kuiperian craters identified over 98.4% of Mercury's surface (Fig. 1) first presented in [5] and subsequently revised utilizing currently available PDS MESSENGER data. The population of craters interpreted to have formed since the onset of the Mansurian includes the dataset of Mansurian craters between 40° N and 40° S presented in [6], combined with craters from the Kuiperian catalog located within this same latitudinal range (Fig. 1). Craters were included down to diameters of 7 km.

The MPF of [3] is derived from the size-frequency distribution (SFD) of Main Belt Asteroids (MBAs) and Near Earth Objects (NEOs) using crater scaling laws. Two scaling laws were applied [10]: Hard Rock (HR) scaling for strengths of $\boldsymbol{Y_0}$ = 2 x 10^8 (nominal hard rock, [11]), 2 x 10^7, and 2 x 10^6 dyne cm^{-2}, and Rubbly Material (RM) scaling for strengths of 2 x 10^6 and 2 x 10^7 dyne cm^{-2}. Other parameters include target densities of 3.4 g/cm^3 (HR) and 2.8 g/cm^3 (RM), and an impactor density of 2.6 g/cm^3. Unless otherwise stated, crater SFDs were fit to the NEO production function.

Results: *Completeness of data.* We assume our density of fresh craters is representative of the population of craters, with diameters ≥7 km, that have formed since the onset of the Mansurian. Although obvious secondaries were excluded, large distant secondaries >7 km in diameter may have been inadvertently included which would lead to slightly overestimated ages. However, numerous undetected distal secondaries >7 km in diameter are not expected to be included, as few Mansurian and Kuiperian primaries are sufficiently large to produce many secondaries of this scale. An independent catalogue of Mansurian and Kuiperian craters between 20° N and 20° S [7] yields similar crater densities (Fig. 1) providing support for completeness of the Mansurian population utilized in this study. As widespread smooth volcanic plains are interpreted to have been emplaced in the Calorian (by ~3.6 Ga) [1,4,12–13], Mansurian and Kuiperian crater populations have not have been significantly altered by this process. Fig. 1b indicates a drop in the density of rayed craters <20 km-diameter. A similar drop in density is not observed in the Mansurian population in this size range. To ensure reliable results, only craters >20 km-in-diameter were used to derive model ages for the

Kuiperian population. Rays for craters <20 km-in-diameter may be more easily and rapidly erased [6,14].

Mansurian system: Using the cumulative density of Mansurian and Kuiperian craters equatorward of 40° latitude [5–6], we obtain estimated model ages of ~2.1, ~1.9, and ~1.8 Ga using HR scaling (Fig. 2), and an estimated model age of ~3.6 Ga using RM scaling for our different assumed strengths. We include the RM scaling primarily for comparison as this scaling is likely not applicable given the size of the craters and expected excavation depths. Using the dataset of [7], we obtain a comparable model age of ~1.9 Ga (HR scaling, 2 x 10^8 dyne cm^{-2}). Model runs using the SFD of MBAs resulted in similar model ages (i.e. ~2.1 Ga for HR scaling, $\boldsymbol{Y_0}$ = 2 x 10^8 dyne cm^{-2}). However, as expected from dynamical models, a particularly good fit was found for the NEO-derived crater distribution and the SFD of our Mansurian crater population [5–6]. Altogether we estimate a model age for the population of craters formed since the onset of the Mansurian of ~1.9 ± 0.3 Ga (using formal model errors).

Kuiperian system: Using the density of Kuiperian craters, we ran similar models to those for the Mansurian population. The most relevant model ages range from ~300–320 Ma using HR scaling for our assumed strengths (rayed craters >20-km-in-diameter). Here again we find a better fit for the Kuiperian SFD with the NEO-derived distribution. Altogether we estimate a model age of ~300 ±40 Ma for the population of craters formed since the onset of the Kuiperian.

Discussion: Using the MPF of [3], a particularly good fit for the Mansurian SFD was found for the NEO-derived crater distribution, similar to findings for crater size distributions in young lunar terrains [15]. However the NEO production function does not fit as well to the Kuiperian SFD. The reasons for this are not clear. While the fit could be telling us something interesting about the evolution of the NEO population in more recent times, it may likely reflect an unknown size-dependency or other issues with processes that form and erase crater rays, which define the Kuiperian/Mansurian boundary Shorter time scales for the Mansurian and Kuiperian compared to the lunar Eratosthenian and Copernican are supported by the higher impact flux and crater degradation rates predicted for Mercury, particularly in regards to erosion from subsequent cratering [e.g. 1,16–17]. Craters of similar sizes and states of degradation are thus expected to be younger on Mercury compared with those on the Moon.

Conclusions: Results indicate that the Mansurian and Kuiperian have shorter time scales than initially estimated and began more recently than the lunar Eratosthenian and Copernican respectively. Estimated model ages for the onset of the Kuiperian and Mansurian are significantly younger than previously suggested onset ages of ~1 Ga and~3.5–3.0 Ga respectively [1]. Based on the work of [3], we estimate the Kuiperian may have begun as recently as ~300 ±40 Ma and the Mansurian as recently as ~1.9 ±0.3 Ga (Fig. 2). Results are consistent with higher impact flux and surface erosion rates on Mercury compared to the Moon.

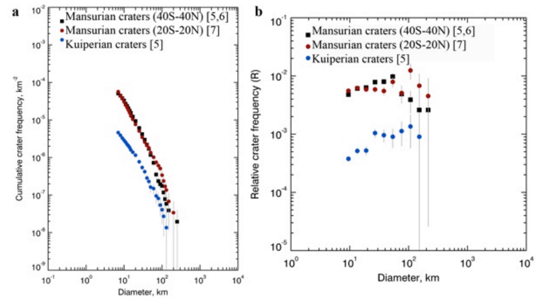

Figure 1: A) Cumulative and B) relative plots of Kuiperian (blue, [5],) and Mansurian (black, [5,6], and red, [7]) craters.

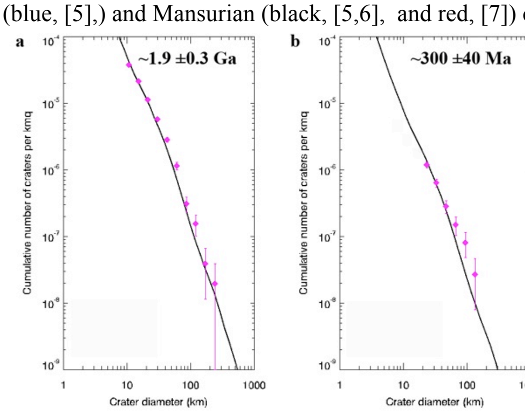

Figure 2. Plots showing estimated model ages for craters that have formed since the onset of the a) Mansurian and b) Kuiperian. Results were derived using the MPF of [3] and HR scaling for a strength of $\boldsymbol{Y_0}$ = 2 x 10^7 dyne cm^{-2}.

References: [1] Spudis P. D. and Guest J. E. (1984) *Mercury*, Univ. Ariz. Press, 118–164. [2] Shoemaker E. M. and Hackman R. J. (1962) *The Moon*, (Z. Kopal and Z. K. Mikhailov eds) 277-339, Academic Press, New York. [3] Marchi S. S. et al. (2009)*ApJ, 137*, 4936–4948. [4] Marchi S. S. et al. (2013) *Nature*, *499*, 59–61. [5] Xiao Z. et al. (2012), LPSC *43*, abstract 2143. [6] Braden S. E. and Robinson M. S. (2013) *JGR*, *118*, 1903–1914. [7] Strom, R. G. et al. (2015) *Res. Astron. and Astrophys.*, *15*, *3,* 407–434. [8] Arthur D. W. G. et al. (1963) *Comm. Lunar Planet. Lab*, *2*, 71–78. [9] Leake M. A. (1982) *Advances in Planet. Geol.*, Technical Memorandum TM-84894, NASA, Washington, D.C., 3–535. [10] Holsapple K. A. and Housen K. R. (2007) *Icarus*, *191*, 586. [11] Asphaug E. et al. (1996) *Icarus*, *120*, 158. [12] Denevi B. W. et al. (2013) *JGR, 118*, 891–907. [13] Byrne P. K. et al. (2016) *LPSC 46*, *this conference*. [14] Morota T. and Furumoto M. (2003) *EPSL.*, *206*, 315-323. [15] Kirchoff M. R. et al. (2013) *Icarus*, *225*, 325-341. [16] Gault D. E. et al. (1975) *JGR.*, *80*, 2444–2460. [17] Cintala M. J. (1992) *JGR*, *97*, 947–973.