MERCURY'S PAST ROTATION AND CRATERING DISTRIBUTION.. J. S. Knibbe[1,*] and W. van Westrenen[1], [1]Faculty of Earth and Life Sciences, VU University Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands, *j.s.knibbe@vu.nl

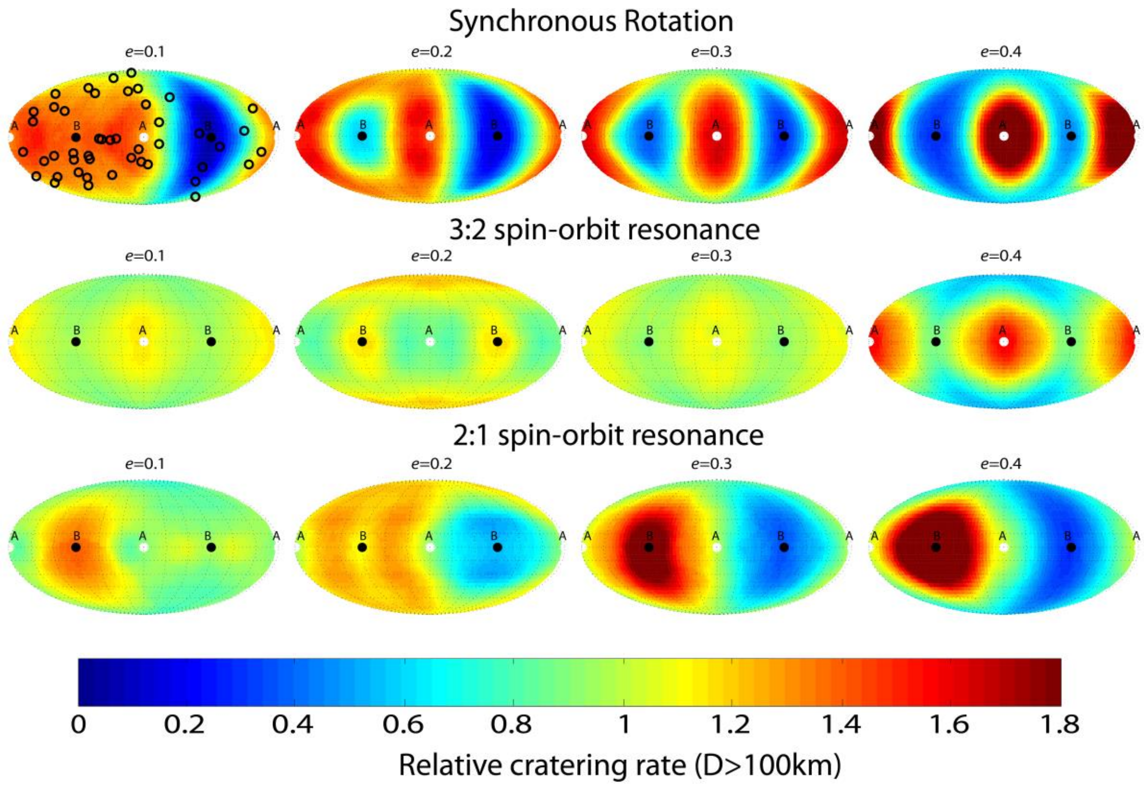

Figure 1: Mercury's spatially resolved relative cratering rate for craters of 100 km diameter at minimum. A and B denote the position of the minimum and intermediate moment of inertia axes. Mercury's spin-orbit resonance varies from 1:1 (synchronous, upper plots), 3:2 (middle plots), and 2:1 (lower plots). The applied orbital eccentricity (*e*) for Mercury varies from 0.1 (left plots), 0.2 (mid-left plots), 0.3 (mid-right plots) to 0.4 (right plots). Open circles in the upper left figure reflect the positions of craters >300 km in radius according to Fasset et al. [1] their table 1. This projection of observed craters on the simulated crater distribution may be off set by precisely 180° longitudes, due to symmetry of having one of the A points located subsolar at perihelion.

Introduction: The globally resolved surface photography from MESSENGER shows that large craters are non-uniformly distributed across Mercurian surface [1]. This can be a result of either a non-uniform impact flux for large craters or large-scale post-impact resurfacing. The prior hypothesis is subject of this study. Wieczorek et al. [2] showed that a locked retrograde synchronous rotation is the most likely (68%) end-scenario if Mercury has despinned from initial rapid retrograde rotation. They simulated the predicted cratering distribution of craters larger than 100 km in diameter for such synchronance, and argued that these simulations matched Mercury's present-day crater distribution. Hence, they concluded that the present-day crater distribution can be explained by a former retrograde synchronous rotation. A large impact was proposed to initiate the transition from the former retrograde synchronous to the current prograde 3:2 spin-orbit resonance. Caloris basin was suggested to be a possible relic of this event. Correia and Laskar [3] showed that such a transition can also be achieved by multiple smaller impacts. Noyelles et al. [4] argued that, if a former retrograde synchronous rotation would get destabilized by impact, Mercury is unlikely to get captured in a 3:2 prograde spin-orbit resonance. Additionally, they questioned whether the simulated cratering distribution of Wieczorek et al. [2] accurately matches the present-day cratering record. In particular, a principal result of the simulations of Wieczorek et al. [2] is the presence of cratering maxima near the 0° and 180° meridians, which, according to Noyelles et al. [4], is not a pronounced feature in the current record of large Mercurian craters. To date, no attempt has been made to examine Mercury's cratering distribution in its current 3:2 spin-orbit prograde resonance, nor for any of the higher order prograde resonances. Given that Mercury's orbit is highly eccentric and may have been more eccentric in the past [5], substantial spatial heterogeneity of the cratering distributions can be expected for such rotational states for two reasons: One, the orientation of Mercury is biased with respect to time in case of substantial eccentricity, two, the collision probability is generally higher at perihelion, which corresponds to particular orientations in case of locked resonances. The advantage of a former higher order resonance is that it can get destabilized by a temporary decrease of eccentricity and, at least in theory, does not require a large impact to initiate a transition, in particular towards lower order resonances.

Aims: The objectives of this study were to examine Mercury's cratering distribution in its current 3:2 spin-orbit resonance, a hypothetical former synchronous rotation, and a hypothetical former 2:1 spin-orbit resonance. For all of these cases, the effect of Mercury's orbital eccentricity is of particular importance.

Method: The formalism of Wetherill [6] and Greenberg [7] is applied to calculate the impact fluxes on Mercury for the spin-orbit resonances subject to study. The procedure of Le Feuvre and Wieczorek [8] is followed to obtain relative cratering rates. Distributions for orbital elements of Mercury-crossing objects are taken from the observed asteroid database compiled by the Lowell observatory. We perform simulations for eccentricities 0.1, 0.2, 0.3 and 0.4 of Mercury's orbit, based on the likely range of variability in this parameter over large timescales [9].

Results: The simulated relative cratering rates (Figure 1) show that significant heterogeneity can be induced by any of the locked resonances studied here. The results of the synchronous rotation for an orbital eccentricity of 0.2 for Mercury's orbit is virtually identical to the corresponding result in Wieczorek et al. [2] (see their supplementary information). For higher eccentricities of Mercury's orbit, the antisolar and subsolar cratering maxima's are more pronounced. For lower eccentricities of Mercury's orbit, the hemispheric asymmetry is more pronounced. Results for Mercury's current 3:2 spin-orbit resonance show only insignificant cratering heterogeneity if Mercury's eccentricity is 0.3 or lower. For an eccentricity of 0.4, there is a clear maximal cratering near the minimum moment of inertia axes (sub-solar and anti-solar points at perihelion). However, the obtained cratering distribution is hemispherically symmetric, which is due to the symmetry in orientation for alternating orbits in this resonant state. The heterogeneity of cratering rates for the 2:1 resonance increases with Mercury's orbital eccentricity. The distribution is clearly hemispherically asymmetric.

Discussion: Taking into account that the evolution of Mercury's orbital eccentricity is highly chaotic over timescales of hundreds of million years [5], it is reasonable to consider the possibility that it has differed substantially from its current value (0.206) during the most intense cratering period. Following the hypothesis of a former synchronous rotation [2], we note that the simulated cratering distribution is sensitive to Mercury's orbital eccentricity. In particular, a lower eccentricity would increase the hemispheric asymmetry, which resolves the criticism by Noyelles et al. [4] on this issue. The question remains whether an impact of sufficient intensity has occurred to enable a transition from retrograde synchronous to the present-day 3:2 prograde spin-orbit resonance. The chaotic nature of Mercury's eccentricity provides the possibility that Mercury has initially been captured in one or several higher-order spin-orbit resonances prior to the final 3:2 resonance capture. The most likely preliminary resonance capture is the 2:1 spin-orbit orbit resonance [5]. If Mercury's eccentricity has been substantially eccentric and locked in the 2:1 resonance during the most intense cratering period, our results show that a clear hemispherically asymmetric crater distribution would result. A later period of near-zero eccentricity is required to destabalize this resonance and make the transition to the current 3:2 spin-orbit resonance possible. The occurrence of a high impact angle impact may help to initiate this transition. We note that results shown here are sensitive to the orbital elements and size distributions among impactors. This dependency will be further studied by adopting the orbital elements and size distribution of Bottke et al. [10] in similar simulations, that on-average include higher values for eccentricities among Mercury-crossing orbits. Preliminary results indicate that this increases the heterogeneity of cratering for Mercury's current 3:2 spin-orbit resonance in particular, also at moderate eccentricities. Extension of our approach to the 4:1 spin-orbit resonance is expected to yield less pronounced asymmetric cratering features at substantial orbital eccentricity of Mercury. An advantage of the 4:1 resonance is that it can get destabilized by variations in eccentricity more easily compared to the 2:1 spin-orbit resonance.

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