Geophysical Research Abstracts
Vol. 13, EGU2011-14012, 2011
EGU General Assembly 2011

A Lunar-like Chronology Model as Estimator for the Mass Depletion of the Asteroid Belt

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The bombardment of the Solar System by small bodies over the past 4.5 Ga is documented by the impact cratering-record of the surfaces of planetary bodies. The cratering record of Earth's moon revealed a typical size frequency-distribution (SFD), which has led to well-known impact cratering chronology models. Comparisons of the SFD of the Near Earth Asteroids (NEA) and magnitude-derived diameter estimates have led to the conclusion that the Asteroid Belt acts as the primary source of projectiles impacting the surfaces of planetary bodies of the Inner Solar System, for the Outer Solar System this is still under debate.

To support the hypothesis that the Asteroid Belt acts as the main source for projectiles impacting planetary surfaces of both the Inner and Outer Solar System, comparisons of the total impacted projectiles and masses on planetary surfaces with the particle and mass distribution of the recent Asteroid Belt as well as estimates of the depleted projectile and mass fraction are performed. To compare the impact-crater SFD with the projectile's SFD, a scaling law is applied to map the impact-crater SFD to a projectile's SFD. This is performed with the assumption of an average impact velocity per planetary body, an average impact angle of $45°$ and an average density of $\varrho = 2.5\ \mathrm{gcm}^{-3}$ of the impactor. By integrating the chronology function derived from impact-crater statistics on the Earth's moon by Neukum and Ivanov (1994), the total impacted projectiles and masses are estimated. Considering the gaps of mean motion-resonances (MMR) of asteroids with Jupiter in the Asteroid Belt as the dominant depletion mechanism, we compare the estimated impact-mass with a hypothetical mass concentration of the dynamically strong 3:1 MMR of a hypothetical pristine Asteroid Belt, and disregard other (mostly weaker) MMRs in this first approach.

Preliminary estimates of the total count of objects with a diameter $\mathrm{d} \geq 1\ \mathrm{km}$ in the recent Asteroid Belt (2.0 $-$ 3.3 AU) by this work, are in good agreement with estimates obtained by different observational methods: $(1.26 \pm 0.3) \cdot 10^6$ by this approach, and $(1.2 \pm 0.5) \cdot 10^6$ by an infrared-based observational approach of Tedesco and Desert (2002). This can be compared to a total of approx. $4.3 \cdot 10^6$ projectiles with diameter $\mathrm{d} \geq 1\ \mathrm{km}$ impacted on planetary surfaces in the Inner Solar System, estimated by this work.

Early mass-estimates of the recent Asteroid Belt in the diameter range of $1.0 - 1000\ \mathrm{km}$ (Ceres included) obtained by the method described above, gives $M_{belt} \approx 3.0 \cdot 10^{21}\ \mathrm{kg}$, which is also in good agreement with results obtained by an analysis of the perturbation of the motions of the major planets due to the mass of the recent Asteroid Belt (Krasinsky et al., 2002), which estimates $M_{belt} \approx 3.6 \cdot 10^{21}\ \mathrm{kg}$. For the Inner Solar System, a total impacted mass of $M_{in} \approx 3.4 \cdot 10^{21}\ \mathrm{kg}$ is obtained, roughly 4 times the mass of Ceres ($M_{\mathrm{Ceres}} \approx 9.35 \cdot 10^{20}\ \mathrm{kg}$), but this outcome is very sensitive to impact crater-to-projectile scaling and the knowledge of the production function towards larger crater sizes. Assuming a hypothetical, pristine Asteroid Belt by expanding its recent highest mass concentration ($\mathrm{kg}/\mathrm{AU}^2$) in the range of $2.96 - 3.276$ AU (which is assumed to be least eroded by dynamical processes (Minton and Malhotra, 2010)) over the range of $2.0 - 3.276$ AU its estimated mass is $M_{Belt/un} \approx 6.5 \cdot 10^{21}\ \mathrm{kg}$. The total impacted mass is roughly 1.5 times the mass concentrated between $2.0 - 2.5$ AU of the hypothetical Asteroid Belt (close to the 3:1 MMR). Assuming the 3:1 MMR as the main dynamical depletion mechanism with a geometrical gap-width of 0.06 AU, the total impacted mass exceeds a hypothetical mass residing within the gap ($\approx 2.89 \cdot 10^{20}\ \mathrm{kg}$) by an order of magnitude. Those numbers are significant higher if a loss of impactors due to dynamical extinction (leaving the Solar System) or impacting the Sun is considered (Gladman et al., 1997). As this early result suggests, it seems unlikely understanding the MMR as an exclusive dynamical depletion and impactor-delivering mechanism for the Inner Solar System, but we expect more precise results and present those at the conference.

Acknowledgement:
The author was partly supported by the German Space Agency (DLR) with support of the Federal Ministry of Economics and Technology, grants 50QH0305 and 50OH1102.