Dynamical and collisional constraints on a stochastic late veneer on the terrestrial planets

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Bottke et al. (2010) proposed that the large Earth-to-Moon abundance ratio of highly-siderophile elements can be explained if the late veneer was characterized by large (D = 1000–4000 km) impactors. Here we simulate the evolution of the terrestrial planets during a stochastic late veneer phase. The eccentricities and inclinations of the terrestrial planets are excited by the largest late veneer bodies. We find the best agreement with their post-veneer orbits if either (a) the terrestrial planets' pre-veneer angular momentum deficit AMD0 was less than half of the current one AMDnow, or (b) AMD0 <~ AMDnow and the veneer was limited to Dmax < 2000 km bodies. Impacts on Venus, Earth and Mars were mostly accretionary but on Mercury and the Moon they were mostly erosive. In ~20% of simulations an energetic impact occurred that could have removed ~25% of Mercury's mass, thereby increasing its iron mass fraction. Due to the erosive nature of larger impacts, the Moon cannot accrete any material from objects larger than 500–1000 km. The large Earth-to-Moon HSE abundance ratio is naturally explained if the late veneer included large impactors (D = 500–1000 km) regardless of their size distribution, as long as most of Earth's veneer came from large bodies.