Asymmetric impacts of near-Earth asteroids on the Moon

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Introduction: It is well known that some satellites of the solar system planets have the synchronous rotation — their rotational and orbital motions are in the 1:1 commensurability. The synchronous rotation of such satellites causes asymmetric spatial distribution of craters: on these satellites, their leading hemisphere tends to have more craters than their trailing hemisphere does. One of the causes is that a satellite with the synchronous rotation is likely to encounter with projectiles more often on its leading side than on its trailing side.

The degree of the asymmetric crater distribution is a function of satellite's orbital velocity and the average relative velocity between projectiles and the satellite–planet system. Quite recently this asymmetry was confirmed on the Moon: A detailed analysis of the Clementine 750-nm mosaic images revealed that there is spatial variation in the density of rayed craters on the Moon [1]. The average density of rayed craters on the leading side of the Moon is substantially higher than that on the trailing side, and the observed ratio of crater density ($D > 5$ km) at the apex to that at the antapex is larger than 1.6.

Our aim is to confirm to which extent the near-Earth asteroids (NEAs) that we currently know can account for the observed asymmetric distribution of the lunar craters, carrying out intensive numerical integrations of test particles. We calculate direct impacts of projectiles on the Moon without analytical approximations.

Model and method: Our numerical integrations comprise two stages. The first stage aims at obtaining collision and encounter probability of NEAs with the Earth over a long term. Numerical integrations of this stage involve major eight planets, the Sun, and NEA-like test particles. We numerically integrated their orbital evolution for up to 100 million years. Although the number of planetary collisions is not large in our first stage numerical integrations, we have many more encounters at the planetary activity spheres. We numerically derived a kind of time-dependent orbital distribution function of the particles to reproduce a large number of their "clones" in order to increase the reliability of the collision statistics on the Earth–Moon system.

Results: Using the clones, we calculated the asymmetric impact distribution of the NEA-like particles on the Moon (Fig. 1). The overall trend of the asymmetric distribution is similar between the crater record and the numerical impacts, with 40–70% more impacts around apex than around antapex. This implies that a large fraction of recent craters on the Moon was created by the impacts of NEAs. However, the actual crater record has a stronger asymmetry than our numerical result does. When we reduce the relative crater density into unity around antapex, the maximum crater density at apex is ~ 1.4 in the numerical result, whereas it is 1.7–1.8 in the crater record as seen in Fig. 1. This result may indicate that there can be a number of projectiles that have even lower relative velocity than that of the NEAs that are currently observed.

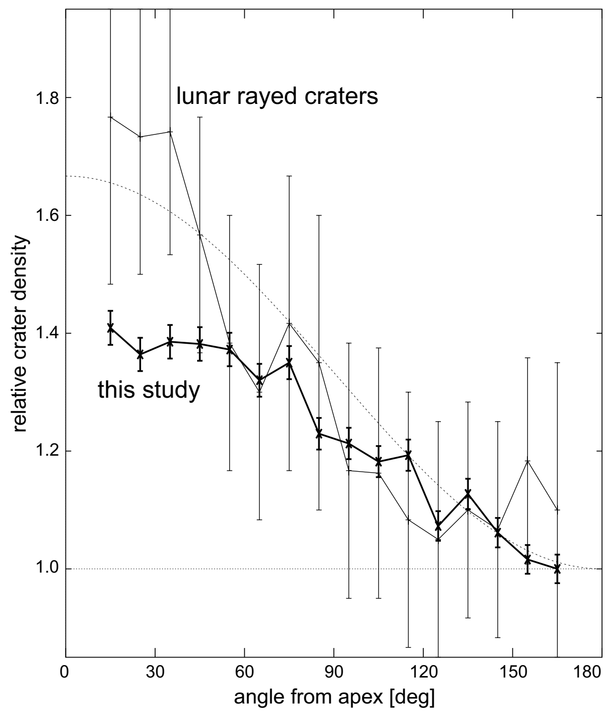

Figure 1: Thin solid line denotes the asymmetric distribution of actual rayed craters ($D > 5$ km) on the Moon [1] as a function of the angle distance from apex. The dotted curve is the best fit sinusoid by the same authors [1]. Thick line shows our numerical results. We reduced the relative crater density into unity around antapex. For the normalization of the actual crater record at antapex, we consulted the best-fit sinusoid.

References

[1] T. Morota and M. Furumoto. Asymmetrical distribution of rayed craters on the moon. *Earth Planet. Sci. Lett.*, 206: 315–323, 2003.