Formation of Moons and Equatorial Ridge around Top-shaped Asteroids after Surface Landslide: Applications to asteroids Ryugu, Bennu, Didymos, and more

Ryuki Hyodo[1] and Keisuke Sugiura[2]
[1]*ISAS/JAXA*
[2]*ELSI*

Top-shaped asteroids have been observed among near-Earth asteroids. About half of them are reported to have moons (on the order of ∼1 wt.% of the top-shaped primary) and many of them have an equatorial ridge. A recent study has shown that the enigmatic top-shaped figure of asteroids (e.g., Ryugu, Bennu, and Didymos) could result from an axisymmetric landslide of the primary during a fast spin-up near the breakup rotation period. Such a landslide would inevitably form a particulate disk around an asteroid with a short timescale (∼3 hr). However, the long-term full dynamical evolution is not investigated. Here, we perform a continuous simulation (∼700 hr) that investigates the sequence of events from the surface landslide that forms a top-shaped asteroid and a particulate disk to disk evolution. We show that the disk quickly spreads and produces moons (within ∼300 hr). The mass of the formed moon is consistent with what is observed around the top-shaped asteroids. We also demonstrate that an equatorial ridge is naturally formed because a fraction of the disk particles re-accretes selectively onto the equatorial region of the primary. We envision that Ryugu and Bennu could once have an ancient moon that was later lost due to a successive moon's orbital evolution. Alternatively, at a top-shaped asteroid that has a moon, such as Didymos, no significant orbital evolution of the moon has occurred that would result in its loss. Our study would also be qualitatively applicable to any rubble-pile asteroids near the breakup rotation period.

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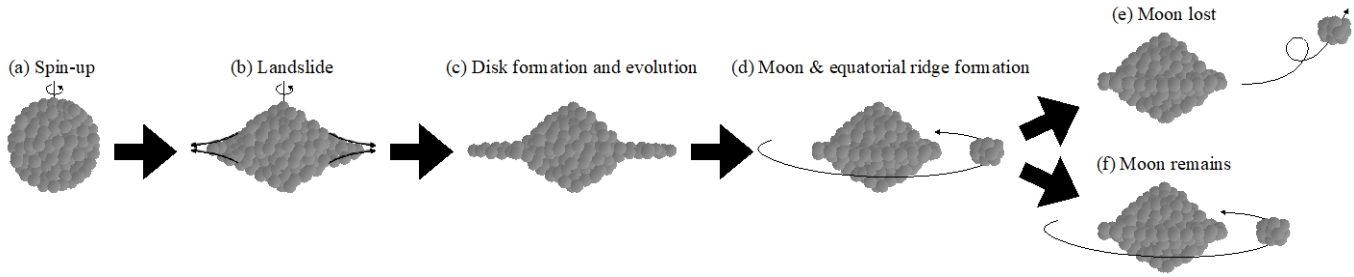

Schematic summary of our paper (a figure from Hyodo & Sugiura 2022, ApJL). Panel (a): a rubble-pile asteroid spins up due to, for example, the YORP effect, small impacts, a close encounter with a planet, or re-accumulation after a catastrophic impact. Panel (b): a surface landslide occurs when a critical spin state is realized and a top-shaped figure is formed (Sugiura et al. 2021). Panel (c): a particulate disk spreads due to inelastic collisions and gravitational interactions among particles. Panel (d): a moon is gravitationally accreted outside the Roche limit of the central top-shaped body, and an axisymmetric equatorial ridge is formed due to the re-accretion of disk particles. Panels (e) and (f): the formed moon is lost or remains, depending on the long-term orbital evolution between the moon and the primary.