

Formation of Saturn's rings by tidal disruption of a passing body: long-term N-body simulation of debris after the disruption

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The question of when and how Saturn's rings formed is an important open question in planetary science. The age of the formation of Saturn's rings has been studied in detail from both observational and theoretical viewpoints, and it is still under debate (e.g., Kempf et al. 2023, Estrada & Durisen, 2023, Hyodo et al. 2025).

On the other hand, several scenarios have been proposed for how Saturn's rings formed.

The scenario we focus on here is that the rings were formed by the tidal disruption of a small passing body in the vicinity of Saturn and the circularization of debris particles generated by the destruction (e.g., Dones et al. 1991).

Hyodo et al. 2017 performed SPH simulations of the tidal disruption of a small body based on this scenario and showed that enough mass could be bound to Saturn to fully compensate for the present-day rings and Saturn's inner satellites, which are thought to have formed from the spreading rings (Crida & Charnoz, 2012).

Hyodo et al. 2017 predicted that collisions between debris particles after tidal disruption would damp the eccentricity and orbital inclination, eventually forming a ring, but the long-term evolution of debris particles taking into account collisions and self-gravity was not investigated.

However, it is important to know how and what kind of rings are formed as a result of collisional evolution in order to constrain the formation scenario of Saturn's rings and inner satellites.

In this study, we investigate the long-term evolution of debris particles after tidal disruption using N-body simulations considering inter-particle collisions.

As in Hyodo et al. 2017, we consider both homogeneous bodies and bodies with core-mantle structure. The simulation results show that the debris particles' eccentricity and orbital inclination are damped by inter-particle inelastic collisions, leading to the formation of a thin disk-like ring.

It is also found that, depending on the value of the pericenter distance at the time of tidal disruption, the peak of the surface density of the ring is located near the Roche limit radius, resulting in the formation of the ring and the satellites at the same time.

This result indicates that satellites can be formed at the same time as the ring by a process different from the satellite formation model by Crida & Charnoz, in which satellites are formed from the material spreading out from the edge of the ring.

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