N-Body Simulation of Chariklo Rings

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Two dense narrow rings around Centaur Chariklo were discovered by occultation observation (Braga-Ribas et al. 2014). The inner and outer rings are located at 391 km and 405 km from the center of Chariklo, respectively. Chariklo's radius is about 125 km. The inner ring has the large optical depth, which is comparable to Saturn's A ring and Uranian delta ring. The width of the rings is about 6-7 km. A ring around Centaur Chiron was also reported (Ruprecht et al. 2015). These observations suggest that rings around large Centaurs may not be as rare as previously thought.

Several mechanisms for the formation of Chariklo's rings have been proposed: collisional ejection from the parent body, satellite disruption, the tidal disruption of the parent body (Pan and Wu 2016, Hyodo et al. 2016). However, the formation mechanisms of the rings is still not well understood. In order to understand the origin of the ring system, we need to investigate the stability and the structure of Chariklo's rings.

In the simulation of Saturn's rings, the global simulation is impossible because the necessary number of the particles is too large. Thus, the local N-body simulation has been used for reducing the computational cost. In this study, we performed the global N-body simulation of the rings for the first time.

We assume that all particles have the same mass and radius. We consider the mutual gravitational forces and the inelastic collisions between particles. We describe a collision as a damped oscillation (e.g., Salo 1995). We use the tree algorithm (Barnes and Hut 1986). Chariklo is located at the center, and its radius and density is 125 km and 1 g/cc, respectively. We use the N-body simulation library FDPS (Iwasawa et al. 2016).

This simulation has two parameters: the particle size and the density. From the theoretical analysis of the apse alignment mechanism, the particle size was estimated as a few meters (Pan and Wu 2016). Thus, in the fiducial model, we assume that the particle size is 5m. We consider the ice particle and assume that the density is 0.5 g/cc in the fiducial model.

After 10 rotational periods, no large-scale structures are visible. However, we find small-scale structures. These structures are known as the self-gravity wakes in Saturn's ring (Salo 1992). Due to the inelastic collisions, the random velocity decreases and finally the gravitational instability takes place. The self-gravity tends to from aggregates. On the other hand the tidal force tends to tear them apart. These competing processes are the cause of these complex structures.

Next we perform the simulations with various particle size and density. The particles size is 2.5 m - 10 m, and the density is 0.05 g/cc - 1.0 g/cc. The number of ring particles is 21 to 345 million. We found that the particle density is important parameter to determine the ring structure. If the particle density is less than 0.1 g/cc, the ring remains uniform and the self-gravity wakes are not visible. This is because the energy dissipation is insufficient and the gravitational instability does not take place. If the particle density is between 0.1g/cc and 0.5 g/cc, the self-gravity wakes are visible as in the fiducial model. If the particle density is larger than 0.5 g/cc, the ring is disrupted to form the satellites. Therefore we conclude that the

particle density should be less than 0.5 g/cc to avoid the disruption of the ring. Namely, the particle density should be less than half of Chariklo's density.

The self-gravity wakes enhance the ring diffusion. Taking into account of the the self-gravity wakes, we estimate the ring diffusion time, which is about 1 - 100 years. This diffusion is considerably shorter than the timescales suggested in previous studies. The diffusion time depends on the particle size. If the particle size sufficiently smaller than a few meter, the diffusion time can be long. If the putative moon exists, it can slow down the diffusion.

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