Accretion Process of Satellites from a debris disk within the Roche limit

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The most favored scenario of the lunar origin is the giant impact hypothesis. In the thesis, it is considered that the Moon was formed from an impact-generated debris disk. Recent N-body simulations showed that a single large satellite would be formed from a massive debris disk (with 3 to 5% of the central planet), which is initially confined within the Roche limit. In the satellite accretion process from a disk within the Roche limit, an essential process is the viscous spreading of the disk, which supplies materials to satellite seeds which are formed just outside the Roche limit.

We performed N-body simulations with wider range of initial disk mass, down to about 1% of the mass of the central planet, and investigated the satellite accretion process. We adopted rubble pile model and initial particle numbers are 100,000. In most simulations, we put a satellite seed near the Roche limit beforehand for the simplicity. This seed grows to the first satellite as the disk material spreads. Comparing these results with full rubble pile simulations, we confirmed that this does not affect the final mass of the first satellite.

If the initial disk is heavy as the proto-lunar disk, the disk spreads rapidly, and typically a single large satellite is formed. When the satellite accretion stops, small amount of material remains in the disk. A less massive debris disk has larger spreading time scale. As a satellite grows, it begins to shepherd the disk, and the material supply to the satellite stops in an earlier stage. The mass ratio between the remaining disk and the satellite is larger than that of the case of the Moon formation. The satellite migrates outward by the disk-satellite interaction, and next satellite formation begins when the first satellite migrates outward enough.

However, we found that such a system with two satellites and a disk with considerable mass is not stable. As the second satellite migrates outward by the disk-satellite interaction, it is captured to the resonance with the first satellite, and its eccentricity grows. In the parameter range of our simulations, the second satellite reenter the Roche limit, and is destroyed. Then another satellite is formed from the remaining disk, and it is destroyed in the similar process. This process continues and the disk mass diminishes. We stopped simulations at this stage since the remaining particles is too sparse to express a disk.

Our result is as follows. If the initial disk is not so heavy as a proto-lunar disk, the satellite truncates the disk and the satellite growth stops, and the satellite migrates outward. When the first satellite migrates outward enough, the second satellite is formed. However, these satellites are destroyed by the reentering to the Roche limit, and similar satellite formation and destroy process continues. Thus, temporal satellites are formed successively from a disk of medium initial mass. In our parameter range, only one large satellite remains, which is formed at first. As the disk mass diminishes, small satellites are formed accordingly. These small satellites may survive, since disk-satellite interaction becomes weak in this last stage, and eccentricity increase due to resonance capture would not occur.