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Local N-body Simulation for Accretion of Particles onto Moonlets in Saturn's Rings

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Gravitational accretion of particles in circumplanetary disks is an important issue related to the origin of ring-satellite systems of giant planets in the Solar System. Observations by the Cassini spacecraft indicate that the small satellites within the orbit of Pandora orbiting just outside Saturn's F ring were formed by accretion of small porous ring particles. N-body simulations demonstrated that a Hill sphere-filling body is produced by accretion of small porous particles onto a larger dense core. Propeller-shaped structures, which are produced by unseen embedded moonlets, have also been found in Cassini images of Saturn's A ring. Some of these moonlets may have formed by accretion of small low-density ring particles onto larger dense fragments. Thus, accretion in the rings may also be related to the origin of these embedded moonlets.

The criteria for gravitational accretion of particles in the Roche zone was derived based on the Hill approximation in the three-body problem. The criteria, which we call the "three-body capture criteria", state that colliding particles can become gravitationally bound if they are within their mutual Hill radius and E becomes negative value after inelastic collisions, where E is the sum of the relative kinetic energy and tidal potential energy of colliding particles. Furthermore, using the criteria, capture probability for collisions between ring particles was obtained by three-body orbital integration. However, many-body effects, which are not included in three-body calculations, are expected to become important as accretion of particles proceeds and aggregates are formed.

In our local N-body simulation, a moonlet is fixed at the center of the rectangular simulation cell. For each time step, particles not yet perturbed by the moonlet are added to the cell from the azimuthal boundaries. Particles leaving the simulation cell through the azimuthal boundaries are removed from the cell, but we retain the periodic boundary condition in the radial direction. In order to examine the accretion process and timescale for the growth of the moonlet in detail, we count the number of particles that form an aggregate by two different methods. First, we use the above three-body capture criteria for the moonlet and each of the colliding particles, and examine if a particle is gravitationally bound within the Hill sphere of the moonlet. However, in this method, the self-gravity of the particles accreted by the moonlet is neglected, and we underestimate the number of particles in the aggregate, because the number of particles accreted onto the moonlet increases with time. Second, in order to correct the above problem, we count the number of particles touching the aggregate as a member of the aggregate; we call this the "aggregate criterion".

Using the aggregate criterion, we calculate the accretion rate as a function of time, for calculations at the distance from Saturn that corresponds to Rp=0.7, where Rp is the ratio of the sum of radii of colliding particles to the Hill sphere radius. The accretion rate obtained by the N-body simulation agrees well with that obtained by the three-body calculation at the initial stage of accretion. As accretion of particles proceeds, the result of N-body simulation is slightly larger than the three-body results, because a significant number of particles have accreted onto the moonlet by this time, and the collision cross section of the aggregate is increased. After that, the aggregate reaches a quasi-steady state with a nearly constant number of constituent particles. Then, the aggregate repeats accretion and releasing of particles again and again. We also calculate the number of particles in the aggregate using the two different methods. We find that the three-body capture criteria underestimate the number of particles in the aggregate. The result obtained from the aggregate criterion also shows recurrent accretion and release of particles in the quasi-steady state.

Keywords: accretion, moonlet, Saturn's rings, N-body simulation