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Viscosity in planetary rings including spinning, self-gravitating particles

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Saturn's rings are composed of many icy particles, and angular momentum is transported due to collision and gravitational interaction between these particles. Viscosity in the rings arising from such interactions between particles governs the rate of dynamical evolution and structure formation in the rings. Local N-body simulations including collision and mutual gravitational forces between particles showed that, in optically thick rings, wake structures are formed due to their self-gravity. Assuming that the rings consist of smooth spherical particles, numerical results show that the viscosity is significantly enhanced due to the effect of self-gravity in dense rings with gravitational wake structures. Viscosity in planetary rings consisting of spinning, non-self-gravitating particles has been estimated, but effects of particles' surface friction and spins on the viscosity in self-gravitating rings was not studied.

In the present study, we examine the viscosity in planetary rings, by local N-body simulations taking effects of particle spins into account, in addition to collision and gravitational interaction between particles. Assuming that a local region in a ring is in a quasi-steady state, the viscosity in such a region can be estimated via the balance between energy loss due to inelastic collisions and the viscous gain due to the shear motion, even in the case of self-gravitating rings. When a collision between particles is detected in our simulation, we calculate the change of velocity due to collision using given restitution coefficients in the normal and tangential directions. In the case with surface friction, we also calculate the change of particles' spin rates. We investigate the dependence of the viscosity on various parameters such as optical depth, distance from Saturn, and normal and tangential restitution coefficients. We also calculate the viscosity with the velocity-dependent restitution coefficient based on laboratory impact experiments. In the case of rings with low optical depth, viscosity can also be evaluated using three-body orbital integration. We also compare our results obtained from N-body simulation with those obtained using three-body calculation.

First, we calculate viscosities in the case without surface friction. In the case of low optical depth, the viscosity was found to increase in proportion to the optical depth, and excellent agreement with the results based on three-body calculation was confirmed. However, in dense rings where gravitational wakes are formed, the results of N-body simulation deviate from the three-body results and the viscosity is significantly enhanced, in agreement with the previous results for rings with self-gravitating, smooth particles. Next, we examine the effect of surface friction and spins of particles. In the case of rings with low optical depth, we found that the viscosity becomes slightly smaller when surface friction is included, because the random motion of particles become suppressed due to the additional energy dissipation arising from the surface friction. On the other hand, in the case of optically thick rings in which wake structures are strongly formed, we found that the dependence of the viscosity on the tangential restitution coefficient is negligible. This is because, in dense rings, the enhancement of the viscosity due to rings' self-gravity is much more significant than the effect of particles' surface friction.

Keywords: planetary rings, viscosity, self-gravity, particles' spin, Local N-body simulation