Damping of velocity dispersion of a protoplanet due to gravitational interaction with disk gas

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When the protoplanet mass is larger than the lunar mass, the gravitational interaction between the protoplanet and a gasous disk effectively damps orbital elements of the protoplanet(semi-major axis, eccentricity, inclination). It is important to study the protoplanet-gasous disk interaction because the damping of orbital elements affects the evolution of protoplanets.

Therefore, We have investigated the damping of protoplanet velocity dispersion due to gravitational interaction with protoplanetary disk gas through two-dimensional fluid dynamical simulation.

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In this study, we focus on the damping of the eccentricity and the inclination(velocity dispersion), since the damping rate of the semi-major axis is much smaller than that of the eccentricity and the inclination. The damping mechanism of the velocity dispersion due to gravitational interaction with a gasous nebula has been studied by a few authors. Ward(1993) and Artymowicz(1993) analyzed density waves in the solar nebula caused by gravitational interaction with the protoplanet and the effects of the waves on the protoplanet orbit, by using linear perturbation theory to estimate the damping timescale of the protoplanet velocity dispersion. They showed that the damping timescale is about one thousand years for an earth-sized protoplanet. The damping timescale is much shorter than typical timescale, 10^6-10^7 years, of planetary formation, which implies that the damping would play an important role in the formation process of planets. Their result by a linear perturbation theory must be examined by numerical simulations including non-linear effects, but few numerical simulations has been done. Takeda et al.(1985) calculated an axisymmetric flow around a gravitating spherical body through fluid dynamical simulations. Their model would be appropriate for relatively large eccentricity. However, they did only a few simulations in the subsonic cases, which are relevant for a protoplanetary system.

Therefore, extending the simulation of Takeda et al.(1985), we calculate the cases with large varieties of Mach number for a large Reynolds number(Re>>1) to clarify fundamental physics of the damping process. We use the CIP method(Yabe et al. 1991) as a numerical scheme and calculate time evolution of the system until a steady state. We evaluate the drag force due to gas gravity and gas pressure on the protoplanet with the steady flow pattern. We found that the typical space length is the same as Bondi radius(Bondi & Hoyle 1944).

In this presentation, we will present more detailed results and compare ours with linear analysis of Ward(1993) and Artymowicz(1993).