Three-dimensional linear calculation for non-isothermal type 1 planetary migration

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Planet migration is one of the serious problems in the standard theory of planet formation. A planet excites density waves, that causes a rapid inward migration in a protoplanetary disk. In this study, we formulate the linear wave excitation by a planet in three-dimensional non-isothermal gaseous disks and calculate the torque on the planet more correctly than previous studies.
The torque on a planet has been studied by linear and non-linear calculations. In previous three-dimensional linear calculations the torque was calculated only for isothermal disks. This is because the three-dimensional linear equation has the term that is strongly divergent at corotation in non-isothermal disks. This problem has not been resolved yet and we cannot test non-linear three-dimensional calculations with linear calculations.
In linear studies of gravitational interaction between a planet and a three-dimensional gaseous disk, there are two-dimensional waves that do not have the z-component of velocity and three-dimensional waves that have non-zero v_z. Only three-dimensional waves have a divergent term but it is known that the absolute values of the torque in three-dimensional waves are much small than those of two-dimensional waves in the isothermal disk. In this study, therefore, we ignored three-dimensional waves and examined the torque on a planet in three-dimensional non-isothermal disk approximately. Actually since there is no sign of divergent in previous non-linear hydro-dynamical simulations, this approximation seems good.
With this approximation, we carry out the three-dimensional non-isothermal linear calculation. The obtained torque coincides with non-linear three-dimensional hydro-dynamical simulations. Because of this, we confirmed that our three-dimensional linear calculation is accurate.

Keywords: Protoplanetary disks, Planetary migration, Linear theory

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