Local numerical simulations of axisymmetric two-dimentional instabilities in the dust layer of a protoplanetary disk

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Two different processes have been proposed for the formation of planetesimals: mutual sticking of dust aggregates, and the gravitational instability of the dust layer. The critical density of the gravitational instability is hundreds times the gas density. However, the turbulent diffusion may prevent dust particles to settle toward the midplane of the protoplanetary disk, and the condition for the gravitational instability is difficult to be satisfied.

The streaming instability by Youdin & Goodman (2005) concentrates dust particles and boosts the planetesimal formation. The streaming instability is very efficient to form dust clumps in the case where dust particles have the stopping time on the order of the Keplerian orbital period (meter-sized particles). However, the streaming instability grows very slowly for small dust particles (1mm or less).

In this work, we carried out numerical simulations of motions of dust particles and gas in the dust layer of a protoplanetary disk. We assume the axisymmetry with respect to the rotation axis of the protoplanetary disk. We employ the local shearing-box approximation. We take account of the radial tidal force as well as the vertical force due to the stellar gravity, the gas drag force acting on dust particles and its back reaction. We include the effect of global pressure gradient by adding radial force to dust particles. We omit the effects of magnetic fields and the self-gravity.

We use the Athena code developed by Bai & Stone (2010) for numerical simulations. We report the results over a wide range of parameters, and consider comprehensively the causes of the instabilities in the dust layer of a protoplanetary disk.

Keywords: protoplanetary disk, dust, instability, planetesimal

