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Two evolutional paths of the axisymmetric gravitational instability in the dust layer of a protoplanetary disk

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The gravitational instability (GI) in the dust layer of a protoplanetary disk is considered to be one of probable models of the planetesimal formation. However, processes of the planetesimal formation by the GI in the dust layer are less well understood. In this work, numerical simulations under the assumption of the axisymmetry are performed to investigate density and velocity evolutions of the dust layer by the GI. We found that there are two different evolutional paths of the GI depending on the gas friction time of dust aggregates, which is defined as the time that the relative velocity between a dust aggregate and gas becomes 1/e, and depends on the dust size and the material density.

In this work, dust aggregates and the gas are treated as separate two fluids in order to take account of a vertical motion by the dust settling and a radial motion by the growth of the GI. Numerical simulations are performed for a local region in the disk. The following assumptions are adopted: The dust layer is axisymmetric with respect to the rotation axis and mirror symmetry with respect to the midplane, and an initial dust density distribution at equilibrium vertical to the midplane is Gaussian. The radial pressure gradient at equilibrium is zero in order to focus on just the GI, rather than the shear instability. All dust aggregates in the dust layer have the same gas friction time which is constant for time.

When the gas friction time normalized by the Keplerian angular velocity is equal to 0.01 (e.g. the dust radius: 4 cm, the material density: 1 g/cm^3 at 1 AU), the GI grows faster than the dust settling and the dust layer turns to a ring shaped structure. On the other hand, when the gas friction time is equal to 0.1 (e.g. the dust radius: 13 cm, the material density: 1 g/cm^3 at 1 AU), the dust settling is faster than the growth of the GI during our numerical simulation in which the dust density grows several tens times as large as the critical density of the GI. For larger densities in the latter case, an approximate analytical calculation reveals that the dust settling is always faster than the growth of the GI. Therefore, two evolutional paths are found: One is that the GI grows faster than the dust settling and the other is that dust aggregates settle sufficiently before the GI grows.

We plan to perform nonaxisymmetric numerical simulations in the future.