Dust concentration and multiple-ring formation via secular gravitational instability in protoplanetary disks

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Recent ALMA observations have been showing that many protoplanetary disks have substructures in the spatial distribution of dust grains. The most common substructures are concentric rings and gaps. Those axisymmetric substructures might imply ongoing or completed planet formation. If planets already exist and carve gaps with radius of tens au, much early planetesimal/planet formation is necessary, which we could not expect from the previous theory of dynamics of dusty gas disks and dust coagulation. Therefore, it is important to revisit dust-gas dynamics in a disk and explore physical processes that have the potential to concentrate grains and help planetesimal/planet formation. Secular gravitational instability (GI) is one possible process. The secular GI was originally proposed as a mechanism leading to the planetesimal formation since the instability can operate even in a self-gravitationally stable disk and concentrate dust grains. Recent work also showed the secular GI itself can be the origin of the observed outer rings and gaps. However, those studies are based on the local linear analyses which do not tell about global structure formation and to what extent grains concentrate. Motivated by these issues, we performed numerical simulations and investigate linear and nonlinear growth of the instability in a global dusty gas disk. Our results show that (1) rings and gaps forming via the linear growth move inward with so-called drift velocity of grains, (2) nonlinear growth makes dust rings much thin, and (3) dust surface density becomes about ten times higher than the initial value. Once the nonlinear growth results in the dust enrichment, the drift speed becomes small and coagulation timescale of grains becomes shorter. Thus, we can expect dust grains to grow in the multiple rings. The region would look darker and be observed as a single wide gap if the grains becomes so large that opacity at millimeter wavelengths becomes smaller.

Keywords: Protoplanetary disks, Instabilities, Numerical simulations

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