Rocky Planetesimal Formation by Gravitational Instability of a Porous Dust Disk

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Recently, it is proposed that porous dust aggregates are formed by pairwise accretion of silicate dust aggregates, which can avoid the radial drift and fragmentation barriers during their growth if the dust monomer size is on the order of nm [1]. Indeed, it is suggested that dust monomers in protoplanetary disks are not same as sub μm-sized interstellar dust grains, but they have experienced evaporation and condensation [1]. Moreover, matrix grains in primitive meteorites [2] and interplanetary dust particles [3] contain nm-sized grains.

We investigate the gravitational instability (GI) of the disk consisting of porous dust aggregates of nm-sized silicate monomers. We calculate the equilibrium random velocity of the dust aggregates considering gravitational scattering and collisions among them, gas drag, and turbulent stirring and scattering according to Michikoshi & Kokubo (2016) [4], and then evaluate Toomre's stability parameter Q [5]. The condition for the GI is defined as $Q < 2$ taking into account the non-axisymmetric mode [6]. We find that for the minimum mass solar nebula (MMSN) model at 1 au, the disk becomes gravitationally unstable as the dust aggregates evolve through gravitational compression if turbulent strength is $\alpha < 5\times 10^{-5}$. We also derive the critical disk mass and dust-to-gas ratio for the GI as a function of α.

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Figure 1. (left) Toomre's Q in the m_d-ρ_{int} plane at 1 au for the MMSN disk with $\alpha = 10^{-5}$, where m_d is the mass and ρ_{int} is the mean internal density of the dust aggregates. The dash-dot, solid, and dash contours correspond to Q = 1, 2, and 4, respectively. The dot line shows the evolutional track of dust aggregates.

Figure 2. (right) Disk parameters for the GI at 1 au. The red triangle, blue circle, and black square shows $\alpha = 10^{-2}$, 10^{-3}, and 10^{-4}, respectively.

Keywords: planetesimal formation, protoplanetary disk, gravitational instability, porous dust aggregate