Dynamics of Porous Dust Aggregates and Gravitational Instability of Their Disk

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Planetesimals are building blocks of planets. The terrestrial planets and the cores of gas giants are considered to be formed by the collisional accretion of planetesimals. In a protoplanetary disk, small dust grains grow to planetesimals. It is not yet understood how dust grains grow into planetesimals, because this process must overcome various obstacles.

Recent studies on the dust growth showed that the icy dust aggregates formed by coagulation are not compact but significantly porous. The internal density of dust aggregates is much smaller than the material density, which is $\sim 10^{-5}\,\mathrm{g\,cm^{-3}}$. A compression mechanism is necessary to form compact planetesimals. In the final stage of the dust growth, the dust aggregates are compressed by the self-gravity [1].

In the previous paper, we considered the final stage of the evolution of icy dust aggregates [2]. We investigated the dynamics of dust aggregates and obtained their random velocity. We found that, for a reasonable range of turbulence strength, the porous dust disk becomes gravitationally unstable as the dust aggregates evolve through self-gravity compression. In the previous paper, we adopted the MMSN model and assumed an isotropic velocity dispersion and an equilibrium random velocity. In this work, we extend the previous work and adopt a more general disk model and a more precise dynamical model. We considered the self-gravity, mutual collisions, aerodynamic drag, turbulent stirring, and scattering due to gas and calculated the eccentricity and inclination. From them we calculated the Toomre's Q and Roche criterion to examine the gravitational instability (GI) [3].

In the standard model, we found that the GI condition is finally satisfied when $\alpha \lesssim 4 \times 10^{-4}$. Next, we assumed the general parameters and checked whether GI occurs. Figure 1 shows the example of the results. The GI is more tend to occur for larger f_g, where f_g is the normalized disk mass. Thus, the upper limit of α for the GI exists, and it depends on the disk parameters.

Considering the simple approximations, we derived the critical α value analytically

$$\alpha < \alpha_\mathrm{cr} = 5.30 \times 10^2 \frac{a^2 \Sigma_\mathrm{d}^3}{\eta C_\mathrm{D} M_* \Sigma_\mathrm{g}^2}. \qquad (1)$$

where a is the distance from the central star, C_D is the gas drag coefficient, M_* is the central star mass, η is the gas pressure gradient parameter, Σ_d is the dust surface density, Σ_g is the dust surface density. Figure 1 shows this estimate, which well agrees with the numerical result. This critical α formula is consistent with that derived in the previous work.

We found that if the turbulence is not strong ($\alpha \lesssim 10^{-3}$), the GI takes place. The GI accelerates the planetesimal formation significantly.

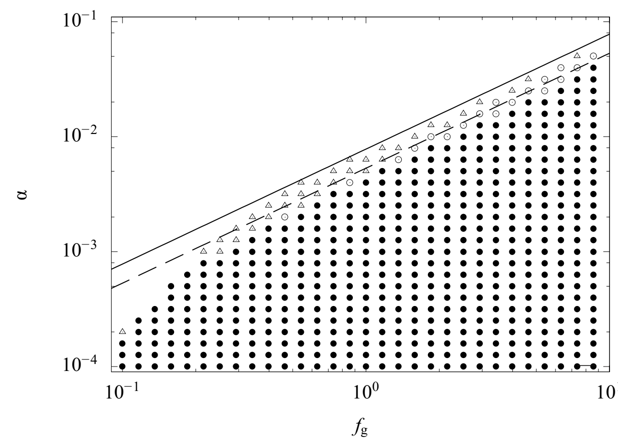

Figure 1: Parameter region for the GI on the normalized disk mass f_g and the turbulent strength α plane. The filled circle points show the cases where the GI takes place. The triangles show the cases where the GI does not take place. The open circles show the cases where the GI does not take place when the non-equilibrium effect is considered. The solid line represents the estimates of the critical α. The dashed line represents the other estimate.

References

[1] Kataoka, A., et al.:2013, *A&A*, **557**, 4.
[2] Michikoshi, S., Kokubo, E.: 2016, *ApJ*, **825**, L28.
[3] Michikoshi, S., Kokubo, E.: 2017, *ApJ*, **842**, 61.