Planetesimal Formation by Gravitational Instability of Porous-Dust Aggregates

MICHIKOSHI, Shugo
(Kyoto Women's University)

KOKUBO, Eiichiro
(NAOJ)

In a protoplanetary disk, small dust grains grow to kilometer-sized objects called planetesimals. The formation mechanism of planetesimals is one of today's most important unsolved problems. 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. A compression mechanism is necessary to form compact planetesimals.

It was found that the dust aggregates can be compressed by the ram pressure when the dust aggregate mass is less than 10^{11} g [1]. The dust aggregates with the mass $\gtrsim 10^{11}$ g are compressed by the self-gravity. Due to these compression mechanisms, the compact planetesimals may be formed.

We focused on the final stage of dust aggregate compression. We investigated the dynamics of porous dust aggregates by using the detailed model. We considered the self-gravity, mutual collisions, aerodynamic drag, turbulent stirring, and scattering due to gas and calculated the equilibrium random velocity. From the equilibrium random velocity we calculated the Toomre's Q to examine the gravitational instability (GI) [2].

For the axisymmetric mode, the instability condition is $Q < 1$ [3]. For $1 < Q < 2$, the non-axisymmetric mode can grow due to the swing amplification mechanism [4,5]. Thus, we adopt the GI condition as $Q < 2$. In the minimum mass solar nebular model with $\alpha = 10^{-3}$, we found that the GI condition is finally satisfied. In other words, the porous dust disk becomes gravitational unstable to fragment to form planetesimals.

However, if the turbulent strength is sufficiently strong, the GI would be suppressed. Thus it depends on α whether the GI takes place. We assumed the various parameters and checked whether GI occurs. Figure 1 shows the summary of the results. The GI is more prone to occur for larger f_g, where f_g is the normalized disk mass. Thus, the upper limit of α for the GI exists.

Using the approximations we derived the condition for GI

$$\alpha < \alpha_{\mathrm{cr}} = 5.34 \times 10^4 \frac{a^2 \Sigma_{\mathrm{d}}^3}{C_{\mathrm{D}} \eta M_* \Sigma_{\mathrm{g}}^2}. \quad (1)$$

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.

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

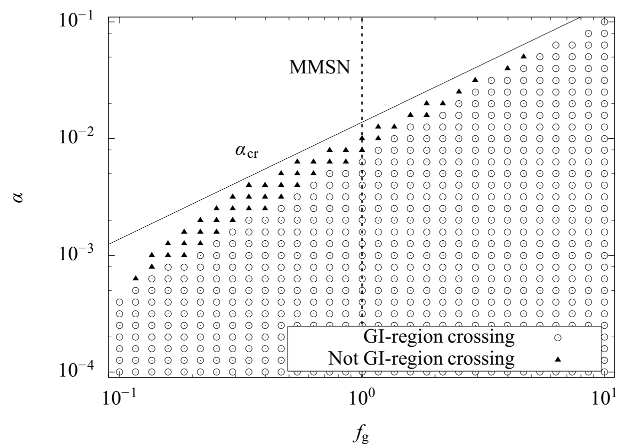

Figure 1: Parameter region for the GI on the normalized disk mass f_g and the turbulent strength α plane. The open circle points show the cases where the GI takes place. The filled triangles show the cases where the GI does not take place. The solid line represents the estimate of the critical α. The minimum mass solar nebular model (MMSN) corresponds to $f_g = 1$.

References

[1] Kataoka, A., et al.: 2013, *A&A*, **557**, 4.
[2] Michikoshi, S., Kokubo, E.: 2016, *ApJL*, **825**, L28.
[3] Toomre, A.: 1964, *ApJ*, **139**, 1217
[4] Michikoshi, S., Kokubo, E.: 2016, *ApJ*, **821**, 35.
[5] Michikoshi, S., Kokubo, E.: 2016, *ApJ*, **823**, 121.