P140-024 Room: 304 Time: May 19 10:15-10:30

Size distribution of dust grains in vortices in a protoplanetary disk

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The process of growing from dust grains to planetesimals has a serious problem that m-sized dust aggregates drift toward the central star in a few hundred years. Thus it would be difficult for dust to grow to planetesimals by simple collisional accretion. Then planetesimal forming scenario by the self-gravitational instability of dust layer is proposed. However, it is pointed out that dust cannot settle down to a layer thin enough to cause the self-gravitational instability because the vertical shear between the dust layer and the upper gas layers lift the dust from the middle plane due to the Kelvin-Helmholtz instability. Sekiya (1998) showed that self-gravitational instability can occur at 1 AU when dust surface density increases to 16.8 times that of the minimum-mass solar nebula model. Thus if dust surface density increases, planetesimals can be formed.

The scenario of planetesimal formation in vortices in the protoplanetary disk has been proposed to solve these problems (e.g., Inaba & Barge 2006). The vortices are suggested that long-lived, elliptic, coherent anticyclonic ones in a Keplerian shear. One of mechanisms of the vortex formation is that hydrodynamic Rossby wave instability resulting from gas density gaps or rings in disk forms vortices. It is suggested that dust aggregates will accumulate in the central part of vortices and planetesimals will be formed there.

In our work, we investigate the dust accumulation by vortices. We determine the total amount and size distribution of accumulated dusts, and explore the possibility of planetesimal formation in the vortices by solving equation of dust motion semi-analytically. We assume that vortices are formed at some radius of the disk and dust particles flow into the vortex from the Keplerian shear flow, spiraling toward the center of the vortex.

We refer to Johansen et al. (2004) for gas velocity field in a vortex and determine it semi-analytically. As for the transitional zone where the vortex embedded in the Keplerian shear, we model by adding the streams. In our work, we assume that gas flow is steady, two-dimensional, and is not affected by the back-reaction of dust motion. In this gas flow, we solved the equations of dust motion semi-analytically. The result is that the dust surface density distribution in the vortex is independent of gas friction parameter and the aspect ratio of the elliptic vortex and increases in proportion to the minus square of the length of the minor-axis of concentric ellipse. We wrote the rate of dust mass increasing in the central part of the vortex in the function of dust size distribution in a disk and dust capturing distance of the vortex.

About the dust size distribution in the vortex, we compared the dust falling time to the center of the vortex and the vortex lifetime (about a few hundred Keplerian time). Then we got the result that the dust bigger than cm-sized can achieve the steady state surface density distribution in the vortex. However, the dust smaller than mm-sized cannot achieve the steady state surface density distribution in the vortex. The bigger the size is, the more rapidly concentration of dust is occur and the smaller the size is, the slower concentrate. We will discuss about comparing the total mass of concentrated dust and the real planetesimals mass and comparing the size distribution of the concentrated dust and the particles which are forming Chondrites.

Reference

Sekiya, M. 1998, Icarus 133, 298.
Inaba, S. & Barge, P. 2006, ApJ 649, 415.
Johansen. A., Andersen, A. C., & Brandenburg, A. 2004, A&A 417,361.