

## Evolution of surface density distribution of solid components in protoplanetary disks

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SED observations of T Tauri stars show that protoplanetary disks typically spread up to several hundred AU, and their surface density of solid components is inversely proportional to distance from the central star  $r$  in their accretion stage (Kitamura et al. 2002). In contrast, from the masses and orbital radii of the present solar planets, the solid surface density in the solar nebula is expected to be proportional to  $r^{-3/2}$ , ranging up to 40 AU from the proto-sun (Hayashi 1981). The solar distribution is consistent with those of the minimum mass nebulae reconstructed from extrasolar planetary systems (Kuchner 2004), suggesting the steeper solid mass distribution relative to that of accretion stage is a common feature of planet formation stage of protoplanetary disks.

Dust aggregates is globally redistributed associated with inward drift induced by gas drag in a disk. The redistribution process is potentially responsible for the discrepancy in the solid mass distribution, but strongly depends on the typical size of dust aggregates. A simulation on the process for growing dust aggregates by collisional agglomeration up to km-sized planetesimal have not reproduced the solid surface density proportional to  $r^{-3/2}$  (Stepinski and Valageas 1997). Collision experiments of dust aggregates show that sticking hardly occurs above a threshold collision velocity (Blum 2004). This suggests that the agglomeration is possibly suspended when the typical aggregate size is much smaller than m-size. A simulation on the redistribution for dust aggregates with a uniform size (taken the typical size of chondrules) has found that dust aggregates generate local enhancement in the dust surface density as they drift inward (Youdin and Shu 2002). This effect also rearranges the solid mass distribution globally, however, the  $r^{-3/2}$  distribution is not generally reproduced, depending on the structure of the disk gas.

In this study, we assume a uniform threshold velocity for sticking, instead of a uniform aggregate size, and reexamine the redistribution process of icy dust in the present outer planet region. In our model, the typical size of dust aggregates at each location in the disk is determined by the disk gas turbulence. The turbulence generates relative motion between aggregates (Weidenschilling 1984), which leads to collisional agglomeration of them. The collision velocity increases with the growth of aggregates, and the growth is finally suspended as the collision velocity reaches the threshold velocity for sticking. This gives the maximum aggregate size achieved by the collisional agglomeration. A numerical simulation including the effect of fragmentation shows the tendency that the larger aggregates occupy the larger part in the total dust mass (Dullmond and Dominik 2005). Thus, we take the maximum size as the typical aggregate size at each location in the disk.

For the typical dust size, it appears that the inward drift velocity of dust aggregates is proportional to  $r^{1/2}$  in case the alpha parameter of turbulent viscosity (Shakura and Snyaev 1973) is constant throughout the disk. In this case, it is analytically shown that the one-dimensional transport equation for icy dust has the steady solution of the solid surface density proportional to  $r^{-3/2}$ , which hardly depends on the initial distribution of solid and the structure of the disk gas.

Next, we perform a set of numerical simulation on the redistribution process to clarify its transient state. As a result, after the onset of disk accretion, the solid surface density begins to decrease from the outermost region of the disk, associated with inward drift of dust. At the same time, it enhances the solid surface density at the region where planets would be formed later. The solid surface density evolves steeper and the  $r^{-3/2}$  distribution is achieved within  $10^6$  yr.