Position of Snow Line Depending on Spatial Distribution of Magnetorotational Instability in Protoplanetary Disks

*Shoji Mori[1], Satoshi Okuzumi[1]

1. Department of Earth and Planetary Sciences, Tokyo Institute of Technology

Icy dust plays important role of planetesimal formation in protoplanetary disks because it dominates mass of the solid material. In addition, because icy dust is also related to origin of ocean of rocky planets, to understand spatial distribution of icy dust is essential for not only planet formation but also origin of life. Icy dust is present beyond sublimation boundary of H^2O ice (snow line). Therefore, to understand radial temperature profile which determines position of snow line is particularly important. Before the disk dissipating, at the inner region in which snow line lies is optically thick, gravitational energy of accreting gas is converted by turbulent viscosity to heat accumulated onto the disk. The heat determines the temperature profile. That is this viscous heating controls the position of snow line (Oka et al. 2011).

The turbulence in protoplanetary disks is driven by an instability (magnetorotational instability) caused by interplay between disk magnetic fields and ionized gas. Growth of magnetorotational instability causes vigorous turbulence, although it needs sufficient ionization fraction of the disk. Therefore, at high density region of too low ionization fraction, magnetorotational instability is stable. In that region, magnetic turbulence would not be generated.

When one considers the viscous heating, heating rate distribution concentrating on midplane is often assumed. However, in the stable region, because absence of turbulence, the turbulent viscosity generates heat at the upper layer (Hirose & Turner 2011). Since viscous heating increases the midplane temperature by accumulation of heat into optically thick region, heat at the upper layer leads to lower midplane temperature than heating at midplane.

In this work, focusing on this fact, we investigate temperature profile based on distribution of magnetic turbulence and the position of snow line. Specifically, we perform three dimensional magnetohydrodynamics simulation including stratification and ionization fraction distribution. As a result, we confirm that peak of the heating rate is located at 3 scale height from midplane. This is consistent with Hirose & Turner (2011). We calculate the position of snow line assuming the accreting heating releases at 3 scale height. As a result, in the case of accretion rate of 10^{-8} M_{solar}/year, snow line of 3 AU with midplane heating changes to snow line of 0.7 AU with upper layer heating. Thus, the distribution of magnetic turbulence would control position of snow line. We also investigate dependence of initial magnetic field strength on the dissipation rate distribution and discuss the position of snow line depending on the initial magnetic field strength.

Keywords: Protoplanetary disk, Magnetohydrodynamics, Snow line