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The Evolution of the Snowline in Protoplanetary Disks with the Absorption by Icy Dust Particles

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The snowline in protoplanetary disks is the boundary exterior to which water ice condenses. Because the temperature in a protoplanetary disk decreases with distance from the central star, water molecules in the outer region condenses to ice while those in the inner region of the disk are vapor. The snowline plays a very important role on the formation of the planets because the amount of solid materials changes drastically with crossing the snowline. For instance, it is thought that the cores of gas giant planets form outside the snowline since the formation of the cores requires large amount of solid mass. Or the process of providing water to terrestrial planets might be affected by the location of the snowline. Given the above importance of the snowline, we numerically investigate the evolution of the location of the snowline in accretion disks around T Tauri stars.

We solve the temperature and density structure of an axisymmetrical accretion disk using 1+1 dimensional plane-parallel radiative transfer code which is similar to that by Dullemond et al. (2002) and determine the location of the snowline in 2 dimensional sectional plane. We consider an optically thick accretion disk around a T Tauri star. The energy sources in the disk are the irradiation by the central star and the viscous dissipation. We evaluate the turbulent viscosity with the alpha-prescription by Shakura and Sunyaev (1973) and the value of alpha is set to be 0.01. We employ two dust species model which includes 0.1micro meter-sized silicate and water ice particles. Absorption and scattering coefficients are taken from Miyake and Nakagawa (1993). We assume spatially well mixed and thermally well coupled dust particles with gas and do not consider the sedimentation and growth of dust particles. The condensation of ice is determined by the saturated water vapor pressure of water. To solve the evolution of the disk, we integrate the diffusion equation of the surface density of the gas from the standard accretion disk model.

This study has an advantage over the previous works on three points: (i) we employ two dust species model and consider vaporization and condensation of ice particles, (ii) we include scattering of radiation by dust particles, and (iii) we solve the evolution of the disk consistently with the thermal and density structure of the disk. It is the most significant point that we consider absorption and scattering by icy dust particles in the ice-existing region.

Using the above numerical model, we obtained the location and evolution of the snowline in a protoplanetary disk with the mass accretion rate onto the central star in the range from 10^{-7} to 10^{-9} solar mass per year in 2 dimensional sectional plane. We found that the disk can be divided in three regions: (1) a hot region in the inner part of the disk where viscous heating is so efficient that only silicate particles exist at every height, (2) a cool region in the outer part of the disk where the energy source is so weak that ice particles exist at every height, and (3) an intermediately hot region between the previous two regions where ice particles exist only at the upper layer of the disk and play a role like a blanket against the energy generated around the midplane by the viscous dissipation. We found that the existence of the region (3) causes the snowline to be 1.5 times more distant than the previous studies which did not include the opacity of ice particles. Thus, we conclude that it is necessary to consider the absorption by ice particles in evaluating the location and evolution of the snowline. If one considers sedimentation and/or growth of dust particles, the location of the snowline may not come to the orbit of the Earth.