Sintering of icy dust aggregates by vertical diffusion in a protoplanetary disk

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A protoplanetary disk consists of gas and dust grains. Coagulation of dust grains is the first step of planetary formation. Therefore, it is important to know whether dust grains can grow or not. There are two types of dust grains. One is made of ice and the other of rock. In this study, we focus on icy dust grains. Icy dust aggregates are sintered when they are heated. Sintering is the material transfer phenomenon to decrease total surface area. When an icy dust aggregate is sintered, its neck connecting dust grains grows. Because collision between sintered dust aggregates results in bouncing, they can not grow. Therefore, sintering greatly affects planetary formation. In a protoplanetary disk, the heat source is visible light irradiation from the central star. Because the dust grains around at the equatorial plane blocks the irradiation, only dust grains around the surface of a protoplaneary disk can be heated. Therefore, if turbulence transports an icy dust aggregate to the surface having high temperature, sintering can proceed.
Using temperature profile at the midplane, timescale required for sintering was estimated by Sirono (2011, ApJ, 735, 131). However, this study did not take account of the vertical diffusion of icy dust aggregates. In this study, we calculate the vertical motion of dust aggregates to clarify the sintering timescale by vertical diffusion.
The vertical motion of dust aggregates is diffusion by turbulence and sedimentation by gravity of the central star. We calculated the positions of aggregates as a function of time. Because sintering strongly depends on temperature (Sirono, 2011, ApJ, 735, 131), sintering of icy dust aggregates can be assumed to quickly proceed at certain height from the midplane. By numerical simulation we calculated the ratio of sintered dust aggregates that experienced high temperature to total number of aggregates. From this ratio, the sintering timescale is determined.
Distribution of dust aggregates reaches a steady state after the sedimentation timescale. In the steady state condition, each aggregate moves up and down in a vertical direction of a protoplanetary disk, icy dust aggregates are sintered if they exceed the altitude of high temperature. The fraction of sintered dust aggregates increases with time. The result can be well fitted by 1-exp(-t/b), where t is time and b is the sintering timescale. It is found that the sintering timescale gets shorter as the altitude of high temperature decreases. The sintering timescale is determined by the diffusion timescale that depend solely on the strength of turbulence irrespective of aggregate size. The altitude of high temperature depends on size of aggregates. As dust aggregates grow, the altitude goes down. Therefore, if they sufficiently grow, sintering by vertical diffusion of turbulence can proceed. It is possible that sintering by vertical diffusion hinders the growth of the aggregates.

Keywords: protoplanetary disk, dust aggregates, sintering, turbulence, diffusion

