Sintering of icy dust aggregates due to turbulence in a protoplanetary disk

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In a protoplanetary disk, coagulation of dust grains is the first step of planetary formation. 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, necks connecting dust grains grow. Because collision between sintered aggregates results in bouncing, they cannot grow. Hence, sintering greatly affects the first step of planetary formation. The heat source is visible light irradiation from the central star in a protoplanetary disk. Because the dust grains around at the midplane blocks the irradiation, only dust grains around the surface of a disk can be heated. Therefore, if turbulence transports an icy dust aggregate to the surface having high temperature, sintering can proceed.
Using radial temperature distribution at the midplane, a timescale required for sintering was estimated by Sirono (2011, ApJ, 735, 131). However, this study did not take account of the vertical motion of icy dust aggregates. In this study, we calculate the vertical motion of each aggregate to clarify the sintering timescale shortened by turbulent diffusion.
The vertical motions of dust aggregates are diffusion by turbulence and sedimentation by gravity of the central star. Distribution of dust aggregates reaches a steady state in 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. We calculated the position 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 a particular height from the midplane. By numerical simulation we calculated the fraction of sintered dust aggregates that experienced high temperature. The fraction of sintered dust aggregates increases with time. From this fraction, the sintering timescale is determined.
It is found that the sintering timescale gets shorter as the altitude of high temperature decreases. If it falls to the dust aggregate disk scale height, the sintering by turbulent diffusion proceeds enough. The altitude of high temperature depends on opacity of aggregates. If the opacity goes down as dust aggregates grow, the new sintering region appears. However, if a little small dust aggregates are present, the height can hardly fall down. Therefore, the sintering by transporting to disk surface does not proceed.

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