Sublimation and recondensation of ice in a protoplanetary disk

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Icy dust aggregates migrate in both radial and vertical directions in a protoplanetary disk. The icy components sublime when the aggregates pass the snow line or a heating event occurs. The sublimed molecules recondense if they pass again the snow line or the temperature decreases after the heating event. The size and the number of the recondensed particles are critical in the growth of the icy dust aggregates and temperature distribution of the protoplanetary disk. If the size of the particles is large, the mechanical strength of an aggregate composed of the particles is low because the number of contact points decreases as the particle size increases. In addition, the formation of small particles increases the opacity, and the temperature distribution of the disk can be changed.

The sublimed molecules recondense in two ways, including homogeneous and heterogeneous nucleation. In homogeneous nucleation, the molecules form nuclei by themselves and the nuclei grow through the sticking of the sublimed molecules. If the amount of the leftover dust aggregate (silicate component + unsublimed ice molecules) is large, the sublimed molecules recondense onto the leftover aggregate. Thus, the outcome of recondensation strongly depends on the size of the icy aggregates before sublimation. If the aggregate size before sublimation is large, the total surface area of the leftover aggregates is small, and heterogeneous nucleation is suppressed.

Simulation of recondensation of H_2O molecules after a heating event has shown that the size of the recondensed particles is larger than $0.16\,\mu$m if the cooling timescale is longer than 0.1 yr and the initial aggregate size is larger than $0.07\,\mu$m. When the size of the composing grains in an icy aggregate is larger than $0.16\,\mu$m, continuous collisional growth of the aggregate is impossible because of the low mechanical strength. Because heating events such as FU Orionis outburst frequently occur in a protoplanetary disk and the cooling timescale is much longer than 0.1 yr in a global heating event, this result strongly suggests that the icy planetesimal formation through the collisional growth of icy dust aggregates is not probable.

The second simulation is the recondensation of various icy molecules after passing the snow line above the midplane of the disk. If the size of the aggregates before the sublimation is larger than $10\,\mu$m, H_2O, NH_3, and H_2S molecules recondense by homogeneous nucleation and form small particles, leading to a substantial increase in the total surface area of the particles compared to that before sublimation. The region with the increased total surface area is limited by the sublimation temperature of the icy component and the temperature distribution of the disk. The opacity due to the recondensed particles can substantially change the temperature distribution of the disk. In summary, sublimation and recondensation of the ice component can affect both the growth of the dust aggregates and the temperature distribution of the disk.