“Improved” kinetic nucleation theory in the formation of carbonaceous grains from core-collapse supernovae

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Total dust masses predicted to form due to core-collapse supernovae have traditionally been up to three orders of magnitude larger than the masses inferred from observations. The applicability of classical nucleation theory in dust formation in astrophysical environments has been questioned. Using an alternative kinetic nucleation theory has been suggested as a means of better describing the dust formation process, but the kinetic theory tends to over-predict nucleation rates when compared to classical nucleation theory. Kinetic nucleation largely depends on the same assumptions used with classical nucleation theory – the capillary approximation and thermodynamic equilibrium – but allows for replacement of these assumptions in favour of more physically realistic cluster properties.

We present an “improved” kinetic nucleation theory that allows for the inclusion of cluster-size dependent binding energy per monomer data, evaporation rate corrections based on Rice-Ramsperger-Kassel (RRK) theory, and cluster temperature fluctuations. All these improvements represent a more accurate description of the nucleation process, however, they may not result in more accurate predictions of the total dust mass formed in the ejecta of core-collapse supernovae or other astrophysical environments. We tested our modified kinetic theory on the formation of water clusters and compared our results with those of cloud chamber experiments and find that our results are highly sensitive to the value of the energies required to eject a monomer from the cluster. When applied to carbonaceous dust formation in core-collapse supernovae, the resulting mass predictions are no better than previous estimates. Our results show that the kinetic nucleation theory is limited by the data available for the microphysical properties, such as binding energy per monomer, and sticking probability, of astrophysically relevant dust species.