Physical Conditions of Supernova Ejecta as Viewed from the Sizes of Presolar Al_2O_3 Grains

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Presolar grains are tiny solid particles identified in meteorites thanks to their anomalous isotopic composition, and are invaluable fossils that allow us to directly observe the detailed chemical compositions and sizes of stellar dust. Among the presolar grains that are considered to have originated in core-collapse supernovae (SNe), Al_2O_3 grains are of great importance because Al_2O_3 is known to be one of the major components of SN condensates [1,2]. In particular, the measured sizes of presolar Al_2O_3 grains are 0.5–1.5 μm in diameter [3,4], which are much larger than those (< 0.05 μm) predicted from theoretical calculations of dust formation in SNe [e.g., 5].

With the aim of clarifying the formation condition of such large Al_2O_3 grains, we investigate the condensation of Al_2O_3 grains for wide ranges of density and cooling rate of the gas [6]. The calculations are performed by applying the formulation of non-steady-state dust formation [7]. The formula enables us to estimate the size distribution of newly formed grains and the condensation efficiency defined as the fraction of Al atoms that are locked up in Al_2O_3 grains.

We first show that the average radius $a_{\rm ave,\infty}$ and condensation efficiency $f_{\rm con,\infty}$ of newly formed Al_2O_3 grains are nicely described by a non-dimensional quantity $\Lambda_{\rm on}$, defined as the ratio of the timescale on which the supersaturation ratio increases to the collision timescale of Al atoms at dust formation. Figure 1 shows that the formation of Al_2O_3 grains can be realized at $\Lambda_{\rm on} \geq 1$, and $f_{\rm con,\infty} = 1$ at $\Lambda_{\rm on} \geq 20$. Since $\Lambda_{\rm on}$ is approximately proportional to the product of gas density and cooling timescale, the average radius is larger for a higher gas density and/or a slower gas cooling.

Then we find that, in order to produce Al_2O_3 grains with radii larger than 0.25 μm as measured in meteorites, $\Lambda_{\rm on}$ should be higher than 3×10^4. Such a high $\Lambda_{\rm on}$ could be achieved by adopting more than one order of magnitude higher gas density than that presented by the one-dimensional SN model. This indicates that presolar Al_2O_3 grains might be formed in dense gas clumps within the SN ejecta. Our analysis strongly suggests that the measured sizes of presolar grains can be a powerful tool for constraining the physical conditions and structure of the SN ejecta.

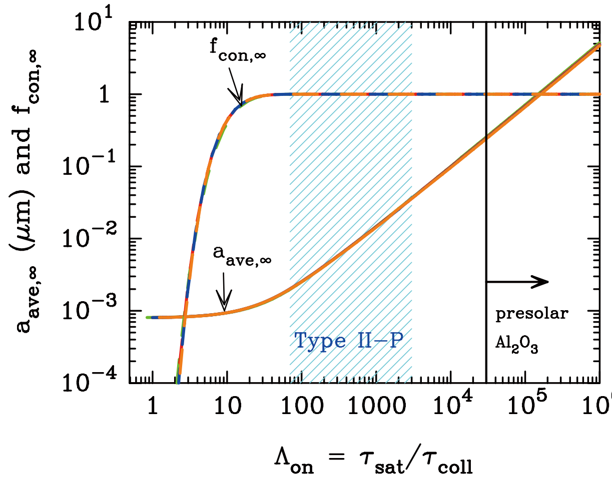

Figure 1: Average radius ($a_{\rm ave,\infty}$) and condensation efficiency ($f_{\rm con,\infty}$) of newly formed Al_2O_3 grains as a function of $\Lambda_{\rm on}$, which is defined as the ratio of the supersaturation timescale ($\tau_{\rm sat}$) to the collision timescale of Al atoms ($\tau_{\rm coll}$) at dust formation. The results for four different cooling rates ($T(t) \propto t^{-3(\gamma-1)}$where γ = 1.1, 1.3, 1.5, and 1.7) are shown in different colors but they are plotted as almost the same curve. The hached region draws the expected range of $\Lambda_{\rm on}$ for the formation of Al_2O_3 grains in the Al-rich region, referring to the one-dimensional model of a Type II-P SN [8]. The solid vertical line indicates the minimum value of $\Lambda_{\rm on}$ necessary for explaining the radii larger than 0.25 μm as measured for presolar Al_2O_3 grains.

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