THE FORMATION OF LARGE SiC GRAINS IN CLUMPY SUPERNOVA EJECTA

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Introduction: Presolar SiC grains of types X and C are thought to have formed in supernova (SN) ejecta [1–3]. Most SN-derived SiC grains are of sub-micrometer size, but larger grains, with diameters between 1 and 3 μm, also occur [4]. Nano-scale structural studies have shown that these "large" grains grow by the successive condensation (rather than the coalescence) of sub-micrometer crystals on each other [5], or they are single crystals [6]. Equilibrium and kinetic condensation models predict that SiC X grain condensation is preceded by that of graphite, if the condensing gas is dominated by matter from the He/C and/or He/N zones, or the H envelope of the SN progenitor [7-9], which is suggested by the grains' isotope compositions [7,10]. The occurrence of several-micron-sized SN-derived presolar graphite grains with ≤ 100 nm SiC inclusions on their rims also indicate that graphite may start to condense before SiC in SN ejecta, although SiC C grains seem to have a higher abundance among inclusions than among individual grains [3,11]. In order to constrain the physical and chemical conditions conducive to the growth of large SiC grains, we built a set of kinetic models that describe graphite and SiC grain growth in SN ejecta, based mostly on published physical and chemical ejecta models, as well as previous thermodynamic data.

Modelling: We used different bulk gas compositions for our grain growth models, and let their number densities evolve along specific pressure-temperature-time paths [8,12], until graphite or SiC became thermodynamically stable. Most gas compositions were taken from the literature [8,12], and represent different mass intervals of two of the nucleosynthesis models of [13] (s15a28c and s21a28g). All but one model composition are dominated by He/C or He/N zone matter (atomic fractions of carbon and silicon in the bulk gas: 10^{-4}–10^{-2} and 10^{-4}, respectively). The only exception is a gas composition from [8] that is rich in silicon (atomic fraction: ~10^{-2}) and transition metals (Si/Fe < 10), as a result of contributions from the Si/S zone and Ni core. The pressure-temperature stabilities of graphite and SiC were either taken from [8], or they were estimated based on the thermodynamic calculations of [14]. From the onset of condensation, we estimated the speed of grain growth based on the kinetic theory of gases, and with the assumption that the growing grains are spherical. The adjustment of gas number densities to account for the matter that is lost from the gas to form the solid phase(s) was done by assuming variable starting concentrations of crystal seeds (usually between 10^{-2} cm^{-3} and 10^{-5} cm^{-3}) that would grow at the calculated speed. One set of models was calculated assuming an extremely low seed number density for SiC (10^{-14} cm^{-3}), to estimate the maximum SiC grain diameter allowed by each gas composition. Since we assumed all carbon in excess of oxygen and all silicon to be available for graphite/SiC condensation, all calculated growth speeds and grain diameters are maximum estimates.

Results: The most important result of our modelling is that SiC grains with diameters > 1 μm cannot grow in ejecta where graphite condenses prior to SiC, unless overall number densities are increased by 1–2 orders of magnitude relative to those prescribed by the used physical models. It is possible that some of the large SN SiC grains formed without prior condensation of graphite from their parent gas, but this is viable only in ejecta with even higher densities. This suggests that clumpy, high-density SN ejecta are the most likely source of large SiC grains.

Outlook: We plan to model the growth of graphite and SiC in carbon- and silicon-rich, but transition metal-poor compositions (atomic fractions of carbon and silicon: ~10^{-2}; C/O > 1; (C−O)/Si ≈ 0.1; Si/Fe >> 10), such as those calculated by mixing different mass intervals of the nucleosynthesis models of [15] to match X and C grain isotope compositions. These nucleosynthesis models predict the formation of a silicon- and carbon-rich zone, the C/Si zone, between the O/C and He/C zones of SNe, as a result of α-capture reactions during the explosion. Carbon and silicon are 1–2 orders of magnitude more abundant in the gas compositions calculated using these nucleosynthesis models, than in the gas compositions obtained using the nucleosynthesis models of [13], which suggests faster SiC growth in ejecta with significant contribution from the C/Si zone, than calculated in our grain growth models.

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