A PRESOLAR SILICON CARBIDE GRAIN OF TYPE C WITH EXTREMELY LOW $^{12}C/^{13}C$ RATIO.

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Introduction: Primitive Solar System materials contain small quantities of presolar grains that formed in the winds of evolved stars and in the ejecta of stellar explosions [1]. Silicon carbide (SiC) is the best studied presolar mineral. Based on C-, N-, and Si-isotopic compositions it is divided into distinct populations. While most SiC grains formed in the winds of low-mass asymptotic giant branch (AGB) stars, supernovae (SNe) made an important contribution to the population of presolar SiC grains as well [1].

Of particular interest are presolar SiC grains with low $^{12}C/^{13}C$ ratios ($^{12}C/^{13}C < \sim 20$). Among them are the Type AB and putative nova grains, some of which may have formed in the ejecta of SN explosions [e.g., 2, 3]. Low $^{12}C/^{13}C$ ratios have also been observed in a significant fraction of the SN Type C grains.

Here, we report on a search for new SiC grains with low $^{12}C/^{13}C$ ratios by NanoSIMS ion imaging, in order to get a better understanding on their origins and on the nucleosynthetic and mixing processes in their parent stars. In this search we identified a Type C grain with extremely low $^{12}C/^{13}C$ ratio. We present the B-, C-, N-, Al-, Si-, and Ti-isotopic compositions of this particularly interesting grain which we discuss in the context of an H ingestion SN model of [4].

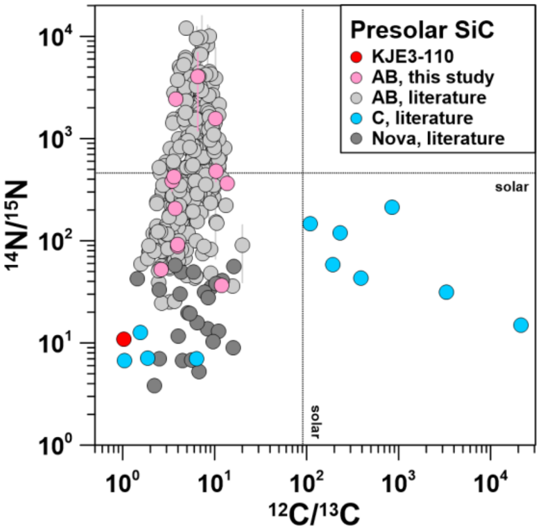

Figure 1. C- and N-isotopic compositions of 13 AB grains and of C grain KJE3-110 from this study in comparison to literature data of presolar SiC grains [5].

Experimental: SiC grains from the Murchison separate KJE (median size: 1.14 μm) [6], dispersed on a clean Au foil, were screened for grains with low $^{12}C/^{13}C$ ratios by C and Si ion imaging with the NanoSIMS at MPI for Chemistry. For this purpose a focused Cs^+ ion beam (~1 pA, 100 nm) was rastered over 149 30 x 30 μm^2-sized areas on the Au foil and negative secondary ion images of ^{12}C, ^{13}C, ^{28}Si, ^{29}Si, and ^{30}Si were recorded in multi-collection. Subsequently, 13 identified AB grains and one C grain were measured for C-, N-, Li-, and B-isotopic compositions, and the C grain in addition for Mg-Al and Ca-Ti-isotopic compositions. We recorded in multi-collection negative secondary ions of ^{12}C, ^{13}C, $^{12}C^{14}N$, $^{12}C^{15}N$, ^{28}Si (Cs^+ ion source, ~1 pA, 100 nm), and positive secondary ions of ^{6}Li, ^{7}Li, ^{10}B, ^{11}B, and ^{28}Si, of ^{24}Mg, ^{25}Mg, ^{26}Mg, ^{27}Al, and ^{28}Si, and of ^{28}Si, ^{40}Ca, ^{44}Ca, ^{48}Ti, and ^{50}Ti (Hyperion O^- source, ~3 pA, 100 nm).

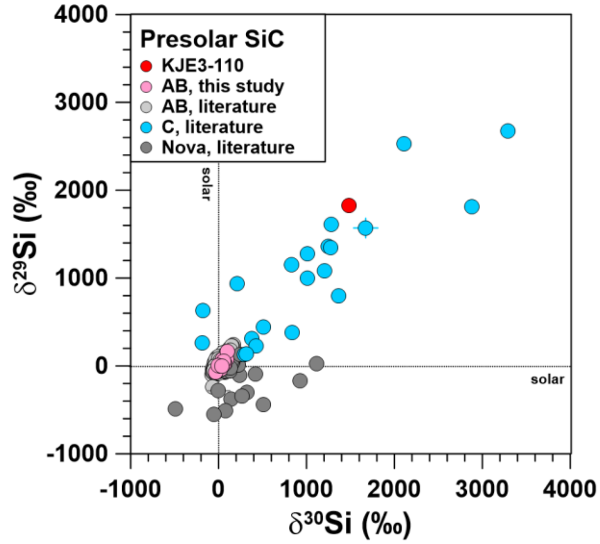

Figure 2. Si-isotopic compositions of 13 AB grains and of C grain KJE3-110 from this study in comparison to literature data of presolar SiC grains [5].

Results and Discussion: The C-, N-, and Si-isotopic ratios of the AB grains from this study are in line with those from the literature [5, and references therein] (Figs. 1, 2). Boron-isotopic ratios are normal, albeit within large experimental uncertainties of ~30%. Type C grain KJE3-110 has a very low $^{12}C/^{13}C$ ratio of 1.03 ± 0.01, very similar to C grain G240-1 from the study of

[7, 8] which has $^{12}C/^{13}C = 1.04 \pm 0.01$ (Fig. 1). Grain KJE3-110 is heavily enriched in ^{15}N, ^{26}Al, and the heavy Si isotopes, with $^{14}N/^{15}N = 11.0 \pm 0.03$, $^{26}Al/^{27}Al = 0.041 \pm 0.002$, $\delta^{29}Si = 1825 \pm 35$ ‰, and $\delta^{30}Si = 1484 \pm 40$ ‰ (Figs. 1-3). No excess ^{44}Ca was observed, which constrains $^{44}Ti/^{48}Ti$ to $< 4.2 \times 10^{-3}$. The $^{50}Ti/^{48}Ti$ ratio is about solar. The B concentration is low ($^{11}B/^{28}Si = 3 \times 10^{-5}$), which did not allow to get a meaningful $^{11}B/^{10}B$ ratio.

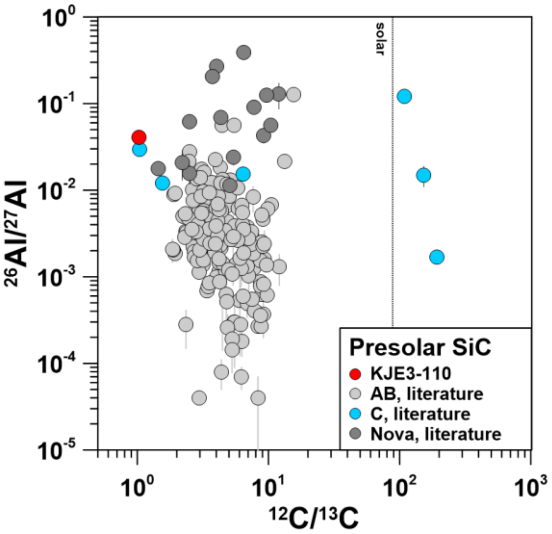

Figure 3. Initial $^{26}Al/^{27}Al$ and $^{12}C/^{13}C$ ratios of C grain KJE3-110 in comparison to literature data of SiC grains [5].

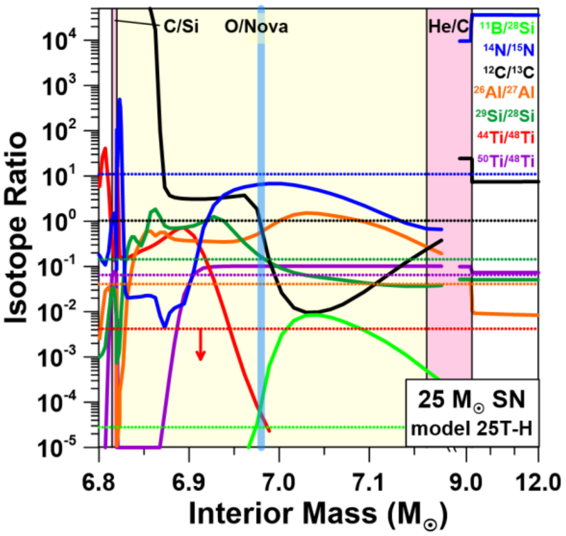

Figure 4. Profiles of isotopic ratios in the interior of a 25 $M_\odot$ SN according to model 25T-H [4]. Predicted ratios are shown by solid lines, those of grain KJE3-110 by dotted lines. Note the x-axis break at M ~ 7.2 $M_\odot$.

It is undisputed that C grains formed in the ejecta of SN explosions [e.g., 9]. The C-, N-, and Al-isotopic ratios of grain KJE3-110 suggest contributions from explosive H burning, favoring H ingestion SN models. In the following we will discuss the data of KJE3-110 in the context of SN model 25T-H [4], which offers the best prerequisites to produce high abundances of ^{13}C, ^{15}N, and ^{26}Al. Model 25T-H describes a 25 $M_\odot$ SN with artificially increased temperature and density in the He burning shell to mimic the explosive conditions of a 15 $M_\odot$ SN, and ingestion of 1.2 % of H into the He burning shell prior to the explosion [4].

Profiles of selected isotopic ratios predicted by model 25T-H are shown in Fig. 4 (solid lines), together with the isotopic ratios measured in KJE3-110 (dotted lines). In a thin layer around M = 6.98 $M_\odot$ (thick light-blue line in Fig. 4) isotopic ratios of grain KJE3-110 are relatively well matched, except for $^{26}Al/^{27}Al$ and $^{30}Si/^{28}Si$ (not shown), which are off by factors of ~10. However, the C/O ratio is only ~10^{-2} which makes formation of SiC very unlikely. Following the approach in [3], considering heterogeneous mixing over larger scales (from 6.82 to 11 $M_\odot$) and adjustment of predicted $^{12}C/^{13}C$ and $^{26}Al/^{27}Al$ ratios by factors of 3 and 5, respectively, it is possible to find a good fit to measured ratios along with C/O >1. The isotopic ratios of KJE3-110 can be reproduced within factors of <1.7; exceptions are the $^{44}Ti/^{48}Ti$ and $^{11}B/^{28}Si$ ratios which are too high by factors of 7 and ~10, respectively. We note that the production of ^{44}Ti and ^{11}B is very sensitive to model parameters and that the B/Si ratio may be affected by fractionation during grain condensation.

While the C-, N-, and Al-isotopic ratios of grains KJE3-110 and G240-1 are very similar, grain KJE3-110 has a much higher enrichment of the heavy Si isotopes. This suggests heterogeneous mixing of matter that experienced explosive H burning (high ^{13}C, ^{15}N, ^{26}Al) with matter that experienced neutron-capture nucleosynthesis (enhanced $^{29,30}Si$) in SNe and supports similar conclusions previously drawn by [8, 10, 11].

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