# A POSSIBLE SUPERNOVA ORIGIN OF TYPE AB PRESOLAR SILICON CARBIDE GRAINS.

W. Fujiya[1,2], P. Hoppe[1], and E. Zinner[3], [1]Max Planck Institute for Chemistry, P.O. Box 3060, 55020 Mainz, Germany (wataru.fujiya@mpic.de), [2]Dep. of Earth and Planetary Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, 113-0033 Tokyo, Japan, [3]Laboratory for Space Sciences and Physics Dept., Campus Box 1105, Washington University, St. Louis, MO 63130, USA.

**Introduction:** Primitive Solar System materials contain small quantities of presolar grains that formed in the winds of evolved stars or in the ejecta of stellar explosions [1-2]. Silicon carbide (SiC) is the best studied presolar mineral. Based on the isotopic compositions of C, N, and Si, presolar SiC is divided into distinct populations. Most abundant are the mainstream (MS) grains (~90%) which originate from 1.5-3 $M_\odot$ asymptotic giant branch (AGB) stars of close-to-solar metallicity [3]. Grains from supernovae (SNe), the Type X and U/C grains, are rare (1-2%). They exhibit characteristic Si- and S-isotopic compositions, have high $^{26}Al/^{27}Al$ ratios (typically between $10^{-2}$ and 1) and sometimes large $^{44}Ca$ excesses due to the decay of radioactive $^{44}Ti$ [4-5].

The origin of the Type AB grains is still not well understood. These grains have $^{12}C/^{13}C < 10$ and a large range of N-isotopic ratios with $^{14}N/^{15}N$ from 50 to >10000. Their Si-isotopic ratios plot on or close to the so-called Si MS line (Fig. 1). Among the proposed stellar sources are J-type C stars and born-again AGB stars [6]. Here, we report C-, N-, Si-, S-, Mg-Al-, and Ca-Ti-isotopic measurements on 34 AB grains. These measurements were performed to investigate whether also supernovae might have contributed to the population of AB grains.

**Experimental:** The SiC grains analyzed here were extracted from a 30 g sample of the Murchison CM2 meteorite [7]. Thousands of SiC grains were dispersed on several clean Au foils, one of which (sample "M7") was used for the present study. Areas suitable for NanoSIMS ion imaging were selected in the Leo 1530 FE-SEM at MPI for Chemistry. NanoSIMS ion imaging of ~2300 SiC grains was conducted with the Cameca NanoSIMS 50 ion microprobe at Washington University using the so-called "NanoSIMS grain mode" [8]. Ion images of $^{12}C^-$, $^{13}C^-$, $^{28}Si^-$, $^{29}Si^-$, and $^{30}Si^-$ were recorded in multi-collection mode, produced by rastering a focused primary $Cs^+$ ion beam (~100 nm, ~1 pA) over 464 20 × 20 $\mu m^2$-sized areas. 105 AB grains were identified in this way. Among those we selected 34 grains with Si-isotopic compositions away from the Si MS line by more than $2\sigma$ (Fig. 1), which we considered possible candidates for SN grains, for isotope studies of N, S, Mg-Al, and Ca-Ti with the NanoSIMS at MPI for Chemistry.

Sulfur-isotopic compositions were determined for all 34 grains by acquiring $^{32}S^-$, $^{33}S^-$, and $^{34}S^-$ along with $^{12}C^-$ and $^{13}C^-$ ion images over 2×2 to 3×3 $\mu m^2$ sized areas covering the AB grains in multi-collection. Subsequently, we carried out Al-Mg and Ca-Ti isotope analyses for 20 and 10 grains, respectively. For the Al-Mg measurements, $^{24}Mg^+$, $^{25}Mg^+$, $^{26}Mg^+$, $^{27}Al^+$ and $^{28}Si^+$ ion images were obtained in multi-collection by rastering an $O^-$ primary ion beam (~300-400 nm, ~5 pA) over 2×2 to 4×4 $\mu m^2$ sized areas. Similarly, $^{28}Si^+$, $^{40}Ca^+$, $^{42}Ca^+$, $^{44}Ca^+$, and $^{48}Ti^+$ ion images were acquired for Ca-Ti isotope measurements. Finally, N-isotopic compositions were determined on two AB grains by recording $^{12}C^-$, $^{13}C^-$, $^{26}CN^-$, $^{27}CN^-$, and $^{28}Si^-$ ion images in a setup similar to the S isotope measurements.

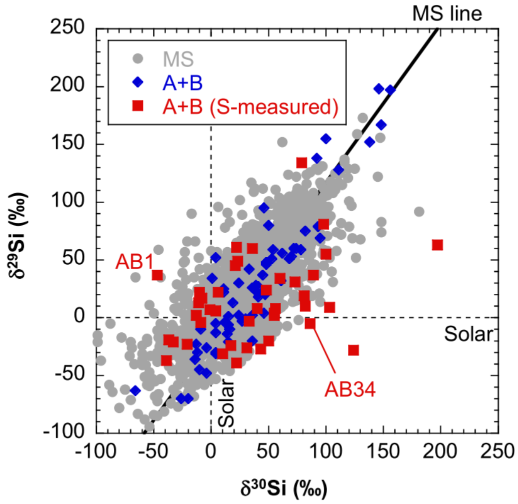

**Figure 1.** Si-isotopic compositions of presolar SiC grains measured by the NanoSIMS automatic grain mode.

**Results and Discussion:** The partial results of 5 particularly interesting grains are summarized in Table 1. Known SN grains are observed to have both isotopically light (X grains) and heavy Si (U/C grains). However, mixing of matter from different SN zones can easily produce SN grains with Si-isotopic compositions close to those of MS grains, as observed for AB grains. In this case S isotope signatures, $^{26}Al/^{27}Al > 0.1$, or evidence for $^{44}Ti$ must be used to identify SN grains.

Eighteen out of the 20 AB grains analyzed for Mg-Al show excesses in $^{26}Mg$ with inferred $^{26}Al/^{27}Al$ ratios of typically between $10^{-3}$ and $10^{-2}$ (Fig. 2). A high

$^{26}$Al/$^{27}$Al ratio of 0.057 was found for grain AB34. This is the highest ratio of AB grains found so far, falling within the range of SN and nova grains. Its Si-isotopic composition plots to the right of the MS line. Unfortunately, no useful S isotope data could be obtained because of S contamination. No material was left for Ca-Ti and N isotope studies. Overall, the Al and Si isotope data of grain AB34 are certainly interesting but present no unambiguous evidence for a SN origin.

**Table 1.** Al-, S-, and Ti-isotopic ratios of SiC AB grains.

| Grain | $^{26}$Al/$^{27}$Al ($10^{-3}$) | $\delta^{33}$S (‰) | $\delta^{34}$S (‰) | $^{44}$Ti/$^{48}$Ti ($10^{-2}$) |
|---|---|---|---|---|
| AB1 | 1.6±1.5 | 630±270 | 34±91 | 3.2±1.7 |
| AB21 | n.m. | -600±230 | -340±130 | <26 |
| AB24 | 3.3±1.0 | -310±140 | -131±67 | n.m. |
| AB34 | 56.5±8.2 | 110±120 | -57±49 | n.m. |
| AB40 | 5.3±1.2 | -320±200 | -264±90 | 0.33±0.36 |

None of the AB grains analyzed for Ca-Ti shows Ca isotope anomalies of >2σ. The largest $^{44}$Ca/$^{40}$Ca anomaly (1.9σ) is observed for grain AB1. Its Si-isotopic composition plots in the upper left quadrant of Fig. 1 and it has a large $^{33}$S excess at the 2.3σ level (Fig. 3). Large $^{33}$Si excesses are predicted for ONe novae [9] but the $^{14}$N/$^{15}$N ratio of 3600 and Si-isotopic signature of AB1 seem to exclude this type of stellar source when the data of known SiC nova grains are considered [10]. SiC SN grains show enhanced $^{32}$S [4]. However, high $^{33}$S/$^{32}$S and ~solar $^{34}$S/$^{32}$S are predicted for the Ni and He/C zones in SNeII [11]. Mixing of matter from the innermost Ni zone with the outermost H zone in a ratio 1:20 together with preferential trapping of S from the Ni zone during SiC condensation [4] could explain all isotopic signatures of grain AB1 reasonably well. However, like for grain AB34 the "smoking gun" is missing and a final conclusion cannot be drawn.

Three grains show enrichments in $^{32}$S of >100 ‰ at significance levels of ≥2σ in $^{33}$S/$^{32}$S and $^{34}$S/$^{32}$S (AB21, AB24) or of ~3σ in $^{34}$S/$^{32}$S (AB40). Given the relatively small number of analyzed grains, it appears unlikely that these three grains just represent statistical outliers. Neither AGB stars nor novae are expected to produce lower than solar $^{33}$S/$^{32}$S (and $^{34}$S/$^{32}$S for AGB stars) ratios [9,12], but $^{32}$S enrichments are the signature of SN grains. No evidence for $^{44}$Ti was obtained for these three grains and $^{26}$Al/$^{27}$Al ratios are at the lower end of what is observed for known SN grains. Despite these shortcomings we favor SN sources for these three grains based on their S-isotopic signatures. It appears possible that about 10% of AB grains have a SN origin. Further studies on AB grains are needed to clarify this issue, and to elucidate the nature of their stellar sources in more detail.

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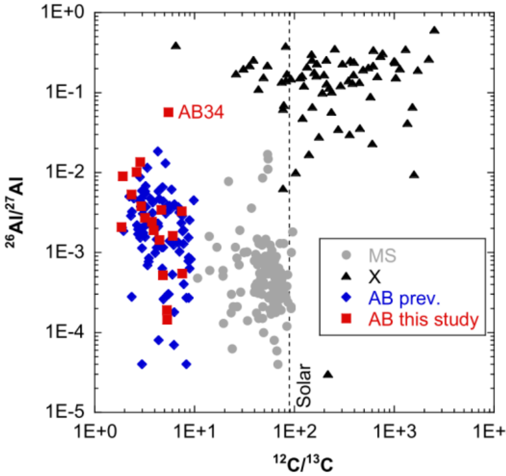

**Figure 2.** $^{26}$Al/$^{27}$Al and $^{12}$C/$^{13}$C ratios of different populations of presolar SiC grains. For references see [1].

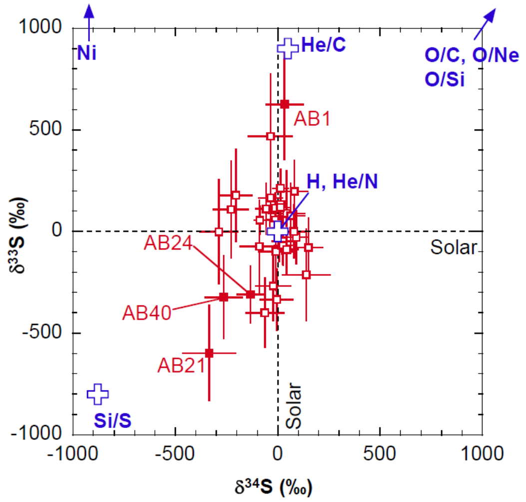

**Figure 3.** S-isotopic compositions of SiC AB grains (red). Predictions for different zones in a 15 $M_\odot$ SNII [11] are shown for comparison (blue).

**References:** [1] Zinner E. (2007) In *Meteorites, Comets, and Planets*, Vol. 1.02 (ed. A. M. Davis), pp. 1. [2] Hoppe P. (2011) *PoS (NIC XI) 021*, available online at http://pos.sissa.it. [3] Lugaro M. et al. (2003) *ApJ*, 593, 486. [4] Hoppe P. et al. (2012) *ApJ*, 745, L26. [5] Lin Y. et al. (2010) *ApJ*, 709, 1157. [6] Amari S. et al. (2001) *ApJ*, 559, 463. [7] Besmehn A. and Hoppe P. (2003) *GCA*, 67, 4693. [8] Gyngard F. et al. (2010) *ApJ*, 717, 107. [9] José J. et al. (2004) *ApJ*, 612, 414. [10] Amari S. et al. (2001) *ApJ*, 551, 1065. [11] Rauscher T. et al. (2002) *ApJ*, 576, 323. [12] Cristallo S. et al. (2009) *ApJ*, 696, 797.