A BORN-AGAIN AGB STAR ORIGIN OF TYPE AB SILICON CARBIDE GRAINS INFERRED FROM RADIOGENIC SULFUR-32.

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Introduction: Small quantities of presolar grains are found in primitive solar system materials [1]. SiC is the best-studied presolar mineral. An important sub-population is SiC grains of Type AB (~4 %) which have $^{12}C/^{13}C < 10$ [2]. The origin of AB grains is still a matter of debate. Born-again asymptotic giant branch (AGB) stars have been proposed to be the sources of AB grains with enhancements of *s*-process elements. For the outer He intershell of these stars, which extends almost up to the stellar surface, Herwig et al. [3] predict a $^{12}C/^{13}C$ ratio of <10, and high abundances of the first-peak *s*-process elements, such as Sr, Y, and Zr, produced by the *i*-process with its high neutron densities. Other proposed sources of AB grains are J-type C stars and Type II supernovae (SNeII).

Fujiya et al. [4] found three AB grains with ^{32}S enrichments, similar to those observed in some supernova Type C and X grains, and suggested that they originated from SNeII. Here, we will explore another possibility, namely, whether born-again AGB stars can produce ^{32}S excesses as observed in the three AB grains. The isotope data of these grains are compared with predictions for SNeII [5] and born-again AGB stars [3]. It is found that the born-again AGB scenario is more viable [6].

Experimental methods and results: Ion imaging of C and Si isotopes for ~2300 SiC grains from Murchison was conducted with the Cameca NanoSIMS 50 ion probe at Washington University. We found 105 AB grains and among those we selected 34 grains with Si-isotopic compositions away from the Si mainstream (MS) line by more than 2σ for further isotope studies of N, S, Mg-Al, and Ca-Ti with the NanoSIMS 50 at the MPI for Chemistry.

We found three AB grains with ^{32}S enrichments 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). C-, Mg-Al-, Si-, S- and Ca-Ti-isotopic ratios and, S, Al and Ti abundances of the three grains are shown in Table 1 (no N isotope data available). These grains have moderate $\delta^{29,30}Si$ values with $\delta^{30}Si$ (~88‰ on average) being larger than $\delta^{29}Si$ (~36‰). AB24 and AB40 have $^{26}Al/^{27}Al$ ratios typical of AB grains (~3–5 × 10^{-3}). None of the three grains shows evidence for ^{44}Ti.

Discussion: Neither AGB stars nor novae are expected to produce lower than solar $^{33}S/^{32}S$ (and $^{34}S/^{32}S$ in AGB stars) ratios [7,8]. Indeed, no SiC grains from low-mass AGB stars show large ^{32}S excesses as inferred from studies of large SiC MS grains [9,10]. Therefore, in the following discussion we will focus on SNeII and born-again AGB stars as potential sources of AB grains with ^{32}S enhancements.

SNeII origin? SiC grains with an accepted SN origin, the X and C grains, exhibit ^{32}S excesses [11]. SNII models by [5] predict large enrichments in ^{32}S for the Si/S zone (Fig. 1). Simple ad-hoc SN mixing models predict ^{32}S excesses to be accompanied by ^{28}Si excesses, which are not observed for our AB grains. If we assume that the ^{32}S excesses of our AB grains originate from the Si/S zone, we must invoke Si-S fractionation due to sulfur molecule chemistry in the still unmixed SNII ejecta as proposed by [11]. If we consider selective mixing of matter from different zones in the 15 $M_\odot$ SNII model of [5] in proportions Si/S: O/Si: He/N: H = 0.0028: 0.0094: 0.25: 1, and assume preferential trapping of S from the Si/S zone by a factor of 20, we find a fairly good match between the observed and predicted isotopic compositions (SN model, Table 1). However, a mismatch between the grain data and the model prediction exists for the C-isotopic composition.

Recently, [12] presented an alternative explanation for ^{32}S excesses in C grains: decay of radioactive ^{32}Si ($T_{1/2}$ = 153 yr), produced by n-capture reactions in the C-rich explosive He/C zone. If we follow the approach of [12], assuming that all ^{33}S and ^{34}S in our AB grains is contamination, $^{32}Si/^{28}Si$ is calculated to be ~1.3 × 10^{-3}. The model of [12] predicts $^{32}Si/^{28}Si$ ratios on the order of 10^{-4} to 10^{-3}, similar to those inferred for C grains and our AB grains, in certain regions of the C-rich explosive He shell. However, the ^{32}Si-rich material from the C-rich layer of [12] has high $^{12}C/^{13}C$ ratios, which is not compatible with those of the AB grains.

In summary, a SN origin of the three AB grains with ^{32}S excesses seems unlikely in view of the missing evidence for ^{44}Ti and the relatively low $^{26}Al/^{27}Al$ ratios, important signatures of SN grains, and especially the low $^{12}C/^{13}C$ ratios of the grains.

Born-again AGB star origin? We explored the *i*-process in the one-dimensional, multi-zone model of [3] to calculate abundance profiles of C and Si isotopes in the He intershell (Fig. 2). The key ingredient of the *i*-process is strong proton capture resulting in low $^{12}C/^{13}C$ ratios and high neutron densities ($N_n \sim 10^{15}$ cm^{-3}) from $^{13}C(\alpha,n)^{16}O$. Model RUN106 of [3] produces an abundance ratio of the second- to first-peak *s*-process elements close to that observed in Sakurai's object. In the outer He intershell, a $^{32}Si/^{28}Si$ ratio of ~8 × 10^{-2} is predicted, significantly higher than that inferred for the three AB grains. If we assume mixing with unprocessed material of solar composition in a ratio 1:35 by mass, it is possible to reproduce the inferred $^{32}Si/^{28}Si$ ratio of ~10^{-3} in our AB grains. Along with ^{32}Si, significant amounts of ^{29}Si and ^{30}Si are produced, with higher enrichments in ^{30}Si than ^{29}Si ($\delta^{29}Si$ = 37 ‰ and $\delta^{30}Si$ = 161 ‰; BA-AGB model in Table 1). The model predicts a $^{12}C/^{13}C$ ratio of <10 in the outer region of the He intershell along with a high C abundance (>100 × solar). In the 1:35 mixture of He intershell material with material of solar composition, C is dominated by C from the He intershell and the $^{12}C/^{13}C$ ratio of the mixture will be relatively close to that in the outer He intershell. In RUN106, $^{12}C/^{13}C$ = 6.6 is predicted for the He intershell, which gives $^{12}C/^{13}C$ = 8.2 in the mixture. The predicted $^{26}Al/^{27}Al$ is 4.4 × 10^{-6}, much lower than observed in the grains. A higher $^{26}Al/^{27}Al$ and slightly lower $^{12}C/^{13}C$ could be achieved if the parent stars experienced cool bottom processing during their AGB phase [13].

In conclusion, born-again AGB stars appear to provide a natural source of ^{32}S excesses via radioactive ^{32}Si decay along with low $^{12}C/^{13}C$ ratios, as observed in the three AB grains. The scenario of radiogenic ^{32}S is supported by measurements of MS grains which indicate that S abundances due to direct condensation of S into SiC are approximately two orders of magnitude lower than the abundance of anomalous S in the three AB grains [10].

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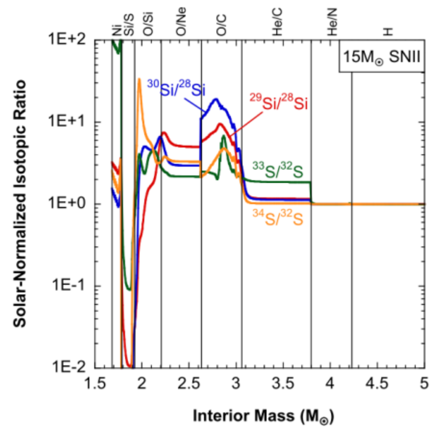

Figure 1. Solar-normalized $^{29,30}Si/^{28}Si$ and $^{33,34}S/^{32}S$ in the interior of a 15 $M_\odot$ SN model of [5]. The different SN zones are shown at the top.

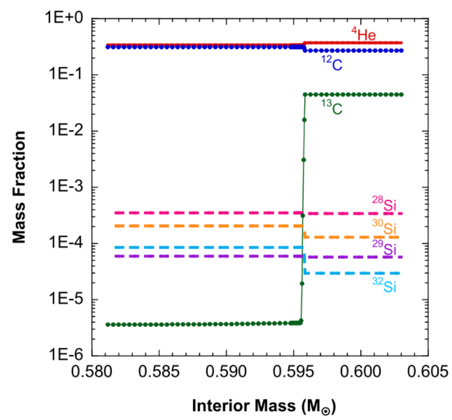

Figure 2. Mass fractions of ^{4}He, and C and Si isotopes in the He intershell of a born-again AGB star model [3]. Figure taken from [6].

Table 1. Isotopic compositions and trace element abundances of ^{32}S-enriched AB grains

Grain	$^{12}C/^{13}C$	$^{26}Al/^{27}Al$ (10^{-3})	[Al]	$\delta^{29}Si$ (‰)	$\delta^{30}Si$ (‰)	$\delta^{33}S$ (‰)	$\delta^{34}S$ (‰)	[S] (wt%)	$^{44}Ti/^{48}Ti$ (10^{-2})	[Ti] (wt%)
M7_AB21	5.71 ± 0.07			2 ± 14	55 ± 17	–600 ± 230	–340 ± 130	0.39	<26	0.06
M7_AB24	7.44 ± 0.06	3.28 ± 0.96	7.8	55 ± 14	100 ± 17	–310 ± 140	–131 ± 67	0.78		
M7_AB40	2.33 ± 0.01	5.3 ± 1.2	17	37 ± 4	89 ± 4	–320 ± 200	–264 ± 90	0.12	0.33 ± 0.36	0.15
Ave. AB21,24,40	2.5 ± 0.7	4.7 ± 0.9		36 ± 7	88 ± 6	–371 ± 103	–202 ± 58		0.24 ± 0.42	
SN model	17	4.0		30	90	–253	–234		0.06	
BA AGB model	8.2	0.0044		37	161					