**MULTI-ELEMENT ISOTOPIC COMPOSITIONS OF PRESOLAR SIC GRAINS FROM THE INDARCH METEORITE.** F.-R. Orthous-Daunay[1], F. Gyngard[1], F. Moynier[2], E. Zinner[1], [1]Laboratory for Space Sciences and the Physics Department, Washington University in St. Louis, One Brookings Dr., St. Louis, MO 63130, USA fdaunay@wustl.edu, [2]Department of Earth and Planetary Sciences and McDonnell Center for Space Sciences, Washington University in St Louis.

**Introduction:** Primitive meteorites contain presolar grains that condensed in stellar outflows and ejecta. These grains have been identified by extreme isotopic anomalies in their major elements. Silicon carbide is the most studied presolar mineral. Isotopic analyses have previously been carried out on grains isolated from the Indarch (EH4) meteorite within a size range between 0.25 and 0.65 µm (called the IH6 fraction) [1,2]. These studies resulted in the discovery of unique grains, which did not fit into any previously defined SiC types, occuring around once per thousand grains. Measurements of C, N, Si and Mg isotopic compositions revealed anomalies consistent with type II supernova (SNII) origins. Their isotopic compositions depend both on the nucleosynthetic structure of the star and on mixing processes of the ejected material. Multi-element isotopic surveys can put strong constraints on theoretical SN models. This requires finding bigger grains since the analytical methods are destructive. We present a NanoSIMS study of grains isolated from Indarch with sizes between 0.4 and 1 µm.

**Experimental:** Half of the material prepared to produce the IH6 fraction [1] had been set aside in 2001 just after acid treatments. At this point, SiC grains were mixed with extraterrestrial organic matter and remnant polytungstate from the density separation procedure. To obtain pure SiC grains, perchloric acid was used 4 times to burn the organic matter in the liquid phase at 160°C for a duration of 2 hours. Subsequently, the suspension was rinsed several times with NaOH followed by water to dissolve polytungstates. A size separation was performed by iterative centrifugational sorting. Suspended grains were deposited on an ultrapure gold foil for NanoSIMS isotopic measurements.

One hundred and ninety four areas of 20×20 µm² were presputtered with a high current $Cs^+$ ion beam to remove surface contamination and to enhance secondary ionization yield. Images of $^{28}Si^-$ were acquired for a particle recognition algorithm which defined 1569 particles. Automated isotopic analysis of C and Si by rastering of the beam over each grain established $^{28}Si/^{12}C$ and $^{12}C/^{13}C$ ratios and $\delta^{29}Si$ and $\delta^{30}Si$ values for classification as A/B, Y, X, Z and Mainstream types. Grains with unusual isotopic ratios were selected for detailed subsequent investigations. This included removal of adjacent grains by ion milling with the Cs primary ion beam and isotopic measurement of other elements.

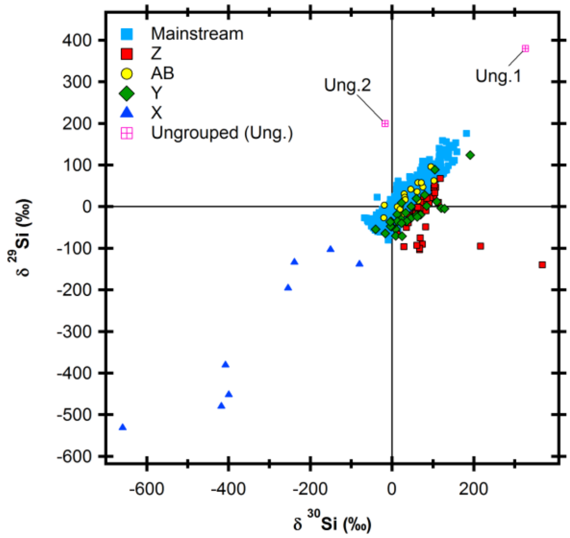


**Figure1**

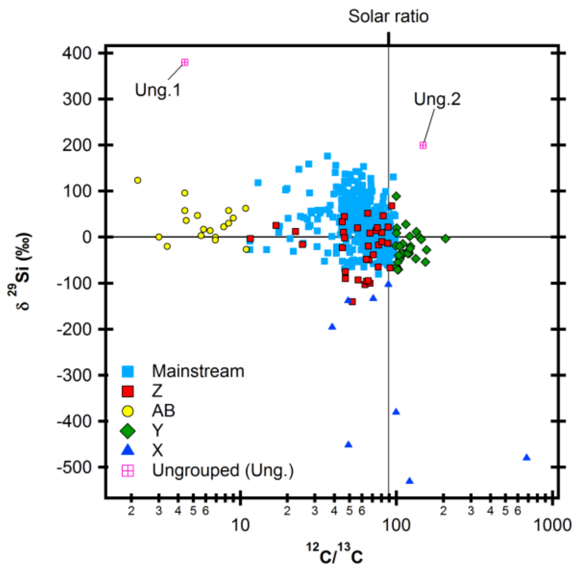


**Figure2**

**Results:** Table 1 summarizes the classification of SiC grains ($^{28}Si/^{12}C$ between 0.4 and 2.5). Figures 1 and 2 show their $\delta^{29}Si$ and $\delta^{30}Si$ values and $^{12}C/^{13}C$ ratios. Most of the grains plot along the so-called mainstream line in the Si three-isotope diagram. Their $^{12}C/^{13}C$ ratios range from 10 to 100, consistent with an AGB origin. A/B grains are characterized by $^{12}C/^{13}C<10$ resulting from high $^{13}C$ production by proton capture in J stars. X grains are classified on the basis of their extreme depletions in $^{29}Si$ and $^{30}Si$ interpreted as massive production of $^{28}Si$ in supernovae. Y grains have $^{12}C/^{13}C \geq 100$ and their origin is thought to be in AGB stars of approximately half solar metallicity. Z grains are characterized by their larger deviation from the mainstream line and their higher enrichment in $^{30}Si$ than in $^{29}Si$, indicative of an origin in AGB stars of a third or less solar metallicity.

| *Type* | *Number* | *Fraction %* | *Previous Study [2]* |
|---|---|---|---|
| Mainstream | 633 | 87.2 | 82.3 |
| AB | 19 | 2.6 | 4.8 |
| X | 8 | 1.1 | 1.2 |
| Y | 28 | 3.9 | 4.9 |
| Z | 36 | 5 | 6.6 |
| Ungrouped | 2 | 0.2 | 0.2 |
| Total | 726 | 100 | 100 |

**Table1**: SiC classification

The lower abundances of Y and Z grains compared to previous studies [1,2] is explained by their size distribution. As their average size is larger than that of SiC grains from the IH6 separate, their abundances are expected to be smaller since the abundances of these two grain types decrease with increasing grain size [1].

Two grains show remarkable isotopic compositions and are referred to "ungrouped" (Figure 3). One grain (Ung.1) exhibits extreme values of both $\delta^{29}Si$ and $\delta^{30}Si$, far from the mainstream composition. To date, about a dozen grains have been reported with such enrichment, reaching $\delta^{29}Si > 2500$‰ and $\delta^{30}Si > 3200$‰ [2-6]. These grains form a new class, termed type C [7]; most of them have $^{12}C/^{13}C > 100$ and in a few $^{32}S$ enrichments

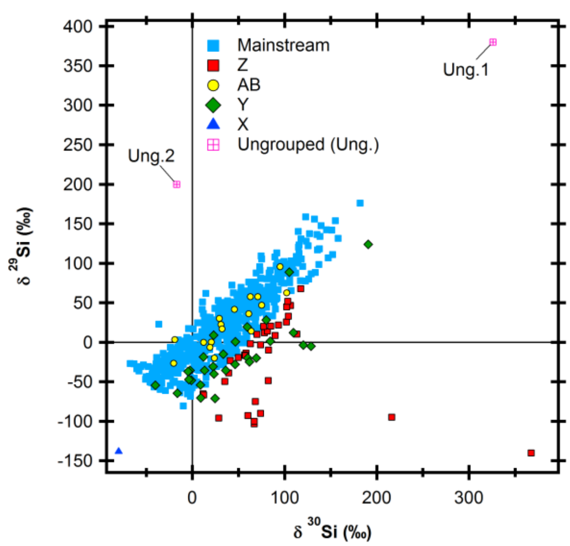

**Figure3**

have been found [3,5,6]. The sulfur isotopic composition of Ung.1 was measured by acquiring 3×3 µm² images of $^{32}S$, $^{33}S$ and $^{34}S$ in multicollection (c.f. Table 2).

| *Grain* | $^{12}C/^{13}C$ | $\delta^{29}Si$ | $\delta^{30}Si$ | $\delta^{33}S$ | $\delta^{34}S$ | $^{14}N/^{15}N$ |
|---|---|---|---|---|---|---|
| Ung.1 | 4.4 ±0.02 | 380 ±15 | 326 ±18 | -203 ±84 | -51 ±39 | 300 ±16 |
| Ung.2 | 148 ±1.5 | 200 ±13 | -17 ±13 | - | - | - |

**Table2**: Isotopic composition of ungrouped grains of this study.

Even though Ung.1 shows $^{29,30}Si$ excesses and $^{33,34}S$ depletions comparable to type C grains, its low $^{12}C/^{13}C$ puts it outside of any classification. The Si and S isotopic compositions of C grains are consistent with a Type II supernova origin [5,6]. Variable mixing ratios between different depths of C-rich layers have been successfully invoked to reproduce the isotopic composition of heavy Si and light C [5]. Such *ad hoc* mixing calculations still fail to explain the presence of light S and heavy Si in type C SiC grains. Fractionation between Si and S due to molecular chemistry during grain formation in the ejecta has been recently invoked as an explanation [5]. Whereas Si and S isotopic compositions are consistent with a type-C SNII origin of Ung.1, its low $^{12}C/^{13}C$ can only be explained by some extreme SN mixing. The He/N zone is the only place in a supernova with a low $^{12}C/^{13}C$ ratio of 3.5. Previously, two SiC grains with $^{29,30}Si$ excesses but even lower $^{12}C/^{13}C$ ratios of 1.0 and 1.3 have been found [5,9]. These ratios are lower than what can be achieved in SN models [10] and a nova origin has been proposed [9].

Grain Ung.2 meets all the isotopic caracteristics described by [8] and termed $X_0$ in [11], with isotopically light C, $^{29}Si$ excess and $^{30}Si$ depletion. This grain could possibly be used to refine the $^{29}Si$ yield in nucleosynthetic models once its SNII origin has been unequivocally confirmed. To do so, Ca and Ti isotopic measurements are planned to determine if the grain contains evidence for initial $^{44}Ti$.

**References:** [1] Zinner E. et al. (2007) *GCA* 71,4786-4813. [2] Zinner E. et al. (2010) *LPS XXXXI*, Abstract #1359. [3] Gyngard F. et al. (2010) *Met. Planet. Sci.* 45, A72. [4] Amari S. et al. (1999) *ApJ* 517, L59-L62. [5] Hoppe P. et al. (2011) *ApJ*, in press. [6] Hoppe P. et al. (2010) *ApJ* 719, 1370-1384. [7] Croat T. K. et al. (2010) *AJ* 139, 2159-2169. [8] Hoppe P. et al. (2009) *ApJ* 691, L20-L23. [9] Nittler L. et al., *Planet. Sci.* 41, A134. [10] Rauscher T. (2002) *ApJ* 476, 323-348. [11] Lin Y. et al. (2010) ApJ 709, 1157-1173.