STUDY OF Si- AND Fe-ISOTOPIC COMPOSITIONS IN PRESOLAR SILICON CARBIDE GRAINS OF TYPE X.
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The SiC grains of type X are a minor subgroup of presolar SiC grains. They make up about 1% of the total presolar SiC found in meteorites and they are characterized by unusual isotopic compositions that are indicative of an origin in Type II supernova explosions [1-3]. Namely, these rare grains show enrichments in ^{12}C (most grains), ^{15}N, and ^{28}Si, high initial $^{26}Al/^{27}Al$ ratios, and clear evidence for extinct ^{44}Ti (some grains). In order to get more information on the X grains we have screened ≈ 2000 SiC grains from the Murchison separate KJE (average size 1.14 μm [4]) by ion imaging with the University of Bern ion microprobe. This yielded 19 new X grains which were subsequently analyzed for the isotopic compositions of Si (all grains) and Fe (8 grains) by the conventional SIMS analysis technique.

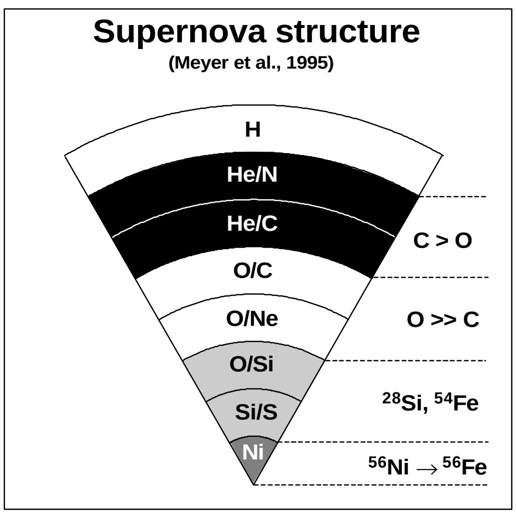

Figure 1. Zones in a Type II supernova. The labels indicate the most abundant elements. Figure adapted from Meyer et al. [5].

The analysis of Fe was restricted to the two most abundant isotopes ^{54}Fe and ^{56}Fe (5.8% and 91.7% of solar Fe, respectively). The SIMS measurements were performed in the positive secondary ion mode under bombardment with O^- primary ions (≈ 0.1 nA) at a mass resolving power of m/Δm ≈ 3000. This is sufficient to resolve all significant isobaric interferences except that of ^{54}Cr. For that reason the most abundant Cr isotope, ^{52}Cr, was measured along with the isotopes of Si and Fe and contributions of ^{54}Cr to ^{54}Fe have been calculated under the asumption that the $^{54}Cr/^{52}Cr$ ratio is solar. The actual contribution of ^{54}Cr to ^{54}Fe might be slightly higher because the supernova models predict $^{54}Cr/^{52}Cr$ ratios of up to 3x solar in the zones that probably contributed matter to the SiC condensation site in the ejecta (see below). The corrections of the ^{54}Fe intensity are in the percent range and are only of minor importance with respect to the rather large analytical uncertainty (several 10%) of the measured $^{54}Fe/^{56}Fe$ ratio. On the average, the Fe signal from the grains is only about a factor of 2 higher than the background contribution from the gold substrate. This is a serious limitation for a precise $^{54}Fe/^{56}Fe$ ratio determination of the SiC X grains. Nevertheless, isotope anomalies of a factor of 2 or higher should still be detectable.

Type II supernovae are believed to consist of eight concentric layers that experienced different stages of nuclear burning prior to the explosion (see Fig. 1) [5]. SiC can form from a gas that satisfies the condition C/O > 1 [6]. This requires significant contributions from the He/C zone to the SiC formation site in the supernova ejecta. The ^{28}Si enrichment of the X grains is indicative of contributions from the O/Si and Si/S zones (Fig. 1). Contributions from the intermediate O/C and O/Ne zones must be strongly limited to preserve the condition C/O > 1. Iron is expected to be an important constituent in the ejeta of Type II supernova explosions. Iron-54 is most abundant in the Si/S zone. Iron-56 is predominantly produced via radioactive decay of ^{56}Ni (half life 6.1 days) and its daughter ^{56}Co (half life 78.8 days) from the innermost Ni-rich zone. The $^{54}Fe/^{56}Fe$ ratio is thus a sensitive measure for contributions from the innermost zones to the SiC formation site in the supernova ejecta.

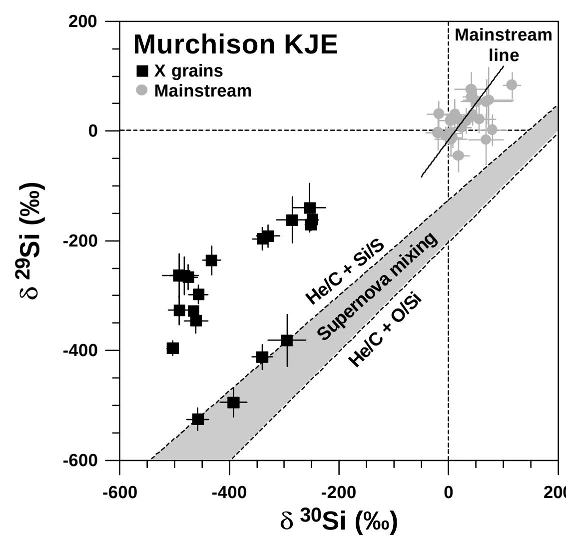

Figure 2. Si-isotopic compositions of SiC X grains from the Murchison separate KJE. Errors are 1σ. Expectations for supernova mixing (matter from the He/C, O/Si, and Si/S zones; gray shaded area) and data for SiC mainstream grains are shown for comparison. The data for the supernova mixing model are from Meyer et al. [5].

The SiC X grains of this study have δ^{29}Si values between -130 and -530‰ and δ^{30}Si values from -250 to -510‰ (Fig. 2), well within the known range of the SiC X grains. Different populations of X grains were observed [7, 8], indicative of a variety of mixing conditions in the supernova ejecta. Supernova mixing models fail to quantitatively account for the observed Si-isotopic compositions of most X grains. An exception are the most ^{29}Si-poor X grains whose Si-isotopic compositions are well explained by mixing matter from the He/C, O/Si, and Si/S zones (Fig. 2).

Upper limits of Fe concentrations in the SiC X grains of between 100 and 900 ppm have been determined (Fig. 3). Normalized to Si and solar abundances, Fe is depleted by a factor of > 1000. Iron might be present as Fe_3C which can form solid solutions with SiC [9]. None of the measurements on the X grains yielded a δ^{54}Fe significantly different from zero (Fig. 3). The average δ^{54}Fe value of all grains is 104 ± 90 ‰. Two interpretations are possible to account for the normal ^{54}Fe/^{56}Fe ratios: (i) Iron was introduced into the X grains from the solar nebula or else during chemical processing of the Murchison sample in the laboratory and does not represent the iron at the stellar site where the X grains formed. (ii) Supernova mixtures may produce Fe with ^{54}Fe/^{56} Fe close to solar. In order to further explore the latter possibility we have performed calculations of the Si- and Fe-isotopic compositions expected from mixtures of matter from the He/C, O/Si, Si/S, and Ni zones using the isotope yield table of Meyer et al. [5] for a 25 $M_{\odot}$ Type II supernova. Two sets of mixtures have been explored: (i) Matter from the He/C, O/Si, and Ni zones in a mixing ratio of 1:0.001…1:0…0.01 (mass fractions of the total zone that must be mixed), and (ii) matter from the He/C, Si/S, and Ni zones with the same range of mixing ratios. As it is evident from Fig. 4 such mixtures are expected to produce ^{54}Fe/^{56}Fe ratios that are within a factor of 2 of solar Fe if δ^{30}Si > -500‰. This is indeed the case for all X grains considered here. Larger Fe-isotopic anomalies are expected for more negative δ^{30}Si values. A few X grains with δ^{30}Si values between -600 and -800‰ have been observed [2, 7]. Analysis of such grains would help to decide whether Fe in the SiC X grains represents Fe at the stellar condensation site and, in case of a positive result, to put further constraints on the mixing in the ejecta of supernova explosions.

This work was supported by the Swiss National Science Foundation and by NASA.

References. [1] Amari S. *et al.* (1992) *Ap. J.* **394**, L43. [2] Hoppe P. *et al.* (1996) *Science* **272**, 1314. [3] Nittler L. R. *et al.* (1996) *Ap. J.* **462**, L31. [4] Amari S. *et al.* (1994) *GCA* **58**, 459. [5] Meyer B. S. *et al.* (1995) *Meteoritics* **30**, 325. [6] Lattimer M. *et al.* (1978) *Astrophys. J.* **219**, 230. [7] Hoppe P. *et al.* (1995) *LPSC* **26**, 621. [8] Nittler L. R. *et al.* (1995) *LPSC* **26**, 1057. [9] Lodders K. and Fegley B., Jr. (1995) *Meteoritics* **30**, 661.

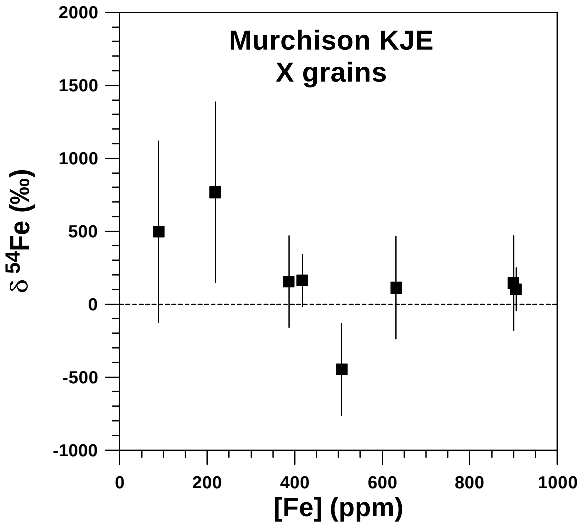

Figure 3. Abundances (upper limits) and isotopic compositions of Fe measured in SiC grains of type X from the Murchison separate KJE. Errors are 1σ.

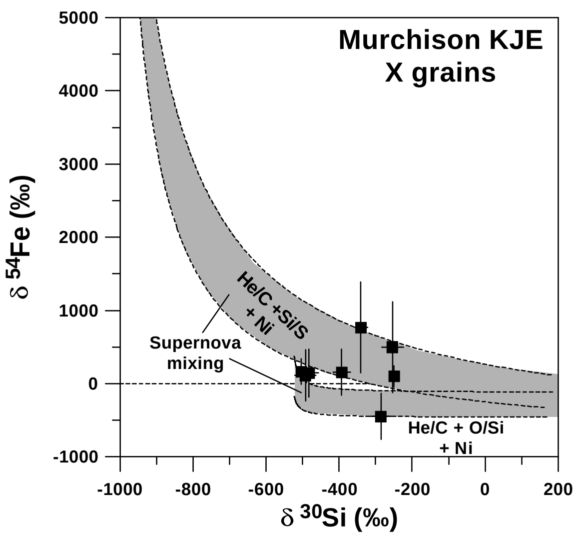

Figure 4. Fe- and Si-isotopic compositions of SiC X grains from the Murchison separate KJE. Errors are 1σ. Predictions from two supernova mixing models are shown for comparison (gray shaded area; all mixtures have C/O > 1). Note that the contribution of matter from the Ni zone is limited to 1% of the total mass in that zone.