DECODING MIXING IN SUPERNOVAE: CORRELATED SILICON AND TITANIUM ISOTOPIC SIGNATURES IN PRESOLAR SIC GRAINS OF TYPE X. N. Liu[1], L. R. Nittler[1], C. M. O'D. Alexander[1], and J. Wang[1] [1]Department of Terrestrial Magnetism, Carnegie Institution for Science, Washington, DC 20015, USA (Email: nliu@carnegiescience.edu).

Introduction: Presolar SiC grains of type X constitute 1−2% of all presolar SiC grains found in primitive meteorites. The initial presence of the short-lived isotope ^{44}Ti (found as ^{44}Ca excess) in X grains clearly indicates an origin in Type II supernovae (SNe) [1]. Although multi-element isotopic compositions of X grains suggest materials from different SN zones, due to the complexities of SNe and model uncertainties, mixing remains one of the poorly understood processes that play an important role in SN nucleosynthesis. In addition, the detection of the predicted extinct ^{49}V in X grains remains elusive. Although most of X grains show ^{49}Ti excesses that might indicate the initial presence of ^{49}V ($t_{1/2}$=329 d) [2−5], in fact, SN models predict ^{49}Ti excesses both in the inner Si/S zone that also produces abundant ^{49}V and in the He/C zone.

Thus, to better investigate the mixing processes in SNe and the role of ^{49}V during X grain condensation, we selected 23 X and two ungrouped grains with a range of Si isotopic compositions for multi-element isotopic studies with the NanoSIMS. Compared to the previous studies of X grains, in which ^{50}Ti was not measured in most cases [2,5], we were able to obtain both ^{49}Ti and ^{50}Ti isotopic data with higher precision. Since the neutron-capture process in the He/C zone overproduces ^{50}Ti while the Si/S zone overproduces ^{49}Ti without any ^{50}Ti, our Ti isotopic data for X grains allows a better understanding of the origin of ^{49}Ti excesses in X grains and thus the mixing process in SNe.

Experimental Methods: The SiC grains in this study were extracted from the Murchison meteorite using the isolation method described in [6] and dispersed on three high purity Au mounts (mounts #1, #2, and #3). Presolar SiC grains of type X were nondestructively identified with the method of [7] and later confirmed by isotopic analysis with the Carnegie NanoSIMS 50L ion microprobe for C, N, and Si isotopic compositions using a Cs^+ beam and standard methods.

Following the C, N, and Si analyses, we selected 23 X and two ungrouped (^{12}C,^{15}N-rich) grains for further study. We analyzed these grains for their Mg-Al, K-Ca, Ca-Ti, and Ti-V isotopic ratios with the NanoSIMS. To avoid contamination, a focused ion beam (FIB) was used to sputter away material that was adjacent to (within ~5×5 μm) the grains of interests with the FIB-SEM at Carnegie Institution. All the isotopic data were acquired in imaging mode to allow further exclusion of contamination during data reduction.

Results: The Si isotopic data suggest that the 23 X grains include 21 X1, one X2, and one X0 grains [5]. Consistent with previous studies [1−5], our X grains show high initial ^{26}Al/^{27}Al (0.01−0.5), with an average of 0.28. For the first time, we found ^{41}K excesses (200−6000‰) in 12 of the 23 X SiC grains that are correlated with Ca/K, thus indicating the presence of short-lived isotope ^{41}Ca (initial ^{41}Ca/^{40}Ca of 0.001−0.004) in the grains. In addition, four of the 23 X grains show ^{44}Ca excesses, indicating initial ^{44}Ti/^{48}Ti from 10^{-3} to 0.3. One of the ungrouped grains, M3-G1472 (δ^{29}Si=122±23‰, δ^{30}Si=17±27‰), had a large ^{44}Ca excess (^{44}Ti/^{48}Ti =0.26) and the other grain (δ^{29}Si=61±18‰, δ^{30}Si=54±14‰), had an initial ^{41}Ca/^{40}Ca ratio of 5×10^{-4}, higher than predicted for AGB stars and thus confirming a SN origin.

Titanium isotopic ratios were obtained for 16 of the 23 X grains (all type X1) and the two ungrouped grains. We were not able to measure δ^{50}Ti in two of the 16 X grains, because their high Cr/Ti ratios resulted in significant ^{50}Cr interferences at mass 50. Almost all of the grains show close-to-solar δ^{46}Ti and δ^{47}Ti values (within <100‰ uncertainties). In contrast, most of the grains show measurable excesses in both ^{49}Ti (0−1000‰) and ^{50}Ti (0−1000‰). The largest Ti isotopic anomaly was found in the ungrouped grain, M3-G1472 (δ^{49}Ti=1087±93‰, δ^{50}Ti=1059±92‰).

Discussions: No clear correlation between δ^{49}Ti and V/Ti ratios can be seen in Fig. 1a. The V/Ti ratios in our grains vary from 0 to 0.3, in good agreement with the values reported in previous studies [2−5]. For δ^{49}Ti, our new data generally agree with the literature data, but with much smaller errors. Also, we did not find any X grain with high δ^{49}Ti and V/Ti ratios <0.05. The lack of correlation in Fig. 1a could indicate (1) a range of initial ^{49}V/^{51}V ratios in the Si/S zone, (2) varying condensation timescales, or (3) overproduction of ^{49}Ti instead of the initial presence of ^{49}V. Detailed mixing calculations in [5] clearly showed that ^{49}Ti excesses in some of the X grains cannot be fully attributed to ^{49}V decay and, therefore, confirmed the third possibility. However, it still remains unclear if this scenario holds true for all the grains and what is (are) the additional ^{49}Ti contributor(s), e.g., ^{49}Ti excesses from Si/S and/or He/C zones.

Since the Si/S zone overproduces ^{28}Si as a result of alpha capture while the outer C-rich zones are predicted to overproduce both ^{29}Si and ^{30}Si because of neutron capture, the range of Si isotopic ratios of X grains, therefore, represents varying mixing ratios between the Si/S and outer C-rich zones. In other words, the lower the $\delta^{29,30}$Si ratios, the higher the percentage of material from the Si/S zone. As shown in Fig. 1b, in fact, δ^{49}Ti is inversely correlated with δ^{30}Si for X grains, clearly linking ^{49}Ti excesses to the Si/S zone that overproduces ^{28}Si. Furthermore, the correlation observed in Fig. 1b argues strongly against the first and second possibilities regarding the ^{49}Ti origin discussed above, because if varying amounts of ^{49}V relative to ^{48}Ti from the Si/S zone were incorporated into the grains, such a correlation would not be expected. Thus, ^{49}Ti excesses in X grains are most likely to have been incorporated as ^{49}Ti with negligible contributions from ^{49}V. This conclusion raises two possibilities: (1) the Si/S zone overproduces ^{49}Ti and/or (2) the grains condensed after all ^{49}V decayed to ^{49}Ti (tens of years after SN explosion). Since dust formation around SNe is typically observed a few years after explosion [e.g., 8], the second scenario is highly unlikely.

Finally, Fig. 1c shows that once δ^{50}Ti is subtracted from δ^{49}Ti to exclude the contribution of ^{49}Ti from the He/C zone that should correlate with ^{50}Ti because of neutron capture, the ^{49}Ti excesses from the Si/S zone (δ^{49}Ti$-\delta^{50}$Ti) become more tightly correlated with the ^{28}Si excesses from the Si/S zone, which further confirms the absence of ^{49}V and mixing between the Si/S and the outer C-rich zones for X grains.

Conclusions: We performed a multi-element isotopic study of 23 X and two ungrouped SiC grains. For the first time, we found ^{41}K excesses in the X grains, indicating initial ^{41}Ca/^{40}Ca ratios of 0.001−0.004. Both ungrouped grains show initial ^{26}Al/^{27}Al ratios of >0.02 with one of the grains showing large excesses of ^{44}Ca, ^{49}Ti, and ^{50}Ti and the other grain showing 1000‰ ^{41}K excess, confirming a SN origin. Thus, mixing processes in SNe clearly yielded diverse Si isotopic signatures, which cover almost the entire three Si isotope plot (e.g., ^{29,30}Si-rich in C1 grains).

More importantly, we found that ^{49}Ti excesses are tightly correlated with ^{28}Si excesses in X grains, especially after correcting for the amount of ^{49}Ti produced by the neutron-capture process in the He/C zone. Thus, the tight correlation between ^{49}Ti and ^{28}Si excesses clearly excludes extinct ^{49}V as a significant contributor to ^{49}Ti excesses in the X grains. Instead, ^{49}Ti is more likely to be overproduced in the Si/S zone, as predicted by SN models. Recent SN models of [9] showed that in SNe with high explosive energy, a Si/C zone can be formed below the He/C zone, in which ^{28}Si and ^{44}Ti are both produced because of alpha capture. Our new Ti data may provide additional tests of this model.

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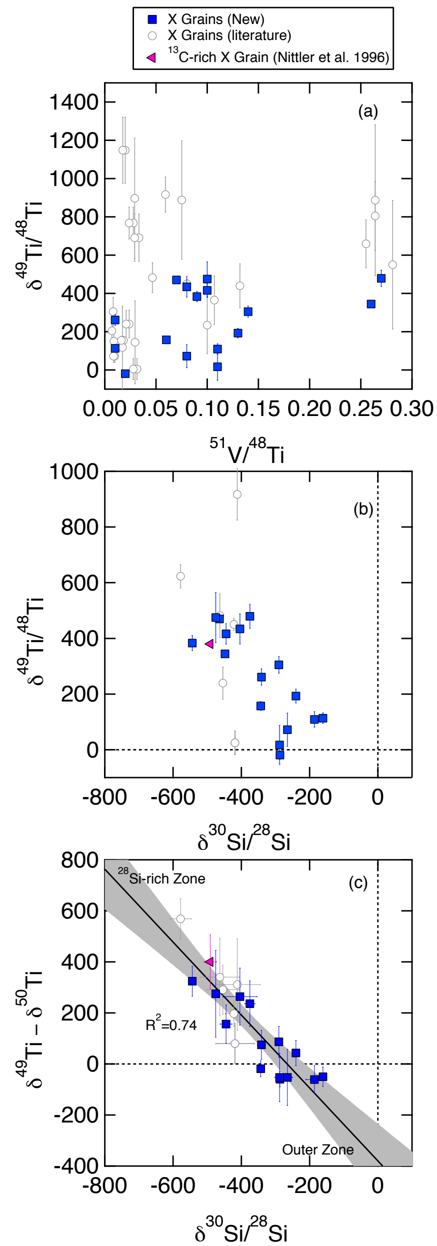

Fig. 1. Plots of δ^{49}Ti versus V/Ti, and δ^{49}Ti and δ^{49}Ti$-\delta^{50}$Ti versus δ^{30}Si. The literature data are from [1−5]. All the data are plotted with 1σ errors.