ON THE ORIGIN OF TITANIUM-49 EXCESSES IN PRESOLAR SILICON CARBIDE GRAINS OF TYPE X.

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Introduction: Primitive meteorites contain small amounts of refractory dust grains that formed in stellar winds or in the ejecta of stellar explosions [1, 2]. Among the presolar minerals studied to date most isotopic information is available for silicon carbide (SiC). Of particular importance are the so-called X grains which make up about 1% of the meteoritic SiC grains. These grains are believed to have formed in the ejecta of Type II supernova (SN) explosions [3-5]. They are characterized by high $^{12}$C/$^{13}$C (most grains; up to 80x solar), high $^{28}$Si/$^{29,30}$Si (up to 5x solar), and low $^{14}$N/$^{15}$N (down to 0.05x solar) ratios. Other features of X grains are large excesses in $^{26}$Mg and, in some grains, $^{44}$Ti, and $^{49}$Ti. While the excesses in $^{26}$Mg and $^{44}$Ca can be attributed to the radioactive decay of now-extinct $^{26}$Al ($t_{1/2} \approx 700000$ y) and $^{44}$Ti ($t_{1/2} = 60$ y), the origin of the $^{49}$Ti excesses is less clear. Enhanced $^{49}$Ti/$^{48}$Ti ratios may be the result of n-capture reactions and/or may be due to the decay of radioactive $^{49}$V ($t_{1/2} = 330$ d) [3, 4]. Evidence for incorporation of live $^{49}$V would constrain the time scale of grain formation in the ejecta of Type II SN explosions to several months.

In order to get more information on the origin of $^{49}$Ti excesses and on the possible presence of live $^{49}$V at the time of grain formation in SiC X grains we have measured the Ti-isotopic compositions together with V in 48 X grains from the Murchison CM2 chondrite.

Experimental: The X grains have been identified by low-mass resolution ion imaging with the Cameca IMS 3f ion microprobe at the Max-Planck-Institute for Chemistry at Mainz. Subsequently, $^{46}$Ti, $^{48}$Ti, $^{49}$Ti, and $^{51}$V (together with Si and Ca isotopes) were measured on 44 X grains with the IMS 3f in a peak-jumping mode at high mass resolution conditions, using a $\approx 100$ pA primary O$^-$ ion beam. In addition, four X grains were studied with the new generation Cameca NanoSIMS 50 ion microprobe which was recently installed in our laboratory. Prior to the Ti-V-isotopic analyses these grains had been studied for Si- and Ca-isotopic compositions and abundance of $^{48}$Ti with high lateral resolution ($\approx 150$ nm under O$^-$ bombardment; Fig. 1), [6]. All Ti isotopes together with $^{28}$Si, $^{51}$V, and $^{52}$Cr were measured in a peak-jumping mode, using a defocussed ($\approx 1-2$ µm) primary O$^-$ ion beam of $\approx 5$ pA. Chromium-52 was included in the measurement cycle to allow for correction of contributions from $^{50}$Cr to $^{54}$Ti.

Results: Most of the X grains studied with the IMS3f have Ti-isotopic compositions compatible with solar. However, because the primary beam diameter of 5-10 µm is distinctly larger than the size of the X grains (typically $\approx 1$ µm), significant contributions from nearby Ti-bearing grains can not be excluded and we will focus the discussion only on those six grains that show a $> 2 \sigma$ anomaly in the $^{49}$Ti/$^{28}$Ti ratio. These grains have comparatively high Ti concentrations from 400 ppm to $> 1$wt%. The X grains studied with the NanoSIMS have lower Ti concentrations of $\approx 100$ ppm. Even in spite of the partial grain consumption during the prior Si- and Ca-isotopic analyses, the high transmission of the NanoSIMS did still allow to obtain sufficiently precise Ti-isotopic data.

Figure 1. SEM image and $^{28}$Si$^+$ and $^{48}$Ti$^+$ ion images of X grain M6-50-2 measured with the NanoSIMS. The field of view in the ion images is 6x6 µm$^2$.

The ten X grains considered here have Si-isotopic compositions compatible with previously published values [3-5, 7]. Of the X grains studied with the IMS 3f three grains have lower than solar $^{49}$Ti/$^{48}$Ti and three have higher than solar $^{49}$Ti/$^{48}$Ti ratios. On the other hand, all grains studied with the NanoSIMS exhibit excesses in $^{49}$Ti. The $^{49}$Ti/$^{48}$Ti ratios of these ten X grains correlate with the $^{51}$V/$^{48}$Ti ratio which varies by more than two orders of magnitude (Fig. 2). All X grains have $^{46}$Ti/$^{48}$Ti and $^{47}$Ti/$^{48}$Ti ratios compatible with solar (within the typical errors of 10-20%). The $^{50}$Ti/$^{48}$Ti ratio of X grain M6-50-2 is clearly higher than solar ($\delta^{50}$Ti/$^{48}$Ti = 870±190‰); however, since the $^{50}$Cr interference accounts for more than 60% of the...
ion signal measured at mass 50 (assuming solar 50Cr/52Cr) this ratio is somehow uncertain.

Discussion: In order to explore whether 49V is needed to explain the 49Ti/48Ti ratios of X grains we will compare our data with the predictions from a SN mixing model. It is based on the 15 M\textsubscript{\odot} Type II SN model of solar metallicity of [8] which has been successfully used in the past to explain many isotopic features of SN grains [4, 5, 9]. The mixing considers matter from the SiS (only inner part because otherwise large 46Ti excesses are expected, contrary to the results for the X grains in this study), HeC, and HeN zones (Fig. 3) in proportions that can reproduce the C-, Al-, and Si-isotopic ratios of X grains reasonably well.

The best match between the data for the X grains with high 49Ti/48Ti ratios and the model predictions is achieved if 49V is considered and if there is no V/Ti fractionation (Fig. 2). Without Ti/V fractionation the predicted 49Ti/48Ti ratio does not depend on the time of grain formation. In order to explain the V/Ti ratios of the X grains with low 49Ti/48Ti ratios a Ti/V fractionation of a factor of 100 must have been occurred during grain condensation. In this case, the 49Ti/48Ti ratio depends not only on how the Ti/V fractionation is achieved (cf. two different scenarios in Fig. 2) but also on the time of grain formation. For t \leq t_{\text{1/2}(49V)} relative contributions of 49V will be only marginal and the 49Ti/48Ti ratios are expected to be lower than those in the unfractonated mix (Fig. 2), compatible with our X grain data. For t >> t_{\text{1/2}(49V)} on the other hand, 49V has decayed to 49Ti and essentially the same range of 49Ti/48Ti ratios as in the unfractonated mix is expected. Our data for X grains thus point to the presence of live 49V at the time of grain formation, i.e., the X grains must have formed within several months after SN explosion. This is consistent with the time-scale for dust formation in SN ejecta inferred from astronomical observations [10].

The conclusion regarding time-scale for grain formation relies heavily on the existence of X grains with low 49Ti/48Ti and V/Ti ratios. The 49Ti/48Ti anomalies in X grains with lower than solar 49Ti/48Ti differ by less than 3\sigma from solar and it can not be strictly ruled out that their Ti is isotopically normal. In this case the Ti might not be intrinsic to the X grains but might be from nearby Ti-bearing grains with solar isotopic composition. A confirmation of the presence of X grains with low 49Ti/48Ti and V/Ti ratios is clearly needed. Use of the NanoSIMS will be crucial in this respect as it allows to largely exclude contamination from the analyses and as its high sensitivity will allow to obtain sufficiently precise Ti-isotopic data.

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