AN INVESTIGATION INTO THE ORIGIN OF GROUP 4 STARDUST GRAINS. M. Bose, F. J. Stadermann and C. Floss; Laboratory for Space Sciences and Physics Department, Washington University, St. Louis MO 63130, USA (mbose@physics.wustl.edu).

Introduction: Silicate and oxide stardust grains characterized by ^{18}O enrichments are referred to as group 4 grains [1]. Low mass/high metallicity red giant or asymptotic giant branch stars and Type II supernovae are possible sources for group 4 grains. Recently it was suggested that all group 4 grains could have condensed in a single supernova (SN) [2]. This model explained the measured O isotope anomalies by mixing variable amounts of material from the inner O-rich zones in a 15$M_{\odot}$ SN with a single mixture of the H envelope and the He/C zone. Some grains which lie in between the group 3 and 4 categories, along the single mixing line, could also be explained by the suggested model.

The small size of silicate and oxide presolar grains often hinders their study using multiple isotope systems. There is also a lack of elemental information for most of these grains. The present work aims to acquire additional isotopic (e.g., Si) and elemental data on group 4 grains. We then try to reproduce the O isotopes of group 4 grains by mixing material from five layers of the SN ejecta as specified in [2] and test if the mixing ratios predict the measured Si isotopic compositions. The Si isotopes are chosen in our study since large numbers of presolar silicates have been discovered in extraterrestrial materials [e.g., 3-5]. Such an investigation should uncover the characteristics of the mixing ratios and shed light on whether the formation of all group 4 grains in a single SN is a viable option.

Experimental Methods And Results: Grain size separates (0.1-0.5 µm) of Acfer 094 matrix material were searched for presolar grains using the NanoSIMS 50 ion microprobe. The NanoSIMS measurements were carried out in raster ion imaging mode by scanning a less than 1 pA Cs^+ primary beam over areas of 10x10 μm^2 (256^2 pixels) and simultaneously collecting secondary ions of $^{12, 13}C^-$ and $^{16, 17, 18}O^-$, as well as secondary electrons. Each measurement consisted of 5-8 repeated scans. Grains are considered presolar if the O isotopic compositions are more than 4σ away from the average of the surrounding material and the anomaly is visible in three consecutive image planes. Subsequently the presolar grains were analyzed in the PHI 700 Auger Nanoprobe. Elemental spectra (10kV 0.25nA) and high resolution maps of the grains were acquired.

Oxygen isotopic compositions of the group 4 grains identified in Acfer 094 [this work, 3, 6, 7] and QUE 99177 meteorites [4], interplanetary dust particle [8] and Antarctic micrometeorites (AMMs) [9] are shown in Figure 1. Five group 4 presolar grains [this work, 3, 4] were then measured for $^{16, 18}O^-$ and $^{28, 29, 30}Si^-$ isotopes in the NanoSIMS. The Si isotopic ratios of the presolar grains were normalized by assuming that the surrounding material has a solar composition. The measured $\delta^{29}Si$ values for the five grains are between −58 ‰ and +48 ‰ and the $\delta^{30}Si$ values are between −22 ‰ and +64 ‰. All compositions are normal within errors except for a single grain which shows depletions in ^{29}Si. Si isotopic data for the remaining grains are from the literature [6-9]. Si isotopic data of all 15 group 4 grains are plotted in Figure 2.

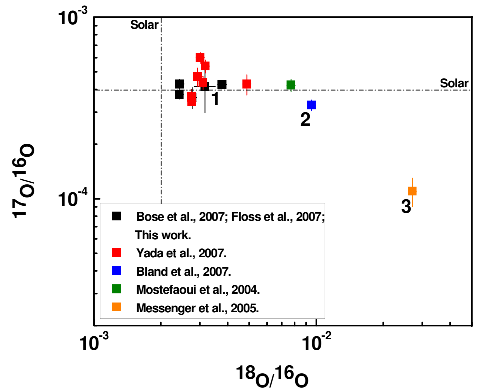

Figure 1. *O three isotope plot of 15 presolar group 4 grains for which Si isotopic data are available.*

Model Calculations And Discussion: The core of a pre-SN star greater than 8$M_{\odot}$ consists of concentric spherical shells as a result of successive stages of nuclear burning. The shells are named for the elements that are predominantly found in them. Mixing of these zones is expected to occur as an after-effect of the supernova explosion. Mixing of material mainly from the H envelope, He/C zone and inner O-rich zones (combining O/Si, O/Ne and O/C zones in a 1:1:1 ratio) has been suggested to produce group 4 presolar grains [2]. The H envelope has ^{17}O enrichments and ^{18}O depletions and the O-rich zones have high ^{16}O abundances. In contrast, the He/C zone is ^{18}O-rich. The three isotopes of Si are mainly produced in the Si- and O-rich layers. A large amount of ^{28}Si is also produced in the Si/S zone, which is not included in the mixing model of [2]. The O/Si zone has ^{30}Si enrichments; the remaining O-rich zones and the innermost region of the He/C zone are ^{28}Si-depleted.

We consider the 15$M_{\odot}$ SN model [10] which provides abundances for a number of isotopes throughout the supernova ejecta. We calculated average O isotope compositions for the H envelope, He/C zone and the O-rich zones. Mixing of material from these zones was done to quantitatively explain the observed O isotopic compositions of the 15 group 4 grains. With only slight variations in the mixing ratios, all of the measured O isotope compositions can be reproduced. The H envelope with C/O<1, contributes the most in the production of oxide and silicate stardust grains. Only about 1-1.5% of the material comes from the O-rich zones. Even smaller amounts of matter from the He/C zone, which is ^{18}O- enriched, are required to be mixed with the H envelope and O-rich zones to account for the observed ^{18}O enrichments.

Assuming that the Si isotopes from the different zones are mixed in the same ratios as the O isotopes, the mixing ratios were used to predict the Si compositions of the grains, which were then compared to the measured Si data. Figure 2 shows the measured Si isotopic compositions plotted as δ-values along with the model results for the 15 group 4 grains. The disparity between predicted (pink open symbols) and observed Si isotopic compositions is large. The predicted δ^{29}Si ranges from +87 ‰ to +362 ‰ and δ^{30}Si ranges from +425 ‰ to +1787 ‰. The large disagreement between the predicted and observed Si isotopic ratios is due to the fact that even a minor contribution from the O- (and Si-) rich inner zones has dramatic effects on the Si isotopic composition of the resulting mixture.

We next tested whether mixing of the H envelope and the He/C zone with material only from the O/C zone, instead of all the inner O-rich zones, could provide a better fit to the data. The O/C zone contains less Si than the O/Si and O/Ne zones and any mixing would, therefore, have a smaller effect on the overall Si isotopic composition. The predicted Si isotopes (purple open symbols) lie close to the measured ones, except for one grain [8]. However, a few of the grains exhibit ^{29}Si depletions, which are not predicted with this mixing model. Although the specific models discussed above cannot account for the Si isotopic compositions of all the grains, it is possible to mix material from different zones in the SN, in order to explain the O and Si isotopic ratios of these grains. However, it may be difficult to do so without producing anomalies in some other element.

Additional Observations: Si isotopic compositions of the mainstream SiC grains plot along a line (slope 1.4), which is interpreted to reflect the initial Si composition in parent stars. Except for two AMM grains [9], which exhibit large errors in their Si isotopic ratios due to low Si signals, the remaining group 4 grains plot close to the correlation line. As noted above, the Si isotopic compositions of three grains (numbered 1, 2 and 3 in both figures) exhibit statistically significant ^{29}Si depletions. Interestingly, the same three grains are among the five most ^{18}O-rich grains. Formation of the most ^{29}Si-depleted and ^{18}O-rich silicate grain was suggested to have occurred through mixing of O-rich material in the He/C and O/C zones and Si-rich material in the Si/S and Ni zones [8]; thus there is a possibility that the other two group 4 grains with ^{29}Si depletions formed under similar conditions.

Finally, elemental compositions might hold clues to the condensation of the group 4 presolar grains in a particular type of stellar object and so we looked at the grains in this study for which such information is available. The grains have olivine or pyroxene like compositions, except for two silicate grains with non-stoichiometric compositions [3, 4]. The compositions of grains from other groups are also similar in their variety and, thus, there appears to be no significant difference in the elemental compositions of grains found in group 4 versus the other groups.

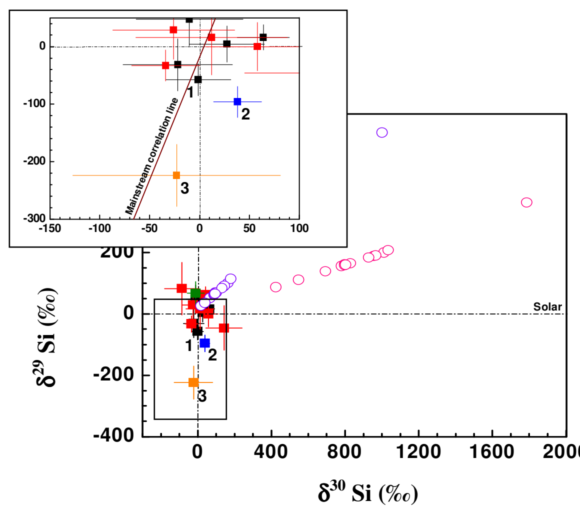

Figure 2. *Measured Si isotope compositions along with the predicted Si isotopes computed by mixing He/C zone and H envelope with all three inner O-rich zones (pink open symbols) and with only the O/C zone (purple open symbols). The mainstream correlation line is drawn in brown. The inset shows the grains with ^{29}Si depletions. Symbols are the same as in Figure 1.*

References: [1] Nittler L. R. et al. (1997) *ApJ* 483, 475. [2] Nittler L. R. (2007) *In Workshop on Met. Chron.*, Abstract # 4016. [3] Bose M. et al. (2007) *Meteorit. Planet. Sci.* 42, A23. [4] Floss C. et al. (2007) *LPSC XXXIX*, this volume. [5] Nguyen A. N. et al. (2007) *ApJ* 656, 1223. [6] Mostefaoui S. and Hoppe P. (2004) *ApJ* 613, L149. [7] Bland P. A. et al. (2007) *Meteorit. Planet. Sci.* 42, 1417. [8] Messenger S. et al. (2005) *Science* 309, 737. [9] Yada T. et al. (2008) *Meteorit. Planet. Sci.*, in revision. [10] Rauscher T. et al. (2002) *ApJ* 576, 323.