SILICON CARBIDE X GRAINS WITH VERY HIGH ^{26}AL/^{27}AL RATIOS: NEW CONSTRAINTS FOR SUPERNOVA MODELS.

P. Hoppe[1], M. Pignatari[2,3,4], and S. Amari[5], [1]MPI for Chemistry, Hahn-Meitner-Weg 1, 55128 Mainz, Germany (email: peter.hoppe@mpic.de), [2]Konkoly Observatory, H-1121 Budapest, Hungary, [3]E.A. Milne Centre for Astrophysics, University of Hull, HU6 7RX, UK, [4]NuGrid Collaboration, http://nugridstars.org, [5]McDonnell Center for the Space Sciences and Physics Dept., Washington University, St. Louis, MO 63130, USA.

Introduction: Primitive Solar System materials contain small quantities of presolar grains that formed in the winds of evolved stars and in the ejecta of stellar explosions [1]. Silicon carbide (SiC) is the best studied presolar mineral. Based on C-, N-, and Si-isotopic compositions it is divided into distinct populations. While most SiC grains formed in the winds of low-mass asymptotic giant branch (AGB) stars, supernovae (SNe) made an important contribution to the population of presolar SiC grains as well [1]. Of particular interest are SiC X grains which formed in the ejecta of Type II (core-collapse) SN explosions [e.g., 2-4]. These grains are characterized by mostly higher than solar ^{12}C/^{13}C, lower than solar ^{14}N/^{15}N, excesses of ^{28}Si, high abundances of now extinct radioactive ^{26}Al (half life: 716 ka), and sometimes evidence for now extinct radioactive ^{44}Ti (half life: 60 a).

Here, we report on a search for new SiC X grains by NanoSIMS ion imaging and subsequent in-depth analyses of C-, N-, Si-, and Mg-Al-isotopic compositions, in order to get better constraints on SN models.

Experimental: SiC grains from the Murchison separate KJF (median size: 1.86 μm) [5], dispersed on a clean Au foil, were screened for X grains by C and Si ion imaging with the NanoSIMS at MPI for Chemistry. For this purpose a focused Cs^+ ion beam (~1 pA, 100 nm) was rastered over 688 30 x 30 μm^2-sized areas on the Au foil and negative secondary ion images of ^{12}C, ^{13}C, ^{28}Si, ^{29}Si, and ^{30}Si were recorded in multi-collection. Subsequently, six identified X grains among a total of 964 identified presolar SiC grains were measured with high spatial resolution for C-, N-, Si-, and Mg-Al-isotopic compositions (image sizes 3 x 3 to 5 x 5 μm^2). We recorded in multi-collection negative secondary ions of (i) ^{12}C, ^{13}C, ^{28}Si, ^{29}Si, and ^{30}Si, (ii) ^{12}C, ^{13}C, ^{12}C^{14}N, ^{12}C^{15}N, ^{28}Si (Cs^+ ion source, ~1 pA, 100 nm), and (iii) positive secondary ions of ^{24}Mg, ^{25}Mg, ^{26}Mg, ^{27}Al, and ^{28}Si (Hyperion O^- source, ~3 pA, 100 nm).

Results and Discussion: The six X grains have ^{12}C/^{13}C ratios between 200 and 738, ^{14}N/^{15}N ratios between 38 and 119, and ^{29}Si/^{28}Si and ^{30}Si/^{28}Si ratios of 0.37-0.74 and 0.41-0.62 times the solar ratios, respectively. Magnesium is essentially monoisotopic ^{26}Mg. This gives clear evidence for the radioactive decay of ^{26}Al with inferred initial ^{26}Al/^{27}Al ratios of 0.60-0.78. These ratios are at the upper end of reported whole-grain ^{26}Al/^{27}Al ratios in the literature, which range from ~0.01 to ~0.6 [e.g., 6]. This suggests that the grains from this study carry only little Al contamination and supports the conclusion of [6] that contamination may contribute 10s of percent of Al in SiC grains from previous studies, which would seriously lower true ^{26}Al/^{27}Al ratios. This makes the X grains from this study particularly useful when isotope data of X grains are quantitatively compared with SN model predictions.

Our new X grain data are compared with predictions from three SN models of [7] , two SN models of [8], and two SN models of [9]. Except for the Ni zone in the innermost part of SN ejecta, ^{26}Al/^{27}Al ratios don't exceed values of 0.3-0.4 (achieved in the He/N zone) in the 'classical' 12-25 M⊙ SN models of [8, 9]. In contrast, the H-ingestion 25 M⊙ SN models of [7] with H concentrations >0.12% in the He shell show high ^{26}Al/^{27}Al ratios of >1 in parts of the O/nova zone that forms near the bottom of the He shell after explosion and shows signatures of explosive H burning. This makes H-ingestion SN models very attractive to account for the isotope data of (^{26}Al-rich) X grains. Following the mixing schemes as outlined in [10], using SN model 25T-H10 from [7], we find relatively good matches for C- and N-isotopic compositions (within a factor <2) and ^{29}Si/^{28}Si ratios (<20%) of the X grains from this study when ^{26}Al/^{27}Al ratios are matched within 15%. Predicted ^{30}Si/^{28}Si ratios are generally too high (up to a factor of 2), which may point to deficiencies in our understanding of ^{30}Si production in SNe. These mixing scenarios consider matter from regions extending over only 0.2-0.4 M⊙, predominantly from the O/nova zone with small admixture of matter from the zones below and above.

Conclusions: Our new data for ^{26}Al/^{27}Al in X grains suggest that literature data for ^{26}Al/^{27}Al may be strongly compromised by Al contamination. The relative good match of our new data set by predictions of H-ingestion SN models helps to better understand the origins of X grains and the data should be used as constraints to develop H-ingestion SN models further, in particular to include 3-dimensional hydrodynamics.

References: [1] Zinner E. (2014) Presolar grains. In Meteorites and Cosmochemical Processes, Vol. 1 (ed. A. M. Davis), pp. 181-213. Elsevier. [2] Amari S. et al. (1992*) Astrophys. J.* 394: L43-L46. [3] Hoppe P. et al. (1996) *Science* 272: 1314-1316. [4] Nittler L. R. et al. (1996) *Astrophys. J.* 462: L31-L34. [5] Amari S. et al. (1994) *Geochim. Cosmochim. Acta* 58: 459-470. [6] Groopman E. et al. (2015) *Astrophys. J.* 809: 31 (16pp). [7] Pignatari M. et al. (2015) *Astrophys. J.* 808: L43 (6pp). [8] Rauscher T. et al. (2002) *Astrophys. J.* 576: 323-348. [9] Woosley S. E. and Heger A. (2007) *Phys. Rep.* 442: 269-283.[10] Hoppe P. et al. (2018) *Geochim. Cosmochim. Acta* 221: 182-199.