ISOTOPIC SIGNATURES OF SUPERNOVA NUCLEOSYNTHESIS IN PRESOLAR SIC GRAINS OF TYPE AB WITH LIGHT NITROGEN. P. Hoppe[1], M. Pignatari[2,3,4,5], and S. Amari[6], [1]Max Planck Institute for Chemistry, Hahn-Meitner-Weg 1, 55128 Mainz, Germany (email: peter.hoppe@mpic.de), [2]E. A. Milne Centre for Astrophysics, University of Hull, UK, [3]Konkoly Observatory, Budapest, Hungary, [4]NuGrid Collaboration, [5]Joint Institute for Nuclear Astrophysics - Center for the Evolution of the Elements (JINA-CEE), [6]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. Most abundant are the mainstream grains, which constitute ~90% of all presolar SiC grains and which originate from low-mass asymptotic giant branch (AGB) stars of about solar metallicity. A minor, but important subgroup are the Type AB grains, which constitute a few percent of all presolar SiC grains. AB grains are characterized by $^{12}C/^{13}C < \sim 10$, Si-isotopic compositions along the SiC mainstream line, a large range of $^{14}N/^{15}N$ ratios, and higher $^{26}Al/^{27}Al$ ratios than those of typical SiC mainstream grains [1]. AB grains with isotopically heavy N ($^{14}N/^{15}N < 440$ = solar) have been named AB1 and those with light N ($^{14}N/^{15}N \geq 440$) AB2 [2]. The origin of AB grains is still a matter of debate. Proposed stellar sources include born-again AGB stars [3] and J-type C stars [4] for AB2 grains, and supernovae (SNe) for AB1 grains [2].

Here we report on measurements of C-, N-, Al-Mg-, Si-, and S-isotopic compositions of 22 submicrometer-sized AB grains from the Murchison meteorite, performed to explore whether SNe can account for the isotopic signatures of both AB1 grains and AB2 grains. The isotope data of 10 of the AB grains presented here were already reported by [5].

Experimental: SiC grains from the Murchison separate KJD (median size: 0.81 μm) [6], dispersed on a clean Au foil, were screened for AB 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 136 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 multicollection. Subsequently, 22 selected AB grains (from a total of 38 identified AB grains) were measured for N- and S-isotopic compositions and 20 of these also for Al-Mg-isotopic compositions. We recorded in multicollection negative secondary ions of $^{12}C^{14}N$, $^{12}C^{15}N$, ^{28}Si or ^{29}Si, ^{32}S, and ^{34}S (Cs^+ ion source, ~1 pA, 100 nm), and 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: Twelve of the AB grains of this study are of type AB1, and 10 of type AB2. Al/Si and N/Si ratios are relatively well correlated, except for two outliers. The $^{12}C/^{13}C$ ratios are between 1.9 and 10 and $^{14}N/^{15}N$ ratios between 50 and 3800 (Fig. 1). Magnesium is in most cases dominated by ^{26}Mg and inferred $^{26}Al/^{27}Al$ ratios vary between 0.001 and 0.03 (Fig. 2). The AB grains of this study have Si isotope anomalies of a few percent, plotting between the SiC [7] and silicate [8] mainstream lines, without a clear distinction between AB1 and AB2 grains. Sulfur-isotopic compositions are normal within ~2σ.

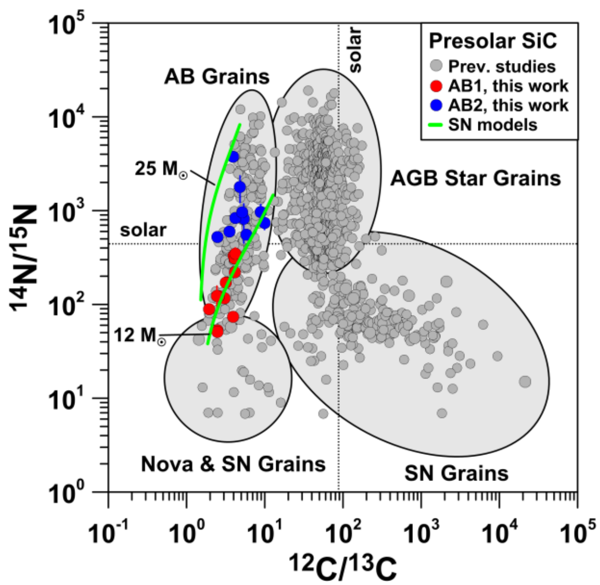

Figure 1. C- and N-isotopic compositions of 22 AB grains from this study in comparison to literature data of presolar SiC grains [9] and two SN model predictions.

Following the approach of [2] we have explored two mixing scenarios based on the 25 $M_\odot$ SN model 25T-H of [10] to see whether the isotope data of our AB1 and AB2 grains can be matched. Model 25T-H considers H ingestion into the He/C zone during the pre-SN stage (1.2% H) with artificially increased temperature and density in the He burning shell during the explosion. Hydrogen ingestion and explosive nucleosynthesis leads to low $^{12}C/^{13}C$ and $^{14}N/^{15}N$ ratios, and high $^{26}Al/^{27}Al$ at the bottom of the He/C zone, called the O/nova zone (Fig. 3). Mixing scenario 1 considers mixing of matter from the He/C zone (including the O/nova zone; M = 6.82–9.23 $M_\odot$) with matter from the outer zone (M = 9.23–13.33 $M_\odot$) in variable proportions (labeled 25 $M_\odot$ in Figs. 1 and 2). For mixing scenario 2 the isotope abundances in the outer zone were replaced by those in the outer zone of a 12 $M_\odot$ SN [11] (labeled 12 $M_\odot$ in Figs. 1 and 2), to mimic the effect of mixing material from explosive H burning with typical matter from the outer zone in a SN of lower mass.

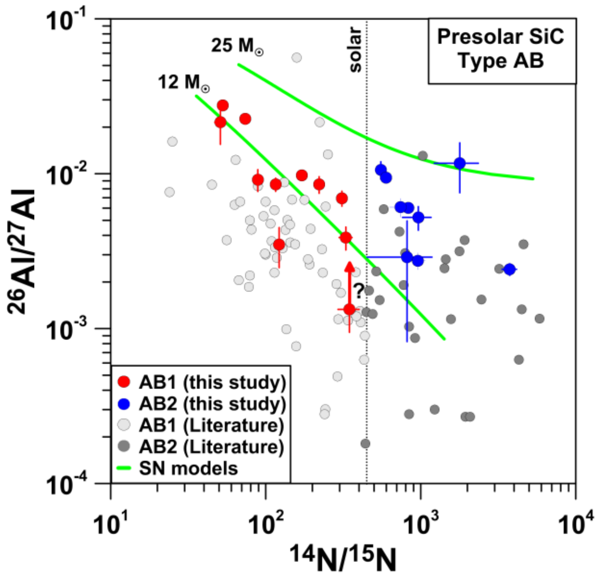

Figure 2. Inferred $^{26}Al/^{27}Al$ vs. $^{14}N/^{15}N$ ratios of 20 AB grains from this study in comparison to literature data for AB grains [2,9] and two SN model predictions.

Carbon-, N-, and Al-isotopic ratios of AB1 grains are reasonably well explained by mixing scenario 2 if we lower the $^{12}C/^{13}C$ ratio by a factor of 5 and the $^{26}Al/^{27}Al$ ratio by a factor of 2 in the He/C zone (Figs. 2 and 3). AB2 grains, on the other hand, plot within mixing scenarios 1 and 2 (Figs. 1 and 2). This suggests that not only AB1 grains are from SNe but possibly also an unknown fraction of AB2 grains. Predicted Si isotope anomalies are larger than observed, which results from very extreme Si-isotopic compositions at the bottom of the O/nova zone.

Liu et al. [4] have argued for an origin in J-type C stars for most of the AB2 grains, based on the absence of s-process signatures. The He/C zones of massive stars are expected to show imprints of a mild s-process from the pre-SN phase [12] and of the n-process from explosive nucleosynthesis [13]. Matching the C, N, and Al isotope data of AB2 grains requires only small contributions from the He/C zone from <1 to at most a few percent which dilutes s- and n-process signatures significantly. Expected isotope anomalies from the s-process, e.g. for Mo, would be at most a few percent, which cannot be detected with currently used analysis setups. For the n-process isotope anomalies may be larger [13], but it is unclear whether they would be large enough for the mixing conditions considered here to be detectable. Detailed studies of the production of heavy elements in SN models with H ingestion will be needed to shed more light on this issue. With the large uncertainties of currently used one-dimensional models of massive stars affected by H ingestion, it is conceivable that SNe might also be sources of AB2 grains.

Acknowledgements: We thank A. Sorowka for SEM analyses, and E. Gröner and P. Schuhmann for technical support on the NanoSIMS. MP acknowldges the support of STFC, through the University of Hull Consolidated Grant ST/R000840/1, and access to the University of Hull HPC Facility, viper.

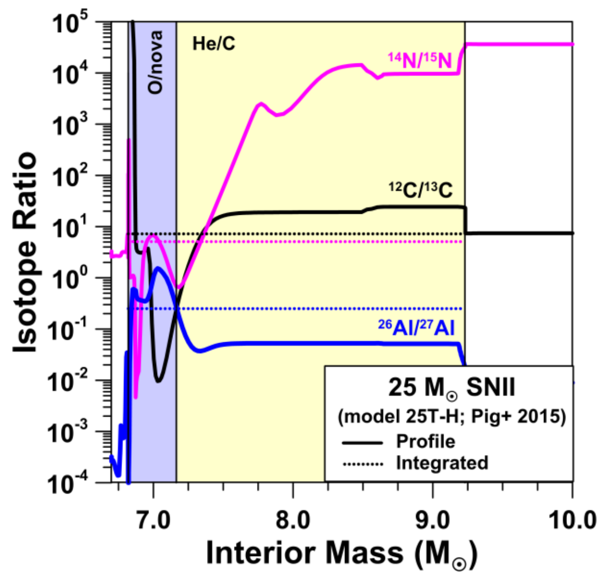

Figure 3. Profiles of C-, N-, and Al-isotopic ratios in the interior of a 25 $M_\odot$ SN according to model 25T-H [10].

References: [1] Zinner E. (2014) In *Meteorites and Cosmochemical Processes*, Vol. 1 (ed. A. M. Davis), pp. 181-213, Elsevier. [2] Liu N. et al. (2017) *ApJ*, 842, L1. [3] Amari S. et al. (2001) *ApJ*, 559, 463-483. [4] Liu N. et al. (2017) *ApJ*, 844, L12. [5] Hoppe P. et al. (2019) In *Nuclei in the Cosmos XV – NIC2018 (ed. A. Formicola)*, Springer Proceedings in Physics, in press. [6] Amari S. et al. (1994) *GCA*, 58, 459-470. [7] Zinner E. et al. (2007) *GCA*, 71, 4786-4813. [8] Hoppe P. et al. (2018) *ApJ*, 869, 47. [9] Hynes K. M. and Gyngard F. (2009) *LPS XL*, Abstract #1198. [10] Pignatari M. et al. (2015) *ApJ*, 808, L43. [11] Woosley S. E. and Heger A. (2007) *PhR*, 442, 269-283. [12] Rauscher T. et al. (2002) *ApJ*, 576, 323-348. [13] Pignatari M. et al. (2018) *GCA*, 221, 37-46.