**MULTIELEMENT ISOTOPIC COMPOSITIONS OF PRESOLAR SIC FROM ASYMPTOTIC GIANT BRANCH STARS.** N. Liu[1], J. Barosch[2], L. R. Nittler[2], C. M. O'D. Alexander[2], J. Wang[2], S. Cristallo[3] and R. C. Ogliore[1], [1]Department of Physics, Washington University in St. Louis, St. Louis, MO 63130, USA, nliu@physics.wustl.edu, [2]Earth & Planets Laboratory, Carnegie Institution for Science, Washington, DC 20015, USA, [3]INAF-Osservatorio Astronomico d'Abruzzo, Teramo 64100, Italy.

**Introduction:** Silicon carbide (SiC) is the best studied presolar mineral phase. Nearly 20,000 presolar SiC grains have been analyzed for their isotopic compositions (Presolar Grain Database (PGD)) [1]. However, complete isotope data for C, N, Si, Mg/Al and Ti are available for only ~100 grains (PGD_SiC_2020-08-18). In addition, asteroidal and terrestrial contamination complicates data interpretation. The possibility of N contamination is particularly important. This is because the wide range of $^{14}N/^{15}N$ ratios observed in mainstream (MS) grains may provide important constraints on astrophysical processes [2], but, alternatively, this large range can be simply caused by differing amounts of terrestrial and/or asteroidal N contamination sampled during laboratory analyses [3]. Thus, we revisited the C, N, Si, Mg-Al and Ti isotopic compositions of presolar SiC in this study with the aims of enlarging the multielement isotope database and also examining the contamination problem for these elements.

**Experimental Methods:** The presolar SiC grains here were extracted from Murchison by using the isolation method in [4]. The grains were first identified by SEM-EDX analyses and then confirmed by isotope analyses of C, N, and Si (Pre-Hyperion data in Fig. 1) with the NanoSIMS 50L ion microprobe at Carnegie Institution using standard procedures [5]. Following the C, N, and Si analyses, we selected 24 MS, 14 AB, 6 X, and 1 Y grain for further isotope study. We analyzed these grains for their Mg-Al and Ti isotope ratios with the NanoSIMS using a Hyperion $O^-$ source. All the isotope data were acquired in imaging mode. After the Mg-Al and Ti isotope analyses, we remeasured the remaining SiC grains for C, N and Si isotopes (Post-Hyperion data). We also analyzed another 41 presolar SiC grains first for Mg-Al and Si isotopes, and 20 of the grains' C and N isotopic compositions were measured afterwards (Post-Hyperion data). The available C, N and Si isotope data show that the 41 grains include 18 MS, 2 AB, 2 X, 1 Y, and 18 unknown (MS SiC candidate) grains. Here we focus on the obtained isotope data for the MS/Y grains.

**Carbon and N Isotopes:** Figure 1 shows that (1) the majority of MS grains have $^{14}N/^{15}N > 1000$ and (2) the N isotope data in the PGD suffer from N contamination of terrestrial and/or solar isotopic compositions to varying degrees. In comparison, our Pre-Hyperion data in Fig. 1 lie well within the distribution of the literature data, while the Post-Hyperion data show significantly enhanced $^{14}N/^{15}N$ ratios by up to a factor of six (and a factor of 3.5 on average), which shifts the average $^{14}N/^{15}N$ ratio to 2700. The significant difference between the Post- and Pre-Hyperion data suggests that N contamination was present on the grain surfaces during the initial analyses and that extensive sputtering is needed to expose clean grain surfaces for obtaining intrinsic N. Differences in $^{12}C/^{13}C$ between the Pre- and Post-Hyperion data are small and both agree with the literature data.

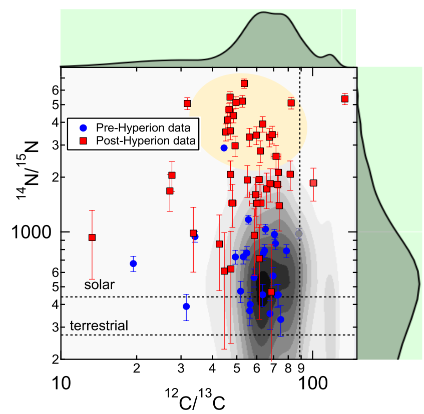


**Fig. 1.** Plot of $^{14}N/^{15}N$ vs $^{12}C/^{13}C$. MS/Y grain data from this study are overlaid on a probability density map (gray scale) of the literature data [1]. Errors are 1σ.

It has been shown that asymptotic giant branch (AGB) model predictions provide a poor match to the C and N isotope ratios of MS SiC [e.g., 3]. The model-data mismatch has been ascribed to the occurrence of cool bottom processing (CBP), which is not included in standard AGB models but can enhance AGB stars' production of $^{13}C$ and $^{14}N$ by proton capture reactions [6]. Standard FRUITY models for low-mass (1.5–3.0 $M_\odot$), close-to-solar metallicity (0.7−1.5 $Z_\odot$) AGB stars predict $^{12}C/^{13}C$ up to 200 and $^{14}N/^{15}N$ values of 900−1700 for the last several thermal pulses (TP) [7], during which the majority of SiC is expected to condense. Given the higher-than-predicted $^{13}C$ and $^{14}N$ abundances observed in the grains, our new data support the occurrence of CBP. Indeed, the MS grains in Fig. 1 with $^{14}N/^{15}N$ above 2000 can be well explained by introducing CBP at red giant branch (RGB) stage in FRUITY models (shaded ellipse in Fig. 1) [3] with a transport rate of (0.20−0.25) × $10^{-6}$ $M_\odot$/yr and a circulation temperature of 0.1−0.3 (defined as $\Delta = \log T_H - \log T_P$ in [3], where $T_H$ is the T at which the energy from the H-burning shell is maximum and $T_P$ the maximum T sampled by circulating material).

**Magnesium-Al Isotopes**: Figure 2 shows that our Y and MS grains had a higher range of $\delta^{26}Mg$ values than the literature data [8]. The higher $\delta^{26}Mg$ values (Fig. 2b) most likely result from sampling less Mg contamination, as supported by our lower Mg/Si ratios (Fig. 2a). We sampled much less Mg contamination, mainly because the data were collected in imaging mode using a Hyperion $O^-$ beam ~200 nm in size so that we were able to exclude contamination when selecting regions of interest (ROIs) for data reduction. Despite the much-reduced Mg contamination, we did not detect any $\delta^{25}$Mg anomalies above 2σ. The lack of large $\delta^{25}$Mg anomalies in the Y and MS grains is consistent with FRUITY model predictions for low-mass AGB stars (< 50‰), although it remains possible that Mg contamination was still not fully suppressed in our study and that the true intrinsic Mg abundances are lower than reported in Fig. 2a.

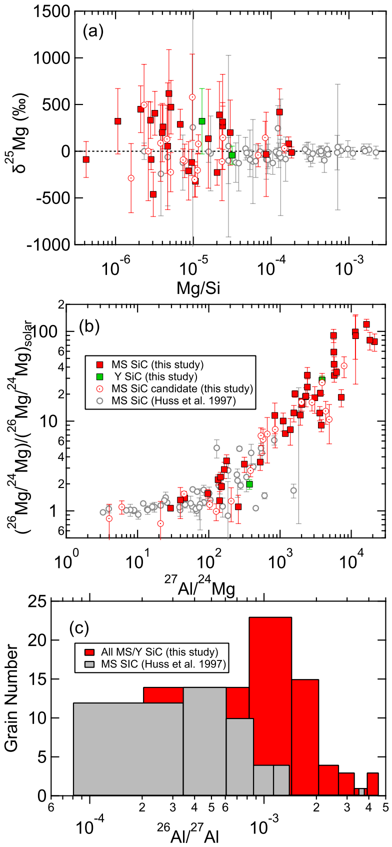


**Fig. 2.** Plots comparing MS/Y SiC grains from this study with MS SiC from [8] for their Mg-Al isotope ratios and atomic Mg/Si and Al/Mg ratios.

All but two MS grains from this study show $^{26}$Mg excesses that are likely caused by the decay of $^{26}$Al ($t_{1/2}$ = 0.72 Myr). The inferred initial $^{26}Al/^{27}Al$ ratios range from $2.0 \times 10^{-4}$ to $4.5 \times 10^{-3}$ with a median value of $1.3 \times 10^{-3}$, a factor of two higher compared to the Huss et al. data (Fig. 2c). Our enhanced $^{26}Al/^{27}Al$ ratios likely result from sampling less Al contamination, given that Al contamination has been shown to be common and significant [9,10]. In comparison, FRUITY models for low-mass, close-to-solar metallicity AGB stars predict $^{26}Al/^{27}Al$ ratios of 0.001–0.004 for the last several TPs, and the predicted value decreases with increasing stellar mass. In addition, the deep mixing AGB models of [3] predict increasing $^{26}Al/^{27}Al$ at the last TP with increasing maximum circulation temperature for the CBP, and our $^{27}Al/^{27}Al$ data, therefore, suggest low maximum circulation temperatures (Δ ≥ 0.2) at the RGB stage.

**Silicon and Ti Isotopes:** Our ion images show that Si and Ti contamination is rare. Chromium mainly appears as contamination in presolar SiC, which can be excluded by using smaller ROIs (Fig. 3) to suppress the isobaric interference of $^{50}$Cr with $^{50}$Ti. The Si and Ti isotope data of Y and MS grains from this study agree well with the literature data [1]. Our MS grains show well correlated $\delta^{46}$Ti and $\delta^{29}$Si values ($R$ = 0.79 and 0.77 for the PGD and our data, respectively), with an average $\delta^{50}$Ti of 155±94‰ (1 σ standard deviation, in comparison to the literature value of 179±75‰). Titanium, V-rich subgrains were present in about half of the studied MS grains. In about one third of the grains, more than one subgrain was observed and had homogeneous Ti isotopic compositions and Ti/V ratios (< 1σ variations). For FRUITY AGB models to explain the Si and Ti isotopic compositions, the effect of Galactic chemical evolution needs to be taken into account, as suggested by MS grains' correlated $\delta^{29}$Si and $\delta^{46,47}$Ti values.

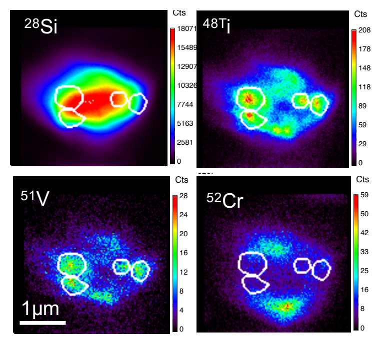


**Fig. 3**. NanoSIMS ion images of a MS grain. The white contours highlight Ti,V-hotspots within the grain.

**Conclusions**: Our multi-element isotope data suggest that the $^{14}N/^{15}N$ and inferred initial $^{26}Al/^{27}Al$ data in the PGD suffer from varying degrees of terrestrial/asteroidal contamination and that high-resolution isotope imaging and extensive presputtering are effective in suppressing N, Mg and Al contamination for presolar SiC. Our observed N and Al contamination explains the mismatch observed between the models of [3] and the literature data. In comparison to FRUITY models for low-mass, close-to-solar metallicity AGB stars, the studied Y and MS grains had lower $^{12}C/^{13}C$, higher $^{14}N/^{15}N$ and comparable $^{26}Al/^{27}Al$, suggesting that CBP occurred in their parent stars during RGB with a transport rate of $(0.20–0.25)\times10^{-6}$ $M_\odot$/yr at low circulation temperatures.

**References:** [1] Stephan T. et al. (2020) *LPS LI,* Abstract #2140. [2] Hedrosa R. P. et al. (12013) *ApJL, 768,* L11. [3] Palmerini S. et al. (2011) *ApJ, 729*, 3. [4] Nittler L. R. & Alexander C. M. O'D. (2003) *GCA, 67*, 4961–4980. [5] Liu N. et al. (2016) *ApJ*, *820*, 140. [6] Wasserburg G. J. et al. (1995) *ApJ*, *447*, L37–L40. [7] Cristallo S. et al. (2009) *ApJ*, *696*, 797–820. [8] Huss G. R. et al. (1997) *GCA*, *61*, 5117–5148. [9] Groopman E. et al. (2015) *ApJ*, *809*, 31. [10] Liu N. et al. (2019) *82nd Meeting of the Meteoritical Society*, Abstract #6194.