NEW LESSONS LEARNED ABOUT STELLAR NUCLEOSYNTHESIS FROM BARIUM ISOTOPIC COMPOSITION OF PRESOLAR SiC FROM THE MURCHISON METEORITE. N. Liu[1,2,3], M. R. Savina[2,3], A. M. Davis[1,2,4], R. Gallino[5], O. Straniero[6], F. Gyngard[7], M. Pellin[1,2,3], D. G. Willingham[3], N. Dauphas[1,2,4], M. Pignatari[8,10], F. Herwig[9,10]. [1]Department of the Geophysical Sciences, [2]Chicago Center for Cosmochemistry, The University of Chicago, Chicago; [3]Materials Science Division, Argonne National Laboratory; [4]Enrico Fermi Institute, The University of Chicago, Chicago; [5]Dipartimento di Fisica Universita' di Torino, Italy; [6]INAF Osservatorio Astronomico di Collurania, 64100 Teramo, Italy; [7]Laboratory for Space Sciences, Washington University, St. Louis; [8]Department of Physics, University of Basel, Basel, Switzerland; [9]Department of Physics & Astronomy, University of Victoria, Victoria, BC, Canada; [10]Nugrid collaboration. (lnsmile@uchicago.edu)

Introduction: Stellar models of Asymptotic Giant Branch (AGB) suffer from several uncertainties, most importantly those related to treatment of convective boundary mixing. The strength of the main neutron source ^{13}C ($^{13}C(\alpha,n)^{16}O$) is therefore poorly predicted by the theory and, therefore, needs constraints from astrophysical observations and presolar grain studies. Ba isotope ratios in mainstream presolar SiC grains can provide such stringent constraints on stellar model calculations, especially the ^{13}C pocket. Indeed, ^{138}Ba is neutron magic (N=82) and acts as a bottleneck in the main *s*-process path due to its small neutron capture cross-section. Thus, $\delta^{138}Ba$, normalized to ^{136}Ba, is a sensitive indicator of the internal structure of the ^{13}C pocket in the He intershell of AGB stars, which are the progenitors of the mainstream grains.

Experimental: The SiC separation and mounting methods have been described [1]. Ba and Nd isotopic compositions in 63 acid-cleaned presolar SiC grains from the Murchison meteorite were measured with the CHARISMA instrument at Argonne National Laboratory using resonance ionization spectrometry (RIMS) [2, 3]. Compared to the previous work, newly developed Ti:sapphire laser cavities produce more powerful beams with broader bandwidth to diminish the effect of isotope shifts of heavy elements, suppress odd/even effects, and mitigate instrumental fractionation. More precise and reliable data can therefore be obtained with these improvements. We obtained Ba isotopic data with sufficient precision to constrain models (2σ uncertainty of $\delta^{138}Ba$ < 200‰) in 41 out of 63 grains. After RIMS analysis, C and Si isotopes in 24 of these grains were determined with the Cameca NanoSIMS 50 at Washington University, St. Louis. We were not able to measure C and Si isotopic ratios of the remaining17 grains due to complete consumption of the grains during RIMS analysis; these are grouped as mainstream grains for purposes of discussion since >90% of SiCs are mainstream. Besides mainstream grains, one Z and one AB grain were found. All uncertainties are reported as 2σ, and include both counting and external reproducibility.

Results: Preliminary results were previously reported [4]. Comparison with previous Ba data in uncontaminated mainstream grains [5] excludes solar system Ba contamination in this study and demonstrates that acid washing is effective in removing solar system Ba contamination. We reported the first $\delta^{130+132}Ba$ values in eight single SiC grains [4]. In good agreement with the conclusion from bulk studies [6], we found that there is no measurable ^{135}Cs decay to ^{135}Ba in individual SiCs. We compared the grain data with postprocess AGB model predictions [7] and found systematic discrepancies of $\delta^{137,138}Ba$ values between them which cannot be explained by uncertainties of the nuclear physics inputs (e.g., $^{22}Ne(\alpha,n)^{25}Mg$ reaction rate) or that of free parameters (e.g., ^{13}C efficiency) considered previously in the calculations.

We found one AB grain extremely enriched in Ba with solar system Ba isotopic composition. It is consistent with previous Ba measurements in AB grains [8] and cannot be explained by nucleosynthesis in born-again AGB stars, which should carry an *s*- or *i*-process (an intermediate process occurring in a stellar environment with the neutron flux inbetween that of *s*- and *r*-processes [9]) signature. In addition, two mainstream grains with negative $\delta^{134}Ba$ ratios that cannot be explained by any of the current AGB model calculations, could carry such *i*-process signature, possibly activated in the Very Late Thermal Pulse (VLTP) event [10].

Discussion: The formation of the ^{13}C pocket in AGB stars and the understanding of the physical mechanisms driving its formation are still a matter of debate in the community [e.g., 11, 12] In the postprocess calculations presented here, the ^{13}C pocket is subdivided into three zones (zone I, II & III) in order to reproduce the solar *s*-process pattern based on their characteristic local mean neutron exposures [e.g., 7, 13]. The only free parameter to characterize the ^{13}C pocket is ^{13}C efficiency (mass fraction of ^{13}C) in the model calculations. Although it was shown that the model predictions for zoned vs. constant ^{13}C profiles are indistinguishable in plots of [hs/ls] vs. metallicity [14], no systematic examination has been done at the isotopic level.

We therefore probed internal structures of the ^{13}C pocket based on the three-zone ^{13}C pocket structure using the postprocess AGB model calculations [7]. Here we present new calculations with different ^{13}C pocket structures characterized by three free parameters: ^{13}C efficiency, ^{13}C density profile, and ^{13}C pocket mass. Two sets of tests were done in a 2 $M_{\odot}$, 0.5 $Z_{\odot}$ AGB star: (1) in model calculations with the normal ^{13}C profile and ½ and ⅔ standard ^{13}C pocket masses, $\delta^{137}Ba$ and $\delta^{138}Ba$ below −400‰ are still unreachable; and (2) in model calculations with zone II ^{13}C profile only, with zone I and zone III excluded, $\delta^{138}Ba$ values below −400‰ are reached. Model predictions with zone II ^{13}C

pocket in the range of D2-to-U2 ^{13}C efficiencies (ST case: best reproduces solar *s*-process pattern; D2: ^{13}C efficiency in ST case divided by two; U2: multiplied by two) are shown along with presolar grains in Fig. 1. Excellent agreement is found between the model predictions and the mainstream SiCs in the $\delta^{137,138}$Ba vs. δ^{135}Ba plots. In addition, a good match is maintained for positive to slightly negative values of δ^{134}Ba, which implies that the strongly negative δ^{134}Ba values for two of the mainstream grains in Fig. 1 are not part of the *s*-process signature. The previous discrepancy between the grain data and the model calculations therefore could be solved by such a smaller zone II ^{13}C pocket (5.3×10^{-4} $M_\odot$) while other possible scenarios need to be explored such as increasing the number of zones and exploring ^{13}C pockets that differ from pulse to pulse during AGB stellar evolution in the future.

In regard to comparison between previous presolar grain data and the calculations with zone II ^{13}C profile, good agreement remains for all Zr, Mo and Ru isotopes and δ^{87}Sr [5, 15, 16, 17]. In the new calculations, δ^{88}Sr values are twice as high as the values in the previous calculations while none of them match with the grain data. As can be seen by comparing Fig. 3 & 4 of [6], δ^{88}Sr values are sensitive to both ^{13}C structure and ^{22}Ne reaction rate while δ^{138}Ba ratios are more sensitive to ^{13}C. We will therefore test the effect of ^{22}Ne reaction rate on δ^{88}Sr values in the new calculations. Additionally, since contamination with solar system Sr may give grain composition close to normal, measurements of Sr isotopic composition in acid-cleaned mainstream SiCs will be done to confirm the discrepancy and further assist the understanding of the ^{13}C internal structure. To conclude, so far, Ba isotopic composition of mainstream SiCs provides the most restrictive constraints on the ^{13}C pocket internal structure and therefore is a powerful tool to test different physical mechanisms of ^{13}C formation with available simulation results in the future.

Two mainstream grains with strongly negative δ^{134}Ba cannot be explained by AGB model calculations. Instead, negative δ^{134}Ba values could be explained as the signature of rapid burning of ingested hydrogen during VLTP events in born-again AGB stars [10] (Fig. 2). In this case, the *i*-process is triggered by the ^{13}C(α,*n*)^{16}O reaction activated deep in the He intershell at the early stage of the H ingestion with neutron densities (~10^{15} neutrons cm^{-3}) reached [10]. It is noteworthy that the huge increase of δ^{138}Ba (off-scale in Fig. 2) occurs when ^{138}Cs is accumulated in such a high neutron density environment. The δ^{138}Ba value drops back to the negative region when ^{138}Cs is bypassed in the neutron flow.

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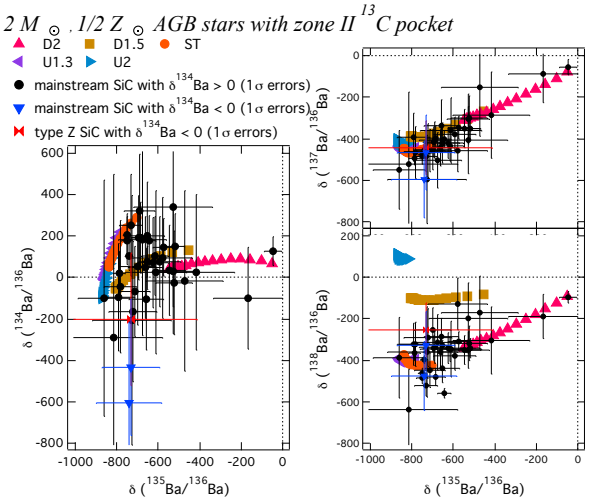

Fig. 1 *Presolar SiCs in Murchison from this study are compared to a set of model predictions in a 2 $M_\odot$, 0.5 $Z_\odot$ AGB star shown as colored symbols with a different internal ^{13}C structure as described in the text.*

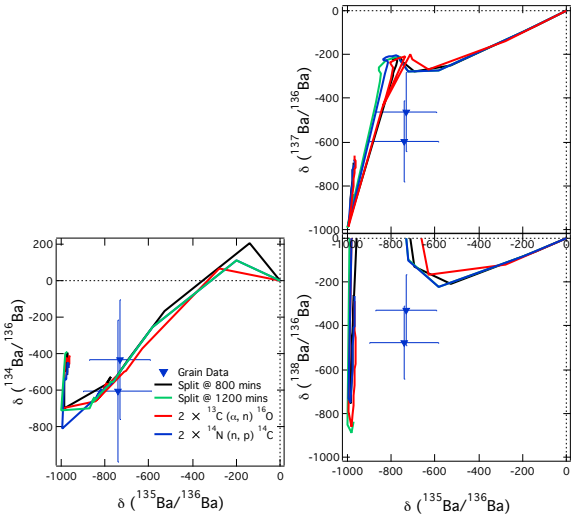

Fig. 2 *Two grains with negative δ^{134}Ba are compared with the weighted average Ba isotopic composition of a He-zone ingested with hydrogen after a VLTP during the post-AGB phase[10]. No s-process enhancement is assumed during the AGB phase.*

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