PRESOLAR SILICON CARBIDE GRAINS OF GROUPS Y AND Z: THEIR STRONTIUM AND BARIUM ISOTOPIC COMPOSITIONS AND STELLAR ORIGINS. N. Liu[1,2], T. Stephan[3], S. Cristallo[4], R. Gallino[5], P. Boehnke[3], L. R. Nittler[2], C. M. O'D. Alexander[2], A. M. Davis[3], R. Trappitsch[6], and M. J. Pellin[3,7], [1]Department of Physics, Washington University in St. Louis, St. Louis, MO 63130, USA, nliu@physics.wustl.edu, [2]Department of Terrestrial Magnetism, Carnegie Institution for Science, Washington, DC 20015, USA, [3]The University of Chicago, Chicago, IL 60637, USA, [4]INAF-Osservatorio Astronomico d'Abruzzo, Teramo 64100, Italy, [5]Dipartimento di Fisica, Università di Torino, Torino 10125, Italy, [6]Lawrence Livermore National Laboratory, CA 94550, USA, [7]Argonne National Laboratory, Argonne, IL 60439, USA.

Introduction: Presolar Y and Z grains, ~1% each of the whole presolar SiC population, are believed to have come from asymptotic giant branch (AGB) stars with lower metallicities and perhaps larger masses with respect to mainstream (MS) grains, the dominant population of presolar SiC grains [1,2]. Type Y grains have $^{12}C/^{13}C>100$ and are more ^{30}Si-rich and ^{29}Si-poor than MS grains. Z grains have $10<^{12}C/^{13}C<100$, similar to MS grains, and are more ^{30}Si-rich and ^{29}Si-poor than Y grains. The definitions of these two rare groups are somewhat arbitrary, and there is considerable isotopic overlap between them and MS grains. In fact, the three groups of grains are indistinguishable in their $^{14}N/^{15}N$ and inferred $^{26}Al/^{27}Al$ ratios [3]. The conclusion that Y and Z grains came from AGB stars of about ½ $Z_\odot$ and ⅓ $Z_\odot$, respectively, relied mainly upon comparison with AGB model predictions to explain their large ^{30}Si excesses [2]. However, it was shown later that these low-metallicity models fail to consistently explain the Si and Ti isotope ratios of Y and Z grains [3]. Thus, the proposed low-metallicity stellar origin of Y and Z grains remains debatable.

To better understand the stellar origins of Y and Z grains, we obtained Sr, Mo, and Ba isotope data in a large number of new Y and Z grains with the Chicago Instrument for Laser Ionization (CHILI) [4]. Strontium, Mo, and Ba are significantly overproduced during the *s*-process, unlike Si; as a result, contributions from the initial abundances incorporated from the interstellar medium barely affect their *s*-process isotopic signatures generated during the AGB phase. Thus, the heavy-element isotope data from this study allow, for the first time, independent investigation of the *s*-process in the parent stars of Y and Z grains. The Mo isotope data [5,6] showed that the three groups of grains share comparable Mo isotope ratios that are linearly correlated in the Mo 3-isotope plots, thus implying that the ^{95}Zr branch remained inactive in their parent stars. Detailed data-model comparisons for Mo isotopes constrained the maximal temperature (T_{MAX}) to lie below 3×10^8 K. Here we report the simultaneously obtained Sr and Ba isotope data, based on which we further discuss the *s*-process efficiency in their parent AGB stars.

Experiments & Models: We analyzed 37 sub-μm- to μm-sized Y and Z grains for their Sr, Mo, and Ba isotopic compositions with CHILI [4]; 15 MS grains were also measured during the same session. These grains had been measured with the Carnegie NanoSIMS 50L ion microprobe for their C, N, and Si isotope ratios prior to the CHILI analyses. Molybdenum isotope ratios were obtained in all the 52 grains, while Sr and Ba isotope ratios were obtained in 36 and 22 out of the 52 grains, respectively.

Updated Torino models for AGB stars with metallicities between 0.5 $Z_\odot$ to 1.5 $Z_\odot$ have been recently presented [7,8]. In this study, we extend the metallicity down to 0.22 $Z_\odot$. The updated nucleosynthesis calculations were conducted based on physical quantities extracted from new FRUITY stellar models [9,10]. Compared to the FRANEC stellar models adopted in previous Torino model calculations, the FRUITY stellar models predict higher third dredge-up efficiencies, lower T_{MAX} values, and higher mass-loss rates.

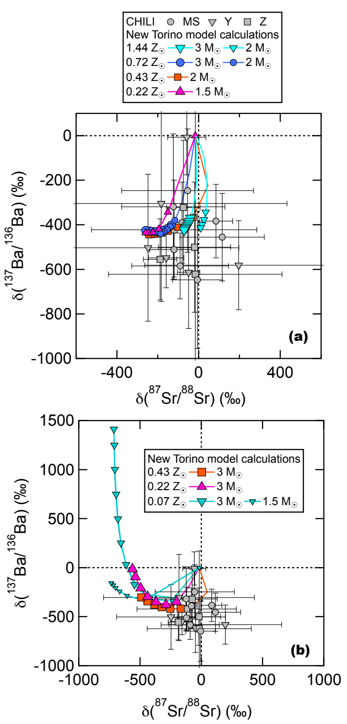

Fig. 1. Ba-Sr 4-isotope plots comparing MS, Y, and Z grains with updated Torino model predictions by adopting the magnetic buoyancy induced ^{13}C-pocket. The entire evolution of the AGB envelope composition is shown, but symbols are plotted only when C>O. Errors are 2σ.

Results: Figure 1 clearly shows that Y and Z grains are indistinguishable from MS grains in their Sr and Ba isotopic compositions. This is consistent with our previous observation that the three groups of grains share comparable Mo isotopic compositions [5,6]. Thus, our and literature data have shown that Y and Z grains overlap with MS grains in the isotope ratios of N, Al, Ni [9], Sr, Zr [11], Mo, Ba and mainly show differences in Si and Ti [2,3].

Discussion: Figure 1b indicates large discrepancies in δ^{137}Ba between the grain data and model predictions for AGB stars of high-mass and low-metallicity. This is because T_{MAX} increases with both decreasing stellar metallicity and increasing stellar mass so that the ^{22}Ne(α,n)^{25}Mg reaction, the minor neutron source for the *s*-process in AGB stars, operates more efficiently to activate the branch point at ^{136}Cs, thus resulting in enhanced ^{137}Ba production. The fact that T_{MAX} values in all the models shown in Fig. 1b exceed 3×10^8 K further strengthens our previous constraint on T_{MAX} ($<3\times10^8$ K) based on the Mo isotope data, thus pointing to the low-mass and/or close-to-solar metallicity stellar origins of Y and Z grains.

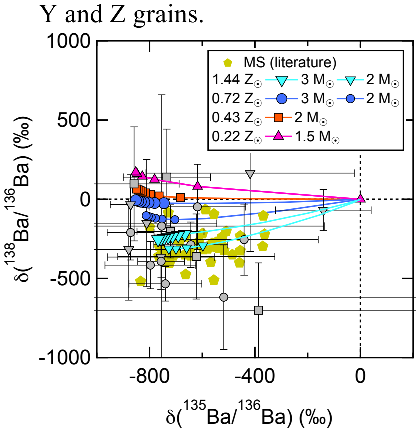

Fig. 2. Ba 3-isotope plots comparing MS, Y, and Z grains with the updated Torino model predictions in Fig. 1a. Errors for literature MS grains [12] are not shown for clarity.

Figure 2 further shows that the low-metallicity AGB models in Fig. 1a predict δ^{138}Ba values that are too high to explain the Y and Z grain data. This is because the *s*-process efficiency is a linear function of the ratio of neutrons to Fe seeds (R_s); as the amount of Fe seeds increases with decreasing metallicity, R_s and in turn the *s*-process efficiency also increase with decreasing metallicity. This R_s-metallicity trend is strongly supported by astronomical observations [13]. Thus, the indistinguishable δ^{138}Ba values among the three groups of grains strongly suggest that similar to MS grains, Y and Z grains also came from AGB stars of low-mass (≤3 $M_\odot$) and close-to-solar metallicity. Y grains, however, are probably sourced from slightly more massive AGB stars than MS and Z grains because of their higher ^{12}C/^{13}C ratios.

On the other hand, Fig. 3 illustrates that the updated Torino models with $T_{MAX} < 3\times10^8$ K predict only up to 30‰ enrichments in δ^{30}Si, which are too low to account for the ^{30}Si excesses of up to 400‰ observed in many of the Z grains. The Si isotopic compositions of MS, Y, and Z grains are interpreted in the literature as the combined results of the *s*-process nucleosynthesis and homogeneous Galactic chemical evolution, which is assumed to move along the linear trend defined by MS grains; as a result, Y and Z grains show large deviations from the line, which are considered as the evidence of more efficient *s*-process occurring in their parent stars with respect to MS grains [2]. As the ^{30}Si production is mostly controlled by ^{22}Ne(α,n)^{25}Mg, the large ^{30}Si excesses observed in Z grains remain unexplained by neutron capture due to the inefficient operation of this reaction at such low T_{MAX} values. Instead, the large ^{30}Si excesses of Z grains could suggest that their parent stars inherited enhanced ^{30}Si from the interstellar medium due to local heterogeneities, *e.g.*, pollution by ONe novae [14], though this needs to be investigated in detail.

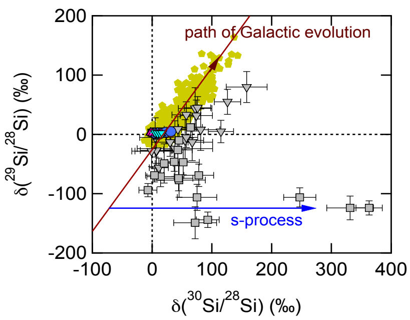

Fig. 3. Si 3-isotope plots comparing MS, Y, and Z grains with the same set of models as in Fig. 2.

Conclusions: The new Sr and Ba isotope data of the Y and Z grains further strengthens our previous constraint on T_{MAX} values ($<3\times10^8$ K) in their parent stars based on Mo isotopes. The inferred low temperatures argue against the previously suggested intermediate-mass AGB stellar origin of Y grains and against neutron capture as the explanation of the large ^{30}Si excesses observed in Z grains. The latter instead may suggest anomalously enhanced initial ^{30}Si abundances due to local heterogeneities. Finally, the indistinguishable R_s values between MS and Y/Z grains suggested by their δ^{138}Ba values strongly argue against the low-metallicity stellar origin of Y and Z grains proposed in the literature.

References: [1] Amari, S. et al. (2001) *ApJ*, *546*, 248–266. [2] Zinner, E. et al. (2006) *ApJ*, *650*, 350–373. [3] Zinner, E. et al. (2007) *GCA*, *71*, 4786–4813. [4] Stephan, T. et al. (2016) *IJMSp*, *407*, 1–15. [5] Liu, N. et al. (2018a) *LPS XLIX,* #2035. [6] Liu, N. et al. (2018b) *MAPS, 81,* #2067. [7] Cristallo, S. et al. (2009) *ApJ*, *696*, 797–820. [8] Cristallo, S. et al. (2011) *ApJS*, *197*, 17–37. [9] Trappitsch, R. et al. (2018) *GCA*, *221*, 87–108. [10] Liu N. et al. (2018c) *ApJ*, *865*, 112–125. [11] Barzyk J. G. et al. (2008) *LPS XXXIX,* #1986. [12] Liu N. et al. (2015) *ApJ*, *803*, 12–44. [13] Busso M. et al. (2001) *ApJ*, *557*, 802–821. [14] José J. et al. (2004) *ApJ*, *612*, 414–428.