PRESOLAR GRAPHITE GRAINS FROM POST-AGB STARS. M. Jadhav[1], M. Pignatari[2,4], F. Herwig[3,4], E. Zinner[5], R. Gallino[6], and G. R. Huss[1], [1]Hawai‘i Institute of Geophysics and Planetology, University of Hawai‘i at Mānoa, Honolulu, HI 96822. E-mail: manavi@higp.hawaii.edu, [2]Department of Physics, University of Basel, [3]Department of Physics & Astronomy, University of Victoria; [4]NuGrid Collaboration, http://www.nugridstars.org; [5]Laboratory for Space Sciences, Washington University in St. Louis; [6]Diparttimento di Fisica Generale, Università di Torino & INAF, Osservatorio di Teramo.

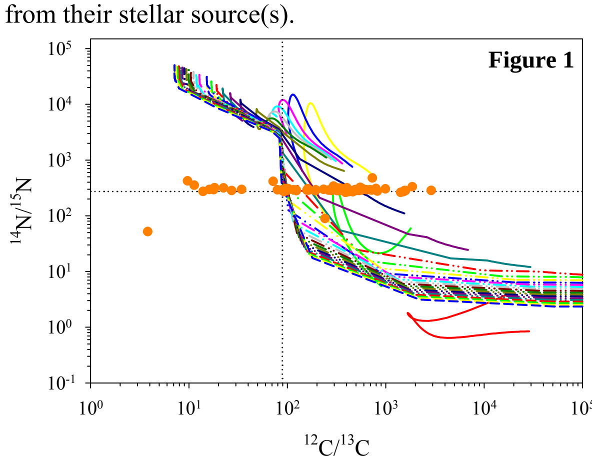
Introduction: In a previous study of high-density (HD; OR1f - 2.02 − 2.04 g cm^{-3}) graphite grains from Orgueil [1], we found extremely anomalous Ca and Ti ratios in some grains with $^{12}C/^{13}C$ ratios < 20. The Ca and Ti anomalies in these graphites match predicted pure He-shell nucleosynthesis values in low mass asymptotic giant branch (AGB) stars. However, the very low $^{12}C/^{13}C$ ratios of the grains, indicative of H-burning, disagree with the almost pure ^{12}C predicted for the He intershell, and with predictions of envelope abundances from baseline AGB models. The study concluded that born-again AGB stars or post-AGB stars that have suffered a very late thermal pulse (VLTP) are likely sources of such graphite grains. Post-AGB stars that undergo a very late He flash may simultaneously exhibit typical He shell abundances for several species, low $^{12}C/^{13}C$ ratios, and signatures of neutron capture processes. At this stage in its evolution, such a star has lost most of its envelope and has only a thin residual H layer left. During the VLTP, the He intershell becomes convective and the residual H on the surface is ingested and burns in hot ^{12}C-rich layers. This reduces the $^{12}C/^{13}C$ ratio as ^{12}C is converted to ^{13}C via $^{12}C(p,\gamma)^{13}N(\beta^{+})^{13}C$. After H ingestion begins, it takes a few hours to a day before the energy produced by H-burning splits the He intershell into two regions [2]. At the same time, ^{13}C burns via the $^{13}C(\alpha,n)^{16}O$ reaction deep at the bottom of the He intershell, where neutron densities reach ~ 10^{15} n cm^{-3}, typical of the i-process [3]. Under these conditions, the abundances in the He intershell from the previous AGB phase are eventually modified.

In order to verify the hypothesis that ^{13}C-enriched graphite grains with extreme Ca and Ti anomalies originate from post-AGB stars, we present here a comparison of grain data and VLTP nucleosynthesis model calculations from [2].

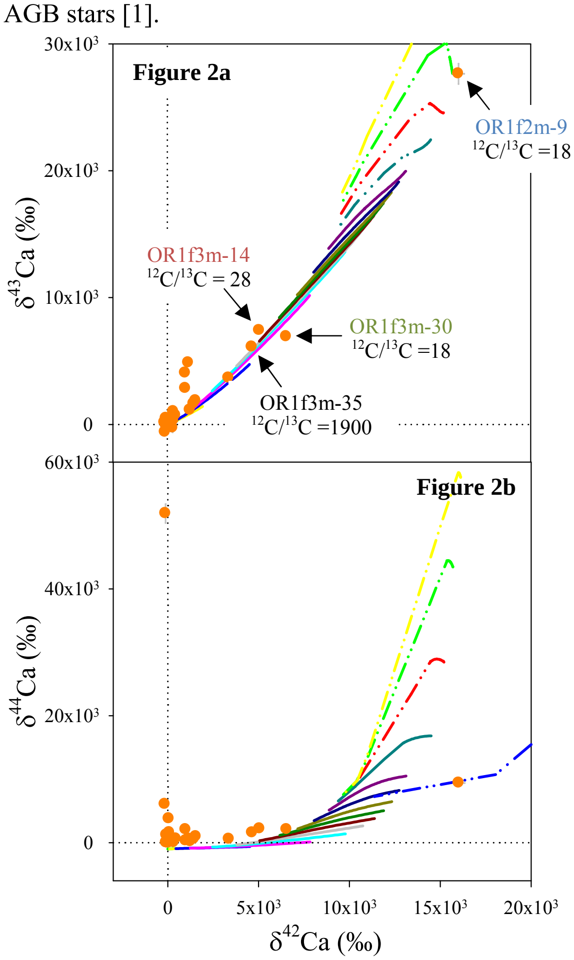
Methods: We compare previously obtained C, N, Ca, and Ti isotopic data for Orgueil HD (OR1f) presolar graphite grains with VLTP model predictions. Experimental details of the measurements and isotopic characteristics of the grains from mounts OR1f2m and 3m are discussed in detail in [1] and [4], respectively.

Calculations by Herwig et al. [2] aimed to reproduce the elemental abundances observed in the born-again AGB star, Sakurai’s object (V4334 Sagittarii) [5, 6]. In their models, a few hours after H ingestion into hotter layers of the He-shell flash-convection zone has started, the energy generated by H-burning forms a radiative zone that splits the He intershell into a top H-burning convection zone and a He-shell burning zone below. This separation of the He-intershell region allows minimal mixing of material between the zones. The C, N, Ca, and Ti isotopic calculations presented here are from VLTP nucleosynthesis taking place in the He intershell region before and after the split.

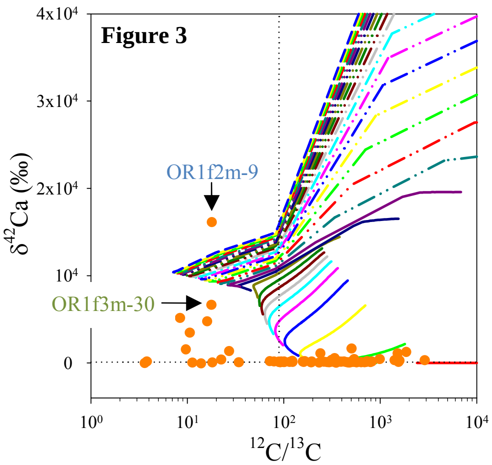
Discussion: We compare HD graphite grain data to the models in Figures 1-4 below. Each line in the plots represents the isotopic composition of different layers in the He-intershell at a given time after H ingestion has started. Carbon and N isotopic ratios from VLTP calculations in Figure 1 clearly show the splitting of the He intershell region into H- and He-burning zones. The upper H-burning zone in characterized by low $^{12}C/^{13}C$ and high $^{14}N/^{15}N$ ratios, while the deeper He-flash driven zone has high $^{12}C/^{13}C$ and low $^{14}N/^{15}N$ ratios. Theoretical $^{12}C/^{13}C$ ratios span the entire range observed in all HD graphites. Unfortunately, HD graphites have terrestrial $^{14}N/^{15}N$ ratios that indicate equilibration with terrestrial N and are, therefore, not indicative of the $^{14}N/^{15}N$ ratios that the grains inherited from their stellar source(s).

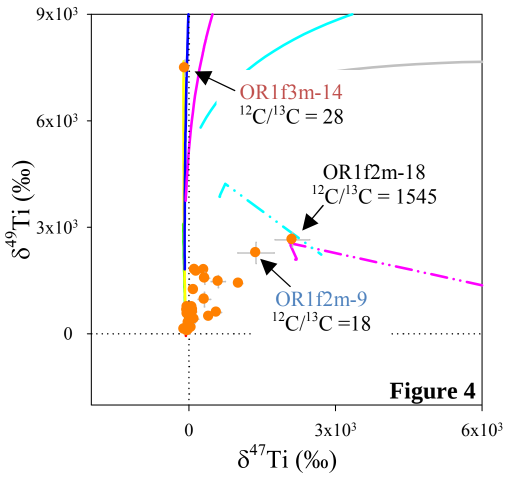


The large neutron densities reached during H ingestion, due to $^{13}C(\alpha,n)$ activation, allow the efficient production of neutron-rich species. Thus, the VLTP models agree fairly well with the large Ca and Ti anomalies observed in grains with low $^{12}C/^{13}C$ ratios. Figure 2 (a,b) compares Ca grain data with model predictions. As suggested in [1], the grains with the largest Ca anomalies and $^{12}C/^{13}C$ ratios < 20 fit the model predictions reasonably well. Surprisingly, grains with $^{12}C/^{13}C$ ratios > solar and moderate Ca anomalies also agree with VLTP calculations. As seen in Figure 1, after the VLTP event, parts of the He intershell can have $^{12}C/^{13}C$ ratios larger than the solar value. Thus, ^{12}C-enriched grains with moderate Ca anomalies that are still too high for AGB envelopes might also originate in post-AGB stars that have suffered a VLTP. Figure 3 compares the $^{12}C/^{13}C$ ratios and $\delta^{42}Ca$ values of HD graphite grains with those predicted by the models. The predicted extreme $\delta^{42}Ca$ values that agree with grain data are also ^{13}C-enriched. This verifies the hypothesis that ^{13}C-enriched graphites with extreme Ca and Ti anomalies can condense around born-again AGB stars [1].



Titanium-46 and ^{48}Ti are efficiently destroyed during VLTP nucleosynthesis. The $^{47,49}Ti$ excesses are due to large contributions from the decay of $^{47,49}Ca$ created during VLTP nucleosynthesis. The extreme Ti isotopic anomalies measured in graphites do not agree with pure $\delta^{46,47,49}Ti$ predictions. However, if $^{46,48}Ca$ predictions are included with the Ti isotopic predictions, then the grain data match theoretical values, indicating that the $^{46,48}Ti$ values measured in graphite grains are due to the isobars $^{46,48}Ca$ that we are unable to resolve during SIMS measurements. Figure 4 compares $\delta^{47,49}Ti$ values measured in grains to model predictions.





Conclusions: The Herwig et al. [2] VLTP nucleosynthesis models are able to fit moderate and extreme Ca and Ti anomalies measured in HD graphite grains. Grains with the most extreme Ca and Ti ratios are ^{13}C-enriched but the ones with moderate anomalies also have high $^{12}C/^{13}C$ ratios. The VLTP models fit both populations reasonably well. This confirms the hypothesis proposed by [1] that some HD graphites originate in born-again AGB stars. Further investigations into grain formation and mixing conditions in such stellar objects are needed.

References: [1] Jadhav M. et al. (2008) *Astrophys. J. 682*, 1479-1485. [2] Herwig F. et al. (2011) *Astrophys. J. 727*, 89-104. [3] Cowan J. J. and Rose W. K. (1977) *Astrophys. J. 217*, 51-55. [4] Jadhav M. et al. (2011) *LPS XLII*, Abstract #1599. [5] Duerbeck et al. (2000) *Astron. J. 119*, 2360-2375. [6] Asplund et al. (1999) *Astron. Astrophys. 343*, 507-518.