MORE Ca AND Ti ISOTOPIC RATIOS IN HIGH-DENSITY, PRESOLAR GRAPHITE GRAINS FROM ORGUEIL.

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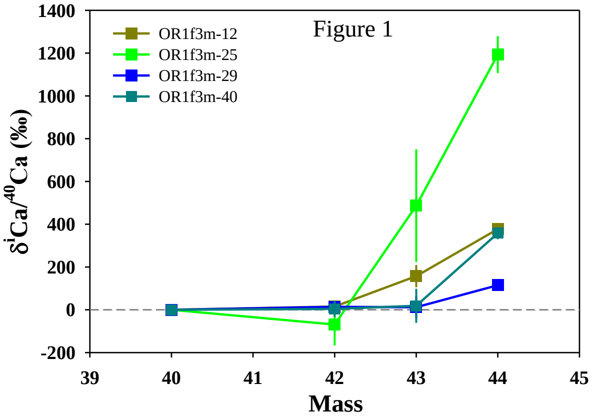
Introduction: In a continued effort to better understand high-density (HD) graphite grains, we report on a correlated study of NanoSIMS and Raman measurements of HD graphite grains from Orgueil. A previous isotopic study [1] of ^{13}C-enriched, HD graphites that contain extreme Ca and Ti anomalies has established that these grains can have multiple stellar sources: supernovae (SNe) and born-again asymptotic giant branch (AGB) stars.

In this study, thirty-nine HD grains from the OR1f ($\rho \sim 2.02$-2.04 g cm^{-3}) density fraction of Orgueil were measured for their K, Ca, and Ti isotopic ratios with the Washington University NanoSIMS. The C, N, O, Si, and Al-Mg isotopic ratios of these grains were reported in a previous abstract [2]. Before the SIMS measurements, full Raman spectra (100-4000 Δcm^{-1}) of twenty-one of these HD grains were obtained and are reported in another abstract of this conference [3].

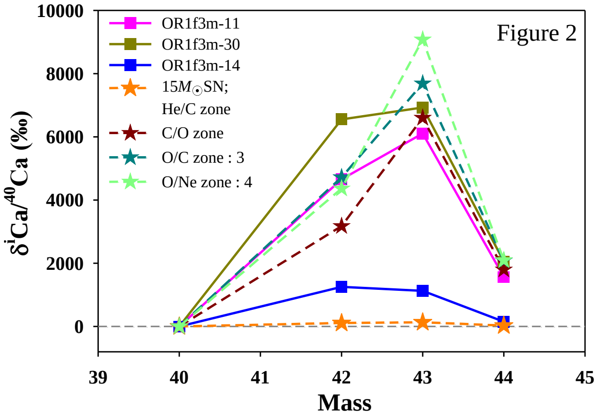
Experimental Methods: The K, Ca, and Ti measurements were carried out with an O$^-$ primary beam in a combination of peak-jumping and multidetection modes. Positive secondary ions of ^{39}K, ^{41}K, and ^{43}Ca (B field 1) and ^{12}C, ^{40}Ca, ^{42}Ca, ^{44}Ca, and ^{48}Ti (B field 2) were measured to obtain K and Ca ratios. Ti isotopes were measured using 3 magnetic fields: at B_1 we detected – ^{46}Ti, ^{48}Ti, and ^{50}Ti; B_2 – ^{47}Ti, ^{49}Ti, and ^{51}V; and B_3 – ^{12}C, ^{40}Ca, ^{48}Ti, ^{50}Ti, and ^{52}Cr. ^{51}V and ^{52}Cr were used to correct the ^{50}Ti signal for isobaric interferences from ^{50}V and ^{50}Cr, and, ^{40}Ca was measured to correct for Ca interferences at masses 46 and 48.

Results: *K isotopes.* Most of the grains have normal ^{41}K/^{39}K ratios. Grains OR1f3m-9 and 33, are the only ones with elevated ^{41}K/^{39}K ratios, from which initial ^{41}Ca/^{40}Ca ratios of 0.0040±0.0004 and 0.0030±0.0004, respectively, can be derived. Most of the HD grains from this and previous studies [1] are highly contaminated with terrestrial K. This is indicated by the large decrease in the ^{39}K signal during the initial period of each measurement, after which ^{41}K excesses begin to surface. Thus, it is possible that many more grains contain ^{41}K excesses due to the decay of ^{41}Ca ($t_{1/2} = 1.03\times10^5$ a) that are difficult to detect due to the large ^{39}K background. Additionally, note that OR1f3m-9 is classified as a kerogen-like grain based on its Raman spectra [3].

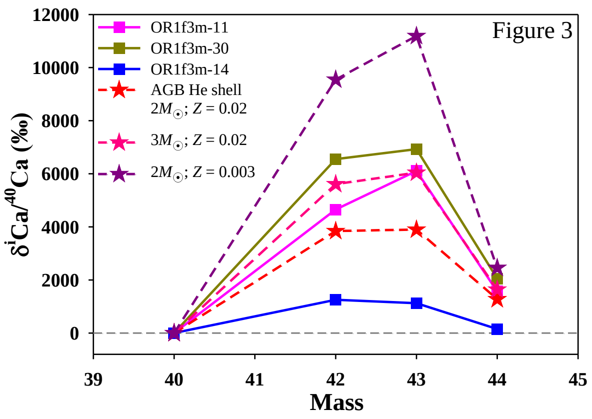
Ca isotopes. Grains OR1f3m-12, 25, 29, and 40 exhibit ^{44}Ca excesses (Figure 1), much higher than expected from neutron capture. Their derived ^{44}Ti/^{48}Ti ratios are as high as 0.057±0.004 (in grain OR1f3m-40). Titanium-44 is only produced by α-rich freezeout in the Ni and Si/S zones of Type II SNe [4] making these grains bonafide SN grains.



Interestingly, the grains with the high, derived ^{44}Ti/^{48}Ti ratios do not contain the largest Ca anomalies. Carbon-13 enriched grains, OR1f3m-11, 14, and 30, have the largest Ca anomalies, along with nine other grains (OR1f3m-8, 12, 17, 19, 25, 29, 35, 40, 41) that have ^{12}C/^{13}C ratios > 100. Figures 2 and 3 show the Ca isotopic patterns for only the ^{13}C-enriched grains and their probable stellar sources. Figure 2 attempts to match the very large Ca anomalies in grains OR1f3m-11, 14, and 30 to the Ca isotopic patterns computed for different shells of a 15$M_\odot$ type II SN model [5]. While the He/C zone does not match any of the anomalies observed in these grains, the O-rich zones (O/C and O/Ne) can account for the $\delta^{43,44}$Ca values. They cannot, however, simultaneously produce the large δ^{42}Ca value seen in OR1f3m-30.



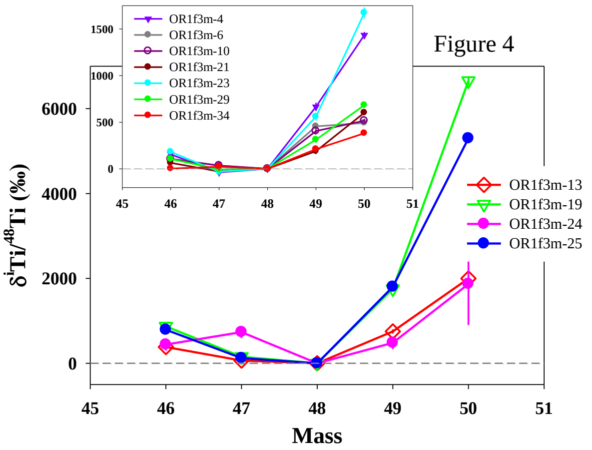
Alternatively, figure 3 shows that the pure He-shell material from 2$M_\odot$ (Z = 0.02, 0.003) and 3$M_\odot$ (Z = 0.02) AGB stars can explain the large Ca anomalies seen in these grains. This confirms previous proposals that HD graphites with low ^{12}C/^{13}C ratios and extremely large Ca anomalies originate from born-again AGB stars that experience a very late thermal pulse [1].



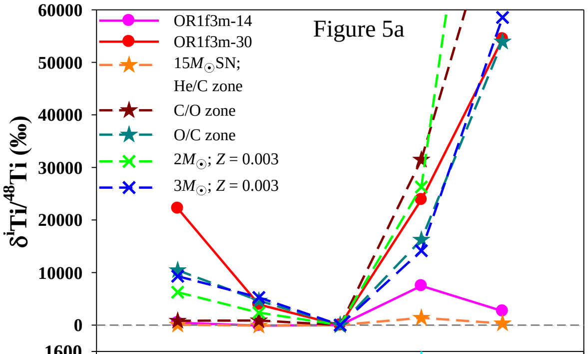
Born-again AGB stars are preferred to a SN source because large Ca anomalies are theoretically expected only in the O-rich zones of the SN, which have extremely high $^{12}C/^{13}C$ ratios; however, admixture of material from these zones to reproduce the Ca anomalies makes the C/O ratio of the grains < 1, which is not conducive to the condensation of carbonaceous grains. Born-again AGB stars can produce low $^{12}C/^{13}C$ ratios and a C-rich environment, simultaneously with large Ca anomalies (explained in detail in [1]).

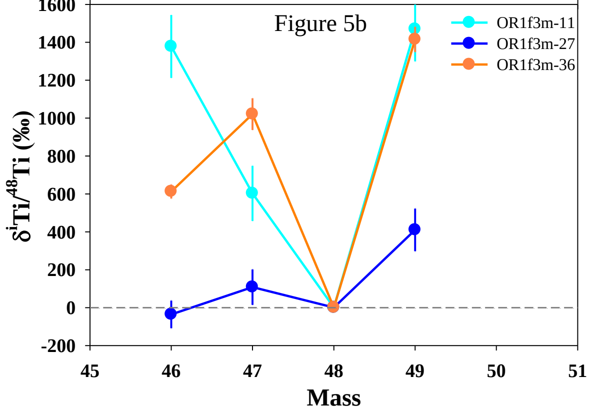
Ti isotopes. Eleven grains with $^{12}C/^{13}C$ ratios > 100 have large Ti anomalies (Figure 4). The isotopic patterns in most of these grains can be explained by a mixture between the O-rich and He/C zones of a SN. The ^{47}Ti excess in grain OR1f3m-24 however, cannot be explained by any model and similar ^{47}Ti excesses have been observed in other grains (e.g. [6, 7, 1]).

Two of the grains with low $^{12}C/^{13}C$ ratios (OR1f3m-14 and 30) have extremely large Ti isotopic anomalies (as well as Ca anomalies; Figure 2). Figure 5a shows the isotopic patterns for these grains. The large ^{46}Ti excess in grain OR1f3m-30 could be from a large ^{46}Ca ion signal that the NanoSIMS is unable to resolve during Ti isotopic measurements. The remaining anomalies can be explained by mixing material from the O-rich zones of a SN with the He/C zone or by pure He-shell material from 2 and 3$M_\odot$ AGB stars with Z = 0.003. The shape of the pattern for OR1f3m-14 where the ^{49}Ti excess is greater than the ^{50}Ti excess (Figure 5a) can be explained by the He/C zone of a SN. However, the magnitude of the theoretically predicted excesses are much smaller than those seen in OR1f3m-14. We were unable to obtain ^{50}Ti data for the other three ^{13}C-enriched grains (OR1f3m-11, 27, and 36; Figure 5b) due to large contributions of ^{50}Cr to the ion signal. This makes it difficult to determine a stellar source for the grains based on the Ti isotopic patterns. However, OR1f3m-27 and 36 both contain ^{28}Si excesses [2] that indicate a SN source for these two grains. OR1f3m-36 also has a ^{47}Ti excess, similar to the one seen in OR1f3m-24 (Figure 4), that cannot be explained by any stellar models.



Other important observations. a) The extreme Ti anomalies in OR1f3m-30 are uniformly distributed within the grain, as opposed to being present in Ti-rich subgrains. Some grains like OR1f3m-19 and 25 have their Ti anomalies arising from subgrains. b) One of the two kerogen-like [3] grains (OR1f3m-19) has large Ti anomalies.





References: [1] Jadhav M. et al. (2008) *ApJ, 682*, 1479-1485. [2] Jadhav et al. (2010) *MAPS, 45*, A94. [3] Wopenka B. et al. (2011) *this meeting* [4] Timmes F. X. (1996) *ApJ 464*, 332-341. [5] Rauscher T. et al. (2002) *ApJ 576*, 323-348. [6] Amari S. et al. (1996) in *Astrophysical Implications of the Laboratory Study of Presolar Materials*, AIP, 287-305. [7] Nittler L. et al. (2005) *ApJ*, L89-L92.