C, CA, AND TI ISOTOPES: ON THE ORIGINS OF HIGH- AND LOW-DENSITY PRESOLAR GRAPHITE GRAINS.

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Introduction: We report on NanoSIMS measurements of 27 new high-density (HD) presolar graphite grains (>2 µm) from the OR1f ($\rho = 2.02$-2.04 g/cm^3; 16 grains) and OR1g ($\rho = 2.04$-2.12 g/cm^3; 11 grains) size/density fractions from the Orgueil meteorite. We measured ^{12,13}C, ^{28,29,30}Si, ^{40,42,43,44}Ca, ^{46,47,48,49,50}Ti, ^{51}V, and ^{52}Cr; however, we did not measure any O, N, Al, or Mg isotopes, as they are often not diagnostic in HD graphite grains [1]. These are the first Ca and Ti analyses on OR1g grains. We also report on measurements of Ca and Ti isotopes from the OR1d6m ($\rho = 1.75$-1.92 g/cm^3) low-density (LD) mount [2].

The origins of presolar graphite grains with extreme anomalies in Ca and Ti isotopes remain enigmatic, although born-again AGB stars have been proposed as stellar sources for those with low ^{12}C/^{13}C ratios (<20) [3]. The isotopic compositions of these grains are incompatible with current AGB models [4] and supernova (SN) zones where C/O > 1 [5]. O-rich SN zones, however, do reproduce the Ti isotopic patterns.

Experimental Methods: C and Si measurements were performed using a Cs$^+$ primary beam, while K, Ca, and Ti measurements were performed with an O$^-$ beam. K and Ca positive secondary ions were measured in peak-jumping and multidetection mode using two magnetic fields: ^{12}C, ^{39}K, ^{41}K, ^{43}Ca, and ^{48}Ti (#1); and ^{40}Ca, ^{42}Ca, ^{44}Ca, ^{49}Ti (#2). Ti secondary ions were measured using three fields: ^{12}C, ^{40}Ca, ^{46}Ti, ^{48}Ti, and ^{50}Ti (#1); ^{47}Ti, ^{49}Ti, and ^{51}V (#2); and ^{48}Ti, ^{50}Ti, and ^{52}Cr (#3). For the Ti isotopes we measured ^{40}Ca to correct for isobaric interferences from ^{46}Ca and ^{48}Ca while ^{51}V and ^{52}Cr were used to correct for interferences from ^{50}V and ^{50}Cr. There exists a considerable amount of Cr contamination on the graphite grains due to the dichromate treatment [6,7] used in the meteorite's acid dissolution. The contamination often makes it difficult to unambiguously determine a grain's ^{50}Ti/^{48}Ti ratio.

HD Grain Results: *C isotopes*: The majority of grains have ^{12}C/^{13}C ratios > solar (=89), ranging up to ^{12}C/^{13}C = 650. Three grains (OR1g2m-5, hereafter g5; OR1f4m-4, f4; OR1f4m-14, f14) fall into the ^{13}C-rich subgroup with ^{12}C/^{13}C < 20. Two grains (f7, g6) have near-solar ^{12}C/^{13}C ratios and minor anomalies, if any, in other isotope systems; these are not unambiguously presolar.

K and Si isotopes: Most grains have normal K isotopic compositions. f2 contains a ^{41}K excess, indicative of an initial ^{41}Ca presence, which coupled with a small excess in ^{28}Si indicates a SN origin. A number of grains contain small Si anomalies, although they are not unambiguously indicative of a specific stellar origin.

Ti isotopes: Of the three grains in the ^{12}C/^{13}C < 20 group (f4, f14, g5) two have very large anomalies in their Ti isotopes (Fig. 1). These patterns are indicative of a born-again AGB origin [3]. Grain g5, however, with ^{12}C/^{13}C = 5, contains excesses of ~450‰ in ^{46,47}Ti, but lacks a clear anomaly in ^{49}Ti. Cr contamination on g5 was too large to accurately determine its ^{50}Ti/^{48}Ti ratio. A SN origin for g5 would require a mix of material predominantly from the He/N zone, where ^{12}C/^{13}C is very low, with an O-rich zone to explain the ^{46,47}Ti excesses [8]. A born-again AGB origin would also explain the low ^{12}C/^{13}C ratio and ^{46,47}Ti anomalies. However, it remains difficult to reconcile either of these explanations with the normal ^{49}Ti/^{48}Ti ratio.

Fig. 1

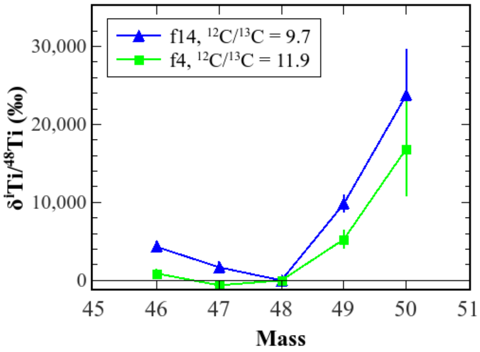
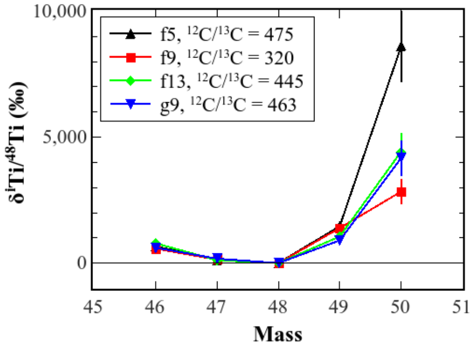


Fig. 2

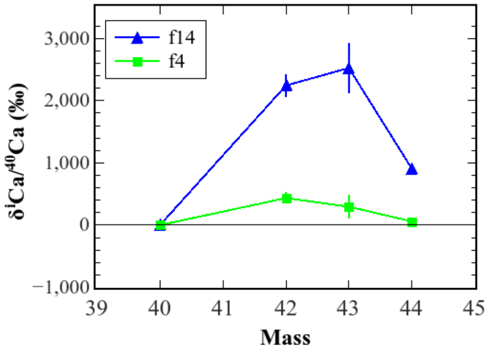


Grains f5, f9, f13, and g9, with ^{12}C/^{13}C > 320 (Fig. 2), also contain large anomalies in their Ti isotopes, which are outside of the range predicted by AGB models [4], though smaller than those from the ^{12}C/^{13}C < 20 group. f5, f9, and f13 have a relatively small correction to mass 50, thus the measured ^{50}Ti anomalies are not likely artifacts; g9 has a larger correction, although its Ti pattern follows the others. These 4 graphite grains are among the 8 from these suites with evidence for internal TiC subgrains, based upon their Ti depth profiles. f9 contained at least 8 peaks in its Ti depth profile, which are indicative of small subgrains. We will get more conclusive evidence for their origins by examining the graphite grains in the TEM and using EDXS to search for enrichments in s-process elements such as Zr and Ru.

Ca isotopes: Grains f5, f9, and f13 contain ^{44}Ca excesses larger than what would be expected from neutron capture if compared to anomalies in the other Ca isotopes, however their ^{44}Ca signals are small and appear to be proportional to their ^{40}Ca signals and not to their ^{48,49}Ti signals. Since Ti has been found to be carried primarily by Ti-rich subgrains, whereas Ca is more homogeneously distributed throughout the graphite [10], we believe that it is unlikely that these ^{44}Ca excesses are due to the initial presence of extinct ^{44}Ti. This does not preclude a SN origin, however.

Grain f14 contains large excesses in ^{42,43,44}Ca, consistent with a possible born-again AGB origin (Fig. 3) [3]. Both f14 and f4 exhibit a classic neutron capture pattern in the Ca isotopes. f14 did not have evidence for any subgrains, based upon its Ti depth profile.

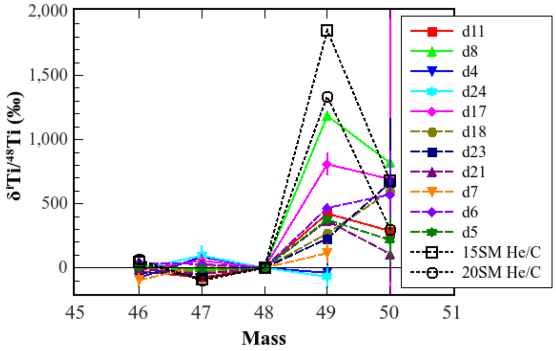
Fig. 3



LD Grain Results: Most of the OR1d6m LD graphite grains contained isotopic signatures of SN origin, including excesses in ^{15}N, ^{18}O, ^{28}Si, and the inferred initial presence of high ^{26}Al/^{27}Al ratios [2]. Fig. 4 shows the Ti isotopic pattern of the LD graphite grains (closed symbols) and models of the He/C zone in 15 and 20 solar mass SNe [5]. A gas mixture of He/C and He/N zone material is thought to be the most likely origin for most of these grains as they are the only SN regions where C/O > 1. The Ti patterns of the LD graphite grains match the predictions for the He/C zone well and also match those of SiC X grains [11]. d4 and d24, however, with low ^{12}C/^{13}C ratios, match models of the He/N zone, where Ti is normal.

Discussion: The isotopic compositions of HD and LD graphite grains are markedly different, suggesting a variety of progenitor environments. LD graphite grains appear to form primarily from various mixtures of He/C and He/N SN zone material, similar to SiC X grains. While most HD graphite grains match the isotopic compositions of low-metallicity AGB stars, it has been suggested that those with large or extreme Ti and Ca anomalies could form either from a mix of He/C, He/N, and O-rich zone material from SNe (those with high ^{12}C/^{13}C) [8] or from born-again AGB stars (for both, high and low ^{12}C/^{13}C ratios) [1,3,9].

Fig. 4



The crystalline structure of presolar graphite grains has been found to be very sensitive to the O content of the surrounding gas; higher O content (still with C/O > 1) appears to inhibit the formation of well-ordered graphite, resulting instead in turbostratic layering, characteristic of LD graphite grains [12]. This appears incompatible with HD graphite grains forming from a mix of O-rich, He/C, and He/N zone material, as HD graphite grains are more highly crystalline than their LD counterparts. The presence of TiC subgrains also requires C/O ~ 1 under reasonable stellar atmospheric pressures [13]. The Ti signals for f5, f9, f13, and g9 are dominated by contributions from TiC subgrains, while the Ca signal is primarily from the host graphite. Since these grains lack Ca anomalies and it is unlikely that the TiC subgrains formed before graphite from O-rich zone material, a SN origin for these grains is doubtful. These grains are also difficult to reconcile a born-again AGB origin since a large fraction of C must come from the He intershell (high ^{12}C/^{13}C ratios), yet we do not observe the concamitant Ca anomalies.

References: [1] Jadhav et al. (2013) *GCA*, in press. [2] Groopman, E. et al. (2012) *ApJ. Let.* 754, L8. [3] Jadhav M. et al. (2008) *ApJ.* 682, 1479. [4] Cristallo et al. (2009) *ApJ.*, 696, 797 [5] Rauscher T. et al. (2002) *ApJ.* 576, 323. [6] Jadhav, M. (2006) *New Astron. Rev.* 50, 591 [7] Amari, S. (1994) *GCA* 58, 459 [8] Jadhav, M. et al. (2011) *42nd LPSC* #1599 [9] Jadhav, M. et al. *this conference* [10] Zinner, E. and Jadhav, M. (2012) *43rd LPSC* #1122 [11] Lin, Y. et al. (2010) *ApJ.* 709, 1157 [12] Croat, T.K. et al. (2008) *MAPS* 43, 1497. [13] Bernatowicz, T. et al. (1996) *ApJ.* 472, 760.