PRESOLAR GRAPHITE FROM A CO NOVA.

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Introduction: Presolar grains constitute remnants of stars that existed before the formation of our solar system. In addition to providing direct information on the materials from which the solar system formed, these grains provide ground-truth information for models of stellar evolution and nucleosynthesis [1]**.** As the carrier of a ^{22}Ne-rich component, presolar graphite grains were isolated through harsh chemical-dissolution treatments and density separations [2]. Over 2000 presolar graphites have been studied so far from only two meteorites, Murchison (CM2) and Orgueil (CI1) [3,4]. Here, we report on the *in situ* identification of a unique presolar graphite grain in the primitive CO3.0 carbonaceous chondrite LAP 031117.

Experimental methods: Graphite grain LAP-149 was identified by NanoSIMS raster C and O secondary ion imaging in a thin section of LAP 031117. Subsequently, the N, Si and S isotopic compositions of LAP-149 were also measured. Additional chemical and structural information was acquired using the PHI 700 Auger Nanoprobe and the Renishaw inVia© Raman microscope.

Results: LAP-149 has one of the lowest ^{12}C/^{13}C ratios (1.41 ± 0.01) ever measured and a high ^{14}N/^{15}N ratio (941 ± 81; Fig. 1). Only one other graphite, KFC1b-202 [3], has a similarly low ^{12}C/^{13}C ratio; however, its N and O isotopic compositions are both solar (Fig. 1). The O, Si and S isotopic compositions of LAP-149 are solar within uncertainties.

Auger elemental data show that LAP-149 is composed only of carbon (Fig. 2). Its Raman spectrum (Fig. 3) differs from the organic matter present in the surrounding matrix but resembles the spectra of well-crystallized presolar graphite grains. Perfectly stacked sp^2-bonded graphitic carbon sheets exhibit only the G-band peak; the presence of a D-band peak indicates either structural defects in the grain or damage from the NanoSIMS Cs beam [5].

Discussion: The origin of LAP-149 is restricted to several types of stars that can produce very low ^{12}C/^{13}C ratios. While these, in principle, include born-again AGB stars, J-type stars and Type II supernovae, in detail the nucleosynthetic models cannot reproduce the C, N, O, Si, and S isotopic compositions of LAP-149 in these stars while still maintaining a C-rich environment (C/O > 1) [3,4,6]. Several studies have also suggested that presolar grains with very low ^{12}C/^{13}C (≤ 5-15) ratios may originate in nova ejecta [7-9]. Below we present several new nova models and show that the isotopic composition of LAP-149 is consistent with an origin in the ejecta of a low-mass CO nova.

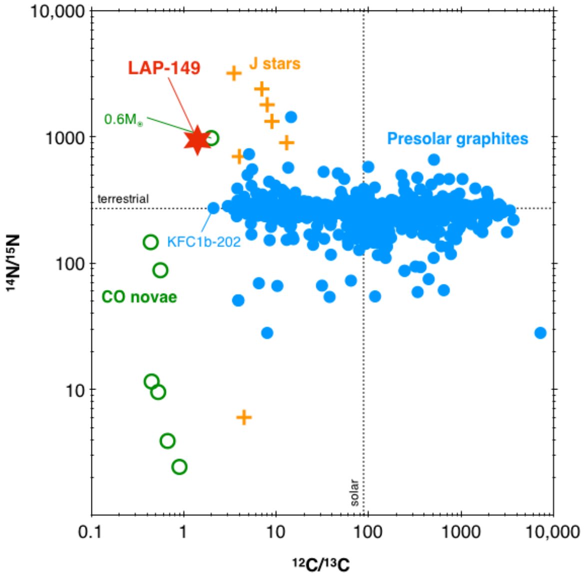

Figure 1. C and N isotopic compositions of LAP-149 compared with other presolar graphite grains [10], astronomical observations of J-type stars [11], and new CO nova models.

A nova explosion occurs when a white dwarf (WD) core accretes enough material from a nearby companion star to cause rapid fusion of the accreted hydrogen and trigger an explosion [9]. Based on the composition of the WD core, we distinguish two types of novae: CO novae (C- and O-rich WD core) and ONe novae (O- and Ne-rich WD core) [9]. Stellar nucleosynthesis models of ONe novae cannot reproduce the isotopic compositions of grain LAP-149: ONe novae ejecta are characterized by very low ^{12}C/^{13}C ratios (0.73-1.1), but also have very low ^{14}N/^{15}N (0.25-3.6) ratios [8], inconsistent with the ^{14}N-rich isotopic composition of LAP-149. However, CO nova models appear to be more promising [8].

We computed seven new one-dimensional CO nova models with WD masses ranging between 0.6-1.15 M$_\odot$ and mixing fractions of 25% or 50% between the outer layers of the WD core and material accreted from the companion star. While most models predict isotopic compositions inconsistent with those of

LAP-149, one model with a WD mass of 0.6 $M_\odot$ predicts C and N isotopic compositions that are virtually identical to those of LAP-149 (Fig. 1). This model is also consistent with the solar Si and S isotopic compositions of LAP-149 because peak temperatures in CO novae are not high enough to significantly modify the Si and S isotopes [7,8].

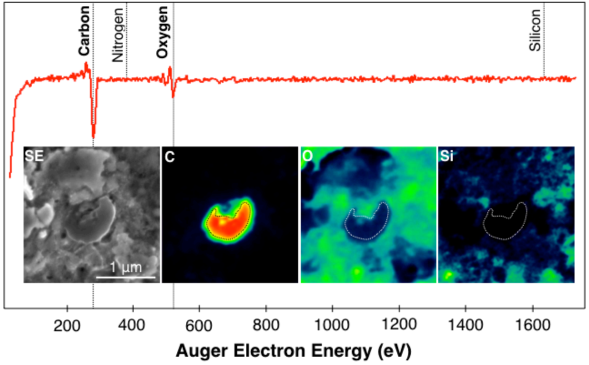

Figure 2. Secondary electron image, differentiated Auger spectrum and elemental distribution maps showing the C-rich composition of LAP-149.

Notably, the C, N, Si, and S isotopic compositions of LAP-149 can be reproduced without any extra mixing with solar composition material. This differs from most nova grain candidates, which require large amounts of solar composition material (> 90%) to be mixed with the nova ejecta in order to reproduce their isotopic compositions (even for major elements such as C) [7,8].

Elemental constraints are also consistent with a CO nova origin. The 0.6 $M_\odot$ CO nova model predicts a C/O ratio above unity, favorable for the condensation of carbonaceous grains, such as graphite. While condensation likely takes place dynamically in a nova environment, equilibrium condensation sequences can provide preliminary estimates on the type of condensates expected in CO nova ejecta for the relevant range of pressures (10^{-5} – 10^{-8} bars) [8,12]. We find that graphite is stable above 1900K, and remains the only major condensate for ~900K below its initial condensation temperature for all pressures. This confirms that graphite grains are stable in low-mass CO nova ejecta.

Finally, we consider the O isotopes, which represent a unique problem. All nova models predict extreme oxygen isotopic compositions with very large excesses in ^{17}O and depletions in ^{18}O that are not observed in any nova grain candidates [7,8,13], including LAP-149.

Mixing of the nova ejecta with solar composition material has been invoked to explain the O isotope discrepancies [7,13]. For our grain LAP-149, more than 99% material of solar composition would have to be mixed with the 0.6 $M_\odot$ CO nova ejecta to match the O isotopic composition. However, such mixing would also greatly affect the C and N ratios, resulting in $^{12}C/^{13}C$ = ~30 and $^{14}N/^{15}N$ = ~300, which are clearly inconsistent with the isotopic composition of LAP-149.

Previous studies have also argued that the close-to-normal N, O and Si isotopic compositions of presolar graphite grains reflect isotopic equilibration by either chemical processing in the laboratory, or secondary aqueous/thermal alteration [4,14]. However, such equilibration is unlikely for LAP-149, as it was found *in situ* and did not undergo the chemical isolation procedures experienced by other presolar graphites. In addition, LAP 031117 has experienced far less secondary alteration than Murchison and Orgueil.

The O isotope discrepancy thus remains a puzzle for all possible nova grains, and underscores the need for additional modeling. Indeed, unlike previous studies, the fact that we can rule out isotopic equilibration and/or mixing with solar composition material for our grain is an important result that future studies will need to consider in nova models.

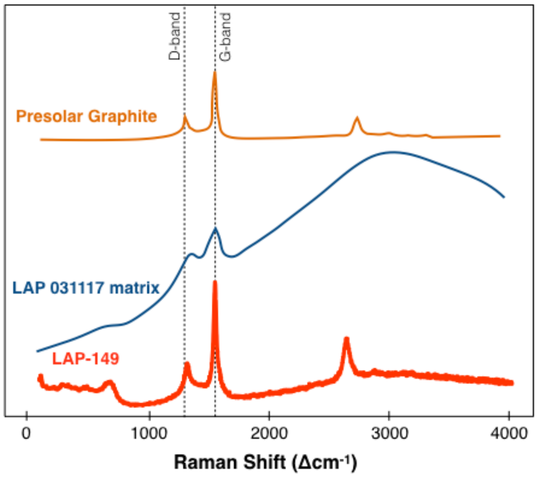

Figure 3. Raman spectrum of grain LAP-149 compared with surrounding matrix material in LAP 031117 and a presolar graphite grain from Murchison [5].

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References: [1] Zinner (2014), in *Treatise on Geochemistry (2^{nd} Ed.),* Elsevier, 181. [2] Amari et al. (1990), *Nature* **345**, 238. [3] Amari et al. (2014), *GCA* **133**, 479. [4] M. Jadhav et al. (2013), *GCA* **113**, 193. [5] Wopenka et al. (2013), *GCA* **106**, 463. [6] Jadhav et al. (2013), *ApJ* **777**, L27. [7] Amari et al. (2001), *ApJ* **551**, 1065. [8] José et al. (2004), *ApJ* **612**, 414. [9] José (2016), Stellar Explosions: Hydrodynamics anfd Nucleosynthesis, CRC Press. [10] Hynes & Gyngard (2009), *LPSC XL*, #1198. [11] Hedrosa *et al.* (2013), *ApJL* **768**, L11. [12] Lodders (2003). *ApJ* **591**, 1220. [13] Gyngard et al. (2010), *NIC-XI*, 141. [14] Stadermann et al. (2005), *GCA* **69**, 177.