PROCEEDINGS OF SCIENCE

Oxygen-rich Stardust Grains from Novae

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Stardust grains which have condensed from nova ejecta are exceedingly rare in meteorites. Principally through proton captures, novae are efficient producers of the stable isotopes ^{13}C, ^{15}N, and ^{17}O, as well as radioactive isotopes such as ^{22}Na and ^{26}Al. To date, primarily carbonaceous phases of stardust grains (e.g., SiC and graphite), have been purported to have a nova origin. Conversely, as material ejected in nova explosions is O-rich, it remains a puzzle why to date mostly carbonaceous nova grain candidates have been discovered. O-rich stardust grains with ^{17}O/^{16}O ratios significantly greater than 0.004, the predicted maximum value that can be reached in low- and intermediate-mass AGB and RGB stars, have been proposed to have a nova origin. The O isotopic compositions of many of these grains can be fairly well matched by CO nova model predictions. However, two grains whose Mg-Al compositions had been determined have much smaller excesses of the heavy Mg isotopes than predicted by nova models, which miss the grain data by up to several orders of magnitude. New nova models computed with recently updated reaction rates further complicate this overall picture.

11th Symposium on Nuclei in the Cosmos - NIC XI
Heidelberg, Germany
July 19–23 2010

[1] Presenter

Introduction

Presolar grains (or, alternatively, stardust) are commonly found in the matrices of primitive meteorites and identified by extreme isotopic compositions when compared to solar system (SS) materials (Fig. 1a) [1]. These grains are astrophysical fossils of various stellar origins, typically asymptotic and red giant branch (AGB and RGB) stars and supernovae; however, some exceptionally rare grains have isotopic compositions suggestive of a nova origin.

Various competing processes, such as cool bottom processing (CBP), hot bottom burning (HBB), galactic chemical evolution (GCE), and dredge-up episodes during the late stages of RGB/AGB stellar evolution affect the O isotopic compositions of dust grains from these stars (Fig. 1b). Carbonaceous grains with combinations of low $^{12}C/^{13}C$ and $^{14}N/^{15}N$ ratios, high $^{30}Si/^{28}Si$, and high inferred $^{26}Al/^{27}Al$ ratios have been purported to be condensates in nova outflows [3-5], although some may actually be SN grains [6].

The maximum $^{17}O/^{16}O$ ratio in low- and intermediate-mass AGB and RGB stars of close-to-solar metallicity is predicted to be 0.004 [7]. Novae are prodigious producers of ^{17}O, and O-rich grains with $^{17}O/^{16}O$ ratios greater than 0.004 are possible candidates for nova grains.

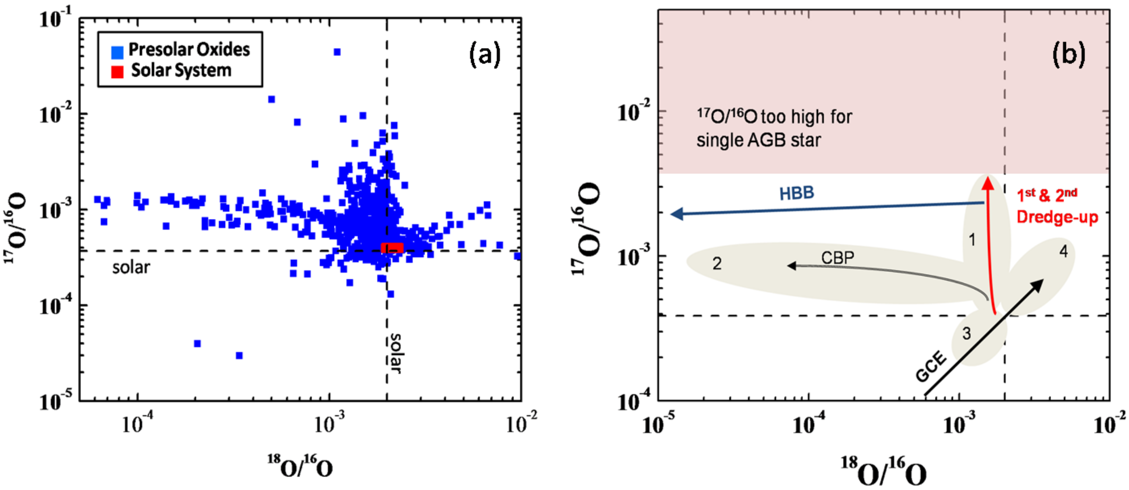

Figure 1. (a) O 3-isotope plot with the entire range observed in solar system matter in red and presolar oxide grains in blue. **(b)** Schematic diagram of the stellar processes responsible for the O isotopic composition of most O-rich presolar grains, with ellipses representing the four groups identified previously [2].

Methods & Discussion

Previously, O isotopic compositions predicted from nova models agreed fairly well with the limited grain data (Fig. 2a) [8]. However, new model compositions computed in this work with updated $^{17}O(p,\gamma)^{18}F$ [9] and $^{18}F(p,\gamma)^{19}Ne$ [10] reaction rates (among others) for both CO and ONe novae fail to reproduce the grain data (Fig. 2b). Automated NanoSIMS searches of large numbers of meteoritic oxide and silicate grains have revealed additional ^{17}O-rich grains [11-13]; however, the Mg isotopic compositions of spinel grain C4-8 [8] and silicate grain 4_7 [13] (Fig. 3) are much less extreme than predicted by nova nucleosynthesis models.

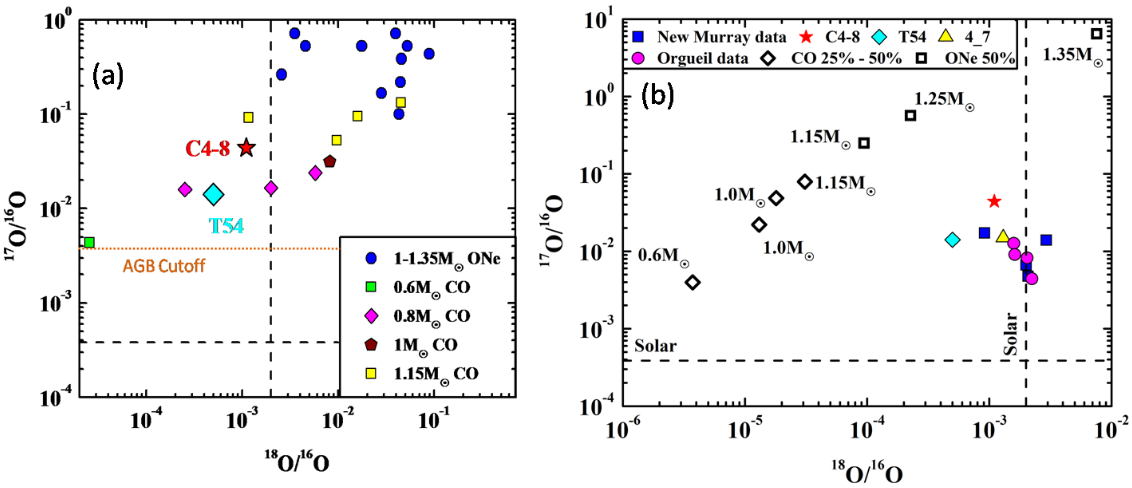

Figure 2. (a) Nova model predictions [4] compared with previous best nova candidate grains (C4-8 and T54). Multiple points for some models are due to variation in mixing amounts between solar accreted material and white dwarf (WD) core. **(b)** New nova model predictions compared with new [11-13] and previously obtained grain data. New Murray data are from [11], Orgueil data are from [12], and Acfer 094 grain 4_7 data from [13]. Models predicting ^{17}O/^{16}O ratios in agreement with the grain data yield much too low ^{18}O/^{16}O ratios. The values next to the open symbols indicate the underlying white dwarf mass assumed for a given nova model.

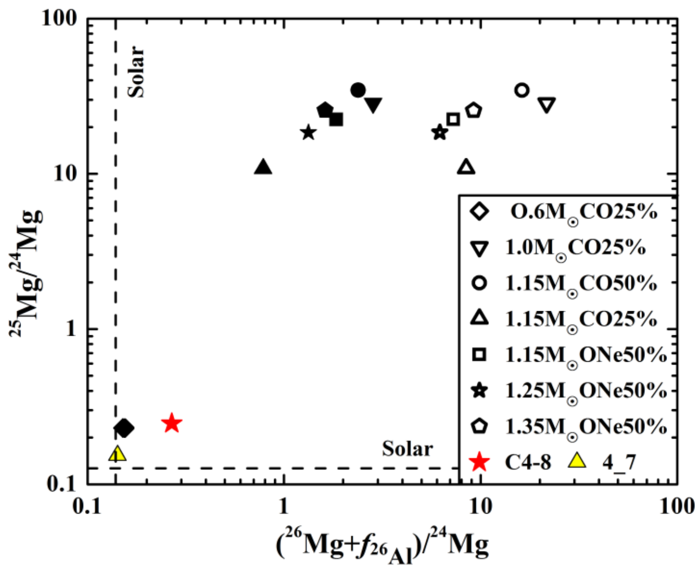

Figure 3. Model predictions for Mg isotopic compositions compared to the two nova candidate grains analyzed for their Mg-Al isotopic compositions. Filled symbols indicate no contribution from ^{26}Al, while open symbols contain a "scaled-up" contribution (*f*) for preferential condensation of Al into spinel grains. The parameter "*f*" is model sensitive and varies depending on the metallicity of the computed nova ejecta.

Astronomical observations show that novae produce a diversity of dust species [14], both C-rich and O-rich, whereas the nova models usually suggest O>C in the ejecta, leading to the straightforward prediction of more O-rich grains than C-rich ones. In contrast, most previously identified presolar nova candidate grains have been C-rich. Analysis of new and previous data indicates that this is largely the result of experimental and sample bias, as meteorites are dominated by O-rich minerals of SS origin, making identification of O-rich presolar nova grains more difficult. In fact, the relative abundance of presolar O-rich grains from novae is probably higher than that of C-rich grains, with respect to grain type (Table 1) [8].

Table 1. Relative abundance of C- and O-rich nova grains among analyzed presolar grains.

Presolar Grain Type	Total Number	Number of Nova Candidates	Relative Abundance
C-rich	~11,000	$\lesssim 10$	0.09%, 0.01%*
O-rich	~1200	$\lesssim 16$	~1.2%

* Corrected for experimental bias from data reported in the literature [15].

Conclusions

Several outstanding questions remain: (1) Do the new model results invalidate a nova origin for the grains? (2) Can adjustments of model parameters, e.g., the amount of accretion from the companion star onto the WD core, or the mass of the progenitor star, lead to agreement with the grain data? (3) Why are the grains' Mg isotopic compositions not nearly as extreme as the models predict? (4) Could the grains have condensed at a later stage in an AGB star polluted with ^{17}O-rich nova ejecta? Hopefully, more multi-element isotopic data and future calculations will lead to better constraints on the origin of these unique grains.

Acknowledgements

F. Gyngard would like to thank the Carnegie Institution of Washington for support. E. Zinner acknowledges support from NASA grant NNX08AG71G. J. Jose acknowledges support from the Spanish MICINN grants AYA2010-15685 and EUI2009-04167, and by the ESF EUROCORES Program EuroGENESIS.

References

[1] E. Zinner, *Presolar grains*, in: Treatise on Geochemistry Update, H. D. Holland, K. K. Turekian and A. Davis, eds., pp. 1, Elsevier Ltd., Oxford, 2007.

[2] Nittler, L. R., Alexander, C. M. O'D., Gao, X., Walker, R. M., and Zinner, E., *Stellar sapphires: The properties and origins of presolar Al_2O_3 in meteorites*. Astrophys. J. **483**, 475-495, 1997.

[3] Amari, S., Gao, X., Nittler, L. R., Zinner, E., José, J., Hernanz, M., and Lewis, R. S., *Presolar grains from novae*. Astrophys. J. **551**, 1065-1072, 2001.

[4] José, J., Hernanz, M., Amari, S., Lodders, K., and Zinner, E., *The imprint of nova nucleosynthesis in presolar grains*. Astrophys. J. **612**, 414-428, 2004.

[5] Heck, P. R., Marhas, K. K., Hoppe, P., Gallino, R., Baur, H., and Wieler, R., *Presolar He and Ne isotopes in single circumstellar SiC grains*. Astrophys. J. **656**, 1208-1222, 2007.

[6] Nittler, L. R. and Hoppe, P., *Are presolar silicon carbide grains from novae actually from supernovae?* Astrophys. J. **631**, L89-L92, 2005.

[7] Boothroyd, A. I. and Sackmann, I.-J., *The CNO isotopes: deep circulation in red giants and first and second dredge-up*. Astrophys. J. **510**, 232-250, 1999.

[8] Gyngard, F., Zinner, E., Nittler, L. R., Morgand, A., Stadermann, F. J., and Mairin Hynes, K., *Automated NanoSIMS measurements of spinel stardust from the Murray meteorite*. Astrophys. J. **717**, 107-120, 2010.

[9] Newton, J. R., Iliadis, C., Champagne, A. E., Cesaratto, J. M., Daigle, S., and Longland, R., *Measurement of* $^{17}O(p,\gamma)^{18}F$ *between the narrow resonances at* $E_r^{lab}=193$ *and 519 keV*. Phys. Rev. C **81**, 45801, 2010.

[10] de Séréville, N. et al., *Low-energy* $^{18}F(p,\alpha)^{15}O$ *cross section measurements relevant to nova* γ*-ray emission.* Phys. Rev. C **79**, 15801, 2009.

[11] Nittler, L. R., Gyngard, F., and Zinner, E., *Extreme O isotopic anomalies in presolar oxides from the Murray CM2 chondrite*. Meteor Planet. Sci. **45**, A153, 2010.

[12] Nittler, L. R., Qin, L., Alexander, C. M. O'D., Wang, J., Carlson, R. W., and Stadermann, F. J., *Extreme uncorrelated* ^{54}Cr, ^{17}O, *and* ^{18}O *enrichments in sub-micron Orgueil grains*. Lunar & Planet. Sci. **41**, 2071, 2010.

[13] Nguyen, A. N., Messenger, S., Ito, M., and Rahman, Z., *Mg Isotopic Measurement of FIB-isolated presolar silicate grains*. Lunar & Planet. Sci. **41**, 2413, 2010.

[14] Gehrz, R. D., Truran, J. W., Williams, R. E., Starrfield, S., *Nucleosynthesis in classical novae and its contribution to the interstellar medium.* Pub. Astron Soc. Pacific **110**, 3, 1998.

[15] Hynes, K. M. and Gyngard, F., *The Presolar Grain Database:* http://presolar.wustl.edu/~pgd. Lunar & Planet. Sci. **40**, 1198, 2009.