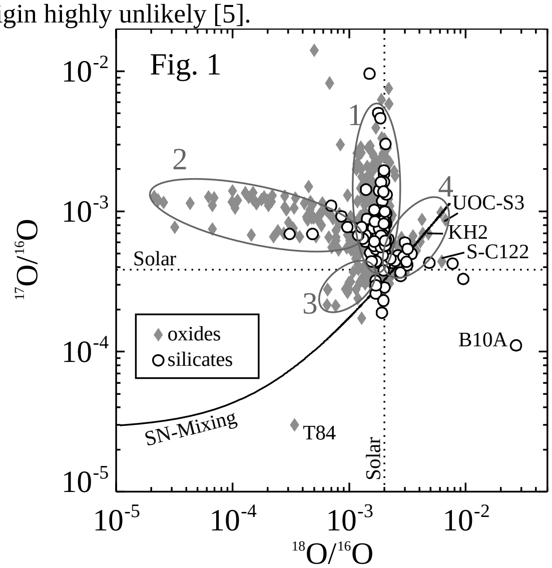
PRESOLAR GRAIN EVIDENCE FOR LOW-MASS SUPERNOVA INJECTION INTO THE SOLAR NEBULA. Larry R. Nittler, Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, lnittler AT ciw.edu

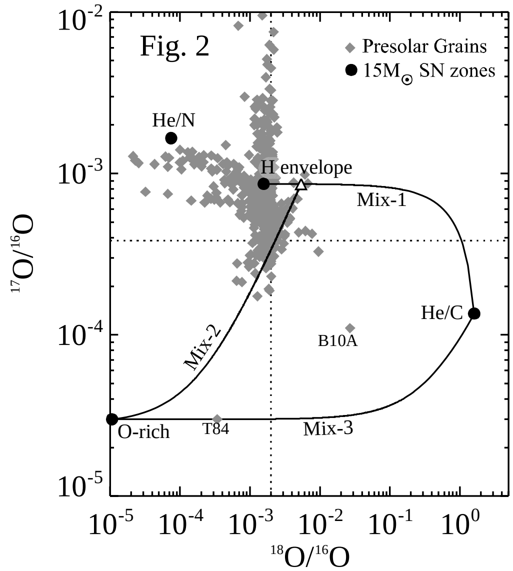
The inferred presence of short-lived radionuclides in the early Solar System suggests that the Sun formed close in time and space to a supernova (SN) explosion. Early ideas focused on the triggered-collapse scenario, where the SN shock wave initiated collapse of the protosolar cloud core and injected radioactivities into it [1]. More recently, an alternative scenario has been proposed [2], namely that a nearby SN injected material directly into an already-formed protoplanetary disk. Possible support for this model has been reported based on Ni isotopes in meteorites [3]. Here I argue that a sub-class of presolar silicate and oxide grains found in meteorites and interplanetary dust particles (IDPs) likely originated in a single SN, perhaps the same one that provided the radioactivities to the early Solar System.

The O isotopic ratios of several hundred presolar oxide and silicate grains are shown in Fig. 1 [4-15], along with the Group designations of [4]. The vast majority of the grains (Groups 1-3) are understood as having formed in low-mass red giants and asymptotic giant branch (AGB) stars [4]. In contrast, the origin of the ^{18}O- and ^{17}O-rich Group 4 grains (10-20% of presolar oxides and silicates, [11]) has been enigmatic. Original suggestions included high-metallicity AGB stars and unusual AGB stars in which very early third dredge-up episodes enriched the surface in ^{18}O from partial He-burning [4]. However, there are major difficulties with both of these suggestions, making an AGB origin highly unlikely [5].



On the other hand, [7] suggested an origin in a Type II SN for a highly ^{18}O-enriched presolar Al_2O_3 grain (S-C122) and a SN is certainly required to explain a few other similar grains [13, 15] and an ^{18}O-rich and ^{17}O-poor olivine grain (B10A) reported by [9]. All of these grains differ from the main Group 4 O isotopic trend, in that they do not show ^{17}O excesses. There is little isotopic data for Group 4 grains besides O, but the extant data argue in favor of a SN origin for these grains. The strongest case comes from a presolar hibonite grain, KH2 (originally named 110-1, [6]). This grain has a typical Group 4 composition, very high inferred ^{26}Al/^{27}Al and ^{41}Ca/^{40}Ca ratios (0.01 and 4×10^{-4} respectively), a 30% ^{25}Mg depletion, 4% depletions in ^{42}Ca and ^{43}Ca and a 6% excess in ^{44}Ca. We have also recently identified a Group 4 presolar spinel grain, UOC-S3, which also exhibits high ^{26}Al/^{27}Al=0.015 and a 24% ^{25}Mg depletion [5]. These compositions are inconsistent with an origin in AGB stars, but can be easily understood in the context of Type II SNe.

Figure 2 shows the O isotopic compositions of several zones of a 15$M_{\odot}$ Type II SN [16], along with the presolar grain data. Clearly, mixing of these zones in variable proportions could produce almost any composition one would desire. Nonetheless, the very high ^{18}O/^{16}O ratio of the partially He-burnt He/C zone provides a natural explanation for presolar grains with large ^{18}O excesses [17]. The Group 4 grains lie along a linear trend that is well explained by mixing (Mix-2) of variable amounts of material from the inner ^{16}O-rich zones with a single mixture (triangle) of the H envelope and the He/C zone (Mix-1). Moreover, simple mixing models of the various zones can quantitatively reproduce 7 of the 8 isotopic ratios measured in KH2 and the 4 ratios measured in UOC-S3. Only the ^{43}Ca/^{40}Ca ratio of KH2 is missed, but nucleosynthesis models are known to under produce ^{43}Ca [18]. The mixtures that explain the two grains are similar and require close to a 50:50 mix of the envelope and He/N zone (to provide ^{26}Al), mixed with small amounts of the He/C (to provide ^{18}O and ^{41}Ca) and the innermost zones (to provide ^{16}O, ^{24}Mg, ^{40}Ca and ^{44}Ti). There is little O in the He/N zone, so this component does not significantly affect the O isotopes. Also, because the contribution from inner zones is small, one does not expect large isotopic anomalies in other elements like Si or Fe in these mixtures. Moreover, we note that the mixing line explaining the Group 4 O data also passes near several ^{16}O-rich grains (outside the Group 3 ellipse on Fig. 1) that are not well-explained by AGB stars, suggesting these might also have formed in SNe. Note also that ^{16}O-rich grain T84 [14] is well explained by a mixture of the inner zones with the He/C zone (Mix-3).



These results argue strongly for a SN origin for most or all Group 4 (and possibly some Group 3) grains. However, an intriguing aspect of this conclusion is the rather narrow range of mixing conditions required to explain the grain data. Mixing in SN ejecta is observed to be highly heterogeneous and variable from remnant to remnant [19, 20]. This is consistent with the wide range of isotopic compositions observed in single presolar SiC and graphitic grains from SNe [21, 22], requiring a range of mixing conditions and probably many different parent SNe. Given the extreme diversity in SN compositions and mixing details, it is difficult to envision a realistic scenario in which different SNe ended up producing grains primarily along a single mixing line as observed in the O-rich grains. The most likely explanation is that these grains formed in a single SN. If so, the observed mixing line might reflect a jet of ^{16}O-rich material from the inner part of the explosion passing through and mixing with the outer partially mixed ejecta, followed by grain formation as the material expands and cools.

An obvious explanation for a preponderance of grains in the Solar System from a single SN would be if they formed in the same SN postulated to have injected radioactivities into the disk. The model of [2] requires that the radioactivities be injected in the form of pre-condensed dust, as gaseous ejecta passes around the disk. Moreover, recent calculations [23] suggest that grains in the size range of the observed presolar grains (0.1-10μm) are preferentially injected and many of these are expected to survive. If the Group 4 grains were indeed injected into an already-formed solar nebula, one might expect to see a heterogeneous distribution of them in the Solar System. In fact, the limited dataset so far suggests a significantly higher fraction of Group 4 grains in IDPs and Antarctic micrometeorites (AMMs), compared to meteorites [8-10, 12]. Since IDPs and possibly AMMs are believed to originate preferentially in comets, this would support a heterogeneous distribution of SN grains in the Solar System. Note that the SN that provided the Group 4 grains apparently did not provide any significant number of SiC or graphite grains as no obvious single source is implicated by their isotopic data (and note that presolar Group 4 silicates are more than 100 times more abundant than SiC X-grains in meteorites). This is also qualitatively consistent with the proposed scenario of a single O-rich jet from the SN intersecting the disk.

We have thus far only considered the $15M_\odot$ model of [16], and it is likely that other SN models could also reproduce the isotopic compositions of the Group 4 grains. We plan to investigate additional SN models to better constrain the nature of the source (e.g., the initial mass) of Group 4 grains and to investigate whether this scenario can simultaneously explain the short-lived nuclide data. In any case, the necessity of mixing material from advanced nuclear burning stages with the stellar envelope constrains the progenitor mass to be less than about $30M_\odot$, since more massive stars lose their entire envelopes due to strong Wolf-Rayet winds prior to the SN explosion. Therefore, if the Group 4 presolar grains indeed were injected into the early Solar System by the same SN that provided the short-lived nuclides, this would argue strongly against the suggestion of [3] that the ^{26}Al was provided in a Wolf-Rayet wind followed by injection of ^{60}Fe from the explosion of a very massive star.

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