DISCOVERY OF ABUNDANT INTERSTELLAR SILICATES IN CLUSTER IDPS.

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Introduction: Many interplanetary dust particles (IDPs) collected in the stratosphere appear chemically, mineralogically, and texturally primitive in comparison to meteorites [1]. The most fragile (cluster) IDPs also exhibit far larger and more common H and N isotopic anomalies than those observed in meteorites, likely marking the survival of abundant presolar molecular cloud materials [2]. In particular, it has been suggested that interstellar silicates, so far undetected in meteorites, may be abundant in anhydrous IDPs [3]. While there have been a few (unsuccessful) searches for presolar grains in IDPs [4,5], it has not previously been possible to analyze the typical constituents of IDPs owing to their extremely small sizes (0.1 – 0.3 μm).

Here we have employed the new Washington University NanoSIMS ion microprobe to search for O-rich presolar grains in IDPs. In comparison to previous measurements with the IMS-3f and IMS-4f ion microprobes, the NanoSIMS is at least 50 times more sensitive for O isotopic measurements, while also affording a spatial resolution of better than 100 nm.

Experimental: To date we have analyzed five chondritic IDPs and two fragments of Murchison matrix by O isotopic imaging. The IDPs selected include four anhydrous cluster IDPs and one hydrated IDP. Two of the IDPs, L2005C13 and the hydrated IDP L2009J5, were measured as thin sections directly on TEM grids prepared with techniques developed by J. Bradley and F. Stadermann. IDPs L2005C3, L2005C2, and L2005C4 were pressed into an Au substrate with a sapphire disc.

Images were acquired by rastering a ~1 pA 16 KeV Cs^+ primary ion beam across each sample, resulting in 5 – 20 scans. Oxygen isotopic images and, in two cases, ^{28}Si and ^{30}Si images were acquired in multidetection mode on five electron multipliers. High mass resolution scans of the ^{17}O peak were acquired on each sample prior to analysis in order to ensure that the contribution from ^{16}OH was less than 1 per mil. Image acquisition times ranged from 3 to 10 hours, consuming on the order of 0.1 μm of surface material.

The images were analyzed by creating an isotopic ratio map together with an anomaly significance image, which scales deviations from solar by the counting statistics. Candidate grains were individually investigated, layer by layer, in order to establish their persistence with depth. Once a grain was defined in the images in three dimensions, its isotopic ratios and uncertainties were determined following normal procedures.

Results: The O isotopic compositions displayed by submicrometer regions of Murchison matrix fall within the range of solar values, approximately within error. Among the 34 arbitrarily defined regions with the lowest counting errors ($\delta^{17}O$ < 20 ‰) 31 fall within a range of +/- 30 ‰, indicating some variability in instrumental mass fractionation from different parts of the sample, but the additional uncertainty is negligible for this study.

The results from the IDPs measured are strikingly different: *every anhydrous cluster IDP in this study clearly contained numerous presolar silicates*. These grains are often well resolved spatially and isotopically from the surrounding material (e.g. Fig. 1). From the five IDPs studied, 30 presolar grains have been identified thus far [Fig. 2], ranging in size from 0.1 to 1 μm. No presolar grains were found in the hydrated IDP. Given the fact that these measurements are performed *in situ*, some contamination from surrounding isotopically solar material is unavoidable, and the number of presolar grains present and their isotopic anomalies should be considered lower limits.

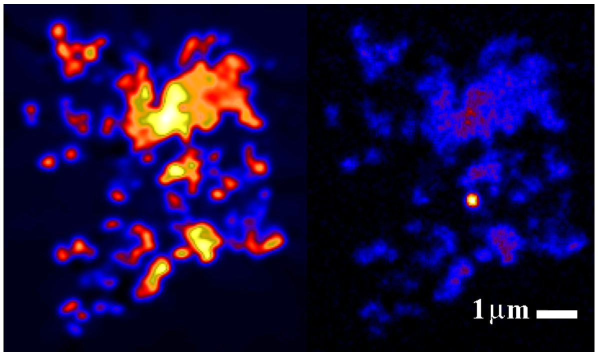

Figure 1: ^{16}O (left) and ^{17}O (right) images of IDP L2005C13. The bright region in the ^{17}O image marks a 0.25 μm presolar silicate grain with $^{16}O/^{17}O$ ~ 440 (solar = 2610).

While these grains fall within the range of values previously observed among meteoritic presolar oxide and spinel grains [6-7 and unpub. by Nittler], the distribution of the grains among the isotopic groups is very different. Seven of these grains are similar to Nittler's group 1 grains, while the remaining 23 are among the group 4 grains, which are rare among the oxides. We note that a recent discovery of a chondritic IDP with a significant *bulk* ^{16}O excess [8] so far cannot be explained by these grains, as no ^{16}O-rich phases were identified.

Stellar sources: The large ^{17}O excesses and moderate ^{18}O depletions of the group 1 grains are characteristic of H burning. As with the presolar oxide grains, it is most likely that these grains are residue of low to intermediate mass O-rich AGB stars [6]. The more numerous ^{17}O- and ^{18}O-rich group 4 grains are more

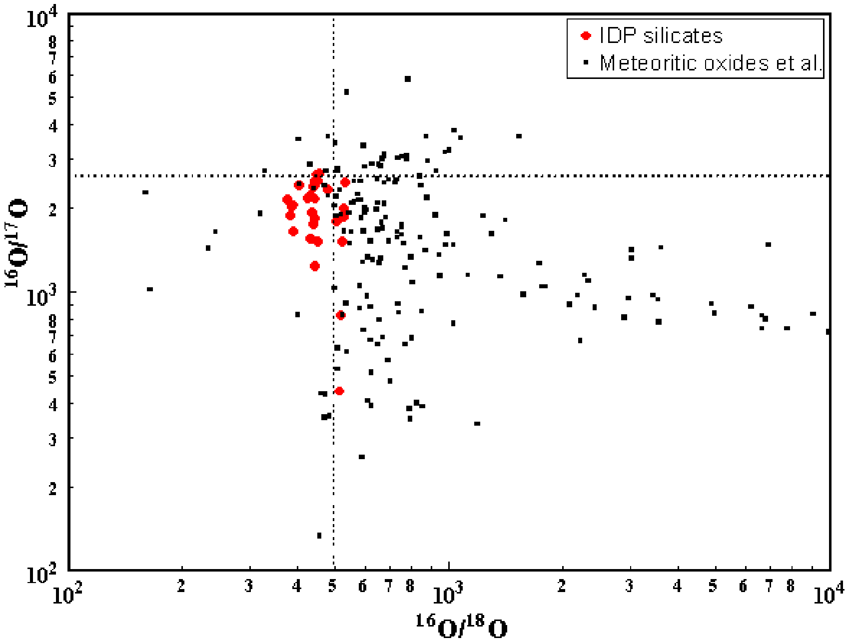

Figure 2: Oxygen isotopic ratios of presolar grains from this study (red points) compared with those of oxide and spinel grains previously identified (black squares [6,7, & unpub. by L. Nittler]). Dashed lines denote the solar O isotopic ratios.

enigmatic. The two proposed sources of these grains are high metallicity stars and type II supernovae [7].

Grain composition: The extremely small sizes of most of the grains complicate their mineralogical identification. However, with one exception, all grains analyzed were Si-bearing, with Si^-/O^- secondary ion ratios falling within the range of the bulk of the IDP silicates. In the one exception, the Si^-/O^- signal was less than half the average of the entire IDP.

Energy dispersive X-ray (EDS) maps were taken of one IDP (L2005C4), which contained several presolar grains, including the largest silicate (~1 µm) and also the most Si-poor grain. EDS maps showed that the four largest grains were Mg-rich, with the Si-poor grain being deficient in Mg. Owing to its small size (~0.3 µm), we cannot exclude the possibility that this grain is an oxide, perhaps magnetite.

The only grain whose mineralogy we have identified is shown in Fig 3. A group 1 grain was identified within the 300 nm cluster of forsterites shown the figure. Interestingly, a different presolar grain (shown in Fig. 1) also appears to be associated with this forsterite cluster, but in an adjacent slice, and is also isotopically distinct from the grain in Figure 3.

In the four cluster IDPs at least 1% of the silicates are presolar. This is very surprising given that the their abundance in meteorites may be less than 10^{-5}, if they are present at all. It is possible that presolar silicates simply did not survive meteoritic parent body alteration.

It is known from ISO spectra that forsterite, enstatite, and amorphous silicates are the major silicate species in circumstellar disks around young stars and in outflows from red giants [10]. While most presolar grains found here contain abundant O, Si, and Mg, their mineralogy is currently unknown. However, at least one group 1 grain is identified here as forsterite. This has important implications for the survival of silicate species in the harsh conditions of the ISM and for the heritage of cometary materials.

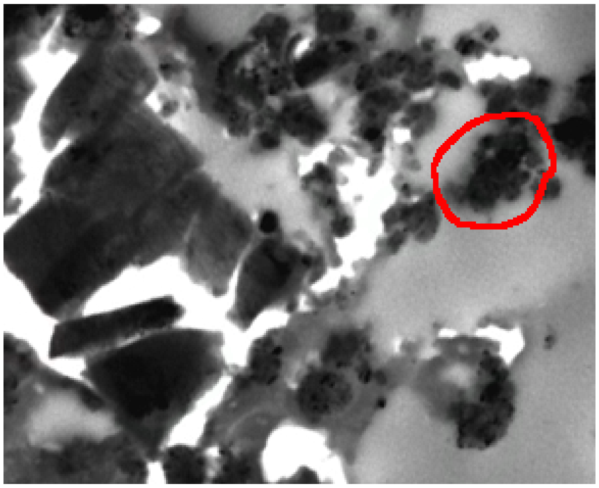

Figure 3: TEM image of L2005C13. The red circle shows the location of a ^{17}O-rich forsterite grain surrounded by isotopically solar forsterites.

Acknowledgments: We are grateful for the vital roles played by F. Stadermann and E. Zinner in making the NanoSIMS a viable instrument and to all those who made its purchase possible.

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