DETERMINATION OF PRESOLAR GRAIN ABUNDANCES IN SAMPLES FROM COMET 81P/WILD 2.

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Introduction: Presolar grains provide information about fundamental astrophysical processes, such as stellar nucleosynthesis, condensation parameters, interstellar processing and galactic evolution. However, it is also possible to make use of the very presence or relative abundance of presolar grains in different types of host materials to learn about pre-accretionary alteration or parent body processing throughout solar system history. The abundance of presolar grains in a given type of extraterrestrial material thus becomes a measure of how well the host material has preserved the original mix of primordial and newly condensed materials from which the solar nebula originated [1-3]. In this context, the abundance of presolar grains in comet 81P/Wild 2 was one of the key questions when NASA's Stardust mission returned samples for laboratory investigation [4, 5]. Here we report results of presolar grain searches in laboratory test shots of meteoritic material and demonstrate how they can be used to calibrate the absolute presolar grain abundances of comet Wild 2 [6].

Experimental: Samples of the Acfer 094 ungrouped carbonaceous chondrite were ground into fine powders and fired as buckshot into Stardust flight spare Al 100 foil with the two-stage light gas gun at the University of Kent, at impact speeds similar to the nominal Stardust encounter speed at comet Wild 2 (~6 km/s). Craters from these foils, as well as ones from several Stardust cometary foils, were analyzed with the Washington University NanoSIMS. A 16 kV, ~1 pA Cs+ primary ion beam was rastered over crater residues and secondary ions ($^{12,13}C^-$, $^{16,17,18}O^-$) were collected in multi-collection mode, along with secondary electrons. The total areas of crater residue measured were ~5000 µm^2 (representing 23 craters with sizes of 0.5–295 µm) for the Stardust foils and ~25,000 µm^2 (88 craters with diameters of 1.5–90 µm) for the Acfer 094 test shot foils.

Results: In the Stardust foils we identified four O-rich presolar grains in four different craters (including one that was found during the PE [5]). All of the grains are enriched in ^{17}O with solar to sub-solar $^{18}O/^{16}O$ ratios (Fig. 1), belonging to Group 1 [7], and range in size from 100–250 nm. A fifth O-rich presolar grain, found by [8] in the Stardust foils, is enriched in ^{18}O (e.g., Group 4; Fig. 1). No presolar SiC has been found in the Stardust foils, but a 300 nm SiC grain was found in aerogel track #141 [9]. In the Acfer 094 test shot foils, we found two O-rich presolar grains (both Group 1) with diameters of 200–300 nm, and two mainstream SiC grains (diameters of 230–310 nm). The nominal (calculated) abundance of presolar grains in the Stardust foils is ~25 ppm (~35 ppm if the Group 4 grain is included), while the abundances are ~4 ppm and ~5 ppm for O-rich grains and SiC, respectively, in the Acfer 094 test shot foils.

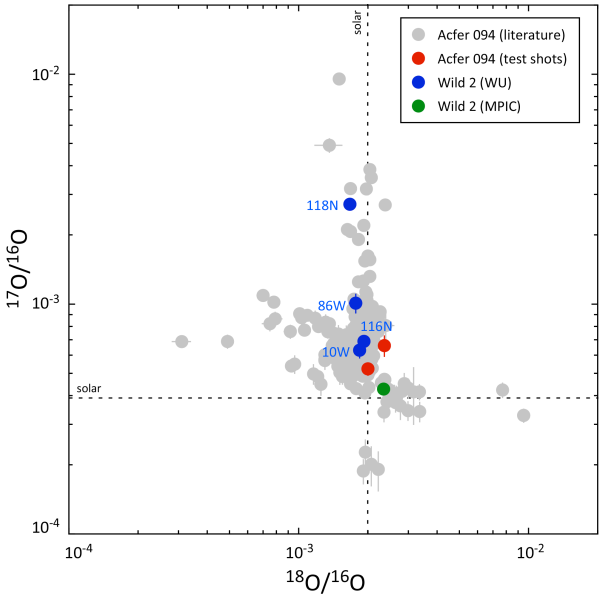

Figure 1. Oxygen 3-isotope plot showing O-rich presolar grains from Acfer 094 and comet 81P/Wild 2 (previously published data from [5, 8, 10] and the Presolar Grain Database [11].

Discussion: The matrix-normalized presolar grain abundances of Acfer 094 are well-established, with 145–190 ppm O-rich presolar grains and ~35 ppm SiC [12-15]. Conversion to bulk abundances, assuming a matrix fraction of 51 vol.% [16], gives 70–95 ppm for O-rich grains and ~15 ppm for SiC. Given the bulk abundances noted above, the number of grains we would expect to find in the 25,000 µm^2 of area measured on these foils is on the order of 25-75 for O-rich grains and 5-10 for SiC, compared to the two grains of each we actually found. This clearly demonstrates the destruction or re-equilibration of a large fraction of the presolar grains as a result of the hypervelocity impacts into Al foil, with the loss of more than 90% of the presolar O-rich grains in Acfer 094; the fraction of SiC lost is lower, indicating a higher resistance to destruction.

Figure 2 shows several scenarios of what may occur to a projectile during hypervelocity impact. One possibility is that only a fraction of the projectile survives, but the relative proportions of the different components remain the same. In this scenario there is no preferential loss of presolar grains relative to other components, and the presolar grain abundances in the residues will be representative of the original projectile. Another possibility is that, upon impact, the grains in the projectile break up into smaller fragments. If the presolar grains are smaller, their isotopic signatures are more likely to be diluted with surrounding isotopically normal material, resulting in a decreased detection efficiency (e.g., [13]) and lower apparent abundances. A final possibility is that the heating that takes place upon impact creates a melt mixture, and the isotopic anomalies carried by the presolar grains become diluted in the melt. Here again, the measured presolar grain abundances will be lower than the actual abundances.

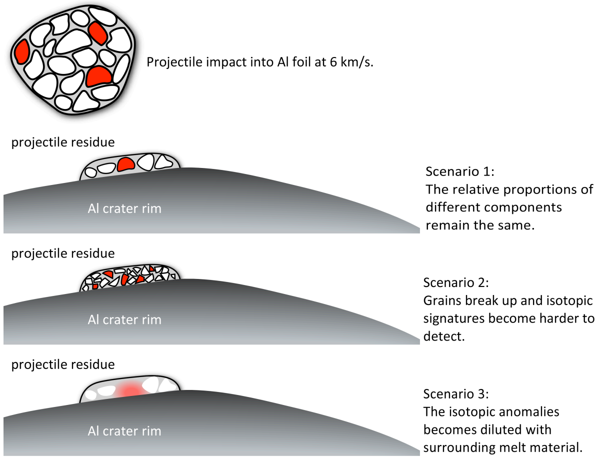

Figure 2. Schematic illustrating possible outcomes upon projectile impact into Al foil under Stardust-like conditions.

Many presolar grains are undoubtedly lost from the craters during impact, but this alone probably does not result in preferential loss of the grains, as much of the other material in the projectiles is also ejected or vaporized. As illustrated in Fig. 2, preferential loss of recognizable presolar grains is likely to be due to dilution of the anomalous isotopic signatures carried by the grains. The ^{18}O-enrichment in the Group 4 grain found by [8] is distributed over much of the 700 nm diameter crater, evidence that the projectile experienced melting upon impact and the isotopic signature of the presolar grain was diluted in the melt mixture. However, the isotopic signatures of the other four O-rich presolar grains found in Wild 2 do not show similar evidence of melting. Hypervelocity impact studies using Stardust analogue materials have shown that impact-generated melts are common, particularly in impacts of aggregate materials [17]. However, TEM analyses of craters from the Stardust foils themselves show evidence of crystalline materials representing surviving impactor material in craters with mixed (sulfide and silicate) compositions [18]. Thus, Scenarios 2 and 3 in Fig. 2 may both be responsible for the apparent low abundances of presolar grains in the Wild 2 samples.

Assuming similar loss rates for the Acfer 094 test foils and the Stardust foils, we can calculate the original pre-impact presolar grain abundances of samples from Wild 2. For O-rich presolar grains, the measured abundance of 35 ppm in the cometary foils suggests original abundances between 600–830 ppm, based on the 70–95 ppm range of O-rich presolar grains in bulk Acfer 094. Based on the size of the SiC grain found by [9], an upper limit of ~45 ppm can be estimated for the original abundance of SiC in Wild 2.

Our work shows that comet Wild 2 contains more presolar grains than measurements on the Stardust samples suggest, with O-rich presolar grain abundances similar to primitive IDPs [19] and significantly higher than in even the most primitive meteorites [e.g., 3]. Wild 2 and IDPs both contain highly unequilibrated assemblages of solar and presolar materials, consistent with accretion in the outer cold regions of the solar nebula. These similarities support arguments for the cometary origin of primitive IDPs. In contrast, the lower presolar silicate abundances observed in even the most primitive meteorites indicates that the accretion processes they experienced, likely in warmer regions of the solar nebula, were sufficient to destroy a substantial fraction of these grains.

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