# ABUNDANCE OF PRESOLAR GRAINS IN COMET WILD 2 AND IMPLICATIONS FOR TRANSPORT AND MIXING IN THE SOLAR NEBULA.

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**Introduction:** In early 2006 NASA's Stardust mission successfully returned samples from comet Wild 2 for laboratory analysis. Among the surprise discoveries during the preliminary examination (PE) of the cometary matter was the observation that these samples are not just mixtures of ice and interstellar grains as previously speculated, but contain significant fractions of high-temperature minerals from the inner solar system [1]. Only a single presolar grain with extremely anomalous O isotopic composition was found during the PE, indicating a relatively low presolar grain abundance [2, 3]. We have continued our search for presolar material in samples from Wild 2 by performing isotope imaging searches in C, N, O, and S at high spatial resolution and located two more presolar grains in the cometary material. With this additional data we can determine the presolar grain abundance in the Wild 2 samples with better statistical significance, compare the abundance to those in other types of solar system materials, and draw conclusions about basic solar nebula properties.

**Experimental Details and Results:** The new analyses expanded on work that was started during the PE [3]. We used the Auger Scanning Auger Nanoprobe for high resolution electron imaging and elemental characterizations [4] and the NanoSIMS for isotope imaging with a ~100 nm primary $Cs^+$ beam and various detector setups, such as [$^{12}C^-$, $^{13}C^-$, $^{12}C^{14}N^-$, $^{12}C^{15}N^-$, $^{28}Si^-$, SE], [$^{12}C^-$, $^{13}C^-$, $^{16}O^-$, $^{17}O^-$, $^{18}O^-$, SE], [$^{16}O^-$, $^{17}O^-$, $^{18}O^-$, $^{28}Si^-$, $^{24}Mg^{16}O^-$, SE] and [$^{16}O^-$, $^{32}S^-$, $^{33}S^-$, $^{34}S^-$, $^{36}S^-$, SE]. In the C, N, and O isotopic measurements we looked for highly localized isotopic variations indicative of presolar grains and used internal calibration where the bulk of the sample and/or the surrounding area is assumed to have a normal isotopic composition. External standards of ZnS and $SrSO_4$ were used for the S isotopic measurements in addition to internal calibration.

Measurements focused on residues in the large Al foil impacts in C2086W (370 µm diameter crater) and C2118N (72 µm), as well as 25 smaller craters in C2010W (ranging in size from 0.22 to 7.4 µm). We also analyzed several aerogel-extracted samples which, however, contributed only a negligible amount to the total measurement area.

We did not find any statistically significant isotopic variations in the C and N isotopic compositions that would be indicative of presolar grains (e.g., SiC) in any of the analyzed samples. We observed topography-related variations in the S isotopic measurements of several (small) craters similar to what has been noted earlier [5], but no statistically significant internal variations.

We previously found a 250 nm O-anomalous presolar silicate/oxide grain on the rim of the large crater on C2086W with a composition of $^{17}O/^{16}O = (1.01 \pm 0.10) \times 10^{-3}$ and $^{18}O/^{16}O = (1.77 \pm 0.12) \times 10^{-3}$ [2, 3], see Fig. 1. An even more $^{17}O$-rich grain was located among the residue in the large crater on C2118N. This grain has a diameter of 170 nm and a composition of $^{17}O/^{16}O = (2.72 \pm 0.15) \times 10^{-3}$ and $^{18}O/^{16}O = (1.67 \pm 0.10) \times 10^{-3}$. We discovered a third O-anomalous presolar grain on the rim of crater 14E (diameter 1.1 µm) on foil C2010W (Fig. 2). The composition of this ~100 nm grain is $^{17}O/^{16}O = (6.3 \pm 0.5) \times 10^{-4}$ and $^{18}O/^{16}O = (1.84 \pm 0.08) \times 10^{-3}$. The three cometary grains show large enrichments (up to ~6000‰) in $^{17}O$ and slight depletions in $^{18}O$. Dividing the total area of these three grains by the cumulative surface area of cometary residue analyzed in our laboratory for O isotopic compositions (4600 µm$^2$) results in a presolar silicate/oxide abundance of 17 ppm.

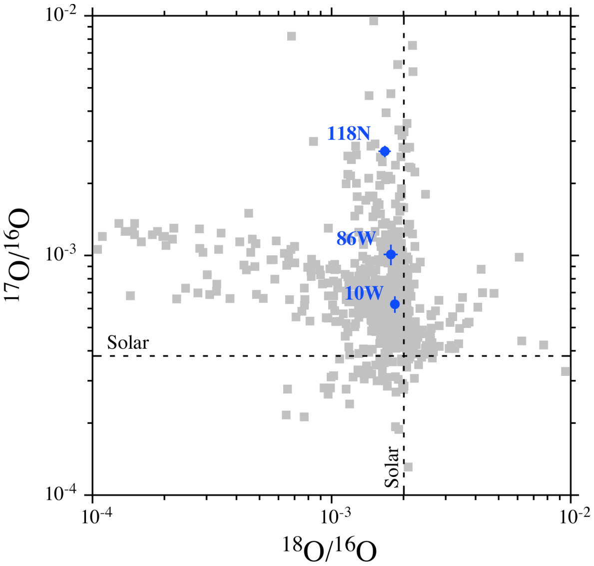

*Figure 1: Oxygen 3 isotope diagram of the cometary presolar grains from Al foils C2086W, C2118N, and C2010W. Reference compositions [gray] of presolar oxides/silicates from primitive meteorites, IDPs, and Antarctic micrometeorites are from [6].*

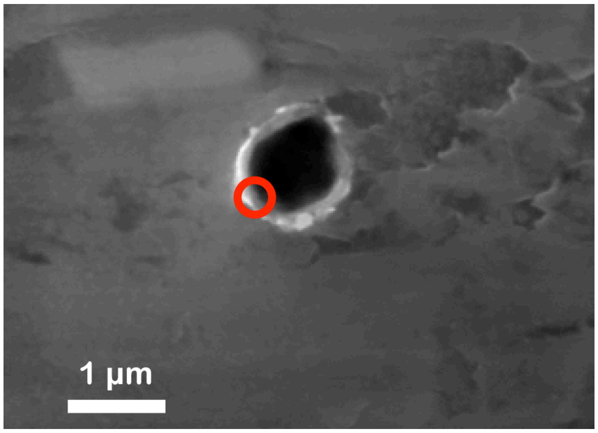

*Figure 2: Location of a ~100 nm presolar grain on the rim of a 1.1 μm diameter cometary impact crater on Al foil C2010W.*

**Discussion:** After finding a single presolar grain during the Stardust PE, it was not unexpected to locate additional grains in continued isotope imaging searches [3]. Interestingly, the three presolar grains were found in three different types of locations on the Al foils: embedded in Si-rich material with a melt texture, as an isolated grain on a large crater rim, and in one of smallest craters studied. This observation corroborates earlier notions that small mineral grains can easily survive hypervelocity impacts on solid metal targets [7].

That all three presolar grains were found on Al foil samples and not in aerogel-extracted material may appear surprising at first, but is likely just a consequence of the one-sided sample availability, at least for this study, where ~30 times more cometary residue area was analyzed on Al foils than in aerogel samples.

The O isotopic compositions of the Wild 2 presolar grains are within the expected range of presolar silicate or oxide particles. The strong $^{17}$O enrichments and slight $^{18}$O depletions of these grains are typical for presolar grains of the most heavily populated 'group 1' for which an origin in low mass asymptotic giant branch or red giant stars has been identified [8].

During the PE, several groups performed isotopic searches that could have led to the identification of presolar grains. However, due to the different analytical approaches used and the resulting variations in presolar grain detection efficiencies, as well as the fact that only a single presolar grain was found, it was difficult to determine a reliable abundance. Because a relatively large amount of Wild 2 material has now been scanned under consistent measurement conditions, the resulting presolar grain abundance can be directly compared to abundances determined in other types of extraterrestrial materials using the same analytical approach.

The 17 ppm presolar silicate/oxide abundance in Wild 2 samples is significantly lower than the abundances in other primitive solar system reservoirs: 125 ppm in ALHA 77307 [9], 145 ppm in Acfer 094 [9], 220 ppm in QUE 99177 [10], 120 ppm in MET 00426 [10], 57 ppm in Antarctic micrometeorites [11], and 375 ppm in the 'isotopically primitive subgroup' of IDPs [12]. To directly compare presolar grain abundances in comet Wild 2 to those in primitive meteorites from the asteroid belt, it is necessary to calculate bulk-normalized values, which are necessarily lower than the matrix-normalized values quoted above. With literature estimates for individual matrix contents, we calculate bulk presolar grain abundances between 30 and 56 ppm for the 4 meteorites mentioned. This value is closer to the 17 ppm measured in Wild 2 and may well be compatible within the uncertainties of the determinations.

Variations in presolar grain abundances in different host materials are typically explained by different degrees of processing, such as thermal metamorphism or aqueous alteration which can lead to partial or complete loss of any recognizable features of presolar materials. However, such parent body processes are not expected for Wild 2, a Jupiter family comet that spent the vast majority of its life in the Kuiper belt [1]. The only viable mechanism to reduce presolar grain abundances appears to be dilution with solar system produced material. Relative to the high abundance of presolar grains found in isotopically primitive IDPs, the collected material from Wild 2 appears to be diluted by at least 95% presolar-grain-free matter, likely from the inner solar system. Such a high abundance of inner solar system material at the Wild 2 formation region would require ballistic transport [13] or an extremely efficient outward transport around the midplane [14]. The fact that many IDPs have so much higher presolar grain abundances indicates that they did not originate in Wild-2-like comets and may be a reflection of inter-cometary heterogeneity, if these IDPs do in fact have a cometary source.

**References:** [1] Brownlee D. et al. (2006) *Science* 314, 1711. [2] McKeegan K. D. et al. (2006) *Science* 314, 1724. [3] Stadermann F. J. et al. (2007) *Meteorit. Planet. Sci.*, in press. [4] Stadermann F. J. et al. (2007) *LPS XXXVIII*, Abstract #1334. [5] Heck P. R. et al. (2007) *Meteorit. Planet. Sci.*, 42, A64. [6] Presolar Grain Database (2007) http://presolar.wustl.edu/~pgd [7] Hörz F. et al. (1991) *First LDEF Symp.*, 487. [8] Nittler L. R. et al. (1997) *Astrophys. J.* 483, 475. [9] Nguyen A. N. et al. (2007) *Astrophys. J.* 656, 1223. [10] Floss C. and Stadermann F. J. (2008) *this conf.* [11] Yada T. et al. (2007) *Meteorit. Planet. Sci.*, in revision. [12] Floss C. et al. (2006) *Geochim. Cosmochim. Acta* 70, 2371. [13] Shu F. H. et al. (2001) *Astrophys. J.* 548, 1029. [14] Ciesla F. J. (2007) *Science* 318, 613.