CALIBRATING THE ABUNDANCE DETERMINATIONS OF PRESOLAR GRAINS IN WILD 2 COMETARY MATTER.

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Introduction: Presolar dust grains which condensed in the environments of evolved stars carry an isotopic memory of the nucleosynthetic conditions at the time of their formation [e.g., 1]. Their anomalous isotopic compositions make it possible to identify them today as ppm-level inclusions in several types of primitive solar system materials. Such presolar grains have been located in meteorites [2], interplanetary dust particles [3], Antarctic micrometeorites [4], and in samples from comet Wild 2 collected by NASA's Stardust mission [5-7]. The abundance of presolar grains is a representation of the 'primitiveness' of its host material, with the least altered material containing the highest density of such grains [8].

Although the residence of comet Wild 2 in the cold Kuiper belt appears to represent an ideal environment for long-time preservation of primitive components [9], laboratory searches so far have found only few grains with clearly presolar isotopic signatures [5-7]. The relatively low abundance of such presolar grains in cometary samples could be explained by extreme dilution with presolar-grain-free matter from the hot inner solar system, but this opens many new questions about mechanisms of transport and mixing in the solar nebula [7]. A precise determination of the presolar grain abundance in matter from Wild 2 therefore represents a key element in our understanding of cometary history. Here we describe efforts to more accurately calibrate this abundance with the help of hypervelocity laboratory shots of meteoritic reference material.

Background: The Stardust mission returned cometary samples on two principal collection media, aerogel tiles and Al foils [10]. While aerogel has the advantage of a somewhat 'gentler' deceleration of cometary dust particles impacting at 6.1 km s^{-1}, the hypervelocity foil impacts provide easily-accessible projectile residues on the surface, which can be searched directly for presolar grains by high resolution isotope imaging. Such isotope searches were performed with the NanoSIMS and led to the identification of three presolar silicate or oxide grains with ^{17}O abundances that are enriched between 65 and 620% above terrestrial values [7]. By determining the surface area of these presolar grains as a fraction of the total cometary residue area searched, a presolar silicate/oxide abundance of 17 ppm was calculated [7]. This value is significantly lower than silicate/oxide abundances of more than 100 ppm seen in the matrices of several primitive meteorites, in which even bulk-normalized abundances are still between 30 and 56 ppm [7, 11].

Three dominant factors may contribute to the remaining uncertainty in the presolar grain abundance determination for Wild 2 cometary matter: (a) the limited statistical significance of currently available data, (b) the difficult definition of the 'reference area' size in abundance calculations, and (c) the possibility of selective sample destruction during hypervelocity impacts [6]. All three issues are addressed in the current study. The most straightforward part of this ongoing investigation is the continued search of Al foil strips from the Stardust mission for impact craters and the isotopic measurement of the cometary debris therein under constant and reproducible analytical conditions. The detection of additional presolar grains from Wild 2 will increase the statistical significance of the abundance value.

To address issues (b) and (c), we have performed comparison hypervelocity shots with pulverized material from the carbonaceous chondrite Acfer 094. This meteorite has been extensively studied for presolar grains, which can be found at relatively high abundances in its matrix [12-14]. By searching the impact residues of these test shots for presolar grains under the same analytical conditions as used in the Wild 2 studies, we can determine relative grain-type specific survival probabilities, which can then be used to calibrate the presolar grain abundances in the cometary samples.

Accurate determination of the reference area size (issue b) is difficult because it is not always possible to unequivocally delimit genuine projectile residue and partially melted target material, especially when both are heterogeneously mixed on a fine scale. However, using data from comparison shots for calibration purposes should cancel out any systematic errors, including possible operator bias.

Experimental Details: Two shots were carried out in a two stage light gas gun at the University of Kent. Powdered Acfer 094, sieved to exclude surviving robust grains (> 53µm), was fired as buckshot (i.e., many grains per shot) at samples of Stardust flight spare Al 1100 foil (in similar fashion to the Stardust foil calibration shots [15]). Impact speeds during the Acfer 094 shots were 6.3 and 6.2 km s^{-1}.

The shots produced two heavily cratered target foils, with individual craters between sub-micrometer and nearly 200 µm in diameter, covering essentially the same size range as craters from Wild 2. In the SEM individual craters appear virtually indistinguishable in shape from those of Stardust and EDX analyses show that practically all craters contain residue from the projectile (indicated by the presence of Si-, Fe-, Mg-, and O-rich material). A crater surface area of ~2500 µm^2 was searched for presolar grains by NanoSIMS high resolution isotope imaging of $^{12}C^-$, $^{13}C^-$, $^{16}O^-$, $^{17}O^-$, and $^{18}O^-$ following previously established analytical routines [6, 16]. So far, one possible SiC grain has been identified in impact craters from the Acfer 094 shots (Fig. 1), but no presolar silicates or oxides. Previous searches of Wild 2 residues yielded three presolar silicates/oxides in an area of 4600 µm^2 [7].

Discussion: Although it has long been known that silicate materials can survive hypervelocity impacts into solid metal targets [17], it is clear that a large fraction of such grains is damaged or lost during impact. Previous determinations of presolar silicate abundances in cometary matter [6, 7] were based on the assumption that presolar silicates *on average* have the same survival probability as other silicate-rich cometary matter, implying comparable presolar grain abundances in cometary matter and in impact residues. This hypothesis may not be valid as indicated by the early results from the presolar grain searches in the Acfer 094 craters presented here. The apparent paucity of presolar silicates/oxides in these samples suggests that the true abundances in Wild 2 are higher than originally estimated.

The calibration of abundance data with the help of reference shots also makes it possible, for the first time, to give estimates on non-silicate presolar grain abundances in Wild 2, since such grains almost certainly have impact survival probabilities that are different from the one for silicates. Grains of presolar SiC, for example, are probably more likely to survive the shock heating and mechanical disruption during the impact than the bulk of the cometary matter. Incidentally, the first presolar grain that we found in the impact debris from the Acfer 094 shots appears to be a SiC grain (Fig. 1), despite the fact that the abundance of SiC in Acfer 094 is much lower than that of presolar silicates.

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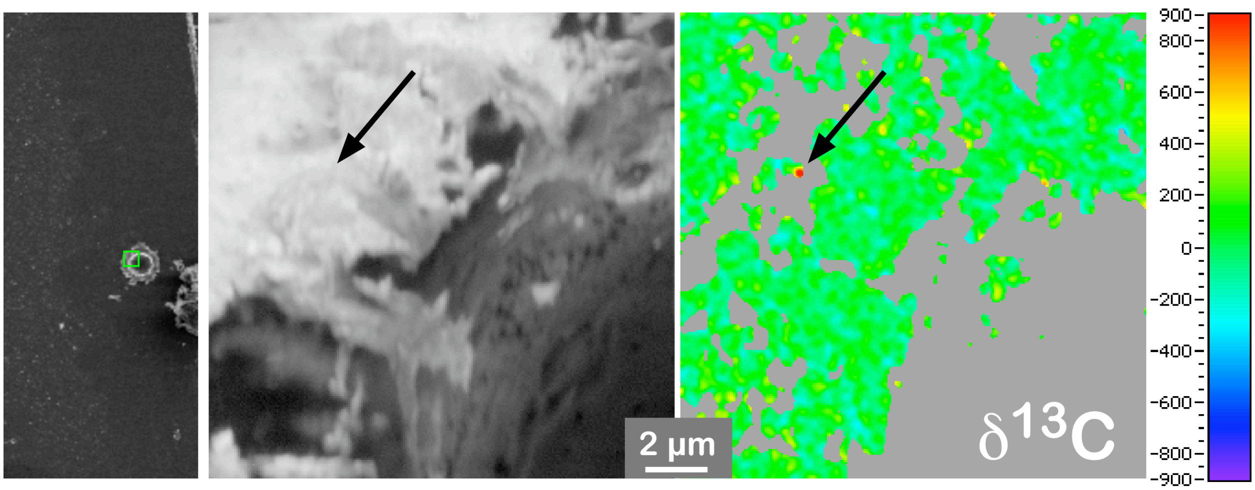

Figure 1: A novel approach for the extraction of presolar grains from primitive meteorites by hypervelocity impact. The 34 µm impact crater 1A003 (left) was created in the laboratory by the impact of a piece of pulverized Acfer 094 onto Stardust-type aluminum foil at an impact velocity of 6.2 km s^{-1}. Among the debris on the north-west rim of the crater we found a highly ^{13}C-enriched grain (likely mainstream SiC) which survived the mechanical disruption, mixing, and shock heating during the violent hypervelocity impact event without losing its isotopic signature.