Extracting Hypervelocity Impact Track Events in Aerogel in Cross-section Wafers. C.J. Snead[1], A.L. Butterworth[1] A.J. Westphal[1] and P.G. Grant[2], [1]Space Sciences Laboratory, Univ. of California, Berkeley, CA 94720-7450 (stardust@berkeley.edu), [2]Lawrence Livermore National Laboratory, Center for Accelerator Mass Spectrometry 7000 East Ave, L-397, Livermore, CA 94550

Introduction: The Stardust spacecraft successfully passed through the trail of Comet Wild-2 in January 2004 and, for the first time, collected cometary particles. These particles, in addition to the contemporary interstellar grains captured during the spacecraft's journey to Wild-2, will be returned to Earth in January 2006 [1]. We have been developing techniques for the extraction and analysis of these particles by working with aerogel collectors from NASA's Orbital Debris Collection Experiment (ODCE), which was exposed on the *Mir* space station.

Particle collectors deployed on the Stardust spacecraft are made of a low density (0.014 g/cm^3) silica aerogel. Particles impacting into the collectors form a carrot shaped track in the aerogel; a so-called terminal particle is often located at the end of the track. For such impact events, we have developed techniques for removing terminal particles (2 μm sized or larger) from the aerogel [2]. Once the cometary particles are removed from the aerogel, they can be analyzed using many of the same techniques developed to examine IDPs.

From our work with the ODCE aerogels, we have discovered that for many impact events the impactor fragments and deposits fine-grained material (<1 μm) along the length of the track (Fig 1). For such events, it becomes extremely challenging to remove all particles completely from the aerogel. Our group has developed a number of extraction techniques designed to remove the entire track in a small block of aerogel a few hundred microns in size, called a "keystone" [3]. We use glass microneedles mounted onto a computer-controlled micromanipulator. The needle moves automatically to a set of points previously generated by our extraction software, slowly perforating the aerogel until a complete cut is made. A complete extraction of an impact event typically takes a few hours to complete.

Material deposited along the impact tracks: It is important to consider the challenging prospect that Stardust's cometary material could be deposited along the track. Particle sizes may be less than 1 μm and there is the possibility of organic films deposited along the inner surface of tracks. If complete removal of ultra-fine particulates proves unfeasible, it may still be possible to analyze track material by minimizing the amount of aerogel affecting measurements.

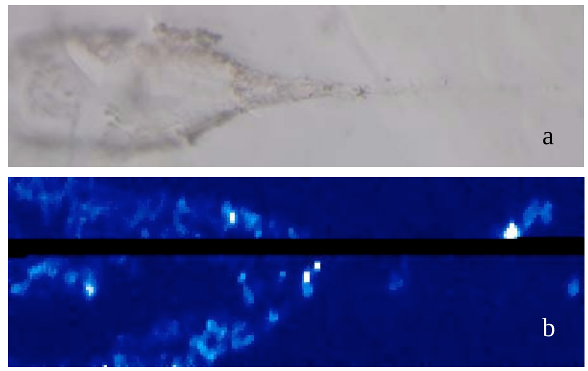

Figure 1. (a) Optical micrograph showing a carrot-shape track from a hypervelocity impact of a chondritic particle in aerogel deployed on the Russian Space Station Mir; (b) An Fe fluorescence map (470 x 140 μm at 2 μm pixel resolution) showing Fe-rich material deposited in the track, as well a terminal particle (ALS X-ray Micro-diffraction Beamline). Black stripe pixels are missing data.

Mining impact track cross-sections: At Berkeley, we have recently developed a method for cross-slicing impact tracks in the aerogel collector (Fig 2). by modifying the existing extraction procedure.

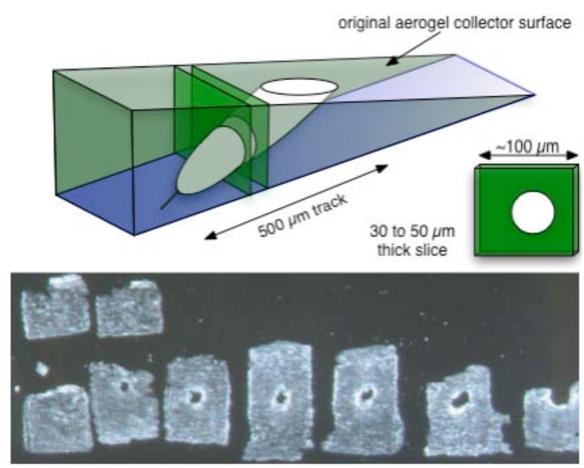

Figure 2. Schematic representation of an aerogel "keystone" extraction of an entire event from the aerogel collector. The track has been sliced across to produce 9 wafers <50-μm thicknesses

Rather than lifting out the completed keystone, each of the nine 30 to 50 μm-thick sections was cut and removed from the collector. Once removed from the ODC, the sections were stored on a silicon chip. Each section was prepared in three hours. This technique has the potential advantage that the impact residue is concentrated in a thin ring rather than being distributed over the larger area of a longitudinally dissected impact track.

Analytical Applications: Two techniques, which have the sensitivity to detect very small quantities of organic material, may benefit from using the track cross-sections:

Scanning Transmission X-ray Microscopy (STXM). STXM based on Carbon-NEXAFS is a soft X-ray absorption technique with the capability of mapping chemical specificity with very fine spatial resolution. The main limitation of transmission X-ray microscopy is that the sample should be optically thin to X-rays, a measure given by Optical Density (OD) by

$$OD = \mu \rho t \qquad \textbf{Eqn 1}.$$

where μ is mass absorption coefficient (cm^2/g), ρ is density (g/cm^3), and t is thickness (cm). Assuming Stardust aerogel has a density of 0.014 g/cm^3, a 20 µm thick slice has OD = 1 at 280 eV near the carbon edge. STXM analyses would be tolerant to the presence of a few microns of aerogel in the beam path, if the total OD remained below 3 for track materials and residual aerogel.

Time-of-flight mass spectrometry (TOF-MS). The TOF-MS is coupled to the Nuclear Microprobe at the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory, which utilizes a 6 MeV O^{3+} ion beam to desorb molecules or molecular fragments.

A thin aerogel track cross-section provides an unobstructed view of material deposited along the track wall, allowing the desorption of ions from the surface of particles. Without the unobstructed access to the interior of the track ions formed would not reach the mass spectrometer.

References: [1] Hörz, F., et.al. (2000) *Icarus 147*, 559-579. [2] Westphal A. J., et al. (2002) *Meteoritics & Planetary Science* 37(6), 855-865. [3] Westphal, A.J., et al. (2004).. *Meteoritics & Planetary Science* **39**(8), 1375-1386

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