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High Resolution Phase Contrast X-ray Imaging of Cosmic Dust Captured in Aerogel

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The primary purpose of NASA's Stardust mission is to sample cometary material ejected from Comet 81P/Wild-2, a young Jupiter family [1]. On January 2004, the spacecraft flew through the tail of the Comet Wild-2 with its dedicated low-density silica aerogel array deployed. Estimates from the spacecraft's dust flux monitor instrument are that over 2800 particles (<15 μm in diameter) impacted the aerogel at ~ 6 km/s [2].

The critical first observations to be made on the aerogel array when it is returned to Earth in 2006 will be to locate the cometary debris preserved in tracks generated during the hypervelocity impact (HVI) collisions of the encounter. Previous studies of aerogel collectors deployed in low-Earth-orbit have shown that HVI capture results in fragmentation/break-up of cosmic dust grains [e.g. 3]. The particles returned by Stardust will be subjected to a number of different analytical measurements to study mineralogical, chemical and isotopic properties [4]. It is therefore important that the initial location of debris is a non-destructive process. Optical microscopy is well suited for imaging the tracks. However, distinguishing "real" particle debris from condensed aerogel fragments generated during the capture is difficult (Fig. 1a), as is study of the particle debris deposited on the interior surface walls of the tracks. In recent years x-ray imaging techniques such as micro CT, have been applied to the analysis of geological materials, however with the exception of synchrotron based techniques, spatial resolutions are typically limited to a few microns [5] and contrast is often poor for samples of low atomic number. Here we describe the use of a point projection x-ray technique that enables the acquisition of high-resolution x-ray phase contrast images using the high brightness source of a field emission scanning electron microscope, constrained x-ray target geometries, direct detection CCD technology and the use of phase retrieval algorithms for image interpretation and analysis [6]. This technique is well-suited to imaging the projectile debris preserved in an impact track as it has a spatial resolution of approximately 100 nm.

We will show results of x-ray phase contrast imaging of an impact track extracted from a bulk aerogel tile that had been exposed in low-Earth orbit. The aerogel fragment containing the impact track was mounted on a silicon microforklift and analyzed using an X-ray ultraMicroscope (XuM) detector fitted to an FEI XL30 SFEG. Low magnification imaging allowed assessment of the entire fragment (Fig. 1b). Rotational imaging followed by tomographic reconstruction allowed 3-D representations of the impact to be generated (Fig. 1c). These low-magnification images revealed areas within the impact track that contained highly contrasting dense material from the surrounding aerogel. These areas were then imaged at high-magnification with the application of post processing phase retrieval techniques in an attempt to resolve individual particles (Fig. 2).

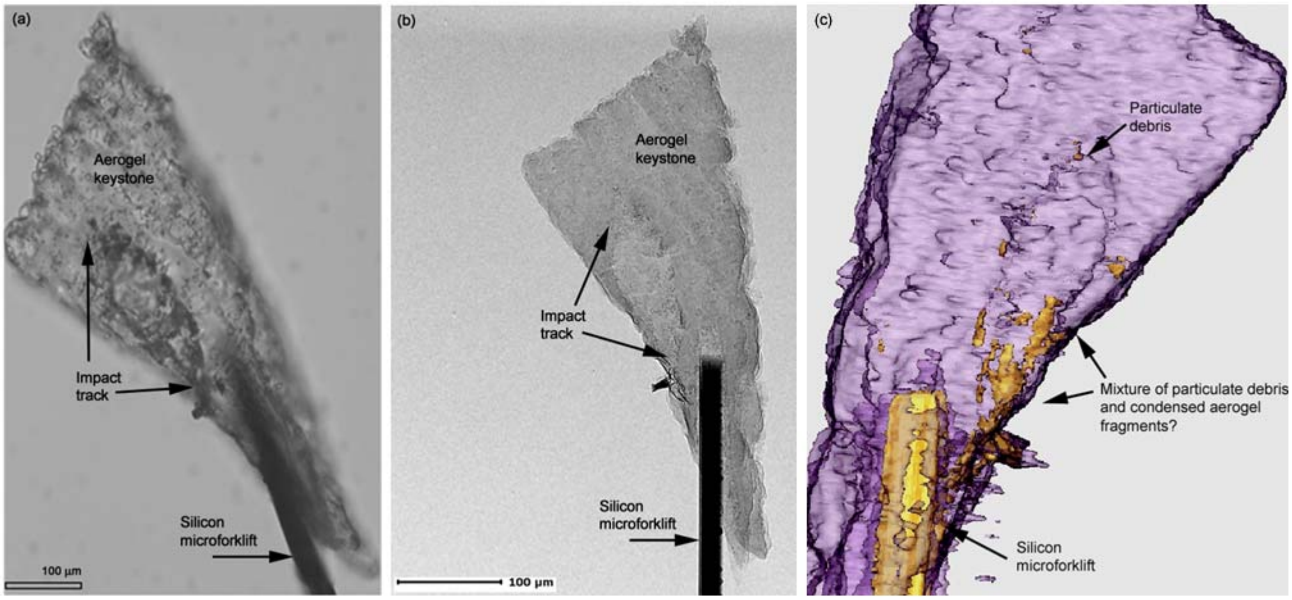

FIG. 1. Shows the comparison between a stacked transmitted light micrograph (a) and an x-ray phase contrast image (b) acquired from the analysis of an impact track extracted from NASA Orbital Debris Collector Experiment (ODCE). (c) A 3-D tomographic rendering of the impact generated from the processing of the multiple x-ray phase contrast images. The higher density material of the silicon microforkslifts supporting the aerogel and the remnants of the impacted extraterrestrial projectile are shown in yellow.

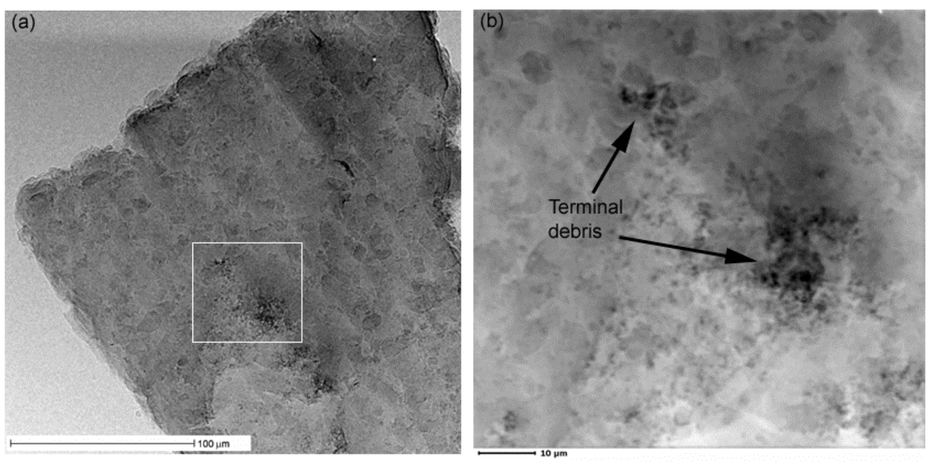

FIG. 2. (a) X-ray phase contrast image of the terminal location of the impact track. (b) A processed Phase-retrieved image resolving the micrometer and sub-micrometer particulates that have been deposited in the track.

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