3D FLUORESCENT AND REFLECTIVE IMAGING OF WHOLE STARDUST TRACKS IN AEROGEL.
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Introduction: The NASA Stardust mission returned to earth in 2006 with the cometary collector having captured over 1,000 particles in an aerogel medium at a relative velocity of 6.1km/s [1,2]. Particles captured in aerogel were heated, disaggregated and dispersed along 'tracks' or cavities in aerogel, singular tracks representing a history of one capture event [3]. It has been our focus to chemically and morphologically characterize whole tracks in 3-dimensions, utilizing solely non-destructive methods. To this end, we have used a variety of methods: 3D Laser Scanning Confocal Microscopy (LSCM), synchrotron X-ray fluorescence (SXRF), and synchrotron X-ray diffraction (SXRD) [4]. In the past months we have developed two new techniques to aid in data collection. 1) We have received a new confocal microscope which has enabled autofluorescent and spectral imaging of aerogel samples. 2) We have developed a stereo-SXRF technique to chemically identify large grains in SXRF maps in 3-space. The addition of both of these methods to our analytic abilities provides a greater understanding of the mechanisms and results of track formation.

Samples: In the past three years we have imaged a total of eleven tracks with LSCM, contained in seven keystones. We have imaged tracks in a wide range of lengths, and spanning the three major track types [4,5]. We have collected complementary SXRF and SXRD data on a majority of tracks. The methods described herein pertain to two such tracks: T163 and T164. Table 1 describes the tracks used in this study.

Track	Length	TPs	*Mount*	*Type*
T163	1250μm	2	On Fork	B
T164	541μm	3	Kapton Box	B

Table 1: Track details (All tracks are in keystones.)

Track 163: (C2117,1,163,0,0) is a 1284μm long type B track with a large (~487μm long, 210μm wide) bulbous section in the beginning of the track. Track 163 has 2 terminal particles; the largest (3μm diameter) terminal particle residing at the end of the track and a slightly smaller particle residing in a stylus ~613μm from the entrance hole. Large cracks in aerogel are seen in the bulb area, and the main stylus is 8 degrees askew from the axis of the bulb. A high quality animation of Track 163 can be viewed online at: bit.ly/Track163

Track 164: (C2063,1,164,0,0) is a 541μm long type B track with a small (~346μm long, 148μm wide) bulbous section in the beginning of the track. Track 164 has 2 terminal particles; both residing at the end of the track, and both ~4μm in diameter. In transit from JSC, the keystone containing Track 164 fell off of its 'forklift' mount, and the keystone was subsequently remounted in an envelope of 4μm thick kapton for analyses and to ensure sample safety.

Imaging and Analysis Techniques: Previous LSCM procedures have been described in detail [4,6]. We have recently taken receipt of an upgraded LSCM, which is housed in the Microscopy and Imaging Facility at the American Museum of Natural History. The new microscope, a Zeiss LSM 710, is vastly superior to our previous model and is equipped with six laser wavelengths for imaging: 405, 458, 488. 514, 561, and 633nm. The LSM 710 is also equipped with a higher-sensitivity 32 channel detector, capable of multispectral imaging of 3.2nm bands in the range 418-728nm. Using two supplementary detectors, total detection range is expanded to 371-756nm, for a maximum of 34 channel imagery. Laser power delivered to the sample is no greater with the newer equipment; rather less laser power can be used due to improvements in the detector. In addition to having higher quantum efficiency the detector on the LSM 710 is capable of 16bit imaging for 4x the dynamic range of previous images. Using these new capabilities we have been able for the first time to view autofluorescence of aerogels.

Tracks 163 and 164 were analyzed with synchrotron XRF and synchrotron XRD at Argonne National Labs, APS, beamline 13-ID run by GSECARS in July 2010. Techniques for processing of SXRF track maps and particle spectra are published elsewhere [4,7]. During our most recent run at APS we have pioneered a stereo-SXRF method of track mapping. This method, involves mapping the track once and then a second time, but with a 15 degree tilt. Traditional stereo imagery is conducted with a ~7 degree tilt, but due to low resolution and small structure size, a larger angle of tilt and visual deflection were chosen. Additionally, SXRD was attempted on Tracks 163 and 164, but was largely unsuccessful due to detector failure.

Results: *LSCM* - Previous LSCM investigations of Stardust cometary material in aerogel have been limited to reflection techniques [6,8]. While Stardust aerogel is known to have light fluorescent properties under UV, autofluorescence of aerogel under visible wavelengths is largely unexplored [9]. Utilizing the upgraded abilities of our LSM 710 we are able to view very faint autofluorescence of aerogel around Track 164. We observed autofluorescence when imaging with the 561nm laser; reflectance images were collected at 588nm, and fluorescence was detected in the range 578-684nm, with 597nm being the wavelength of greatest fluorescence. Options provided in software have allowed us to map the spectral properties of this fluorescence and will be used for future analyses. Fluorescence, reflective and composite confocal images can be seen in Figure 1:

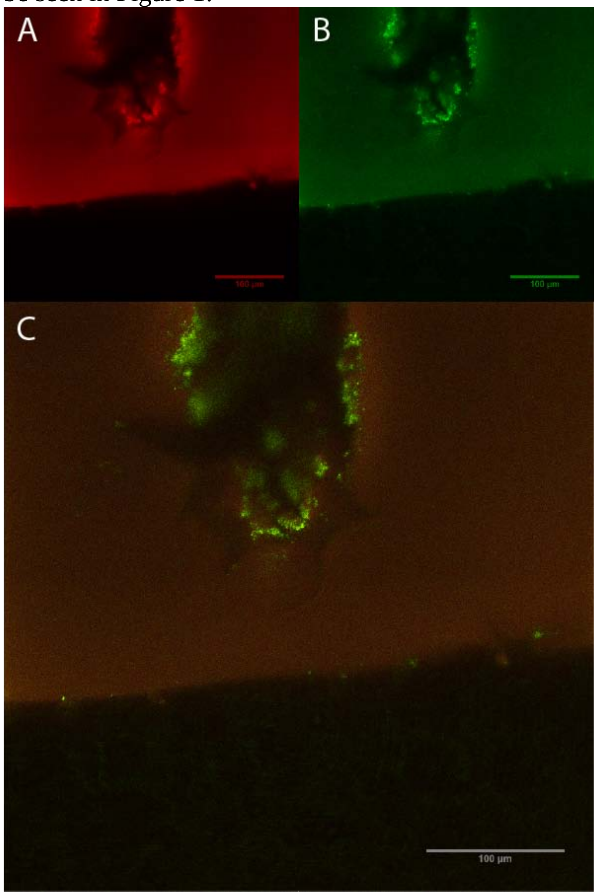

Figure 1: Fluorescent and reflective image of T164. Image shows one slice through the bulbous entrance area of the track. The keystone edge can clearly be seen at bottom of the images and the direction of impactor motion is upwards A) Image of greatest fluorescence intensity at 597nm. B) Reflectance image at 558nm C) Composite image of A and B, highlighting differences. Higher fidelity, full scale images are available online [6].

It is clear when analyzing these images that fluorescent material has large visual separation from highly reflective material. Very faint fluorescence can be seen in unaltered aerogel, at a significant distance from the track. Much higher fluorescence can be seen around track walls, indicating either aerogel compaction or silica glass. It is unclear at this moment what material in T164 is reflecting with high intensity, certainly it is not unaltered aerogel. It is possible that the highly reflective material is either submicron cometary fragments, silica glass, or a mixture of both. Subsequent calibrations of spectral and visible point spread properties of candidate materials might allow for discrimination between phases. We are currently gathering a suite of materials for characterization and subsequent spectral separation.

Stereo-SXRF - In combination with the new methods described above we have developed a Stereo-SXRF method for location and identification of stardust particles in 3-space. Figure 2 shows two SXRF maps side by side, these images can be overlaid or 'blinked' back and forth to highlight their differences. A movie of 'blinking' has been posted online at: bit.ly/T164blink .

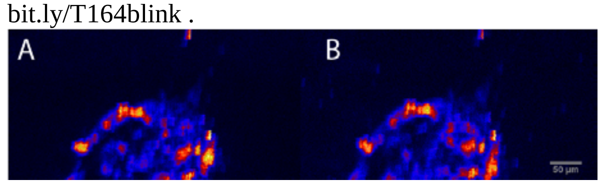

Figure 2: Fe Kα intensity SXRF maps of Track 164, top of bulbous area. A) Original Fe Kα map. B) Fe Kα map after 15 degree tilt.

Comparing the two SXRF maps it is clear that visible deflection of the particles is apparent even with a 15 degree tilt. Particles moving upward represent particles on the front of the bulb, while particles moving downwards are on the rear of the bulb. These particles, with chemical compositions mapped by SXRF can then be correlated one-to-one with previously acquired 3D LSCM images for identification and future harvesting.

Conclusions: Fluorescent properties of aerogels, and spectral properties of captured particles imaged using the LSCM are an exciting prospect, for it could lead to large-scale, non-destructive identification of particle phases along entire tracks. This development, along with Stereo-SXRF imagery, furthers our goal of non-destructive whole track characterization. Applying these new datasets in conjunction with associated modeling efforts will provide improved results in whole impactor reconstruction estimations [10,11]. In the coming months we anticipate collecting data on a large number of tracks, in an effort to create a 3D catalog of whole Stardust cometary track data.

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