AN IMPROVED EXPERIMENTAL DECOVOLUTION TECHNIQUE FOR 3-DIMENSIONAL LASER CONFOCAL MICROSCOPY OF PARTICLES IN AEROGEL. A. J. White[1,3], D. S. Ebel[1], M. Greenberg[1,2]. [1]Dept. of Earth and Planetary Sciences, American Museum of Natural History, New York, NY 10024. [2]Northwestern University, Evanston, IL 60208. [3](awhite@amnh.org).

Introduction: Aerogel is an effective capture medium for hypervelocity particles. An ultra-low-density solid, the molecular structure and transparency of aerogel allow it to capture particles impacting at hypervelocity intact and for researchers to locate the captured particles [1, 2]. Aerogel has been used successfully in past particle capture missions, including the NASA Stardust mission which returned material from comet Wild2 in 2006 [3]. It will potentially be used again in future sample return missions. Particles captured in aerogel through hypervelocity impacts create three-dimensional (3D) tracks representing unique impact events. The nature of each track-forming event, including the original state of the impactor, is recorded in 3D track morphology and material distribution. Locating single grain particle fragments and identifying true track and particle size and shape are necessary to understanding original impactor properties.

We use a Zeiss LSM 710 laser scanning confocal microscope (LSCM), located at the Microscopy and Imaging Facility of the American Museum of Natural History, to acquire high-resolution (<80nm/pixel) 3D imagery of tracks returned by the NASA Stardust mission. Using the instrument's confocal pinhole to block all unfocused light, LSCM quickly produces high-resolution 3D image stacks of particle tracks including the distribution of compressed aerogel and particles larger than 100nm without disturbing or destroying the sample.

A central goal of this work is to develop the capability of distinguishing between deposited cometary material and melted silica aerogel. Our best route toward this goal is to take advantage of aerogel fluorescence at discrete wavelengths, using the spectroscopic capabilities of the LSCM [4]. A second goal is to use 3D images, combined with synchrotron X-ray fluorescence imaging (SXRF) [5], and studies of experimental impacts, to back-calculate the nature of original impactors and impact events using hydrodynamic simulations of hypervelocity impacts in aerogel. This requires an understanding of how material is distributed throughout the track and not only in the terminal particle. Here, we report significant progress in understanding and perfecting LSCM image processing to maximize recovered information from whole cometary tracks.

Deconvolution: Deconvolving confocal images is a necessary image processing step which is required to remove distortion along the Z-axis (optic axis) of 3D images. This Z-axis aberration is due to the configuration of the optical path in any confocal microscope and must be corrected before reliable quantitative measurements can be made. For 3D deconvolution of raw image data, we use SVI's Huygens Professional v4.2 software. The Huygens' software [6] is designed to restore convoluted images using an instrumental point spread function (PSF) which can be obtained from either a theoretical calculation or through a series of measurements.

In our previous work on Stardust tracks [4,5,7-10], we have used a theoretical PSF which, while a good approximation, assumes the best alignment and imaging conditions of a confocal configuration and does not account for any deviations from the ideal set-up. In the case of particle tracks captured in aerogel, the aerogel itself is a deviation as the PSF calculation assumes samples are in air. Using a set of custom made keystones of flight grade aerogel with 100nm fluorescent beads mixed into the precursor solution, we have created a measured PSF [11] which should in principle better account for any deviations in our experimental setup and provide more accurate dimensional measurements in deconvolved images.

Comparing PSFs: In order to quantitatively compare the functionality of both the measured and theoretical PSFs, we imaged an aerogel keystone containing 500nm beads using the same LSCM scan parameters that were used to create the measured PSF. Deconvolutions using both measured and theoretical PSFs were then performed on this data. The image used in these tests consisted of an average of many different beads (10 images of individual beads and one large image of ~7 beads) which were imaged at different depths and locations within the keystone. This was done in order to reduce the effects of the background aerogel in images, limit photon noise, and to account for light/signal drop-off at deeper locations in the keystone.

Deconvolution is expected to increase an image's contrast and to bring out small spatial features by removing larger, out of focus features. This can be seen in Figure 1, which shows the 3D center of the initial raw data (a) alongside the results of both deconvolution tests (b and c). Comparing the raw data (a) with the results of a deconvolution using a theoretically determined PSF (c), one can observe how the deconvolution enhances some features from the original image; however, these features are not necessarily real. The image

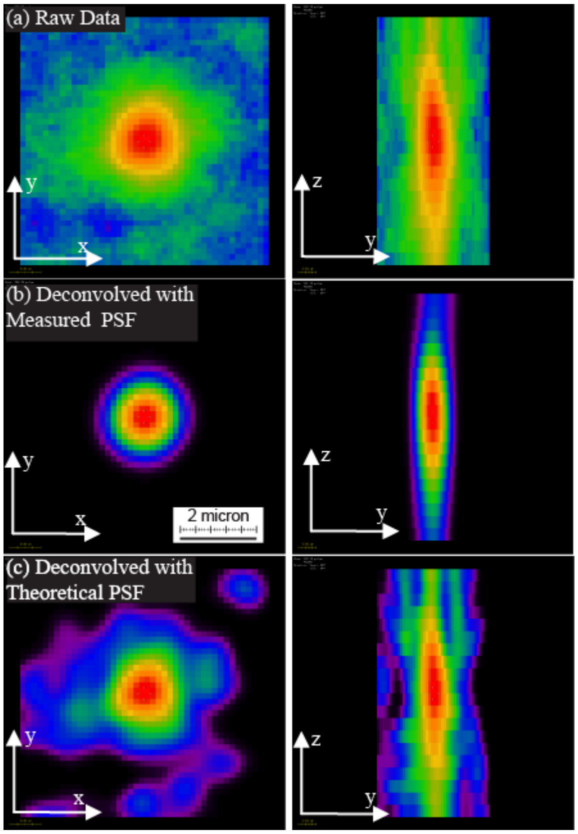

Figure 1: A side by side, same scale comparison of a 500nm fluorescent bead image before it has been processed (a), and after being deconvolved using a measured PSF (b) and a theoretical PSF (c). Both deconvolutions improve image contrast. The measured PSF (b) removes more structure from the image which is believed to be unreal and caused by reflections off background aerogel.

that was deconvolved represented a 500nm bead which is better represented by the results of the deconvolution performed using a measured PSF (b).

The extra structure could be due to a deviation from ideality in our optical setup, the aerogel that the beads are embedded in causing a mismatch of refractive indices, or a combination of the two. Both the optical setup of our instrument and the effects of the aerogel are better accounted for by the measured PSF than by the theoretical PSF. This is further shown in Figure 2 which displays the intensity profile along the Z plane and X plane for the raw data as well as the results of both deconvolution tests. In both deconvolution tests, the intensity peaks were sharper than in the raw data and a decrease in the full width half max (FWHM) was observed. The measured PSF restored much more of the image's intensity than the theoretical PSF did. As FWHM is a good estimation of spatial resolution [6], the sharper peak also indicates a greater positional accuracy for resolved grains.

References: [1] Tsou P. (1995) *J. Non-Crystal. Solids*, 186:415–27. [2] Westphal et al. (2002) *Meteoritics & Planet. Sci.*, *37*, 855-865. [3] Brownlee D. et al. (2006) *Science*, *314*, 1711-1716. [4] Greenberg M. et al. (2011) *LPSC XLII* #2640. [5] Greenberg M. et al. (2010) *LPSC XLI* #2346. [6] http://www.svi.nl/HuygensProfessional [7] Greenberg M. et al. (2008) *LPSC XXXIX* #1800. [8] Greenberg M. et al. (2010) *Geosphere*, *6*, 515-523 [9] Ebel D. S. et al. (2009) *Meteoritics & Planet. Sci.*, *44*, 1445-1463. [10] Greenberg M, and Ebel D. S. (2012) *Meteoritics & Planet Sci.*, *47*, 634-648. [11] White A.J. et al. (2012) *LPSC XLIII* #1542.

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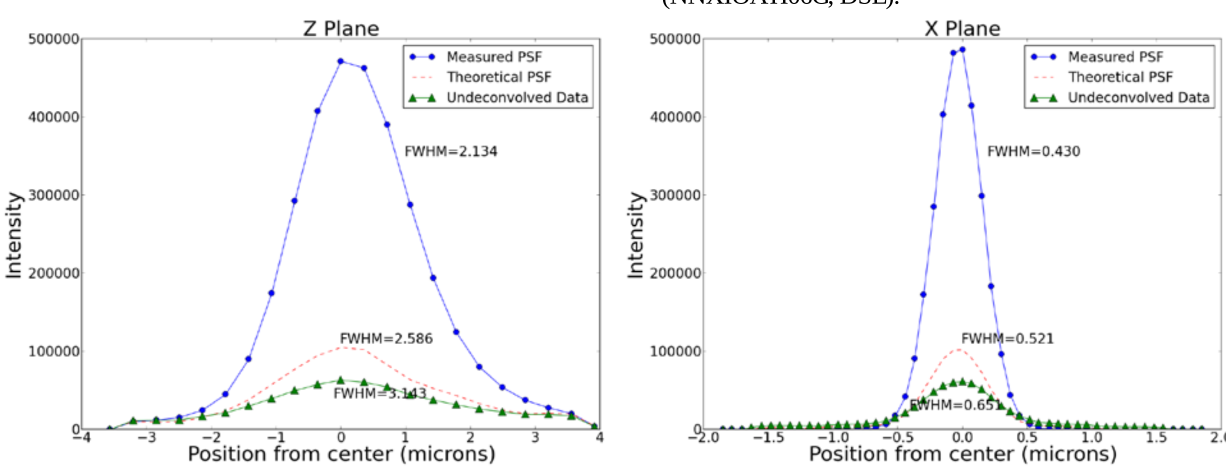

Figure 2: Intensity profiles of the deconvolved and raw data in the Z plane (left) and X Plane (right). Y plane data is nearly identical to the X plane. Both deconvolution techniques resulted in a sharper peak and smaller FWHM over the raw data. The measured PSF restored much more intensity and positional accuracy to the image than the theoretical PSF did.