A NEW EXPERIMENTAL DECONVOLUTION TECHNIQUE FOR 3-DIMENSIONAL LASER CONFOCAL MICROSCOPY OF STARDUST TRACKS IN AEROGEL.

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Introduction: The NASA Stardust mission to comet Wild 2 returned to Earth in 2006 with cometary material trapped in aerogel. The cometary particles were captured at a relative velocity of 6.1 km/s, creating three-dimensional (3D) tracks containing void space, compressed aerogel, melted aerogel, and fragmented cometary material [1]. Each track represents a unique hypervelocity impact event. The nature of each track-forming event, including the original state of the impactor, is recorded in 3D track morphology and material distribution.

We use a Zeiss LSM 710, a laser scanning confocal microscope (LSCM), located at the Microscopy and Imaging Facility in the American Museum of Natural History to acquire 3D imagery of tracks at high resolution (< 80 nm/pixel). LSCM is preferable to other methods of imaging because it quickly produces high-resolution 3D images of the distribution of compressed aerogel and particles larger than 100 nm along the track without disturbing or destroying the sample. An in-house instrument allows for easy access and rapid analysis of allocated tracks.

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 [2]. A second goal is to use 3D images, combined with synchrotron X-ray fluorescence imaging (SXRF) [3], and studies of experimental impacts, to back-calculate the nature of original impact events using hydrodynamic simulations of hypervelocity impacts in aerogel. Here, we report significant progress in understanding and perfecting LSCM image processing to maximize recovered information from whole cometary tracks.

Deconvolution Technique: Due to the configuration of the optical path in any LSCM, axial distortion occurs along the z-axis of 3D images. Removing this aberration is a necessary step in order to accurately quantify track dimensions and particle locations [4]. For 3D deconvolution of raw image data, we use SVI's Huygens Professional v4.1 software. The Huygens's Software [5] is designed to restore convoluted images using an instrumental point spread function (PSF). The PSF can be obtained from either a theoretical calculation, or by experimental investigation.

Theoretical vs. Experimental PSF. In previous work on a Zeiss LSM 510, we have used a theoretical PSF [2,3,4,6,7]. While a good approximation, the theoretical PSF only takes into account the best alignment and imaging conditions on a given microscope and does not account for any deviations from an ideal setup. As an alternative, an experimental PSF can be determined from images of very small grains of known shape and size. We have used fluorescent latex beads embedded in aerogel during its manufacture.

Because the bead images used to create the experimental PSF are obtained under the same conditions as the images of Stardust cometary tracks in aerogel, the experimental PSF accurately accounts for more variables of the experimental setup than the theoretical PSF. As shown in Figure 1, the measured experimental PSF is highly elongated in the direction of the optical axis. This implies that the alignment of lenses in our instrument may deviate from the optimal setup [5]. The elongation is also, at least partially, due to a mismatch between the refractive indices of air and aerogel. The difference of refractive indices causes distortions in the PSF; however, it is not accounted for in the theoretical calculation.

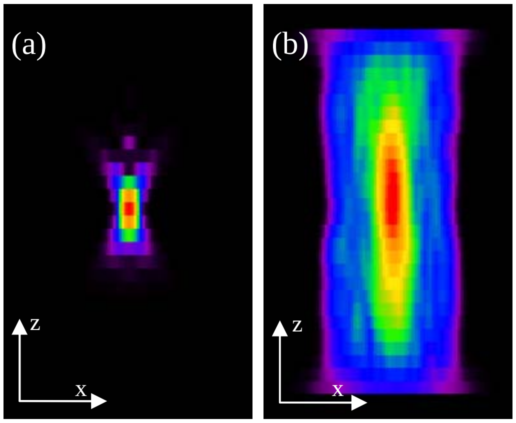
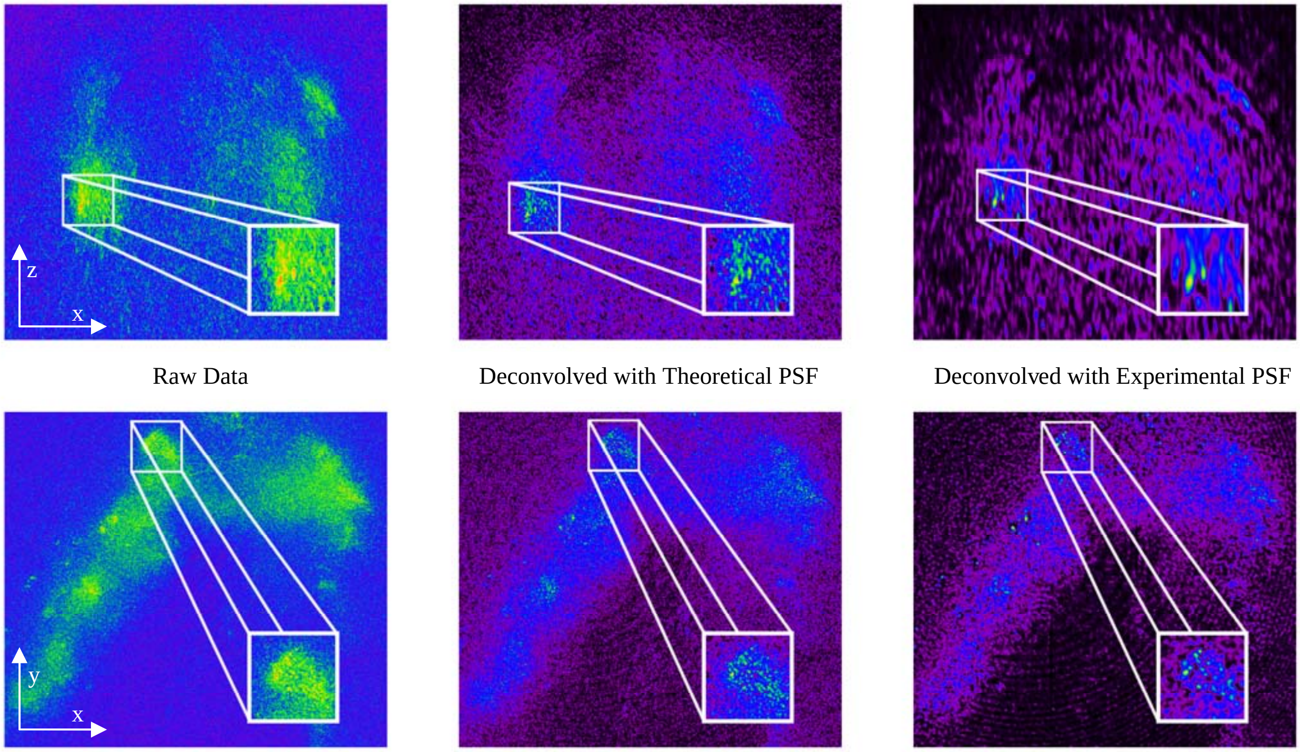


Figure 1: A side-by-side, same scale view of the theoretical PSF (a) and experimental PSF (b) in the xz plane. The experimental PSF is noticeably larger and more elongated along the optical axis (z-direction) of the instrument. The measured PSF is also less symmetrical than its theoretical counterpart. Pixels measure 80 nm x 360 nm (x by z).

Measuring an Experimental PSF. Blocks of uniform density, flight-grade aerogel with 100 nm fluorescent latex beads suspended in solution were manufactured at the Jet Propulsion Laboratory using the same methods as flown Stardust aerogel [8]. Keystones were cut from these blocks at Johnson Space Center [9]. We imaged several different beads at a



Raw Data

Deconvolved with Theoretical PSF

Deconvolved with Experimental PSF

Figure 2: Above is a particle from Track 169 viewed in both the xz and xy planes as well as in the raw, deconvolved with a theoretical 3D PSF, and deconvolved with an experimental PSF data sets.

voxel (3D pixel) size of 80 x 80 x 360 nm. Bead images were averaged together, and the PSF (Figure 1b) distilled from that average, all within the Huygens Software.

Results: We performed several LSCM scans of Stardust Track 169 (C2088,1,169,0,0) using the same voxel resolution and microscope parameters used to create the experimental PSF. Deconvolutions using both theoretical and experimental PSFs were then tested with this data. Figure 2 illustrates the results. The first panel in each column shows raw data from Track 169, the following columns show the same data after a deconvolution has been performed using a theoretical PSF and an experimental PSF, respectively. The top row displays a specific slice of Track 169 in the xz plane and the bottom row displays an orthogonal slice in the xy plane. The same region of interest is enlarged in each image. From these different views, it is easily seen how performing deconvolution is an essential first step in identifying grains. Both deconvolutions remove excess noise and sharpen grain outlines. The theoretical PSF over-sharpens, making the two grains of the experimental PSF image appear as three, more pixilated grains.

Future Work: We have successfully measured and used an experimental 3D PSF. We will now be able to better quantitatively constrain the size and location of reflective single grains in aerogel. This will allow for more accurate measurements of track morphology and grain location and size. We are now poised to explore the spectroscopic capabilities of the LSM 710 and identify previously missed particles. Using the natural fluorescence of aerogel and LSCM spectroscopy, our goal is to identify the difference between cometary material and melted aerogel as well as identify the composition of cometary material. These techniques can be tested using well controlled analog tracks.

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