PHOTOEMISSION ELECTRON MICROSCOPY OF STARDUST COMETARY FOILS. R. C. Ogliore[1], A. L. Butterworth[1], A. Doran[2], Z. Gainsforth[1], A. Scholl[2], A. J. Westphal[1], and A. Young[2], [1]Space Sciences Laboratory, U. C. Berkeley, Berkeley, CA 94720, USA, [2]Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Introduction

Stardust samples have been studied using a wide variety of analytical techniques. We report results on an instrument that lends unique insight into the samples of comet Wild2 collected in the Stardust cometary foils: photoemission electron microscopy (PEEM). PEEM also has the advantage of minimal C deposition on samples as compared with e-beam techniques.

Methods

Photoemission electron microscopy (PEEM) instruments image electrons photoemitted from samples illuminated by x-rays from a synchrotron. PEEM can be thought of as the x-ray equivalent of Auger electron spectroscopy. An image of the emitted electrons is produced by accelerating them through an electric potential and focusing them with electron optics (magnetic and electrostatic lenses). The image is recorded with a CCD. PEEM is a surface technique, probing a few nm into the sample, as the emitted electrons originating deeper into the sample are absorbed.

The PEEM microscope used in this study was PEEM-3 at the Advanced Light Source [1]. With an energy resolution E/ΔE of 4000 and an energy range of 100–2000 eV, the PEEM3 microscope can obtain x-ray absorption near-edge structure (XANES) spectra of Si, O, Ca, Mg, C, Cr, Ti, Fe and other elements likely to be present in cometary and interstellar dust. The spatial resolution is $\sim$50 nm.

Impacts into foils can be analyzed by PEEM with minimal sample manipulation because the foil provides the conducting medium required to replenish photoemitted electrons. An ideal PEEM sample is flat – the surface acts as the first element in the electron optics chain. A 10μm-sized impact crater into Al foil will cause the final image to be somewhat distorted so spatial resolution can be compromised.

We analyzed two sections of foil: C2044N,3 contains 3 craters 12 μm in diameter and one double crater $\sim$4 μm across, and C2103W,1 which contains one large crater 23 μm across. We found PEEM-3 to be more effective in analyzing the smaller craters. While we were able to obtain information on material at the bottom of the large crater, the depth of the crater required a sacrifice in spatial resolution. Here we report results from PEEM analysis of the double crater in foil C2044N,3.

Results

We detected significant amounts of Fe and Mg inside the two craters, as well as Si slightly above background. We detected no significant material on the lips of the crater, nor did we detect any material that had been ejected onto the surrounding Al foil. The smaller crater (right-hand crater in Figure 1) contains about the same amount of Fe as the larger crater (left-hand crater in Figure 1), but less than half as much Mg.

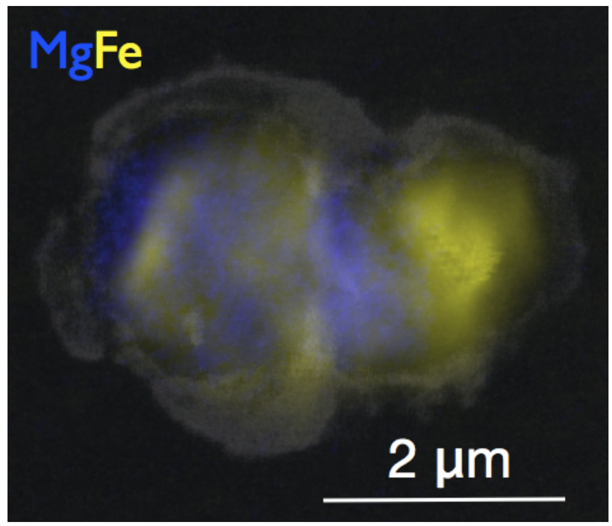

Figure 1: SEM image of the double crater in C2044N,3 (courtesy of F. Stadermann, Wash. Univ.) overlaid with PEEM maps of Mg (blue) and Fe (yellow).

We can investigate the nature of this presumed double impactor with PEEM: was it two separate cometary particles of different composition, held together until impact, or was it a particle of uniform composition that broke apart and created two craters immediately upon hitting the foil?

We acquired Fe L-edge XANES and Mg K-edge XANES on the double crater. Since PEEM-3 is a full-field instrument, we are able to analyze small regions of the field of view separately after the data has been acquired, given sufficient statistics. A comparison of the Fe and Mg XANES for the left and right crater is shown in Figure 2. The spectra for the left crater look very similar to the spectra for the right crater (the difference between Fe and Mg XANES spectra for different minerals is much greater than the differences seen in Figure 2). Additionally, we detected the same elements (Mg, Fe, Si) in both craters. We conclude that the craters contain residue of similar composition. The double crater was likely created by an impactor with a well-defined bulk composition that broke apart upon hitting the foil.

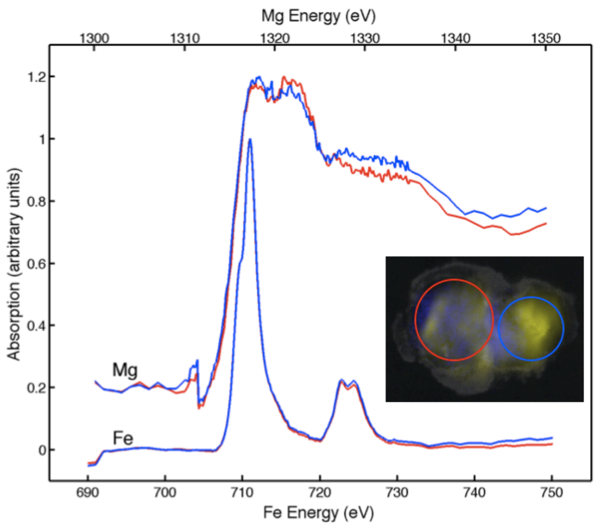

Figure 2: Fe L-edge XANES (lower abscissa) and Mg K-edge XANES (upper abscissa) for the left crater (red curve) and the right crater (blue curve). Mg spectra are shifted vertically for clarity.

Cometary particles impacted the Al foil on the Stardust collector at 6.1 km/s, creating craters and dramatically altering the original impactor under great heat and pressure for a short duration. The original particle could melt, and the impactor could transform from crystalline to amorphous. Thompson [2] studied the effect of thermal annealing on the XANES of amorphous silicates of various composition. Comparing this work with our Mg XANES for the double crater (which cooled much faster than the silicates in [2]), we find that our spectrum is most consistent (in a least-squares sense) to an amorphous silicate of forsteritic olivine composition heated to (at least) 1300 K.

PEEM-3 for Analysis of Interstellar Candidate Foil Craters

To determine how much C is deposited by PEEM-3, we acquired C XANES before we began analysis of the double crater, and again after we finished. We found that there was no increase in the amount of C deposited on the sample. We could see a small increase in C in the region of the foil that was previously scanned by SEM compared to elsewhere on the foil, but even with about 20 hours of sample illumination, PEEM-3 did not appear to contaminate the sample further.

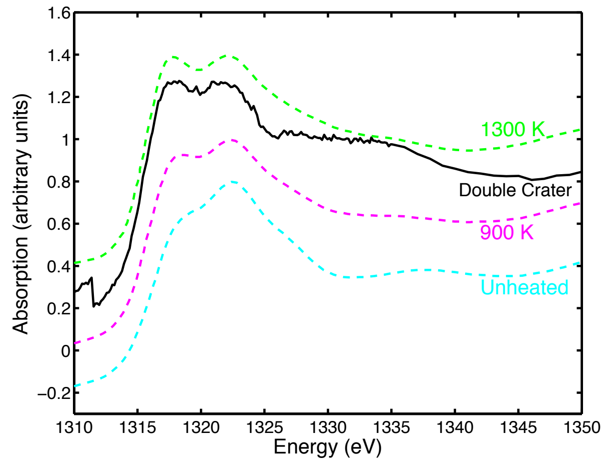

Figure 3: Mg XANES from the entire double crater (black curve) compared to spectra of an amorphous silicate of forsteritic olivine composition heated to various temperatures (data from [2]). Spectra are shifted vertically for clarity.

Initial analysis of identified Stardust interstellar candidate craters requires a technique that can analyze small, μm-sized craters with as little damage as possible to the sample. PEEM-3 may be ideally suited for this task – quantitative assessment of C deposition rates will answer this question.

Acknowledgements

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References

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[2] Thompson, S. P., A&A, 484, 251 (2008)