

**CHARACTERIZATION OF EARLY SOLAR SYSTEM ORGANIC MATTER IN PRIMITIVE INTERPLANETARY DUST PARTICLES.** George J. Flynn<sup>1</sup>, Sue Wirick<sup>2</sup> and Lindsay P. Keller<sup>3</sup>, Dept. of Physics, SUNY-Plattsburgh, 101 Broad Street, Plattsburgh, NY 12901 (george.flynn@plattsburgh.edu), <sup>2</sup>CARS, University of Chicago, Chicago IL 60637, <sup>3</sup>NASA Johnson Space Center, NASA Parkway, Houston, TX 77058.

**Introduction:** The chondritic porous interplanetary dust particles (CP IDPs), asteroid and comet dust collected by NASA from the Earth's stratosphere, have experienced minimal aqueous or thermal alteration since their formation. These CP IDPs are the best preserved samples of the minerals and organic matter that was present in the primitive Solar Nebula currently available for laboratory analysis [1]. The ~10  $\mu\text{m}$  CP IDPs are aggregates of tens-of-thousands of mostly sub-micron grains of diverse compositions and mineralogies. Many of the individual mineral grains are coated by 50 to 200 nm thick rims of carbonaceous material (Fig. 1). Other carbonaceous material occurs as larger, discrete subunits in the IDPs [2]. We characterize the carbonaceous material using high-resolution, synchrotron-based instruments: a Scanning Transmission X-ray Microscope (STXM) to locate and map the carbon and to identify its major functional groups by X-ray Absorption Near-Edge Structure (XANES) spectroscopy, and a micro-Fourier Transform Infrared ( $\mu$ -FTIR) spectrometer to further characterize the functional groups by mid-infrared spectroscopy.

**Results:** Carbon-XANES spectroscopy identifies the rims coating the individual grains in CP IDPs as organic matter, dominated by the C=C, likely C-rings, and the C=O functional groups [3]. This structure, with the organic rims being the contact surfaces between the grains, implies a 3-step formation sequence: grain condensation, organic rim emplacement, and, finally, aggregation of the grains to form the dust particles. This indicates that these organic rims formed very early in the evolution of the Solar Nebula, after grain condensation but before grain aggregation [3].

These organic rims coat grains of diverse compositions, including silicates, sulfides, and carbonates, which is inconsistent with formation by Fischer-Tropsch-like, mineral-specific catalysis, one of the mechanisms suggested for the formation of primitive organic matter. Our observations are consistent with an alternate model where carbon-bearing ices condense on the surfaces of grains, the ices are irradiated by ionizing radiation, and subsequent heating removes the ices leaving more refractory organic matter on the grain surfaces, as described by Bernstein et al. [4].

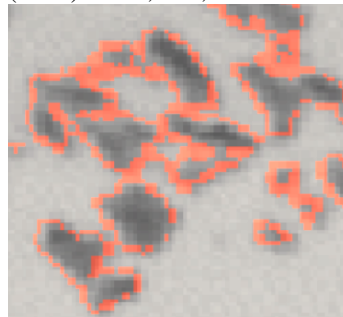
In one case we obtained C-, N-, and O-XANES spectra on the rim material. The O-XANES confirmed the presence of C=O. We found high N:C and O:C ratios that plot on the extension of the N:C vs. O:C

correlation line, found in analysis of meteoritic organic matter [5], towards even more primitive organic matter than found in any meteorite.

The organic rims are too thin for  $\mu$ -FTIR spectroscopy, which is diffraction limited to about the wavelength/2, or ~2  $\mu\text{m}$  for the aliphatic C-H stretching features. However, mid-infrared spectra obtained on CP IDPs show the presence of aliphatic C-H, C=O, C-C, and O-H, as well as crystalline and amorphous silicates [6]. Aromatic C-H is rarely detected in CP IDPs. Neither the organic rims nor the bulk organic matter in CP IDPs show the graphite exciton feature, whose strength in meteorite organic matter correlates with increasing parent body thermal metamorphism [7], indicating the organic matter in CP IDPs experienced minimal metamorphism after it formed. The spectra show variation in the aliphatic -C-H<sub>2</sub>- to -C-H<sub>3</sub> and C=O to aliphatic C-H ratios from spot to spot on the same particle. C-XANES of ultramicrotome sections of CP IDPs also show significant variability, particularly in the C=O to C=C ratio. Variability in the C-XANES and the mid-infrared spectra indicates the organic matter in primitive CP IDPs consists of several compositionally distinct components.

**Conclusions:** Our results indicate *the organic matter in CP IDPs is extremely primitive and that much of the pre-biotic organic matter of our Solar System formed early in the evolution of the Solar Nebula, by a process that preceded parent body aqueous activity.*

**References:** [1] Ishii, H. A. et al. (2008) *Science*, 319, 447-450. [2] Thomas, K. L. et al. (1996) *ASP Conference Series*, 104, 295-298. [3] Flynn, G. J. et al. (2013) *Earth, Planets and Space*, 65, 1159-1166. [4] Bernstein, M. P. et al. (1995) *Astrophys. J.*, 454, 327-344. [5] Sandford et al. (2006) *Science*, 314, 1720-1724. [6] Flynn, G. J. et al. (2003) *Geochim. Cosmochim. Acta*, 67, 4791-4806. [7] Cody, G. D. et al. (2008) *EPSL*, 272, 446-455.



**Figure 1:** ~25 nm per pixel x-ray absorption image of L2011\*B6, showing mineral grains (dark gray) with the organic matter (red) superimposed.