

**CORRELATED MICROANALYSIS OF COMETARY ORGANIC GRAINS RETURNED BY STARDUST.**

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**Introduction:** Preliminary examination (PE) of samples returned from Comet 81P/Wild 2 by the NASA Stardust mission revealed a wide variety of carbonaceous samples [e.g. 1]. Carbonaceous matter is present as inclusions, rinds, and films in polymineralic terminal particles [2-4], as carbon-rich particles along track walls [2, 5, 6], and as organic matter in aerogel around tracks [7, 8]. The organic chemistry of these samples ranges from purely aliphatic hydrocarbons to highly-aromatic material, often modified by various organic functional groups [2, 4, 5, 9-11].

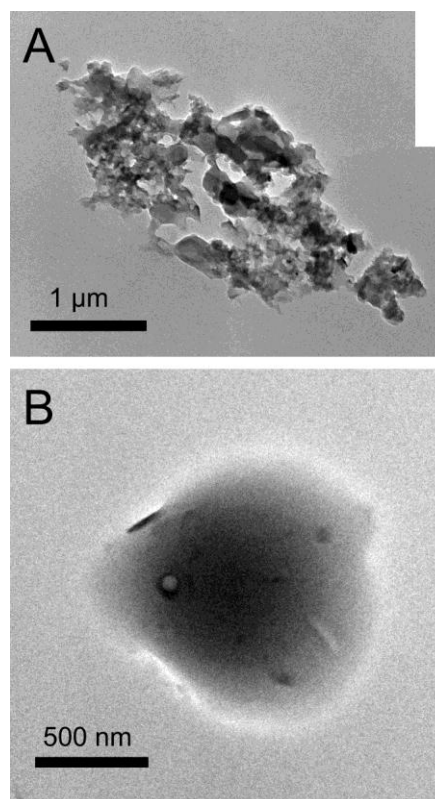
Difficulty arises when interpreting the genesis of these carbonaceous samples, since contaminants could be introduced from the spacecraft [12], aerogel [1, 8], or during sample preparation. In addition, hypervelocity capture into aerogel may have heated cometary material in excess of 1000 °C, which could have significantly altered the structure and chemistry of carbonaceous matter. Fortunately, much of this contamination or alteration can be identified through correlated microanalysis with transmission electron microscopy (TEM), scanning-transmission X-ray microscopy (STXM), and nanoscale secondary ion mass spectroscopy (SIMS).

**Methods:** Six PE samples, previously described in [2] were selected for further analysis. Three additional particles from the wall of Track 80 were embedded in sulfur and ultramicrotomed. All TEM was performed with a JEOL 2200FS 200 keV field-emission microscope at the Naval Research Laboratory. X-ray absorption near-edge structure spectroscopy (XANES) and STXM was performed at beam line X1A1 at the National Synchrotron Light Source, at beam line 5.3.2 at the Advanced Light Source, and at beam line 10ID-1 at the Canadian Light Source. All SIMS was performed with a Cameca NanoSIMS 50L ion microprobe at the Carnegie Institution of Washington.

**Results and Discussion:** Cometary material can be identified on the basis of <sup>15</sup>N and/or D isotopic excesses outside the range of terrestrial samples. Two samples in this study (FC9,0,13,1,5 and C2092,6,80,43,2) have such associated isotope anomalies. In both samples the cometary organic matter is free of other mineral material and contains little to no aerogel (although adjacent microtome sections of FC9,0,13,1,5 contain enstatite). XANES indicates that

both samples contain polyaromatic amorphous carbon with abundant carbonyl (C=O) functional groups [2, 11]. The XANES spectral features are similar to those for insoluble organic matter (IOM) from primitive meteorites and interplanetary dust particles (IDPs), although the cometary organics appear to contain slightly less aromatic carbon and slightly more carbonyl groups.

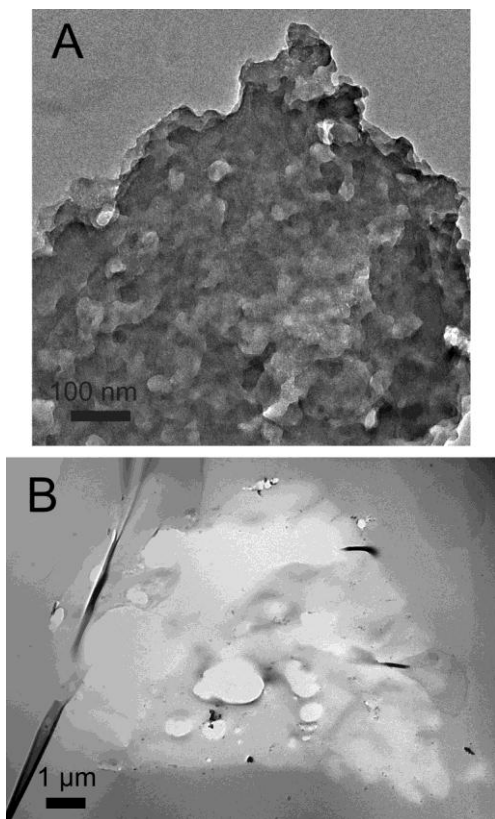
*Aromatic cometary organics.* Two samples (C2092,6,80,43,2 and C2092,6,80,41,1) contained spherical carbonaceous features. XANES of these features revealed highly aromatic organic matter with only small amounts of carbonyl groups. NanoSIMS measurements of C2092,6,80,43,2 revealed a <sup>15</sup>N excess of  $+1120 \pm 30\%$ , clearly indicating a cometary origin [11]. Unfortunately sample C2092,6,80,41,1 did not contain enough N to make a similar measurement.



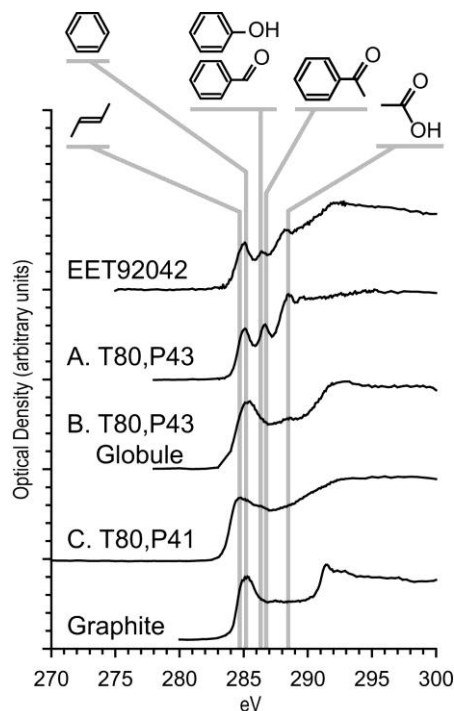
**Figure 1.** TEM images of (A) IOM-like cometary organic matter in sample C2092,6,80,43,2 and (B) a highly-aromatic feature in sample C2092,6,80,41,1.

However, Comet Wild 2 does contain a highly aromatic globular component with striking morphological and chemical similarities to organic nanoglobules in primitive meteorites and IDPs [11].

*Aliphatic cometary organics.* XANES from several PE samples indicated a predominantly aliphatic organic chemistry [2]. XANES of samples from Track 35 (C2054,0,35,32,8 and C2054,0,35,32,10) also indicated high Si/C [2]. Subsequent TEM revealed mixtures of densified aerogel and organic matter. We interpret this material as relatively labile cometary organic matter infiltrating aerogel during capture. Alternatively, these samples may contain heavy contamination intrinsic to the aerogel, as interpreted for other Track 35 samples [8]. Aliphatic O-rich organic matter was also observed in a few samples mixed with the surrounding epoxy [2]. We believe that this aliphatic organic matter is cometary and was extracted out of the terminal particle during embedding. Based on these interpretations, it is likely that Comet Wild 2 includes a significant aliphatic component, but this component is difficult to isolate in Stardust samples from the surrounding aerogel or epoxy, into which it can migrate.



**Figure 2.** TEM images of (A) aerogel infiltrated by cometary organic matter (C2054,0,35,32,8) and (B) cometary organics mixed with epoxy (FC12,0,16,1,10).



**Figure 3.** XANES of samples from Stardust Track 80, compared with IOM from the primitive chondrite Elephant Moraine (EET) 92042 and a graphite standard.

*N-rich organic contaminants.* We analyzed three N-rich carbonaceous samples ( $N/C > \sim 0.15$ ), but our observations suggest that all samples (FC3,0,2,4,5, C2115,24,22,1,5 and a section on C2092,6,80,43,2) contain contaminants. Aside from their N-rich chemistry, the latter two samples contain embedded Fe-, Ti-, Si-, Zr-, and Al-bearing nanoparticles. Sample FC3,0,2,4,5 exhibits similar XANES spectral features as cyanoacrylate adhesive used during sample preparation [11]. These kinds of organic contaminants are not included in [12], but samples with similar chemistry and morphology were described in [4]. In future studies, N-rich organic matter in Stardust samples should be closely scrutinized for evidence of contamination.

**References:** [1] Sandford, S. A. et al. (2006) *Science*, 314, 1720-1724. [2] Cody, G. D. et al. (2008) *M&PS*, 43, 353-365. [3] Matrajt, G. et al. (2008) *M&PS*, 43, 315-334. [4] Wirick, S. et al. (2009) *M&PS*, 44, 1611-1626. [5] Rotundi, A. et al. (2008) *M&PS*, 43, 367-397. [6] Gallien, J.-P. et al. (2008) *M&PS*, 43, 335-351. [7] Bajt, S. et al. (2009) *M&PS*, 44, 471-484. [8] Muñoz Caro, G. M. et al. (2008) *A&A*, 485, 743-751. [9] Keller, L. P. et al. (2006) *Science*, 314, 1728-1731. [10] Clemett, S. J. et al. (2010) *M&PS*, 45, 701-722. [11] De Gregorio et al. (2010) *GCA*, 74, 4454-4470. [12] Sandford, S. A. et al. (2010) *M&PS*, 45, 406-433.