

**METAL CONTENT OF A GIANT CLUSTER INTERPLANETARY DUST PARTICLE.** A. J. Westphal, A. L. Butterworth, Z. Gainsforth, *Space Sciences Laboratory, U. C. Berkeley, 7 Gauss Way, Berkeley CA 94720-7450.*

**Introduction:** Although chondritic-porous interplanetary dust particles (CP-IDPs), collected in the stratosphere, are thought to originate from comets, there appear to be significant differences between them and *bona fide* cometary particles collected by the Stardust mission from the Jupiter-family comet 81P/Wild 2. Metal content is one such difference: Wild 2 contains abundant metal[1], while small CP-IDPs contain relatively little[2]. The difference may be due to intrinsic differences between Wild 2 and the CP-IDP parent bodies: such a difference might be due to radial heterogeneity in the structure of comets, or difference between comets. In principle, two confounding selection effects could also be responsible for the difference: metal might be oxidized to magnetite during atmospheric entry, and metal-rich CP-IDPs might be preferentially selected against during high-altitude collection due to smaller residence times in the stratosphere. Here we investigate these two possible confounding effects by measuring the oxidation state of Fe in a giant cluster IDP. The abundance of magnetite sets an upper limit on metal loss due to atmospheric oxidation during entry, and the selection effect due to residence time should be strongly mitigated in giant cluster CP-IDPs as compared with small ( $<30\mu\text{m}$ ) individual CP-IDPs[2].

**Methods:** Particles were extracted from cluster 28 from the L2071 collector at NASA/Johnson Space Center. These particles had been collected in the stratosphere in silicone oil, so were transferred to a Nucleopore filter and were washed in hexane. The particles were then prepared for shipping by placing the filter in its graphite frame on dry ice, and dropping a single drop of 1-hexanol on the filter. 1-hexanol freezes above the temperature of dry ice. The filter was placed in a glass vial and was shipped to U. C. Berkeley packed in dry ice. After receipt in Berkeley, the filter was removed from dry ice, and placed in an  $\text{N}_2(\text{g})$  purge, and allowed to warm to room temperature. The 1-hexanol evaporated within a few hours.

We analyzed the particles directly on the Nucleopore filter on beamline 10.3.2 at the Advanced Light Source at Lawrence Berkeley National Laboratory. We used a monochromatic 10 keV X-ray beam, focussed to a  $6\mu\text{m}$  by  $6\mu\text{m}$  spot, and an X-ray fluorescence detector to identify Fe-rich particles on the filter. We automatically collected X-ray Absorption Near-Edge Structure (XANES) spectra for 96 of the identified particles, using the “quickXANES” mode, in which individual spectra are acquired rapidly, then summed in analysis. This approach reduces problems with sample drift during data acquisition. We maximized the number of particles analyzed by taking fewer spectra on each point ( $N=4$ ) than would be acquired in a high-statistics (e.g., EXAFS) analysis, using the standard energy profile defined for Fe K-edge XANES at 10.3.2. Because the particles were well-dispersed on the filter, given the same available analysis time, this approach produced a better result than collecting a few energy steps per pixel in chemical mapping mode [7] of a large area.

**Analysis:** The nucleopore filter exhibited a small, uniform

background Fe signal, which was subtracted from the particle spectra. We fit the background-subtracted spectra using a non-negative least-squared fitting algorithm in MATLAB, `lsqnonneg`, to a library of 54 Fe XANES spectra. The library includes metals, sulfides, magnetite, and numerous  $\text{Fe}^{2+}$ - and  $\text{Fe}^{3+}$ -bearing minerals and glasses. We rejected 7 analyses based on their weak intensity; these particles may have moved during the course of the analysis. Our results were insensitive to the choice in brightness cut.

Using the 89 measurements of metal or magnetite fraction for the particles that passed the intensity cut, we calculated confidence limits in the content of the cluster IDP using a Monte Carlo bootstrap method: in 10,000 trials, we drew random sets from the ensemble of 89 measurements, and in each trial, we calculated the metal or magnetite fraction. This method assumes only that the distribution of content in the subset of particles is representative of the overall distribution for the cluster. When the resulting distribution is sorted in increasing value, the mean is rank 5000,  $2\sigma$  lower limit is rank 450, and the  $2\sigma$  upper limit is rank 9550.

**Results:** Confidence limits for the metal, magnetite and combined metal and magnetite fractions are given in Table 1. We also compare in Fig. 1 the summed absorption spectrum, weighted by the Fe abundance for each point, to the averaged absorption spectra in our standards library.

Fe fraction	mean	$2\sigma$ lower limit	$2\sigma$ upper limit
metal	5.6%	3.3%	8.4%
magnetite	1.8%	0.8%	3.1%
metal + magnetite	7.5%	4.7%	10.6%

Table 1: Fe fractions in metal and magnetite in L2071 cluster 28.

**Discussion:** The fraction of Fe in metal, in magnetite, and jointly in metal and magnetite, are all significantly smaller than the metal fraction measured in Stardust samples of 81P/Wild 2. We conclude that the formation of magnetite during atmospheric entry cannot explain the difference, because even the  $2\sigma$  upper limit on the joint probability is inconsistent with the confidence interval on the metal fraction observed in Wild 2[1]. The magnetite, however, may be indigenous to the particles: magnetite has been reported in cometary Wild 2 samples[6]. If so, the indigenous metal fraction in this particle is even more

discrepant with the metal fraction in Wild 2.

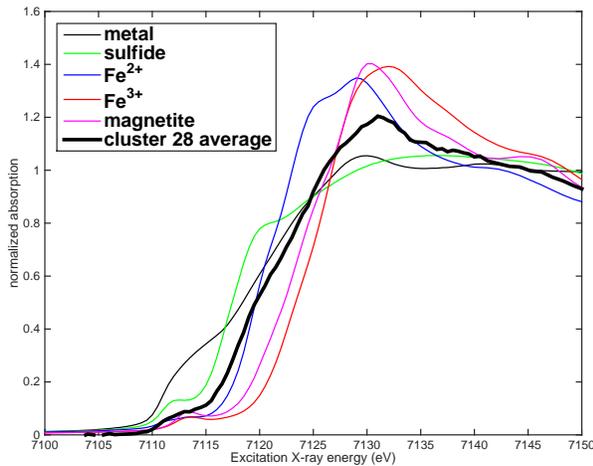


Fig. 1: Comparison of the summed Fe K-edge absorption spectrum of L2071c128 with the average absorption spectra of standards in our library.

We confirm the theoretical argument presented in Ogliore *et al.*[2] that a selection bias against collection of metal-rich IDPs is unlikely to explain the difference. Giant cluster IDPs are  $\gg 100$  times larger than isolated CP-IDPs identified in the stratospheric collectors, so the random fluctuations in metal content would be expected to be  $> (\sqrt{100} = 10)$  times smaller. A remaining possible confounding effect, however, is that metal particles in IDPs preferentially separate during atmospheric entry. Their relatively short residence time in the stratosphere might reduce their collection efficiency, and they might not be recognized readily on the collecting plates. An *in situ* synchrotron survey of apparently blank areas on collection flags might test this hypothesis.

Previously, Flynn *et al.* conducted surveys of four large anhydrous cluster IDPs[3]. In all four, no metal was reported initially, but later a single pixel in the map of one of the four, L2009R2, was found to be consistent with Fe metal. The resulting nominal metal fraction of L2009R2 was 14-21%, depending on which minerals were included [4], but Flynn *et al.* did not report statistical confidence intervals for metal content, so a quantitative comparison with our results is not yet possible. A specific analysis for magnetite was not reported, but the relative large abundance of  $\text{Fe}^{3+}$  in one Zn-depleted IDP led to the inference that atmospheric heating might have

lowered its metal content by conversion to magnetite. Setting this particle aside, it appears that one of four giant cluster IDPs surveyed so far contains metal.

The diversity of metal content among particles of definite or probable cometary origin seems to point to a surprising diversity among comets. The collection statistics are still too poor to test the hypothesis that there is a systematic difference between IDPs and Wild 2. If most CP-IDPs are metal poor, in contrast to the Stardust samples from Wild 2, this may indicate a sampling bias between CP-IDPs and Stardust samples. Nesvorný *et al.*[5] have suggested that interplanetary dust particles principally originate from disrupted Jupiter-family comets (JFCs). In this model, CP-IDPs sample the bulk of JFCs, including their cores. In contrast, Stardust collected particles from the coma of Wild 2, which probably originate within the thermal skin depth of the comet, no more than 10 m below the surface. This veneer of material may have accreted as the final stage of cometary growth, and thus have been “contaminated” with inner solar-system materials, such as microchondrules (e.g., [8]) and micro-CAIs (e.g., [9]). Thus, a systematic difference between CP-IDPs and Wild 2 samples, if confirmed through the analyses of many more CP-IDPs, may shed light not only on the extent but also the relative timing of large-scale transport of materials in the early solar system.

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