

**COMPARING THE OXIDATION STATE OF FE IN COMET 81P/WILD 2 AND CP-IDPS** R. C. Ogliore<sup>1</sup>, A. L. Butterworth<sup>1</sup>, S. C. Fakra<sup>2</sup>, Z. Gainsforth<sup>1</sup>, M. A. Marcus<sup>2</sup>, and A. J. Westphal<sup>1</sup>, <sup>1</sup>Space Sciences Laboratory, U. C. Berkeley, Berkeley, CA 94720, USA, <sup>2</sup>Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

### Introduction

Chondritic-porous interplanetary dust particles (CP-IDPs) are widely thought to originate in comets [1]. The collisional history of asteroids makes it unlikely that these fragile particles are asteroidal [2]. Cometary material is thought to be made of porous aggregates of small grains which is consistent with the structure of CP-IDPs. The atmospheric entry speed of CP-IDPs (deduced from heat alteration of the stratospherically collected particles) is consistent with cometary, rather than asteroidal, orbits [3]. Anhydrous CP-IDPs, showing very little parent-body alteration, originate from either anhydrous objects or hydrous objects that have been kept at very low temperature, again consistent with a cometary origin. With the return of cometary samples by NASA's Stardust mission, it is now possible to compare CP-IDPs with material from comet Wild 2. Ishii et al. [5] reported several differences between CP-IDPs and the Wild 2 material such as a lack of GEMS and elongated enstatite whiskers and platelets. They concluded that the Wild 2 material was dissimilar to CP-IDPs and more closely resembled asteroidal material.

Meteorite groups are distinguished from each other by their differing Fe oxidation states, as Urey and Craig first reported more than fifty years ago [10]. We report on the oxidation state of Fe in 15 CP-IDPs, and directly compare these measurements to the Fe oxidation state of comet Wild 2, deduced from 194 Stardust fragments in 11 aerogel tracks.

### Methods

We identified 15 CP-IDPs in volumes 16 and 17 of the Cosmic Dust Catalogs (Johnson Space Center, Astromaterials Acquisition and Curation Office). These particles, collected in the stratosphere, have been identified as having an extraterrestrial origin. We chose particles with approximately chondritic composition as shown in the catalog's energy dispersive X-ray spectra. Additionally, we required the particles to appear highly porous in the SEM images supplied in the Cosmic Dust Catalogs.

Eleven Stardust tracks were selected at random. Within these tracks, we acquired Fe K-edge micro x-ray absorption near-edge structure ( $\mu$ XANES) spectroscopy on 194 fragments. Details are given in [11]. The measurements were performed on beamline 10.3.2 at the Advanced Light Source synchrotron [7]. The fragments

were selected as the richest Fe-bearing spots in the track, and varied in size from one to several  $\mu\text{m}$  in size.

The absorption edge for multivalent elements varies strongly with oxidation state. Exploiting this fact, XANES can be used to determine oxidation state with high confidence [12]. We employ Fe XANES to determine the Fe oxidation state of the 194 Stardust fragments and the 15 CP-IDPs. We did this by fitting the Fe  $\mu$ XANES data to a library of 51 Fe-bearing mineral standards from 20 mineral groups. The mineral standards can be categorized as  $\text{Fe}^0$ , sulfide,  $\text{Fe}^{2+}$ , and  $\text{Fe}^{3+}$ , and therefore the relative fraction of Fe atoms in each of these states is determined for an unknown cometary particle or CP-IDP. Because we use the same beamline and very similar experimental conditions, the Fe oxidation state of the cometary material can be directly compared to that of our sample of CP-IDPs. Confidence limits were de-

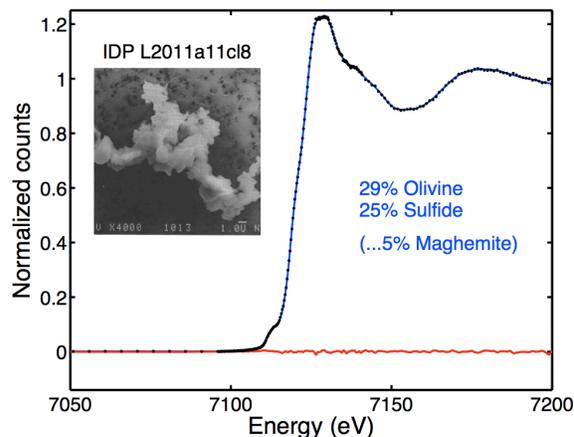


Figure 1: Fe K-edge XANES spectrum for a CP-IDP (SEM image from Cosmic Dust Catalog #16) is shown by black dots, its fit to mineral standards is shown in blue, the residual is shown in red.

termined using the bootstrap method [4], a Monte Carlo based approach that is appropriate to use when the dispersion and mean of the data is not known a priori. This method is equivalent to asking: How different would the result be if we looked at a different set of 15 CP-IDPs chosen from the same ensemble? After calculating the mean contribution of  $\text{Fe}^0$ , sulfides, and oxides from  $10^5$  such trials, we took as our  $2\sigma$  allowed region the convex hull in the space defined by the Fe oxidation state that contained 95.45% of the  $10^5$  numerical trials. Similarly,

we calculated this region for the cometary particles in the 11 Stardust tracks.

## Results

An additional IDP not included in our final analysis is IDP L2021-A7. The Fe XANES spectrum of L2021-A7 fit predominantly to ferrihydrite, so we conclude that it is likely a hydrated CP-IDP and exclude it from our data set. The remaining 15 CP-IDPs are not consistent with significant amounts of any of our hydrated Fe-bearing mineral standards; this is consistent with the hypothesis that these are anhydrous.

About 5% of the total CP-IDP Fe XANES contribution is maghemite and magnetite. The presence of these phases is evidence of heating upon entry into the atmosphere [6, 9]. We assume that this material was originally either sulfide or oxide. The ternary plot of the fraction of  $\text{Fe}^0$  vs. sulfides vs. oxidized Fe (silicates, oxides, etc.) for CP-IDPs, the Stardust tracks, and various meteorite groups is shown in Figure 2. The regions for our measurements of CP-IDPs and Wild 2 correspond to  $2\sigma$  uncertainties, as described above. If the magnetite and maghemite was originally sulfide, the CP-IDP region would be shifted left (shown by the pale green region), if the magnetite and maghemite was originally oxide, the CP-IDP region would be shifted right.

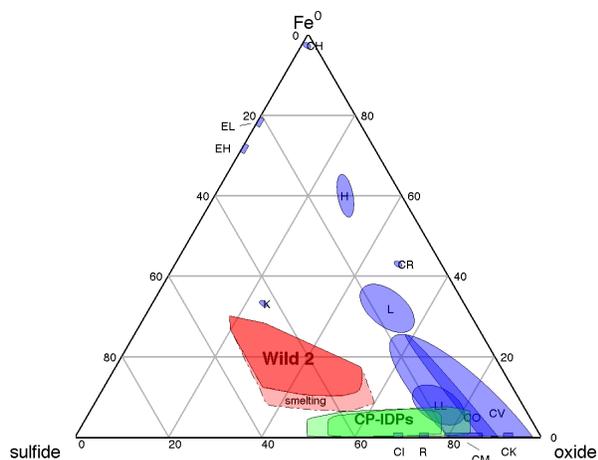


Figure 2: Ternary plot showing the distribution of Fe into  $\text{Fe}^0$ , sulfide, and oxide ( $\text{Fe}^{2+}$ , and  $\text{Fe}^{3+}$ ) for the Stardust samples, our set of CP-IDPs, and various meteorite groups. The effect of reduction of Fe oxide during high-speed capture of cometary particles in aerogel [8] is shown by the "smelting" region.

## Discussion

Our results show that the Fe oxidation state of CP-IDPs differs from the Stardust sample at the  $2\sigma$  level. An obvious difference between these two samples of extraterrestrial matter is that Wild 2 contains substantial Fe metal whereas the CP-IDPs contain very little. This could be the result of a selection effect: perhaps the Fe-metal-containing CP-IDPs do not appear porous, or perhaps their residence time in the atmosphere is shorter because of their higher density.

In comparing these two samples, we must also acknowledge the possibility that Wild 2 is anomalous and is not representative of Jupiter-family comets. Also, since we measured a very small fraction of a large object, the Fe oxidation state of the bulk comet may be different than the measurements we report here.

The origin of CP-IDPs is unknown. In this work we have quantitatively compared the Fe oxidation state of 15 CP-IDPs to a sample from a known comet and found that they differ significantly. Although selection biases, mentioned above, may complicate the comparison, the simplest interpretation of these results is that CP-IDPs do not originate in Jupiter-family comets.

## Acknowledgements

The Advanced Light Source is supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

## References

- [1] Bradley, J. P., *Science*, 265, 925 (1994)
- [2] Brownlee, D. E., *Ann. Rev. Earth Planet. Sci.*, 13:147 (1985)
- [3] Brownlee, D. E. *et al.*, *Lunar Planet. Sci.* XXVI, 183 (1995)
- [4] Chernick, M. R. 1999, *Bootstrap Methods: A Practitioner's Guide*, Wiley Series in Probability and Statistics, (New York: Wiley)
- [5] Ishii, H. A. *et al.*, *Science*, 319, 447 (2008)
- [6] Keller, L. P. *et al.*, *Lunar Planet. Sci.* XXIII, 675 (1992)
- [7] Marcus, M. A. *et al.*, *J. Synch. Rad.*, 11, 239 (2008)
- [8] Marcus, M. A. *et al.*, *MAPS*, 43, 87 (2008)
- [9] Rietmeijer, F. J. M., *MAPS*, 31, 278 (1996)
- [10] Urey, H. C., & Craig, H., *Geochim. Cosmochim. Acta*, 4, 36 (1953)
- [11] Westphal *et al.*, *ApJ*, 694, 18
- [12] Wilke, M., *et al.* 2001, *Am. Mineral.*, 86, 714