Chemical Analysis of a Large Stardust Track Associated with a Presolar Grain

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Introduction: The Stardust spacecraft returned samples from Jupiter-family comet Wild2 to earth in January 2006. 85% of the collector area consisted of aerogel tiles. Cometary particles were captured at 6 km/sec, and formed long tracks in the aerogel. Most cometary particles were friable and so fragmented during capture. As a result the largest tracks contain hundreds of particles dispersed within the walls of the tracks. Analyzing all particles in a given track individually is often not feasible. We report a method using a synchrotron-based x-ray microprobe to derive the oxidation state of iron in every particle in a Stardust track. Knowledge of the Fe oxidation state can be used to compare the Stardust cometary samples with other extraterrestrial material [1]. This method was used to analyze one of the largest Stardust tracks, whose progenitor particle was likely the source of the only presolar grain found to date in the Stardust samples.

Methods: A large (~4mm) track, C2086,0,124 (hereafter Track 124), was extracted in a small block from a Stardust aerogel tile using a razor semi-automatically controlled by a micromanipulator [2]. Whereas most comet particles hit the aerogel collector nearly normal to its surface, this track is nearly 80° from the normal. This track is associated with a punch-through hole in a neighboring aluminum foil – a large comet particle hit the foil, and some of the ejecta from this impact plowed into the neighboring aerogel tile. During the preliminary examination of the Stardust cometary sample, a presolar grain was found in the residue in this punch-through crater [3]. This is the only presolar grain found in the Stardust sample reported so far. Track 124 is therefore a promising place to look for more presolar grains.

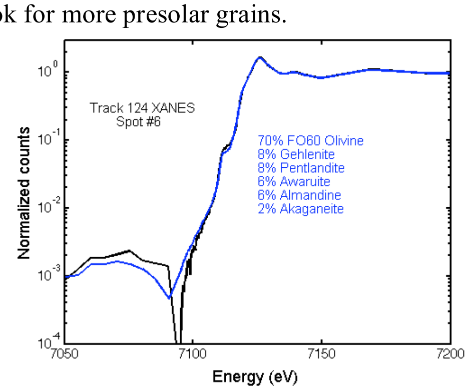

Figure 1: XANES spectrum (black) of an iron-rich particle of Track 124 and its best fit (blue).

Track 124 XANES & XRF: We performed microbeam x-ray absorption near-edge structure spectroscopy (μXANES) at beamline 10.3.2 at Lawrence Berkeley Lab's Advanced Light Source [4] for standards from 21 different mineral groups thought to be present in the Stardust samples. Of the seven XANES spectra of randomly chosen iron-rich particles in Track 124, five had olivine as the dominant component (an example of an olivine-rich particle is shown in Figure 1). Enstatite was the next most abundant constituent, and one particle of the seven was mostly iron metal.

X-ray fluorescence elemental maps of the track were also taken; a stereo-pair (Figure 4) shows the large number and compositional distribution of cometary particles in the track.

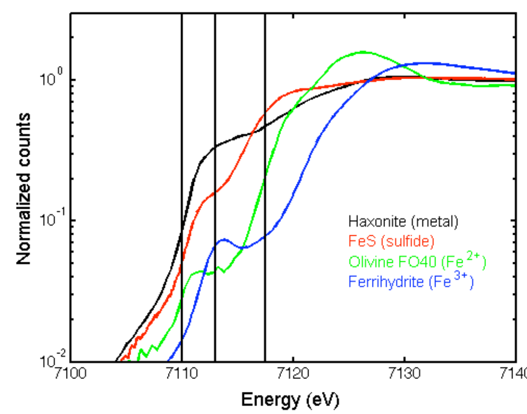

Figure 2: The shape of the k-edge iron XANES spectra near the absorption edge depends strongly on the oxidation state, as shown here by four standards with four different Fe oxidation state. The spectra are shifted vertically for clarity. As oxidation increases the position of the edge moves to higher energy. The values of the XANES spectra at 7110 eV, 7113 eV, and 7117.5 eV (vertical lines) can be used to determine the oxidation state of the mineral.

Track 124 Chemical Map: The shape of the XANES spectrum around the iron edge region is very sensitive to the oxidation state [5], as shown in Figure 2. Because of this, it is possible to determine the oxidation state of iron in a given iron-bearing mineral by measuring the x-ray fluorescence at just three energies, 7110 eV, 7113 eV, and 7117.5 eV, in addition to measurements before and after the edge to account for background and normalization [6].

From previous analysis of individual particles in 11 Stardust tracks and their fits to mineral standards, weighted-average spectra for metal, sulfide, Fe^{2+}, and Fe^{3+} were derived. The x-ray fluorescence of Track 124 was mapped in its entirety with incident beam energies of 7100, 7110, 7113, 7117.5, and 7210.8 eV. For each pixel, corresponding to a 16x5 μm area on the track, the five-energy spectrum was fit to a linear combination of the metal, sulfide, Fe^{2+}, and Fe^{3+} standards plus a background.

Discussion: Track 124 is imaged in terms of its oxidation state in Figure 3. This image gives a picture of the iron-oxidation environment of the Wild2 particle that contained at least one Group 1 presolar grain, thought to originate from asymptotic giant branch stars or red giants. Olivines (Fe^{2+}), which would show up as blue in Figure 3, are abundant. The chemical segregation of iron is dramatic in Track 124, and the diversity of iron-bearing minerals indicates a complex cometary particle.

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References: [1] A. J. Westphal et al., *Proceedings of the 39th LPSC* [2] A. J. Westphal et al., *Meteoritics & Planet. Sci.*, 39 1375 (2004) [3] K. D. McKeegan et al., *Science*, 314 1724 (2006) [4] M. A. Marcus et al., *J. Synchrotron Rad.*, 11 239 (2004) [5] M. Wilke et al., *Am. Mineralogist*, 86 714 (2001) [6] I. J. Pickering, et al., *PNAS*, 97 10717 (2000)

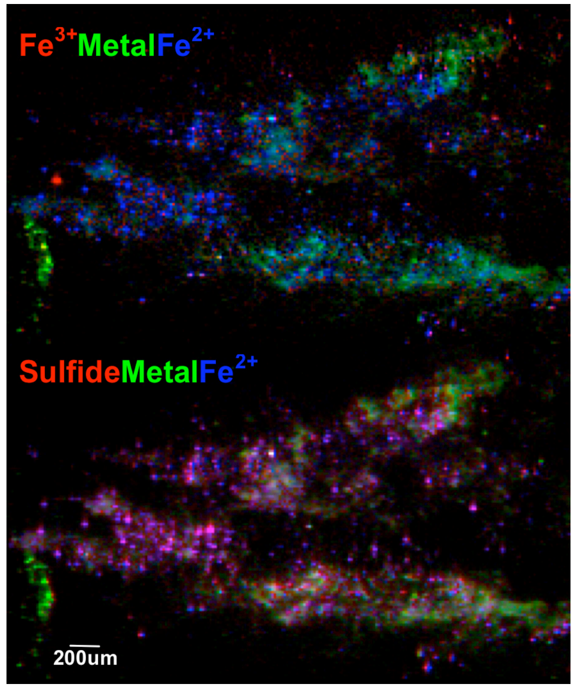

Figure 3: RGB images of Track 124 with red=Fe3+ in the top image, red=sulfide in the bottom and green=metal, blue=Fe2+ in both images. The particle entered the aerogel on the right and traveled to the left.

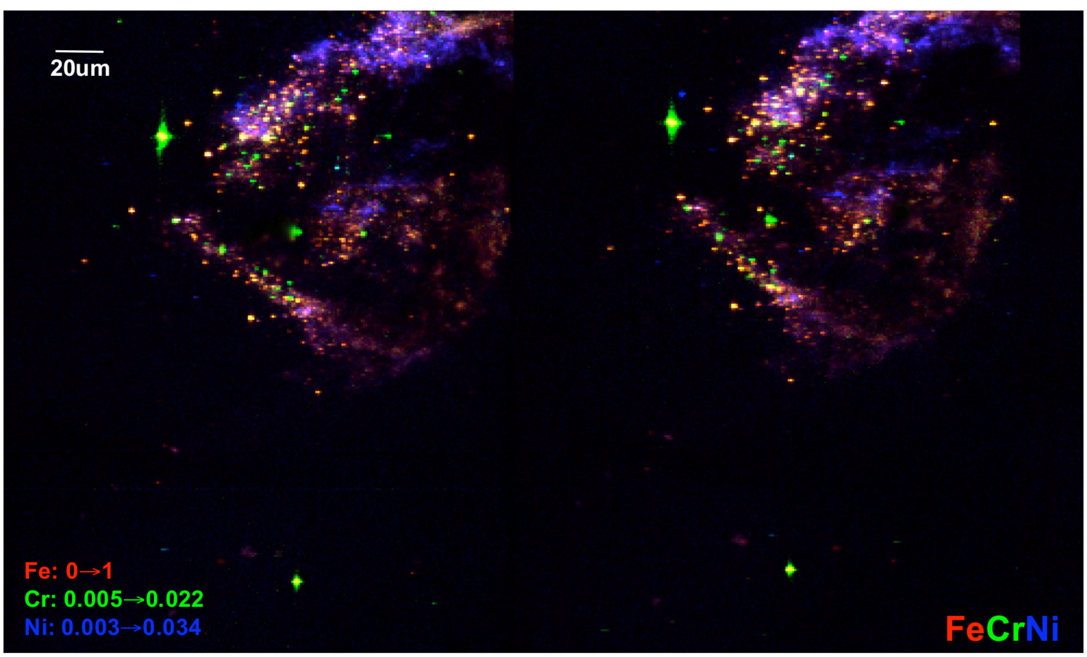

Figure 4: Stereo-pair iron-chromium-nickel elemental map of Track 124. The track is rotated with respect to Figure 3 – this image is looking down through the 'mouth' of the track, the incoming particle's trajectory is approximately into the page. The range of normalized counts for each element/color is given in the lower left.