New Candidate Interstellar Particle in Stardust IS Aerogel Collector: Analysis by STXM and Ptychography.

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Introduction: The Stardust Interstellar Preliminary Examination (ISPE) reported in 2014 the discovery of 7 probable contemporary interstellar (IS) particles captured in Stardust IS Collector aerogel and foils [1]. The ISPE reports represented work done over 6 years by more than 60 scientists and >30,000 volunteers, which emphasizes the challenge identifying and analyzing Stardust IS samples was far beyond the primary Stardust cometary collection. We present a new potentially interstellar particle resulting from a continuation of analyses of the IS aerogel collection.

Methods: Three of the reported candidate-IS particles were found in the IS aerogel [2]. The workflow, in brief, involved 1) optical scanning of the IS aerogel collector tiles at the JSC Stardust curation facility; 2) online distributed searching for impact tracks in the scanned data using the Stardust At Home (http://stardustathome.ssl.berkeley.edu, SAH) Virtual Microscope; 3) extracting candidate track features in pico-keystones at JSC [3, 4]; and 4) non-destructive coordinated synchrotron x-ray analyses. We applied each of these steps for analysis of 5 new candidate tracks.

During ISPE, we analyzed 40 extracted candidate impact tracks using Scanning Transmission X-ray Microscopy (STXM) at the Advanced Light Source (ALS) Beamline 11.0.2 [2]. We developed methods to discount candidate impact tracks of spacecraft origin. First, STXM absorption images mapped aerogel density, and could show that a particle was associated with an impact track (using 800eV – 1200 eV, depending on aerogel density). Next, Ce M-edge (890eV) maps identified solar panel material. Finally, we used Al K-edge (1560eV) XANES, where the spectrum of Al-metal is 6eV lower than any Al-oxidized material.

We expected the direction of impact tracks in the collector to be indicative of impact origin. With the collector envisioned as a clock, the “midnight” direction impacts were consistent with an interstellar dust stream origin. We found that angled impacted of more than 10° to either side were more likely to be solar panel secondary impacts. We also found midnight tracks were either Al metal from the Stardust collector lid, or a likely cosmic composition.

We applied a similar workflow of tests to new candidates, focusing on midnight tracks identified in SAH. New candidates were extracted in pico-keystones, so that the track was exposed in 70 µm-thick aerogel suitable for soft x-ray STXM. Thicker 400 µm-thick aerogel provided support when mounted in a silicon nitride membrane sandwich supported by two 200-µm thick Si frames.

Since the IS Collector analyses has been a long-term project, there have been some key changes in personnel and capabilities, including pico-keystone extractions at JSC and development of ALS STXM Ptychography beamlines. We transitioned to a newly commissioned STXM beamline at ALS 7.0.1 COSMIC, which combines STXM and Ptychography capabilities [5]. We developed a new compatible, reliable pico-keystone mount and tested it on a previously identified solar panel IS Collector sample.

We performed standard STXM analyses, including aerogel imaging, chemical maps and XANES spectroscopy for Al and Mg K-edges, Ce M-edge, Fe-L edge. Typical spatial resolution was 50 nm for XANES stack data-cubes. The full energy range of ALS 7.0.1 when fully commissioned will be 0.25 to 2.5 keV. Energy resolution was estimated to be 0.15 eV at Fe-L edge (708eV), and 0.6 eV at Al K-edge (1560eV). COSMIC Fe detection sensitivity was ~5 pg/µm^2 surface density.

ALS 7.0.1 ptychography provides a method for chemical mapping at resolution finer than the 50 nm spot size, by phase retrieval from coherent diffraction data. To demonstrate the ptychography technique potential, we acquired ptychography images of a microtomed section of Stardust cometary sample XXX, achieving spatial resolution of 7 nm at 710 eV. The presence of aerogel substrate was not ideal for ptychography on the IS candidate particle, but some phase analysis was possible.

Results: Stardust At Home launched in 2008 and logged over 30,000 volunteers, self-named “Dusters”, during ISPE. A smaller number of Dusters stayed with the project, becoming an expert search team for the latest set of midnight candidates. Per tradition, the first finder names a candidate track: Duster McAngus found the “midnight” track in SAH field-of-view 9089438V1 and named the extracted sample I1022,1,47,0,0 “Bianca”.

Figure 1 shows the tiles that have been optically scanned and searched in the decade-long effort.

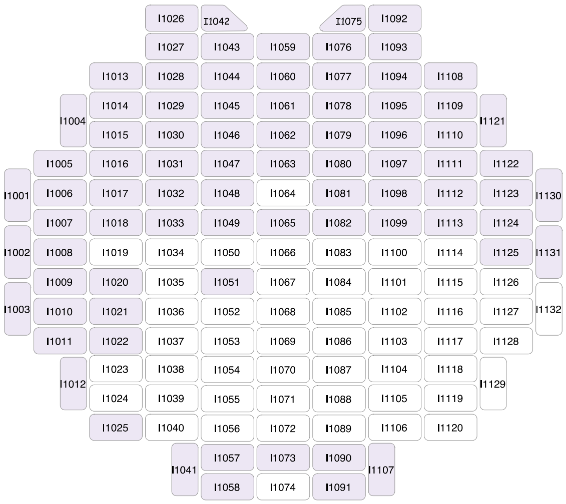

Fig. 1. Schematic of the Stardust Interstellar Dust Collector aerogel tiles. Shaded tiles have been optically scanned and searched in Stardust At Home.

I1022,1,47,0,0 "Bianca": Preliminary results from STXM analyses of Track I1022,1,47,0,0 confirmed a 1µm-long particle present at the expected pico-keystone aerogel coordinates. We found no Ce. From Al XANES we found no metal, but possibly a few fg oxidized Al in a small <100 nm areas.

We detected approximately 0.1 pg Mg, which appears to be evenly distributed over the particle. The Mg XANES resonance enhancement (peak to edge-jump ratio) was ~3, which is typical of silicates. The Mg spectrum was too noisy to distinguish crystalline from amorphous by comparing medium range order. Ptychographic phase analysis results suggested the particle is comprised of a single Mg-rich phase.

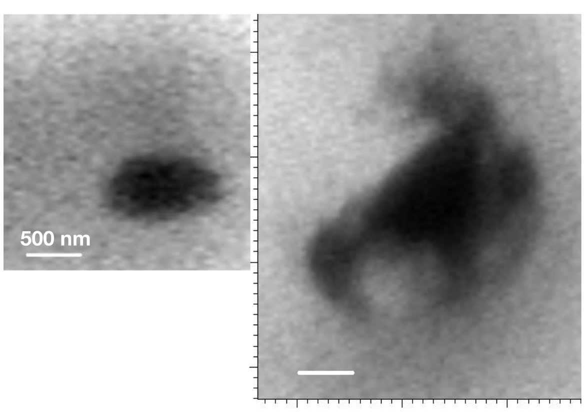

Fig. 2. STXM absorption image of I1022,1,47,0,0 Bianca (Left, 1545eV) shown at the same scale with I1047,1,34 Hylabrook (Right, 875 eV).

Fe was not detected, giving an upper limit of 10 fg Fe. The detection sensitivity for Fe was noise limited. The detection of Fe is also limited by aerogel density.

Discussion: Considering Bianca to be an ellipsoid particle, the volume was 0.13 μm^3. We then find 0.1pg Mg is about half the amount expected if the particle was Fo100 olivine. The Mg abundance may be improved with lower noise data acquisition. It may also be explained by presence of another cation, or by Bianca having lower density than olivine.

Bianca has some similarities with the previous IS samples Orion and Hylabrook. All three particles have Mg as a major element. Orion and Hylabrook both contained olivine, with crystallinity confirmed by synchrotron XRD; both contained amorphous Mg silicate; and Hylabrook had a lower density "halo" (see Fig 2). The average densities of all the particles was lower than a compact crystalline phase would imply. Bianca is the smallest of the three IS candidates and appears to have the least Al and Fe.

Bianca composition has an upper limit of 10% Fe/Mg (by mass), which is much lower than the bulk Fe/Mg particle compositions of Hylabrook and Orion. The evidence suggested that most Mg and Fe were present in different phases; all three particles appear to contain Mg-rich (low-Fe) silicate.

Further analyses may be possible, but we purposefully limited photon dose to Bianca to limit damage. The final step would be further removal from aerogel for O-isotope analysis.

Conclusion: IS sample I1022,1,47,0,0 Bianca shares some similarities with previous IS samples Orion and Hylabrook, reported as having probable interstellar origin. Taken together, observations of the three IS particles can be compared with astronomical dust particle models.

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