Hunting Starstuff: Searching for Calcium Aluminum Rich Inclusions in Cometary Dust as returned by Stardust

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1. Abstract:

The presence of Calcium-Aluminum - rich Inclusions (CAIs) was one of the surprises of the results of the Stardust mission. Due to the practical challenges involved in the extraction and analysis of the samples returned by Stardust, not all of the samples have been analyzed to find CAIs. This research is an attempt to systematically find evidence of CAIs in the 8 years of X-Ray Fluorescence (XRF) data already acquired.

2. Introduction:

Wild 2 is a comet from the Jupiter Family of comets, recently perturbed by Jupiter to pass in close proximity to the Sun on an eccentric orbit (1). Its constituents were formed in the early solar system and have been frozen in their pristine state ever since (2).

Stardust, a NASA mission, intercepted Wild 2's coma and collected the ejected particles in an aerogel collection tray. These particles range in size from sub-micron to hundreds of microns across (2). Some of these particles are evidence for CAIs.

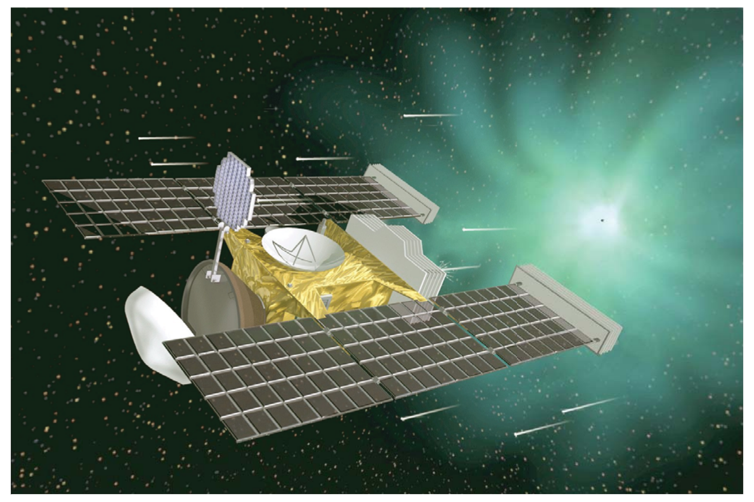

Fig 1. Artists' concept of Stardust at Wild 2

3. Aerogel Tracks:

Aerogel is an ultra low density solid foam created by supercritically drying gel, which is used in some commercial applications. Ejected material from Wild 2 was captured in an aerogel grid, creating roughly carrot shaped tracks on the order of a few millimeters. This material was sometimes heavily fragmented in the hypervelocity impact, and other times left an intact terminal particle for further study.

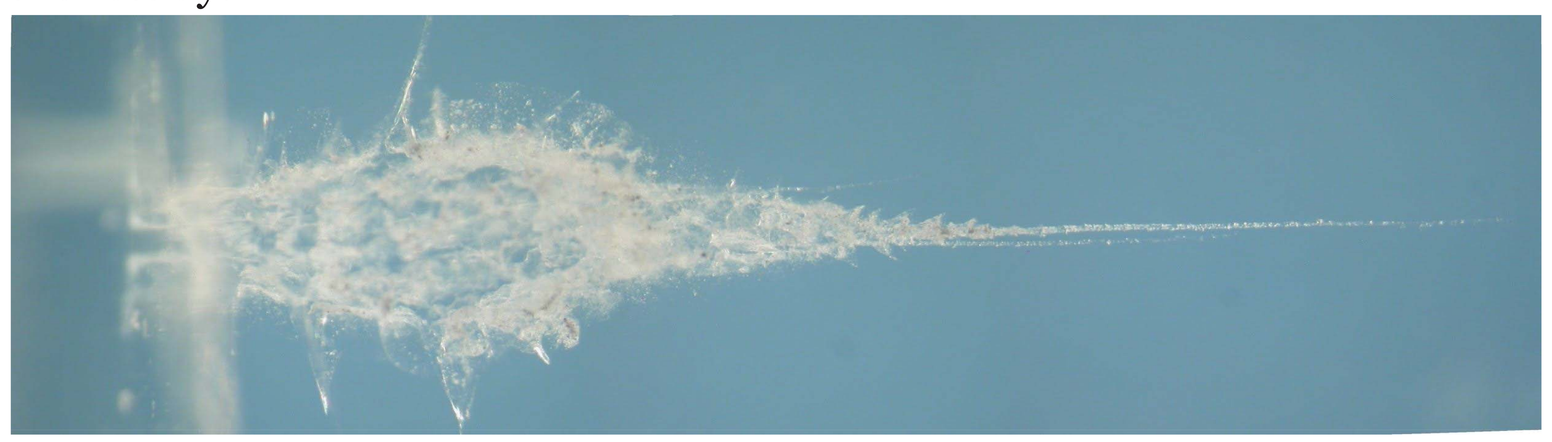

Fig 2. An optical image of an aerogel track containing a Stardust particle. Note the bulbous shape created from the high velocity impact, and the tapering ending in a terminal particle. The width of the track is ~5mm.

4. Why CAIs?:

Calcium-Aluminum - rich Inclusions are fragments of rock, composed of refractory minerals whose mineralogy and chemistry are unique. They are the first solids to have condensed out of the young cooling pre-solar nebula, and are the oldest solid material in the solar system (3). At least 2 CAIs have been found in Wild 2 thus far (4)(5).

Their presence in comets, which are formed in the Kuiper Belt far outside of the hot inner solar system, creates questions about the process of radial mixing of material in the solar system (3)

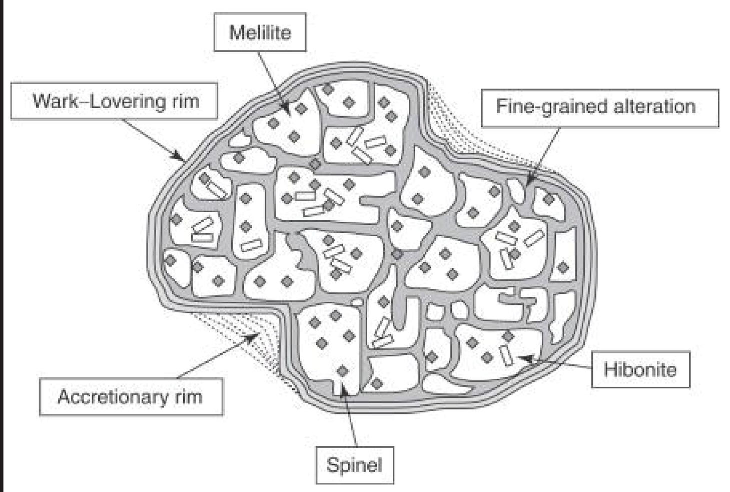

Fig 3. Schematic of a generic CAI (3).

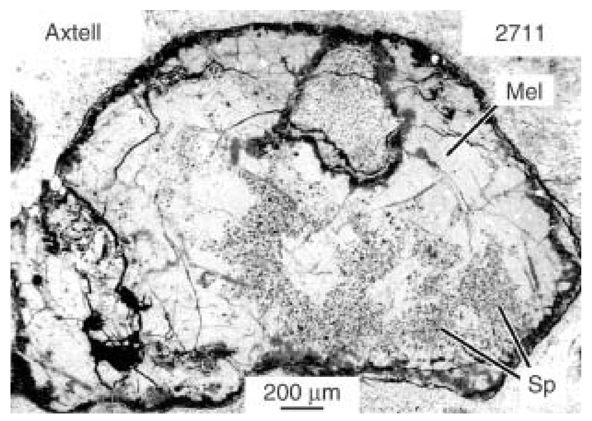

Fig 4. Backscattered electron image of a CAI (6).

5. X-Ray Fluorescence:

At the Advanced Light Source facility at Lawrence Berkeley National Laboratory, synchrotron radiation is used to probe the Stardust samples using X-Ray fluorescence. The beam has a spatial resolution of ~2 - 15 μm and an energy range of ~2.5 - 17 keV, sufficient to scan the K-edge of most common metals.

These XRF maps are used to determine the elemental contents of the tracks, after which Transmission Electron Microscopy (TEM) and other techniques are used for further study, including determining mineralogy and isotopic composition.

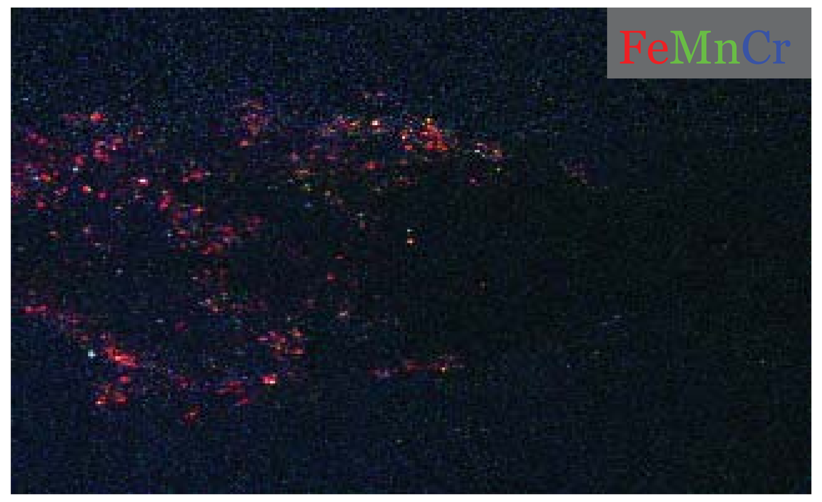

Fig 5. X-Ray Fluoresence (XRF) image of the bulb of Fig 2. Iron is imaged in red, Manganese in green, Chromium in blue.

6. Procedure and Results:

Since the structure of the CAI might have been broken up into its constituent minerals in the collection process, we can look for traces of those minerals in the XRF maps. Once a candidate has been confirmed as a potential CAI, more sophisticated techniques can be used to confirm its presence.

In order to find CAIs efficiently, the data needed to be organized into a datamine-able format. This was a two step process, done in Python:

1. Sorting data through the use of regular expressions, to organize the data by track number and subsample.
2. Once sorted, the data could be processed by looking for combined hotspots in the calcium and titanium channels using a Laplacian of Gaussian function. The aerogel however contains calcium impurities, making the titanium hotspots crucial in differentiating between potential CAIs and aerogel contaminants.

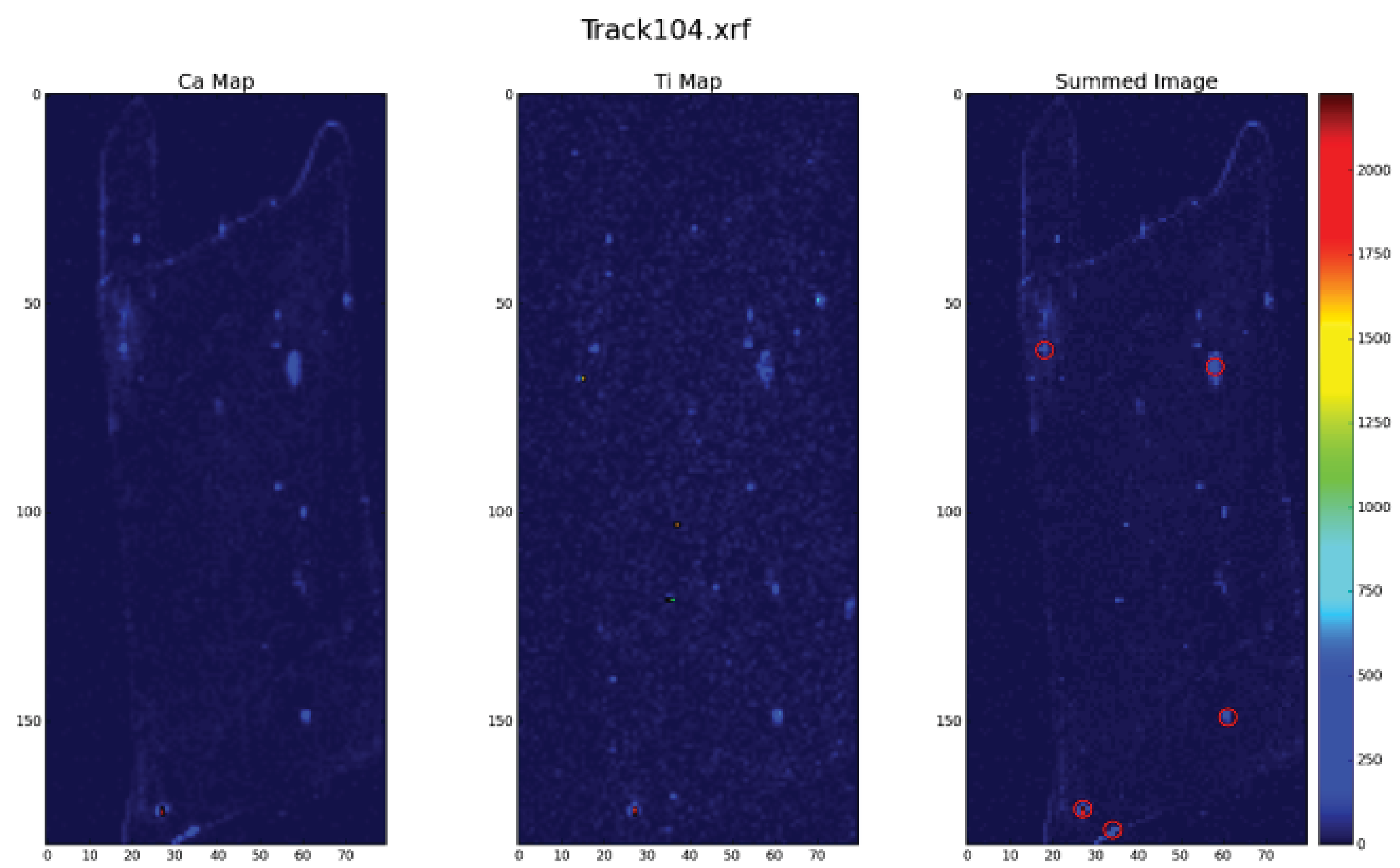

Fig 6. Image analysis of an aerogel track. Left and middle subplots are XRF images in the Ca and Ti channels. The rightmost subplot is the sum of the two images, and has hotspots highlighted, as returned from the Laplacian of Gaussian function. In this case, a pixel with a value above two standard deviations in the summed image returned a hotspot.

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