FINDING INTERSTELLAR PARTICLE IMPACTS ON STARDUST ALUMINIUM FOILS: THE SAFE HANDLING, IMAGING AND ANALYSIS OF SAMPLES CONTAINING FEMTOGRAM RESIDUES.

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Stardust Interstellar Particles (ISP): Impact ionisation detectors on a suite of spacecraft have shown the direction, velocity, flux and mass distribution of smaller ISP entering the Solar System [1]. During the aphelion segments of the Stardust flight, a dedicated collector surface was oriented to intercept ISP of beta = 1 [2], and returned to Earth in January 2006. A sample collection model [3] gave an estimate of the probable number of captured ISP, their size, trajectory relative to the collector surface and velocity on capture. Both aerogel and aluminium foils should contain ISP remnants worthy of analysis. Stardust@home [4] has already found candidate aerogel tracks, some now analysed by synchrotron techniques [5]. Although there are µm-scale Fe-, Si- and Ti-rich inclusions in Stardust foil, which complicate analysis [6], and high impact shock pressures may result in greater initial damage to grains, the substrate has very low levels of most elements of interest for trace and isotopic analysis [6]. Whilst residues in craters will be very thin, they are relatively easy to access and, after preliminary examination (PE), diverse analytical techniques could be applied. However, the very low total number (< 20) and small size (< µm) of ISP impacts expected on the foils make handling, transport, PE and subsequent analysis much more difficult than Stardust cometary samples. Perhaps only 1 in 5 foils will contain even a single IS crater, and secondary ejecta impacts from the spacecraft may be more numerous. In this paper we describe the probable appeareance and size of IS particle craters from initial results of experimental impacts and numerical simulation, explain how foils are being prepared and mounted for crater searching by automated acquisition of high magnification electron images (whilst avoiding contamination of the foils) and comment on appropriate analytical techniques for Preliminary Examination (PE).

Impact analogues: Calibrations by experiments with known particle composition and size at appropriate IS velocities [3] are being conducted at Heidelberg [7]. Initial numerical modeling at Kent suggests craters made by impactors > 5 µm are ~ 8 times particle diameter at 20 km s^{-1}. Recent light gas gun (LGG) shots at 6 km s^{-1} show that craters of < 1 µm diameter are not much larger than the projectile itself [8]. We do not yet know if this applies to cratering at ISP collection velocities, which may exceed 20 km s^{-1}.

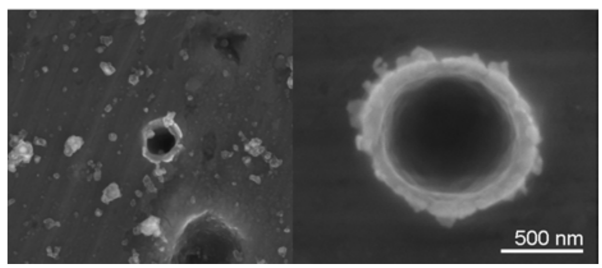

Figure 1. Craters from (left) Kent LGG shot of 100 nm silica sphere at 6 km s^{-1}, and (right) Heidelberg VdG impact of sub-µm latex particle [9] at ~ 20 km s^{-1}.

Handing, examination, analysis of foil samples: Although handling and clamping of foils by side tabs would avoid touching or contaminating any of the space-exposed foil surface, testing at JSC revealed that even very gentle teasing of complete foils from the collector frame can cause breakage of neighbouring aerogel blocks. Instead, foil strips must be cut from the collector frame using twin rotary cutters, as in the cometary PE [10]. Each released strip is ~ 1.7- 2 mm wide and ~ 15 or 30 mm long. Mounting with thin soft metal wire restraints [10] is not adequate for safe transport or permanent mounting, as foil movement can lose location information so hard-won by prolonged crater searching. Tests of spot welding for permanent mounting of flight-spare foil samples also proved unsatisfactory. Following extensive discussion between users of instrument types likely to be used during PE (and later analysis), a design involving mechanical clamping of foil ends (and stretching to ensure flatness) was selected. A prototype was machined at Berkeley (Fig. 2), suitable for mounting in scanning electron (SEM), Auger and NanoSIMS microscopes, although later remounting may be necessary for other ion microprobes. In the Zeiss Leo 1455VP and Ultra SEMs at NHM, the foil was found to be so flat that high magnification focus was held over cm length (~53 µm height variation across 2 cm). This meets the requirement for automatic image acquisition across mm-square areas, necessary for IS crater searching.

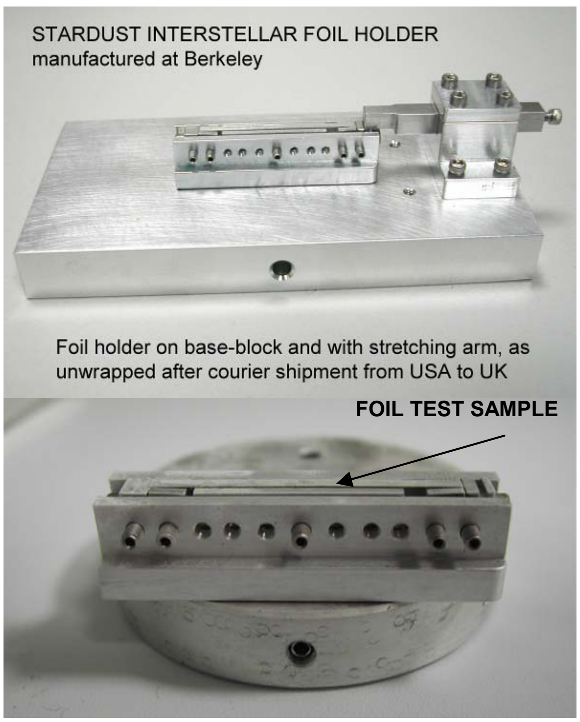

Figure 2. The sample holder: (top) on the prototype stretcher assembly; (bottom) firmly mounted on analytical SEM plate, after thermal cycling tests.

Stability testing at WashU and NHM: To check whether ground and air transportation between laboratories might cause mechanical loosening of the foil-holder assembly, it was sent from Berkeley to St Louis, and then by international courier to the UK. At NHM, the holder was mounted on a SEM plate (Fig. 2) then subjected to repeated rapid cold-hot-cold cycling between a freezer (-19 °C) and a glassware drier (+57 °C). After each step, holder and foil were photographed. A final stability test used ultrasonic vibration for 10, then 30 secs. When the photographs were compared, there was no evidence of movement of the foil.

Contamination monitoring: Carbon-coat standards of known thickness were distributed to laboratories worldwide, for use in determining the rate of contamination deposition, ensuring that SEM imaging during crater searches will not compromise subsequent analysis. The threshold for serious degradation of Auger electron spectroscopy [11], the only analytical method likely to be used during PE, was determined at St Louis. It was found that 4 nm of carbon will obscure Auger emission from an underlying Al layer (Fig. 3). Image acquisition in the proven crater searching protocol generates less than 1/1000th of this critical level. To date, four instruments have been verified as sufficiently clean for ISPE, one in the US, two in the UK, and one in Germany. More should follow quickly.

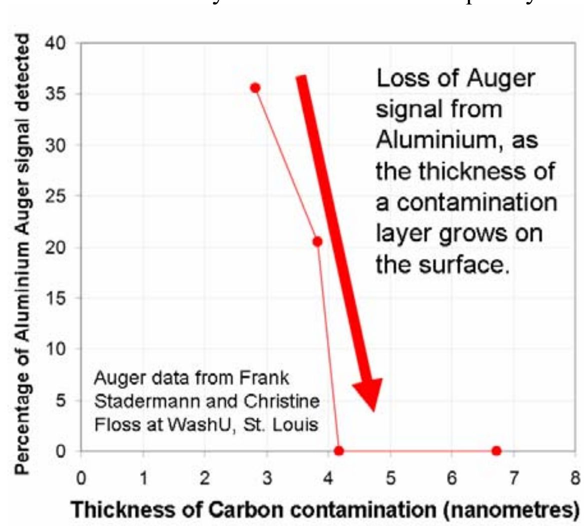

Figure 3. Attenuation of Auger signal from Al beneath four thicknesses of SEM-deposited contamination.

Conclusions: With foils now cut from the Stardust collector, the production of a robust sample holder design, a protocol for monitoring contamination build-up and a suite of verified instruments, we are now (finally) ready to begin the search for IS particle impact craters on Stardust foils.

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