IDENTIFICATION OF CANDIDATE INTERSTELLAR DUST IMPACT FEATURES ON STARDUST FOIL I1020W,1.

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Introduction: The NASA *STARDUST* spacecraft carried two dust collection trays: one for capture of dust from comet 81P/Wild 2, and one for capture of contemporary interstellar dust [1]. Whereas the successful capture of Wild 2 grains was readily apparent from the first direct visual observations of the returned cometary collector tray [2], achieving a reasonable level of confidence that detectable interstellar grains were captured in the interstellar collector tray required a multi-year preliminary examination research campaign. At the conclusion of the interstellar preliminary examination (ISPE), 7 probable interstellar dust impact features were reported [3-5], along with a large background of features associated with secondary impacts of spacecraft debris. Four impact craters with residue attributed to interstellar dust were identified on Al foils, after searching only ~5% of the available foil collection area. The post-ISPE search for additional impact features is ongoing [6]. We report here the discovery of four new candidate interstellar impact features, identified through a combination of automated SEM imaging, and an online citizen-scientist distributed search, that expands on the successful stardust@home program [4] for feature identification in the aerogel collection medium.

Samples and Methods: Foil I1020W,1 was removed from the collection tray and allocated to us by the Stardust curation team at NASA Johnson Space Center. For SEM imaging, the foil was mounted on an archival stretcher [5] at the Space Sciences Laboratory, U.C. Berkeley.

Automated SEM imaging was performed with the FEI Nova600 FIB-SEM, equipped with an Evactron plasma cleaning system, at the Naval Research Laboratory in Washington, DC. To reduce the possibility of hydrocarbon contamination of the foil surface during imaging, the quality of the FIB-SEM vacuum (base pressure < 10^{-6} Torr) was monitored, and the chamber was plasma cleaned with the Evactron prior to loading the foil into the microscope. The mapping was performed in two parts with custom scripts. First, the sample height variation along the length of the foil was determined every 1 mm, and saved in a log file. These values were then used by a second script to keep the sample in focus at a constant 5 mm working distance from the pole piece, while acquiring images of the entire foil. A series of 1768px × 2048px secondary electron (SE) images were acquired at 10 kV, at a resolution of 31.3 nm/px. A total of 7,076 images of were obtained. Compared to the Level 2 curation optical image of I1020W,1, the SE images are rotated ~ 180°.

The search for possible impact features on the foil was performed as a new effort of the Stardust@home campaign, in which volunteers, known as "dusters", use a virtual on-line microscope to manually scan the acquired images. Features were ranked according to how often, and how confidently, they are identified as candidates by the "dusters". The highest ranking features were then re-imaged at higher resolution in the FIB-SEM. Details of the Stardust@home foils effort are reported at this meeting [7].

Results: Nineteen high-graded candidate features were reimaged. Of these, 15 were found to be defects in the Al foil; one is an apparent impact, with a wider rim-crater diameter than is typically seen (Fig. 1A); and the remaining 3 (Fig. 1 B-D) are definite impact craters. Two of the craters (C and D) have an asymmetric shape that records the trajectory of the impacting particles [8], at azimuthal angles of 52° and 45°, respectively. The crater equivalent diameters are A = 300nm, B = 350nm, C = 390nm and D = 560nm.

Discussion: Based on comparison with the information learned from ISPE, studies of the impact features in Al foils from the Stardust cometary tray, and analog impacts, we can infer a significant amount about the likely properties of the impacting particles that produced each crater. From the diameter of the craters, we can infer that impacting particles were likely between 150 nm and 1000 nm in diameter. i.e., crater diameter 1× to 2× the size of the impactor [9]. These values are consistent with the range of crater sizes observed during ISPE.

Most of the secondary impact features from spacecraft debris identified during ISPE produced visibly shallow (depth < ½ diameter), asymmetric craters, characteristic of low velocity (<<5 km/s), glancing angle impacts. Crater D fits this description, whereas craters A and B do not. Crater C is asymmetric, but has a depth that appears to be ~ ½ the diameter, consistent with two of the ISPE probable interstellar dust impact craters. Like those craters, it could have been produced by an aggregate of nanoscale silicate and sulfide, or other minerallic grains. Crater A has an unusual microstructure, with a well-defined, deep crater, and wide rim. If this crater is a true impact crater from

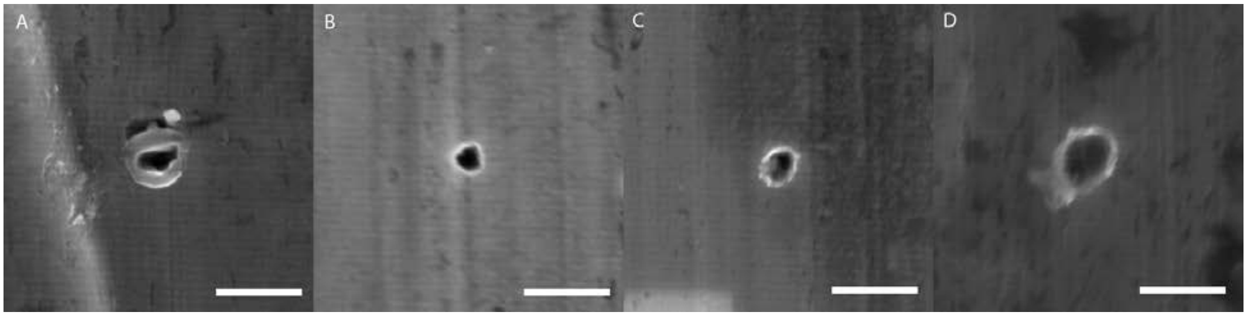

Figure 1. (Above) SE images of candidate interstellar dust impact features. The scale bars are 1 μm.

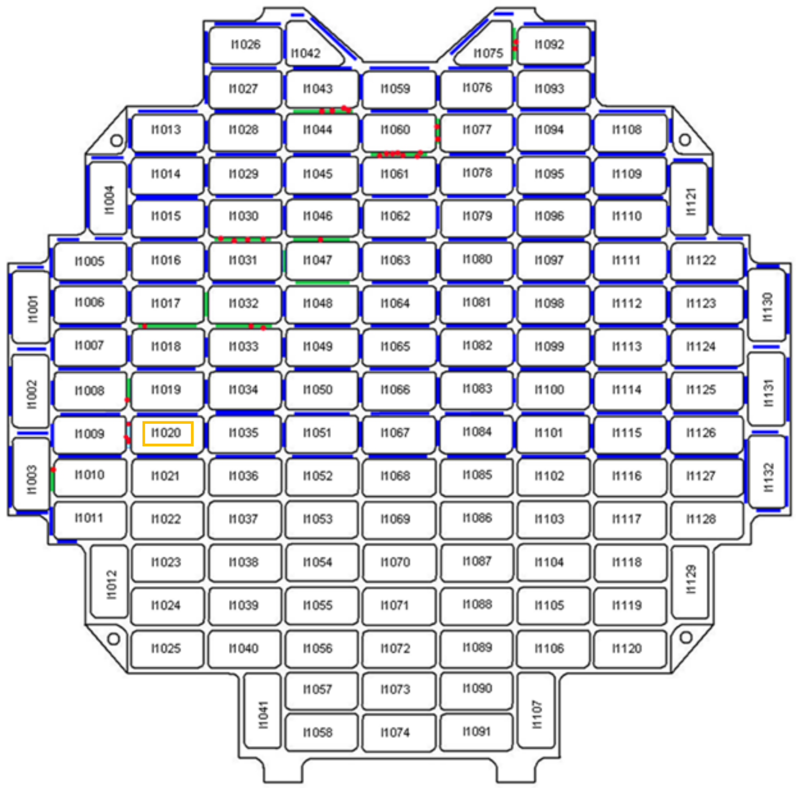

Figure 2. (Left) Schematic of the interstellar tray showing features identified during ISPE and reported here. Foil I1020W is shown in cyan, with the approximate locations of the four new candidate interstellar impact features in red.

interstellar dust, it is likely to have been formed by a dust grain with an uncommon composition, i.e., not simply sub-micrometer silicate and sulfide. One possibility is carbonaceous matter, along with denser inorganic material.

In order to provide more definitive information about the origin of the impact features, additional measurements are required. No SEM-EDS was performed during the re-imaging, due to the observed contamination rate on nearby regions of Al foil. Although C contamination does not alter any impact residue itself, it complicates or prevents additional minimally invasive analysis, such as Auger spectroscopy. Because the source of C contamination is the foil itself, rather than the plasma cleaned microscope chamber, it is unlikely that either SEM-EDS or Auger spectroscopy will provide high quality elemental analysis of features on this foil. Cross-sectional analysis of FIB-extracted sections, with analytical transmission electron microscopy are the most likely next steps, in order to determine the elemental composition and microstructure of any retained residue. Oxygen isotope measurements on any oxide or silicate residues would be useful for providing more definitive signatures of the interstellar origin of such residues. These types of destructive analyses will require specific authorization from CAPTEM, which is pending at the time of abstract submission.

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