COMPUTER-ASSISTED DETECTION OF INTERSTELLAR DUST IMPACTS IN STARDUST FOILS.

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Introduction: Observational spectroscopy of contemporary dust in the interstellar medium indicates that it is dominated by ~200 nm amorphous silicate particles [1,2], but the exact particle size distribution, shape, and grain compositions are highly model dependent [3]. The NASA Stardust spacecraft included an extra array of aerogel cells for collecting contemporary interstellar dust for laboratory study [4]. Al foils lining the collector tray also captured interstellar dust as impact residues inside craters, but fewer than 40 particles across all of the foils are expected, in addition to a known background of on average 1 to 3 secondary impact craters per foil from spacecraft debris. [5]. We have developed a fast computer algorithm for detecting foil craters based on their morphological characteristics, which significantly reduces the time and mental fatigue of manually reviewing tens of thousands of images of the foil surfaces.

Sample and Methods: Twelve Stardust interstellar foils were imaged using either a FEI Nova Nanolab 600 or a FEI Helios G3 focused ion beam scanning electron microscope (FIB-SEM). Between 7,000 and 22,000 images were acquired from each foil strip, depending on its length, at spatial resolutions between 30 and 40.5 nm/pixel, sufficient to observe craters as small as 250 nm. Automated mapping software or scripting was used to acquire the images overnight. The same FIB-SEM systems were used for re-imaging at higher resolution following candidate detection, energy-dispersive X-ray spectroscopy (EDS) of crater residues, and FIB extraction of likely interstellar residues for transmission electron microscopy (TEM).

We developed a Python-based algorithm which detects circular features with a dark center and bright rim, the same morphological characteristics that a human expert uses to recognize an impact crater. The core of the algorithm uses Canny edge detection, followed by a circular Hough transform, to detect the inner and outer edges of the crater rim, followed by a number of conditional tests for roughness, center brightness, and rim brightness. The code also includes multi-core processing to significantly decrease the time required to process an entire foil dataset.

Results: The crater searching code detects a crater candidate in approximately 1-5% of the images, requiring manual review of > 600 candidate features. Of these, only ~20 candidates from each foil were considered likely craters and reimaged. In total, 28 impact craters were located on ten of the foils (analysis of the last two foils are in progress), in keeping with previous estimates of crater abundance [5]. The algorithm was successful in identifying craters that were also previously identified by citizen scientists using the Foils@Home website, an extension of the Stardust@Home effort [6].

Two foils, I1009N,1 and I1020W,1, contained 13 and 6 craters, respectively, while the remaining foils contained 0-4 craters each. All of the crater residues on these two foils were consistent with secondary impacts from the spacecraft solar cells [7], suggesting that dust impacts onto the solar cells can create ricochet ejecta sprays and multiple craters on a single foil. These two foils are also adjacent to each other on the collector tray, and it is likely that all secondary impacts on these foils were caused by a single large dust impact onto the solar cells. FIB lift out and TEM analysis of the remaining crater residues is ongoing.

Discussion: The new crater searching code significantly speeds up evaluation of SEM imaging datasets of Stardust interstellar foils for locating dust impact craters, and was validated against known craters in datasets from the Interstellar Preliminary Examination (ISPE). The reliability of the core algorithm for crater detection stems from its procedural similarity to the way a human expert would recognize an impact crater, and is an improvement from the image cross-correlation approach used during the ISPE period [8]. The algorithm was also able to successfully detect craters in image datasets acquired under non-optimal imaging conditions (e.g., defocus and/or astigmatism), but suffered when processing high noise datasets.

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