STARDUST INTERSTELLAR FOILS I1061N,1 AND I1031N,1: FIRST RESULTS FROM AUTOMATED CRATER SEARCHES AND FUTURE ANALYTICAL POSSIBILITIES. C. Floss, C. Allen, S. Bajt, H. A. Bechtel, J. Borg, F. Brenker, J. Bridges, D. E. Brownlee, M. Burchell, M. Burghammer, A. L. Butterworth, P. Cloetens, A. M. Davis, R. Doll, G. J. Flynn, D. Frank, Z. Gainsforth, E. Grün, P. R. Heck, J. K. Hillier, P. Hoppe, L. Howard, G. R. Huss, J. Huth, A. Kearsley, A. J. King, B. Lai, J. Leitner, L. Lemelle, A. Leonard, H. Leroux, L. R. Nittler, R. C. Ogliore, W. J. Ong, F. Postberg, M. C. Price, S. A. Sandford, J. A. Sans Tresseras, S. Schmitz, T. Schoonjans, K. Schreiber, G. Silversmit, A. Simionovici, R. Srama, F. J. Stadermann, T. Stephan, J. Stodolna, R. M. Stroud, S. R. Sutton, R. Toucoulou, M. Trieloff, P. Tsou, A. Tsuchiyama, T. Tyliczszak, B. Vekemans, L. Vincze, A. J. Westphal, M. E. Zolensky, and >29,000 Stardust@home dusters. ISPE author affiliations are listed at http://www.ssl.berkeley.edu/~westphal/ISPE/.

Introduction: In addition to samples from comet 81P/Wild 2 [1], NASA's Stardust mission may have returned the first samples of contemporary interstellar dust. The interstellar tray collected particles for 229 days during two exposures prior to the spacecraft encounter with Wild 2 and tracked the interstellar dust stream for all but 34 days of that time. In addition to aerogel capture cells, the tray contains Al foils that make up ~15% of the total exposed collection surface [2]. Interstellar dust fluxes are poorly constrained, but suggest that on the order of 12-15 particles may have impacted the total exposed foil area of 15,300 mm^2; 2/3 of these are estimated to be less than ~1 µm in size [3]. Examination of the interstellar foils to locate the small rare craters expected from these impacts is proceeding under the auspices of the Stardust Interstellar Preliminary Examination (ISPE) plan. Below we outline the automated high-resolution imaging protocol we have established for this work and report results obtained from two interstellar foils.

Experimental: Secondary electron (SE) imaging of the interstellar foils is being carried out with a JEOL 840a SEM equipped with Noran System Seven software for automated image acquisition. The imaging protocol that we are using allows us to locate craters of the appropriate sizes (~300 nm or larger) while minimizing C contamination to the foils (e.g., [4]). Individual images of 106 x 80 µm (2048 x 1536 pixels at 16 bit grayscale) are mapped at 15 kV, 5 nA for 10 sec per frame, providing a resolution of ~50 nm/pixel with a dwell time of 0.001 sec/μm^2.

After defining the four corners of the foil, the foil area is divided into multiple grids about 0.25 mm^2 in size. Manual z-axis focusing is done in the center of each region, after which the grids are further divided into areas of the appropriate size. A minor amount of image overlap (5%) is incorporated into both steps so that no portion of the foil is omitted. The z-axis positions are interpolated from one grid center to the next to ensure good focus for all individual images in a grid. The entire array is then imaged automatically in sequence, and each image is saved with a unique label identifying its position on the foil. The resulting images are examined manually by a minimum of two independent undergraduate students and candidate craters are flagged for later verification.

Verification of crater candidates is carried out with our PHI 700 Auger Nanoprobe equipped with a field emission electron source. Mapping parameters are similar to those used for the automated searches, but images are scanned at a higher resolution of ~15 nm/px. The C contamination rate during verification imaging is also monitored, with record images taken once per session on a clean Al stub, and locally on the foil within 100 µm of each candidate.

Results: We have carried out automated SE mapping on a total of four interstellar foils and have completed image examination for two of them. Table 1 shows that a large number of the images examined contain features that were identified as possible craters by our students. Visual examination of these crater candidates indicates that while some are clearly not actual craters, others cannot be ruled out as easily. However, in earlier work searching for craters on a portion of the Genesis polished Al kidney under conditions identical to those implemented here [5], we found the vast majority of crater-like features to be micrometer-sized dust particles whose bright rims and dark centers resembled craters in the original SE images. The interstellar foils contain abundant debris on their surfaces, and many of the identified features are probably also simply dust grains.

Table 1. Automated interstellar foil scans.

Foil	Area	# of images	# of 'craters'
I1061N,1	~76 mm^2	9870	491
I1031N,1	~76 mm^2	8040	531
I1032W,1	~30 mm^2	5793	not completed
I1047N,1	~76 mm^2	9750	not completed

We carried out a ranking of the crater-like features flagged by our students in foils I1061N,1 and I1031N,1 and identified approximately 5% as the best candidates to be actual craters. Imaging of these candidates at higher resolution showed that 6 of 33 features in I1061N,1 and 4 of 32 features in I1031N,1 are actual craters (Table 2). A fifth feature on I1031N,1 remains a potential crater candidate. Sizes of the impact craters range from ~235 nm to ~700 nm; some craters are circular, but others are asymmetrical and have non-uniform rims (Fig. 1). On both foils the craters are distributed randomly over the foil area. Thus, the high abundance of craters observed cannot be attributed to clusters of secondary impacts. Selection of additional candidate features for high-resolution imaging is currently underway.

Table 2. Impact craters on I1061N,1 and I1031N,1.

Foil	Image	Crater shape	Crater size (nm)
I1061N,1	022@44	circular	350
I1061N,1	036@33	asymmetric	330 x 405
I1061N,1	069@22	circular	390
I1061N,1	135@30	asymmetric	375 x 515
I1061N,1	188@24	asymmetric	600 x 715
I1061N,1	205@32	asymmetric	690 x 575
I1031N,1	037@02	circular	235
I1031N,1	158@35	circular	555
I1031N,1	216@45	asymmetric	640 x 705
*I1031N,1**	*218@25*	*asymmetric*	*505 x 720*
I1031N,1	239@11	asymmetric	535 x 675

*identification as crater remains uncertain.

Outlook: Ongoing work on the interstellar tray aerogel tiles has shown the presence of numerous secondary impacts [e.g., 6, 7], and it is likely that many of the craters identified in the Al foils are also produced by secondary ejecta from spacecraft sources. While interstellar dust is expected to have hit the collector in the normal direction, secondary impacts are more likely to come from an off-normal direction. However, unlike the aerogel tracks, trajectory determination is difficult for impact craters in the foils [8, 9]. We have used Auger spectroscopy to identify the presence of thin directional spray ejecta in craters produced by experimental hypervelocity dust shots at various impact angles into Al foils [10]. These ejecta are observed only around off-normal impacts and have not been seen around normal-incidence impacts. Similar Auger measurements could be carried out on all interstellar craters to provide possible trajectory information prior to other analyses.

Compositional information provides another primary method for distinguishing spacecraft residue from likely extraterrestrial matter. The amount of residue in the interstellar craters is likely to be significantly lower than in the cometary craters, due to the higher impact velocities of the interstellar particles, with melt layers probably <10 nm thick [11]. Auger spectroscopy provides elemental information from a small volume of a few nanometers in depth from directly under the primary electron beam and can, in principle, detect all elements in the periodic table except for H and He. In past work on craters from the Stardust cometary foils, we have shown that the elemental compositions of particles as small as 100 nm can be clearly distinguished in crater interiors [12] and compositional heterogeneities can be detected in craters as small as 200 nm [13]. Auger spectroscopy is, thus, a promising technique for analyzing the small amounts of residue likely to be found in these craters.

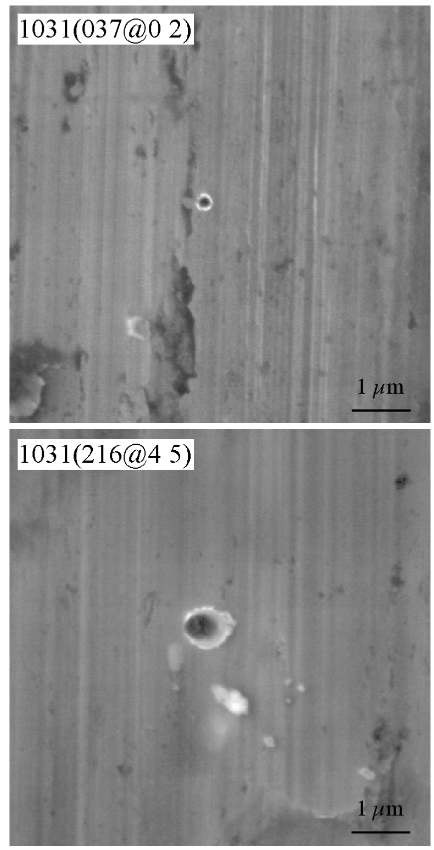

Figure 1. Secondary electron images of impact craters from interstellar foil I1031N,1.

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