PRELIMINARY EXAMINATION OF THE INTERSTELLAR COLLECTOR OF STARDUST. A. J. Westphal[1], C. Allen[2], R. Bastien[2], J. Borg[3], F. Brenker[4], J. Bridges[5], D. E. Brownlee[6], A. L. Butterworth[1], C. Floss[7], G. Flynn[8], D. Frank[1], Z. Gainsforth[1], E. Grün[9], P. Hoppe[10], A. Kearsley[11], H. Leroux[12], L. R. Nittler[13], S. A. Sandford[14], A. Simionovici[15], F. Stadermann[6], R. M. Stroud[16], P. Tsou[17] T. Tyliczszak[18], J. Warren[2], M. E. Zolensky[2], >23,000 Stardust@home dusters[19] , [1] *Space Sciences Laboratory, U. C. Berkeley, Berkeley CA 94720, USA* [2] *KT NASA Johnson Space Center, Houston, TX 77058, USA* [3] *IAS Orsay, F-91405 Orsay-Cedex, France* [4] *Geoscience Institute, Universität Frankfurt am Main, Frankfurt, Germany* [5] *Space Research Centre, University of Leicester, Leicester, UK* [6] *Astronomy Dept., University of Washington, Seattle, WA 98195, USA* [7] *Physics Dept., Washington University, St. Louis MO 63130, USA* [8] *Dept. of Physics, SUNY – Plattsburgh, Plattsburgh, NY 12901, USA* [9] *Max-Planck-Institut für Kernphysik, Heidelberg, Germany* [10] *Max-Plank-Institut für Chemie, P. O. Box 3060, D-55020 Mainz, Germany* [11] *IARC, Dept. of Mineralogy, The Natural History Museum, London SW7 5BD, UK* [12] *Laboratoire de Structure et Propriétés de l'Etat Solide UMR 8008 Université des Sciences et Technologies de Lille* [13] *Carnegie Institution of Washington, Washington DC 20015* [14] *Astrophysics Branch, NASA-Ames Research Center, Moffett Field, CA 94035 USA* [15] *Observatoire des Sciences de l'Univers de Grenoble LGIT, BP32, 38041 Grenoble Cedex 9, France* [16] *Naval Research Laboratory, Washington DC, USA* [17] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA* [18] *Advanced Light Source, Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA* [19] *Worldwide* .

In January 2006, the Stardust spacecraft returned to earth two unprecedented and independent extraterrestrial samples: the first *bona fide* samples of a comet, and the first samples of contemporary interstellar dust. The Preliminary Examination (PE) of the cometary collection was a planned part of the mission and took place in the first months after recovery. Results of the cometary PE were reported in a special issue of *Science* [1].

Approximately 85% of the $1039\,\mathrm{cm}^2$ collector area of the Stardust Interstellar tray consists of aerogel tiles, and the remaining area consists of aluminum foils[2]. The collection time was 196 days. The recent incorporation of data from varying heliocentric distances and better understanding of particle size filtering as a function of approach to Solar Maximum [3, 4] now suggest that an interstellar particle flux of $> 7 \times 10^{-5}$ $\mathrm{m}^{-2}\ \mathrm{s}^{-1}$ might have been expected at the relatively modest heliocentric distance ($\sim$ 2.0 – 2.5 AU). With the simplifying assumption that the flux was constant over the collection periods, this would imply $\sim$120 particles >300 nm in size to have hit aerogel and $\sim$15 to have impacted the aluminum foil.

An important lesson from the cometary PE was that the Stardust cometary samples in aerogel are extremely technically challenging — in many ways, the most technically challenging materials ever returned from space. Captured particles often separate into multiple fragments, intimately mix with aerogel, and they are typically buried hundreds of microns to millimeters deep in the aerogel collectors. Nonetheless, the samples provided invaluable information about Wild 2 [1]. Larger fragment surfaces are strongly heated, but below ~ 1 μm depth they are excellently preserved. **If the cometary samples are challenging, the interstellar samples are likely much more so, since they are expected to be orders of magnitude smaller in mass, and their fluence is two orders of magnitude smaller than that of the cometary particles.** To separate the compositional signatures of these quantities from a complex background will demand extraordinary measures in analysis and contamination control. As the interstellar samples will typically be less than a micron in size, their interior cannot be protected from impact-induced heating by thermal inertia, and heating, mixing and abrasion effects are likely to be severe, generating nanometer-scale mixtures similar to those observed on the outer micron of comet dust. This may dilute the characteristic oxygen isotope signature to levels beyond the resolution of present instrumentation. Following mixture with aerogel, the very small quantities of several important solar-system major elements (SSME) (Na, Mg, Al, P, S, as well as Si) may also not be detectable above background by X-ray fluorescence methods, due to absorption of their characteristic X-ray emission in the surrounding aerogel. Paradoxically, interstellar grain aerogel tracks may prove much easier to find than aluminum foil craters, but are likely to prove more difficult to analyse for the SSME.

Identification of interstellar impacts

Approximately 36% of the tiles on the Stardust interstellar tray have been scanned using an automated microscope, and the stacks of digital images have been searched for tracks of captured interstellar dust particles by Stardust@home "dusters." Approximately 20% of the fields of view were in high-relief regions of the aerogel, such that the surface was not captured in the imaging. These high-relief regions will be rescanned during ISPE with a very large focus range. Approximately 50 features have been identified in the Stardust interstellar tray, through the Stardust@home project [5]. Because of a lack of even limited laboratory studies of $\sim$20 km sec^{-1} impacts of micron-scale dust into interstellar Stardust flight spares, the selection of criteria for identification of track candidates is entirely subjective. Some, all, or none of these may be actual interstellar particle tracks. Adding to the challenge of interstellar samples is their considerably higher encounter velocity with aerogel or foil.

In addition to these candidates, 15 large tracks and hundreds of small tracks have been identified so far that enter the aerogel at large zenith angles, and show none of the shock-induced track flaring characteristic of hypervelocity capture of particles in aerogel. These tracks are likely to be secondaries from micrometeoroid impacts on the aft solar panels of the Stardust spacecraft, and may be a significant source of contamination for very small tracks and craters. No foils have yet been scanned at high magnification.

Once identified and extracted, the trajectories of tracks in aerogel can in principle be used to identify interstellar dust candidates, since the majority of ISDP enter the solar system in a stream. However, this is complicated by the as yet unknown intrinsic trajectory dispersion plus Lorentz effects from the interplanetary magnetic field and light pressure effects which may cause the interstellar dust radiant to disperse to some degree on the sky. The spacecraft attitude control deadband plus attitude excursions during the asteroid flyby, during safe modes and during various maneuvers all cause additional and unconstrained dispersion in particle trajectories with respect to the tray. It is not yet well understood how accurately and precisely trajectory reconstructions can be made. Trajectories in the cometary collector can be measured and back-plotted with a precision of $\sim$5 degrees [6]. This may or may not prove similar to the reconstruction of trajectories on the interstellar side. The goal is to reconstruct the original particle vector to aerogel collector surface relationship to within an error of 10 degrees, although this may not be possible in practice for all or even any of the tracks.

Because craters do not preserve obvious trajectory information except at very large zenith angle, impactor interstellar origin may perhaps only be obtained from a distinctive isotopic signature in impact residue. The profusion of small oblique tracks found in the aerogel also suggests that abundant craters may have been produced by spacecraft ejecta, which will need to be distinguished before selection of candidates for further analysis. It is possible that some of these can be identified in the foils through measurements of crater rim ellipticity, although experimental craters have shown a strong control of crater subsurface morphology by impactor shape as well as incidence angle [7], hampering determination of trajectory. We plan to perform a detailed evaluation of the composition of ejecta from possible spacecraft sources at an early stage of the ISPE, to determine reliable diagnostic compositional criteria for their identification on both aerogel and foil substrates.

Goals of the ISPE

The goal of the Stardust Interstellar Preliminary Examination (ISPE) is to answer the following five broad questions:

• Which features in the interstellar collector aerogel were generated by hypervelocity impacts, and how much morphological and trajectory information can be gleaned?

• How well resolved are the trajectories of probable interstellar particles from those of interplanetary origin? Which specific aerogel impact features can be recognized as of interstellar origin from morphology, measured trajectories and from results of non-invasive chemical analysis? Conversely, what fraction of the impact features were created by spacecraft-derived secondary ejecta (SDSE) or interplanetary dust particles?

• By comparison to impacts by known particle dimensions in laboratory experiments, what was the mass distribution of the impacting particles? What is the preservation state of impactors? Are they particulate at a scale suitable for analytical trasmission electron microscopy or are they diffuse? Are distinctive silicates, oxides, carbides and nitrides present? Is there any crystalline material? Are extraterrestrial organics present?

• How many detectable impact craters (>500nm) are on the foils, and what is their size distribution? How does the inferred particle size (and hence mass) distribution compare to that determined from the aerogel tracks?

• Can craters produced by SDSE be recognized on the basis of morphology (e.g., ellipticity) or from residues of distinctive spacecraft materials composition? How many craters have residue that is consistent with extraterrestrial material?

To answer these five questions, we will perform non-destructive, sequential, non-invasive analyses of interstellar dust candidates extracted from the Stardust interstellar tray. Destructive or invasive analyses will be left for post-ISPE allocations. For particles trapped in aerogel, we will employ synchrotron-based x-ray analyses, at high spatial resolution ($\leq$ 500 nm), of interstellar dust candidates extracted by micromanipulator from the aerogel collectors in picokeystones [8]. These analyses may be sensitive to organic materials that have diffused into the aerogel surrounding the tracks if their concentrations are sufficiently high. For particles captured as residues in craters in aluminum foil, we will identify and analyze craters using FE-SEM and Auger spectroscopy. High-resolution automated SEM surveys using instruments of high cleanliness will be performed to locate craters of $>$500nm diameter, across many cm^2 of Al foil area. Many thousands of high resolution ($<$50nm) images will need to be examined, requiring weeks of instrument and staff time across the PE span. We suggest that the combination of these methods should suffice to answer the five questions, without unnecessary damage to the precious samples.

The ISPE does not seek to answer the following questions regarding dust from the local interstellar medium, which will fall within the remit of post-PE research:

• What is its detailed mineralogy/petrology?

• What are its trace elemental abundances?

• What specific organic species are present?

• What is the isotopic composition IS dust?

The total duration of the ISPE will be three years. ISPE will differ from the Stardust cometary PE in that data acquisition for the initial characterisation stage (measurement of individual track and crater morphology and orientation, followed by *in situ*, non-invasive analysis) will necessarily be prolonged and piecemeal, and will continue simultaneously and in parallel with data publication and release of the first samples for further investigation. The guiding principle of the ISPE is to do non-invasive characterization of the tracks — in other words, “look, but don’t touch.” The ISPE is open to all qualified investigators with analytical techniques that satisfy the technical requirements. A complete description of the ISPE effort may be found at http://curator.jsc.nasa.gov/stardust/index.cfm.

References

[1] Brownlee D. E. *et al.*, Science, **314**, 1711 (2006).
[2] Tsou, P., *et al.* JGR 108, E10 (2003).
[3] Altobelli, N., *et al.* JGR 110, A7 (2005).
[4] Krüger, H. *et al.* PSS **54** 932 (2006).
[5] Westphal A. J. *et al.* 38th LPSC, 1338 (2007).
[6] Westphal A. J. *et al.* MAPS, in press.
[7] Kearsley A. *et al.* in press.
[8] Westphal A. J. *et al.* MAPS, **39** 1375-1386 (2004)