WHAT CAN YOU DO WITH A RETURNED SAMPLE OF MARTIAN *DUST*?

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Stardust PET: A major issue that we managed to successfully address for the Stardust Mission was the magnitude and manner of preliminary examination (PET) of the returned samples [1], which totaled much less than 1 mg. Not since Apollo and Luna days had anyone faced this issue, and the lessons of Apollo PET were not extremely useful because of the very different sample masses in this case, and the incredible advances in analytical capabilities since the 1960s. After *considerable* discussion with the Curation and Analysis Planning Team for Extraterrestrial Materials we finally all agreed that we would make the 9 month long sample PET as comprehensive as possible, and to also be as inclusive as reasonable with respect to the PET team. We divided the PET effort into six parallel and interrelated efforts: (1) Bulk Composition, (2) Mineralogy and Petrology, (3) Organics, (4) Optical Properties, (5) Isotopes, and (6) Small Craters in Aluminum. All qualified scientists were invited to join any number of these groups, provided they met some minimal background requirements and agreed to group publication all PET results in *Science* (see Brownlee et al., 2006 [1] and all the adjacent papers). Initially we limited PET participation to PhDs with prior experience with analysis of astromaterials. As the effort progressed these rules were relaxed to permit new techniques to be employed and new expertise to be involved. An attractive result of this exercise was the entry of numerous new groups into the astromaterials field and the formation of very powerful new collaborations.

The PET was designed to proceed from the least invasive analyses through marginally destructive ones, and finally to some completely destructive procedures, to maximize the data harvest from minimal sample mass [2]. Thus we began many analysis trees using synchrotron X-ray fluorescence (SXRF), synchrotron tomography (SCT), and/or scanning transmission X-ray microscopy (STXM) of entire keystoned tracks, before actually removing individual grains from the tracks for analysis. These analyses enabled us to focus later characterization efforts on the most interesting captured grains, that would then be removed from the aerogel. We did not always have the time to follow this incremental analytical protocol during PET, but it was a model we followed whenever possible. For these separated grains we usually performed Vis-IR spectroscopy before proceeding to ultramicrotomy, isotopic, mineralogic or organic analyses of sections of grains. Table 1 lists the most commonly applied analytical techniques for nanogram-sized astromaterials, along with their relative, general level of sample destructiveness (modified after [2]). The techniques actually applied to Stardust samples during PET are underlined. Considering the short time (9 months) available for sample PET the range of applied analyses is remarkable, reflecting the value of the returned samples and the depth and dedication of the sample community. When we began to test silica aerogel as a capture media for cometary coma grains in the mid-1980s, the list of available analytical techniques was far shorter than what it is today, and the roster of nanogram-able sample analysts in the astromaterials community was far smaller. A principal value of a returned sample over what may be accomplished remotely is that the samples can be reanalyzed as new techniques are developed and new ideas and hypotheses are proposed. As long as we continue to take good care of dust-sized samples, we can expect far more and improved analyses to be made of them in the coming decades.

References: [1] Brownlee et al. (2006) *Science* **314**, 1711-1716; [2] Zolensky et al. (2000) *Meteoritics and Planetary Science* **35**, 9-29.

Table 1. A Lengthy But Not Exhaustive Summary of Analytical Techniques Available for Nanogram-sized Samples; Analyses Performed During Stardust PET are Underlined

Technique	Destructiveness
Imaging	
Light-Optical Techniques	non-destructive
Scanning Electron Microscopy/ Energy Dispersive Spectrometry	non-destructive
Synchrotron Tomography	non-destructive
Transmission/Analytical Electron Microscopy	partially
Scanning Transmission X-Ray Microscopy	partially
Atomic Force Microscopy	partially
Force Spectroscopy	partially
Holographic Low-Energy Electron Diffraction	partially
SIMS Ion Imaging	destructive

Table 1 continued

Technique	Destructiveness
Bulk and Mineral Compositional Analyses	
Microparticle Instrumental Neutron Activation Analysis	non-destructive
Synchrotron X-ray Fluorescence	non-destructive
XRF Tomography	non-destructive
Scanning Transmission X-ray Microscopy	non-destructive
Micro Raman Spectroscopy	non-destructive
Electron Microprobe Analysis	partially
Protron Induced X-ray Emission	partially
X-ray Spectroscopy	partially
Secondary Ion Mass Spectrometry (incl the Nano persuasion)	destructive
Time-of-Flight Secondary Ion Mass Spectrometry	destructive
Laser Ablation Microprobe- Inductively Coupled Plasma-Mass Spectrometry	destructive
Double Focusing Secondary Ion Mass Spectrometry	destructive
Resonance Ion Mass Spectrometry	destructive
Thermal Ionization Mass Spectrometry	destructive
Organic Analyses	
Micro Raman Spectroscopy	non-destructive
Fluorescence	non-destructive
Electron Energy-Loss Near Edge Structure	partially
Scanning Transmission X-Ray Microscopy	partially
Transmission and Reflectance IR-Vis Spectroscopy	partially
Optically- and Acoustically-Excited Phonon Spectroscopy	partially
Time-of-Flight Secondary Ion Mass Spectrometry	destructive
Chromatography	destructive
Secondary Ion Mass Spectrometry (incl the Nano persuasion)	destructive
Stepped Combustion and Static Mass Spectrometry	destructive
Two-Stage Laser Desorption/Laser Multiphoton Ionization Mass Spectrometry	destructive
Noble Gas and Sample Exposure History	
Solar Flare Track Analysis	partially
Double-Focusing Mass Spectrometer	destructive
Age Dating	
Laser Ablation Mass Spectrometry	destructive
Mineralogy and Atomic Structure	
Synchrotron X-ray Diffraction	non-destructive
X-ray Absorption Spectroscopy	non-destructive
Transmission IR-Vis Spectroscopy	non-destructive
Micro Raman Spectroscopy	non-destructive
Transmission Electron Microscopy	partially
Electron Energy-Loss Near Edge Structure	partially
Atomic Force Microscopy	partially
Electron Energy Loss Spectroscopy	partially
Extended X-ray Absorption Fine Structure	partially
X-ray Absorption Near-edge Structure	partially
IR-Vis Reflectance Spectroscopy	partially
Cathodoluminescence Microscopy and Spectroscopy	partially
Physical Properties	
Density Measurements	non-destructive
Atomic Force Spectroscopy	partially
Magnetic Force Microscopy	partially