LESSONS LEARNED FROM THE STARDUST SAMPLE RETURN MISSION.

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Introduction: These are science and mission design and operations lessons learned from the Stardust Mission, which returned grains from comet Wild-2 and fresh interstellar dust to Earth in 2006 [1].

Science Lessons: Major discoveries of the Stardust Wild-2 samples include the presence of numerous chondrules and CAI in a comet, which requires a much more dynamic early solar system than many had envisaged, and verified predictions made by models requiring outward flow of early solar system solids before the early nebular gas had dissipated [1-3]. No evidence has been found for the presence of live ^{26}Al in the comet, suggesting late accretion [4]. Carbonates and unusual sulfides were found which potentially require activity of liquid water within the comet, but to only a minor degree at best [5-6]. The presence of abundant thermally-metamorphosed silicates in Wild-2 appears to require assembly from an earlier generation of bodies [7]. The abundance of presolar grains in the Wild-2 samples appears to be below what has been found in most chondritic IDPs and primitive chondrites [1]. The bulk mineralogy of Wild-2 grains does not match the mineralogy from any single other known astromaterial [7], and is also strikingly unlike that inferred from Spitzer Telescope spectra of Comet Temple 1 dust [8]. Amino acids and other fragile organics have been detected among the Wild-2 samples [9], which highlights the critical importance of further developing techniques for organic analysis in small samples, and cleaning outbound spacecraft.

Sample Contamination Issues: Stardust contamination control procedures were integral to the flow of spacecraft manufacture, assembly, testing, flight and recovery. The science team took a very active role in planning and implementing contamination control measures. We monitored contamination through numerous witness materials, which were all archived for later analysis. However, despite these precautions the Stardust spacecraft outgassing was sufficient to degrade camera operations, and the aerogel capture media was significantly contaminated during manufacture. We also never completely solved the problem of defining useful limits for organic contaminants of spacecraft hardware, which haunts us as we rather unexpectedly captured primitive cometary organics.

Spacecraft Recovery Operations: A full year of planning for Stardust recovery operations was insufficient, adding strain to the field teams. Care must be taken to coordinate recovery operations with local organizations and inform relevant government bodies well in advance. Recovery plans for Stardust had to be adjusted for unexpectedly wet landing site conditions at the Utah Test and Training Range (UTTR). We found the operation of the Woomera Text Range (South Australia) to be very robust in the case of Hayabusa, and in many respects we prefer this site to the UTTR. Recovery operations for Stardust significantly suffered from the lack of a canister seal for the samples, a problem which has become more severe as detailed analyses of the returned samples proceed. Mission engineers should be pushed to provide true seals for returned samples, especially those from organic-rich bodies.

Sample Curation Issues: More than two full years were required to prepare curation facilities for Stardust. Despite this seemingly adequate lead time, major changes to curation procedures were required once the actual state of the returned samples became apparent. Two years of Curation preparation are insufficient. The Stardust sample database was not fully implemented before sample return –we did not adequately think through *all* of the possible sub-sampling and analytical activities before settling on a database design. Remote storage of a sample subset is critical, for Stardust the remote samples are in a vault in New Mexico.

Preliminary Examination (PE) of Samples: There must be some determination of the state and quantity of the returned samples, to provide a necessary guide to samples requesters and the inevitable oversight committee tasked with sample curation oversight. The Stardust PE was designed so that late additions to the analysis protocols were strongly encouraged, as new analytical techniques become available. No two sample return missions have used the same PE procedures. Stardust operated with an inclusive PE with in-depth investigation of a limited, but representative, subset of the returned samples (<10%). By being as inclusive as possible during PE sample analysis data was maximized and a broader community become acquainted with both the scientific value and problems associated with the samples in the shortest possible time

References: [1] Brownlee et al. (2006) *Science* **314**, 1724-1726; [2] Zolensky et al. (2006) *Science* **314**, 1735-1740; [3] Nakamura et al. (2008) *Science* **321**, 1664-1667; [4] Ogliore et al. (2012) *Ap. J.* **745**, 19-24; [5] Mikouchi et al. (2007) *Lunar And Planetary Science XXXVIII*; [6] Berger et al. (2011) *GCA* **75**, 3501-3513; [7] Frank et al. Submitted to *GCA*; [8] Lisse et al. (2006) *Science* **313**, 635; [9] Sandford S.A. et al. (2010) *Meteoritics and Planetary Science* **45**, 406-433.