

DISTINCTIVE IMPACT CRATERS ARE FORMED BY ORGANIC-RICH COMETARY DUST GRAINS.

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Introduction: Preliminary Examination (PE) of the Stardust cometary collector [1] revealed many tracks in the silica aerogel and impact craters on aluminium (Al) foil, from which Wild 2 dust particle fluence and size distribution were determined [2,3]. Laboratory light gas gun (LGG) shots provided impactor size calibrations [4-6]. Analogue impacts of diverse mineral compositions [7] and aggregate particles aided interpretation of dust composition and structure [8]. We now describe our recent impact experiments on foil by organic materials, which reveal distinctive crater surface textures, and even preserved residue.

Organic matter in comet Wild 2 dust: A major goal of the Stardust mission was to document and interpret organic matter in the collected dust [9]. Although remnant terrestrial organics from production can complicate interpretation [9], studies of extracted grains and whole aerogel tracks by a suite of sophisticated techniques [e.g. 10, 11] have revealed extraterrestrial organic matter. Survival of organic matter in impacts on Al, with high peak shock pressure and temperature (>60 GPa [12] and >>100 °C?) seems inherently more unlikely, yet mapping of craters on Stardust Al foils has shown some do contain residues rich in carbon (C) [3,13]. For future work, it would be helpful to know exactly which craters are most suitable for analysis of residue from organic matter, but how can the right craters be recognised? In new LGG shots under Stardust encounter conditions, and also in some of our earlier calibration experiments using polymer projectiles, we have seen a distinctive surface texture on the crater floor and walls, but only in craters produced by impact of organic-rich particles.

Laboratory experiments: LGG shots were performed using the University of Kent gun at Canterbury [14]. Targets were Stardust flight-spare Al1100 foil, with fine particle projectiles (Table 1) made of: Poly(methyl methacrylate) PMMA, poly[C₃H₈O₂]; Poly(styrene) PST, poly[C₈H₈]; Poly(oxymethylene) POM, poly[CH₂O]; Glycine (C₂H₅NO₂) and Urea (CH₄N₂O). PMMA and PST were chosen to provide low density impact crater size calibration, POM as a possible cometary dust coating [15], with Glycine and Urea as labelled tracers for study of migration and isotopic fractionation in other impact experiments. Impacted foil targets were examined by secondary and backscattered electron imagery (SEI and BEI) at NHM, London and the Open University, UK.

Table 1. Projectiles used in this study

Shot	Projectile	Dens. (g cm ⁻³)	Dia. (µm)	Vel. (km s ⁻¹)
G140109#2	PMMA	1.19	~ 10	6.18
G030909#1	PMMA	1.19	~ 20	5.87
G090506#1	PMMA	1.19	~ 30	5.97
G080506#1	PMMA	1.19	~ 80	5.89
G180209#3	PST	1.05	~ 40	6.10
G111109#1	POM	1.46	Mix	6.00
G111109#2	Urea	1.32	Mix	6.00
G110909#2	Glycine	1.16	Mix	5.89

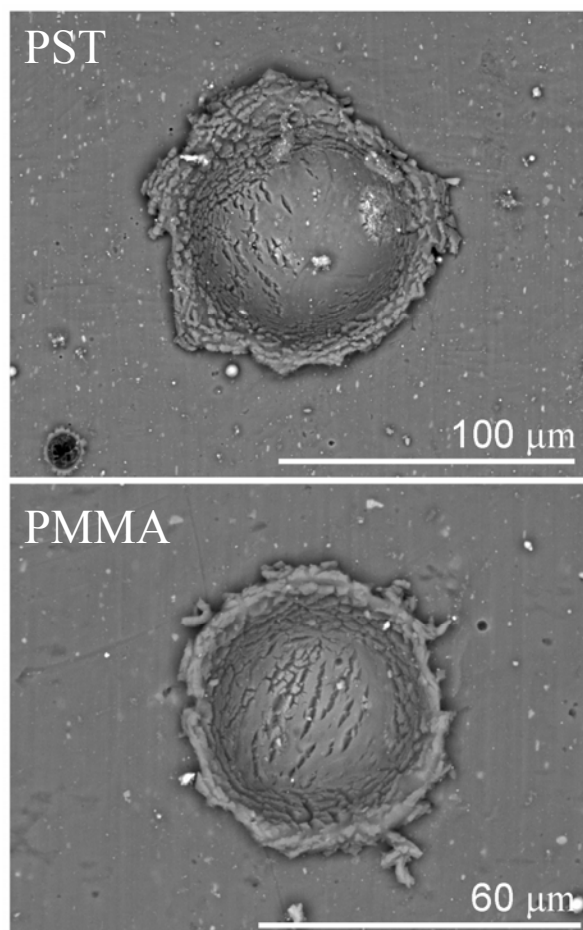


Figure 1. BEI of crater floor textures from laboratory impacts by organic particles onto Stardust Al 1100 foil at ~ 6 km s⁻¹: Poly(styrene) PST at top and Poly(methyl methacrylate) PMMA at bottom.

Experimental crater morphology: The craters from experimental organic projectiles are quite shallow relative to width. Typical depth (D_e) / diameter on ambient plane (D_i) values are: PMMA ~ 0.43 ; PST ~ 0.41 ; and Glycine ~ 0.48 . Crater floors and walls show a distinctive texture, a smooth surface cut by linear, sigmoidal or polygonal fractures. By contrast, impacts by glass particles yield a smooth surface with little cracking, and craters formed by crystalline mineral grains have a very rough floor, usually covered by obvious fragmental residue from the impactor.

Analysis of retained organic residue: Energy dispersive (ED) X-ray microanalyses of C films of known thickness, deposited on Al., show a surprising sensitivity, with layers less than 10 nm being detectable. Although both theoretical modeling and experimental data from inorganic impactor craters show C X-ray count rates from inclined surfaces (e.g. crater walls) are enhanced due to geometrical artefacts, our experimental organic impactor craters also show other light element X-ray peaks above Al background, e.g. N and O, as appropriate to the specific impactor composition (Fig. 2), implying that real residue is present.

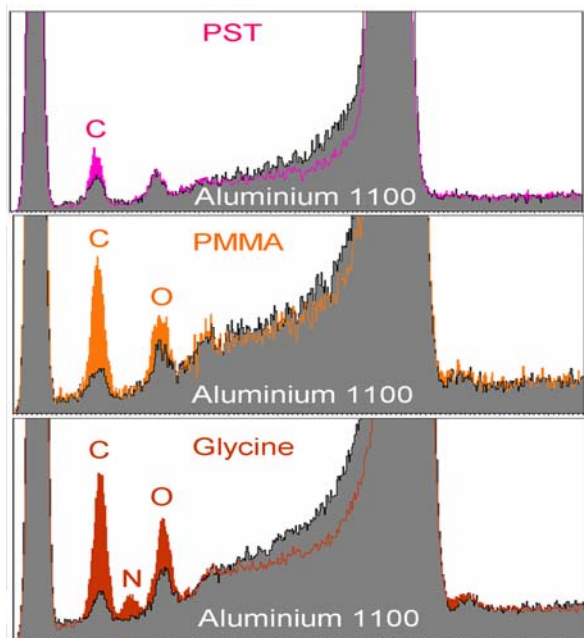


Figure 2. ED X-ray spectra of residues in Al. craters.

Implications: Some Stardust craters show higher carbon count rates within craters [3] than can be explained by surface topography and detector window secondary fluorescence alone. Localised enrichment of C-H bonded material has been confirmed by ToF-SIMS [13]. At least one Stardust crater (Fig. 3) shows the diagnostic morphology we see in our experiments.

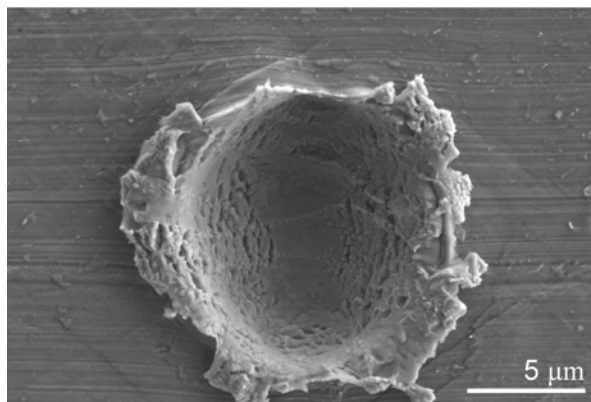


Figure 3. SEI of Wild 2 dust impact on Stardust foil C054N,1. Impactor composition not yet determined, but the crater is shallow, and the surface texture is very similar to that in experimental organic impacts.

Survival of sufficient organic matter to be detectable by EDX after impact at $\sim 6 \text{ km s}^{-1}$ is surprising, especially given low temperatures of melting, boiling or dissociation into volatile monomers: PMMA melts at 130-140 °C and boils at ~ 200 °C; PST melts at 240 °C, with monomer boiling at 145 °C; Glycine melts 182 °C, boils 233 °C, decomposes 238 °C; POM melts 123-175 °C, decomposes at ~ 230 °C; Urea melts 132 °C, then decomposes. Nevertheless, it appears that a substantial proportion (up to 5%) of the original mass is retained. We do not yet know how much modification of composition and molecular structure occurred.

Conclusions: Distinctive surface textures within shallow experimental craters on Al foil allow us to recognize impacts by organic-rich particles under Stardust Wild-2 encounter conditions. Similar craters do occur on Stardust foils. The presence of residue within this type of crater makes them worthy of further analysis by sophisticated techniques.

References: [1] Brownlee D. E. et al. (2006) *Science*, 314, 1711-1716. [2] Hörz F. et al. (2006) *Science*, 314, 1716-1719. [3] Kearsley A. T. et al. (2008) *MAPS*, 43, 41-74. [4] Kearsley A. T. et al. (2006) *MAPS*, 41, 167-180. [5] Price M. C. et al. (2009) *LPS*, XXXX Abstract #1564 [6] Burchell M. J. et al. (2008) *MAPS*, 43, 23 – 40. [7] Kearsley A. T. et al. (2008) *IJE*, 35, 1616-1624. [8] Kearsley A. T. et al. (2009) *MAPS*, 44, 1489-1509. [9] Sandford S. A. et al. (2006) *Science*, 314, 1720-1724. [10] Cody G. D. et al. (2008) *MAPS*, 43, 353-365. [11] Rotundi A. et al. (2008) *MAPS*, 43, 367-397. [12] Burchell M. J. & Kearsley A. T. (2009) *Planet. Spa. Sci.*, 57, 1146 – 1161. [13] Leitner J. et al. (2008) *MAPS*, 43, 161-185. [14] Burchell M. J. et al. (1999) *Meas. Sci Tech.*, 10, 41-50. [15] Cottin H. et al. (2004) *Icarus*, 167, 397-416.