

TOF-SIMS ANALYSIS OF WILD 2 COMETARY MATTER COLLECTED BY STARDUST ALUMINUM FOIL. J. Leitner¹, T. Stephan¹, A. T. Kearsley², F. Hörz³, G. J. Flynn⁴, and S. A. Sandford⁵, ¹Institut für Planetologie, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (leitner@uni-muenster.de), ²Impact and Astromaterials Research Centre, Department of Mineralogy, The Natural History Museum, London SW7 5BD, UK, ³NASA Johnson Space Center, Houston, Texas 77058, USA, ⁴Department of Physics, SUNY Plattsburgh, Plattsburgh, New York 12901, USA, ⁵Astrophysics Branch, NASA-Ames Research Center, Moffett Field, California 94035, USA

Introduction: Samples collected by the *Stardust* mission during its passage through the coma of comet 81P/Wild 2 [1–3] offer the first opportunity to analyze cometary matter collected under controlled conditions. *Stardust* used two different types of capture media for collecting cometary samples [2, 3]. Besides low-density aerogel, aluminum foil (Al 1100; >99 % pure) that was mainly used to facilitate the removal of the aerogel tiles from the modular collector trays, provided a valuable capture medium [4]. Impactor residues were found, typically as discontinuous layers of shock-produced melts, inside crater cavities or on crater rims.

Residual cometary matter in craters on the *Stardust* Al foils was analyzed by time-of-flight secondary ion mass spectrometry (TOF-SIMS) in order to determine the elemental and organic composition of the dust and thereby properties of the cometary nucleus itself. Earlier investigations [5–8] on experimental craters have shown that from the elemental composition of the crater residues, the projectile material can be identified and its composition can be determined, despite the significant, shock-induced alterations at the *Stardust* encounter speed of 6.12 km/s.

Samples and Experimental Procedures: A total of nine foils from the cometary side of the Sample Tray Assembly (STA) of the *Stardust* spacecraft was selected for TOF-SIMS analysis. Only six foils contained craters with diameters >10 μm . After foil straightening, the samples were analyzed using a TOF-SIMS IV instrument from ION-TOF equipped with a Ga^+ liquid metal ion source for SIMS analysis and an Ar^+ ion source for sputter cleaning. Because of the instrument geometry, only the lips of the impact craters are accessible for TOF-SIMS analysis. In order to remove an omnipresent, thin contamination layer, the sample surfaces had to be cleaned by Ar^+ ion bombardment prior to measurement. Because complex molecular ions are destroyed during this process, TOF-SIMS measurements were also carried out before sputter cleaning.

During the analyses, individual sample areas were rastered with a $\sim 0.2 \mu\text{m}$ $^{69}\text{Ga}^+$ primary ion beam with a repetition rate of 10 kHz and a pulse width of ~ 1.5 ns.

Based on the lateral distributions of secondary ions of the major elements, regions of interest were selected for the generation of quantitative mass spectra and determination of element ratios using relative SIMS sen-

sitivity factors derived from glass standards. Further details are given in the literature [6, 9].

All data were corrected using elemental ratios from the surrounding aluminum blank as described by [6]. In addition, several standards of well-known compositions were shot at 4.2–6.1 km/s into aluminum foil and investigated by TOF-SIMS [5–8] in order to evaluate the reproducibility of the chemical composition of the projectile materials by TOF-SIMS analysis. These standards included powders from the CV chondrite Allende [5, 6], hornblende (USNM 143965), diopside (BM.2005,M310 from Yates Mine, Quebec, Canada), olivine (BM.1950,337 from the Admire pallasite meteorite), bytownite (BM.2005,M312, from Majorqap qava in Greenland) and pyrrhotite (BM.2005,M317 from Drag in Norway).

Results:

Standards. All single-mineral standards could be identified unambiguously from the TOF-SIMS analysis of their crater residues. In comparison to their element ratios from literature data or SEM-EDX data [10, 15], correlation coefficients >0.989 were found, suggesting that there are no major modifications for major elements of the impactor composition during the impact process at velocities up to 6.1 km/s. The largest deviations from the nominal values occur only for some minor constituents, especially Na and K, with abundances of less than 1 wt%. These elements may be affected by mobilization effects, as observed in previous studies [11, 15]. The increased alkali abundances in the residue on the crater lips possibly are the result of recondensation of mobilized volatiles on the crater rim. These processes seem to affect only volatiles that occur in associated traces, and not those elements that are bound tightly within the mineral structure. Furthermore, contamination has to be taken into account.

Foils without large craters. No craters with diameters >10 μm were found on foils C2026N,1, C2070W,1, and C2101W,1. Instead, a variety of features was observed: Depressions and scratches in the Al foils, deposits and grains on the foil surfaces as well as impurities inherent to the Al foils. Analyses were carried out to determine the nature of these features, so that a discrimination between terrestrial contaminants and potential deposits of cometary origin is possible.

Large foil craters. On six of the foils (C2009N,1, C2029W,1, C2086N,1, C2086W,1, C2091N,1, and C2102N,1), seven large impact craters between 50 and 240 μm in diameter were found and their residues were analyzed with TOF-SIMS.

The element abundances of individual crater residues show a wide variation, thus indicating a wide compositional range of the cometary dust grains. Nevertheless, the geometric means of most major element ratios are close to CI chondrite values (Fig. 1).

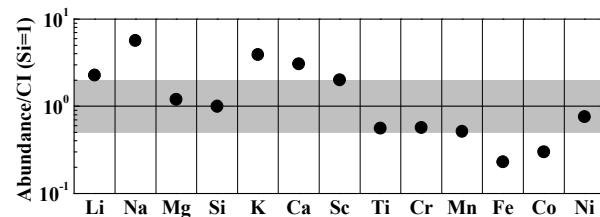


Fig. 1: Geometric means of element ratios normalized to Si and CI for all seven crater residues analyzed. Data points between $0.5 \times \text{CI}$ and $2 \times \text{CI}$ abundances plot within the grey area.

Organic material. Traces of polycyclic aromatic hydrocarbons (PAHs) were found in six of the seven analyzed residues. Since PAHs are nearly omnipresent in nature [12], the origin of the observed molecules was not initially clear.

Generally, the decrease of PAHs with increasing carbon number was observed to be less pronounced than it is for terrestrial samples and even for PAHs from primitive meteorites [13,14]. I.e., the cometary residues contain relatively more 'heavy' PAH molecules than other extraterrestrial and terrestrial samples investigated so far.

Discussion:

Foils without large craters. Features observed on these foils include fine-grained aerogel debris clinging to the aluminum foils, surface grains of different elemental compositions, and metallurgical contaminants of the Al foils, containing Mg, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Ba, and Tl. A wide range of minor and trace element contents have been reported from within the flown *Stardust* foils [10,15]. As these elements are not spatially associated with crater-like structures, and, similar features occurred on the Al-1100-foils used in laboratory experiments [6, 7, 8, 15] an extraterrestrial origin of these contaminants can be excluded.

Large foil craters. The determination of the elemental compositions of the seven investigated foil crater residues was complicated by impurities intrinsic to the Al-foil targets used on *Stardust*, as well as surface contaminations. However, the cometary matter in the impact craters displays a wide compositional span; nearly monomineralic grains, aggregates of non-silicate

composition, as well as compact and aggregate particles of polymict compounds were observed. The unusual high Na and K abundances observed in the majority of the residues do probably not reflect the true cometary composition, but are rather the result of mobilization of volatiles during foil impacts or might be attributed to contamination.

Mg-rich silicates are, together with Fe-Ni-sulfides, a dominant component of the residue material. This is consistent with [16], where a wide range of olivine and low-Ca pyroxene compositions from the cometary grains are reported, together with several alkali-rich mineral phases. However, the average element composition of the seven analyzed cometary residues is quite similar to bulk CI-chondritic values (Fig. 1).

Organics. The larger fraction of the observed PAH-bearing materials is richer in heavier PAHs relative to C_9H_7^+ than other extraterrestrial and also terrestrial samples. This is either due to a higher abundance of heavy PAHs in the cometary particles, or to preferential fractionation of low-mass molecules during the impact [13,14].

Conclusion: This study clearly demonstrates that cometary impact residues captured in aluminum foil at ~ 6 km/s can be identified by TOF-SIMS analysis.

The TOF-SIMS investigation of elements as well as of organic compounds in the crater residues reveals a quite heterogeneous composition of the dust of 81P/Wild 2. On average the crater residues show a CI-like composition.

Acknowledgements: This work was supported by the *Deutsche Forschungsgemeinschaft* through grant STE 576/17-1.

References: [1] Brownlee D. E. et al. (2003) *JGR*, 108, E8111. [2] Tsou P. et al. (2003) *JGR*, 108, E8113. [3] Brownlee D. E. et al. (2006) *Science*, 314, 1711–1716. [4] Hörz F. et al. (2006) *Science*, 314, 1716–1719. [5] Stephan T. et al. (2005) *Workshop on Dust in Planetary Systems, LPI Contrib.*, 1280, 136–137. [6] Hoppe P. et al. (2006) *MAPS*, 41, 197–209. [7] Leitner J. et al. (2006) *LPS XXXVII*, #1576. [8] Leitner J. et al. (2006) *MAPS*, 41, A105. [9] Stephan T. (2001) *Planet. Space Sci.*, 49, 859–906. [10] Jarosewich E. et al. (1980) *Geostand. Newslett.*, 4, 43–47. [11] Hörz F. et al. (1983) *JGR*, 88, B353–B363. [12] Allamandola L. J. (1996) In *The Cosmic Dust Connection*. Kluwer Academic Publishers, pp. 81–102. [13] Stephan T. et al. (2003) *MAPS*, 38, 109–116. [14] Sandford S. A. et al. (2006) *Science*, 314, 1720–1724. [15] Kearsley A. T. et al. (2006) *MAPS*, 41, 167–180. [16] Zolensky M. E. et al. (2006) *Science*, 314, 1735–1739.