TOF-SIMS ANALYSIS OF AEROGEL PICOKEYSTONES — AN ANALOGUE TO STARDUST'S INTERSTELLAR DUST COLLECTION. T. Stephan[1], A. L. Butterworth[2], C. J. Snead[2], R. Srama[3], and A. J. Westphal[2], [1]Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (stephan@uni-muenster.de), [2]Space Sciences Laboratory, University of California at Berkeley, Berkeley, CA 94720, USA, [3]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany.

Introduction: Besides material from comet *81P/Wild 2*, the *Stardust* mission also collected a sample of contemporary interstellar dust during the cruise phase before the cometary encounter [1, 2]. While ~2800 cometary particles >15 µm are expected for the *Stardust* collection [3], only 40 interstellar particles with masses >1 pg, equivalent to sizes >1 µm, are predicted [4]. Therefore, identification, extraction, and analysis of interstellar particles will be extremely challenging.

In order to investigate this material, the interstellar matter has to be either separated from the capture medium – aerogel – or analyzed *in situ*. Although, in general, particle removal is preferred, it will be difficult to carry out and highly risky for particles in the pg range. In cases where the impacting particle has disintegrated into many pieces along the track, *in-situ* analysis of the fine grains becomes the only way to determine the properties of the impactor.

Very small impact tracks that may be similar to those of interstellar grains can be extracted as so-called "picokeystones" [5]. The prefix "pico" was chosen according to the estimated mass of the projectiles on the picogram scale.

In the present study, time-of-flight secondary ion mass spectrometry (TOF-SIMS) was used to analyze experimentally produced particle tracks in aerogel. Since TOF-SIMS is a surface technique, tracks had to be exposed to the very surface of the sample. Therefore, a dissected aerogel picokeystone [5] was prepared for this analysis. Earlier studies on a larger keystone had demonstrated that these techniques work well for cometary analogues [6].

Samples and Experimental Procedures: Carbonyl iron particles with typical sizes of ~0.5 µm where shot at ~20 km/s into aerogel using the Heidelberg 2 MV dust accelerator [7]. Such particles typically generate tracks ~50 µm in size. In this study, a track that was ~60 µm in length was selected. The entire track was extracted in a dissected picokeystone. Since TOF-SIMS requires ideally flat surfaces, the keystone was flattened after dissection. Flattening was achieved by pressing the keystone between a silicon chip and a glass slide covered with Kapton film, using a microscope as a press. Unfortunately, the keystone adhered to the Kapton and not to the silicon chip as intended. After removing it from the Kapton, the keystone was placed on a standard SEM stub using double sticky tape.

Although the classical keystone shape was not retained during preparation (Fig. 1), the keystone was flat to within a few micrometers and well suited for TOF-SIMS analysis.

In the present study, the entire keystone was sputter cleaned by Ar^+ ion bombardment prior to the actual TOF-SIMS analysis that was performed with a Ga^+ primary ion beam. Further details on the TOF-SIMS technique are given in the literature [8].

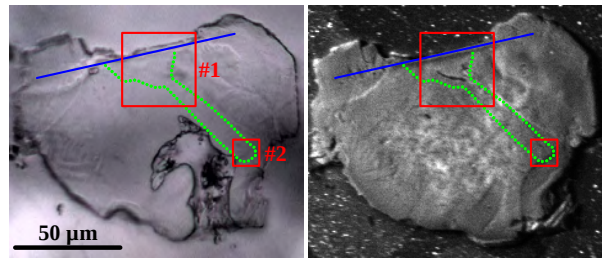

Fig. 1. Optical (left) and total secondary ion image (right) of a picokeystone. The original surface of the aerogel is shown in blue. The outline of the track is given in green. Two regions analyzed in more detail are marked with red squares.

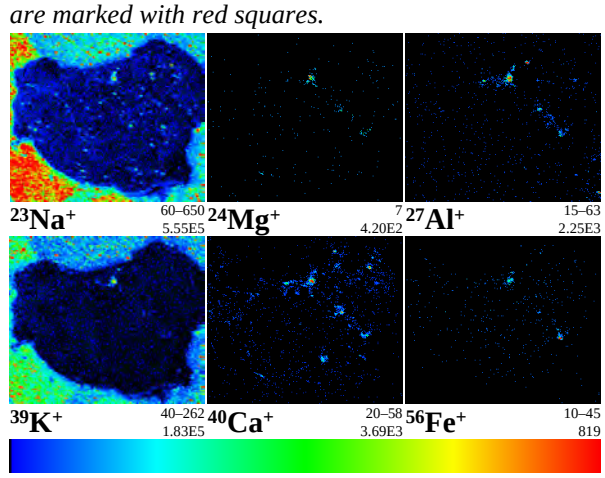

Fig. 2. TOF-SIMS secondary ion images showing the entire picokeystone. Field of view is 140×120 µm^2. All individual ion images use the same linear color scale shown, where black always corresponds to zero counts and red is used for an intensity range given below every image (e.g., 60–650 counts for $^{23}Na^+$). The other number underneath each image is the integrated intensity of the entire field of view (e.g., 5.55×10^5 counts for $^{23}Na^+$).

Results: Secondary ion images shown in Fig. 2 give an overview of the investigated picokeystone. The track can be seen in Mg, Al, C, and Fe images. Selected regions at the start and the end, respectively, of the track were analyzed in more detail (Figs. 3 and 4).

At the beginning of the track, elements lighter than Fe dominate the ion signals (Fig. 3). Sub-micrometer and micrometer sized grains rich in Na, Al, K, and Ca were found. A 10 µm thick rim of hydrogen and hydrocarbon rich material can be seen at the upper left part, corresponding to the exposed surface.

At the very end of the track, an Fe-rich hot spot dominates the ion images (Fig. 4). The size of this elongated region is 0.7 µm×1.4 µm, with the long axis approximately parallel to the track.

The compositional variation between residual material at the start and the end of the track is quantified in Table 1. Here element ratios relative to iron for Fe-rich regions in Figs. 3 and 4 are compared with PIXE data [9] for the projectile material. PIXE data are from two regions (Al-poor and Al-rich) in the projectile material, exemplifying its chemical heterogeneity.

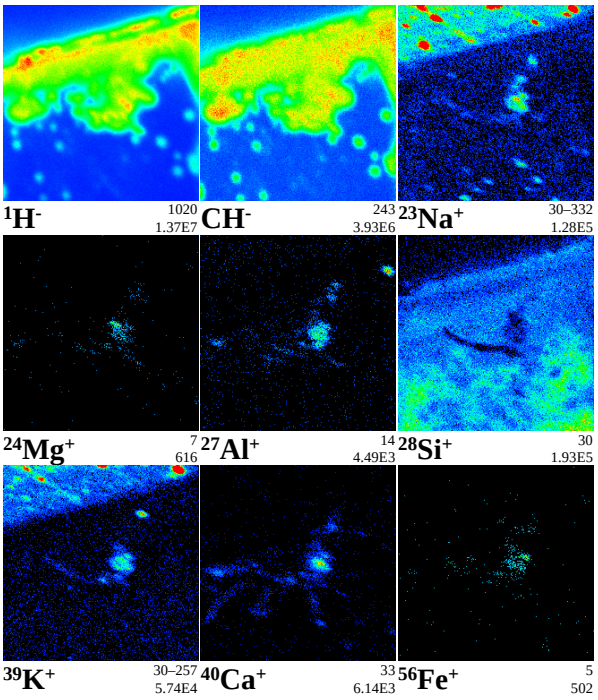

Fig. 3. TOF-SIMS secondary ion images of region #1. Field of view is 35×35 µm^2.

Discussion: The TOF-SIMS results show that particles impacting at ~20 km/s into aerogel distribute their material heterogeneously along their tracks. While Fe and some indigenous Cr dominate the terminal particle, elements probably due to contamination like Na, Mg, Al, K, Ca, and Cu are lost along the particle track, Ca in some sort of spray (Fig. 3). Since this list includes refractory as well as volatile elements, the loss seems to be caused by mechanical effects and not by volatility. It seems plausible that the contaminating elements reside on the very surface of the pure Fe grains. Abrasion of this surface layer probably occurred during passage through the aerogel.

Conclusions: The results clearly indicate that TOF-SIMS is well suited to localize and identify particle residues on dissected aerogel picokeystones. The exact distribution of the various elements along the particle track allows drawing conclusions about the spatial distribution of these elements in the projectiles. If such heterogeneities also apply to *Stardust's* interstellar samples, this might be evaluated by TOF-SIMS.

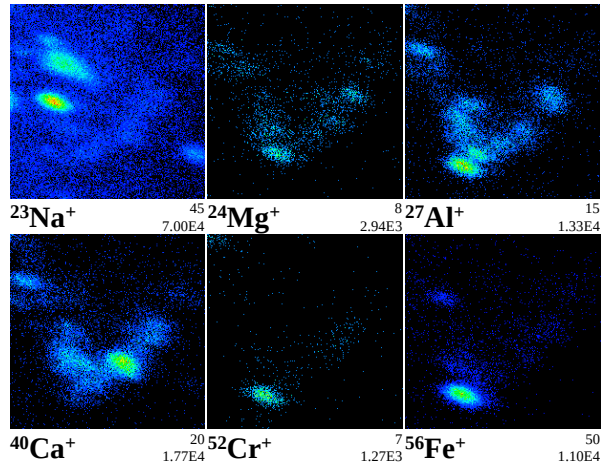

Fig. 4. TOF-SIMS secondary ion images of region #2. Field of view is 12.5×12.5 µm^2.

Table 1. Atomic element ratios measured by PIXE [9] for two regions of the projectile material and by TOF-SIMS for residual material in aerogel at the beginning (#1) and the end (#2) of the particle track.

	PIXE A	PIXE B	TOF-SIMS #1	TOF-SIMS #2
Na	0.09	0.16	1.30	0.0083
Mg	0.011	0.026	0.24	0.0016
Al	0.028	0.56	1.25	0.103
K	0.042	0.079	0.52	0.0014
Ca	0.042	0.062	1.42	0.0052
Cr	0.0031	0.0021	0.05	0.044
Fe	1	1	1	1
Cu	0.073	0.12	0.16	0.005

References: [1] Brownlee D. E. et al. (2003) *JGR, 108,* E8111. [2] Tsou P. et al. (2003) *JGR, 108,* E8113. [3] Tuzzolino A. J. et al. (2004) *Science, 304,* 1776–1780. [4] Landgraf M. et al. (1999) *PSS, 47,* 1029–1050. [5] Westphal A. J. et al. (2004) *MAPS, 39,* 1375–1386. [6] Stephan T. et al. (2006) *MAPS,* submitted. [7] Stübig M. et al. (2001) *PSS, 49,* 853–858. [8] Stephan T. (2001) *PSS, 49,* 859–906. [9] Arndt P. (1994) *pers. comm.*