CAI–LIKE FRAGMENTS DETECTED IN WILD 2 COMETARY IMPACT TRACK C 2012, 110.

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Introduction: Calcium-Aluminum-rich inclusions (CAIs) are thought to originate near the centre of protoplanetary disc in the early state of its formation. The presence of CAIs in the outer regions - beyond the frost line - were comets are formed can be used as evidence for unexepected highly dynamic processes (mixing, mass transport) during the early stage of evolution of the solar system. As Such material is usually rich in Calcium, Aluminum and Titanium it can be identified by synchrotron XRF (S-XRF) methods scanning for Ca and Ti-rich spectra. Applying high resolution techniques even CAI-framents, containing several different mineral species, can be recognized.

The first CAI-like material found in comet Wild 2 was a grain from track 25, known as "Inti" [1]. This object contains several refractory minerals such as anorthite, Ca-, Al-, Ti rich clinopyroxene, gehlenite, spinel, corundum, FeS, osbornite, and probably perovskite [1]. Here we present the first results of a second candidate for a CAI-like fragment from STARDUST mission material of comet Wild 2 which was detected during track mapping applying high resolution S-XRF.

Method: The entire impact track C 2012, 110 (180 µm in length) was analyzed with Synchrotron induced XRF at beamline ID13 at the European Synchrotron Radiation Facility (ESRF) in Grenoble (France). The incident X–ray beam (13keV) size varied between 300x1000nm and 300x300nm depending on the respective set-up. The fluorescence radiation was simultaneously collected in a confocal and a conventional detection mode for direct comparison of the signals. The confocal set-up allows to avoid most of the signal originate from the surrounding aerogel. The polycapillary half lens is located in front of an energy dispersive Si(Li) detector. The probing volume depend on the acceptance volume of the polycapillary and is defined as the intersection of the focus of the half lens with the incident nano X-ray beam. We performed point analysis (300 s life time, Fig. 1) and 2D scans over smaller areas (e.g. 3x3µm^2 up to 6x6µm^2, Fig. 2A, 2B) simultaneously in confocal and conventional detection mode.

Results and Discussion: XRF analysis of the entire track (scanned area: 180x20µm^2) revealed several compositionally different hot spots along the penetration path. Track 110 consists of a terminal particle (TP) and four sub-particles which have been characterized and localized by their Ca, Ti, Fe, Ni and Mn content in an broad overview scan (step size 1µm). There are two Fe, Ni-rich fragments and also one Ti rich particle. The most interesting observations are two grains enriched in Ca, one of them also enriched in Ti (additionally to Fe, ± Ni).

CAI-like fragments. The S-XRF 2D maps reveal two hot spots enriched in Ca and one also enriched in Ti. The approximately 2x2µm^2 sized TP ("Arthur") and a second 1.5x1.5µm^2 sized fragment ("Marvin") reveal Ca concentrations of a few wt. % together with a slightly enhanced Ti-signal. Quantitative results from the MC simulation of two point spectra (life time 300s, Fig. 1) obtained in the conventional detection mode from the two Ca-rich particles are listed in Table 1. For comparison C1-values are listed as well. The MC Simulation was performed on spectra for maximum Ca intensity. The TP shows a Ca concentration which is nearly twice the Ca concentration of the second particle but has a Ti concentration which is a factor of 7 less than for "Marvin". Both grains also contain Fe and Ni whereas the concentration of these elements in the TP is three and four times higher, respectively.

An area of 3x3µm^2 of particle "Marvin" was scanned for the elemental maps of Ca, Ti, Fe and Ni shown in Fig. 2A (for "TP": 6x6µm^2; Fig. 2B). The element maps show, that the highest concentration of Ca, Ti and Fe, Ni do not correlate. The Ni XRF map for "Marvin" shows a diffuse scattering of the signal due to its low concentration. The distribution of elements supports the idea that the grains are CAI-like fragments composed of a mixture of different phases [1-3].

Table 1: Concentrations of S-XRF measurements of impact track 110: all data are given in wt. % except data with # (in ppm), also listed CI values (Anders & Grevesse 1989) for comparison

	CI	TP "Arthur"	"Marvin"
Ca	9,280#	3.64 ± 0.06	2.17 ± 0.04
Ti	436#	0.02 ± 0.01	0.15 ± 0.01
Fe	19.04	0.28 ± 0.03	0.11 ± 0.02
Ni	1.10	0.013 ± 0.005	0.003 ± 0.001
Mn	1,990#	0.03 ± 0.01	0.02 ± 0.005
Cu	126#	0.002 ± 0.001	0.002 ± 0.001

CI normalization for Ca, Ti, Fe and Ni after Anders & Grevesse (1989, values in table 1) shows that Ca (as expected) is enriched by a factor of 3.9 (TP) respectively 2.3 ("Marvin") and Ti is only enriched for the second particle by a factor of 3.4 (TP is depleted over CI by a factor of 0.5). Fe and Ni are depleted in both cases (< 0.01).

Mineralogy. Ca concentrations of nearly 2–4 wt.% are obtained, but mineralogy could not be identified by S–XRF alone. An attempt applying micro–Raman analysis failed due to the high luminescence and disturbance (absorption) of the aerogel. Both CAI–like fragments show that the maxima for Ca, Ti, Fe and Ni concentrations do not coincide which supports the idea of several different mineral phases. This is in agreement with the complex structure of grain "Inti" [1-3]. Due to the chemical data, we suppose that some of the mineral phases involved might be hibbonite ($CaAl_{12}O_{19}$) or gehlenite ($Ca_2Al_2SiO_7$).

Conclusion: The high spatial resolution allows the detection of several mineral phases inside CAI-like fragments. The complexetivity was already described in [1-3]. Due to the required high formation temperature of 1400–2000 K, CAIs most likely originate close to the proto - Sun. The detection of these refractory materials rich in Ca and Ti inside cometary matter requires mass transport and mixing processes between the inner region of the protoplanetary disc and the outer region during or before formation of comets. Mixing processes must occur over distances to at least 30 AU [5] where short period comets were formed in the Kuiper belt and refractory minerals were implanted. [6] suggest that the first observed Stardust CAI "Inti" might be transported to the regions where comets are formed by turbulent diffusion processes [7]. [8] supposed that CAIs are formed when small particles spiral through the SN disk to the X point. The repeated observation of CAIs in Wild 2 shows that comets are not formed in total isolation in the solar system.

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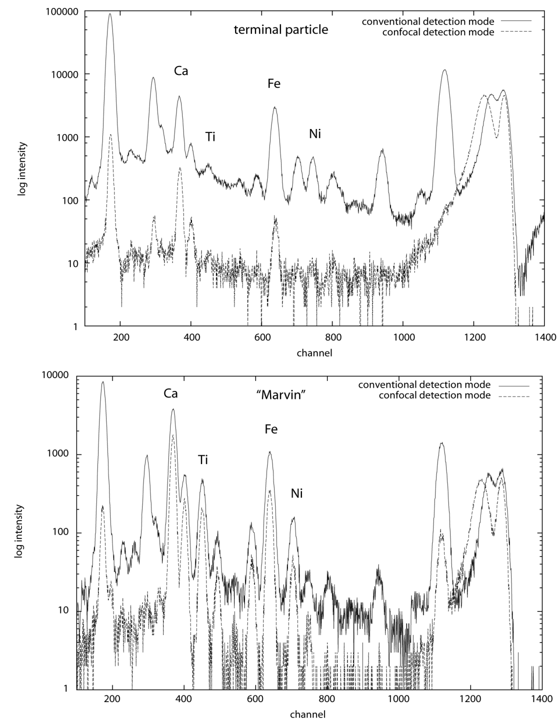

Figure 1: top: XRF spectra of the terminal particle in conventional and confocal (dashed) detection mode. below: XRF spectra for the fragment "Marvin" showing Ca and Ti enrichment.

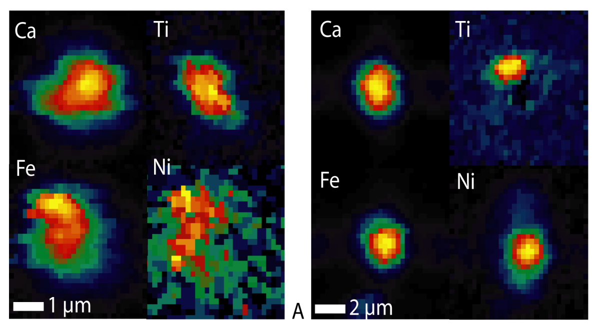

Figure 2: A) XRF map of "Marvin". Scanned area was 3x3µm^2. B) XRF map for the TP (6x6 µm^2) - The highest concentrations for the elements do not coincide indicating different mineral phases.