

NM-SCALE ANATOMY OF AN ENTIRE STARDUST CARROT TRACK. K.Nakamura-Messenger^{1,2}, L. P. Keller¹, S. J. Clemett^{1,3} and S. Messenger¹. ¹Robert M. Walker Laboratory for Space Science/Astromaterials Research and Exploration Science Directorate NASA Johnson Space Center, Houston, TX 77058, USA, ²ESCG/ Jacobs Technology, TX 77058, USA, ³ESCG/ ERC Inc., TX 77058, USA (keiko.nakamura-1@nasa.gov).

Introduction: Comet Wild-2 samples collected by NASA's Stardust mission are extremely complex, heterogeneous, and have experienced wide ranges of alteration during the capture process. There are two major types of track morphologies: "carrot" and "bulbous," that reflect different structural/compositional properties of the impactors. Carrot type tracks are typically produced by compact or single mineral grains which survive essentially intact as a single large terminal particle. Bulbous tracks are likely produced by fine-grained or organic-rich impactors [1]. Owing to their challenging nature and especially high value of Stardust samples, we have invested considerable effort in developing both sample preparation and analytical techniques tailored for Stardust sample analyses. Our report focuses on our systematic disassembly and coordinated analysis of Stardust carrot track #112 from the mm to nm-scale.

Cometary Track# 112: is 1947 μm long carrot track extracted from aerogel tile C2067 as a keystone that was subsequently allocated to our team. The terminal particle extracted from track T112 consists of an $\sim 10 \mu\text{m}$ rounded grain of forsteritic olivine [2]. The O isotopic composition of this terminal particle measured by JSC NanoSIMS 50L was found to be ^{16}O -rich ($\delta^{17}\text{O} = -65 \pm 4$, $\delta^{18}\text{O} = -59 \pm 3$) [2], which is similar to both the refractory CAI-like Wild-2 sample previously reported by [3], and the recently determined oxygen isotopic composition of the Sun [4]. Trace organic (PAH molecules) measurements of the terminal particle by $\mu\text{L}^2\text{MS}$ are reported in [5]. We systematically examined all the fine grains along the track wall to determine if they are small fragments of the same material as the terminal particle shed during the capture event, or whether they represent discrete materials different from the terminal particle. Our preliminary investigation focused on the detailed mineralogy and chemistry of the small fragments using transmission electron microscopy (TEM). Follow-on analyses will include coordinated isotopic analyses using the JSC NanoSIMS.

Dissect a track in aerogel: The track 112 track wall was photo-documented using an extended depth-of-field image processing technique that generates a single in-focus image from a series of photographs (Fig. 1). We also imaged the sample under UV light to discriminate compressed aerogel from indigenous cometary material. The terminal particle was removed and processed separately. The keystone containing

track# 112 was gently placed on a very thin layer of low-viscosity epoxy and heated at $\sim 70^\circ \text{C}$ under vacuum for a couple of hours. This process conserves the original shape and size of the track. Additional aliquots of epoxy were added little by little under vacuum until the keystone was completely impregnated by epoxy. The epoxy block was then trimmed down along the track (Fig. 2). To date, we have prepared 385 sections of 70 nm-thickness using ultramicrotomy and deposited on TEM grids (Fig.3). Imaging and selected area electron diffraction data were obtained using a JEOL 2500SE field-emission scanning TEM (FE-STEM) equipped with an energy-dispersive X-ray detector (EDX) analysis system capable of nanometer-scale compositional mapping.

Terminal Particle Mineralogy: We have previously reported preliminary data on the mineralogy and microstructure of the terminal particle [6]. EDX spectra show that the core of the grain is Fo99 - x-ray mapping reveals a slight enhancement in Fe towards the rim of the grain to Fo97. The forsterite is strained and shows a high density ($2 \times 10^{10}/\text{cm}^2$) of oriented planar defects along (100). The planar defects in the forsteritic terminal particle likely result from shock. It is unknown whether the shock effects resulted from processes that occurred on Wild-2 or if they formed during the capture event.

Track Mineralogy: As shown in Fig. 4, the track morphology is well-preserved in ultramicrotome thin sections and material is intact. The aerogel within 20 μm of the track wall (darker contrast in Fig. 4) was compressed by the impact. Numerous sub-micrometer sized grains are observed along the track wall. Many of these tiny grains consist of melt particles (cometary material intimately mixed with melted aerogel) (Fig.5). Their compositions are enriched in Si, and minor Mg, Ca, S, Cr and Fe. One enstatite grain (200 nm in size) encapsulated in melt aerogel was observed but no forsterite grains were found so far. Three diamond grains (100-350 nm in size) are found both along the track and inside the compressed aerogel area (Fig. 5).

Conclusions: We have demonstrated the ability to ultramicrotome an entire track along its axis without first compressing the aerogel. This innovation allows us to examine the distribution of fragments along the entire track from the entrance hole all the way to the terminal particle. For Track 112, we observed that the mineralogy of fragments along the track axis was different from that of the terminal particle. The fragments

are dominated by melt particles that result from the interaction of the impacting particle with molten aerogel. In addition, we have observed multiple grains of well-crystallized diamond. Future NanoSIMS isotopic analyses are planned to constrain their origin.

References: [1] Hörz, F. et al. (2006) *Science* 314, 1716. [2] Messenger, S. et al. (2008) *MAPS Supp.*, 43, #5308. [3] McKeegan K. D. et al (2006) *Science* 314, 1724. [4] McKeegan K. D. et al (2008) AGU, P42A-07 [5] Clemett, S. J. et al. (2008) *this volume*. [6] Keller, L. P. et al. (2008) *GCA*, 72, A459

