THE COMPOSITION OF SURVIVING FINE-GRAINED COMETARY MATERIAL IN STARDUST AL FOIL CRATERS. T. K. Croat, B. Haas, and C. Floss, Laboratory for Space Sciences and Department of Physics, Washington University, St. Louis, MO 63130, USA, tkc@wustl.edu

Introduction: The composition and size distribution of fine cometary dust is not easily accessible from aerogel-captured Stardust samples, due to mixing and melting with aerogel on capture. The study of fine-grained material captured in Al foils can offer a complementary approach [1], and indeed many Al foil craters have been found to contain intact, well preserved crystals [2]. Preliminary SEM-EDX studies have shown that most small craters are mixtures of silicates and sulfides, but semi-quantitative analysis of the composition of the surviving material was not attempted [3]. Here we describe development of semi-quantitative SEM-EDX and Auger spectroscopy techniques for in-situ, non-destructive characterization of the material captured in Al foils. We then present the compositions and size distribution data of the surviving fine-grained cometary material from 150 C2010W craters and compare these with similar data from analog craters [4-5].

Experimental Methods: Craters with diameters larger than >0.5 µm (N=346) were found on the 1.7 by 10.6 mm scanned area of the C2010W Stardust foil using both automated image template matching [6] as well as visual searches. SEM-EDX spectra were acquired from 150 of these craters with a 10kV primary beam (200s livetime), and Mg, Fe, Si, S and Ca were all clearly detectable among the crater spectra. The voltage was chosen to minimize the beam interaction volume while also giving sufficient overvoltage for Fe-K quantification. Auger spectra (10kV, 10nA, 20 min total acquisition time) were then acquired from material at the bottoms of the same craters using a PHI 700 Scanning Auger Nanoprobe. For these crater spectra, the Auger signal comprises 0.5% to 3% of the electrons detected for Mg, Si, Fe, Ca and S (the major elements in the cometary material aside from possible Al), with the large background signal coming primarily from electrons backscattered from the foil (Fig 1b).

Sensitivity factors using the Cliff-Lorimer method for SEM-EDX quantification were determined both by comparison with TEM-EDX compositions measured in FIB-extracted craters [5] and also by setting the bulk average C2010W composition from 150 craters to match the CI values [as suggested by 7]. In craters with weak Mg peaks, determination of the Mg content from SEM-EDX is complicated by presence of high background counts from the adjacent Al peak (Fig. 1a). Sensitivity factors for Auger quantification were then determined by matching the already-determined SEM-EDX compositions. The reproducibility of the Auger spectral quantification method was tested with repeated acquisitions from ~10 craters, and these determined compositions were equivalent within 4-5 at.% for Mg, Si, S and Fe. Larger deviations (10-25 at. %) were seen for Ca, due to the influence of the large adjacent C peak. The Al content of the surviving material cannot be determined with either technique due to the Al foil background, and C content determinations are complicated by the presence of C on unsputtered Al foils.

Results: Our compositional results are broadly consistent with prior SEM-EDX of Stardust craters [2], in which craters were characterized as containing residues from silicates, sulfides or mixtures of the two. The crater compositions as derived from SEM-EDX and Auger are not necessarily concordant; SEM-EDX quantification yields the average bulk composition of all surviving material, whereas the Auger measurements of the same craters give the average composition of the thin top layer (~10nm). Despite this, the SEM-EDX and Auger compositions from the same craters are in good agreement; the average magnitude of the

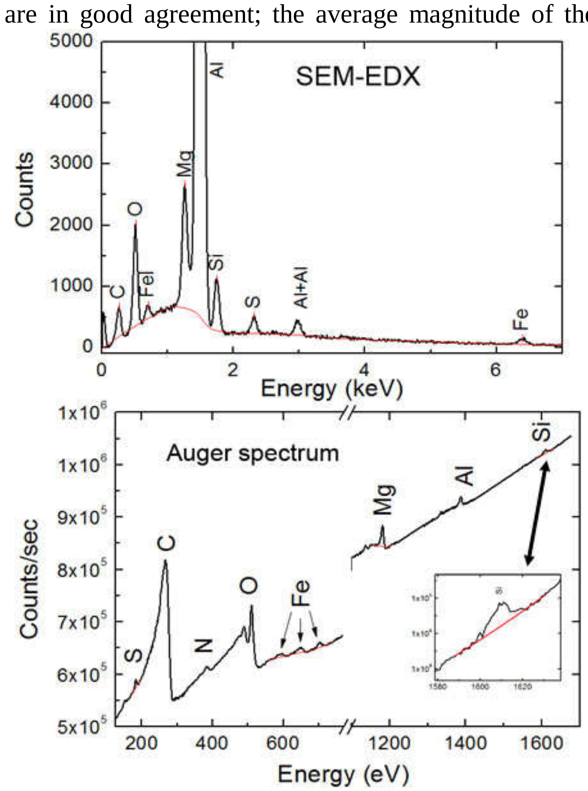

Fig.1. Representative SEM-EDX (a) and Auger electron (b) spectra (with inset Si peak) from a Stardust crater (C2010W f8-1c1), both of which show Mg, Si, Fe, and S peaks from cometary material. C, N and O peaks from unsputtered Al foil surfaces are also seen.

atomic percent differences between the two range from 1-10% for Mg, Si, Fe, S, and Ca. The fractions of craters with detectable Mg, Si, Fe, S, and Ca from the surviving cometary material were 77%, 82%, 85%, 83% and 38%, respectively, and this fraction was similar whether using SEM-EDX or Auger quantification techniques. Figure 2 shows the average compositions of the surviving material at the crater bottoms for 130 craters from SEM-EDX and/or Auger quantitative analyses (20 are excluded due to insufficient counts). These are shown as separate Fe-Si-Mg and Fe-S-Mg ternary plots, and for Ca-bearing craters (>10 at.% Ca), the Ca content is combined with Mg in the ternary.

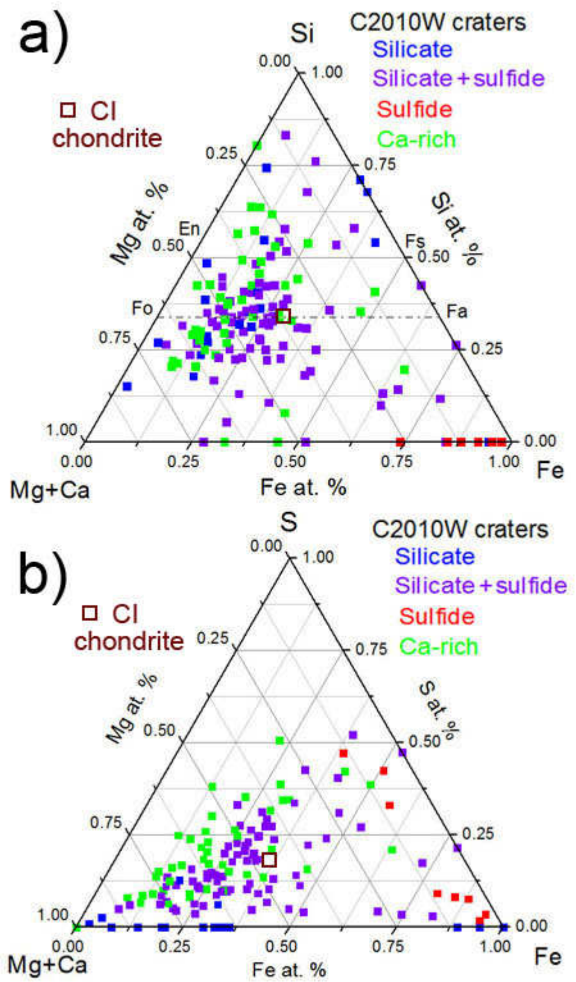

Fig. 2. Ternary composition diagram of Fe-Si-Mg (+Ca) and Fe-S-Mg (+Ca) showing the average composition of the surviving material in 130 C2010W Stardust craters along with CI chondrite average.

Since all craters from this foil were measured in an unbiased manner (aside from the ~0.5µm diameter detection limit), this population is a more representative sample of the fine material than is possible from aerogel tracks, particularly since fine material in aerogel is scattered into different parts of the track wall depending on its size and density [8]. Using established crater-to-projectile size relationships [9], the impacting grains are estimated to have diameters ~1.8x smaller than those of the craters (assuming typical densities of ~3.3 for olivine/pyroxene). Figure 3 shows the composition and size distribution of the fine grains (or more often clusters of grains) that impacted the C2010W foil. The falloff towards smaller impactors (beginning at <0.3µm diameter) results from the detection limit of ~0.5µm for small craters.

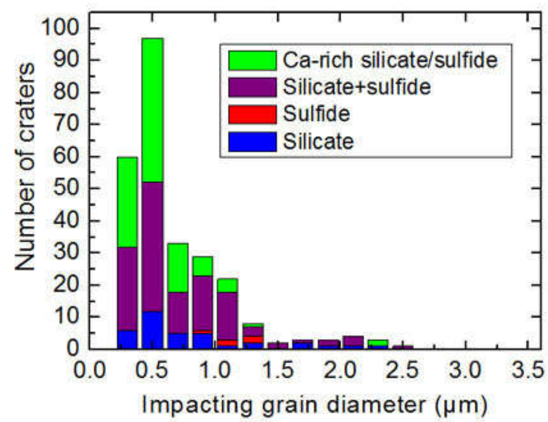

Fig.3 Impacting grain size distribution split by compositional type.

Discussion: The Fe-S-Mg grain compositional distribution (Fig. 2b) is in good agreement with that measured in aerogel-captured fine grains [8]; however the Si content cannot be compared with aerogel-captured grains due to the large Si background from aerogel. Compared with Acfer 094 analog craters that showed clear S loss after impact [5], the surviving cometary material in C2010W craters has significantly higher S content roughly consistent with the CI composition. This observation gives further evidence that foils created by light gas gun impacts at ~6 km/sec are imperfect analogs of the actual collision process [5], and that the surviving material in the true Stardust foils is less modified. FIB-TEM studies [e.g., 2] are planned to both assure the accuracy of these compositional results and to determine the microstructures of the surviving material from the various compositional groups.

References: [1] Croat et al. (2015) *Met. Planet Sci.* 50, 1378. [2] Leroux H. et al. (2008) *Met. Planet. Sci. 43*, 143. [3] Hörz F. et al. (2006) *Science* 314, 1716. [4] Croat et al. (2015) *Met. Planet Sci.* 78,#5130. [5] Haas et al. (2015) *Met. Planet Sci.* 78,#5141. [6] Ogliore et al. (2012) *Met. Planet Sci*. 47, 729. [7] Flynn et al. (2006) *Science* 314, 1731. [8] Stodolna et al. (2012) *GCA* 87,35. [9] Price et al. (2010) *Met. Planet Sci.* 45,1409.