PRISTINE AMORPHOUS GEMS IN ANHYDROUS INTERPLANETARY DUST PARTICLES ARE VERY UNDERDENSE. H. A. Ishii[1] and J. P. Bradley[1], [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, 1680 East West Road, POST 602, Honolulu, HI 96822, USA (hope.ishii@hawaii.edu).

Introduction: Amorphous silicates are arguably the least-understood solids in extraterrestrial materials, despite comprising the majority of rock-forming material in the interstellar (IS) medium from which our Solar System formed. Their significance arises from astronomical observations that IS silicates are >99% amorphous, while protoplanetary disks contain crystalline silicate fractions varying by heliocentric distance (and from disk to disk) [e.g. 1,2]. Thus, amorphous (a-) silicates in comets and primitive meteorites are potential survivors from the original interstellar a-silicate population that dominated the presolar dust from which the Sun and Solar System formed. Some a-silicates retain unambiguous evidence of a pre-solar origin demonstrated by non-solar isotopic compositions [3], but it remains an open and debated question how much of the IS presolar a-silicates survive in recognizable form in primitive bodies [e.g. 4]. Since a-silicates are, by nature, metastable, they are far more susceptible than crystalline solids to alteration prior to, during and after release from their parent bodies. Alteration by heating and hydration have been shown to alter their elemental and isotopic chemistries and morphologies [e.g. 5-7]. Among the most-studied a-silicates are GEMS (glass with embedded metal and sulfides) in anhydrous IDPs, believed to originate from comets that formed at large heliocentric distances and cold temperatures, optimal for preserving a-silicates.

In this study, we explore the densities of the least-altered GEMS in chondritic porous (CP) IDPs. Melt glass densities are typically ~95% of their corresponding crystals, and GEMS have been assumed to be similarly dense. Assessing actual densities of pristine GEMS is important to estimating survivability of recognizeable GEMS in other solar system bodies and a key to understanding mechanisms of alteration. GEM densities also determine their contribution to bulk CP IDP compositions, relevant to claims of complementary compositions between amorphous and crystalline components of CP IDPs [8]. (We have observed that sub-solar GEMS compositions can be an artifact of alteration or Si contamination from collection [e.g. 7].) Here, we apply TEM-EDX mapping and spectroscopy with uniform acquisition times to assess the relative densities of least altered, most pristine GEMS and find them to be systematically and significantly underdense relative to similar composition crystalline aggregates.

Methods: An ultramicrotomed section of Stardust impact Track 123 was analyzed using the UH FEI 80-300 kV Titan (scanning) transmission electron microscope (S)TEM. Regions of equal area and thickness of silica (SiO_2) aerogel and neighboring (SiO_2) impact-melt were analyzed by energy dispersive x-ray spectroscopy (EDX) at 200 kV for equal amounts of time. Regions in crystalline equilibrated aggregates (EAs) and in neighboring, individual GEMS of similar composition in ultramicrotomed sections of an anhydrous

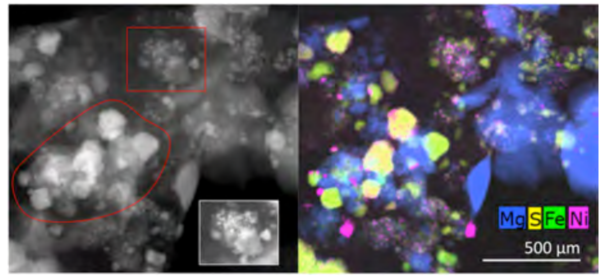

Figure 1. *(left) STEM-HAADF image of GEMS showing lower HAADF contrast than equilibrated aggregate (EA, circled) in IDP W7207A 8D due to their lower average electron density. Inset: GEMS grain from red box with contrast optimized. (right) EDX map shows elemental distributions.*

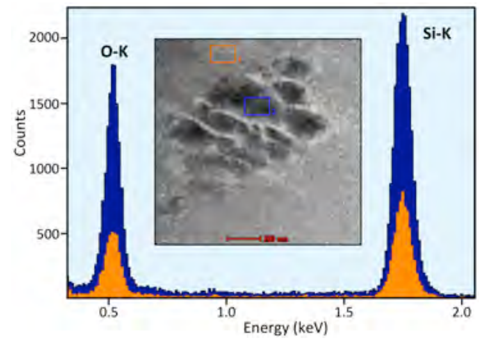

Figure 2. *STEM-EDX spectra from equal volumes of SiO_2 aerogel and SiO_2 impact-melt. The red line spectrum corresponds to aerogel in region 1, and the blue solid spectrum, to impact-melt in region 2 (inset HAADF image). Differences in x-ray fluorescent intensity are due to density.*

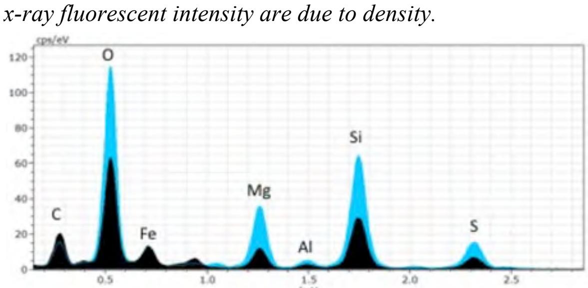

Figure 3: *STEM-EDX spectra from equal volumes of a crystalline equilibrated aggregate (EA) (blue) and a neighboring amorphous silicate GEMS grain (black) in IDP W7207A 8D. Despite nearly identical compositions (el/Si ratios), counts from the GEMS are 0.54× those from the EA.*

IDP (U220GCA) were also analyzed using equal analysis volumes and times. EA crystals are small and show no evidence of microtome chatter. GEMS with no evidence of atmospheric entry alteration (magnetite, rounding indicative of partial sintering, sulfide beads on surfaces or volatile element loss [7]) were targeted.

Ultramicrotomed sections of additional anhydrous IDPs (W7207 8D, U217B19) were analyzed using a TitanX (S)TEM with 4 windowless EDX detectors with solid angle totaling 0.7 sr (Molecular Foundry, LBNL). Maps were acquired by rastering an electron probe with constant dwell time per pixel, 1.6 or 3.3 nm pixel spacing at 200 kV, and ~700 pA beam current. Si element maps enabled exclusion of silicone-oil-contaminated GEMS. Regions containing individual GEMS or EAs, similar in composition and in close proximity, were post-processed. Total counts from GEMS regions were scaled to equivalent pixels in the accompanying EA region to scale all analyses to the same volume and analysis time in each sample.

Results and Discussion: Figure 1 shows a HAADF image of GEMS and EAs in IDP W7207A. TEM practitioners historically noted the low contrast from GEMS relative to crystals: When GEMS were first discovered and analyzed by EDX detectors lacking light element analysis, they were assumed to have carbon matrices and referred to as “tar-balls” [9].

To demonstrate our method, EDX signal was collected from regions of silica aerogel and impact-melt with identical volume (thickness and area) and measurement duration (Fig. 2). Table 1 shows the ratio of total counts from aerogel to melted aerogel of 0.34-0.37. (This impact track was compressed to concentrate comet dust. A ratio of ~0.01-0.02 would be expected from uncompressed aerogel.) Composition, analyzed volume and analysis time are identical, so differences in x-ray counts are due solely to density.

The same approach was used to compare GEMS and equilibrated aggregates (EAs) of similar composition. Table 1 shows total counts from GEMS and EAs from equivalent areas and their ratio from several different anhydrous IDPs. EAs are crystalline and thus expected to be fully dense. Figure 3 compares (equal volume, equal time) EDX spectra of an EA and a GEMS in IDP W7207A 8D. The ratio of total counts from GEMS to EA is 0.54. Table 1 data from GEMS in all IDPs have an average ratio of total counts of GEMS to EA of 0.52±0.16. The GEMS 1* grain in Table 1 showed evidence of heating: rounding of constituents and volatile loss. Omitting that GEMS, the average ratio is 0.50±0.015. GEMS are thus significantly underdense, far less than the ~ 95% for melt glasses. GEMS densities of ~40-60% of corresponding crystals is consistent with differences in HAADF contrast.

Implication 1: The very low densities of minimally-altered GEMS indicate that they should not be expected to survive in the same form in bodies that experienced even weak or gentle compaction, thermal metamorphism, or aqueous alteration.

Implication 2: The contribution of GEMS to whole IDP compositions is small and must be weighted by GEMS densities, which can be significantly lower than has been assumed, in addition to their (variable) volume fraction.

Implication 3: There is probable selection bias in historical GEMS analyses: Altered GEMS that have experienced densification of their amorphous silicate matrix show higher contrast in TEM imaging, drawing the eye. Pristine GEMS, lower in density, are less visible and less likely to be analyzed due to lower contrast.

Future Work: We are assembling a database of GEMS minimally impacted by silicone oil absorption and thermal alteration from atmospheric entry that drive GEMS densities higher and GEMS compositions (element/Si ratios) subsolar. Also, while differences in density cause differences in EDX signal between GEMS and EAs, small differences in composition introduce some additional error. In future, we will quantify GEMS densities using a neighbor silicate of known composition and k-factors.

Stardust T123	analysis 1 0.37	analysis 2 0.34		
W7207A 8D	GEMS 1 0.54	GEMS 2 0.57	GEMS 3 0.49	GEMS 4 0.48
U217B19	GEMS 1* 0.85*	GEMS 2 0.63	GEMS 3 0.47	GEMS 4 0.66
	GEMS 5 0.39	GEMS 6 0.54	GEMS 7 0.44	GEMS 8 0.45
U220GCA	GEMS 1 0.48	GEMS 2 0.92	GEMS 3 0.33	GEMS 4 0.31
	GEMS 5 0.56	GEMS 6 0.24	GEMS 7 0.52	GEMS 8 0.52

Table 1: *Ratio of total x-ray counts from aerogel and impact-melted aerogel regions in a Stardust impact track and from GEMS and EA regions in several anhydrous IDPs.*

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