CHEMICALLY *AND* ISOTOPICALLY ANOMALOUS PRESOLAR INTERSTELLAR GEMS?

J. Matzel, Zu Rong Dai, N. Teslich, I. Hutcheon, P. Weber and J. P. Bradley, Institute of Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, Livermore, CA 94550.

Introduction: It has been proposed that GEMS, the most abundant silicates in the anhydrous chondritic porous (CP) IDPs, are presolar interstellar (IS) "amorphous silicates", one of the fundamental building blocks of the solar system [1]. Non-solar O isotope abundances have since confirmed that some GEMS are indeed presolar IS silicates [2, 3], and the presolar origins of other isotopically normal (solar) GEMS have been inferred from petrographic observations [4, 5] Circumstellar (CS) outflows are major sources of IS silicates and, as expected, at least some of them retain an isotopic "memory" of their circumstellar (CS) origins [2, 3, 6]. However, most GEMS appear to be isotopically normal (solar), consistent with the expectation that IS grains undergo reprocessing and homogenization during their ~10^8 year lifetimes in the ISM [6, 7]. A typical GEMS grain may be a blend of sputtered and deposited material from many IS grains. Evidence of grain homogenization in the ISM manifests itself in the isotopic composition of galactic cosmic rays, believed to originate from shock accelerated IS dust, that with a few exceptions is isotopically normal (solar) [7, 8].

Bradley [1] proposed that chemical as well isotopic properties of GEMS reflect exposure to irradiation during their prolonged lifetimes in the ISM. IS silicates are believed to be Mg-rich and irradiation of Mg-rich silicates causes changes in the relative proportions of cations, most notably the Mg/Si ratio [1, 9]. Assuming all GEMS are IS silicates, the most extensively irradiated (and chemically homogenized) GEMS should have the lowest Mg/Si ratios. Conversely, the least irradiated and least homogenized GEMS should have the highest Mg/Si ratios, and it is these GEMS that are most likely to retain a non-solar isotopic memory of their stellar origins. In other words, GEMS with high Mg/Si ratios are more likely to be isotopically anomalous. Until now, it has not been possible to test this hypotheses because of the small number of isotopically anomalous GEMS (~10) that have been reported and an even smaller number of reported Mg/Si ratios.

Experimental: We are investigating the predicted correlation between Mg/Si and isotope anomalies by measuring the chemical and isotopic compositions of individual GEMS. We selected a classical GEMS-rich CP IDP U220A19 because it contains an unusually large number of GEMS with elevated Mg/Si ratios. Thin-sections prepared using ultramicrotomy were initially characterized using both a 200 keV monochromated STEM and 300 a keV SuperSTEM with a monochromator and dual spherical aberration (C_s) correctors. Individual GEMS were examined using brightfield and darkfield (HAADF) imaging (Fig. 1) and their compositions were measured using energy-dispersive x-ray spectroscopy. X-ray mapping was used to investigate the petrographic setting of GEMS in the thin sections. Following the STEM work the sample was back-coated with patterned straps of Pt ~1 μm thick using the FIB. The straps provide a robust noble metal substrate and a conductive path to the Cu grid, both of which stabilize the specimens for subsequent NanoSIMS measurements. A major advantage of this precision patterning using electron- and ion-beam deposition of Pt in the FIB is that it is possible to revisit isotopically anomalous "hotspots" using STEM after the NanoSIMS measurements.

Isotopic measurements of two sections of IDP U220A19 (Fig. 2) were performed with the LLNL NanoSIMS 50 ion microprobe. O isotopic images were obtained by rastering a ~1 pA, ~100 nm Cs^+ beam over 4-8 μm fields of view while simultaneously acquiring $^{16,17,18}O^-$, $^{28}Si^-$ and $^{24}Mg^{16}O^-$ secondary ion counts on five electron multipliers using a mass resolving power of ~6500. Each image was acquired for a total of 65-100 layers/planes per analysis.

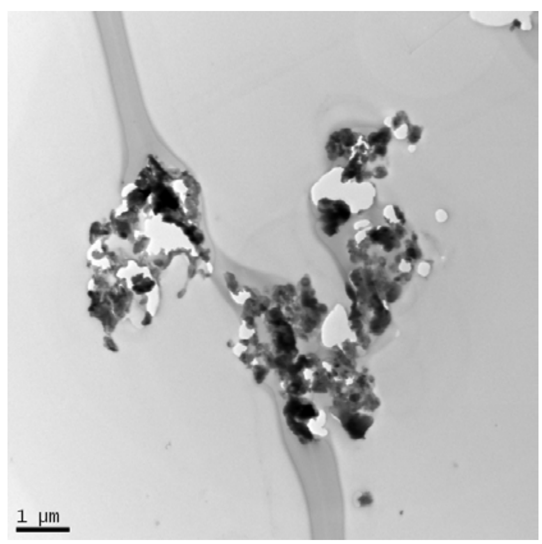

Figure 1: Brightfield electron micrograph of an ultramicrotomed thin section of IDP U220A19.

Results: Results: Four O isotope images from two sections of IDP U220A19 were divided into 158 spatially-resolved subgrains based on local intensity maxima in $^{16}O^{-}$ images and $^{18}O/^{16}O$ ratios that were >3 sigma outside the mean ratio for the whole image. The subgrains ranged in size from ~x-x nm. Most subgrains had O isotopic compositions within analytical uncertainty of terrestrial standards. Analytical uncertainties (1σ) averaged 50‰ for $\delta^{17}O$ and 20‰ for $\delta^{18}O$.

Nine subgrains show enrichments in ^{18}O with respect to the majority of the subgrains. Of these anomalous subgrains, at least three were confirmed as GEMS. Further work is necessary to determine N and C isotope compositions and the Mg/Si ratio of the anomalous regions and to compare their chemical composition to solar and diffuse ISM compositions.

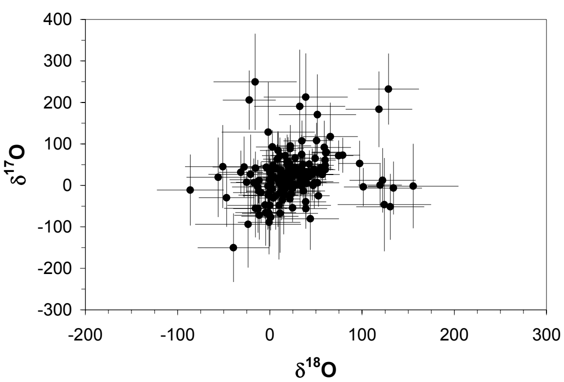

Figure 2: O isotopic ratios of 158 subgrain regions of IDP U220A19; uncertainties are 1σ.

Table 1 compares Mg/Si, S/Si and Fe/Si ratios in GEMS with solar and diffuse ISM abundances. GEMS are on average depleted in Mg and Fe relative to solar (CI) and diffuse ISM grain abundances [10, 11]. They are depleted in S relative to solar and enriched in S relative to ISM abundance. Even isotopically anomalous GEMS known to have been members of the ISM grain population are enriched in S. (S is one of the most difficult elements to quantify in the ISM due to line oversaturation [11]).

Discussion: Although only a small number of isotopically anomalous GEMS (<10) have been reported and an even smaller number of Mg/Si ratios reported, all exhibit Mg/Si ratios higher than the GEMS average value (Table 1). However, our statistics are limited due to the small number of isotopically anomalous GEMS identified to date. In addition, we have identified GEMS with higher than average Mg/Si ratios that are not isotopically anomalous. One explanation is that the starting Mg/Si ratio varied from one GEMS grain to another. A forsterite (Mg/Si=2) relict grain has been identified in at least one GEMS [16]. However, forsterite, enstatite (Mg/Si=1) and silicate glasses (Mg/Si unknown) have all been identified in CS outflows and/or the ISM [17]. Any one of these silicates could have could have formed the seed nuclei of GEMS. If the correlation between isoptope anomalies and high Mg/Si ratios in GEMS persists it may mean that: (a) the properties of GEMS were indeed shaped primarily by exposure to ionizing radiation, and (b) regardless of their isotopic compositions all GEMS were inherited from a common IS reservoir.

	Mg/Si	**S/Si**	**Fe/Si**	**Reference**
Solar	1.01	0.52	0.9	[10]
Diffuse ISM	1	<0.12	0.9	[11]
Average (200 GEMS)	0.6	0.31	0.54	[12]
Average (42 GEMS)	0.65	0.26	0.44	[13]
Individual isotopically anomalous GEMS	0.75	0.31	1.3	[14]
	1.1	0.26	0.44	"
	0.72	0.19	0.48	[15]
	"	"	"	"
	1.2	0.19	0.43	"
	"	"	"	“

Table 1: Comparison of major element compositions (atom ratios) of GEMS with solar and ISM abundances.

References: **[1]** Bradley, J. P. (1994) Science 265, 925-929. [2] Messenger, S. et al. (2004) *Science,* 300, 105-108. [3] Floss, C. et al., (2006) GCA, 70, 2371-2399. [4] *Keller, L. P.* et al. (2000) JGR, 105, 10,397-10, 402. [5] Messenger S. et al. (2007) *LPS* XXXVIII, Abstract #2122. [6] Ebel, D. E. (2000) JGR, JGR, 105, 10,363-10,370; [7] Westphal, A. J. & Bradley, J. P. (2004) *Ap. J.* 617, 1131. [8] Wiedenbeck, M. E. (1987) *Adv. Space Res.* 4(2-3), 15-24. [9] Toppani, A. et al. (2006) LPS XXXVII, Abs. # 2056. [10] Anders, E. & Ebihara, M. (1982) *GCA*, 46, 2363-2380. [11] Sofia, U. 2004, In *Astrophysics of Dust* (ASP Conf. Series, Vol 309, eds. A. N. Witt, G. C. Clayton & B. T. Draine) 393-414. [12] Keller, L. P. & Messenger, S. (2004) [13] Ishii, H. et al., (2008) *Science* (in press). [14] Floss, C. et al. (2006) *GCA* 70, 2371-2399. [15] Keller, L. P. & Messenger, S. (2007) *MAPS*, 42, A81. [16] Bradley, J. P. et al. *Science* 285, 1716-1718. [17] Moslter, F. J. & Waters, L. B. F. M. (2003) In *Astromineralogy* (Ed. Th. Henning, Springer) 121-170.