

**ON THE ORIGIN OF GEMS.** L. P. Keller and S. Messenger, Mail Code SR, NASA Johnson Space Center, Houston, TX 77058 (Lindsay.P.Keller@jsc.nasa.gov).

**Introduction.** GEMS (glass with embedded metal and sulfides) are a major component of anhydrous interplanetary dust particles (IDPs) – their physical and chemical characteristics show marked similarities to contemporary interstellar dust [1, 2]. Recent oxygen isotopic measurements confirm that at least a small fraction (<5%) of GEMS are demonstrably presolar, while the remainder have ratios that are indistinguishable from solar values [3, 4]. GEMS with solar oxygen isotopic compositions either (1) had their isotopic compositions “homogenized” through processing in the interstellar medium (ISM) [e.g. 5], or (2) formed in the early solar system. Isotopic homogenization necessarily implies chemical homogenization, so (interstellar) GEMS compositions should reflect the average composition of dust in the local ISM. We performed a systematic examination of the bulk chemistry of GEMS in primitive IDPs in order to test this hypothesis.

**Methods and Samples.** Quantitative bulk compositions of GEMS were measured in ultramicrotome thin sections of IDPs using a JEOL 2000FX transmission electron microscope (TEM) equipped with a thin window energy-dispersive X-ray (EDX) spectrometer. Seven anhydrous IDPs were selected for this study. All of the IDPs belong to the chondritic-porous subset and contain abundant solar flare tracks and little or no magnetite in the form of rims formed during atmospheric entry. For this study, all GEMS (typically ~20) within one IDP thin section were analyzed to establish the range of their compositions. A total of 144 individual GEMS were analyzed.

**Results.** GEMS have been reported to be approximately chondritic within a factor of 3 for major elements [1, 2]. However, the results of this study show that on average, GEMS are systematically sub-chondritic with respect to S/Si, Mg/Si, Ca/Si, and Fe/Si (Figures 1-2). For these element/Si ratios, the average GEMS compositions are ~60% of solar values, although the average Al/Si ratio in GEMS is indistinguishable from solar. Within an individual IDP thin section, order-of-magnitude variations are observed in GEMS compositions for most elements. Figure 3 shows the frequency distribution of Mg/Si ratios for all the GEMS analyzed in this study along with the Mg/Si ratios from analyses of whole anhydrous IDPs [6]. No preferred grouping of GEMS Mg/Si ratios is observed, and the average Mg/Si is displaced from both solar and the average IDP bulk composition. The trend in GEMS compositions in Figure 4 either reflects sulfidization of pre-existing GEMS grains, or the loss of S from grains of solar composition. These results are consistent with previous work on compositional trends in strongly heated GEMS from cometary IDPs [7]

**Discussion.** Astronomical observations show that ISM silicates are predominantly amorphous - recent limits on the abundance of crystalline silicates in the ISM are <1% [8]. Based on measured depletions from the gas phase, ISM dust is inferred to have solar compositions for Mg, Si, Fe, Ca, and Al [9]. Sulfur remains primarily in the gas-phase in the ISM and does not appear to be incorporated into ISM dust [9, 10].

The majority of GEMS do not match the element abundance pattern of ISM dust, containing on average, too little Mg, Fe, and Ca, and too much S. The S content of GEMS was identified previously as a problem for their ISM origin [11]. The bulk chemical compositions of GEMS are divided into two groups: *ISM-candidate GEMS* have compositions that are consistent with predicted ISM grains; they are S-depleted and have solar Mg and Fe. Only 10-20% of the GEMS analyzed satisfy these constraints. The remaining 80-90% of GEMS grains are termed *solar system GEMS*.

It is interesting to note that while *solar system GEMS* do not have solar elemental abundances, their IDP hosts on average, are solar. GEMS are a major component of IDPs and significantly influence bulk IDP compositions. In order for IDPs to attain bulk solar element compositions, the GEMS compositions must be counter-balanced by the crystalline components (e.g. forsterite, enstatite, FeS). This observation suggests that the origins of the crystalline phases in IDPs and solar system GEMS are related.

The bulk elemental compositions and the current O isotopic data are consistent with most GEMS having a solar system origin. This would require the formation of abundant, amorphous silicates with compositions different from typical ISM silicates, or the extensive processing of pre-existing amorphous grains in the early nebula [5, 12]. In either scenario, a close relationship must exist between the origin of crystalline silicates and GEMS in IDPs in order to retain the compositional balance. GEMS may have formed initially as condensates or as shock melts because both processes can produce glassy materials with inclusions of nano-phase metal and sulfides. Forsterite, enstatite and Fe metal are predicted high temperature nebular condensates – their formation would drive the remaining gas closer to the bulk composition of solar system GEMS. In this model, GEMS are non-equilibrium condensates that have escaped annealing and further reaction with the gas phase (except for late sulfidization of Fe). The pre-accretional radiation processing of GEMS does pose problems with this model. A mechanism also has to exist to transport the GEMS grains (as well as some forsterite and enstatite) to the comet forming region, perhaps through bipolar outflows during the early accretion phase of the disk [5].

It is now possible to measure trace element abundances at the spatial scale of individual GEMS [13], providing additional points for comparison with observed ISM gas phase depletions. A group of GEMS have been identified that are likely ISM grains based on their chemical compositions, however, the definitive test for presolar origins will continue to be the combination of NanoSIMS isotopic analyses and TEM/EDX measurements of the same GEMS grains.

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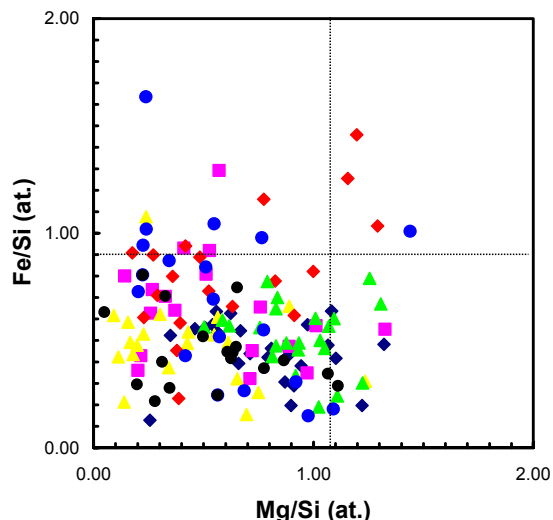


Figure 1. A plot of Mg/Si versus Fe/Si atom ratios for bulk GEMS grains in seven anhydrous IDPs. The dashed lines are the solar values and the symbol legend is given in Figure 4. Approximately 80% of the GEMS grain compositions lie in the subsolar quadrant.

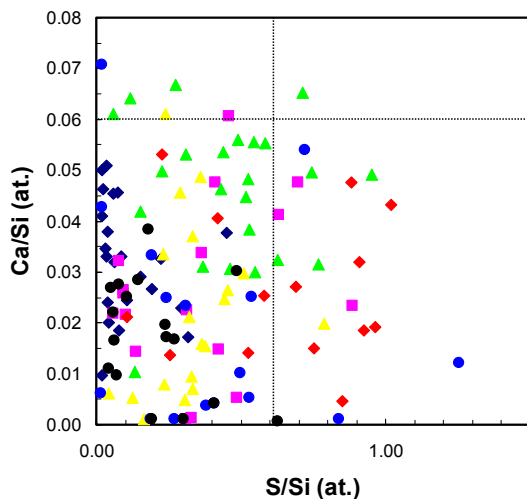


Figure 2. A plot of S/Si versus Ca/Si atom ratios for bulk GEMS grains in anhydrous IDPs. The dashed lines are the solar values and the symbol legend is given in Figure 4. Approximately 80% of the GEMS grain compositions lie in the subsolar quadrant.

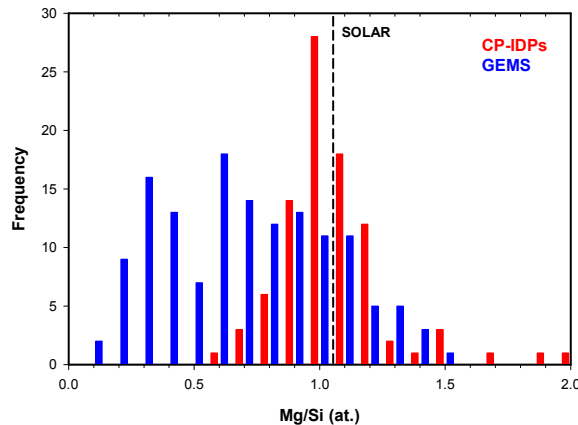


Figure 3. Frequency distribution of Mg/Si atom ratios in bulk GEMS (blue) compared to chondritic porous IDPs (red, data from [6]). The GEMS mean Mg/Si is ~60% of the solar value.

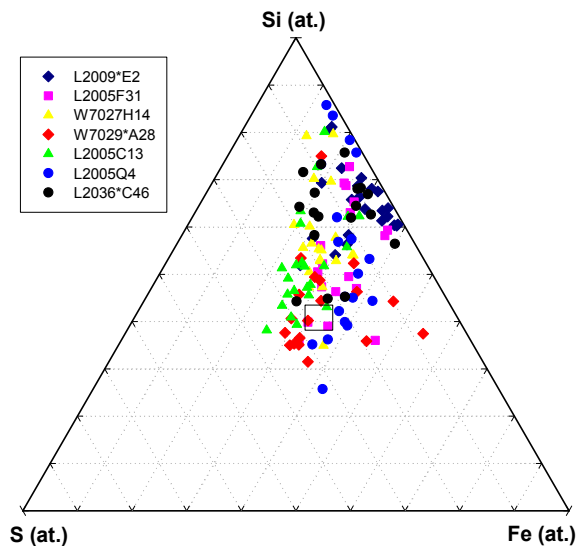


Figure 4. Ternary plot of measured Fe, Si, and S atomic abundances in bulk GEMS grains. The open box is the solar value.