**Non-GEMS Silicate Glasses in Chondritic Porous Interplanetary Dust Particles.** D. J. Joswiak and D. E. Brownlee, Department of Astronomy, MS 351580, University of Washington, Seattle, WA 98195. e-mail: joswiak@astro.washington.edu

**Introduction**. Spectroscopic observations on the circumstellar disks of young stars have shown that amorphous silicates rather than crystalline silicates comprise the bulk of solid materials while in the interstellar medium (ISM), nearly all solids are amorphous [1]. Significantly, amorphous silicates are major components in chondritic, porous interplanetary dust particles (CP IDPs) which may have originated in comets. Since comets formed in cold, grain-preserving regions of the solar nebula they should retain pristine amorphous silicate grains (among many other species) that accreted during the dust forming phases of early nebula growth as well as pre-solar grains. The characterization of amorphous silicates in comet IDPs is vital to understand the grain-forming processes in the early nebula, and by analogy, may provide insights into other disk systems of stars that are actively producing silicate dust.

Common amorphous silicate grains found in comet IDPs are GEMS (Glass with Embedded Metal and Sufides) which are Si-rich glassy spheroids containing nanophase Fe+Ni metal and Fe-sulfides. GEMs have their origins in either the solar nebula or the ISM and fit well with astronomical observations of amorphous silicates in interstellar space [2]. GEMS, however, are not the only amorphous silicates present in CP IDPs. Non-GEMS silicate glasses are relatively common though little work has been done of these materials. These non-GEMS silicate glasses are distinct from GEMS glass in that they do not contain the abundant metal and sulfide nanophase inclusions that are characteristic of GEMS.

Here we discuss some observations of non-GEMS silicate glasses and suggest that at least two distinct types are present in CP IDPs. Of interest is whether apparently different glasses found in these IDPs are unique species of amorphous silicate derived from different parent sources or are endmembers of a silicate glass continuum that may have formed by a common process. Equallly important is whether non-GEMS silicate glass may have a common origin to the matrix glass in GEMS.

**Techniques.** The silicate glasses were studied in 10 - 20 μm stratospheric IDPs that were removed from collector flags obtained through the JSC curatorial facility. Each particle was placed on a polycarbonate membrane and rinsed in hexane before analysis by SEM. Particles with a chondritic composition were removed and embedded in either epoxy resin or sulfur followed by microtoming with an Ultracut ultramicrotome and then placed onto 10 nm thick carbon support films. Standard TEM techniques using a 200 kV Tecnai F20 FEG were employed including bright and dark field imaging, HRTEM and x-ray analyses by EDX in STEM mode. Quantifiication of EDX spectra was done with a standardless technique using software developed by Emispec Corporation (now with FEI).

**Bulk Silicate Glass.** Bulk silicate glass, studied in 15 IDPs, was easily observed using dark field imaging. Morphologically, this glass varies from large discrete patches, shown in Figure 1, to small indiscrete regions or isolated grains. A single GEMs grain with nanophase inclusions is also shown in Figure 1 for comparison.

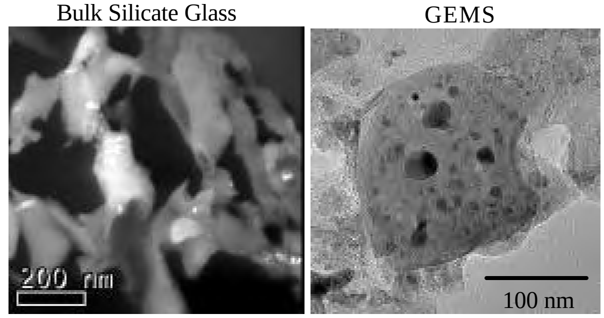



Figure 1: Dark field image of bulk silicate glass in the interior of a CP IDP shown as uniform medium gray areas (left) compared to GEMS (right). Note that nanophase inclusions are not present in the bulk silicate glass.

EDX spot analyses collected from typical regions in the interiors of the bulk silicate glasses show that this glass is very rich in $SiO_2$ with small quantities of Fe and Mg. This is shown in the ternary diagram in Figure 2 as open blue circles obtained from 39 glass analyses. Fe+Mg+Si comprise > ~90 % of the total cations present in the glass. Small quantitites of Al or Ca are sometimes observed.

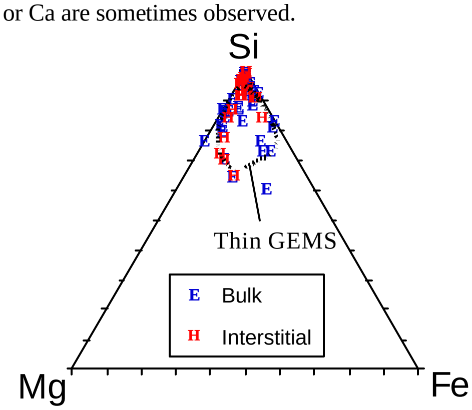



Figure 2: Fe-Mg-Si ternary diagram showing that bulk silicate and interstial glass are rich in Si with small but variable quantities of Fe and Mg. Thin-GEMS analyses, measured previously [3], are shown by the dotted field near Si.

**Interstitial Silicate Glass.** A second type of non-GEMS silicate glass present in the IDPs is texturally and compositionally distinct from bulk silicate glass. This glass type occurs interstitially between crystalline Fe-Mg silicate grains (Figure 3), principally Fe-bearing olivines, and is very high in $SiO_2$ with minor quantities of Fe and Mg (Fig 2-solid red triangles) similar to bulk silicate glass. Higher Al concentrations (up to 8.4 atom%) show that this glass is compositionally distinct, however.

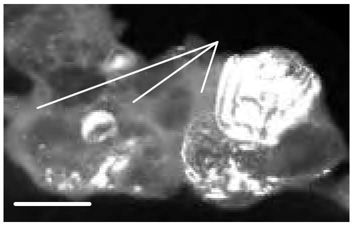
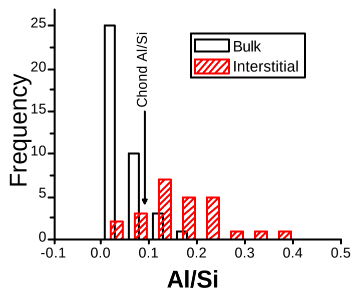


Figure 3: DF image of typical interstitial Al-rich silicate glass shown in medium gray between crystalline Fe-Mg silicates. Interstitial glass indicated. Scale bar = 100 nm.

This can be seen in Figure 4 where the Al/Si ratio of interstitial silicate glass is up to 2.5X higher than bulk silicate glass.

Figure 4: Histogram showing the difference in measured Al/Si ratios from bulk silicate glass compared to interstitial glass. Arrow shows chondritic Al/Si ratio.




The association of interstitial glass with olivine (and sometimes pyroxenes), is a feature also unique to this glass type. The olivine grains typically occur in clusters, are Fe-rich with sub-angular shapes and vary in size from 100 - 200 nm. Narrow compostional ranges of the olivine grains within individual clusters are suggestive of equilibrium assemblages.

The Fo contents of olvines within individual clusters are weakly correlated with the Mg contents of their associated interstitial glasses. This is shown in Figure 5 where the average Fo content in olivines from 13 clusters are plotted against the average Mg content of their associated glasses. The results from several heating experiments on terrestrial saponite and Orgueil matrix [4] and 2 micrometeorites are also given.

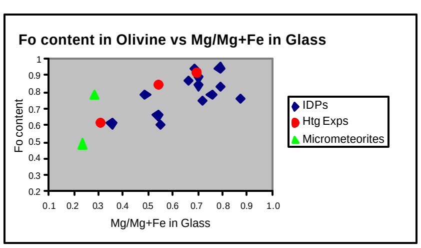



Figure 5: Average Fo content of olivines vs average Mg/Mg+Fe in associated interstitial glasses from 12 IDPs, 3 heating experiments and 2 micrometeorites.

**Discussion.** We do not observe 'olivine' or 'pyroxene' bulk silicate glass commonly reported in astronomical literature. Instead, the bulk silicate glass in cometary IDPs is very high in Si with small but variable Fe and Mg contents. The high Si contents suggest that if this glass condensed directly from a nebular gas, the gas was nonchondritic and presumably depleted in Fe and Mg.

Bulk silicate glass has similar Fe, Mg and Si abundances as GEMS glass (not whole GEMS) begging the question of whether these two phases may have a common origin Bulk glass does not have the nanophase inclusions that are present in GEMS, so if these phases do indeed have a common parent then, with respect to Fe, either bulk glass must have lost much of its Fe after formation or GEMS glass must have gained more Fe which ultimately was incorporated into the Fe-rich nanophase inclusions. Perhaps continual irradiation of GEMS resulted in removal of Fe to produce bulk silicate glass.

Interstitial silicate glass must have a very different origin than bulk silicate glass. It is very likely a secondary product from recrystallization of precursor fine-grained materials. At least two possibilities exist: 1) Reheating of previsouly formed fine-grained solids in the nebula. This mechanism would imply sunward mixing of condensed grains where temperatures were high enough to melt precursor materials. 2) Melting of fine-grained, low temperature minerals during atmospheric entry heating. High speed cometary IDPs do encounter high temperatures when decelerating in Earth's atmosphere. This fact, coupled with the high Al-contents of the interstitial glass and Fe-bearing olivines are consistent with such a mechanism [4].

When compared to chondrule glasses, bulk silicate and interstitial glasses in cometary IDPs are also distinct. Porphyritic chondrule mesostases contain significant quantities of Na and Ca which are absent in the glasses in IDPs.

**Conclusions.** At least two distinct types of non-GEMS silicate glass are present in cometary IDPs. The first type - bulk silicate glass - has a composition similar to GEMS glass but is distinct due to its lack of Fe-bearing inclusions. The similarity in composition between bulk silicate glass and GEMS matrix glass may suggest that these two types of amorphous silicates are connected through a common parent or nebular process.

A second population of silicate glass occurs interstitially between Fe-bearing olivine grains which are found in distinct clusters. The higher Al contents in the interstitial glass along its association with olivine show that this glass is distinct from bulk silicate glass. The textures suggest melting of a precursor, fine-grained material, either in high temperature regions in the solar nebula, implying mixing, or melting of low temperature phases during entry into Earth's atmosphere.

**References.** [1] Molster, F. J and Waters, B. F.M. (2003) in *Astromineralogy*, ed. Th. Henning, 121-170. [2] Bradley, J. P. et al. (1999), *Science 285*, 1716-1718. [3] Brownlee, D. E., Joswiak D. J. and Bradley, J. P. (1999) *LPSCXXXX*. [4] Joswiak D. J. and Brownlee. D. E. (1998) *LPSCXXVIIII*.