**STARTING COMPOSITION OF THE SOLAR SYSTEM SOLIDS AND PROCESSING OF DUST IN THE INTERSTELLAR MEDIUM.** L. P. Keller[1], S. Messenger[1] and L. R. Nittler[2]. [1]Robert M. Walker Laboratory for Space Science, ARES, Mail Code KR, NASA Johnson Space Center, Houston, TX 77058, [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, (Lindsay.P.Keller@nasa.gov).

**Introduction**. Silicate dust is pervasive throughout the Galaxy, and constitutes a key building block of planetary systems and interstellar clouds. The majority of this silicate dust originates in the outflows of evolved O-rich stars, with a smaller contribution from supernovae [1]. Once injected into the interstellar medium (ISM), these grains cycle between diffuse and dense clouds for millions of years before being altered, destroyed or incorporated into the disks of young stars [1]. Some of these grains are preserved in comets and meteorites, enabling direct studies of the mineralogy, microstructure, and isotopic composition of interstellar dust. These studies yield unique insights into the processes occurring in diverse astrophysical environments ranging from the birth of new planetary systems to the final stages of the lives of stars and the fate of their detritus in interstellar clouds.

Astronomical infrared spectroscopic observations of evolved, O-rich red giant branch (RGB) and asymptotic giant branch (AGB) stars show that circumstellar silicates are predominantly amorphous, with minor and variable (~10-20%) amounts of crystalline silicates [2]. The amorphous silicates are mostly fine-grained (<100 nm), Mg-rich and have an average composition intermediate between olivine and pyroxene stoichiometry [3]. The amorphous silicates form as non-equilibrium condensates at temperatures lower than ~950K [4] and likely contain nanophase inclusions of Fe metal [5]. The crystalline silicate fraction is dominated by the Mg-rich silicates forsterite and enstatite along with minor phases such as diopside, anorthite and gehlenite [6].

Silicates are the most abundant type of circumstellar dust preserved in meteoritic materials [7,8]. They are distinguished from Solar System materials by their highly anomalous oxygen isotopic compositions [e.g. 7, 8]. Coordinated analyses of these isotopically anomalous grains with transmission electron microscopy and other techniques show that their mineralogy is dominated by amorphous silicates, olivines ($Fo_{83\text{-}100}$) and pyroxenes ($En_{99}$). The circumstellar amorphous silicates include GEMS (glass with embedded metal and sulfides) grains in interplanetary dust particles (IDPs) [9] and GEMS-like grains that may have been altered on meteorite parent bodies [10]. The best preserved circumstellar amorphous silicates in anhydrous IDPs are compositionally heterogeneous, but on average have Mg, Fe, and Ca abundances relative to Si that are within a factor 2 of chondritic values (except for S which is uniformly depleted [9]. Their average oxygen isotopic composition is $^{17}O$-rich relative to solar [9].

Most circumstellar grains undergo radiation and shock processing in the ISM that fundamentally changes their mineralogy and compositions. Spectroscopic observations show that crystalline silicates are rapidly amorphized in the ISM such that <2% of the crystalline silicate grains survive in the diffuse ISM [2]. Sputtering via supernova shocks is the most effective destruction mechanism for interstellar dust, and low energy cosmic rays also likely play an important role in the amorphization of silicates [11,12]. These processes are stochastic, and do not affect all interstellar dust grains equally or at the same rate. The circumstellar grains found in meteoritic materials are the rare survivors that either spent a relatively short time in the ISM, or were fortunate enough to avoid strong interstellar shocks or prolonged exposure to high radiation environments [13]. Some interstellar grains may also be protected by coatings of organic or other materials accreted in dense molecular clouds [14].

The chemical compositions of interstellar dust grains have been inferred from element depletion patterns in the diffuse ISM obtained through UV absorption measurements [15]. The bulk chemical composition of dust in the ISM is inferred to be the difference between observed abundances in the gas phase and the overall cosmic abundances based on stellar standards. Based on strong gas phase depletions, ISM dust is inferred to have, on average, solar abundances for Mg, Si, Fe, Ca, and Al [16,17]. A similar result is obtained for Mg, Si, S and Fe through direct measurements of the dust and gas compositions by X-ray absorption studies [18]. Sulfur behaves differently than Mg, Si and Fe. ISM gas phase S abundances are within error of solar abundance, so S is widely considered to be undepleted from the gas phase [16,19]. Ueda et al. [18] noted that while a significant fraction of S resides in the gas-phase, their X-ray measurements could not rule out a partial contribution from solid FeS or elemental S. Given the typical errors on diffuse ISM S determinations as much as ~5% of the S could reside in interstellar grains [9]. The behavior of S relative to silicates likely results from the rapid sputter erosion rate of sulfides compared to silicates [20]. Iron and Si depletion patterns suggest that these elements reside in different hosts, with most Fe in the form of metal or oxides, and Si primarily in silicates.

Most circumstellar silicate and oxide grains are $^{17}O$-rich and $^{18}O$-poor compared with Solar System materials; the average O isotopic composition of circumstellar oxides is ($\delta^{17}O$=1,870‰,$\delta^{18}O$= -270‰). These grains are a minor fraction of the solid material from which the Solar System was made, accounting for at most ~1 % of the mass of the most stardust-rich sample identified, a cluster IDP [21]. As these grains are identified by their anomalous isotopic compositions, they may not be representative of typical dust grains in the ISM, or of the primordial dust grains from which the Solar System formed. Indeed, there is evidence that dust grains form in the ISM from the processed remnants of destroyed ISM grains, and thus may have isotopic compositions closer to the average and therefore less 'anomalous.'

If the typical ISM grains from which the Solar System formed were isotopically homogenized, they ought to have O isotopic compositions similar to the bulk Solar System value. The O isotopic composition of the Sun, as inferred from measurements of solar wind collected by the Genesis spacecraft, is $^{16}O$-rich compared with terrestrial materials and bulk meteorites with $\delta^{17}O$, $\delta^{18}O$ = -60 ‰ [22]. So far, the only known materials sharing this composition are refractory inclusions in meteorites and comet Wild-2 samples, including Ca- and Al-rich inclusions (CAIs), chondrules, and ameboid olivine aggregates. These materials clearly formed at high-temperatures and pressures and are not candidates for grains formed in the ISM.

Fine-grained amorphous silicates, such as GEMS grains, are the most likely candidates for processed ISM grains. Unfortunately, owing to their small size, O isotopic measurements of individual GEMS grains lack the precision to distinguish between terrestrial (~0 ‰) and Solar (-60 ‰) composition. However, the bulk O isotopic compositions of GEMS grains have recently been shown to be close to terrestrial composition ($\delta^{17}O$ = -7 ±24‰,$\delta^{18}O$ = 0 ±8‰; 2σ) [9]. Previous high precision O isotopic measurements of anhydrous GEMS-rich IDPs showed variable enrichments and depletions in $^{16}O$ ranging from -20 to +6 ‰ [23] that are likely related to variable proportions of $^{16}O$-rich crystalline silicates and GEMS grains [9].

Chemical, mineralogical, and isotopic studies indicate that the vast majority of crystalline and amorphous silicate material in anhydrous IDPs likely formed from the same isotopic reservoir in the inner solar system and was transported to comet forming region of the solar nebula [9]. Most GEMS grains in anhydrous IDPs are believed to have formed in the early Solar System as non-equilibrium condensates. As yet there is no direct evidence of an abundant population of amorphous silicates formed in the ISM in meteorites and IDPs. Primordial ISM amorphous silicates may have been destroyed by nebular and parent body processes or they have avoided detection owing to their small sizes.

Spectroscopic observations of young stellar systems reveal a progressive change in the composition of dust from predominantly amorphous silicates (presumed to be interstellar grains) into crystalline grains [24, 25]. The details of the transformation mechanism and the subsequent transport of the crystalline grains from the hot inner part of the disk to cooler regions are poorly constrained. The large range in circumstellar silicate abundances among anhydrous IDPs (300 to > 10,000 ppm) reflect this thermal processing in the early solar nebula. Equilibrated aggregates (EAs) in anhydrous IDPs are polycrystalline grains whose textures are consistent with annealing of amorphous precursors [26]. Most EAs have terrestrial oxygen isotopic compositions, although two presolar EAs have preserved circumstellar oxygen isotopic signatures despite their thermal transformation [27].

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