Distinguishing solar and extrasolar origins of submicrometer grains in IDPs

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Interplanetary dust particles (IDPs) are primitive solar system objects from comets and asteroids that contain abundant interstellar materials [1]. These materials include D- and ^{15}N-rich organic matter formed in a cold molecular cloud environment and grains of stardust [2]. The presolar (stardust) grains are identified by their exotic isotopic compositions that significantly differ from solar isotopic compositions [3]. Silicates are the most abundant type of stardust, but because of their small size (< 1 µm) were only recently discovered. The Cameca NanoSIMS ion microprobe was key to this discovery. The NanoSIMS uses an ultra fine beam of (50 nm) Cs^+ or (200 nm) O^- and detects five mass lines simultaneously in imaging mode with high transmission at high mass resolving power. In practice, presolar grains as small as 200 nm can be distinguished *in situ* from solar system materials.

Silicates are more abundant in IDPs (450 – 5,500 ppm) than in meteorites (< 130 ppm), possibly because they are from comets [3,4]. A key issue to be resolved is the true proportion of presolar grains and solar system materials. Much of the material in IDPs is too fine grained (< 200 nm) to distinguish between solar and extrasolar origin. Some presolar silcates are amorphous (GEMS; 5), and may be mixtures of stardust and deposited material. The problem is further compounded by recent compositional mapping of GEMS grains by field emission TEM, showing that many GEMS grains are composite objects [6]. The isotopic measurement of GEMS grains may thus represent an average of still smaller subgrains. Resolving this issue may require higher precision isotopic measurements as the NanoSIMS is near the limiting size scale accessible to SIMS.

References

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NanoSIMS Mg isotope analyses of refractory inclusions in metal-rich CB chondrites

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Hammadah al Hamra (HH) 237 is a metal-rich (CB) chondrite with unusual mineralogical and chemical signatures. HH237 appears to be a remarkably pristine relic of large-scale high temperature processes in the very early solar nebula [1]. We present Mg isotope analyses of refractory inclusions in HH237, collected with the LLNL NanoSIMS, demonstrating large mass-dependent isotope fractionation and excesses of radiogenic ^{26}Mg.

Mg isotope compositions were measured by static multi-collection at a mass resolving power of ~4000, using a 20 pA, 250 nm $^{16}O^-$ primary ion beam rastered over a 4x4 mm area. Isotope ratios were calculated using the sample-standard bracketing approach [2]. Ca-Al-rich inclusion (CAI) HH237-s #1 is a compact CAI composed of grossite ($CaAl_4O_7$) surrounded by a melilite-pyroxene rim with enclosed metal blebs; HH237-MW #4 is a fine-grained, hibonite-rich CAI containing minor spinel, melilite and perovskite, surrounded by layers of melilite and Al-diopside; HH237-104 CAI#1 is a spinel-hibonite spherule containing hibonite laths surrounded by a spinel mantle and a melilite-pyroxene rim. NanoSIMS analyses show large mass-dependent fractionation in all three CAIs favoring the lighter Mg isotopes with F_{Mg} values ranging from -20 to -12 ‰/amu; 2σ is ~4‰/amu. Both hibonite-rich CAIs exhibit large ^{26}Mg excesses, with initial $^{26}Al/^{27}Al$ ratios of (7.5±3.3) x 10^{-5}, while the grossite-rich inclusion contains no excess ^{26}Mg with $^{26}Al/^{27}Al<2x10^{-6}$.

The large enrichment of the lighter Mg isotopes is unusual for igneous CAIs and, together with group II REE patterns [1], indicate many CAIs in CB meteorites preserve primary condensation signatures inherited from the nebular gas. The isotope fractionation effects appear decoupled from incorporation of ^{26}Al. Additional refinement of initial ^{26}Al abundances will elucidate the time scales of condensation and melting and test the hypopthesis grossite-rich CAIs formed before injection of ^{26}Al into the solar nebula.

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