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Renewed Search for FUN (Fractionated and Unidentified Nuclear Effects) in Primitive Chondrites

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RENEWED SEARCH FOR FUN (FRACTIONATED AND UNIDENTIFIED NUCLEAR EFFECTS) IN PRIMITIVE CHONDRITES. D. L. Tollstrup[1], J. B. Wimpenny[1], Q.-Z. Yin[1], D. S. Ebel[2], B. Jacobsen[3], I. D. Hutcheon[3] [1]Department of Geology, One Shields Ave. University of California, Davis, CA 95616 (dltollstrup@ucdavis.edu; qyin@ucdavis.edu), [2]Department of Earth and Planetary Sciences, American Museum of Natural History, New York, NY 10024, [3]Glenn T. Seaborg Institute, Lawrence Livermore National Laboratory, Livermore, CA 94551.

Introduction: Ca-Al-rich inclusions (CAIs) found in primitive chondrites record processes and conditions of the earliest solar system as they are the oldest known solid objects formed in the solar system [1,2]. CAIs with fractionation and unidentified nuclear anomalies (FUN CAIs; [3]) are very rare and thusfar found exclusively in CV carbonaceous chondrites (e.g., Allende and Vigarano)[4]. FUN CAIs are characterized by large nucleosynthetic anomalies in several elements (Ca, Ti, Si, Sr, Ba, Nd, and Sm), large mass-dependant isotope fractionation (Mg, Si, and O), and very little initial ^{26}Al [4,5 and references therein]. Formation of FUN CAIs by thermal processing of presolar dust aggregates prior to the injection of ^{26}Al into the protoplanetary disk has been proposed [6,7]. More recently [5] proposed that FUN CAIs formed from a protosolar molecular cloud after injection of ^{26}Al but before ^{26}Al and ^{27}Al were completely homogenized. Therefore discovering more FUN CAIs to perform U-Pb and other short-lived chronometric dating will provide key constraints on the age of the solar system, the isotopic composition of the protosolar molecular cloud, the earliest stages of the thermal processing in the solar system and the timing of ^{26}Al and other short-lived radionuclide injection into the nascent solar system.

Most known FUN CAIs were discovered and studied > 30 yr ago, and their isotope ratios determined using thermal ionization mass spectrometry (TIMS). Most of these FUN CAIs were almost or entirely consumed during their respective analyses. [5] recently identified a new FUN CAI (NWA 779 KS-1) based on O and Mg isotope ratios determined by SIMS and MC-ICPMS, respectively.

We have initiated a systematic search for FUN CAIs in primitive chondrites, taking advantage of the large mass-dependant Mg isotope effects known for FUN inclusions with little or no inferred ^{26}Al. Our strategy is to use newly developed sample cells capable of holding very large slabs of meteorites for laser ablation interfaced with a multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS) at UC Davis. Here report the initial findings of our search and describe the instrument setup we use that provides rapid throughput and accurate results.

Methods: Mg isotopes and Al/Mg ratios are collected using a ThermoFisherScientific *Neptune Plus* MC-ICP-MS connected to a PhotonMachines Analyte 193 excimer laser ablation system. Collectors are aligned to allow for the simultaneous acquisition of all isotopes in static multicollection mode using 10^{11} Ω resistors: ^{24}Mg (L4), ^{25}Mg (L1), ^{26}Mg (H1), and ^{27}Al (H4) without dispersion or magnet jumps. A laser spot size of 30-40 μm and 70 μm is used for high-Mg (e.g., olivine) and low-Mg phases, respectively. The laser was operated at 5 Hz, an energy of 5 mJ and a fluence of 1.2 Jcm^{-2}. Data are collected in medium resolution (mass resolving power of ~4000) to avoid the small (< 5 mV) but present $^{12}C^{14}N$ interference on ^{26}Mg.

Data are corrected for mass bias and instrument drift by standard-sample bracketing to San Carlos olivine, assuming linear drift between successive analyses, and the data are presented in delta notation: $\Delta^{x}Mg = [(^{x}Mg/^{24}Mg)_{smpl}/(^{x}Mg/^{24}Mg)_{SC\text{-}Ol} - 1]*10^{3}$, where x is either ^{25}Mg or ^{26}Mg. Excess ^{26}Mg is presented calculated as $\delta^{26*}Mg = \Delta^{26}Mg - \Delta^{25}Mg/0.511$. $^{27}Al/^{24}Mg$ ratios were corrected for instrumental mass bias and laser-induced elemental fractionation by standard-sample bracketing to MPI-DING GOR128 (assuming $^{27}Al/^{24}Mg = 0.381$; [8]).

Small-Volume Very Large Sample (SV-VLS) cell: A new sample cell is currently being developed at UC Davis in collaboration with PhotonMachines that combines the benefits of small-volume cells (i.e., rapid washout and limited contamination) with the ability to analyze very large and irregularly-shaped slabs (Figure 1). Slabs must have at least one flat surface and be < ~3 cm thick. Although polished surfaces are preferred, unpolished flat surfaces are also acceptable.

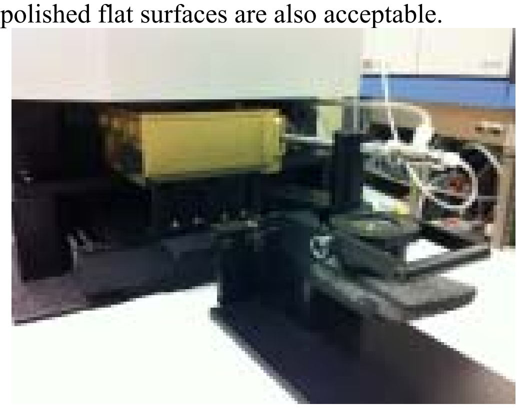

Figure 1. Photograph of PhotonMachines *Analyte 193* laser ablation). Slab of Allende CV3 carbonaceous chondrite is loaded under the small volume sample cell of the VLS as it would be for analysis.

Large Sample insert for the HelEx (LS-HelEx) cell: A new insert for the dual volume PhotonMachines HelEx cell has been developed (Figure 2) that allows the entire surface of large slabs (up to 8 cm x 11 cm x 1.5 cm) to be sampled by the laser. This insert also includes two ~ 1.25 cm round mounts for standards and does not require any modification of the laser stage.

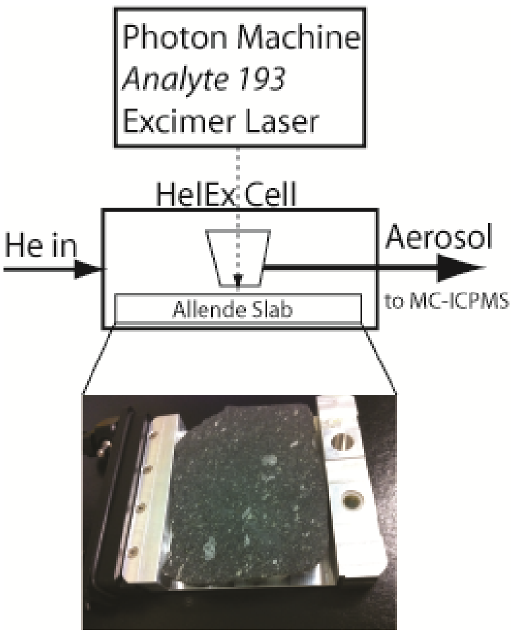

Figure 2. Photograph of modified sample holder for PhotonMachines *HelEx* cell. Allende slab measuring 8 cm x 10.5 cm x 0.5 cm is sitting in sample holder for reference.

Results: Reproducibility of Mg isotope measurements, as determined from replicate analyses of a single grain of San Carlos olivine (δ^{25}Mg = 0.00 ± 0.12, δ^{26}Mg = 0.00 ± 0.15, δ^{26*}Mg = -0.01 ± 0.13), compare favorably with those reported elsewhere [9].

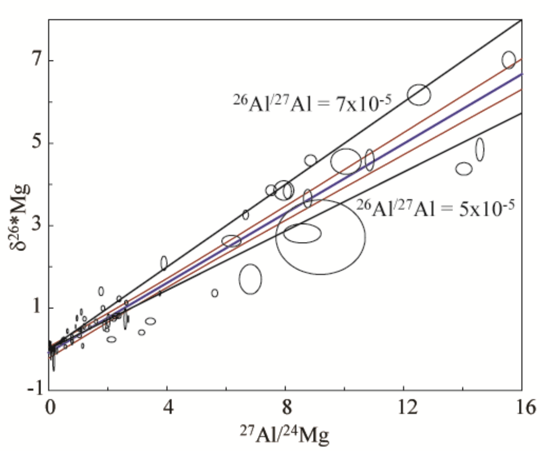

Figure 3. Plot of δ^{26*}Mg versus ^{27}Al/^{24}Mg for CAIs and chondrules from Allende slab 5046-1A and 5046-1C. Each datum is shown as 2σ standard error ellipse. An error-weighted regression of the data (blue line) and error envelope (red lines) corresponds to $(^{26}Al/^{27}Al)_o = 5.89 \times 10^{-5} \pm 0.38 \times 10^{-5}$.

So far, no FUN CAIs were found in our initial search in two slabs of Allende (5046-1A and 5046-1C), however the Al-Mg isotope data obtained from 75 analyses are presented in Figure 3 in 26Al-26Mg fossil isochron diagram.. The results obtained from Allende CAIs are consistent with those reported in [9] for different Allende CAIs.

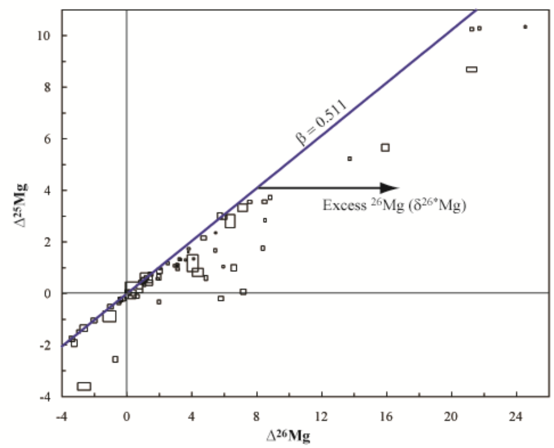

Figure 4. Plot of Δ^{25}Mg versus Δ^{26}Mg for CAIs and chondrules from Allende slab 5046-1A and 5046-1C. Each datum is shown as 2σ standard error rectangle. Mass-dependant fractionation is shown as blue line with a slope of 0.511. Excess ^{26}Mg results in data that deviate to the right of the fractionation line (arrow).

Conclusions: We have developed a method for rapidly searching for FUN CAIs in meteorite slabs of almost any dimension, with very little solid material consumptions (~ng range). The method does not require to take the CAI inclusions out from the museum slab specimen. Although we have yet to discover any new FUN CAIs, results of normal CAIs and chondrules are nevertheless accurate and reproducible and are therefore useful for constructing fossil isochrones (Figure 3) or stable isotope work (Figure 4). We will extend the search systematically for wider range of materials. The analyses could include, in future, Si and other isotopes as well.

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