From dust to planets: Time scales of accretion and differentiation in the early solar system

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In recent years, several chronometers based on the decay of short-lived radionuclides have been applied towards obtaining high-resolution time constraints for events in the early solar system (e.g. [1]). However, it is still a matter of debate whether many of these extinct radionuclides may be applied as chronometers since their origin and initial distribution in the early solar system are not yet well constrained. Neverthless, several recent studies have demonstrated that high precision absolute (U-Pb) ages obtained for some meteoritic materials are concordant with relative high-resolution ages obtained from the application of the ^{26}Al-^{26}Mg (half life ~0.72 My) and the ^{53}Mn-^{53}Cr (half life ~3.7 My) chronometers [2,3,4]. Specifically, it has been shown that the earliest solids in the solar nebula (i.e., Ca-Al-rich inclusions) were formed at 4567.2 ± 0.6 Ma [3]. Furthermore, our recent work on U-Pb, ^{26}Al-^{26}Mg and ^{53}Mn-^{53}Cr systematics in the eucrite Asuka 881394 suggests that some asteroidal bodies had accreted and differentiated within ~3 My of CAIs [4].

We have recently also applied the ^{182}Hf-^{182}W (half life ~9 My) and ^{146}Sm-^{142}Nd (half life ~103 My) systems to the shergottite-nakhlite-chassignite (SNC/martian) meteorites to constrain the timing of metal segregation and silicate differentiation on Mars [5]. This work demonstrates that major silicate differentiation on Mars occurred well within ~50 My of solar system formation. Specifically, the mantle source reservoir of the shergottites was established at 4525 ± 20 Ma, while that of the nakhlites was likely established prior to ~4542 Ma.

References

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The formation of the solar system: New constraints from the ^{247}Cm-^{235}U chronometer

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The *r*-process only nuclide ^{247}Cm decays to ^{235}U with a characteristic half-life of ~16 million years. ^{247}Cm is presently extinct, but offers potential as a short-lived *r*-process chronometer, providing constraints on the time interval between the last *r*-process nucleosynthetic event and the formation of the solar system. The existence of "live" ^{247}Cm in the early solar system should be observed today as variations in ^{238}U/^{235}U, provided Cm/U fractionation occurred. The Cm-U system also has a direct bearing on the U-Pb cosmochronometer, which currently assumes no Cm effects in early solar system material.

Using a Nu Instruments NuPlasma and new techniques in MC-ICPMS, we are able to resolve variations in ^{238}U/^{235}U at the two epsilon level ($2\sigma_M$) on sample sizes consisting of <20 pg of ^{235}U. Because no long-lived isotope of Cm exists, our study uses Nd as a chemical proxy for Cm. Thus, additional concentration data for ^{144}Nd, ^{147}Sm and ^{238}U were acquired by MC-ICPMS using techniques in isotope dilution. Uranium isotopic measurements and Nd/U values for a suite of bulk meteorites show no well-resolved excursions in ^{235}U/^{238}U from the terrestrial value at the ~2 epsilon level. These data provide an upper limit on ^{247}Cm/^{235}U at the start of the solar system of 1 x 10^{-4}, assuming Nd is a suitable proxy for Cm and the Nd/U ratios have not been significantly modified (Stirling et al., in press, GCA).

We have extended the search for "live" ^{247}Cm in the early solar system to small samples from mineral phases in primitive objects that are likely to display strong Cm-U fractionations. Uranium isotopic measurements have been acquired on acid-etched leachates for a suite of chondritic meteorites, and for a suite of minerals separated from early-formed carbonaceous chondrites and angrites. Some of these phases show significant ^{235}U excesses with respect to the bulk chondritic value, although no correlation with Nd/U is observed. These data may indeed reflect ^{247}Cm effects. The suitability of Nd as a chemical proxy for Cm, however, may require revision. These new results have important implications for the ^{247}Cm-^{235}U cosmochronometer and the timing of *r*-process nucleosynthesis relative to the formation of the first solar system materials.