SHORT-LIVED RADIONUCLIDE ABUNDANCES AND NUCLEOSYNTHETIC ISOTOPE ANOMALIES IN BULK PLANETARY RESERVOIRS: IS THERE A CONNECTION?

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Introduction: The big bang explosion at the start of the universe was responsible for the production of the light elements hydrogen and helium, along with some fraction of lithium. All other heavier elements (except beryllium and boron) have been subsequently synthesized in diverse stellar environments, including the terminal supernova phase of massive stars [1]. Nucleosynthesis of these elements are now well understood such that the formation of the so-called *s*–, *r*– and *p*– process isotopes can be linked to specific stellar environments [2]. The relative abundances of these isotopes in molecular clouds reflects mixtures of old, galactically-inherited material with a recently-synthesized component(s) that may include short-lived radionuclides. Whether these various components existed and were well mixed or not in the protosolar molecular cloud core is important to our understanding of the astrophysical setting of the solar system, the tempo of molecular cloud core collapse and the applicability of chronometers based on short-lived nuclides.

The presence of nucleosynthetic anomalies in solar system materials has long been recognized for a number of nuclides (i.e. ^{48}Ca, ^{50}Ti, ^{54}Cr, ^{62}Ni and ^{64}Ni, ^{84}Sr), especially for early-formed objects such as normal and FUN-type (Fractionation and Unidentified Nuclear isotope anomalies [3]) refractory inclusions [4]. This nucleosynthetic heterogeneity, which has now also been documented in bulk meteorite samples originating from primitive and differentiated asteroids [i.e. 5-7], is commonly interpreted as reflecting the inefficient mixing of presolar components following collapse of the protosolar molecular cloud. Here, we explore the idea that the variability in the stable isotope composition of some heavy elements amongst bulk planetary reservoirs does not reflect initial heterogeneity, but instead results from selective thermal processing of newly-formed, anomalous young dust inherited from the protosolar molecular cloud.

Correlated nucleosynthetic heterogeneity: The observation that variations in the abundances of nuclides with apparently distinct nucleosynthetic origins are correlated at the scale of bulk solar system reservoirs provides an important constraint regarding the origin of the solar system's nucleosynthetic heterogeneity. For example, Trinquier et al. [6] proposed that correlated variations in ^{46}Ti and ^{50}Ti cannot reflect initial disk heterogeneity, given that the anomalous ^{46}Ti and ^{50}Ti were identified as residing in distinct silicate carriers based on step-leaching experiments. Instead, it suggests that the presolar dust inherited from the protosolar molecular cloud was initially homogeneously distributed within the inner protoplanetary disk, but requires the existence of a secondary process imparting selective loss of presolar carriers (silicates?) before the formation of solar system solids and accretion of asteroidal and planetary bodies. Based on a correlation between the ^{54}Cr composition and the degree of depletion in moderately volatile elements of carbonaceous chondrite meteorites, it was suggested that thermal processing of molecular cloud material resulted in preferential loss by sublimation of thermally unstable and isotopically anomalous presolar carriers, producing residual isotopic heterogeneity. Although this interpretation has been challenged by a recent study on the basis that ^{46}Ti and ^{50}Ti could, in principle, be produced in a single massive star [8], our new high-precision Ca and Sr isotope data for a sample suite similar to that analyzed by Trinquier et al. [6] confirms the presence of correlated variability for nuclides with clearly contrasting nucleosynthetic origin, namely ^{43}Ca, ^{46}Ca, ^{48}Ca and ^{84}Sr [9-10]. Therefore, we conclude that primordial heterogeneity or, alternatively, heterogeneous seeding of the nascent solar system by a single massive star, cannot easily explain the presence of correlated nucleosynthetic anomalies among bulk solar system reservoirs.

^{26}Al heterogeneity: The former presence of short-lived radionuclides such as ^{26}Al in meteorites and their components provides unequivocal evidence of a late stellar addition to the nuclesynthetic make-up of the solar system. Despite the observation of large-scale isotopic heterogeneity in isotope composition of a number of stable nuclides across the protoplanetary disk, the distribution of ^{26}Al and other short-lived nuclides is commonly assumed to have been homogenous. To assess the level of ^{26}Al heterogeneity in the solar protoplanetary disk, and its potential temporal relationship to the heterogeneity in stable nuclides, we have conducted high-precision measurements of the mass-independent composition of ^{26}Mg (^{26}Mg*) of early solar system reservoirs, including including CAIs and amoeboid olivine aggregates (AOAs) from the reduced CV (Vigarano type) chondrite Efremovka as well as a number of primitive and differentiated meteorites [11]. Our new data demonstrate the existence of widespread heterogeneity in ^{26}Mg* composition of bulk solar system reservoirs with solar or near-solar Al/Mg ratios. By comparing the U–Pb and ^{26}Al–^{26}Mg ages of pristine solar system materials, we infer that the bulk of the $^{26}Mg^*$ variability reflects heterogeneity in the initial abundance of ^{26}Al across the solar protoplanetary disk. The initial abundance of ^{26}Al inferred for the various bulk solar system reservoirs correlates with their ^{54}Cr (Fig. 1a) as well as their ^{43}Ca, ^{46}Ca and ^{48}Ca compositions [9], thus providing evidence for a relationship between the distribution of short-lived nuclides and that of stable isotope anomalies in the early solar system. Thus, similarly to the ^{54}Cr heterogeneity, we suggests that ^{26}Al heterogeneity in solar system objects reflects variable degrees of thermal processing of their precursor material, probably associated with volatile-element depletions in the inner solar system. In this view, CAIs and AOAs represent samples of the complementary gaseous reservoir enriched in ^{26}Al by thermal processing, which resulted in the widespread ^{26}Al depletions observed among inner solar system bodies (Fig. 1b). Moreover, the $^{26}Mg^*$-^{54}Cr correlation supports the idea that nucleosynthetic heterogeneity in solar system reservoirs represent a recent stellar contribution(s) to the solar system's nucleosynthetic make-up.

Young *vs*. old dust components: The correlation between the initial abundance of ^{26}Al and that of stable nuclides with contrasting nucleosynthesis is not consistent with variable incorporation of debris from a single nearby star. Rather, it supports the idea that the solar system's inventory of ^{26}Al as well as that of anomalous stable nuclides represent a new labile dust component inherited from multiple generations of massive stars during the chemical evolution of the giant molecular cloud (GMC) parental to the the protosolar molecular cloud core. This labile new dust component is in contrast to a more resilient older dust component, which may represent dust that was isotopically homogenized through sputtering, re-accretion and thermal processing in the interstellar medium prior to the formation of the GMC. Although a two-component dust model may be overly simplistic, it provides a first order approximation of the expected anomalous pattern resulting from thermal processing of young dust in the protoplanetary disk. For example, if the solar system's parental molecular cloud was isolated within ~20 Myr of GMC formation, then the new dust component will be dominated from input by type II supernovae with masses greater than 25 solar masses. Thermal processing of this dust within our solar system would result in enhancement of neutron-rich iron-group element isotopes (i.e. ^{54}Cr and ^{50}Ti) as well as *p*– and *r*–process nuclides in the gas phase, which is apparently consistent with the isotope pattern observed in CAIs. s

In a recent contribution [12], we have initiated numerical simulations of GMCs where stellar birth, death and rebirth takes place, tracking the production, distribution and admixing of ^{26}Al and ^{60}Fe in pre-stellar cores. Using the same code, we are expanding these simulations to now include stable isotope species such as ^{54}Cr and ^{50}Ti, in order to provide a quantitative assessment of the abundance of these stable nuclides in star-forming gas, as well as their relationship to the abundance of short-lived radioisotope such as ^{26}Al and ^{60}Fe. We expect to present results emerging from these new simulations at the meeting.

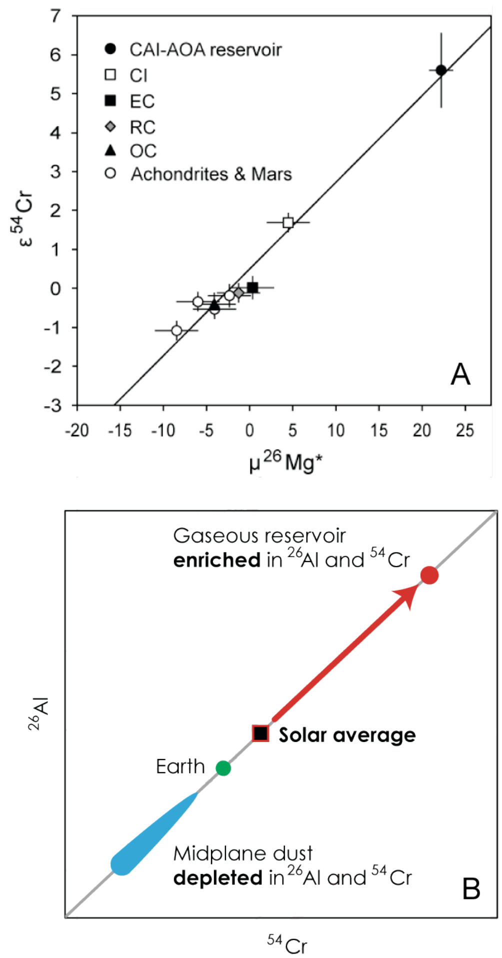

Figure 1: The solar system $^{26}Mg^*$-^{54}Cr correlation.

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