THE ORIGIN OF THE MISSING NUCLEOSYNTHETIC ISOTOPE VARIATIONS IN HEAVY REFRACTORY ELEMENTS.

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Introduction: Terrestrial planets and asteroids are characterized by distinct nucleosynthetic compositions. These stem from the heterogeneous distribution of presolar grains from different stellar sources in the solar protoplanetary disk. Four first order characteristics of theses variations are: (i) Enrichments in neutron-rich isotopes of lighter elements (e.g., ^{48}Ca, ^{50}Ti and ^{54}Cr) relative to the Earth are well established for carbonaceous chondrites. These data point towards an enrichment of supernova material in the outer solar system. (ii) Correlated variations of Zr, Mo, Ru and Pd isotopes in different planetary bodies reflect the heterogeneous distribution of *s*-process material, with the Earth displaying the strongest *s*-process enrichment [1]. (iii) Such *s*-process excesses are also identified for the heavier elements Nd and W e.g., [2]. However, these elements show variations that are consistently smaller (few parts per million) than those of lighter isotopes (e.g. Zr and Mo; 10 - 200 ppm). Overall, nucleosynthetic variations of heavier elements (Hf, W, Os, Pt, Hg) at bulk rock scale are very small or not resolvable. (iv) Non-refractory elements (Pd, Cd, Sn) display subdued or no nucleosynthetic variations [1,3].

Discussion: In previous work, we attributed the subdued nucleosynthetic variations in Pd isotopes relative to the neighboring refractory elements (Zr, Mo, Ru) to incomplete condensation around asymptotic giant branch (AGB) stars, the site of *s*-process nucleosynthesis [1]. It mirrors the fact that Pd is less refractory than Zr, Mo and Ru. This conclusion is also supported by new high precision data of moderately volatile elements (Cd, Sn), which generally show isotopic homogeneity in the solar system [3]. In agreement with this idea, a limited fraction of the synthesized mass in AGB stars condenses in the envelope of the star itself, while the rest enters the interstellar medium (ISM) as a gas [4]. The more volatile elements returned in the gas phase to the ISM become well mixed with those from other nucleosynthetic sources and are incorporated into ISM solids without preserving a distinct *s*-process signature [5]. In line with this, most presolar grains in primitive meteorites originate from AGB stars with only small contributions from supernovae environments.

While the volatility dependence readily explains the general nucleosynthetic homogeneity in volatile elements, it cannot account for the subdued or missing effects in heavy refractory elements. Missing nucleosynthetic offsets in neutron-rich Hf isotopes compared to the geochemically similar, lighter Zr isotopes were attributed to the decoupling of nucleosynthetic production sites [6]. Akram and co-worker [6] proposed that the light neutron-capture isotopes (e.g., ^{96}Zr) were mainly produced in Type II supernovae (SN) with higher mass progenitors than the SN that synthesized the heavy *r*-process isotopes. Since recent advances indicate that neutron star mergers may be the source of the main *r*-process, this could also indicate a decoupling of SN versus neutron star merger material. In the context of the Akram et al. model [6], the light isotopes (e.g. ^{96}Zr or ^{50}Ti) were mainly formed via charged-particle reactions in a high entropy wind environment, in which Hf isotopes are not produced, thereby explaining the missing Hf isotope variations. Hence, this scenario can account for the missing *r*-process/supernova anomalies in heavier elements ($Z > 55$). It cannot, however, explain the subdued or missing anomalies in *s*-process isotopes. Here, we propose that the *s*-process trend was set by the initial metallicity of the AGB stars that contributed most presolar grains to the solar system. Based on SiC grains, most *s*-process presolar grains in the solar protoplanetary disk likely originated from AGB stars with high metallicities [7]. Elements heavier than Cs ($Z > 55$) are less readily produced in AGB stars as metallicity increases, relative to Zr, Mo, Ru and Pd. This is because Fe seeds are more abundant in higher metallicity stars and thus capture more neutrons [8]. This impedes the production of heavier *s*-process elements. At the same time, the production of SiC and silicate dust increases with metallicity [4]. The reduced production of heavy nuclei combined with increased dust production leads to a presolar grain population depleted in heavy isotopes. As a result, the concentrations of heavier elements ($Z > 55$), relative to Zr, Mo and Ru, are lower than in the bulk solar system *s*-process component inherited from ISM dust. The heavier elements are primarily carried by ISM dust, which acquired homogenized material from AGB stars with a variety of metallicities. This led to the smaller or non-detectable *s*-process effects of heavier refractory elements in planets and asteroids.

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