Intrinsic isotope variations in the solar nebula and the multifarious origin of planetary scale nucleosynthetic heterogeneities

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Nucleosynthetic isotope anomalies among planetary bodies are currently revolutionizing our understanding of planetary genetics and the solar system's early dynamical evolution. For example, nucleosynthetic anomalies demonstrate that the Earth's building blocks were distinct from all known chondrite classes [1,2], and that the asteroid belt is a dynamical assemblage of bodies originating from at least two fundamentally different nebular source regions which have been isolated from each other for several million years, most likely through the early formation of Jupiter [3-5]. While these findings are a game changer for accretion disk dynamics, the processes and main components responsible for the generation of the planetary-scale anomalies, as well as how they relate to the mineral-scale isotopic heterogeneity inherited from the molecular cloud, are poorly understood. Thus, the full potential of nucleosynthetic anomalies for constraining material processing, mixing, and transport in the disk has yet to be realized.

Direct information about the materials present at the initial stages of solar system formation – and the processes acting on them – can be obtained by the analysis of components from chondritic meteorites, namely chondrules, CAIs, fine-grained matrix and presolar grains. Although the data base is still limited, by combining Ca, Ti, Cr, Ni, Sr, Zr, Mo and Ru concentration and isotope anomaly data of nebular and planetary materials I will discuss how the generation of planetary-scale isotopic anomalies can be understood as the interplay of nebular dust and three main components: CAIs, non-refractory materials with CAI-like isotopic composition, and presolar carriers. The magnitude of planetary-scale anomalies is a function of the elemental and isotopic composition of these components and their relative abundances at a given time and disk location. Anomalies in each element thus provide a unique set of information on the physico-chemical evolution of the disk, and combining these constraints for various elements provides a roadmap towards a quantitative description of the early solar system.

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