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Tracing the early dynamical evolution of proto-planetary disk using Si isotope signatures of chondrules from Leoville CV chondrite

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Vigarano-type (CV) chondrites are characterized by abundant chondrules and Ca-Al-rich inclusions (CAIs). These chondrules are millimeter-sized igneous silicate spherules formed by high-temperature transient heating events in the protoplanetary disk (PPD). Recent studies show that chondrules in carbonaceous chondrites exhibit distinct crystallization ages and neutron-rich isotopic signatures [e.g. 1, 2]. These findings suggest that chondrules acted as efficient carriers, making them perfect tracers to track material transport across the protoplanetary disk.

Nucleosynthetic Si isotopic compositions provide a robust tracer for identifying the source region of materials in the PPD [3, 4]. To further investigate the origin and evolution history of chondrules in CV chondrites, we selected 16 porphyritic chondrules from an unaltered CV3-reduced chondrite Leoville and measured their silicon isotope compositions. The mass-bias-corrected silicon isotope values ($\mu^{30}Si$) of individual chondrules range from -6.1±2.9 ppm to 37.1±5.8 ppm. Mass-dependent Si isotope composition ($\delta^{30}Si$) of these chondrules exhibit a broad range from -0.61±0.01 ‰ to 0.10±0.01 ‰. Both $\mu^{30}Si$ and $\delta^{30}Si$ of Leoville chondrules are overlapping with values reported for chondrules from the CV3-oxidized chondrite Allende [1]. It suggests that the $\mu^{30}Si$ is not significantly modified during parent body alteration. The $\mu^{30}Si$ signatures of the Allende and Leoville chondrules identify three distinct populations, corresponding to isotopic signatures typically linked to 1) non-carbonaceous material, 2) a signature comparable to the CV bulk compositions, and 3) signatures similar to CI-chondrites. Notably, the Leoville chondrules were also dated using absolute Pb-Pb chronometry. Isotope signatures combined with Pb-Pb ages shows that the earliest formed chondrules (>4567 Ma) already display $\mu^{30}Si$ values encompassing the entire observed range in the chondrule population, which is comparable to the range of planetary objects. This suggests that the nucleosynthetic diversity present in the CV chondrite chondrule population was established within the first Ma of CAI formation and required the incorporation of materials derived from both the inner and outer regions of the protoplanetary disk.

[1] Onyett *et al., (2024), EPSL,* 646, 118985.

[2] Bollard et al., *(*2017*),* Sci. Adv. 3, e1700407.

[3] van Kooten *et al., (2024),* Sci. Adv. 10, eadp1613.

[4] Onyett et al., *(2023),* Nature, 619, 539-544.