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Accretionary relationships and early outer disk substructures traced through N isotopes in iron meteorites

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Magmatic iron meteorites sample the metal cores of planetesimals formed within the first million years of Solar System history [1]. They record a wide range of $\delta^{15}N$ values (–95.8 ‰ to +155.6 ‰ [2-9]), with predominantly negative $\delta^{15}N$ values in non-carbonaceous (NC) irons and higher values in carbonaceous (CC) irons. This apparent dichotomy is consistent with accretion of isotopically distinct N in the inner and outer protoplanetary disk [10]. Notably, the highest $\delta^{15}N$ values (>+100 ‰), comparable to those of late-formed Renazzo-type (CR) carbonaceous chondrites [11-17], are restricted to IIC irons, whereas other CC iron groups record substantially lower $\delta^{15}N$, suggesting heterogeneity in the distribution of ^{15}N-rich N-bearing carriers in the early outer disk.

To further constrain the N isotope systematics of CC iron meteorites and the spatiotemporal evolution of N in the outer disk, we obtained N isotopic data for 10 ungrouped irons of established CC heritage [18]. Three samples—New Baltimore (+104 ‰), Hammond (+112 ‰), and La Caille (+206 ‰)—show $\delta^{15}N$ values similar to IIC irons and CR chondrites, reinforcing their genetic link to the IIC/CR reservoir, where ammonia ice was likely a major N carrier. These results imply that an isotopically CR-like, ammonia-rich reservoir was established early in the outer protoplanetary disk and persisted for several million years. Overall, the primary N isotopic compositions of differentiated and undifferentiated planetesimals likely reflect local mixtures of isotopically distinct N-bearing phases, controlled by evolving condensation and evaporation fronts in the disk.

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