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Distinct generations of CR chondrite chondrule formation revealed by their Cr and Ca isotope systematics

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The nucleosynthetic diversity preserved in solar system's solids highlights the diverse stellar sources contributing to its proto-solar molecular cloud material. One of the key observations is the isotopic dichotomy between carbonaceous and non-carbonaceous materials [1], which is thought to broadly represent their accretion outside and inside of Jupiter's orbit, respectively. The asteroids and planets that record this dichotomy accreted relatively late in the formative history of our solar system and, as such, are of limited use in understanding the origin of this dichotomy. In contrast, chondrules, mm-sized spherules in primitive meteorites, are more conducive to this task as their formation began contemporaneously with the oldest solar system solids and continued throughout the protoplanetary disk's lifetime [2].

In this study, we measured the calcium and chromium isotope composition of Pb-Pb dated chondrules from the CR2 NWA 7502 to track changes to the isotopic makeup in their formation region. Our data reveal three isotopically distinct populations: seven chondrules have indistinguishable ^{54}Cr but variable ^{48}Ca signatures and a ^{53}Mn-^{53}Cr isochron age of 4565.6±0.3 Myr when anchored relative to D'Orbigny. Two highly volatile-depleted chondrules have lower ^{54}Cr and higher ^{48}Ca signatures and form a two-point ^{53}Mn-^{53}Cr isochron with an age of ~4566.6 Myr. The remaining chondrule has a higher ^{54}Cr and lower ^{48}Ca signature than the rest. Notably, the ^{53}Mn-^{53}Cr isochron ages are consistent with the absolute chondrule Pb-Pb ages indicating recurrent CR chondrule formation that is delayed relative to ordinary chondrite chondrule formation in the inner solar system [2]. Moreover, given the systematic isotope shifts with CR chondrule age, these data also points towards a secular evolution of the CR chondrule forming reservoir. Considering that CR chondrites likely accreted beyond Jupiter, the isotopic evolution cannot reflect changing dust processing close to the sun but is better understood as reflecting a secular isotopic evolution of the CR chondrite forming reservoir via admixing of infalling, isotopically distinct dust during the Sun's late accretion phase.

[1] Trinquier *et al*., 2007, *APJ* **655**, 1179–1185. [2] Bollard *et al.*, 2017*, Sci. Adv.* **3**, e1700407.