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Tracking chondrule histories with chromium isotopes

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Chondrules are mm-to-cm sized igneous silicate spherules abundant in chondrite meteorites. However, their formation and redistribution in the protoplanetary disk are still debated. Chromium with its four isotopes is suitable to address this topic because ^{54}Cr records nucleosynthetic variability between solar reservoirs and ^{53}Cr is part of the short-lived ^{53}Mn-^{53}Cr chronometer. In this study, we investigated the chromium isotopic compositions of 31 chondrules from the ordinary chondrite (OC) NWA 5697 and the Vigarano-type carbonaceous chondrite (CV3) Leoville.

All chondrules analyzed from NWA 5697 exhibit negative μ^{54}Cr values, ranging from –104.7 ± 5.9 to –8.0 ± 5.6 ppm. In contrast, most chondrules from Leoville display positive μ^{54}Cr, consistent with previous work [2], ranging from -67.6 ± 4.5 to 95.1 ± 5.5 ppm. We subdivided distinct populations in OC and CC based on μ^{54}Cr and determined the ages of chondrules via bulk chondrule isochrons where possible. The ^{53}Mn-^{53}Cr chronometry yields two regressions for NWA 5697 chondrules with absolute ages of $4568.6^{+0.5}_{-0.6}$ Ma (n=5, MSWD=2.5) and $4565.2^{+1.3}_{-1.7}$ Ma (n=3, MSWD=8.4) when mapped onto absolute timescales using the D'Orbigny angrite. These ages likely represent largescale heating episodes through the wholesale processing of chondrule precursors resetting the bulk chondrule Mn-Cr systematics. As such, these ^{53}Mn-^{53}Cr ages indicate multiple episodes of chondrule formation that contributed to the OC reservoir.

For CV3 chondrules, we observed a bimodal distribution in both age and isotopic composition. Chondrules with positive μ^{54}Cr values form an error-chron with an absolute age of $4568.6^{+0.6}_{-0.7}$ Ma (n=8, MSWD=15). The population characterized by negative μ^{54}Cr values, indicative of a non-carbonaceous (NC) or inner-disk origin, regress with a younger age of $4564.1^{+1.4}_{-1.9}$ Ma (n=4, MSWD=13). The presence of these inner-disk-like chondrules within an outer-disk (CC) meteorite provides strong support for the outward transport of material from the inner solar system to the CC accretion region [3], but the young chondrule ages indicate that this may have occurred over protracted timescales.

[1] Schiller et al., (2018), Nature 555. 507–510

[2] Burkhardt et al. (2019) GCA, 261, 145–170

[3] Williams et al. (2019). PNAS, 117, 23426–23435