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Time of chondrule formation in unequilibrated ordinary chondrites from ^{53}Mn-^{53}Cr chronometry

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Chondrules are mm-sized pebbles formed by flash-melting of dust aggregates in the early Solar System. They are widely regarded as fundamental building blocks of terrestrial planets. Constraining the timing of chondrule formation is therefore critical for understanding the processes and timescales of planet formation.

The formation ages of individual chondrules have been determined so far using the short-lived ^{26}Al-^{26}Mg chronometer and the long-lived U-Pb decay system. This study reports the first individual isochron of a chondrule from Northwest Africa (NWA) 8667 (L3.2) obtained using the short-lived ^{53}Mn-^{53}Cr chronometer ($t_{1/2}$ = 3.80 ± 0.23 Ma [1]), together with Cr isotope analyses of bulk chondrules from unequilibrated ordinary chondrites.

To constrain an internal isochron, an individual chondrule (Ch-1) was sequentially digested using acids of increasing strength. Chromium isotope ratios were analysed by Thermal Ionization Mass Spectrometry (TIMS) at the University of Bern and Imperial College London. The four-point isochron for Ch-1 yields a ^{53}Mn/^{55}Mn ratio of 3.88 ± 0.32 × 10^{-6} (MSWD = 0.8), which corresponds to an absolute age of 4564.50 +0.47/-0.43 Ma. This age is in good agreement with previously reported Pb-Pb ages of individual chondrules [2] and suggests that the last isotopic closure in Ch-1 occurred 4.04 Ma after the start of Solar System (i.e. CAI) formation, setting an absolute age of the Solar System to 4568.54 Ma [3]. This age further implies that chondrule formation was still ongoing after ^{26}Al became effectively extinct, and at a time when early generations of planetesimals had already formed. Chondrule formation over several million years [2,4] and petrographic evidence of chondrule reworking (e.g. [5]) suggest that late-formed chondrules, such as Ch-1, are the result of recycling of previous generations via planetesimal or planetary embryo bow shocks.

[1] Desch et al. (2023), *Icarus* 402, 115611. [2] Bollard et al. (2017), *Sci. Adv.* 3(8), e1700407. [3] Kruttasch & Mezger (2025), *Sci. Adv.* 11(31), eadw1280. [4] Pape et al. (2019), *Geochim. Cosmochim. Acta* 244, 416-436. [5] Pape et al. (2021), *Geochim. Cosmochim. Acta* 292, 499-517.