Hf-W CHRONOLOGY OF CR CHONDRITES. G. Budde, T. S. Kruijer, and T. Kleine, Institut für Planetologie, University of Münster, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany (gerrit.budde@uni-muenster.de).

Introduction: Understanding the origin of chondrules is key for constraining the processes affecting solid material in the solar nebula, ultimately leading to the formation of planetesimals. Addressing these issues requires information on the timescale of chondrule formation, and on genetic links between the individual components of chondrites. Previous studies have shown that most chondrules formed at ~2 Ma after formation of Ca-Al-rich inclusions (CAIs), although some chondrules may have formed as early as CAIs, while others may have formed ~4 Ma later (see [1] for an overview). In particular, chondrules from CR chondrites appear to be significantly younger than other chondrules [2,3]. However, the relatively young ages obtained for CR chondrules do not necessarily require a late formation, but might, at least in part, reflect disturbance or resetting during alteration on the CR parent body.

Compared to the Al-Mg and Pb-Pb systems, which are most commonly used to assess the chronology of chondrule formation, the ^{182}Hf-^{182}W system ($t_{1/2}$ = 8.9 Ma) is far more robust against resetting by parent body processes. This makes the Hf-W system ideally suited to assess whether or not CR chondrules formed later than other chondrules. Moreover, CR chondrites can be well dated using the Hf-W system, because they contain abundant Fe-Ni metal. As chondrule formation was associated with metal-silicate separation [*e.g.*, 1], chondrule formation can be dated via metal-silicate Hf-W isochrons for CR chondrites.

We present precise Hf-W ages for four different CR chondrites. In addition, we also determined high-precision (non-radiogenic) W and Mo isotope compositions for individual components of CR chondrites. These data provide important insights into the genetic links between these components, which in turn allows us to assess the chondrule-forming mechanism [1,4].

Methods: We obtained Hf-W and Mo isotope data for bulk samples, magnetic separates, and individual components (metal, chondrules) from four CR2 chondrites (Acfer 097, GRA 06100, NWA 1180, NWA 801). The analytical methods followed our established procedures [1,4], and all isotope measurements were made using the Neptune *Plus* MC-ICP-MS at Münster. The Mo and W isotope data are internally normalized to ^{98}Mo/^{96}Mo and either ^{186}W/^{183}W or ^{186}W/^{184}W, and are reported as ε-unit deviations (i.e., 0.01%) relative to the bracketing solution standards. Repeated analyses of terrestrial rock and metal standards (BHVO-2, NIST 129c) define an external reproducibility (2 s.d.) for the W and Mo isotope ratios of ~0.1 and 0.2–0.4 ε-units, respectively.

Nucleosynthetic isotope anomalies in CR components: The analyzed samples show variable anomalies in ε^{183}W (~0.1–0.7), where the metal fractions have the lowest and the silicate-dominated fractions the highest excesses in ε^{183}W. The ε^{183}W variations are correlated with measured Mo isotope variations (ε^{92}Mo: ~2–10), and are attributable to the uneven distribution of a presolar carrier enriched in *s*-process nuclides. Of note, metal and silicates show complementary nucleosynthetic isotope anomalies, indicating that relative to the bulk meteorite, metals are enriched in an *s*-process carrier, whereas silicates are depleted in this carrier. This finding is consistent with the isotopic complementarity observed for Allende chondrules and matrix [1,4] and provides further evidence that the major components of (carbonaceous) chondrites are genetically linked and formed together from one common reservoir of solar nebula dust.

Timescale of chondrule formation: After correction of the measured ε^{182}W for nucleosynthetic anomalies after [1], all analyzed samples plot on well-defined isochrons. Note that the correction for nucleosynthetic isotope anomalies is <0.05ε for most samples and thus smaller than the analytical uncertainty. All investigated CR chondrites have indistinguishable Hf-W ages and combined define an age of 3.7±0.6 Ma after CAI formation. This age is in excellent agreement with the mean Al-Mg age for CR chondrules of 3.7±0.3 Ma [3], as well as a Pb-Pb age of 3.7±0.6 Ma (corrected to ^{238}U/^{235}U = 137.786) obtained for six chondrules from the CR2 chondrite Acfer 059 [2]. Thus, three different chronometers provide consistent ages for the formation of CR chondrules, demonstrating that they formed ~1–2 Ma later than chondrules from ordinary chondrites. Collectively, these data suggest that the CR chondrite parent body accreted later than several other chondrite parent bodies, perhaps because the CR chondrites derive from a greater heliocentric distance. This is consistent with the ^{15}N signatures of the CR chondrites, and with the idea that carbonaceous chondrites initially accreted in the outer solar system, beyond the orbit of Jupiter [4,5].

References: [1] Budde G. et al. (2016) *PNAS*, 113, 2886–2891. [2] Amelin Y. et al. (2002) *Science*, 297, 1678–1683. [3] Schrader D. L. et al. (2016) *GCA*, in press (10.1016/j.gca.2016.06.023). [4] Budde G. et al. (2016) *EPSL*, 454, 293–303. [5] Warren P. H. (2011) *EPSL*, 311, 93–100.