TUNGSTEN ISOTOPES AND THE AGE AND ORIGIN OF CHONDRULES. T. Kleine, G. Budde, J. L. Hellmann, T. S. Kruijer, and C. Burkhardt, Institut für Planetologie, University of Münster, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany (thorsten.kleine@wwu.de).

Introduction: The short-lived ^{182}Hf-^{182}W system ($t_{1/2}$ ~8.9 Ma) is a versatile tool to study the timescales and processes of chondrule formation and chondrite accretion. Dating chondrites is possible because chondrule formation typically was associated with metal-silicate separation. As W is siderophile, whereas Hf is lithophile, metal-silicate separation leads to Hf/W fractionation, making it possible to determine Hf-W isochrons [1]. Tungsten isotopes also provide information on genetic links between chondrules and other components of primitive chondrites. This is because chondrules, matrix, and metal in at least carbonaceous chondrites exhibit nucleosynthetic W isotope anomalies that arise through the uneven distribution of presolar components among chondrite components [2].

Isotopic complementarity of chondrules and matrix: Chondrules and matrix from the CV3 chondrite Allende exhibit complementary ^{183}W anomalies: chondrules have ^{183}W excesses, the matrix has ^{183}W deficits [2]. The same samples also show complementary isotope anomalies for Mo, but not for Ba [3]. These data are best explained by the preferential incorporation of a presolar metal carrier enriched in *s*-process nuclides into the matrix, and the complementary depletion of this carrier in the chondrules. This uneven distribution of a presolar metal probably results from metal-silicate fractionation during chondrule formation [3].

Bulk meteorites, including Allende, show only small if any ^{183}W anomalies. This observation, and the presence of large ^{183}W variations in chondrules and matrix, indicates that these two components derive from a single reservoir of nebular dust; otherwise they would not show complementary isotope anomalies resulting from the uneven distribution of a single presolar carrier [2]. As such, the ^{183}W data are inconsistent with an impact origin of chondrules, but instead require that chondrules formed in the solar nebula. Moreover, after their formation, neither appreciable chondrules nor matrix could have been lost, because otherwise bulk Allende would show a significant ^{183}W anomaly. This implies that after their formation chondrules and matrix accreted rapidly to their parent body and that chondrules from a given chondrite group formed within a narrow time interval [2].

Hf-W chronology of chondrule formation: Allende chondrules and matrix define a precise Hf-W isochron, corresponding to an age of 2.2±0.8 Ma after CAI formation [2]. Metal and silicate separates from four CR chondrites define an isochron corresponding to an age of 3.7±0.6 Ma after CAI formation [8]. Thus, chondrules from CR chondrites formed 1.5±0.7 Ma later than those from CV chondrites. The CR chondrules also formed later than chondrules from ordinary chondrites, which based on Al-Mg systematics formed at ~2 Ma after CAI formation [4]. To date, no isochrons for type 3 ordinary chondrites have been obtained, and so the formation of ordinary chondrite chondrules has not been dated directly using the Hf-W system. However, Hf-W ages for equilibrated ordinary chondrites of petrologic types 4 to 6 indicate that the different bulk Hf/W of H, L and LL chondrites were established at ~2–3 Ma after CAI formation, most likely as a result of nebular metal-silicate separation that was coeval with chondrule formation [9]. Combined, these data indicate that most chondrules formed at ~2–3 Ma, and that chondrule formation extended until at least ~4 Ma, post CAI formation.

Implications for the distribution of ^{26}Al in the solar nebula: The Hf-W ages for CV and CR chondrites not only constrain the chronology of chondrule formation, but they also provide insights into the distribution of ^{26}Al within the solar nebula. There are now four different types of samples, spanning an age range of ~5 Ma, that have been dated with both the Hf-W and Al-Mg systems: bulk CAI, CV chondrules, CR chondrules and the angrites D'Orbigny and Sahara 99555. For all four samples the Hf-W and Al-Mg ages are in excellent agreement, and so provide no evidence for ^{26}Al heterogeneity. Using the scatter around the correlation line of ages from both systems shows that any potential ^{26}Al heterogeneity was <10–20%, i.e., much smaller than proposed based on the comparison of Al-Mg and Pb-Pb ages [5].

Conclusions: Tungsten isotope measurements on chondrites have led to the following constraints: (1) chondrules formed in the solar nebula; (2) chondrules from a given chondrite group formed in a narrow time interval; (3) most chondrules formed at ~2–3 Ma after CAIs, but CR chondrules formed ~1.5 Ma later; (4) ^{26}Al was homogeneously distributed in the nebula.

References: [1] Kleine, T. et al. (2008) *EPSL*, *270, 106-118*. [2] Budde, G. et al. (2016) *PNAS*, *113, 2886-2891*. [3] Budde, G. et al. (2016) *EPSL*, *454, 293-303*. [4] Kita, N.T. and T. Ushikubo (2012) *MAPS*, *47, 1108-1119*. [5] Schiller, M. et al. (2015) *EPSL*, *420, 45-54*. [8] Budde, G. et al., this meeting. [9] Hellmann, J. et al., this meeting.