CHRONOLOGY OF CARBONACEOUS ACHONDRITES FROM THE OUTER SOLAR SYSTEM. M. H. Huyskens[1], M. E. Sanborn[1], Q.-Z. Yin[1], Y. Amelin[2] and P. Koefoed[3]. [1]Dept. of Earth and Planetary Sciences, University of California-Davis, One Shields Avenue, Davis, CA 95616, [2]Research School of Earth Sciences, The Australian National University, Canberra ACT 0200, Australia. [3]Dept. of Earth and Planetary Sciences, Washington University in St. Louis, 1 Brookings Dr., Saint Louis, MO 63130. (mhuyskens@ucdavis.edu)

Introduction: A growing number of achondrites are being identified that have O, Cr, and Ti isotopic similarities with carbonaceous chondrites (CC) [1-3]. Due to these similarities, it is likely that CC and those "carbonaceous" achondrites ostensibly originated from the outer solar system.

So far, four distinct reservoirs for achondrites with isotopic affinities to CR chondrites have been identified (Fig. 1). These are Northwest Africa (NWA) 6704/ 6693/10132, Tafassasset/NWA 3100, NWA 7680/ 6962, and NWA 011/2976/4587 [1-3]. In this study, we investigate the chronology of NWA 4587 and NWA 10132 and compare with available chronological information of other achondrites from the same region to investigate the accretion and differentiation history in the outer solar system.

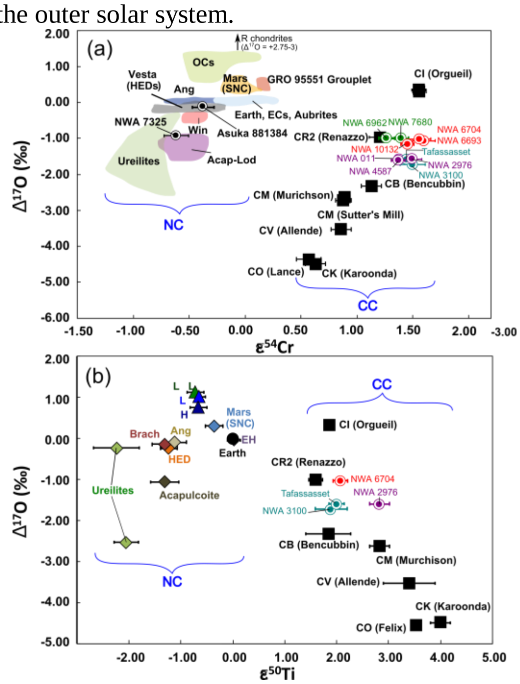

Figure 1: Comparison of the Δ^{17}O-ε^{54}Cr and Δ^{17}O-ε^{50}Ti systematics of achondrites in the CR chondrite region. Figure adapted from [1].

Material and Methods: NWA 4587 is a basaltic achondrite paired with NWA 011 and NWA 2976 and is mainly composed of pyroxene, plagioclase and minor silica and oxides [4]. NWA 10132 is from the same region in the protoplanetary disk as NWA 6704 and NWA 6693 and most likely from the same parent body [5]. It is an ultramafic achondrite composed of mainly pyroxene and olivine and minor plagioclase [6].

For Al-Mg chronology, four fractions were separated for each meteorite. For NWA 4587, those are pyroxene, plagioclase and two "bulk" rock fractions, one 125-150 µm depleted in pyroxene and one <125 µm. For NWA 10132, the four fractions are plagioclase, pyroxene, olivine and "bulk" rock depleted in plagioclase. After dissolution, a 5% aliquot was taken for ^{27}Al/^{24}Mg ratio determination while, for the remaining sample, Mg was separated using column chromatography. Measurements for ^{27}Al/^{24}Mg as well as Mg isotopes were performed on a Thermo *Neptune Plus* MC-ICP-MS following the protocol described in [1, 7]. For the ^{27}Al/^{24}Mg ratios an uncertainty of 2% was assumed based on long term measurement reproducibility. δ^{26}Mg* is based on at least seven repeat measurements per sample and uncertainties are reported at 2σ.

Results: The ^{27}Al/^{24}Mg ratios for NWA 4587 range between 0.61 and 400 and the δ^{26}Mg* between 0.012 and 1.66‰ (Fig. 2). The ^{26}Al/^{27}Al at the time of last isotopic closure determined from the ^{26}Al-^{26}Mg isochron is $(5.78\pm0.14)\times10^{-7}$ (MSWD=1.4) with a corresponding initial δ^{26}Mg* of 0.0045±0.0085‰. For NWA 10132, the ^{27}Al/^{24}Mg ratios are between 0.014 and 14.2 and the δ^{26}Mg* between -0.013 and 0.021‰ (Fig.2). The initial ^{26}Al/^{27}Al determined from the isochron is $(2.84\pm1.67)\times10^{-7}$ (MSWD=0.77) with an initial δ^{26}Mg* of -0.0079 ±0.0087 ‰. Anchoring to an ^{26}Al/^{27}Al ratio of 3.93×10^{-7} for the angrite D'Orbigny and the corresponding U-corrected Pb-Pb age [8-12], NWA 4587 has an absolute age of 4563.76±0.36 Ma and NWA 10132 of 4563.04±0.59 Ma.

Discussion: Chronological information is available for at least one meteorite of each of the four distinct groups of achondrites within the CR region. NWA 6704 was investigated by multiple chronometers and yielded consistent ages in the Mn-Cr, Al-Mg and Pb-Pb chronometers, with 4562.17±0.76 Ma, 4563.14±0.38 Ma and 4562.76+0.22-0.30 Ma, respectively [1, 13] This is indistinguishable from the Al-Mg age determined in this study and previously reported Mn-Cr and Pb-Pb ages for NWA 10132 [5], which is interpreted to originate from the same parent body based on Cr and O isotopes as well as petrology [5, 6]. Tafassasset, a primitive achondrite, has been investigated with the Hf-W, Pb-Pb and Mn-Cr systematics. The Hf-W age is 4564.5±0.9 Ma [14], whereas the Mn-Cr age is 4563.5±0.3 Ma [15] and the Pb-Pb age is 4563±1 Ma [16]. NWA 7680/6962 was investigated with the Mn-

Cr system and yielded an age of 4562.37±0.34 Ma [17]. NWA 011 was dated by SIMS with the Mn-Cr and Al-Mg chronometers with ages of 4562.6±2.6 Ma and 4563.95±0.30 Ma (recalculated to the D'Orbigny anchor), respectively [18].

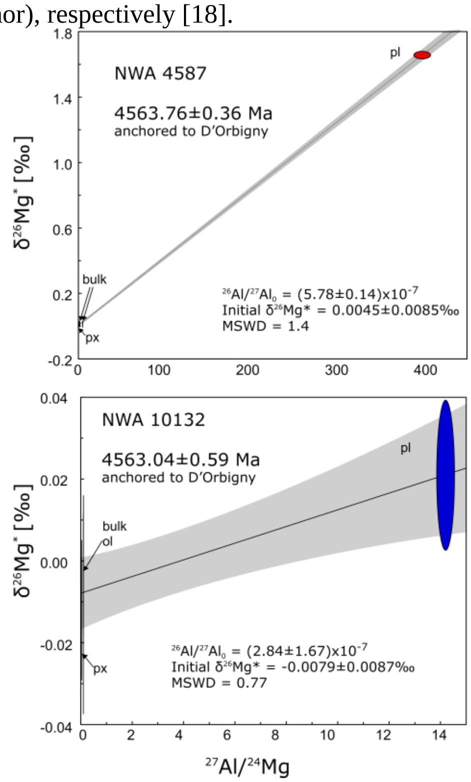

Figure 2: Al-Mg systematics of NWA 4587 and NWA 10132. Grey band represents the error envelope of the regression and ellipses represent the measurement uncertainty of the individual data points. pl: plagioclase; ol: olivine, px: pyroxene.

NWA 2976 was dated by the Pb-Pb and Al-Mg system in two studies. The two determined Al-Mg ages (recalculated to the same anchor for D'Orbigny) are 4563.37±0.40 Ma [19] and 4563.60±0.40 Ma [9]. The determined Pb-Pb age is 4562.89±0.59 Ma, using the measured $^{238}U/^{235}U$ of 137.751 [19]. If using the $^{238}U/^{235}U$ ratio of 137.787 for the same meteorite determined in a different study [20], the recalculated age is 4563.27 Ma, agreeing better with the short-lived isotope systems. The Al-Mg and Mn-Cr ages for NWA 4587 from this study is indistinguishable from those values. The short lived isotope systems show good agreement between these paired meteorites. The Pb-Pb age for NWA 4587 [21] is significantly younger (Fig. 3), requiring further investigation.

Overall these ages suggest that magmatism in the CR chondrite region is very early and spans a brief time period of ~1 Myr (Fig. 3). Similarly, iron meteorites that formed in the CC region (as determined by Mo isotopes) have a very narrow range of core formation (Hf-W) ages of 2.9-2.2 Ma after CAI formation as well [22]. These observations suggest that accretion, differentiation and magmatism of multiple parent bodies occurred within a narrow timespan within the CR forming region and possibly the entire CC forming region.

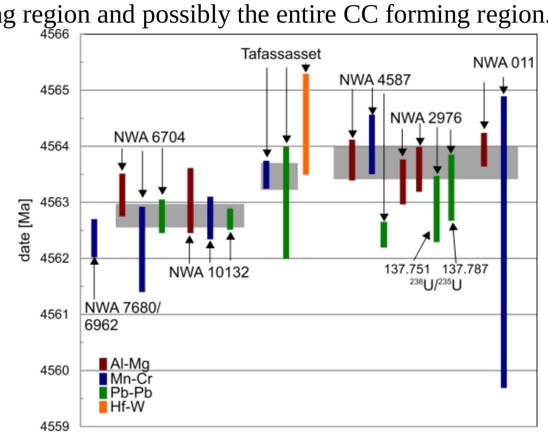

Figure 3: Comparison of all available chronological data for achondrites from the outer solar system. Data is from this study and [1, 2, 5, 9, 13-19, 21]. Grey bands reflect the weighted average age for each distinct group (not including Hf-W age for Tafassasset, and Pb-Pb age for NWA 4587).

The initial $\delta^{26}Mg^*$ for NWA 10132 is identical to the one determined for NWA 6704. Both are slightly negative, although indistinguishable from 0. The initial $\delta^{26}Mg^*$ of NWA 4587 agrees with one previous determination from the paired stone NWA 2976 [19], however, it does not agree with the second study [9].

Conclusions: At least four distinct parent bodies with magmatism in the early solar system forming within the CR chondrite region are identified. The magmatism on those parent bodies occurred within a narrow time range of ~4562.4 to 4563.7 Ma.

References: [1] Sanborn M. E. et al. (2019) *GCA*, *245*, 577–596.[2] Sanborn M. E. et al. (2018) *LPSC*, *#2296*. [3] Sanborn M. E. and Yin Q.-Z. (2019) *This conference*. [4] Connolly Jr H. C. et al. (2007) *MAPS*, *42*, 1647-1694. [5] Sanborn M. E. et al. (2018) *81st MetSoc*, *#2067*. [6] Irving A. et al. (2015) *78th MetSoc*, *#5254*. [7] Wimpenny J. et al. (2019) *GCA*, *244*, 478-501. [8] Spivak-Birndorf L. et al. (2009) *GCA*, *73*, 5202-5211. [9] Schiller M. et al. (2010) *GCA*, *74*, 4844-4864. [10] Brennecka G. A. and Wadhwa M. (2012) *PNAS*, *109*, 9299-9303. [11] Amelin Y. (2008) *GCA*, *72*, 221-232. [12] Schiller M. et al. (2015) *EPSL*, *420*, 45-54. [13] Amelin Y. et al. (2019) *GCA*, *245*, 628-642. [14] Breton T. et al. (2015) *EPSL*, *425*, 193-203. [15] Göpel C. et al. (2015) *GCA*, *156*, 1-24. [16] Göpel C. et al. (2009) *72nd MetSoc*, *#5267*. [17] Sanborn M. E. et al. (in prep.). [18] Sugiura N. and Yamaguchi A. (2007) *LPSC*, *#1431*. [19] Bouvier A. et al. (2011) *GCA*, *75*, 5310-5323. [20] Connelly J. N. et al. (2012) *Sci*, *338*, 651-655.[21] Amelin Y. et al. (2019) *This conference*. [22] Kruijer T. S. et al. (2017) *PNAS*, *114*, 6712-6716.