CONSTRAINING THE SOLAR SYSTEM INITIAL K ISOTOPE COMPOSITION: THE K ISOTOPES OF CI CHONDRITES P. Koefoed[1,2], J.A. Barrat[3], O. Pravdivtseva[1,4], C.M.O'D. Alexander[5], K. Lodders[1,2], and K. Wang (王昆)[1,2] [1]McDonnell Center for the Space Sciences, [2]Dept. of Earth & Planetary Sciences, Washington University in St. Louis, One Brookings Drive, St. Louis, MO 63130 USA (piers.koefoed@wustl.edu), [3]Institut Universitaire Européen de la Mer, Université de Bretagne Occidentale, CNRS UMS 3113, F-29280 Plouzané, France, [4]Dept. of Physics, Washington University in St. Louis. [5]Earth and Planets Laboratory, Carnegie Institution for Science, Washington, DC 20015, USA

Introduction: Chondrites represent some of the oldest and most primitive solids within our solar system. Of the chondrite groups, CI chondrites are generally considered the most chemically primitive, with their bulk compositions matching closely with that of the Sun [1,2,3]. This correlation between the Solar photosphere and CI chondrites has led to a general consensus that the elemental composition of CI chondrites are representative of the overall solar system. One isotope system which has gained significant interest in cosmochemistry over the last few years is the moderately volatile K. Potassium possesses the ideal volatility to record key evaporation and condensation processes which occurred in the early solar system. The CI chondrite K isotope composition, is currently not well constrained which is important if it is representative of the initial composition of the solar system.

Currently, results for seven CI chondrite samples have been reported, with six of these from Orgueil and one from Ivuna [4,5,6]. The K isotope compositions of these samples cover a significant range from −0.58 to −0.04‰ δ^{41}K. Excluding the sample with the lightest analysis, which may have terrestrial contamination, the total δ^{41}K range reduces slightly to −0.46 to −0.04‰ [5,6]. This range is still significantly larger than current analytical uncertainties (~0.05‰) and cannot be explained by inter-laboratory discrepancies as all these laboratories reported identical geostandard values. The lightest δ^{41}K analyses is from the single Ivuna sample and Ivuna is known to be more heterogeneous and often somewhat different in chemical composition. Much of the observed K isotope variability among Orgeuil samples could be related to the known chemical heterogeneity observed at the <1g scale in CIs [7]. As the bulk Silicate Earth (BSE) shows a δ^{41}K of −0.43 ± 0.17‰ (2sd) [8], it is still uncertain whether CIs and the Earth share a K isotope composition or not. Here, in order to address the uncertainty surrounding the CI K isotope composition, we undertook a systematic study looking the K isotope compositions of multiple fractions, from multiple separate chips from the CI chondrites Orgueil and Ivuna.

Methods: We analyzed a total of nine CI chondrite samples, consisting of eight chips of Orgueil and one chip of Ivuna. The eight chips form Orgueil came from six distinct stones from two different sources (see Figure 1). The fraction masses ranged from 45 to 218 mg. In addition, four CR Antarctic finds were measured for comparison with sample masses ranging from 53 to 66 mg. Dissolution was done using concentrated HF and HNO_3 at a 3:1 ratio for one week at 140 °C. Following complete dissolution, an aliquot comprising 5% of each fraction was taken for elemental analysis using a Thermo Fisher iCAP Q ICP-MS. For K isotope analysis, an aliquot of 50% of each fraction was taken that then underwent K separation by means of a triple pass column chemistry procedure using Bio-Rad AG50W-X8 100-200 mesh cation exchange resin where 0.5 M HNO_3 was used as the elution liquid. The subsequent K isotope analyses were conducted using a Neptune Plus MC-ICP-MS. SRM 3141a was used as the standard for all analysis, while BHVO-2 was analyzed alongside all unknowns to monitored data quality.

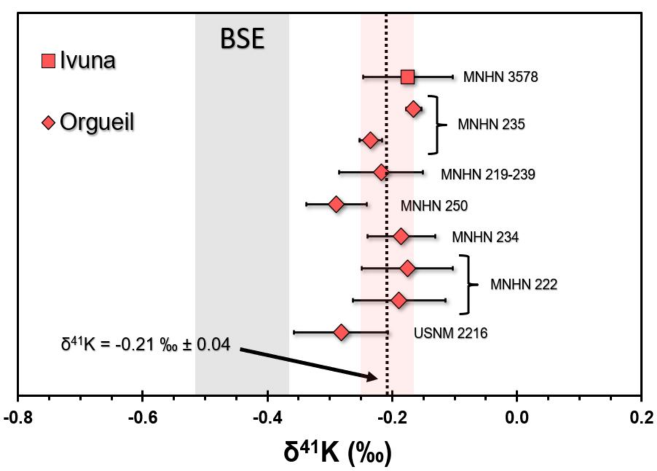

Figure 1. *K isotope compositions of all CI fractions analyzed in this study. The museum catalogue numbers are shown (MNHN = National d'Histoire Naturelle, Paris, USMN = Smithsonian National Museum of Natural History). Errors shown are 95% C.I. The CI average using the analyses from this study is also displayed. BSE represents the Bulk Silicate Earth value [8].*

Results: As shown in Figure 1, the δ^{41}K for all CI chondrites analyzed in this study range from −0.29 to −0.17‰. This overall range is significantly narrower than the combined range from all previous CI analyses (−0.46 to −0.04‰) [4,5,6]. The mean δ^{41}K of all nine analyses from this study is −0.21 ± 0.04‰ (95% C.I.), which is distinct from the BSE value (δ^{41}K = −0.43 ± 0.17‰). No significant difference is observed between Orgueil and Ivuna, which is in contrast to previous analyses that reported that Ivuna has a lighter K isotope composition comparted to Orgueil [6]. The different Orgueil pieces and different chips of the same Orgueil piece also show no significant variation. The slight variations observed are likely due to small heterogeneities within Orgueil as all the fractions analyzed were <1g in mass. The K concentrations of CIs in this study range from 370 to 601 ppm, agreeing with previous analyses (365 to 677 ppm) done on many of the same sample stones (but not identical aliquots) [9]. The four CRs measured in this study show δ^{41}K values from −0.61 to −0.43‰

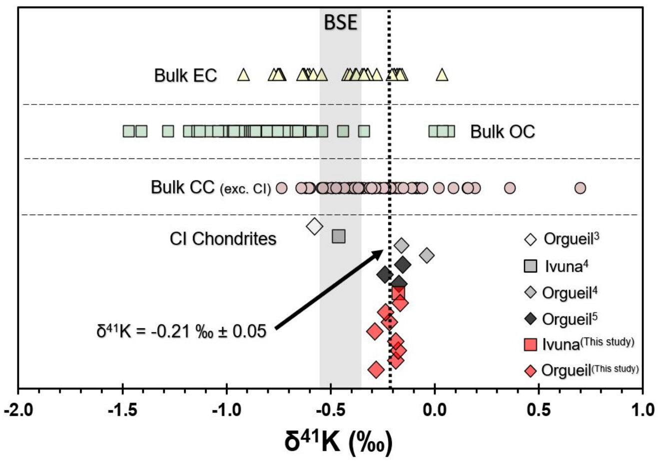

Figure 2. *δ^{41}K for all CI fractions analyzed so far. Bulk EC (enstatite chondrite), OC (ordinary chondrite) and CC (carbonaceous chondrite) data, along with the BSE value, are also shown for comparison [4,5,6,8,10,11]. Individual error bars have been removed for clarity.*

Discussion: When combined with the previous data (excluding the analysis from [4]) an overall CI δ^{41}K value of −0.21 ± 0.05‰ (95% C.I.) is obtained (shown in Figure 2). This value is essentially identical to the value determined using the data from this study alone. This value provides a precise K isotope composition for CI chondrites, and thus may represent the solar system initial K isotope composition. Compared to ECs, OCs, and other CCs, CIs are constrained within a very restricted range. Indeed, thirteen of the fifteen CI analyses lie between the range of −0.29 to −0.15‰ δ^{41}K, suggesting that CIs likely contain limited δ^{41}K variation. For comparison, the majority of other CCs lie between 0 and −0.6‰ δ^{41}K, OCs between −0.6 and −1.2‰ δ^{41}K, and ECs between −0.1 and −0.8‰ δ^{41}K.

Figure 3 shows a comparison of the mean values of all CC types. All CCs groups show K isotope compositions about the same as, or lighter than, CIs. Of the CC types, the CM, CO and CK meteorites appear similar in K isotopes to CIs, while CV and CRs are lighter (and close to the BSE value). Nevertheless, each of these chondrite groups show significant scatter. This scatter may be due to heterogeneous K isotope compositions, terrestrial weathering/contamination, laboratory analysis variations, or a combination of these effects. By assessing only falls it could be possible to better assess the causes of variability. However, some chondrite groups include very few falls, if any, analyzed for K isotopes. With more robust K isotope analyses of chondrites we can continue to refine δ^{41}K values of the other CC groups. From this, we will be able to conclusively determine which K isotope variations could be taken as representative for the solar system, and whether the observed variations are of nucleosynthetic origin [6], or due to volatility fractionation processes and/or chondrule to matrix ratios [5,10].

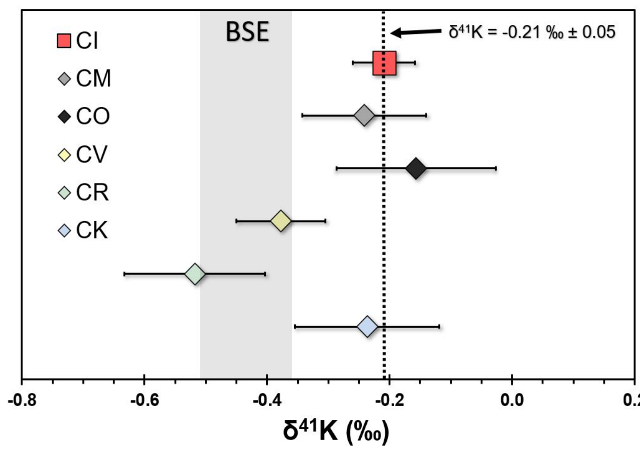

Figure 3. *Comparison of the K isotopic compositions of all CC groups. CI: n = 15, CM: n = 19, CO: n = 14, CV: n = 18, CR: n = 4, CK: n = 8. Errors shown are 95% C.I. Comparison data for other CCs taken from [5,6,10].*

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References: [1] Anders E. and Grevesse N. (1989) GCA, 53, 197-214. [2] Lodders K. (2003) APJ, 591, 1220-1247. [3] Lodders K. (2020) Ox. Res. Enc. Pla. Sci. arXiv:1912.00844. [4] Wang K. and Jacobsen S. B. (2016) *Nature,* 538, 487-490. [5] Nie N.X. et al. (2021) Sci. Adv. 7, eabl3929. [6] Ku Y. and Jacobsen S. B. (2020) Sci. Adv. 6. [7] Morlock A. et al. (2006) GCA, 70, 5371-5394. [8] Tuller-Ross B. et al. (2019) GCA, 259, 144-154. [9] Barrat J.A. et al. (2012) GCA, 83, 79-92. [10] Bloom H. et al. (2020) GCA, 277, 111-131. [11] Koefoed P. et al. (2020) MAPS, 55, 1833-1847.