GENETIC HERITAGE AND CHRONOLOGY OF UNGROUPED IRON METEORITES. F. Spitzer[1], C. Burkhardt[1], G. Budde[1], T. S. Kruijer[2], and T. Kleine[1], [1]University of Münster, Institut für Planetologie, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (fridolin.spitzer@uni-muenster.de). [2]Lawrence Livermore National Laboratory, CA 94550, USA.

Introduction: Nucleosynthetic isotope anomalies at the bulk meteorite scale reflect the heterogeneous distribution of isotopically diverse presolar materials in the early solar nebula, and have been identified for a variety of elements. Of these, the isotope anomalies in Mo are particularly important because they have revealed a fundamental dichotomy in the genetic heritage of meteorites, distinguishing between *non-carbonaceous* (NC) and *carbonaceous* (CC) materials [1]. In conjunction with age constraints, this dichotomy has led to major advances in our understanding of early solar system dynamics [*e.g.*, 2].

Prior studies mainly relied on samples from the major meteorite groups, representing a total of ~15 undifferentiated and ~20 differentiated parent bodies. This number is small, however, when compared to the 283 meteorites currently listed as ungrouped (72 chondrites, 125 iron meteorites, 86 achondrites), which—taking potential pairings into account—represent at least an additional ~150 parent bodies. This means that so far only less than one quarter of the planetary bodies sampled by meteorites have been investigated for their nucleosynthetic heritage. Given the considerable potential of this untapped sample reservoir for better constraining early solar system dynamics, we initiated a systematic study on ungrouped meteorites, with the ultimate goal to constrain their genetic heritage and chronology. Here we present the first Mo isotope data, as well as Hf-W model ages for a set of ungrouped iron meteorites.

Samples and methods: Samples were selected to cover a wide range of different chemical compositions (*e.g.*, Ir vs. Ni). In addition, samples for which O isotopic data exist were chosen preferentially. The digestion and chromatography methods for Mo and W are adapted from [3]. In addition to Mo and W, Pt isotope compositions were determined on digestion aliquots of each sample, following the methods described in [4]. Isotopic compositions of Mo, W, and Pt were determined using a Thermo-Fischer Neptune *Plus* MC-ICP-MC at the University of Münster. Isotopic compositions are reported in the ε-notation (parts-per-10,000 deviations from terrestrial standard values) after mass bias correction by internal normalization using the exponential law.

Platinum isotopes are used as neutron dosimeters to correct measured W and Mo isotopic compositions for cosmic ray exposure effects. For W, the approach of [4] was used, utilizing the average slope obtained from empirical ε^{182}W vs. ε^{196}Pt correlations defined by the major iron meteorite groups. For Mo, we used the same approach, and determined empirical correlations of ε^{i}Mo vs. ε^{196}Pt for a set of IIAB and IID irons with variable exposure effects. These slopes were then used to correct the measured Mo isotopic composition of the ungrouped irons individually.

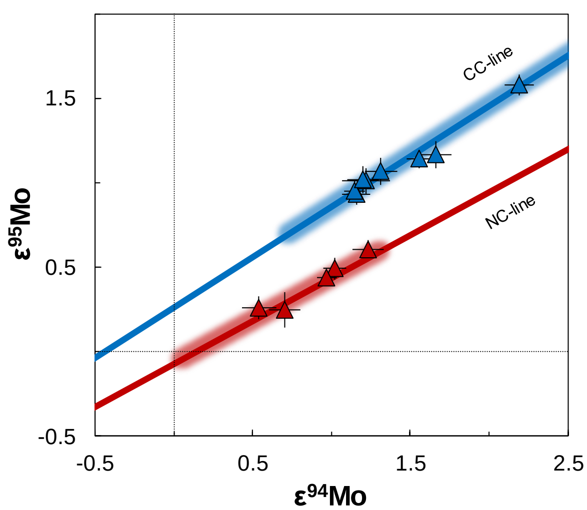

Fig. 1. Diagram of ε^{95}Mo vs. ε^{94}Mo for ungrouped irons from this study, modified after [5]. Shaded area indicates the range of bulk meteorite literature data.

Hf-W chronology: The pre-exposure ε^{182}W values of the analyzed ungrouped irons are similar to those reported previously for the major groups of iron meteorites, indicating that on all these bodies metal-silicate separation and core formation occurred at about the same time, between ~1 and 3 Ma after formation of Ca,Al-rich inclusions (CAIs). Previous studies have shown that CC irons tend to have slightly higher ε^{182}W values than NC irons [2,4]. However, because the pre-exposure ε^{182}W values for the ungrouped irons are based on the analyses of single samples, they are less precise than the pre-exposure ε^{182}W values of the major iron groups, which are based on the intercept values of ε^{182}W vs. ε^{196}Pt correlations defined by multiple samples from a given chemical group of irons. As such, currently available data to do not allow resolving the ~0.1 ε^{182}W difference observed between the major groups of CC and NC irons.

Implications for the NC-CC isotope dichotomy: All analyzed ungrouped irons exhibit well-resolved nucleosynthetic Mo isotope anomalies, which fall within the known range of anomalies from previously analyzed bulk meteorites. In a diagram of ε^{95}Mo vs. ε^{94}Mo, the ungrouped irons plot on one of the two distinct *s*-process mixing lines defined by the NC and CC reservoirs (Fig. 1). Furthermore, for a few of the analyzed ungrouped irons O isotopic data are also available. These data show that in general ungrouped irons with a CC-like Mo isotopic composition display negative Δ^{17}O values, whereas NC-like ungrouped irons have positive Δ^{17}O.

Collectively, the new data confirm the fundamental dichotomy between CC and NC materials for an additional 11 different parent bodies (Fig. 1). The ungrouped irons thus support the notion of an efficient separation of two genetically distinct source regions of planetesimals in the early solar nebula [6]. The most plausible mechanism for such an efficient separation over several millions of years is the early formation of Jupiter, which acted as a barrier against exchange of material between the NC (inside Jupiter's orbit) and CC reservoirs (outside Jupiter's orbit) [2,6].

Distinction formation conditions in the NC and CC reservoirs? The ungrouped irons derive from a chemically diverse suite of parent bodies, which likely formed under different nebula conditions. The genetic heritage of these bodies (as constrained by the Mo isotopic data) can therefore be used to evaluate as to whether the formation conditions of NC and CC bodies were systematically different. Such as difference might be expected, as these bodies are thought to derive from the inner and outer solar system, respectively. For instance, on the basis of available data for the major groups of irons, a prior study suggested that NC and CC irons are characterized by systematic differences in chemical properties, such as their median Ni content [7]. This difference could reflect the higher oxidation state of CC parent bodies [7], which would be consistent with the presumed formation location of these bodies beyond the ice line. However, the ungrouped irons do not reveal systematically different Ni contents between NC and CC bodies (Fig. 2). For instance, Butler has a high Ni content of 16 wt.%, but is belongs to the NC suite of meteorites. Likewise, Tucson, which is a CC meteorite, is characterized by high Si and Cr content in the metal and the presence of highly reduced silicate inclusions, indicative of very reducing formation conditions [8], similar to those otherwise only observed for enstatite chondrites [9].

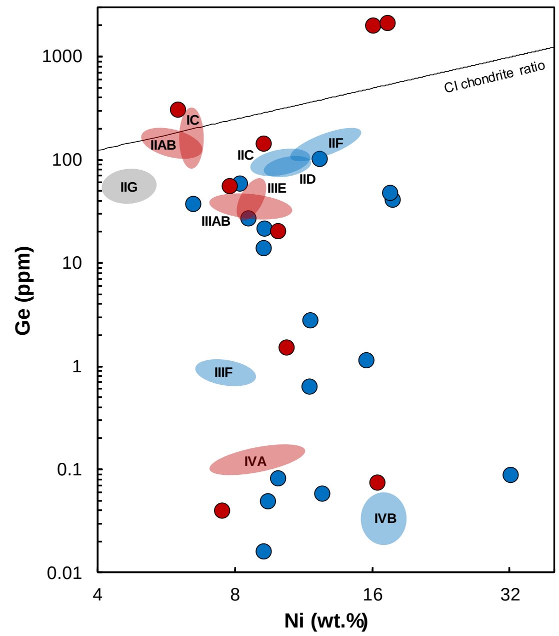

Fig. 2. Ge vs. Ni for iron meteorites. Compositional fields of the major magmatic iron groups from [10]. Ungrouped irons from this study are shown as red (NC) and blue symbols (CC). Of the 25 ungrouped irons analyzed for Mo isotopes, only 13 are shown in Fig. 1. For the other samples no Pt isotope data are yet available, which are necessary for the correction of cosmic ray effects.

Conclusions: Extending the Mo isotopic analyses to the large pool of ungrouped meteorites confirms the fundamental dichotomy between NC and CC meteorites, and highlights that formation of planetesimals in both reservoirs occurred under variable conditions. The lack of systematic chemical differences between NC and CC irons suggests that the chemical diversity among iron meteorite parent bodies does not only reflect their formation location, but also later, post-accretionary processes. Such processes may have included impact disruption and mantle stripping, and associated metal-silicate re-equilibration and degassing[11,12].

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