**180W ANOMALIES IN IRON METEORITES: IMPLICATIONS FOR P-PROCESS HETEROGENEITY.**

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**Introduction:** The investigation of W isotope anomalies in meteorites is of interest because of the former presence of the short-lived isotope $^{182}$Hf, which decays to $^{182}$W. $^{182}$Hf-$^{182}$W systematics can be used to infer timescales of core formation on differentiated bodies, of parent body accretion, and of parent body processes such as the duration of magmatism and metamorphism [*e.g.*, 1,2,3]. However, the application of the $^{182}$Hf-$^{182}$W chronometer relies on the assumption that W isotopes were homogeneously distributed in the solar nebula. This assumption appears to be valid for most meteoritic samples, although small deficits in *s*-process W isotopes have been observed in group IVB irons [2,4], CAIs [5], and acid leachates of primitive chondrites [6]. More recently, excesses in $^{180}$W have been measured in several magmatic iron groups [7]. These data seem to imply heterogeneity of W isotopes in the early nebula and were used to argue for large-scale *p*-process heterogeneities in the inner nebula, but these results have been questioned [8]. We report isotopic measurements for several magmatic irons to examine the extent of nucleosynthetic W isotope anomalies in the early solar system and to assess the origin of $^{180}$W anomalies in iron meteorites.

**Samples and Methods:** We analyzed magmatic iron meteorites from the following groups: IIAB, IID, IVA, and IVB. In addition, we analyzed the ungrouped iron Chinga and metal separated from the CB chondrite Gujba. Sample sizes ranged from 0.5 to 1.0 g. For an external standard, we chose an NIST Fe-Ni steel (SRM 129c). Multiple aliquots of SRM 129c were measured during each analytical session and were used to verify the accuracy of the measurements and to define the long-term external reproducibility. As an additional check on the analytical techniques, we processed two aliquots of the NIST W solution standard (SRM 3163) using our chemical separation protocol. Tungsten was separated from the matrix using a two-step anion exchange procedure.

Isotopic measurements were made with the ThermoScientific Neptune *Plus* MC-ICPMS (University of Münster) in low resolution mode. Samples were introduced using an Aridus II desolvating system. A single measurement was made for each sample (20 cycles of 8.4s) bracketed by SRM 3163. Signal intensities for both $^{180}$W and $^{178}$Hf were measured using $10^{12}$ Ohm resistors. The interference correction for $^{180}$Hf on $^{180}$W was tested by analyzing several aliquots of SRM 3163 doped with various amounts of Hf.

**Results:** The repeated analyses of SRM 129c (n = 24) yield a mean $\varepsilon^{180}$W = 0.2 ± 1.2 (2 S.D.). The two aliquots of SRM 3163 processed through the anion exchange chemistry have $\varepsilon^{180}$W values within uncertainty of zero and show that the method is free from analytical artifacts. Moreover, we see no evidence in the measurements of SRM 129c or 3163 for apparent excesses in $\varepsilon^{180}$W due to interferences from organic molecules as suggested by [8] to explain observed anomalies in $^{180}$W and $^{184}$W. Additionally, the aliquots of SRM 3163 doped with Hf show that the interference correction for $^{180}$Hf on $^{180}$W is accurate for the range of Hf/W ratios ($\approx 8 \times 10^{-6}$) measured in the samples.

The results for the measurements of iron meteorites and the metal separate from the CB chondrite Gujba are shown in Fig. 1. The ungrouped iron Chinga shows

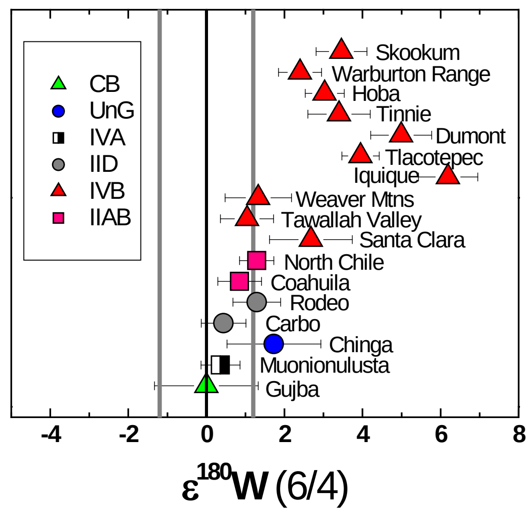


**Fig 1**. Measurements of $^{180}$W in meteoritic metal expressed relative to the bracketing standard (SRM 3163) in parts per 10,000. (6/4) indicates that the mass bias has been corrected using $^{186}$W/$^{184}$W = 0.927672 [9]. Gray vertical lines represent the external precision of ± 1.2ε based on the analyses of SRM 129c (2 S.D.).

a small positive excess in $\varepsilon^{180}$W. Many of the IVB irons also show resolvable excesses, although two do not. No other samples show clearly resolvable anomalies in $^{180}$W. In addition, the IVB irons show small excesses in $\varepsilon^{183}$W, consistent with results from previous studies [2,4].

**Discussion:** Selected data from the current study are compared to those of [7] in Fig. 2. In constrast to the results of [7], we do not observe large $^{180}$W excesses in

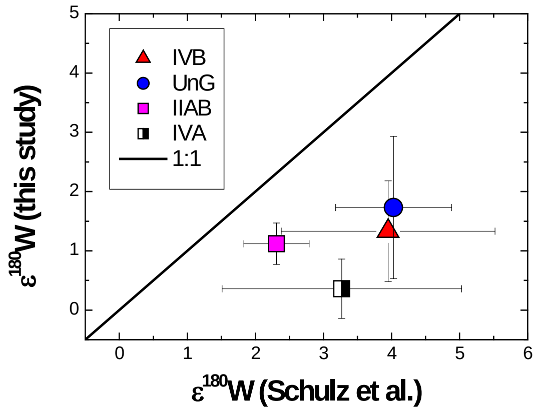


**Fig 2**. Values of $\varepsilon^{180}$W for selected samples compared to the results given in [**7**]; all data were corrected using $^{186}$W/$^{184}$W. Samples: IVB (Weaver Mtns), UnG (Chinga), IVA (La Grange [**7**]; Muonionulusta [this study]. The datum for IIAB irons represents the weighted means of multiple samples. The black line has a slope of 1.

the ungrouped iron Chinga, in a group IVA iron, or in IIAB irons. The lack of clear excesses in $\varepsilon^{180}$W (Fig. 1) for many samples, as well as the large variation among the IVB irons, are not consistent with the large scale *p*-process heterogeneity observed by [7]

*Neutron capture effects.* Capture of secondary neutrons produced during cosmic ray exposure of the iron meteroids can lead to changes in isotope abundances in meteorites. For W isotopes, this effect has been recognized as burnout of $^{182}$W [*e.g.*, 10]. Such effects are predicted to also cause burnout of $^{180}$W with a magnitude that is ≈ 1.5 times the effect on $^{182}$W [I. Leya; pers. commun.]. We can compare the measured $\varepsilon^{182}$W to the pre-exposure values determined for IIAB, IID, IVA, and IVB irons [4,11] to calculate the expected effect on $^{180}$W for each sample in these groups. For most of the samples, the effect is relatively minor (≤ 0.5ε) and cannot explain the $\varepsilon^{180}$W variation observed in the IVB irons, which ranges from 1.0 to 6.2ε. However, the effect on Carbo (IID) is 1.5ε and explains why the measured value is lower than in Rodeo (IID), which shows no evidence for irradiation effects.

*s-deficit effects.* Group IVB and IID irons and the ungrouped iron Chinga show evidence for small deficits in *s*-process W isotopes [2,4,12]. Such deficits can cause apparent excesses in the *p*-process isotope $^{180}$W via the mass bias correction. Figure 3 shows the results for irons characterized by an *s*-deficit and illustrates that an s-deficit leads to apparent excesses in $\varepsilon^{180}$W

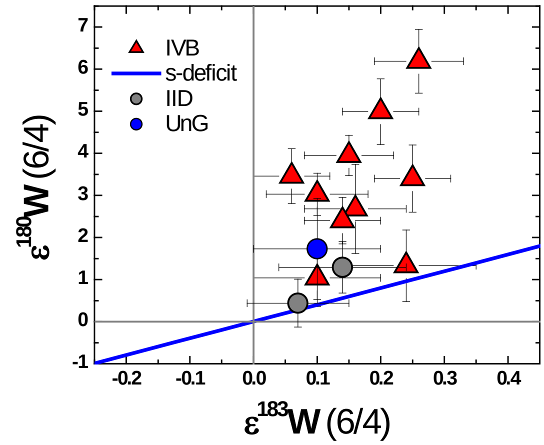


**Fig 3**. $\varepsilon^{180}$W vs. $\varepsilon^{183}$W for IID and IVB irons and the ungrouped iron Chinga. The blue line shows the expected effects on W isotopes due to an *s*-deficit and is based the model of [**13**].

and $\varepsilon^{183}$W that are positively correlated. The majority of the $\varepsilon^{180}$W excesses in the IID irons, Chinga, and two of the IVB irons can be explained by an *s*-deficit; thus, these samples do not provide evidence for an excess in *p*-process isotopes. However, the total variation in the IVB irons cannot be accounted for due to this effect.

**Conclusions:** Only the IVB irons show large, clearly resolvable excesses in $^{180}$W after the effects of both neutron capture and an *s*-deficit have been taken into account. The lack of large excesses in other groups contrasts with the results of [7], and we do not find evidence for widespread heterogeneity in the *p*-process isotope $^{180}$W. Furthermore, the large variation of $\varepsilon^{180}$W values in IVB irons is not consistent with a nucleosynthetic origin since the IVB core was well-mixed during fractional crystallization. Therefore, the origin for the excesses is most likely related to an as yet unknown process on the IVB parent body.

**References:** [1] Markowski et al. (2007) *EPSL* **262**, 214-229. [2] Qin et al. (2008) *ApJ* **674**, 1234-1241. [3] Kleine et al. (2009) *GCA* **73**, 5150-5188. [4] Kruijer et al. *EPSL* **in press**. [5] Burkhardt et al. (2008) *GCA* **72**, 6177-6197. [6] Burkhardt et al. (2012) *ApJ* **753**, L19. [7] Schulz T. et al. (2012) *EPSL* **in press**. [8] Holst et al. (2011) *Workshop on Formation of the First Solids in the Solar System* **#9065**. [9] Völkening et al. (1991) *Inter. Jour. Mass Spec. Ion Proc.* **107**, 361-368. [10] Masarik J. (1997) *EPSL* **152**, 181-185. [11] Kruijer et al. (2013) *LPSC* **this volume**. [12] Kruijer et al. (2012) *GCA* **99**, 287-304. [13] Arlandini et al. (2008) *ApJ* **525**, 886-900.