REVISITING THE ^{53}Mn-^{53}Cr ISOTOPIC SYSTEMATICS IN PHOSPHATES MINERALS IN IIIAB IRON METEORITES: IMPLICATIONS FOR THE FINE STRUCTURE CONSTANT VARIATION.

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Introduction: The fine structure constant, usually denoted as $\alpha=e^2/\hbar c$ ~1/137, where e is the elementary charge, $\hbar=h/2\pi$ is the reduced Planck's constant, and c is the speed of light in a vacuum, is the fundamental physical constant characterizing the strength of the electromagnetic interaction. Richard Feynman referred to this dimensionless number as "one of the greatest damn mysteries of physics: a magic number that comes to use with no understanding by man." Ever since Paul Dirac proposed the Large Number Hypothesis [1], numerous theoretical and experimental researches have been conducted on whether the fine structure constant is really a constant, i.e. whether it always had the same value over the history of the universe. After all, extrapolation of local physical laws throughout the spacetime is an unproven assumption. Some theories (e.g. superstring theory or Kaluza-Klein theories) explicitly predict that this not to be the case [2], which continuously motivate the investigations. Recent observation of quasar absorption systems [3,4] at cosmological redshifts z = 0.5-3.5 have stimulated further investigations in the idea that the fundamental constants of nature can vary through time. However, there exists various sensitive experimental checks that constrain the variations of fundamental constants [2,5]. One such example is using the long-lived ^{187}Re radionuclide in conjunction with precise meteorite ^{187}Re-^{187}Os data to constrain the radioactive decay rates back to the time of solar system formation 4.56 Gyr ago. This corresponds to redshift z = 0.45, which is bordering the range z = 0.5-3.5 over which such variations are claimed to be observed. The idea was formulated over four decades ago by [6,7] who pointed out that the radioisotope with the lowest β-decay end-point energy (Q_β for ^{187}Re is 2470±5 eV [8]) is most sensitive to changes in α, and have derived the theoretical relation [7], considering only the variation of the Coulomb term in Q_β:

$$\frac{\Delta\lambda}{\lambda} \approx -1.9\times10^4 \frac{\Delta\alpha}{\alpha} \qquad \text{Eq. 1}$$

where the large "amplification factor" on the right hand side comes from an exceptionally small Q_β value. Thus, given the uncertainty of λ as allowable variation in decay rate, one can place limits on the possible variation of α.

Recently, ^{187}Re constraints on time variations of the fundamental couplings was revisited [5,9,10] based on new Re-Os data in iron meteorites [11,12]. The decay constant of ^{187}Re (λ_{187Re} = 1.666×10^{-11}/y) with 0.5% uncertainty [11] is derived from an iron meteorite isochron. A suite of iron meteorites with present measured (^{187}Os/^{188}Os)$_m$ and (^{187}Re/^{188}Os)$_m$ define a linear correlation, whose slope is [exp(λ_{187Re}*t)-1], and intercept is the initial (^{187}Os/^{188}Os)$_i$ present at the beginning of the solar system, when the iron meteorites formed. In order to determine λ_{187Re}, one needs an independent estimate on t, the precise age of the iron meteorites. Unfortunately, all other suitable radioactive clocks that have suitable half-lifes (U-Pb, Sm-Nd, Lu-Hf, Rb-Sr, and K-Ar systems) for this purpose are made of large ion lithophile (rock-loving) elements or rare gas (Ar). Therefore these elements are not found in measurable quantities in iron meteorites. In order to obtain the precise age for iron meteorites, the following arguments are made [11]: a unique class of the solar system basalts known as angrites have precisely determined Pb-Pb ages of 4557.8 ± 0.5 Ma [13], which also contains live ^{53}Mn (3.7 Ma) with ^{53}Mn/^{55}Mn = (1.25±0.07)×10^{-6} [14]. The preliminary data for the initial ^{53}Mn/^{55}Mn = 1×10^{-6} determined in trace inclusions of the phosphate minerals found in one of the IIIB iron meteorites (Grant) by [15] was compared to be equal to that of angrite [14]. Since the angrite U-Pb age is precisely known [13], the absolute age for IIIAB is therefore known by inference. Through this method, the Re-Os isochron determined for group IIIA iron meteorites got an age anchor. Thus the decay constant calculated for ^{187}Re (1.666×10^{-11}/y) by [11] depended on a preliminary data reported in abstract [15] over one and half decades ago. This weak link was lost in the discussion [9,10], however. Unfortunately these data were never re-examined. Especially, considering that [16,18] showed IIIAB Iron meteorites comprise many different phosphate phases that have different closure ages. Given the pivotal role of the Grant iron meteorite in isotope geochemistry and cosmochemistry for constraining the ^{187}Re decay scheme, it is important to have a better-constrained initial ^{53}Mn/^{55}Mn ratio in the IIIAB iron meteorites. We note that recent work [16] produced a factor of three higher ^{53}Mn/^{55}Mn value for Grant than that of [15], casting doubt on the very foundation of the age comparison of angrite "equals" IIIAB iron meteorites. We have therefore studied the ^{53}Mn-^{53}Cr systematics in the phosphate inclusions of IIIAB group iron meteorites with secondary ion mass spectrometry (SIMS). Revisiting the ^{53}Mn issues in IIIAB iron meteorites, we re-evaluate the bound on the limit of fine structure constant variations provided by comparing with the direct determination of ^{187}Re decay constant [8, 17].

Experimental: A polished section of the Grant (IIIAB) sample was obtained from the collections of the Smithsonian Institution (Ed Olsen's research collection). The mineralogical and petrographic characterization of the sample was performed at UC Davis, using a Cameca SX-100 electron microprobe. Sarcopsides suitable for the Mn-Cr isotopic investigation by SIMS were identified. Chromite sample having low Mn/Cr ratio and high Cr content were also measured to precisely determine the y-intercept of the isochron. The isotopic analyses by ion probe were performed at LLNL SIMS facility using a modified Cameca 3f on the selected sarcopside grains.

Results: The δ^{53}Cr vs. ^{55}Mn/^{52}Cr diagrams for the Grant IIIAB iron meteorite sample is shown in Fig. 1. Errors given are 2σ. The δ^{53}Cr isotopic anomalies are well correlated with the Mn/Cr ratios, suggesting they are due to in situ decay of ^{53}Mn. The inferred ^{53}Mn/^{55}Mn initial ratio is $(3.10\pm0.17)\times10^{-6}$ (2σ). The initial δ^{53}Cr = -1.62±0.41.

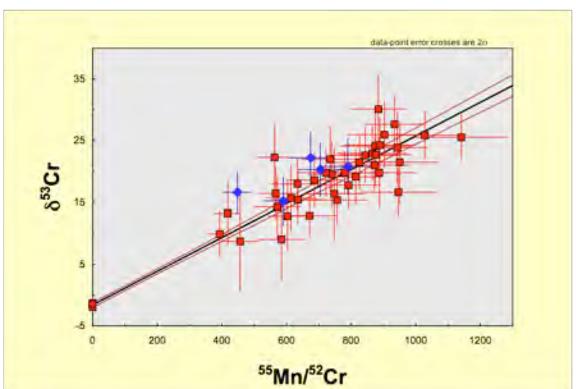

Fig. 1. The "fossil" isochron diagram of δ^{53}Cr vs. ^{55}Mn/^{52}Cr the phosphate mineral (sarcopside) from the iron meteorite Grant (group IIIAB). The chromites situated as small inclusions within the phosphate matrix were also measured. The Mn/Cr ratios for chromites are virtually zero. The filled red squares, is data from this study. The filled blue diamonds is from [16]. Error bars are 2σ. The slope gives ^{53}Mn/^{55}Mn = $(3.10\pm0.17)\times10^{-6}$, indicating the amount of live radioactive ^{53}Mn (half-life 3.7Ma) relative to stable ^{55}Mn when the mineral sarcopside crystallized and cooled.

Our results are essentially consistent with [16] who obtained ^{53}Mn/^{55}Mn = $(3.39\pm0.76)\times10^{-6}$ (2σ) for Grant sarcopside and similar ratios for other IIIAB sarcopsides (see Table 6 of [16]). The inferred ^{53}Mn/^{55}Mn ratios and the corresponding Mn-Cr ages for different phosphate minerals are substantially lower and not as reproducible as what was observed in sarcopside, due to a combined effect of slow cooling rates of IIIAB iron meteorites and the difference in the diffusion properties of Cr and Mn in the phosphates [16,18]. This could also explain the lower initial ^{53}Mn/^{55}Mn ratio of 1×10^{-6} reported in [15].

Conclusions: We have studied the ^{53}Mn-^{53}Cr systematics in phosphate mineral inclusions in Grant, a IIIB iron meteorite and obtained a precise ^{53}Mn/^{55}Mn ratio of $(3.10\pm0.17)\times10^{-6}$ for this meteorite. This is a factor of three higher than the ^{53}Mn/^{55}Mn ratio of $(1.25\pm0.07)\times10^{-6}$ in angrites LEW86010 and Angra dos Reis. Thus IIIA group of iron meteorites may not have the same absolute age as angrites, an underling assumption used to derive the ^{187}Re decay constant through the meteorite Re-Os isochron. The bound on the limit of the fine structure constant through the ^{187}Re decay constant is best provided by the directly determined uncertainty of 3% [8,17] rather than 0.5%, which leads to a $\Delta\alpha/\alpha = 1.5\times10^{-6}$. Normalized over entire solar system history of 4,567Ma, α dot/$\alpha = 3.3\times10^{-16}$ /y.

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