Potassium Isotope Differences among Chondrites, Earth, Moon, Mars, and 4-Vesta - Implication on the Planet Accretion Mechanisms. Z. Tian[1], H. Chen[1], B. Fegley, Jr.[1], K. Lodders[1], J.-A. Barrat[2], and K. Wang (王昆)[1], [1]Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University in St. Louis, One Brookings Drive, St. Louis, MO 63130, USA (t.zhen@wustl.edu), [2]Université de Bretagne Occidentale, Institut Universitaire Européen de la Mer, CNRS UMR 6538, Plouzané, France.

Introduction: The sources and distributions of volatile elements in our solar system are one of the key questions in cosmochemistry. Potassium (K) is one of the moderately volatile elements (50% condensation temperature ~1006K [1]). It was initially reported that there is no isotopic fractionation among any planetary body [2-3]. In the last two years, the analytical ability of potassium isotopes has been improved by at least an order of magnitude (*i.e.*, two standard errors of ten repeat measurements of $^{41}K/^{39}K$ ~0.05 vs. 0.5 per mil), making it possible to distinguish the marginal isotopic difference among different igneous systems [4-7]. Here we apply this new method to samples that from the Earth, Moon, Mars and 4-Vesta. The K isotopes compositions of Mars and 4-Vesta are the first time to be reported. These data, combined with the previous data on the Earth, Moon, and chondrites [4-5], will contribute to depict a complete picture of the volatile depletions during planetary formation and to reveal the accretion histories of these inner solar system bodies.

Samples and Methods: In this study, twenty-five HED (Howardite–Eucrite–Diogenite) meteorites from 4-Vesta, four martian meteorites, one lunar meteorite, as well as one ordinary chondrite sample are analyzed. In addition to these extraterrestrial samples, we also measured five terrestrial igneous rocks from the collection of USGS geo-standards (BHVO-2, BCR-1, BIR-1, AGV-1, and G-2) to compare with the literature data from other laboratories.

Depending on the concentrations of K in different meteorites, about 100-500 mg are digested and prepared for the following column chemistry. The column separation procedure is designed to separate K from the matrix elements to avoid any potential matrix effect. In this study, we used "cold plasma" method with a Thermo Scientific Neptune Plus MC-ICP-MS to achieve the high precision K isotopic composition measurements. The detail of this "cold plasma" method is described in Ref. [8]. The measurements are done on the shoulder of the peak of $^{41}K^+$, which is not affected by the $^{40}Ar^1H^+$ interference. Sample-standard bracketing technique is applied here, and the final data are expressed as delta values ($\delta^{41}K$). The standard we used here is NIST SRM 3141a.

Results: All terrestrial igneous samples measured in this study yield the same $\delta^{41}K$ value within error bars. The average value is −0.459 ± 0.011‰ (2 se), which agrees very well with the Bulk Silicate Earth value −0.479 ± 0.027‰ [4]. As shown in *Fig.1*, both the ordinary chondrite and the lunar basaltic meteorite are comparable to the previous study [5].

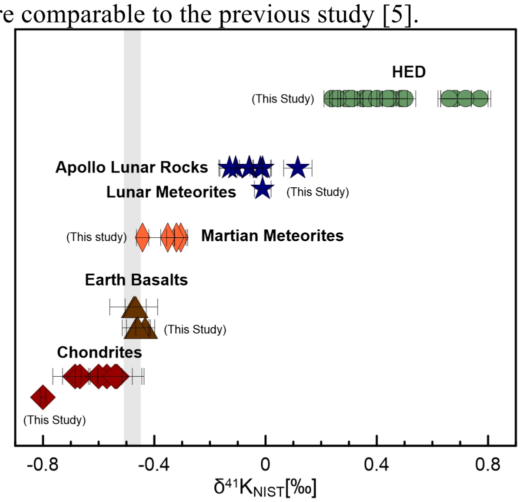

Fig. 1 The K isotopic compositions of chondrites, terrestrial basalts, martian meteorites, Apollo lunar rocks and lunar meteorites, and HEDs. Literature values for chondrites, Earth basalts, and Apollo lunar rocks are from [4-5]. The shaded area is the Bulk Silicate Earth $\delta^{41}K$ value (−0.48±0.03‰) [4].

The $\delta^{41}K$ values of martian meteorites and HEDs are first reported in this study. Martian meteorites resemble the Bulk Silicate Earth (BSE) $\delta^{41}K$ value [4]; whereas all the HED samples are extremely enriched in heavy K isotope comparing to other planetary bodies (*Fig. 1*). As shown in the histogram (*Fig. 2*), the majority of the HED samples define a rather narrow range of K isotopic composition. The Juvinas duplicates and the two residual eucrites are offset towards heavier K isotopic composition; whereas the NWA (Northwest Africa) samples shift towards lighter $\delta^{41}K$ direction. Pasamonte is the anomalous eucrite based on the oxygen isotope evidence [9]. These samples are excluded from the average $\delta^{41}K$ value calculation, and the average $\delta^{41}K$ value of fourteen HED meteorites is +0.36 ± 0.16‰ (2 sd).

All NWA meteorites except of one show lighter $\delta^{41}K$ than the average value of HED meteorites (*Fig. 3*). Leaching experiment in room temperature (0.5 hour using 1N HCl) is applied to five NWA samples. The

$\delta^{41}K$ values of residues after leaching consistently shift towards heavier K isotopic composition and are approaching to the average value of non-desert HED meteorites. In contrast, the leaching supernatants are relatively enriched in light K isotope, which are similar, yet lighter, to terrestrial samples. Only NWA 4523 shows "normal" bulk $\delta^{41}K$ value (+0.29 ± 0.06‰) and the leaching supernatant of NWA 4523 only has a trace amount of K. This leaching experiments demonstrated that most NWA meteorites are contaminated by terrestrial K.

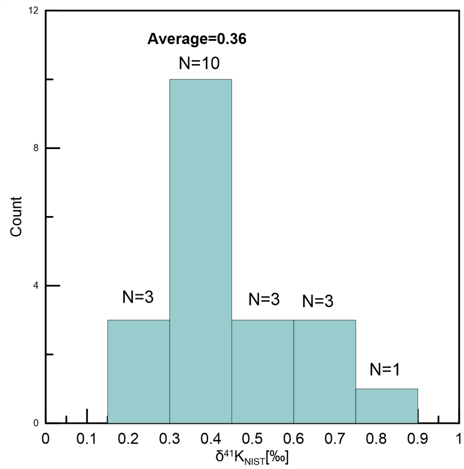

Fig.2 Histogram of $\delta^{41}K$ distribution of twenty non-hot dessert HED meteorites.

Discussion: In this study, we found that HED samples are extremely enriched in heavy K isotopes compared with samples from other planetary bodies (*Fig. 1*). Previous K isotope studies of terrestrial igneous rocks showed no variation of K isotopes and indicated limited isotopic fractionation during high-temperature magmatic processes [4]. In addition, two major chemical groups (main-group trend and Stannern trend) of eucrites that formed through different igneous processes [10] do not show any K isotopic difference. Moreover, no clear correlation is shown between [K] and the corresponding $\delta^{41}K$. All the evidences further prove that K isotopic composition could remain the same during magmatic differentiations. Therefore, we proposed that the average $\delta^{41}K$ (+0.36 ± 0.16‰, 2sd) obtained from HED meteorites clan can be the representative of the Bulk Silicate 4 Vesta.

The most important question is why Vesta exhibited such heavy K isotopic composition. Vesta is also the most K (and other moderately volatile elements) depleted body among the Earth, Moon, Mars and Vesta, and its K/U ratio is more than one order of magnitude lower than that of CI chondrites [11]. Two plausible explanations for this coupled volatile depletion and heavy K isotope enrichment in Vesta should be taken into account. 1) Vesta has accreted with materials that have already depleted in volatiles and fractionated in K isotopes [12]. 2) magma ocean degassing on a small body. If magma ocean is the sole cause for the heavy K isotopic feature, the ubiquitous high $\delta^{41}K$ and the depletion of K and other alkali elements should be expected on other small planetary bodies (*i.e.* aubrite parent body) that are capable to develop magma oceans. However, aubrites exhibit albitic feldspars instead of the high An content plagioclase found in lunar and HED samples. Continuous study will focus on the modeling, and will be reported during the conference.

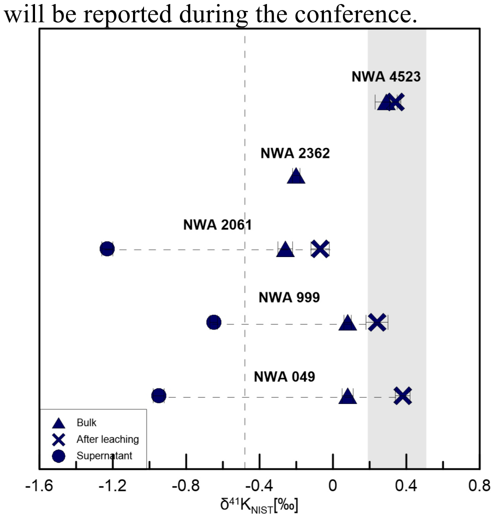

Fig. 3 Terrestrial contaminations of NWA hot desert meteorites. The shaded area is the average of HED meteorites (0.36±0.16‰, 2sd), the dash line stands for the Bulk Silicate Earth $\delta^{41}K$ value (−0.48‰) [4].

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