AN ION MICROPROBE STUDY OF FUN-LIKE HIBONITE-BEARING INCLUSIONS FROM THE MURCHISON (CM2) METEORITE. K. Fukuda[1], H. Hiyagon[1], S. Sasaki[1], W. Fujiya[1,2], N. Takahata[3], Y. Sano[3] and Y. Morishita[4], [1]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, Tokyo 113-0033, Japan (k.fukuda@eps.s.u-tokyo.ac.jp), [2]Max Planck Institute for Chemistry, Particle Chemistry Department, 55128 Mainz, Germany, [3]Atmosphere and Ocean Institute, The University of Tokyo, Chiba 277-8564, Japan, [4]National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8567, Japan.

Introduction: There is a minor group of refractory inclusions, so called FUN (*F*ractionation and *U*nkown *N*uclear effects) inclusions, which exibit distinct isotopic characteristics: (i) large mass-dependent fractionation in O, Mg and Si preferring heavy isotopes (F-signature), (ii) presence of unknown nuclear effects, esp., positive or negative anomalies in ^{48}Ca and ^{50}Ti (UN-signature), and (iii) little or no excess ^{26}Mg (and excess ^{41}K) from the decay of ^{26}Al (^{41}Ca) [1]. Absence of excess ^{26}Mg suggests either their late formation *after* the complete decay of ^{26}Al, or their early formation *before* injection of ^{26}Al into the solar system from (a) stellar sorce(s). The presence of Ca and Ti isotopic anomalies may suggest their earlier formation. The origin of FUN inclusions is still not well understood, but they may have important information about evolution and isotopic homogenization process(es) in the early solar system.

We found two FUN-like hibonite-bearing inclusions from the Murchison (CM2) meteorite, which exibit extremely large mass-dependent fractionation in Mg isotopes (up to ~50 ‰/amu) but almost no excess in ^{26}Mg. Assuming a Rayleigh distillation process, more than 95% of Mg must have been lost (evaporated) from the molten precursors of these inclusions [2]. In order to better understand their isotopic characteristics, we further conducted ion microprobe analyses of Mg, Ca and Ti isotopes on these inclusions.

Samples: Two inclusions, MC037 (~150μm x ~200μm) and MC040 (~200μm x ~200μm), consist of abundant hibonite grains (5-30μm) with some spinel grains (5-10μm for MC037 and 10-30μm for MC040) embedded in Fe-rich silicates. Numerous μm-sized perovskite grains are almost uniformly distributed in Fe-rich silicate portion of MC040. They are probably the exsolution product from rapidly cooling melt. MC037 also contains perovskite in the Fe-rich silicate portion. Five μm-sized ultra-refractory metal grains (enriched in Pt, Ru, Ir, etc.) are found in both inclusions. They also may be produced by severe evaporation of more volatile Fe-Ni-rich metal grains [3].

Analytical conditions: *Mg isotopes:* Magnesium isotopes were measured using a NanoSIMS at AORI, The University of Tokyo. A primary beam of $^{16}O^-$ with a diameter of 1-3μm and an intensity of 50-200pA was used for the analyses. Positive ions of Mg isotopes, $^{24}Mg^+$, $^{25}Mg^+$ and $^{26}Mg^+$, were detected using an electron multiplier (EM) (Tr4) by a peak jumping mode, and $^{27}Al^{++}$ was detected simultaneously with $^{24}Mg^+$ using another EM (Tr2). MRP was set to ~4000 to separate interfering ions. Primary beam was rastered by 4μm x 4μm during the analysis to stabilize the secondary ion intensities. Dead time (44ns) and instrumental mass fractionation, estimated using Madagascar hibonite standard, were corrected. In order to precisely estimate excess ^{26}Mg, a correction for mass-dependent fractionation, presumably caused by an evaporation process, is essential and we adopted the formula recommended by Davis et al. [4], that is,

$$\varphi(^{25}Mg) = 1000 \ln\{(^{25}Mg/^{24}Mg)_{sample}/(^{25}Mg/^{24}Mg)_{std}\}$$

and similarly for $\varphi(^{26}Mg)$,

and

$$\Delta(^{26}Mg) = \varphi(^{26}Mg) - \varphi(^{25}Mg)/0.514.$$

The fractionation factor 0.514 was experimentally determined using a CAI-like melt composition [4], which may also be applied to the FUN-like inclusions in this study.

Ca and Ti isotopes: Calcium and titanium isotopes were measured using a CAMECA ims-1270 ion microprobe at AIST, Tsukuba, Japan. The analytical procedure was similar to that described in [1,5]. A primary beam of $^{16}O^-$ with an intensity of 0.2-1nA and a diameter of 10-20μm was used for the analysis. MRP was set to ~11000 to separate interfering peaks. The analyzed peaks were $^{40}Ca^+$, $^{42}Ca^+$, $^{43}Ca^+$, $^{87}Sr^{++}$, $^{44}Ca^+$, $^{46}Ti^+$, $^{47}Ti^+$, $^{48}Ti^+$, $^{48}Ca^+$, $^{49}Ti^+$, $^{50}Ti^+$, $^{51}V^+$, $^{52}Cr^+$ and $^{53}Cr^+$. In order to correct for the tailing effect of $^{48}Ti^+$ on $^{48}Ca^+$, tail of $^{40}Ca^+$ (with the same distance of $^{48}Ti^+$-$^{48}Ca^+$) was also monitored. An exponential law was applied for Ca and Ti isotopes, with ^{40}Ca and ^{44}Ca for reference isotopes of Ca, and ^{46}Ti and ^{48}Ti for reference isotopes of Ti [8]. Measured ratios for Madagascar hibonite standard were consistent with the literature values within uncertainties [6,7].

Results and discussion: Magnesium isotope data are plotted in the $\varphi(^{25}Mg)$ *vs* $\varphi(^{26}Mg)$ diagram (Fig. 1). All the data for MC037 and MC040 lie on the mass fractionation line within uncertainties. Data for MC040 show rather homogeneous composition with $\varphi(^{26}Mg)$ from ~97‰ to ~107‰, while MC037 data show highly

heterogeneous composition with $\varphi(^{26}Mg)$ from ~27‰ up to ~95‰. Hibonite and spinel in MC037 probably crystallized at various stages of the evaporation event, while those in MC040 only at the last stage of the evaporation event, suggesting slightly different heating conditions for these two inclusions. Figure 2 shows a $\Delta^{26}Mg$ *vs* $^{27}Al/^{24}Mg$ diagram. Both MC037 and MC040 data show no excess ^{26}Mg ($\Delta^{26}Mg$ ~0) within uncertainties. Again MC037 data show large variations in the $^{27}Al/^{24}Mg$ ratio.

The obtained Ca and Ti isotopic compositions are shown in Figs. 3 and 4, respectively. Both MC037 and MC040 do not show anomalies in ^{48}Ca within analytical errors, but have small (<10‰) but resolvable anomalies in ^{50}Ti.

Highly fractionated Mg isotopes, lack of resolvable excess in ^{26}Mg and existence of ^{50}Ti anomaly suggest that MC037 and MC040 are newly found FUN inclusions. The present results and previous works show that there are variations in F, UN, and ^{26}Mg excess signatures among different types of FUN (F) inclusions [1,8,9]. Further studies are required to better understand their relations and formation conditions.

References:

[1] Ushikubo T. et al. (2007) *EPSL*, 254, 115-126. [2] Sasaki S. et al. (2011) *NIPR Antarctic Meteorite XXXIV*. [3] Fukuda K. et al. (2012) *NIPR Antarctic Meteorite XXXV*. [4] Davis A. M. et al. (2005) *LPS XXXVI,* Abstract #2334. [5] Zinner E. K. (1986) *ApJ,* 52, 2827-2839. [6] Niederer F. R. and Papanastassiou D. A. (1984) *GCA,* 48, 1279-1293. [7] Niederer F. R. et al. (1981) *GCA,* 45, 1017-1031. [8] Fahey A. J. et al. (1986) *GCA,* 51, 329-350. [9] Ireland T. R. et al. (1992) *GCA,* 56, 2503-2520.

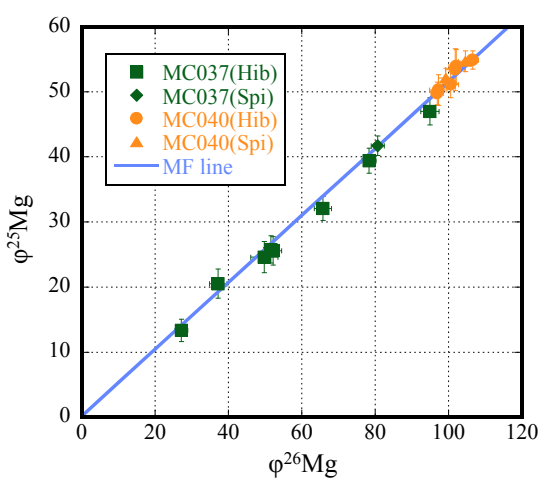

Fig. 1. The $\varphi^{26}Mg$-$\varphi^{25}Mg$ plot for MC037 and MC040. Hibonite and Spinel in these inclusions show extremely large mass fractionation of up to ~50‰/amu.

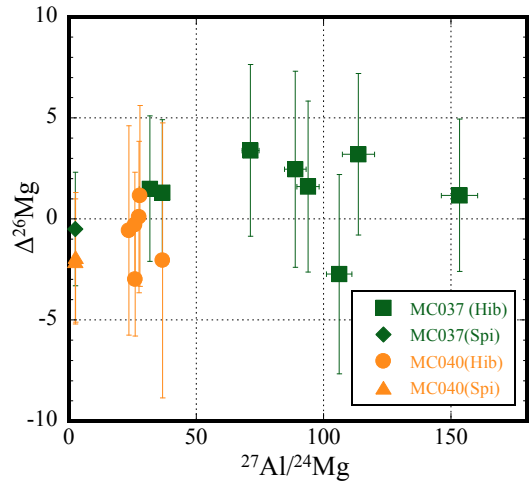

Fig. 2. Excess ^{26}Mg ($\Delta^{26}Mg$) *vs* $^{27}Al/^{24}Mg$ diagram for MC037 and MC040. All the data for two inclusions show almost no excess ^{26}Mg.

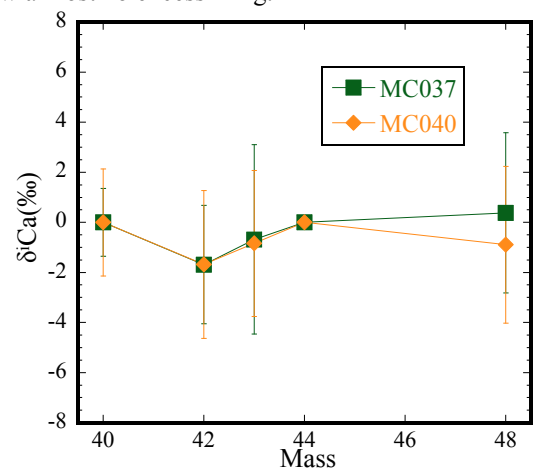

Fig. 3. Normalized Ca-isotopic compositions of the MC037 and MC040. These inclusions do not show anomaly within analytical error.

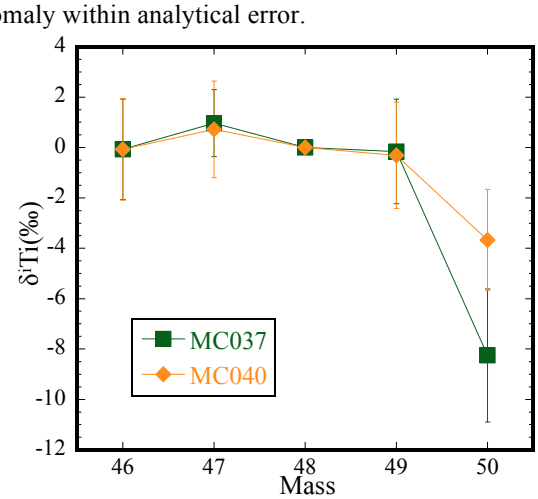

Fig. 4. Normalized Ti-isotopic compositions of the MC037 and MC040. These inclusions have negative anomaly in ^{50}Ti relative to the terrestrial value [7].