FUN IN THE LABORATORY: EVAPORATION OF FORSTERITE-RICH MELTS AND FRACTIONATION OF MAGNESIUM ISOTOPES. R. A. Mendybaev[1,2], F. M. Richter[1,2], and A. M. Davis[1,2,3], [1]Department of the Geophysical Sciences, [2]Chicago Center for Cosmochemistry, [3]Enrico Fermi Institute, University of Chicago, Chicago, IL, 60637 (ramendyb@uchicago.edu)

Introduction: Some FUN inclusions are similar to Type B CAIs in chemical and mineralogical compositions, but have little or no excess of radiogenic ^{26}Mg, and show large mass-dependent isotopic **F**ractionation effects in magnesium, silicon and oxygen and large **U**nidentified **N**uclear effects in a number of elements. Figure 1 illustrates that the enrichment factors of FUN CAIs in heavy Mg and Si isotopes lie on an extension of the trend defined by the CAI fractionation, with the values of δ^{25}Mg up to ~30 and δ^{30}Si up to 14 in C1 from Allende CV3 and 1623-5 from Vigarano CV3 [1, 2]. The heavy isotope enrichment is usually attributed to isotopic fractionation caused by the partial evaporation of volatile components of CAI precursors during a high temperature molten stage.

The isotopic fractionations caused by evaporation have been intensively studied in laboratories. The results show that the evaporation residues become enriched in heavy Mg and Si, but the fractionation factors for CMAS liquids is systematically lower than the values expected for simple theory. For example, evaporation of a Type B CAI-like starting composition [3] at 1900ºC in vacuum results in a kinetic isotopic fractionation factor for Mg, α_{Mg}, of 0.98704±0.00025 while the expected value of α_{Mg} is $\sqrt{24/25}$=0.97980. In contrast to large amount of experimental data on the evaporation of CAI-like compositions, there have not been evaporation experiments aimed at reproducing the chemical compositions and extremely large isotopic fractionations of the FUN inclusions. We present here results from our vacuum evaporation of potential precursors for the FUN inclusions Vigarano 1623-5.

Starting Material and Experimental Methods: As a starting material we used the spinel-corrected (to get the solar Ca/Al ratio) bulk composition of Vigarano 1623-5 which was than modified by adding forsterite. The amount of forsterite added was such that evaporation at 1900°C of the starting composition would lead to the observed δ^{25}Mg value (30.6‰) and bulk MgO content of Vig 1623-5. In the calculations we assumed α_{Mg}=0.98607, as was determined in our experiments on evaporation of CAIB-liquids at 1900ºC [3]. The mixture of 53.41 wt% MgO, 41.27 wt% SiO$_2$, 2.97 wt% Al$_2$O$_3$ and 2.36 wt% CaO was carefully mixed for ~10 hours in agate mortar under ethanol, and then ~10 to 40 mg of the mixture was suspended on Ir-wire loops of 2.5 mm in diameter. The experiments were conducted at 1900ºC in the same high-

vacuum (P≤10^{-6} torr) furnace as used in [3]. A JEOL JSM-5800LV scanning electron microscope with an Oxford/Link ISIS-300 x-ray microanalysis system was used to determine the chemical composition of run products. The magnesium isotopic compositions of the evaporation residues were measured using a Micromass Isoprobe multi-collector ICPMS at the University of Chicago. The detailed experimental protocol is presented in [3].
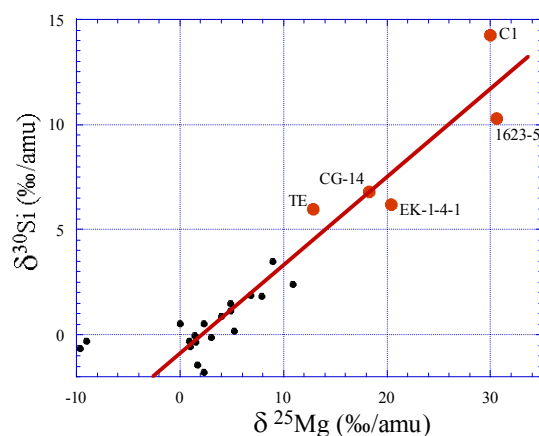

Fig. 1. Mass-dependent isotope fractionation in Mg and Si in CAIs [1], with FUN CAIs shown as red circles.

Results and Discussion: Figures 2 and 3 show the evolution of the composition of FUN CAI as it evaporates in vacuum at 1900°C. It can be seen that during the initial stages of the evaporation of FUN CAI, the rate of Mg loss is considerably higher than that of Si, which results in enrichment of the residual liquid in SiO$_2$. As the MgO content in the residue reaches ~46 wt%, evaporation rates of Si and Mg become proportional to one another, resulting in the linear relation of fraction of Si and Mg remaining in the liquid shown in Fig. 3. The initial enrichment of FUN CAI melt in SiO$_2$ is opposite to what was observed when melt of CAIB composition was evaporated under the same conditions. Evaporation of CAIB melt starts with much faster evaporation of SiO$_2$ compared to MgO followed by linearly related rates afterwards (but, interestingly, with a different slope than the FUN CAI composition and a nonzero intercept). This type of evaporation behavior of Si and Mg in case of CAIB

melt is in agreement with the expectations from the thermodynamic modeling [4], but such calculations are neede for evolution of the FUN CAI melt.
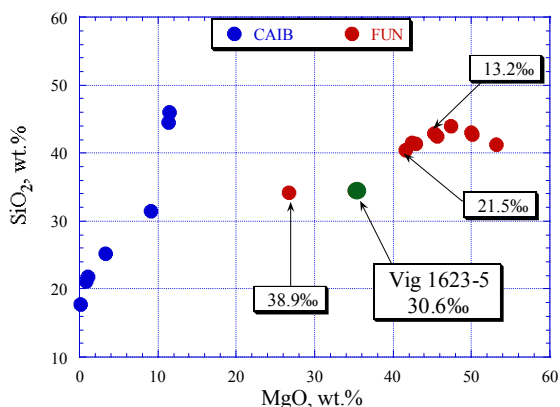

Fig. 2. Measured concentrations of MgO and SiO$_2$ (in weight %) in starting material, Vigarano 1623-5 FUN CAI and evaporation residues from vacuum experiments at 1900°C. Also shown are values of $\delta^{25}Mg$ in evaporation residues. Blue symbols show the composition of evaporation residues when CAIB-like melt was used as a starting material.
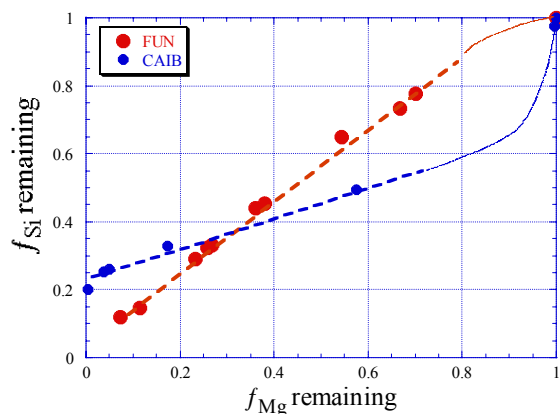

Fig. 3. Compositions of the starting materials and run products expressed as fractions of Mg and Si remaining in the samples. Symbols are the same as in Fig. 2.

Figure 4 is a summary of the data on Mg isotopic fractionation by evaporation in vacuum at 1900°C obtained in our laboratory. In this log-log plot the linear dependency of the Mg isotopic composition of the evolving FUN CAI melt as a function of Mg remaining indicates that fractionation follows a Rayleigh law with α_{Mg}=0.98545±0.00064 which, within 2σ, is the same as 0.98607±0.00017 measured for evaporation of CAIB melt [3]. The data for molten Mg$_2$SiO$_4$ [5], except for the point representing the most highly evaporated residue, are also follow the same trend. We are in the process of measuring the Mg isotopic composition from more FUN CAI melt evaporation residues and planning to obtain Si isotopic compositions.

Conclusions: The results obtained on the evaporation of melt with the composition of the Vigarano 1623-5 precursor (FUN CAI) and comparison with the data obtained for melt of CAIB composition allowed us to conclude the following. (1) Evaporation of FUN CAI precursors in a vacuum results in the Mg isotopic compositions Vig 1623-5. (2) The initial stage of the evaporation of FUN CAI includes faster evaporation of Mg than Si resulting to the initial enrichment of the residual melt in SiO$_2$ compared to the starting composition. This is opposite to what was observed for CAIB melts. (3) Despite differences in the initial stages of the evaporation of FUN CAI and CAIB liquids, the magnesium isotope fractionation factor of FUN CAI at 1900°C, α_{Mg}=0.98545±0.00064, is, within 2σ, the same as for CAIB melts.
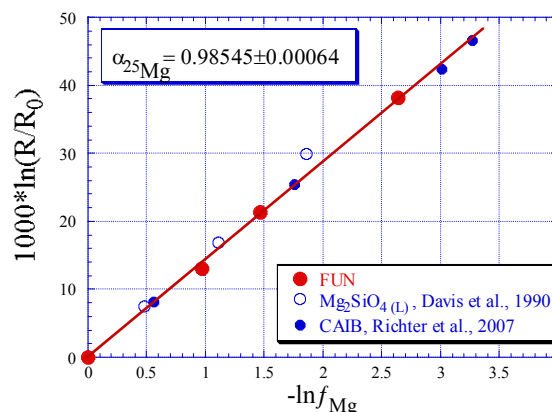

Fig. 4. Magnesium isotope fractionation at 1900°C as a function of Mg remaining in the samples. The results the experiments using FUN CAI composition (closed red circles) compared to those for CAIB [3] (closed blue diamonds) and molten forsterite [2] (open blue circles) at the same temperature.

References: [1] Clayton R. N., Hinton R. W., and Davis A. M., (1988) *Phil. Trans. Roy. Soc. London, A325,* 483–501. [2] Davis A. M. et al. (1991) *GCA, 45,* 621–637. [3] Richter F. M. et al. (2007) *GCA, 71,* 5544–5564. [4] Richter F. M. et al. (2002) *GCA, 66,* 521–540. [5] Davis A. M. et al. (1990) *Nature 347,* 655–658.