MG ISOTOPIC STUDY OF CA-, AL-RICH REFRACTORY INCLUSIONS FROM CARBONACEAOUS CHONDRITES: CONSTRAINTS ON 26AL DISTRIBUTION IN THE ACCRETION DISK AND CONDENSATION PROCESSES. R. Mishra[1] and M. Chaussidon[2], [1]CRPG-CNRS, Université de Lorraine, 15 Rue Notre Dame des Pauvres, BP 20, 54501 Vandoeuvre-lès-Nancy, France (ritesh@crpg.cnrs-nancy.fr), [2]CRPG-CNRS, Université de Lorraine, 15 Rue Notre Dame des Pauvres, BP 20, 54501 Vandoeuvre-lès-Nancy, France (cho-cho@crpg.cnrs-nancy.fr).

Introduction: Short-lived ^{26}Al is potentially one of the most powerful chronometers of the early solar system. However, calculation of relative ^{26}Al ages from variable ^{26}Mg excesses measured in meteoritic components relies on the key assumption that some homogeneity was reached for ^{26}Al and Mg isotopes in the accretion disk (or at least in its inner part) before the majority of high temperature components of meteorites started to form. Ultra-refractory hibonite-bearing inclusions or hibonite grains, which show variable $^{26}Al/^{27}Al$ (from $\approx 6\times10^{-6}$ to $\approx 6\times10^{-5}$) or variable ^{26}Mg deficits or excesses (not related to ^{26}Al decay), presumably formed at a stage where such an homogeneity was not reached [1, 2 and refs therein]. In the last few years, the development of multi-collector isotopic analysis by ion microprobe and by MC-ICPMS has allowed to improve by one or two orders of magnitude the precision on the initial (i.e. $\delta^{26}Mg^*_0$) and the slope (i.e. $^{26}Al/^{27}Al_0$) of ^{26}Al isochrons, either mineral isochrons or bulk isochrons. It thus became possible to quantify the homogeneity of ^{26}Al and Mg isotopes in the disk [3] by comparing the $\delta^{26}Mg^*_0$ and $^{26}Al/^{27}Al_0$ of a given object with that predicted from the appropriate Mg isotope growth curve (calculated with the $^{27}Al/^{24}Mg$ of the parent reservoir). Doing so for type II chondrules from the LL3 Semarkona ordinary chondrite showed [3] that all the $\delta^{26}Mg^*_0$ and $^{26}Al/^{27}Al_0$ pairs of these chondrules were falling on a solar system Mg isotopes growth curve anchored on one side by Allende bulk CAIs ($\delta^{26}Mg^*_0$ = -0.040 (±0.029) ‰ and $^{26}Al/^{27}Al_0$ = 5.23 (±0.13) $\times10^{-5}$, [4]) and on the other side by the Earth ($\delta^{26}Mg^*_0$ = 0 and $^{26}Al/^{27}Al_0$ = 0). The composition of the Earth and chondrule data are consistent with formation from a reservoir homogenized at ±10% relative (at the time of formation of CAIs) with $^{26}Al/^{27}Al_0$ = 5.23 $\times10^{-5}$ and $\delta^{26}Mg^*_0$ = -0.038‰. Recently, very high precision MC-ICPMS data (reaching the ppm level precision for Mg isotope compositions) were published [5]: these data show that a ^{26}Al isochron can be calculated between bulk AOAs and bulk CAIs from Efremovka giving a slope of $^{26}Al/^{27}Al_0$ = 5.252 (±0.019) $\times10^{-5}$ and an intercept of $\delta^{26}Mg^*_0$ = -0.0159 (±0.0014) ‰. The intercept of this isochron is constrained from the AOAs composition, since the intercept calculated from the CAIs alone is of $\delta^{26}Mg^*_0$ = -0.034 (±0.032)‰, the slope being unchanged within errors. This impressive work re-opens the question of the level of homogeneity of ^{26}Al and/or Mg isotopes in the disk: if the Efremovka AOAs-CAIs line is not a mixing line but a real isochron then up to 50% (relative) heterogeneity in $\delta^{26}Mg^*$ was present in the CAI-AOA forming region implying errors on ^{26}Al ages obtained from comparing objects to the solar system growth curve of a factor of two (i.e. 0.72 Myr, one half life of ^{26}Al).

To try to further constrain the level of homogeneity of ^{26}Al and Mg isotopes in the disk at the time of formation of CAIs, we applied to CAIs the same approach than that applied to chondrules by [3]. Such an approach has been recently followed by [6] for a set of ≈ 10 CAIs and AOAs showing that for most CAIs their Mg isotopic is consistent within errors with formation from a reservoir having the same $\delta^{26}Mg^*$ and $^{26}Al/^{27}Al$ than derived from chondrules [4]. In addition, important information can be obtained on CAI history: the data by [6] also indicate that the major Al/Mg fractionation in CAIs occurred when $^{26}Al/^{27}Al$= 5.2 $\times10^{-5}$ and not at the time of last melting event. We present in the following a study of $\delta^{26}Mg^*$ and $^{26}Al/^{27}Al$ in a set of 10 CAIs, 1 AOA and 2 chondrules from the Vigarano and Efremovka CV chondrites. Clearly, some statistic view is required to look for the ^{26}Al and Mg isotopes distribution in the disk at the time of formation of CAIs.

Analytical approach: The Mg isotopic compositions were measured with the multi-collector ims 1270 and ims 1280 HR2 ion microprobes at CRPG-CNRS (Nancy) refining procedures previously described [3, 7] and also shown at this conference by [8]. A set of terrestrial and synthetic standards with varying mineralogy (olivine, spinel, hibonite, pyroxene, melilite, anorthite, basaltic glasses), composition and Al/Mg ratio was developed to constrain matrix effects on instrumental mass fractionation (noted $\alpha^{25/24}_{inst}$ for the $^{25}Mg/^{24}Mg$ ratio) and Al/Mg relative ion yields. The ^{24}Mg, ^{25}Mg, ^{26}Mg and ^{27}Al ion beams are measured on four Faraday cups at a mass resolution M/ΔM of 2500 with a continuous monitoring of vacuum in the chamber (to check the lack of significant ^{24}MgH interference on ^{25}Mg). The instrumental Mg isotopes mass fractionation law is determined using an exponential law from the different standards (this law was of the form : $\ln(\alpha^{25/24}{}_{inst}) = \beta \times \ln(\alpha^{26/24}{}_{inst}) + b$, with β ranging from 0.510 to 0.521 and the intercept b at a level of ≈-0.0003). After correction for $\alpha^{25/24}{}_{inst}$ and $\alpha^{26/24}{}_{inst}$ (using the appropriate values to account for matrix effects), the δ^{26}Mg* excesses are calculated from the ^{25}Mg/^{24}Mg and ^{26}Mg/^{24}Mg ratios using an exponential law for Mg isotopes with an exponent of 0.514 for CAIs [9]. The external reproducibility of δ^{26}Mg* on terrestrial standards reach ±0.05‰ (2 s.d.) on Mg-rich minerals like olivine and is slightly poorer on phases with lower Mg contents.

The bulk Al/Mg ratio of each CAIs was determined from electron probe analysis of its individual phases and measurement of the surface fraction of each phase from image analysis of maps made by secondary electron microscope.

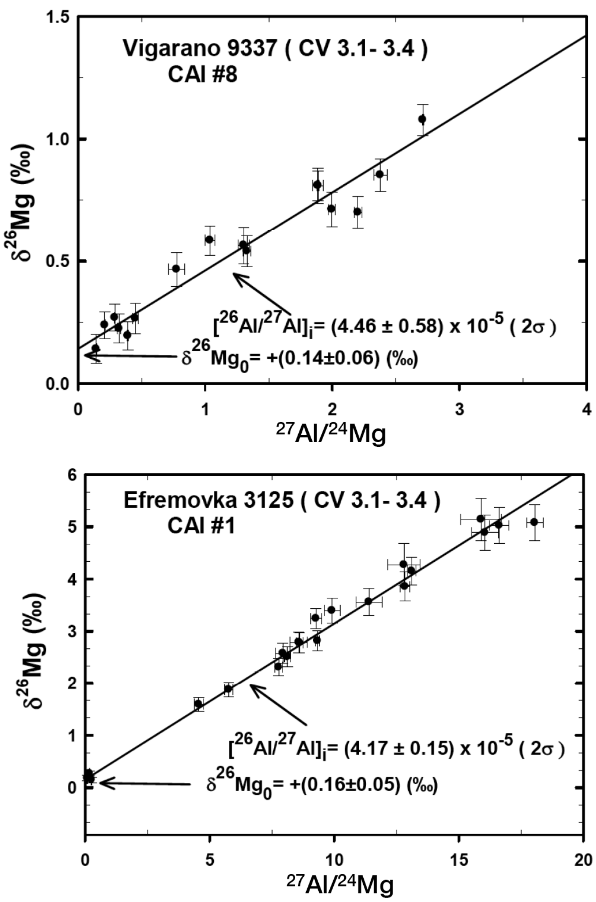

Fig 1: ^{26}Al isochrons for two CAIS

Results and discussion: An example of the ^{26}Al isochrons obtained for the different CAIs and the AOA is given in Fig. 1. The ^{26}Al/^{27}Al$_0$ range from 5.94 (±1.18) x10^{-5} to 9.3 (±3.2) x10^{-6}. The two chondrules have lower of 2.3 x10^{-6} and 4.0 x10^{-6}. The bulk ^{27}Al/^{24}Mg ratios range for the CAIs from 2.4 to 7.1. Several of the CAIs can be interpreted in a simple scenario (Fig. 2) made of (i) condensation of precursors from a reservoir with δ^{26}Mg* = -0.035‰ and ^{26}Al/^{27}Al$_0$ = 5.23 x10^{-5} and, (ii) evolution in closed system until a last melting event corresponding to the ^{26}Al/^{27}Al ratio defined by the mineral isochron. However this is not the case for all of them: CAI Vig9337#14 with ^{26}Al/^{27}Al = 9.3 x10^{-6} and a bulk ^{27}Al/^{24}Mg ratio of 2.7 is an example for which, if it condensed from the same reservoir than the other ones, its ^{27}Al/^{24}Mg ratio must have been increased by a factor of at least 2 late in its evolution (evaporation can increase the Al/Mg ratio but no sign of this process is visible from the δ^{25}Mg value). This is not yet understood and could suggest either some heterogeneities in ^{26}Al/^{27}Al in the disk or a late condensation of some CAI precursors. Both interpretations have their caveats and are being tested.

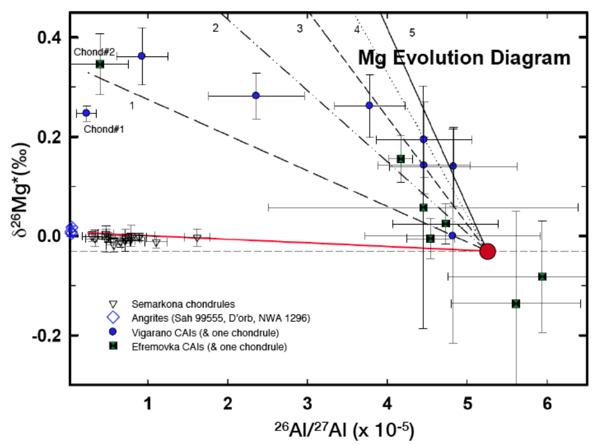

Fig 2: Mg isotopes evolution diagram and compositions measured for the present set of CAIs, AOA and chondrules. The red dot is the "initial" composition derived from CAIs and chondrules [3,4] and the red line the growth curve of δ^{26}Mg* for a chondritic (or solar) ^{27}Al/^{24}Mg ratio of 0.101. Different growth curves are shown for ^{27}Al/^{24}Mg ratio from 1 to 5.

References: [1] Liu et al. (2009) *Geochim. Cosmochim. Acta* 73, 5051-5079. [2] Liu et al. (accepted) *Earth Planet. Sci. Lett.* [3] Villeneuve et al. (2009) *Science* 325, 985-988. [4] Jacobsen et al. (2008) *Earth Planet Sci. Lett.* 272, 353-364. [5] Larsen et al. (2011) *Ap. J.* 735, L37- [6] Davis et al., (2010) *LPSC XXXXI* abstract # 2496. [7] Villeneuve et al. (2011) *Earth Planet. Sci. Lett.* 301, 107-116. [8] Luu et al. (2012) *LPSC XXXXII* abstract. [9] Davis et al. (2005) *LPSC XXXVI*, Abstract #2334.