MAGNESIUM ISOTOPE MAPPING OF SILICA-RICH GRAINS HAVING EXTREME OXYGEN ISOTOPE ANOMALIES. J. Aléon[1], I. D. Hutcheon[2], P. K. Weber[2] and J. Duprat[3], [1]CRPG-CNRS, 15 rue Notre-Dame des Pauvres, 54501 Vandoeuvre-les-Nancy, France (aleon@crpg.cnrs-nancy.fr), [2]Lawrence Livermore National Laboratory, Livermore CA 94550, USA, [3]CSNSM, Bat 104, 91405 Orsay Campus, France.

Introduction: Aléon et al. reported extreme ^{17}O and ^{18}O excesses in silica-rich grains embedded in the insoluble organic matter from the Murchison meteorite [1]. Silicon isotopes in these grains were found to be close to solar (within 10‰). A striking feature of these grains is that they all have the same isotopic composition, indicating that they come from a single source. From comparison with existing data and irradiation calculations, it was proposed that the oxygen isotope anomalies originated within the young solar system upon irradiation of the gas by ^{3}He-rich particles with characteristics of impulsive solar flares. Because the level of ^{26}Al production by stellar nucleosynthesis and irradiation processes can be discriminatory, we measured magnesium isotopes and Al/Mg ratios in several grains by ion microprobe to get more insights on their formation and thus on the origin of the oxygen isotope anomalies.

Samples and methods: The grains selected for Mg isotopic mapping were M3, M4 and M5 with $^{17}O/^{16}O$ and $^{18}O/^{16}O$ ratios close to the endmember oxygen isotope composition, ~ 7×10^{-2} and ~10^{-1}, respectively. Only three grains were selected in order to preserve other grains from being eroded and/or implanted with oxygen from the ion probe beam for further high spatial resolution mapping of O and preparation of electron transparent sections. The grains being partially sputtered away by the previous O and Si isotopic analyses, Mg isotopic mapping was done by NanoSIMS at Lawrence Livermore National Laboratory. Analyses were done using four electron multipliers (EM), at a mass resolving power close to 5000 to avoid magnesium hydride interferences at mass 25 and 26. Grains were located using a silicon image. A primary $^{16}O^{-}$ beam of 250 nm diameter and 1.4 pA was rastered over a 3 µm by 3 µm area to acquire Mg isotope data for 200 cycles of 16 s (128^2 pixels by 1ms/pixel). Because both Al and Mg are minor elements in the grains (concentration ≤ 1%), the typical 1σ precision was about 20‰. Data were corrected for EM dead time and for instrumental mass fractionation using terrestrial spinel standards. The overall reproducibility on ^{26}Mg excess on the standards was better than 5‰. Eleven µm- to sub µm-size MgAl-rich grains (spinel?) and 2 Al-rich grains (corundum?) from Murchison mounted adjacent to the SiO_2-rich grains were measured as secondary standards.

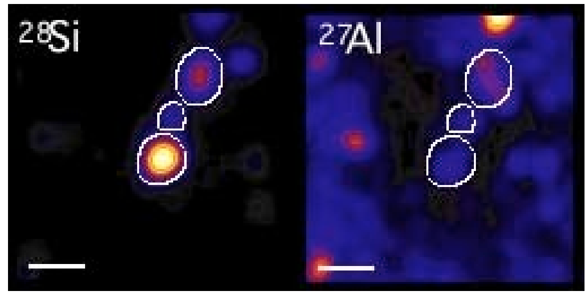

Fig.1. Location map of Si and Al. The SiO_2-rich grains with O isotope anomalies are shown by the white contours. Scale bars are 2 µm. Image intensities are normalized to the maximum pixel for purpose of display

Results: *Spinels and corundum.* All grains from Murchison surrounding the SiO_2-rich grains were found to have normal isotopic composition within error. Measurements spread along the terrestrial mass fractionation (TMF) line of slope 0.5 indicating matrix effects between corundum and spinel. No ^{26}Mg excess was detected.

SiO_2-rich grains. The Al and Mg ion images show that the grains are heterogeneous at a sub-µm scale. M3 consists of several sub grains hereafter called regions of interest (ROI). ROI 1 is Al-rich and was Mg-rich in a limited area at the beginning becoming more Al-rich at the end of the measurement, probably indicating erosion of a Mg-rich sub-grain. ROI 2 consists of two Mg-rich and Al-poor sub-grains next to ROI 1 that appeared during analysis. These ROIs were grouped during image processing to improve counting statistics. M4 is mostly Al-rich and M5 contains little Mg but almost no Al. Depth profiles show cycle to cycle variations with Al/Mg ratios as low as 2 in the Mg-rich regions and as high as 20 in the Al-rich regions. Mg isotopic compositions are thus the average composition of each ROI determined by image processing. Initial $^{26}Al/^{27}Al$ ratios were inferred using the average Al/Mg of the ROIs and the $^{26}Mg/^{24}Mg$ deviation of the ROIs from the TMF line. M5 disappeared during analysis resulting in high errors. All Mg isotopic compositions were found to be solar within error and no ^{26}Mg excess was detected. Weighted mean $\delta^{25}Mg$ and $\delta^{26}Mg$ are 12 ± 18 ‰ and 17 ± 17 ‰ (2 σ). Upper limits on the initial $^{26}Al/^{27}Al$ ratios were determined using the upper errors on the

^{26}Mg excess. The weighted mean upper limit is 4.8 $\times$ 10^{-4} (95% confidence interval).

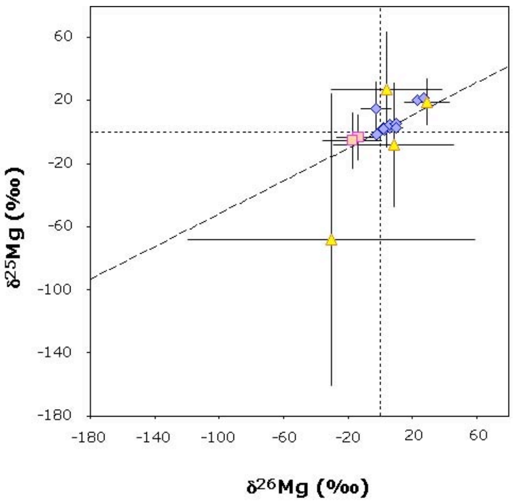

Fig. 2. Mg isotopic composition of grains from Murchison. Blue diamonds are spinels, pink squares are corundum and yellow triangles are the anomalous SiO_2-rich grains. The TMF line is shown as a dashed line. Errors are 2 σ.

Discussion: Similar to O and Si isotopes, all grains and sub-grains have similar Mg isotopic compositions, which is consistent with origin from a single source.

Sources that could potentially produce heavy O isotopes include (1) massive stars and supernovae, (2) novae, (3) trapping of GCR and (4) spallation. Regardless of the difficulties that each of these hypotheses could face with the amplitude of the O isotope anomalies (GCR) or with producing the correct Si isotopes (stars) [1], Mg isotopes should provide independent clues to distinguish among them.

Stellar nucleosynthesis. All stellar types mentioned above are massive producers of ^{26}Al, with initial $^{26}Al/^{27}Al$ ratios of $>10^{-3}$ (massive stars and supernovae, [e.g. 2]) or $>10^{-2}$ (novae, [e.g. 3]). The 4.8 $\times$ 10^{-4} upper limit determined here thus suggests the grains probably do not have a presolar stellar origin.

Trapping of Galactic Cosmic Rays. The galactic interstellar medium is extremely rich in ^{26}Al. Indeed ^{26}Al is detected all over the galactic plane from gamma-ray emission [4]. Its origin is explained by the contribution of Wolf-Rayet stars and/or of type II supernovae, in debated proportions [5] Recent measurements of the $^{26}Al/^{27}Al$ ratio in near-earth GCR give a value of ~ 4 $\times$ 10^{-2} [6]. Assuming that the GCR composition was similar 4.5 Gyrs ago, this value is two orders of magnitude higher than our upper limit.

Spallation upon irradiation in the early solar system. Since the spallation by GCR is ruled out by unrealistic irradiation time [1], the hypothesis left is spallation upon irradiation by energetic protons, alphas and ^{3}He from the young Sun. In-situ irradiation of the grains should have left large Si and Mg isotope anomalies that are not observed, therefore, the most likely hypothesis is irradiation of the circumsolar gas followed by condensation of SiO_2 in a SiO-rich environment. Our upper limits are fully consistent with the solar system initial $^{26}Al/^{27}Al$ ratio of 5 $\times$ 10^{-5} (or even 7 $\times$ 10^{-5}, as proposed recently [7]) that is observed in Ca-Al-rich inclusions [8]. The absence of Mg isotope anomalies indicate that the grains must have formed by a process that does not favor the trapping of nuclear-induced Mg (Mg*) in the gas. The amplitude of Mg* production and its level of preservation in the grains still remains to be determined. We note, however, that, as for Si [1], the delta values of the weighted mean are at the upper limit of solar values leaving room for ^{25}Mg and ^{26}Mg excesses of spallogenic origin of up to 20‰.

Conclusion: The absence of Mg isotope anomalies in SiO_2-rich grains from Murchison containing extremely anomalous O, strongly supports the conclusion that the grains formed in the early solar system and selectively preserved anomalous oxygen produced by irradiation of nebular gas. This re-enforces the previous conclusion that very large (10-100‰) variations in stable isotope abundances may be produced in the young solar system and do not necessarily require an extra-solar source.

References: [1] Aléon J. et al. (2005) *This meeting*. [2] Woosley S.E & Weaver T.A. (1995) *ApJS 101*, 181-235. [3] Jose J. et al. (2004) *ApJ 612*, 414-428. [4] Prantzos N. & Diehl R. (1996) *Phys. Rep. 267*, 1-69. [5] Prantzos N. (2004) *A&A 420*, 1033-1037. [6] Yanasak N.E. et al. (2001) *ApJ 563*, 768-792. [7] Galy et al. (2004) *LPS XXXV* #1790. [8] MacPherson G.J. et al. (1995) *Meteoritics 30*, 365-390. Performed under the auspices of the U. S. DOE by the Univ. of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.