HIGH-RESOLUTION NANOSIMS MEASUREMENTS OF MAGNESIUM AND ALUMINUM ISOTOPES IN O-RICH PRESOLAR SPINELS FROM ORGUEIL. N. Liu[1], N. Dauphas[2], and R. C. Ogliore[1], [1]Department of Physics, Washington University in St. Louis, St. Louis, MO 63130, USA, nliu@physics.wustl.edu, [2]Department of the Geophysical Sciences, The University of Chicago, Chicago, IL 60637, USA.

Introduction: Presolar O-rich grains (silicates, oxides) are divided into four groups based on their O isotope ratios [1]. Groups 1 and 2 O-rich grains are long believed to have come from low-mass (<2.5 $M_\odot$) asymptotic giant branch (AGB) stars [e.g., 2], although an intermediate-mass AGB stellar origin (4−8 $M_\odot$) has been suggested for Group 2 grains based on the newly determined proton-capture rate of ^{17}O [3]. The recent finding of large ^{25}Mg excesses in a number of Groups 1 and 2 presolar silicate grains [4−6], however, is incompatible with state-of-the-art nucleosynthesis model predictions for AGB stars, thus posing a challenge to their proposed AGB stellar origins. Instead, a Type II supernova (SNII) origin is proposed for Group 1 grains with δ^{25}Mg above 600 ‰ [4].

In addition to presolar silicates, presolar spinels also carry a significant amount of Mg and are, therefore, suitable for investigating Al-Mg isotopic systematics. Previous studies showed that Groups 1 and 2 presolar spinel grains exhibit close-to-solar δ^{25}Mg and enhanced δ^{26}Mg values, which can be explained by Galactic chemical evolution (GCE) and ^{26}Al decay [e.g., 7]. Large ^{25}Mg excesses (>200 ‰) were only found in three Group 2 spinel grains [2,7,8]. In comparison, such large ^{25}Mg excesses were observed in six out of 19 Group 1 presolar silicates recently studied [5,9], implying differences in the Mg isotopic composition between Group 1 spinel and silicate grains. However, the Group 1 spinel grains previously measured for Mg isotopes generally had quite low ^{17}O/^{16}O ratios: only eight grains had ^{17}O/^{16}O ratios above 1.2×10^{-3} and none above 1.5×10^{-3} (Fig. 1). In contrast, five of the six Group 1 silicates with >200 ‰ ^{25}Mg excesses [5] had ^{17}O/^{16}O ratios above 1.5×10^{-3}. Thus, for direct comparison with the recent high-spatial-resolution Mg isotope data for presolar silicates [5,9], we investigated Al-Mg isotopic systematics in presolar spinels, especially in those with high ^{17}O/^{16}O ratios at comparable spatial resolution. Here we report Mg isotope data for 23 new presolar spinels from the Orgueil meteorite (CI), including three Group 2, one putative nova and 20 Group 1 grains. The presolar spinels investigated here have a mean size of ~200 nm [10], similar to typical presolar silicates but much smaller than presolar spinels (400−700 nm) reported in the literature [2,7,8].

Methods: The analyzed spinel grains from Orgueil were all found on the <200 nm spinel-rich separate mount previously studied for Cr isotopes in [10]. We imaged ~100 15×15 μm^2 areas for O isotopes using a ~1 pA Cs$^+$ beam on the NanoSIMS 50 instrument at WashU and identified ~80 presolar O-rich grains with >4σ anomalies in their O isotope ratios. Most of the identified presolar grains are Al-rich. We then selected 35 Al-rich grains with high ^{17}O/^{16}O ratios and analyzed their Al-Mg isotopic systematics by rastering a ~1 pA O$^-$ primary ion beam produced by the Hyperion RF source over 5×5 μm^2 areas. In both negative and positive NanoSIMS modes, we were able to achieve a spatial resolution of ~100 nm, sufficient to resolve contamination from adjacent spinel grains. We succeeded in obtaining Al-Mg isotope data in 23 out of the 35 selected grains.

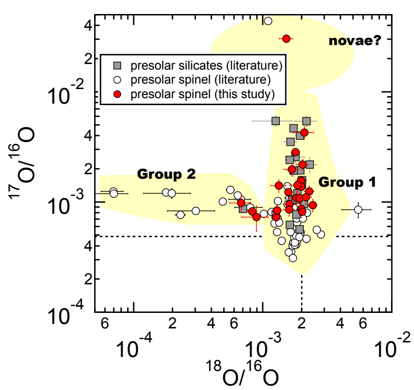

Fig. 1. *O three-isotope plot. The dashed lines represent terrestrial values. The literature data (1σ errors) for presolar silicate and spinel grains are from [5,9] and [2,7,8], respectively.*

Results: Figure 1 compares the O isotopic compositions of presolar silicate and spinel grains that have available Mg isotope data. The distribution of our spinel grain data is in general agreement with those of the literature data. Compared to the literature spinel data, the higher ^{17}O/^{16}O ratios of the grains from this study results from our selection bias as discussed earlier. Our presolar spinel grains overlap with the presolar silicates from [5,9] in Fig. 1, thus allowing for a direct comparison of their Mg isotopic compositions.

Figure 2 compares the literature spinel grains with the spinels from this study for Mg isotopes. The larger analytical uncertainties in this study are caused by the much smaller grain sizes. The comparison in Fig. 2 seems to indicate that the spinel grains from this study had more normal Mg isotopic compositions than spinel grains from the literature. This difference, however, is not statistically significant, given that only five out of 57 Groups 1 and 2 grains from the literature had Mg isotopic anomalies >400 ‰. In addition, we did not find any grains lying in the yellow shaded region in Fig. 2, consistent with the results of [2,7]. Although the new putative nova spinel does not exhibit any large

^{25,26}Mg excesses as the one reported in [8], it shows the largest ^{25}Mg enhancement among the spinel grains analyzed in this study.

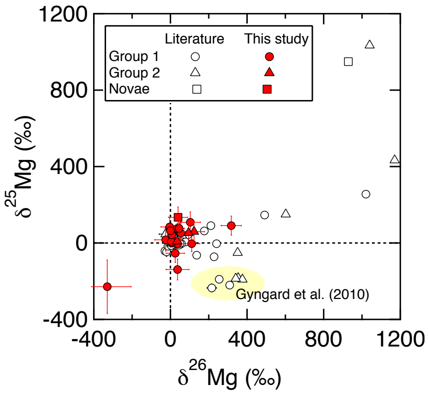

Fig. 2. *Mg three-isotope plot comparing the literature data with the spinel data from this study (1σ errors). The same set of grains as in Fig. 1 is shown here. All the six (out of 22 Groups 1 and 2 spinels) grains in the shaded region are from [8].*

Discussion & Conclusion: Figure 2 shows that four spinel grains from this study had resolvable (>2σ), small (<150 ‰) ^{25}Mg excesses accompanied by smaller ^{26}Mg excesses, including two Group 1, one Group 2 and one nova grain. The close-to-solar Mg isotopic compositions of Groups 1 and 2 spinel grains from this study are consistent with them originating from low-mass (<2.5 $M_\odot$) AGB stars as previously proposed [2]. The ~300 ‰ enrichment in ^{26}Mg observed in one of the spinels from this study is likely caused by the decay of ^{26}Al, corresponding to an initial ^{26}Al/^{27}Al ratio of $(1.23\pm0.31)\times10^{-2}$. On the other hand, we notice that the putative nova grain from this study had a much smaller excess in ^{25}Mg than the literature nova grain, which can be explained by originating from a CO nova with a lowered initial mass [8].

Figure 3 reveals a clear difference in the Mg isotopic composition between presolar spinel and silicate grains. Although the two types of presolar minerals overlap in the region close to the terrestrial composition in Fig. 3, none of the 23 presolar spinels show δ^{25}Mg above 150 ‰ as observed in six of the 19 literature presolar silicates. Our result is supported by the fact that >150 ‰ ^{25}Mg excesses were only observed in one nova, one Group 1 and three Group 2 spinel grains (out of 57 grains) in the literature (Fig. 2). The difference in the Mg isotopic composition between presolar silicate and spinel grains is significant, especially when considering grains with high ^{17}O/^{16}O values ($>1.0\times10^{-3}$): δ^{25}Mg above 150 ‰ were found in seven of the 14 literature presolar silicates but none of the 12 grains from this study. As discussed in [2], this difference in the Mg isotopic composition seems unlikely to be explained by parent body processing. This is because the presolar spinels from this study are from Orgueil that experienced a minimal amount of heating on its parent body [11]. In addition, we do not observe any difference in the Mg isotopic composition between presolar spinels from type 3 ordinary chondrites [7] and those from aqueously altered chondrites [2,7,8, and this study]. Thus, the effect of aqueous alteration seems unlikely to explain the large discrepancy observed in Fig. 3. Also, it is unclear how aqueous alteration could have solely resulted in normal Mg isotopic compositions without affecting O in presolar spinels.

Instead, the different Mg isotopic compositions probably reflect differences in their stellar origins and/or in their residence histories in the interstellar medium (ISM). If the former, it implies that Groups 1 and 2 O-rich grains with δ^{25}Mg>150 ‰ and with δ^{25}Mg<150 ‰ came from different stellar sources and also that the former stellar source produced a limited amount of spinel compared to silicate dust. If the latter, it implies that presolar spinel grains spent longer time and/or experienced a higher amount of heating in the ISM so that the effect of Mg isotopic equilibration is more significant for presolar spinel. In turn, the Mg isotope data alone cannot be used to infer their stellar origins. We plan to conduct Ti and Cr isotope analyses in the remaining spinel grains soon to further investigate their stellar origins.

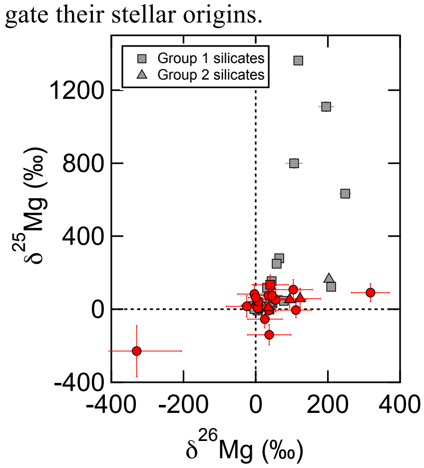

Fig. 3. *Mg three-isotope plot comparing the literature silicates with spinels from this study (1σ errors). The same set of grains as in Fig. 1 is shown here.*

References: [1] Nittler L. R. and Ciesla F. (2016) *ARA&A, 54,* 53–93. [2] Nittler L. R. et al. (2008) *ApJ*, *682*, 1450–1478. [3] Lugaro M. et al. (2017) *Nat. Astron.*, *1*, 0027. [4] Leitner J. and Hoppe P. (2019) *Nat. Astron.*, *3*, 725–729. [5] Leitner J. et al. (2019) *Meteoritics & Planet. Sci., 82,* Abstract #6256. [6] Verdier-Paoletti M. J. et al. (2019) *Meteoritics & Planet. Sci., 82,* Abstract #6433. [7] Zinner E. et al. (2005) *GCA, 69*, 4149–4165. [8] Gyngard F. et al. (2010) *ApJ*, *717*, 107–120. [9] Hoppe P. et al. (2018) *ApJ*, *86*, 479 (13 pp). [10] Dauphas N. et al. (2010) *ApJ*, *720*, 1577–1591. [11] Bullock E. et al. (2005) *GCA*, *69*, 2687–2700. [12] Lee M. R. and Greenwood R. C. (1994) *Meteoritics*, *29*, 780–790.