PRESOLAR GRAINS FROM HIGHER-MASS AGB STARS?

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Introduction: Isotopically anomalous dust that formed in the outflows of evolved stars or in the ejecta of stellar explosions [1] is a minor, but important component of primitive solar system materials. Silicates are the most abundant type of "presolar" dust available for single grain analyses [2], with characteristic sizes of ~150 nm [3]. Based on their O isotopes, most (>99%) presolar silicates and oxides are divided into four distinct groups [4]. Group 1 grains (~70%) are believed to come from low-mass (1.2–2.2$M_\odot$) asymptotic giant branch (AGB) stars of ~solar metallicity, with higher than solar $^{17}O/^{16}O$ ratios and $^{18}O/^{16}O$ ratios ranging from about solar down to ~1×10^{-3}. However, recent studies of Mg-isotopes in Group 1 silicates showed that not all of these grains come from low-mass AGB stars; instead, a fraction of them displays large ^{25}Mg-excesses incompatible with a low-mass AGB origin, indicating stellar explosions as their sources [5]. Group 2 grains also have enhanced $^{17}O/^{16}O$ ratios, but significantly lower $^{18}O/^{16}O$ (<1×10^{-3}). Likely sources are red giant/AGB stars of M <1.5 $M_\odot$ and Z <$Z_\odot$ experiencing additional mixing processes like cool bottom processing [e.g., 6]. Alternatively, some of the grains could stem from higher-mass (4–8 $M_\odot$) AGB stars undergoing hot bottom burning (HBB) [7]; and finally, a few of the Group 2 grains might have formed in the winds of post-AGB stars [e.g., 8]. Here, we report on two Group 2 silicates with Mg-isotopic compositions indicative of an origin in ~6 $M_\odot$ AGB stars, and on several Group 1 silicates possibly coming from ~4-5 $M_\odot$ AGB stars with higher-than-solar metallicities.

Methods: Mg isotope studies were conducted with the new Hyperion RF plasma O primary ion source installed on the MPIC Cameca NanoSIMS 50 on presolar silicates previously identified during standard O-isotopic mapping of Meteorite Hills 00426, Elephant Moraine 92161, and Acfer 094. A focused O^- beam (<100 nm, ~0.5 pA) was rastered over 2×2 µm^2-sized areas around the presolar silicate grains, and secondary ion images of $^{24,25,26}Mg^+$, $^{27}Al^+$, and $^{28}Si^+$ were acquired simultaneously. Subsequently, $^{24,25}Mg^+$ and $^{28,29,30}Si^+$ were measured for selected grains.

Results and Discussion: The two Group 2 silicates display ^{25}Mg-enrichments of 165 ‰ and 1050 ‰, respectively, and $\delta^{26}Mg$-values of 200–300 ‰; five Group 1 silicates have ^{25}Mg-enrichments of 104 ‰–280 ‰, with $\delta^{26}Mg$ between 18 and 65 ‰ (all errors ≤13 ‰). For low-mass AGB stars, no major modifications of the Mg isotopes are expected, and their compositions mainly reflect Galactic chemical evolution (GCE) [e.g., 9]. HBB, however, can strongly affect the $^{25,26}Mg/^{24}Mg$ ratios, resulting in larger excesses for the Group 2 grains [7,10]. Comparison of these models with the grain data indicates an origin from 6–7 $M_\odot$ AGB stars of ~solar metallicity for the two Group 2 silicates, as similarly inferred previously for two Group 2 spinel grains [7]. The ^{25}Mg-enrichments of the five Group 1 silicates are not accompanied by similarly high ^{26}Mg-excesses; thus, a GCE-related origin can be excluded. One possible explanation for their isotopic signatures is the occurrence of explosive H-burning in supernova explosions [5], but given the only moderate ^{25}Mg enrichments another potential source are intermediate-mass AGB stars of supersolar metallicity [10]. In the latter case, we find a good match between the 3.75–4.75 $M_\odot$-models with Z = 0.03 and the grain data, especially when adopting a less effective ^{26}Mg-production via $^{22}Ne(\alpha,\gamma)^{26}Mg$ than typically assumed [11]. The Group 2 silicate grain with the largest ^{25}Mg-excess also shows small enrichments in ^{29}Si and ^{30}Si, while the three Group 1 grains measured so far show no significant deviations from the Solar System Si-isotopic composition. In summary, we find that, by taking the latest AGB star models and reaction rate updates into account [7,10], the two Group 2 silicates discussed here originate from higher-mass AGB stars (M~6 $M_\odot$). Several Group 1 silicates with moderate ^{25}Mg-enrichments could have formed around AGB stars with masses of 3.75–4.75 $M_\odot$ and Z>$Z_\odot$, although an alternative source of this sub-population could be core-collapse supernovae with H-ingestion [5]. AGB stars with M>4 $M_\odot$ are expected to have contributed a significant fraction of silicate and oxide dust to the presolar grain inventory of the nascent Solar System [12]; however, evidence for such grains has been exceptionally rare so far [7], and was restricted to presolar grains of Group 2. Our results show that high-resolution Mg isotope studies are a suitable tool for the identification of HBB signatures, and that the Group 1 grains might contain a sub-population of dust from intermediate-mass AGB stars with supersolar metallicity.

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