MAGNESIUM-26 DEFICITS IN CM HIBONITE GRAINS: NUCLEOSYNTHETIC, GALACTIC CHEMICAL EVOLUTION, OR SPALLOGENIC? Ming-Chang Liu, Kevin D. McKeegan, Andrew M. Davis and Trevor R. Ireland

Introduction: Recent ion microprobe analyses of CM hibonite grains [1] confirm the existence of apparent $\Delta^{26}\text{Mg}$ deficits in a suite of PLAty hibonite Crystals (PLACs), revealing a $\sim 3$–$4 \%$ depletion relative to the terrestrial reference value [2]. The $\Delta^{26}\text{Mg}$ deficits are independent of the Al/Mg ratios of the grains, and are associated with normal $\delta^{25}\text{Mg} (-2\% < \delta^{25}\text{Mg} < 1\%)$. The PLAC samples are characterized by a wide range in $\delta^{50}\text{Ti}$, from approximately $+200\%$ to $-70\%$. However, the magnitude of anomalous $\delta^{50}\text{Ti}$ is poorly correlated with $\Delta^{26}\text{Mg}$*. Up to now, only [3] has explored the possible mechanisms that could have led to the negative $^{26}\text{Mg}$ anomaly in the early solar system. Here, we consider several processes that could possibly be responsible for the observed $\Delta^{26}\text{Mg}$ deficits.

Discussion: Although an apparent $\Delta^{26}\text{Mg}$* deficit could in principle be due to either $^{26}\text{Mg}$ or $^{24}\text{Mg}$ depletion, or to a $^{25}\text{Mg}$ enrichment, the normal intrinsic mass fractionation of the grains strongly favors an interpretation of $^{26}\text{Mg}$ deficiency. Therefore, we only take into account the question: why was $^{26}\text{Mg}$ depleted in these PLACs? There are several possibilities:

1. Initial Mg isotopic composition of the solar nebula. Esat et al. [3] first suggested that the solar system Mg isotopic composition was initially depleted in $^{26}\text{Mg}$ by 1–3$\%$ and the solar $^{26}\text{Mg}$ abundance was enhanced by subsequent $^{26}\text{Al}$ decay. However, the new observed magnitude of $^{26}\text{Mg}$ depletion in PLACs by up to $\sim 4\%$ argues against this hypothesis. With a solar $^{27}\text{Al}/^{24}\text{Mg} \sim 0.1$ [4], the initial $^{26}\text{Al}$ abundance would have to have been $\sim (5-6) \times 10^{-3}$ $^{27}\text{Al}$ throughout the whole solar nebula to complement such a large depletion. This is highly implausible. Moreover, the proposition of a large initial depletion in $^{26}\text{Mg}$ also contradicts observations by [5]. Since this deficit is independent of Al/Mg ratio of platy hibonite, $^{26}\text{Al}$ should not have been present during the formation of these grains. Therefore, the data do not support incorporation of $^{26}\text{Al}$ correlated with a $^{26}\text{Mg}$ deficit in the solar nebula.

2. Nucleosynthetic origin: So far, there has been no study of $^{26}\text{Mg}$ deficit in meteoritic material in the context of stellar nucleosynthesis. A calculated profile in a 25M$\odot$ supernova, provided by B. Meyer (pers. communication), suggested that production of $^{26}\text{Mg}$ is in excess of that of $^{25}\text{Mg}$ until reaching the Ne/O zone. From this view, grains forming from material originat-
only gradual flares in which protons and alpha particles are the dominant species that induced nuclear reactions which led to the destruction and the production of Mg isotopes. Reactions considered here include $^{24}$Mg($p$, $\alpha$)$^{21}$Na, $^{25}$Mg($p$, $\alpha$)$^{22}$Na, $^{26}$Mg($p$,n)$^{26}$Al, $^{26}$Mg($p$, $\alpha$)$^{23}$Na, $^{25}$Mg($\alpha$,p)$^{27}$Al, $^{25}$Mg($\alpha,n$)$^{28}$Si, $^{26}$Mg($\alpha$,n)$^{29}$Si, $^{27}$Al($p$, $\alpha$)$^{24}$Mg and $^{27}$Al(p, pn)$^{26}$Al.

Theoretical nuclear cross-sections, based on the Hauser-Feshbach model, are obtained from the website maintained by T. Rauscher [17]. Radiogenic $^{26}$Mg ingrowth due to the decay of $^{26}$Al produced from $^{26}$Mg($p$,n)$^{26}$Al and $^{27}$Al(p, pn)$^{26}$Al is also accounted for. The chemistry of irradiated material is assumed to be similar to PLACs; specifically we take $^{27}$Al/$^{24}$Mg = 100. Calculations were carried out by expressing the energy flux of solar energetic particles in the form of kinetic energy $E$, $dn/dE = KE^{-\gamma}$, where $\gamma$ determines the steepness of the spectrum and $K$ is a proportionality constant. We picked $\gamma = 2.7$ to represent gradual events and normalize results to a fiducial proton flux of $10^7$ cm$^{-2}$sec$^{-1}$ for $E \geq 10$ MeV, which is suggested by X-ray observations of young stellar objects [18]. The abundance of alpha particles is fixed at 1/300 of that of protons and, we also assume that energy dissipation is negligible as projectiles propagated through the thin (typically 50–70 $\mu$m diameter) targets.

Preliminary results show that it is possible to produce $^{26}$Mg deficits in these targets by irradiation. Figure 1 shows the calculated shift of $\Delta^{26}$Mg* (in permil) plotted as a function of irradiation time under our assumed flux. A negative anomaly of 4‰ is reached if targets were irradiated for 600 years. If the flux was higher, as would happen if the irradiation was very close to the Sun, e.g. as in the X-wind model [12, 13, 19], the required irradiation duration is reduced. The total fluence (Fig. 2) necessary to produce a 4‰ depletion in $^{26}$Mg is $\sim 2 \times 10^{17}$ cm$^{-2}$, which is roughly consistent with that considered by [12, 13, 19] within the typical X-wind timescale of ~20 years.

**Inference and conclusion:** Our results demonstrate a plausible mechanism to account for $\Delta^{26}$Mg* deficits in PLAC hibonites, however they must be considered preliminary because there are still a few possible nuclear reactions that were not yet included in our calculations due to the lack of cross section estimates. Because some irradiation-induced nuclear reactions convert Mg into Si, one approach to further constrain this model would be to analyze the Si isotopic compositions of these PLACs. In addition, proton irradiation of $\sim 2 \times 10^{17}$ cm$^{-2}$ should also produce $^{10}$Be at a level close to the “canonical” value of $\sim 1 \times 10^{-3}$x$^{10}$Be [20]; measurements are ongoing to see if these PLACs contain sufficient $^{10}$Be.

**References:**


![Fig. 1](image1.png)  
Fig. 1 $\Delta^{26}$Mg* evolution with irradiation time, assuming the proton flux is $10^7$ cm$^{-2}$sec$^{-1}$.  

![Fig. 2](image2.png)  
Fig. 2 $\Delta^{26}$Mg* evolves with fluence. The total fluence of $\sim 2 \times 10^{17}$ cm$^{-2}$ is required to produce a 4‰ depletion in $^{26}$Mg