MAGNESIUM-26 DEFICITS IN CM HIBONITE GRAINS: NUCLEOSYNTHETIC, GALACTIC CHEMICAL EVOLUTION, OR SPALLOGENIC? Ming-Chang Liu[1], Kevin D. McKeegan[1], Andrew M. Davis[2] and Trevor R. Ireland[3] [1]Department of Earth and Space Sciences, UCLA, Los Angeles, CA 90095 (mcliu@ess.ucla.edu), [2]Department of the Geophysical Sciences, Enrico Fermi Institute, and Chicago Center for Cosmochemistry, University of Chicago, Chicago, IL 60637, [3]Research School of Earth Sciences, ANU, Canberra, ACT, Australia.

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

Discussion: Although an apparent Δ^{26}Mg* deficit could in principle be due to either ^{26}Mg or ^{24}Mg depletion, or to a ^{25}Mg enrichment, the normal intrinsic mass fractionation of the grains strongly favors an interpretation of ^{26}Mg deficiency. Therefore, we only take into account the question: why was ^{26}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}Mg by 1~3‰ and the solar ^{26}Mg abundance was enhanced by subsequent ^{26}Al decay. However, the new observed magnitude of ^{26}Mg depletion in PLACs by up to ~4‰ argues against this hypothesis. With a solar ^{27}Al/^{24}Mg ~ 0.1 [4], the initial ^{26}Al abundance would have to have been ~ $(5–6)\times10^{-3}\times{}^{27}$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}Mg also contradicts observations by [5]. Since this deficit is independent of Al/Mg ratio of platy hibonite, ^{26}Al should not have been present during the formation of these grains. Therefore, the data do not support incorporation of ^{26}Al correlated with a ^{26}Mg deficit in the solar nebula.

(2) *Nucleosynthetic origin*: So far, there has been no study of ^{26}Mg deficit in meteoritic material in the context of stellar nucleosynthesis. A calculated profile in a 25$M_\odot$ supernova, provided by B. Meyer (pers. communication), suggested that production of ^{26}Mg is in excess of that of ^{25}Mg until reaching the Ne/O zone. From this view, grains forming from material originating from a very deep layer of a supernova will exhibit ^{26}Mg deficits. Ti isotope anomalies do coexist with negative Δ^{26}Mg* in these grains even though the magnitudes are not correlated. It has been suggested that nuclear statistical equilibrium (NSE) followed by multizone mixing (MZM) in Type II supernova and multiple-component (>4) mixing in the interstellar medium can account for the wide range of δ^{50}Ti (and δ^{48}Ca) anomalies found in FUN CAIs and meteoritic hibonite [6–9]. Therefore, it is conceivable that some PLACs have retained a memory of isotopic signatures near the mass cut of supernovae and this chemical memory may include a component characterized by ^{26}Mg deficits. However, one difficulty with this scenario is the apparent uniformity of the Mg anomaly, especially compared to the widely variable δ^{50}Ti anomalies. Since the magnitude of ^{26}Mg depletion throughout different grains is quite consistent, it would be hard to produce a uniform value by mixing between multiple components. Of course, we can not rule out the possibility of the existence of negative anomalies with different magnitudes, even though they have not yet been found in any meteoritic sample.

(3) *Galactic chemical evolution*: Clayton [10] suggested that galactic chemical evolution could result in a large ^{26}Mg deficiency of 1.9% in the interstellar medium, relative to the solar composition, Even though ^{26}Al has been observed in the interstellar medium, its abundance (~$8\times10^{-6}\times{}^{27}$Al) [11] is too low to make up such a large deficiency. Therefore, it is also plausible that an admixture of interstellar material mixing with the normal solar Mg composition could have given rise to a ~4‰ ^{26}Mg depletion in hibonite. However, one still has to face the same problem of the uniformity of ^{26}Mg anomaly, as mentioned in the previous section.

(4) *Irradiation in the early solar system*: Early solar system irradiation models have been proposed for the origin of some short-lived radionuclides [12–15]. Heymann et al. [16] considered proton irradiation of nebular gas as a means to produce stable Mg isotope anomalies in condensates. Here, we take a somewhat different approach that avoids the energetics problems encountered in the models of [16] . Because ^{26}Al was absent in PLAC grains, we consider that irradiation by ^{3}He in impulsive events, proposed for synthesis of short-lived radionuclides addressed by [12] and [14], was not significant. Instead, we assume involvement of

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,α)^{21}Na, ^{25}Mg(p,α)^{22}Na, ^{26}Mg(p,n)^{26}Al, ^{26}Mg(p,α)^{23}Na, ^{24}Mg(α,p)^{27}Al, ^{25}Mg(α,n)^{28}Si, ^{26}Mg(α,n)^{29}Si, ^{27}Al(p,α)^{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 kinectic energy E, dn/dE = KE$^{-\gamma}$, where γ determines the steepness of the spectrum and K is a proportionality constant. We picked γ =2 .7 to represent gradual events and normalize results to a fiducial proton flux of 10^7 cm^{-2}sec^{-1} for E≥10MeV, 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 μm 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 Δ^{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 ~ 2×10^{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 Δ^{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 ~ 2×10^{17} cm^{-2} should also produce ^{10}Be at a level close to the "canonical" value of ~ $1\times10^{-3}\times^{9}$Be [20]; measurements are ongoing to see if these PLACs contain sufficient ^{10}Be.

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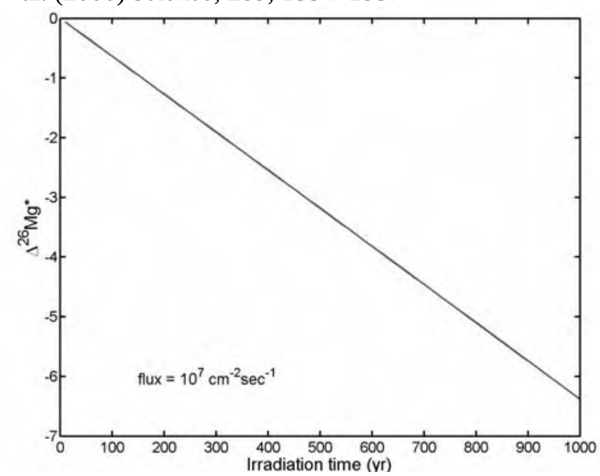

Fig. 1 Δ^{26}Mg* evolution with irradiation time, assuming the proton flux is 10^7 cm^{-2}sec^{-1}.

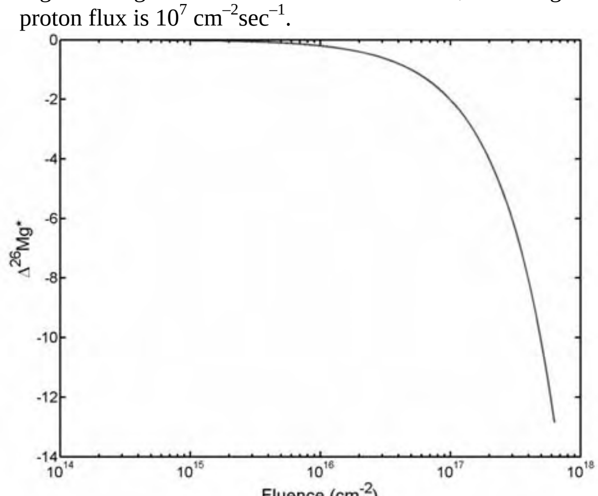

Fig. 2 Δ^{26}Mg* evolves with fluence. The total fluence of ~2×10^{17} cm^{-2} is required to produce a 4‰ depletion in ^{26}Mg