THE ORIGIN OF Al-26. D. Dearborn[1], T. Lee[2] and C. J. Wasserburg[3]. (1) Lawrence Livermore Nat. Lab., Livermore, CA; (2) Inst. of Earth Sci., Academia Sinica, Taipei; Div. Geol. & Planet. Sci., Caltech, Pasadena, CA 91125.

It has been known for a decade that large amounts of ^{26}Al were present in the early solar system [1]. More recently, a surprisingly strong 1.8 MeV γ-ray emission line, characteristic of ^{26}Al decay (mean life 1 Ma), has been detected in the interstellar medium [2,3,4]. In the following, we discuss some of the implications of this discovery on the origin of ^{26}Al.

The observed γ-ray flux implies the presence of about $4M_\odot$ of ^{26}Al if its sources are concentrated toward the interior of the galaxy (e.g., point source at the center, mimicking the CO distribution, etc.). If this represents a steady state abundance, then 4×10^{-6} $M_\odot$ of ^{26}Al must be injected into the interstellar medium every year. The directional data suggest, but do not require, that this ^{26}Al is distributed within ±5° (i.e., ±1 kpc if the distance is 10 kpc) of the galactic center. If correct, these observations pose severe constraints on the possible production sites of ^{26}Al which so far include Wolf-Rayet stars, Type II supernovae, novae, and asymptotic branch giants (AGB).

Observations of the radio and far infrared flux, produced when Lyman continuum photons of O and B stars are reprocessed in H-II regions, indicate that about 10% of these stars reside in the inner kps of the galaxy [5]. This directly impacts the suggestions that massive stars (including Wolf-Rayet stars and Type II supernovae) are the source of ^{26}Al, since in that case 90% of the ^{26}Al would reside outside of the central region of the galaxy. However, more refined measurement of angular distribution of ^{26}Al is required before these sources can be conclusively rejected.

In low mass sources, such as novae and AGB stars, ^{26}Al is produced via proton capture on Mg seeds. For $T_7 < 7$ (temperature in units of 10^7°K), the capture on ^{24}Mg is too slow to contribute, so only the initial ^{25}Mg abundance is available as seed for ^{26}Al production. If that abundance is solar (6×10^{-5} by mass) and if the yield, defined as the ratio of ejected ^{26}Al to initial ^{25}Mg, is Y, then the total amount of ejecta that the ^{26}Al sources return to the interstellar medium must be $0.067/Y$ $M_\odot$/yr. If f denotes the fractional contribution of ejecta from ^{26}Al sources to total mass ejected by all stars, then the total rate of returning mass to the interstellar medium would be $0.067/Y/f$ $M_\odot$/yr. This return mass flux must be balanced by the removal rate due to star formation, if we are to have an interstellar medium at steady state. Therefore, the rate of star formation for the central kpc of the galaxy is $0.067/Y/f$ $M_\odot$/yr from the ^{26}Al observation. The star formation rate can also be derived from the above estimate that about 10% of all O and B stars are being formed in the galactic center. If the initial mass function estimated for stars for the solar neighborhood also applies to the galactic center, then the total star formation rate for the latter should be about 0.3 $M_\odot$/yr using the simple Salpeter formula [5]. The comparison between these two estimates then implies $Y\times f=0.2$. So Y is at least 20% since f must be less than 1. For more reasonable values of f, Y must approach 100%. Thus, nearly all initial ^{25}Mg must be converted and quickly ejected. This can be relaxed by a factor of 7 if ^{24}Mg can be utilized as seed nuclei. It can also be relaxed by a factor of about 10 if the ^{26}Al is not restricted only to the galactic center. In any case, the ^{26}Al production must be a highly efficient process. As we shall see below, this represents a challenge for nuclear astrophysics, yet to be satisfactorily met.

Recent calculations [6] of nucleosynthesis in novae indicate that Y = 1 is possible for the artificial case of a low mass envelope containing exceed-

ingly high initial ^{12}C. However, the small mass of the ejecta ($\sim 2.5\times10^{-5}$ $M_\odot$) coupled with the low mass fraction for ^{26}Al ($\sim 5\times10^{-5}$) results in the production of only 1.4×10^{-9} $M_\odot$ ^{26}Al per nova. The ^{26}Al injection rate discussed above thus requires 3000 novae per year in the central region of the galaxy, in contrast to the typical estimate of 40 novae per year for the entire galaxy. The high temperature of the novae explosion (T_7 = 15-32) not only causes proton reactions on ^{24}Mg but also destroys ^{26}Al. Hence, it does not help. Higher initial Mg abundance would enhance the production, reducing the above rate, and some novae seem to have such high initial abundance. Nonetheless, it is probably difficult to reconcile such a large disparity. Also, novae are believed to be a major source of ^{15}N in the galaxy. A nearly two orders of magnitude increase in novae rate over the generally accepted value would have difficulty avoiding overproducing ^{15}N in the galactic center. However, this cannot be dismissed outright without a modeling of chemical evolution, including ^{15}N destruction mechanisms.

AGB stars are thought to have formed when thermal pulses caused their convective envelopes to penetrate more deeply and dredge up carbon-rich materials. If the base of the convective envelope enters a sufficiently hot region, then ^{26}Al can be produced via proton capture. Subsequent loss of the envelope would then inject the newly synthesized ^{26}Al into the interstellar medium. AGB stars cover spectral types M, C, S and J. Among these, only the J type stars were observed to have $^{17}O/^{18}O$ ratios consistent with base temperatures high enough to produce ^{26}Al and must be considered as candidate sources. A simple model was constructed to evaluate Y for a range of base temperatures of T_7 = 5-10 and for envelope mass loss time scales in the range of 10^5-10^9 years. Typical values for Y were less than 0.03, insufficient to sustain ^{26}Al, but for $T_7 > 7$ and timescales commensurate with the mean life of ^{26}Al, Y could approach unity. However, at these temperatures, ^{24}Mg is becoming a significant seed while the destruction of ^{26}Al by protons also becomes substantial. Neither of these effects were included in our calculation. Thus a more detailed network calculation would be necessary to evaluate how large a value of Y can actually be obtained.

All of the sources considered here have difficulty in producing the observed interstellar ^{26}Al. These difficulties are reduced but not eliminated if the ^{26}Al production is not confined to the central region of the galaxy. Possible solutions include an initial mass function tailored to form primarily the ^{26}Al sources and changes in key nuclear reaction rates to permit a large increase in seed nuclei (^{24}Mg, perhaps even ^{20}Ne) without enhancing the ^{26}Al destruction rates. Other alternatives might be opened up by postulating rare transient conditions, such as a short burst of star formation or supermassive objects; but such ad hoc resolutions are difficult to prove and their invocation does little to teach us about the evolution of the galaxy.

The abundance of ^{26}Al in the early solar system is several times higher than the presently observed interstellar value. If this is not the result from a nearby local source but represents the typical intestellar value, 4.6 gigayears ago, then the problem of its origin requires even more extreme resolutions than those just discussed.

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