Neutron Nucleosynthesis in a Low-Mass, Low-Metallicity AGB Star

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Stellar evolution calculations confirm that semiconvection will occur below the convective envelope of a low-mass, low-metallicity AGB star, after a thermal pulse. These calculations show how semiconvection leads to the creation of a "^{13}C layer" in the star, which can provide a potent source of neutrons (via the $^{13}C[\alpha,n]^{16}O$ reaction) in a convective shell during later evolution. The rate at which neutrons are released is largely determined by the rate at which the ^{13}C layer is introduced into the convective shell. The ^{13}C neutron source maintains neutron densities of 10^9–10^{10} n/cm^3 for ~ 10 years. This provides a neutron exposure $\tau \approx 0.15$ mb^{-1} during most of the pulses calculated. Because of the strong filtering effect by light elements, only 10–20% of the neutrons produced will be captured by iron-seed nuclei, each such nucleus capturing 4–5 neutrons per pulse. Approximately one half of the irradiated material in a convective shell survives to be irradiated during a subsequent pulse, and this material is characterized by a neutron exposure parameter $0.2 \leq \tau_0(\text{mb}^{-1}) \leq 0.3$, which is remarkably similar to the exposure parameter characterizing solar system material.

Dredge up of interior processed material does not occur unless some form of convective overshoot is adopted. Dredge up will occur when the model star is dimmer than $M_{bol} \approx -4.5$, creating either MS-, S-, or C-star surface characteristics. Besides inducing dredge up, overshoot leads to the production of more ^{13}C, as well as to the production of more neutron filters (such as ^{14}N and ^{22}Ne) near the ^{13}C layer. The neutron irradiation in overshoot models also occurs at neutron densities of 10^9–10^{10} n/cm^3, but leads to a neutron exposure that is approximately 1.5 times that of models without overshoot.

It is found that ^{99}Tc, a very temperature sensitive radioactive isotope, can survive the temperatures in excess of $300 \cdot 10^6$ K that are reached at the base of the convective shell. This is because ^{99}Tc spends most of its time in much lower temperature regions of the convective shell.