From Lithium to Uranium: Elemental Tracers of Early Cosmic Evolution
Proceedings IAU Symposium No. 228, 2005
V. Hill, P. François & F. Primas, eds.

doi:10.1017/S1743921305006320

Neutron sources during shell C-burning in massive stars

Marco Pignatari[1], R. Gallino[1], C. Baldovin[1] and F. Herwig[2]

[1]Dipartimento di Fisica Generale, Via P. Giuria 1, Torino 10125, Italia
email: pignatar@ph.unito.it, gallino@ph.unito.it, baldovin@studenti.ph.unito.it

[2]Los Alamos National Laboratory, Los Alamos, NM 87544, USA
email: fherwig@lanl.gov

Abstract. We present a study of the s−process nucleosynthesis (weak s-process) occurring during convective core He−burning and convective shell Carbon−burning in a massive star of 25 $M_{\odot}$. We use an updated nuclear network for the various neutron sources and for all neutron captures and β-decay rates involved. Large uncertainties affect the final yields due to the present unsatisfactory knowledge of all neutron capture cross sections involved.

Keywords. Nuclear reactions, nucleosynthesis,abundances, stars: abundances

---

During the presupernova evolution of a massive star, the convective core He−burning and the convective shell Carbon−burning phases are the astrophysical sites of the *weak* s-process, the region between iron and $A \simeq 90$. During core He burning, we use the same stellar evolutionary model as in Raiteri *et al.* (1991a). The ^{22}Ne(α,n)^{25}Mg reaction by Jaeger *et al.* (2001) is the major neutron source. The neutron capture network has been updated, using the Bao *et al.* (2000) recommended cross sections for radiative neutron captures, and a number of recent (n,p) and (n,α) channels. During core He burning the most important neutron poisons are the primary ^{16}O and the metallicity-dependent ^{25}Mg. As a test, the shell C−burning nucleosynthesis is followed with a post−processing code, as in Raiteri *et al.* (1991b), using a constant temperature $T = 1.05 \times 10^9$ K and a density $\rho = 10^5$ cm^{-3}. The network is extended up to all unstable isotopes along the s-path with a β^- half−life down to 5 minutes. During C burning, α particles and protons are made available by the direct channels ^{12}C(^{12}C,α)^{20}Ne and ^{12}C(^{12}C,p)^{23}Na. The neutron density reaches a peak value of 3×10^{11} cm^{-3} in the initial phase and then decreases following the decrease of α−particles. As shown in Fig. 1a, the most important neutron source is ^{13}C(α,n)^{16}O, where primary ^{13}C results from ^{12}C(p,γ)^{13}N(β^+)^{13}C. A primary abundance of ^{17}O is synthesised by the ^{16}O(n,γ)^{17}O channel. It gives rise to another important neutron source via the reaction ^{17}O(α,n)^{20}Ne (Caughlan & Fowler 1988). However a strong competing reaction is ^{17}O(n,α)^{14}C (Schatz *et al.* 1993). As shown in Fig. 1b, ^{16}O is the most important neutron poison during the initial phase of shell C−burning, followed by ^{25}Mg and ^{17}O. In Fig. 2a the final production factors $X_i/(X_i)_{\odot}$ in the shell C−burning region are compared with the production factors at the end of core He−burning. The strong contribution to the final weak s−process yields by shell C−burning is evident, in particular in the Kr−Rb−Sr region. The final yields suffer from a large uncertainty in the Kr−Rb−Sr region close to neutron magic N = 50. This is due to the quite large uncertainty (up to 20%) of all the neutron capture cross sections involved, including the light neutron poisons. In Fig. 2b we show that increasing by 20% the neutron capture cross sections of all stable isotopes between ^{57}Fe and ^{82}Se, the final production factors in the region Kr−Rb−Sr change by a factor of

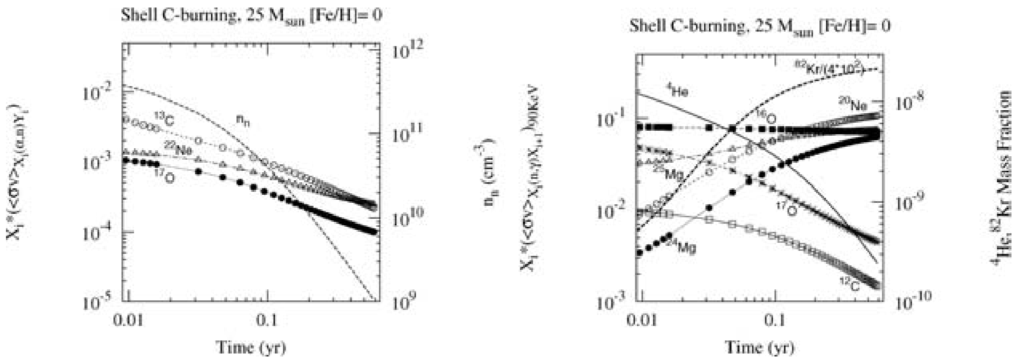

Figure 1. Panel a): Temporal behaviour during shell C−burning of the neutron density and of the mass fractions of the major neutron sources multiplied by their ^{i}X(α,n)^{i}Y rates (90 KeV). Panel b): Temporal behaviour during shell C−burning of the most important neutron poisons multiplied by their respective neutron capture cross sections at 90 KeV. Plotted are also the mass fractions of ^{4}He and ^{82}Kr$\cdot 10^{2}$.

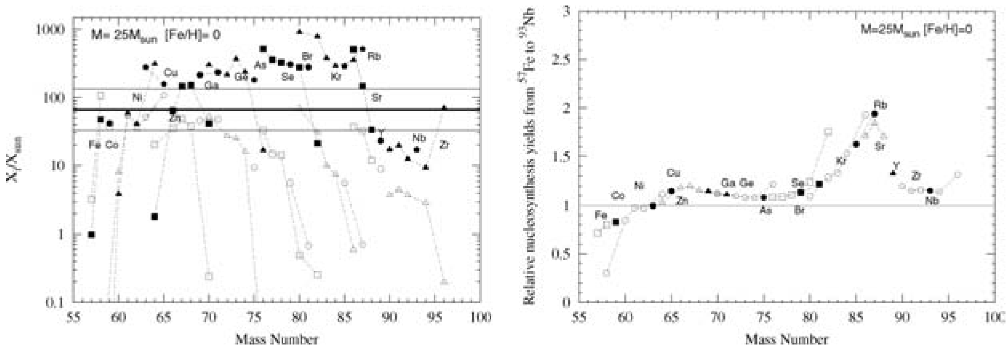

Figure 2. Panel a): Production factors between ^{57}Fe and ^{93}Nb at the end of core He−burning (empty symbols) and at the end of shell C−burning (full symbols). Panel b): Ratio with respect to the standard case of the final yields after shell C−burning in a test case where all neutron capture cross sections between ^{57}Fe and ^{82}Se have been increased by 20%.

1.5−2. To conclude, during the shell C−burning the most important neutron source is primary ^{13}C(α,n)^{16}O and the most important neutron poison is primary ^{16}O(n,γ)^{17}O. This implies a secondary-like behaviour of the weak s-process with varying the initial metallicity.

References

Bao, Z.Y., Beer, H., Käppeler, F., Voss, F., Wisshak, K., & Rauscher, T. 2000, *ADNDT* 76, 70
Caughlan, G.R. & Fowler, W.A. 1988, *ADNDT* 40, 283
Jaeger, M., *et al.* 2001, *Phys. Rev. Lett.* 87, 2501
Raiteri, C.M., Busso, M., Gallino, R., Picchio, G., & Pulone, L. 1991, *ApJ* 367, 228
Raiteri, C.M., Busso, M., Picchio, G., & Gallino, R. 1991, *ApJ* 371, 665
Schatz, H., Käppeler, F., Koehler, P.E., Wiescher, M., & Trautvetter, H.-P. 1993, *ApJ* 413, 750

https://doi.org/10.1017/S1743921305006320 Published online by Cambridge University Press