The Weak s-process after Core He-burning: the convective Shell C-burning contribution

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(Santa Barbara, March 9, 2006)

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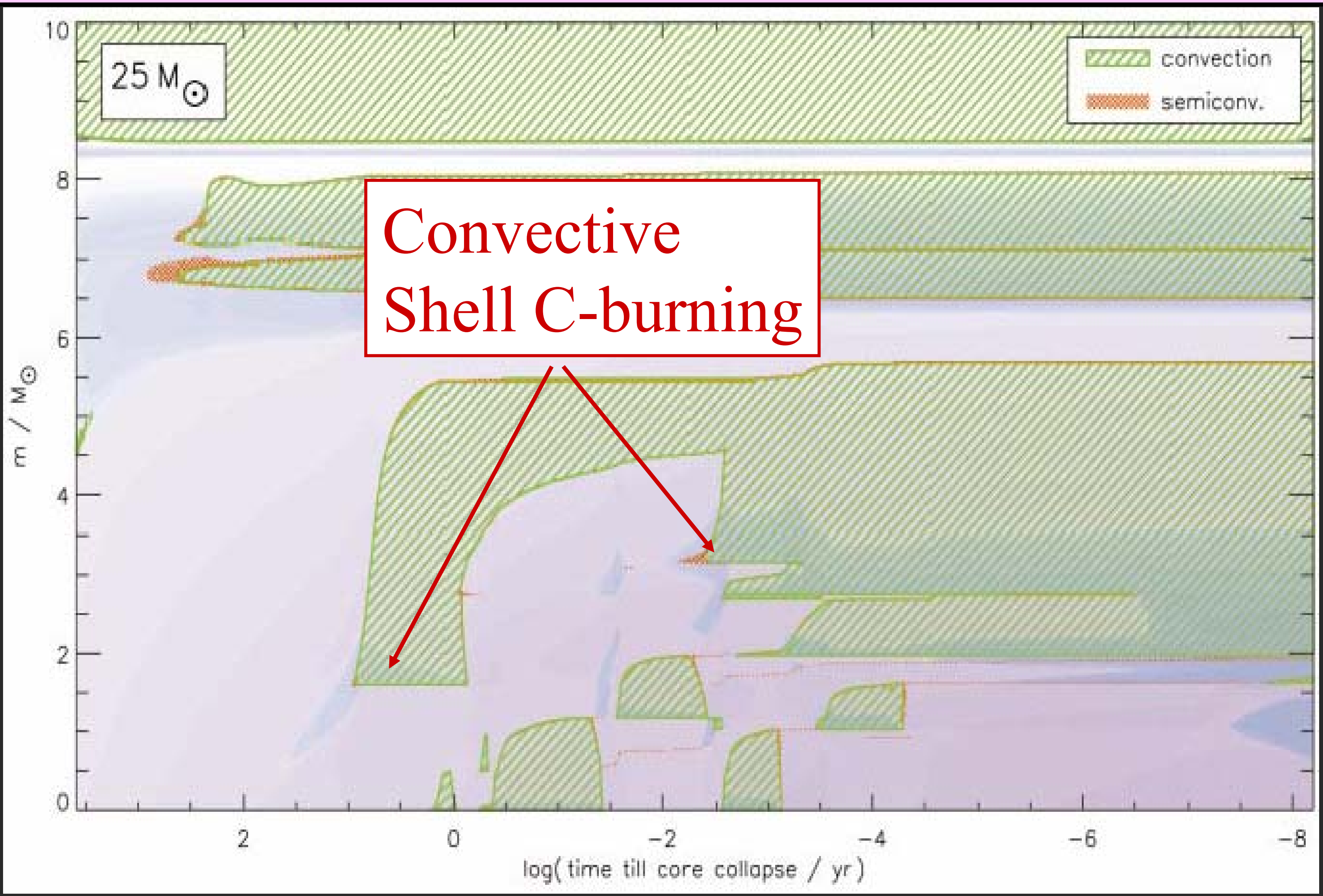
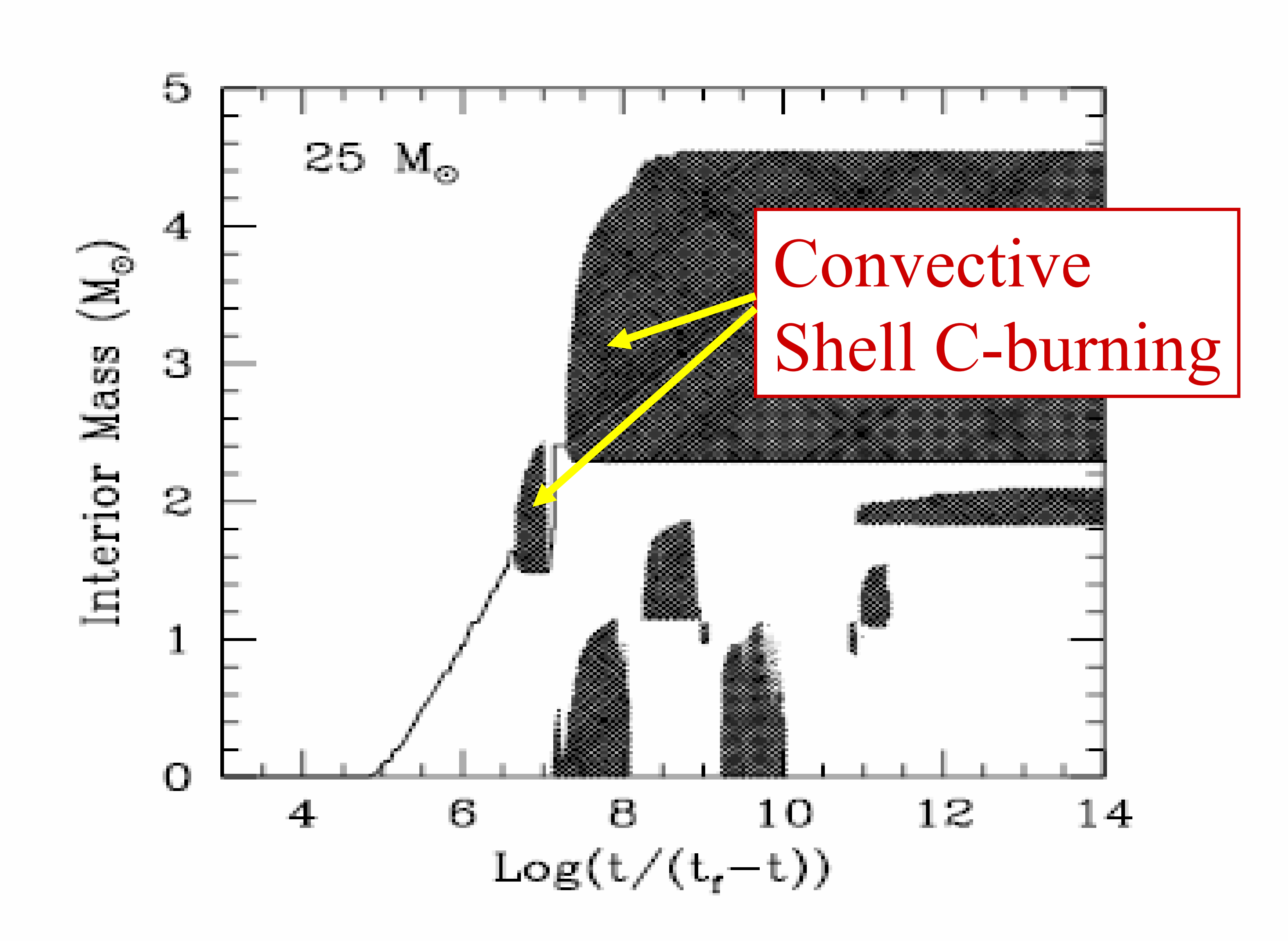
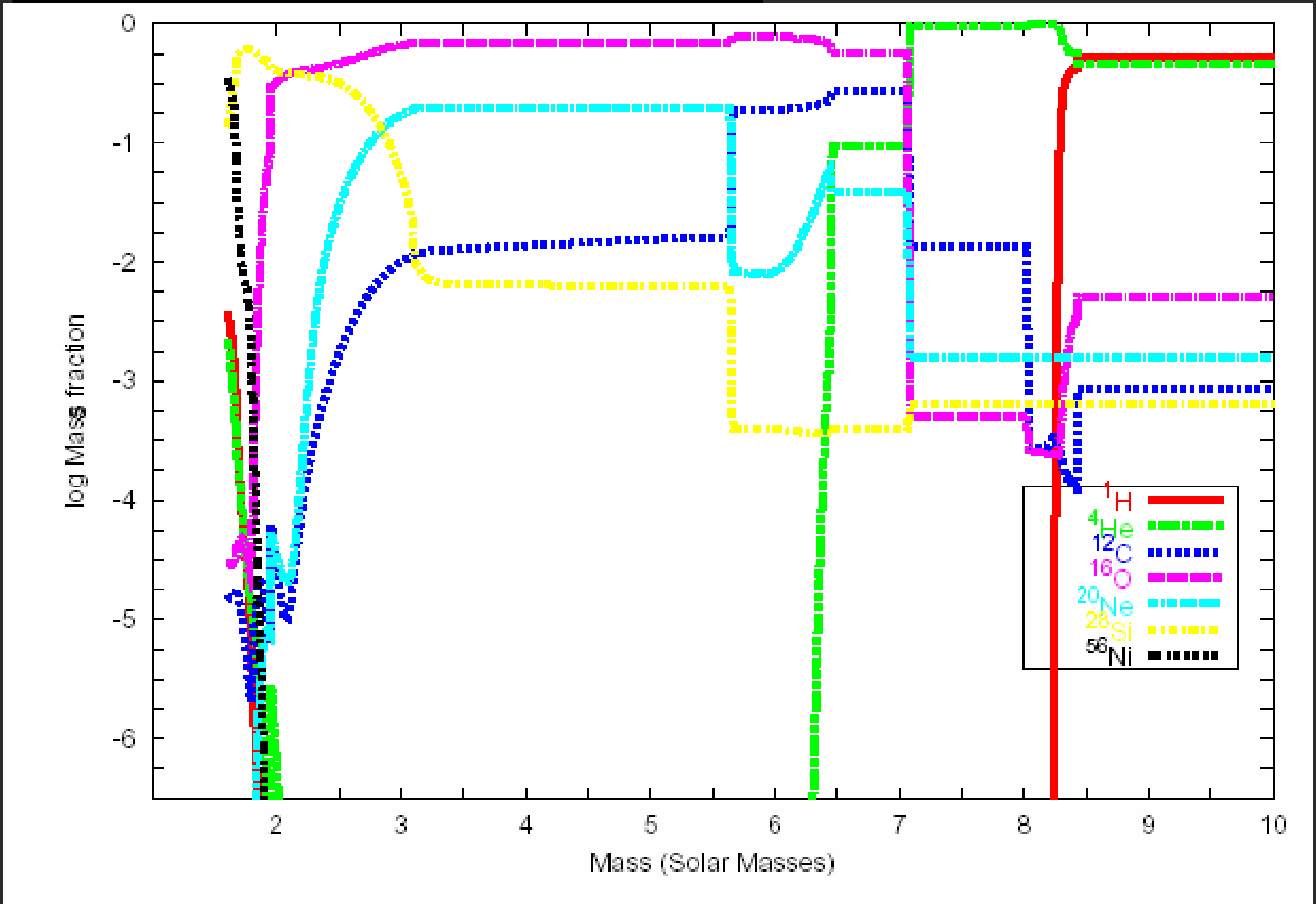
Kippenhahn's Diagram for a star with M= 25 M(sun) and solar metallicity (Woosley, Heger & Weaver 2002)



Kippenhahn's Diagram for a star with M= 25 M(sun) and solar metallicity (Limongi, Straniero & Chieffi 2000)



Pre-Supernova composition



$M = 25\ M_{sun}\quad Z = Z_{sun}$ (Alex Heger homepage)

Models:
Hydrostatic nucleosynthesis in massive stars

- Post-processing models follow:

  Convective Core He-burning and

  Convective Shell C-burning

  (Raiteri et al. 1991, 1993)

- Updated network

  Bao et al. 2000 for (n,γ),

  β decay rates from various sources,

  (n,p) and (n,α) channels....

The weak s-process:

Convective Core He-burning

Low neutron density (~10^6 n/cm^3)
T~3-3.5 10^8 K
Classical s-process

See Lamb et al., Couch et al., Raiteri et al., Prantzos et al. ......

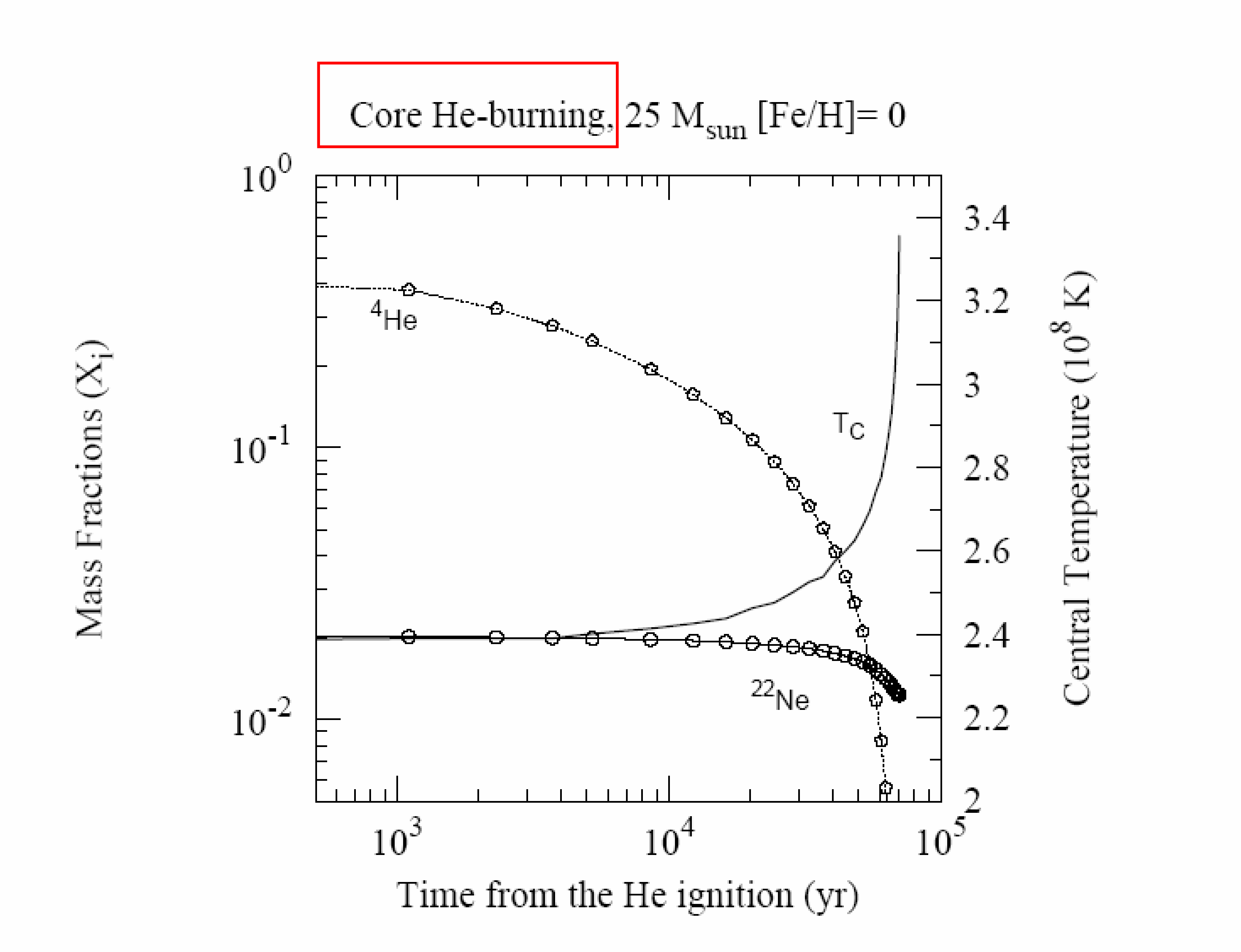
Convective Shell C-burning

Peak neutron density
(10^{11}- 10^{12} n/cm^3) (?)

T~ 10^9 K (?)

See Arnett & Truran 1969, Raiteri et al. 1991

The final weak s component is an overposition of two different s(s+) components



Neutron source: $^{22}Ne(\alpha,n)^{25}Mg$ $T_{eff} > 2.5\text{-}3*10^8$ K!!!!

Neutron poisons: ^{25}Mg, ^{16}O

In the following C Shell:

C-burning:

$^{12}C(^{12}C,\alpha)^{20}Ne$, α-source ((α,n) channels are activated!)
$^{12}C(^{12}C,p)^{23}Na$, p-source
$^{12}C(^{12}C,n)^{23}Mg^*$, negligible (~ 1 ‰) ...

^{16}O is the most abundant isotope (and the most important neutron poison!)

Neutron exposure in the C Shell comparable with the Core He-burning neutron exposure!

In the convective C Shell:

Neutron sources:

$^{13}C(\alpha,n)^{16}O$, (Clayton 1968, Arnett & Truran 1969);
^{13}C is produced by $^{12}C(p,\gamma)^{13}N(\beta+)^{13}C$.
Temperature dependence for this neutron source.

$^{22}Ne(\alpha,n)^{25}Mg$, (….);
^{22}Ne unburned in the Core He-burning ashes.

$^{17}O(\alpha,n)^{20}Ne$, is it inportant?
^{17}O strongly produced by $^{16}O(n,\gamma)^{17}O$

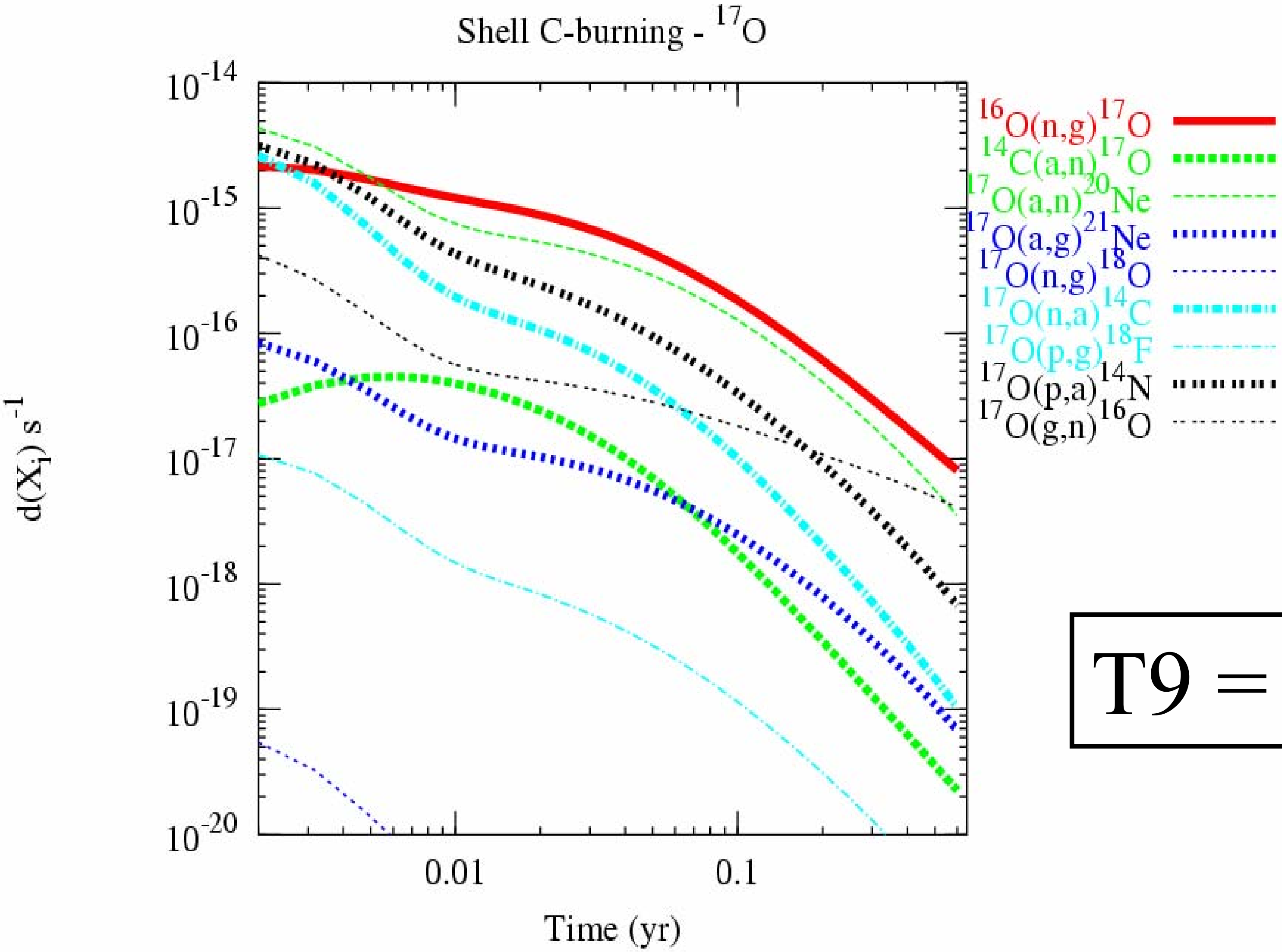
Photodisintegrations to consider during Shell C-burning (up to T9 ~ 1.2):

- $^{13}N(\gamma,p)^{12}C$*
- $^{17}F(\gamma,p)^{16}O$*
- $^{17}O(\gamma,n)^{16}O$
- $^{21}Na(\gamma,p)^{20}Ne$
- $^{25}Al(\gamma,p)^{24}Mg$*

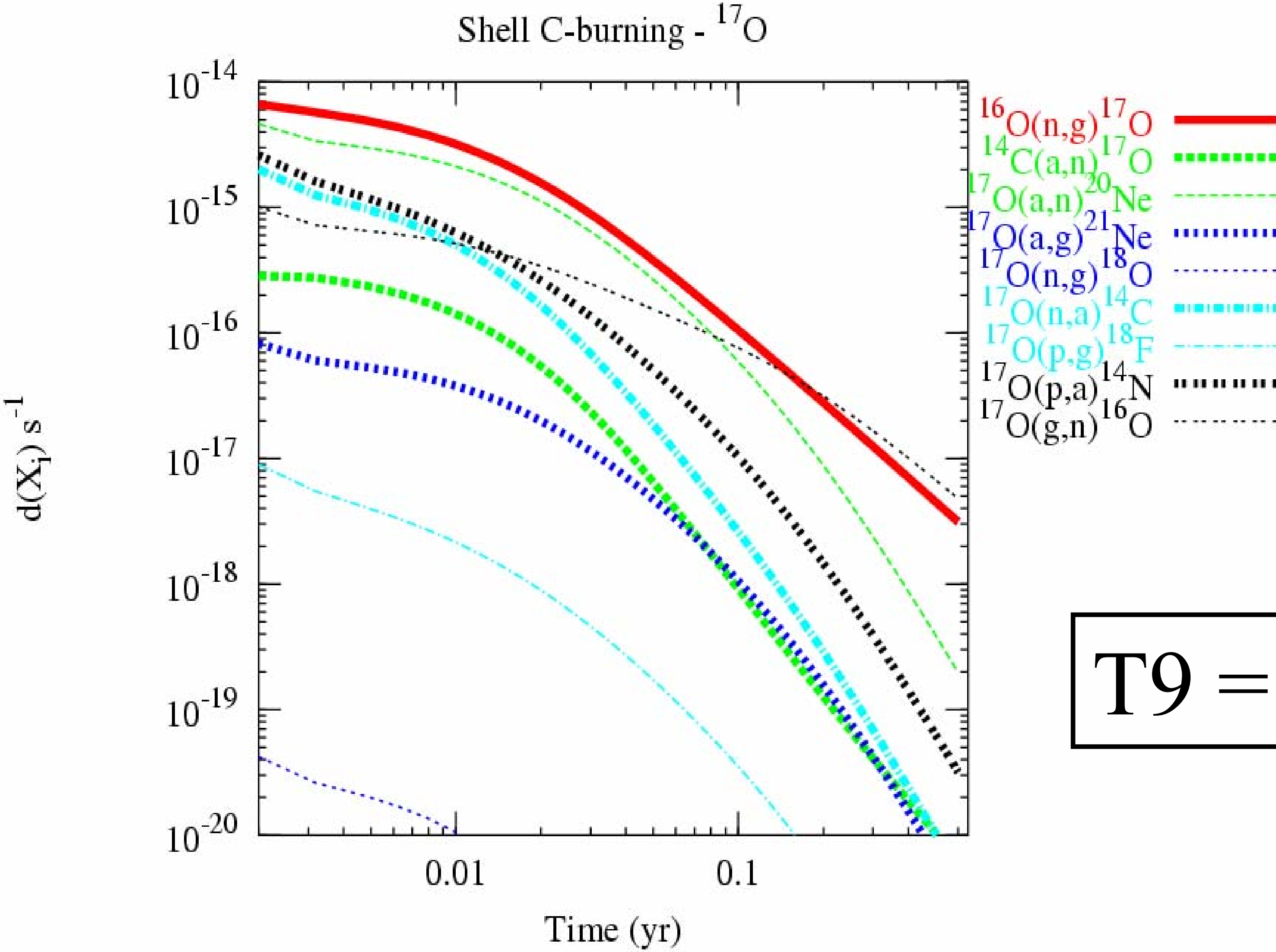
For T9 > 1.2

$^{29}P(\gamma,p)^{28}Si$, …

D(x(i)/A(i))/Dt = ρ*(x(j)/A(j))*(x(k)/A(k))*rate(jk)



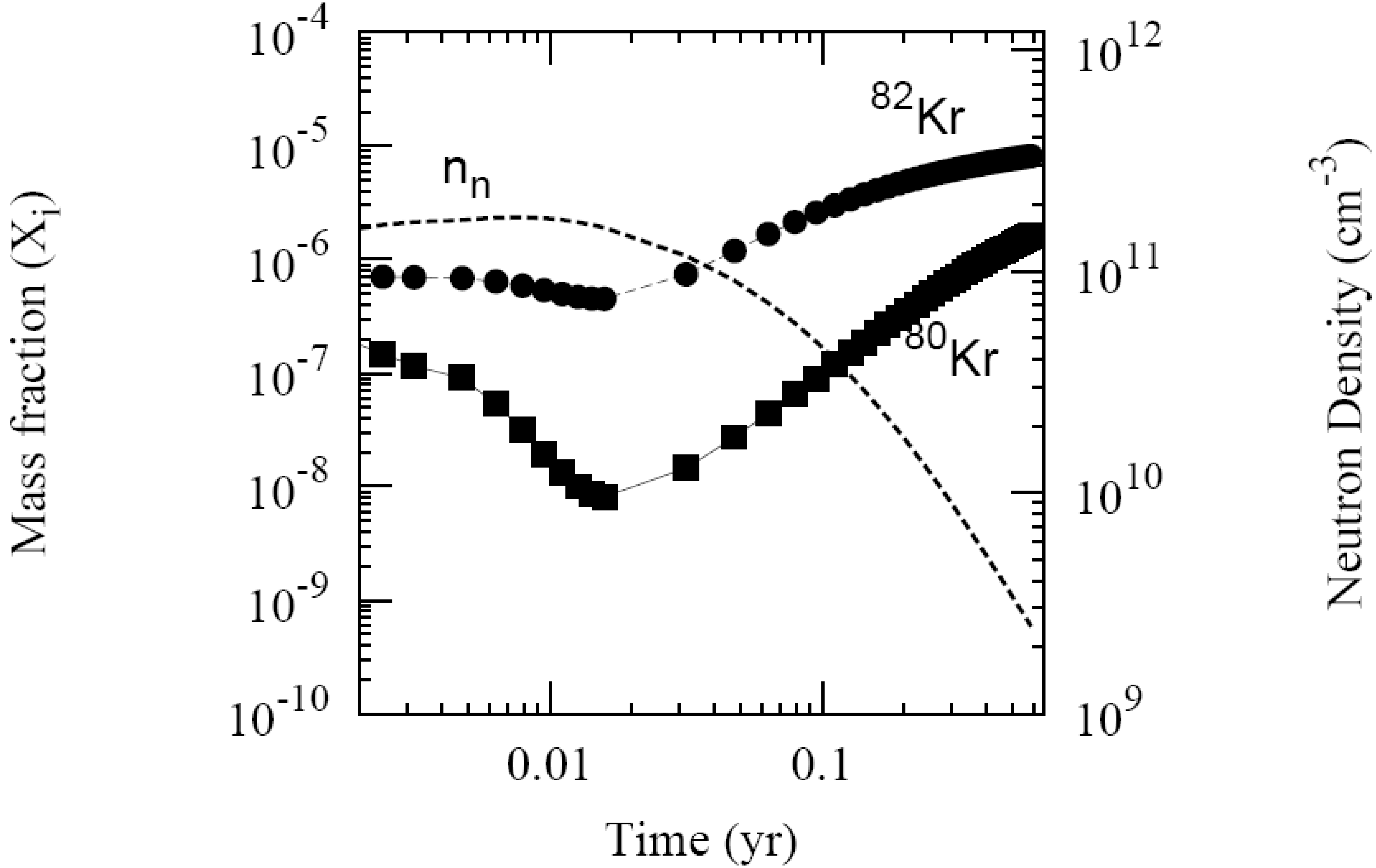
T9 = 1.05

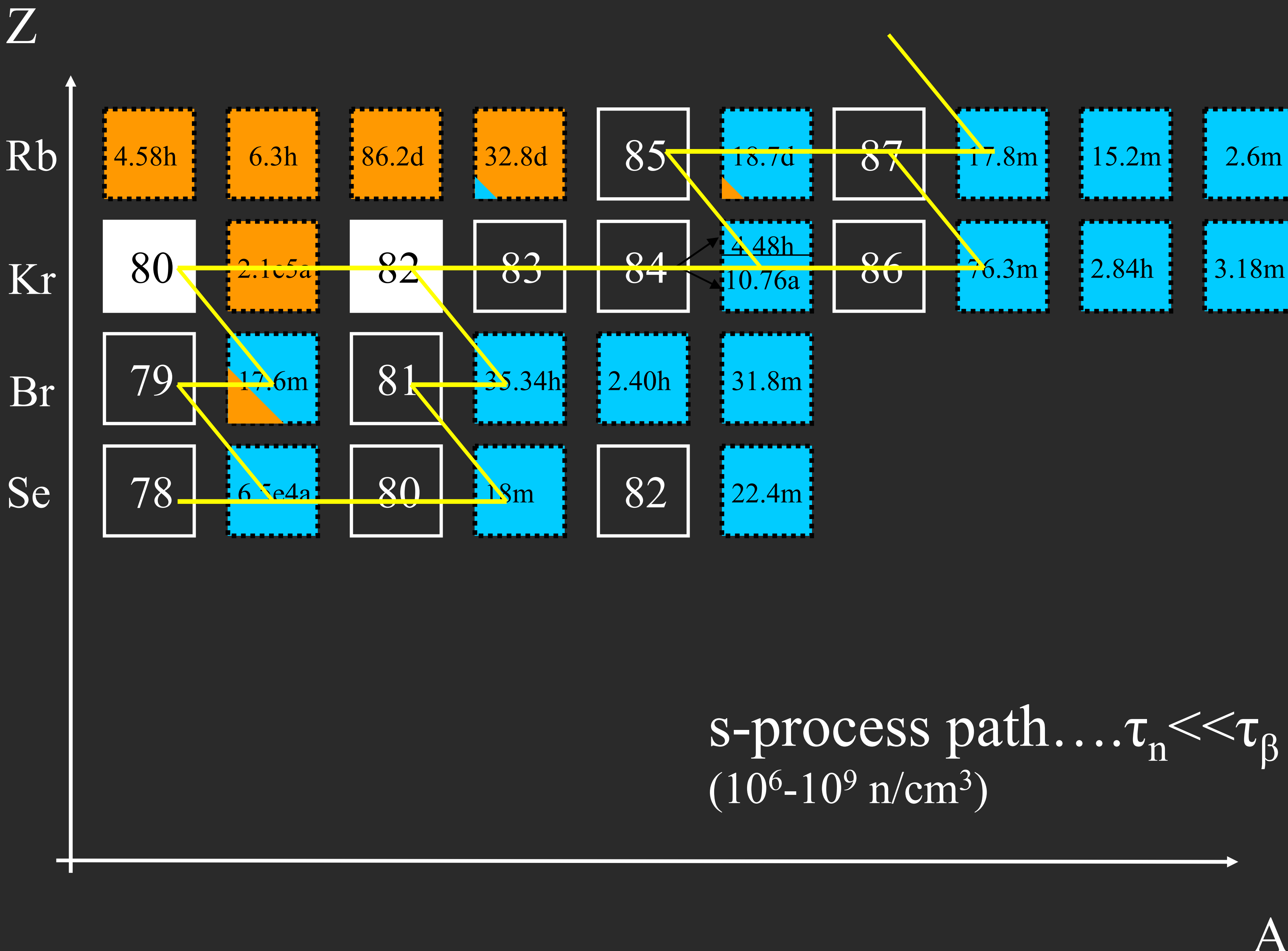


Shell C-burning - ^{17}O
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
$d(X_i)\ s^{-1}$
0.01
0.1
Time (yr)
$^{16}O(n,g)^{17}O$
$^{14}C(a,n)^{17}O$
$^{17}O(a,n)^{20}Ne$
$^{17}O(a,g)^{21}Ne$
$^{17}O(n,g)^{18}O$
$^{17}O(n,a)^{14}C$
$^{17}O(p,g)^{18}F$
$^{17}O(p,a)^{14}N$
$^{17}O(g,n)^{16}O$

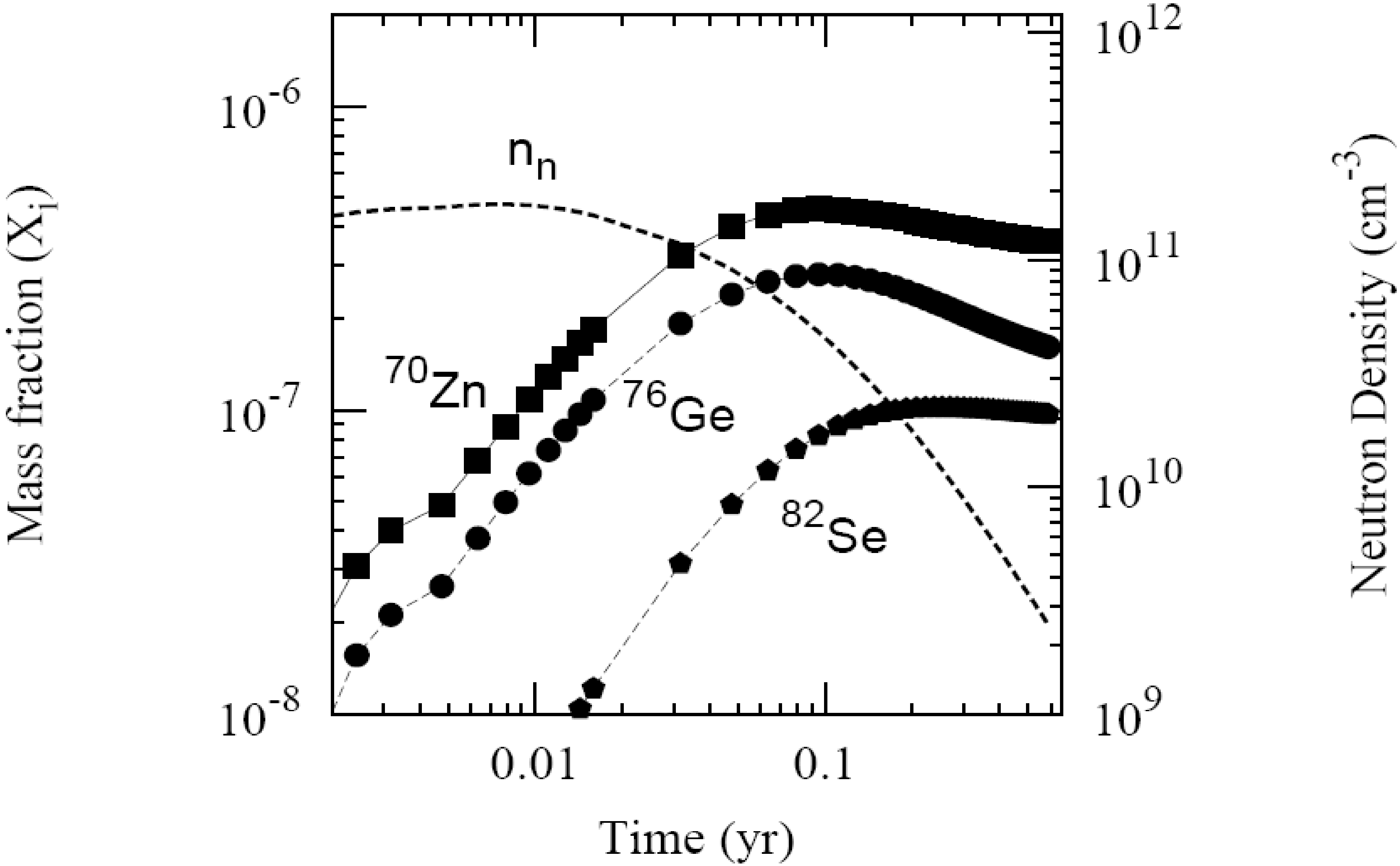
T9 = 1.10

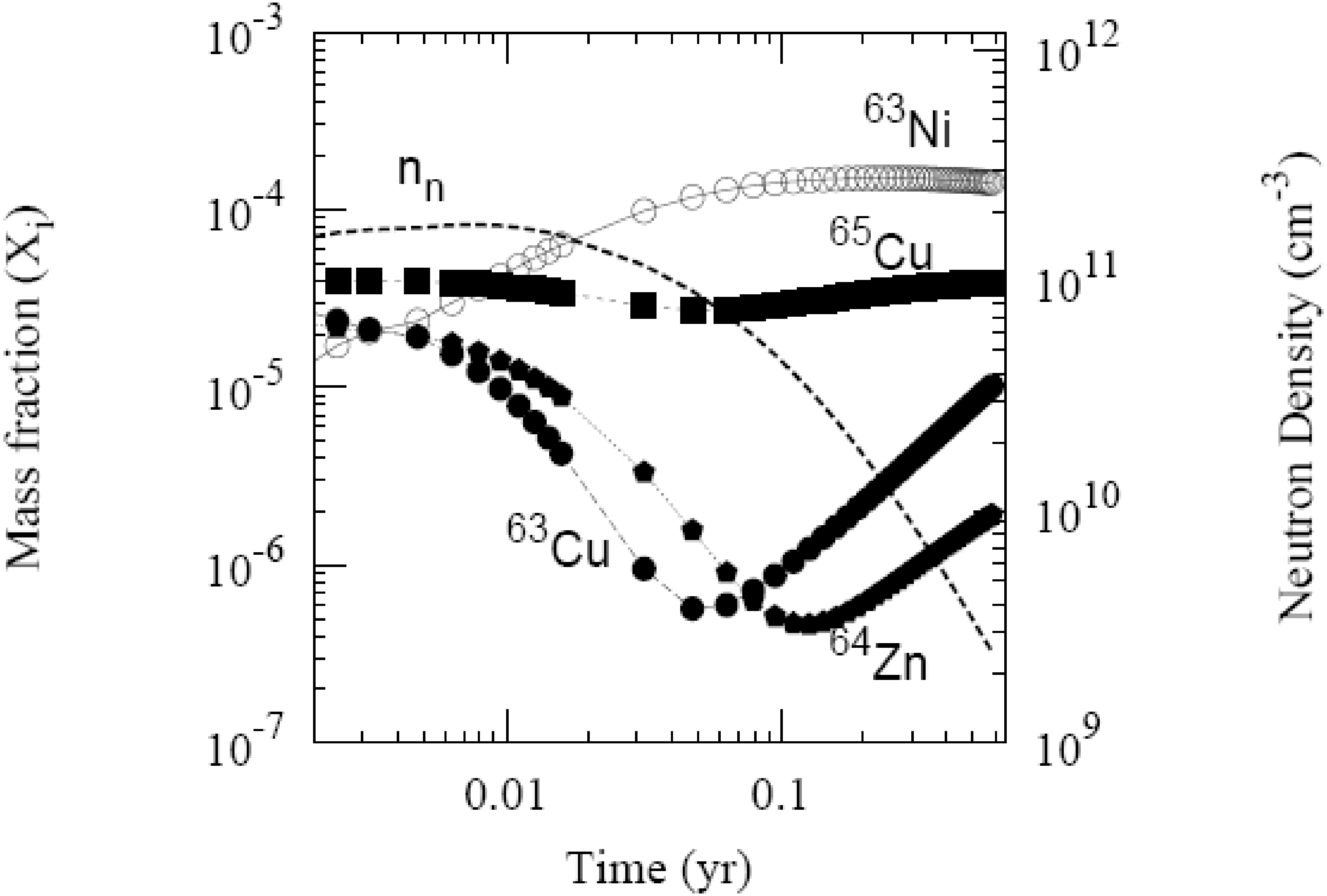
This is not a classic s-process!



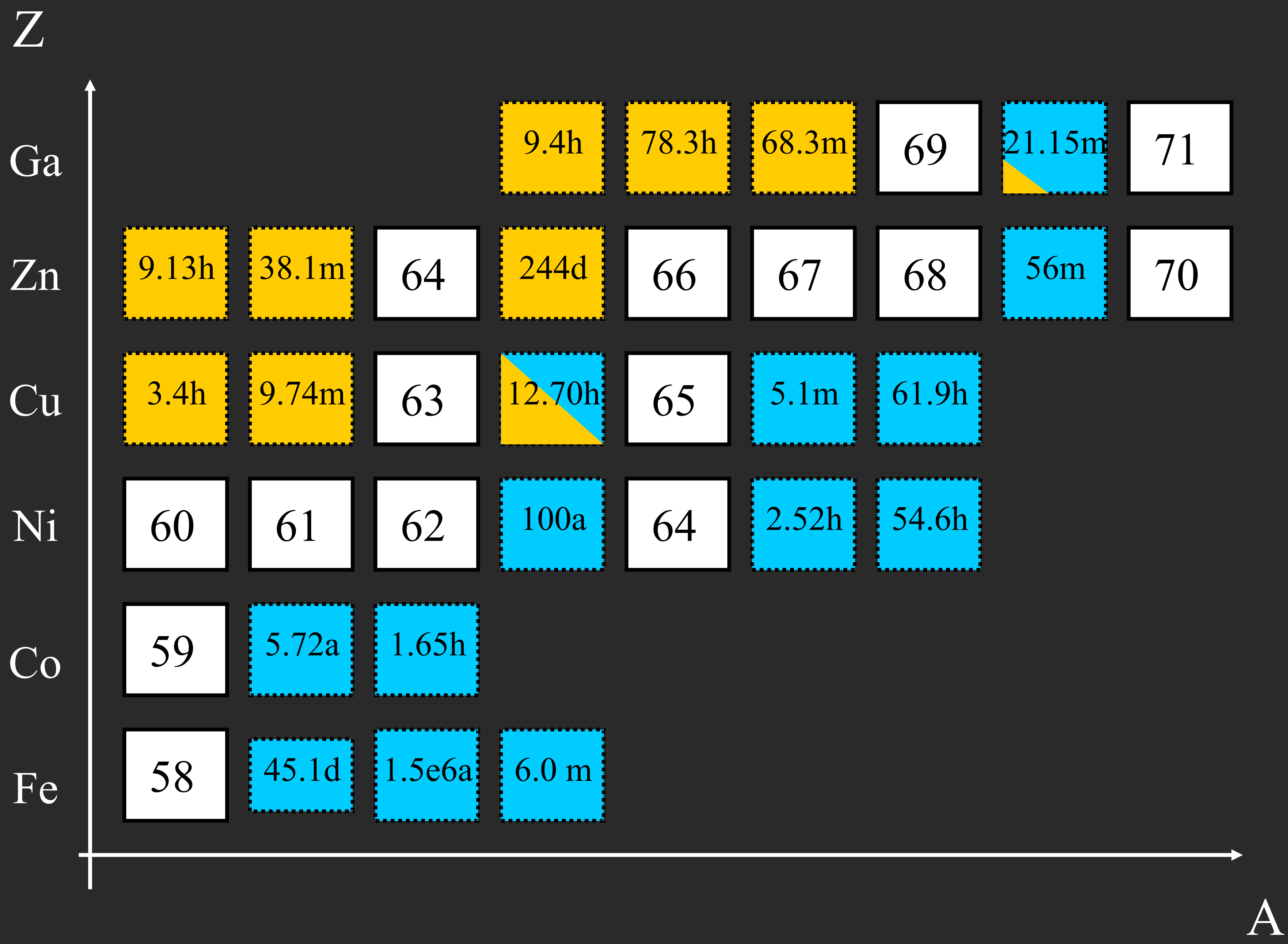

Z
Rb
Kr
Br
Se
4.58h
6.3h
86.2d
32.8d
85
18.7d
87
17.8m
15.2m
2.6m
80
2.1e5a
82
83
84
4.48h
10.76a
86
76.3m
2.84h
3.18m
79
17.6m
81
35.34h
2.40h
31.8m
78
6.5e4a
80
18m
82
22.4m
A
s-process path….$\tau_n << \tau_\beta$
(10^6-10^9 n/cm^3)

This is not a classic s-process!

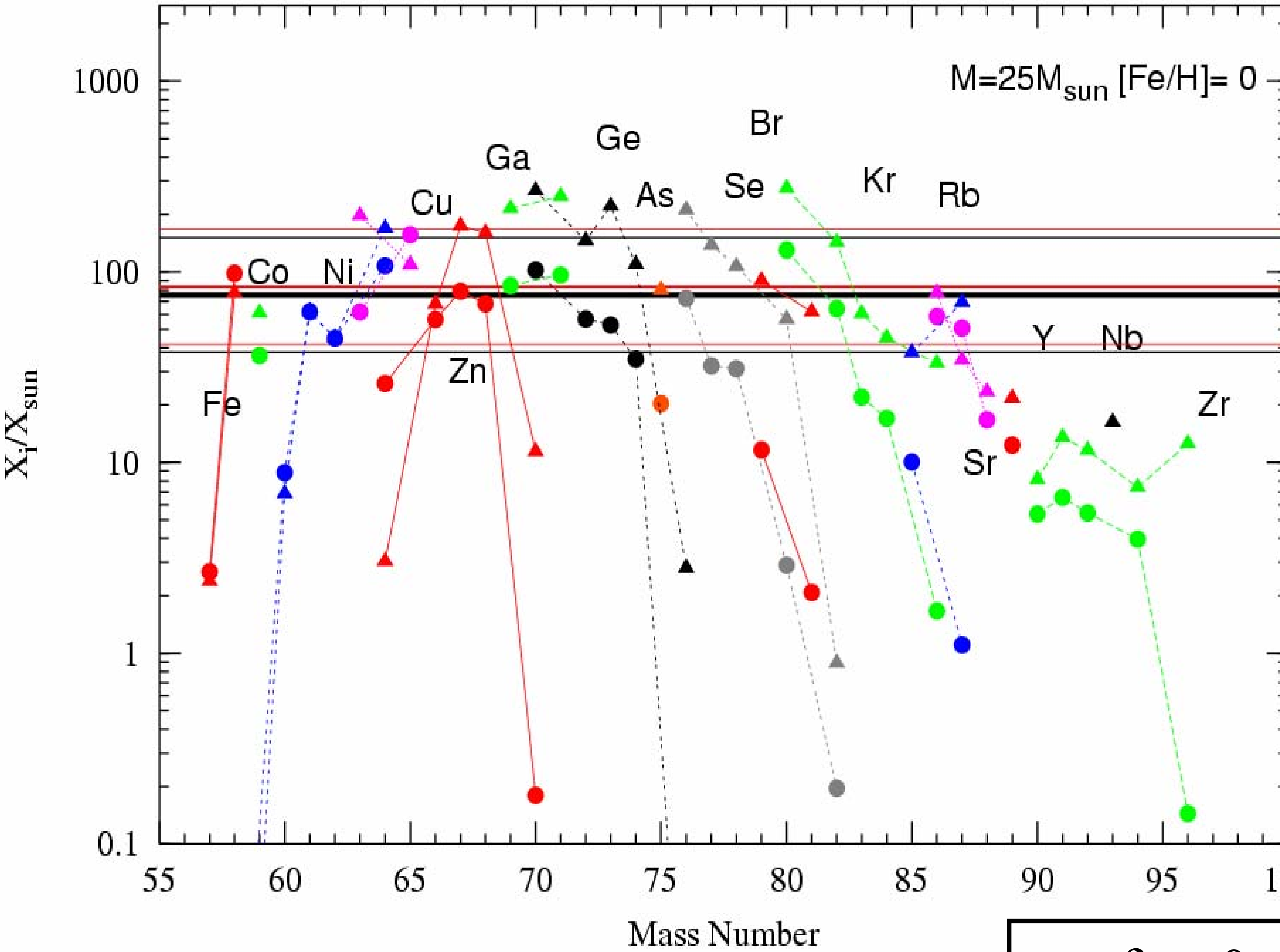




10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{12}
10^{11}
10^{10}
10^{9}
Mass fraction (X_i)
Neutron Density (cm^{-3})
Time (yr)
0.01
0.1
n_n
^{63}Ni
^{65}Cu
^{63}Cu
^{64}Zn

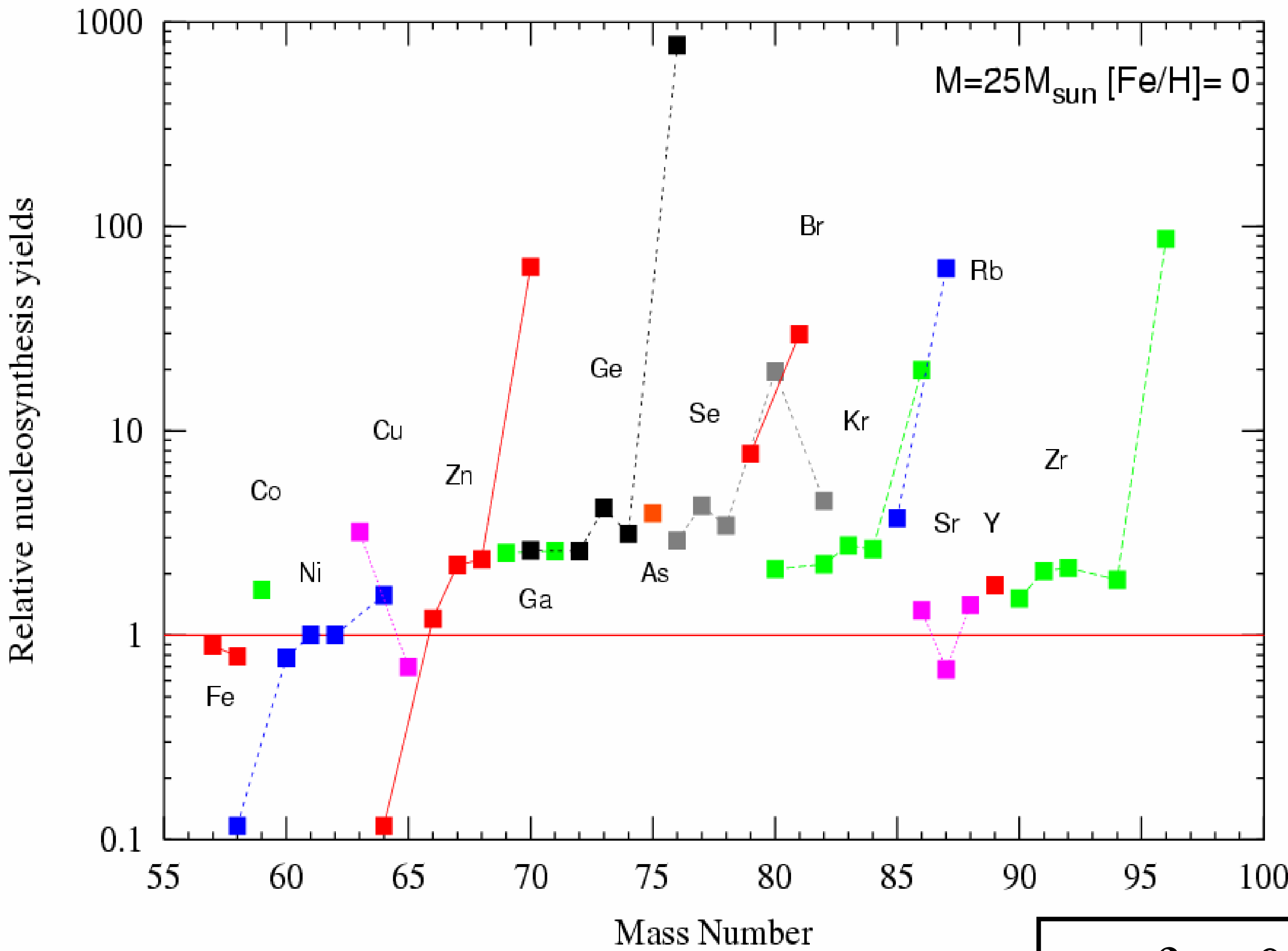

Z
Ga
Zn
Cu
Ni
Co
Fe
A
9.4h
78.3h
68.3m
69
21.15m
71
9.13h
38.1m
64
244d
66
67
68
56m
70
3.4h
9.74m
63
12.70h
65
5.1m
61.9h
60
61
62
100a
64
2.52h
54.6h
59
5.72a
1.65h
58
45.1d
1.5e6a
6.0 m

C-burning (T9 ~ 1.05) over the Core He-burning ashes...



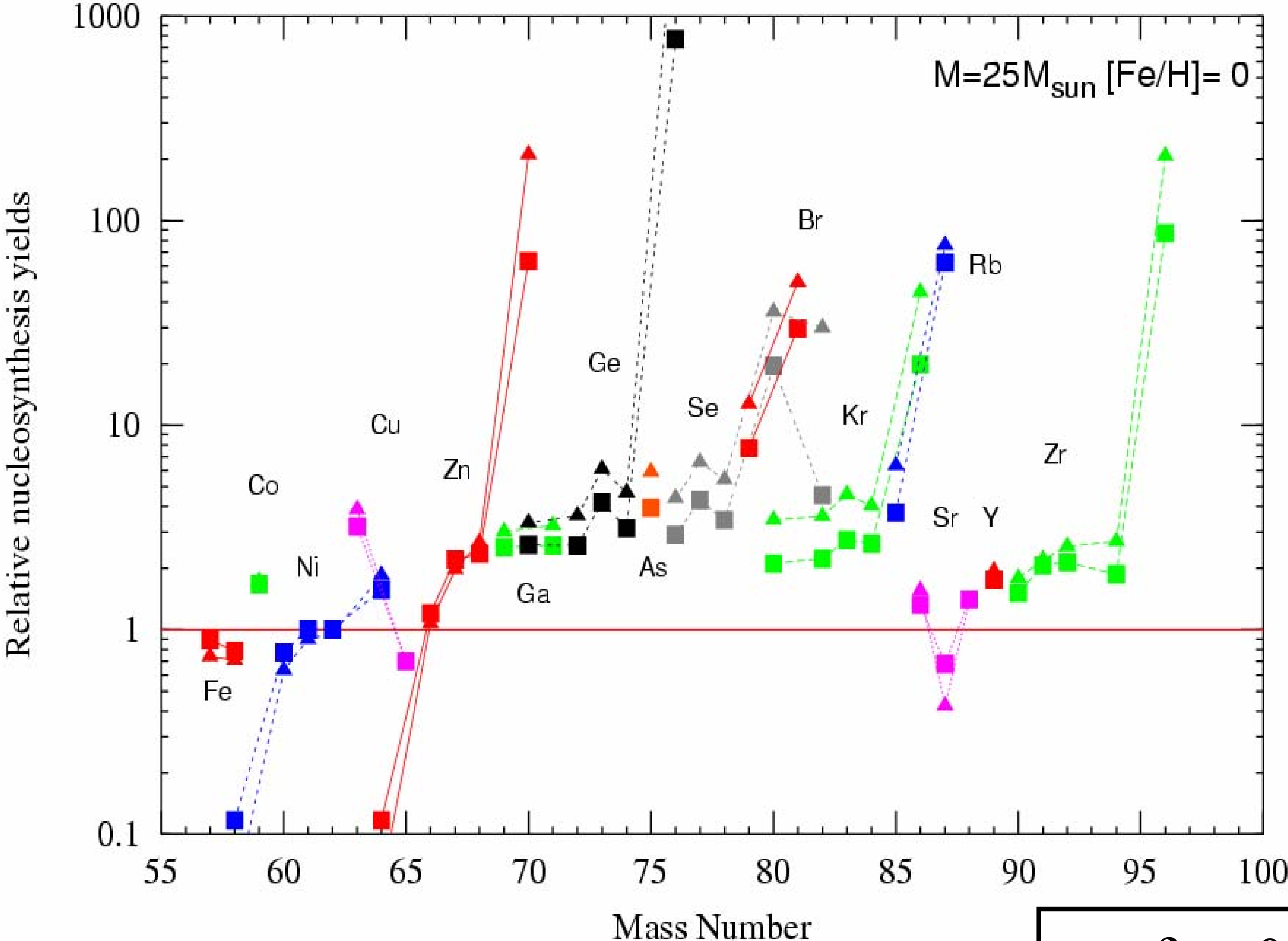
…after 0.6 yr

C-burning (T9 ~ 1.05) over the Core He-burning ashes...



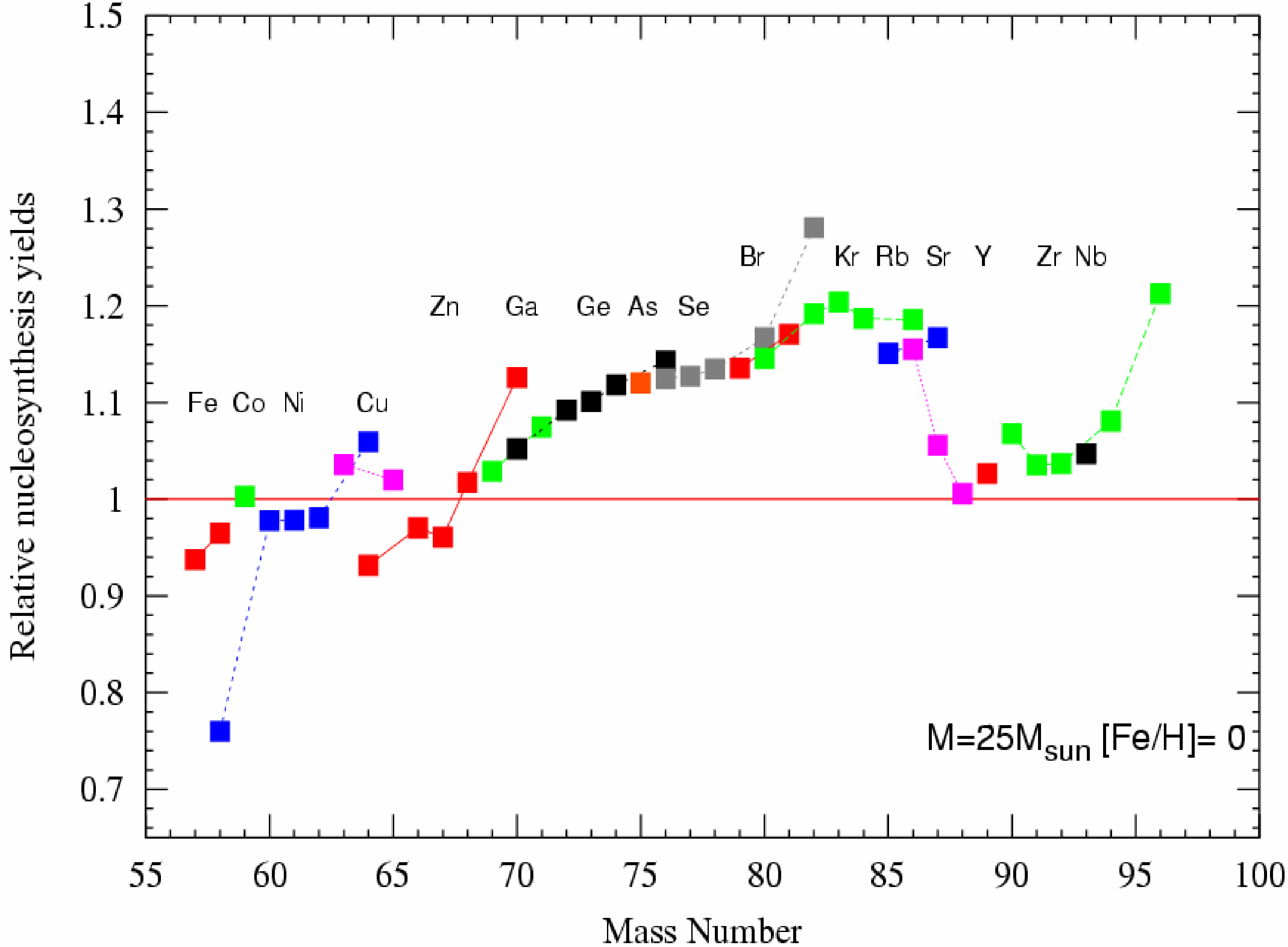
…after 0.6 yr

C-burning (T9 ~ 1.05, 1.10) over the Core He-burning ashes...



…after 0.6 yr

Test on the ^{12}C-burning channels, 65:35/50:50



Propagation effects of the neutron capture cross sections uncertainties on the weak s component

The case of the ^{62}Ni

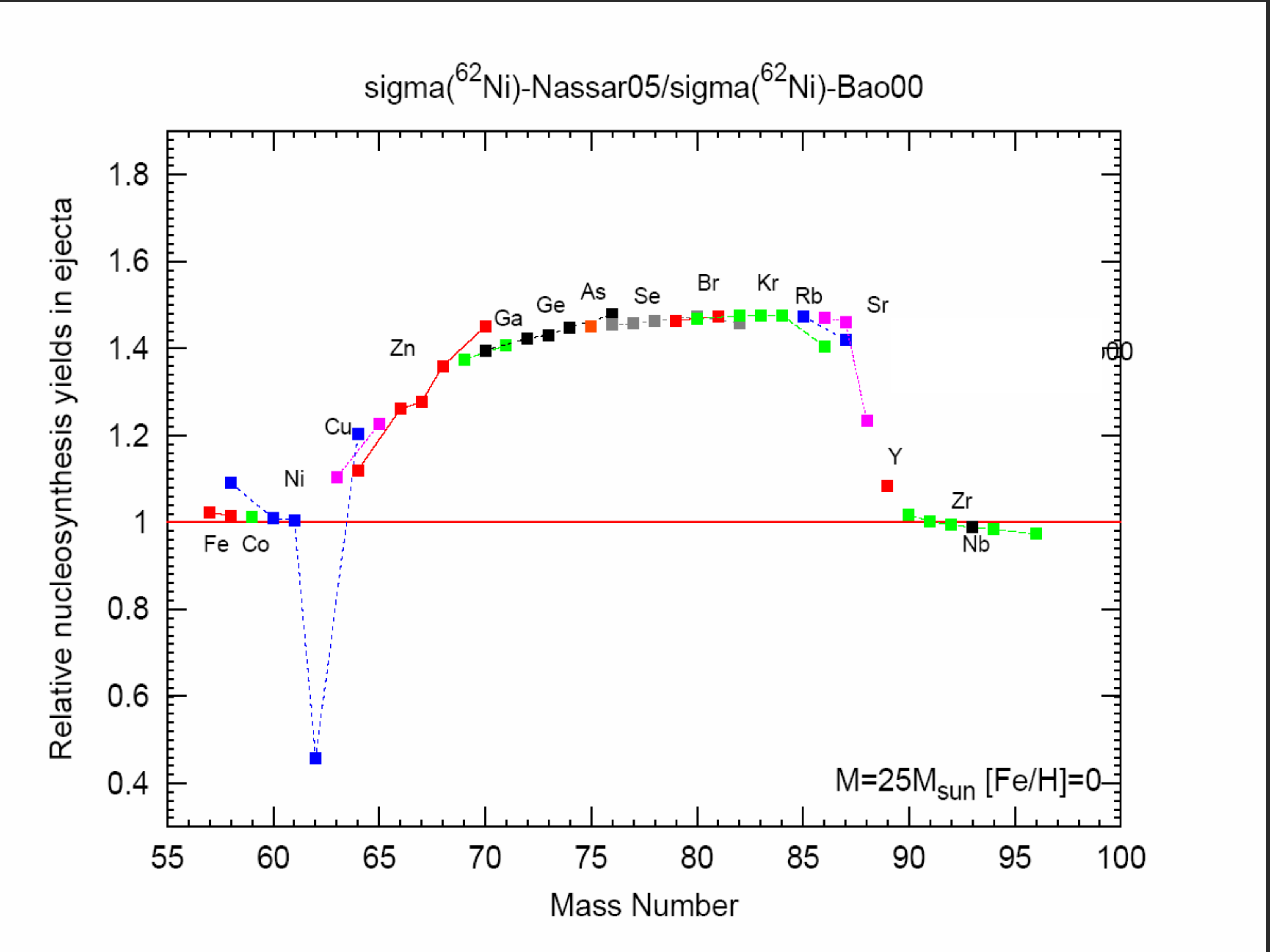
Two discrepant estimates of the Maxwellian cross section at 30 KeV in the literature, based on the same experiment:

35.5 mb   Bao et al. 1987

13.5 mb   Bao et al. 2000

A new measurement provides:

30.5 ± 2.8 mb   Nassar et al. 2005

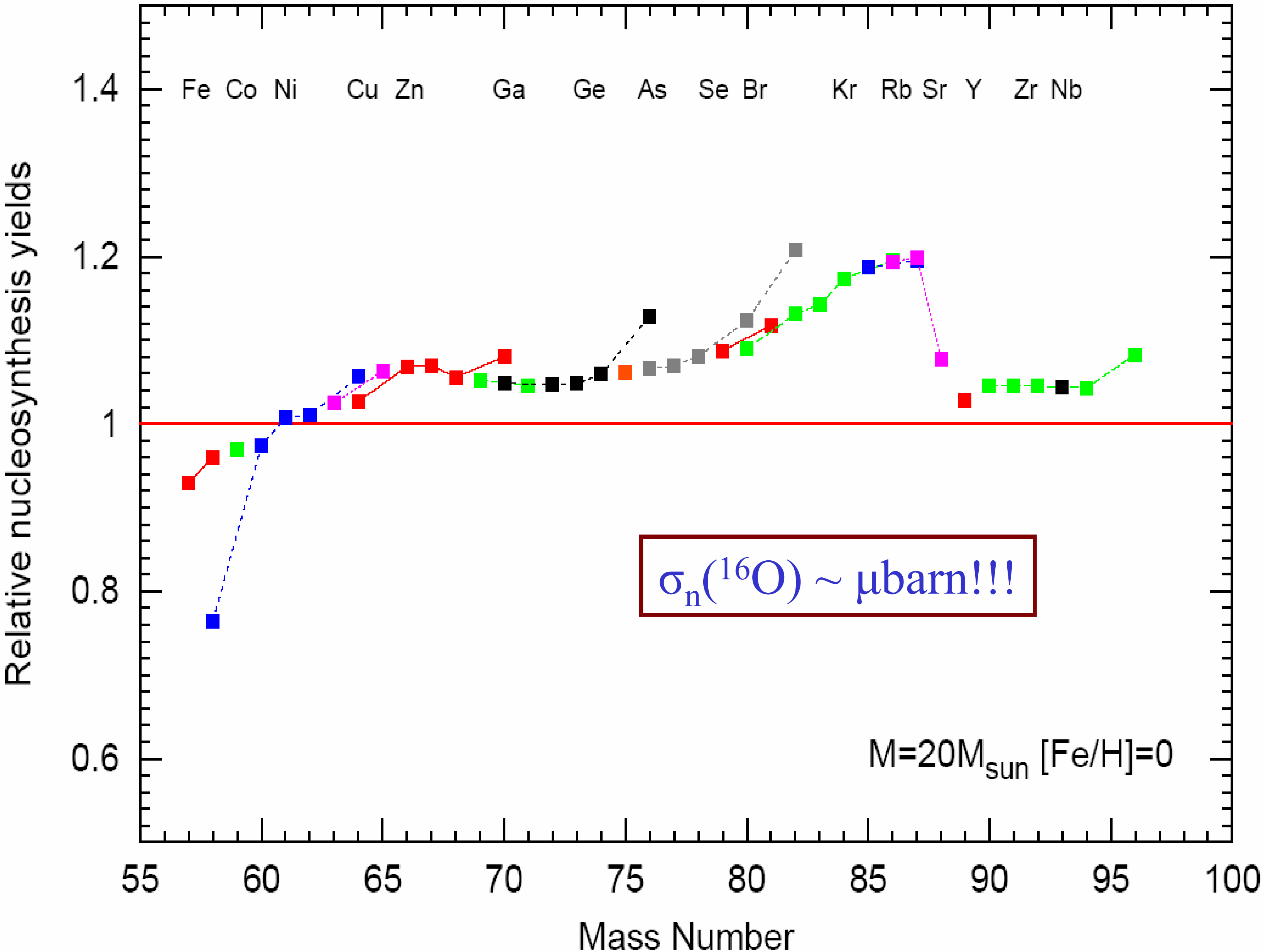


See also Nassar et al. 2005

Neutron poisons of the weak s-process: effect of cross section uncertainties

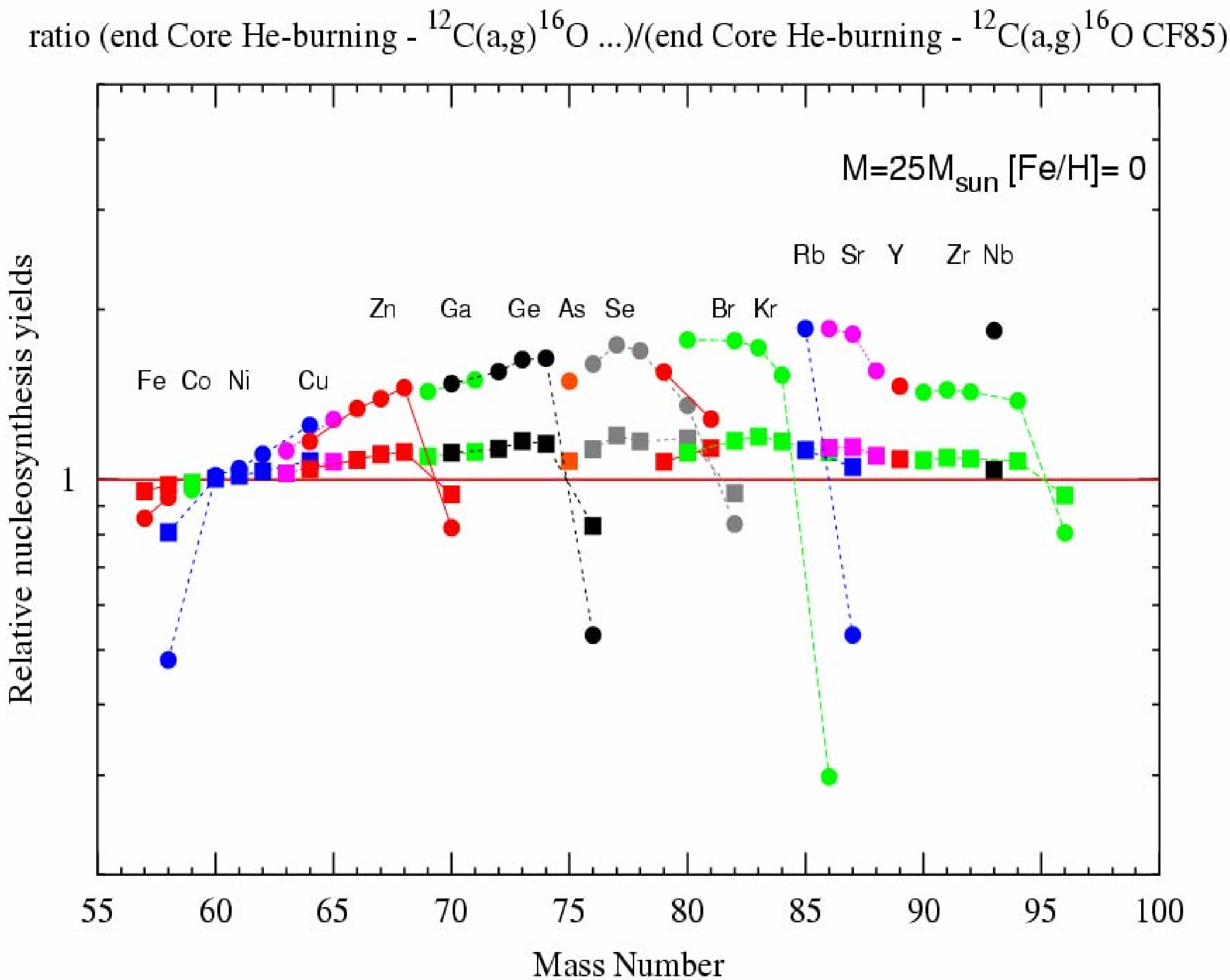
- The light isotopes capture the major fraction of the available neutrons, behaving as poisons for the weak s-process.
- The major poison is ^{16}O
- Other important poisons: ^{25}Mg, ^{23}Na, $^{17}O(n,\alpha)$….

Standard case/sigma(^{16}O)*1.1

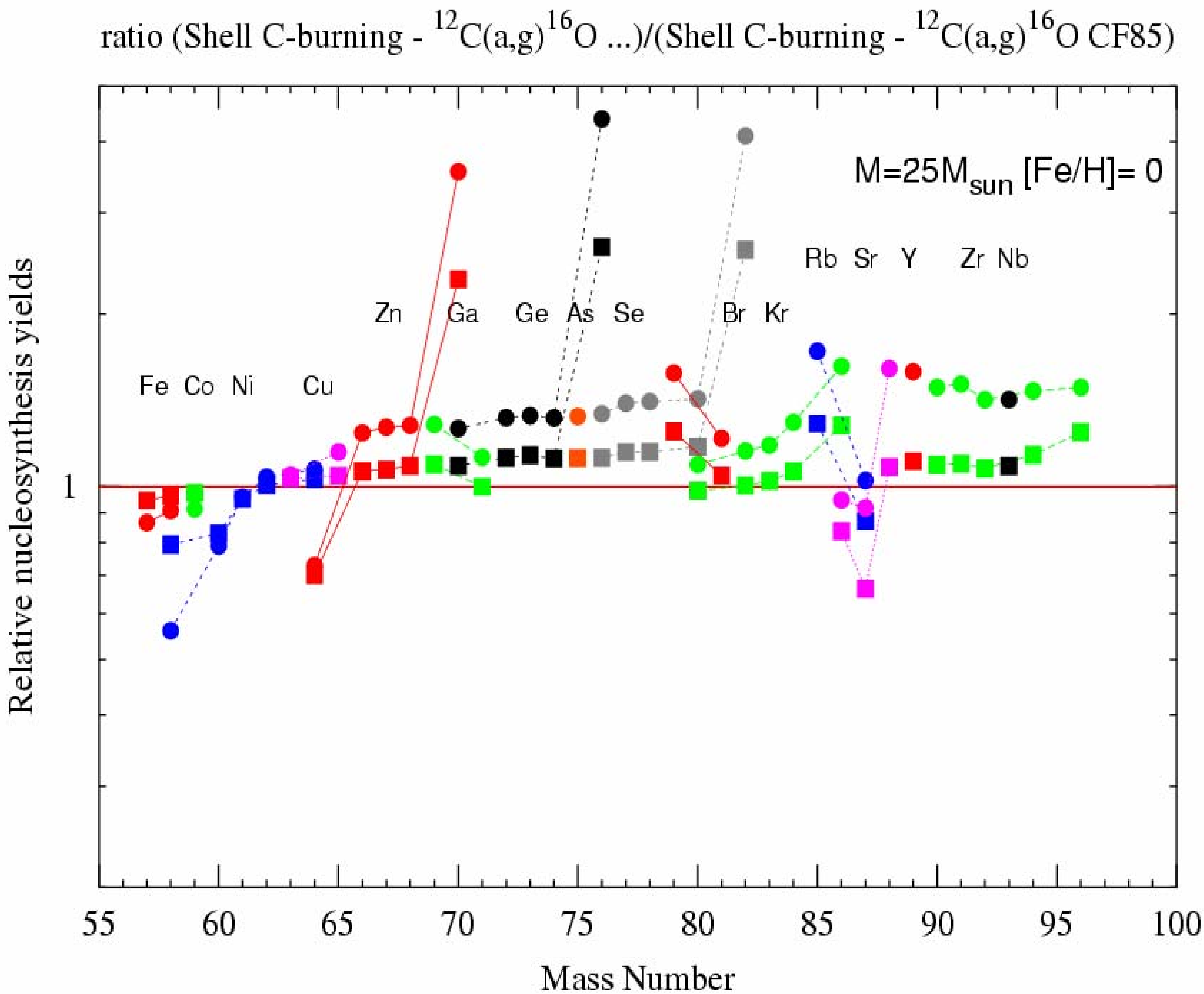


Conclusions

- The weak s component is an overposition of two weak s components with different neutron exposures and different neutron densities: the convective core He-burning and the convective shell C-burning.
- The s-process in the convective C-Shell is important for massive stars, but it is affected from several parameters and nuclear uncertainties.



ratio (end Core He-burning - 12C(a,g)16O ...)/(end Core He-burning - 12C(a,g)16O CF85)
M=25Msun [Fe/H]= 0
Fe Co Ni Cu Zn Ga Ge As Se Br Kr Rb Sr Y Zr Nb
Relative nucleosynthesis yields
1
55 60 65 70 75 80 85 90 95 100
Mass Number



ratio (Shell C-burning - $^{12}C(a,g)^{16}O$ ...)/(Shell C-burning - $^{12}C(a,g)^{16}O$ CF85)
M=25M$_{sun}$ [Fe/H]= 0
Fe Co Ni
Cu
Zn
Ga
Ge As Se
Br Kr
Rb Sr Y
Zr Nb
1
Relative nucleosynthesis yields
55 60 65 70 75 80 85 90 95 100
Mass Number