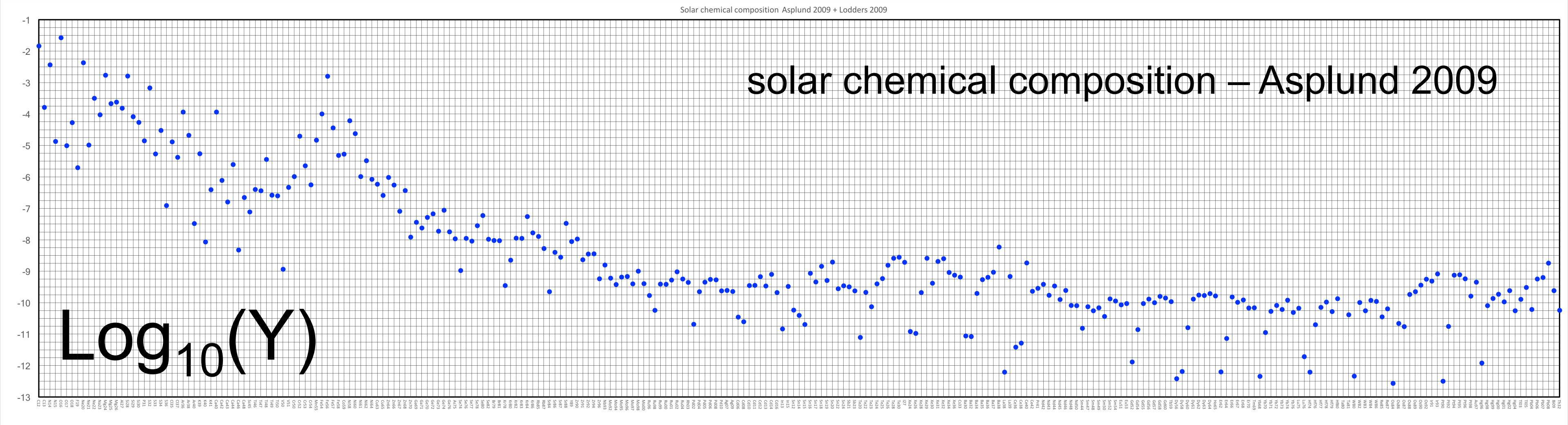
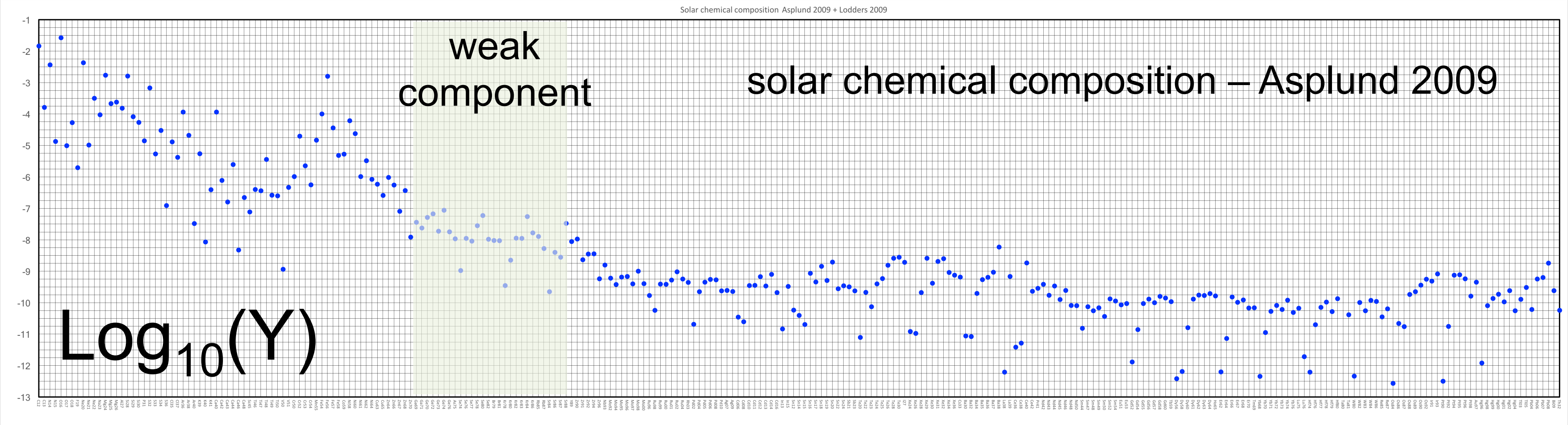
The contribution of the “weak component” to the synthesis of the elements

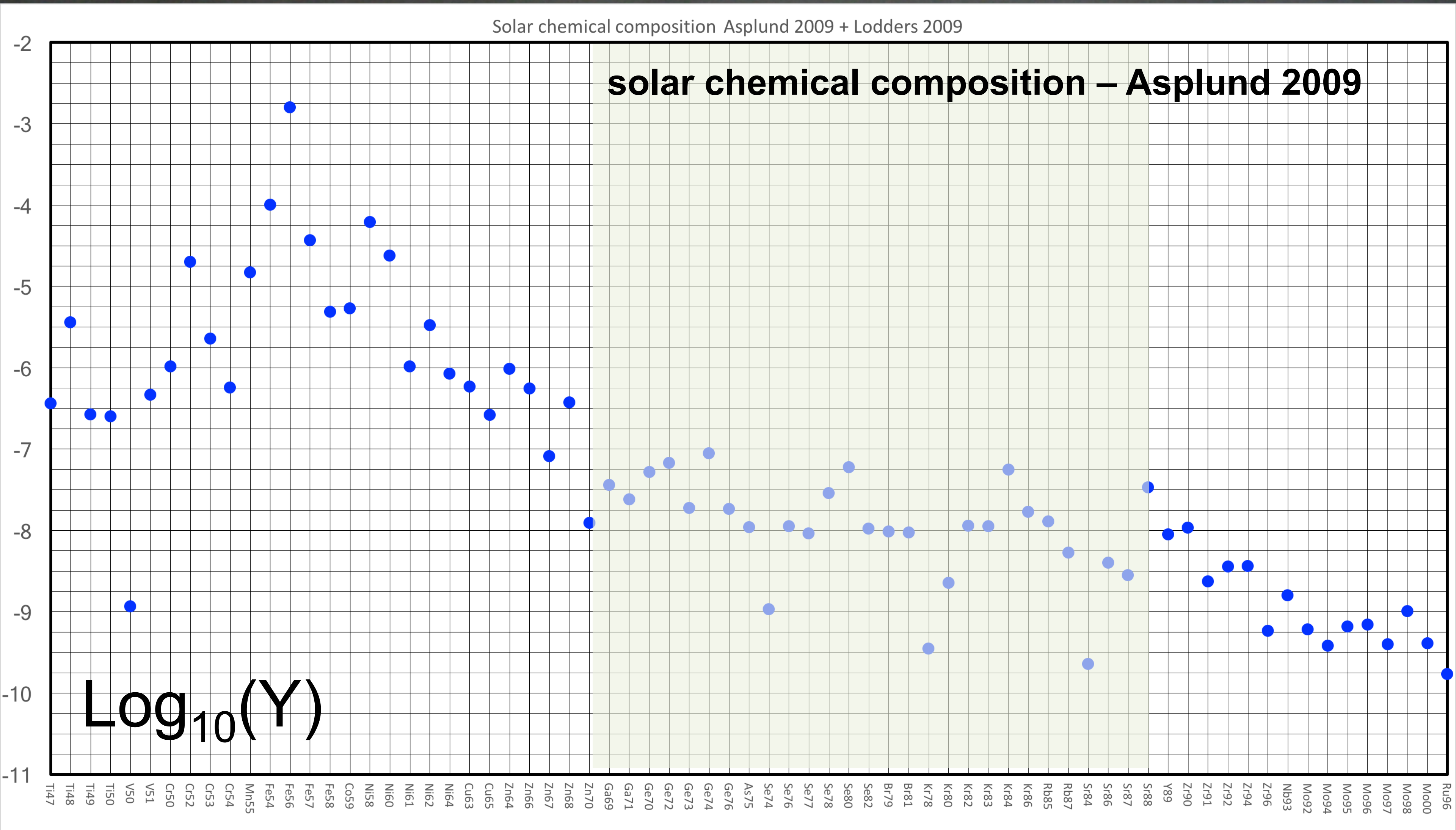
Alessandro Chieffi
INAF – Istituto di Astrofisica e Planetologia Spaziali Italy
Centre for Stellar and Planetary Astrophysics Monash University – Australia
Institut d’Astronomie et Astrophysique - ULB – Bruxelles
alessandro.chieffi@inaf.it

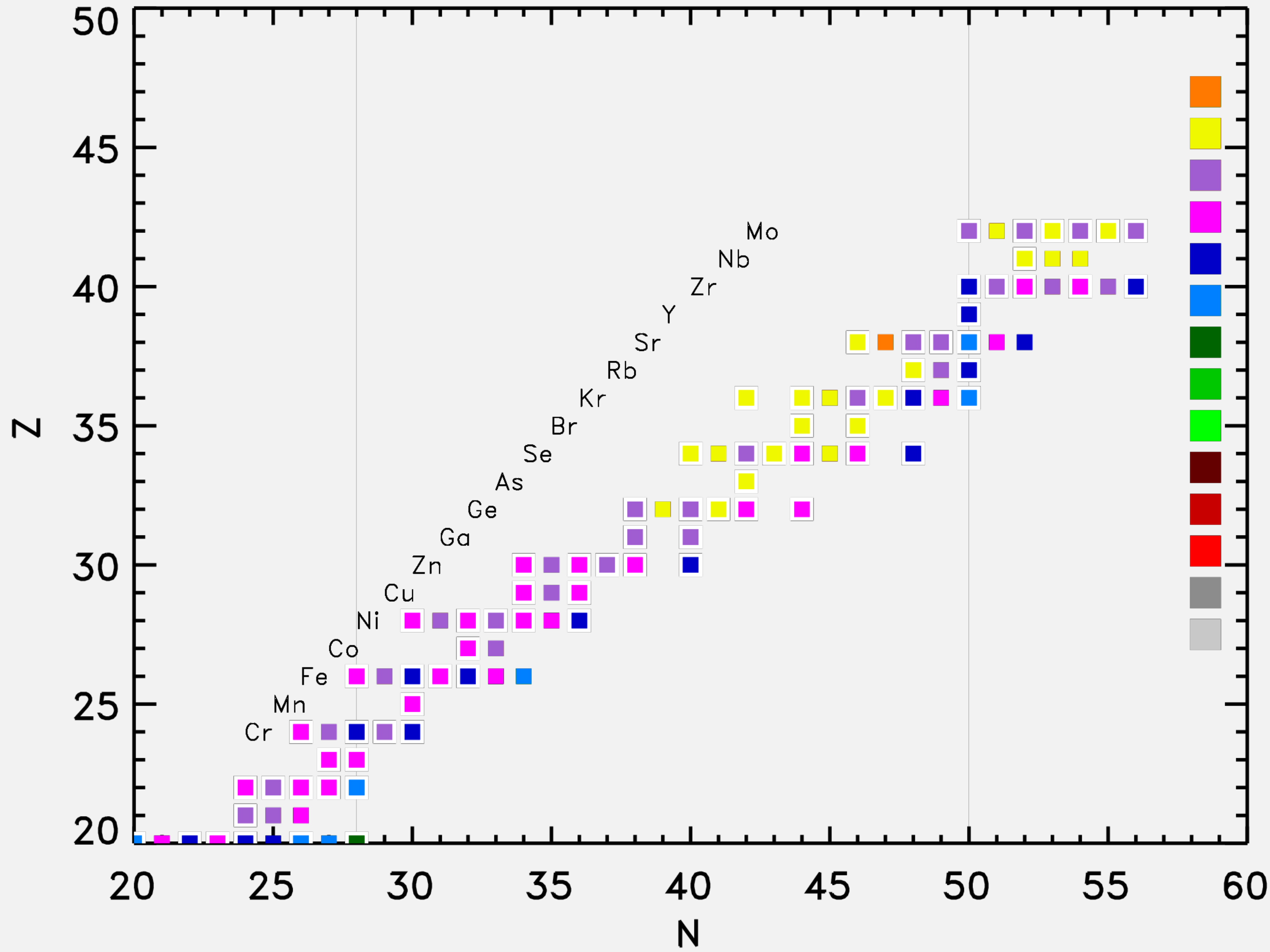
Marco Limongi
INAF – Osservatorio Astronomico di Roma, Italy
Institute for the Physics and Mathematics of the Universe, Japan
Centre for Stellar and Planetary Astrophysics Monash University – Australia
marco.limongi@oa-roma.inaf.it


Solar chemical composition Asplund 2009 + Lodders 2009
solar chemical composition – Asplund 2009
Log10(Y)
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13



# ratio	N(Fe)/N(S) = 2600 – N(weak)/N(S) = 0.947	N(n>50)/N(S)=0.0525
mass fraction	X(Fe)/X(S) = 1800 – N(weak)/N(S) = 0.917	N(n>50)/N(S)=0.0831


Solar chemical composition Asplund 2009 + Lodders 2009
solar chemical composition – Asplund 2009
Log$_{10}$(Y)
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
Ti47 Ti48 Ti49 Ti50 V50 V51 Cr50 Cr52 Cr53 Cr54 Mn55 Fe54 Fe56 Fe57 Fe58 Co59 Ni58 Ni60 Ni61 Ni62 Ni64 Cu63 Cu65 Zn64 Zn66 Zn67 Zn68 Zn70 Ga69 Ga71 Ge70 Ge72 Ge73 Ge74 Ge76 As75 Se74 Se76 Se77 Se78 Se80 Se82 Br79 Br81 Kr78 Kr80 Kr82 Kr83 Kr84 Kr86 Rb85 Rb87 Sr84 Sr86 Sr87 Sr88 Y89 Zr90 Zr91 Zr92 Zr94 Zr96 Nb93 Mo92 Mo94 Mo95 Mo96 Mo97 Mo98 Mo00 Ru96



Z
N
50
45
40
35
30
25
20
20
25
30
35
40
45
50
55
60
Mo
Nb
Zr
Y
Sr
Rb
Kr
Br
Se
As
Ge
Ga
Zn
Cu
Ni
Co
Fe
Mn
Cr

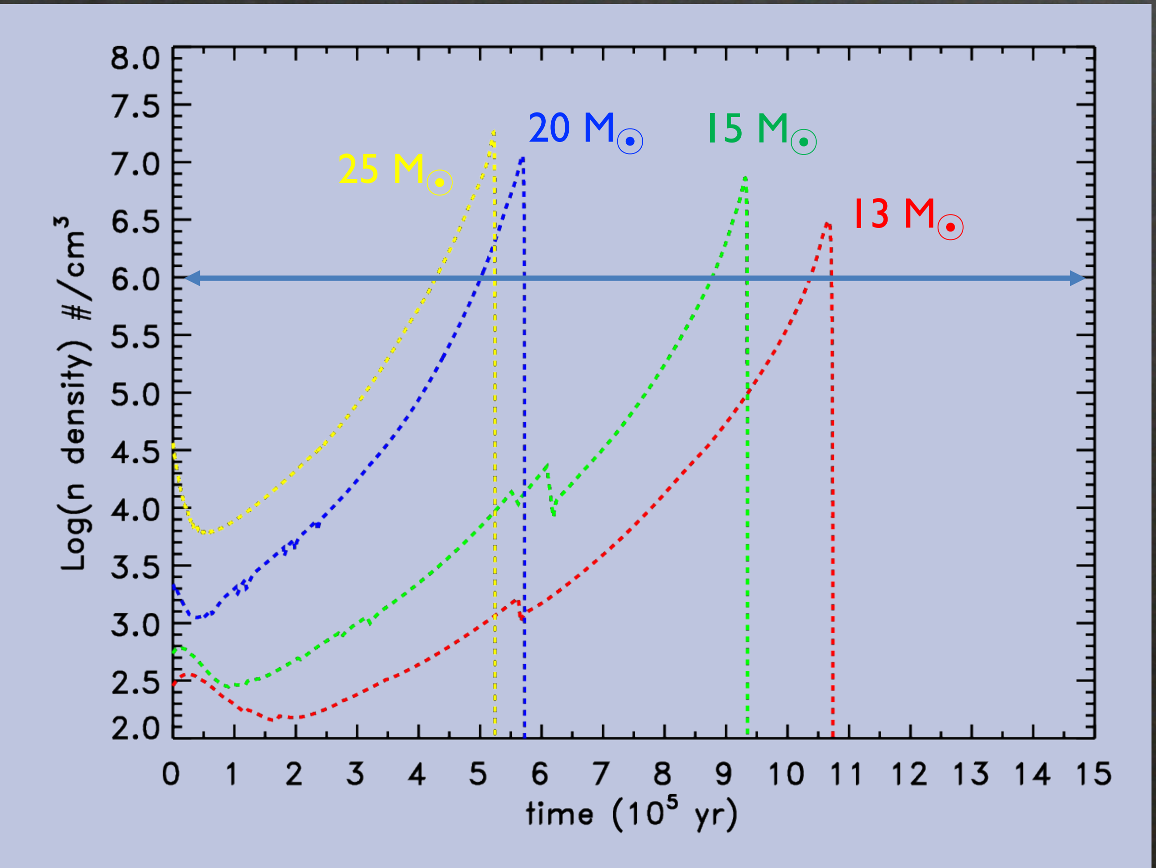
$$R_{ij} = y_i \, y_j \, Na \, \rho^2 \, Na < \sigma \, v >_{ij}$$

# of reactions per unit volume

$$\tau = \frac{8.5 \; 10^{10}}{N_n \; \sigma(\mathrm{mbarn})} \quad (\mathrm{yr})$$

neutron capture lifetime at 25 KeV

$$N_n \sim 3 \; 10^6 \;\; \mathrm{neutrons\ cm^{-3}} \qquad \sigma(^{88}\mathrm{Sr}) \sim 6 \; \mathrm{mbarn}$$



$$\tau \sim 4 \; 10^3 \;\; \mathrm{yr}$$

$$\tau_{\mathrm{neu\ exp}} = \int_0^t N_n(t') \, v_{th} \, dt'$$

neutron exposure ($mbarn^{-1}$)

	v=0
13	0.007
15	0.014
20	0.021
25	0.033

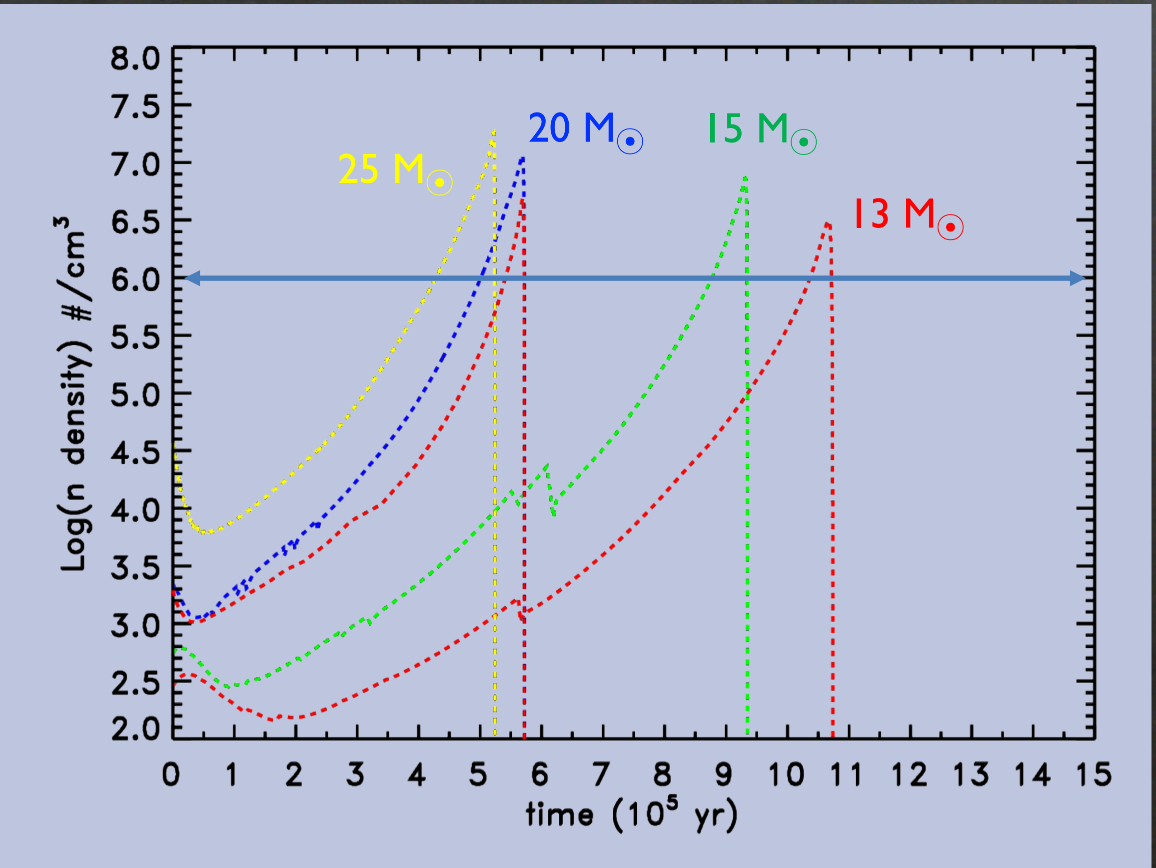
$$R_{ij} = y_i \; y_j \; Na \; \rho^2 \; Na < \sigma \; v >_{ij}$$

# of reactions
per unit volume

$$\tau = \frac{8.5 \; 10^{10}}{N_n \; \sigma(\mathrm{mbarn})} \quad (\mathrm{yr})$$

neutron capture lifetime at 25 KeV

$$N_n \sim 3 \; 10^6 \quad \text{neutrons cm}^{-3} \qquad \sigma(^{88}\mathrm{Sr}) \sim 6 \text{ mbarn}$$



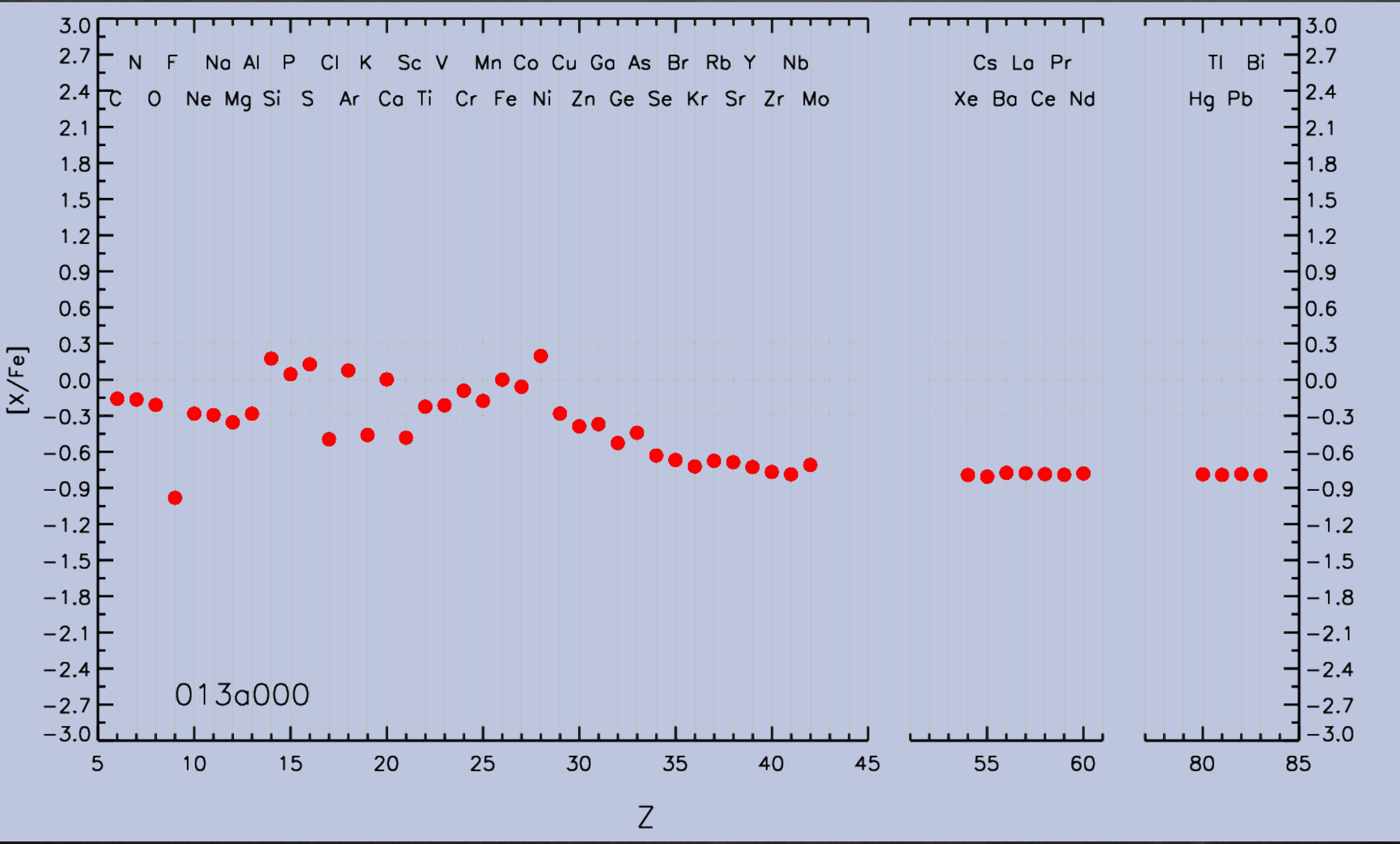
$$\tau \sim 4 \; 10^3 \quad \mathrm{yr}$$

$$\tau_{\mathrm{neu\ exp}} = \int_0^t N_n(t') \, v_{th} \, dt'$$

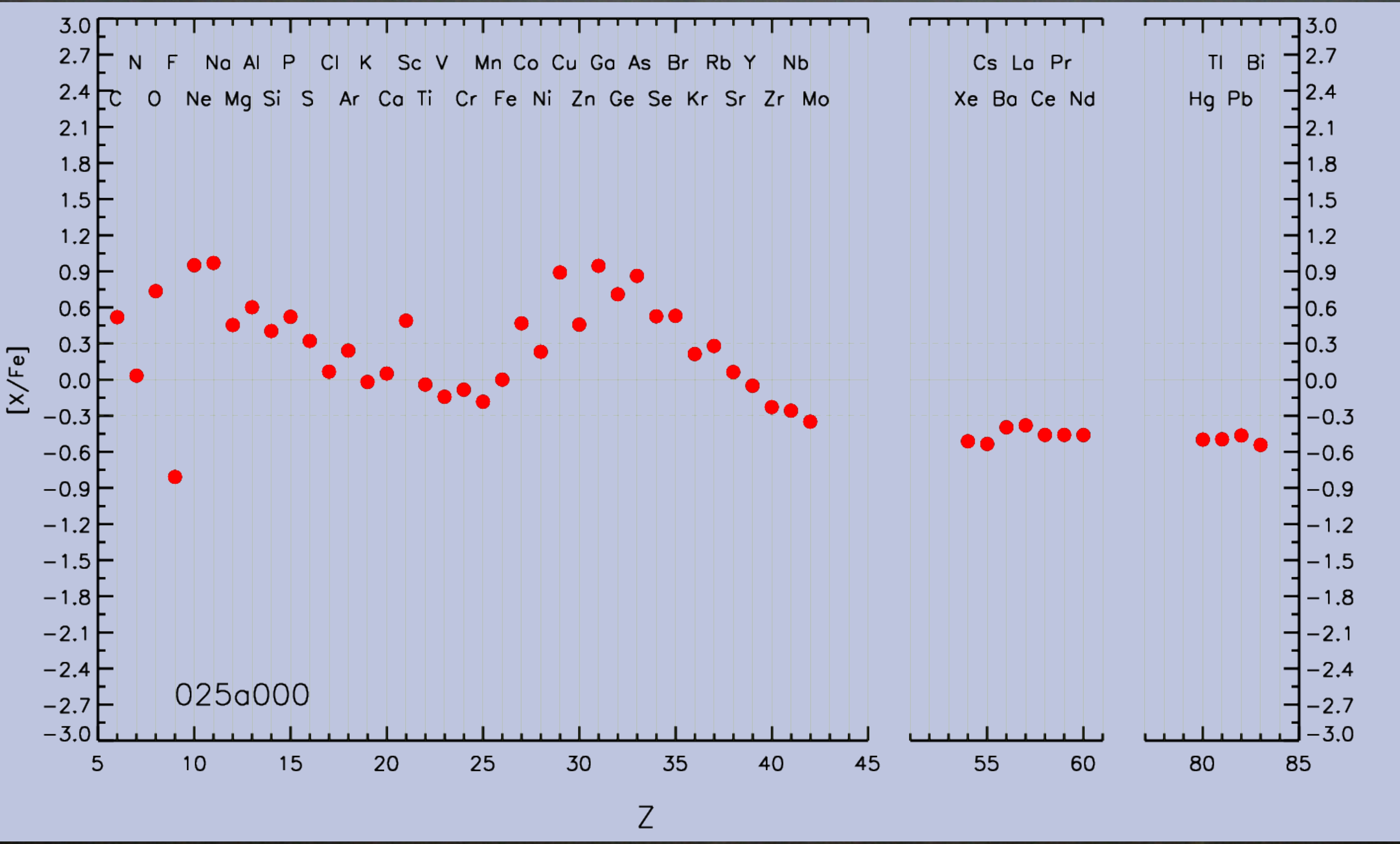
neutron exposure (mbarn^{-1})

	v=0
13	0.007
15	0.014
20	0.021
25	0.033

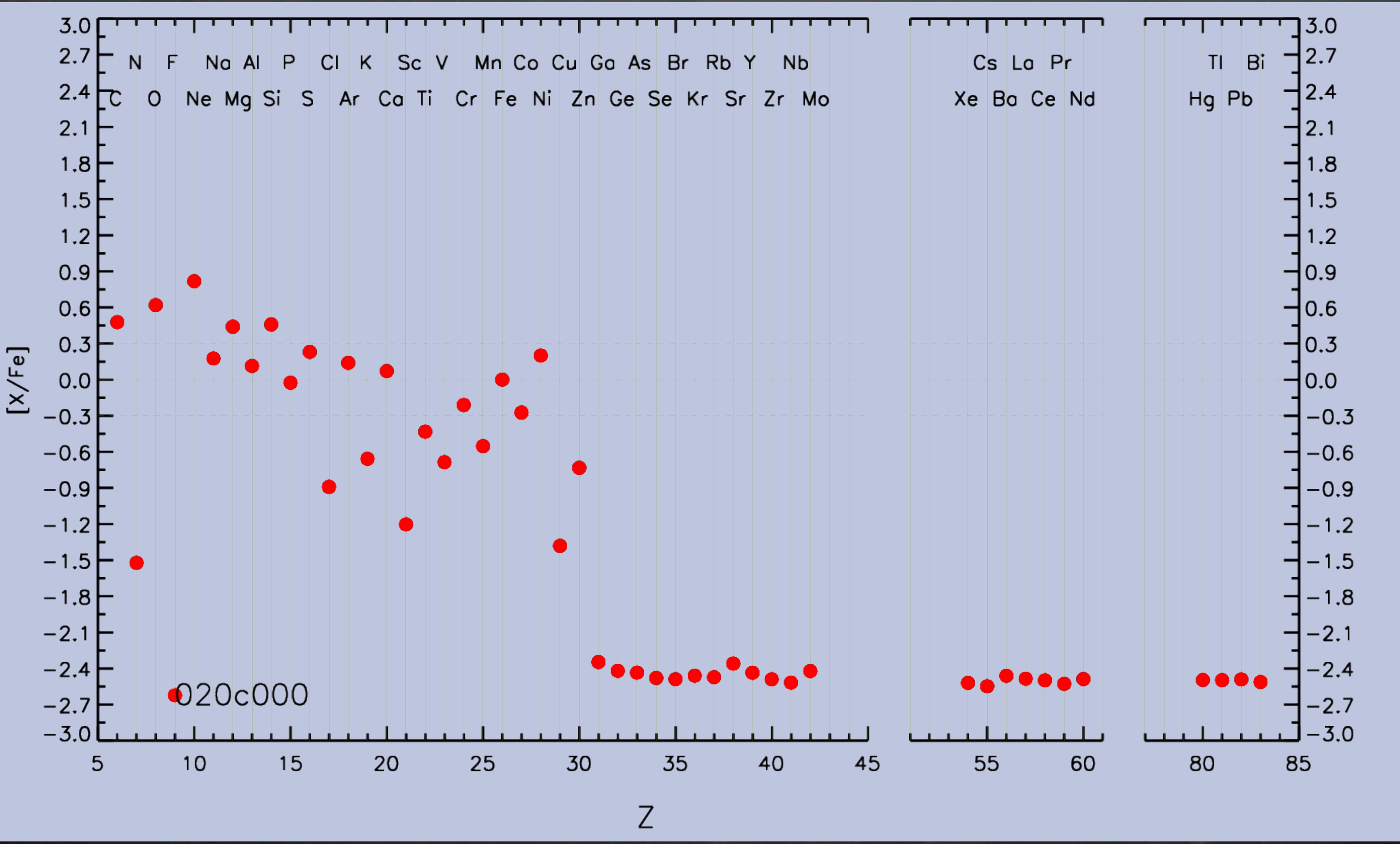
20 M$_\odot$ [Fe/H]-2 0.006



N F Na Al P Cl K Sc V Mn Co Cu Ga As Br Rb Y Nb
C O Ne Mg Si S Ar Ca Ti Cr Fe Ni Zn Ge Se Kr Sr Zr Mo
Cs La Pr
Xe Ba Ce Nd
Tl Bi
Hg Pb
[X/Fe]
Z
013a000



N F Na Al P Cl K Sc V Mn Co Cu Ga As Br Rb Y Nb
C O Ne Mg Si S Ar Ca Ti Cr Fe Ni Zn Ge Se Kr Sr Zr Mo
Cs La Pr
Xe Ba Ce Nd
Tl Bi
Hg Pb
[X/Fe]
Z
025a000

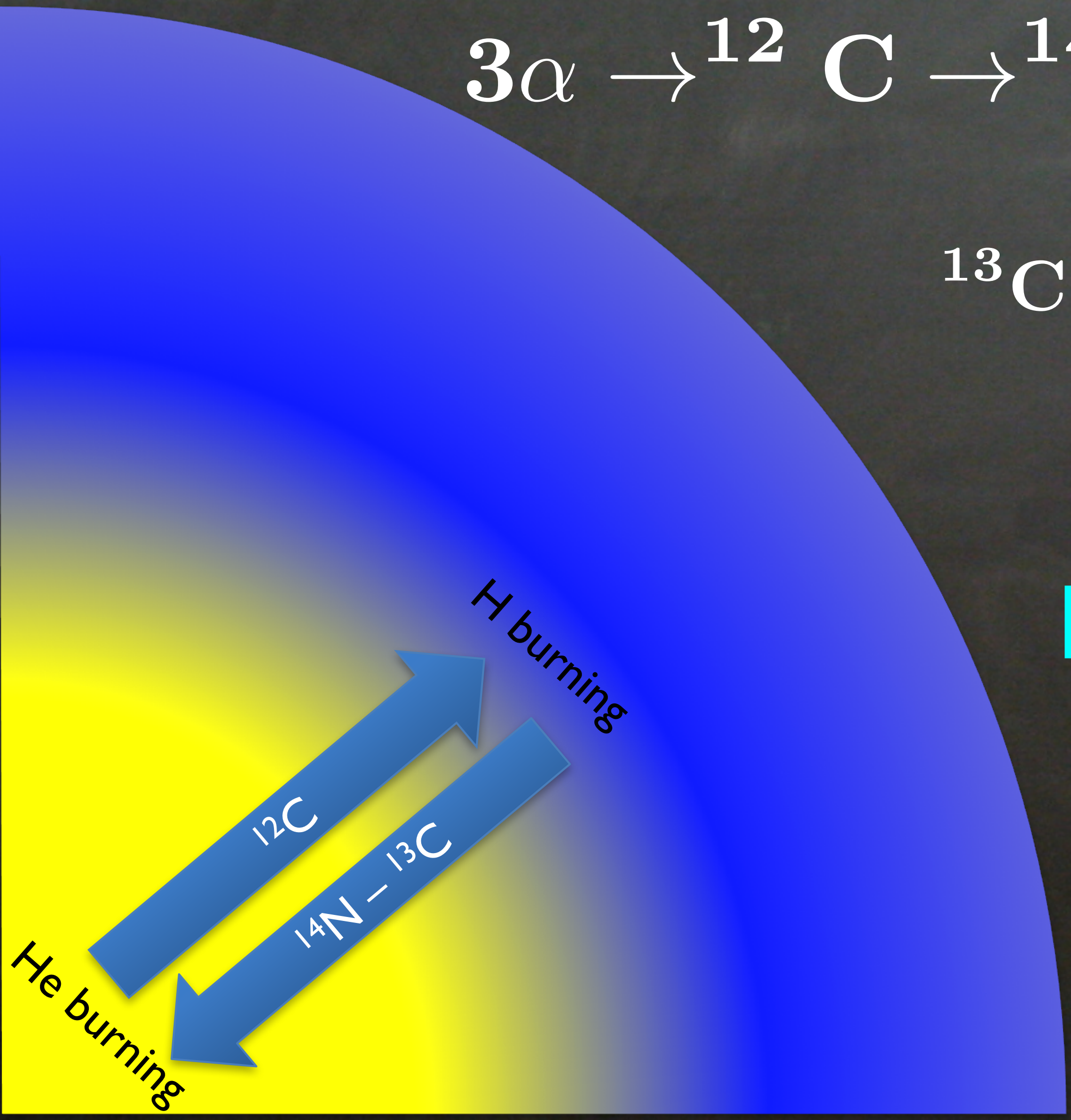


[X/Fe]
Z
020c000
N F Na Al P Cl K Sc V Mn Co Cu Ga As Br Rb Y Nb
C O Ne Mg Si S Ar Ca Ti Cr Fe Ni Zn Ge Se Kr Sr Zr Mo
Cs La Pr
Xe Ba Ce Nd
Tl Bi
Hg Pb
3.0 2.7 2.4 2.1 1.8 1.5 1.2 0.9 0.6 0.3 0.0 −0.3 −0.6 −0.9 −1.2 −1.5 −1.8 −2.1 −2.4 −2.7 −3.0
5 10 15 20 25 30 35 40 45 55 60 80 85

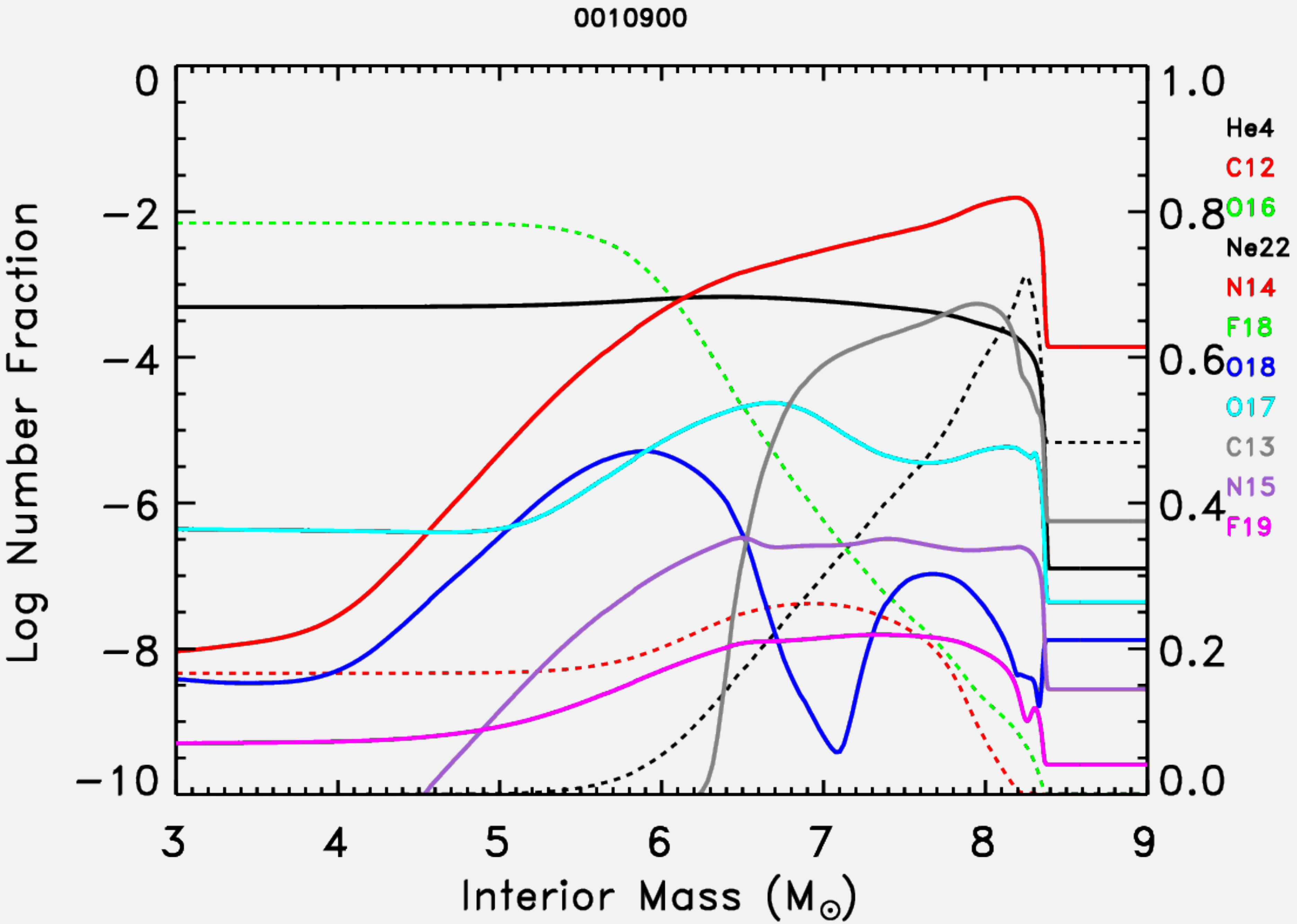
The interplay between He and H burnings in Core He Burning

$$3\alpha \rightarrow {}^{12}\mathrm{C} \rightarrow {}^{14}\mathrm{N} \rightarrow {}^{22}\mathrm{Ne} \rightarrow n$$

$${}^{13}\mathrm{C}/{}^{14}\mathrm{N} \simeq 5.7 \cdot 10^{-3}$$



Primary Nitrogen

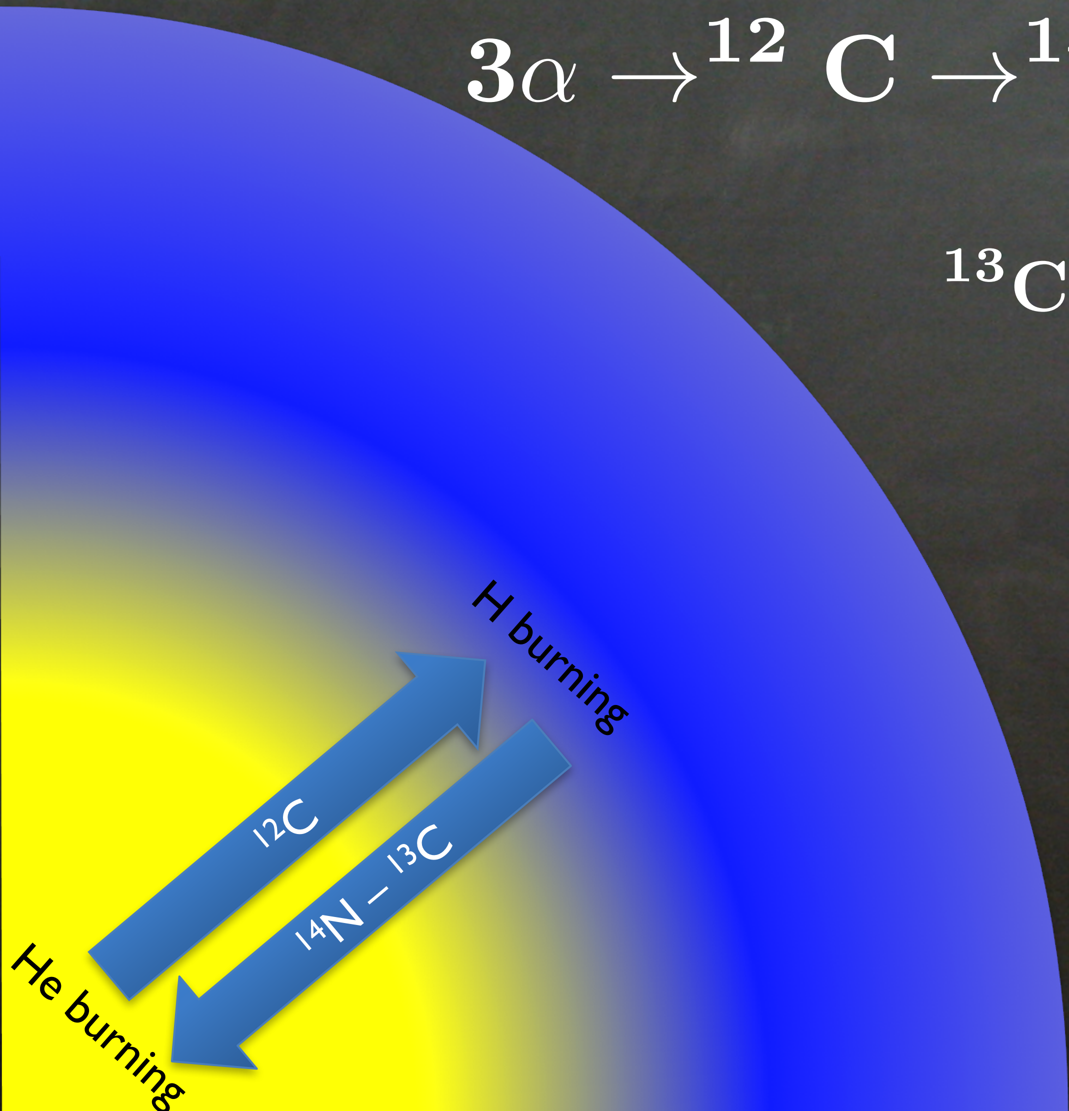


0010900
Log Number Fraction
Interior Mass ($M_\odot$)
0
−2
−4
−6
−8
−10
1.0
0.8
0.6
0.4
0.2
0.0
3
4
5
6
7
8
9
He4
C12
O16
Ne22
N14
F18
O18
O17
C13
N15
F19

The interplay between He and H burnings in Core He Burning

$$3\alpha \rightarrow {}^{12}\mathrm{C} \rightarrow {}^{14}\mathrm{N} \rightarrow {}^{22}\mathrm{Ne} \rightarrow n$$

$${}^{13}\mathrm{C}/{}^{14}\mathrm{N} \simeq 5.7 \cdot 10^{-3}$$



$^{14}N(\alpha,\gamma)^{18}F(\beta^+)^{18}O(p,\alpha)^{15}N(\alpha,\gamma)^{19}F$

$^{14}N(n,p)^{14}C$

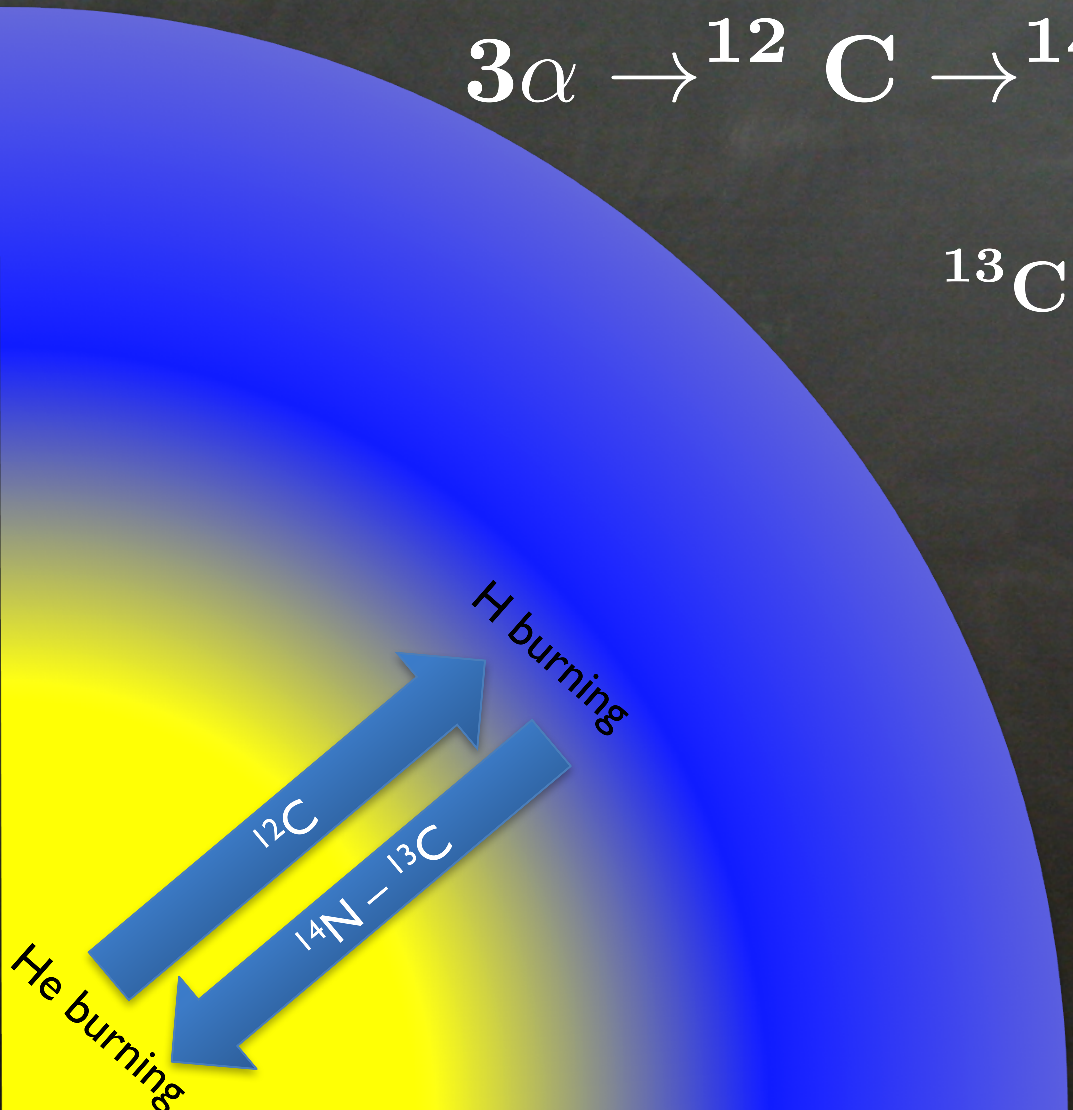
$^{13}C(\alpha,n)^{16}O$

Goriely, S., Jorissen, A., Arnould, M. 1989

The interplay between He and H burnings in Core He Burning

$$3\alpha \rightarrow {}^{12}\mathrm{C} \rightarrow {}^{14}\mathrm{N} \rightarrow {}^{22}\mathrm{Ne} \rightarrow n$$

$$^{13}\mathrm{C}/^{14}\mathrm{N} \simeq 5.7 \cdot 10^{-3}$$



$^{14}N(\alpha,\gamma)^{18}F(\beta^+)^{18}O(p,\alpha)^{15}N(\alpha,\gamma)^{19}F$

$^{14}N(n,p)^{14}C$

$^{13}C(\alpha,n)^{16}O$

Goriely, S., Jorissen, A., Arnould, M. 1989

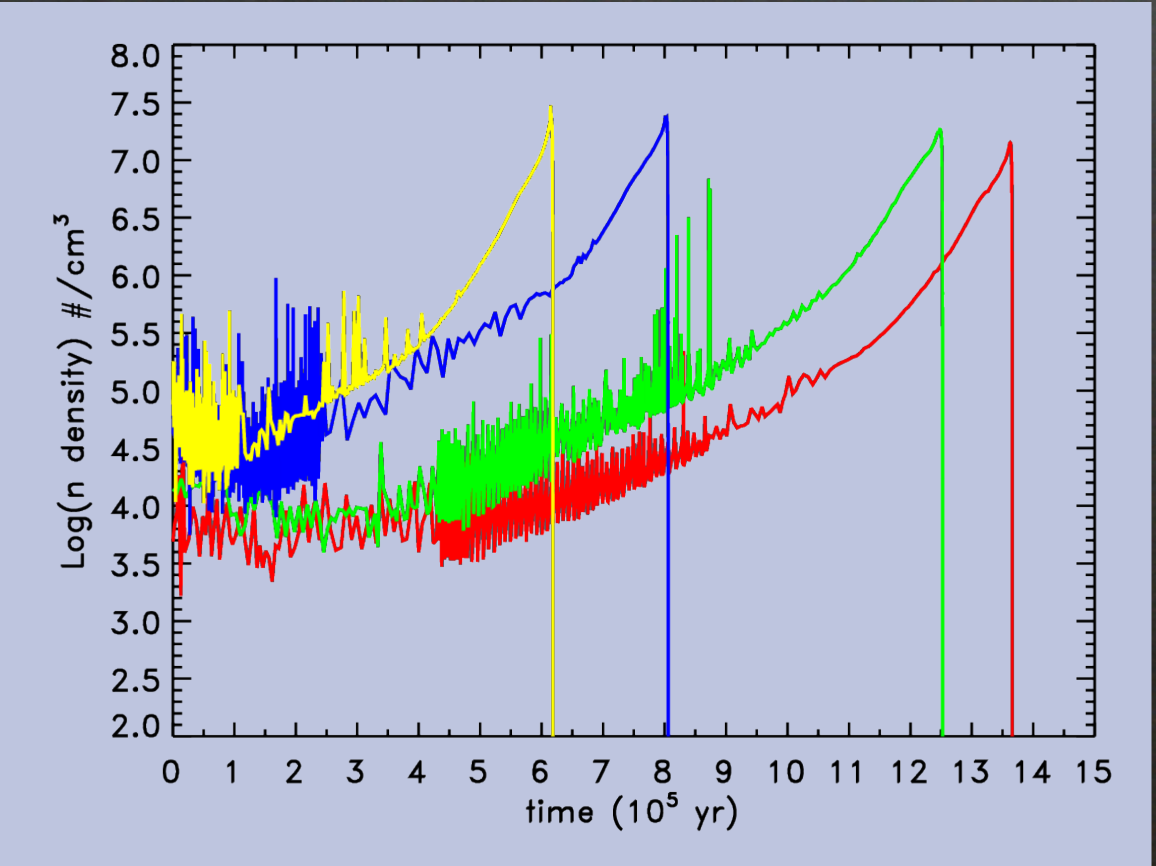
$$R_{ij} = y_i \, y_j \, Na \, \rho^2 \, Na < \sigma \, v >_{ij}$$

# of reactions
per unit volume

$$\tau = \frac{8.5 \; 10^{10}}{N_n \, \sigma(\mathrm{mbarn})} \quad (\mathrm{yr})$$

neutron capture lifetime at 25 KeV

$$N_n \sim 6 \; 10^6 \;\; \mathrm{neutrons \; cm^{-3}} \qquad \sigma(^{88}\mathrm{Sr}) \sim 6 \; \mathrm{mbarn}$$



$$\tau \sim 2 \; 10^3 \;\; \mathrm{yr}$$

$$\tau_{neu\;exp} = \int_0^t N_n(t') \, v_{th} \, dt'$$

neutron exposure ($mbarn^{-1}$)

	v=0	v=300 km/s
13	0.007	0.041
15	0.014	0.066
20	0.021	0.070
25	0.033	0.055

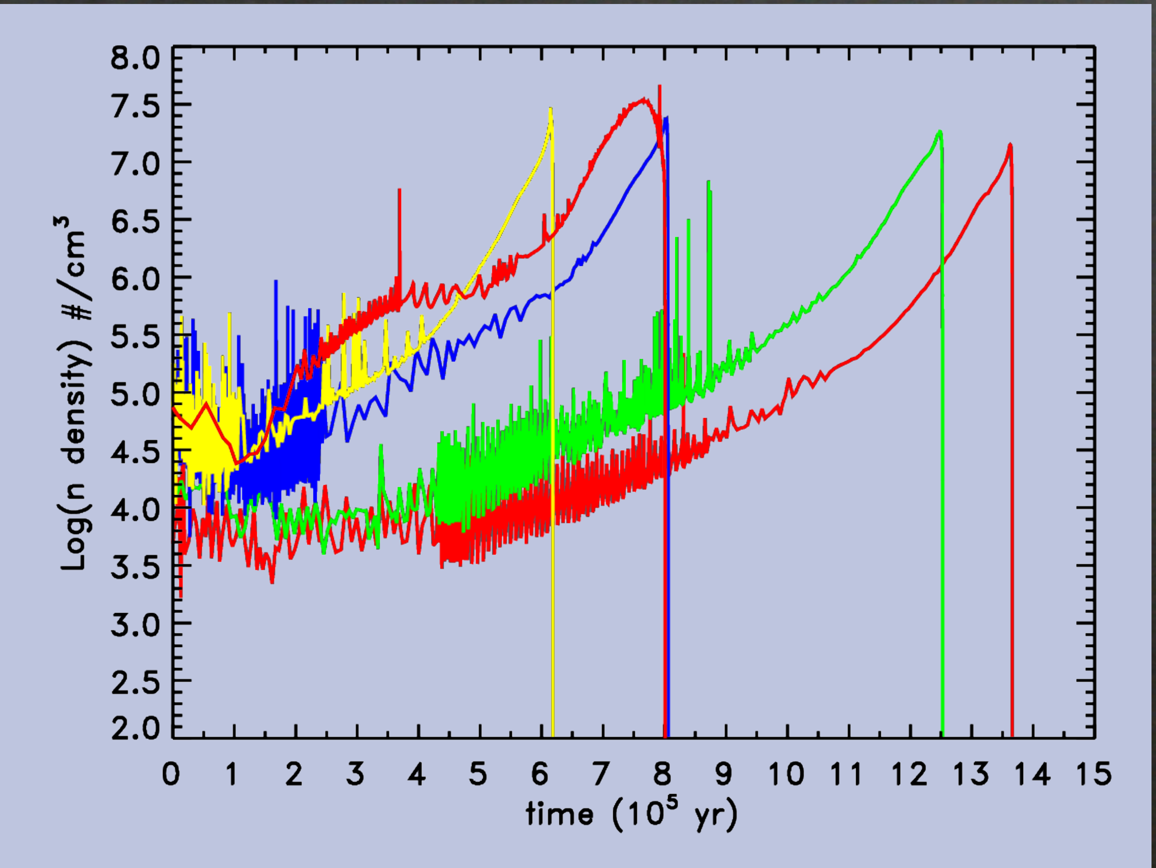
$$R_{ij} = y_i \; y_j \; Na \; \rho^2 \; Na < \sigma \; v >_{ij}$$

# of reactions per unit volume

$$\tau = \frac{8.5 \; 10^{10}}{N_n \; \sigma(\mathrm{mbarn})} \quad (\mathrm{yr})$$

neutron capture lifetime at 25 KeV

$$N_n \sim 6 \; 10^6 \;\; \mathrm{neutrons \; cm^{-3}} \qquad \sigma(^{88}\mathrm{Sr}) \sim 6 \; \mathrm{mbarn}$$



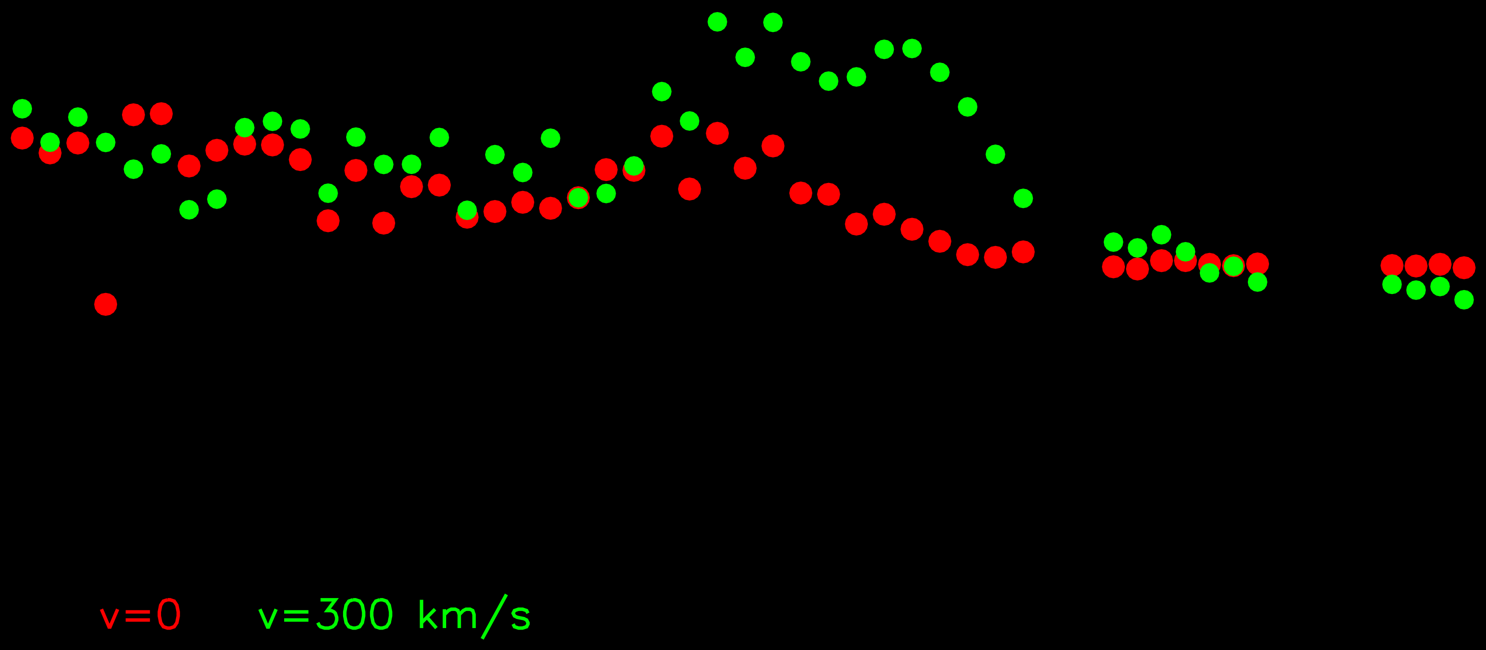
$$\tau \sim 2 \; 10^3 \;\; \mathrm{yr}$$

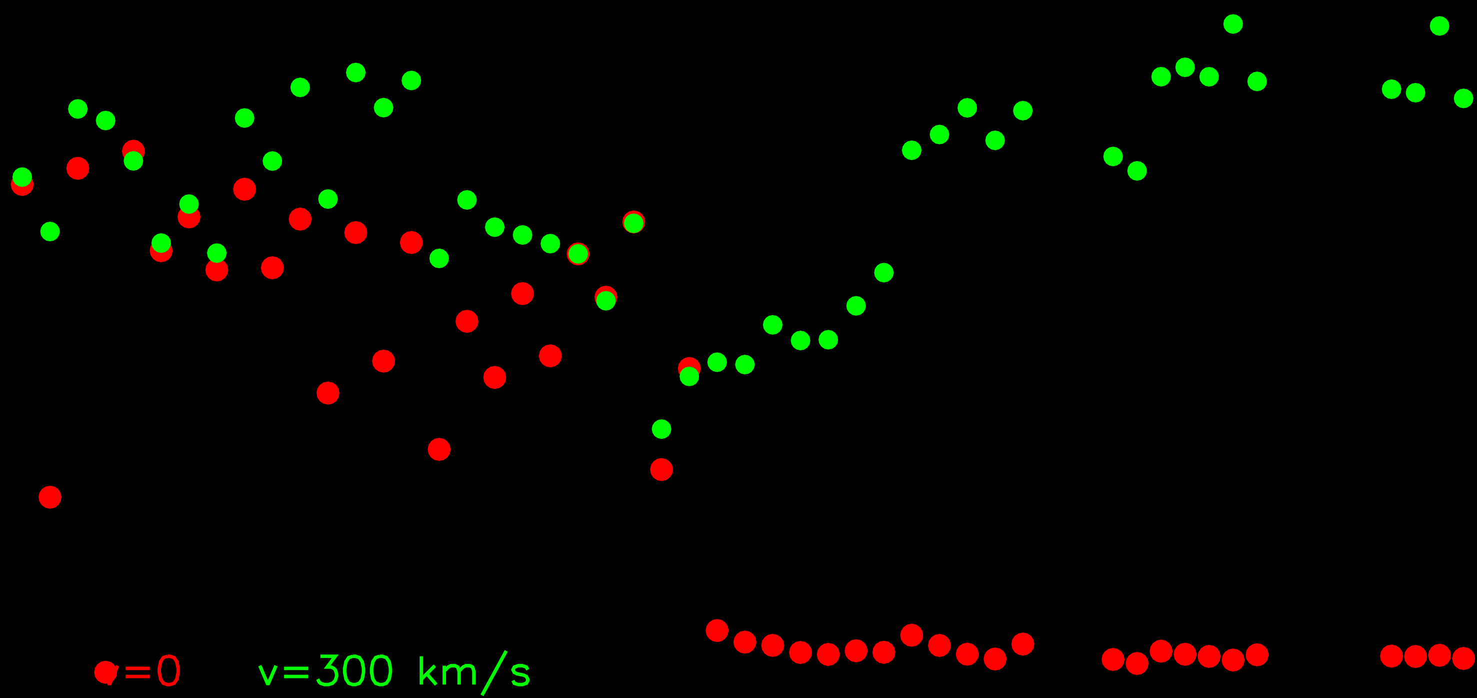
$$\tau_{\mathrm{neu\;exp}} = \int_0^t N_n(t') \; v_{th} \; dt'$$

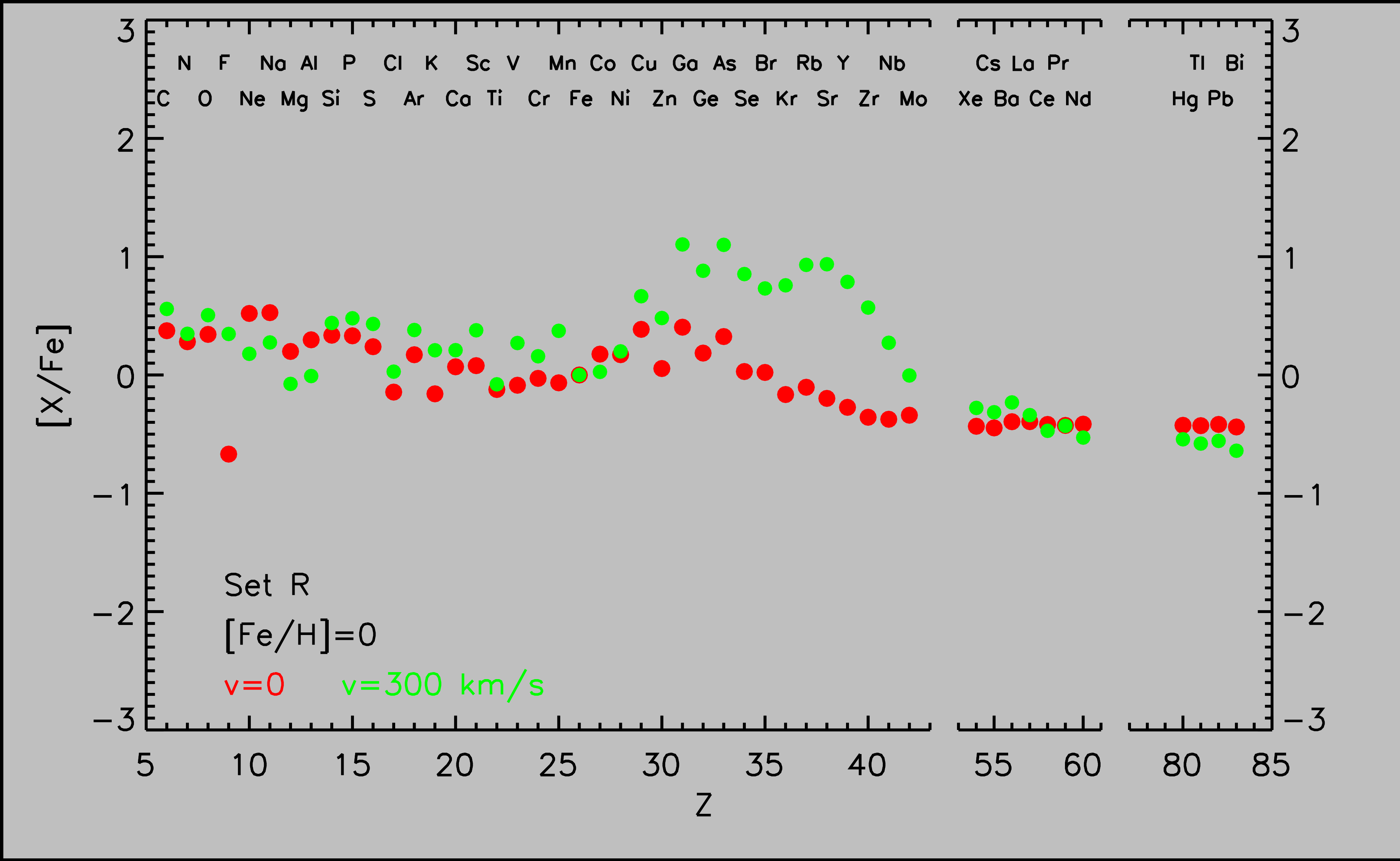
neutron exposure (mbarn^{-1})

	v=0	v=300 km/s
13	0.007	0.041
15	0.014	0.066
20	0.021	0.070
25	0.033	0.055

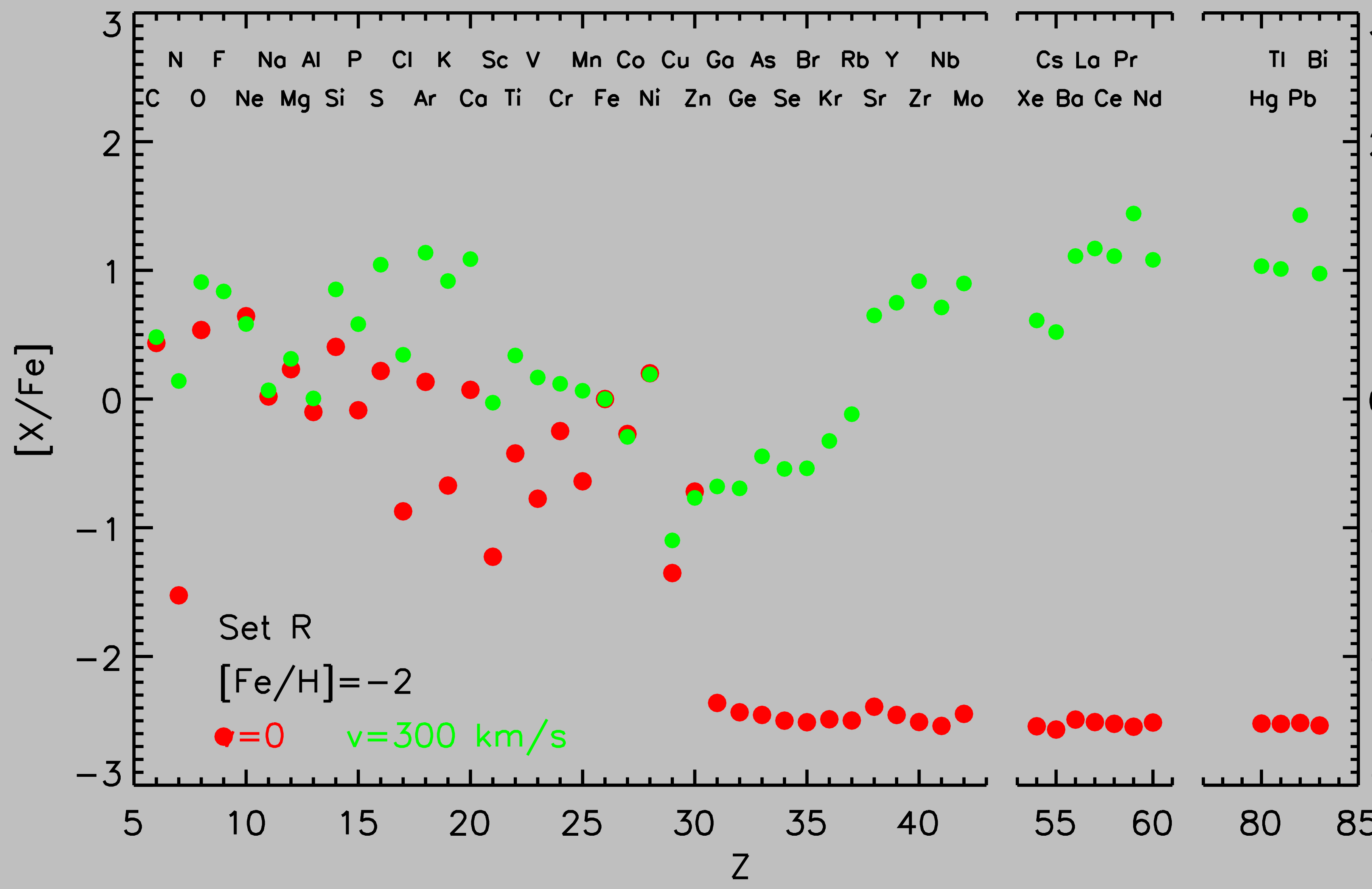
20 $M_\odot$ [Fe/H]-2 0.22


v=0
v=300 km/s


=0
v=300 km/s



N F Na Al P Cl K Sc V Mn Co Cu Ga As Br Rb Y Nb
C O Ne Mg Si S Ar Ca Ti Cr Fe Ni Zn Ge Se Kr Sr Zr Mo
Cs La Pr
Xe Ba Ce Nd
Tl Bi
Hg Pb
[X/Fe]
Z
Set R
[Fe/H]=0
v=0
v=300 km/s



N F Na Al P Cl K Sc V Mn Co Cu Ga As Br Rb Y Nb Cs La Pr Tl Bi
C O Ne Mg Si S Ar Ca Ti Cr Fe Ni Zn Ge Se Kr Sr Zr Mo Xe Ba Ce Nd Hg Pb
[X/Fe]
Z
Set R
[Fe/H]=−2
v=0
v=300 km/s

Summary

Elements between Ga and Sr are produced (moderately) by n captures in non rotating more massive stars (weak component)

The low neutron capture cross section on ^{88}Sr (neutron closure shell at N=50) coupled to low neutron densities (a few 10^6 n/cm^3) prevents the synthesis of elements beyond this nucleus (main component)

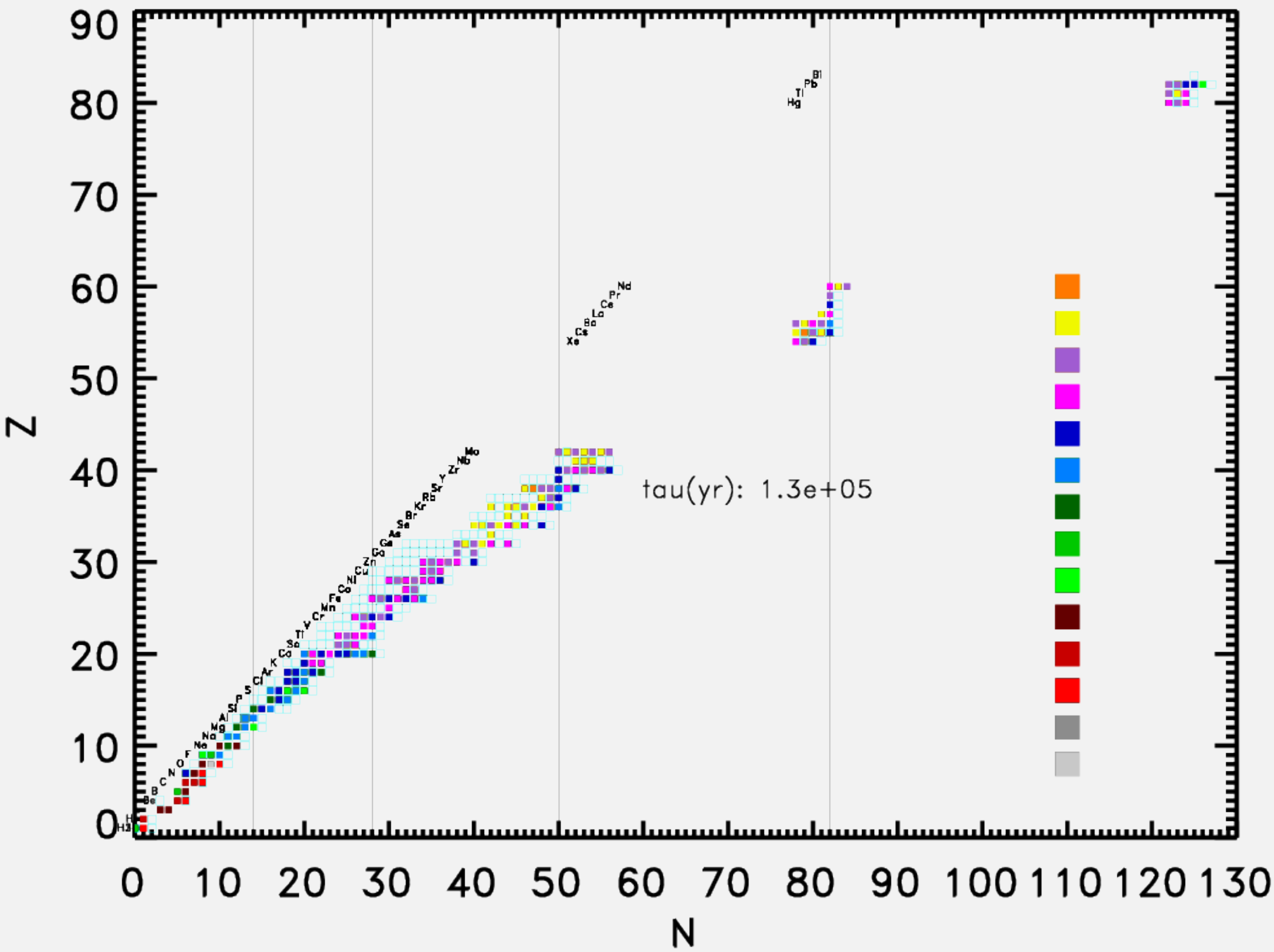
At low metallicities the very low neutron exposure (0.006 mbarn^{-1}) prevents also the synthesis of the weak component

The inclusion of a mild initial rotational velocity of 300 km/s triggers instabilities (meridional circulation ans secular shear) that stir matter from the He burning to the H burning and vice versa, leading to the synthesis of a large amount of primary N and, in turn, of ^{22}Ne, that becomes in this way a very powerful neutron source.

P

														85Tc ≈0.5 S ϵ	86Tc 54 MS ϵ	87Tc 2.2 S ϵ: 100.00%	88Tc 5.8 S ϵ: 100.00%	89Tc 12.8 S ϵ: 100.00%	90Tc 8.7 S ϵ: 100.00%	91Tc 3.14 M ϵ: 100.00%	92Tc 4.25 M ϵ: 100.00%	93Tc 2.75 H ϵ: 100.00%	94Tc 293 M ϵ: 100.00%
													83Mo 6 MS ϵ: 100.00%	84Mo 3.7 S ϵ: 100.00%	85Mo 3.2 S ϵp: 0.14% ϵ	86Mo 19.6 S ϵ: 100.00%	87Mo 14.02 S ϵ: 100.00% ϵp: 15.00%	88Mo 8.0 M ϵ: 100.00%	89Mo 2.11 M ϵ: 100.00%	90Mo 5.56 H ϵ: 100.00%	91Mo 15.49 M ϵ: 100.00%	92Mo STABLE 14.84%	93Mo 4.0E+3 Y ϵ: 100.00%
													82Nb 50 MS ϵ: 100.00%	83Nb 4.1 S ϵ: 100.00%	84Nb 9.5 S ϵ: 100.00% ϵp	85Nb 20.9 S ϵ: 100.00%	86Nb 56 S ϵ	87Nb 3.75 M ϵ: 100.00%	88Nb 14.55 M ϵ: 100.00%	89Nb 2.03 H ϵ: 100.00%	90Nb 14.60 H ϵ: 100.00%	91Nb 6.8E+2 Y ϵ: 100.00%	92Nb 3.47E+7 Y ϵ: 100.00% β- < 0.05%
													81Zr 5.5 S ϵ: 100.00% ϵp: 0.12%	82Zr 32 S ϵ: 100.00%	83Zr 41.6 S ϵ: 100.00% ϵp	84Zr 25.9 M ϵ: 100.00%	85Zr 7.86 M ϵ: 100.00%	86Zr 16.5 H ϵ: 100.00%	87Zr 1.68 H ϵ: 100.00%	88Zr 83.4 D ϵ: 100.00%	89Zr 78.41 H ϵ: 100.00%	90Zr STABLE 51.45%	91Zr STABLE 11.22%
													80Y 30.1 S ϵ: 100.00% ϵp	81Y 70.4 S ϵ: 100.00%	82Y 8.30 S ϵ: 100.00%	83Y 7.08 M ϵ: 100.00%	84Y 4.6 S ϵ: 100.00%	85Y 2.68 H ϵ: 100.00%	86Y 14.74 H ϵ: 100.00%	87Y 79.8 H ϵ: 100.00%	88Y 106.626 D ϵ: 100.00%	89Y STABLE 100%	90Y 64.053 H β-: 100.00%
													79Sr 2.25 M ϵ: 100.00%	80Sr 106.3 M ϵ: 100.00%	81Sr 22.3 M ϵ: 100.00%	82Sr 25.55 D ϵ: 100.00%	83Sr 32.41 H ϵ: 100.00%	84Sr STABLE 0.56%	85Sr 64.84 D ϵ: 100.00%	86Sr STABLE 9.86%	87Sr STABLE 7.00%	88Sr STABLE 82.58%	89Sr 50.57 D β-: 100.00%
						71Rb P	72Rb <1.2 μS P	73Rb >30 NS P > 0.00% ϵ	74Rb 64.9 MS ϵ: 100.00%	75Rb 19.0 S ϵ: 100.00%	76Rb 36.5 S ϵ: 100.00% ϵα: 3.8E-7%	77Rb 3.77 M ϵ: 100.00%	78Rb 17.66 M ϵ: 100.00%	79Rb 22.9 M ϵ: 100.00%	80Rb 33.4 S ϵ: 100.00%	81Rb 4.570 H ϵ: 100.00%	82Rb 1.273 M ϵ: 100.00%	83Rb 86.2 D ϵ: 100.00%	84Rb 33.1 D ϵ: 96.20% β-: 3.80%	85Rb STABLE 72.17%	86Rb 18.642 D β-: 99.99% ϵ: 5.2E-3%	87Rb 4.81E+10 Y 27.83% β-: 100.00%	88Rb 17.773 M β-: 100.00%
					69Kr 32 MS ϵ: 100.00%	70Kr 52 MS ϵ: 100.00% ϵp≤ 1.30%	71Kr 100 MS ϵ: 100.00% ϵp: 5.20%	72Kr 17.1 S ϵ: 100.00%	73Kr 27.3 S ϵ: 100.00% ϵp: 0.25%	74Kr 11.50 M ϵ: 100.00%	75Kr 4.29 M ϵ: 100.00%	76Kr 14.8 H ϵ: 100.00%	77Kr 74.4 M ϵ: 100.00%	78Kr ≥2.3E+20 Y 0.35% 2ϵ	79Kr 35.04 H ϵ: 100.00%	80Kr STABLE 2.28%	81Kr 2.29E+5 Y ϵ: 100.00%	82Kr STABLE 11.58%	83Kr STABLE 11.49%	84Kr STABLE 57.00%	85Kr 3916.8 D β-: 100.00%	86Kr STABLE 17.30%	87Kr 76.3 M β-: 100.00%
				67Br P	68Br <1.2 μS P	69Br <24 NS P	70Br 79.1 MS ϵ: 100.00%	71Br 21.4 S ϵ: 100.00%	72Br 78.6 S ϵ: 100.00%	73Br 3.4 M ϵ: 100.00%	74Br 25.4 M ϵ: 100.00%	75Br 96.7 M ϵ: 100.00%	76Br 16.2 H ϵ: 100.00%	77Br 57.036 H ϵ: 100.00%	78Br 6.46 M ϵ≥ 99.99% β-≤ 0.01%	79Br STABLE 50.69%	80Br 17.68 M β-: 91.70% ϵ: 8.30%	81Br STABLE 49.31%	82Br 35.282 H β-: 100.00%	83Br 2.40 H β-: 100.00%	84Br 31.80 M β-: 100.00%	85Br 2.90 M β-: 100.00%	86Br 55.1 S β-: 100.00%
		64Se >180 NS ϵ: 100.00%	65Se <50 MS ϵ: 100.00%	66Se 33 MS ϵ: 100.00%	67Se 136 MS ϵ: 100.00% BP: 0.50%	68Se 35.5 S ϵ: 100.00%	69Se 27.4 S ϵ: 100.00% ϵp: 0.05%	70Se 41.1 M ϵ: 100.00%	71Se 4.74 M ϵ: 100.00%	72Se 8.40 D ϵ: 100.00%	73Se 7.15 H ϵ: 100.00%	74Se STABLE 0.89%	75Se 119.79 D ϵ: 100.00%	76Se STABLE 9.37%	77Se STABLE 7.63%	78Se STABLE 23.77%	79Se 2.95E+5 Y β-: 100.00%	80Se STABLE 49.61% 2β-	81Se 18.45 M β-: 100.00%	82Se STABLE 8.73%	83Se 22.3 M β-: 100.00%	84Se 3.10 M β-: 100.00%	85Se 31.7 S β-: 100.00%
61As P	62As P	63As P	64As 18 MS ϵ: 100.00%	65As 128 MS ϵ: 100.00%	66As 95.79 MS ϵ: 100.00%	67As 42.5 S ϵ: 100.00%	68As 151.6 S ϵ: 100.00%	69As 15.2 M ϵ: 100.00%	70As 52.6 M ϵ: 100.00%	71As 65.28 H ϵ: 100.00%	72As 26.0 H ϵ: 100.00%	73As 80.30 D ϵ: 100.00%	74As 17.77 D ϵ: 66.00% β-: 34.00%	75As STABLE 100%	76As 1.0942 D β-: 100.00%	77As 38.83 H β-: 100.00%	78As 90.7 M β-: 100.00%	79As 9.01 M β-: 100.00%	80As 15.2 S β-: 100.00%	81As 33.3 S β-: 100.00%	82As 19.1 S β-: 100.00%	83As 13.4 S β-: 100.00%	84As 3.24 S β-: 100.00% β-n: 0.28%
60Ge ≈30 MS 2P ϵ	61Ge 39 MS ϵ: 100.00% ϵp≈ 80.00%	62Ge 129 MS ϵ	63Ge 142 MS ϵ: 100.00%	64Ge 63.7 S ϵ: 100.00%	65Ge 30.9 S ϵ: 100.00%	66Ge 2.26 H ϵ: 100.00%	67Ge 18.9 M ϵ: 100.00%	68Ge 270.95 D ϵ: 100.00%	69Ge 39.05 H ϵ: 100.00%	70Ge STABLE 20.37%	71Ge 11.43 D ϵ: 100.00%	72Ge STABLE 27.31%	73Ge STABLE 7.76%	74Ge STABLE 36.73%	75Ge 82.78 M β-: 100.00%	76Ge 1.78E+21 Y 7.83% 2β-	77Ge 11.30 H β-: 100.00%	78Ge 88.0 M β-: 100.00%	79Ge 18.98 S β-: 100.00%	80Ge 29.5 S β-: 100.00%	81Ge 7.6 S β-: 100.00%	82Ge 4.55 S β-: 100.00%	83Ge 1.85 S β-: 100.00%
59Ga P	60Ga 70 MS ϵ: 98.40% ϵp: 1.60%	61Ga 168 MS ϵ: 100.00%	62Ga 116.18 MS ϵ: 100.00%	63Ga 32.4 S ϵ: 100.00%	64Ga 2.627 M ϵ: 100.00%	65Ga 15.2 M ϵ: 100.00%	66Ga 9.49 H ϵ: 100.00%	67Ga 3.2617 D ϵ: 100.00%	68Ga 67.71 M ϵ: 100.00%	69Ga STABLE 60.108%	70Ga 21.14 M β-: 99.59% ϵ: 0.41%	71Ga STABLE 39.892%	72Ga 14.095 H β-: 100.00%	73Ga 4.86 H β-: 100.00%	74Ga 8.12 M β-: 100.00%	75Ga 126 S β-: 100.00%	76Ga 32.6 S β-: 100.00%	77Ga 13.2 S β-: 100.00%	78Ga 5.09 S β-: 100.00%	79Ga 2.847 S β-: 100.00% β-n: 0.09%	80Ga 1.676 S β-: 100.00% β-n: 0.86%	81Ga 1.217 S β-: 100.00% β-n: 11.90%	82Ga 0.599 S β-: 100.00% β-n: 19.80%
58Zn 84 MS ϵ: 100.00%	59Zn 182.0 MS ϵ: 100.00% ϵp: 0.10%	60Zn 2.38 M ϵ: 100.00%	61Zn 89.1 S ϵ: 100.00%	62Zn 9.186 H ϵ: 100.00%	63Zn 38.47 M ϵ: 100.00%	64Zn STABLE 48.63%	65Zn 243.66 D ϵ: 100.00%	66Zn STABLE 27.90%	67Zn STABLE 4.10%	68Zn STABLE 18.75%	69Zn 56.4 M β-: 100.00%	70Zn >1.3E+16 Y 0.62% 2β-	71Zn 2.45 M β-: 100.00%	72Zn 46.5 H β-: 100.00%	73Zn 23.5 S β-: 100.00%	74Zn 95.6 S β-: 100.00%	75Zn 10.2 S β-: 100.00%	76Zn 5.7 S β-: 100.00%	77Zn 2.08 S β-: 100.00%	78Zn 1.47 S β-: 100.00%	79Zn 0.995 S β-: 100.00% β-n: 1.30%	80Zn 0.54 S β-: 100.00% β-n: 1.00%	81Zn 0.29 S β-: 100.00% β-n: 7.50%
57Cu 196.3 MS ϵ: 100.00%	58Cu 3.204 S ϵ: 100.00%	59Cu 81.5 S ϵ: 100.00%	60Cu 23.7 M ϵ: 100.00%	61Cu 3.333 H ϵ: 100.00%	62Cu 9.67 M ϵ: 100.00%	63Cu STABLE 69.17%	64Cu 12.701 H ϵ: 61.50% β-: 38.50%	65Cu STABLE 30.83%	66Cu 5.120 M β-: 100.00%	67Cu 61.83 H β-: 100.00%	68Cu 31.1 S β-: 100.00%	69Cu 2.85 M β-: 100.00%	70Cu 44.5 S β-: 100.00%	71Cu 19.5 S β-: 100.00%	72Cu 6.6 S β-: 100.00%	73Cu 4.2 S β-: 100.00%	74Cu 1.594 S β-: 100.00%	75Cu 1.224 S β-: 100.00% β-n: 3.50%	76Cu 1.27 S β-: 100.00% β-: 100.00%	77Cu 0.469 S β-: 100.00%	78Cu 342 MS β-: 100.00%	79Cu 188 MS β-: 100.00% β-n: 55.00%	80Cu >300 NS β-
56Ni 6.075 D ϵ: 100.00%	57Ni 35.60 H ϵ: 100.00%	58Ni STABLE 68.077%	59Ni 7.6E+4 Y ϵ: 100.00%	60Ni STABLE 26.223%	61Ni STABLE 1.140%	62Ni STABLE 3.634%	63Ni 100.1 Y β-: 100.00%	64Ni STABLE 0.926%	65Ni 2.5172 H β-: 100.00%	66Ni 54.6 H β-: 100.00%	67Ni 21 S β-: 100.00%	68Ni 29 S β-: 100.00%	69Ni 11.4 S β-: 100.00%	70Ni 6.0 S β-: 100.00%	71Ni 2.56 S β-: 100.00%	72Ni 1.57 S β-: 100.00% β-n	73Ni 0.84 S β-: 100.00%	74Ni 0.68 S β-: 100.00% β-n	75Ni 0.6 S β-: 100.00% β-n: 8.43%	76Ni 0.24 S β-: 100.00% β-n	77Ni >150 NS β-	78Ni >150 NS β-	
55Co 17.53 H ϵ: 100.00%	56Co 77.233 D ϵ: 100.00%	57Co 271.74 D ϵ: 100.00%	58Co 70.86 D ϵ: 100.00%	59Co STABLE 100%	60Co 1925.28 D β-: 100.00%	61Co 1.650 H β-: 100.00%	62Co 1.50 M β-: 100.00%	63Co 27.4 S β-: 100.00%	64Co 0.30 S β-: 100.00%	65Co 1.20 S β-: 100.00%	66Co 0.18 S β-: 100.00%	67Co 0.425 S β-: 100.00%	68Co 0.199 S β-: 100.00%	69Co 0.22 S β-: 100.00%	70Co 119 MS β-: 100.00%	71Co 79 MS β-: 100.00% β-n: 2.61%	72Co 62 MS β-: 100.00% β-n: 4.80%	73Co 41 MS β-	74Co >150 NS β-	75Co >150 NS β-: 100.00%			
54Fe STABLE 5.845%	55Fe 2.737 Y ϵ: 100.00%	56Fe STABLE 91.754%	57Fe STABLE 2.119%	58Fe STABLE 0.282%	59Fe 44.495 D β-: 100.00%	60Fe 1.5E+6 Y β-: 100.00%	61Fe 5.98 M β-: 100.00%	62Fe 68 S β-: 100.00%	63Fe 6.1 S β-: 100.00%	64Fe 2.0 S β-: 100.00%	65Fe 1.3 S β-: 100.00%	66Fe 0.44 S β-: 100.00%	67Fe 0.6 S β-: 100.00%	68Fe 187 MS β-: 100.00%	69Fe 109 MS β-: 100.00%	70Fe 94 MS β-: 100.00%	71Fe >150 NS β-	72Fe >150 NS β-					

N



Z
N
tau(yr): 1.3e+05
0
10
20
30
40
50
60
70
80
90
100
110
120
130