Electron Capture Reactions in Simmering White Dwarfs

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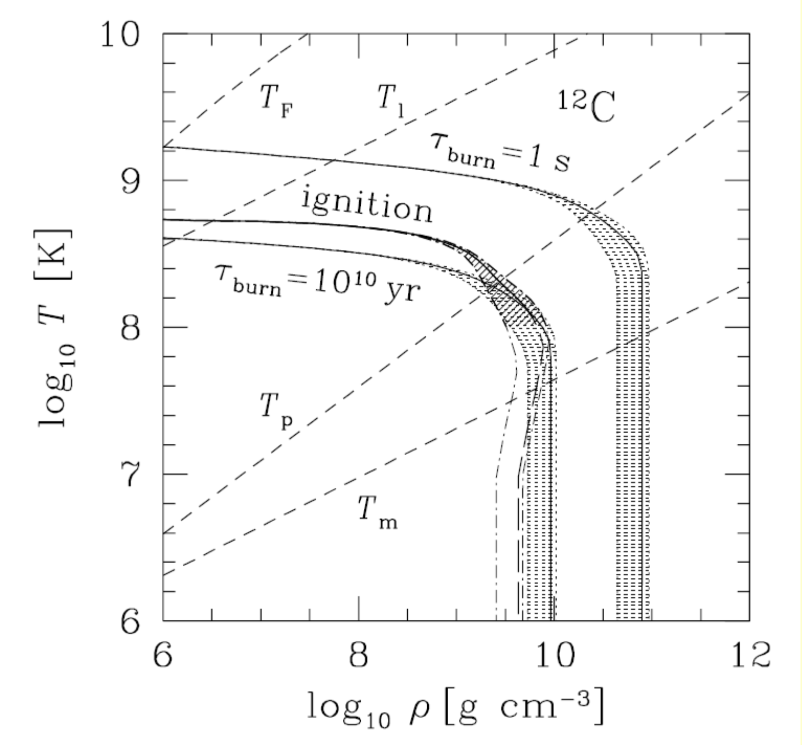
Type Ia Supernovae

- Thermonuclear incineration of a C/O white dwarf near the Chandrasekhar limit (1.4 Solar Masses). [see Hillebrandt & Niemeyer 2000]
- Light we see is produced by the decay of ^{56}Ni.

[NASA/ESA, The Hubble Key Project Team, and The High-Z Supernova Search Team]

Simmering

- As matter is accreted the center of the white dwarf increases in temperature and density.
- A period of convective burning starts.
- When the star can no longer adjust to the heat being released a flame is launched.
- The flame is hot enough to burn material to nuclear statistical equilibrium.



[Gasques et al. 2007]

Why do we care about electron captures?

Lets pretend that ^{56}Ni and ^{58}Ni are the only species in nuclear statistical equilibrium. The equations for mass and charge conservation

$$\sum_{i=1}^{n} X_i = 1 \qquad\qquad Y_e = \sum_{i=1}^{n} \frac{Z_i}{A_i} X_i$$

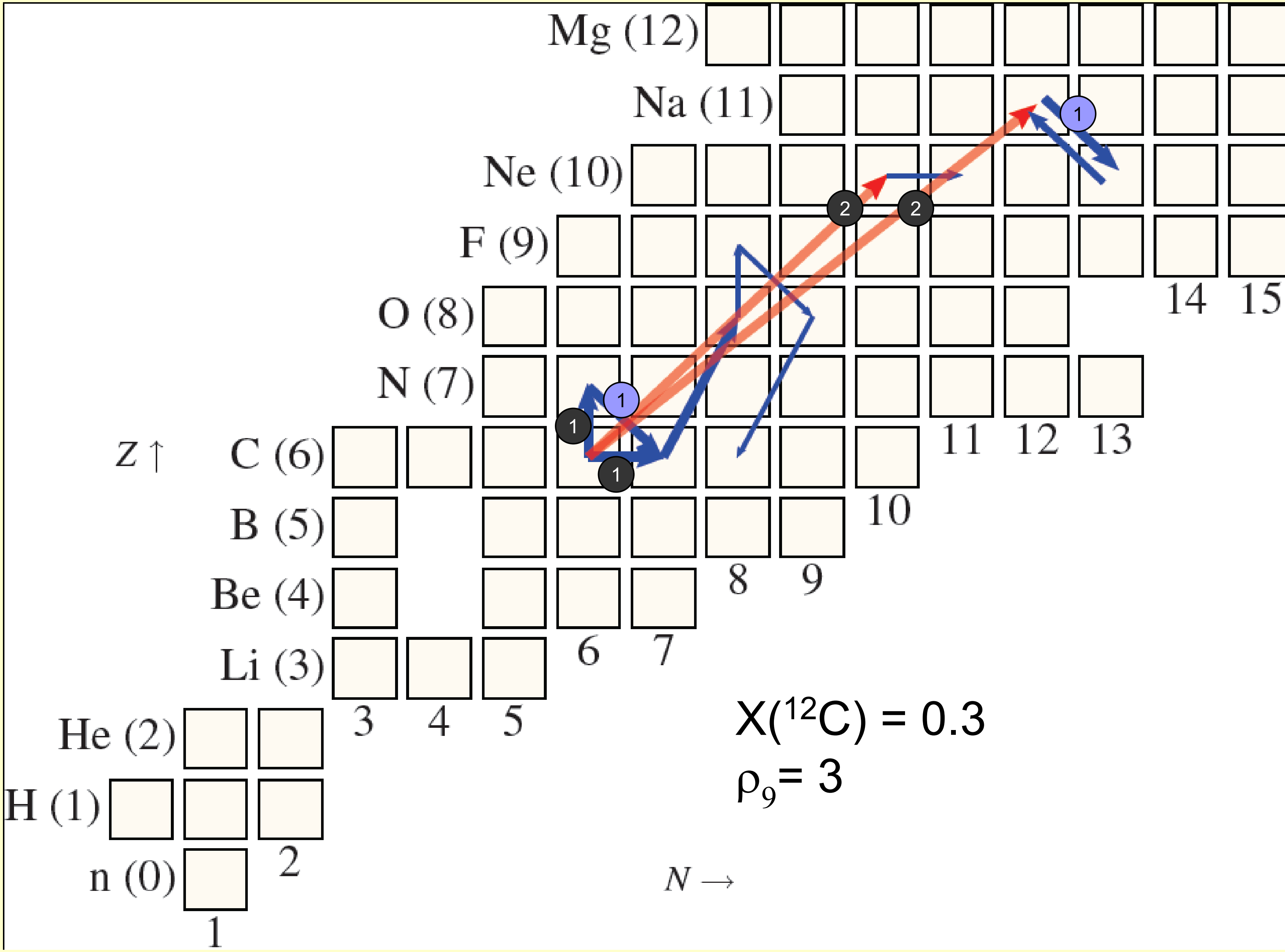
imply a relation between the mass fraction of ^{56}Ni and Y_e

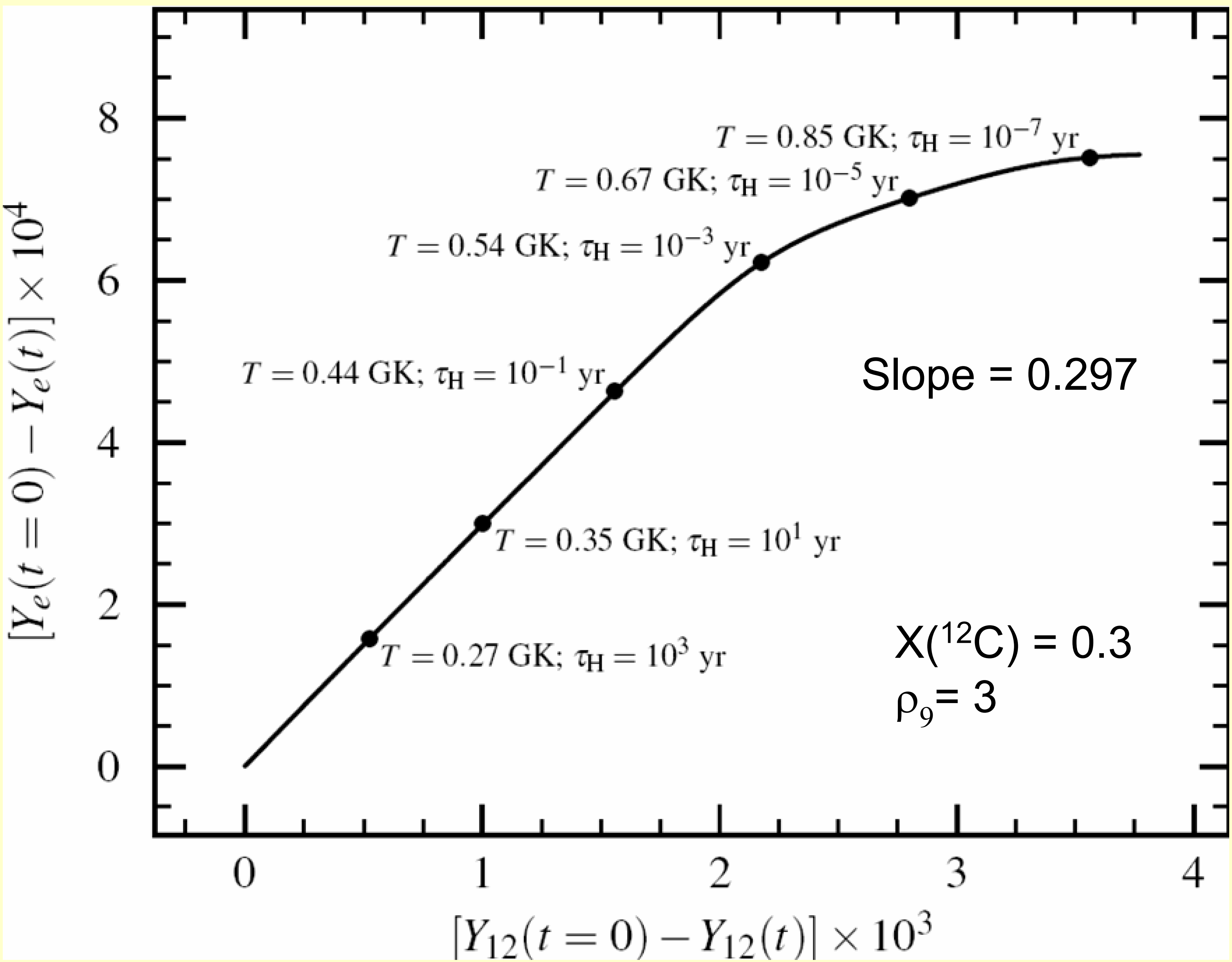
$$X(56) = 1 - X(58) = 58Y_e - 28$$

[Timmes, Brown, Truran 2003]

What we did

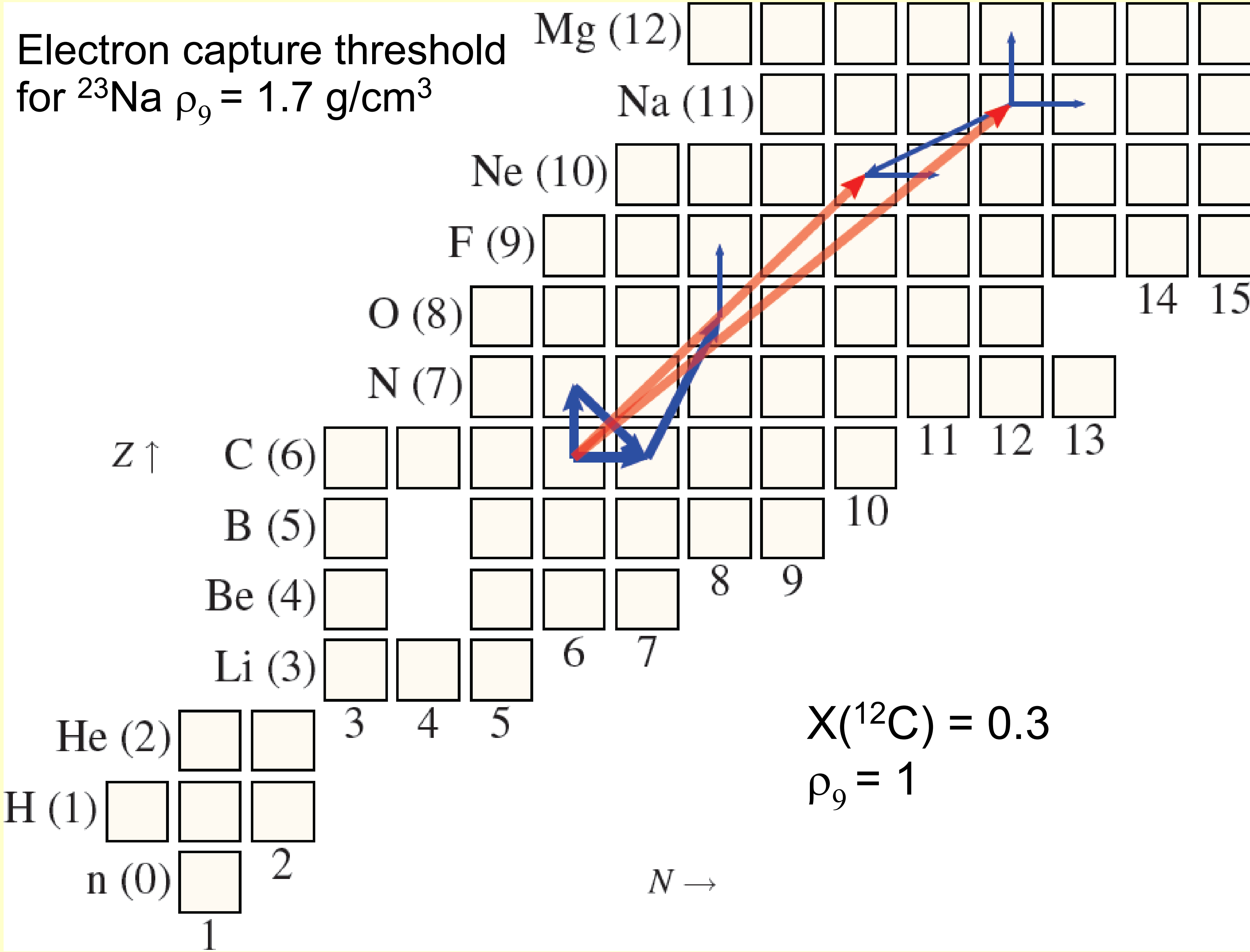
- Allowed a one zone model to self-heat
- Reaction network used rates found in reaclib
- Calculated the how much ^{56}Ni would be produced as prescribed by Woosley et. al. 2007 and compared with observation.
- Independently confirmed by Piro & Bildsten (2007)


Mg (12)
Na (11)
Ne (10)
F (9)
O (8)
N (7)
Z ↑
C (6)
B (5)
Be (4)
Li (3)
He (2)
H (1)
n (0)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1
1
1
1
2
2
X(^{12}C) = 0.3
ρ_9= 3
N →



$T = 0.85$ GK; $\tau_H = 10^{-7}$ yr
$T = 0.67$ GK; $\tau_H = 10^{-5}$ yr
$T = 0.54$ GK; $\tau_H = 10^{-3}$ yr
$T = 0.44$ GK; $\tau_H = 10^{-1}$ yr
$T = 0.35$ GK; $\tau_H = 10^{1}$ yr
$T = 0.27$ GK; $\tau_H = 10^{3}$ yr
Slope = 0.297
X(^{12}C) = 0.3
ρ_9= 3
$[Y_e(t=0) - Y_e(t)] \times 10^4$
$[Y_{12}(t=0) - Y_{12}(t)] \times 10^3$
0
2
4
6
8
0
1
2
3
4

Electron capture threshold for ^{23}Na $\rho_9 = 1.7$ g/cm^3



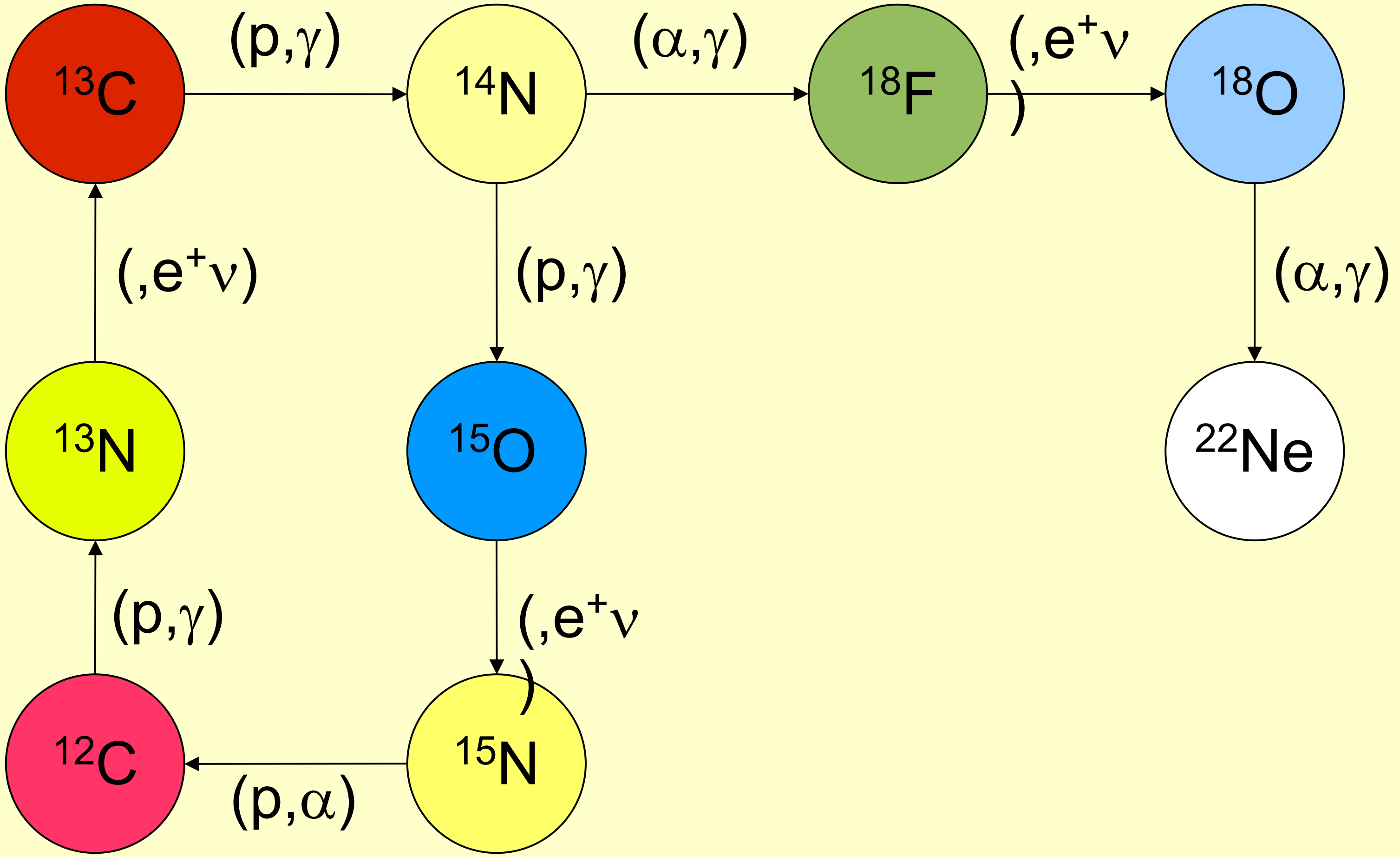
$X(^{12}C) = 0.3$

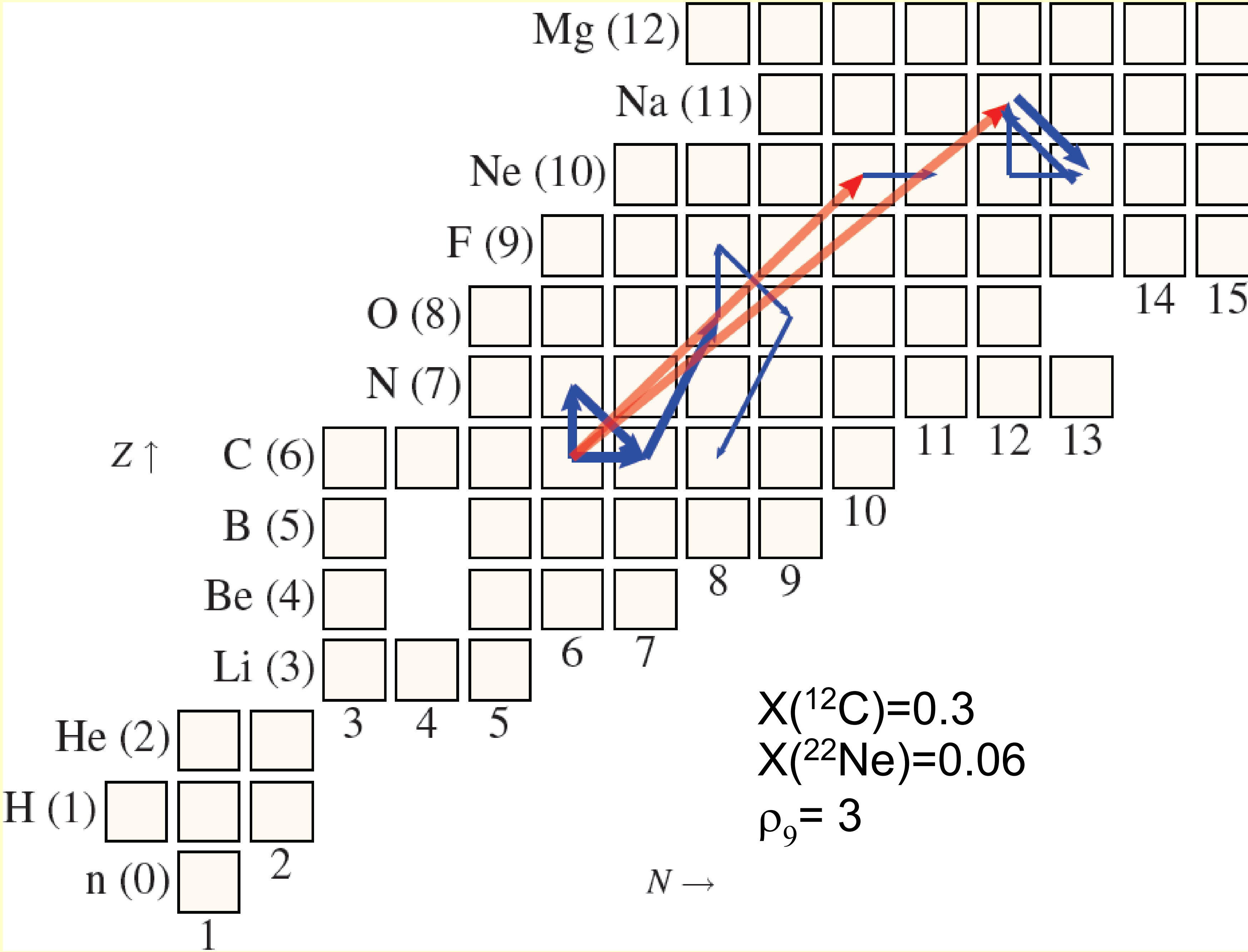
$\rho_9 = 1$

^{22}Ne

- Next to carbon and oxygen, neon should be the third most abundant elements in the white dwarf.
- The abundance of ^{22}Ne should track along with the metalicity of the main-sequence progenitor of the white dwarf.

The origin of ^{22}Ne





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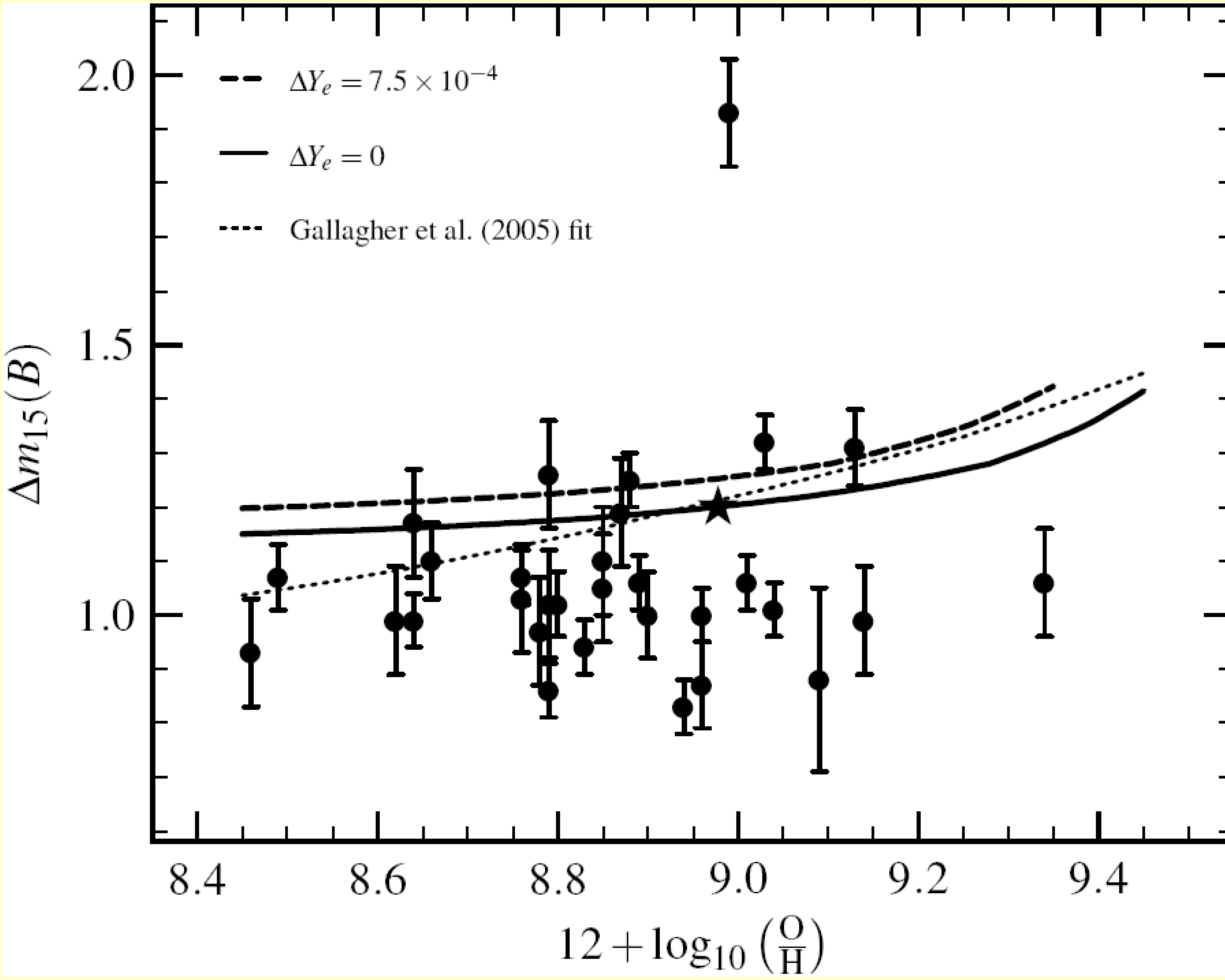
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
N →
X(^{12}C)=0.3
X(^{22}Ne)=0.06
ρ_9= 3

Table 1. Change in electron abundance per carbon consumed during the pre-explosion convective burning

composition[a]	density $10^9\ \mathrm{g\,cm^{-3}}$	$\mathrm{d}Y_e/\mathrm{d}Y_{12}$
$X_{22} = 0.00$	1.0	0.136
···	3.0	0.297
···	6.0	0.302
$X_{22} = 0.06$	1.0	0.125
···	3.0	0.301
···	6.0	0.305
$3Z_\odot$	1.0	0.130
···	3.0	0.349
···	6.0	0.355

[a]In all cases the mass fraction of ^{12}C is 0.3.

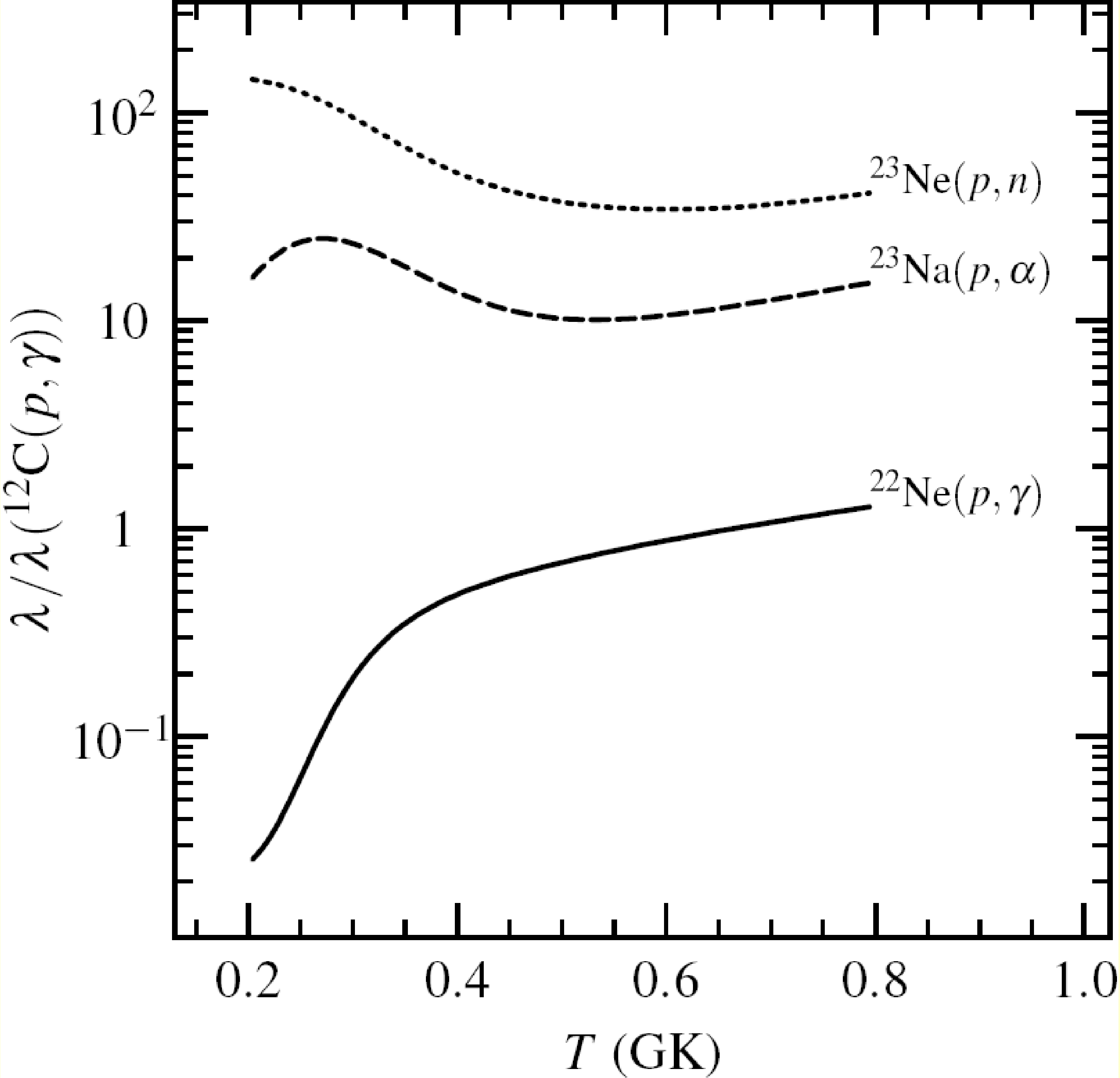
[Chamulak et. al. 2007]



$\Delta Y_e = 7.5 \times 10^{-4}$
$\Delta Y_e = 0$
Gallagher et al. (2005) fit
2.0
1.5
1.0
$\Delta m_{15}(B)$
8.4
8.6
8.8
9.0
9.2
9.4
$12 + \log_{10}\left(\frac{\mathrm{O}}{\mathrm{H}}\right)$

Summery and Conclusion

- A lower Ye leads to a lower abundance of ^{56}Ni and hence a dimmer supernova
- Simmering reduces Ye linearly with ^{12}C
- The reduction in ^{56}Ni is not enough to account for the scatter in the observed brightnesses



10^2
10
1
10^{-1}
$\lambda/\lambda(^{12}\mathrm{C}(p,\gamma))$
$^{23}\mathrm{Ne}(p,n)$
$^{23}\mathrm{Na}(p,\alpha)$
$^{22}\mathrm{Ne}(p,\gamma)$
0.2
0.4
0.6
0.8
1.0
T (GK)