# $^{22}$Ne and SNe Ia

## KITP conference

*Paths to Exploding Stars*

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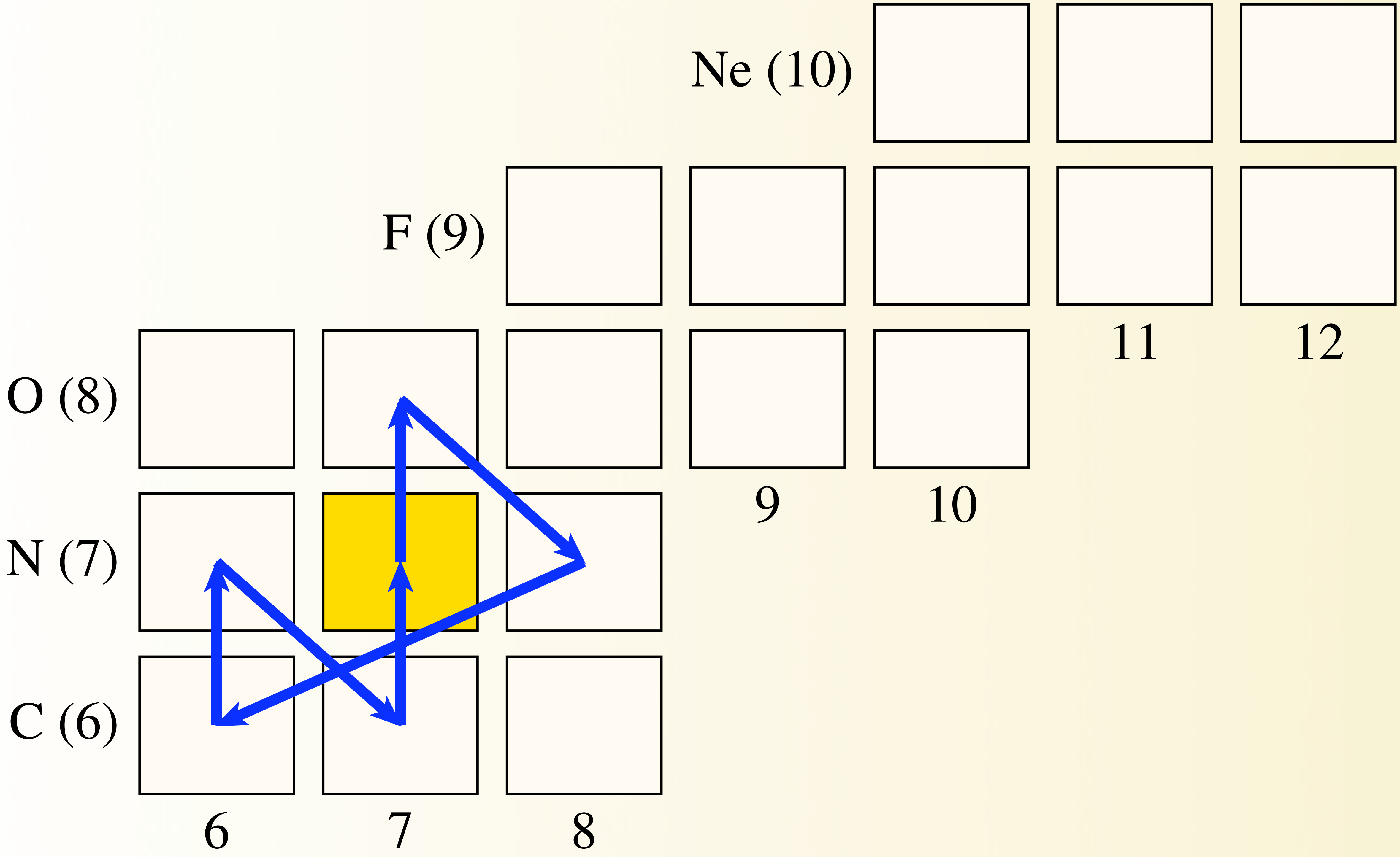
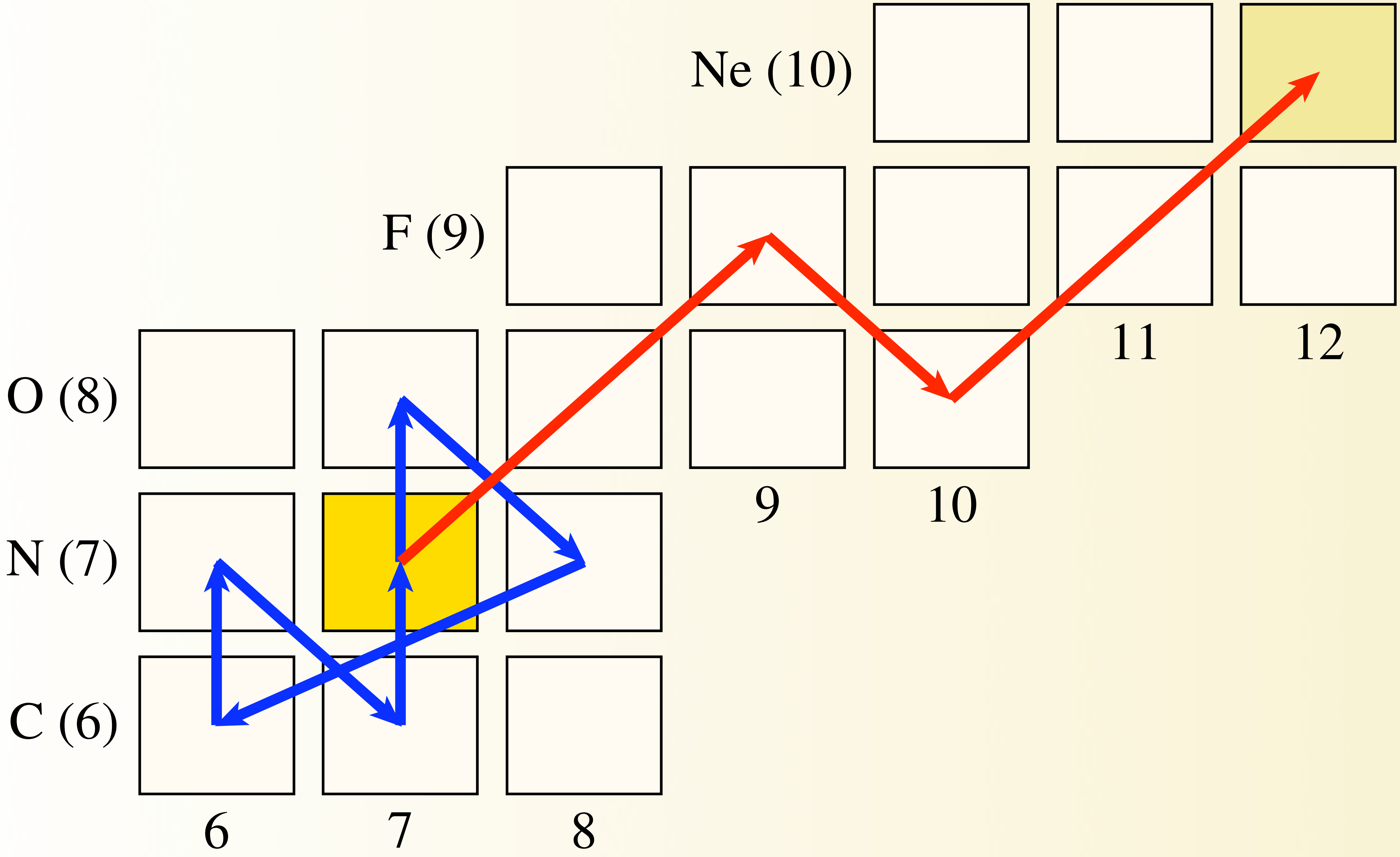
# Outline

- The abundance of $^{22}$Ne in white dwarf stars
- The production of $^{56}$Ni during explosive nucleosynthesis
- The contribution to variations in the peak luminosity of SNeIa
- New stuff
  - Effects on burning
  - Electron captures during “simmering”

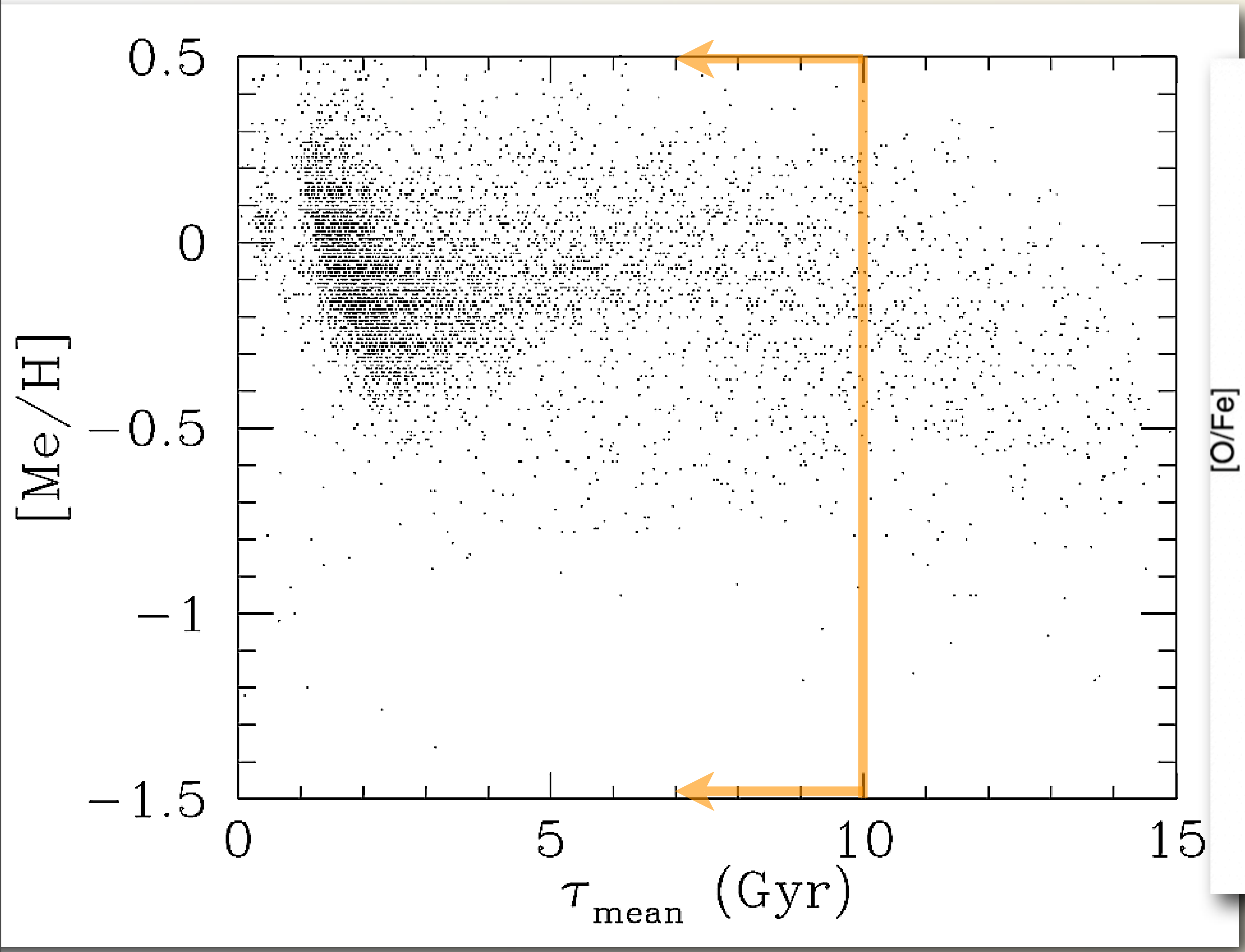
# $^{14}N(p,\gamma)^{15}O$ limits CNO cycle



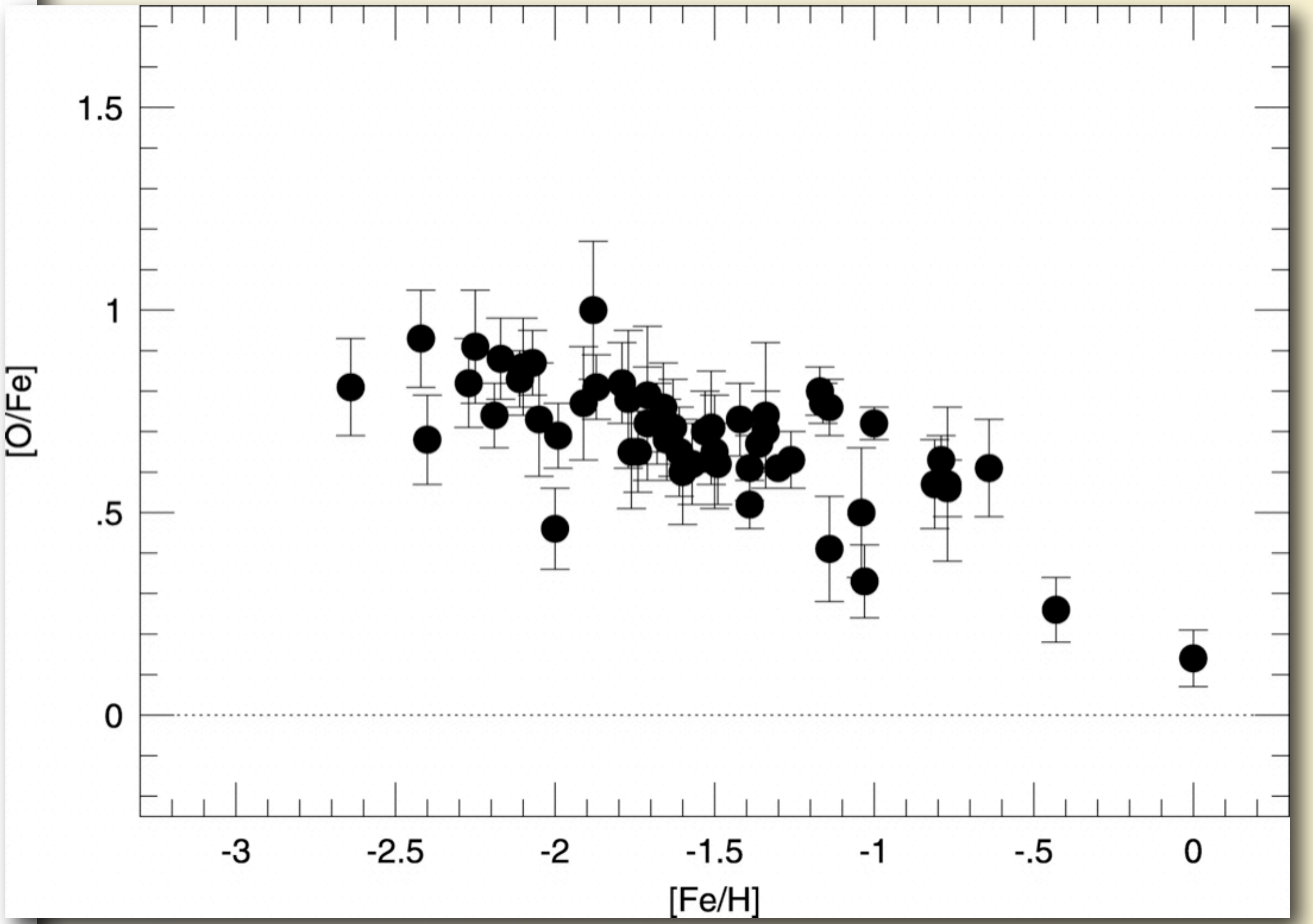
# $^{14}N(\alpha,\gamma)^{18}F(\beta+)^{18}O(\alpha,\gamma)\,^{22}Ne$



# Scatter in [O/H]



Feltzing, Holmberg & Hurley 2001



Fulbright & Johnson 2003

# Production of $^{56}$Ni during explosion

Suppose NSE dominated by $^{56}\mathrm{Ni}$ and $^{58}\mathrm{Ni}$, and $Y_e = \mathrm{const.}$ Then

$$X(^{56}\mathrm{Ni}) = 58Y_e - 28$$

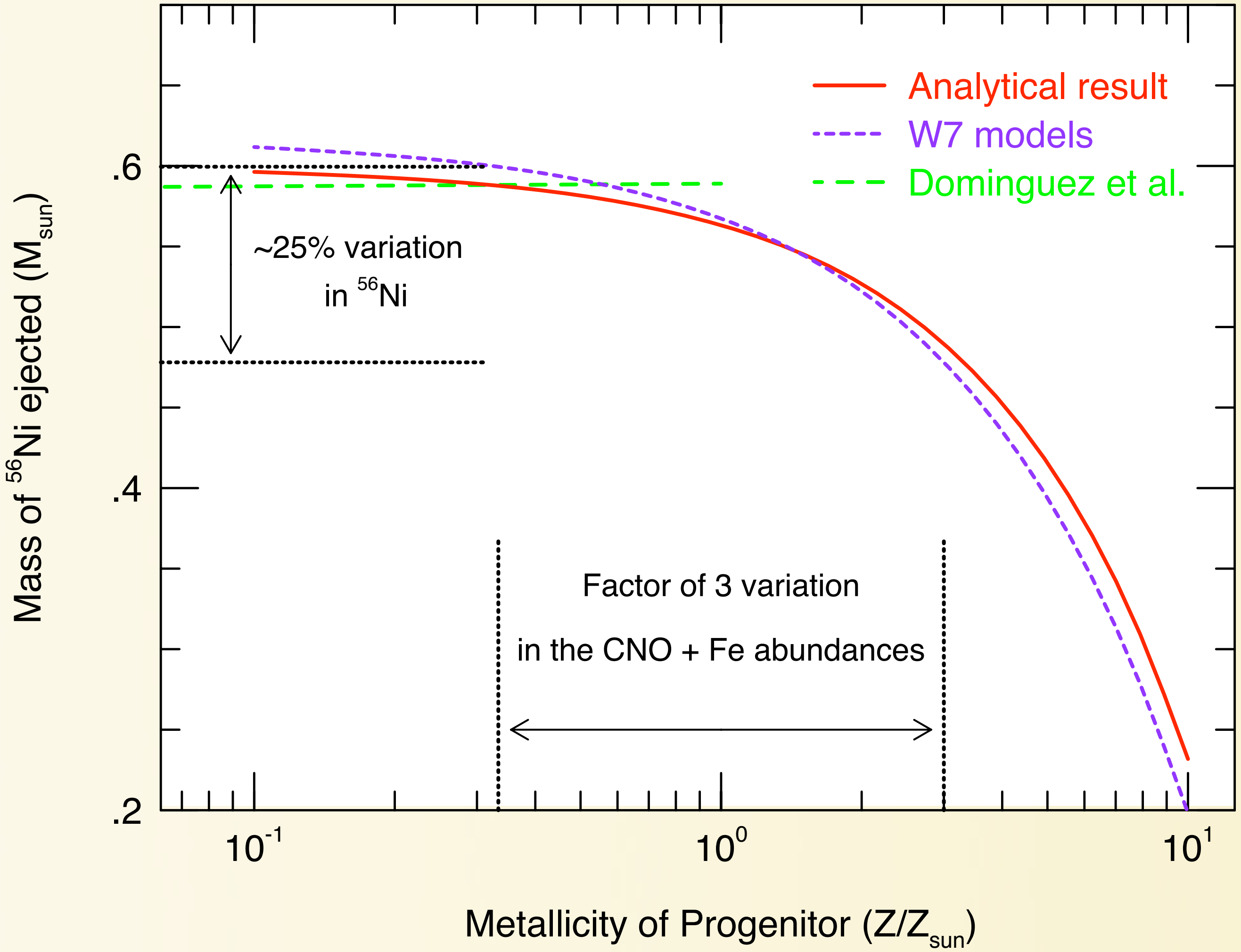
and if there are no captures *in situ* then

$$Y_e = \frac{10}{22}X(^{22}\mathrm{Ne}) + \frac{26}{56}X(^{56}\mathrm{Fe}) + \frac{1}{2}\left[1 - X(^{22}\mathrm{Ne}) - X(^{56}\mathrm{Fe})\right].$$

For a solar distribution of metals, this gives

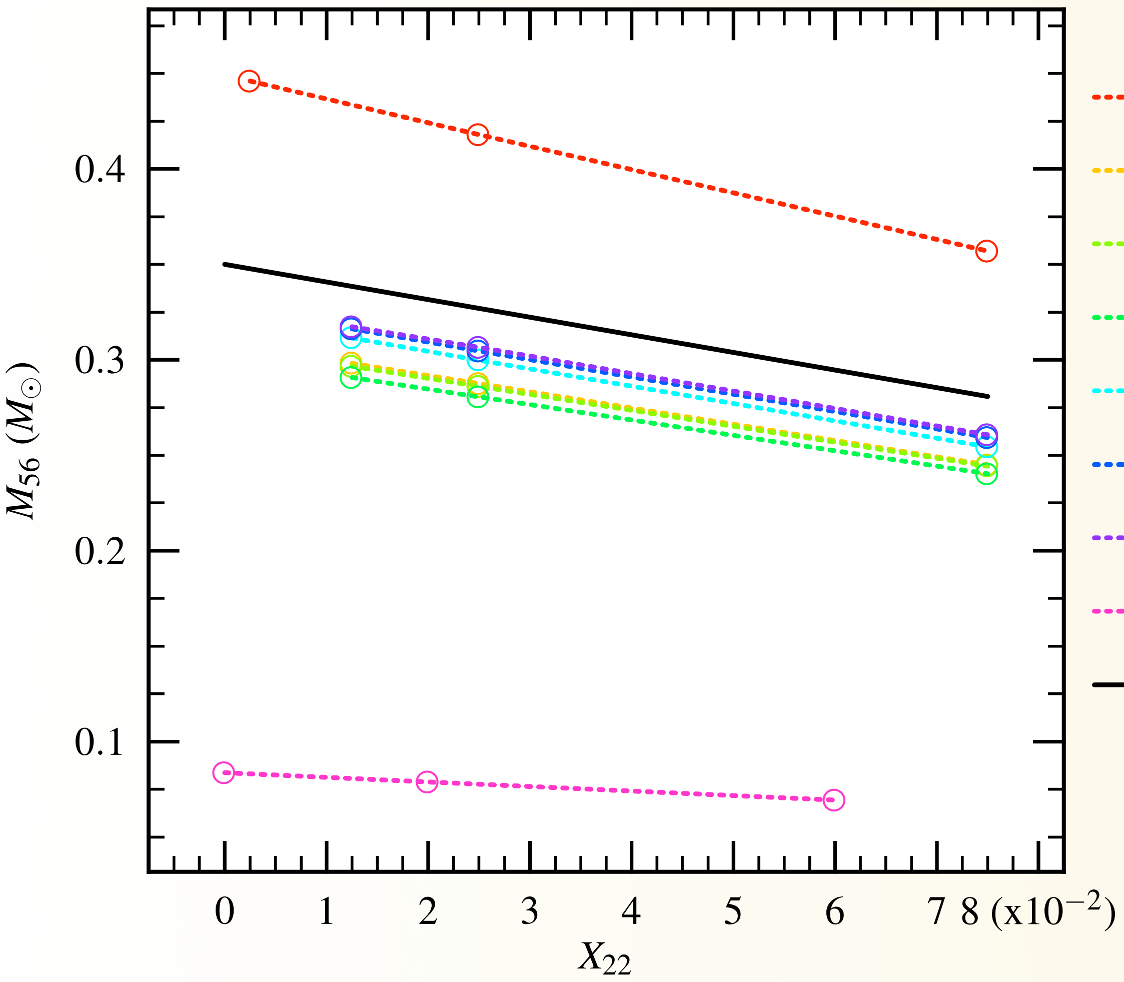
$$M(^{56}\mathrm{Ni}) = M_0(^{56}\mathrm{Ni})\left[1 - 0.057\frac{Z}{Z_\odot}\right].$$

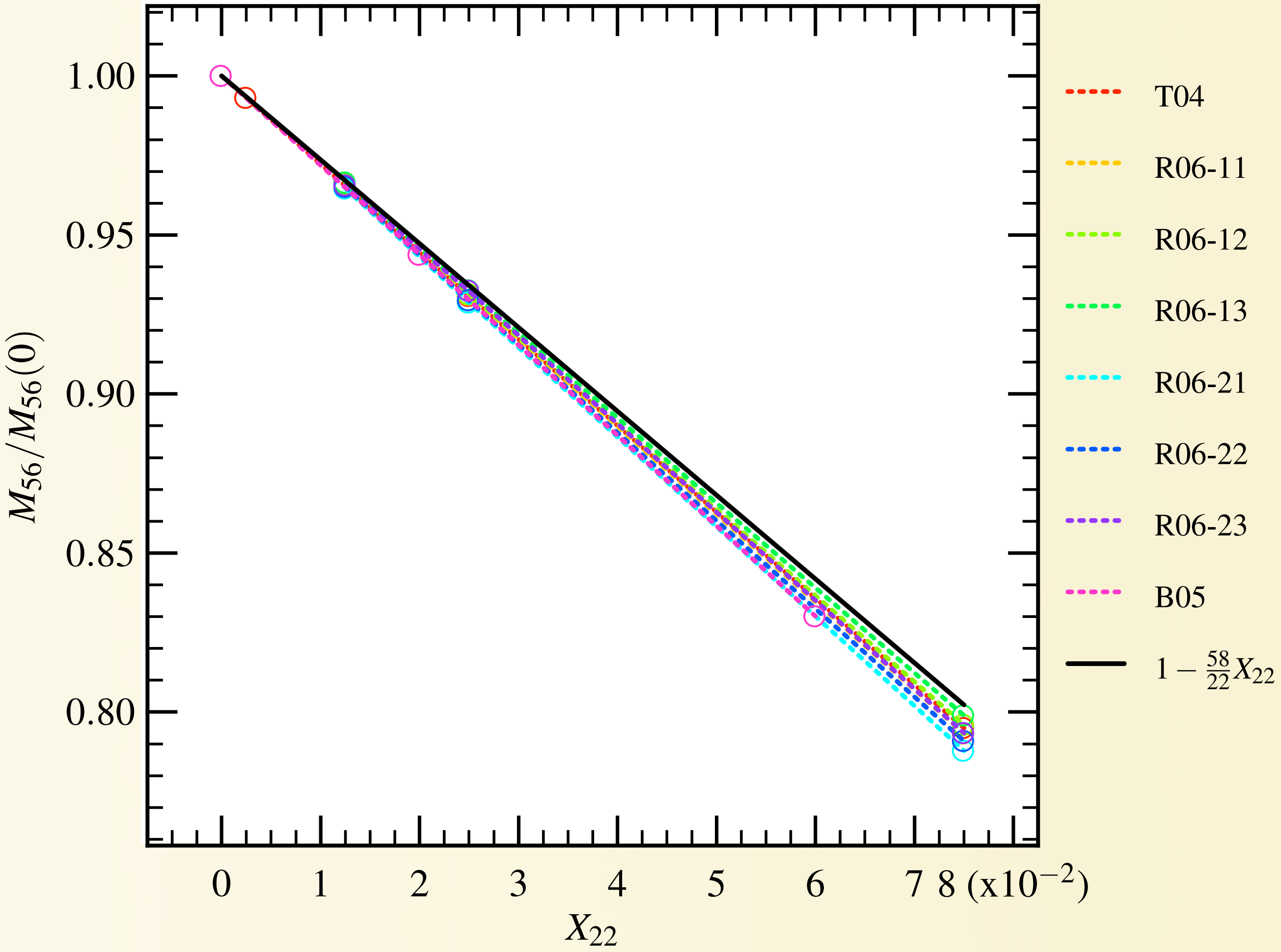
Timmes, Brown & Truran 2003



# Post-processing of hydro-simulations

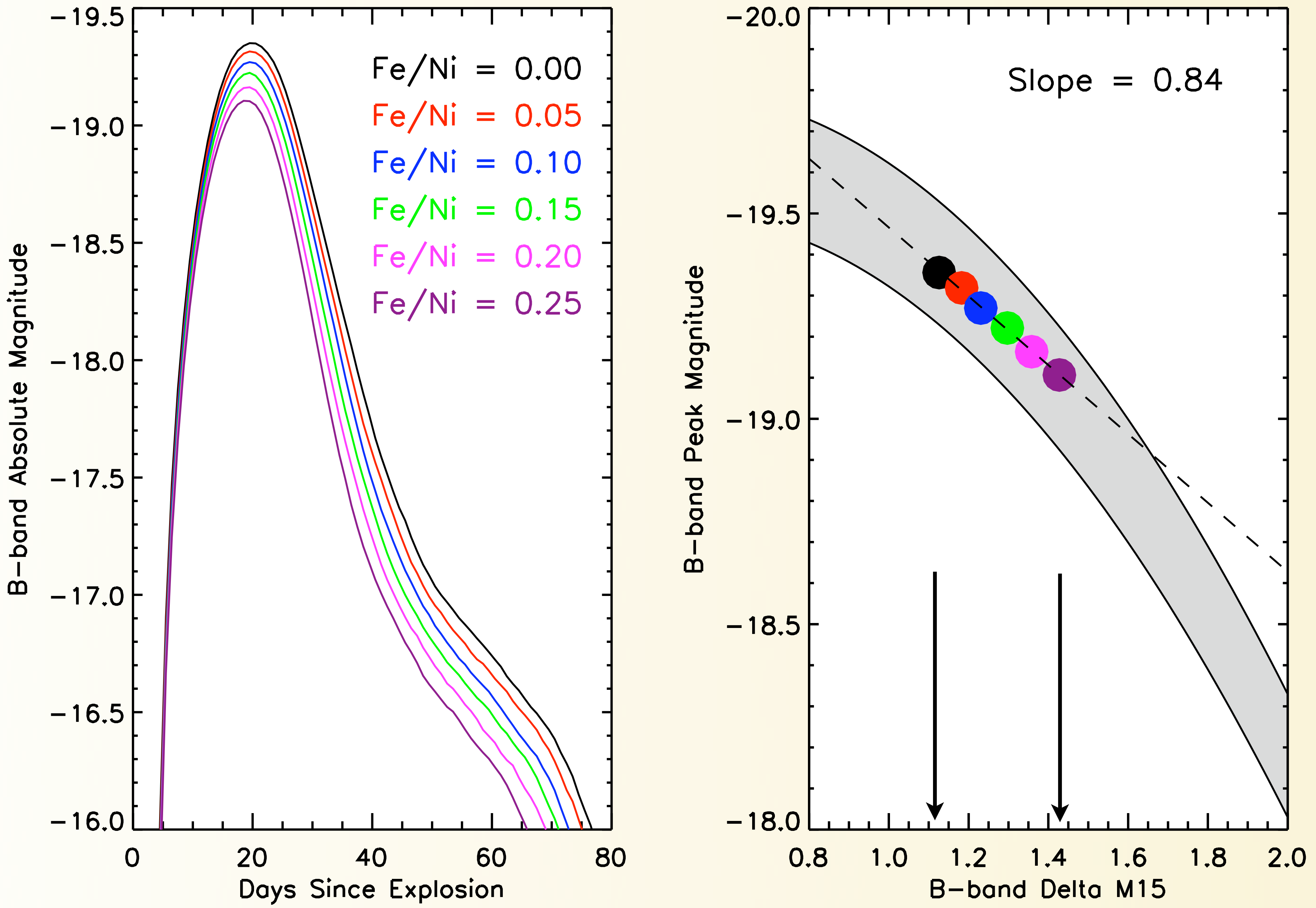
Travaglio et al. 2005, Brown et al. 2005, Röpke et al. 2006



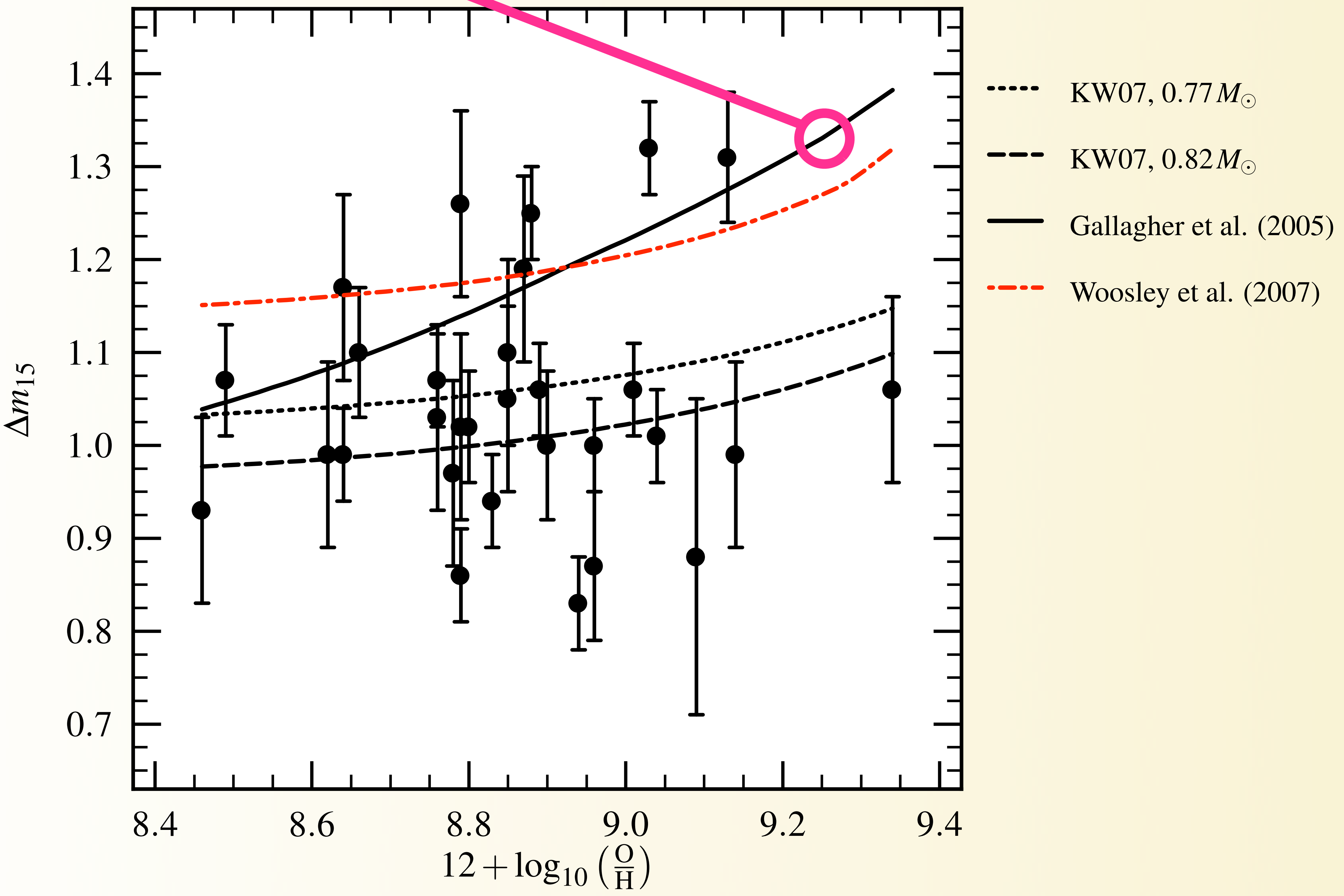


# Predicted "brighter-broader" relation for *M*(Fe+Ni) = constant

Woosley et al. (2007), fig. 22

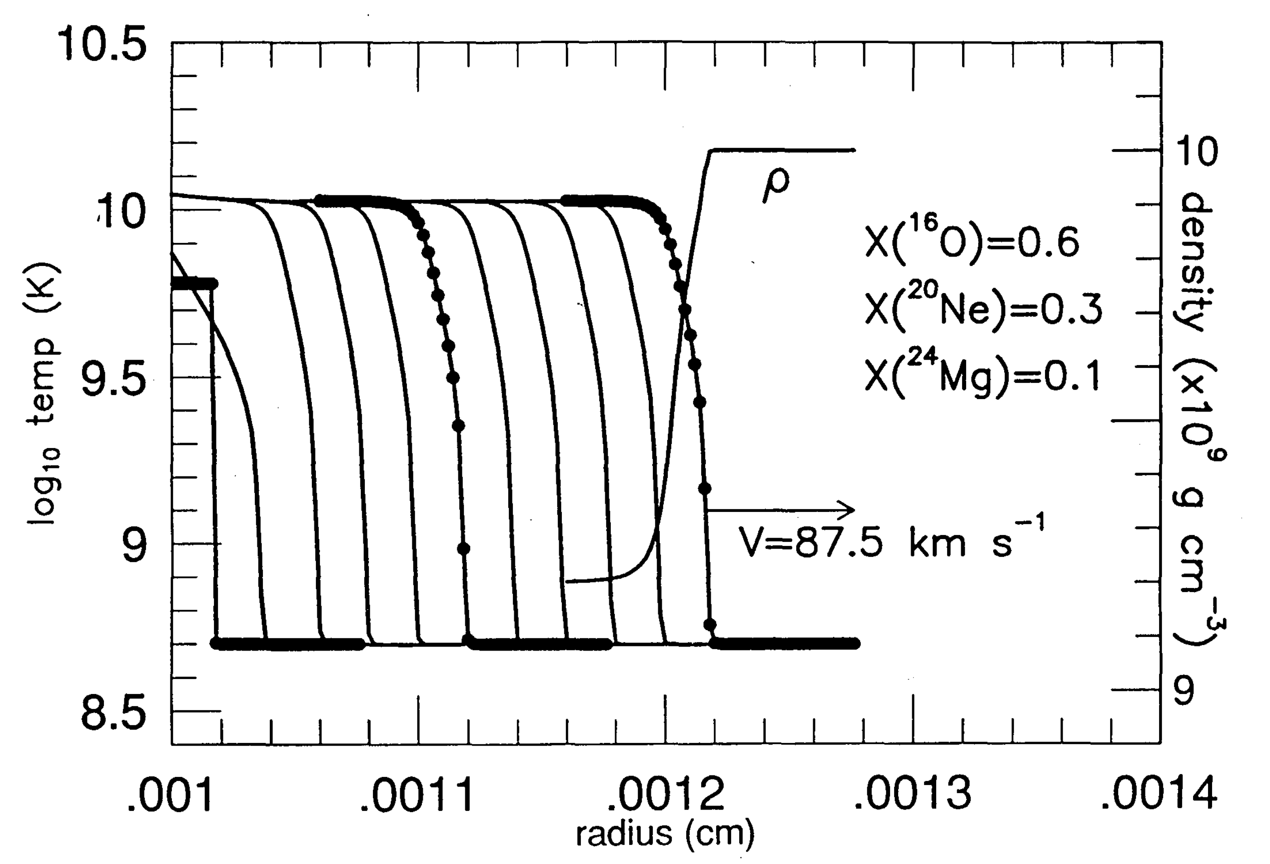


# Gallagher et al. Sample



M($^{56}$Ni) varied by
changing density of DDT
(Höflich et al. 2002)

# Flame structure



Timmes & Woosley 1992

Flame width determined by

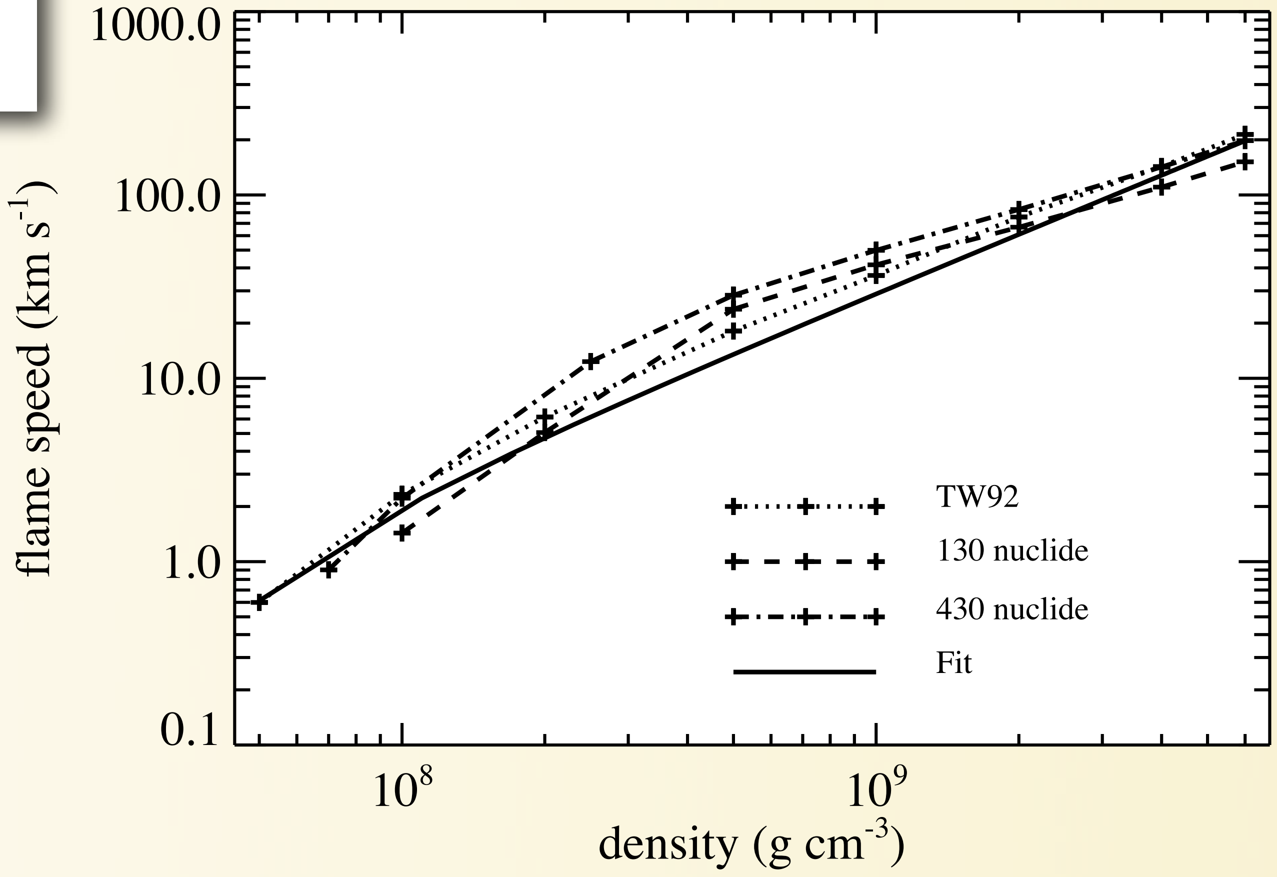
$$\text{thermal time} \sim \text{heating time}$$

$$\frac{\delta^2}{\chi} \sim \frac{CT}{\varepsilon}$$

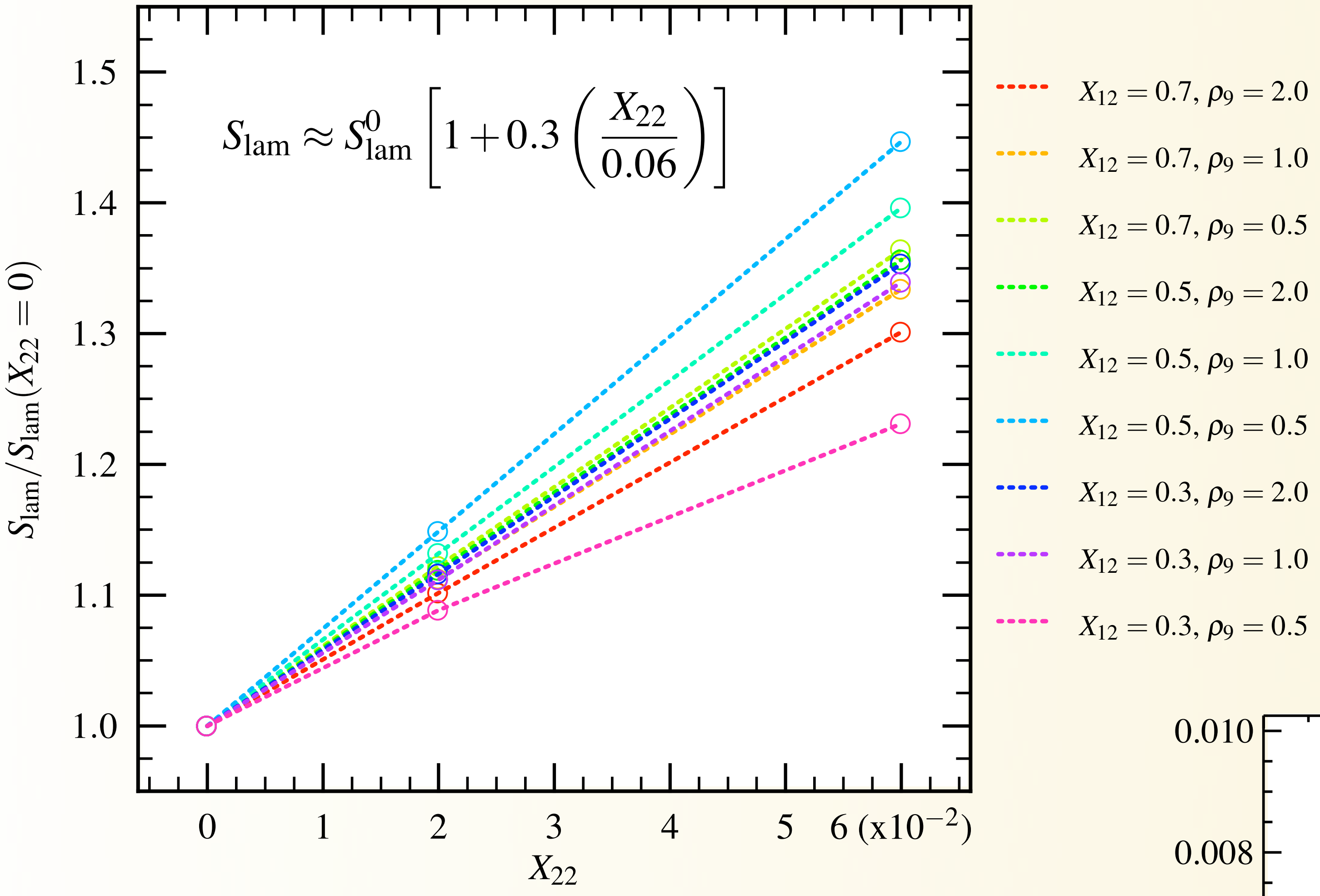
and the flame velocity is then

$$S_{\mathrm{lam}} \sim \frac{\delta}{CT/\varepsilon}$$

$$\propto (\varepsilon\chi)^{1/2}$$



# $^{22}$Ne($\alpha$,*n*) accelerates $^{4}$He production



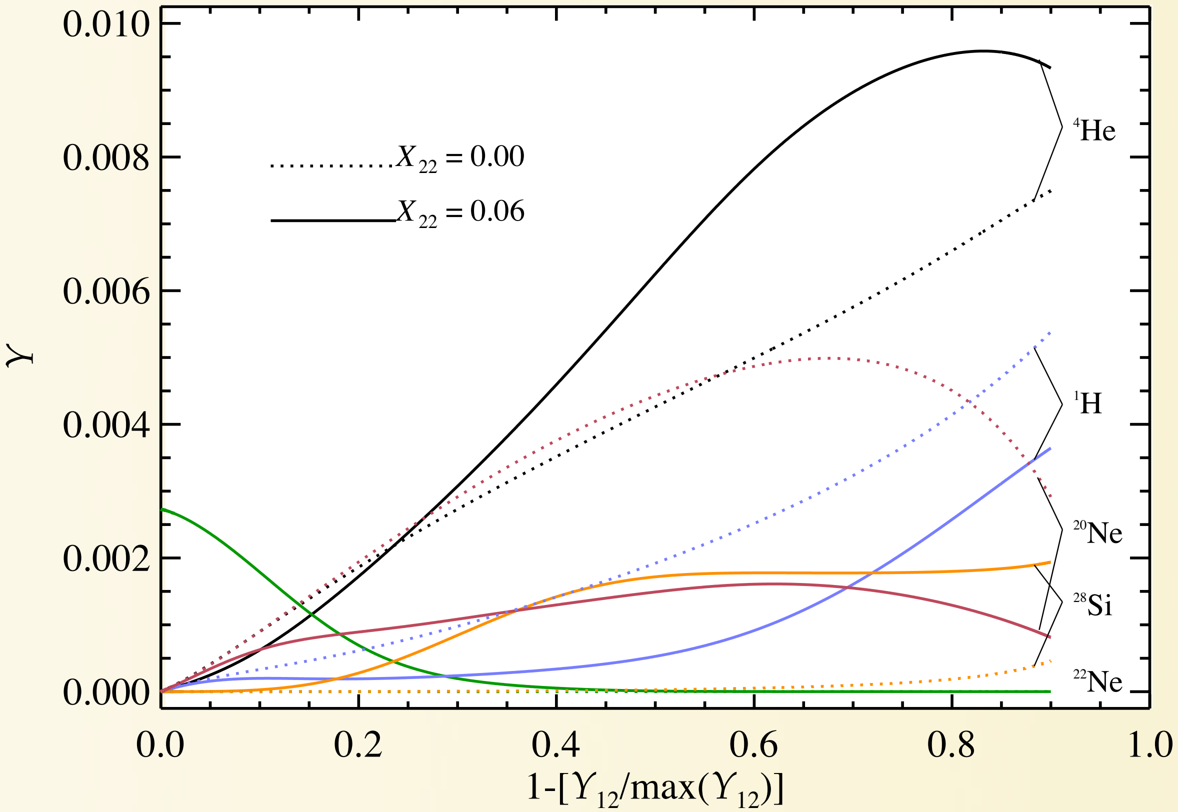
Important in two places

- At ignition, before flame speed set by turbulence
- At transition to distributed burning

Transition to distributed burning may occur where $\delta \sim \ell_{\rm G}$ (Niemeyer & Woosley 1997, e.g.). For Kolmogorov turbulence,

$$\ell_{\rm G} \propto S^3_{\rm lam}$$

so increasing the burning rate makes $\delta$ smaller and $\ell_{\rm G}$ larger—delays transition?



Chamulak, Brown, & Timmes 2007

# Where have all the protons gone?

The importance of the simmering phase (Podsialowski et al. 2006)

During simmering, we have protons and $^4\mathrm{He}$ available via

$$^{12}\mathrm{C}(^{12}\mathrm{C},p)^{23}\mathrm{Na}$$

and

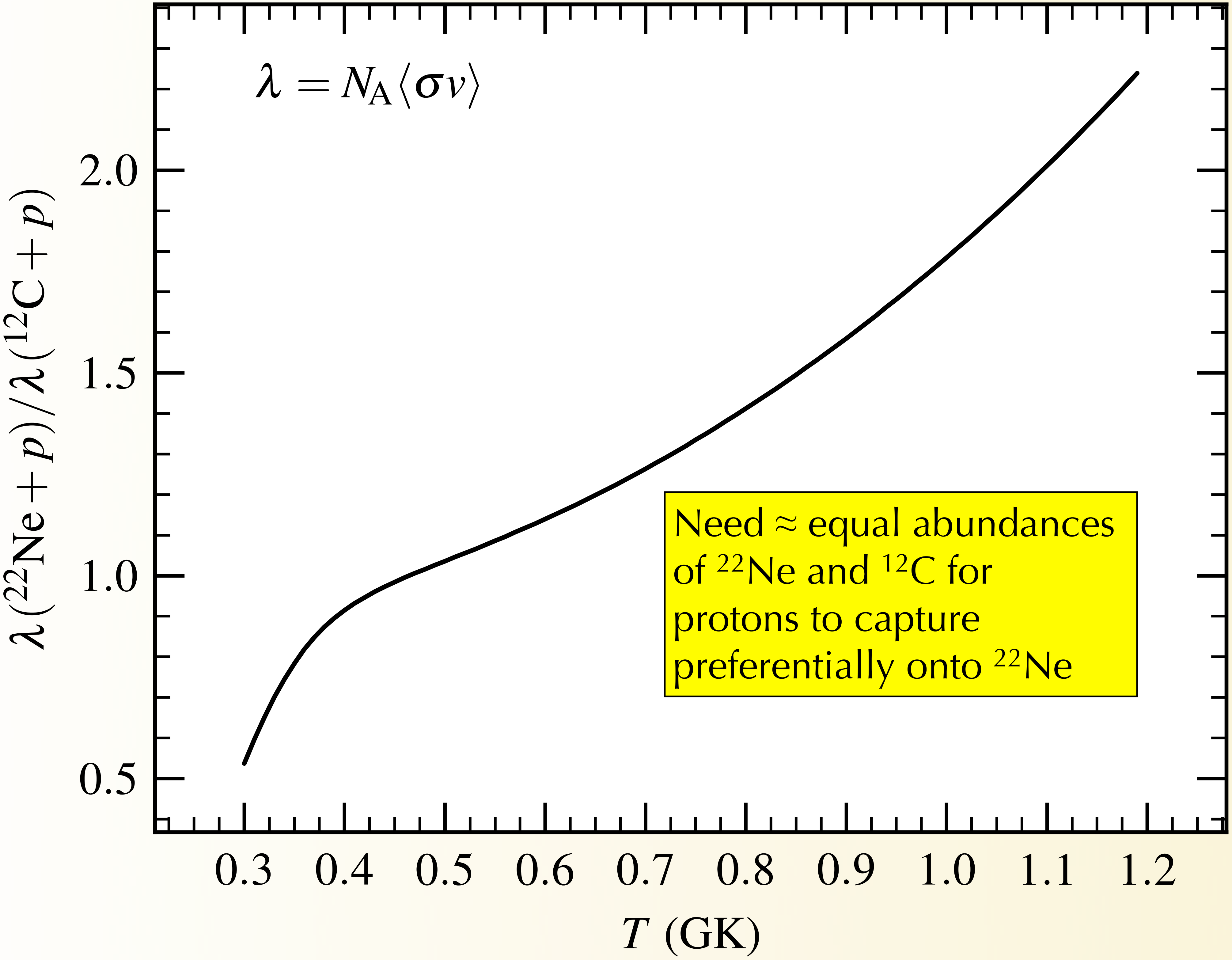
$$^{12}\mathrm{C}(^{12}\mathrm{C},\alpha)^{20}\mathrm{Ne}.$$

Podsialowski et al. (2006) proposed that

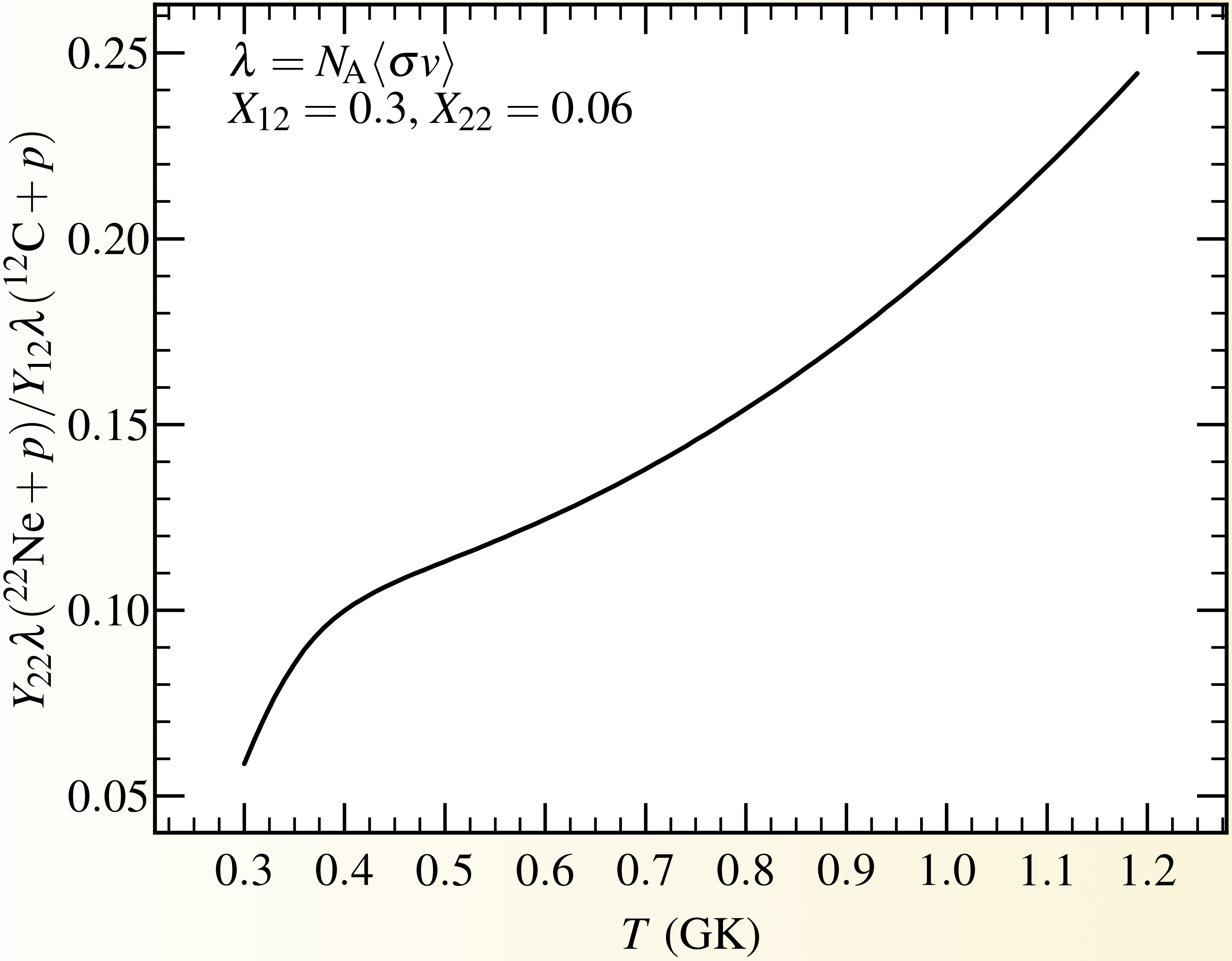
$$^{22}\mathrm{Ne}(p,\gamma)^{23}\mathrm{Na}$$

and subsequent $p$ and $e$-captures would reduce $Y_e$.

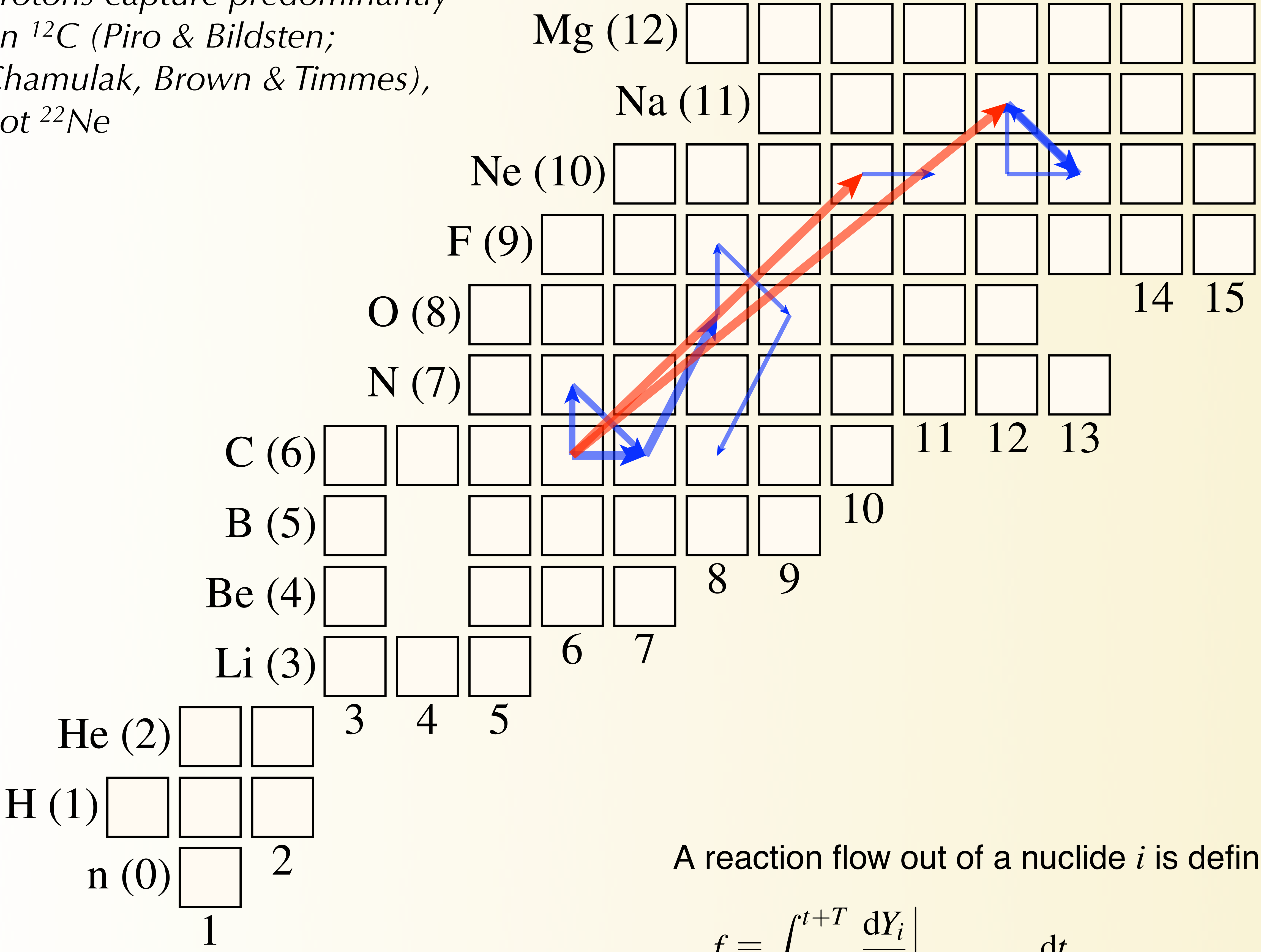
Neutronization would still be proportional to $^{22}\mathrm{Ne}$ abundance, but with a larger amplitude!



Need ≈ equal abundances of $^{22}$Ne and $^{12}$C for protons to capture preferentially onto $^{22}$Ne

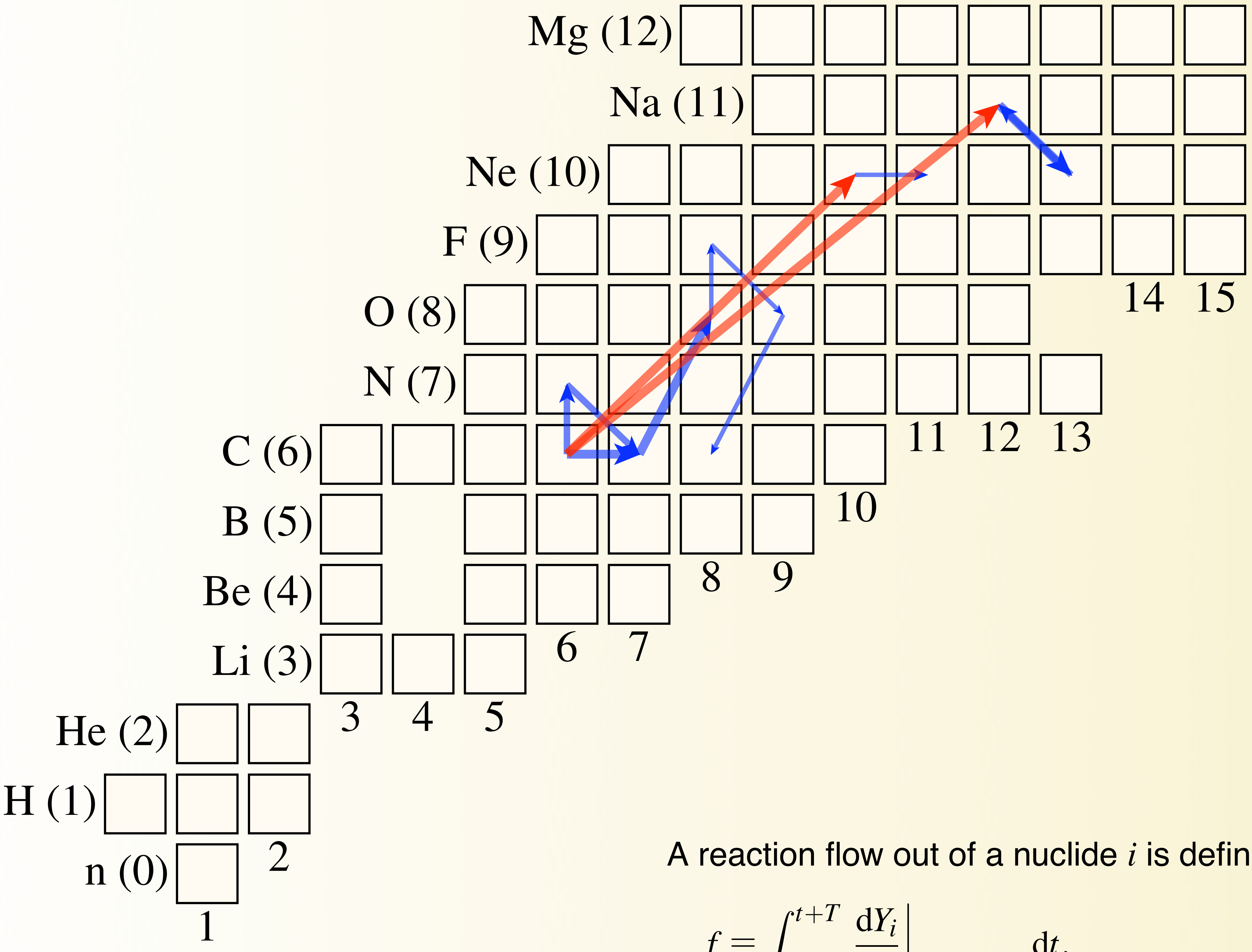

$\lambda = N_{\rm A}\langle\sigma v\rangle$
$X_{12} = 0.3, X_{22} = 0.06$
$Y_{22}\lambda(^{22}\mathrm{Ne}+p)/Y_{12}\lambda(^{12}\mathrm{C}+p)$
0.25
0.20
0.15
0.10
0.05
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
$T$ (GK)

*protons capture predominantly on $^{12}$C (Piro & Bildsten; Chamulak, Brown & Timmes), not $^{22}$Ne*



A reaction flow out of a nuclide $i$ is defined by

$$f \equiv \int_t^{t+T} \left.\frac{\mathrm{d}Y_i}{\mathrm{d}t}\right|_{\text{reaction}} \mathrm{d}t\,.$$



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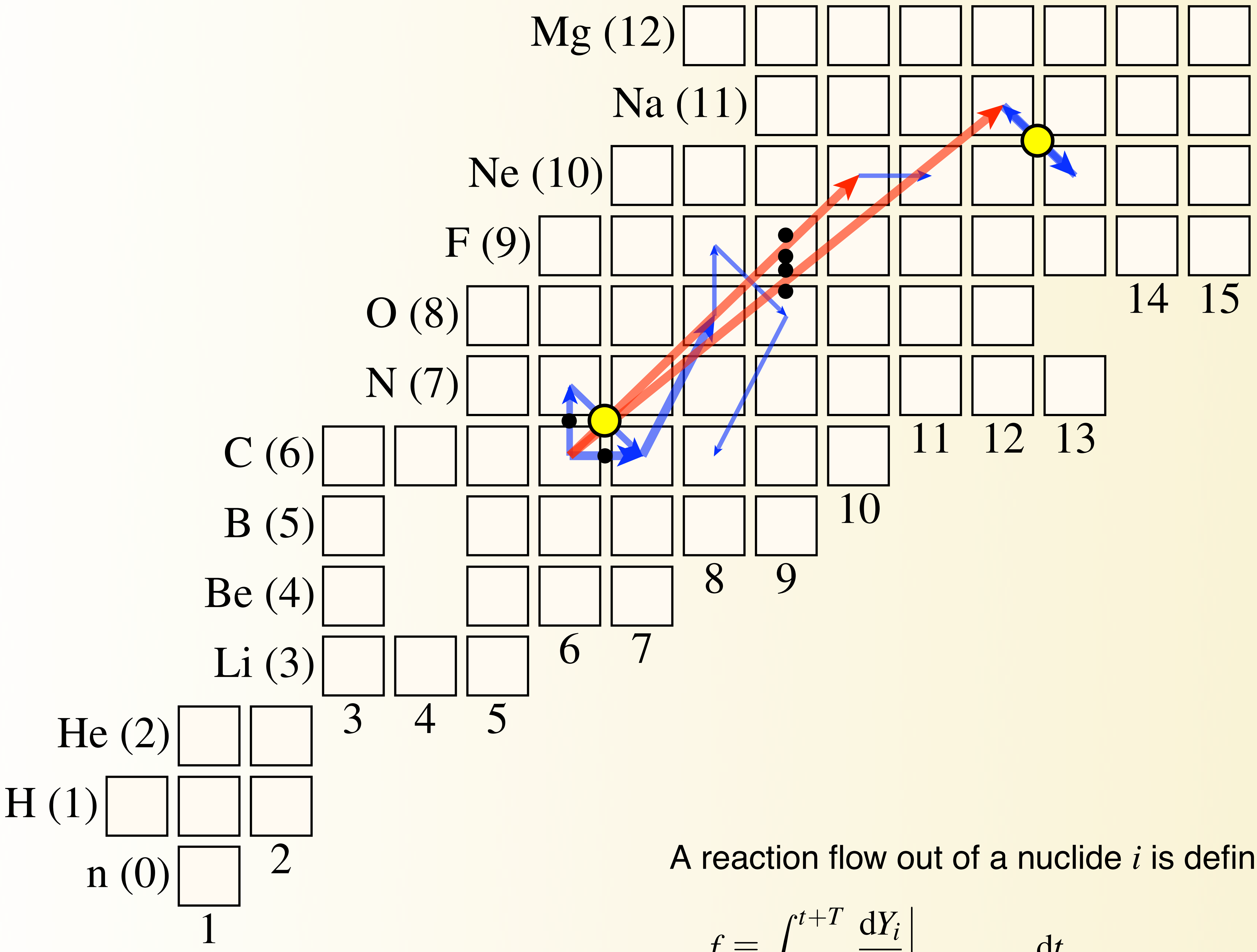

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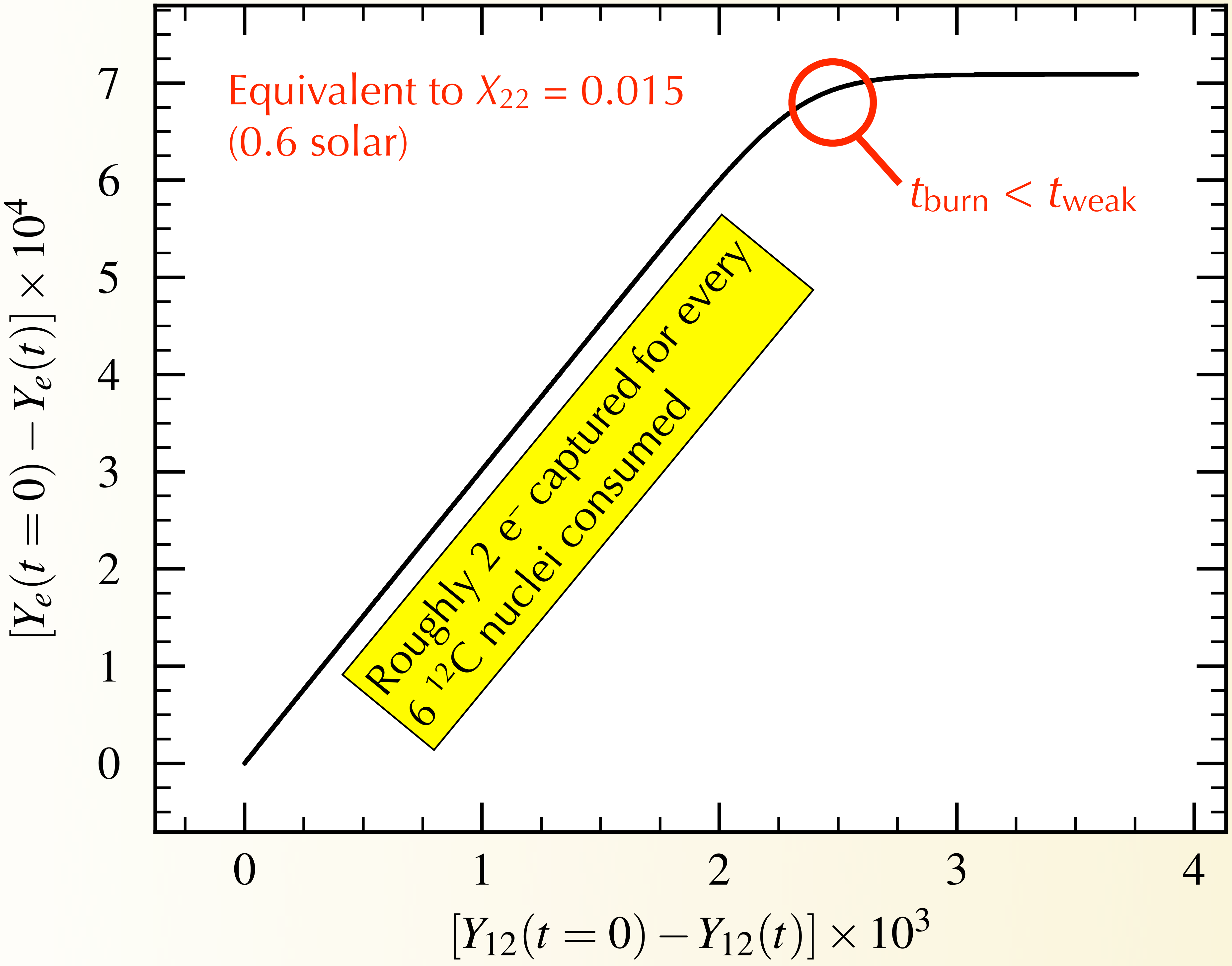
# Change in electron fraction with $^{12}$C consumption



# Summary and conclusions

- $^{22}$Ne is a function of the composition of the progenitor white dwarf, and this can vary by a factor of 10.
- All else being equal, a higher $^{22}$Ne abundance leads to a lower $^{56}$Ni yield and a dimmer Ia.
- Other effects: Increase in burning rate, delay of transition to distributed burning?
- Neutronization during “simmering”—sets base $Y_e$ during explosion (Piro & Bildsten; Chamulak, Brown & Timmes)

- Much undone...
    - Correlated changes in other progenitor properties (see Umeda et al. 1999, Domínguez et al. 2001)
    - Electron captures during explosion (see Iwamoto et al. 1999, Brachwitz et al. 2000, Calder et al. 2007, Townsley et al. 2007)