Simplified ^{12}C burning for simmering CO white dwarfs

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or... fast and accurate ^{12}C burning for pre-supernova CO WD models

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Overview

1. Path to SN Ia

2. Convective Urca process

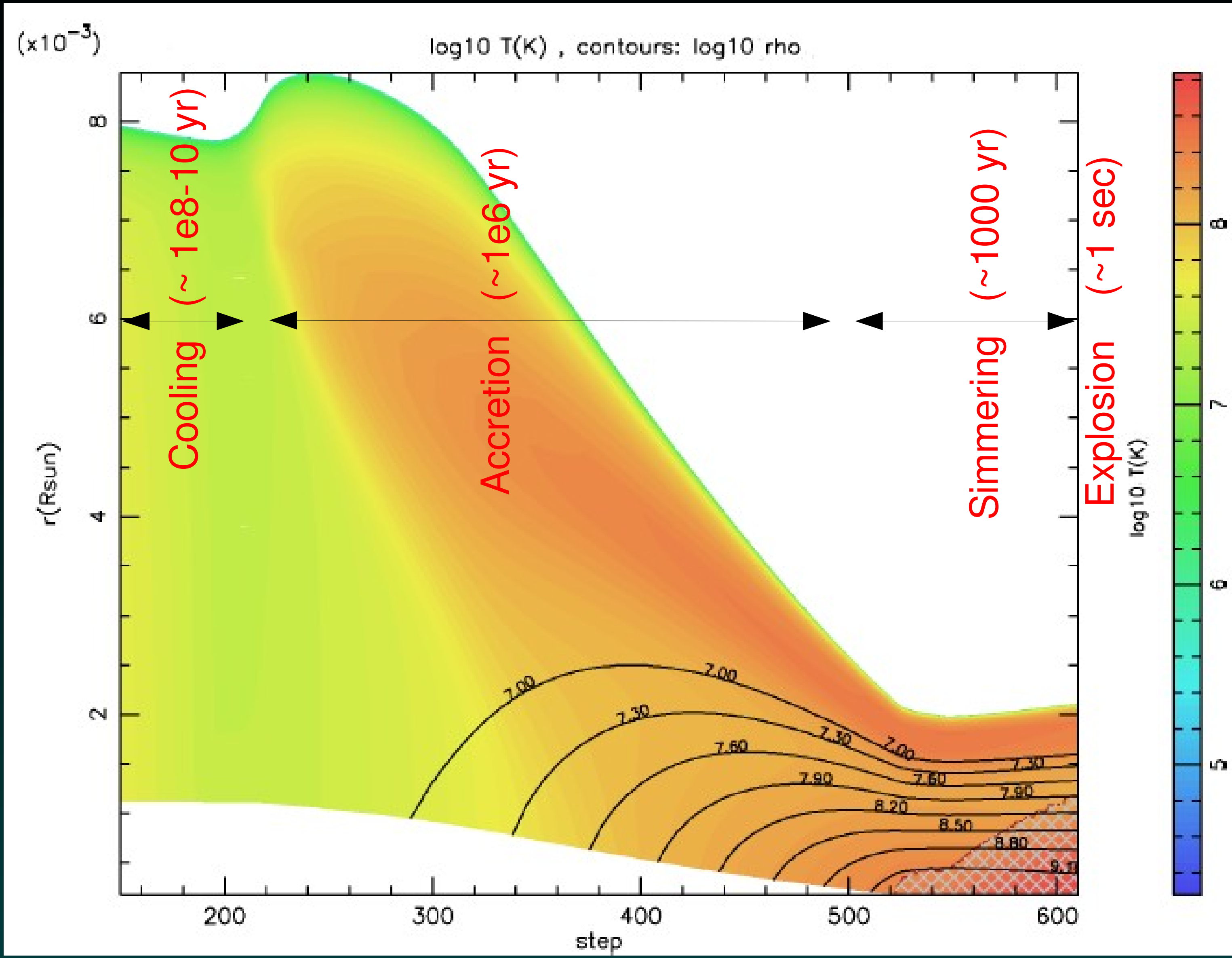
3. Nuclear physics prior to ignition

4. Simplified networks

5. Results

1. Path to Type Ia Supernova

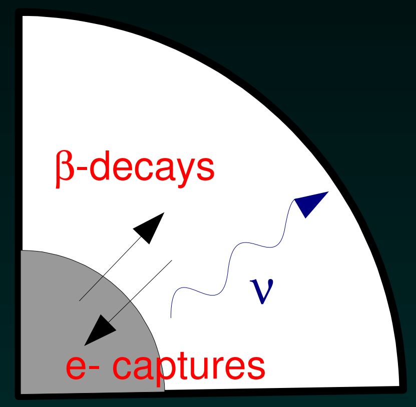
- Close binary system formation: CO WD + companion
- Mass transfer phase: accretion + shrinking + heating
- Hydrostatic ^{12}C burning: energy release + ashes pollution
- Simmering phase: steep T gradient + strong convection
- C-flash: convective core growth + steep L gradient



FF's thesis (2009)

2. Convective Urca process

- Convection + high ρ_c: β-decays + e- captures in up and down moving flows.



τ_{conv} , $\tau_{\beta /EC}$, $\tau_{burning}$

- ν cooling originally thought to stabilize burning (Paczinski et al. 1970)

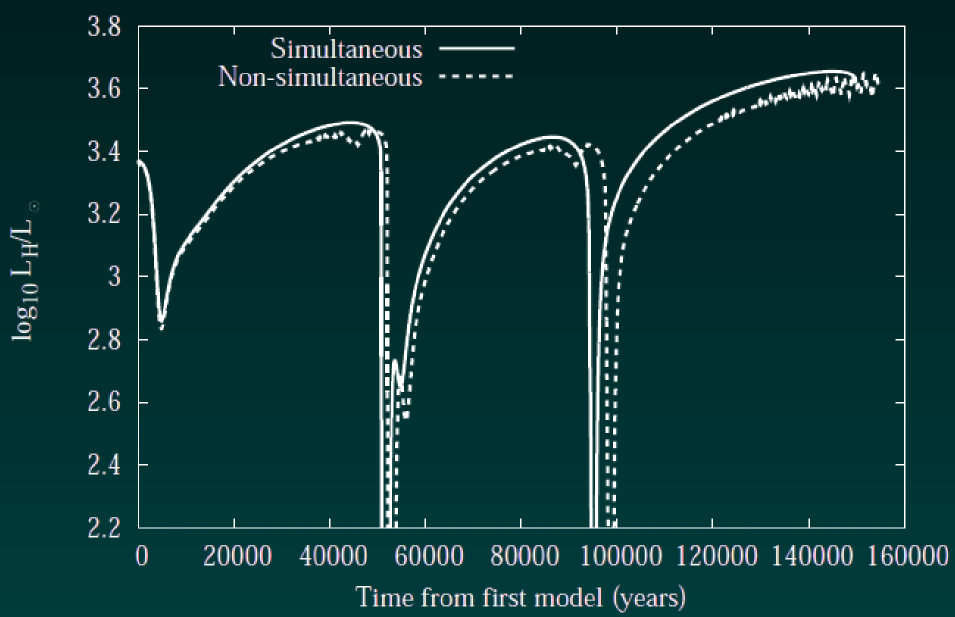
- Later shown that e^- captures cause heating (Bruenn 1973)

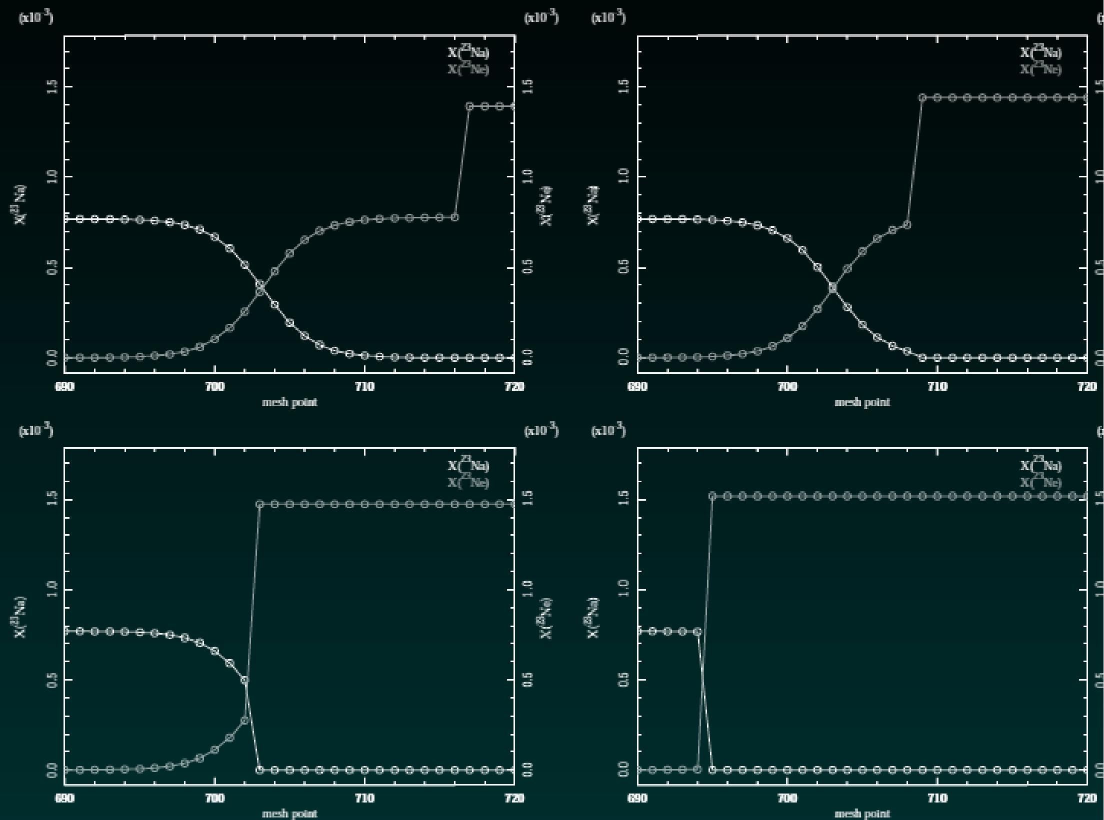
- Known to influence ρ, T and v_{conv} at ignition (Lesaffre et al. 2005, 2006)

- Numerically challenging (Iben 1978), *known unknown* in pre-SN Ia theory

Convective Urca process

FF's thesis (2009)



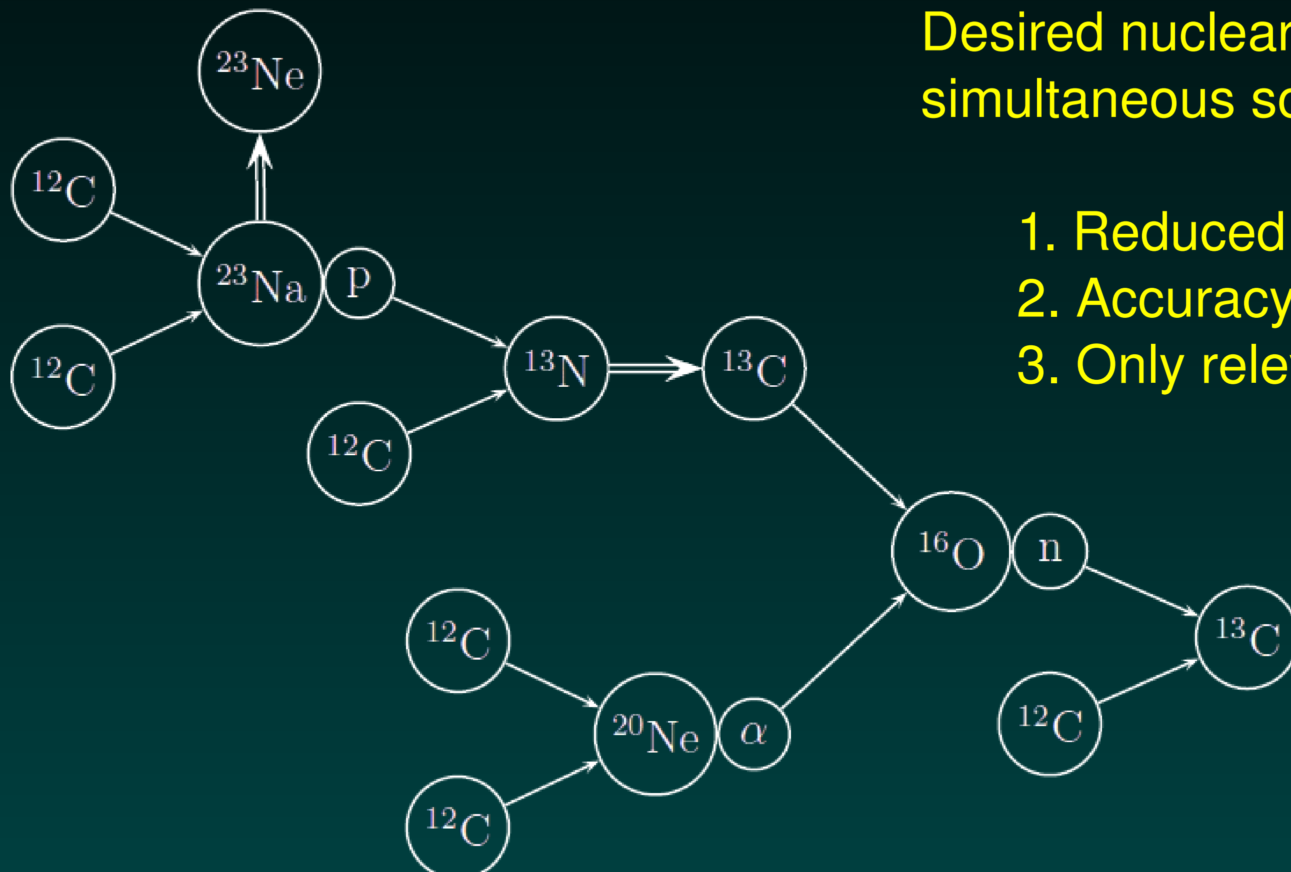


Stancliffe et al. 2006

Need simultaneous solver of structure and chemistry of the star.

3. Nuclear physics

- *Burning prior to ignition*: approximately six ^{12}C nuclei become ^{20}Ne, ^{23}Na, ^{16}O and ^{13}C, with one or two electron captures (Piro et al. 2008)



FF's thesis (2009)

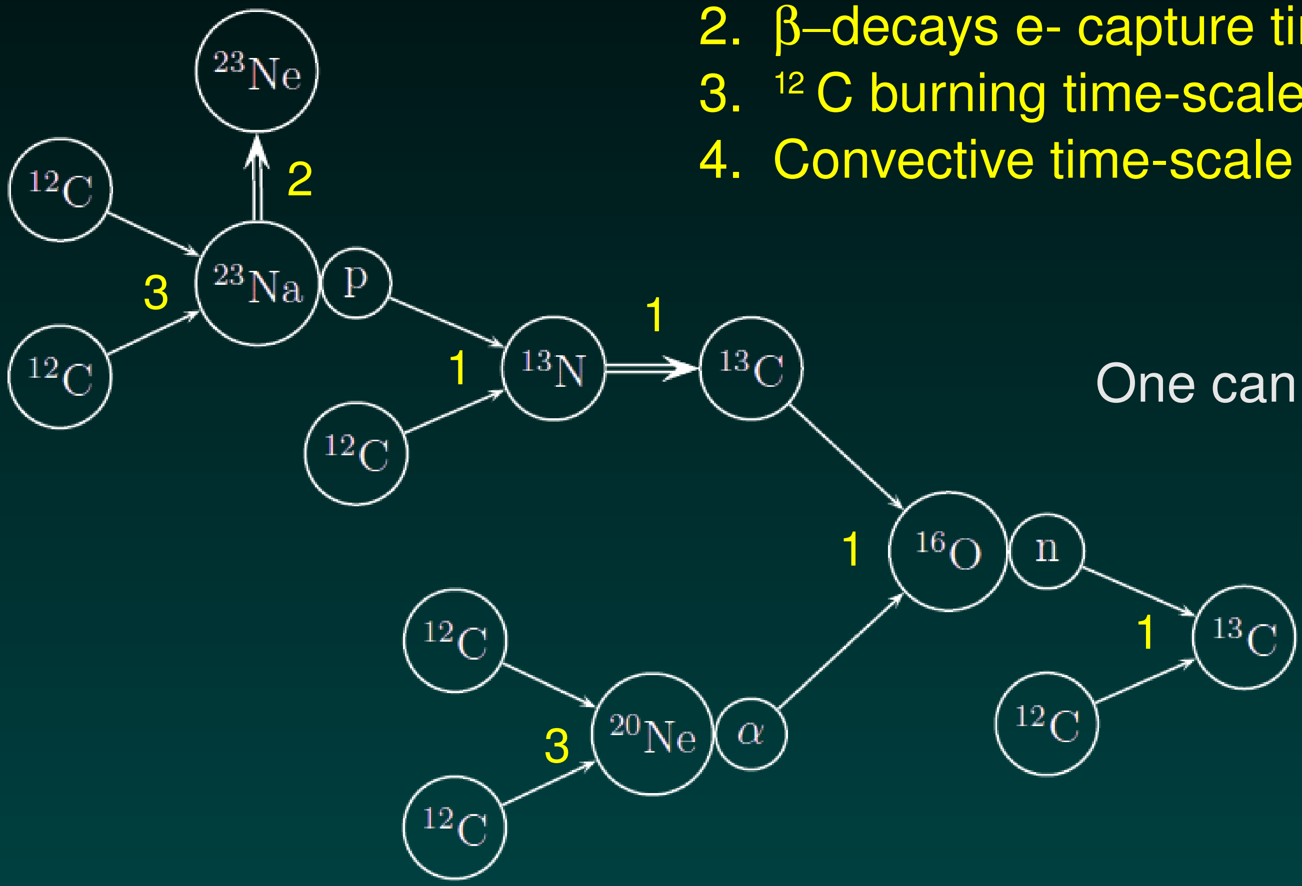
Desired nuclear physics for simultaneous solver:

1. Reduced number of variables
2. Accuracy in relevant quantities
3. Only relevant time-scales

4. Simplified networks

Four time-scales in the problem:

1. Trace nuclei time-scale: *n, p,* α, ^{13}N
2. β–decays e- capture time-scale
3. ^{12}C burning time-scale
4. Convective time-scale

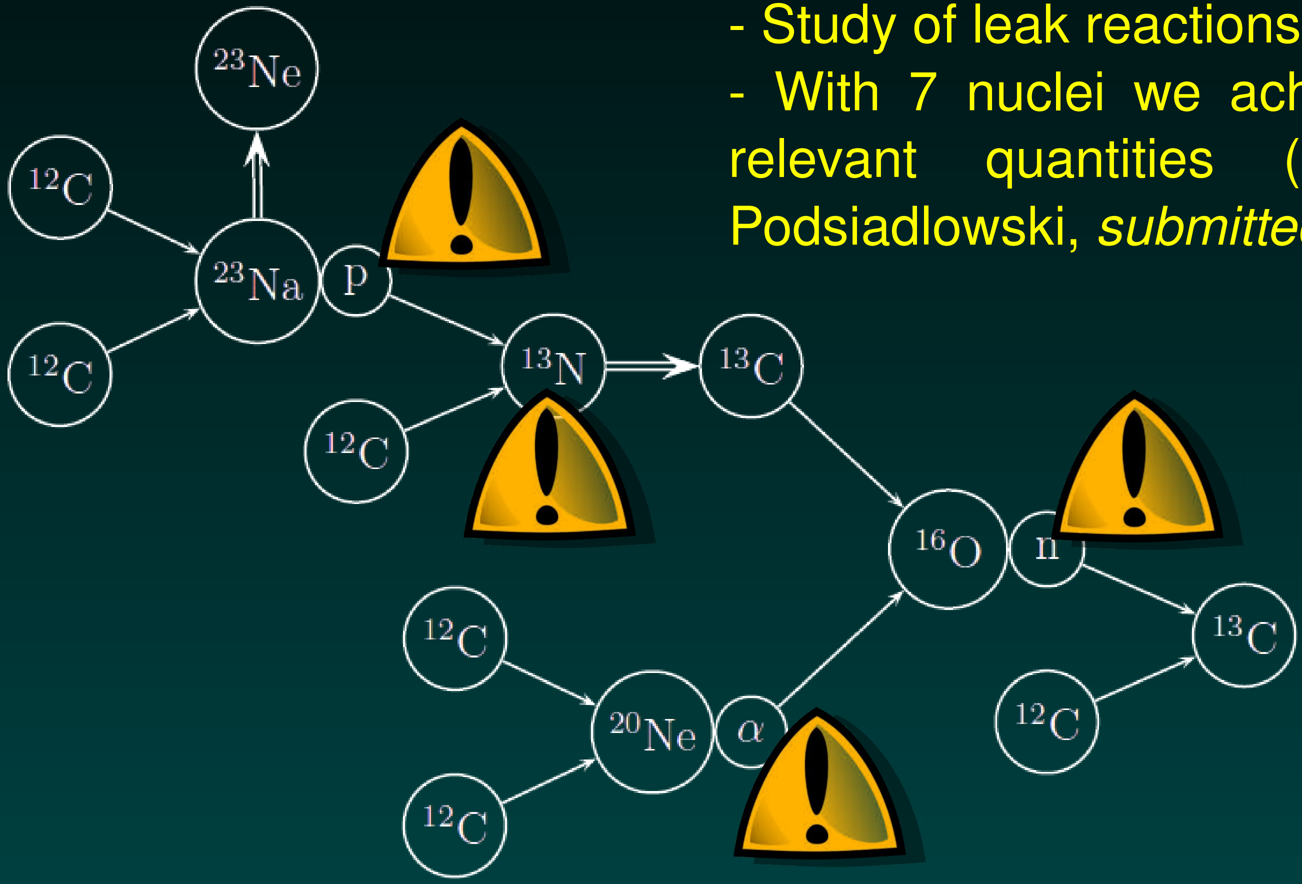


One can show $\tau_1 < \tau_2, \tau_3, \tau_4$

FF's thesis (2009)

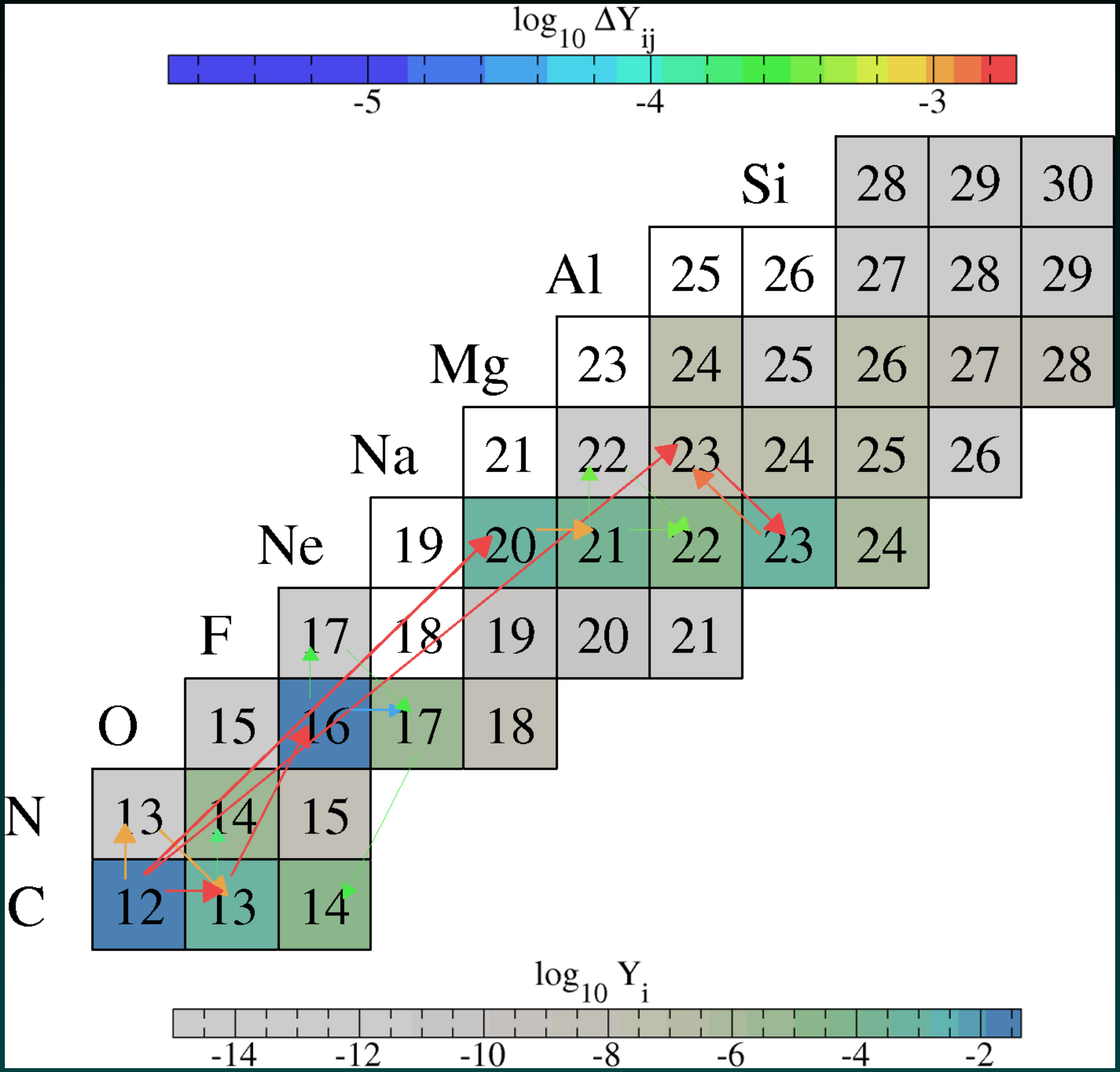
Simplified networks: leak reactions

When pollution by ^{12}C ashes occurs, all trace nuclei are affected by leak reactions → need detailed reaction network (Chamulak et al. 2008)



- Study of leak reactions using detailed network
- With 7 nuclei we achieve *5% accuracy* for relevant quantities (Förster, Lesaffre & Podsiadlowski, *submitted to ApJ*)

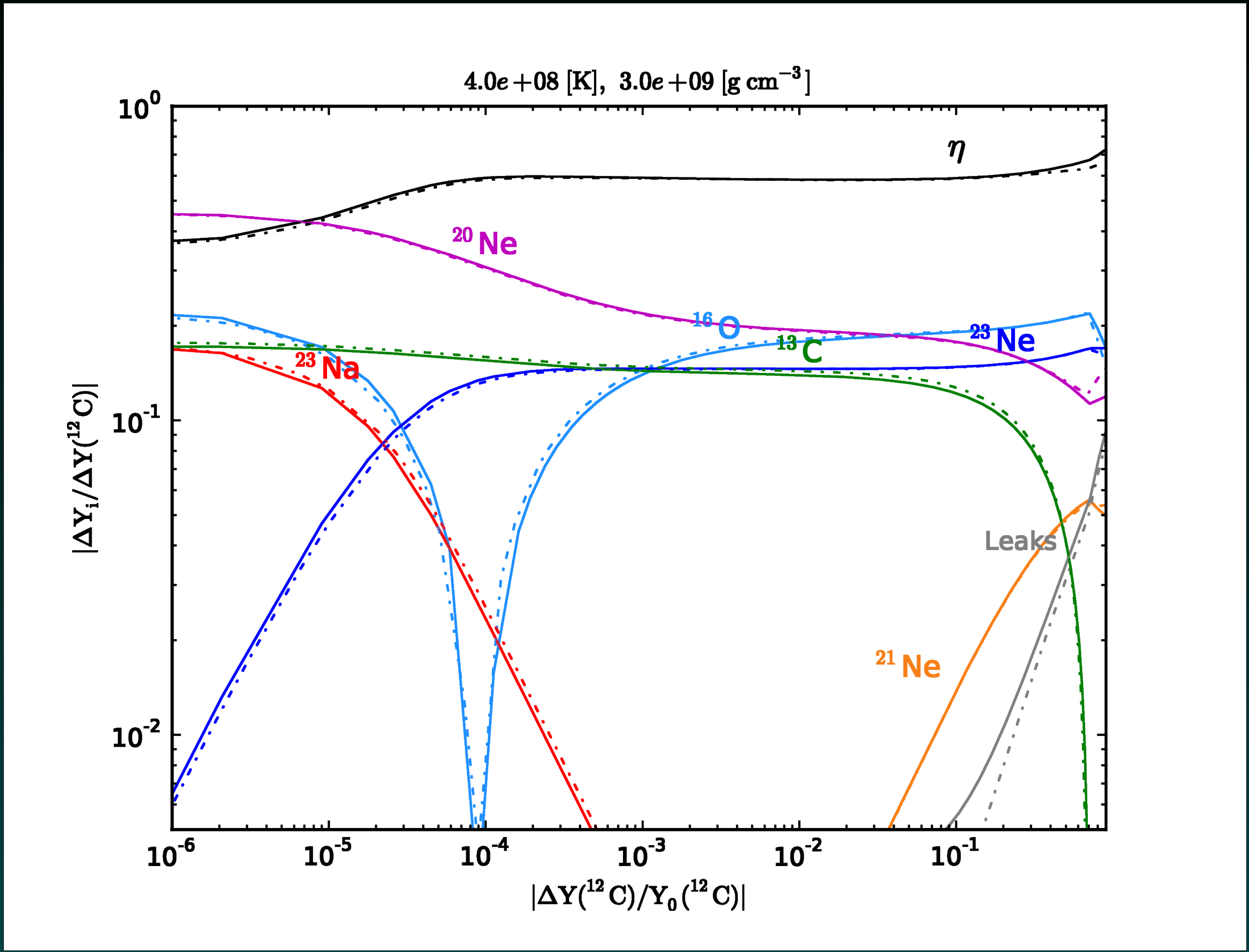
Detailed reaction network



Flows at fixed ρ, T
4e8 K, 3e9 g cm^{-3}

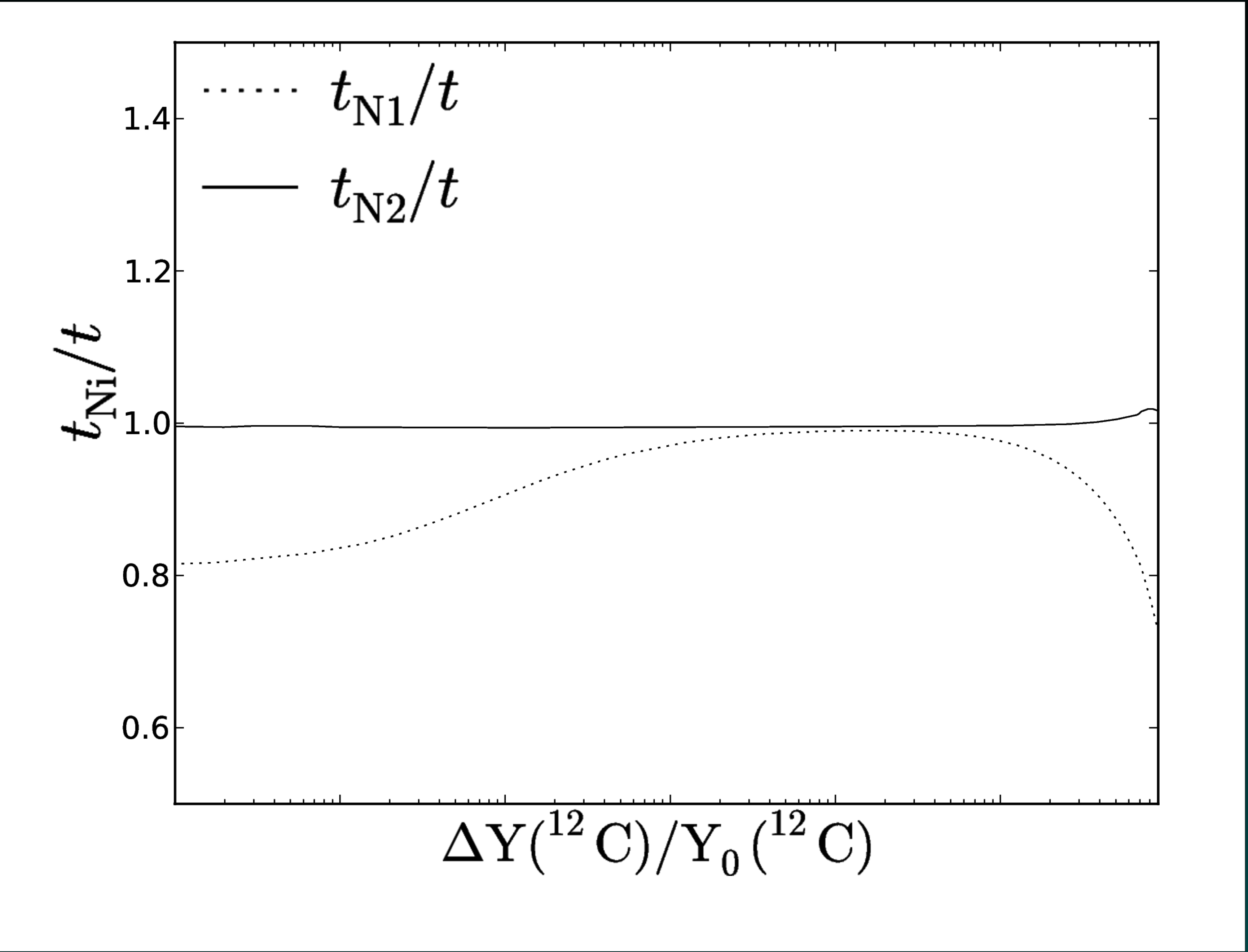
5. Results

Abundances

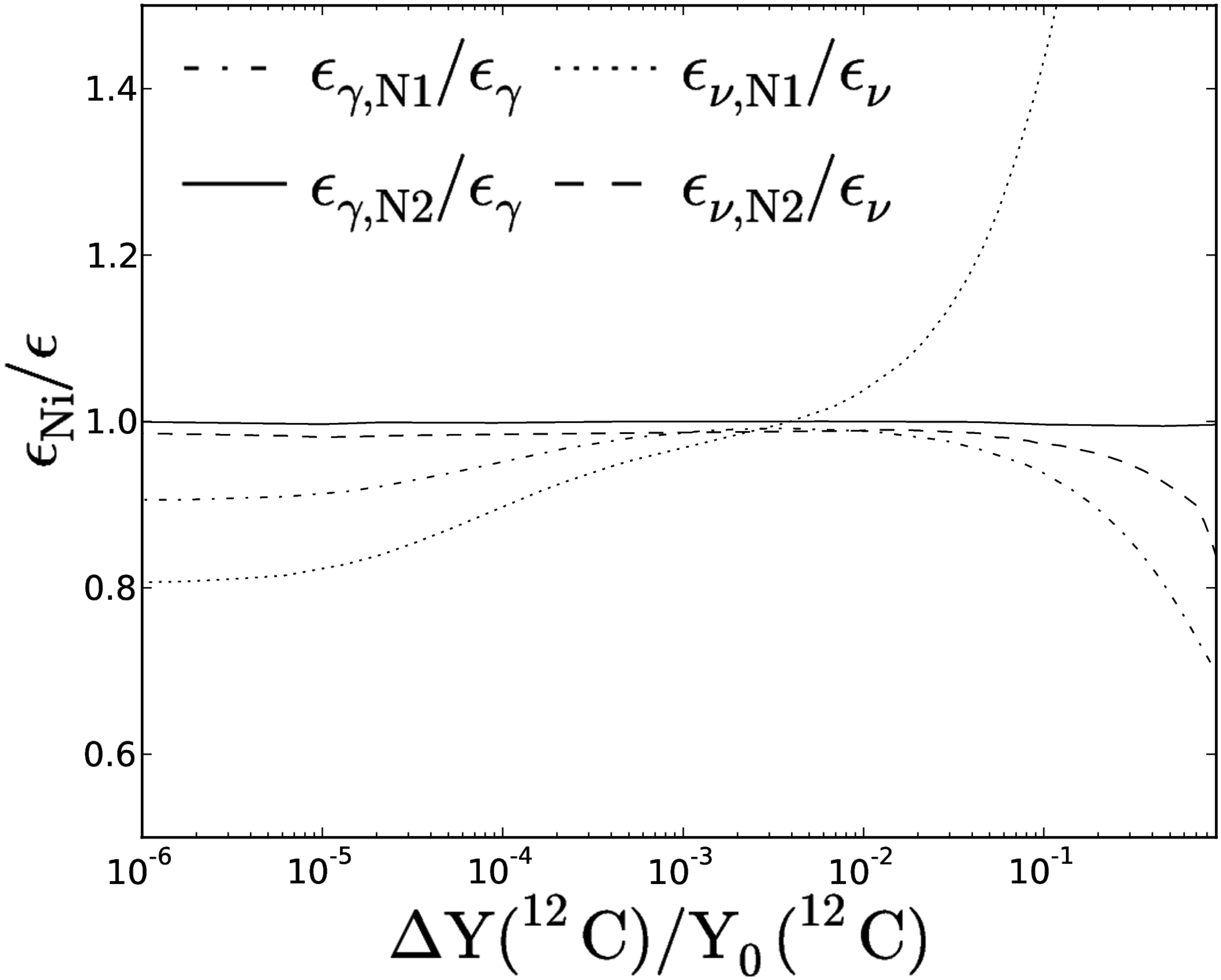


4.0e+08 [K], 3.0e+09 [g cm^{-3}]
$|\Delta Y_i/\Delta Y(^{12}C)|$
$|\Delta Y(^{12}C)/Y_0(^{12}C)|$
10^0
10^{-1}
10^{-2}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
η
^{20}Ne
^{16}O
^{13}C
^{23}Ne
^{23}Na
Leaks
^{21}Ne

Time evolution



Energy generation



Conclusions & Discussion

- Basics of ^{12}C burning prior to ignition understood (Piro et al. 2008, Chamulak et al. 2008 and *this work*)

- New tool for stellar evolution calculations of the convective Urca process. Potential application in 3D simulations!

- Two networks introduced, N1 and N2. N1 offers basic estimation of most quantities, N2 is 5% accurate.

- ^{21}F or other nuclei can be included to include higher density e- captures if more accuracy were required.

- Presupernova evolution should be used to explain systematic differences with environment (e.g. talks by J. Anderson or M. Sullivan). Convective Urca process is important ingredient.

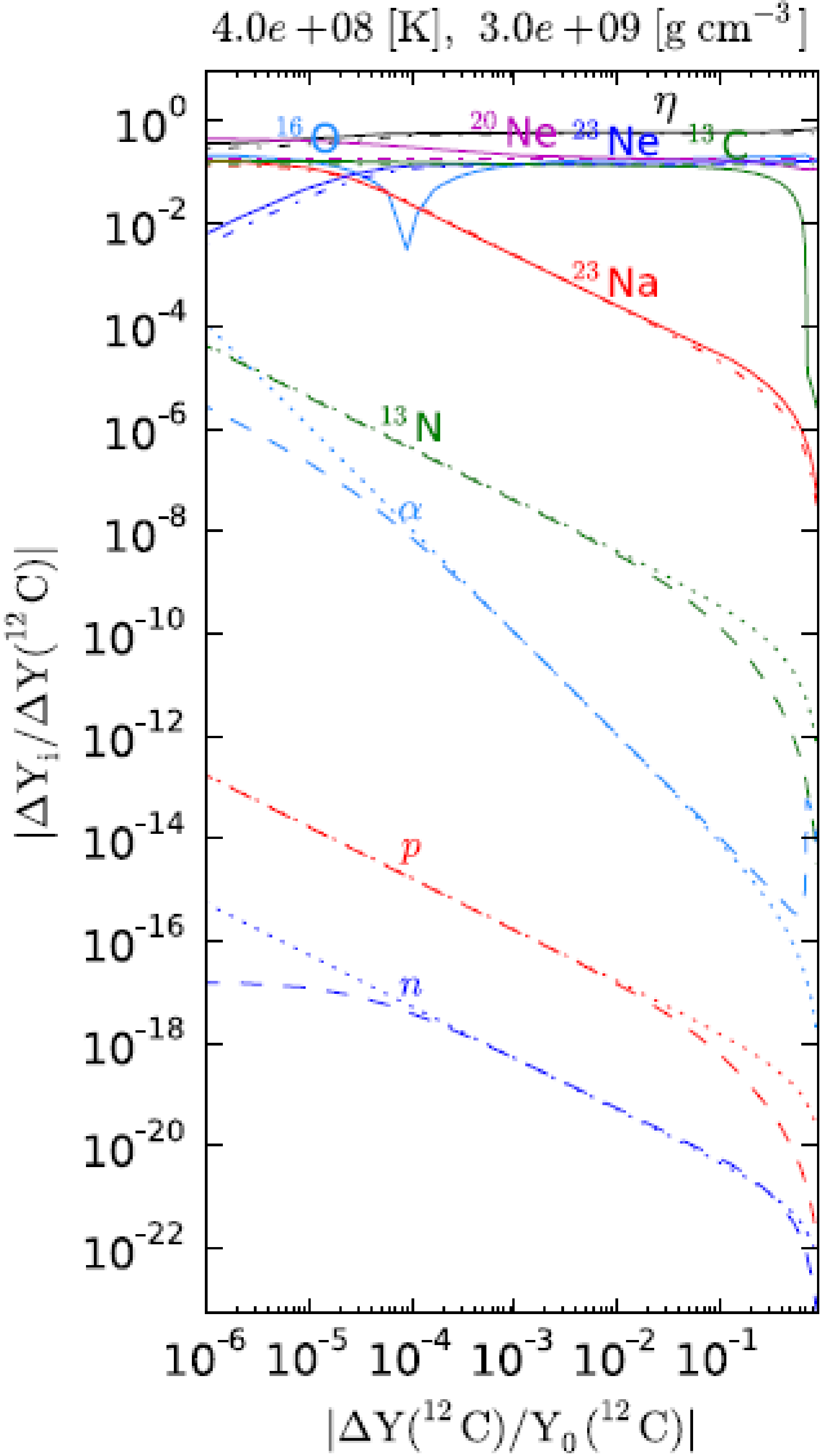
Two simplified networks: N1 and N2

N1. Six independent species: ^{12}C, ^{13}C, ^{16}O, ^{20}Ne, ^{23}Na, ^{23}Ne.
Straightfoward trace nuclei abundances give very simple analytic formulae, e.g.

$$\frac{dY(^{13}\mathrm{C})}{dY(^{12}\mathrm{C})} = -\frac{1}{3(1+\lambda_2/\lambda_1)} \approx -0.15,$$
$$\frac{dY(^{16}\mathrm{O})}{dY(^{12}\mathrm{C})} = -\frac{1}{3(1+\lambda_1/\lambda_2)} \approx -0.19,$$
$$\frac{dY(^{20}\mathrm{Ne})}{dY(^{12}\mathrm{C})} = -\frac{1}{3(1+\lambda_1/\lambda_2)} \approx -0.19.$$

N2. One additional nuclei: ^{21}Ne.
Implemented with correction factors to N1, measure contribution of leak reactions, e.g.

$$\tilde{Y}(p) = \bar{Y}(p)\ f_{\mathrm{p}}, \qquad \tilde{Y}(\alpha) = \bar{Y}(\alpha)\ f_{\alpha},$$
$$\tilde{Y}(n) = \bar{Y}(n)\ f_{\alpha}\ f_{\mathrm{n}}, \qquad \tilde{Y}(^{13}\mathrm{N}) = \bar{Y}(^{13}\mathrm{N})\ f_{\mathrm{p}},$$


4.0e+08 [K], 3.0e+09 [g cm^-3]
η
16O
20Ne
23Ne
13C
23Na
13N
α
p
n
|ΔY_i/ΔY(12C)|
|ΔY(12C)/Y_0(12C)|

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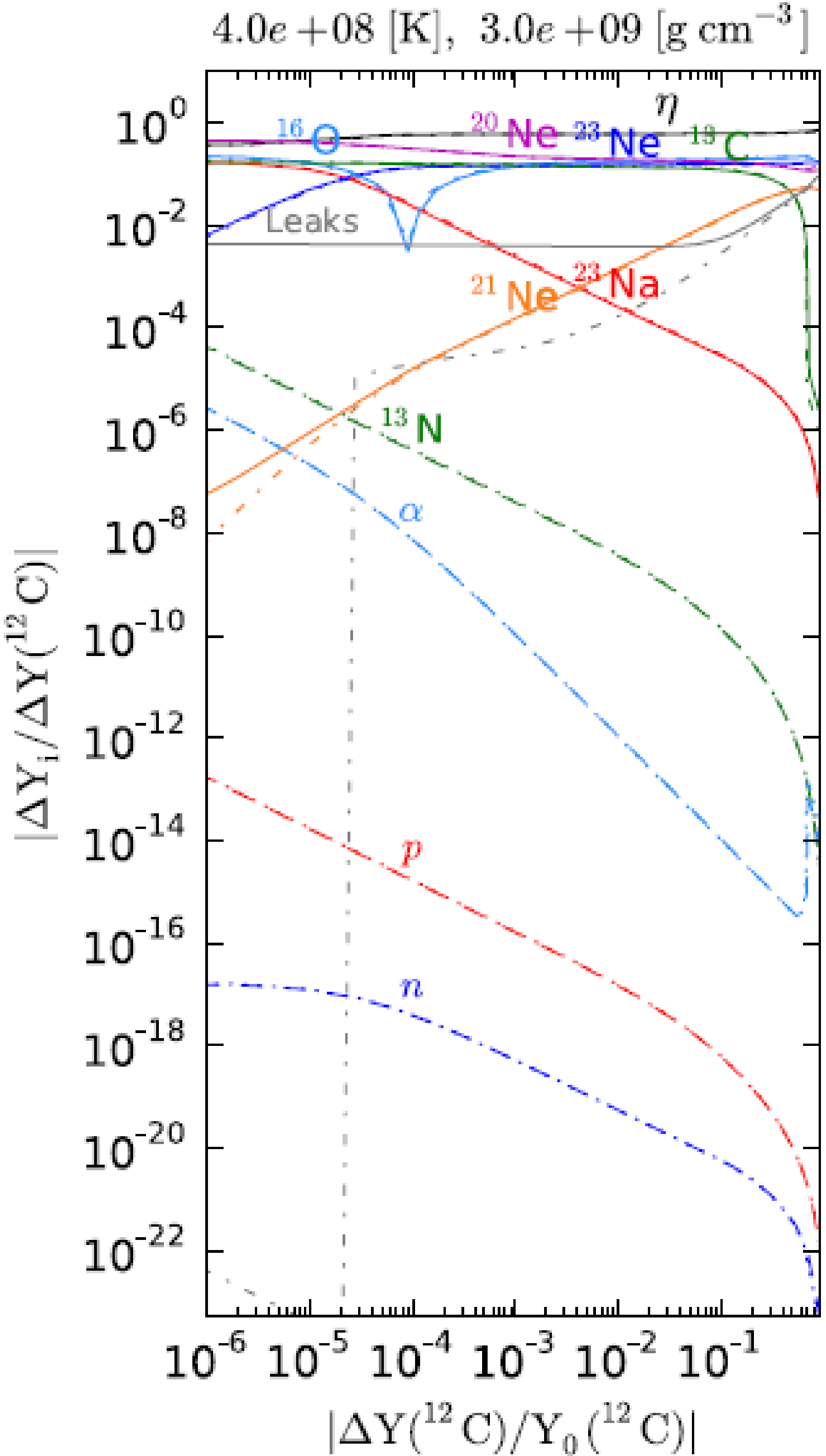
4.0e+08 [K], 3.0e+09 [g cm^-3]
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16O
20Ne
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Leaks
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