Effect of $^{12}C+^{12}C$ Rate & Convective Mixing on the Mass of ONe WD Progenitors

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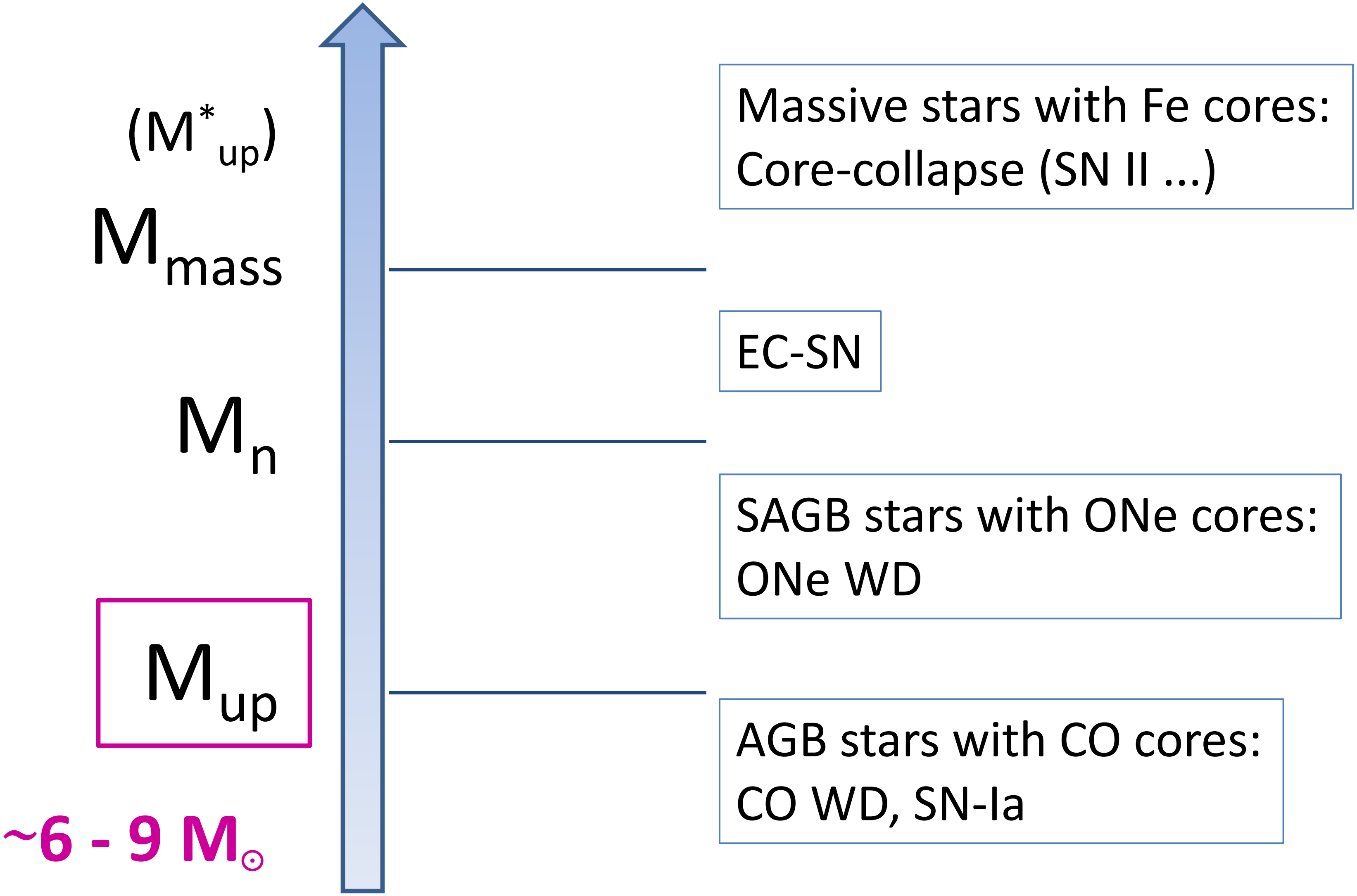
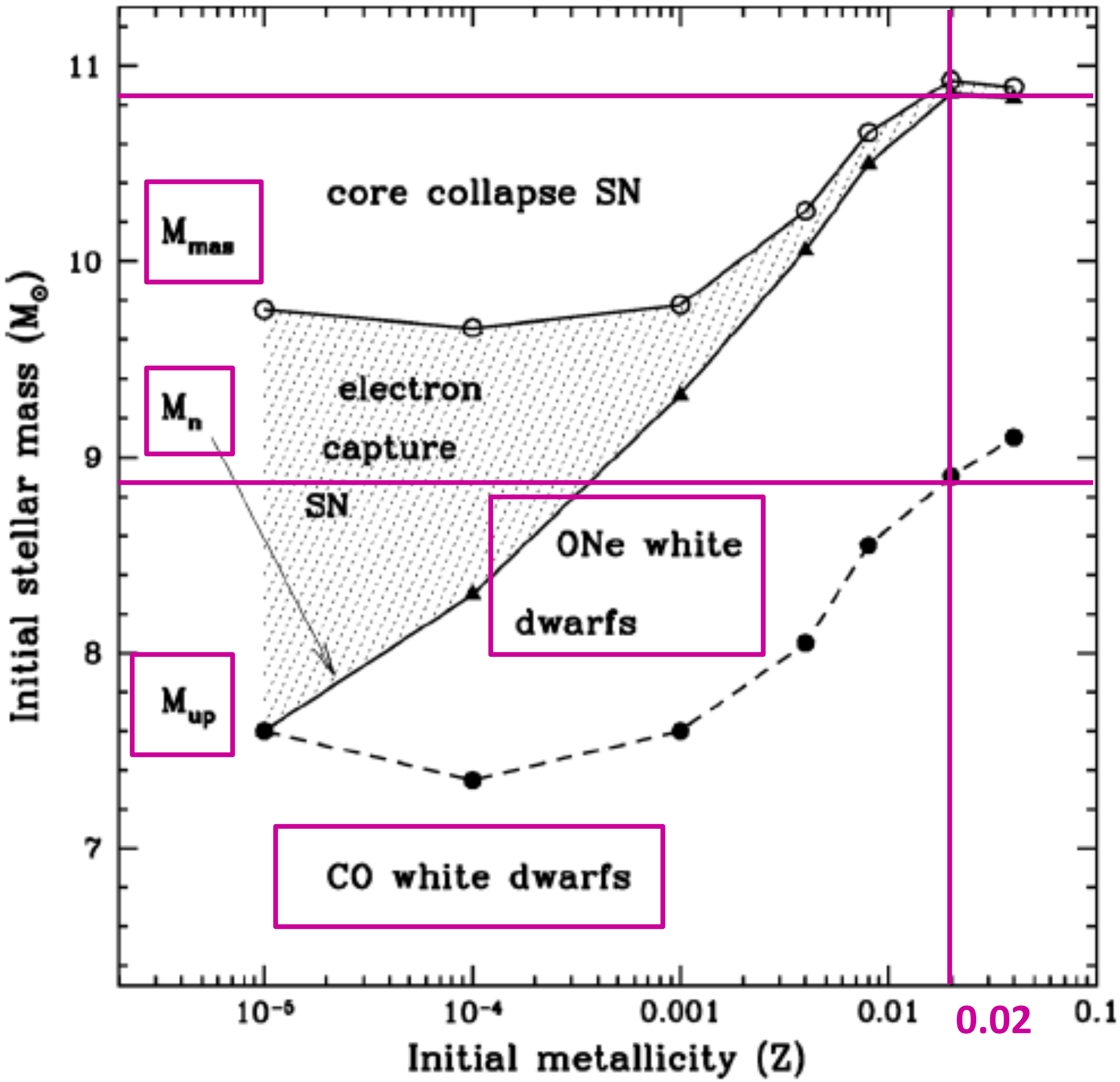
CSSP 13
Sinaia, Romania
2014



(M*up)
Mmass
Mn
Mup
~6 - 9 M⊙
Massive stars with Fe cores:
Core-collapse (SN II ...)
EC-SN
SAGB stars with ONe cores:
ONe WD
AGB stars with CO cores:
CO WD, SN-Ia


core collapse SN
electron
capture
SN
ONe white
dwarfs
CO white dwarfs
M mas
M n
M up
Initial stellar mass (M⊙)
Initial metallicity (Z)
11
10
9
8
7
10⁻⁵
10⁻⁴
0.001
0.01
0.02
0.1

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Featured Research

Earth-size 'diamond' in space: Remarkable white dwarf star possibly coldest, dimmest ever detected

Date: June 23, 2014

Source: National Radio Astronomy Observatory

Summary: Astronomers have identified possibly the coldest, faintest white dwarf star ever detected. This ancient stellar remnant is so cool that its carbon has crystallized, forming -- in effect -- an Earth-size diamond in space. The object in this new study is likely the same age as the Milky Way, approximately 11 billion years old.

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TECH SPACEFLIGHT SCIENCE

Cold Dead Star May Be a Giant Diamond

By Megan Gannon, News Editor | June 24, 2014 09:20am ET

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An arti...

Astronomers aren't being poetic when they say this star is a diam...

Scientists have identified what is possibly the coldest white dwarf ev... detected. In fact, this dim stellar corpse is ... its carbon has ... forming a ... th,

THE ASTROPHYSICAL JOURNAL, 789:119 (9pp), 2014 July 10 doi:10.1088/0004-637X/789/2/119

A 1.05 $M_\odot$ COMPANION TO PSR J2222−0137: THE COOLEST KNOWN WHITE DWARF?

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Received 2014 April 4; accepted 2014 May 20; published 2014 June 20

Importance of M_{up}
Astrophysical consequences

- Important for the **theory of novae outbursts** in cataclysmic variables when these stars belong to close binary systems
- Mass limits of **WDs** and their progenitors
- Mass limits of **SNe** and their progenitors
- Chemical **yield of massive AGB stars** and enrichment of ISM.
- For the **SNe Rates**: SNIa explosion requires a CO WD growing to the Chandrasekhar mass, which is favoured with a higher M_{up}
- A lot of **debate** over M_{up}
- Etc...

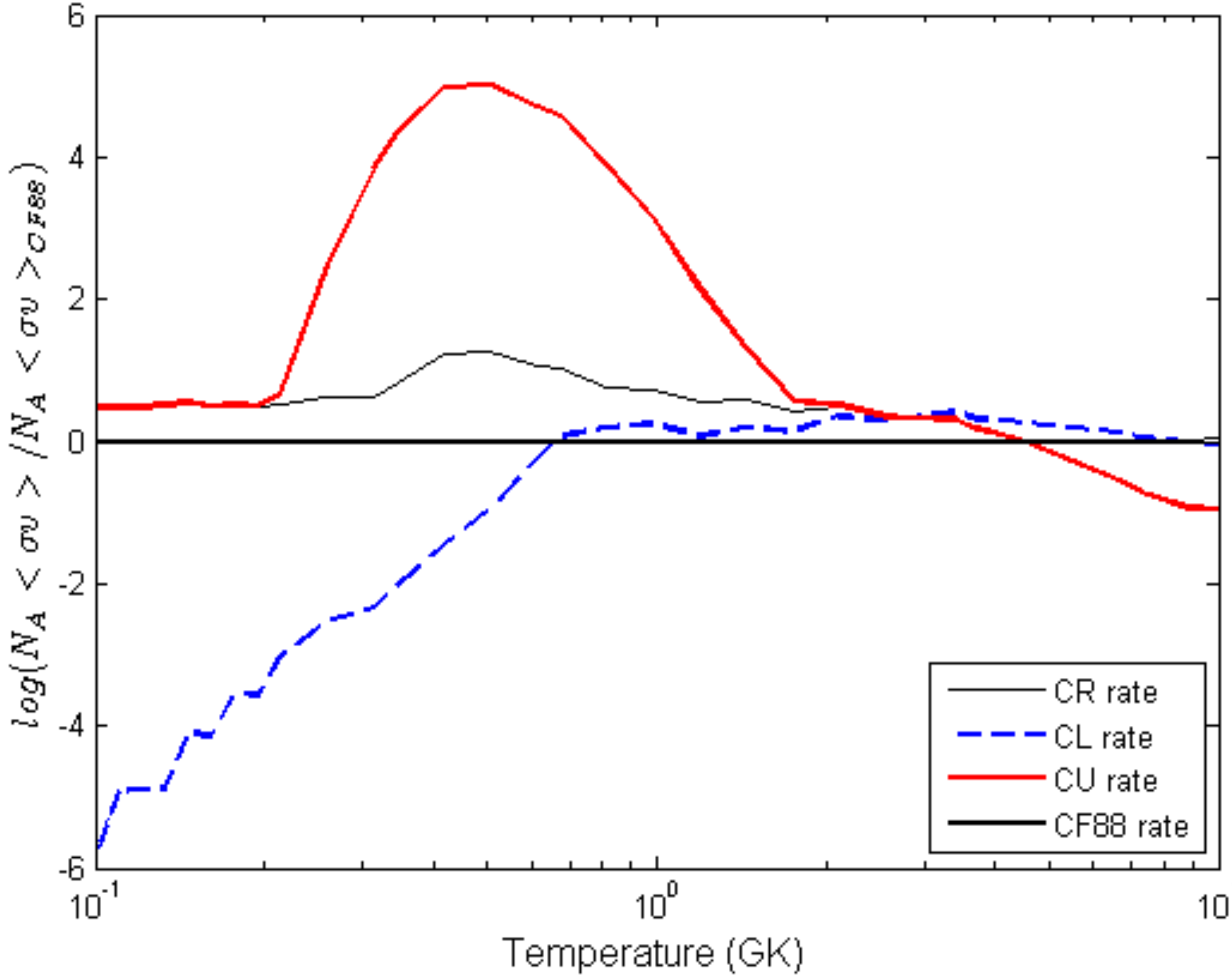
What Affects M_{up} ?

- Rates: eg. $^{12}C + ^{12}C$
- Convective mixing
- Metallicity
- Binarity
- Rotation
- Multi-dimensional simulations
- Mass-loss (?)

$^{12}C+^{12}C$: Current Status

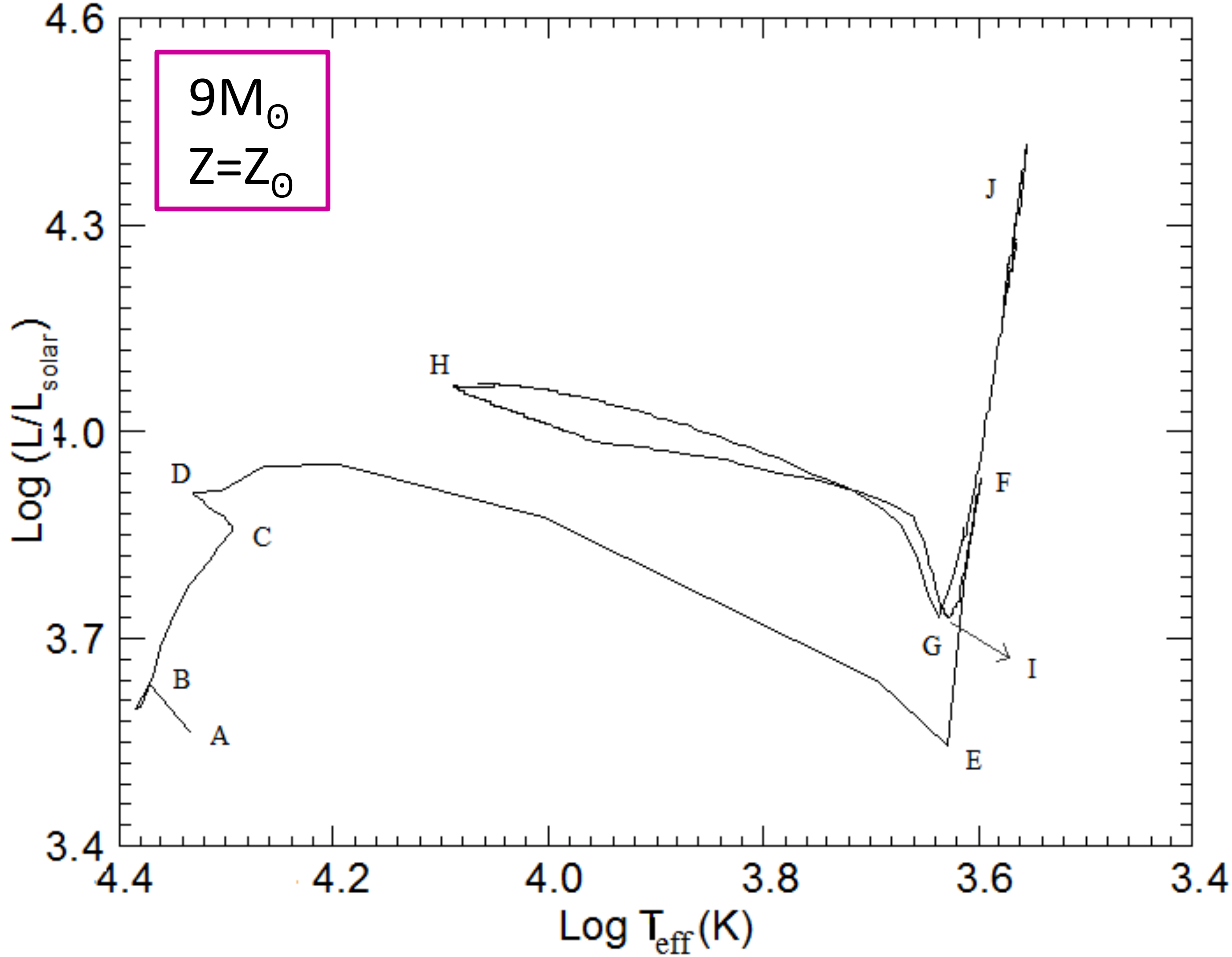
- **CF88** (Caughlan & Fowler 1988)
- Pignatari et al. 2013 (ApJ, 762, 31), M. Wiescher:

Possible **strong cluster resonance** at E_{cm} = 1.5MeV (Perez-Torres et al. 2006)	⇨	**Upper limit (CU)**
Pronounced $^{12}C+^{12}C$ **resonance structure** reported in the p and α channels, at $E_{cm} = 2.138\ MeV$ (Spillane et al. 2007)	⇨	**Recommended rate (CR)**
Existence of a **hindrance term** for low energy fusion processes	⇨	**Lower limit (CL)**



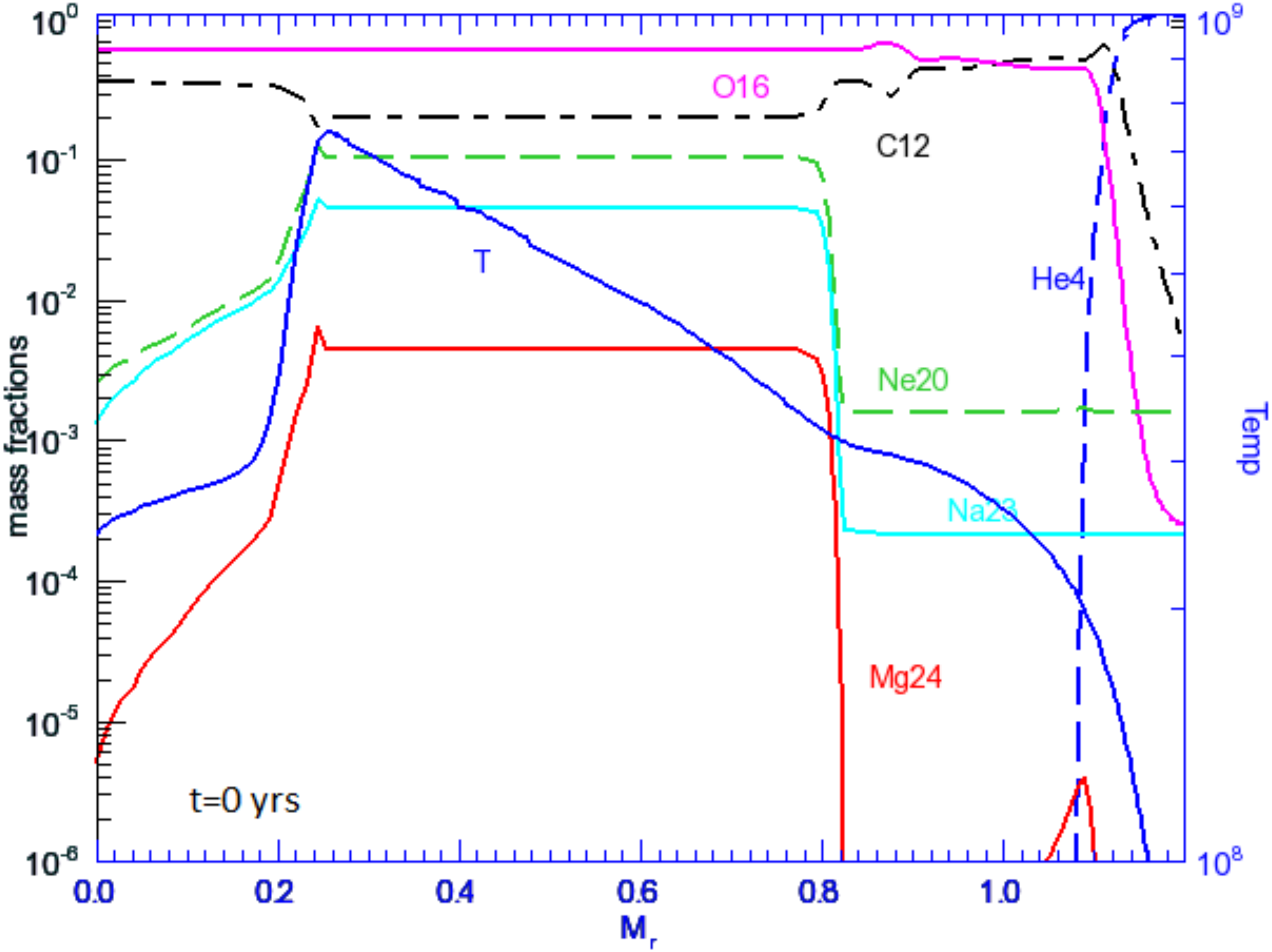
6
4
2
0
-2
-4
-6
$log(N_A < \sigma v > / N_A < \sigma v >_{CF88})$
10^{-1}
10^{0}
10^{1}
Temperature (GK)
CR rate
CL rate
CU rate
CF88 rate

Evolution of a $9M_{\odot}$ model

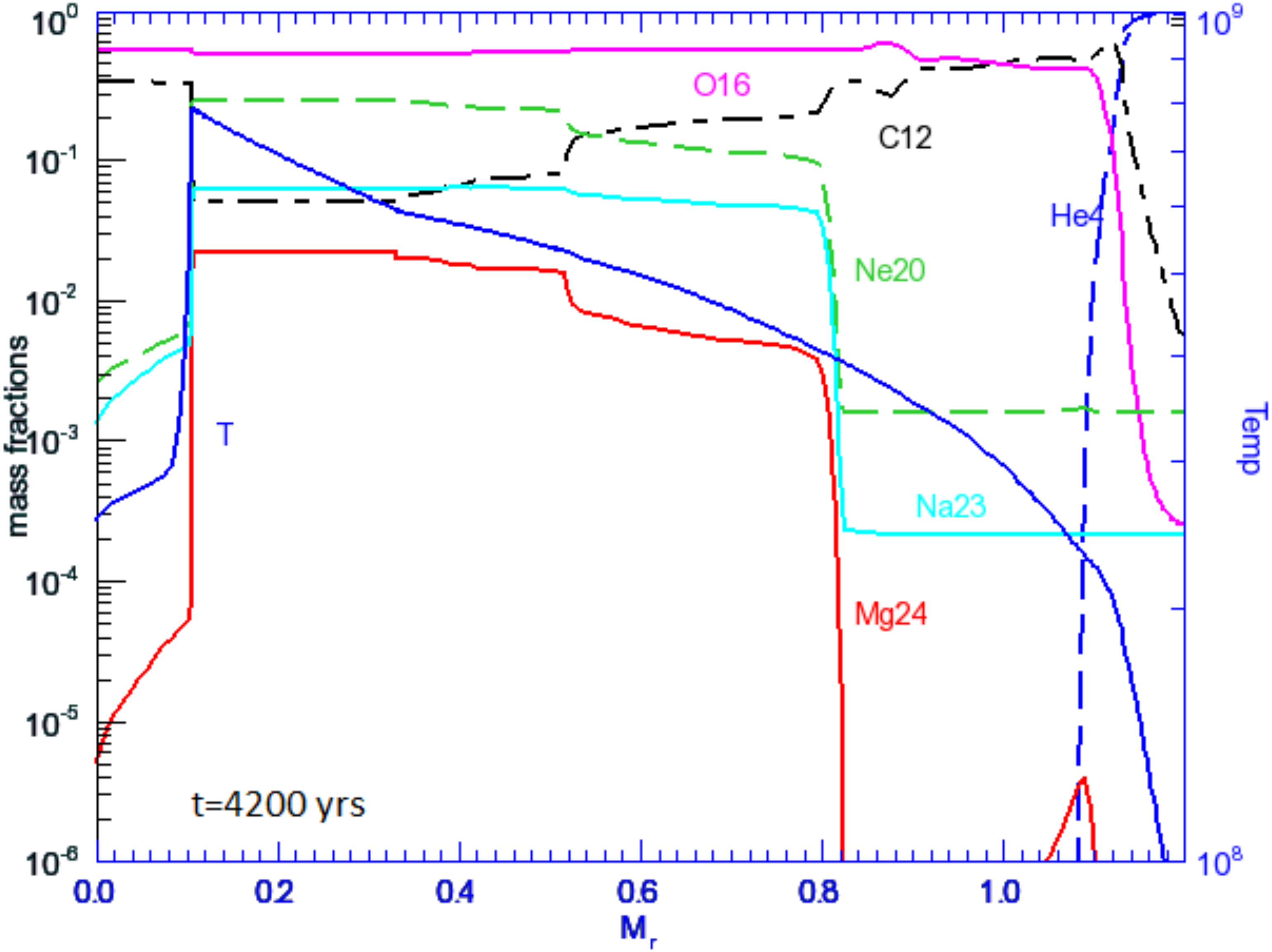


with the **CF88** rate ...

Off-center C-ignition



Off-center C-ignition



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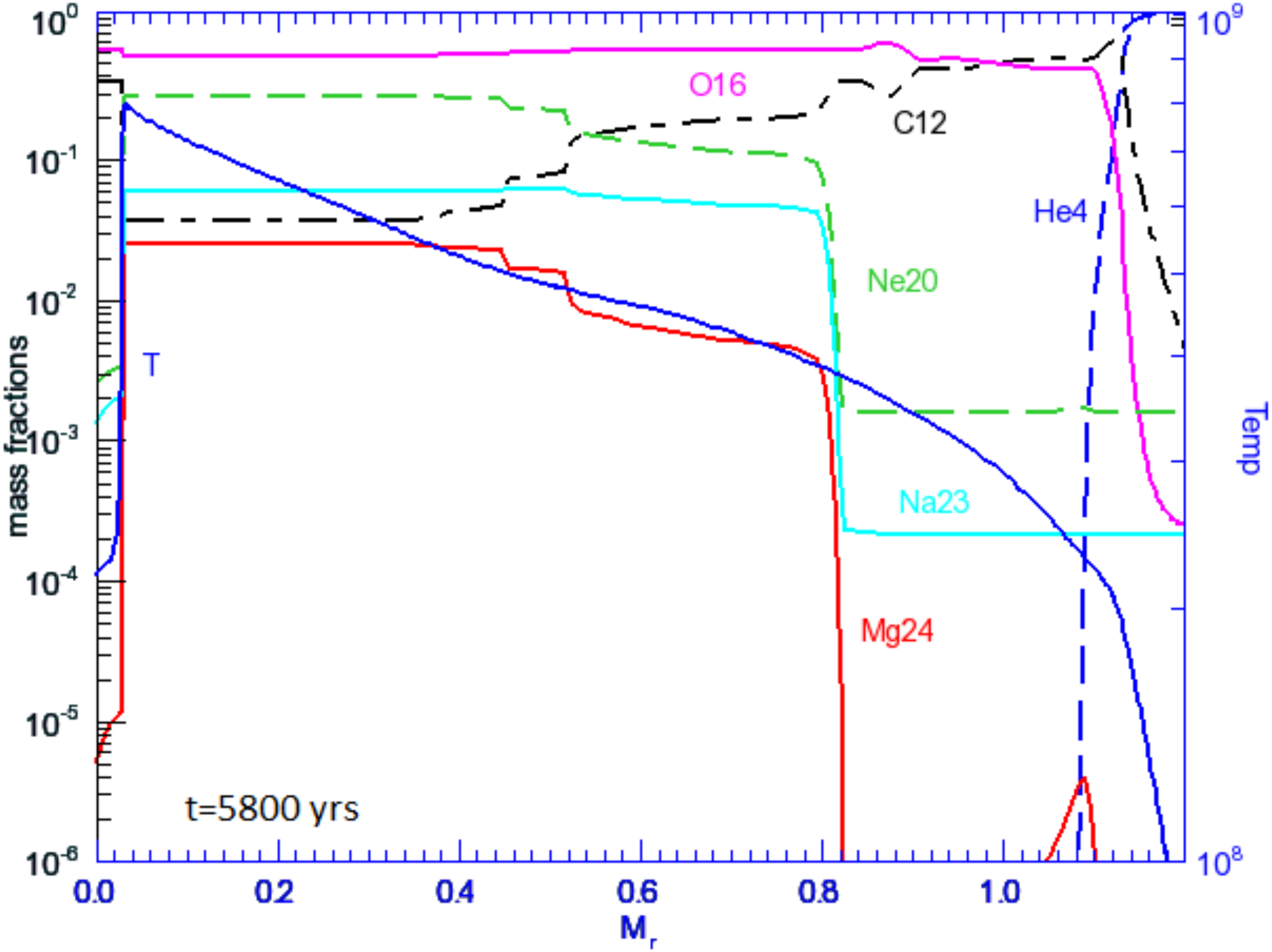
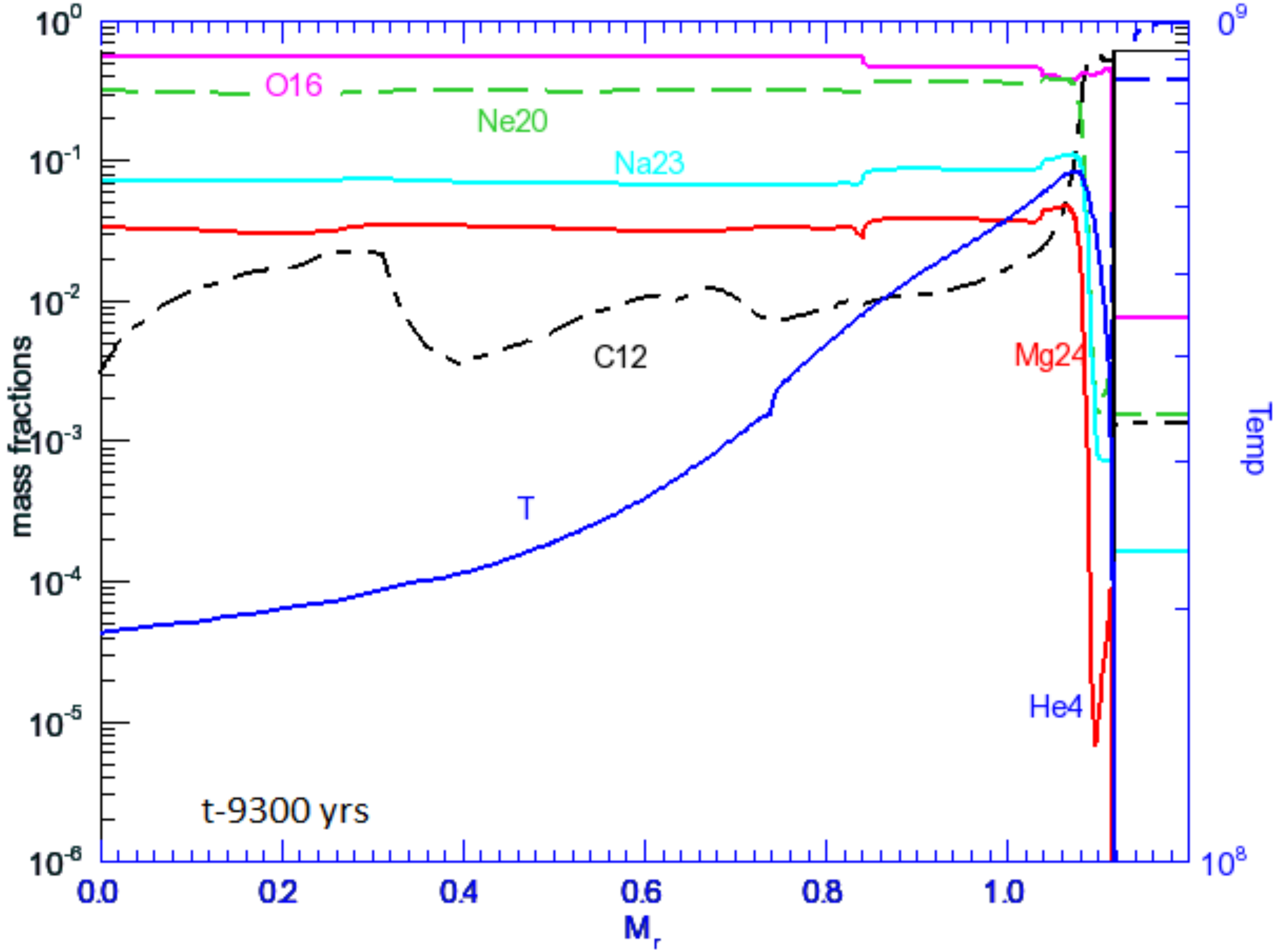
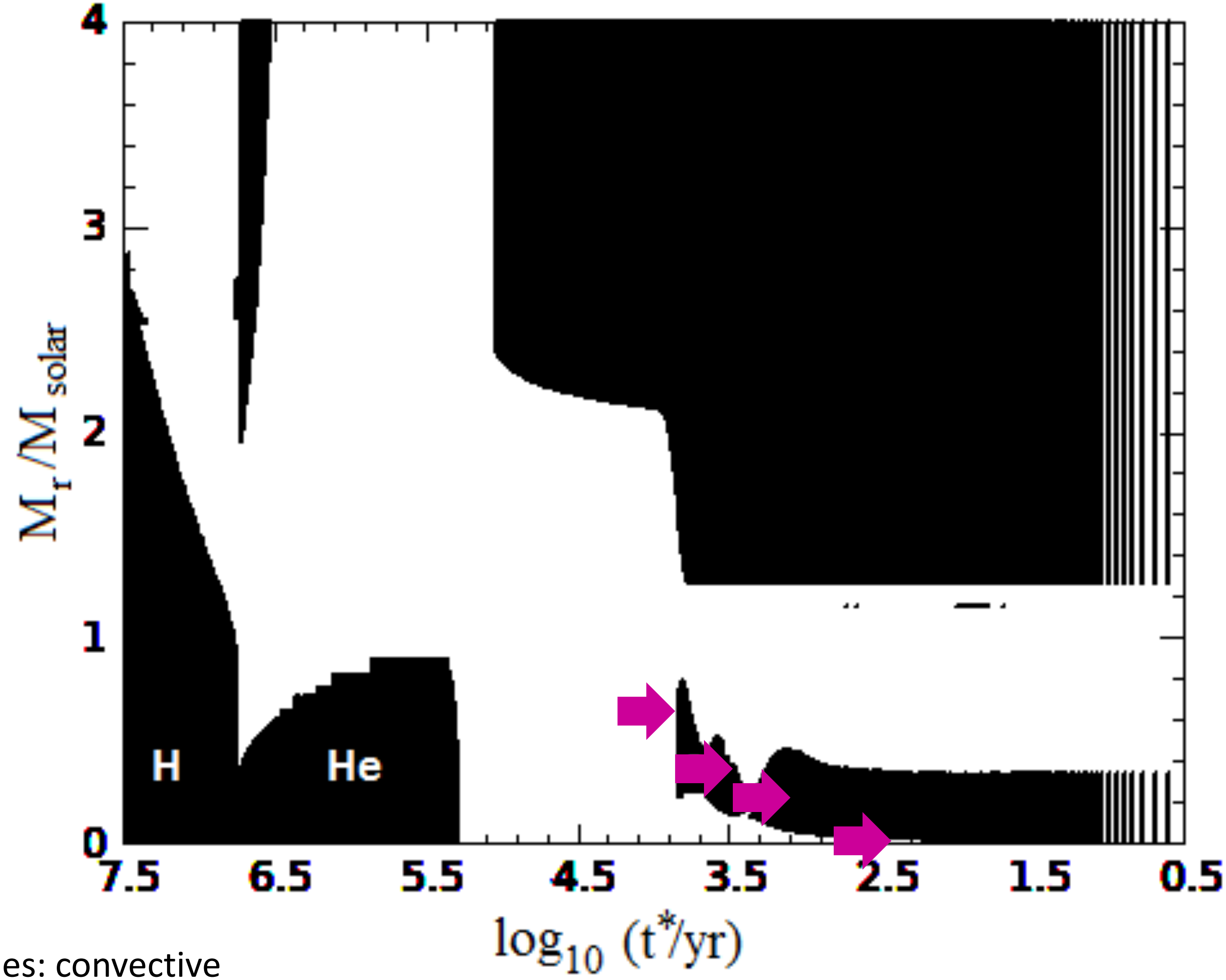


Off-center C-ignition



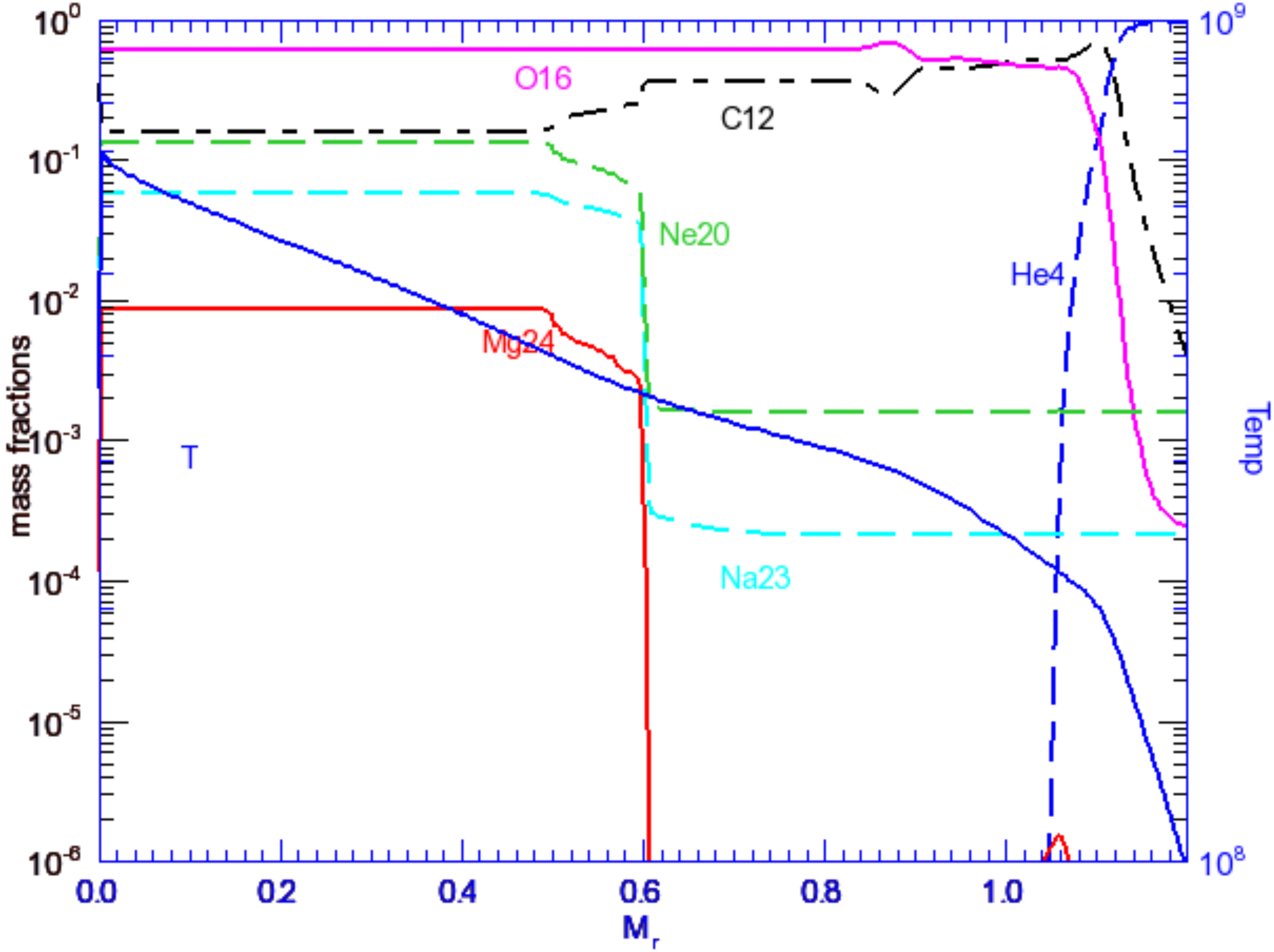


$9M_\odot$
$Z=Z_\odot$
CF88 rate

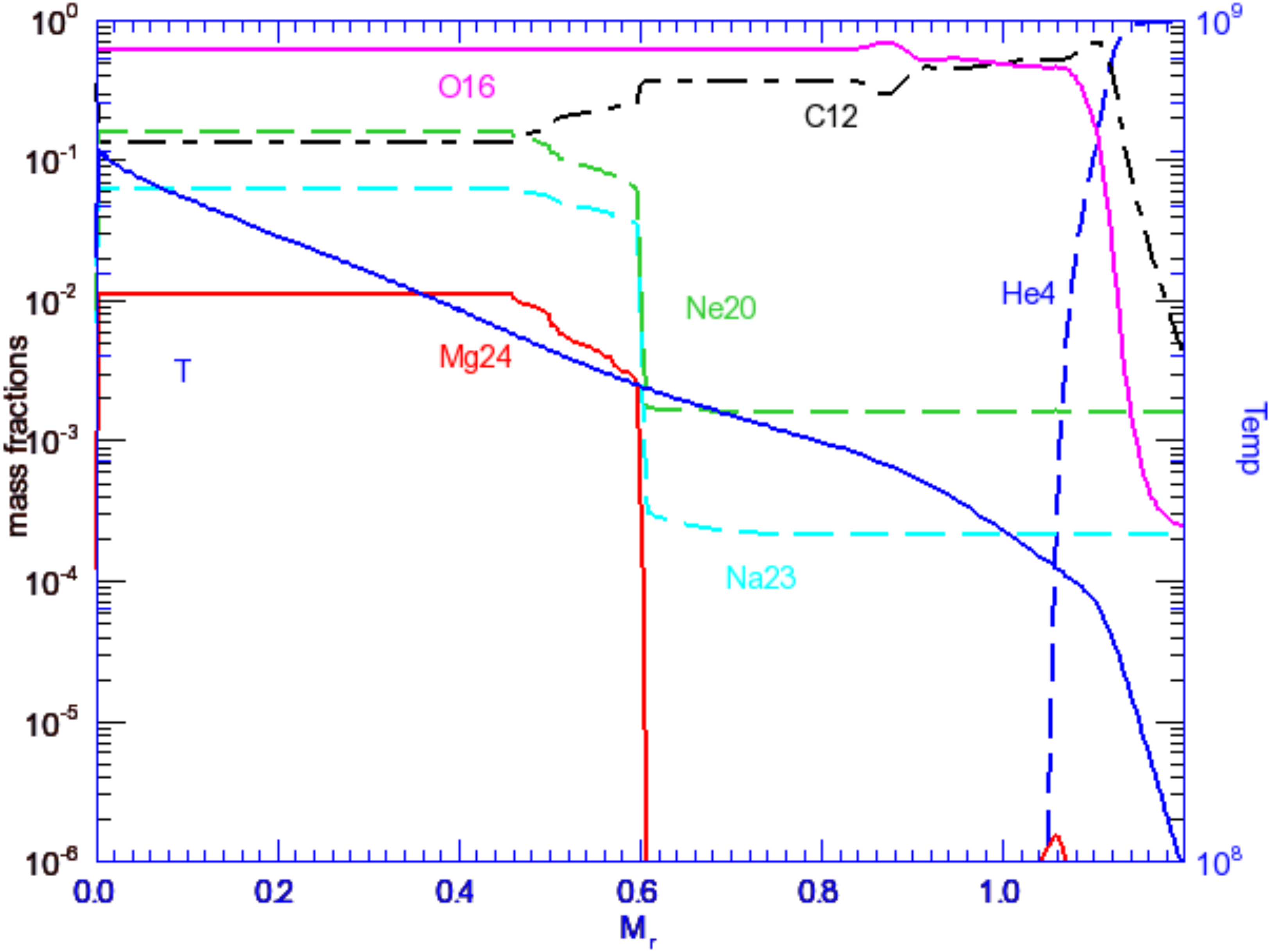
Black zones: convective
White zones: radiative

with the **CR** rate ...

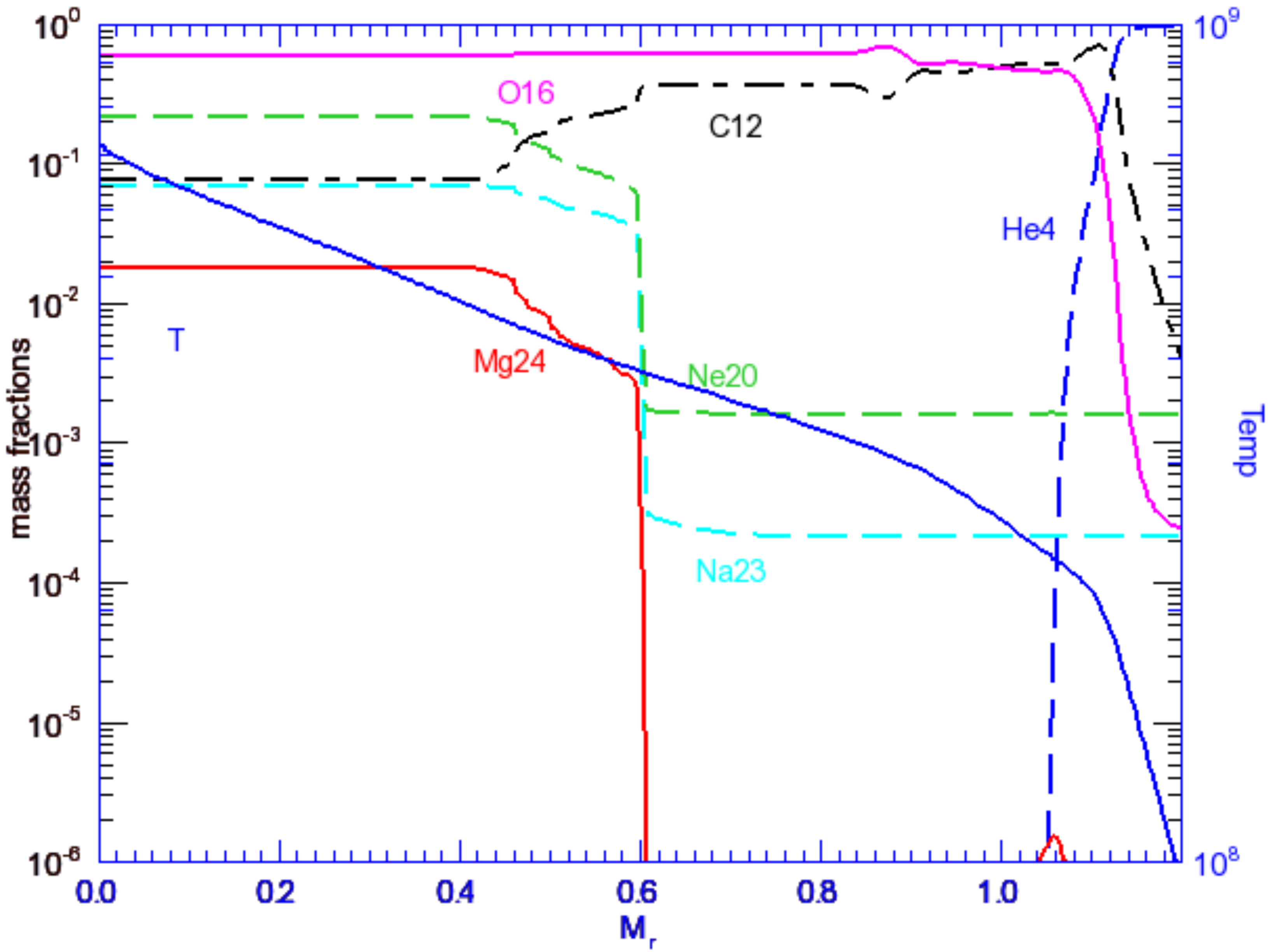
central C-ignition



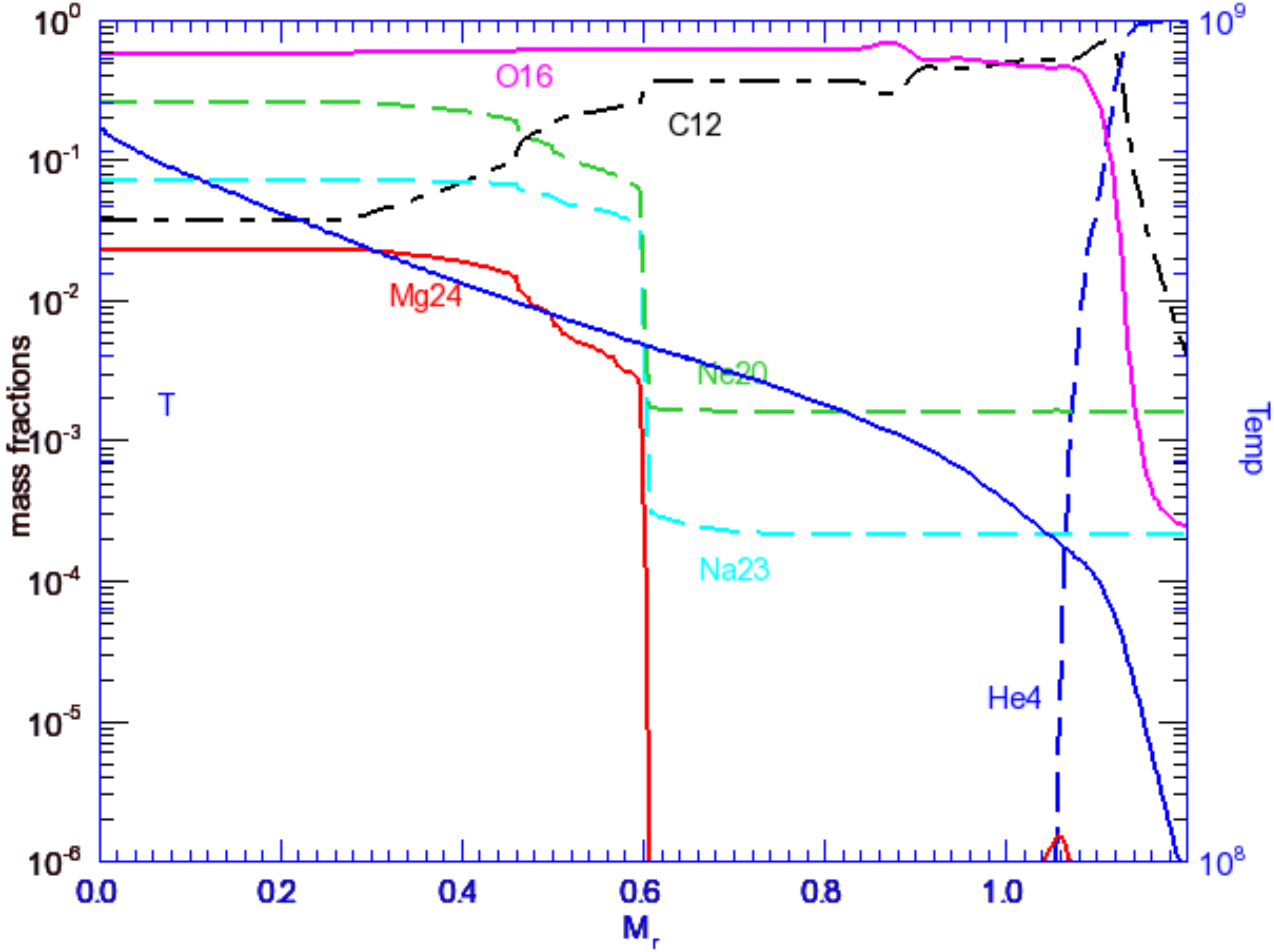
central C-ignition



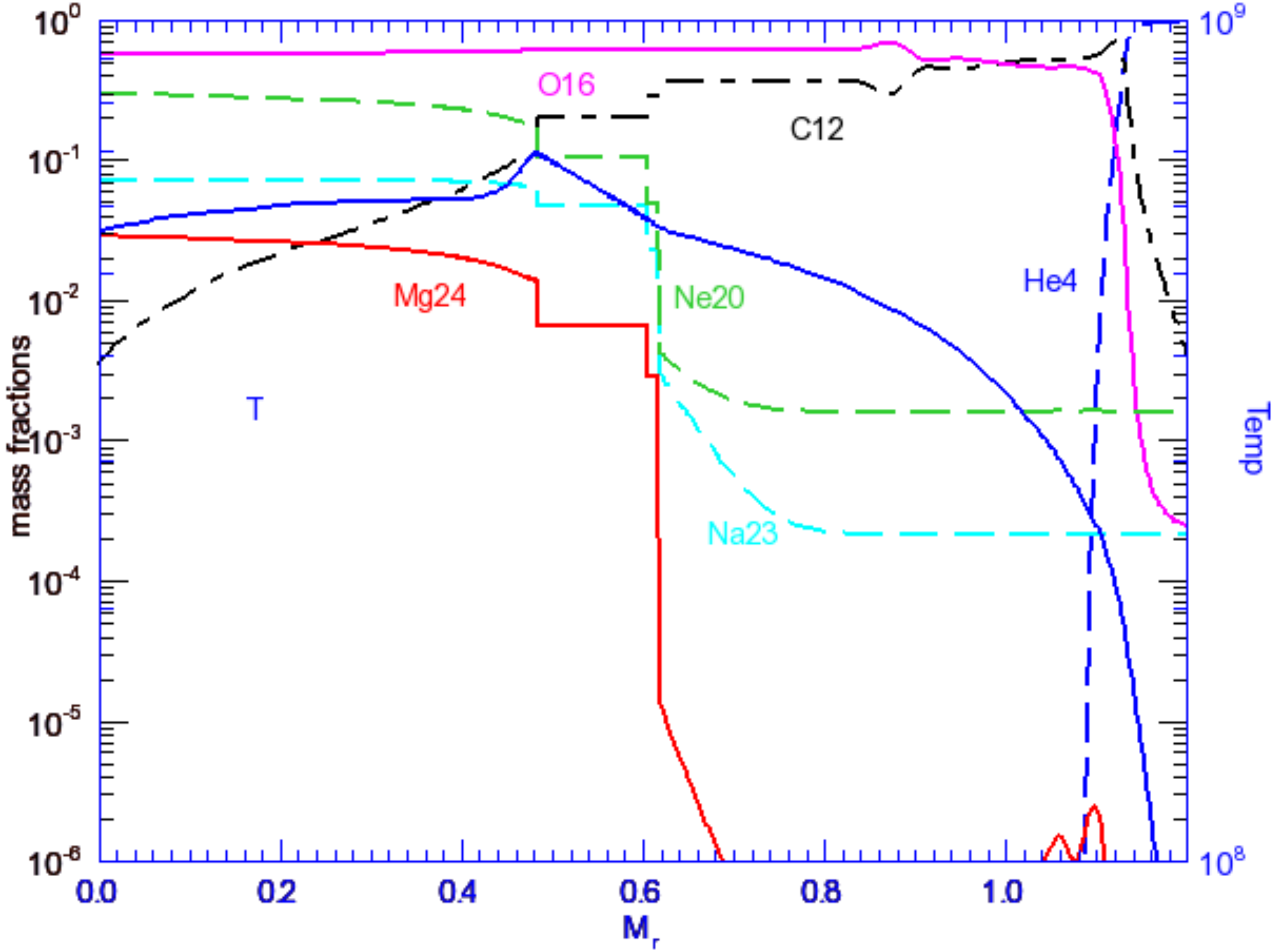
central C-ignition



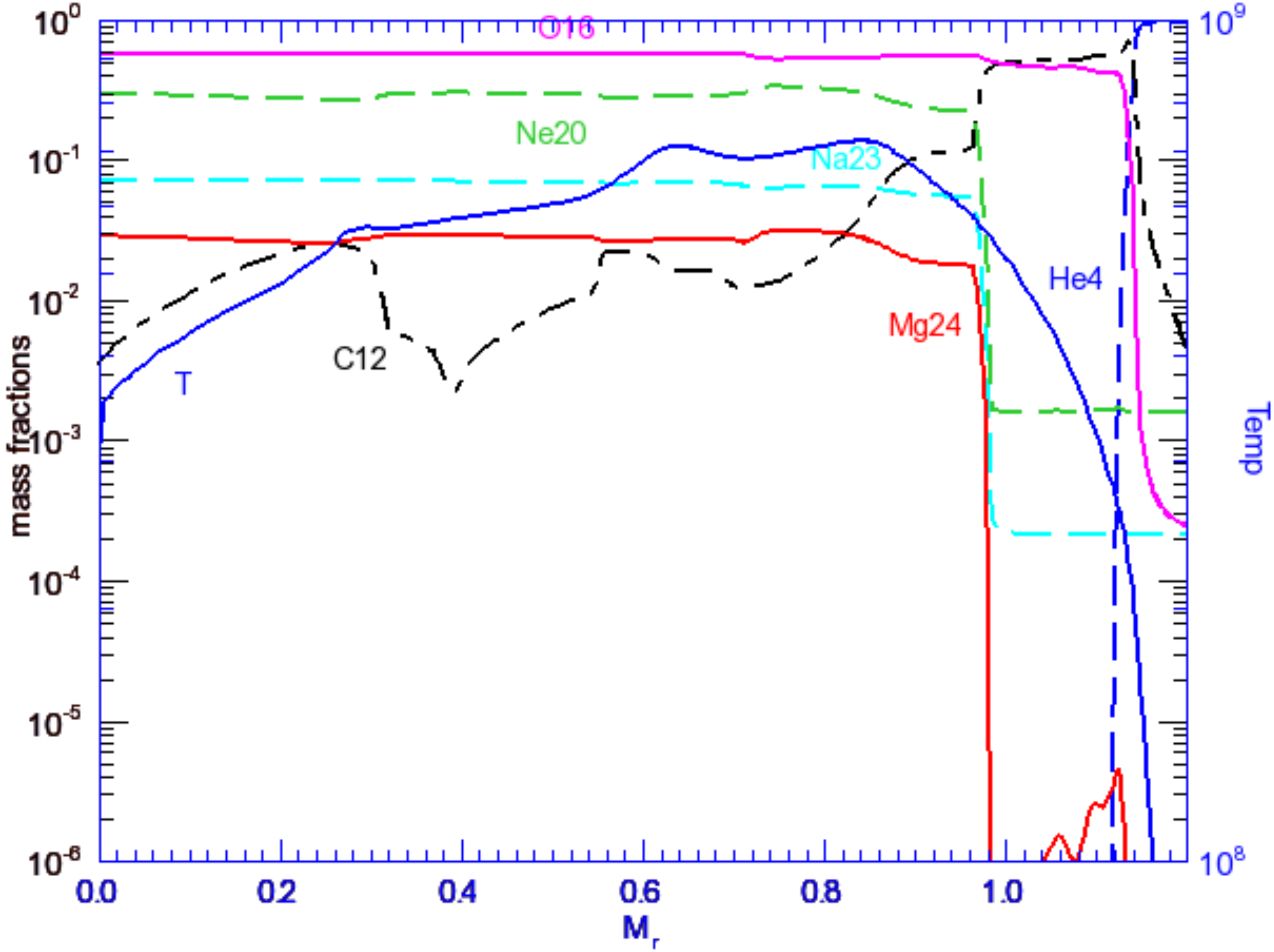
central C-ignition



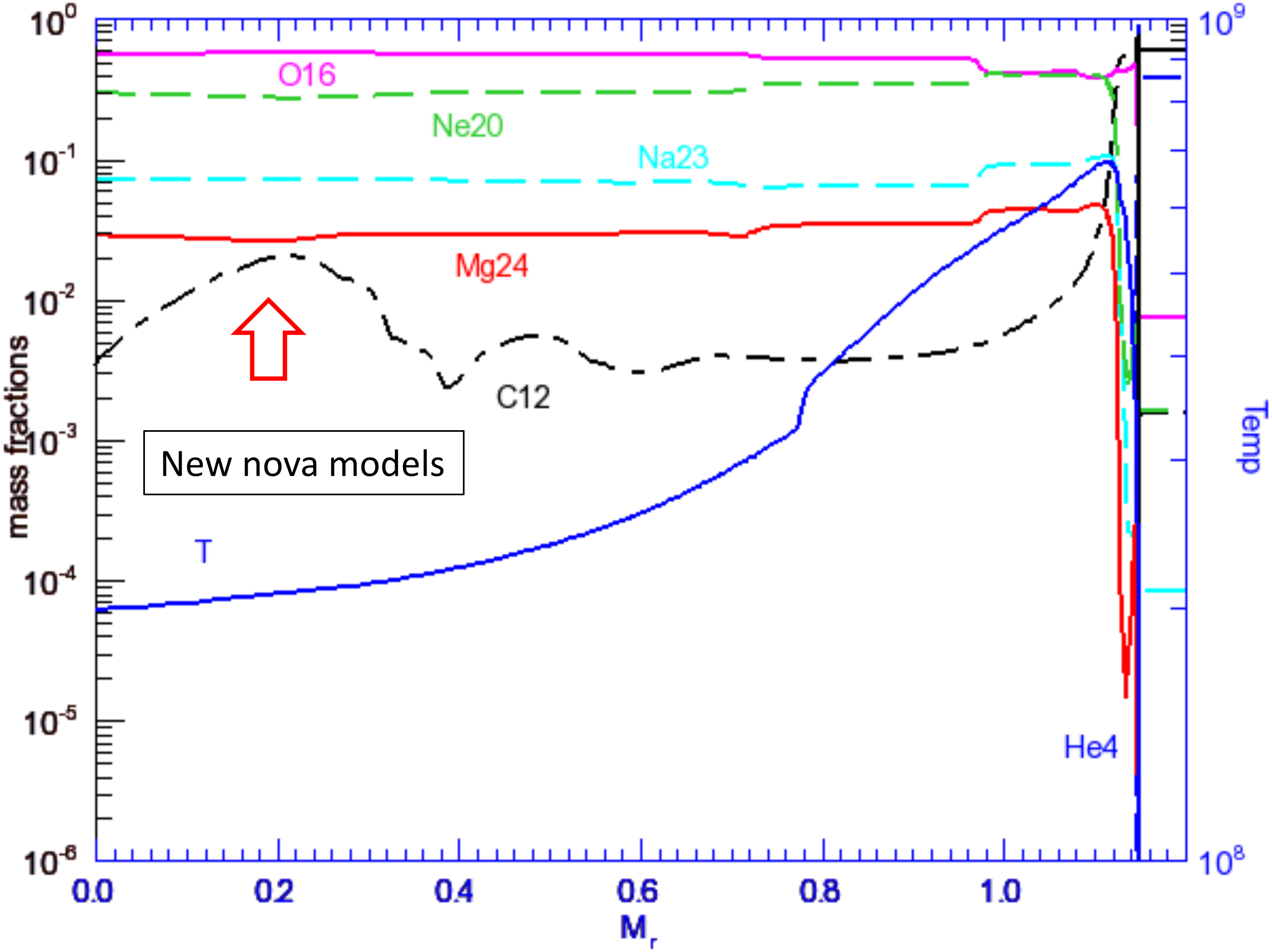
central C-ignition

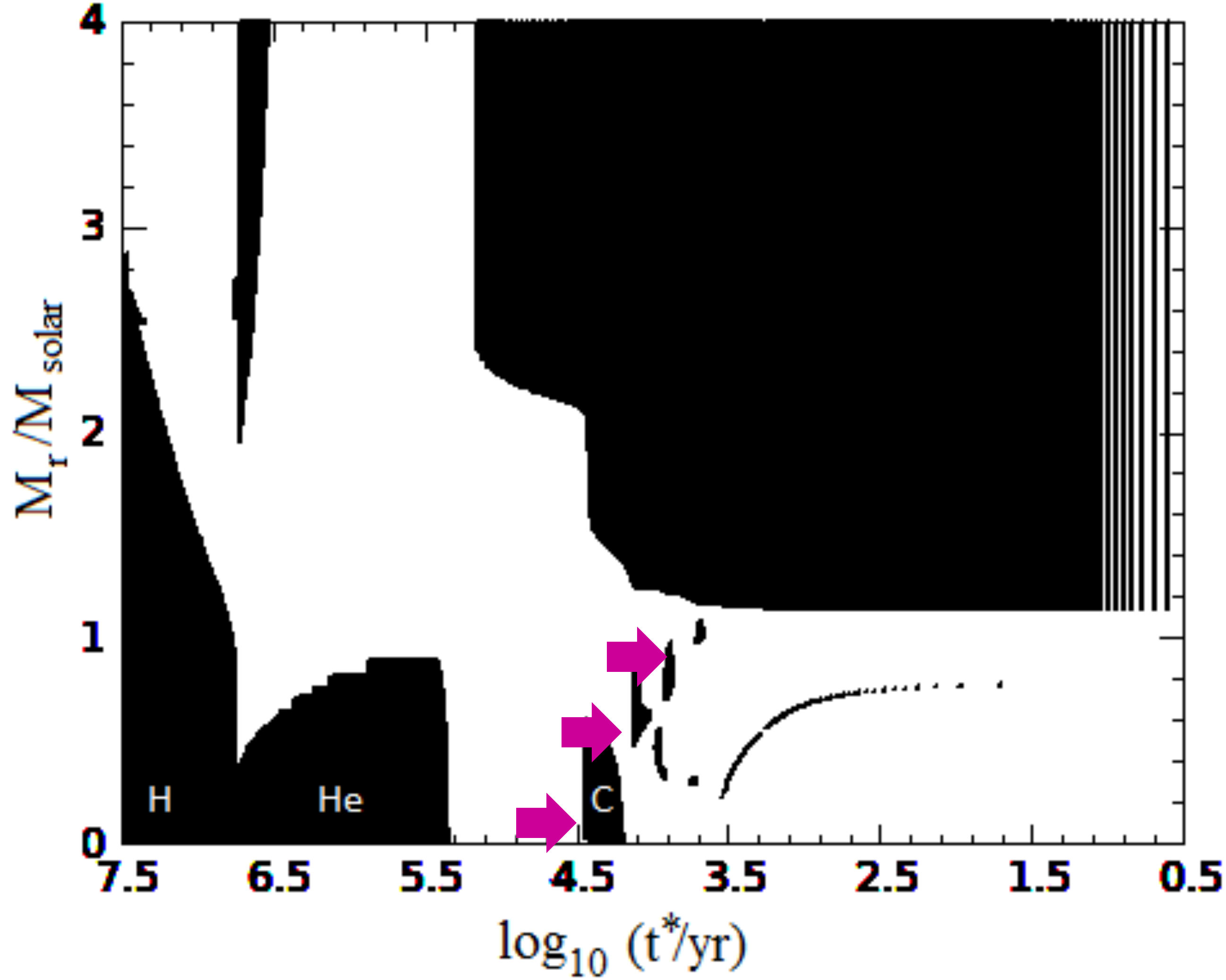


central C-ignition



central C-ignition

- 



$9M_\odot$

$Z=Z_\odot$

CR rate

Determination of M_{up}

Effect of the $^{12}C+^{12}C$ rate

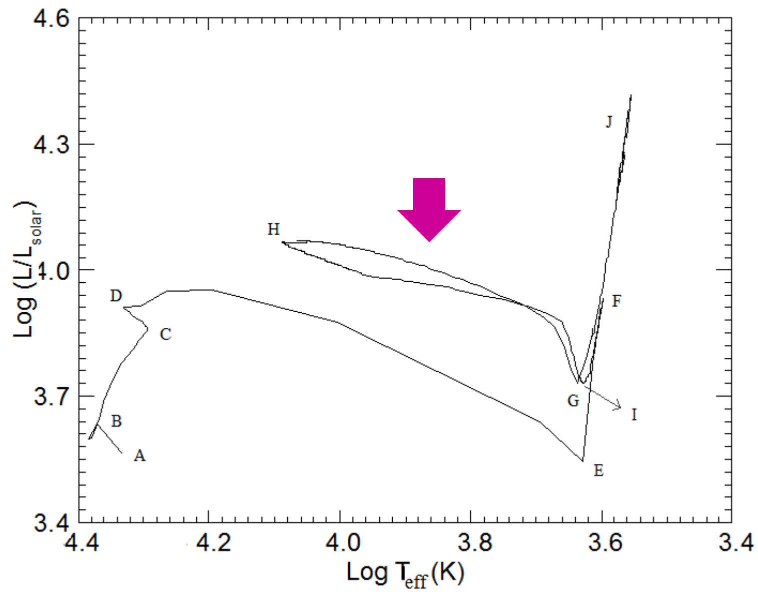
Rate	M_{up} (Standard mixing)
CF88	8.5 $M_{\odot}$
CR	8.3 $M_{\odot}$
CU	7 $M_{\odot}$
CL	9 $M_{\odot}$

Effect of core overshooting

$$\frac{dX_i}{dt} = \frac{\partial}{\partial M_r}\left[(4\pi r^2\rho)^2 D \frac{\partial X_i}{\partial M_r}\right]$$

D = 0 in radiative zones
D ≠ 0 in convective zones
D in convective boundaries given by:

$$D_{os\ \mathrm{region}}(z) = D_{conv\ boundary}\, e^{\frac{-2z}{fH_p}} \qquad z =$$



f free parameter, H_p pressure scale height.

$$z = 0.1H_p$$

Halabi, El Eid, Champagne, ApJ (2012)
Halabi AIP Conf.Proc (2014)

Effect of the $^{12}C+^{12}C$ rate **+ Overshooting**

Rate	M_{up} (Standard mixing)	M_{up} (Core overshooting)
CF88	8.5 $M_\odot$	8 $M_\odot$
CR	8.3 $M_\odot$	7.5 $M_\odot$
CU	7 $M_\odot$	--
CL	9 $M_\odot$	--

Comments on Mass-loss

No mass-loss	----	----
"low" mass-loss	Reimer's (η=0.5) +Bowen	10^{-6}-10^{-7} $M_{\odot}$/yr + 10^{-5} $M_{\odot}$/yr
"high" mass-loss	Reimer's (η=1.0) +Bowen	2x(10^{-6}-10^{-7})$M_{\odot}$/yr + 2x10^{-5} $M_{\odot}$/yr

M_{up} is not affected by mass-loss BUT

"high" mass-loss suppresses thermal pulsation (envelope mass cannot support effective He-shell burning)

"low" mass-loss has slight effect on central abundances

eg. prior to carbon burning for $M_{initial} = 8.3M_{\odot}$

$^{12}C = 0.4869$ and **$^{16}O = 0.4886$** (no mass-loss)

$^{12}C = 0.5072$ and **$^{16}O = 0.4682$** ("low" mass-loss)

($M_{TP\text{-}AGB} = 7.98M_{\odot}$)

Conclusions and Future work

- The determination of **M_{up} is important** and has several astrophysical consequences.
- M_{up} is affected by the **uncertainty in the carbon-fusion rate.** We need Better experimental determination & more insight on the probability of the α and p channels.
- M_{up} is also affected by the efficiency of **convective mixing** during the helium and hydrogen burning phases. Other factors are worth investigating.
- **Mass-loss** affects the core composition and thus, the composition of resulting ONe WD.
- SAGB evolution is extremely **computationally demanding** (high spatial and temporal resolutions)- we hope to investigate more masses/effects in the near future.
- The **consequences on novae eruptions** will be investigated through a collaboration with Prof. Jordi Jose, Universitat Politècnica de Catalunya, Barcelona (Halabi, El Eid, Jose 2014, in preparation).