Explosive End of primordial AGB stars

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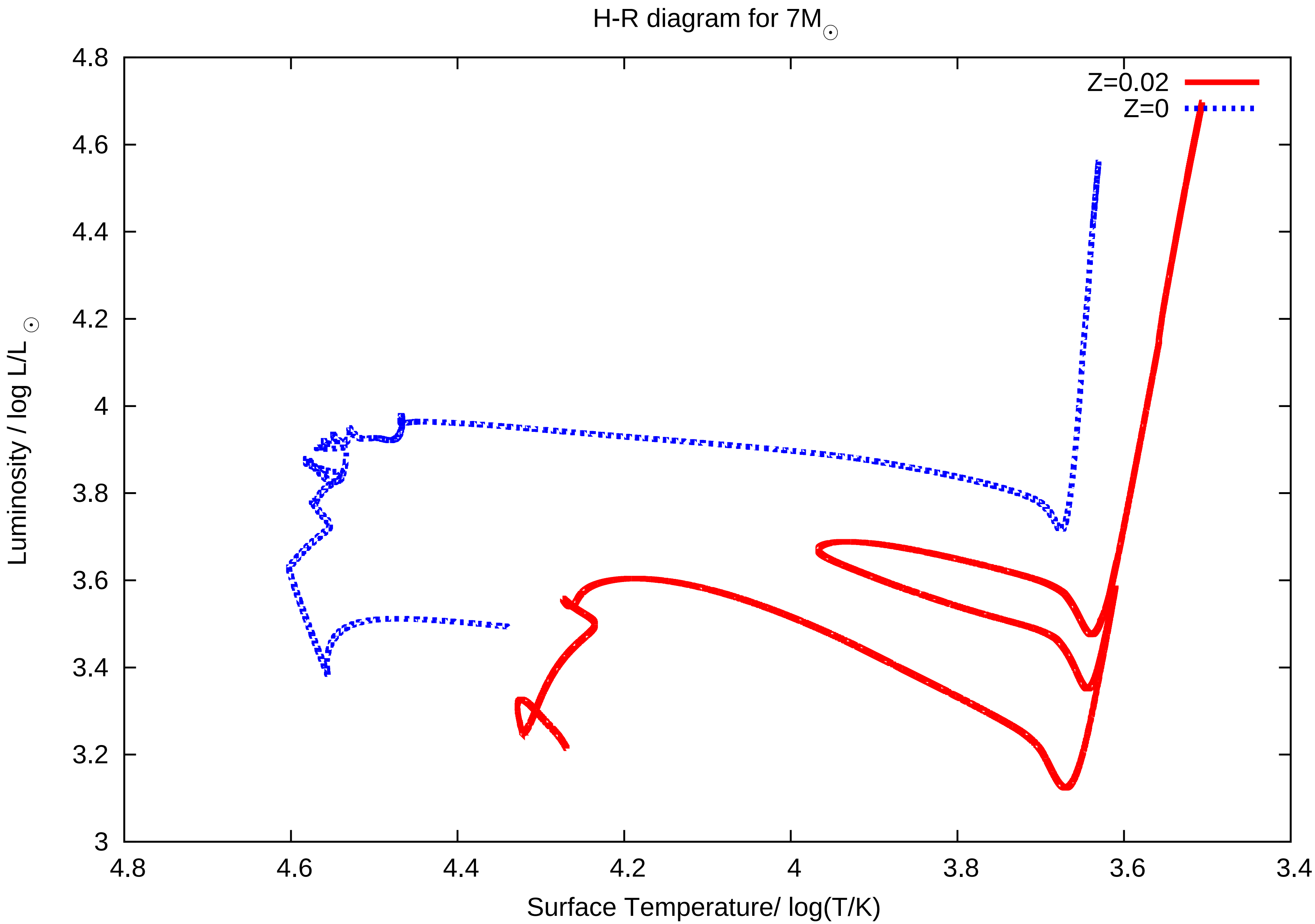
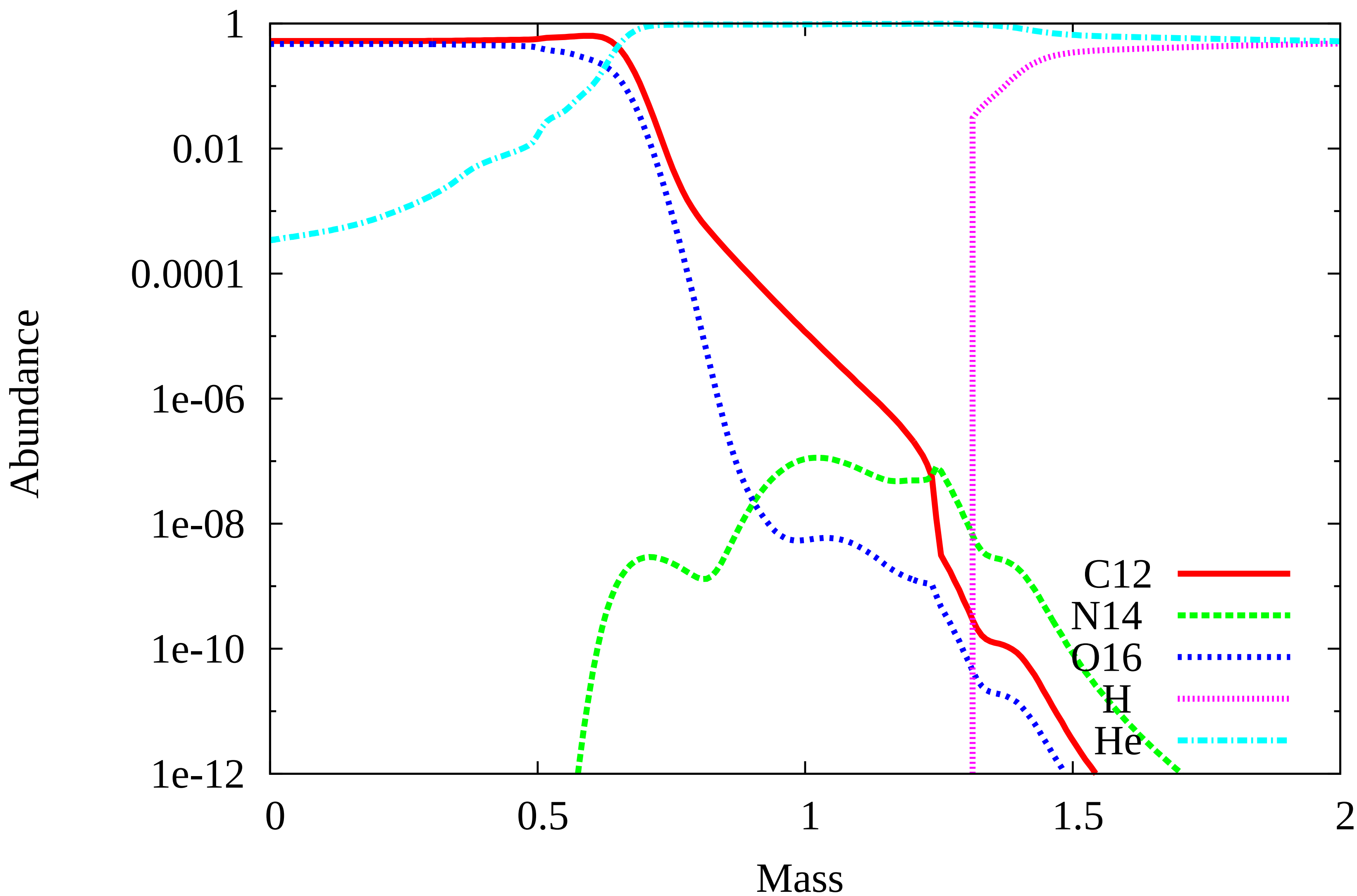
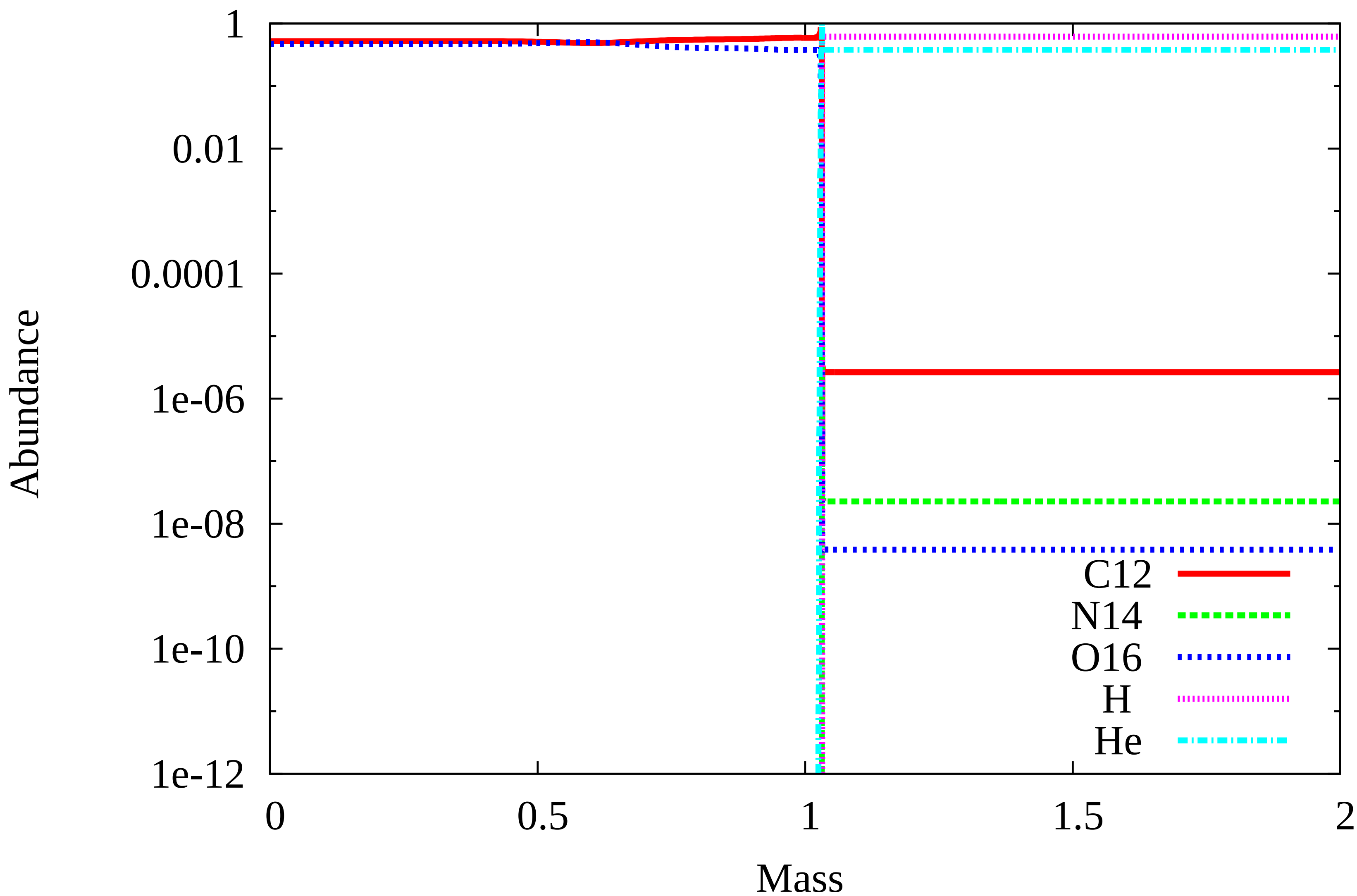
Overview

- Cambridge STARS is used to evolve $Z - 0\ 5\,M_\odot$ and $7\,M_\odot$ stars
- Without overshooting, first modelled without mass loss and then with Reimers’mass loss rate
- Through its entire TPAGB phases
- Carbon ignites degenerated at core
- Relation of different mass loss rate and its fate

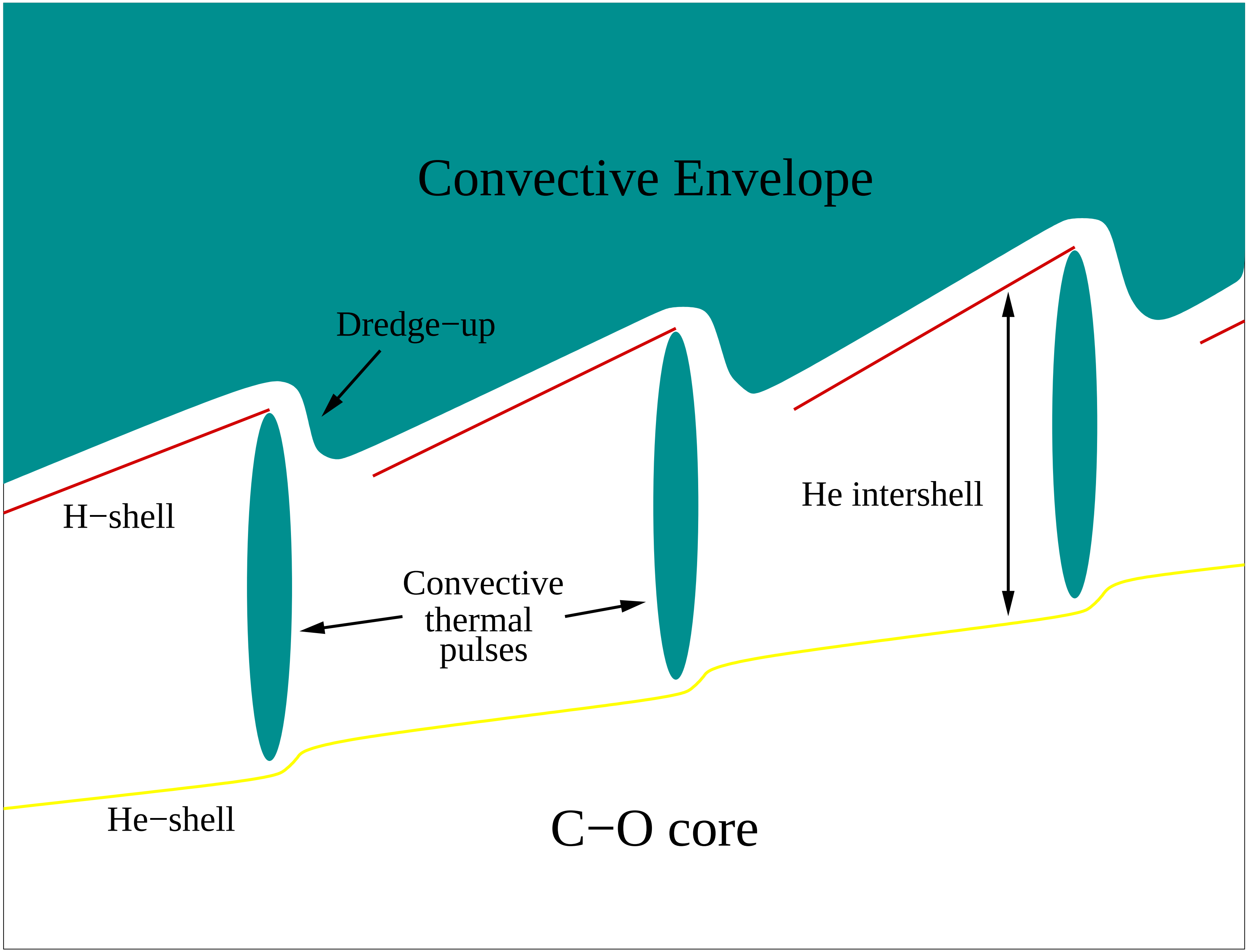

H-R diagram for 7M☉
Z=0.02
Z=0
Luminosity / log L/L☉
Surface Temperature/ log(T/K)
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4



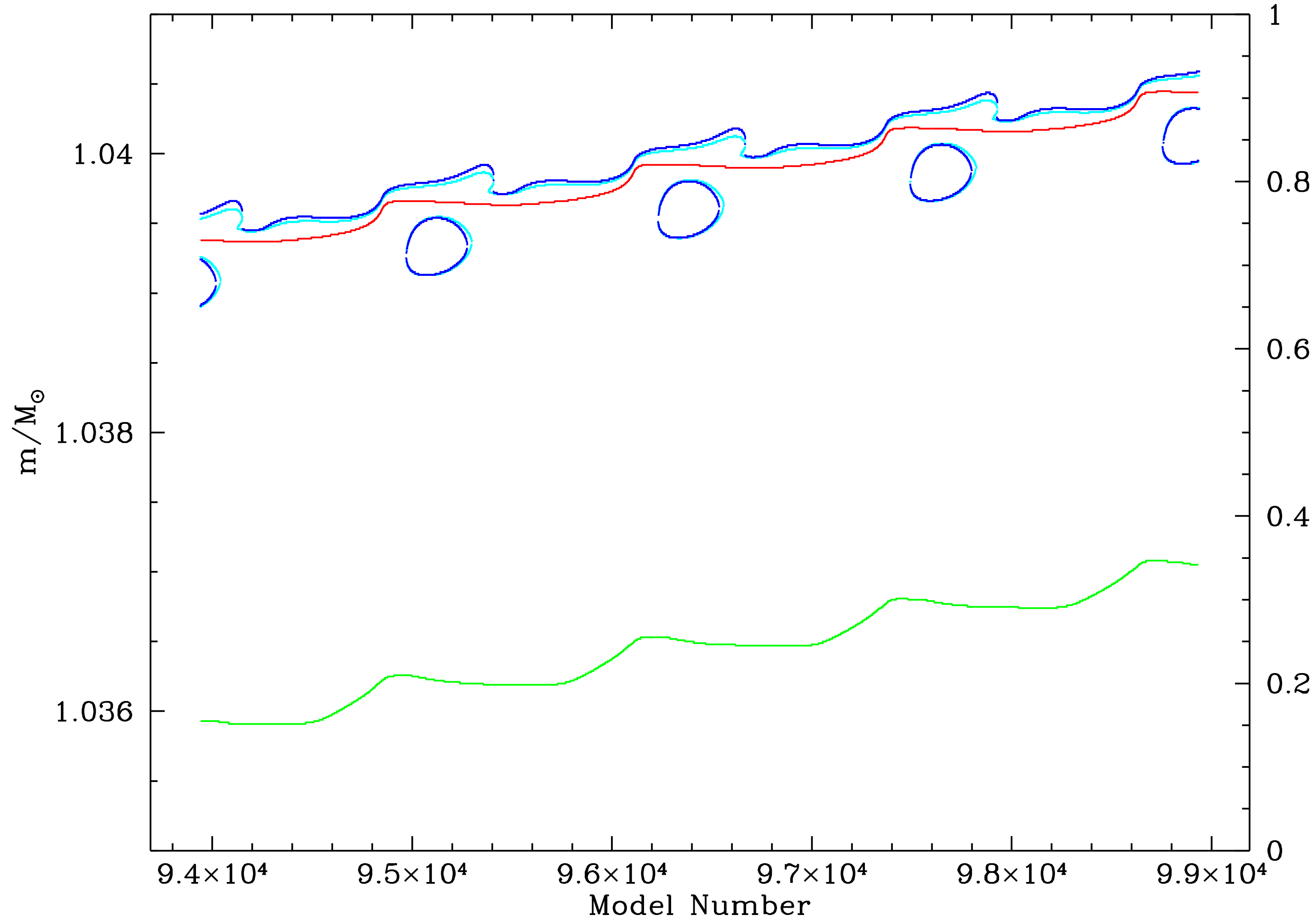
Mass fraction profile near the centre of our $7\,M_\odot$ model at the end of central He burning



Mass fraction profile near the centre of our $7\,M_\odot$ model after 2nd dredge up


Convective Envelope
Dredge−up
H−shell
He intershell
Convective
thermal
pulses
He−shell
C−O core

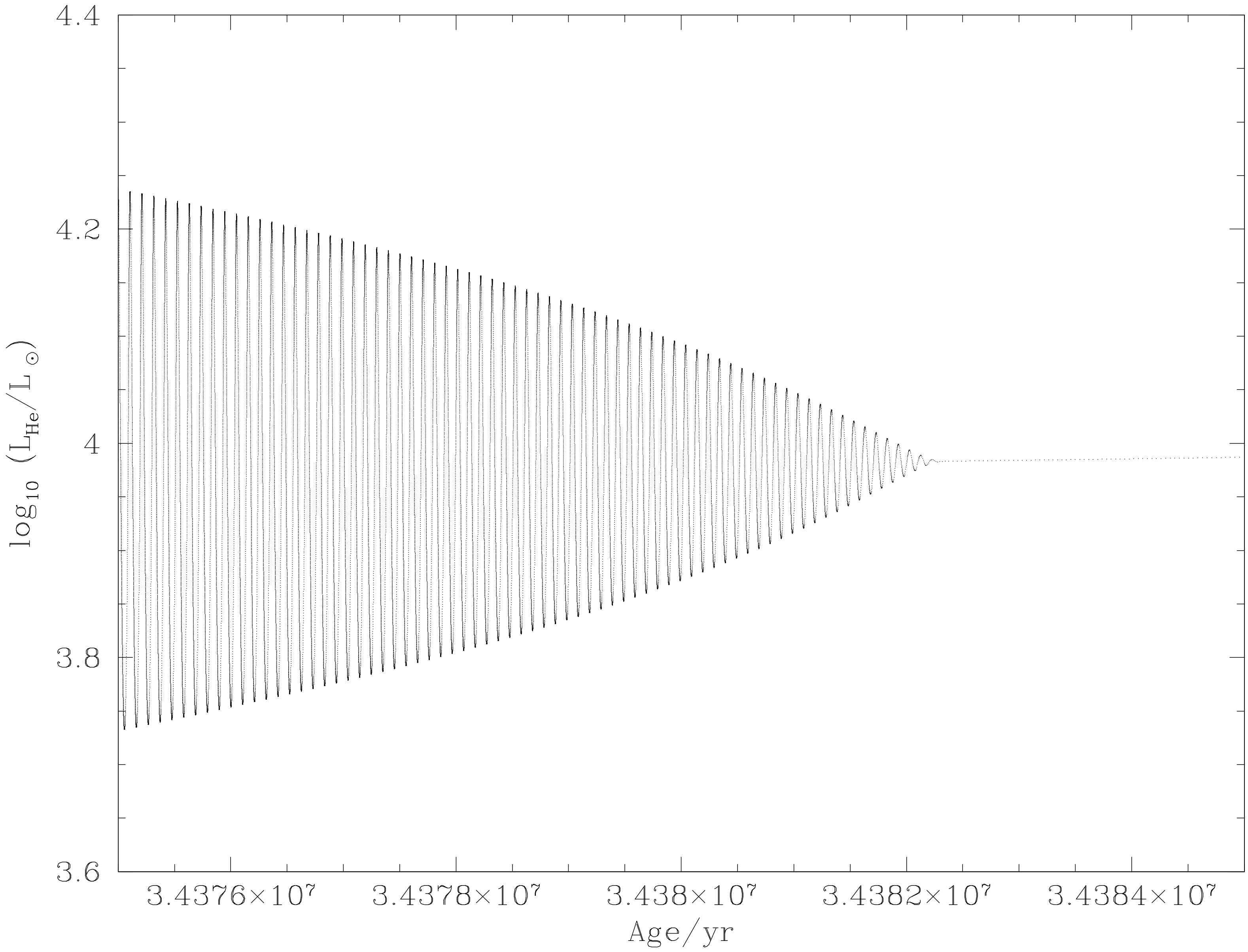
Blue: con-



vective zone boundary, Red: hydrogen burning shell, yellow: helium burning shell

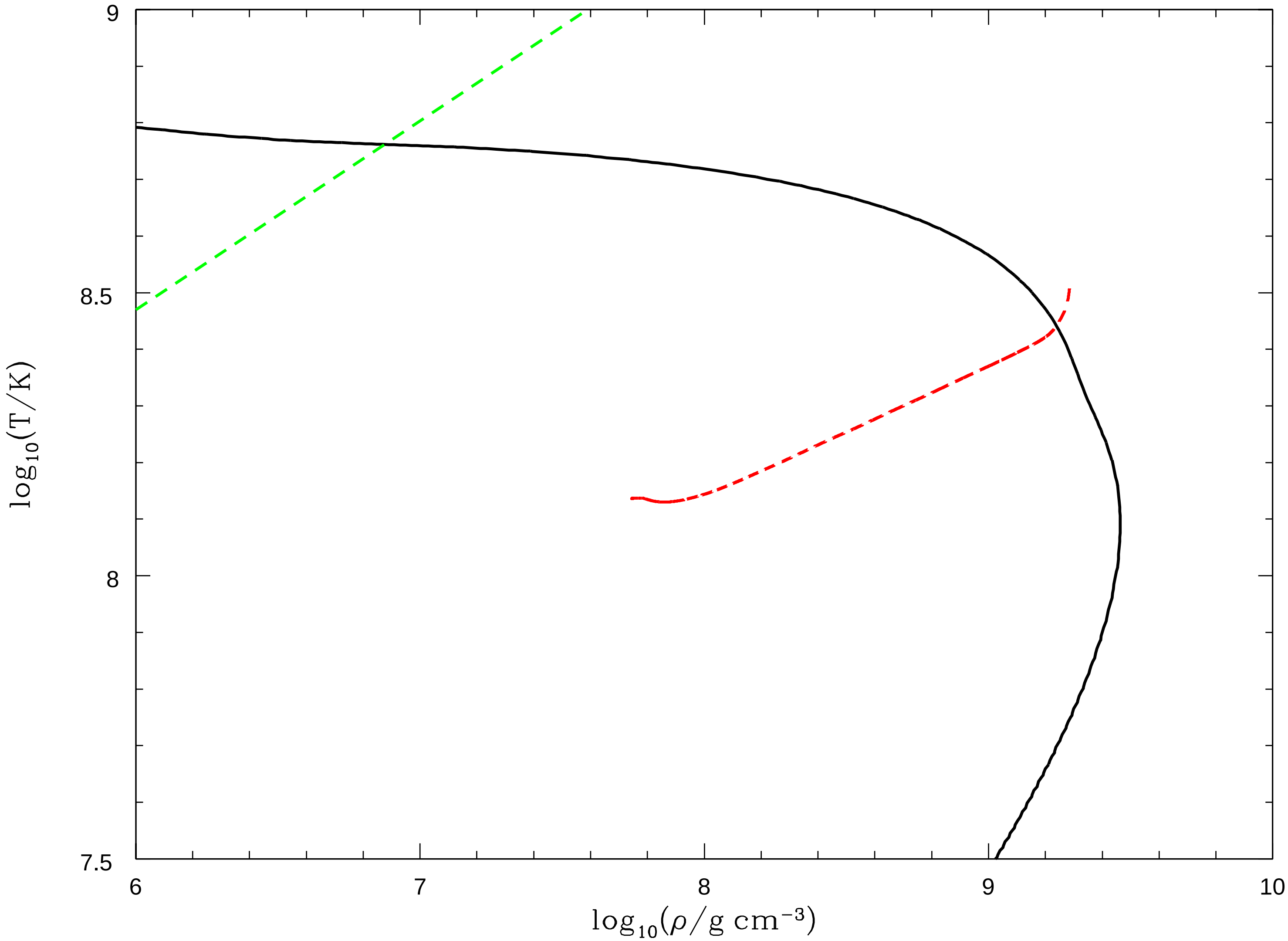
Late AGB phases of $7\,M_\odot$ model

- Around 600 thermal pulses in $1.1 \times 10^5\,\mathrm{yr}$
- Interpulse period:700 yr at the start, about 100 yr at the end of the TP phase.
- The core mass is $1.04\,M_\odot$ when TP starts, $1.10\,M_\odot$ when TP ends
- Max He luminosity never exceeds $10^{5.5}\,L_\odot$
- Pulses are too weak to lead to any third dredge up
- a quiescent evolutionary phase, core keep growing, for about $1.8 \times 10^5\,\mathrm{yr}$

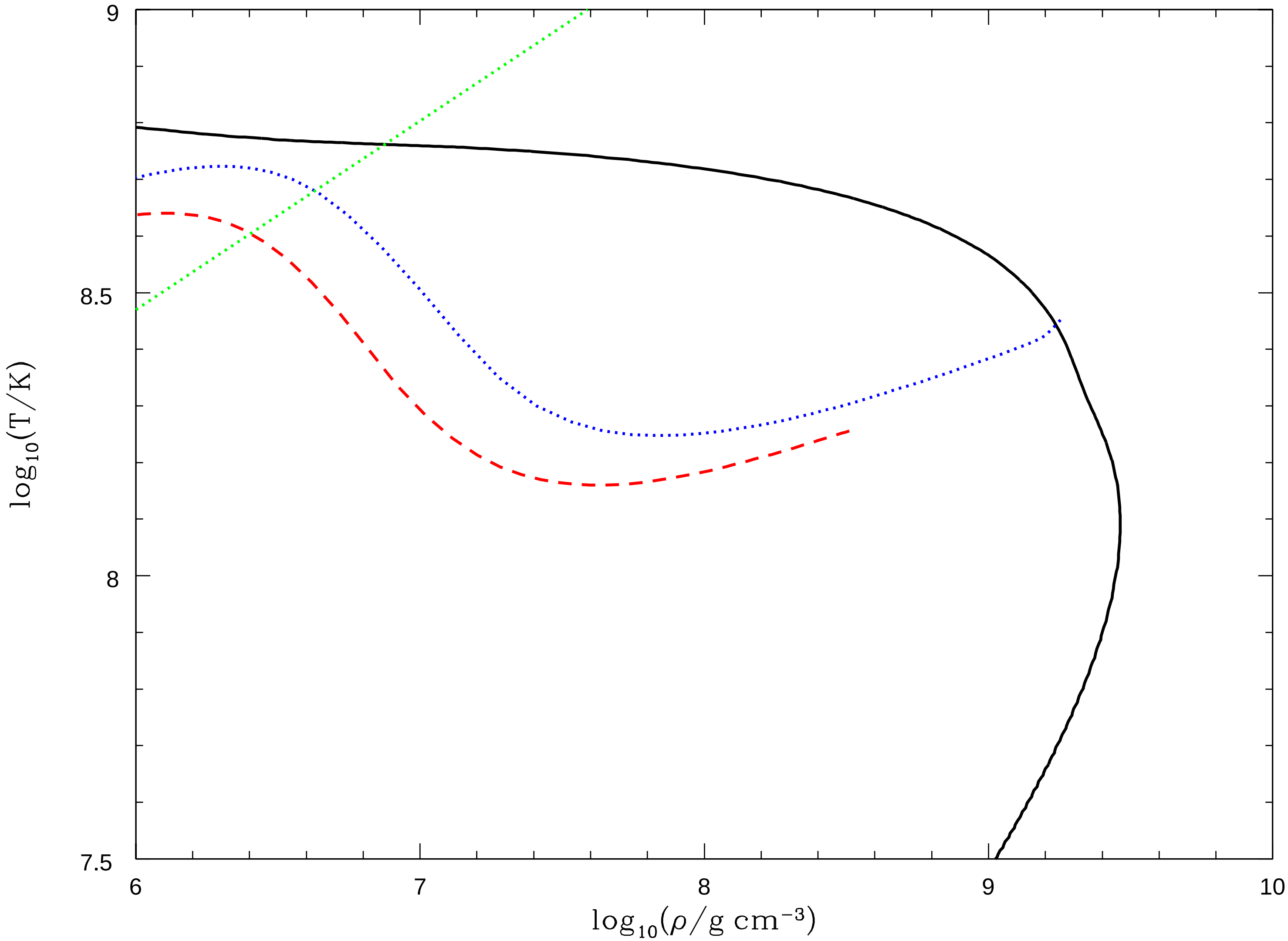

4.4
4.2
4
3.8
3.6
$\log_{10}(L_{He}/L_{\odot})$
3.4376×10⁷
3.4378×10⁷
3.438×10⁷
3.4382×10⁷
3.4384×10⁷
Age/yr

Supernovae type 1.5

- carbon ignition at degenerate core ($1.36\,M_\odot$) leads to thermonuclear runaway.
- similar to Type Ia, but with hydrogen envelope
- Can estimate nucleosynthesis yield from Supernovae Type Ia model, e.g. Iwamoto et al(1999)
- ^{12}C: $\sim\ 10^{-2}\,M_\odot$, ^{14}N: $\sim\ 10^{-8}\,M_\odot$ (deflagration) $\sim\ 10^{-4}\,M_\odot$ (delayed detonation) $3.31\times10^{-8}\,M_\odot$ for and ^{16}O:$\sim 10^{-1}\,M_\odot$



$7.0\,M_\odot$ model.Carbon ignition curve as described by Martin, Tout & Lesaffre(2006). Green line: Boundary of degeneracy



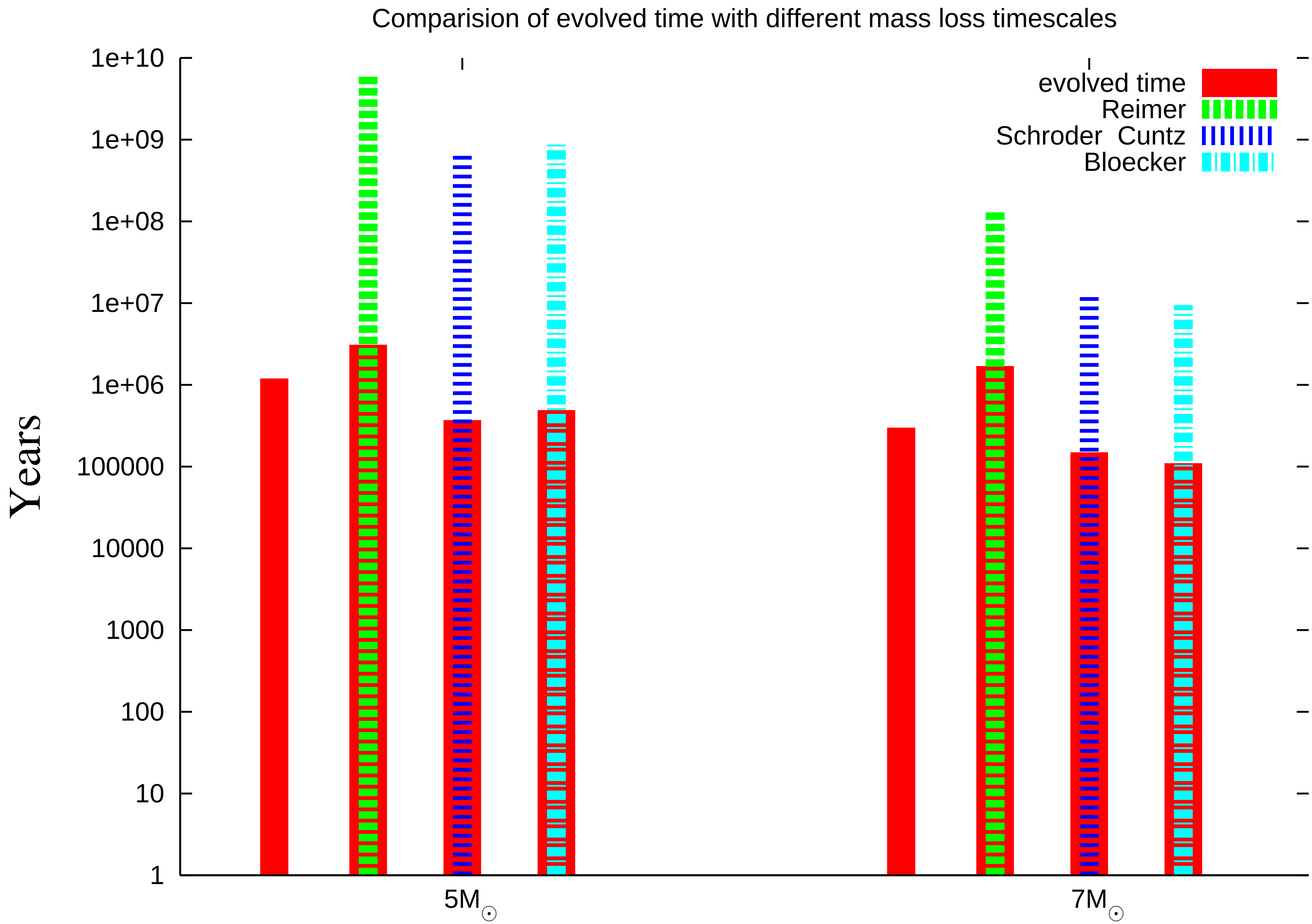
$7.0\,M_\odot$ model. Internal structure profile evolution (red to blue) with the core at highest density and burning shell at highest temp.

Models with mass loss

- The Reimers' mass-loss rate is

$$\dot{M}_{\rm R} = -4.0 \times 10^{-13} \eta \frac{(L/L_\odot)(R/R_\odot)}{(M/M_\odot)} M_\odot \, {\rm yr}^{-1}, \tag{1}$$

- We uses $\eta = 1$, likely to be overestimate
- Models with and without mass loss has almost identical evolution.
- Total mass loss: $1.0\,M_\odot$ for $7.0\,M_\odot$, $1.4\,M_\odot$ for $5.0\,M_\odot$
- Could Mass loss be high enough that envelope is lost before carbon ignition?
- Estimate of mass loss timescales of other mass loss rate with and without $\dot{M}(Z) = \dot{M}(Z_\odot)(\frac{Z}{Z_\odot})^{0.5}$ scaling


Comparision of evolved time with different mass loss timescales
Years
1e+10
1e+09
1e+08
1e+07
1e+06
100000
10000
1000
100
10
1
evolved time
Reimer
Schroder Cuntz
Bloecker
5M☉
7M☉

Conclusion

- We have modeled the whole evolution of AGB stars with zero metallicity
- Carbon ignites degenerately, core near Chandrasakher mass, but with hydrogen envelope: supernovae type 1.5
- It is unlikely that the stars will lose all its envelope before carbon ignition for these two stars.
- For other stars of higher (but still low) metallicity, mass loss-metallicity relationship could be important

$M_{\mathrm{ZAMS}}/M_\odot$	evolved time/yr	Reimers/yr	Schroder/yr	Blocker/yr
5	1.2×10^6	3.1×10^6	3.7×10^5	4.9×10^5
7	3.0×10^5	1.7×10^6	1.5×10^5	1.1×10^5
5	1.2×10^6	6.0×10^9	6.9×10^8	9.0×10^8
7	3.0×10^5	1.4×10^8	1.3×10^7	9.5×10^6

timescales associated with loss of the envelope for different mass loss rate compared with the actual evolved time. Top section is where no metallicity-scaled mass loss is used. Bottom section used the relation $\dot{M}_{\mathrm{B}} = -4.83 \times 10^{-9} \frac{L^{2.7}}{M^{2.1}} \dot{M}_{\mathrm{R}} M_\odot \,\mathrm{yr}^{-1}$