Massive stars

School on “The synthesis of the elements”

Granada (12-16 April 2010)

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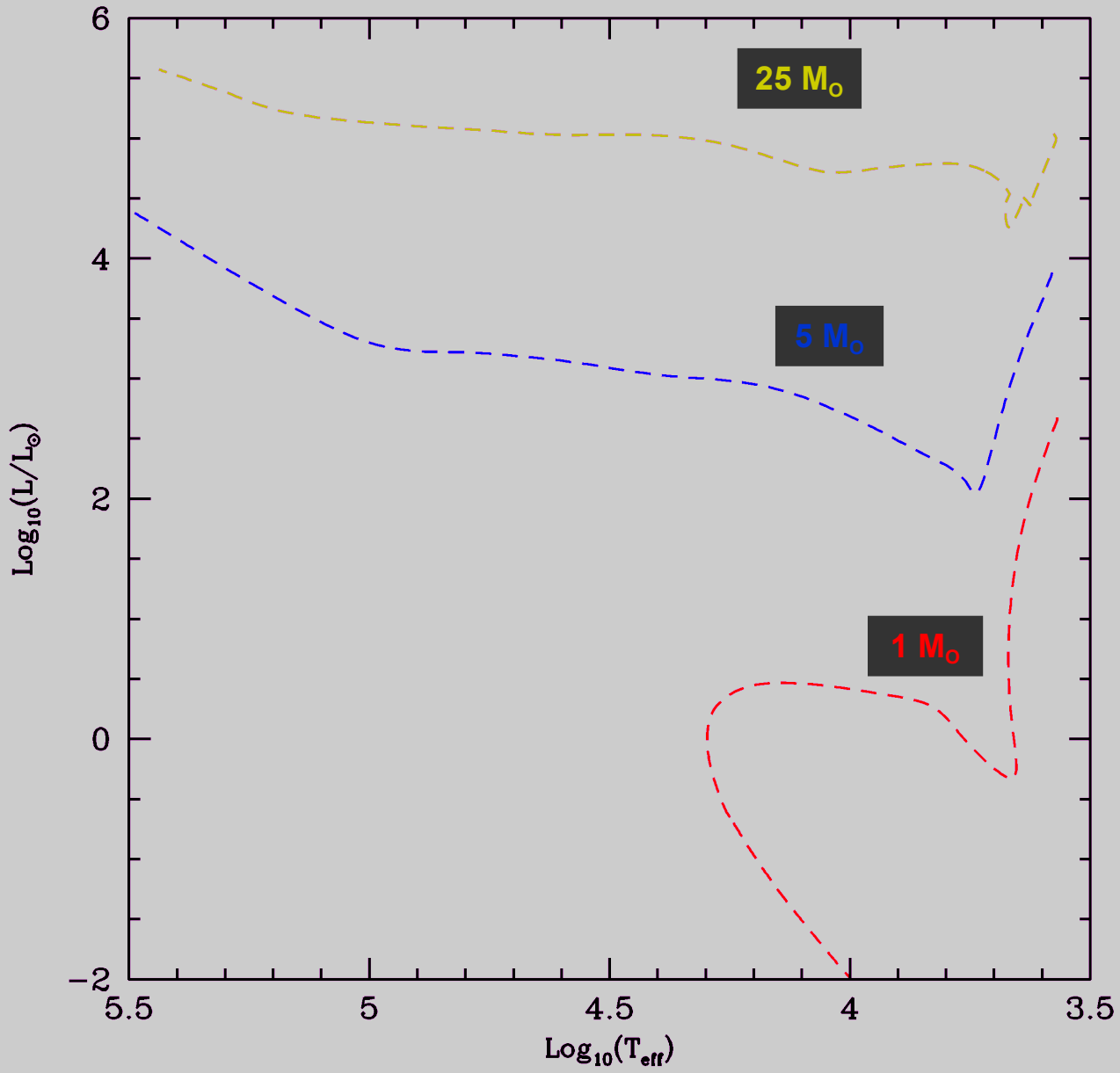
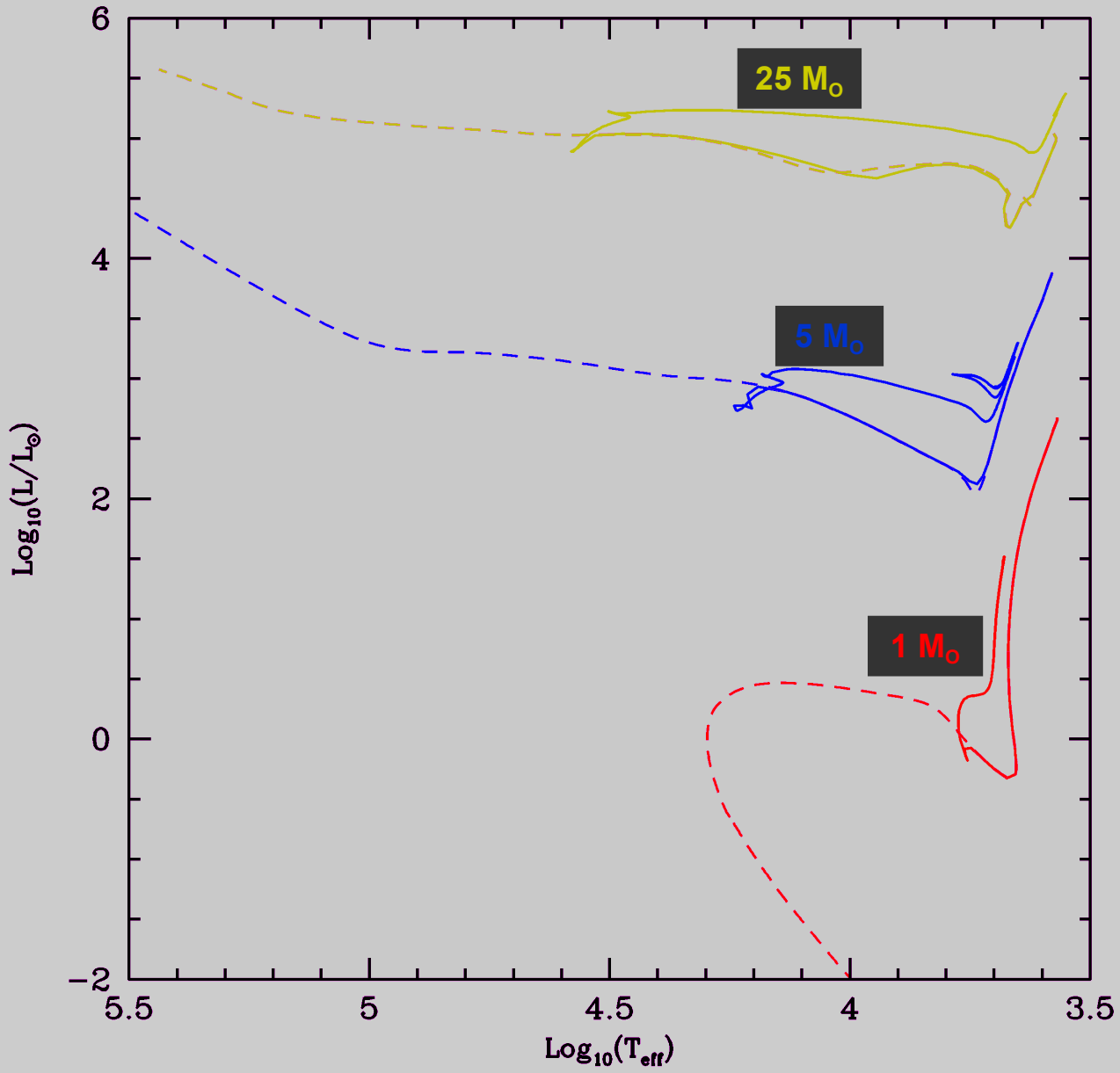
Part 2


25 M$_\odot$
5 M$_\odot$
1 M$_\odot$
6
4
2
0
−2
5.5
5
4.5
4
3.5
Log$_{10}$(L/L$_\odot$)
Log$_{10}$(T$_{eff}$)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Log$_{10}$(L/L$_\odot$)
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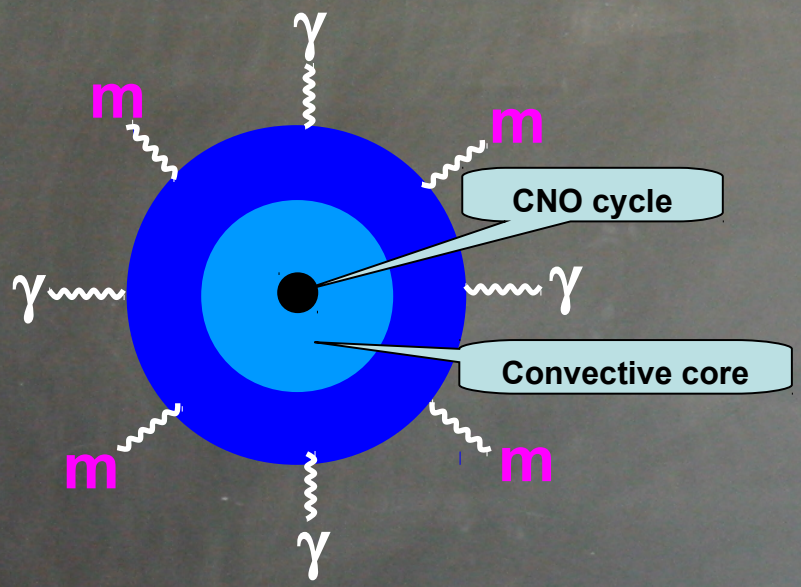
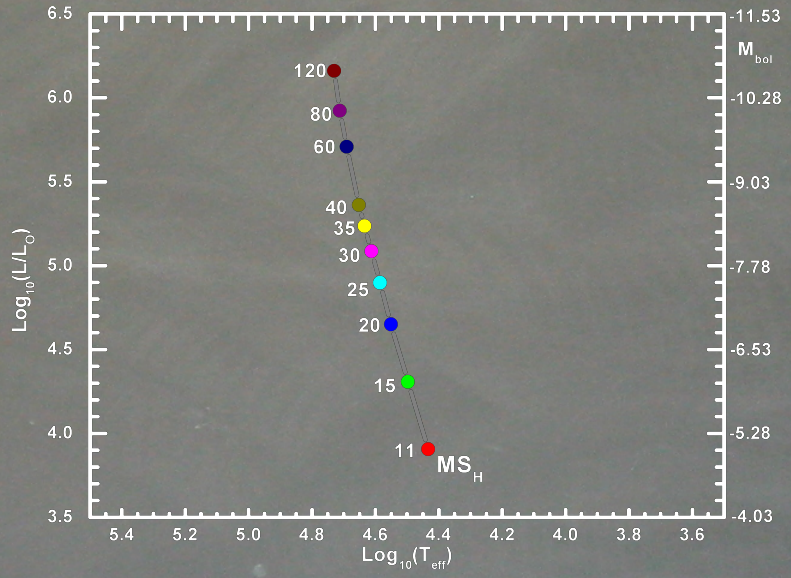
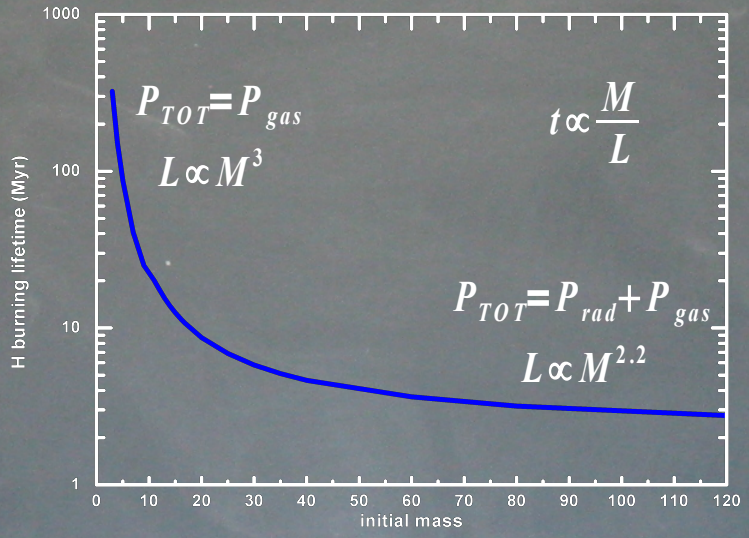
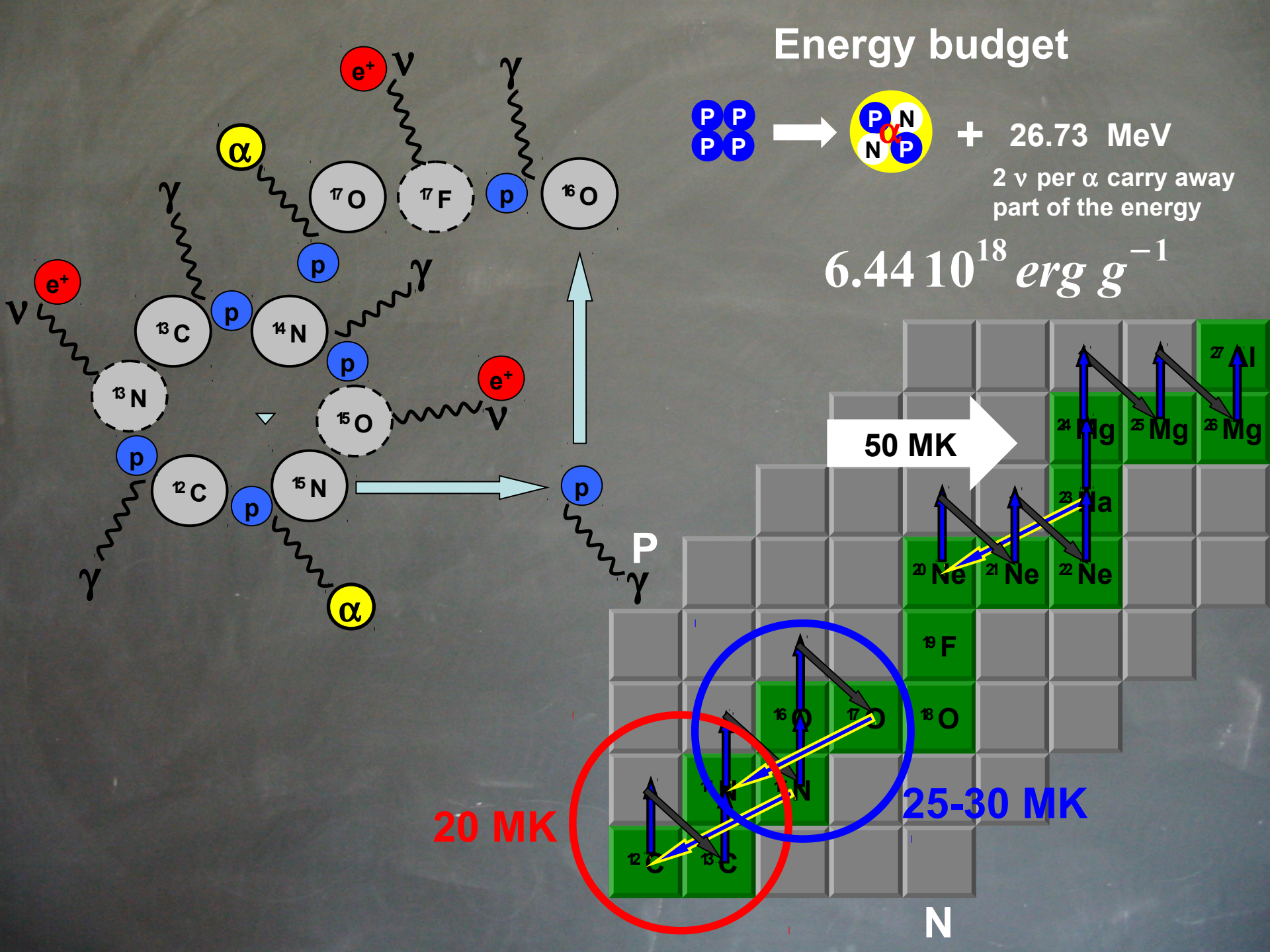
H – burning: luminosity and lifetime



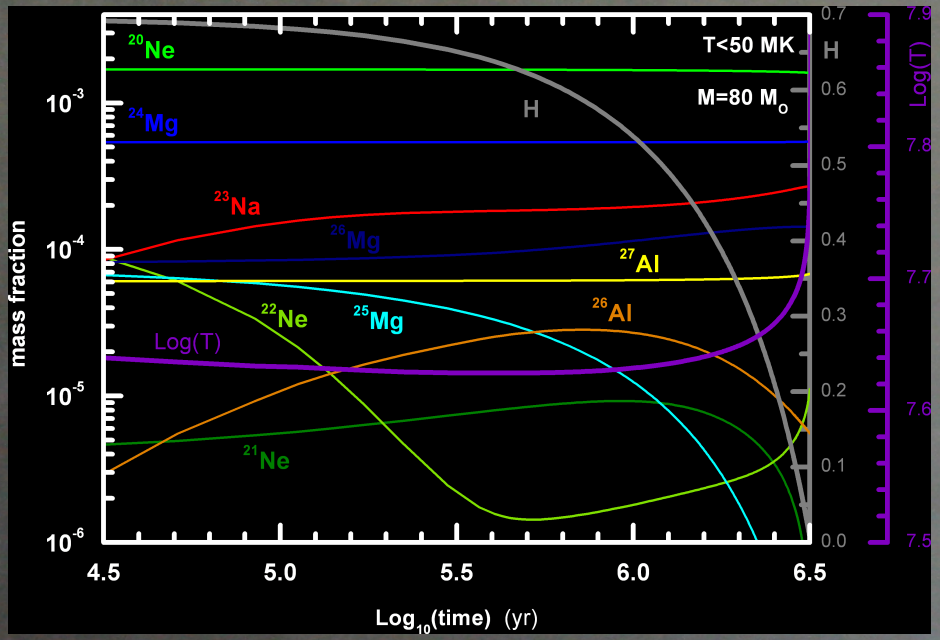


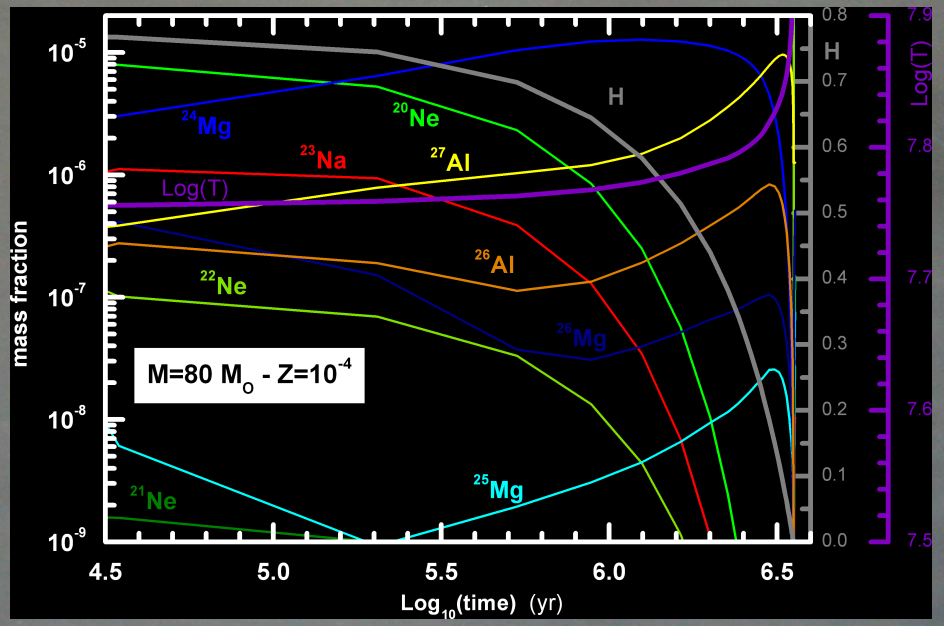


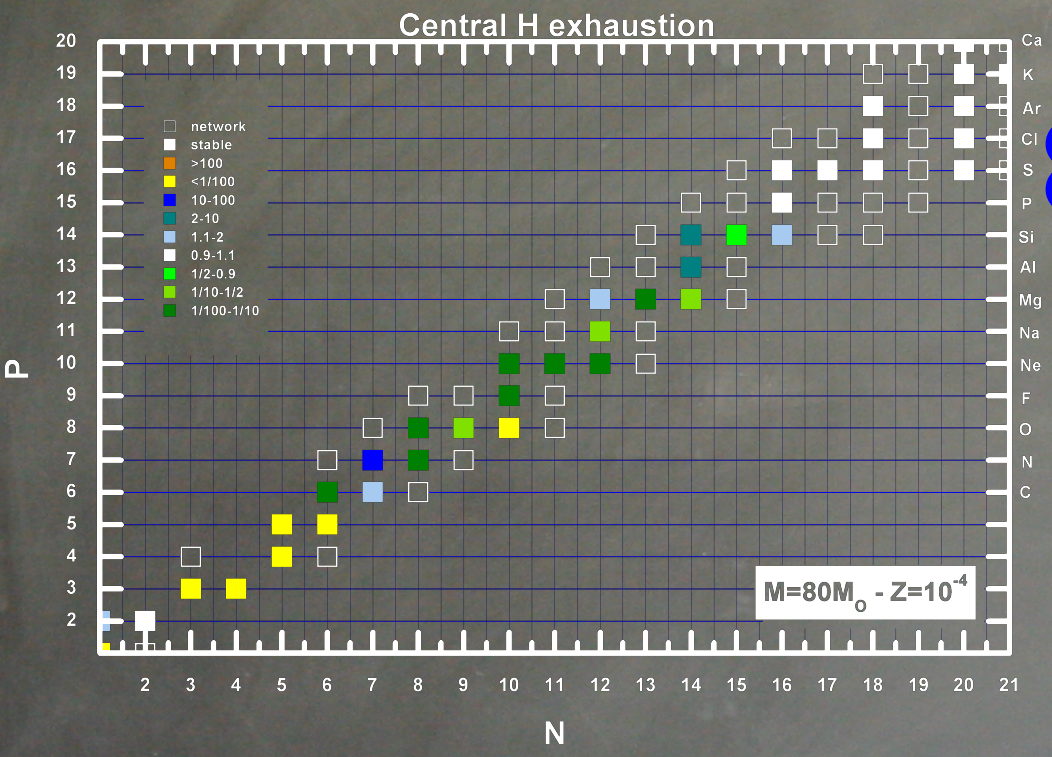

Energy budget
P P P P
P N N P
+ 26.73 MeV
2 ν per α carry away part of the energy
$6.44\,10^{18}\ erg\ g^{-1}$
e+
ν
γ
α
p
P
17O
17F
16O
13C
14N
13N
15O
12C
15N
50 MK
20 MK
25-30 MK
N
27Al
24Mg
25Mg
26Mg
23Na
20Ne
21Ne
22Ne
19F
18O
16O
17O
14N
12C
13C

Trailer time!

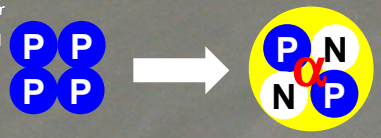
H burning movie


T<50 MK
M=80 M$_o$
^{20}Ne
^{24}Mg
H
^{23}Na
^{26}Mg
^{27}Al
^{22}Ne
^{25}Mg
^{26}Al
Log(T)
^{21}Ne
mass fraction
Log$_{10}$(time) (yr)
H
Log(T)


M=80 M$_o$ - Z=10^{-4}
^{24}Mg
^{20}Ne
^{23}Na
^{27}Al
H
Log(T)
^{26}Al
^{22}Ne
^{26}Mg
^{25}Mg
^{21}Ne
mass fraction
Log$_{10}$(time) (yr)
H
Log(T)



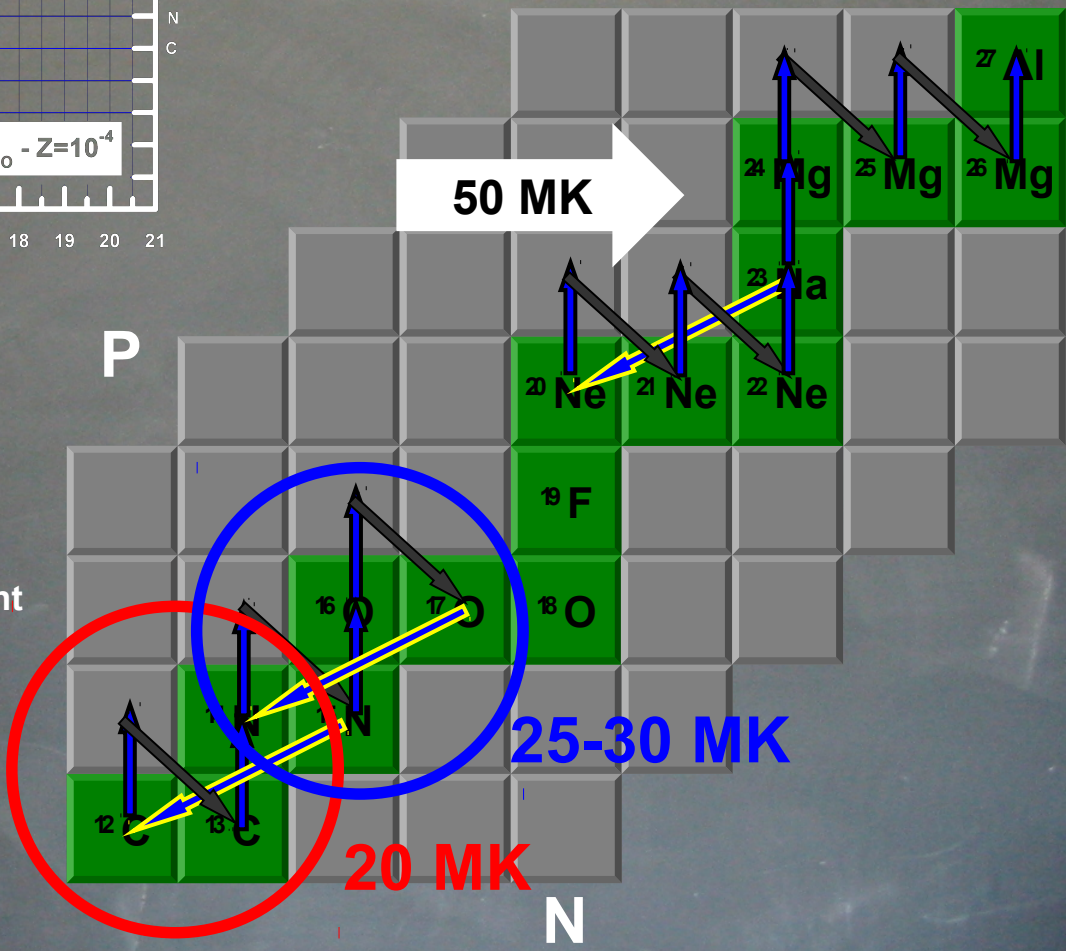
Energy budget



+ 26.73 MeV

2 ν per α carry away part of the energy

$$6.44\,10^{18}\ erg\ g^{-1}$$



Basic effects of the H burning on the elemental abundances:

H converted in He (strong neutronization)

O & C converted in N (becomes the most abundant element after H and He!)

Redistribution among Ne – Na – Mg – Al

F destroyed

H – burning: mass loss

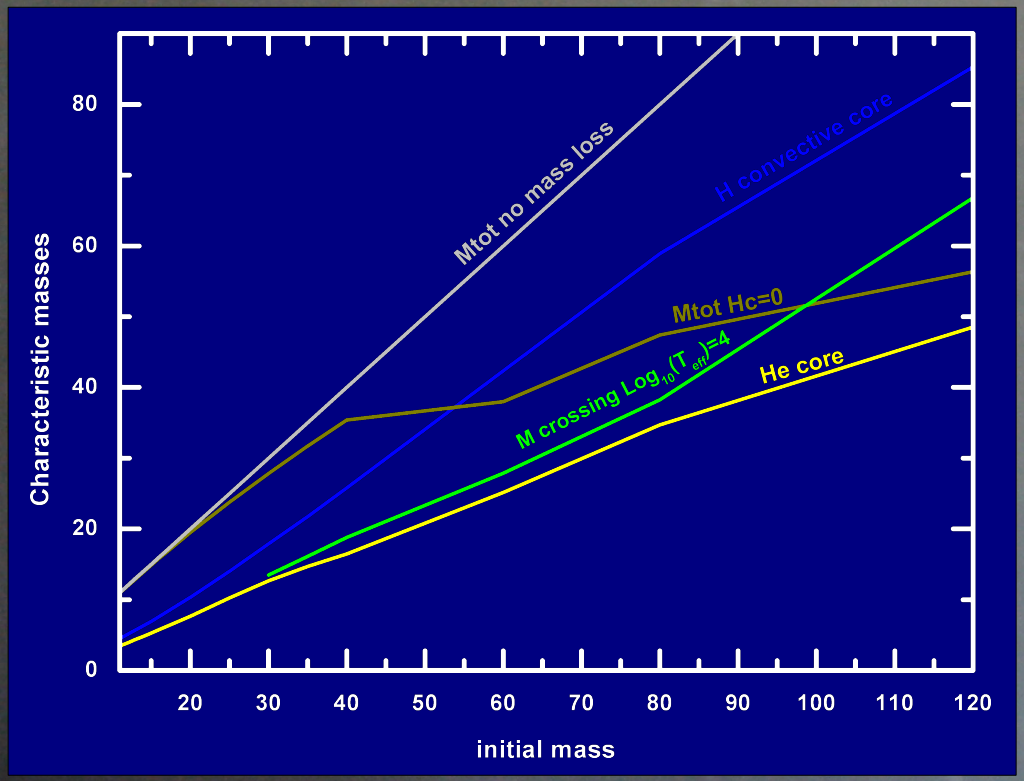
Astron. Astrophys. 362, 295–309 (2000)

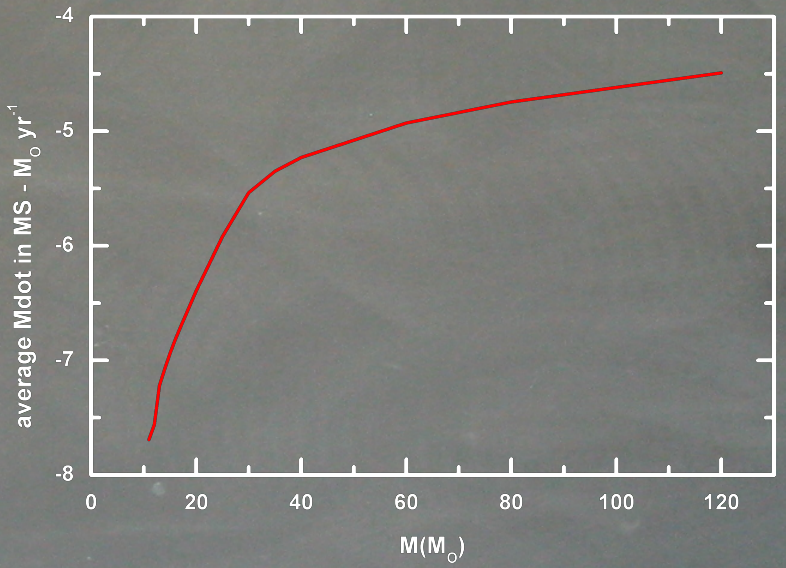
ASTRONOMY AND ASTROPHYSICS

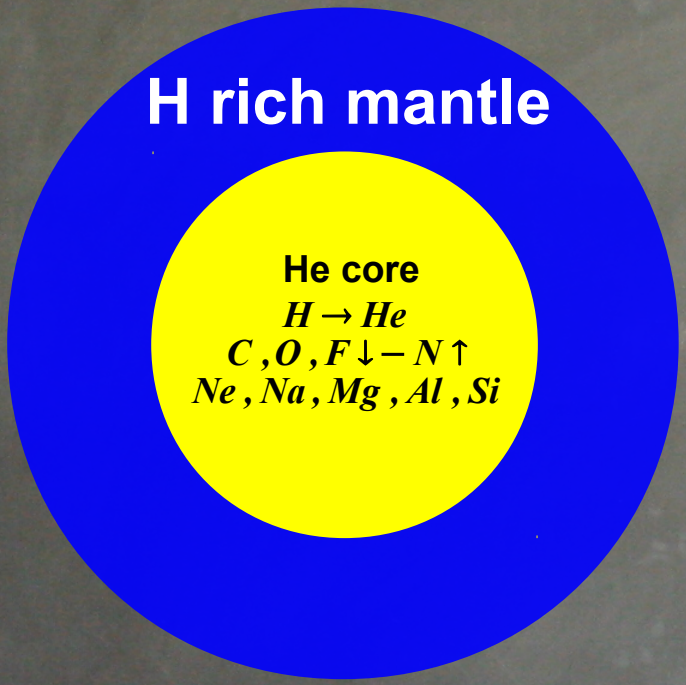
New theoretical mass-loss rates of O and B stars

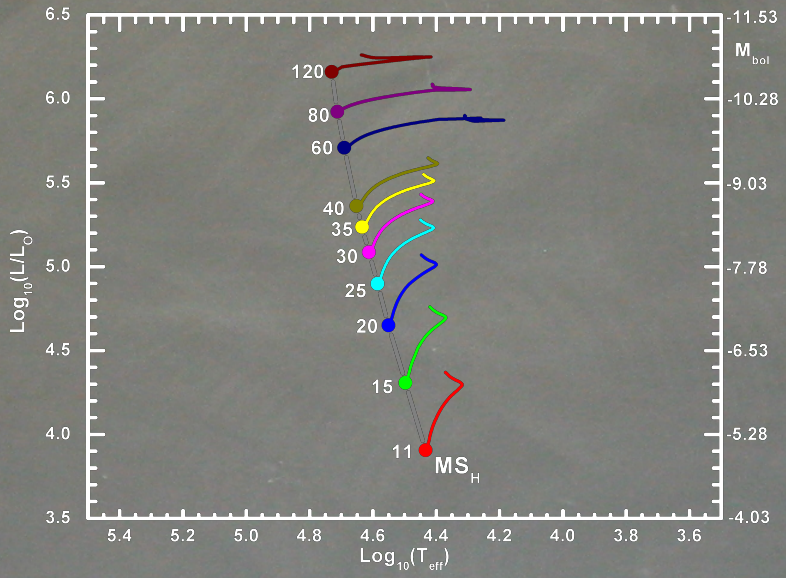
J.S. Vink[1], A. de Koter[2], and H.J.G.L.M. Lamers[1,3]

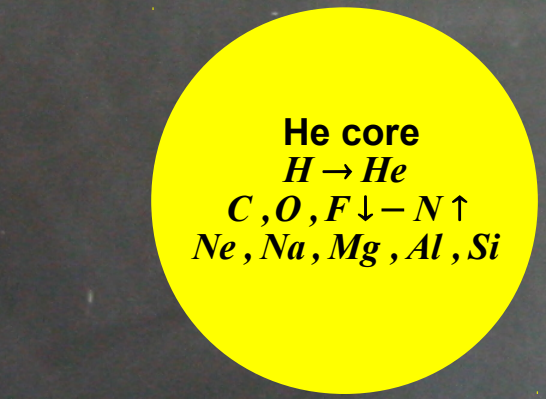
$$\dot{M}\,(\text{O B stars}) \propto \frac{L^{2.2}}{M^{1.3}} \;\&\; (T_{eff}\,,\; V_{inf} / V_{esc})$$

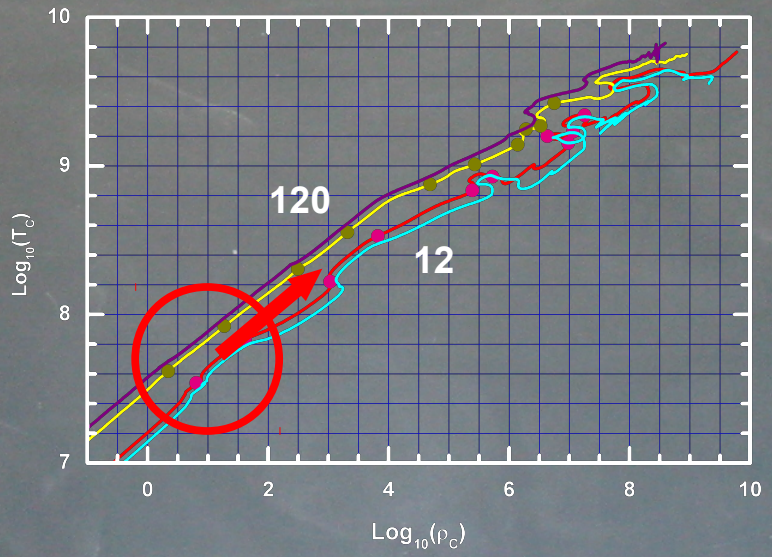




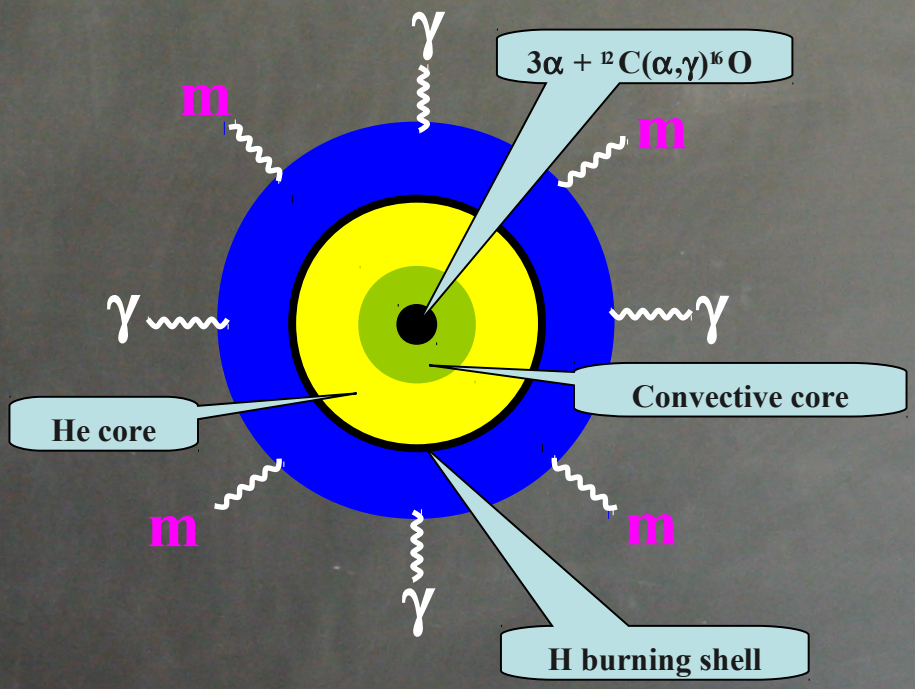

H rich mantle
He core
H → He
C , O , F ↓ – N ↑
Ne , Na , Mg , Al , Si


120
80
60
40
35
30
25
20
15
11
MS_H
M_bol
-11.53
-10.28
-9.03
-7.78
-6.53
-5.28
-4.03
6.5
6.0
5.5
5.0
4.5
4.0
3.5
Log10(L/L⊙)
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
Log10(Teff)


He core
H → He
C , O , F ↓ – N ↑
Ne , Na , Mg , Al , Si


120
12
10
9
8
7
Log10(Tc)
0
2
4
6
8
10
Log10(ρc)

The central He burning



All stars form a convective core

The physical evolution of the star requires the inclusion of just 2 processes:

$$\alpha(2\alpha,\gamma)^{12}C \quad \text{and} \quad {}^{12}C(\alpha,\gamma)^{16}O$$

The chemical evolution of the star requires the inclusion of many, many processes because an efficient n producing chain activates:

$$^{14}N(\alpha,\gamma)^{18}F(\beta^{+})^{18}O(\alpha,\gamma)^{22}Ne(\alpha,n)^{25}Mg$$

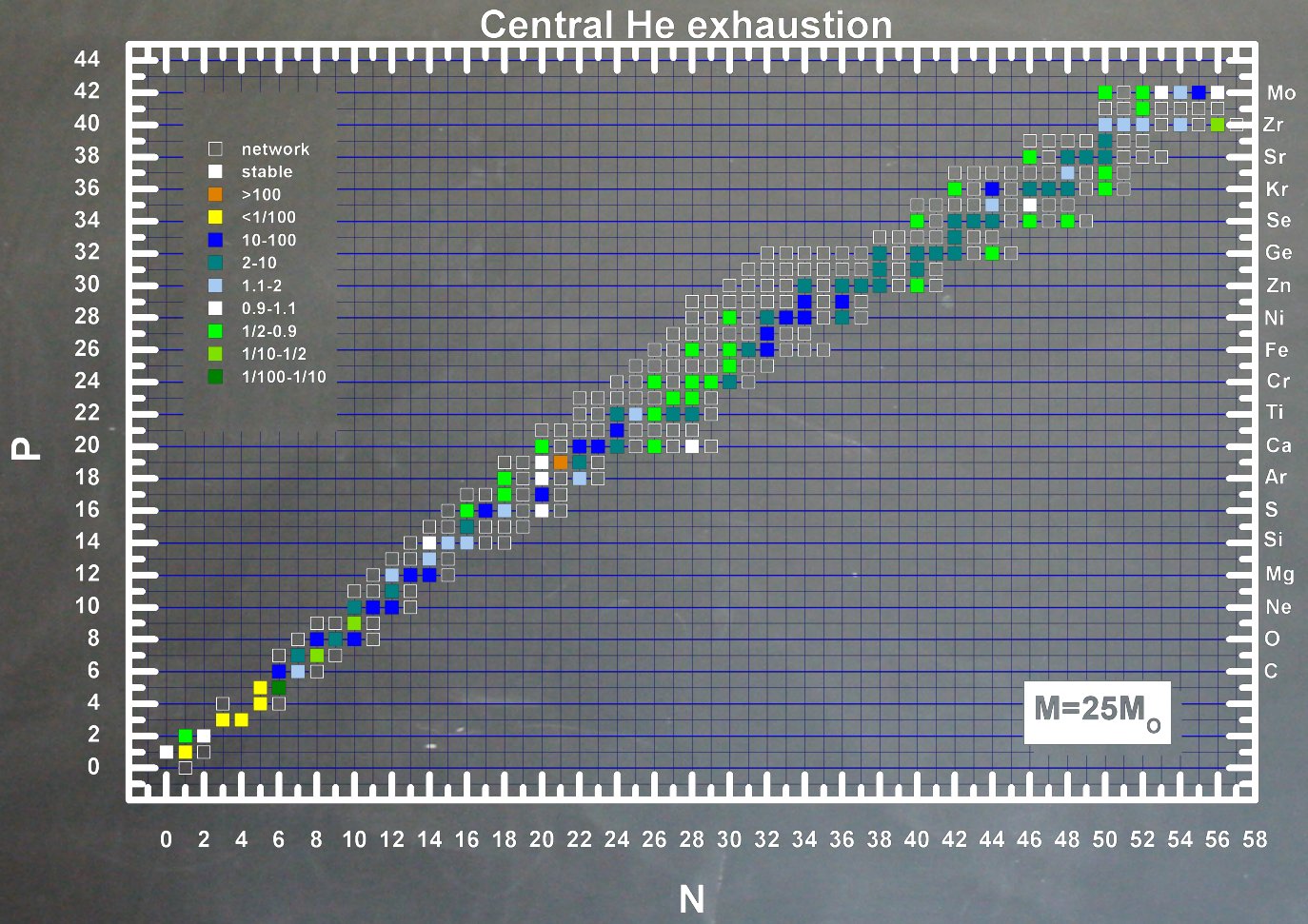
Note that the ^{14}N abundance is roughly equal to the initial abundance of the sum of the CNO nuclei that are more than 70% of the initial metallicity of the star!

Trailer time!

He burning movie

The central He burning

The n emitted by the ^{22}Ne(a,n)^{25}Mg process are mainly captured by the Fe peak nuclei so that nuclei up to A=90 (S weak-component) are produced



The central He burning

Note that the stars are not any more an homogeneous group !

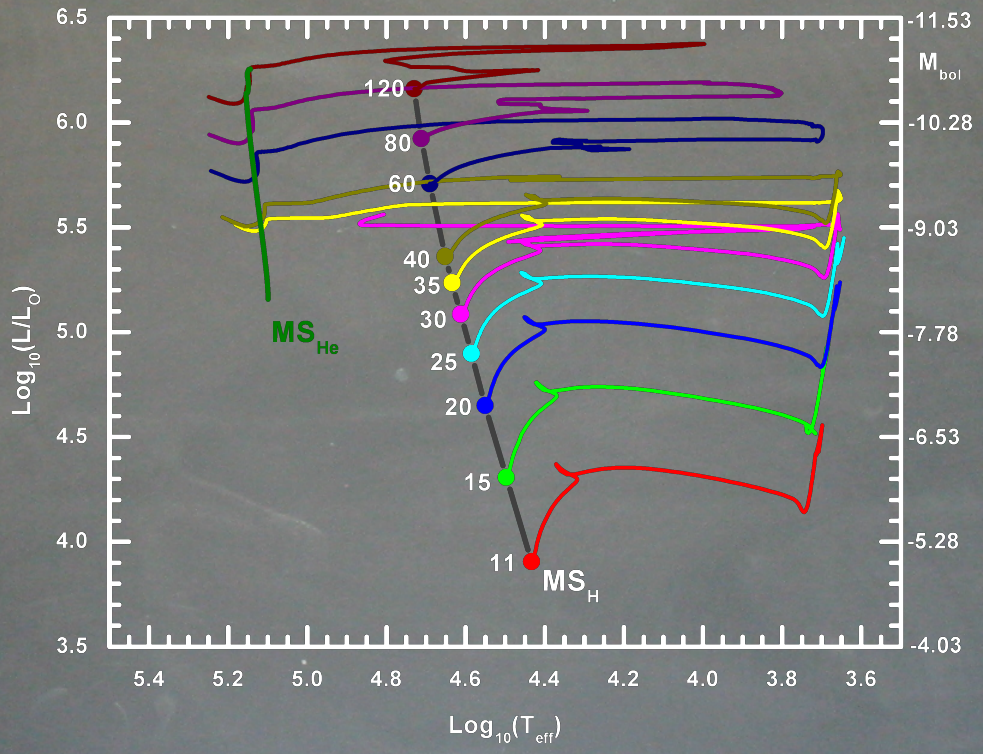
Two different groups:

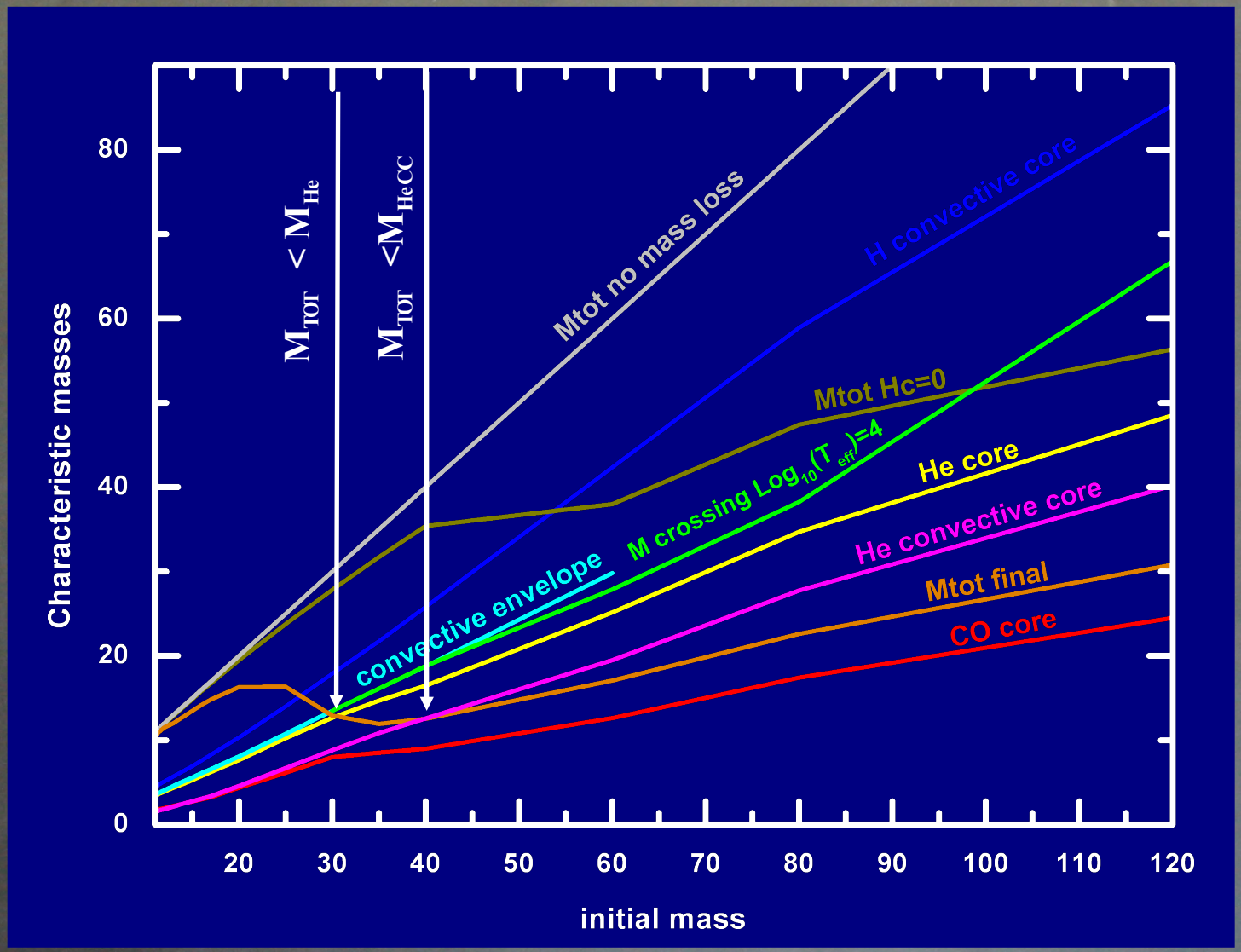
$$M < 60\ M_O < M$$

ignite He as RSG — He burnt as WR stars

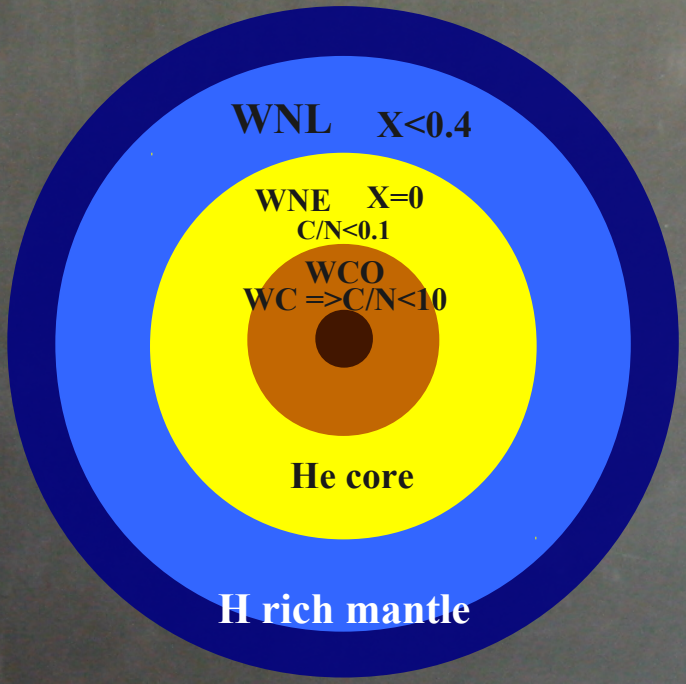
$$M < 25\ M_O < M$$

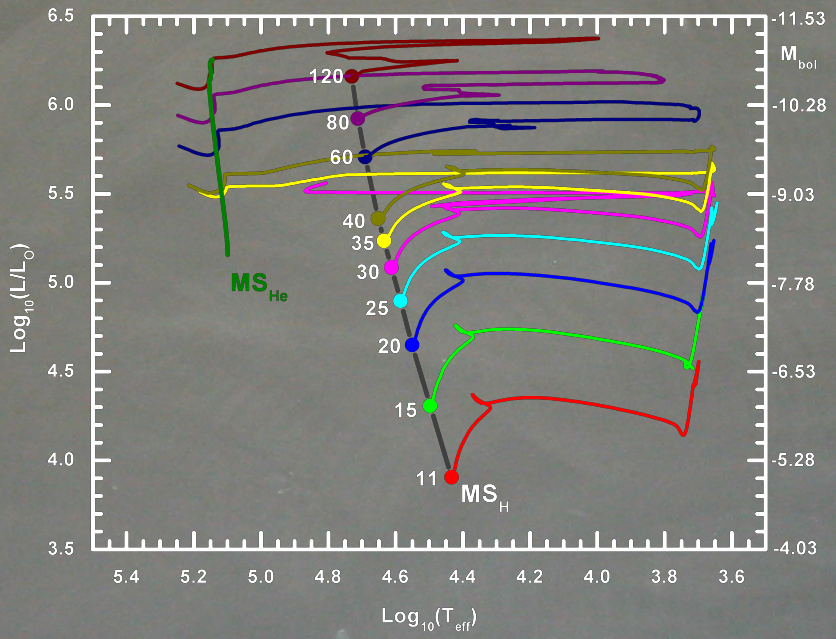
always RSG — partly as RSG, partly as WR stars

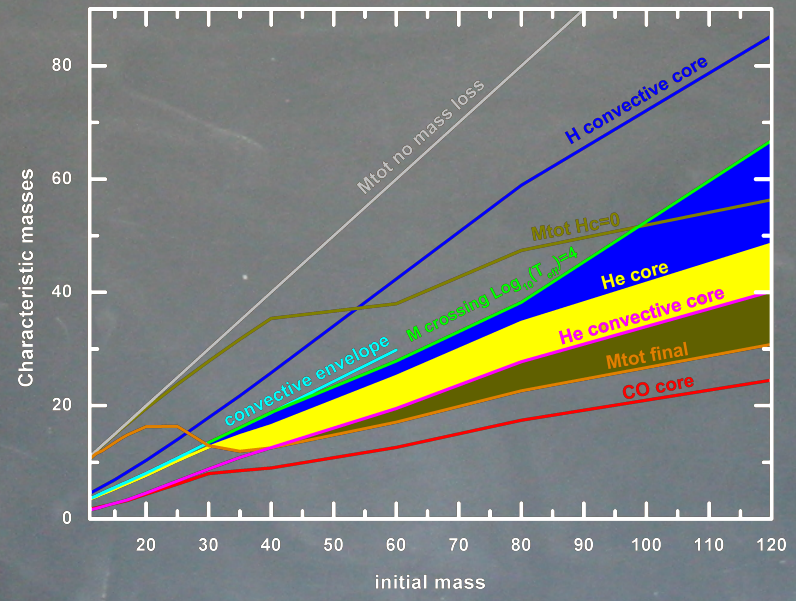


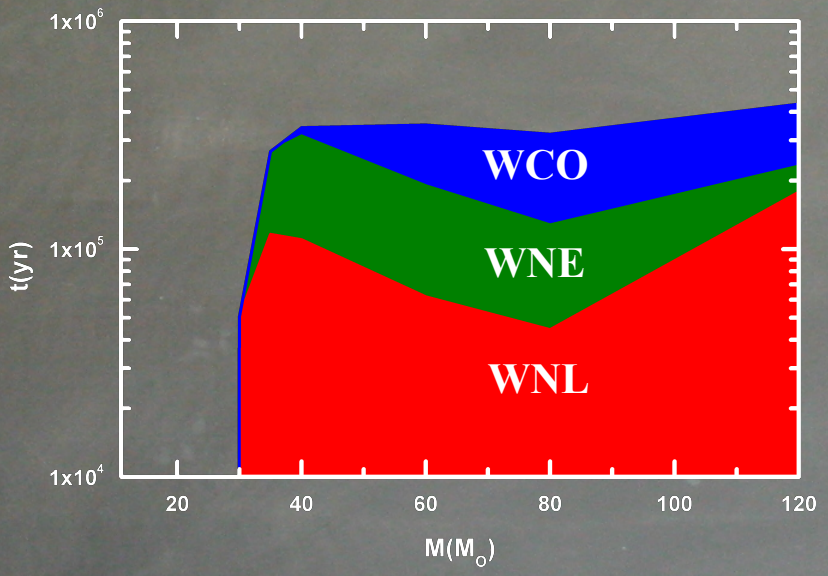

Characteristic masses
initial mass
0
20
40
60
80
20
30
40
50
60
70
80
90
100
110
120
$M_{TOT} < M_{He}$
$M_{TOT} < M_{HeCC}$
Mtot no mass loss
H convective core
Mtot Hc=0
M crossing $Log_{10}(T_{eff})=4$
He core
He convective core
convective envelope
Mtot final
CO core

$Log_{10}(T_{eff})>4.0$









Summarizing:

RSG	< 30 M_O <	RSG	< 40 M_O <	RSG	< 60 M_O <	WNL
		WNL		WNL		WNE
		WNE		WNE		WCO
				WCO		