How well do we know oxygen yields from massive stars?

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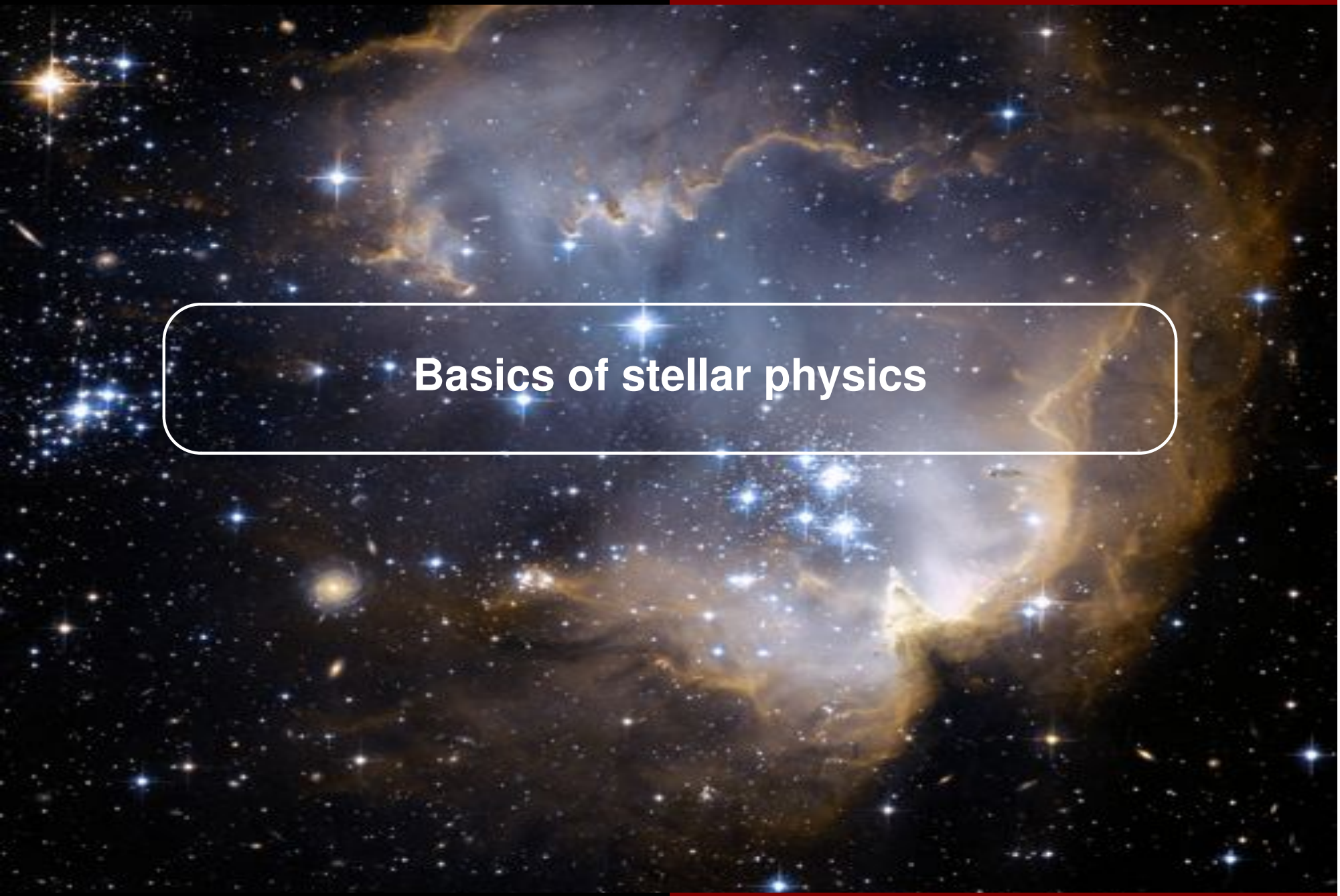
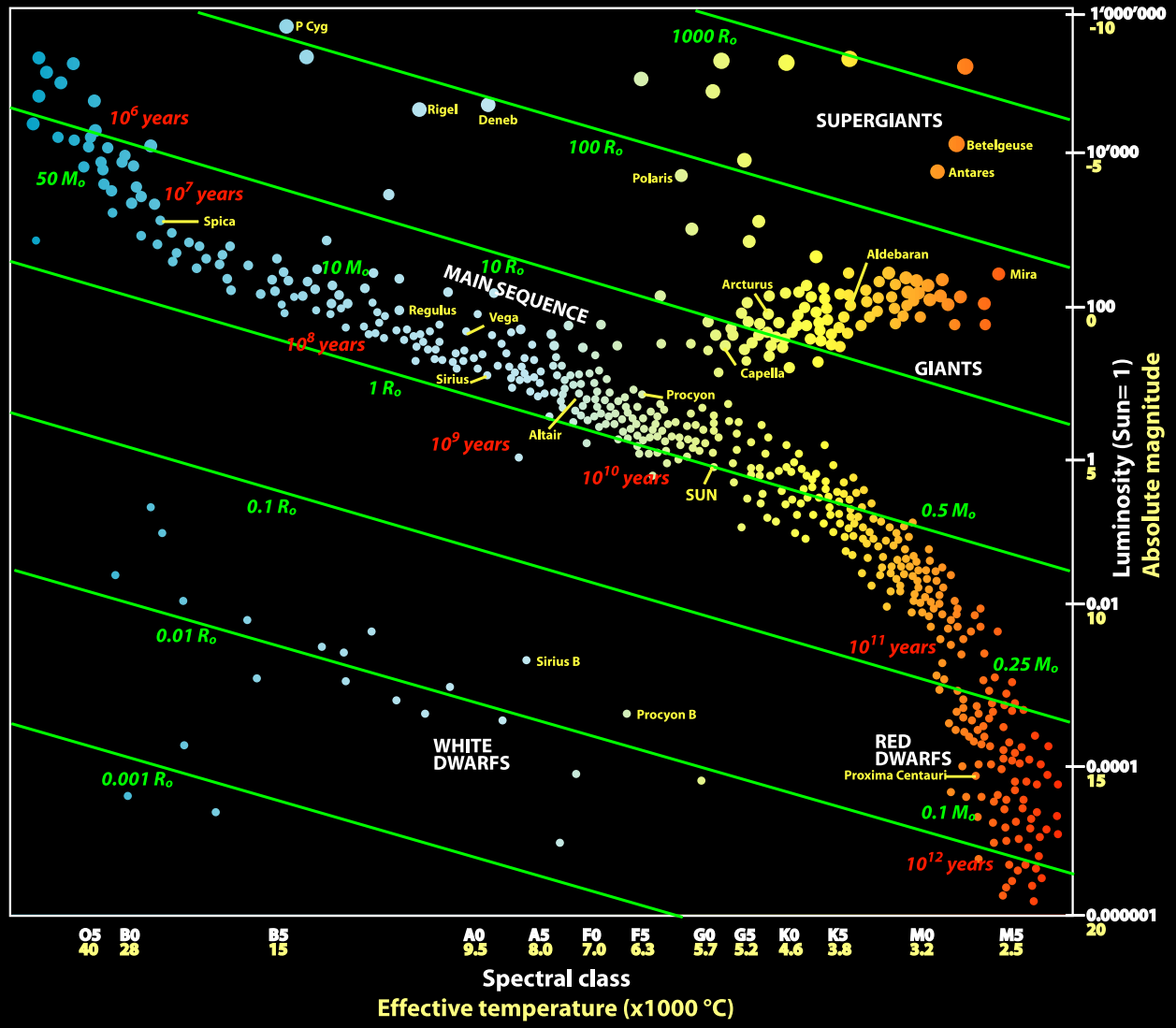
Mapping oxygen in the Universe
14-18 May 2012

Outline



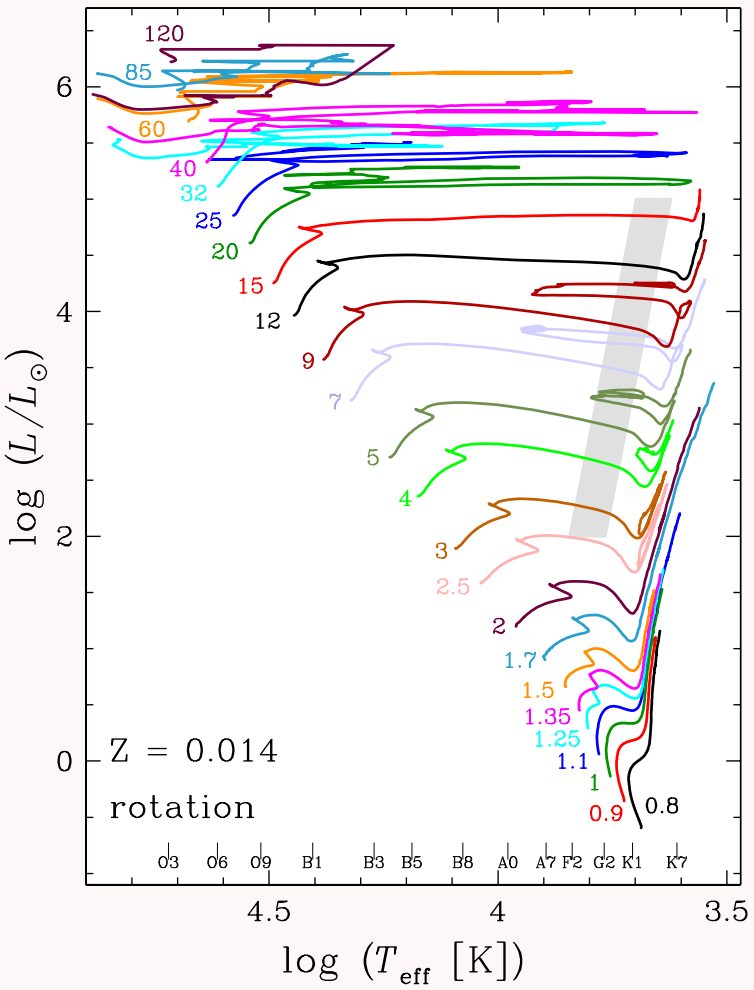
Basics of stellar physics

Stellar characteristics



Stellar characteristics

models from Ekström et al. (2012)



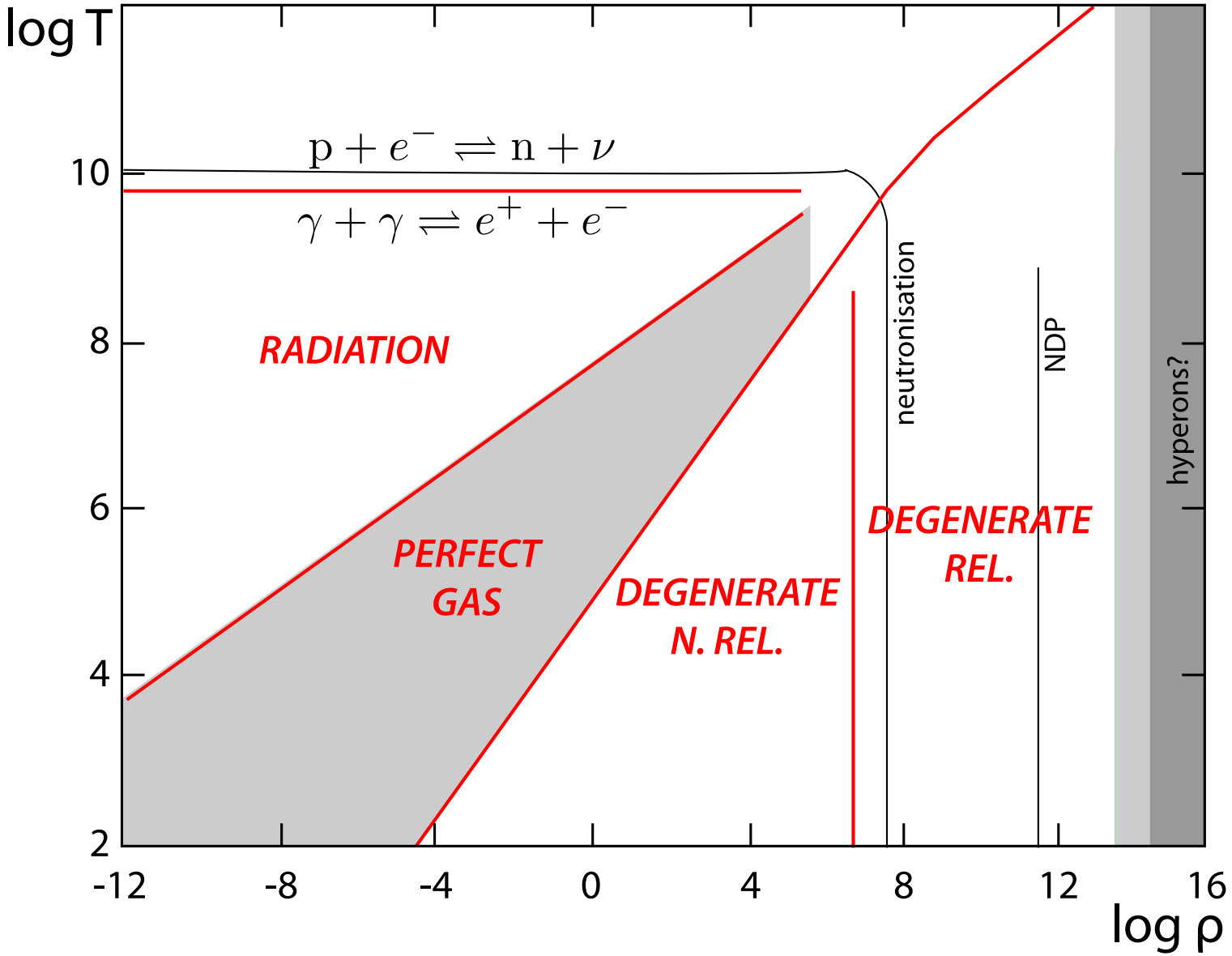
mass-luminosity relation: $L \propto M^3$

L comes from the maintaining of hydrostatic equilibrium

its duration comes from the energy generation in the core:

$$\tau = \frac{E}{L} \propto \frac{Mc^2}{M^3} \propto M^{-2}$$

Stellar characteristics



Stellar characteristics

2 basic structure equations:

$\frac{dM_r}{dr} = 4\pi r^2 \rho$ mass conservation

$\frac{dP}{dr} = -\frac{GM_r}{r^2}\rho$ hydrostatic equilibrium

combining them we get:

$$\Delta \ln P = \frac{4}{3}\Delta \ln \rho$$

using a standard EOS in the form:

$$\Delta \ln \rho = \alpha \Delta \ln P - \delta \Delta \ln T$$

we end up with:

$$\Delta \ln T = \left(\frac{4\alpha - 3}{3\delta}\right) \Delta \ln \rho$$

PG: $\alpha = \delta = 1$

$\rightarrow \quad \Delta \ln T = \frac{1}{3}\Delta \ln \rho$

in that case:

stable hydrostatic burning

if an excess energy is produced:

$T \nearrow \Rightarrow P \nearrow \Rightarrow$ expansion

virial: $E_{pot} \nearrow \Rightarrow E_{int} \searrow$

$\Rightarrow T \searrow$

no runaway!

Stellar characteristics

Degenerate case: $\alpha = 3/5,\ \delta = 0$

$P \propto \rho^{5/3}$
no dependency with T

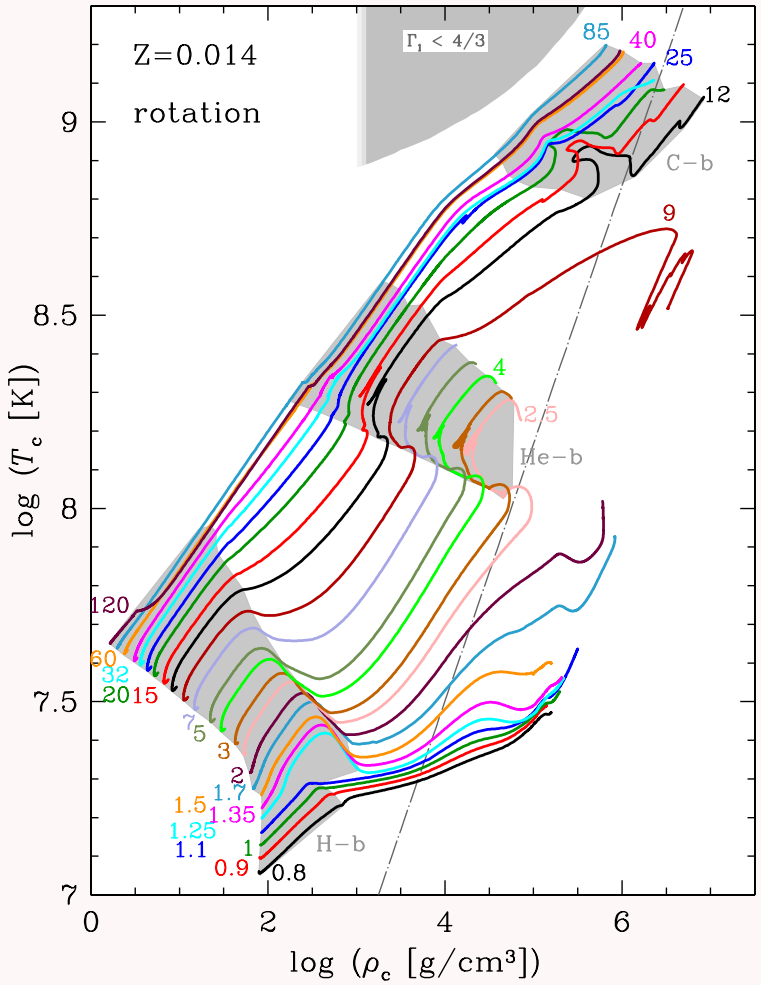
if an excess energy is produced:

$T \nearrow$:
no increase of P, no expansion
reaction rates increase
$\Rightarrow \quad T \nearrow$

runaway!

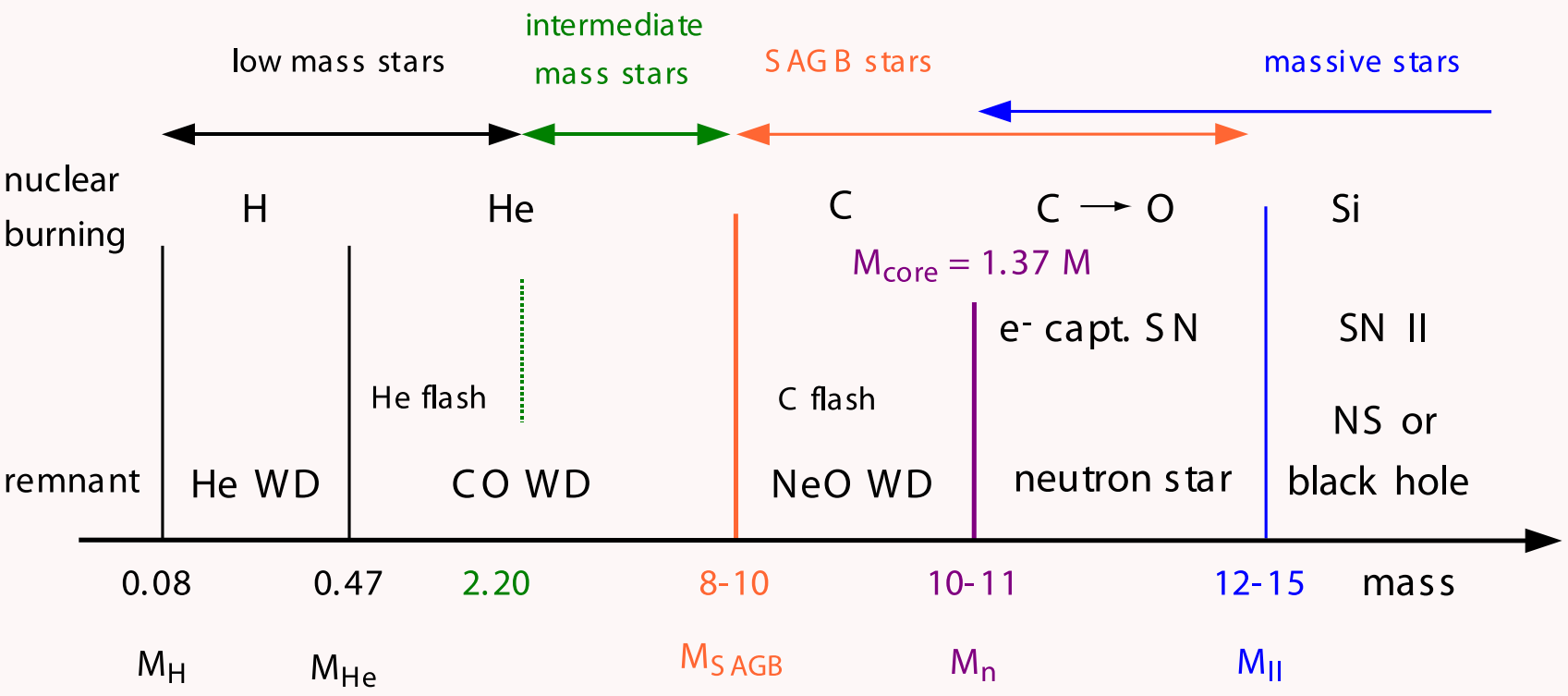
stellar evolution: slope 1/3
degeneracy: slope 2/3

models from Ekström et al. (2012)



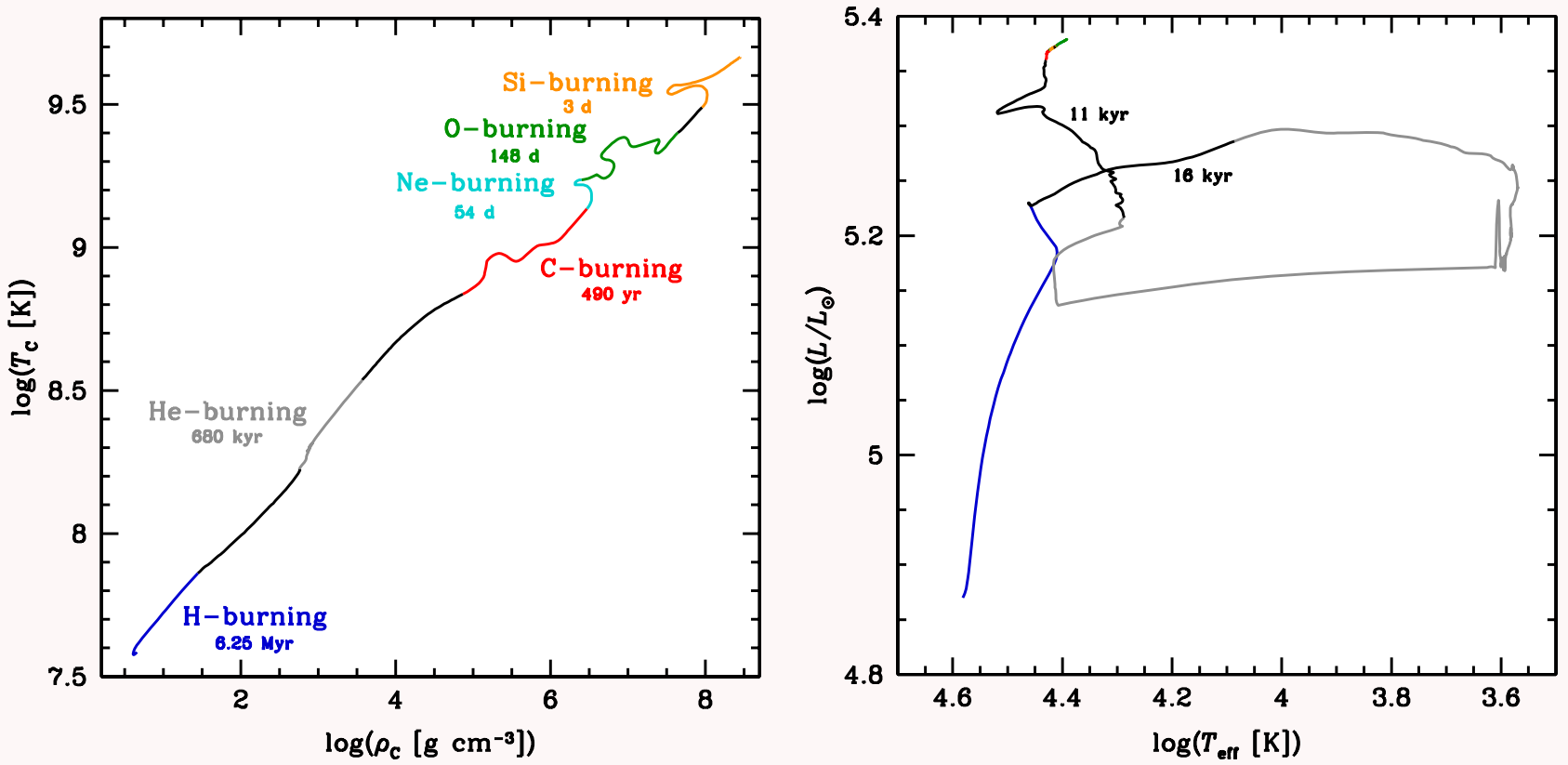
The evolution depends on the initial mass

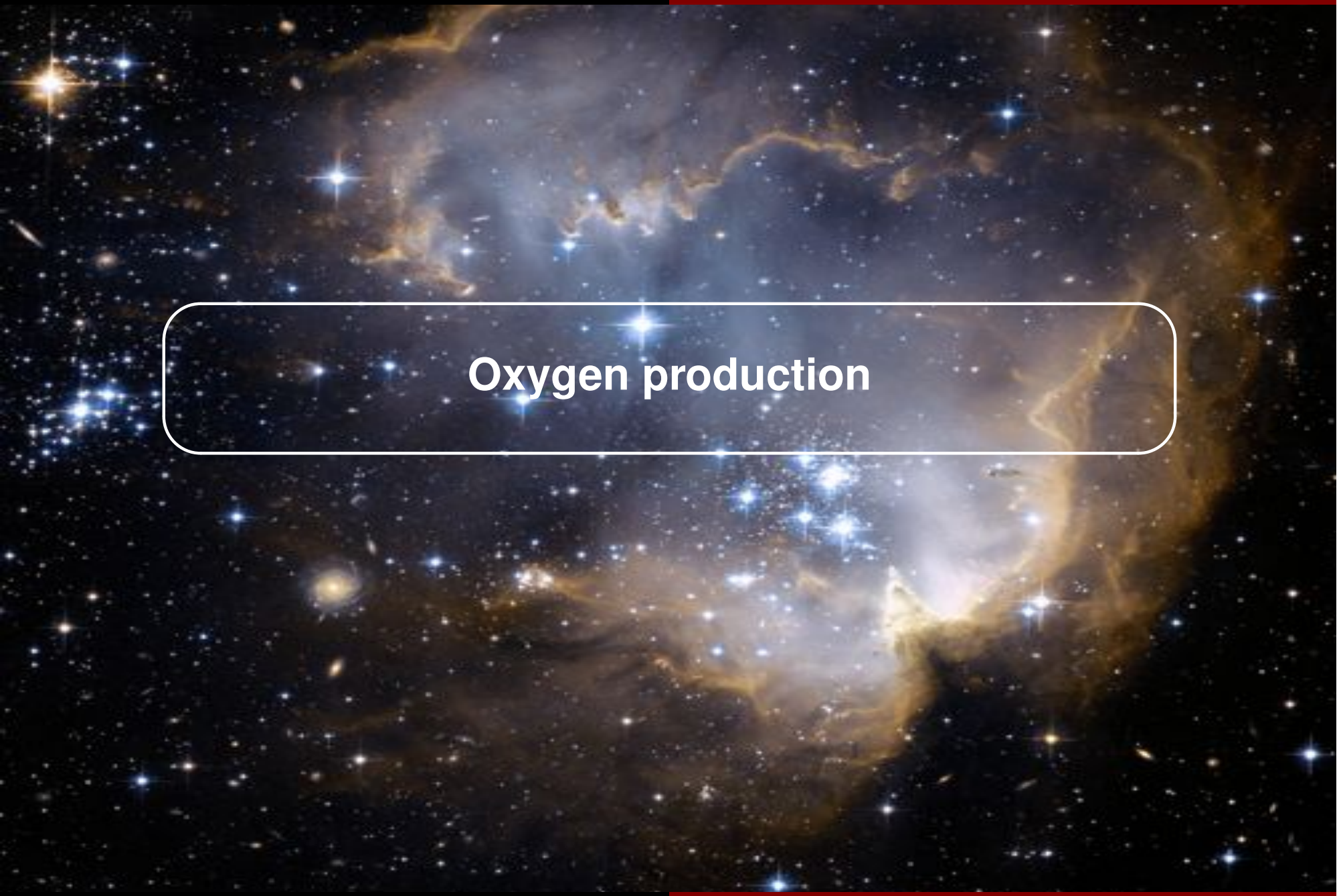
from Siess (2008)



Hydrostatic nuclear-burning phases

fig. courtesy C. Georgy — *25 $M_\odot$ at Z = 0.020*





Oxygen production

^{16}O production

global behaviour

- H-b: destruction in the CNO-II cycle
  ^{16}O(p,γ)^{17}F(β)^{17}O(p,α)^{14}N
- He-b: large production
  ^{12}C(α,γ)^{16}O
- C-b: destruction
  ^{16}O(α,γ)^{20}Ne
- Ne-b: production
  ^{20}Ne(γ,α)^{16}O
- O-b: destruction
  ^{16}O(^{16}O,γ)^{32}S

^{16}O production

note that shell fusions often change these behaviours because of incomplete burning

overall:

- large production of ^{16}O in massive stars
  full He-b effect
- partial destruction of ^{16}O in low- and intermediate-mass stars
  H-b effect, CNO cycle more or less complete

^{17,18}O production

the heavy isotopes are all transitional elements in the reaction chains:
→ production only in zones of partial burnings

for example, during He-b:

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

- in the core burning
  production of ^{22}Ne, no ^{18}O
- in the shell burning
  the chain stops with the production of ^{18}O

mixing processes can "save" elements from further burning (dredge-up, rotation, . . .)

^{17,18}O production

overall:

- destruction of both ^{17}O and ^{18}O in massive stars ($\gtrsim 20\ M_\odot$)
  advanced burnings effect
- net production of ^{17}O and partial destruction of ^{18}O in low- and intermediate-mass stars
  dredge-up, winds, partial H-b effect

Dependencies and uncertainties of the yields

Sources of variations

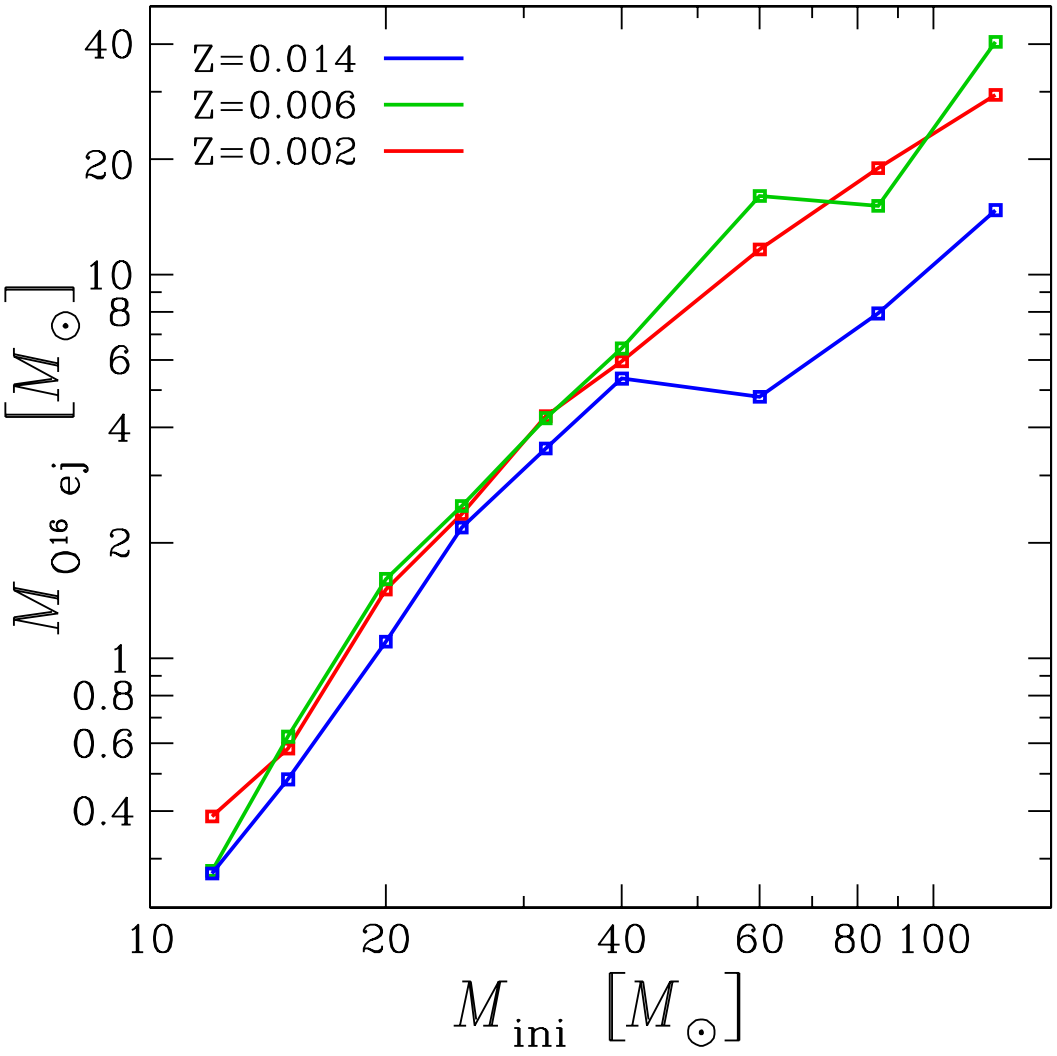
Dependencies

- mass, metallicity
- physics included in the codes
  (treatment of convection, rotation, . . .)
- stage reached at the end of the evolution

Uncertainties

- rates are still not well determined

Mass and metallicity effects



Overshooting, mass loss, binarity

^{16}O yields increase linearly with M_{CO}

enhanced by any mechanism able to increase the core mass

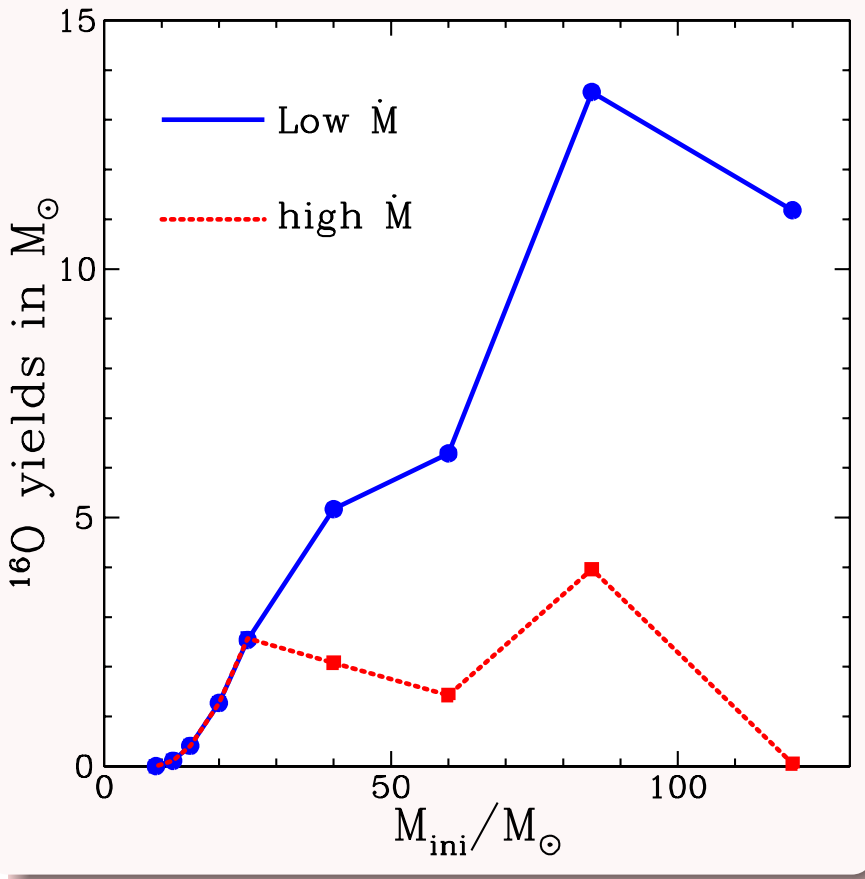
winds remove from further burning the precursors of ^{16}O: He, C

strong winds lower the ^{16}O yields

binarity:
large increase of the CNO yields
Langer (2003)

role of magnetic fields?

adapted from Stasińska et al. (2012)



Rotation effect

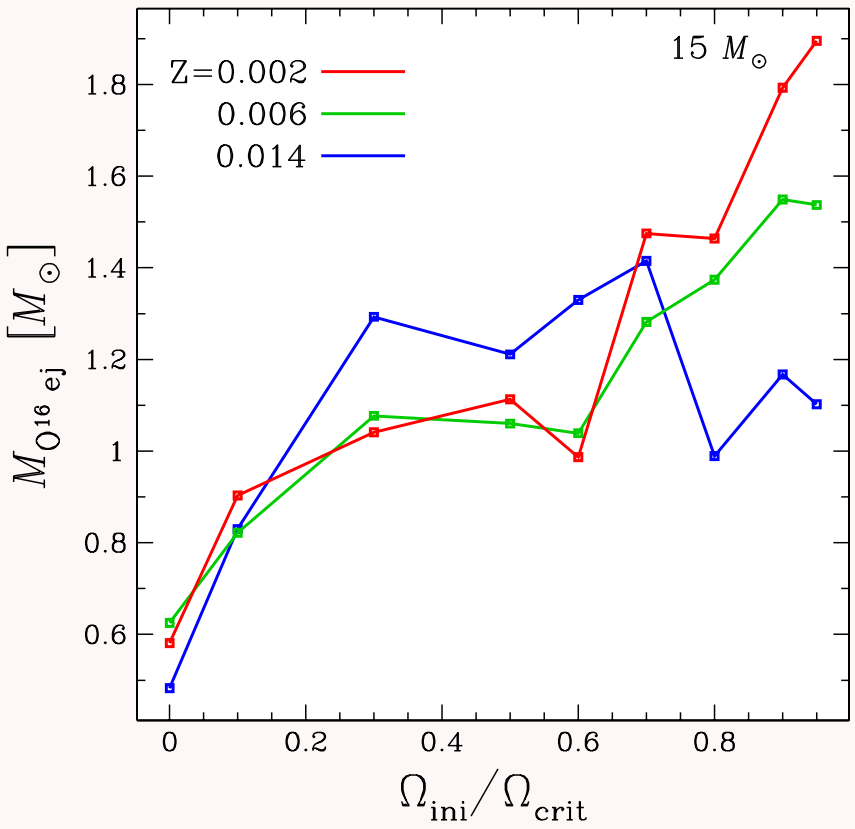
many effects
sometimes contradictory...

- bigger cores
- stronger winds
- mixing

rotation → factor of 2-3

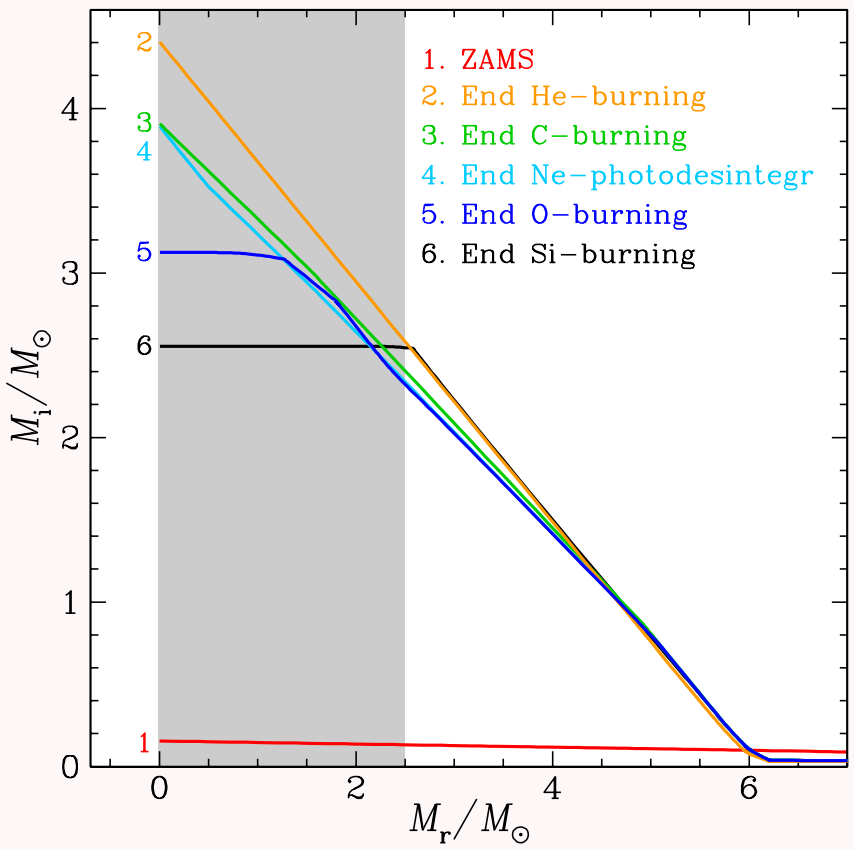
highest yields not necessarily
from the most rapid rotators!

models from Georgy et al. (in prep.)



Evolutionary stage, explosion and mass cut

adapted from Stasińska et al. (2012)



^{16}O mostly produced during He-b and Ne-photodesintegration (core and shell)

destroyed by O-b in parts that will remain locked inside the remnant

not much affected by explosion

Woosley & Weaver (1995)

uncertainty on the mass cut

Generalities

reaction rates are known from laboratory experiments

in the astrophysical range of energy

Gamov window is very low → often not covered by experiments

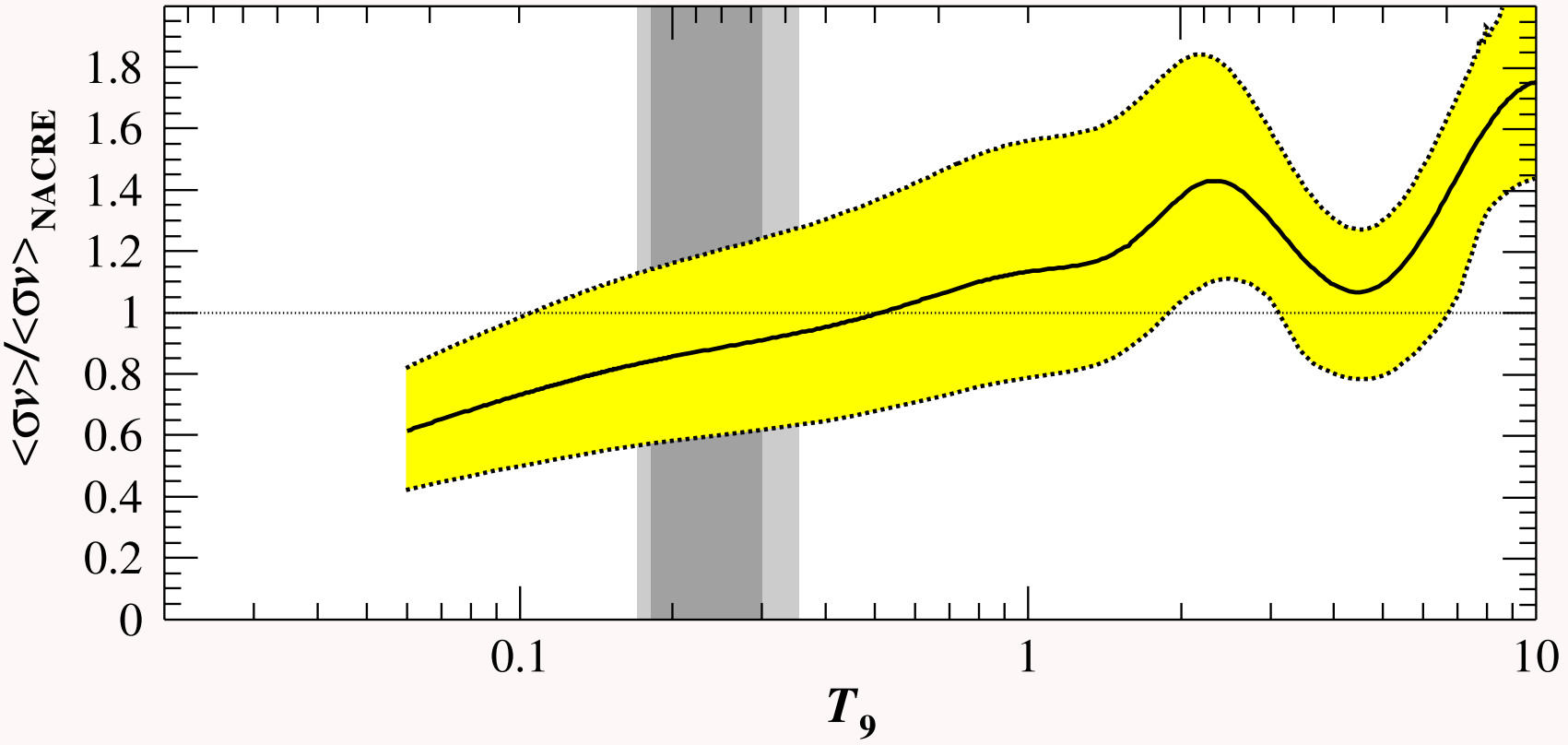
need for:

- indirect measurement
- extrapolation technics

possibility of missing a resonnance

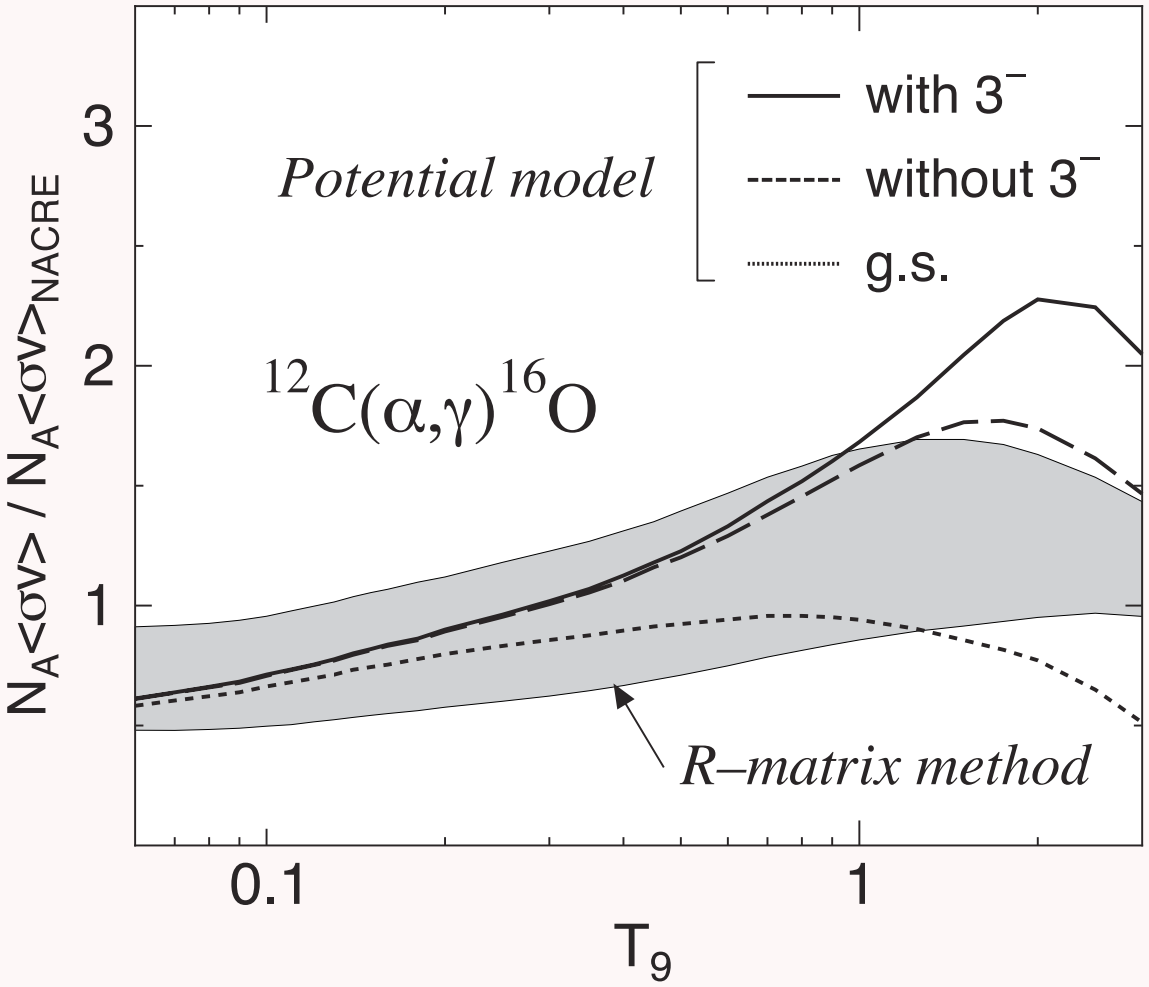
New determinations of the $^{12}C(\alpha,\gamma)^{16}O$ rate

adapted from Kunz et al. (2002)



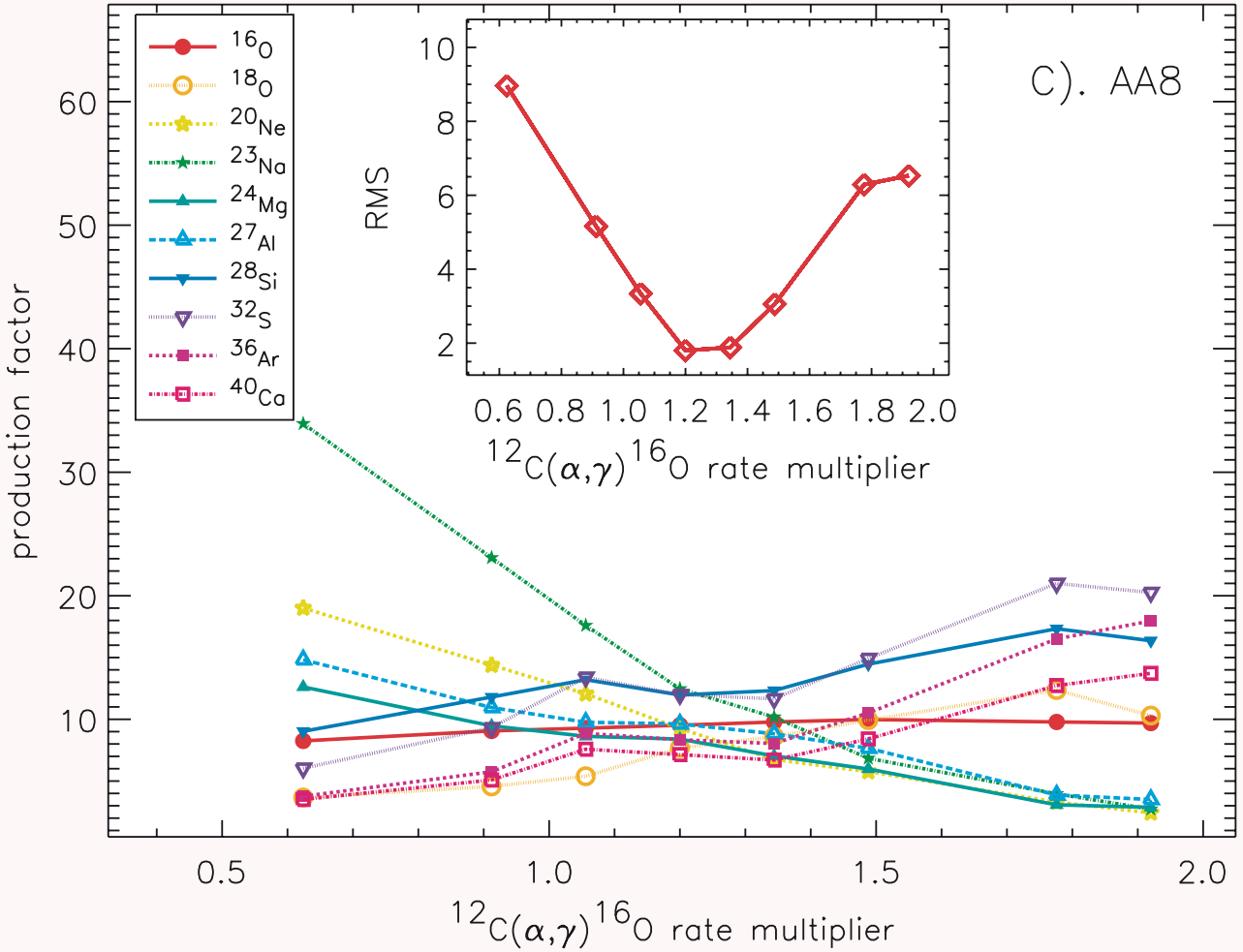
New determinations of the $^{12}C(\alpha,\gamma)^{16}O$ rate

Katsuma (2008)



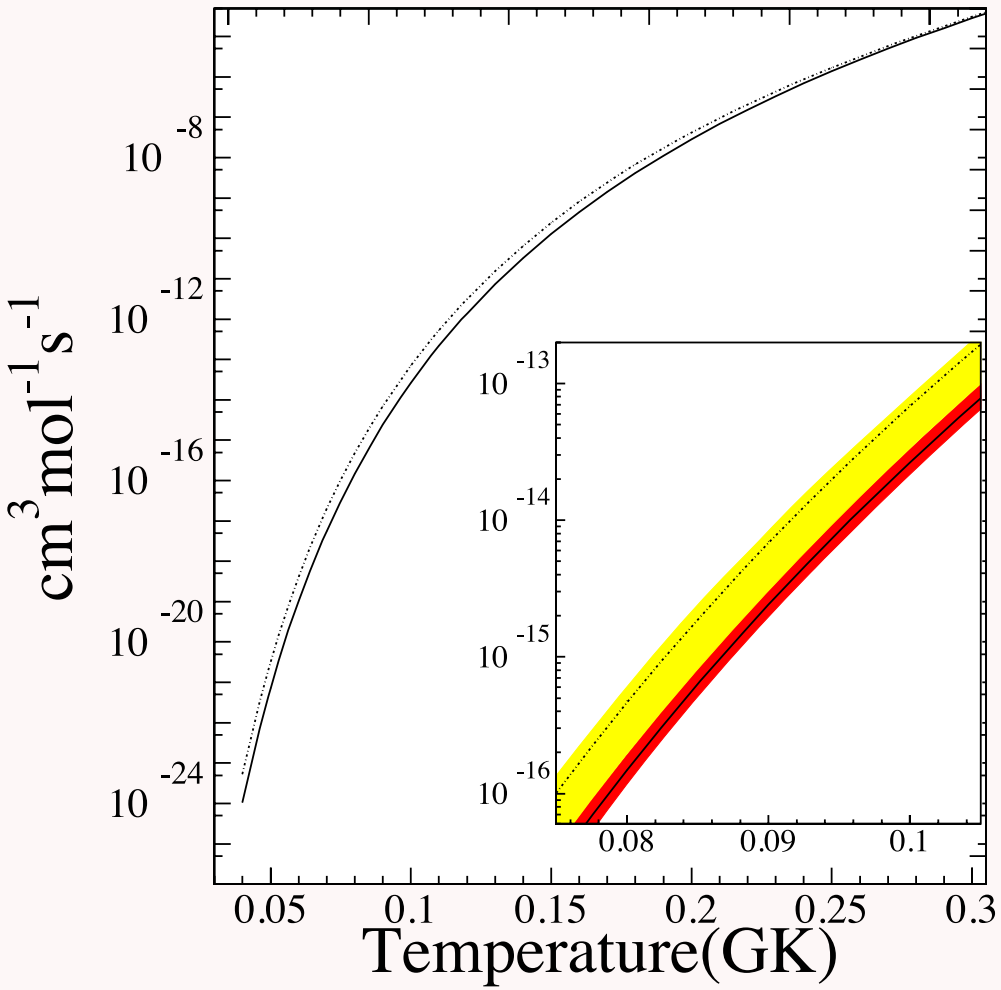
Effects of varying the $^{12}C(\alpha,\gamma)^{16}O$ rate

Tur et al. (2007)



New determinations of the $^{13}C(\alpha,n)^{16}O$ rate

Johnson et al. (2006) *(see also Kubono et al., 2003)*



Other revised rates

- ^{15}N(p,γ)^{16}O: *Mukhamedzhanov et al. (2008)*
- ^{14}N(α,γ)^{18}F: *Görres et al. (2000)*
- ^{17}O(p,α)^{14}N: *Chafa et al. (2007); Newton et al. (2007)*
- ^{17}O(p,γ)^{18}F: *Chafa et al. (2007); Fox et al. (2005)*
- ^{18}O(p,α)^{15}N: *La Cognata et al. (2008)*
- ^{18}O(α,γ)^{22}Ne: *Dababneh et al. (2003)*

probably some more soon . . .

Conclusions

some unavoidable uncertainties:

- direct measurements of the rates are often out of reach
- stellar physics is limited by our current knowledge and understanding

observational constraints are highly needed!

- WR stars abundances *Crowther (2007)*
- SN survivor secondary *González Hernández et al. (2008)*

THANK YOU FOR YOUR ATTENTION !

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