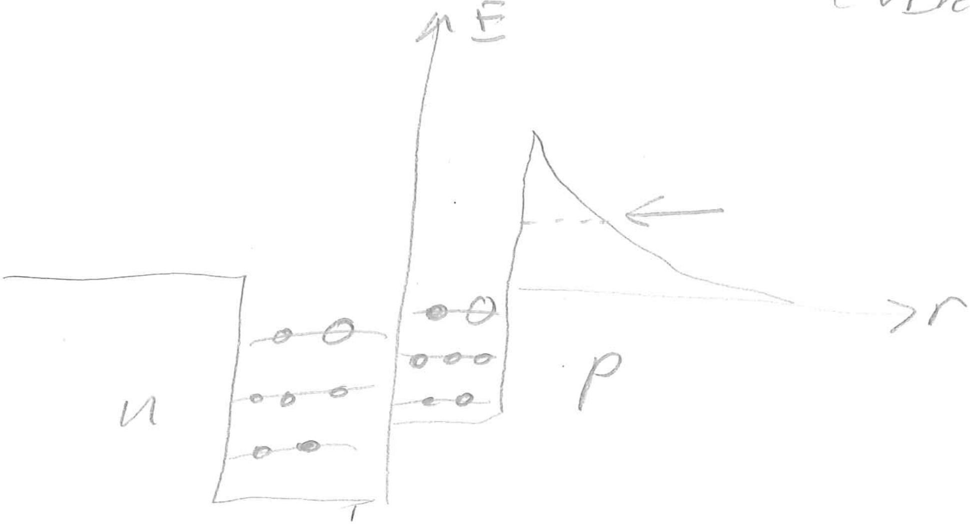
20160316-1

Thermonuclear Reactions

(VERY BRIEF)

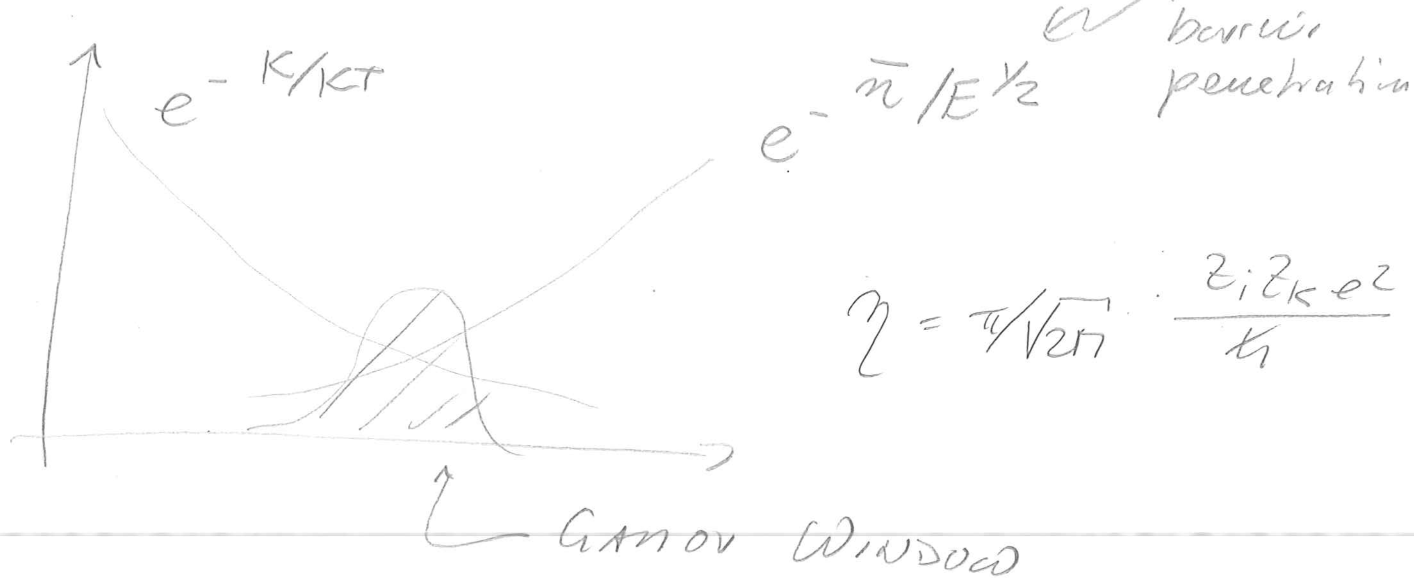


typical $E = k_B T \ll E_B$

Q: so, how can we have reactions?
- high-E tail of distribution
- tunnelling (QM)

NOTE: SCREENING @ high ρ

QUANTITATIVE:



$\eta = \pi/\sqrt{2m} \cdot \frac{z_i z_k e^2}{\hbar}$

→ compute reaction rate $\langle \sigma v \rangle$

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Reactions often parametrised using astrophysical S-factor:

$$S(E) = \sigma(E) \cdot E \cdot e^{2\pi\eta} \quad \text{such that}$$

$$N_A \langle \sigma v \rangle = \left(\frac{8}{\pi m}\right)^{1/2} \frac{N_A}{(k_B T)^{3/2}} \int_0^\infty e^{-2\pi\eta} S(E) e^{-E/kT} \, dE$$

$$\simeq \left(\frac{8}{\pi m}\right)^{1/2} \frac{N_A}{k_B T} S_0 \int_0^\infty e^{-2\pi\eta - E/kT} \, dE$$

Nuclear burning stages

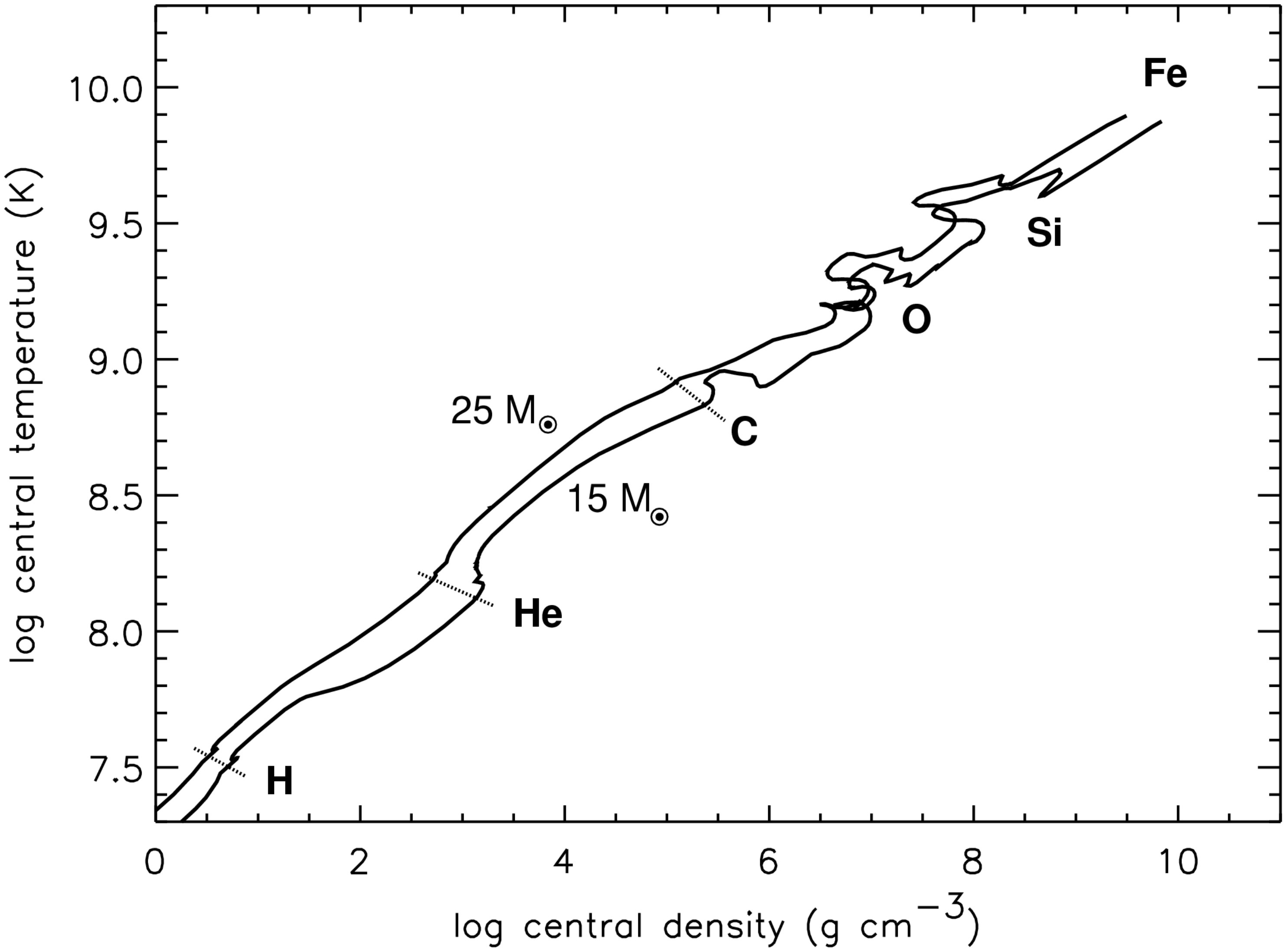
(20 $M_\odot$ stars)

Fuel	Main Product	Secondary Product	T (10^9 K)	Time (yr)	Main Reaction
H	He	^{14}N	0.02	10^7	$4\,H \xrightarrow{CNO} {}^4He$
He	O, C	^{18}O, ^{22}Ne s-process	0.2	10^6	$3\,He^4 \rightarrow {}^{12}C$ $^{12}C(\alpha,\gamma)^{16}O$
C	Ne, Mg	Na	0.8	10^3	$^{12}C + {}^{12}C$
Ne	O, Mg	Al, P	1.5	3	$^{20}Ne(\gamma,\alpha)^{16}O$ $^{20}Ne(\alpha,\gamma)^{24}Mg$
O	Si, S	Cl, Ar, K, Ca	2.0	0.8	$^{16}O + {}^{16}O$
Si,S	Fe	Ti, V, Cr, Mn, Co, Ni	3.5	0.02	$^{28}Si(\gamma,\alpha)\ldots$

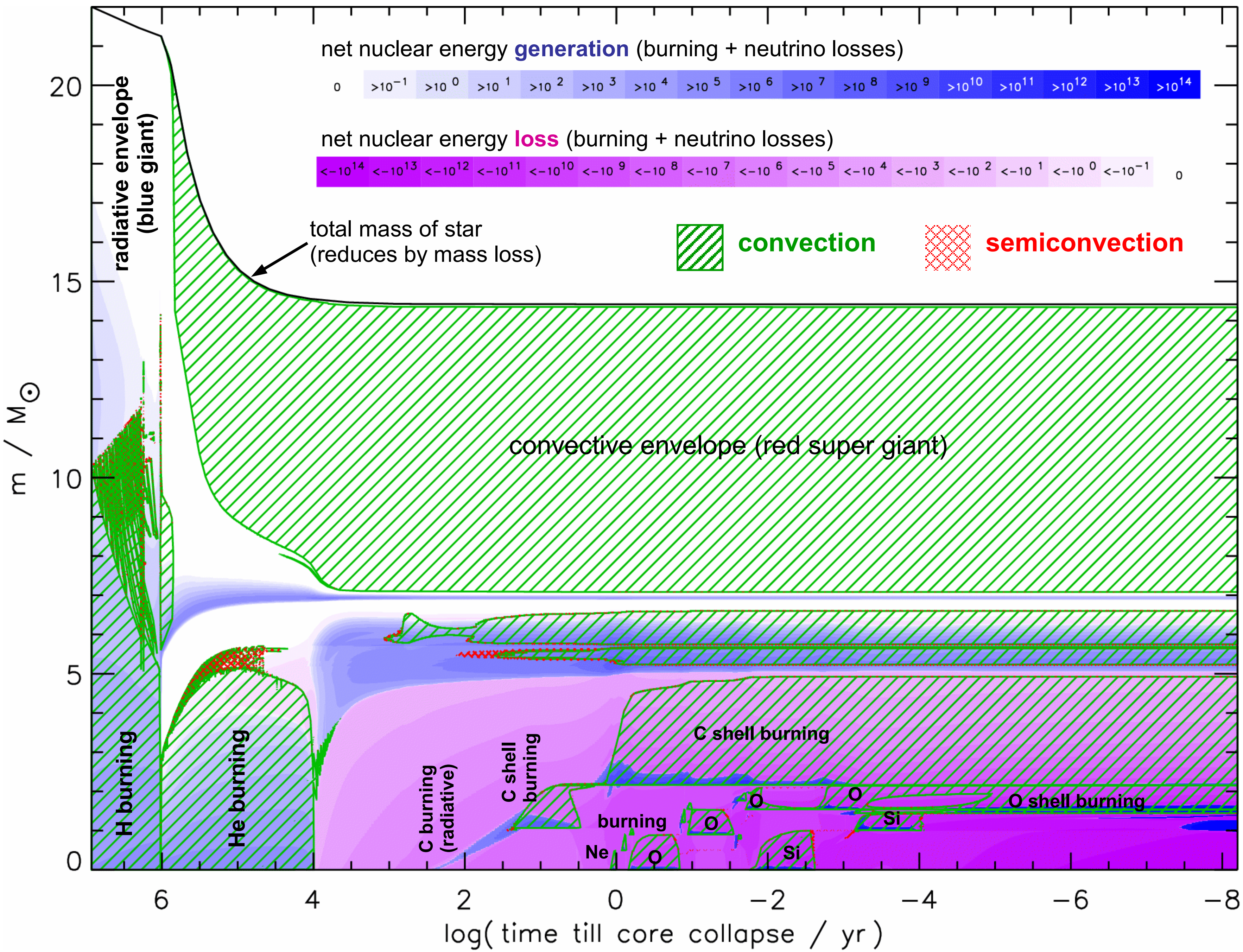
Once formed, the evolution of a star is governed by gravity:

continuing contraction

to higher central densities and temperatures



Evolution of central density and temperature of 15 $M_\odot$ and 25 $M_\odot$ stars


net nuclear energy generation (burning + neutrino losses)
0
>10^−1
>10 0
>10 1
>10 2
>10 3
>10 4
>10 5
>10 6
>10 7
>10 8
>10 9
>10^10
>10^11
>10^12
>10^13
>10^14
net nuclear energy loss (burning + neutrino losses)
<−10^14
<−10^13
<−10^12
<−10^11
<−10^10
<−10 9
<−10 8
<−10 7
<−10 6
<−10 5
<−10 4
<−10 3
<−10 2
<−10 1
<−10 0
<−10^−1
0
total mass of star
(reduces by mass loss)
convection
semiconvection
radiative envelope
(blue giant)
convective envelope (red super giant)
H burning
He burning
C burning
(radiative)
C shell
burning
C shell burning
Ne
burning
O
O
O
O
Si
Si
O shell burning
m / M⊙
20
15
10
5
0
6
4
2
0
−2
−4
−6
−8
log(time till core collapse / yr)