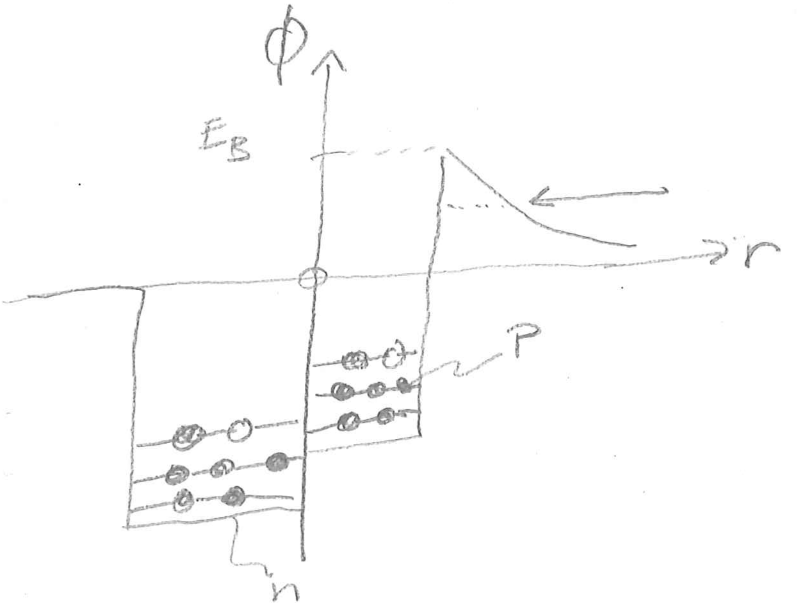
Thermonuclear Reactions



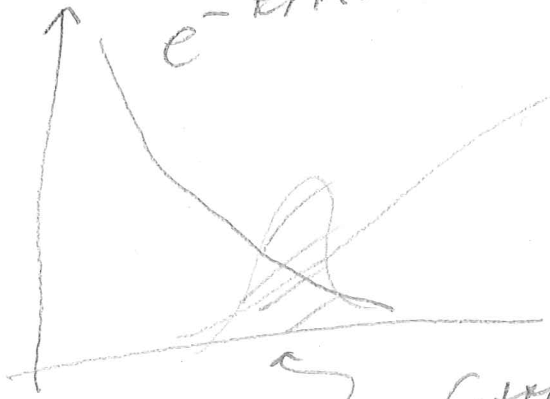
Typical $E = kT \ll E_B$

Q: How can we have reactions

- high-E tail of distrib.
- tunnelling (QM)

NOTE: SCREENING @ high ρ

QUANTITATIVE:



$e^{-E/kT}$ ~ BOLTZMANN

$e^{-\eta/E^{1/2}}$ ~ tunnel BARRIER PENETRATION

$$\eta = \pi\sqrt{2m}\,\frac{Z_1 Z_2 k e^2}{\hbar}$$

GAMOV WINDOW

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

REACTION OFTEN PARAMETRIZED USING ASTROPHYSICAL S(E) - FACTOR

MASS EXCESS

$$\Delta M = c^2 (m - A \cdot u) \quad \text{UNIT OF } E$$

neutral ATOM

BINDING ENERGY

$A = N + Z$

$$E_B = c^2 (m - (N \cdot m_n + Z \cdot (m_p + m_e)))$$

Q: what is the difference, and why

Q: typical values?

Nuclear burning stages

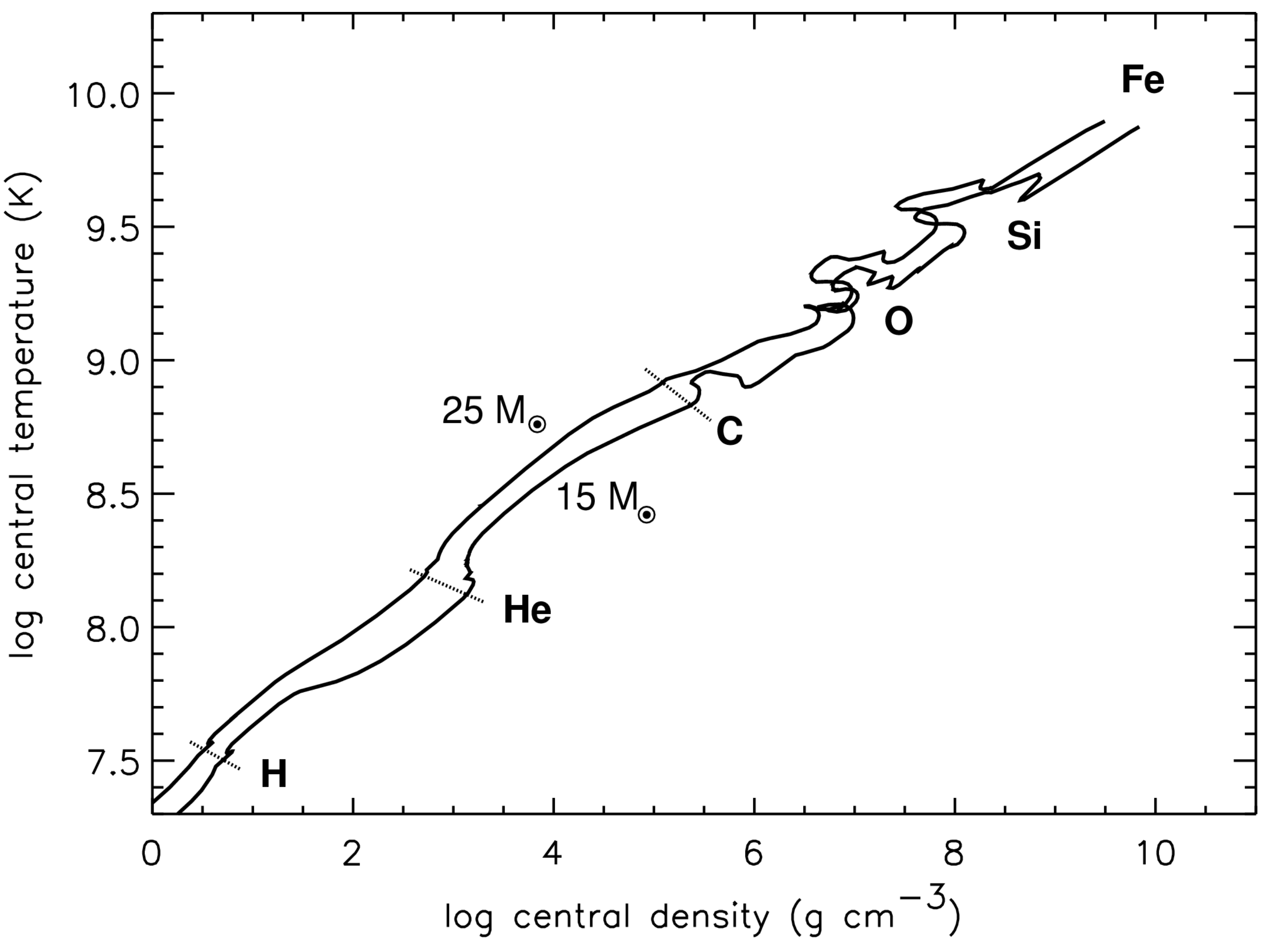
(20 $M_{\odot}$ stars)

Fuel	Main Product	Secondary Product	T (10^9 K)	Time (yr)	Main Reaction
H	He	^{14}N	0.02	10^7	$4\,H \xrightarrow{CNO} {}^{4}He$
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	$^{28}Si(\gamma,\alpha)\ldots$

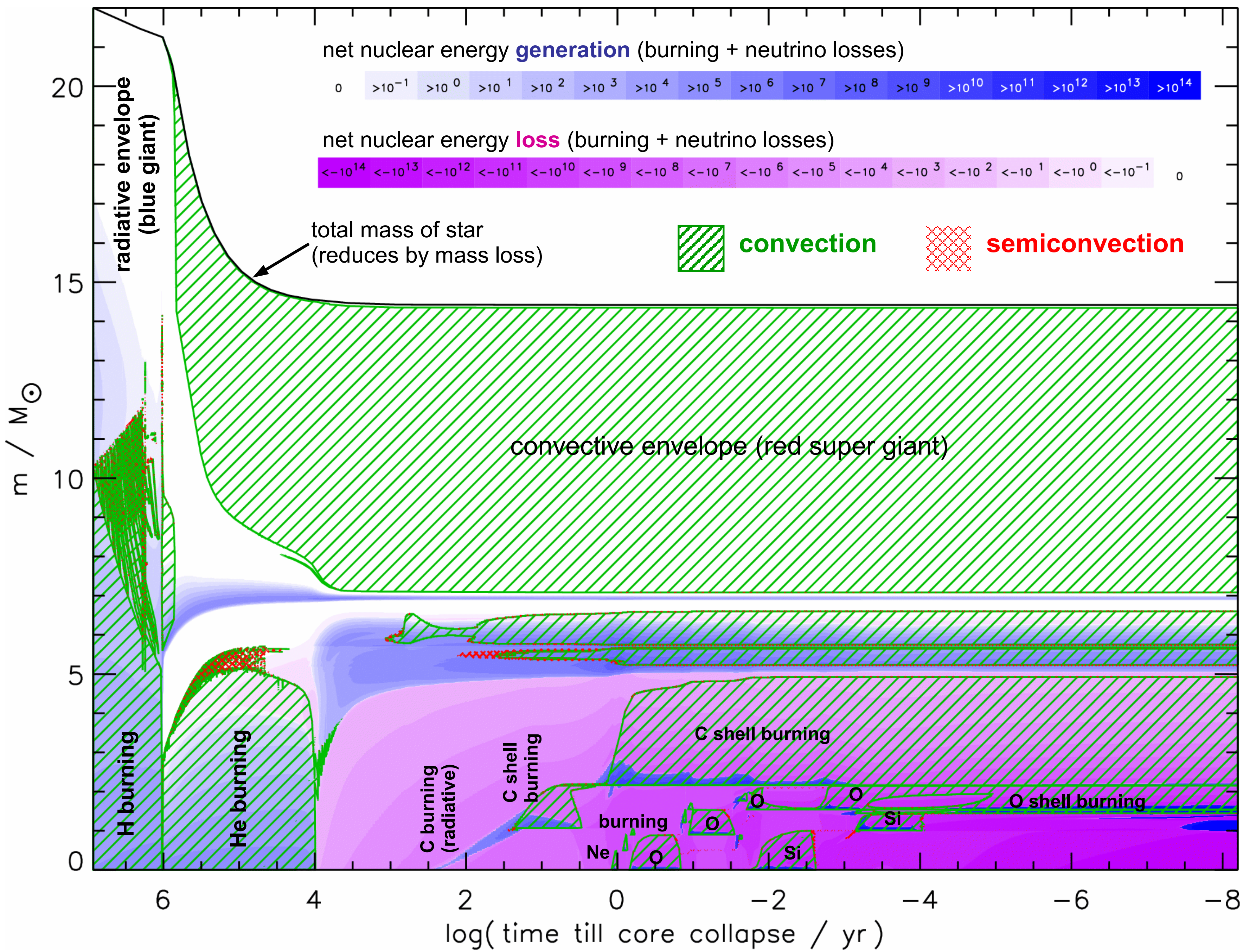
Once formed, the evolution of a star is governed by gravity:

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
convection
semiconvection
total mass of star
(reduces by mass loss)
radiative envelope
(blue giant)
convective envelope (red super giant)
H burning
He burning
C burning
(radiative)
C shell
burning
C shell burning
O shell burning
burning
Ne
O
Si
m / M☉
log(time till core collapse / yr)