Nuclear Theory for Chemical Evolution of Galaxies

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JINA GCE Workshop “Building Virtual Galaxies”

April 30, 2010

(based on review by Janka et al. 2007 in Physics Reports)

Stellar input for chemical evolution of galaxies

star formation

↓

stellar evolution → nucleosynthesis

↓

end states → gas return

↓

Type Ia &
core-collapse SNe → nucleosynthesis
energy injection, mixing

Nuclear theory input for chemical evolution

- nuclear reaction rates for:

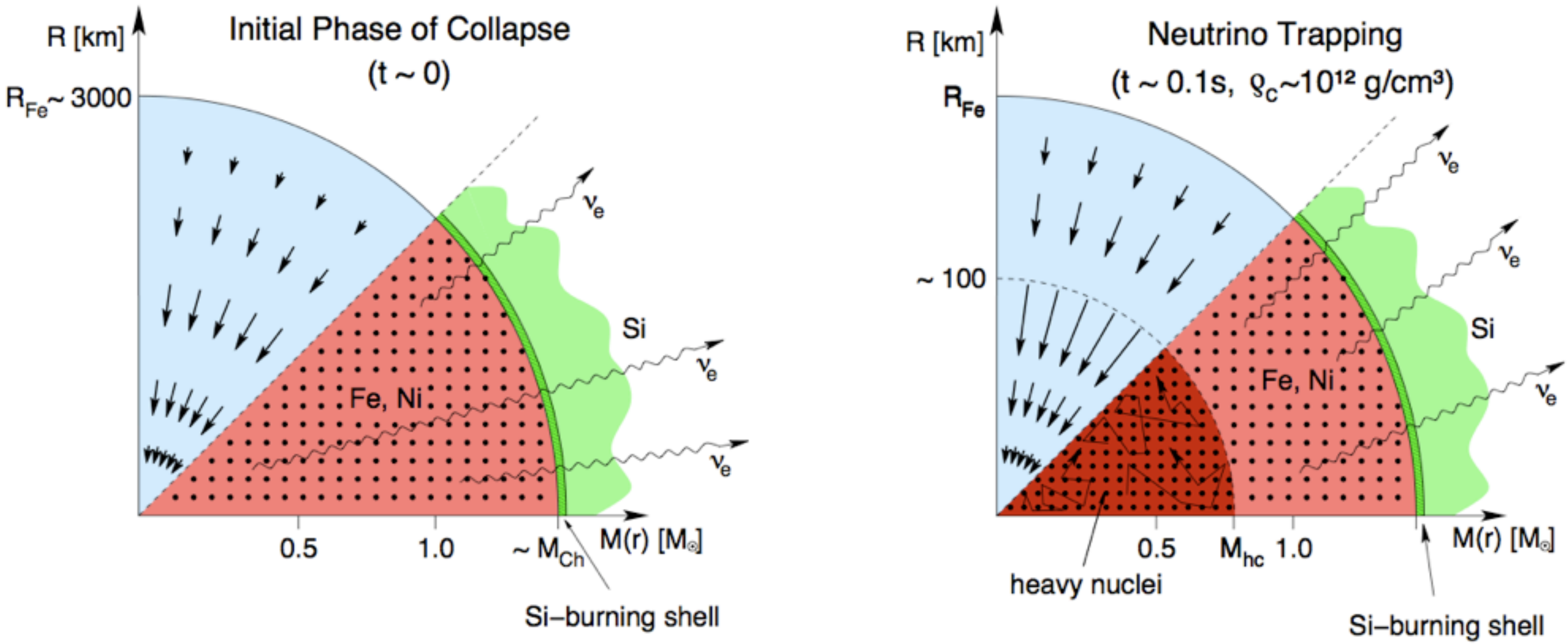
hydrostatic & explosive burning

r-process, s-process, p-process, rp-process

- nuclear theory input for core-collapse SNe:

weak interaction rates

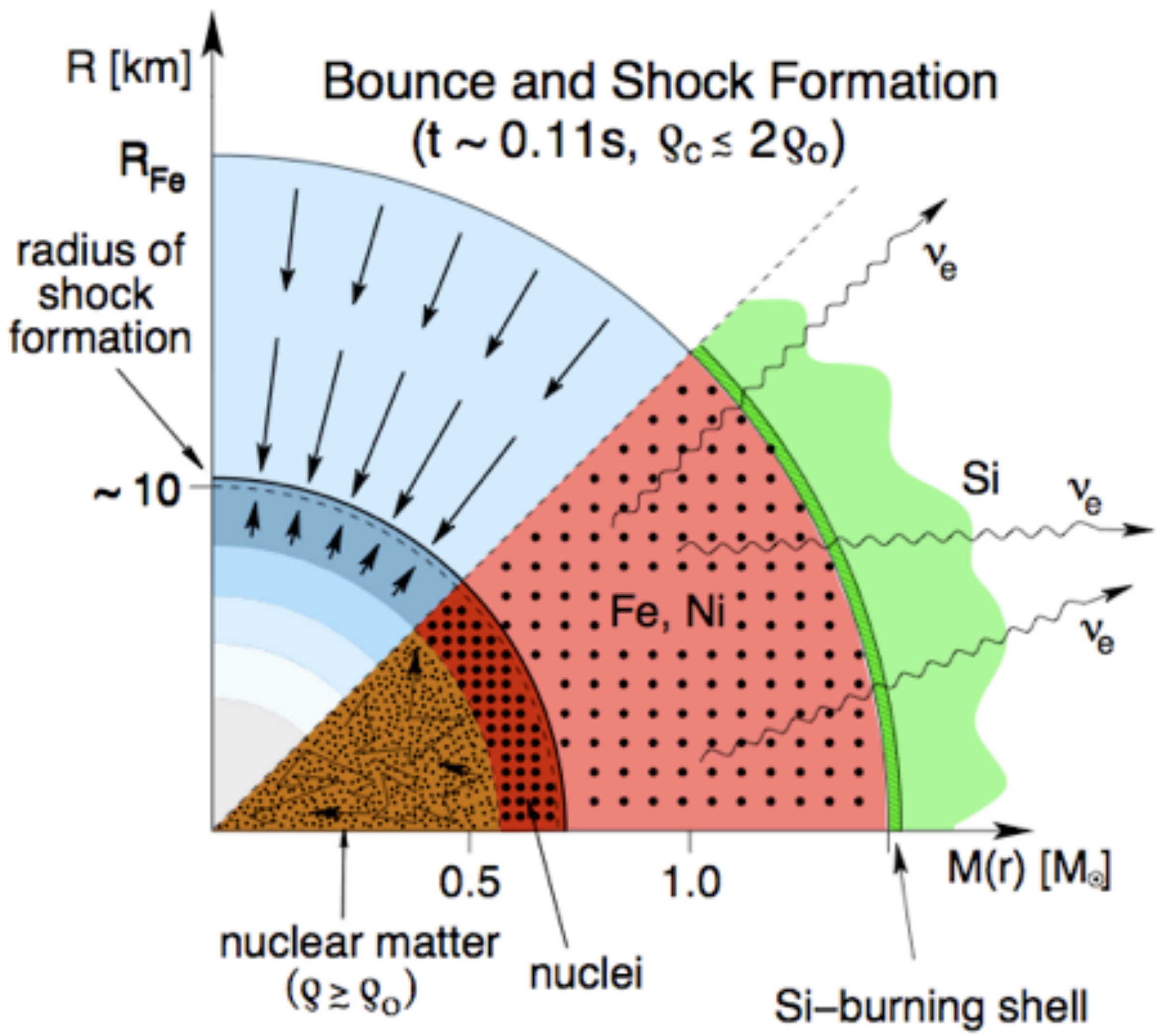
nuclear equation of state

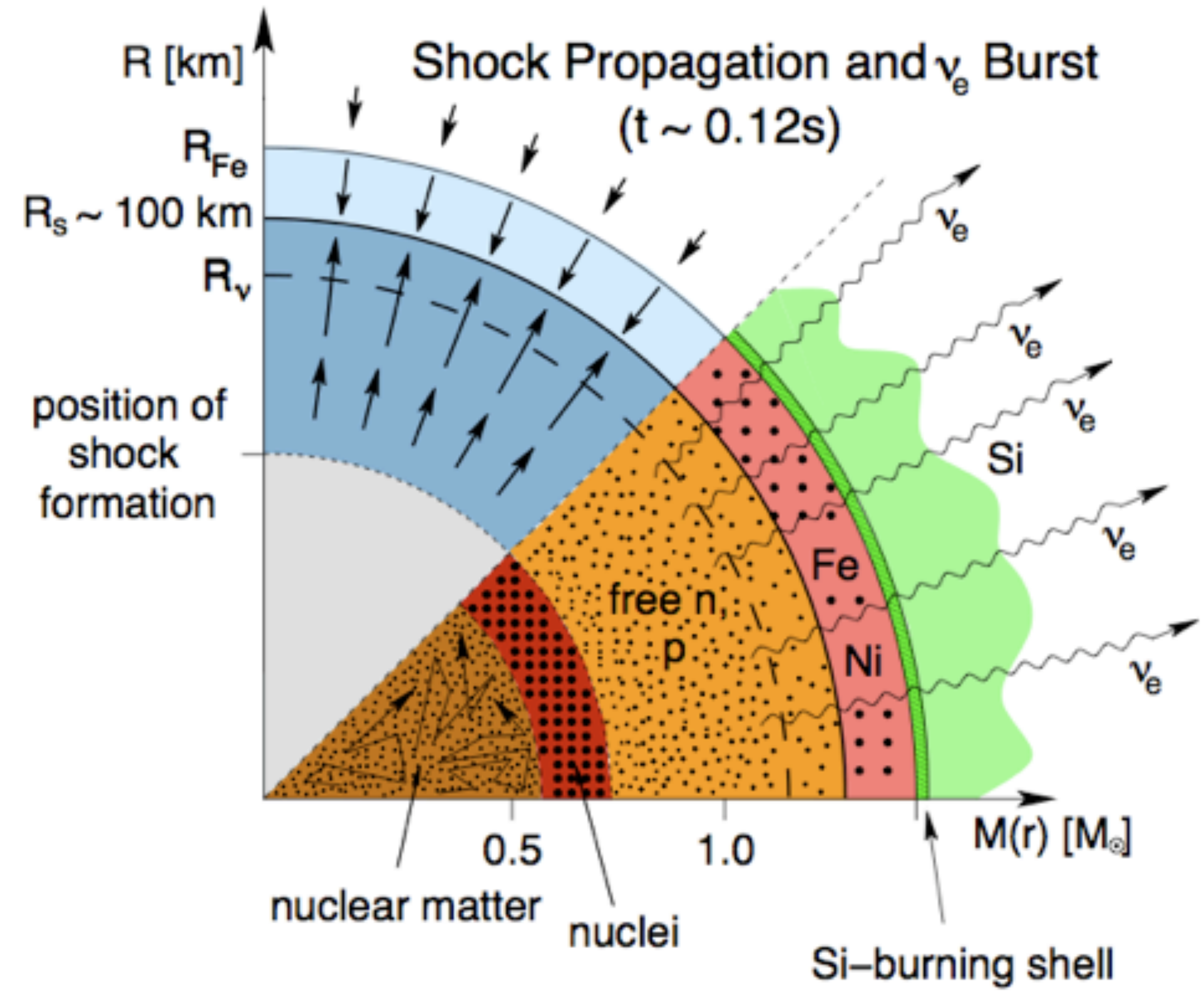


weak rates during pre-SN evolution & core collapse

mass, Ye, entropy of “Fe” core

mass of inner core



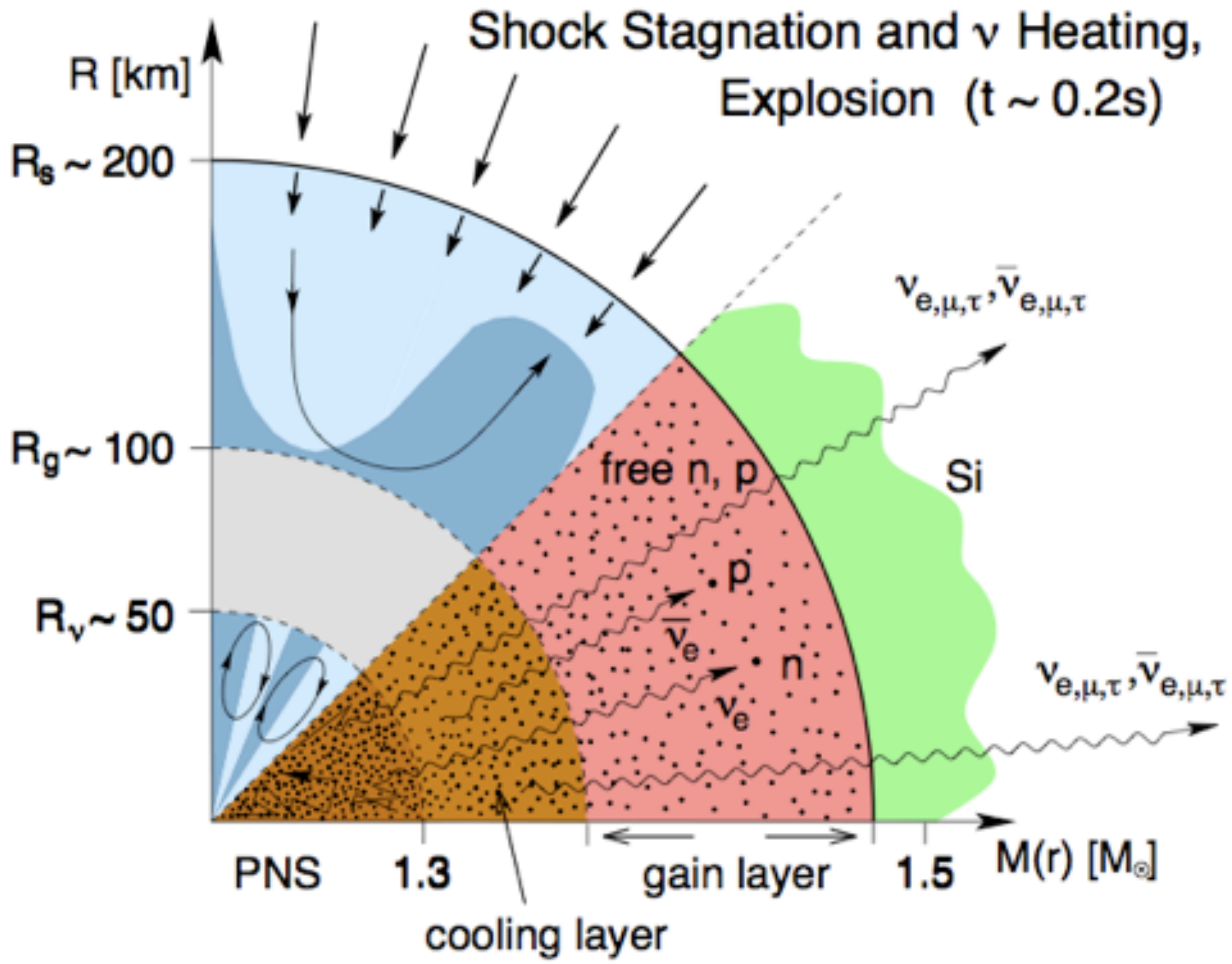


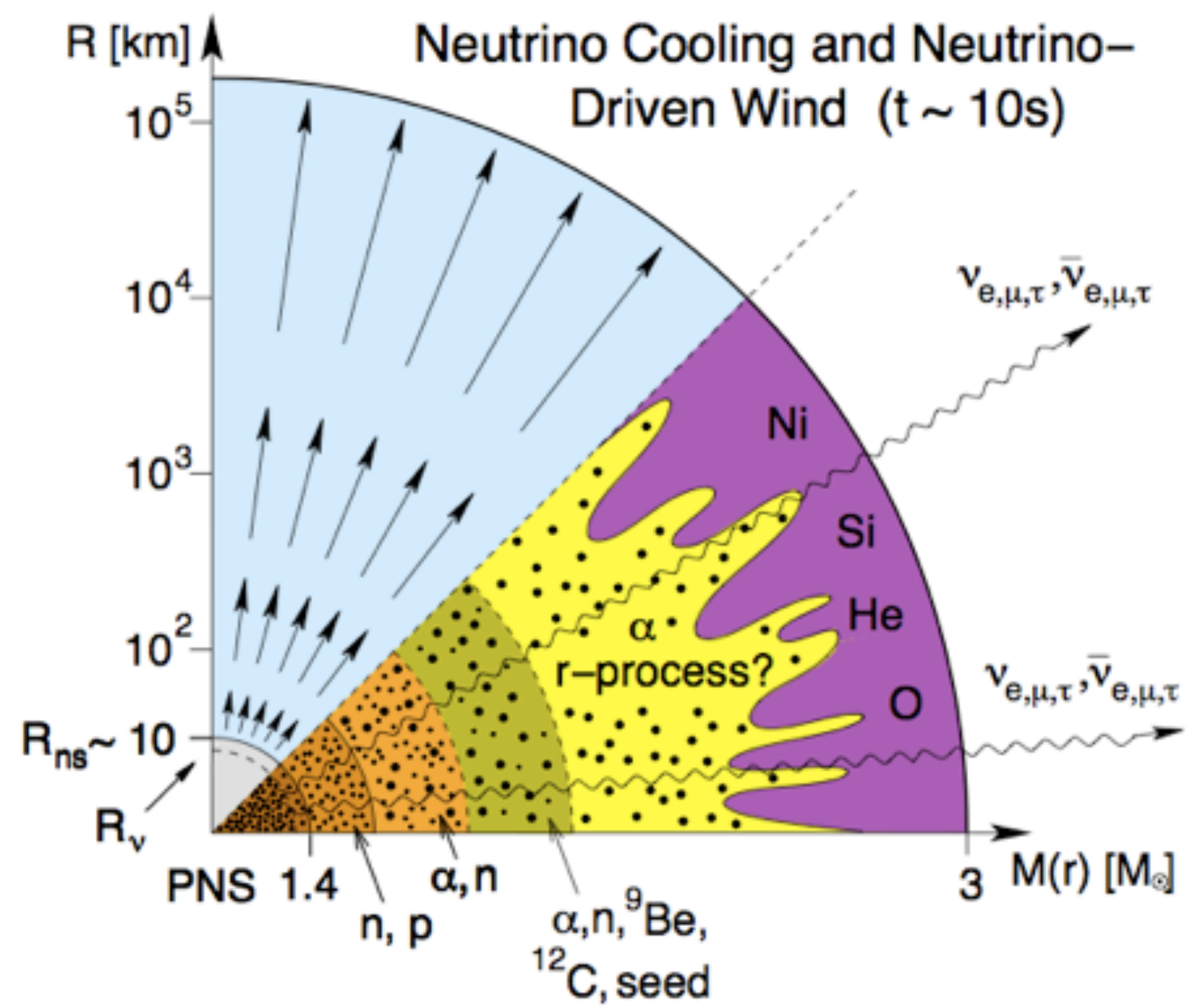
nuclear equation of state (EOS)

radius of inner core at bounce

initial shock energy

later neutrino luminosity





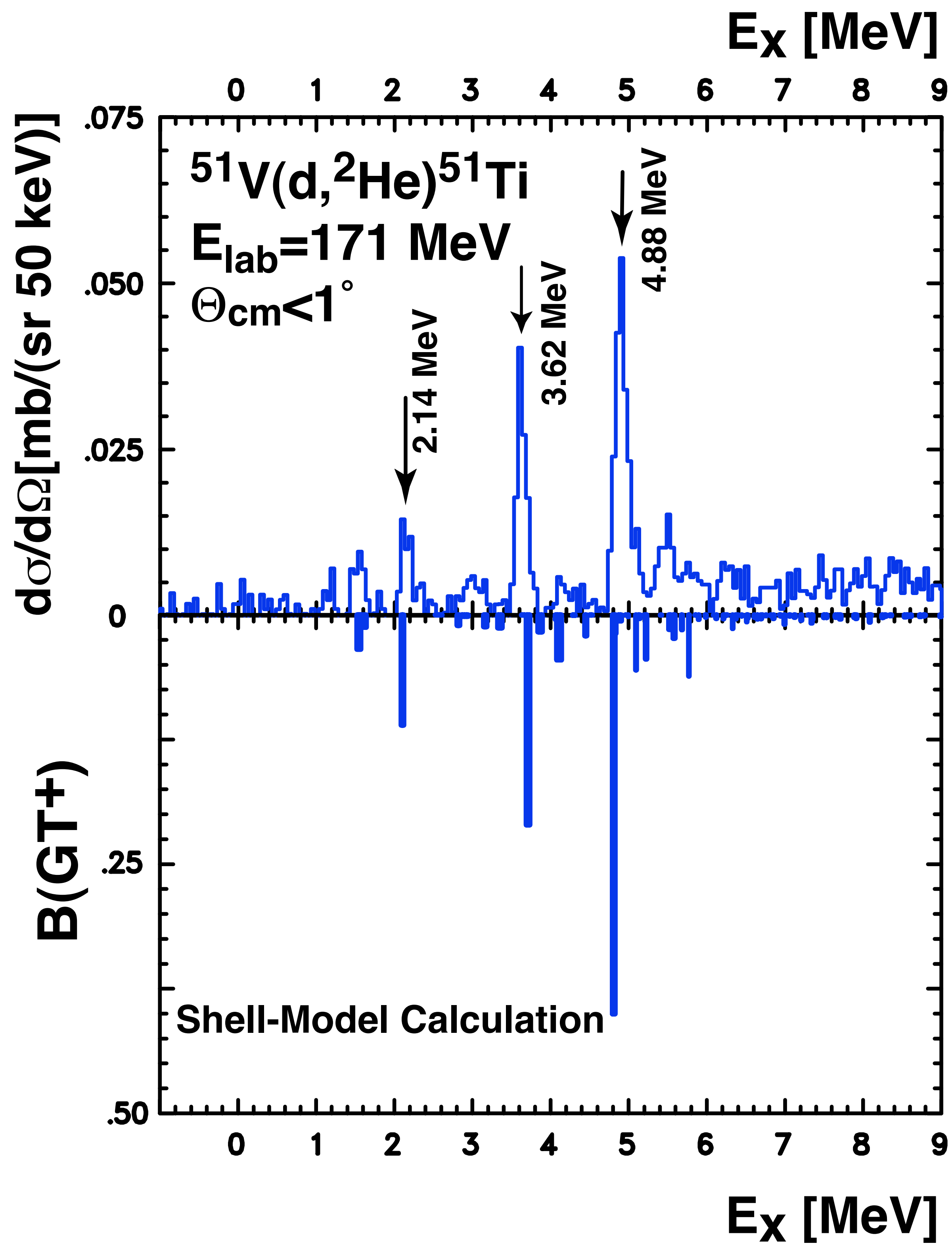
nuclear EoS & neutrino processes

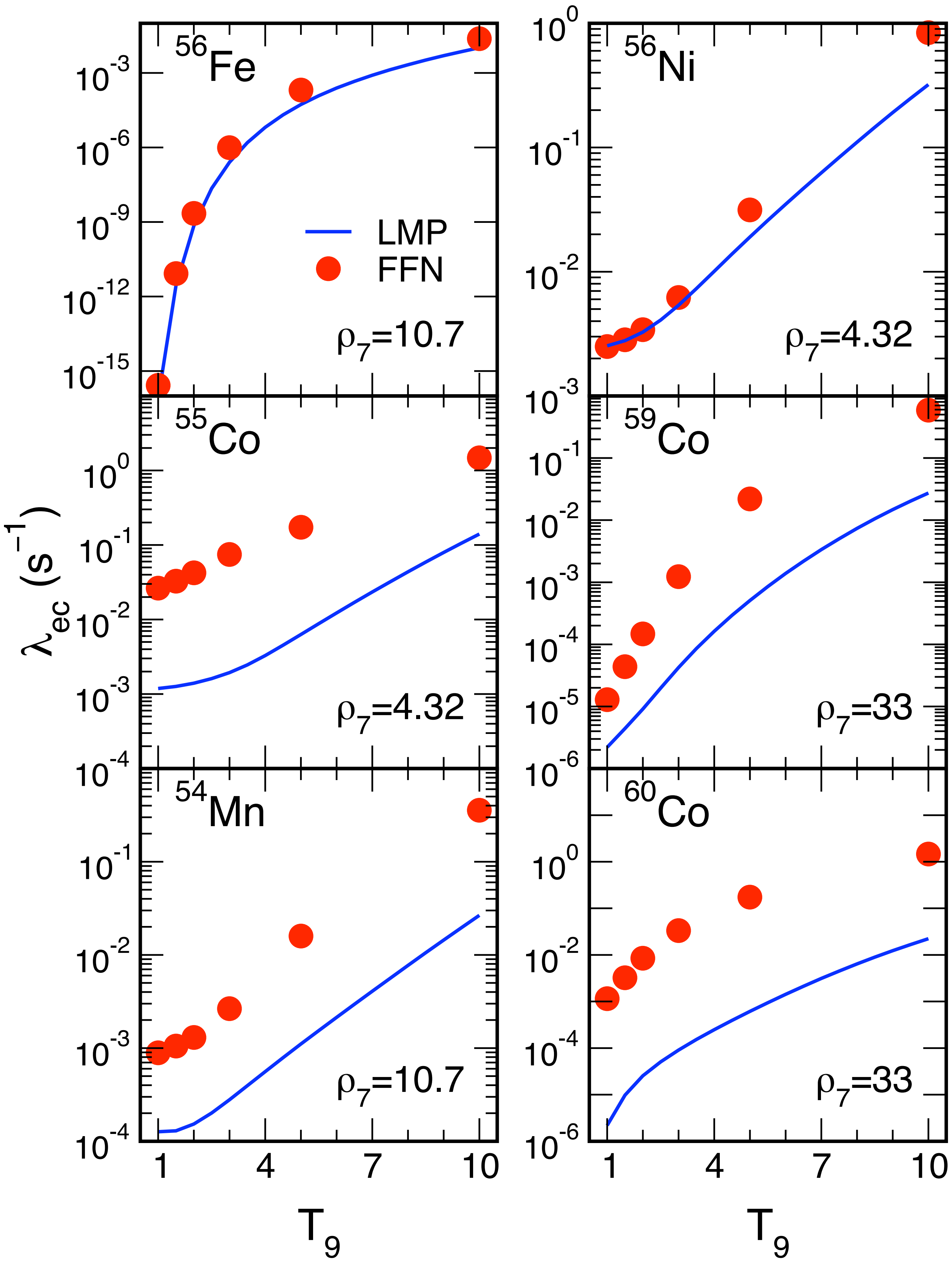
neutrino luminosity & spectra

explosion & nucleosynthesis

e-capture & beta-decay rates for pre-SN evolution

Langanke & Martinez-Pinedo (LMP 2000)

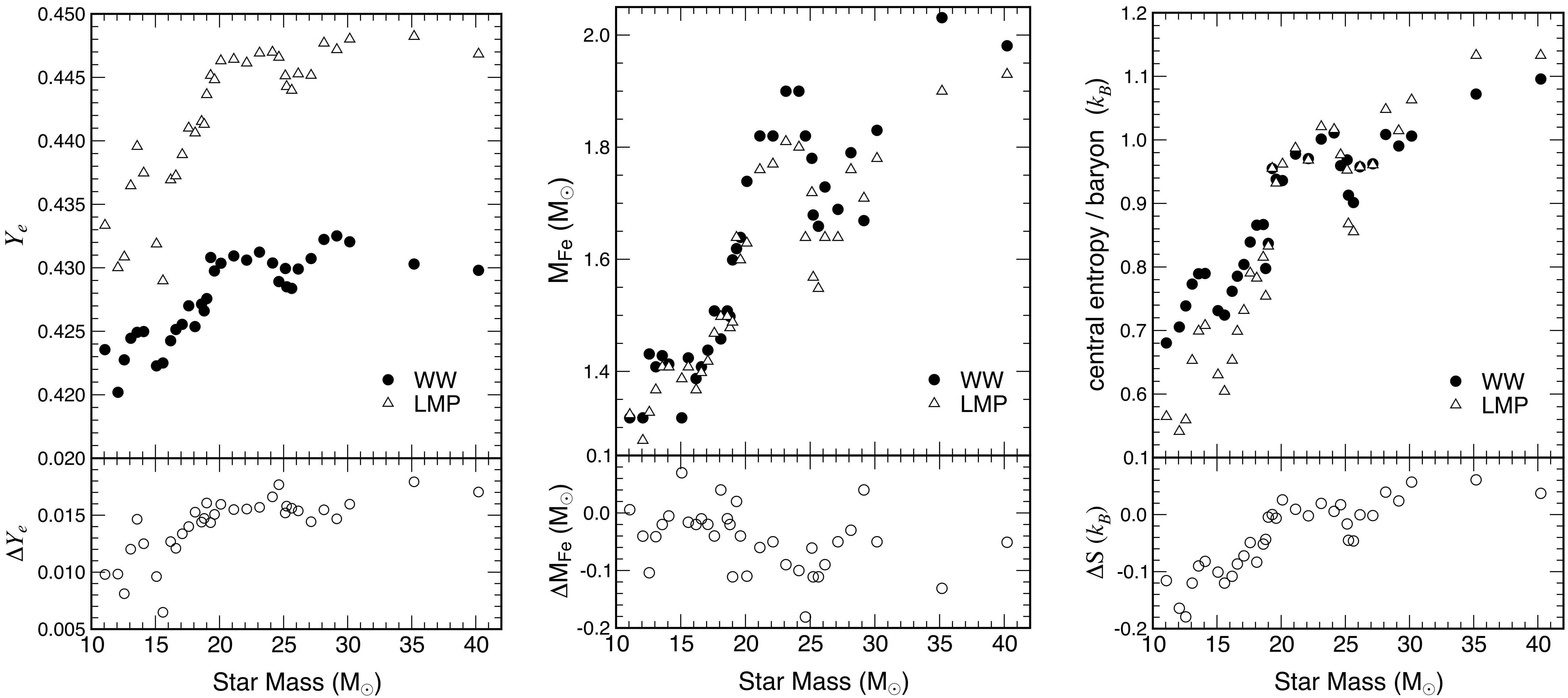


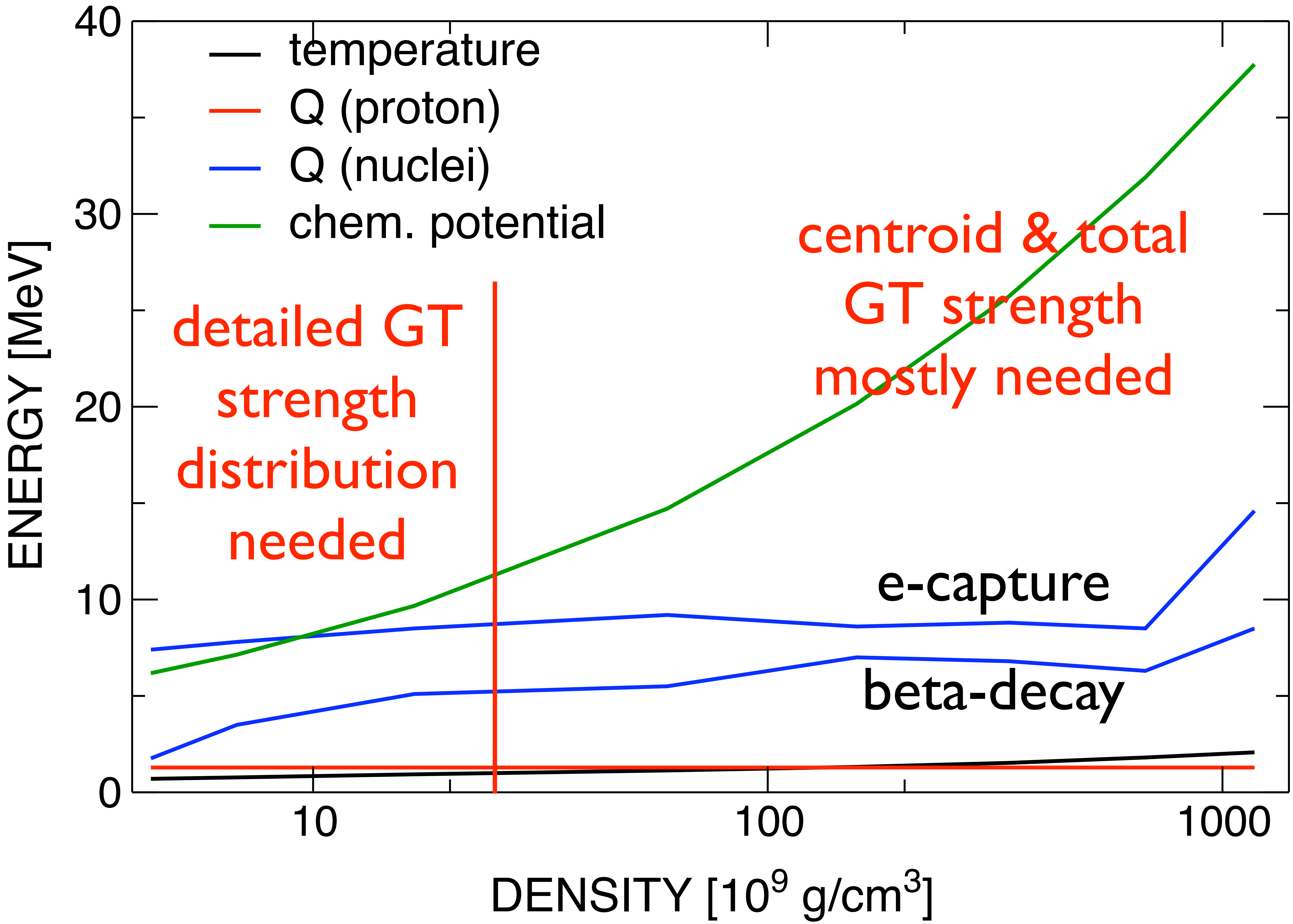


comparison with
Fuller, Fowler, & Newman
(FFN 1980, '82, '85)
for late stages of
pre-SN evolution

smaller,
non-systematic
differences
for beta-decay

further constraints on
shell model calculations
from FRIB?


0.450
0.445
0.440
0.435
0.430
0.425
0.420
0.020
0.015
0.010
0.005
Y_e
ΔY_e
WW
LMP
10
15
20
25
30
35
40
Star Mass ($M_\odot$)
2.0
1.8
1.6
1.4
0.1
0.0
-0.1
-0.2
M_{Fe} ($M_\odot$)
ΔM_{Fe} ($M_\odot$)
WW
LMP
Star Mass ($M_\odot$)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.1
0.0
-0.1
-0.2
central entropy / baryon (k_B)
ΔS (k_B)
WW
LMP
Star Mass ($M_\odot$)

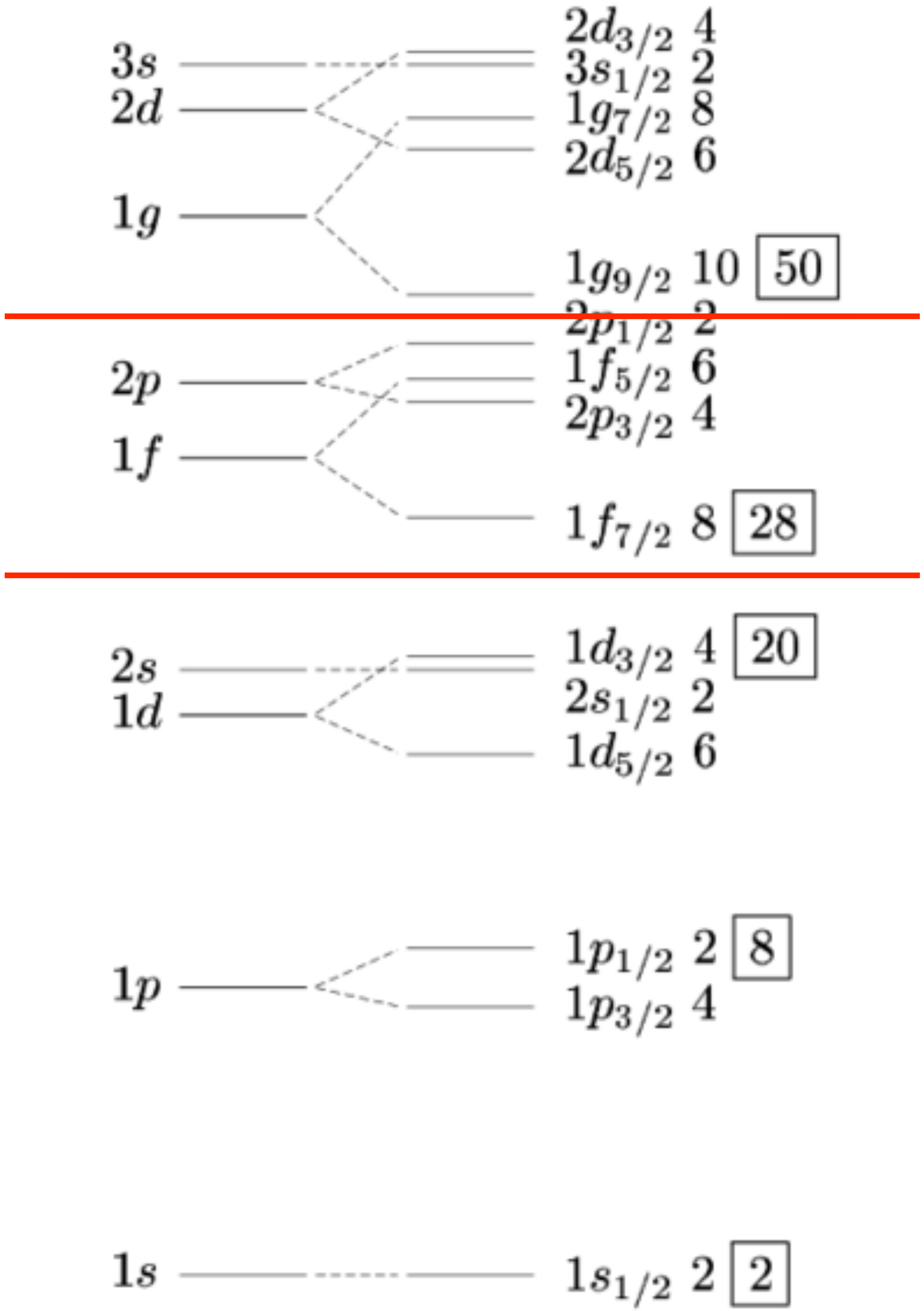


40
30
20
10
0
10
100
1000
ENERGY [MeV]
DENSITY [10^9 g/cm^3]
temperature
Q (proton)
Q (nuclei)
chem. potential
detailed GT strength distribution needed
centroid & total GT strength mostly needed
e-capture
beta-decay

e capture during core collapse

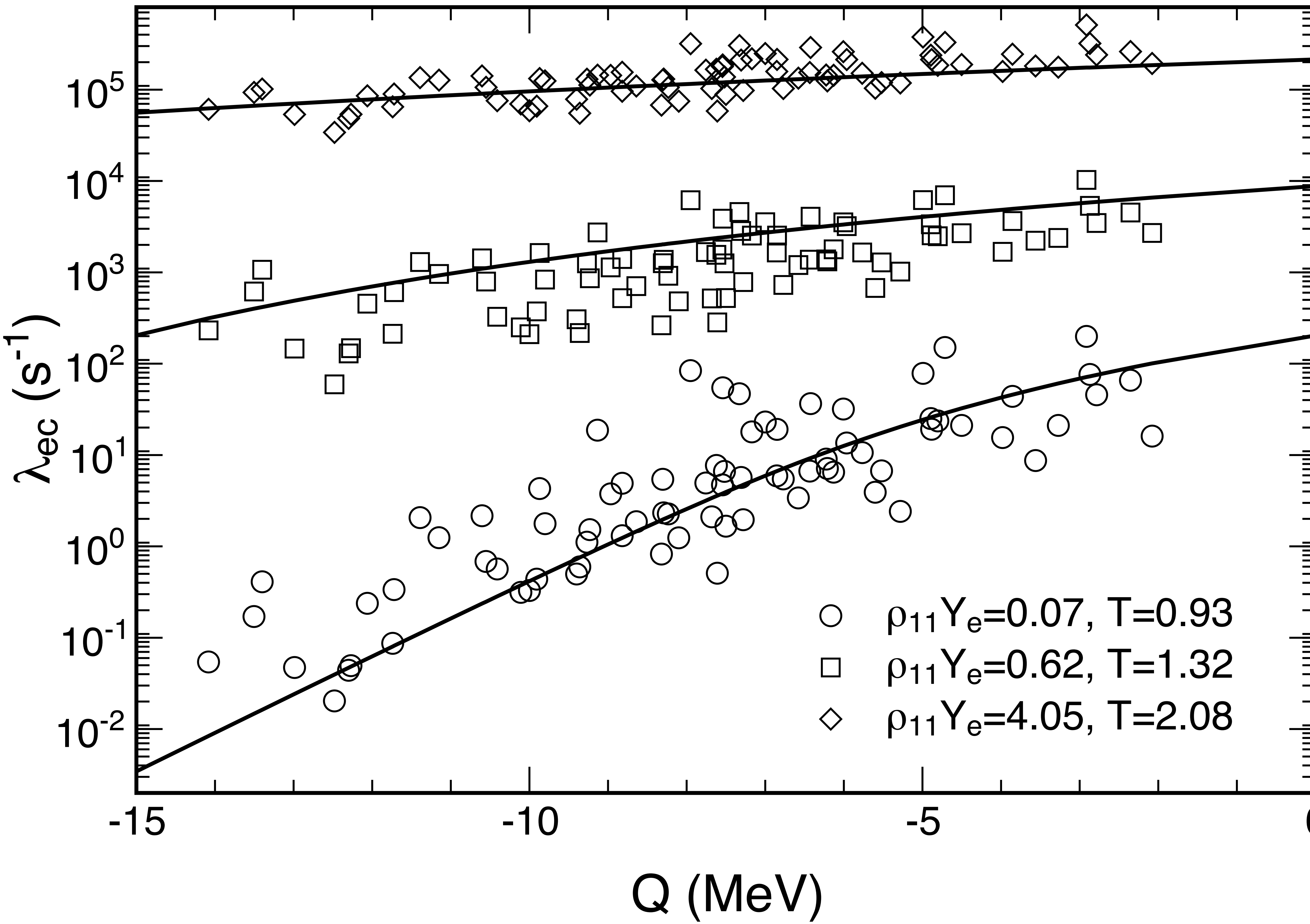
- nuclear statistical equilibrium (NSE) has many nuclei with significant abundances
- reduction of Ye depends on the product of nuclear abundance & the corresponding e-capture rate
- decreasing Ye changes NSE composition to favor more n-rich nuclei

when Z<40 & N>40 nuclei have significant abundances, more sophisticated shell model calculations needed, but computational capability forces alternative: Random Phase Approximation (RPA)

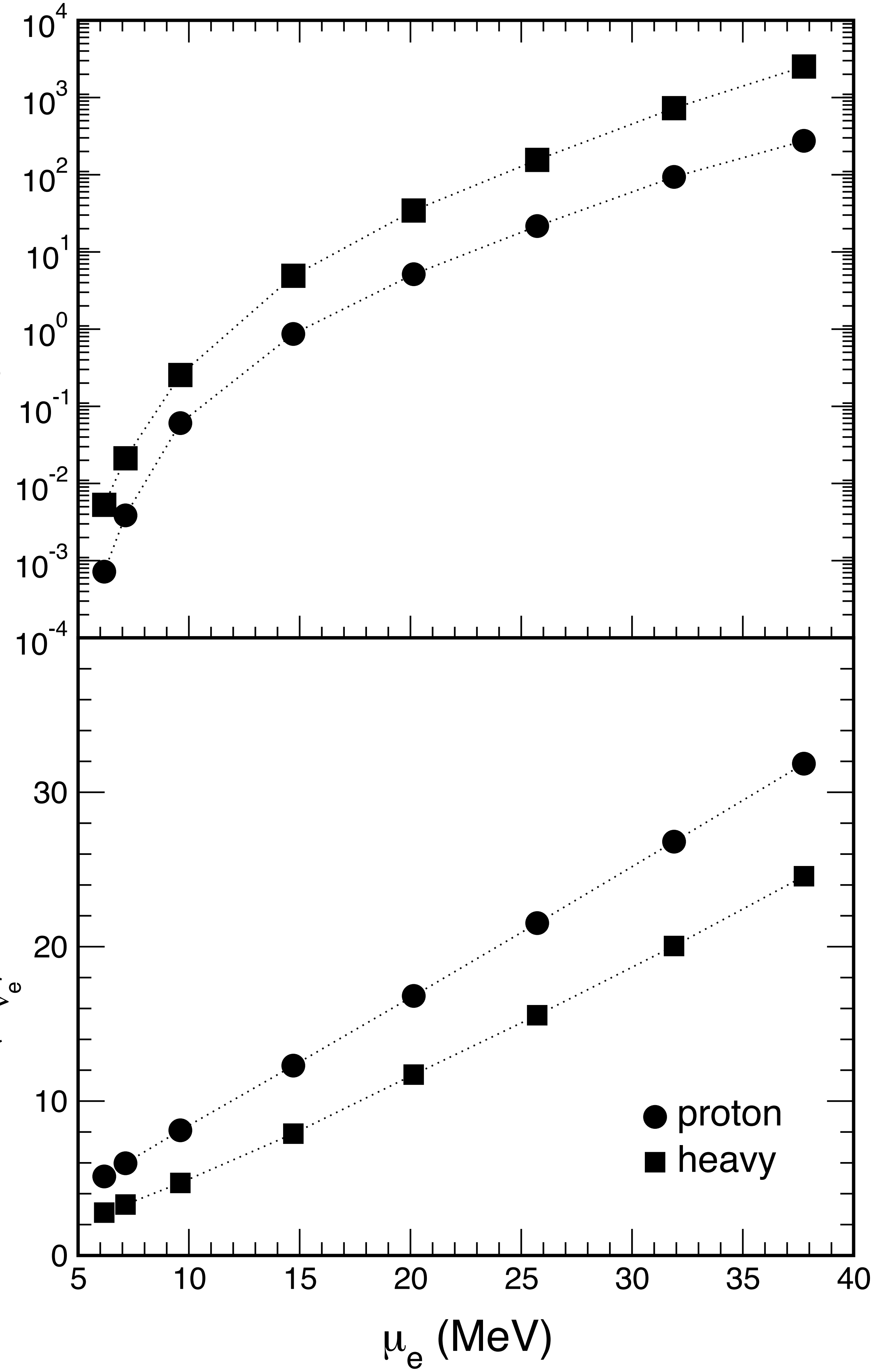


Independent Particle Shell Model gives no GT strength for e capture on nuclei with Z<40 & N>40

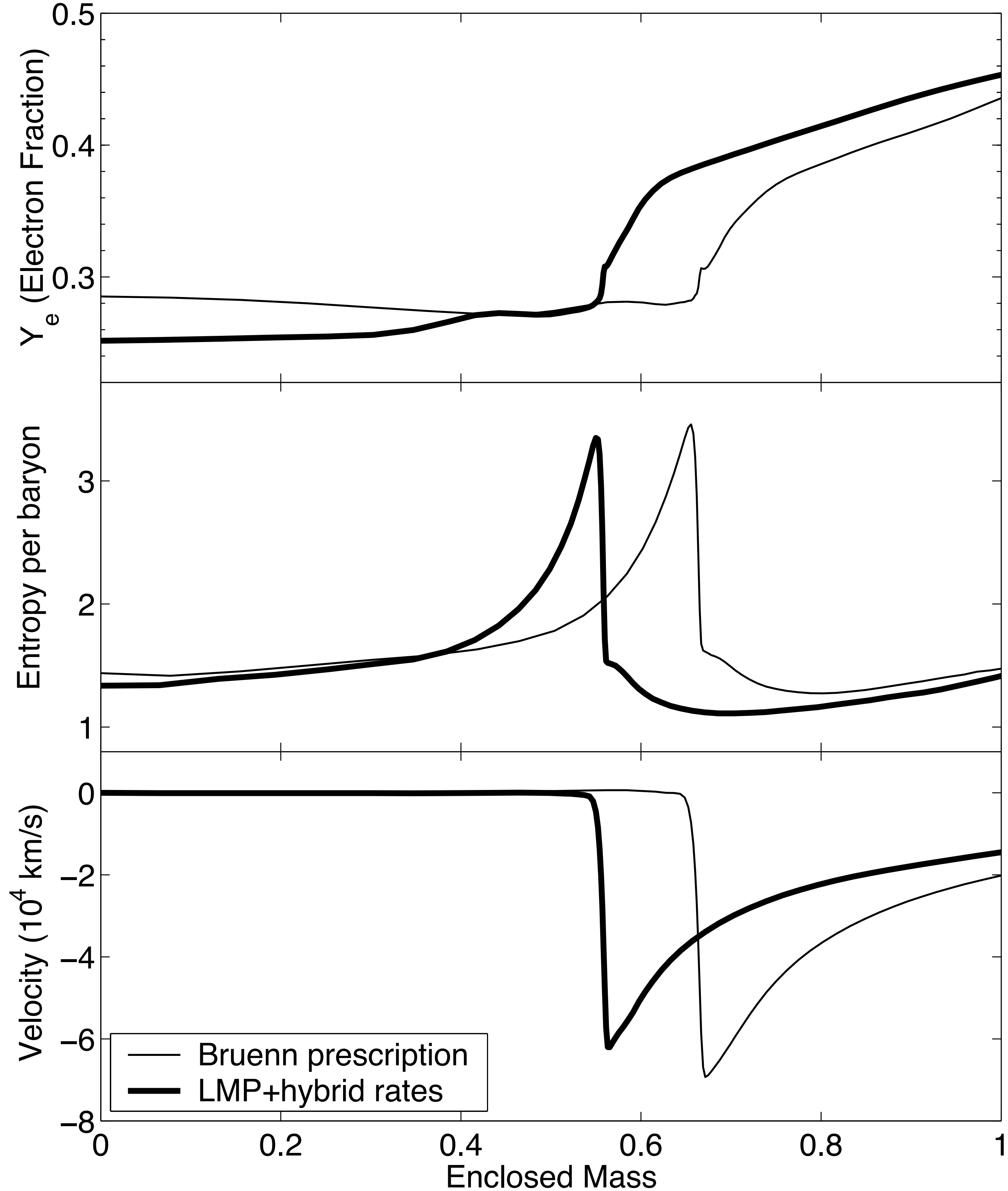
but finite temperature & residual interaction lead to unblocking



Friday, April 30, 2010



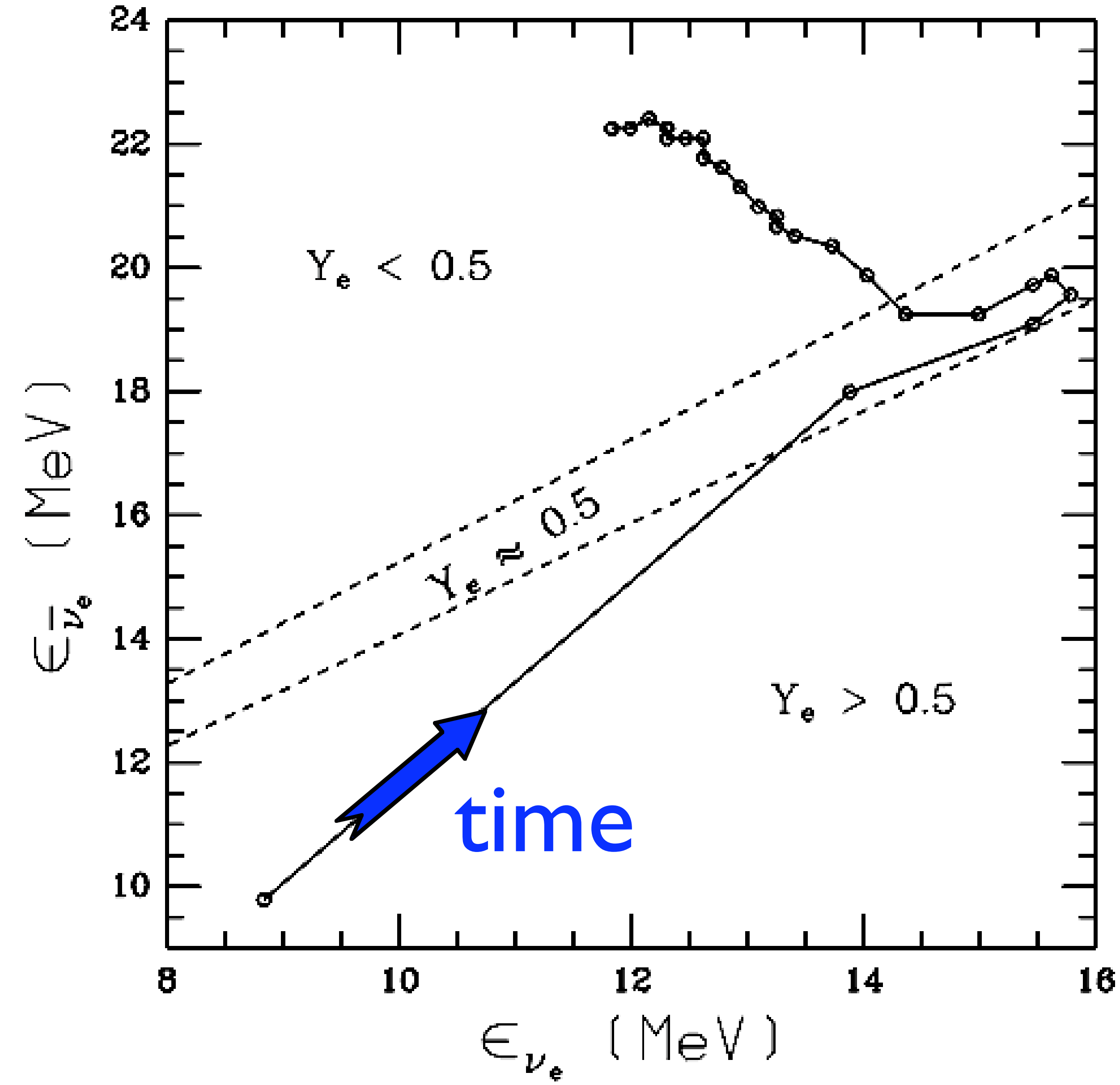
r_{ec} (s^{-1})
$\langle E_{\nu_e} \rangle$ (MeV)
μ_e (MeV)
proton
heavy



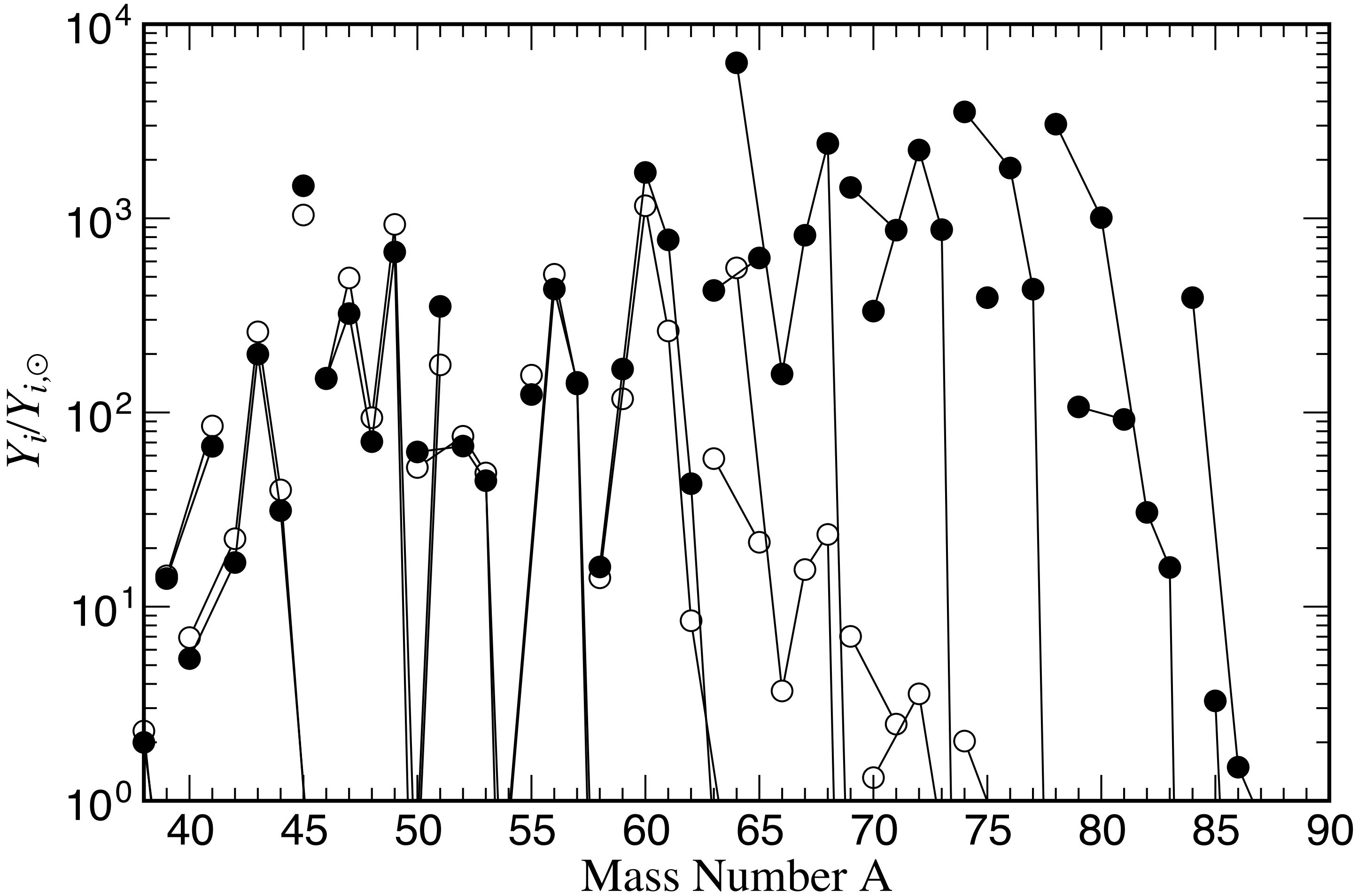
Y_e (Electron Fraction)
Entropy per baryon
Velocity (10^4 km/s)
Enclosed Mass
Bruenn prescription
LMP+hybrid rates

Nuclear theory input for supernova neutrino emission

nuclear EoS, neutrino emission & interaction processes



Qian & Woosley 1996



νp-process

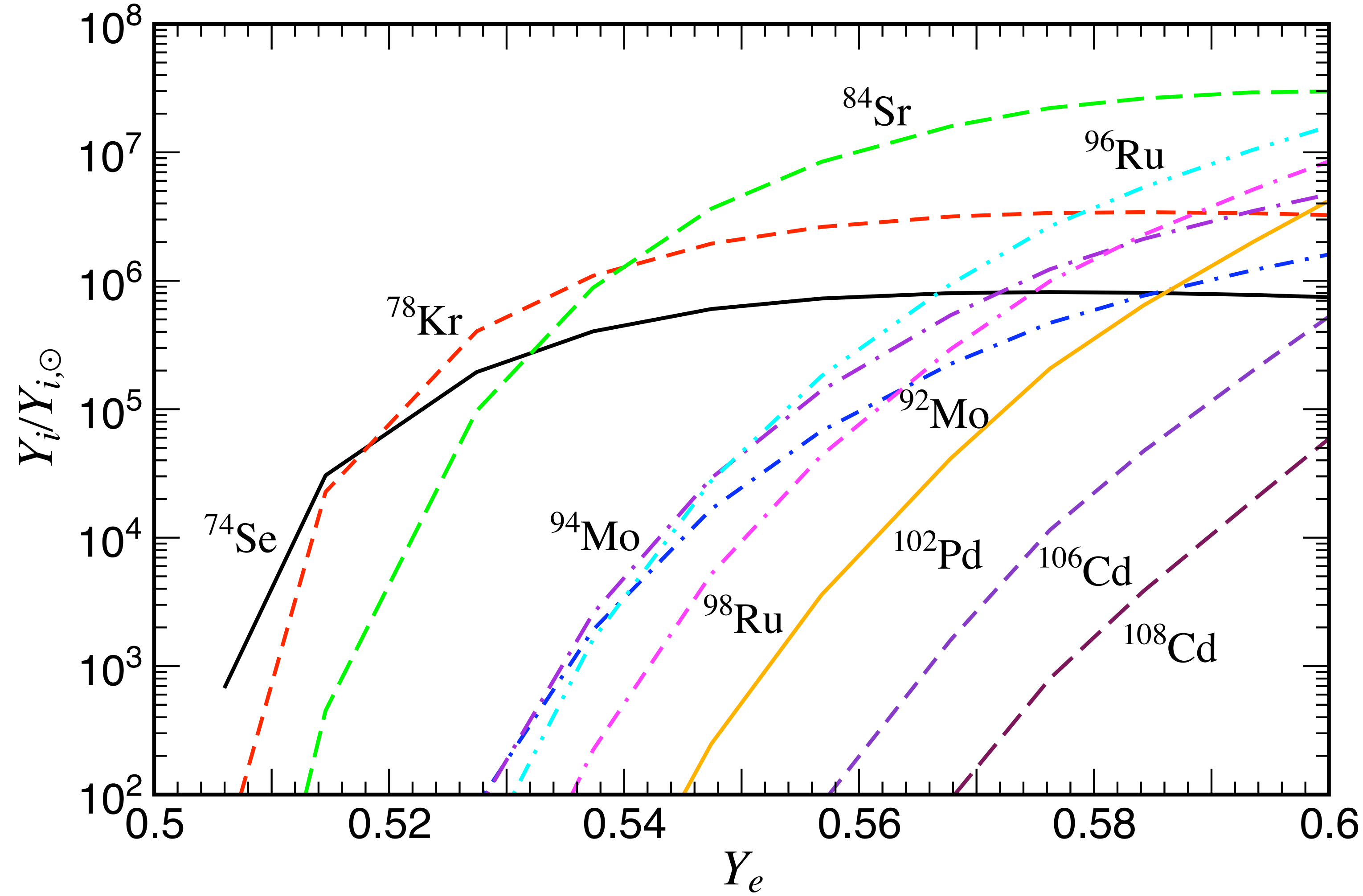
Frohlich et al. 2004, '06
Pruet et al. 2005

without neutrinos, nuclear flow ends at $^{64}\mathrm{Ge}$

$$\bar{\nu}_e + p \rightarrow n + e^+$$

$$(n,p)\ \&\ (p,\gamma)$$

lead to heavier nuclei



Nuclear theory input for the r-process

- during the r-process, assuming $(n,\gamma) \rightleftharpoons (\gamma,n)$ equilibrium

neutron separation energy, beta-decay rates
both depend on nuclear masses

macro-microscopic (e.g., FRDM) vs.
ab initio (e.g., RMF) mass models

possible role of fission cycling ➡

n-induced fission cross sections & yields

- during freeze-out

n capture cross sections, beta-delayed n emission

possible role of neutrino-induced n emission