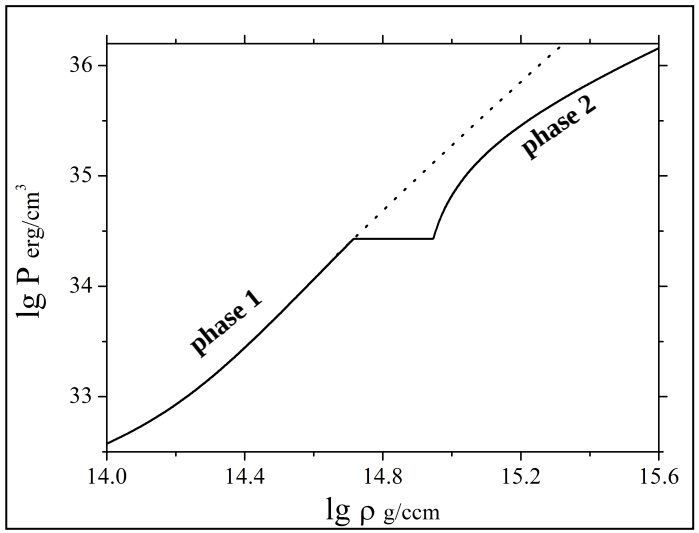
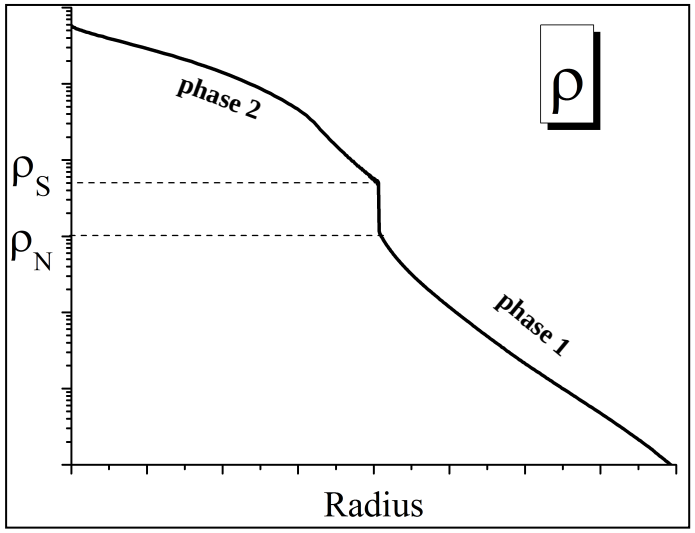
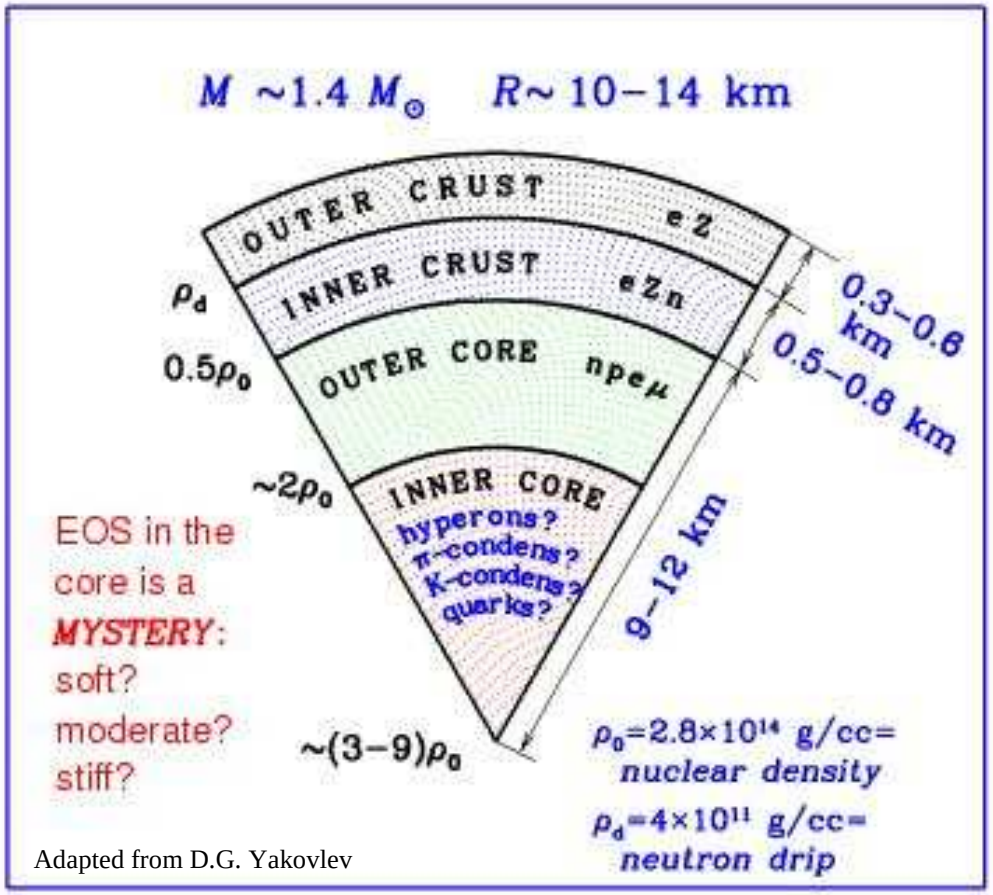
Hybrid stars, supernova and convection





Maxwellian type phase transition causes a density jump inside the star



Adapted from D.G. Yakovlev

Mixing phase: the most interesting place inside the star

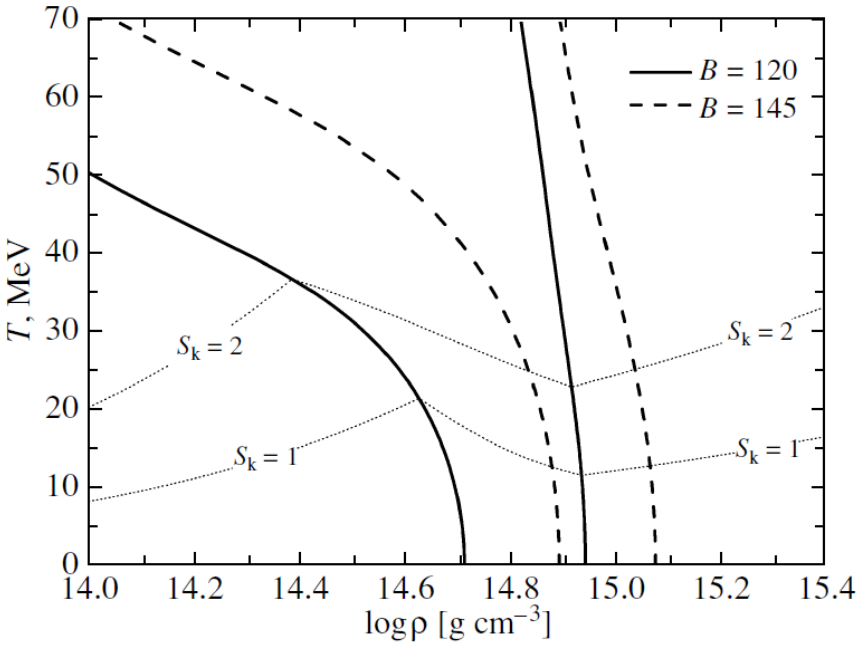
Clapeyron–Clausius:

$$\left(\frac{\partial P}{\partial T}\right)_{\rm pt} = \frac{S_1 - S_2}{\frac{1}{\rho_1} - \frac{1}{\rho_2}} < 0,$$

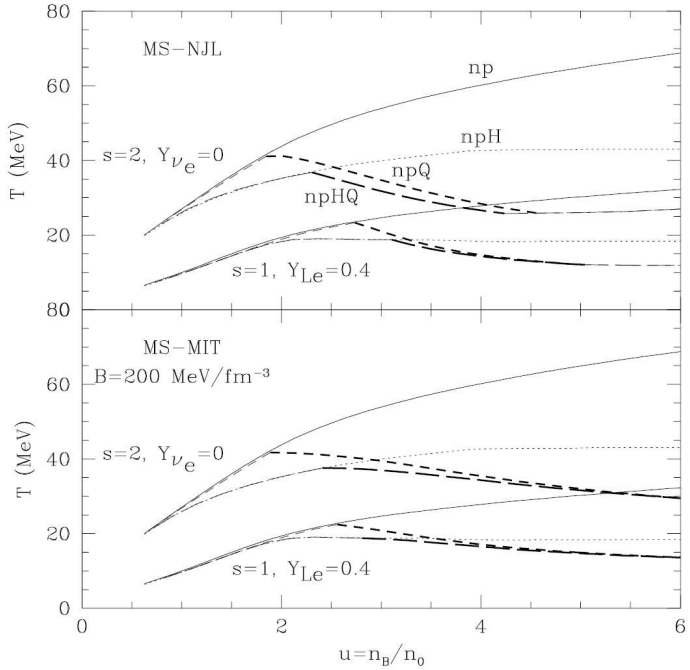
$$\triangle q = T(S_2 - S_1) > 0.$$

Noncongruence of the nuclear liquid-gas and deconfinement phase transitions

M. Hempel, V. Dexheimer, S. Schramm, and I. Iosilevskiy
Phys. Rev. C 88, (2013)



Quark-Hadron Phase Transitions in Young and Old Neutron Stars
A. Steiner, M. Prakash, and J.M. Lattimer
Physics Letters B, Volume 486, Issue 3-4, p. 239-248.



Convective instability condition

$$\begin{cases} \triangle\epsilon_{\rm ce} = \left(\dfrac{\partial\epsilon}{\partial P}\right)_{S,Y}\triangle P, \\ \triangle\epsilon_{\rm sm} = \left(\dfrac{\partial\epsilon}{\partial P}\right)_{S,Y}\triangle P + \left(\dfrac{\partial\epsilon}{\partial S}\right)_{P,Y}\triangle S + \left(\dfrac{\partial\epsilon}{\partial Y}\right)_{P,S}\triangle Y, \end{cases}$$

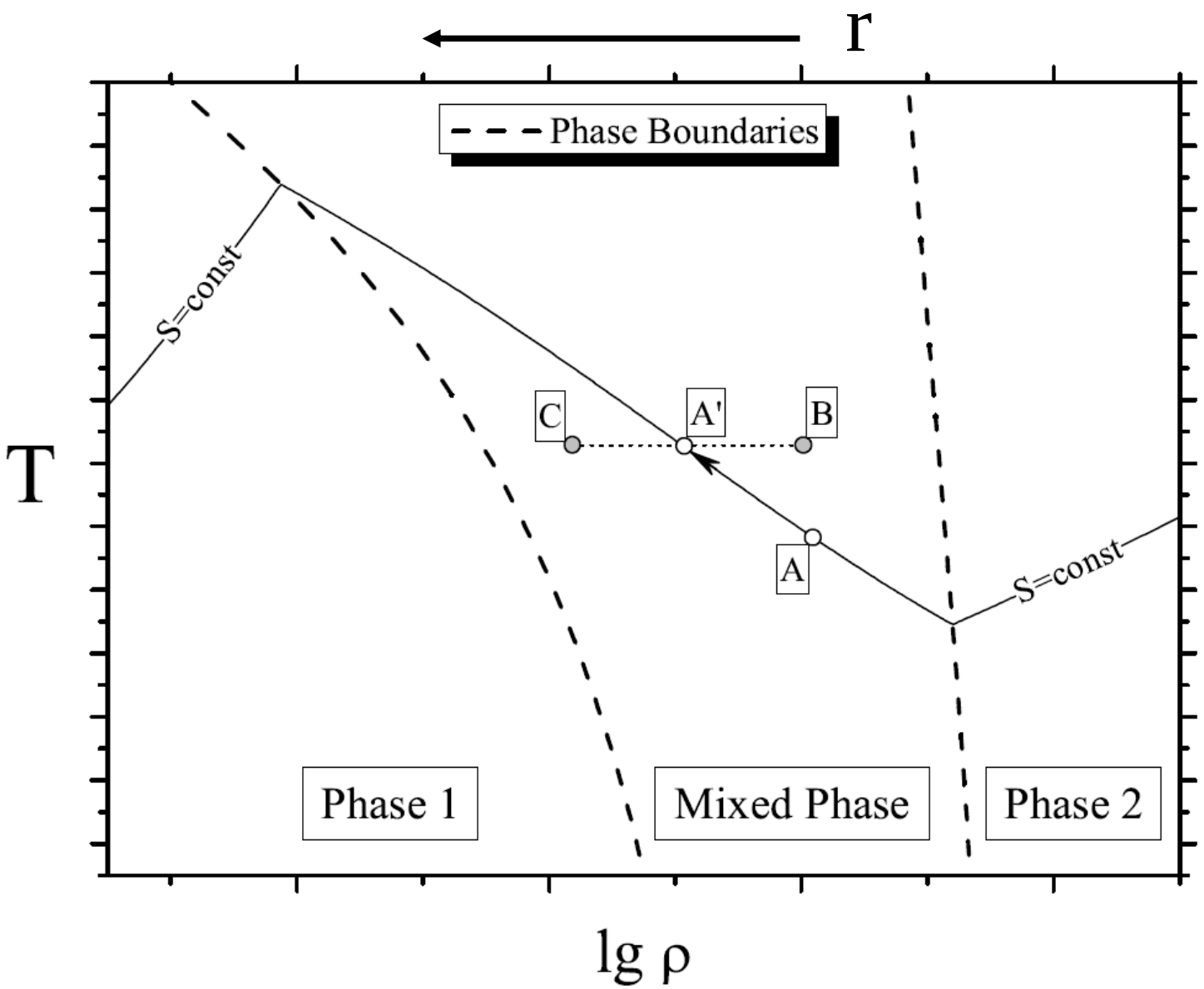
Energy (density) change inside convective element and surrounding matter

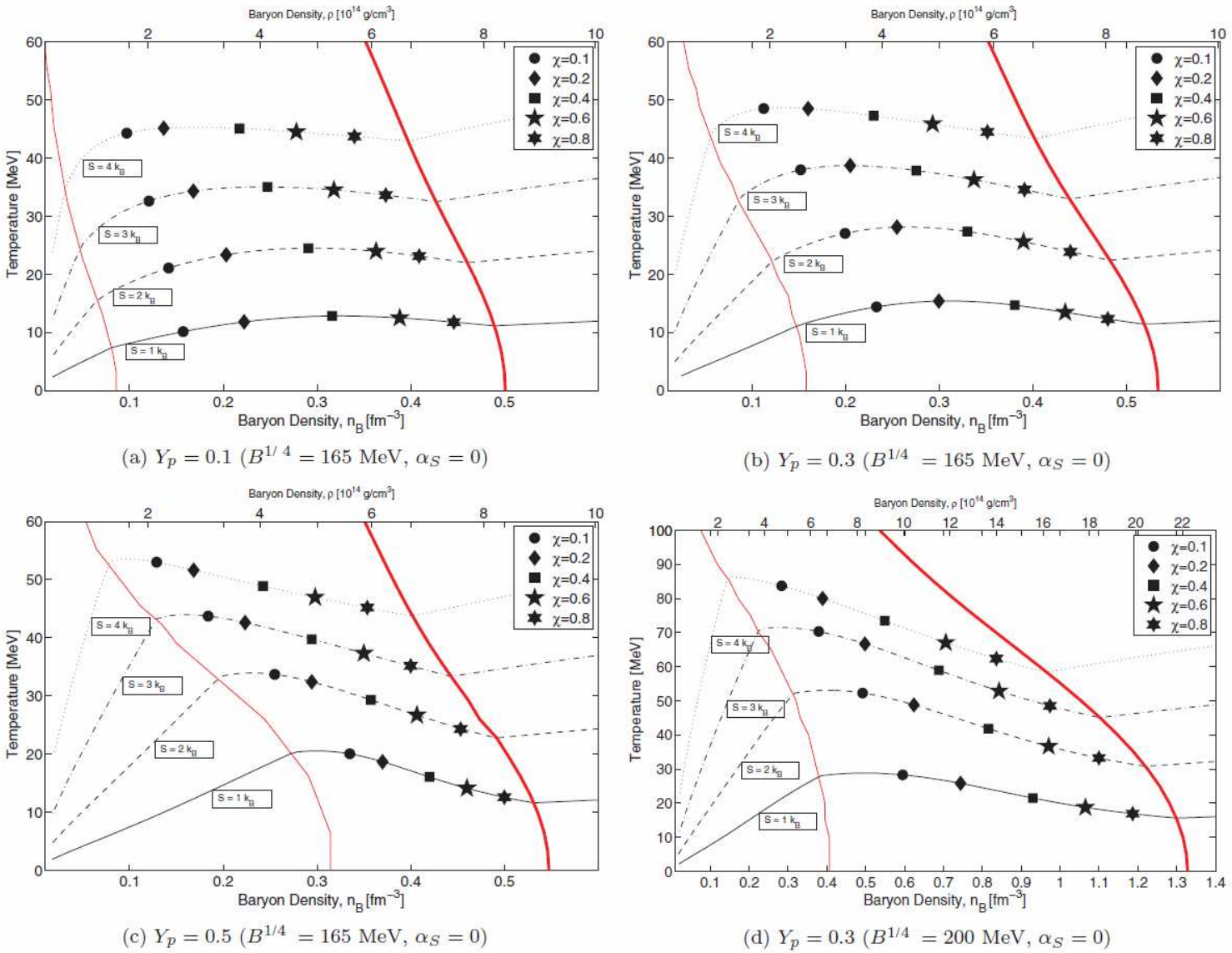
$$\left(\frac{\partial\epsilon}{\partial S}\right)_{P,Y}\frac{dS}{dr} + \left(\frac{\partial\epsilon}{\partial Y}\right)_{P,S}\frac{dY}{dr} > 0.$$

$$\left(\frac{\partial\rho}{\partial S}\right)_{P} = -\frac{\rho^2}{\left(\frac{\partial P}{\partial T}\right)_S} = -\frac{T\rho}{P\gamma c_{\rm V}}\left(\frac{\partial P}{\partial T}\right)_{\rho}$$

$$\left(\frac{\partial\epsilon}{\partial S}\right)_{P,Y} = \rho T\left[1 - \frac{\epsilon + P}{T\left(\frac{\partial P}{\partial T}\right)_S}\right]$$

Schematic explanation





(a) $Y_p = 0.1$ ($B^{1/4} = 165$ MeV, $\alpha_S = 0$)

(b) $Y_p = 0.3$ ($B^{1/4} = 165$ MeV, $\alpha_S = 0$)

(c) $Y_p = 0.5$ ($B^{1/4} = 165$ MeV, $\alpha_S = 0$)

(d) $Y_p = 0.3$ ($B^{1/4} = 200$ MeV, $\alpha_S = 0$)

Figure 6. Temperature evolution in the mixed phase for the different entropies per baryon $s = 1, 2, 3, 4\ k_B$. Graphs (a)–(c) show calculations for global proton fractions of $Y_p = 0.1$, $Y_p = 0.3$, and $Y_p = 0.5$ with $B^{1/4} = 165$ MeV. The red solid lines show the onset of the mixed phase (thin lines) and the beginning of the pure quark phase (thick lines) and are the same as in Figure 5(a). For comparison, graph (d) shows the temperature evolution in the mixed phase for $Y_p = 0.3$ and $B^{1/4} = 200$ MeV.

Possible astrophysical scenario