Neutron Stars as a Probe for Dense Matter

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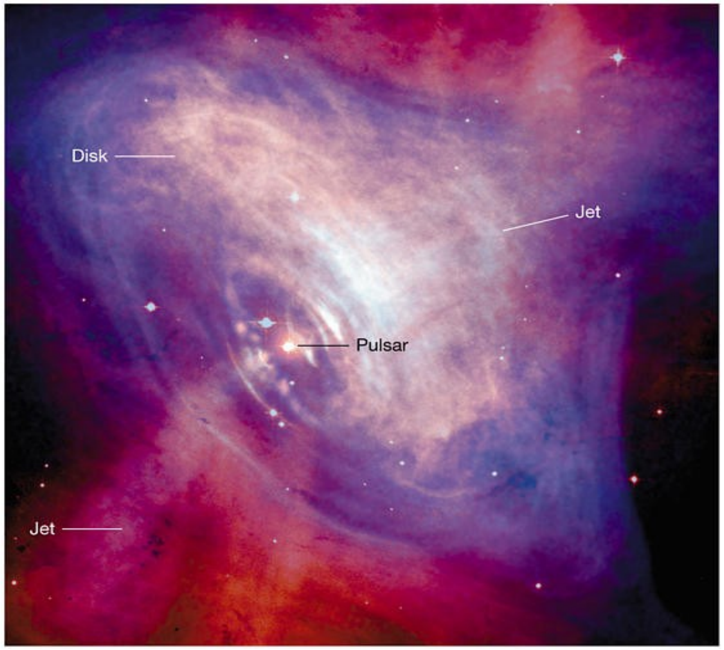


1. Motivation

- Having a model that can be used for:

  - small temperatures and high densities

    neutron stars

  - high temperatures and small densities

    heavy ion collisions

  - everything in the middle

- Study the effect of finite temperature and entropy in chiral symmetry restoration and deconfinement inside neutron stars

2. Non Linear Sigma Model

$$L_{MFT} = L_{Kin} + L_{Bscal} + L_{Bvec} + L_{scal} + L_{vec} + L_{SB}$$

$$L_{Bscal} + L_{Bvec} = -\sum_i \bar{\psi}_i [g_{i\omega}\gamma_0\omega + g_{i\phi}\gamma_0\phi + g_{i\rho}\gamma_0\tau_3\rho + m_i^*]\psi_i$$

$$L_{vec} = -\frac{1}{2}(m_\omega^2\omega^2 + m_\rho^2\rho^2 + m_\phi^2\phi^2)\frac{\chi^2}{\chi_o^2} -g_4\left(\omega^4 + \frac{\phi^4}{4} + 3\omega^2\phi^2 + \frac{4\omega^3\phi}{\sqrt{2}} + \frac{2\omega\phi^3}{\sqrt{2}}\right)$$

$$L_{scal} = \frac{1}{2}k_0\chi^2(\sigma^2 + \zeta^2 + \delta^2) - k_1(\sigma^2 + \zeta^2 + \delta^2)^2 - k_2\left(\frac{\sigma^4}{2} + \frac{\delta^4}{2} + 3\sigma^2\delta^2 + \zeta^4\right)$$

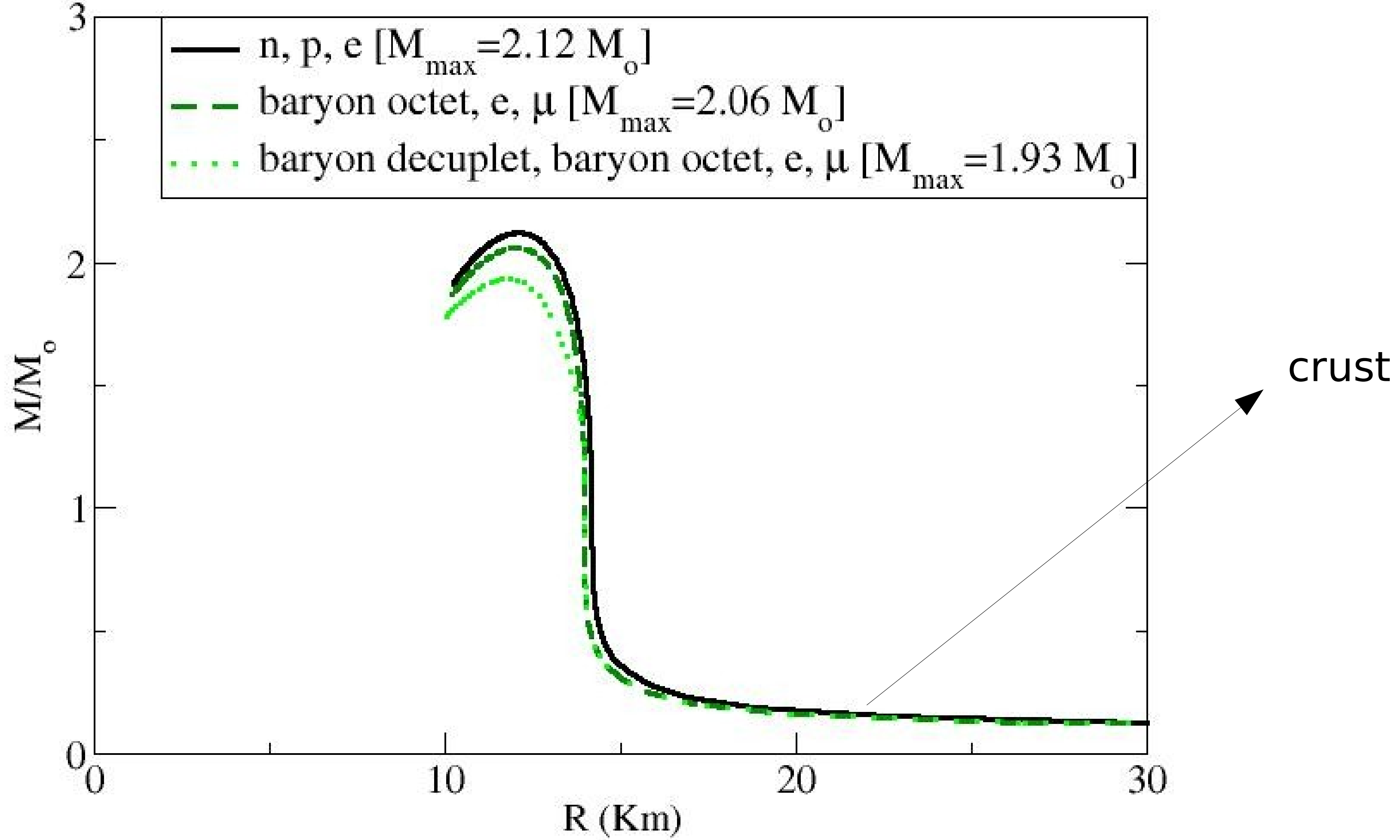
$$-k_3\chi(\sigma^2 - \delta^2)\zeta + k_4\chi^4 + \frac{1}{4}\chi^4 \ln\frac{\chi^4}{\chi_0^4} - \epsilon \quad \chi^4 \ln\frac{(\sigma^2 - \delta^2)\zeta}{\sigma_0^2\zeta_0}$$

$$L_{SB} = \left(\frac{\chi}{\chi_0}\right)^2 \left[m_\pi^2 f_\pi \sigma + \left(\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi\right)\zeta\right]$$

$$m^* = g_{i\sigma}\sigma + g_{i\delta}\tau_3\delta + g_{i\zeta}\zeta + \delta m$$

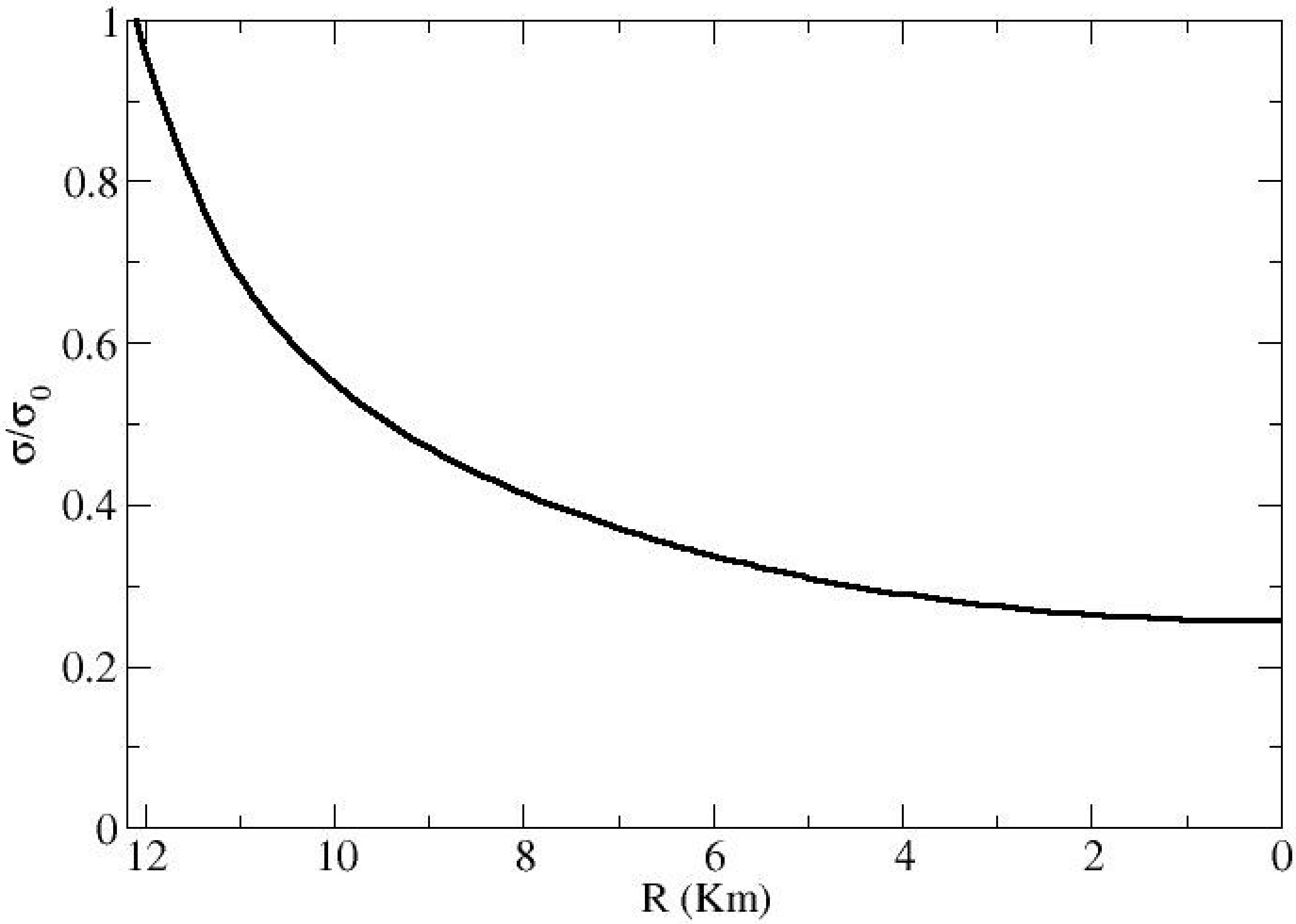
3. Results for Neutron Stars

Champion et al. (2008) J1903+0327 e-Print: astro-ph/08052396 **1.74±0.04**$M_\odot$



The new degrees of freedom decrease the neutron star mass.

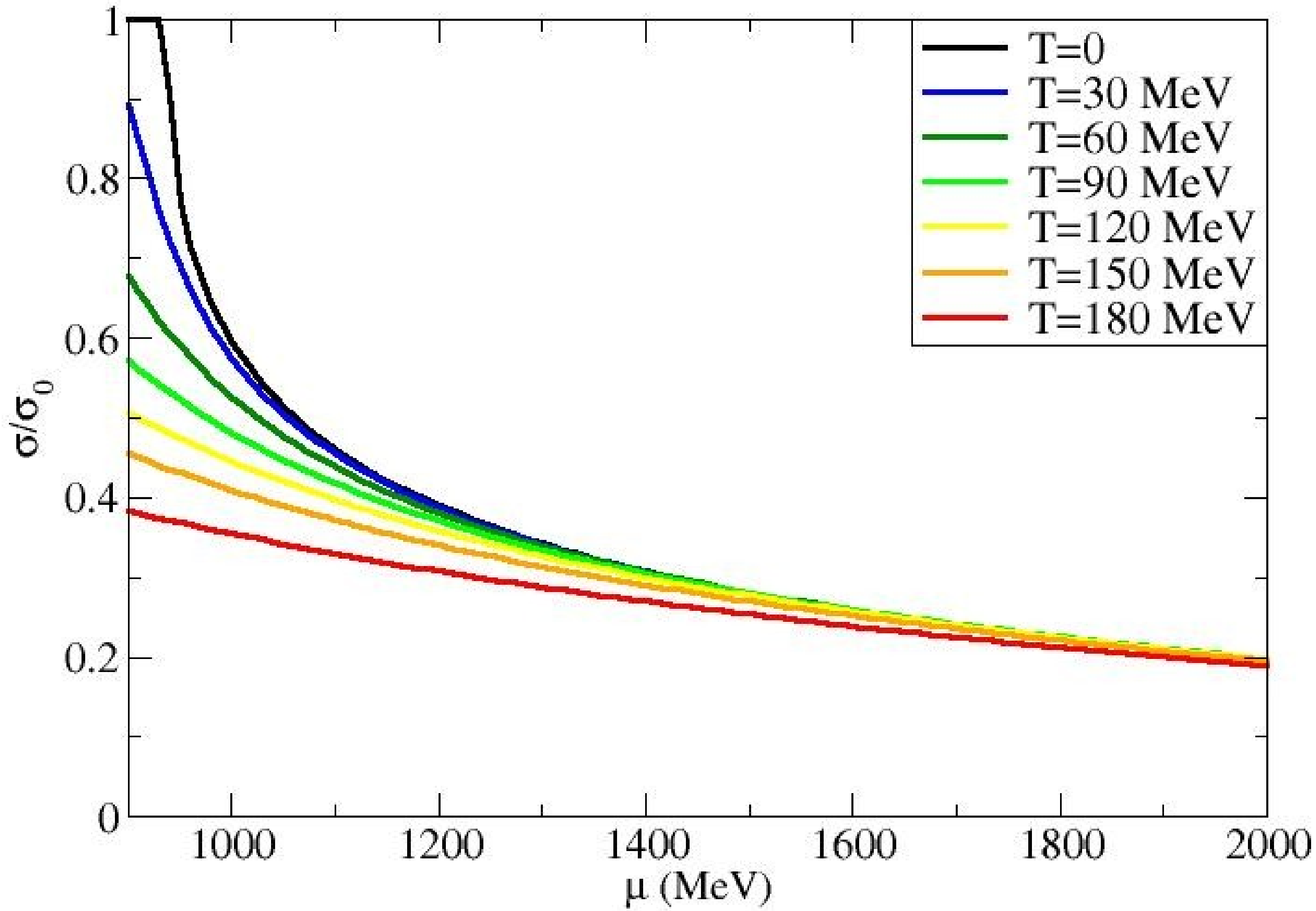
Scalar Condensate $\sigma = \langle \bar{q}q \rangle$



The chiral symmetry is partially restored in neutron stars.

The transition is a crossover.

Scalar Condensate $\sigma(\rho_B, T)$



The chiral symmetry is restored before (smaller chemical potential) for higher temperatures.

4. Deconfinement

- Same model for quarks and hadrons

$$m_h^* = g_{h\sigma}\sigma + g_{h\zeta}\zeta + \delta m + g_{h\phi}\phi^2$$

order parameter

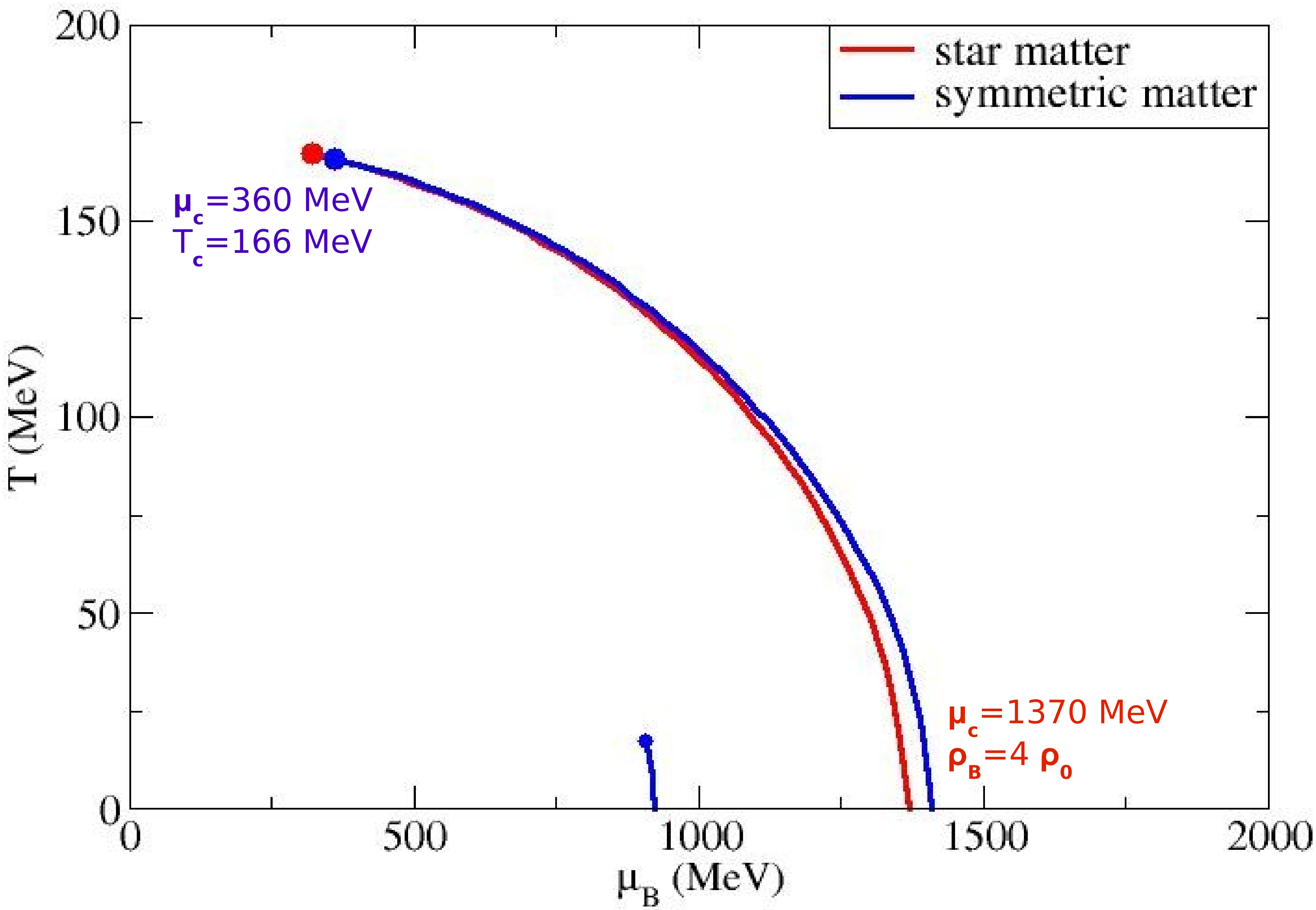
$$m_q^* = g_{q\sigma}\sigma + g_{q\zeta}\zeta + g_{q\phi}(1-\phi)$$

Ratti et al. Phys.Rev.D73:014019,2006
Ratti et al. Phys.Rev.D75:034007,2007

$$U = (a_0\ T^4 + a_1\ \mu^4 + a_2\ T^2\mu^2)\phi^2 + a_3 T_0^4 \ln(1 - 6\phi^2 + 8\phi^3 - 3\phi^4)$$

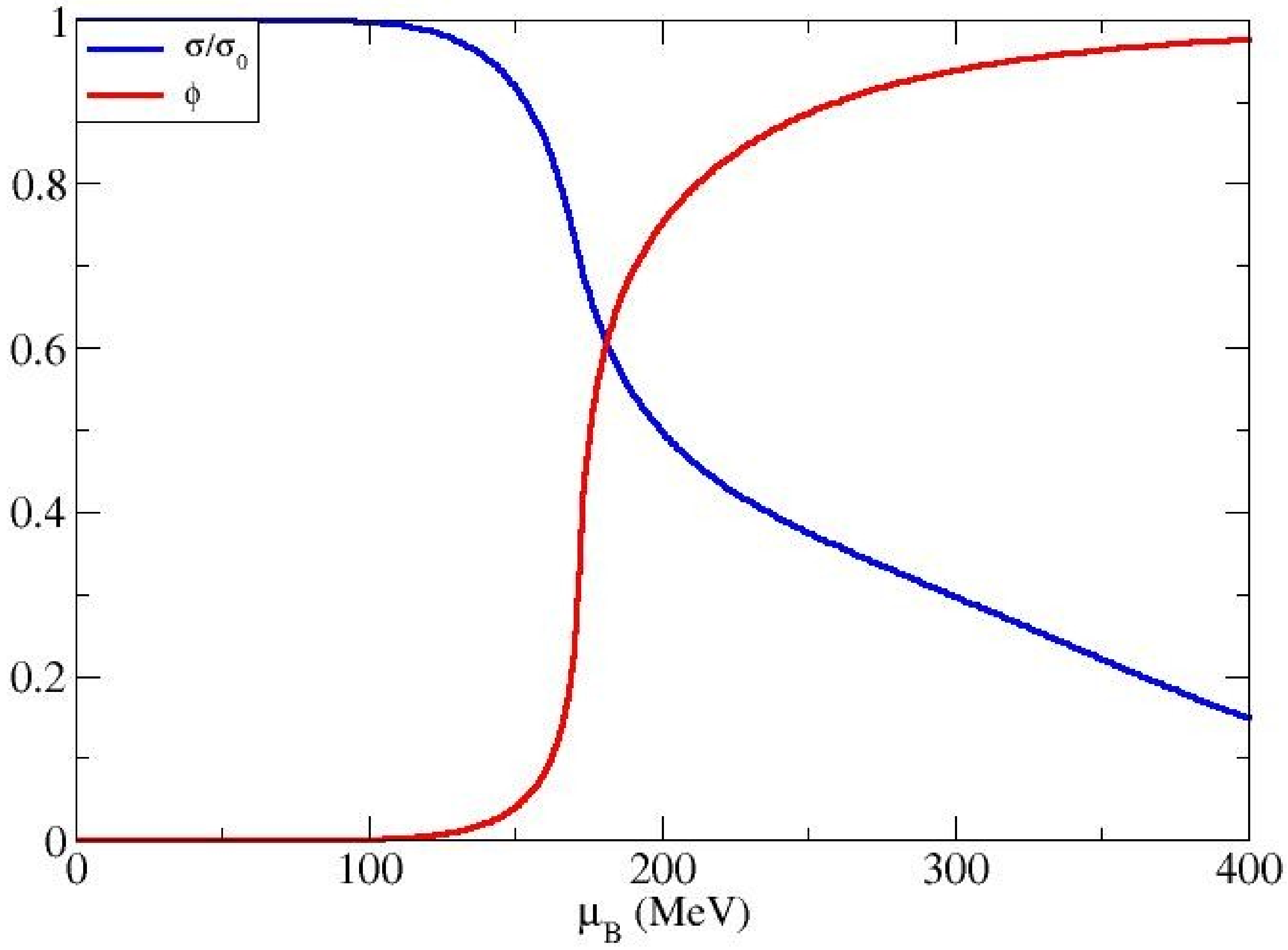
T_0: 270 MeV

5. Phase Diagram



The first order phase transition line ends up on a critical point.

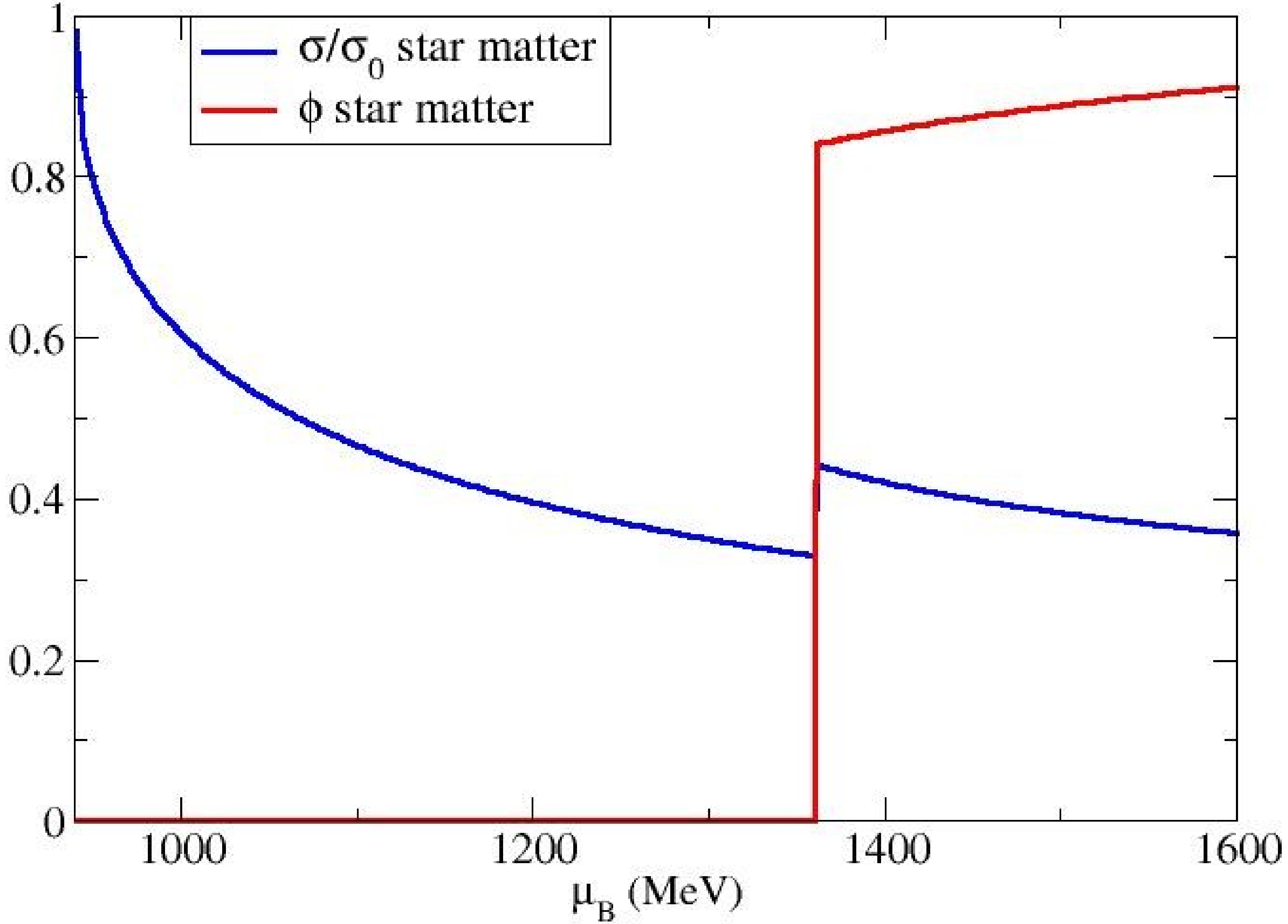
μ=0



For small chemical potential the transition to the deconfined phase is a cross over.

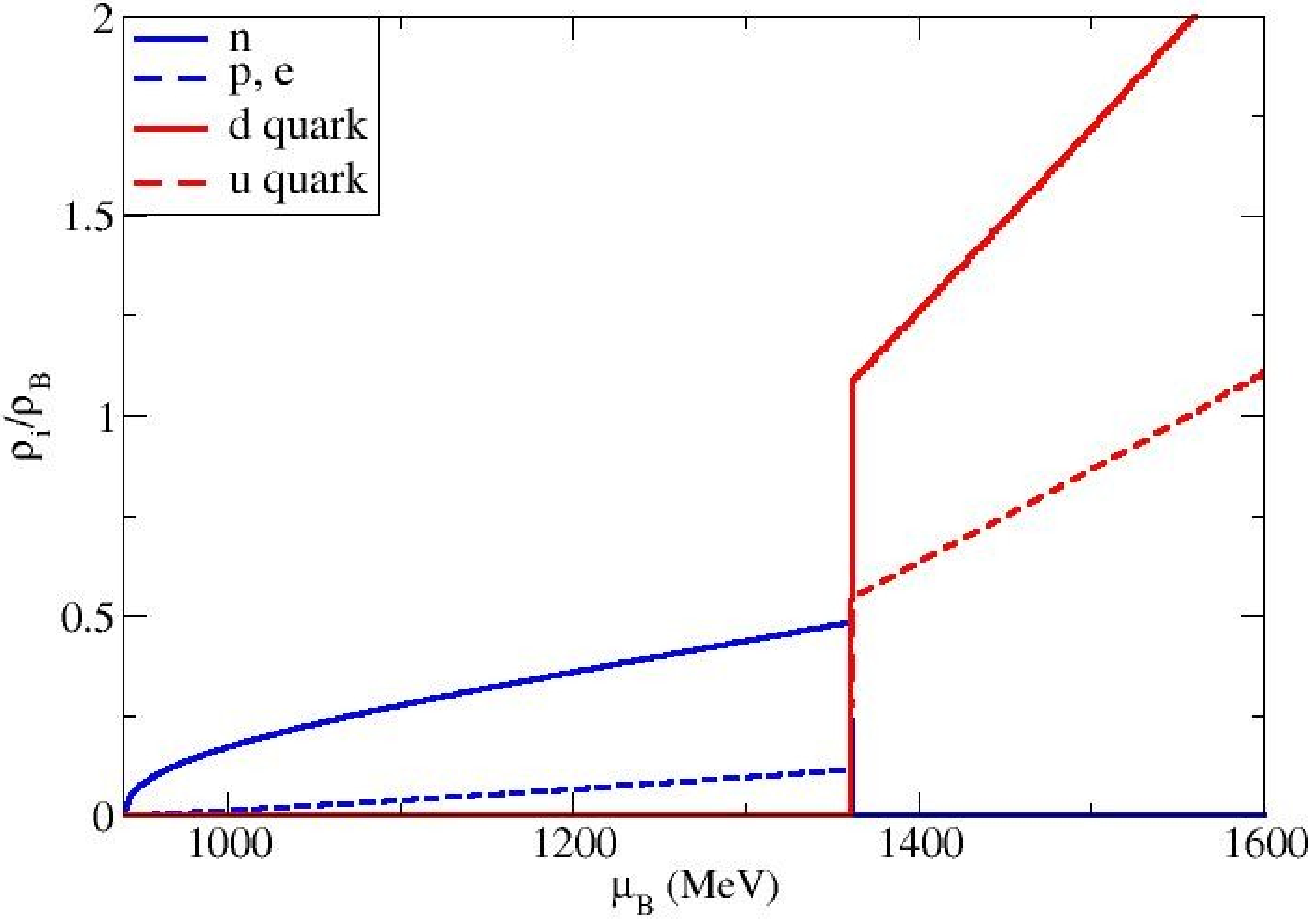
6. Results for Hybrid Stars

T=0



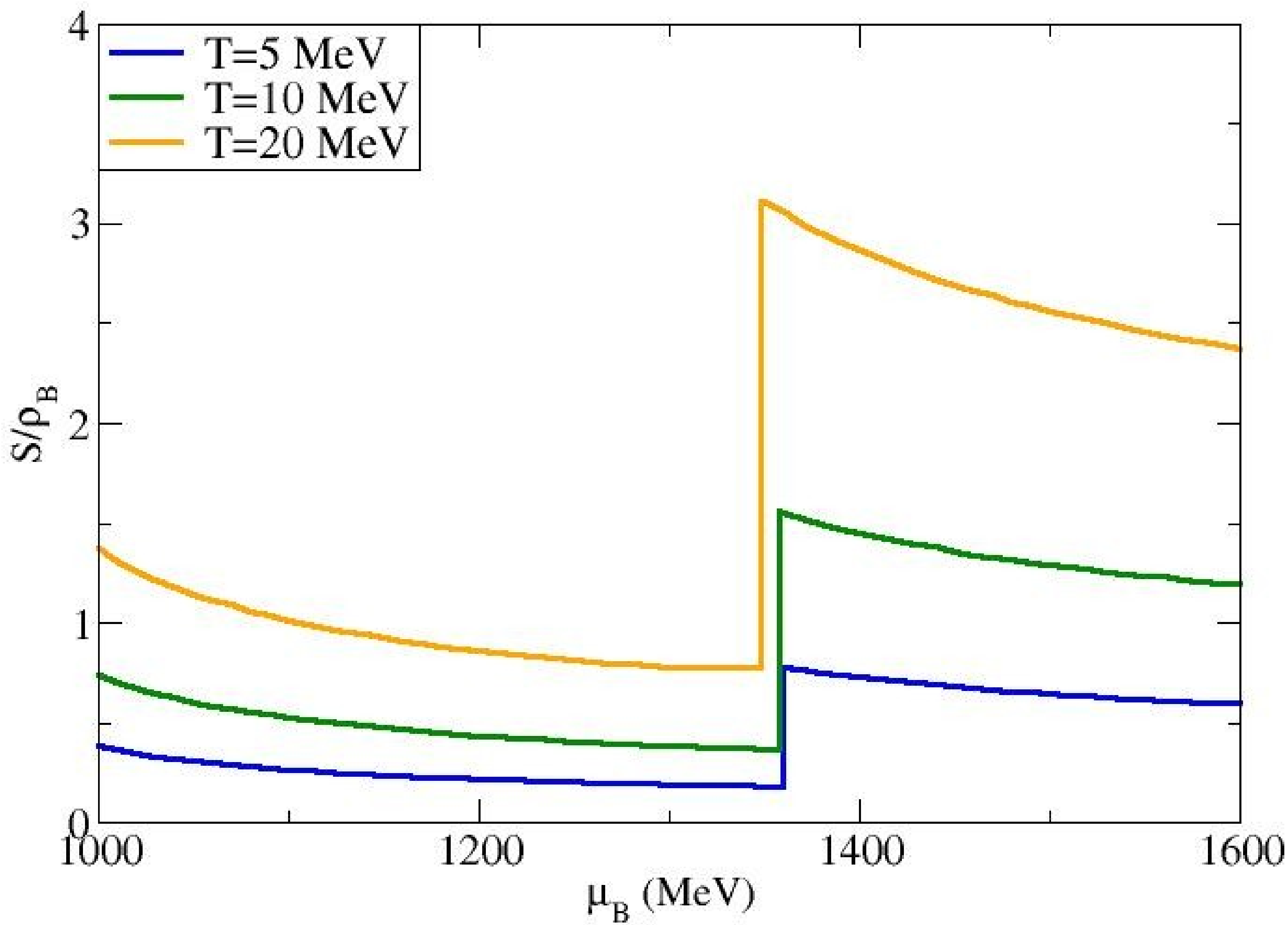
First order phase transition for the Polyakov field and the chiral condensate.

Population



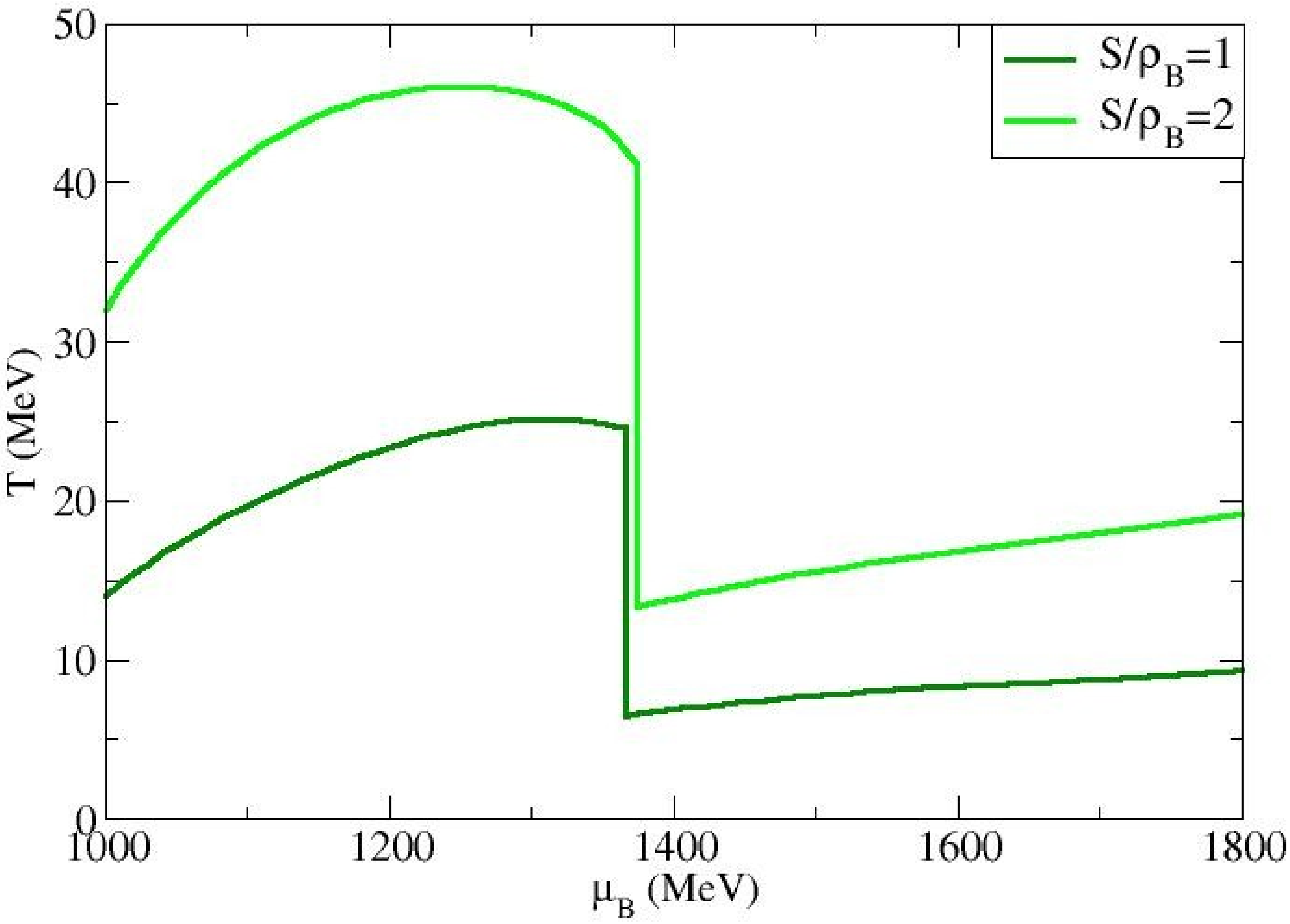
No mixed phase: just hadron matter or quark matter.

Finite temperature



For a fixed temperature there is a jump in the entropy at deconfinement.

Finite entropy



For a fixed entropy there is a jump in the temperature at deconfinement.

7. Conclusions

- Found out that the chiral symmetry is partially restored inside neutron stars and the transition is a cross over
- Included quarks and used Polyakov loop expected value as an order parameter for deconfinement
- Used the knowledge of the phase diagram to calibrate the model
- Obtained two distinct phases (no mixing) at zero temperature
- Observed a entropy/ temperature jump caused by the change of degrees of freedom during deconfinement

7. Outlook

- Calculate star properties including mixed phase
- Study the influence of star cooling and fast rotation on deconfinement