Parity doubling and repulsive interactions in the phenomenology of neutron stars

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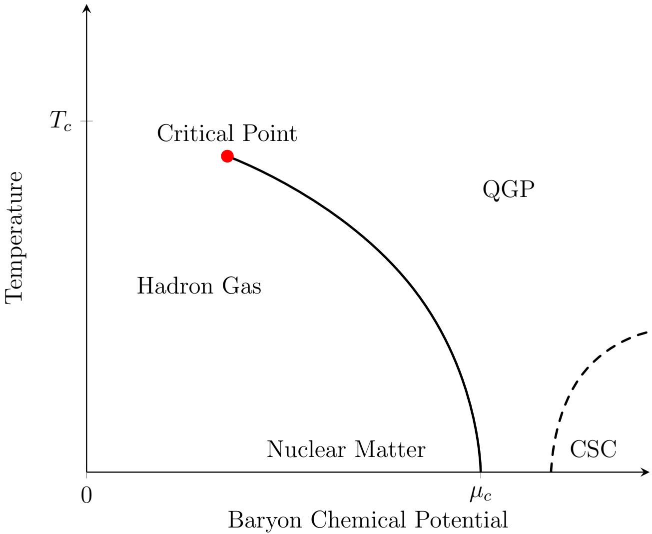
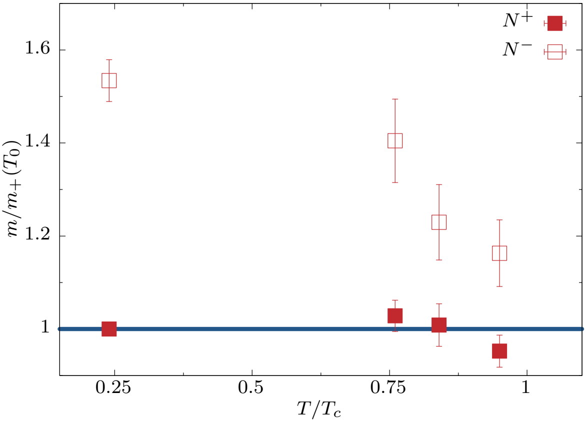
QCD Phase Diagram

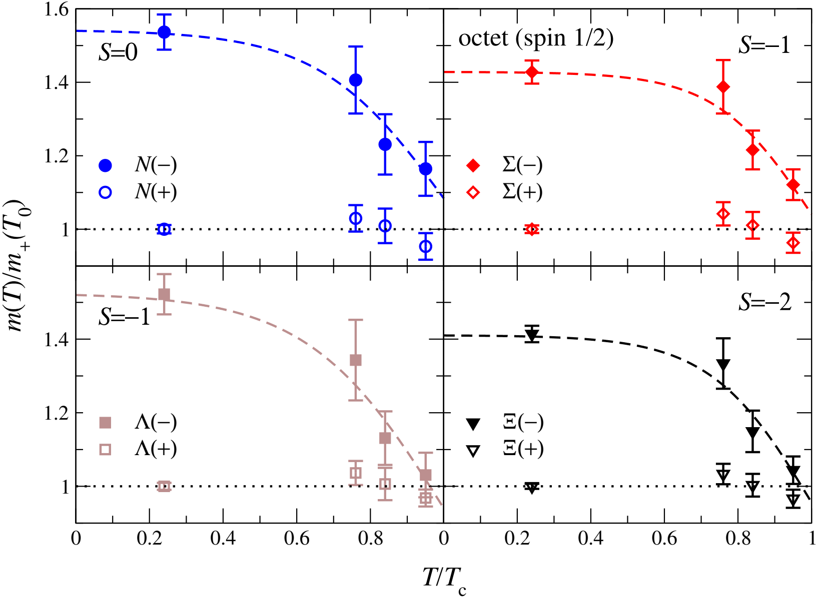


Parity Doubling in Lattice QCD Aarts *et al*, JHEP **1706**, 034 (2017)

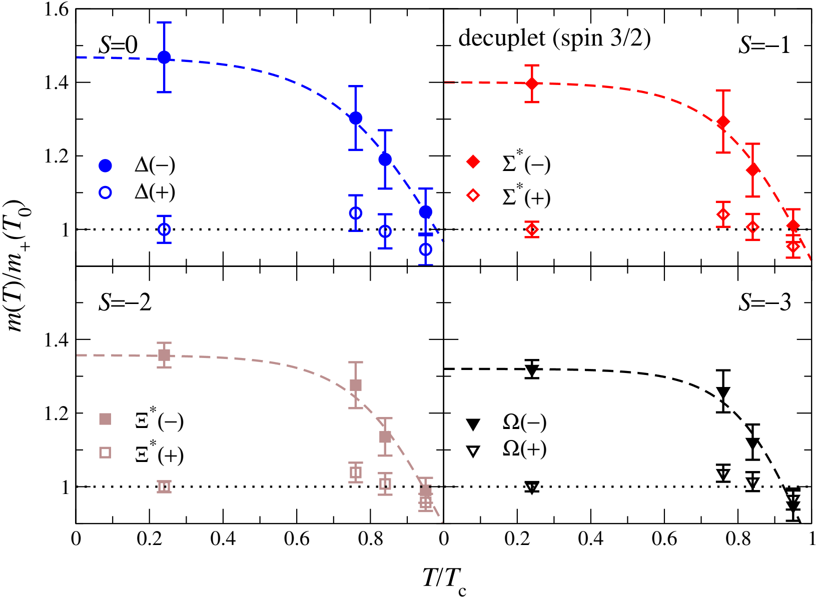


- Imprint of chiral symmetry restoration in the baryonic sector
- Expected to occur at low temperature
- $N^+ \rightarrow N(939), \quad N^- \rightarrow N(1535)$

Parity Doubling for Light Baryons Aarts *et al*, PRD **99** (2019)

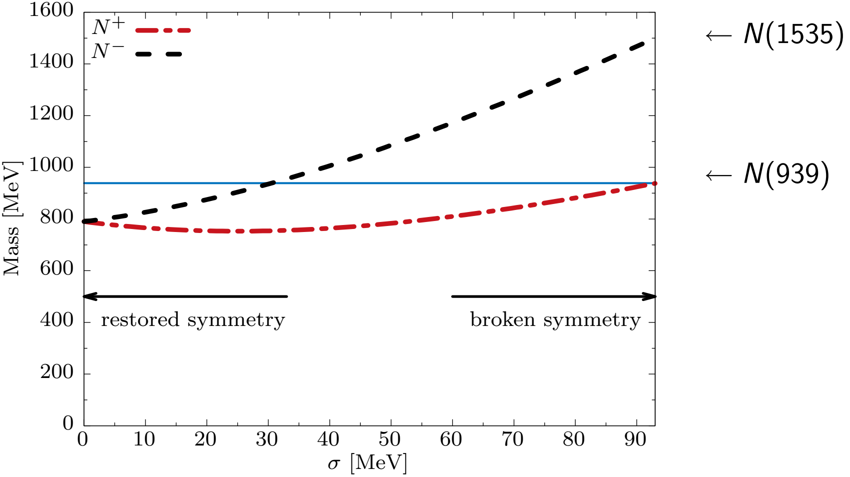


Parity Doubling for Light Baryons Aarts *et al*, PRD **99** (2019)



Parity Doubling in SU(2) Chiral Models DeTar, Kunihiro PRD **39** (1989)

$$m^{\pm} = \frac{1}{2}\left[\sqrt{4m_0^2 + c_1^2\sigma^2} \mp c_2\sigma\right] \xrightarrow{\sigma\to 0} m_0$$



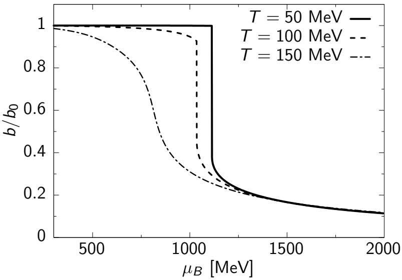
Hybrid Quark-Meson-Nucleon Model
Benić, Mishustin, Sasaki, PRD **91** (2015)

Parity Doublet Model + Quark-Meson Coupling

Statistical Confinement

UV cutoff: $\theta\left(\alpha^2 b^2 - \boldsymbol{p}^2\right) f_N$ + IR cutoff: $\theta\left(\boldsymbol{p}^2 - b^2\right) f_q$

↑ model parameter



const b $\longrightarrow$ scalar field b

↓

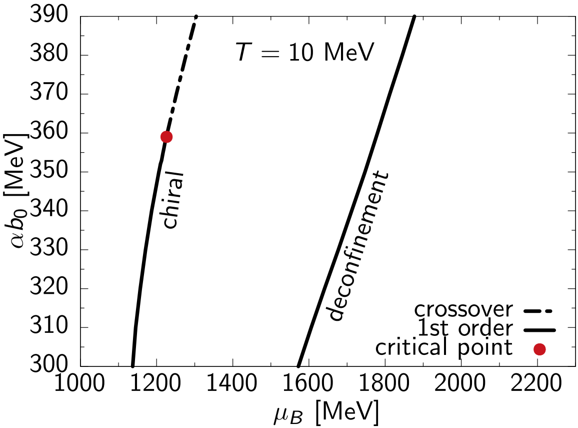
generated from potential

↓

$b > 0$ favors nucleons

$b \to 0$ favors quarks

Phase Structure with Sequential Transitions

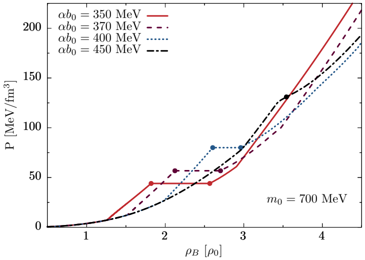


- 1st Order Deconfinement Transition
- $\alpha \to$ Order of Chiral Transition $\to$ Critical Point

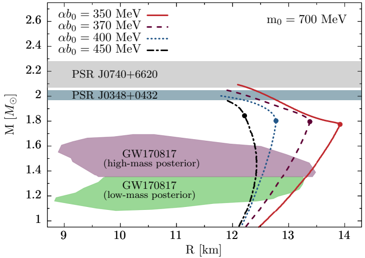
Marczenko, Sasaki, PRD **97** (2018)

Parity Doubling and Characteristics of Neutron Stars

- Neutron star conditions:
  - β-equilibrium
  - charge neutrality
- $P(\rho) \leftrightarrow$ TOV Equation $\leftrightarrow M(r)$



- 2 $M_\odot$ with chirally restored and confined core
- Deconfinement above 2 $M_\odot$
- Flattening not necessarily signals deconfinement



Marczenko, Blaschke, Sasaki, Redlich, PRD**98** (2018), Universe **5** (2019)

Astrophysical Constraints

Neutron star cooling

- Threshold $M \gtrsim 1.4\ M_\odot$

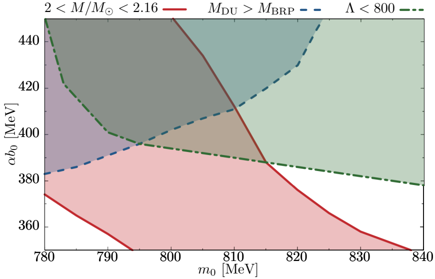
Tidal deformability

- $\Lambda \sim (M/R)^{-5}$
- $\Lambda(1.4\ M_\odot) < 800$

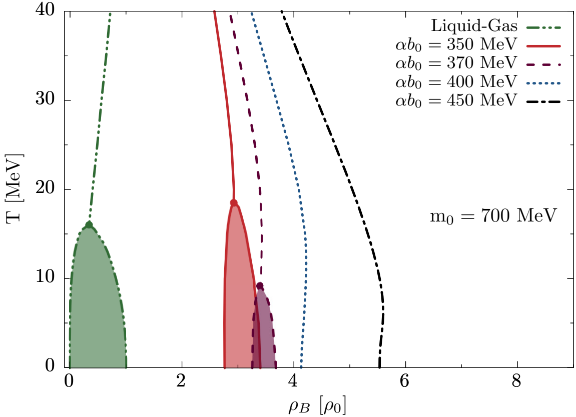
- Two-solar mass: stiff EoS
- Cooling threshold: soft EoS
- Compactness: soft EoS

$\downarrow$

Limit the parameter space

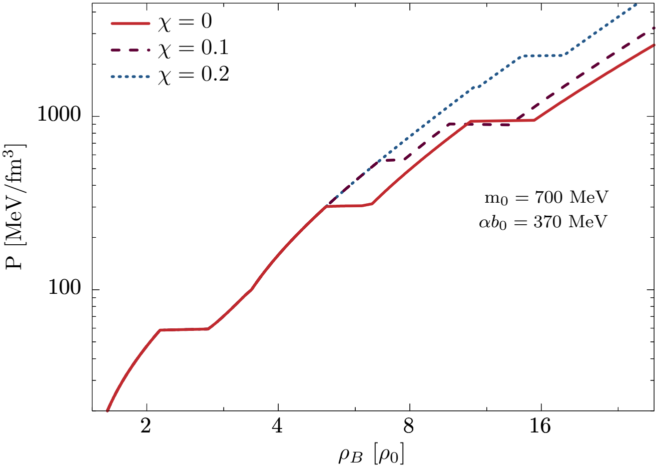


From Constraints to Phase Diagram



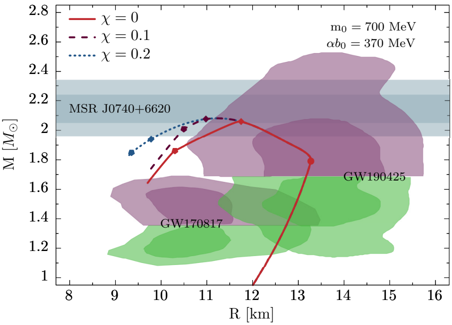
- Possible Critical Point at low T or even absent!

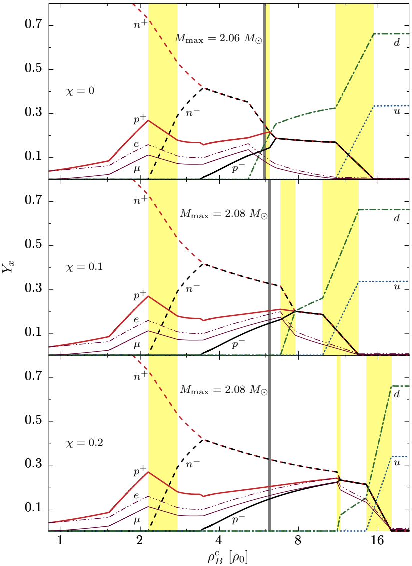
Repulsive Quark-Vector Interactions



- isoscalar-vector: $g_\omega^q = \chi g_\omega^N$ isovector-vector: $g_\rho^q = \chi g_\rho^N$
- Onset of quarks shifted to higher densities

Mass-radius and Particle Content





- $M_{\max}$ reached in chirally restored but confined phase
- Quarks appear only in the unstable branch

Conclusions

Hybrid QMN model - unified framework for cold and dense matter:

- Parity doubling has an influence on NS phenomenology
- Astrophysical constraints $\rightarrow$ CP at low T or even absent
- 2 $M_{\odot}$ NS with chirally restored but confined core
  - quarkyonic matter?
- No deconfined neutron-star cores

Thank You