Effect of repulsive interaction on strongly interacting matter and neutron stars in chiral mean field model

Anton Motornenko[1,2], Somenath Pal[3,*] Abhijit Bhattacharyya[3], Jan Steinheimer[2], and Horst Stoecker[1,2,4]

[1] *Institut für Theoretische Physik, Goethe Universität, D-60438 Frankfurt am Main, Germany*

[2] *Frankfurt Institute for Advanced Studies, Giersch Science Center, D-60438 Frankfurt am Main, Germany*

[3] *Department of Physics, University of Calcutta, 92, A.P.C. Road, Kolkata-700009, India and*

[4] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt, Germany*

Introduction

Effective models with symmetries of Quantum Chromodynamics (QCD) are used to describe the thermodynamics of the hot/dense strongly interacting matter in the non-perturbative regime. Such matter is expected to be present inside astrophysical objects like neutron stars and can be recreated in relativistic heavy-ion colliders. The Chiral Mean Field (CMF) model [1, 2], which we discuss here, does not require any phase matching and thus allows for a continuous transition from confined to deconfined degrees of freedom while at the same time giving a proper description of nuclear matter and neutron star matter phenomenology.

Model description

It incorporates major concepts of QCD phenomenology: chiral interactions in the baryon octet [3], the full PDG hadron list, excluded volume repulsive interactions among all hadrons, baryon parity doubling [4], and quarks coupled to an effective Polyakov loop potential (similar to the Polyakov Nambu Jona-Lasinio model). The Grand Canonical Partition function can be written as

$$\Omega = \Omega_{\mathrm{q}} + \Omega_{\bar{\mathrm{q}}} + \Omega_{\mathrm{h}} + \Omega_{\bar{\mathrm{h}}} - \left(U_{\mathrm{sc}} + U_{\mathrm{vec}} + U_{\mathrm{Pol}}\right) , \qquad (1)$$

where the subscripts q, $\bar{q}$, h, $\bar{h}$, sc, vec and Pol denote contributions from quarks, anti-quarks, hadrons, anti-hadrons, scalar mesons, vector mesons and effective gluon potential respectively.

Results

In this work, the CMF model is employed to study the change of hadronic properties and the EOS dependence on repulsive interactions. We have considered the excluded volume of non-strange barons to be 1 fm^3, that of mesons as 1/8 fm^3. We have taken four different values of radius of strange baryons (v_{BS}=1,1/2,1/4,1/8 fm^3) and have compared their results.

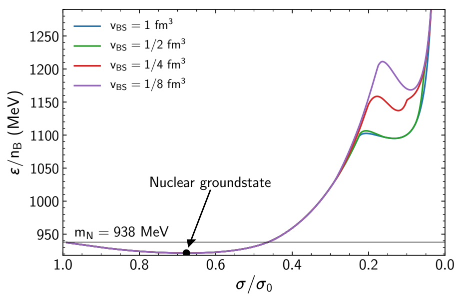

FIG. 1: Energy per baryon ε/n_B as a function of the chiral condensate σ/σ_0 for $T = 0$, isospin symmetric nuclear matter.

The properties of nuclear ground state such as energy per baryon (ε/n_B) is not affected by the value of the excluded volume

*Electronic address: `somenathpal1@gmail.com`

parameter. The presence of a excluded volume dependent second minimum in (ε/n_B) at small chiral condensate indicates that the chiral phase transition is sensitive to the excluded volume parameter and the presence of a phase transition with a metastable state. From Fig. (2) one can see that the phase transition gets slightly stronger with the decrease of excluded volume of hyperons, also the chemical potential at which the phase transition occurs, increases. As shown in Fig. (3), the strangeness-baryon susceptibility (χ_{BS}^{11}) along the chemical freeze-out line shows significant dependence on the EV parameter of hyperons.

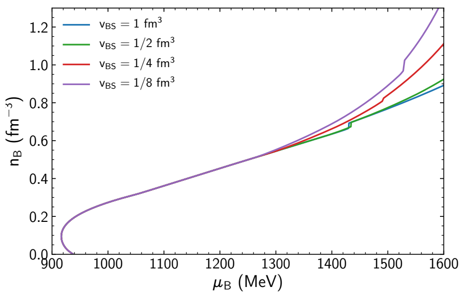

FIG. 2: Net baryon density n_B as a function of baryon chemical potential μ_B for $T = 0$ isospin symmetric nuclear matter for strange baryon excluded volume $v_{\text{BS}} = 1$, 1/2, 1/4, 1/8 fm^3.

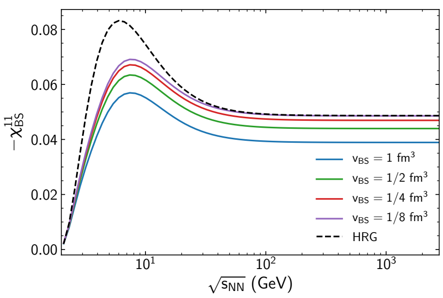

FIG. 3: Collision energy dependence of baryon-strangeness second-order susceptibility χ_{BS}^{11} along the chemical freeze-out curve for zero net-strangeness isospin-symmetric matter.

Fig. (4) shows the mass-radius diagram of neutron stars for different excluded volumes of hyperons. The properties of static neutron stars and the properties of the QCD phase transition in cold Neutron Star matter seem to be dominated by the non-strange baryon degrees of freedom.

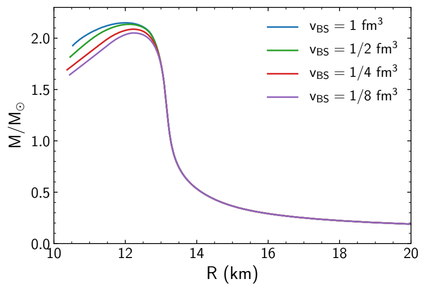

FIG. 4: The CMF mass-radius diagrams for four different excluded volume parameters of strange baryons.

Acknowledgments

We thank Roman Poberezhnyuk for carefully reading the manuscript and fruitful discussions. The authors thank the support from HIC for FAIR and HGS-HIRe for FAIR. The authors appreciate support by the Alexander von Humboldt (AvH) foundation and the BMBF through a Research Group Linkage programme. SP thanks University Grants Commission (India) for support. JS thanks the Samson AG and the BMBF through the ErUMData project for funding. JS and HSt thank the Walter Greiner Gesellschaft zur Förderung der physikalischen Grundlagenforschung e.V. for support. HSt acknowledges the support through the Judah M. Eisenberg Laureatus Chair at Goethe University.

References

[1] J. Steinheimer et al. Phys. Rev. C **84**, 045208 (2011).
[2] A. Motornenko et al. Phys. Rev. C **101**, 034904 (2020).
[3] P. Papazoglouet al. Phys. Rev. C **59**, 411-427 (1999).
[4] C. E. Detar and T. Kunihiro, Phys. Rev. D **39**, 2805 (1989).