QUARK DECONFINEMENT IN PROTONEUTRON STARS CORES: ANALYSIS WITHIN THE MIT BAG MODEL

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I. INTRODUCTION

It is currently a matter of speculation the actual occurrence of quark matter during protoneutron star (PNS) evolution. The standard scenario for the birth of neutron stars indicates that these objects are formed as consequence of the gravitational collapse of massive stars. Initially, PNSs are very hot and lepton-rich objects, where neutrons are temporarily trapped. During the first tens of seconds of evolution the PNS evolves to form a cold ($T < 10^8$ K) catalyzed neutron star. As neutrons are radiated, the lepton - per - baryon content of matter goes down and the neutrino chemical potential tends to essentially zero in 50 seconds. Deleptonization is fundamental for quark matter formation inside neutron stars, since it has been shown that the presence of trapped neutrons in hadronic strongly disfavors the deconfinement transition. In fact, neutrino trapping makes the density for the deconfinement transition to be higher than in the case of neutrino-free hadronic matter. As a consequence, the transition could be delayed several seconds after the bounce of the stellar core. When color superconductivity is taken into account, the decrease of temperature decreases the transition density and increases the pairing gap.

II. THE HADRONIC PHASE

For hadronic phase we shall use a model based on a relativistic Lagrangian of hadrons interacting via the exchange of $\alpha$, $\rho$, and $\omega$ mesons: a nonlinear Walecka model (NLWM) which includes the whole baryon octet, electrons and electrino neutrons in equilibrium with weak interactions. The Lagrangian of the model is given by:

$$L = \frac{1}{4} \left( \partial_{\mu} \psi \right) \left( \partial_{\nu} \psi \right) - \frac{1}{2} m_{\psi}^2 \left( \psi \right) \left( \psi \right) + \frac{1}{4} \left( \partial_{\mu} \rho_\mu \right) \left( \partial_{\nu} \rho_\nu \right) - \frac{1}{2} m_{\rho}^2 \left( \rho_\mu \right) \left( \rho_\mu \right) + \frac{1}{4} \left( \partial_{\mu} \omega_\mu \right) \left( \partial_{\nu} \omega_\nu \right) - \frac{1}{2} m_{\omega}^2 \left( \omega_\mu \right) \left( \omega_\mu \right) + \left( \frac{1}{2} \left( \partial_{\mu} A_\mu \right) \left( \partial_{\nu} A_\nu \right) - \frac{1}{2} m_{A}^2 \left( A_\mu \right) \left( A_\mu \right) \right)$$

where $\psi$, $\rho_\mu$, $\omega_\mu$, and $A_\mu$ are the fields for the electron, baryon, meson, and photon, respectively. The coefficients $m_{\psi}$, $m_{\rho}$, $m_{\omega}$, and $m_{A}$ are the mass parameters of the fields. The constants $\lambda_{\rho}$, $\lambda_{\omega}$, and $\lambda_{A}$ are the coupling constants of the meson fields.

III. THE QUARK MATTER PHASE

The quark phase is composed by $u$, $d$, and $s$ quarks, electrons, electron neutrinos and the corresponding antiparticles. We describe this phase by means of the MIT bag model at finite temperature with zero strong coupling constant, zero $u$ and $d$ quark masses and strange quark mass $m_s = 150$ MeV.

IV. DECONFINEMENT TRANSITION IN PROTONEUTRON STARS

The flavor composition of hadronic matter in $\beta$-equilibrium is different from that of a $\beta$-stable quark-matter drop. Roughly speaking, the direct formation of a $\beta$-stable quark-drop with N quarks will need the almost simultaneous conversion of N/3 up and down quarks into strange quarks, a process which is strongly suppressed with respect to the formation of a non-$\beta$-stable drop by a factor $\approx G^N_{\text{QCD}}$. For typical values of the critical-size $\beta$-stable drop ($N \approx 1000$), the suppression factor is actually tiny. Thus, quark matter must be conserved during the deconfinement transition.

V. CONCLUSIONS

The expected effects on protoneutron star evolution are as follows:

- When a PNS is formed it is hot and it has a large amount of trapped neutrinos. If color superconductivity were not considered, cooling will increase the transition density while deleptonization will decrease it.

VI. REFERENCES