Protoneutron star within the extended field theoretical model

Gulshan Mahajan and Shashi K. Dhiman
Department of Physics, Himachal Pradesh University, Shimla - 171005, India.

The structure of compact star can be very well understood if the equation of state (EOS) for dense matter is known. Large number of EOSs exist in literature [1] but still there are large uncertainties in the EOS at supranuclear densities. It is preassumed that the protoneutron stars are formed as consequence of the gravitational collapse and supernova explosion of a massive star. Initially protoneutron star(PNS) are very hot and lepton rich star. During the first tens of second of evaluation the PNS temperature reduces to tens of MeV and the catalyzed compact star is formed. Lot of efforts are going on to attain the perfect EOS that exist in nature so that we may understand the high density behavior of nuclear matter. In this paper we attempted to explore the effect of temperature on mass of the protoneutron star with varied particle composition within the extended field theoretical model by using parameterization generated by varying the neutron skin thickness (Δr) and ω-meson self coupling (ζ) [2, 3]. The Lagrangian density for the extended ERMF model can be written as $\mathcal{L} = \mathcal{L_{BM}} + \mathcal{L}_\sigma + \mathcal{L}_\omega + \mathcal{L}_\rho + \mathcal{L}_{\sigma\omega\rho}$ [2, 4]. The Lagrangian terms and the Euler-Lagrangian equations for ground state expectation values of the meson fields are same as in [2]. At finite temperatures the baryon vector density ρ_B, scalar density ρ_{sB} and charge density ρ_p are, $\rho_B = \frac{\gamma}{(2\pi)^3}\int_0^{k_B} d^3k(n_i - \overline{n_i}), \rho_{sB} = \frac{\gamma}{(2\pi)^3}\int_0^{k_B} d^3k\frac{M_B^*}{\sqrt{k^2+M_B^{*2}}}(n_i + \overline{n_i}), \rho_p = \left\langle\overline{\Psi}_B\gamma^0\frac{1+\tau_{3B}}{2}\Psi_B\right\rangle(n_i + \overline{n_i})$. Where, γ is the spin-isospin degeneracy. The $M_B^* = M_B - g_{\sigma B}\sigma - g_{\sigma^* B}\sigma^*$ is the baryon effective mass , k_B is its Fermi momentum and τ_{3B} denotes the isospin projections of baryon B. The thermal distribution function in these expression are defined by $n_i = \frac{1}{e^{\beta(\epsilon_i^* - \mu^*)}+1}, \overline{n_i} = \frac{1}{e^{\beta(\epsilon_i^* + \mu^*)}+1}$ where $\epsilon_i^* = \sqrt{k^2 + M_B^{*2}}$ and $\mu^* = \mu - g_{\omega N}\omega$.

The Fig.1 shows the particle fraction with changing density at different temperatures having BSR15 parametrization. On increasing temperature the threshold density for the Λ decreases significantly whereas for other hyperons it increases slightly. Normally the hyperons appear for 0 MeV temperature at a density of $\sim 0.4 fm^{-3}$ (threshold density for $\Lambda = 0.376, \Sigma^- = 0.482$ and $\Xi^- = 0.490 fm^{-3}$) but as temperature is increased to 10 MeV the appearing density decreases for Λ to $0.112 fm^{-3}$ while for Σ^- it increases to $0.902 fm^{-3}$ and Ξ^- disappears. We also explored the effect on particle fraction without hyperons and found that on increasing temperature the neutron fraction increases slightly whereas the proton,electron and muon fraction decreases. The change in EOSs for various parametrization is presented in Fig.2 for the temperatures of 0,3,5,and 10 MeV respectively. The dotted lines represent the EOSs on inclusion of hyperons . It is clear from figure that the induction of hyperons softens the EOS at all temperature. The variation of maximum mass with ζ and Δr and temperature is summerised in Fig.3 for all the parametrisation BSR1-BSR21. It is found that the soft EOSs having ζ =0.03 and 0.06 follow a symmetric pattern whereas the mass data for EOSs with ζ =0.0 show no such pattern. On increasing temperature the EOSs becomes stiff and thereby resulting in increase of mass of PNS. We also present the variations in the properties of the star on inclusion of hyperons. It is clear from data that on inclusion of hyperons the EOSs becomes soft and thereby resulting in the decrease of maximum gravitational masses of the star. We varied the hyperon meson coupling parameter $X_{wy}$from 0.50 to 0.70 at all temperatures and we found that on increasing the coupling parameter the maximum gravitational mass of the star also increased. This increase was large for the smaller values of ζ and small for larger

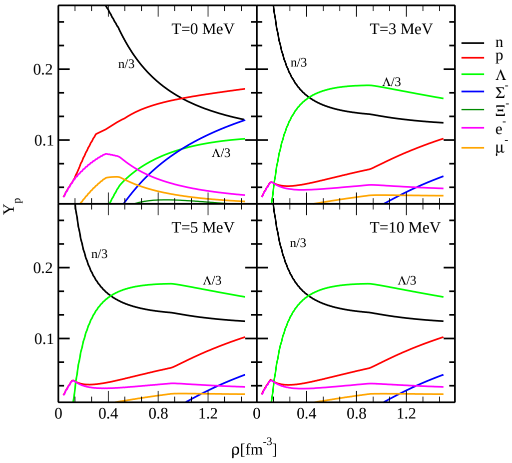

FIG. 1: Particle fraction as a function of density of the compact star obtained for BSR15 parametrization and having hyperon meson coupling X_{wy}=0.50 parameter at different temperatures. The curve labeled as n/3 and Λ/3 should be multiplied by 3 to get actual neutron and Λ fractions.

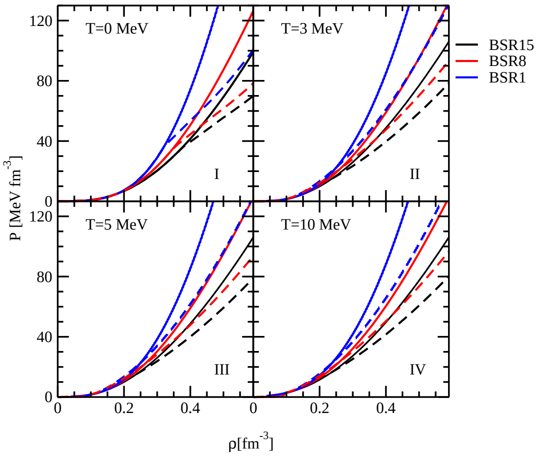

FIG. 2: The pressure is plotted against density for EOS obtained by using BSR1, BSR8 and BSR15 parametrization. The dashed lines represent EOSs with hyperons having hyperon meson coupling X_{wy}=0.50 and solid lines represent EOSs without hyperons at temperatures of 0,3,5 and 10 MeV.

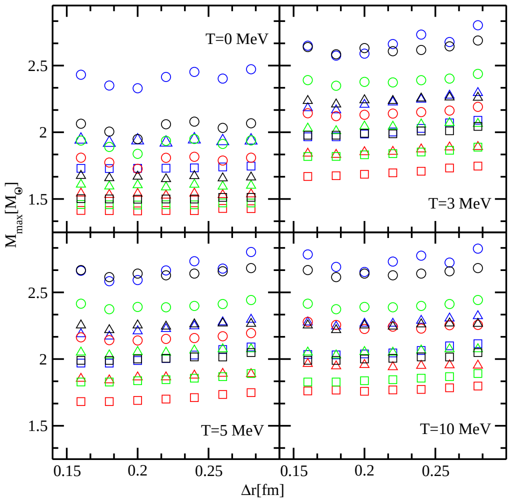

FIG. 3: The maximum gravitational mass of compact star is plotted for different values of neutron skin thickness(Δr) for the ^{208}Pb nucleus at temperature of 0,3,5 and 10 MeV. Circles, triangles and squares are for the ζ = 0.0,0.03 and 0.06 respectively. The blue color represents the masses of EOSs without hyperons whereas red color represent EOSs having hyperon with hyperon meson coupling X_{wy}=0.50 .The green and black color represent EOSs having hyperon with hyperon meson coupling X_{wy} 0.60 and 0.70 respectively.

values of ζ.

References

[1] S. K. Dhiman, G. Mahajan, and B. K. Agrawal, Nucl. Phys. A **836**, 183 (2010).

[2] S. K. Dhiman, R. Kumar, and B. K. Agrawal, Phys. Rev. C **76**, 045801 (2007).

[3] B. K. Agrawal, Phys. Rev. C **81**, 034323 (2010).

[4] B. D. Serot and J. D. Walecka, Int. J. Mod. Phys. E **6**, 515 (1997).