Properties of strange quark stars within vector MIT Bag model with modified vector channels

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Introduction

According to the strange matter (SM) hypothesis proposed by Witten, SM may be the true ground state of strongly interacting matter. SM is a kind of quark matter that consists of up, and down along with strange quarks. When the core of a neutron star (NS) goes into phase transition from hadronic to quark phase, the entire core could convert into a strange quark star (SQS). The SM hypothesis has been studied using different models, and one of the initial models is the MIT bag model. The MIT bag model was improved by incorporating interactions among quarks through their coupling to a mediating vector field, known as the vector MIT bag model [1, 2]. Although these models provided valuable insights for theoretical exploration, still further refinements are necessary to fully understand the dynamics of quark matter and its impact on compact objects like neutron stars. In the present work, we shall use the vector MIT bag model considering the contributions of vector fields ω, ρ and ϕ to obtain the mass-radius relationship of the SQSs.

Methodology

The vector MIT bag model is used in the present work to study the effect of ρ and ϕ mesons along with ω meson. The Lagrangian density of such a configuration [1]

$$\begin{aligned}\mathcal{L} = \sum_{q=u,d,s} & \left\{\bar{\psi}_q \left[\gamma^\mu(i\partial_\mu - (g_q^\omega \omega + g_q^\rho \rho + g_q^\phi \phi))\right.\right. \\ & \left.\left. -m_q\right] \psi_q - B\right\} \Theta(\bar{\psi}_q \psi_q) \\ & + \frac{1}{2}(m_\omega^2 \omega^2 + m_\rho^2 \rho^2 + m_\phi^2 \phi^2) \\ & + \frac{b_4 (g^2 V_\mu V^\mu)^2}{4} \\ & + \sum_{l=e,\mu} \bar{\psi}_l \left(i\gamma_\mu \partial^\mu - m_l\right) \psi_l. \end{aligned} \quad (1)$$

where m_q represents the mass of quark q, ψ_q is the Dirac field, B is the density-dependent bag constant, and Θ is the Heaviside step function, which is used to make sure quarks are confined inside the bag. The second term in Eq.(1) is the mass term for the mesonic fields. Using the third term Dirac sea contribution is introduced for the vector meson field [2]. The coupling constant g is defined in terms of g_q^V, and b_4 is a dimensionless parameter. The last term in Eq.(1) is dedicated to leptons. The density-dependent bag constant B is defined as

$$B = B_0 - (B_0 - B_{as})(1 - \exp(-\beta(\frac{n}{n_0})^2)), \quad (2)$$

here B_{as} is bag constant defined at asymptotic densities and parameter β controls the decrease of B with increase in density n and n_0 is saturation density taken as 0.15 fm^{-3}.

Using the equation of state (EOS), the mass-radius relation of SQSs can be obtained by solving the Tolman-Oppenheimer-Volkoff (TOV) equation [3], which can be written as

$$\begin{aligned}\frac{dP(r)}{dr} &= -\frac{M(r)[\varepsilon(r) + p(r)]}{r^2}[1 + \frac{4\pi p(r) r^3}{M(r)}] \\ & \times \ [1 - \frac{2M(r)}{r}]^{-1}, \end{aligned} \quad (3)$$

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here $\varepsilon(r)$ is the energy density and $p(r)$ is the pressure obtained from the equation of state. $M(r)$ is the gravitational mass inside the radius r of the star, given by using Eq.(3)

$$\frac{dM(r)}{dr} = 4\pi r^2 \varepsilon(r). \tag{4}$$

Results and Discussion

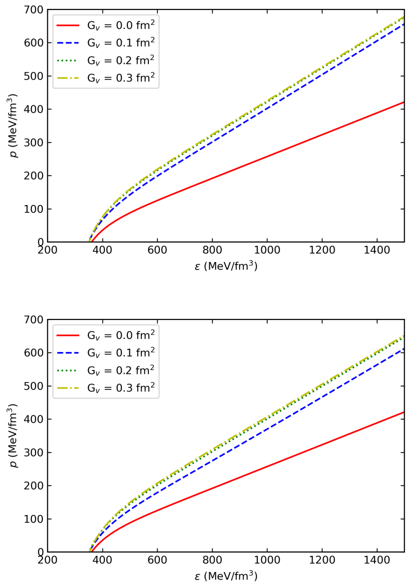

FIG. 1: EOS of SQS as a function of G_V for X_V = 1 (top) and X_V = 0.4 (bottom)

We plot the EOS profile in Fig. 1 with different values of G_V considering $B_0^{1/4}$ = 218 MeV. The relation for G_V and X_V are $(g_q^V/m_V)^2 = G_V$ and $g_s^V/g_u^V = X_V$ [2]. With the increase in value of G_V EOS profile gets stiffened for $X_V = 1$ and 0.4. In Fig. 2, we plot the mass-radius relation of stable SQSs. The curve is obtained by using the EOS profile of SQM and solving the TOV equations for static quark stars. We constructed stable SQSs at G_V = 0.3 fm^2 with a maximum mass of 2.55 $M_\odot$ and radius 11.46 km, which is satisfied with the constraints provided by GW190814 event.

In summary, we implemented the vector MIT

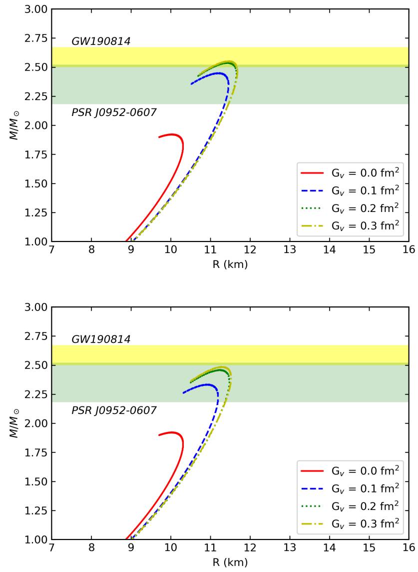

FIG. 2: Mass-radius relation as a function of G_V for $X_V = 1$ (top) and $X_V = 0.4$ (bottom)

bag model which includes self-interacting vector fields and their mass terms. Although similar modifications are implemented by [1, 2], these all are limited to only one vector field that is ω. With the modification, we showed the possibility of the presence of ρ and ϕ meson fields. Comparing our results with Refs. [1, 2], we observe that after adding ρ and ϕ mesons, at $X_V = 1$ and G_V = 0.3 fm^2, there is a difference in mass and radius of 0.10 $M_\odot$ and 0.28 km, respectively.

References

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