Effects of δ-meson on the maximum mass of the hyperon star.

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Introduction

Equation of state (EOS) of the neutron star provides a well rich plat-form to study the nucleon-nucleon interaction, which is the main aim of the nuclear physics since form its birth. The main constituent of the neutron star are the neutrons, but still a significant amount of protons and electrons are present, which are required for the β-equilibrium condition. Neutron star has an onion like structure and the density goes on increasing as we go from surface to the center of the star. In the core of neutron star the density can reaches value of several times $10^{15} gcm^{-3}$. As the constituent particles are fermion, the Fermi energy increases with the density and at some point it exceed the rest mass energy of the baryons, and hence favor the production of hyperon. Again as the time scale associated with neutron stars are much greater than the weak interaction time scale, violation of stergness conservation due to weak interaction would result appearance of hyperon (stranged baryon). With inclusion of hyperon as new degrees of freedom the EOS become more softer, hence the maximum mass of the neutron star decreases. This create a puzzle with the recent observation of neutron star with mass 1.97 $\pm 0.04\ M_{\odot}$[1]. Main culprit of this puzzle is the equation of state of the hyperon star. In this manuscript we have included a new meson degrees of freedom along with the hyperon degrees of freedom. Usually δ-meson is neglected due its small contribution but its contribution increases with increase of density and asymmetry of the system [2]. We studied the effects of δ-meson on the maximum mass of hypron star and also its effects on the static and rotating neutron star are discussed.

Formalism

To calculate the equation of state of the neutron and hyperon star we used the relativistic mean field (RMF) formalism [3]. RMF is an effective theory in which nucleons are interact with each other through the exchange of various effective mesons like σ, ω, and ρ-mesons. Here we have taken extra δ-meson contribution. The formalism start with the effective Lagrangian :

$$\begin{aligned}
\mathcal{L} \ = \ & \sum_B \overline{\psi}_B \left(i\gamma^\mu D_\mu - m_B + g_{\sigma B}\sigma + g_{\delta B}\delta.\tau\right)\psi_B + \frac{1}{2}\partial_\mu\sigma\partial_\mu\sigma \\
& -m_\sigma^2\sigma^2\left(\frac{1}{2} + \frac{\kappa_3}{3!}\frac{g_\sigma\sigma}{m_B} + \frac{\kappa_4}{4!}\frac{g_\sigma^2\sigma^2}{m_B^2}\right) - \frac{1}{4}\Omega_{\mu\nu}\Omega^{\mu\nu} \\
& +\frac{1}{2}m_\omega^2\omega_\mu\omega^\mu\left(1 + \eta_1\frac{g_\sigma\sigma}{m_B} + \frac{\eta_2}{2}\frac{g_\sigma^2\sigma^2}{m_B^2}\right) - \frac{1}{4}R^a_{\mu\nu}R^{\mu\nu a} \\
& +\frac{1}{2}m_\rho^2\rho^a_\mu\rho^{a\mu}\left(1 + \eta_\rho\frac{g_\sigma\sigma}{m_B}\right) + \frac{1}{2}\partial_\mu\delta.\partial_\mu\delta - m_\delta^2\delta^2 \\
& +\frac{1}{4!}\zeta_0\left(g_\omega\omega_\mu\omega^\mu\right)^2 + \sum_l \overline{\psi}_l\left(i\gamma^\mu\partial_\mu - m_l\right)\psi_l. \qquad (1)
\end{aligned}$$

Here symbol caries their usual meaning. From the definition of the energy-momentum tensor

$$T^{\mu\nu} = \mathcal{L}g_{\mu\nu} - \frac{\partial\mathcal{L}}{\partial(\partial_\mu\phi)}\partial_\nu\phi, \qquad (2)$$

we can calculate the pressure and energy of the system from Eq. 2. The variation of pressure and energy with density gives the EOS of any system. Taking as these EOS as the inputs we solved the Tolman-Oppenheimer-Volkoff (TOV) equation to find the mass-radius profile of the static neutron star. To obtain the

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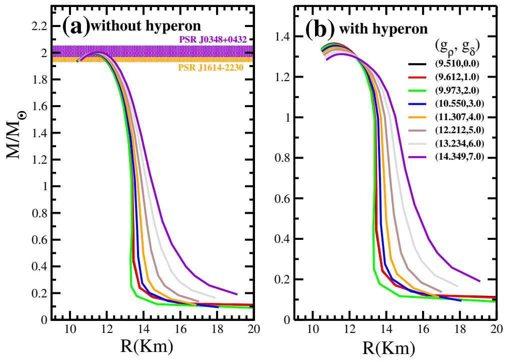

FIG. 1: Mass and radius profile of the static neutron and hyperon star with different combination of g_ρ and g_δ

mass-radius profile of the rotating neutron we used the standard RNS code available in the market.

Result and Discussion

The main objective of this paper is to discuss the effects of the δ-meson on the mass-radius profile of the neutron and hyperon star. We used the δ-meson interaction on top of the original G2 parameter set. But we can not use the g_δ as a free parameter as the both the ρ and δ-meson contribute the isospin asymmetry. So we have to take care of the g_ρ, while fixing the value of the g_δ. We got various combination of the g_δ and g_ρ by fixing the symmetry energy. All the pair of the g_δ and g_ρ are given in the figure 1 and 2. In Fig.1, we have shown the effects δ-meson on mass-radius profile of static star. The mass and radius profile are calculated by taking various combination of g_ρ and g_δ. From the graph it is clear δ-meson has very less impact on the maximum mass of the neutron star. But in panel (b) of Fig.1, we have shown same thing for the hyperon star. δ- meson has relatively more impact on the hyperon star than the pure neutron star. In Fig.2, we shown the similar results but for the rotating neutron and hyperon star. From the graph it is clear that effects of g_ρ and g_δ pair are relatively more in case of rotating hyperon star than the static hyperon star.

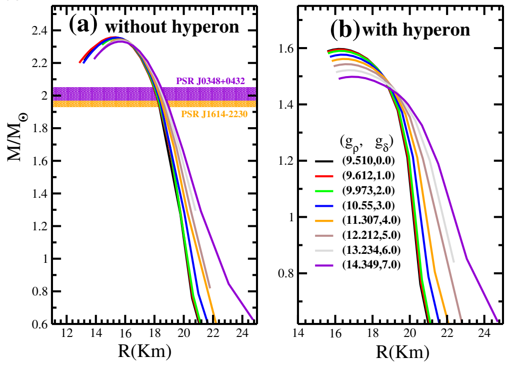

FIG. 2: Mass and radius profile of the rotating neutron and hyperon star with different combination of g_ρ and g_δ

1. conclusion

In summary, we have discussed the effects of g_δ on the neutron and hyperon star both in static and rotating condition. The δ-meson has relatively more impact on the maximum mass of hyperon star both on the static and rotating case.

References

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