GW190814 secondary component as massively rotating hybrid star

M. Imran[1],* Ishfaq A. Rather[1], Usuf Rahaman[1], A. A. Usmani[1], and S. K. Patra[2,3]
[1] *Department of Physics, Aligarh Muslim University, Aligarh- 202002, India*
[2] *Institute of Physics, Bhubaneswar-751005, India and*
[3] *Homi Bhabha National Institute, Training School Complex, Anushakti Nagar, Mumbai-400094, India*

Introduction

Various massive stars have been observed in the past and theoretical constraints have limited the maximum mass to $\sim 2M_{\odot}$. Among the observed massive stars, some are fast rotating stars while others may be slowly or non-rotating stars. The multimassenger gravitaional-wave event GW170817 put a constraint on the upper limit of the masss of the non-rotating stars by $M \sim 2.3M_{\odot}$ [1]. Recently, the GW190814 data from LIGO/Virgo collaboration suggest that the event is a binary coalescence of a $23.2^{+1.1}_{-1.0} M_{\odot}$ black hole and a $2.59^{+0.08}_{-0.09} M_{\odot}$ secondary component [2]. The mass of the secondary component lies in the so called mass-gap region making its identification ambigous. Numerous work has been done regarding the nature of secondary component of GW190814 [3, 4]. Keeping in mind the fact that the rapidly rotating stars can have masses upto $\geq 2.5M_{\odot}$, we investigate the nature of the secondary component of GW190814 event. We use the DD-RMF model with different parameter sets for the hadron matter (HM) EoS while the vBag model is used to study the quark matter (QM).

Formalism

The DD-RMF Lagrangian density along with the parameter sets used, such as DD-LZ1 and DD-MEX, can be found in Ref. [6]. For the quark matter, employing the vBag model [5], the energy density and pressure are defined as

$$\mathcal{E}_{vBag,f}(\mu_f) = \mathcal{E}_{FG,f}(\mu_f^*) + \frac{1}{2}K_\nu n^2_{FG,f}(\mu_f^*) + B_{\chi,f}, \quad (1)$$

$$P_{vBag,f}(\mu_f) = P_{FG,f}(\mu_f^*) + \frac{1}{2}K_\nu n^2_{FG,f}(\mu_f^*) - B_{\chi,f}, \quad (2)$$

where the coupling constant parameter K_ν results from the vector interactions and controls the stiffness of the star matter curve. The bag constant for a single quark flavor is denoted $B_{\chi,f}$.

The Gibbs construction method which accounts for the global charge neutrality condition is used to construct the phase transition from hadron matter to quark matter. The equations governing the mixed-phase pressure and energy density are defined as:

$$P_H(\mu_B, \mu_l) = P_Q(\mu_B, \mu_l) = P_{MP}, \quad (3)$$

$$\varepsilon_{MP} = \chi\varepsilon_Q + (1-\chi)\varepsilon_H + \varepsilon_l. \quad (4)$$

In the current study, the coupling constant parameter K_ν is fixed with a value of 6 GeV^{-2} while the effective bag constant $B^{1/4}_{eff}$ is taken as 130, 145, and 160 MeV.

Results and discussion

Fig. 1 shows the hadron-quark phase transition with DD-RMF parameter sets for hadronic matter and vBag model for QM using the Gibbs method for constructing mixed-phase which ensures a smooth transition between the two different phases. The green region shows the constraints on the Equation

*Electronic address: `imran.phys.amu@gmail.com`

of State (EoS) imposed from the GW170817 and GW190814 data when its secondary component is considerd to be a supermassive NS. The pure hadron region satisfies the EoS constraints at low and high density. The phase transition to the quark matter deviates the EoS away from the imposed constraints. With the increasing effective bag constant $B_{eff}^{1/4}$, the phase transition density increases, and the mixed-phase region also expands.

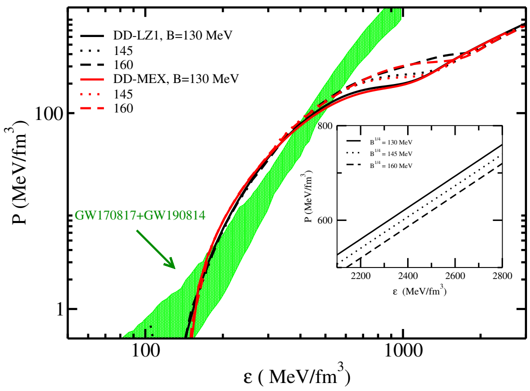

FIG. 1: Equation of state for the hadron-quark phase transition for DD-LZ1 and DD-MEX hadronic parameter sets and vBag QM at different effective bag constants. The solid lines represents the hybrid EoS at $B_{eff}^{1/4}$=130 MeV while dotted and dot-dashed lines represent the hybrid EoS at $B_{eff}^{1/4}$=145 and 160 MeV, respectively.

The mass-radius profile for maximally rotating NS (RNS) for DD-LZ1 and DD-MEX EoSs are displayed in Fig. 2. The solid lines represent the pure hadronic star while the dotted, dashed, and dot-dashed lines represent the HS at different bag constants. For DD-LZ1 EoS, the pure hadronic RNS produces a maximum mass of $3.11M_\odot$ with a radius of 18.23 km. The phase transition from HM to QM decreases the maximum mass and the corresponding radius. For the DD-LZ1 set, with the bag constant $B^{1/4}$ = 130 MeV, the maximum mass decreases from $3.11M_\odot$ to $2.98M_\odot$. For $B^{1/4}$=145 and 160 MeV, the maximum mass decreases to a value $2.75M_\odot$ and $2.64M_\odot$, respectively. The radius at the NS canonical mass, $R_{1.4}$, decreases from 18.32 km to 16.64 km for hybrid star matter at bag value 160 MeV. The similar results follow for

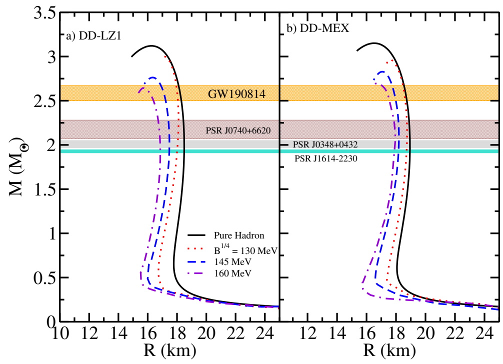

FIG. 2: Mass-Radius profile for pure hadronic and hybrid rotating NSs for (a) DD-LZ1 and (b) DD-MEX parameter sets at bag values $B_{eff}^{1/4}$=130, 145 & 160 MeV. The shaded regions represent recent constraints on the mass from various measured astronomical observables.

the DD-MEX parameter set, where the maximum mass for pure hadronic matter is $3.15M_\odot$ at radius 16.53 km which then decreases to $2.69M_\odot$ at 16.63 km for bag constant of 160 MeV. Therefore, while the pure hadronic RNS predicts a large maximum mass, the phase transition to QM softens the EoS thereby decreasing the maximum mass. These calculations predict the possibility of the secondary component of GW190814 to be a fast-rotating hybrid star. Similar results have been discussed in detail in Ref. [6].

References

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