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On the possibility of a $2.6M_\odot$ Neutron star

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Introduction

August 14, 2019 the gravitational wave (GW) signal of a compact binary coalescence with the most unequal mass ratio yet measured, the GW190814 event presents a possible most massive neutron star of mass $\approx (2.5{-}2.67)M_\odot$ [1], although not yet confirmed. In addition, the event GW170817 was the first event to be observed of a binary neutron star coalescence. With ever growing possibility of massive stars being observed, the role of exotic matter such as hyperons in compact star core becomes questionable. Presence of hyperons is known to have a softening effect on the EoS on one hand but on the other hand we require a stiffer EoS in order to achieve massive neutron star configuration. In the present work, we consider neutron stars composed of octet of baryons using a calibrated effective chiral model [2]. We fix the coupling strength of hyperons to the potentials observed from hypernuclear experiments, such as for the $\Lambda^0(1114MeV)$ $U_{\Lambda^0} = -28MeV$, for the U_Σ lies in the range $30 \pm 20MeV$ and Ξ $U_\Xi = -14MeV$ at normal nuclear density. Our focus is to check if the maximum mass constraint from the observation of high mass stars can be obtained with hyperon degrees of freedom and for what interaction strength.

Results and discussion

In the relativistic mean field framework using the effective chiral model, we calculated the equation of state of neutron star matter. We analyzed the effect of hyperon couplings on the resulting equation of state by varying the scalar meson-hyperon coupling to fit the aforementioned hyperon potential depths. The equation of state is then subjected to the hadrodynamic equilibrium conditions and the dominant properties of the static neutron star configuration is calculated. In Fig. 1, we plot the Mass-Radius profile of sequence of neutron stars for different couplings and compare them with available constraints. We required $x_{\sigma H} > 0.5$ in order to obtain high mass non-rotating neutron star configuration and satisfy the maximum mass constraints from few observations about $2M_\odot$. Our results also agree with the most probable radius ($R_{1.4}$) limits on canonical mass $1.4M_\odot$ pulsar as shown. It is to be noted that the secondary component of the GW190814 if assumed to be the most massive pulsar observed till date, then $R_{1.4}$ is limited to (12.2 – 13.7 km). The present model then predicts $x_\sigma > 0.5$ to satisfy this constraint. Similarly for a pulsar of $1.97M_\odot$, GW data predicts the radius to be within (10.5 – 12.3km), to which values of scalar couplings agrees with lower bound on scalar coupling to $x_\sigma \geq 0.3$. Overall based on all of these constraints we limit $0.5 < x_\sigma < 0.7$ within the limitations of the model to satisfy the maximum mass constraint. Measurement/ estimation of radius of compact stars remains one of the poorly known quantities and so it becomes even more important to constrain them through GW data and other canonical inputs.

Primarily we wanted to figure out the correlation between the hyperon coupling to the

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TABLE I: Existing constraints on radius and compactness parameter is compared with the results obtained within the model with variation in the scalar coupling strength.

$x_{\sigma H}$	M $(M_\odot)$	R (km)	$GW170817$ $R(M_{1.97})$	$GW190814$ $R(M_{1.4})$	$R_{1.4}$ $(M_{1.4})$	M/R
0.3	1.54	10.68	×	×	✓	0.144
0.5	1.86	11.42	×	×	✓	0.163
0.7	2.05	11.73	✓	✓	✓	0.175
1.0	2.17	11.79	✓	✓	✓	0.184

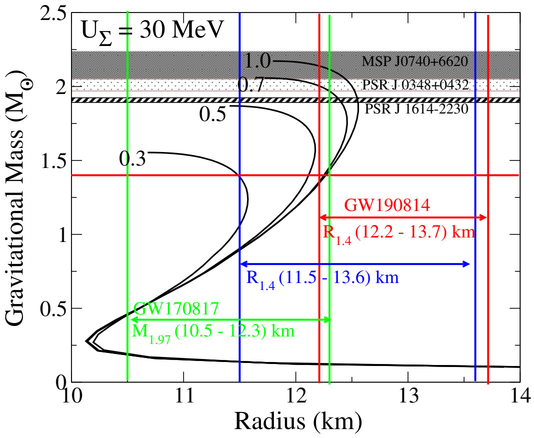

FIG. 1: Neutron star Mass-Radius curve for a fixed potential $U_\Sigma = 30\ MeV$ corresponding to different scalar meson-hyperon coupling $x_{\sigma H} = (0.3, 0.5, 0.7, 1.0)$. The radius constraints obtained from few GW events as indicated and the canonical value $R_{1.4}$ ($M = 1.4M_\odot$) is also indicated.

neutron star properties using the model calibrated to the symmetry energy slope parameters. We also varied the strength of the coupling and analyze the compact star properties and the particle composition of such a star.

We also find that one can obtain massive stars by increasing the scalar coupling as the underlying pressure also increases with increase in the coupling strength. We then compare the star properties with that of analysis of few GW events. It is interesting to note that the radii constraints from GW170817 and GW190814 do not agree with small magnitudes of the scalar couplings ($x_{\sigma H} \leq 0.5$), however the corresponding compactness parameter from recent bayesian analysis do. We could also explain large mass stars ($M \geq 2M_\odot$) with hyperon core with larger coupling strengths $x_{\sigma H} \geq 0.5$ which agrees with some of the recent observations of high mass stars. Overall the model predicts the lower bound on the hyperon couplings (agreeing to the hypernuclear potentials) to that of the half of the nucleons. However within the model, we are unable to reproduce the massive compact star of ($\approx 2.5M_\odot$) configuration, the secondary component of the GW190814 event. According to our analysis it is highly unlikely that the component is a neutron star with the hyperonic core. Moreover, it would be interesting to check the same by including more exotic species such as quarks/ dark matter/ condensates, which may help in increasing the maximum mass. Inclusion of rotation may also be another such possibility, as rotation gives extra pressure component from the centrifugal force and may require more mass to negate the pressure. Work is in progress in this direction.

References

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