A new RMF parameterization constraints of properties of finite nuclei, bulk nuclear matter, neutron stars and GW170817

Shashi K Dhiman,* Raj Kumar, and Virender Thakur
Department of Physics, Himachal Pradesh University, Summer-Hill, Shimla-171005, INDIA

Introduction

The knowledge of neutron star properties is necessary to probe the high density behaviour of the equation of state (EoS) for the baryonic matter in the beta equilibrium. Neutron stars are the densest manifestations of massive objects in the observable universe and a sound knowledge of Equation of State(EoS) of the dense matter is thus required to understand the properties of neutron stars. The precise gravitational mass and radius measurement of the neutron stars are the effective ways to constrain the equation of state of the high dense matter in its interiors. The several models of relativistic mean field (RMF) effective lagrangian density consisting of non-linear σ, ω and ρ terms and cross terms have been analyzed for nucleonic matter and nucleonic along with hyperonic matter and accosted with the constraints of nuclear matter properties and astrophysical observations of compact star masses. Only RMF models BSR [1] with $\zeta = 0$ and NL3$\omega\delta$ can sustain the condition of maximum mass $M \geq 2.0M_\odot$ when hyperons are included in the EOSs with appropriate meson-hyperon couplings, otherwise, the inclusion of hyperons may lead for the famous hyperon puzzle.

Theoretical model

The effective lagrangian density for the FTRMF model generally describe the interaction of the baryons via the exchange of σ, ω and ρ mesons upto the quartic order. The lagrangian density for the FTRMF model [1, 3] is given by

$$\mathcal{L} = \sum_B \overline{\Psi}_B[i\gamma^\mu\partial_\mu - (M_B - g_{\sigma B}\sigma) - (g_{\omega B}\gamma^\mu\omega_\mu + \frac{1}{2}g_{\rho B}\gamma^\mu\tau_B.\rho_\mu)]\Psi_B$$
$$+\frac{1}{2}(\partial_\mu\sigma\partial^\mu\sigma - m_\sigma^2\sigma^2) - \frac{\overline{\kappa}}{3!}g_{\sigma N}^3\sigma^3 - \frac{\overline{\lambda}}{4!}g_{\sigma N}^4\sigma^4 - \frac{1}{4}\omega_{\mu\nu}\omega^{\mu\nu} + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu +$$
$$\frac{1}{4!}\zeta g_{\omega N}^4(\omega_\mu\omega^\mu)^2 - \frac{1}{4}\rho_{\mu\nu}\rho^{\mu\nu} + \frac{1}{2}m_\rho^2\rho_\mu\rho^\mu + \frac{1}{4!}\xi g_{\rho N}^4(\rho_\mu\rho^\mu)^2 + g_{\sigma N}g_{\omega N}^2\sigma\omega_\mu\omega^\mu$$
$$\left(\overline{\alpha_1} + \frac{1}{2}\overline{\alpha_1}'\sigma\right) + g_{\sigma N}g_{\rho N}^2\sigma\rho_\mu\rho^\mu\left(\overline{\alpha_2} + \frac{1}{2}\overline{\alpha_2}'\sigma\right) + \frac{1}{2}\overline{\alpha_3}'g_{\omega N}^2g_{\rho N}^2\omega_\mu\omega^\mu\rho_\mu\rho^\mu$$

Result and Discussion

In the present work, two new parameter sets SRV01 and SRV02 (Table(I)) are obtained for Field theoretical Relativistic Mean Field model [1] for fixed value of omega-meson self coupling $\zeta = 0.01$ and 0.02 respectively by adjusting the remaining parameters of the model to fit exactly the available experimental data of total binding energies, charge rms radii for some closed shell nuclei $^{16,24}O$,$^{40,48}Ca$,$^{56,78}Ni$,^{88}Sr,^{90}Zr,$^{100,116,132}Sn$ and ^{208}Pb. We also include in our fit, the value of neutron skin thickness Δr=0.18 fm for the ^{208}Pb nucleus. In table(II), we presents results for properties of symmetric nuclear matter and neutron star and its tidal deformability at canonical mass ($\Lambda_{1.4}$) for SRV01 and SRV02 parameters. All the nuclear matter properties are more or less close to each other. This is attributed to the fact that omega meson self coupling parameter ζ only effects at higher densities.

In Fig.(1), we have plotted mass radius relationship of the neutron star using parameterization SRV01 and SRV02. The neutron star mass shows the dependence of the parameter ζ as their is decrease in the neutron star mass decreases from 2.11 to 2.05 solar mass as ζ slightly increases from 0.01 to 0.02 showing that EOS at higher densities

*Electronic address: shashi.dhiman@gmail.com

TABLE I: The newly generated parameter sets SRV01 and SRV02 for FTRMF models [1]. The parameters $\overline{\kappa}$ $\overline{\alpha_1}$, and $\overline{\alpha_2}$ are in fm^{-1}, and m_σ values are in MeV. The values of $\overline{\kappa}$, $\overline{\lambda}$, $\overline{\alpha_1}$, $\overline{\alpha_1}'$, $\overline{\alpha_2}$, $\overline{\alpha_2}'$ and $\overline{\alpha_3}'$ are multiplied by 10^2.

	$g_{\sigma N}$	$g_{\omega N}$	$g_{\rho N}$	$\overline{\kappa}$	$\overline{\lambda}$	$\overline{\alpha_1}$	$\overline{\alpha_1}'$	$\overline{\alpha_2}$	$\overline{\alpha_2}'$	$\overline{\alpha_3}'$	m_σ
SRV01	10.8459	14.1231	14.8981	3.0082	-0.0789	0.0883	0.04636	0.7927	0.9899	0.6371	492.8478
SRV02	10.4795	13.5345	14.6481	1.9723	-0.01144	0.19106	0.026996	0.7726	0.8959	0.7035	502.3739

TABLE II: The nuclear matter properties at saturation density and neutron star properties for parameter sets SRV01 and SRV02

	ϵ(MeV)	K(MeV)	J(MeV)	L(MeV)	M^*/M	$\rho_0(fm^{-3})$	$\Lambda_{1.4}$	$R_{1.4}$(Km)	$M_{max}(M_\odot)$
SRV01	-16.03	232.73	31.76	66.00	0.611	0.148	590	13.24	2.11
SRV02	-16.04	227.50	31.84	66.74	0.605	0.148	607	13.25	2.05

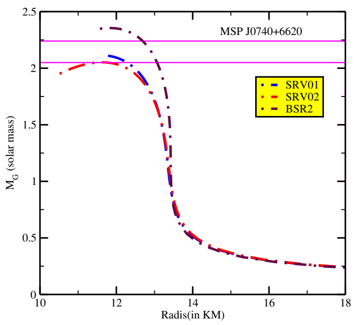

FIG. 1: (color online) Relationship between neutron star mass and its radius for SRV01 and SRV02 parameterization.

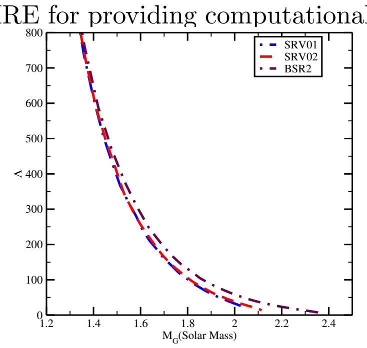

FIG. 2: (color online) Relationship between neutron star tidal Deformability and its mass for SRV01 and SRV02 parameterization.

becomes slightly softer. Fig.(2) presents our results for the dimensionless tidal Deformability (Λ) as a function of the neutron star mass for SRV01 and SRV02 parameters. It is observed that Λ decreases with neutron star mass. The value of $\Lambda_{1.4}$ for EOSs computed with SRV01 and SRV02 parameterization are about 590 and 607 respectively which are consistent with recents constraints from the GW170817 event. The present results of SRV01 and SRV02 shown in Fig. (1 and 2) are also compared with the results of BSR2 parameters [1].

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