Nuclear and Neutron star properties within the PREX-II motivated parameterization of relativistic mean field model

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Introduction

Neutron star is a highly dense and asymmetric nuclear system having a central density about 5-6 times the nuclear saturation density. The study of neutron stars proclaims that its internal structure is more complex as new degrees of freedo like hyperons and quark appear in the core. The Lead Radius Experiment (PREX) has recently given a model-independent extraction of neutron skin thickness of ^{208}Pb as $\Delta r_{np} = 0.283 \pm 0.071$ fm [1] by combining the original PREX result with the new PREX-II. Δr_{np} has been identified as an ideal probe on symmetry energy - a key but poorly known quantity that describes the isospin dependence of the equation of state (EOS) of nuclear matter and plays a critical role in various issues in nuclear physics and astrophysics. The large value of $\Delta r_{np} = 0.283 \pm 0.071$ fm suggests a very stiff EOS and large value of L around saturation density and generally gives rise to a large value of neutron star ra- dius and the tidal deformability [17].

Theoretical model

The Lagrangian density for the RMF model used in the present study [2, 3], is given by

$$\begin{aligned}
\mathcal{L} &= \sum_q \overline{\Psi}[i\gamma^\mu\partial_\mu - (M - g_\sigma\sigma - g_\delta\delta\cdot\tau) \\
&- (g_\omega\gamma^\mu\omega_\mu + \frac{1}{2}g_\rho\gamma^\mu\tau\cdot\rho_\mu)]\Psi + \frac{1}{2}(\partial_\mu\sigma\partial^\mu\sigma - m_\sigma^2\sigma^2) \\
&- \frac{\overline{\kappa}}{3!}g_\sigma^3\sigma^3 - \frac{\overline{\lambda}}{4!}g_\sigma^4\sigma^4 - \frac{1}{4}\omega_{\mu\nu}\omega^{\mu\nu} + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu \\
&+ \frac{1}{4!}\zeta g_\omega^4(\omega_\mu\omega^\mu)^2 - \frac{1}{4}\rho_{\mu\nu}\rho^{\mu\nu} + \frac{1}{2}m_\rho^2\rho_\mu\rho^\mu \\
&+ \frac{1}{2}(\partial_\mu\delta\partial^\mu\delta - m_\delta^2\delta^2) + \frac{1}{2}c_1g_\omega^2g_\rho^2\omega_\mu\omega^\mu\rho_\mu\rho^\mu. \qquad (1)
\end{aligned}$$

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Result and Discussion

In the present work, new parameter set HPU (Table(I)) are obtained for Relativistic Mean Field (RMF) model by adjusting 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 of ^{208}Pb from PREX-II Experimental data [1]. In table(II), we present results for properties of symmetric nuclear matter and neutron star and its tidal deformability at canonical mass ($\Lambda_{1.4}$) for HPU parameterization. The results are also compared with NL3 and IOPB-1 parameter sets. [4, 5]. The nuclear matter properties obtained by HPU parameterization are consistent with the empirical and the observed values. The value of neutron skin thickness Δr_{np} for ^{208}Pb is found to be 0.242 fm for HPU parameterization. In Fig.(1), we have plotted mass radius relationship of the neutron star using parameterization HPU,NL3 and IOPB-1 parameterization.It is observed that the maximum gravitational mass of the non rotating neutron star for HPU parameter set is 2.02 M$\odot$ which is in good agreement with the mass constraints from GW170817 event, pulsars PSRJ1614-2230, PSRJ0348+0432, and PSRJ0740+6620 [7–11]. The radius (including BPS crust) of canonical mass ($R_{1.4}$) is 13.35 Km for HPU parameterization which satisfies the recent radius constraints from NICER. The value of $\Lambda_{1.4}$ for EOSs computed with HPU parameterization is 629.09 which is consistent with the constraints from the GW170817

TABLE I: The newly generated parameter set HPU for RMF model [6]. The parameters $\overline{\kappa}$ is in fm^{-1}, and m$_\sigma$ values are in MeV. The values of $\overline{\kappa}$, $\overline{\lambda}$, $\overline{c_1}$ are multiplied by 10^2.

	g_σ	g_ω	g_ρ	g_δ	$\overline{\kappa}$	$\overline{\lambda}$	c_1	ζ	m_σ
HPU	10.41851	13.38412	10.27951	1.19517	1.85581	-0.75516	0.02903	0.02572	502.00502
NL3	10.21743	12.86762	8.94880	0.00000	1.95734	-1.59137	0.00000	0.00000	508.194
IOPB-1	10.41851	13.38412	11.11560	0.00000	1.85581	-0.75516	4.80000	0.01744	500.487

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

	ϵ(MeV)	K(MeV)	J(MeV)	L(MeV)	M^*/M	$\rho_0(fm^{-3})$	$\Lambda_{1.4}$	$R_{1.4}$(Km)	$M_{max}(M_\odot)$
HPU	-16.10	227.45	34.41	77.06	0.606	0.148	629.09	13.35	2.02
NL3	-16.25	271.56	37.40	118.56	0.595	0.148	1234.8	14.67	2.77
IOPB-1	-16.10	222.57	33.30	63.85	0.595	0.149	680.79	13.29	2.16

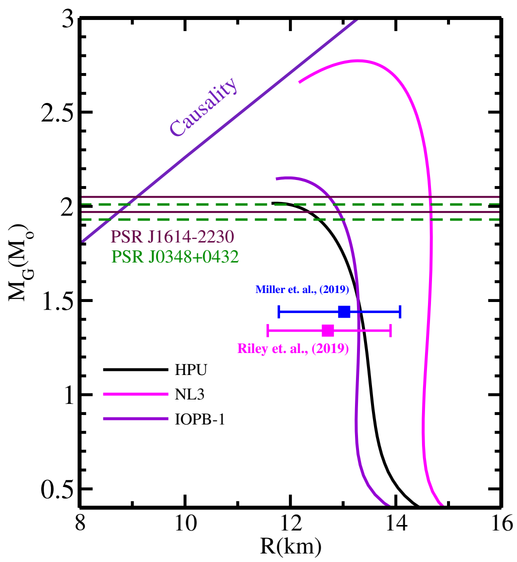

FIG. 1: (color online) Relationship between neutron star mass and its radius.

event [12].

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