

# Dense nuclear matter in relativistic mean field model with isoscalar and isovector meson mixing interaction

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## INTRODUCTION

The astrophysical phenomena concerning compact stars as well as the finite nuclei and nuclear matter properties are determined by the nuclear equation of state (EoS) that is established by the relationship between the energy density and pressure of the system. As a result of precise observations of neutron stars, such as the Shapiro delay measurement of a binary millisecond pulsar J1614+2230 [1] and the radius measurement of PSR J0740+6620 from Neutron Star Interior Composition Explorer (NICER) and from X-ray Multi-Mirror (XMM-Newton) Data [2, 3], theoretical studies have been currently performed more than ever to explain the neutron star physics through the EoS for dense nuclear matter. The tidal deformability of a neutron star has very significant role to construct EoS of neutron star. The aim of the present study is to construct new effective interaction to investigate the effects of quartic interaction of  $\sigma$ - $\delta$  meson on the properties of finite nuclei, bulk nuclear matter, and asymmetric dense nuclear matter within the framework of relativistic mean field model(RMF) model.

## THEORETICAL MODEL

The effective Lagrangian density for the RMF model [4, 5] generally describes the interaction of the baryons via the exchange of  $\sigma$ ,  $\omega$ ,  $\rho$  and  $\delta$  mesons up to the quartic order

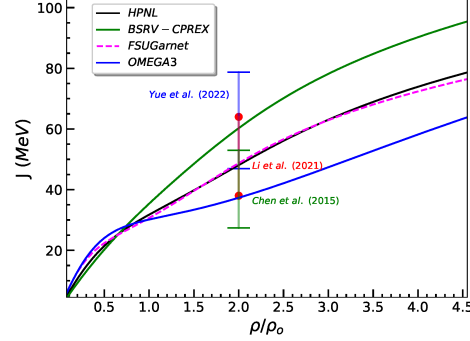


FIG. 1. (color online) Density dependence of symmetry energy.

of nucleon system is given by

$$\begin{aligned}
 \mathcal{L} = & \sum_{N=n,p} \bar{\Psi}_N [i\gamma^\mu \partial_\mu - (M_N - g_{\sigma N}\sigma - g_{\delta N}\delta)\tau_N] \Psi_N \\
 & - (g_\omega \gamma^\mu \omega_\mu + \frac{1}{2}g_\rho \gamma^\mu \tau_N \cdot \rho_\mu + e\gamma_\mu \frac{1 + \tau_{3N}}{2} A_\mu) \Psi_N \\
 & + \frac{1}{2}(\partial_\mu \sigma \partial^\mu \sigma - m_\sigma^2 \sigma^2) - \frac{\bar{\kappa}}{3!} g_{\sigma N}^3 \sigma^3 - \frac{\bar{\lambda}}{4!} g_{\sigma N}^4 \sigma^4 \\
 & - \frac{1}{4} \omega_{\mu\nu} \omega^{\mu\nu} + \frac{1}{2} m_\omega^2 \omega_\mu \omega^\mu + \frac{1}{4!} \zeta g_{\omega N}^4 (\omega_\mu \omega^\mu)^2 - \frac{1}{4} \rho_{\mu\nu} \rho^{\mu\nu} \\
 & + \frac{1}{2} m_\rho^2 \rho_\mu \rho^\mu + \frac{1}{2} (\partial_\mu \delta \partial^\mu \delta - m_\delta^2 \delta^2) - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\
 & + \frac{1}{2} \Lambda_{\omega\rho} g_{\omega N}^2 g_{\rho N}^2 \omega_\mu \omega^\mu \rho_\mu \rho^\mu + \Lambda_{\sigma\delta} g_{\sigma N}^2 g_{\delta N}^2 \sigma^2 \delta^2 \quad (1)
 \end{aligned}$$

## RESULTS AND DISCUSSION

In the present work, new parameter set HPNL (Table(I)) is 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  $^{16,24}\text{O}$ ,  $^{40,48}\text{Ca}$ ,  $^{56,68,78}\text{Ni}$ ,  $^{88}\text{Sr}$ ,  $^{90}\text{Zr}$ ,  $^{100,116,132}\text{Sn}$ ,  $^{144}\text{Sm}$  and  $^{208}\text{Pb}$ . We also include in our fitting protocol, the value of neutron skin thickness of  $^{208}\text{Pb}$  from PREX-II Experimental data [6]. 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 various parameterization. The nuclear matter properties obtained by HPNL parameterization are consistent with the empirical and the observed values.

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TABLE I. The new effective interaction HPNL for RMF model. The parameters  $\bar{\kappa}$  is in  $\text{fm}^{-1}$ , and  $m_\sigma$  values are in MeV. The values of  $\bar{\kappa}$  and  $\bar{\lambda}$  are expressed in  $10^{-2}$ . The parameters for BSRV-CPREX[4],FSUGarnet[7] and OMEGA3 [8] are also shown.

	$g_\sigma$	$g_\omega$	$g_\rho$	$g_\delta$	$\bar{\kappa}$	$\bar{\lambda}$	$\Lambda_{\omega\rho}$	$\zeta$	$\Lambda_{\sigma\delta}$	$m_\sigma$
HPNL	10.18252	12.86925	12.36143	2.70417	1.96148	-0.57113	0.04748	0.02065	0.05000	504.914
BSRV-CPREX	10.44537	13.43408	10.28003	1.70339	1.66238	-0.20868	0.02257	0.024293	0.00000	501.933
FSUGarnet	10.49876	13.69695	13.87880	0.00000	1.65229	-0.35330	0.08600	0.02349	0.00000	496.731
OMEGA3	9.98591	12.89180	15.17234	3.87298	1.57301	-0.06734	0.04754	0.02170	0.04680	498.015

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

	$\epsilon(\text{MeV})$	$K(\text{MeV})$	$J(\text{MeV})$	$L(\text{MeV})$	$M^*/M$	$\rho_0(\text{fm}^{-3})$	$\Lambda_{1.4}$	$R_{1.4}(\text{Km})$	$M_{max}(M_\odot)$
HPNL	-16.06	225.65	31.62	49.02	0.619	0.149	557.19	12.89	2.07
BSRV-CPREX	-16.10	226.99	33.99	82.32	0.602	0.148	682.57	13.41	2.04
FSUGarnet	-16.23	229.62	30.98	50.92	0.579	0.153	622.15	13.02	2.06
OMEGA3	-16.38	256.06	30.06	20.41	0.620	0.148	503.04	12.51	2.05

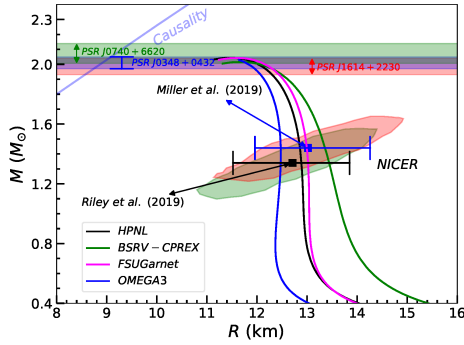


FIG. 2. (color online) Relationship between neutron star mass and its radius.

In Fig.(1), we plot the symmetry energy ( $J$ ) as a function of baryon density for various parametrizations. It is evident from the figure that the value of  $J$  increases with baryon density for various models. It can be noticed

that for HPNL model, the curve of  $J$  is neither too stiff nor too softer in high-density regime. The value of  $J$  satisfies the constraints on magnitude of symmetry energy coefficient at  $J(2\rho_0)$  [7, 9]. In Fig.2, we present the results for the gravitational mass of static neutron stars and their radius for various parametrizations considered in the present work. It is observed that the maximum mass of the neutron star for HPNL parameter sets is  $2.07 M_\odot$  which is in good agreement with the mass constraints  $2.08^{+0.07}_{-0.07} M_\odot$  PSR J0740+6620, [10]. The radius of canonical mass ( $R_{1.4}$ ) for HPNL parametrization is 12.89 Km, which satisfies the radius constraints from NICER on  $R_{1.4}$  [2, 3]. The value of  $\Lambda_{1.4}$  for EOSs computed with HPNL parameterization is 557.19 which is consistent with the constraints from the GW170817 event [11].

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