Effective relativistic mean field model for finite nuclei and neutron stars

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Introduction

In the present scenario, nuclear physics and nuclear astrophysics are well described within the self-consistent effective mean field models. These effective theories are not only successful to describe finite nuclei properties but also explain well the nuclear matter system at supranormal densities. The relativistic as well as non-relativistic effective models are only the viable means to describe the nuclear systems over a wide range of masses. In recent decades, using the relativistic and non-relativistic formalisms, a large number of nuclear phenomena have been predicted near the nuclear drip-lines. As a results, several experiments are planed in various laboratories to probe more deeper side of the unknown nuclear territories, i.e., the regions of neutron and proton drip-lines.

Here we present the results for newly proposed parameterizations IOPB-I along with the recently published two parameter sets G3 [1] and FSU2R[2]. We compare the behavior of the equation of states (EOSs) of pure neutron matter (PNM) at sub-saturation densities for the different parameterization considered. The saturation properties for the symmetry energy and slope of the symmetry energy of the modified interactions are compared to recent experimental and theoretical models. Finally, we calculate the mass-radius of the neutron stars for the NL3, IOPB-I, FSU2R and G3 sets.

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Results and Discussions

The IOPB-I set is obtained from the effective field theory motivated relativistic mean field (ERMF) energy density functional, which includes the contributions from δ-meson to the lowest order and the cross-coupling between ω and ρ-meson [1]. The optimization of the energy density functional is performed for a given set of fitting data using the simulated annealing method. The parameters fitted with experimental data for the binding energies and charge radii for ^{16}O, ^{40}Ca, ^{48}Ca, ^{68}Ni, ^{90}Zr, ^{100,132}Sn, and ^{208}Pb nuclei with some constraints on the properties of the nuclear matter at the saturation density. The newly developed IOPB-I parameters along with other sets are displayed in Table I. Fig. 1, displays the energy per neutron in pure neutron matter at sub-saturation densities, which are encountered in finite nuclei and in clusterization of nucleons. The results of NL3 set deviates significantly and FSU2R, IOPB-I sets are marginally deviated from the experimental data (shaded regions). However, parameter set G3 passes well through the shaded region.

Finally, we use our parameter set to evaluate the mass and radius of the static neutron star composed of neutrons, protons, electrons and muons and the computed results are shown in Fig. 2. From recent observations, it is clearly illustrated that the maximum mass predicted by any theoretical model should reach the limit $\sim 2.0M_{\odot}$, which is consistent with our present prediction from the G3 equation of state of a nucleonic matter compact star with mass $2.02M_{\odot}$ and radius 10.87 km. The IOPB-I set gives a larger

TABLE I: The obtained new parameter set IOPB-I along with NL3 [3], FSU2R [2], G3[1] forces. The nucleon mass M is 939.0 MeV. All the coupling constants are dimensionless, except k_3 which is in fm^{-1}. The lower portion of the table indicates the nuclear matter properties such as binding energy per nucleon $\mathcal{E}_0$(MeV), saturation density $\rho_0(\mathrm{fm}^{-3})$, incompressibility coefficient for symmetric nuclear matter K_∞(MeV), effective mass ratio M^*/M, symmetry energy J(MeV) and slope of the symmetry energy L(MeV).

	NL3	IOPB-I	FSU2R	G3
m_s/M	0.541	0.533	0.529	0.559
m_ω/M	0.833	0.833	0.833	0.832
m_ρ/M	0.812	0.812	0.812	0.820
m_δ/M	0.0	0.0	0.0	1.043
$g_s/4\pi$	0.813	0.827	0.825	0.782
$g_\omega/4\pi$	1.024	1.062	1.074	0.923
$g_\rho/4\pi$	0.712	0.885	1.1433	0.962
$g_\delta/4\pi$	0.0	0.0	0.0	0.160
k_3	1.465	1.495	1.261	2.606
k_4	-5.688	-2.932	-0.644	1.694
ζ_0	0.0	3.103	4.377	1.010
η_1	0.0	0.0	0.0	0.424
η_2	0.0	0.0	0.0	0.114
η_ρ	0.0	0.0	0.0	0.645
$\eta_{2\rho}$	0.0	18.258	56.275	33.250
α_1	0.0	0.0	0.0	2.000
α_2	0.0	0.0	0.0	-1.468
$f_\omega/4$	0.0	0.0	0.0	0.220
$\mathcal{E}_0$	-16.29	-16.10	-16.28	-16.02
ρ_0	0.148	0.149	0.150	0.148
K_∞	271.5	222.6	238.0	243.9
M^*/M	0.595	0.593	0.593	0.699
J	37.40	33.30	30.7	31.8
L	118.6	63.6	55.7	47.3

and heavier NS with mass $2.17M_\odot$ and radius 11.89 km comparable to the prediction of FSU2R set[2].

Summary and Conclusions

In the present report, we have constructed a new parameter set termed as IOPB-I for the ERMF model by fitting the experimental binding energy and charge radius of eight spherical nuclei. In addition to the finite nuclei data, we have also imposed some constraint on the nuclear matter at saturation density. The neutron matter EOS at sub-saturation densities for IOPB-I and G3 parameter sets show reasonable improvement over other considered parameter sets. The maximum mass of G3 parameter set is compatible with the measurements and the radius of the neutron star with the canonical mass agree quite well with the empirical values. However, IOPB-I set gives larger mass and radius of the neutron star.

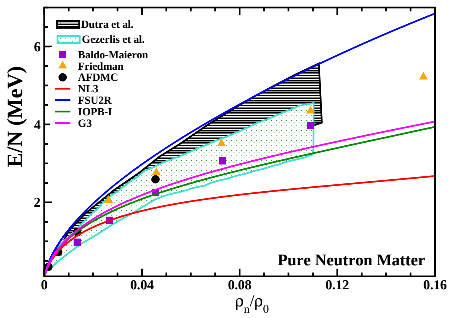

FIG. 1: (Colour online) The binding energy per neutron as a function of neutron density for the region of sub-saturation density.

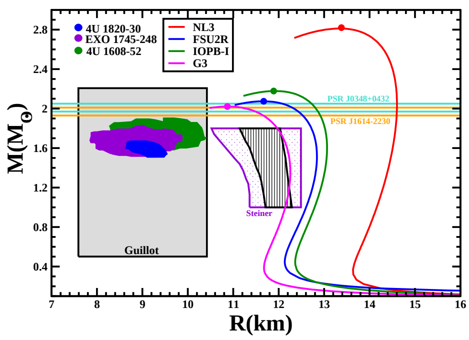

FIG. 2: (Colour online) Mass versus radius of the neutron stars for various EOSs.

References

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