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Description of Nuclear Matter and Neutron Stars in Density-dependent Relativistic Mean Field Theory*

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Abstract: The density dependencies of various effective interaction strengths in the relativistic mean field and their influences on the properties of nuclear matter and neutron stars are studied and carefully compared. The differences of saturation properties given by various effective interactions are subtle in symmetric nuclear matter. The Oppenheimer-Volkoff mass limits of neutron stars calculated from different equations of state are 1.52—2.06 $M_\odot$, and the radii are 10.24—11.38 km with hyperons included.

Key words: relativistic mean field; effective interaction; equation of state; nuclear matter; neutron stars

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1 Introduction

A widely used and successful approach for nuclear matter and finite nuclei is the relativistic mean field (RMF) theory[1]. In RMF theory, the effective interactions are adjusted to various properties of nuclear matter and finite nuclei. It is well known that the nonlinear interactions have problems of stability at high densities, as well as the question of their physical foundation[2]. A more natural alternative is to introduce the density dependence in the couplings. Based on the Dirac-Brueckner calculations, Typel and Wolter proposed the density-dependent effective interaction TW-99 and expected that the model could be reasonably extrapolated to extreme conditions of isospin and/or density[3]. Along this line, Nikšic et al developed another effective interaction DD-ME1[4]. Recently, Long et al developed new effective interactions PK1, PK1r, and PKDD[5].

Here we will report on our recent works on the density dependencies of various effective interaction strengths, including PK1, PK1r and PKDD, in RMF theory and their influences on the properties of nuclear matter and neutron stars[6—10]. The details of theory frame can be found in Refs. [6, 7].

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2 Effective Interaction Strengths

The details for density dependences of the effective interactions can be found in Refs. [6, 8—10]. In Fig. 1, the density dependencies of the effective interaction strengths in symmetric nuclear matter as functions of nucleon density are shown, where for the nonlinear effective interactions, the "equivalent" density dependencies are extracted from the meson field equations. For σ-meson, the interaction strengths given by TW-99 and DD-ME1 are quite different from the others in either magnitudes or slopes. In particular, strengths of TW-99 and DD-ME1 for the density interval in Fig. 1 are almost twice as large as that of GL-97. Differences for nonlinear and density-dependent interactions can be also seen in the region of the empirical nuclear matter densities. For the ω-meson, except TW-99, DD-ME1, TM1 and TM2, all the other strengths are density-independent. All the strengths are similar to each other in the region of the empirical saturation densities compared with those of the σ-meson, although large differences can also be seen at low densities. For the ρ-meson which describes the isospin asymmetry, the strengths for TW-99 and DD-ME1 show strong density dependencies in contrast with the constants in the other interactions. They cross the nonlinear interactions at a density much lower than the empirical saturation density. The density dependencies of the effective interaction strengths in neutron stars are also studied as shown in Ref. [6].

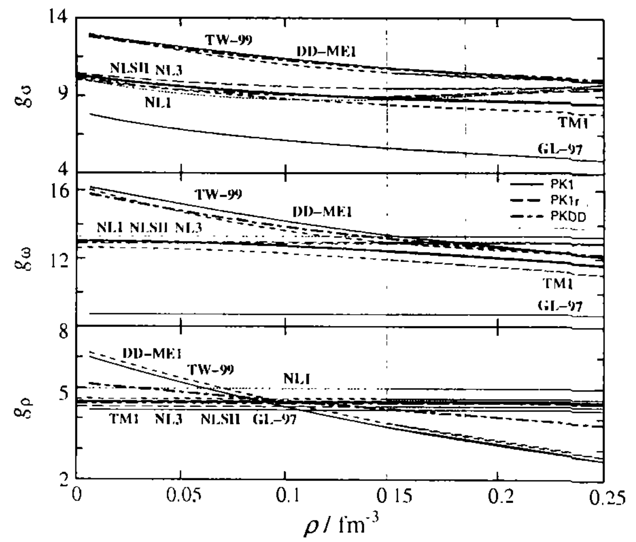

Fig. 1 The effective interaction strengths for σ, ω and ρ in symmetric nuclear matter as functions of the Baryon density. The shadowed area corresponds to the empirical value of the saturation density in nuclear matter (Fermi momentum $k_F = (1.35 \pm 0.05)$ fm^{-1} or density $\rho = (0.166 \pm 0.018)$ fm^{-3}). The curves are labeled from the top to the bottom at $\rho = 0.15$ fm^{-3} orderly from left to right.

3 Properties of Nuclear Matter and Neutron Stars

The influences of different density dependencies are presented and discussed on properties of nuclear matter and neutron stars[6].

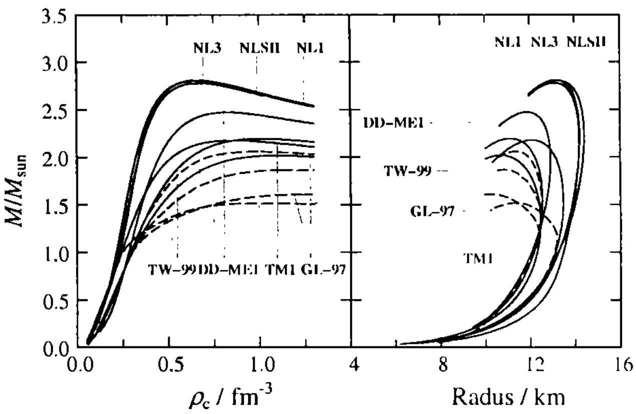

Fig. 2 The masses versus the central densities and radii in neutron starts for different effective interactions (as marked in Figure). The solid lines represent those with neutrons and protons only, and the dashed lines represent the corresponding ones with hyperons included.

For nuclear matter, though the interaction strengths given by various interactions are quite different. The differences of saturation properties are subtle in symmetric nuclear matter, except for NL2 and TM2, which are mainly used for light nuclei, while the properties by various interactions for pure neutron matter are different due to the contribution of isospin meson[6—8]. For neutron stars, the interactions with large interaction strengths give strong potentials and large Oppenheimer-Volkoff (OV) mass limits. The density-dependent interactions DD-ME1 and TW-99 favor a large neutron population due to their weak ρ-meson field at high densities. The OV mass limits calculated from different equations of state are 2.02—2.81 $M_{\odot}$, and the corresponding radii are 10.78—3.27 km. After the inclusion of the hyperons, the corresponding values become 1.52—2.06 $M_{\odot}$ and 10.24—1.38 km as shown in Fig. 2[6-8].

4 Summary

The density dependencies of various effective interaction strengths, including PK1, PK1r and PKDD, in the relativistic mean field theory and their influences on the properties of nuclear matter and neutron stars are studied and carefully compared. The differences of saturation properties are subtle in symmetric nuclear matter, except for NL2 and TM2, which are mainly used for light nuclei. The OV mass limits of neutron stars calculated from different equations of state are 2.02—2.81 $M_{\odot}$, and the radii are 10.78—13.27 km. After including hyperons, the corresponding values become 1.52—2.06 $M_{\odot}$ and 10.24—11.38 km.

References:

[1] Walecka J D. Ann Phys (N. Y.), 1974, **83**: 491; Meng J, Ring P. Phys Rev Lett, 1996, **77**: 3 963; Phys ReV Lett, 1998, **80**: 460.

[2] Lee Suk-joon, *et al*. Phys Rev Lett, 1986, **57**: 2 916.

[3] Typel S, Wolter H H. Nucl Phys, 1999, **A656**: 331.

[4] Nikšic T, Vretenar D, Finelli P, *et al*. Phys Rev, 2002, **C66**: 024306.

[5] Long W H, Meng J, Giai N V, *et al*. Phys Rev, 2004, **C69**: 034319.

[6] Ban S F, Li J, Zhang S Q, *et al*. Phys Rev, 2004, **C69**: 045805

[7] 李 俊，班淑芳，贾焕玉等. 高能物理与核物理，2004，**28**(2)：140.

[8] Meng J, Ban S F, Li J, *et al*. Yadernaya Fizika, 2004, **67**(9).

[9] 孟 杰，班淑芳，李 俊等. 高能物理与核物理，待发表.

[10] Meng J, Ban S F, Geng L S, *et al*. Proceeding of 5th Japan and China Nuclear Phyisics Conference.

利用密度相关的相对论平均场理论对核物质与中子星的研究*

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摘　要：研究和详细地比较了 RMF 理论中不同的有效相互作用强度的密度依赖性，并且讨论了这种密度依赖性对于核物质和中子星性质的影响. 对于核物质，不同的参数组给出的对称核物质的饱和点非常接近，基本都在经验值的范围内. 对于中子星，考虑超子后不同参数组给出的质量极限的范围为 1.52—2.06 $M_{\odot}$，半径为 10.24—11.38 km.

关 键 词：相对论平均场；有效相互作用；物态方程；核物质；中子星

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