

Quarks and Compact Stars 2019

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The short-range correlation effect on the properties of neutron star

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Outline

- ! **Introduction**
- ! **Relativistic Hartree-Fock method with UCOM**
- ! **Numerical results**

! **Summary**

Semi-empirical mass formula

$$
B(Z, A) = a_V A - a_S A^{2/3} - a_C Z (Z - 1) A^{-1/3} - a_{\text{sym}} \frac{(A - 2Z)^2}{A}
$$

$$
+ a_p \frac{(-1)^Z [1 + (-1)^A]}{2} A^{-3/4}
$$

and adapting (10.35), viz. **Symmetry energy in nuclear matter**

$$
E_{\text{sym}}(\rho) = S_0 + L \left(\frac{\rho - \rho_0}{3\rho_0}\right) + \frac{K_{\text{sym}}}{2} \left(\frac{\rho - \rho_0}{3\rho_0}\right)^2 + \cdots
$$

that one may use to estimate m(**The slope of symmetry energy**

$$
L = 3\rho_0 \frac{\partial E_{\text{sym}}(\rho)}{\partial \rho} \bigg|_{\rho = \rho_0}
$$

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Assumption from experiments:

The density dependence

The ab initio calculations

I. Tews, J. M. Lattimer, A. Ohnishi, and E. E. Kolomeitsev, Astrophy. J. 848(2017)105

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27/09/2019 Jinniu Hu text and Ref.[122] for details. Figure taken from Ref.[122].

The tensor and short range complete the tensor and short range complete the state of the sta

The repulsion at short range distance

250 -21.55 The strong tensor force $30₀$ $24.1₁$ $24.1₂$ $24.1₂$ **at intermediate range**

 200 -21.60 200 -21.60 200 -21.69 3.6 3.9 3.6 3.9

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The short range correlation

Correlation function:

Jastrow function, coupled-cluster method…

Renormalize interaction:

- **J. Hu, H. Toki, and H. Shen, J. Phys. G 38(2011)08515**
- **J. Hu, H. Toki, and Y. Ogawa, Prog. Theor. Exp. Phys. 103D02 (2013)**
- J. Hu, H. Shen and H. Toki, Phys. Rev. C, 95(2017)025804
J. Hu, Y. Zhene, E. Englhoum, H. C. Meissner, and J. Mane, Phys. Rev. C. 06(2017)034307
	- J. Hu, H. Shen and H. Toki, Phys. Rev. C, 95(2017)025804
J. Hu, Y. Zhang, E. Epelbaum, <u>U. G. Meissner, and J. Meng, Phys. Rev. C 96(2017)034307</u>

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The Lagrangian of Bonn potentials The Lagrangian of Bonn potentials

$$
\mathcal{L}_{int} = \bar{\psi} \bigg[-g_{\sigma}\sigma - g_{\delta}\tau_a \delta^a - \frac{f_{\eta}}{m_{\eta}} \gamma_5 \gamma_{\mu} \partial^{\mu} \eta - \frac{f_{\pi}}{m_{\pi}} \gamma_5 \gamma_{\mu} \tau_a \partial^{\mu} \pi^a
$$

\n
$$
- g_{\omega} \gamma_{\mu} \omega^{\mu} + \frac{f_{\omega}}{2M} \sigma_{\mu\nu} \partial^{\nu} \omega^{\mu} - g_{\rho} \gamma_{\mu} \tau_a \rho^{a\mu} + \frac{f_{\rho}}{2M} \sigma_{\mu\nu} \partial^{\nu} \tau_a \rho^{a\mu} \bigg] \psi
$$

\n
$$
+ \frac{1}{2} \partial_{\mu} \sigma \partial^{\mu} \sigma - \frac{1}{2} m_{\sigma}^2 \sigma^2 + \frac{1}{2} \partial_{\mu} \delta^a \partial^{\mu} \delta^a - \frac{1}{2} m_{\delta}^2 \delta^{a2}
$$

\n
$$
+ \frac{1}{2} \partial_{\mu} \eta \partial^{\mu} \eta - \frac{1}{2} m_{\eta}^2 \eta^2 + \frac{1}{2} \partial_{\mu} \pi^a \partial^{\mu} \pi^a - \frac{1}{2} m_{\pi}^2 \pi^{a2}
$$

\n
$$
- \frac{1}{4} W_{\mu\nu} W^{\mu\nu} + \frac{1}{2} m_{\omega}^2 \omega_{\mu} \omega^{\mu} - \frac{1}{4} R_{\mu\nu}^a R^{a\mu\nu} + \frac{1}{2} m_{\rho}^2 \rho_{\mu}^a \rho^{a\mu} ,
$$

R. Machleidt. Avd. Nucl. Phys. 19(1989)189

R^a µν

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Παρα

µ .

Unitary correlation operator method with $\frac{1}{2}$ **Unitary correlation operator method was all to the set of the correlation of UCOM up to the set of the correlation of the set of the correlation of UCOM up to the set of the correlation of the set of the correlation of th** Unitary correlation operator method \mathbb{R} \mathbb{R} at \mathbb{R} $\sqrt{\frac{1919}{191}}$ ($\sqrt{ }$

Correlation operator Unitary nuclear matter density. Now, we can use the two-body correlation operator under two-body correlation operator u **borrelation operator** correlation correlation operator unit of $\frac{1}{2}$

efficient to provide the reasonable binding energies and wave functions of light nucleich nucleich nucleich nu

Unitary

 $\bigcup_{i=1}^{n}$ UNIV $\bigcup_{i=1}^{n}$

, \mathcal{L}

$$
\psi = U\phi.
$$

\n
$$
\mathcal{H}\psi = E\psi,
$$

\n
$$
U^{\dagger}HU\psi = E\psi.
$$

 T is just the short-range correlation is just the short-range correlation, because the proba-

$$
\widetilde{V}(i,j) = u^{\dagger}(i,j)Vu(i,j) + u^{\dagger}(i,j)(T_i + T_j)u(i,j) - (T_i + T_j).
$$

H. Feldmeier, T. Neff, R. Roth, J. Schnack, Nucl. Phys. A 632(1998)61

27/09/2019 Jinniu Hu Jinniu Hu $\frac{1}{27}$ $T_{\rm F}$ effective interaction in $T_{\rm F}$ short range correlation plays a same role as $T_{\rm F}$ $-37/00/2010$ In actual calculation, it is not convenient to directly adopt to directly adopt to directly adopt the operator

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The equations of state of nuclear matter The equations of state of nuclear matter at *pure neutron matter* at *neutron matter* at *new at 15.* The total energy is 25.7 MeV and the total energy is 25.7 MeV and the total energy is 25.7 MeV and the total energy is 12.2 MeV.

J. Hu, H. Toki, W. Wen, and H. Shen, Phys. Lett. B 687(2010)271

Fig. 1. The present tramework can reprod solid curve is the result of the RHFU model, which is compared with the result of **Ean Chill the tensen connelation is** the short range correlation. **Fig. 2.** The EOS's of asymmetric nuclear matter with the Bonn-A potential for various The present framework can reproduce the results of RBHF for PNM are the results of the results of the corresponding results of the corresponding results of the corresponding r For SNM, the tensor correlation is important at low density region

27/09/2019 Jinniu Hu in Fig. 1. We represent the result of the result of the RBHF theory theory theory theory theory theory theory t

to symmetric nuclear matter. The results for neutron-rich matter

The properties of nuclear matter **《 》为 引 大** *奖* s_{max} at empirical saturation density, ρ $\frac{1}{2}$ and the lack of the

> J. Hu, H. Toki, W. Wen, and H. Shen, Phys. Lett. B 687(2010)271 Bonn C potentials are less than those from Bonn A potential, since their binding

Asymmetry nuclear matter and Syr

er Symmetry energy

density increasing, the short range correlation becomes more important. At 2₀₀, the short range correlation becomes

would like to the top thank Dr. E.N.E. van Dalen for providing RBHF results.
E.N.E. van Dalen for providing RBHF results.

Fig. 3. The Symmetry energies from more bon the tensor effects on SNM The symmetry energies from three Bonn potentials are different due to Fig. 1. The symmetry energies as functions of density within Bonn A, B, C potentials in the

27/09/2019 Jinniu Hu \mathbf{t} , the resulting EOS is not so bad, but other cases are largely cases

 $T_{\rm eff}$ is $T_{\rm eff}$ matter, i.e., $T_{\rm eff}$ relation, are evaluated by $r_{\rm eff}$

The fractions of baryons and leptons

The Direct URCA process will firstly occur at Bonn A potential due to **its largest symmetry energy.**

that are higher than those in RMF model, like TM1 parameter set. These densities

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 \blacksquare The maximum masses of neutron star are about 2.2M☉ The radii at 1.4M☉ are less than 13 km

star in an external gravitational filed from another star can be extracted from the **27/09/2019 Jinniu Hu**

when there is a collision between the tidal deformability of a collision between two neutron stars, the tidal deformability of a obtained by solving a differential equation relation relatio

 \mathbf{F} as a function of neutron star mass from Bonn A, B, C potentials. The star mass from Bonn A, B, C potentials. **The tidal deformabilities at 1.4M**⊙ **are less than 400**

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dy(r)

 $+$ $+$ $+$ $+$

tively. These values are completely consistent with the present constraint about **Jinniu Hu** Q(r)=0, (16)

r
F

r
Frans

 $\frac{1}{2}$

(r) + y(r)F(r) + r²

constraint region from GW170817.

The tidal deformabilities with constraint of GW170817

Data from: B. P. Abbott et al. Phys. Rev. Lett. 121(2018)161101

27/09/2019 Jinniu Hu t_{1} , where $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ credible intervals from the 90% credible

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The properties of neutron star were calculated in framework relativistic Hartree-Fock model with UCOM

The maximum masses and radius from Bonn potentials are almost identical.

The properties of neutron star at 1.4M⊙ **from three Bonn potentials are distinguished due to their different density dependences of symmetry energy.**

Thank you very much for your attention!

Neutron rich system

H. Schatz, J. Phys. G 43(2016)064001

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Nuclear matter **is a is not convenient to directly a** if *k 2* R+(r) = r + α

$$
R_+(r)=r+\alpha\left(\frac{r}{\beta}\right)^\eta\exp(-\exp(r/\beta)).\qquad\qquad \textrm{as}\qquad \textrm{as}\qquad \textrm{on}\qquad \tex
$$

 $Q = \frac{Q}{Q}$

The correlations on quantum operator

$$
u^{\dagger}(i,j)ru(i,j) = R_{+}(r)
$$

$$
u^{\dagger}(i,j)V(r)u(i,j) = V(R_{+}(r))
$$

$$
u^{\dagger}(i,j)p_r u(i,j) = \frac{1}{\sqrt{R'_{+}(r)}} \frac{1}{r} p_r \frac{1}{\sqrt{R'_{+}(r)}},
$$

The correlation on kinetic energy The correlation on Kinefic energy

$$
c^{\dagger}(i,j)T(i,j) - T = \sum_{i < j} (\vec{\alpha}_i - \vec{\alpha}_j) \cdot \frac{\vec{r}}{r} \frac{1}{\sqrt{R'_+(r)}} \frac{1}{r} q_r \frac{r}{\sqrt{R'_+(r)}}
$$
\n
$$
+ (\vec{\alpha}_i - \vec{\alpha}_j) \cdot \frac{\vec{r}}{r} \left(\frac{1}{R'_+(r)} - \frac{r}{R_+(r)} \right) q_r + \left(\frac{r}{R_+(r)} - 1 \right) (\vec{\alpha}_i - \vec{\alpha}_j) \cdot \vec{q}.
$$

Symmetry energy

Fig. 1. The multipaceted influence of the nuclear symmetry energy. The nuclear symmetry energy symmetry energy. **A. Steiner, M. Prakash, J. Lattimer and P. Ellis, Phys. Rep. 411(2005)325**

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