TBF effect on the EOS of Asymmetric Nuclear Matter

-------- to my best friend: Umberto Lombardo

Wei Zuo
Institute of Modern Physics, Lanzhou, China
Introduction: My research activities in Catania

Sept. 1995 ---- Apr. 1996: HIC with microscopic mean field and NN cross section
Apr. 1997 ---- Apr. 1999: INFN Postdoc. Fellow, Brueckner theory, g.s. correlations, ANM
May 2001 ---- Aug. 2001: Microscopic three-body force (TBF)
Jul. 2004 ---- Jul. 2004: TBF effect on nucleon superfluidity in nuclear matter
Feb. 2006 ---- Mar. 2006: Asia-Europe Link program
May 2007 ---- Jun. 2007: Asia-Europe Link program
Jan. 2010 ---- Feb. 2010: Skyrme functional based BHF predictions
Nov. 2011 --- Nov. 2011: Nucleon superfluidity in neutron matter
May 15 --- May 31, 2014: Effective NN interactions
Jun. 17 --- Jun. 27, 2015: NNINT and NN conferences
Effect of g.s. correlations (1997-1998)
neutron matter

Single-particle properties in neutron matter from extended Brueckner theory

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Abstract

The Brueckner-Hartree-Fock approximation extended to include ground-state correlations is applied to neutron matter. Single-particle properties are calculated including neutron mean field, effective mass and mean free path. The main result is a pronounced enhancement of the effective mass at the Fermi surface whose influence on neutron star properties is discussed. © 1998 Elsevier Science B.V.

PACS: 25.70.e, 12.75.Ce, 21.65.+f, 24.10.Cn
Keywords: Neutron matter; Brueckner theory; Neutron stars; Nuclear mean field; Effective mass; Mean free path

Fig. 4. The mean free path calculated for several Fermi momenta.
Mean free path in nuclear matter from extended Brueckner-Hartree-Fock approximation

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Received 3 December 1997; revised 29 March 1998
Editor: J.-P. Biaucourt

Abstract

The nucleon mean free path in nuclear matter is studied within the framework of the Brueckner-Hartree-Fock approximation extended to incorporate ground-state correlations. The ground state particle-hole excitations give rise to a partial opening of the Fermi sphere and to an enhancement of the mean free path above the Fermi surface. A comparison with the classical limit and the mean free path in neutron matter is discussed along with a simple prescription to include the isospin dependence. © 1998 Published by Elsevier Science B.V. All rights reserved.

PACS: 25.70.-t; 13.75.Cg; 21.65.+f; 24.10.Cn
Keywords: Nuclear matter; Brueckner theory; Heavy ion collisions; Nuclear mean field; Mean free path

Fig. 3. Mean free path in symmetric nuclear matter from the three
Research work on asymmetric nuclear matter within BHF framework by Ignazio and Umberto in 1991

Asymmetric nuclear matter equation of state

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(Received 25 June 1991)

Systematic calculations of asymmetric nuclear matter have been performed in the framework of the Brueckner-Bethe-Goldstone approach in a wide range of both density and asymmetry parameter. The


ting energy per nucleon is confirmed by the present results in us. The predominant role of the $^3S_1, ^3P_1$ component of the

ution of the proton and neutron single-particle potentials is

eviation from the phenomenological potentials occurs for
Asymmetric nuclear matter from an extended Brueckner-Hartree-Fock approach

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(Received 30 November 1998, published 6 July 1999)

The properties of isospin-asymmetric nuclear matter have been investigated in the framework of the extended Brueckner-Hartree-Fock approximation at zero temperature. Self-consistent calculations using the Argonne $V_{14}$ interaction are reported for several values of the asymmetry parameter $\beta = (N-Z)/A$, ranging from symmetric nuclear matter to pure neutron matter. The binding energy per nucleon fulfills the $\beta^2$ law in the whole asymmetry range. The symmetry energy is calculated for different densities and discussed in comparison with other predictions. At the saturation point it is in fairly good agreement with the empirical value. The present approximation, based on the Landau definition of quasiparticle energy, is investigated in terms of the Hugenholtz–Van Hove theorem, which is proved to be fulfilled with a good accuracy at various asymmetries. The isospin dependence of the single-particle properties is discussed, including mean field, effective mass, and mean free path of neutrons and protons. The isospin effects in nuclear physics and nuclear astrophysics are briefly discussed. [S0556-2813(99)03108-8]
Extended BHF approach for asymmetric nuclear matter (1998 - 1999)

HVH theorem for asymmetric nuclear matter

<table>
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<tr>
<th>( \rho ) (fm(^{-3}))</th>
<th>0.2</th>
<th>0.085</th>
<th>0.6</th>
<th>0.8</th>
<th>0.2</th>
<th>0.6</th>
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<td>93.15</td>
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<td>64.90</td>
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<td>46.00</td>
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<td>92.00</td>
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<td>64.59</td>
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TABLE III. Proton and neutron chemical potentials (Fermi energies) calculated in different approximations and compared with the symmetry energy. The results corresponding to four values of the asymmetry parameter \( \beta \) for each of the three densities are reported.
My life in Catania (1997 -1999)

Working group in Catania

Exotic trip to the top of Etna

Dinner at Umberto’s home

Snow on Etna

Friends from 5 countries

Beautiful ladies at LNS
Microscopic Three-body Forces (Belgium, 1999)

- Based on meson exchange approach
- Be constructed in a consistent way with the adopted two-body force----------microscopic TBF!
- Grange et. al PRC40(1989)1040
Nuclear matter EOS with a three-body force

A. Lejeune, U. Lombardo, W. Zuo

1. Consistency between TBF and two-body force was missing
2. Symmetry energy was extracted according to the $\beta^2$ law
TBF effect on the properties of symmetric nuclear matter: consistent TBF and saturation mechanism (2001 - 2002)

Interplay of three-body interactions in the EOS of nuclear matter

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Received 10 October 2001; received in revised form 14 February 2002; accepted 26 February 2002

Abstract

The equation of state of symmetric nuclear matter has been investigated within a approach adopting the charge-dependent Argonne V18 two-body force plus a macroscopic force based on a mean-exchange model. The effects on the equation of state of the processes giving rise to the three-body force are explored up to high baryonic density that the major role is played by the competition between the strongly repulsive $(\sigma,\omega)$ term and virtual nucleon-nucleon excitation and the large attractive contribution of exchange with $(\omega,\omega)$ resonance excitation. The net result is a repulsive term with saturation density corresponding to the only two-body force much closer to the empirical keeping constant the saturation energy per particle. The contributions from $(\sigma,\omega)$ such shown to be attractive and rather small. The analysis of the separate three-body force allows to make a comparison with the predictions of Dirac-Breitners approach which to incorporate via the dressed Dirac spinors the same virtual nucleon-nucleon excitation the present three-body force. The numerical results suggest that the three-body force missing from the Dirac-Breitners approach are not negligible, especially at high calculation of the nuclear mass and the effective mass shows that the three-body force to a limited extent such properties, c 2002 Elsevier Science B V. All rights reserved.

<table>
<thead>
<tr>
<th>$\rho$ (fm$^{-3}$)</th>
<th>$E_A$ (MeV)</th>
<th>$K$ (MeV)</th>
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</thead>
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<td>210</td>
</tr>
<tr>
<td>0.26</td>
<td>-18.0</td>
<td>230</td>
</tr>
</tbody>
</table>

Fig. 2. Left side: $\sigma$–(\$\omega$) TBF contribution to the energy shift from the BHF energy per particle in symmetric
Microscopic TBF for asymmetric nuclear matter: \( \beta^2 \)-law and symmetry energy (2001 - 2002)

W. Zuo et al.: Microscopic three-body force for asymmetric nuclear matter

Microscopic three-body force for asymmetric nuclear matter

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Received: 18 February 2002 / Revised version: 25 April 2002
Communicated by P. Schuck

Abstract. Banderer calculations including a microscopic three-body force in asymmetric nuclear matter. The effects of the three-body force on the equation of state of the energy per nucleon \( E\) is fulfilled in 0 \( \leq \beta \leq 1 \) up to high densities. This three-body force provides a strong effect which increases with density in good agreement with the predictions of Land's assumption that proton and neutron mean field linearly vary as the density due to the three-body force, while the momentum dependence to be only weakly affected. Consequently, a linear isospin spin of the neutron is found for both cases of and without the three-body force. The isospin dependent and collective flows in heavy-ion collisions are briefly discussed along with URCA processes that occur in the neutron star cooling.
TBF effect on nucleon pairing in nuclear matter and neutron matter (2002 - 2004)

PHYSICAL REVIEW C 66, 037303 (2002)

Short-range effects on nuclear pairing

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(Received 18 June 2002; published 17 September 2002)

We determine the influence of the three-body force and the medium modification of meson masses on pairing in nuclear and neutron matter. A reduction of the pairing gap is found and increases with density.

DOI: 10.1103/PhysRevC.66.037303 PACS number(s): 21.65.+f, 24.10.Cn

FIG. 2. $^1S_0$ gap in neutron matter and in symmetric nuclear matter. Solid, dashed, and dotted curves correspond to AV18, AV18 + TBF, and AV18 + free spectrum.
$^{1}\!S_{0}$ proton and neutron superfluidity in $\beta$-stable neutron star matter

W. Zuo $^{a,b}$, Z.H. Li $^{a}$, G.C. Lu $^{a}$, J.Q. Li $^{a,b}$, W. Scheid $^{b}$, U. Lombardo $^{c,d}$, H.-J. Schulze $^{e}$, C.W. Shen $^{d}$

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Received 5 March 2004; accepted 5 May 2004
Available online 22 June 2004
Editor: J.-P. B blends

Abstract

We investigate the effect of a microscopic three-body force on the proton and neutron superfluidity in the $^{1}\!S_{0}$ channel in $\beta$-stable neutron star matter. It is found that the three-body force has only a small effect on the neutron $^{1}\!S_{0}$ pairing gap, but it suppresses strongly the proton $^{1}\!S_{0}$ superfluidity in $\beta$-stable neutron star matter.

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Fig. 1. Neutron $^{1}\!S_{0}$ energy gap in $\beta$-stable matter
TBF effect on Landau parameters (2002 - 2004)

Landau parameters of nuclear matter in the spin and spin-isospin channels

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(Received 20 December 2002; published 12 March 2003)

The equation of state of spin and isospin polarized nuclear matter is determined in
Brueckner theory including three-body forces. The Landau parameters in the spin and
spin-isospin channels are derived as a function of the baryonic density. The results
are compared with the Ga
c mode calculations. The relevance of \(G_0\) and \(G_0'\) for neutron stars is shortly discussed, including the
and the neutron star cooling.

DOI: 10.1103/PhysRevC.67.037301 PACS number(s): 21.65.+.

FIG. 2. Landau parameters of SNM in the spin and spin-isospin channel. The square (triangle)
symbols are from 2BF (2BF and 3BF) calculations and the solid (open) ones are for \(G_0\) (\(G_0'\)).
Asia-Europe Link program [CN/ASIA-LINK/008(094-791)] (2005 - 2007)

Coordinator: Umberto Lombardo, Catania

Partners:
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Peter Ring, Technology Uni. Munich, Germany
Dao Tien Khoa, INST, Hanoi, Vietnam
Zhingyu Ma, CIAE, Beijing, China
Jie Meng, Beijing Uni., Beijing, China
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Asia-Europe scholarships from Lanzhou
Nuclear matter saturation point and symmetry energy with modern nucleon-nucleon potentials


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(Received 23 June 2006; published 20 October 2006)

We determine the saturation properties of nuclear matter within the Brueckner-Hartree-Fock approach by a large set of modern nucleon-nucleon potentials and confirm the validity of the Coester band. The improvement of the saturation point when including nuclear three-body forces is pointed out and comparison with the Brueckner-Hartree-Fock results is made.
Extended BHF calculation at finite temperatures (2005 - 2007)

PHYSICAL REVIEW C 73, 035208 (2006)

Temperature dependence of single-particle properties in nuclear matter

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(Received 22 April 2005; published 17 March 2006)

The single-nucleon potential in hot nuclear matter is investigated in the framework of the Brueckner theory by adopting the realistic Argonne $V_{18}$ or Nijmegen 93 two-body nucleon-nucleon interaction supplemented by a microscopic three-body force. The rearrangement contribution to the single-particle potential induced by the ground state correlations is calculated in terms of the hole-line expansion of the mass operator and provides a significant repulsive contribution in the low-momentum region around and below the Fermi surface. Increasing temperature leads to a reduction of the effect, while increasing density makes it become stronger. The three-body force suppresses somewhat the ground state correlations due to its strong short-range repulsion, increasing with density. Inclusion of the three-body force contribution results in a quite different temperature dependence of the single-particle potential at high enough densities as compared to that adopting the pure two-body force. The effects of three-body force and ground state correlations on the nucleon effective mass are also discussed.
TBF effect on the Kaon condensation in neutrino-trapped matter (2005 - 2007)
Nucleon-nucleon cross sections in dense nuclear matter

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(Received 1 August 2007; published 12 November 2007)

Table II. $NN$ total effective cross sections (in mb) in symmetric matter calculated with various many-body models. The results shown in column 3 are obtained with Bonn B and the DBHF model.

<table>
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<tr>
<th>$k_F$ ($fm^{-1}$)</th>
<th>$q^0$ (MeV)</th>
<th>$\sigma_{NN}^{DBHF}$</th>
<th>$\sigma_{NN}^{2bf+3bf}$</th>
<th>$\sigma_{NN}^{3bf}$</th>
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<td>18.00</td>
<td>18.15</td>
<td>22.98</td>
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<td>13.96</td>
<td>11.48</td>
<td>16.43</td>
</tr>
</tbody>
</table>
Nuclear mean field : TBF rearrangement contribution ( 2005 - 2007 )

The isospin splitting of the nucleon mean field is derived from the Brueckner theory extended to asymmetric nuclear matter. The Argonne $V_{nn}$ has been adopted as bare interaction in combination with a microscopic three-body force. 

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**PHYSICAL REVIEW C 72, 014005 (2005)**

**Isospin splitting of the nucleon mean field**

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(Received 11 May 2005; published 14 July 2005)
Three-body force rearrangement effect on single particle properties in neutron-rich nuclear matter

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(Received 4 May 2006; published 28 July 2006)
PHYSICAL REVIEW C 77, 034316 (2008)

Consistent nucleon-nucleon potentials and three-body forces

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(Received 6 December 2007; published 31 March 2008)

TABLE II. Binding energy per nucleon $E/A$ (in MeV) in different approximations using the Bonn $B$ potential.

<table>
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<th>$k_F$ (fm$^{-1}$)</th>
<th>BHF</th>
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<th>BHF + TBF</th>
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Asia-Europe Link workshops

Beijing, 2005

Lanzhou, 2006

Hanoi, 2007

Catania, 2007
Umberto Lombardo was awarded the Visiting Professorship for Senior International Scientist of Chinese Academy of Sciences (CAS) in recognition of his exceptional scholarly merit and extraordinary efforts to collaborative research with the Institute of Modern Physics (IMP) of CAS over years.
Determination of local energy density functionals from Brueckner-Hartree-Fock calculations

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Thank you for attention！

谢谢大家！