FAST/Future Pulsar Symposium 13
Kunming, Yunnan

Nuclear and Neutron Star Properties from a density-dependent meson-exchange perspective

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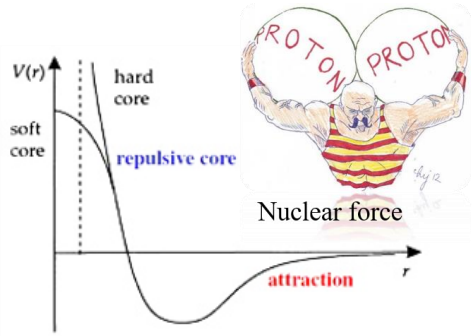
Intro | Fock Terms | Altered D.D. | New Mesons | Summary

Density Dependence of Effective Nuclear Force

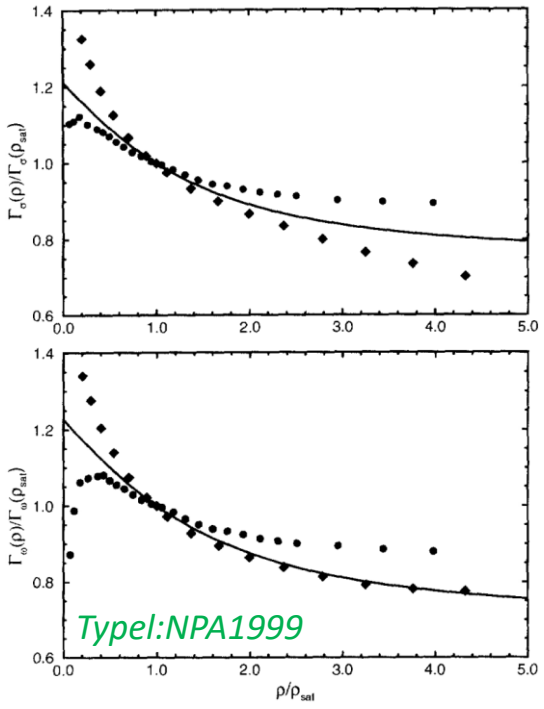
Many-Body Correlations → **Nuclear In-Medium Effects**

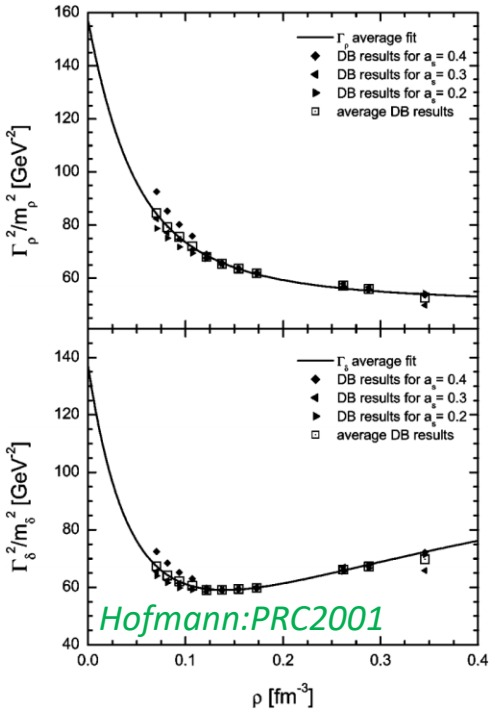
The features of nuclear force depend on the
density, isospin, nucleon momentum of nuclear matter



DDRMF

Brockmann1992
Lenske1995
Fuchs1995
Long2005



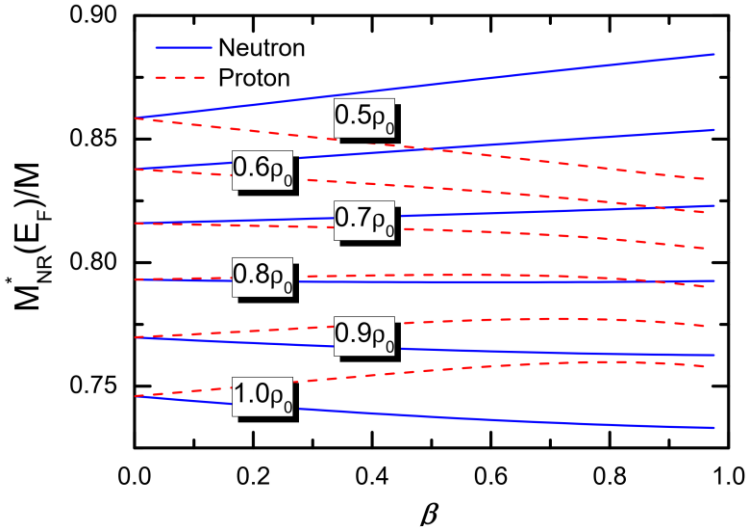


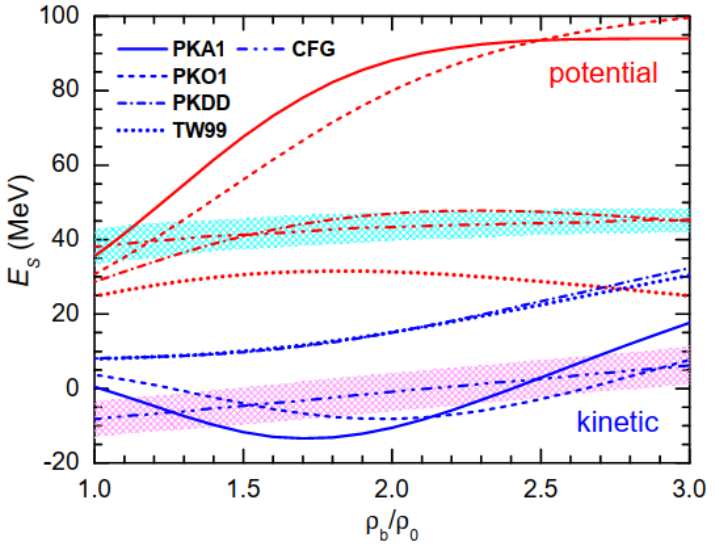
Related Aspects

- Completeness of two-body IME
- New baryon-density dependence
- New meson exchange D.o.F.

Impact on nuclear matter properties:

W.H.Long:PLB2006, B.Y.Sun:PRC2008, Z.W.Liu:PRC2018





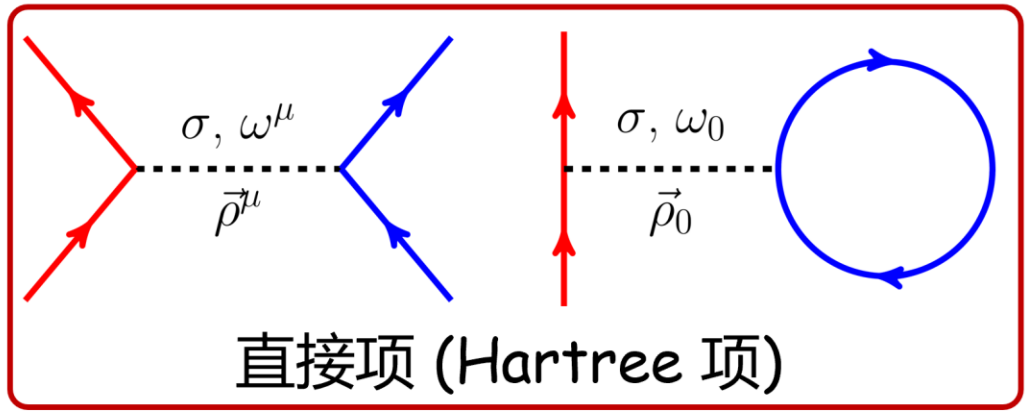
Q. Zhao, BYS, WHL, JPG 42 (2015) 095101

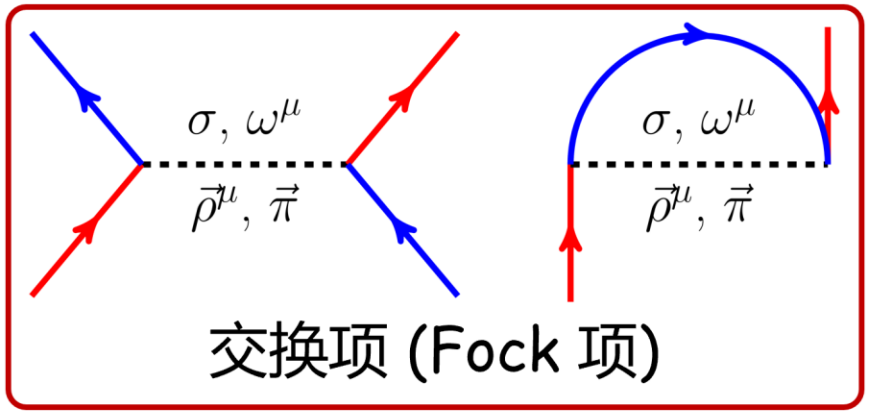
- 相对论平均场 (RMF) 模型

Walecka(1974), Serot(1986), Reihard(1989), Ring(1996), Bender(2003), Meng(2006)……

✓ 自然的自旋-轨道耦合：**相对论协变性**

✓ **Hartree 近似：无法处理张量力**





- 相对论 Hartree-Fock (RHF) 模型

Bouyssy (1987), Bernardos (1993), Shi (1995), Marcos (2004), Long (2004-), ……

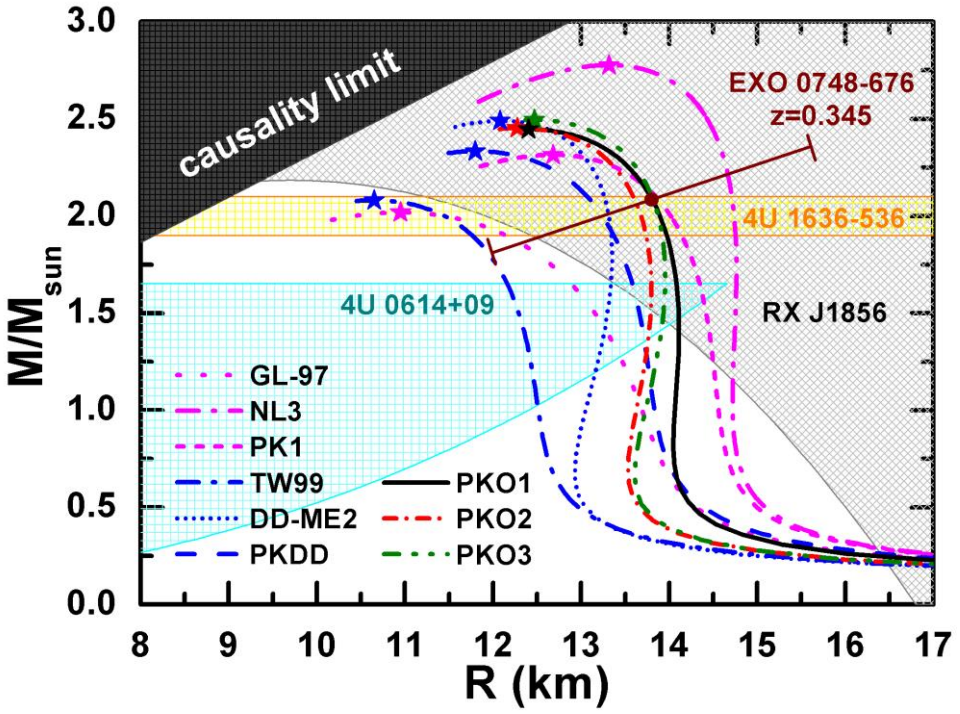
✓ 保留 RMF 模型的优越性

✓ **自然引入张量力成分**：Fock 项

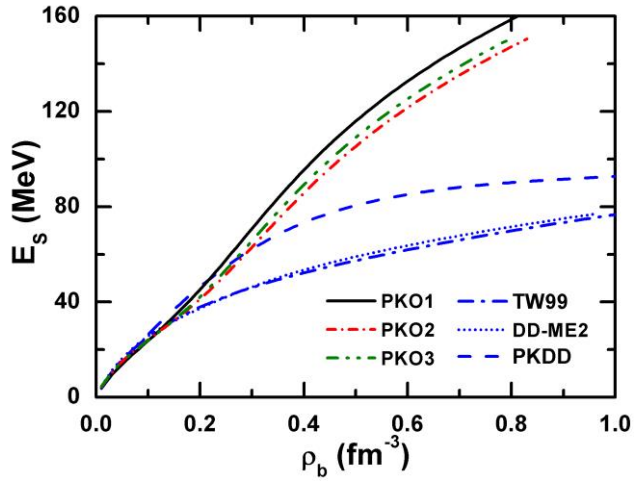
Jiang, Yang, BYS, WHL, Gu, PRC 91, 034326 (2015); Zong, BYS, CPC 42, 024101 (2018)

交换项在核物质、有限核性质描述中的作用：改变有效核力演化行为、核介质中动力学平衡

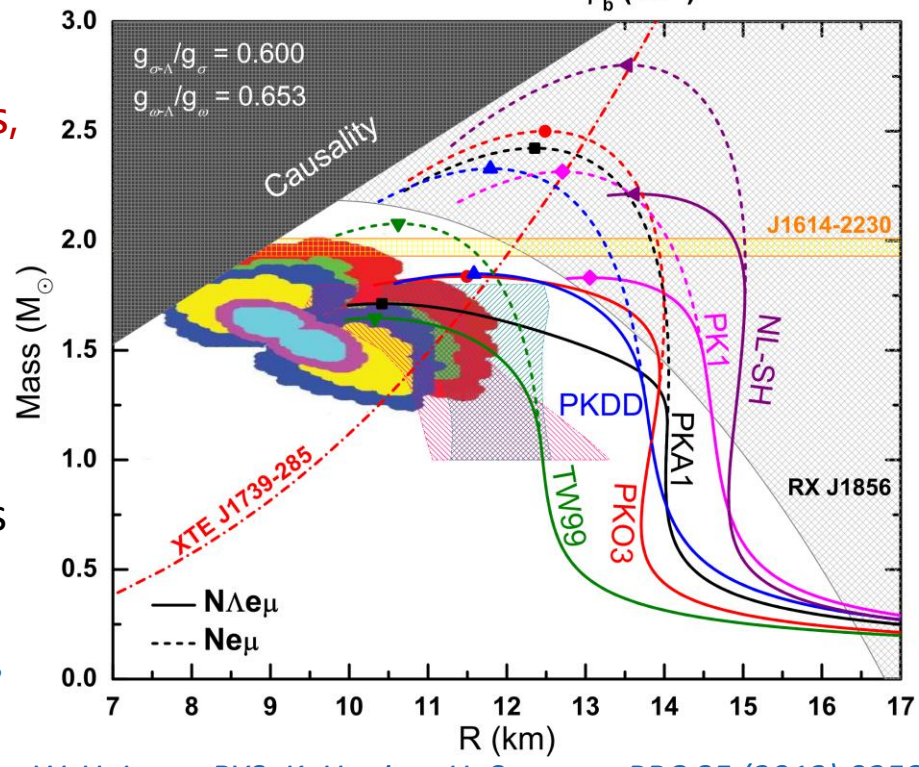
The Role of Fock Terms in NS Properties



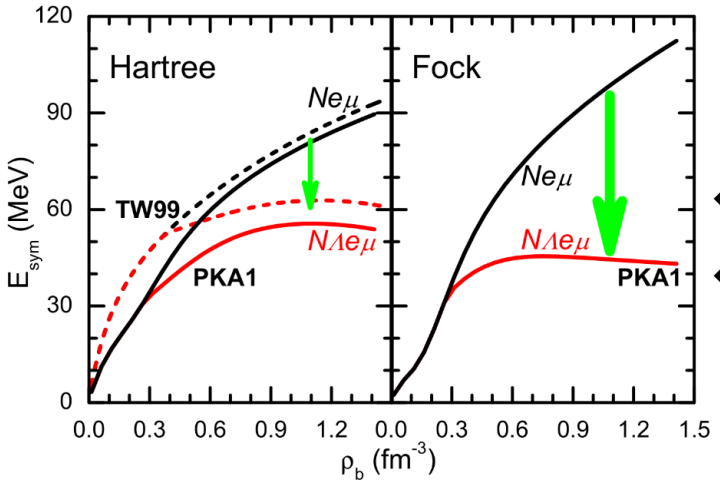
The effects of Fock terms are remarkable for properties of asymmetric nuclear matter at high densities, such as E_S



Nuclear in-medium balance and dynamics affected by Fock terms, then M-R prediction



BYS, W. H. Long, J. Meng et al., PRC 78 (2008) 065805



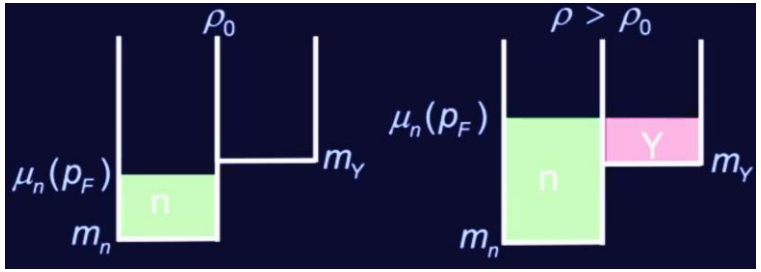
Hyperon Fock Effects

- Extra E_{sym} softening due to Fock terms
- Change of NN&YN coupling strengths

孙保元, 中国科学: 物理学 力学 天文学 46 (2016) 012018

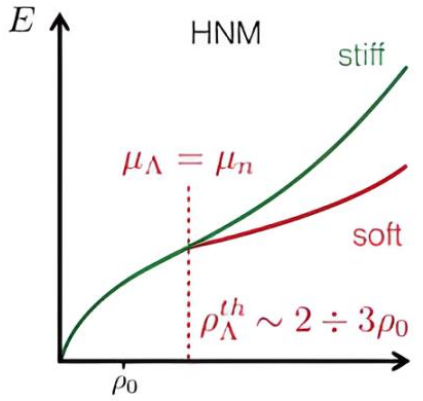
W. H. Long, BYS, K. Hagino, H. Sagawa, PRC 85 (2012) 025806

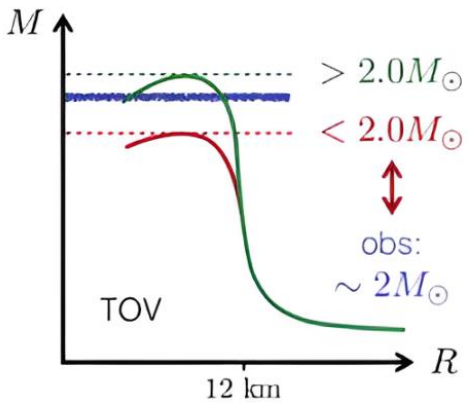
Neutron Stars: Hyperon Puzzle



$$e^- + p \rightarrow \nu_e + \Lambda$$

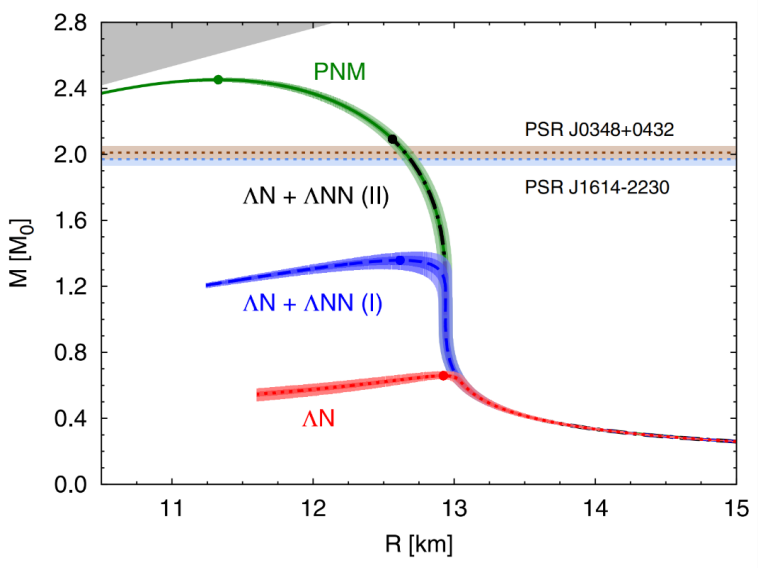
$$p_{F,n}^2 + m_n^2 \geq m_\Lambda^2$$



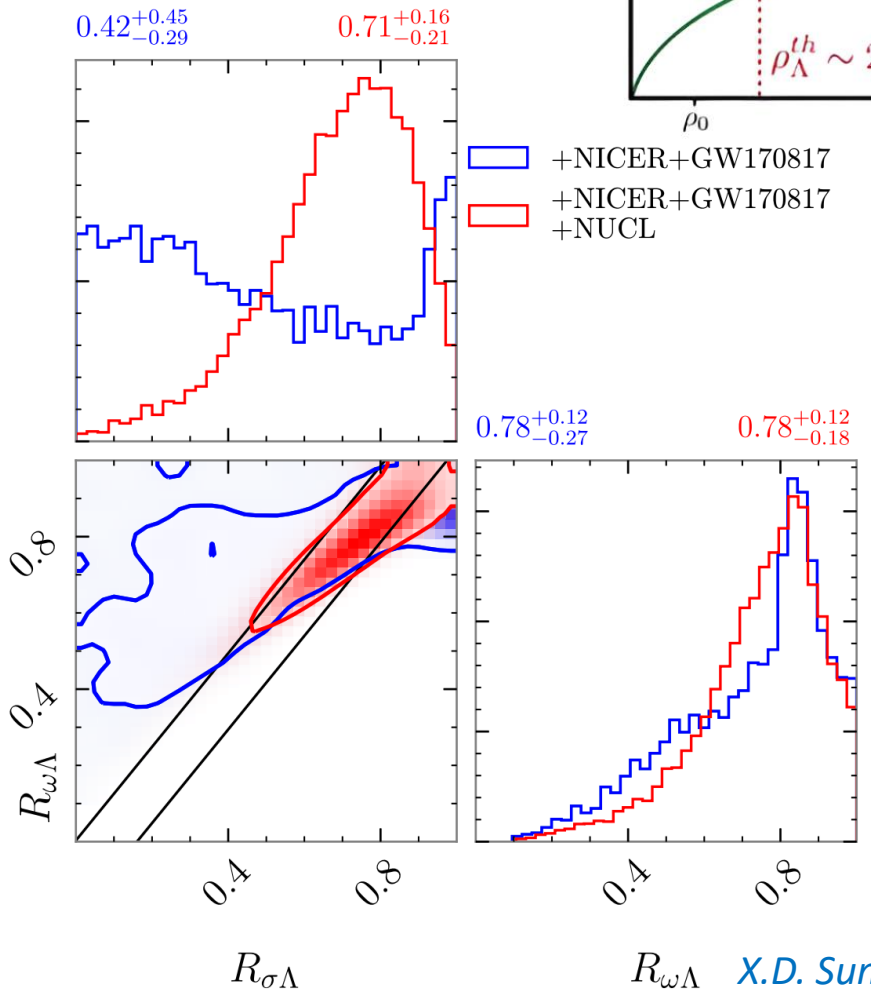


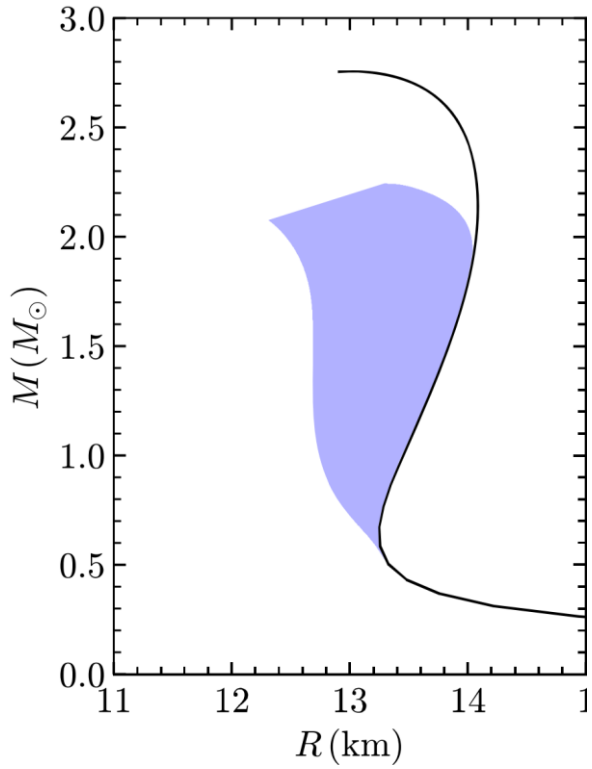
The appearance of hyperons

- Relieve of Fermi pressure
- Softer equation of state
- Reduction of maximal mass



Lonardoni, Diego et al., PRL 114 (2015) 092301





X.D. Sun, Z.Q. Miao, BYS, A. Li, ApJ 942 (2023) 55

Physics of Hypernuclei

- Hypernuclei: D.o.F. beyond nucleons

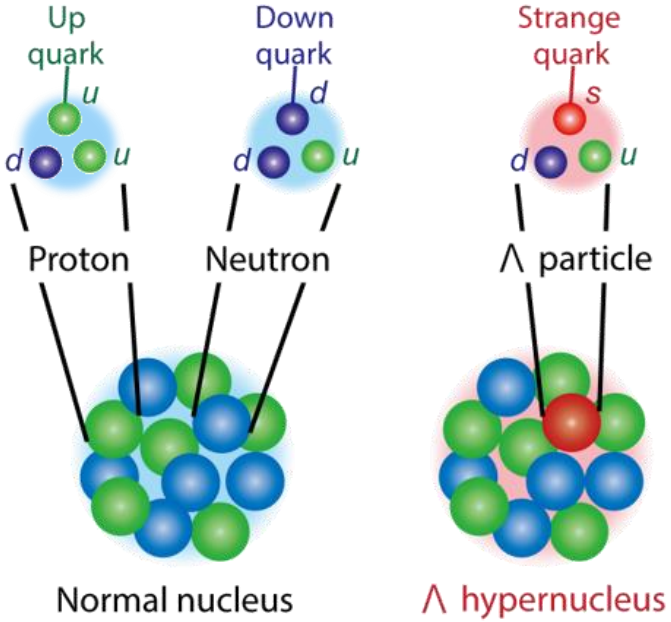
  M. Danysz and J. Pniewski, Phil. Mag. 44 (1953) 348

- Hypernuclear Structure (and Reaction)
  - Baryon-Baryon Interaction

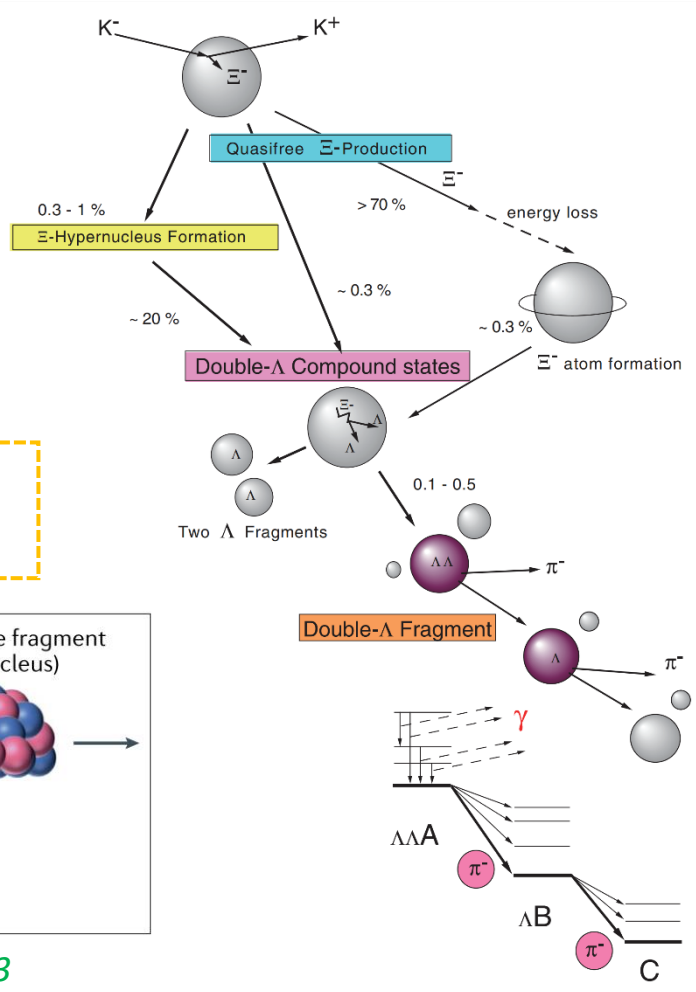
    B. F. Gibson, Phys. Rep. 257 (1995) 349
    E. Epelbaum, RMP 81 (2009) 1773
  - Neutron Star Interior Structure

    M. Prakash, Phys. Rep. 280 (1997) 1
    L. Tolos, PPNP 112 (2020) 103770

- Experiments: (π^+, K^+)、(K^-, π^-) .....

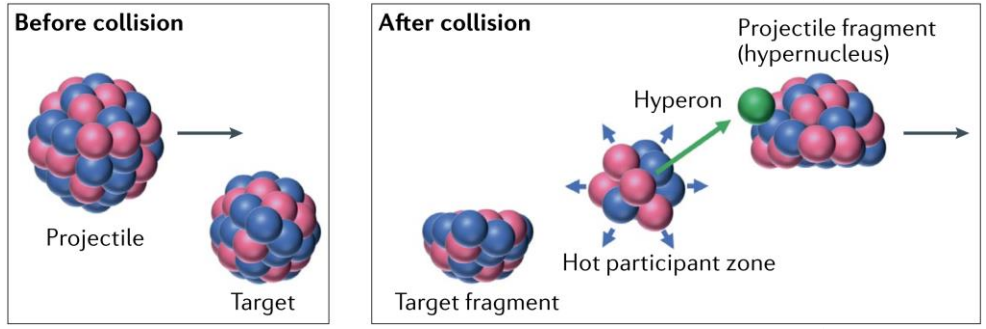


O.Hashimoto and H.Tamura, PPNP 57 (2006) 564
A. Gal et al., Rev. Mod. Phys. 88 (2016) 035004



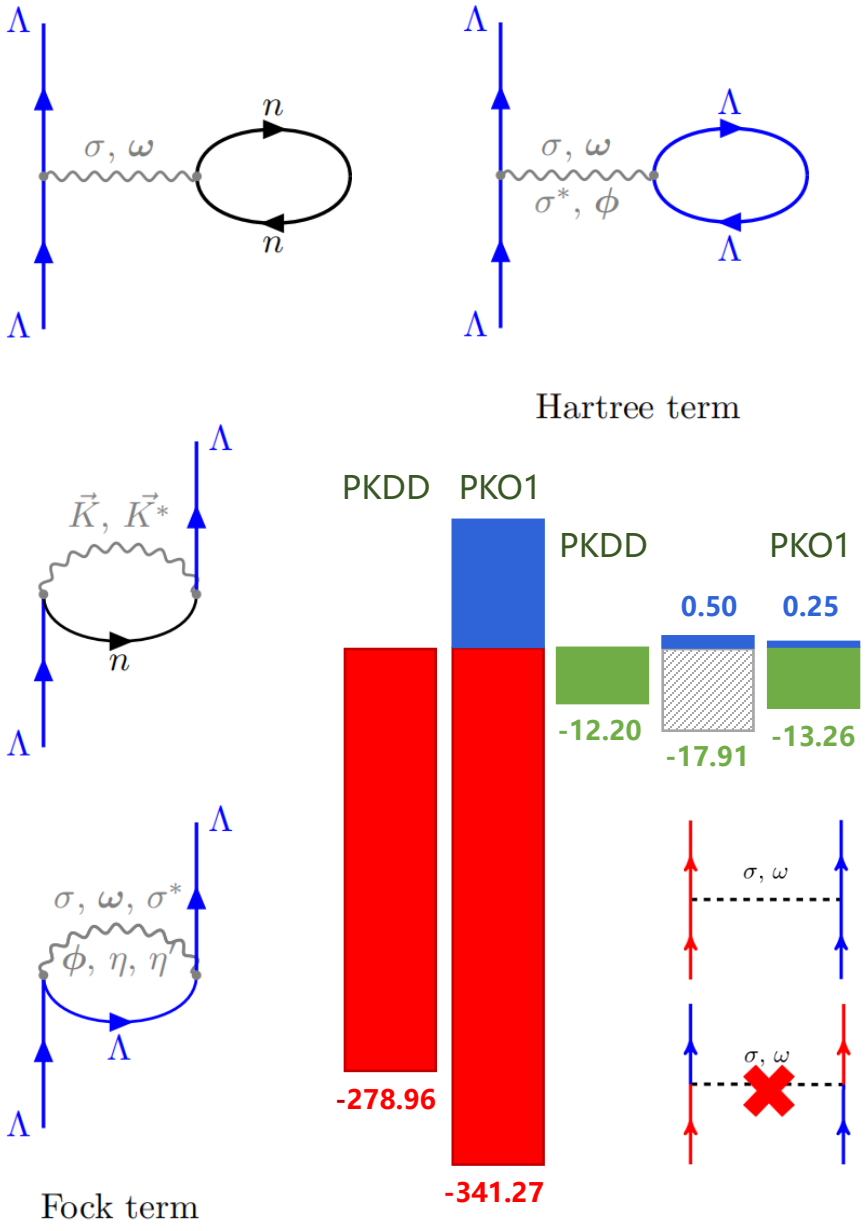
强流重离子加速器装置HIAF

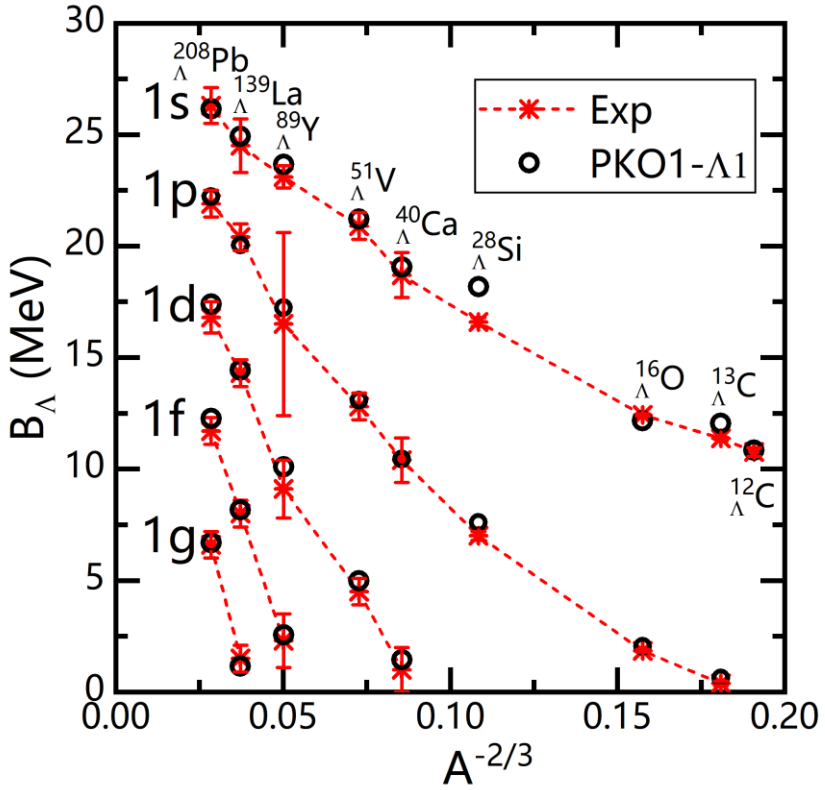
charge-exchange reactions with heavy ion projectiles

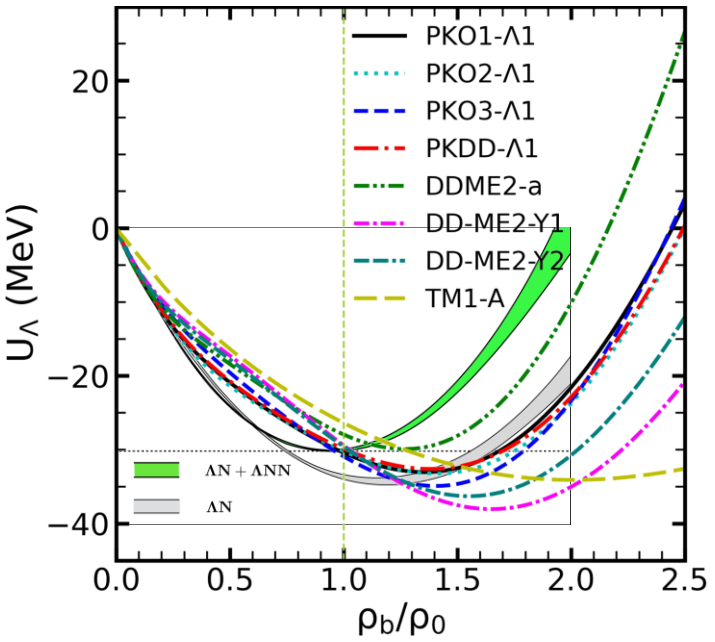


T. R. Saito, Nature Reviews Physics 3 (2021) 803

Nuclear Forces associated with Hypernuclei







SU(3) chiral EFT at NLO

D. Gerstung, Eur. Phys. J. A (2020) 56:175

Equilibrium of Hypernuclear Dynamics

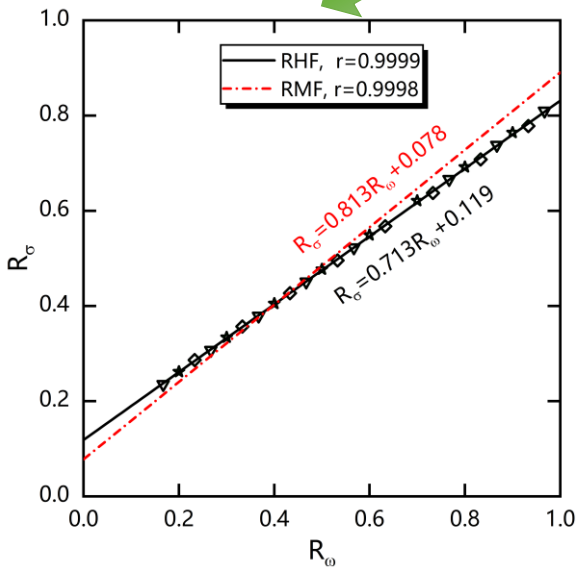
- single-Λ: weaker E_Λ^E than $E_{\rm N}^E$
- $E_\Lambda^D \sim E_\Lambda^E$ imbalance requires a reduction in $g_{\sigma\Lambda}/g_{\sigma{\rm N}}$
- Σ_+^Λ similar but Σ_-^Λ softened, so a smaller V_{SO}^Λ in RHF

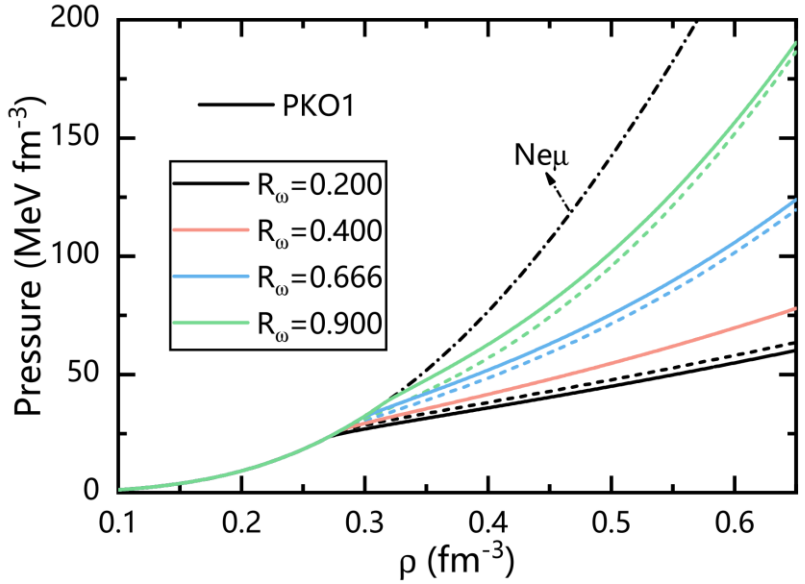
S.Y. Ding, Z. Qian, BYS, W.H. Long, Phys. Rev. C 106 (2022) 054311

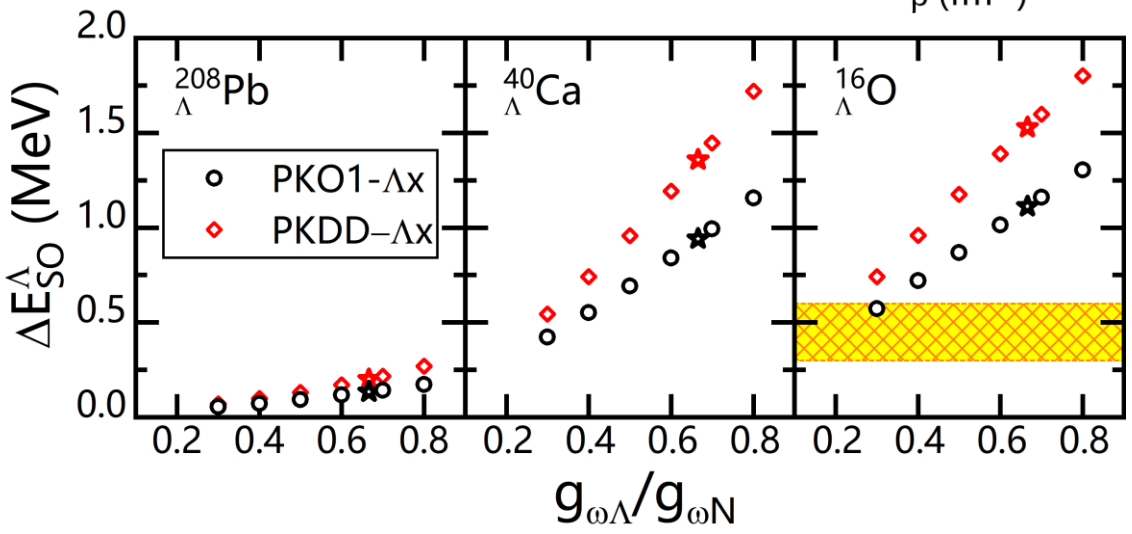
S.Y. Ding, W. Yang, BYS, Chin. Phys. C 47 (2023) 124103

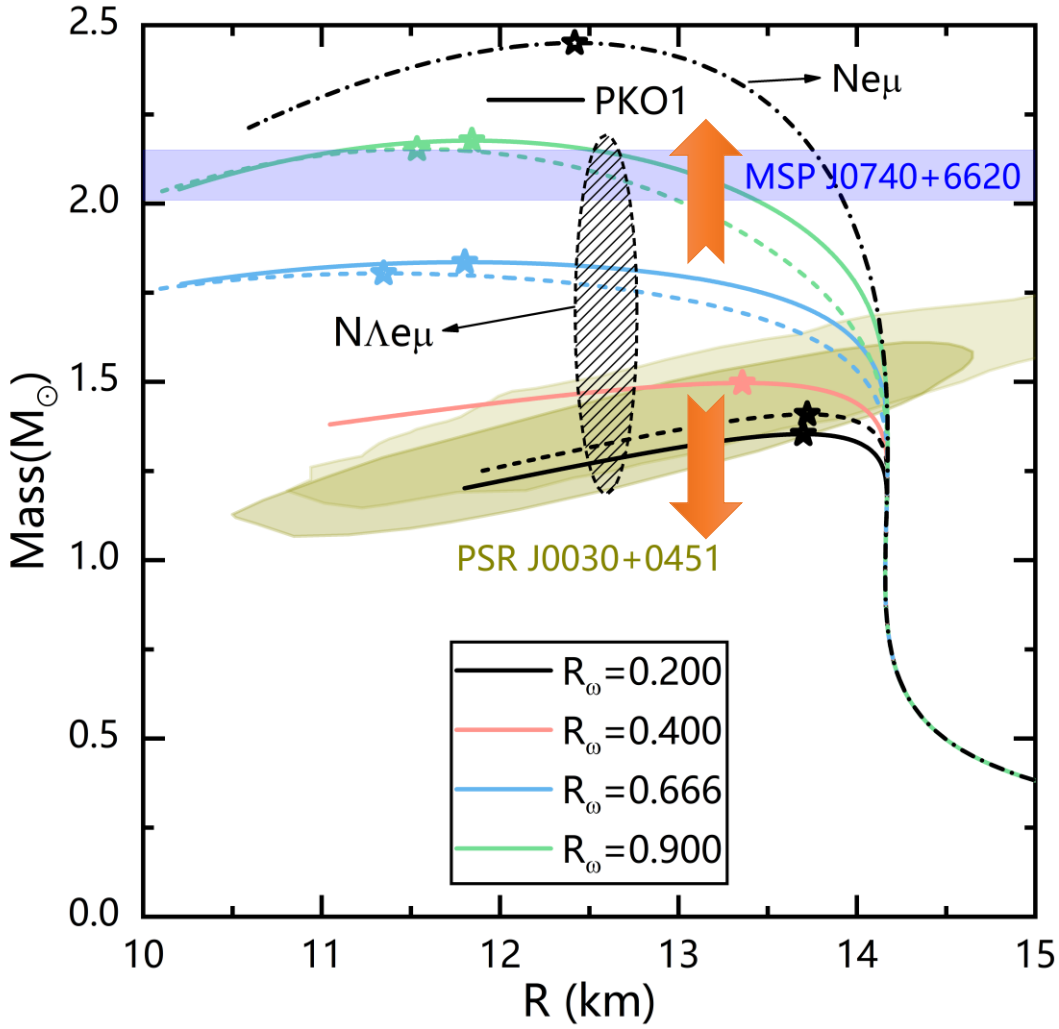
Uncertainty in ΛN coupling strength

Linear correlation of coupling strengths



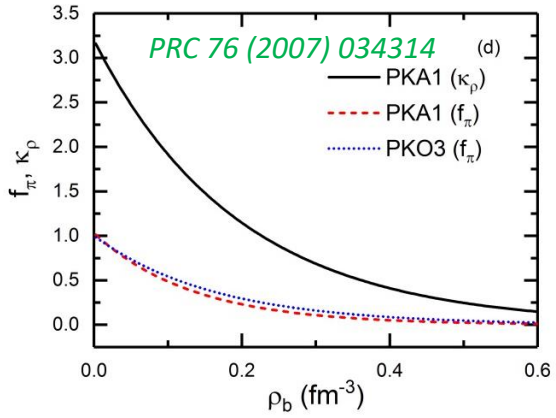


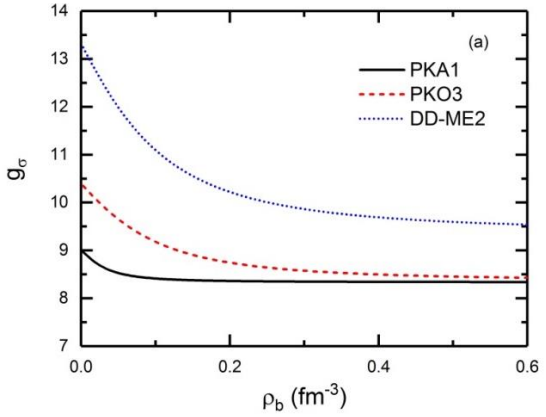


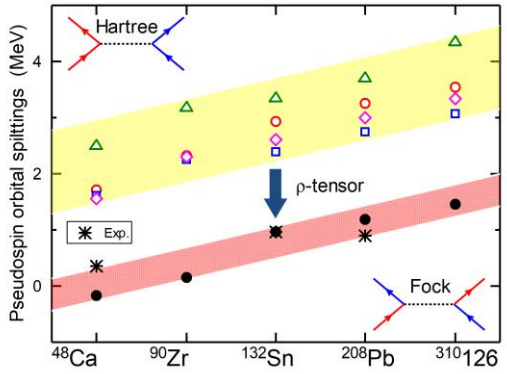


The role of Fock terms is affected by specific R_ω value

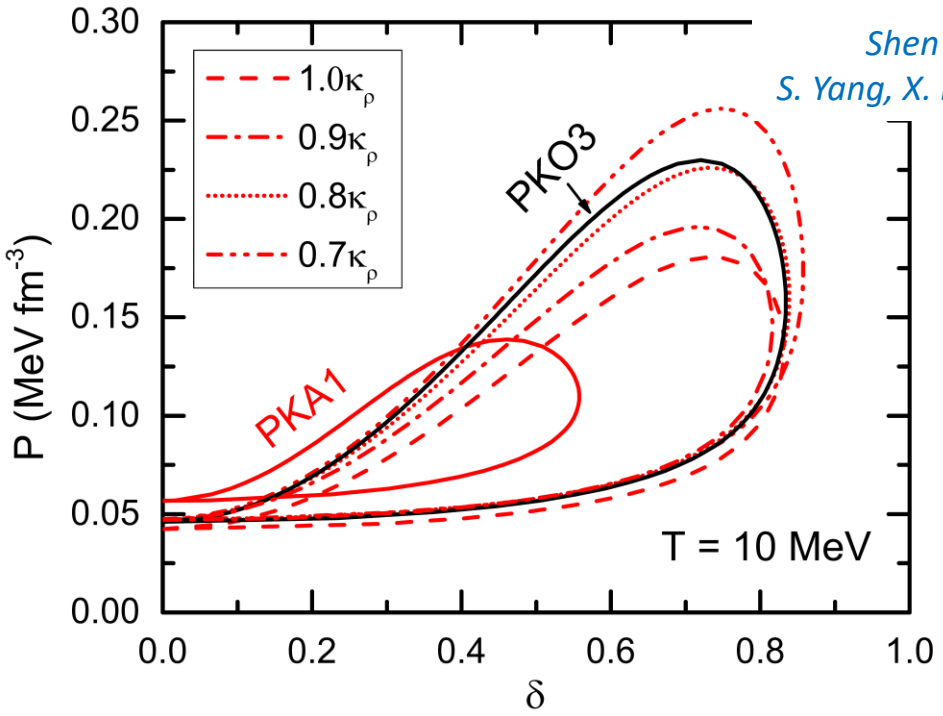
Nuclear In-Medium Effects at Low Densities



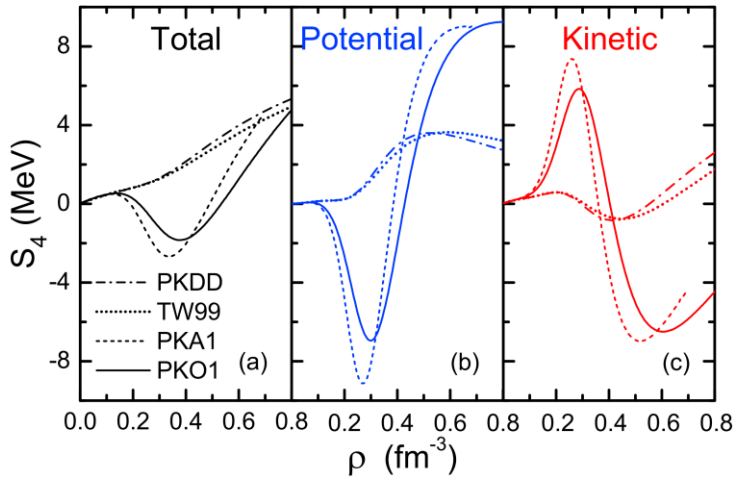




J. Geng et al., PRC 100 (2019) 051301(R)



Shen Yang, Bo Nan Zhang, BYS, Phys. Rev. C 100 (2019) 054314
S. Yang, X. D. Sun, J. Geng, BYS, W. H. Long, Phys. Rev. C 103 (2021) 014304

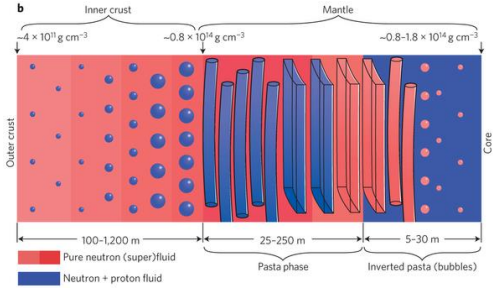


Nuclear fourth-order symmetry energy:
S_4 suppressed in RHF, but $S_{4,\mathrm{kin}}$ enhanced at ρ_0

Intrinsic stability condition of any single phase:

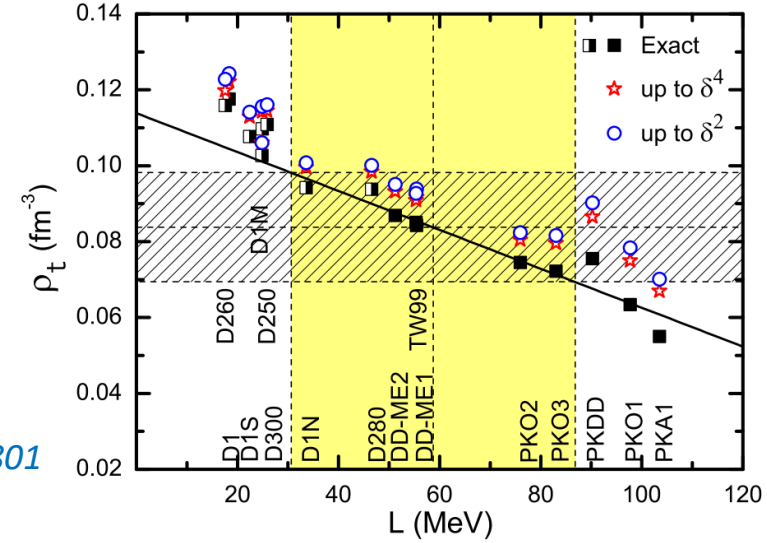
$$-\left(\frac{\partial \mu}{\partial q}\right)_v > 0, \qquad -\left(\frac{\partial P}{\partial v}\right)_\mu > 0$$

☼ *S. Kubis: PRC **76**, 025801 (2007).* Thermodynamical Method



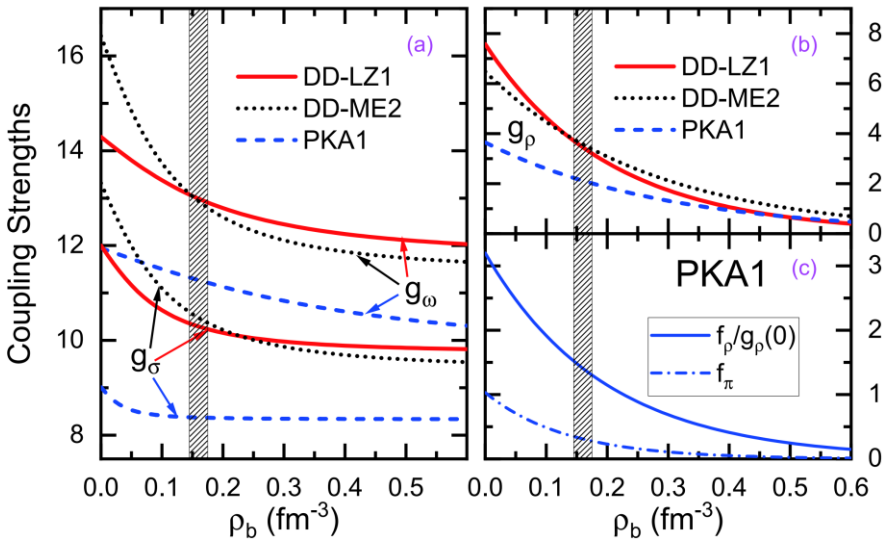
$$\rho_t \sim [0.069, 0.098]\ \mathrm{fm}^{-3}$$

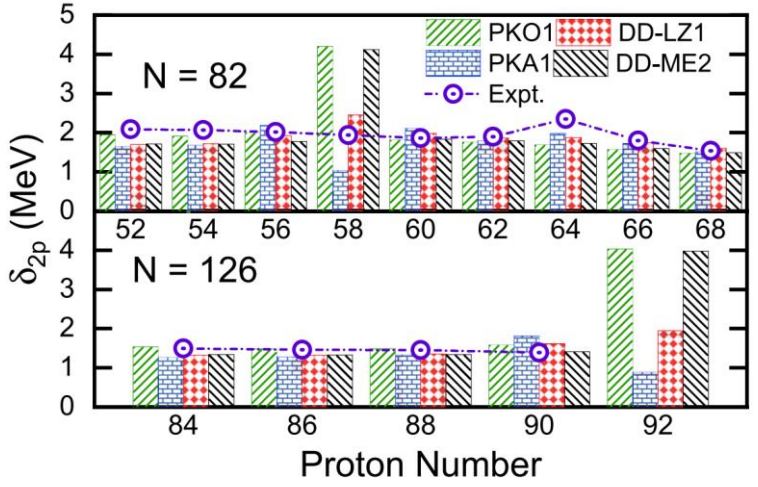
Z. W. Liu, Z. Qian, R. Y. Xing, J. R. Niu, B. Y. Sun, Phys. Rev. C 97 (2018) 025801



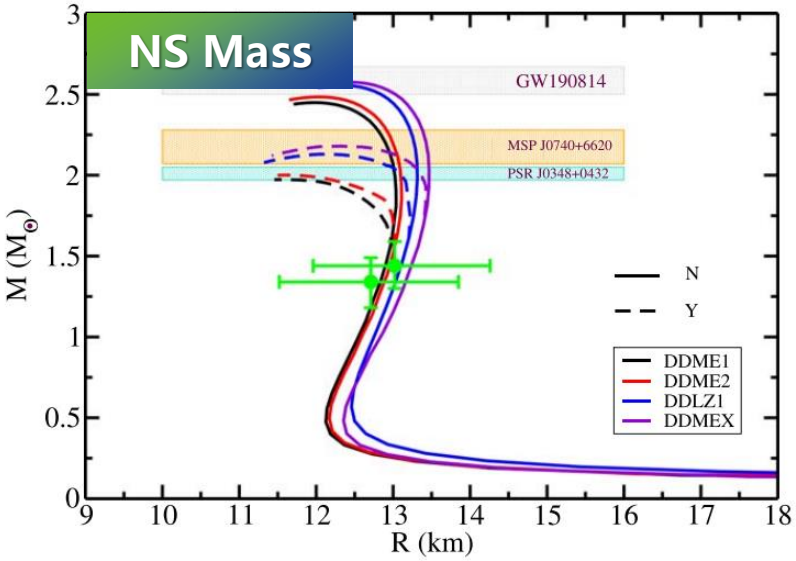
New Density Dependence of Coupling Strengths

Spurious shell closures Z=58/92 eliminated





B. Wei et al., CPC 44 (2020) 074107



I. A. Rather, APJ 917 (2021) 46

PHYSICAL REVIEW C **105**, 045803 (2022)

Unified nuclear matter equations of state constrained by the in-medium balance in density-dependent covariant density functionals

Cheng-Jun Xia,[1,2,3,*] Bao Yuan Sun,[4,5,†] Toshiki Maruyama,[3,‡] Wen-Hui Long,[4,5,§] and Ang Li[6,‖]

[1]*Center for Gravitation and Cosmology, College of Physical Science and Technology, Yangzhou University, Yangzhou 225009, China*
[2]*School of Information Science and Engineering, NingboTech University, Ningbo 315100, China*
[3]*Advanced Science Research Center, Japan Atomic Energy Agency, Shirakata 2-4, Tokai, Ibaraki 319-1195, Japan*
[4]*School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China*
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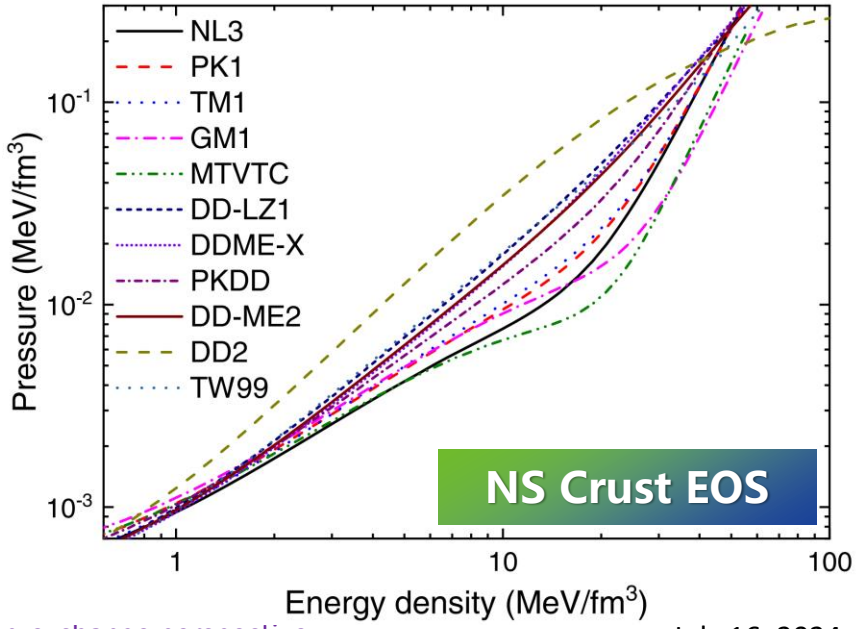
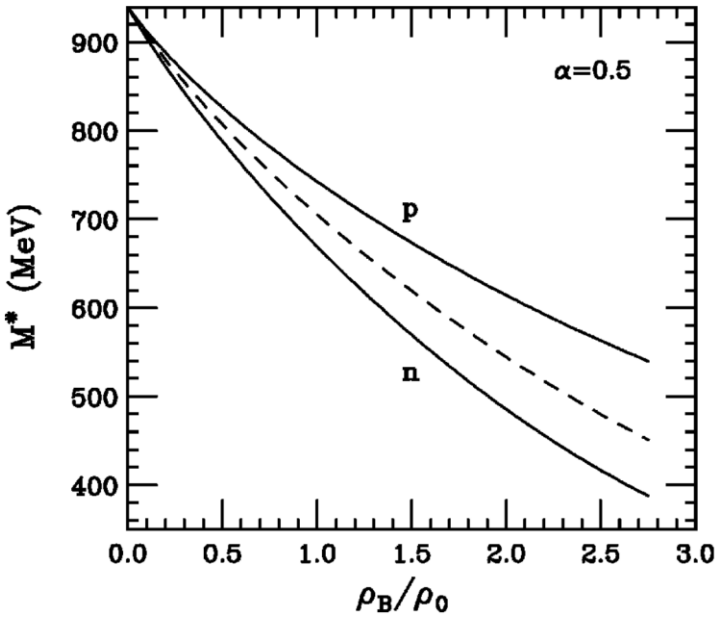
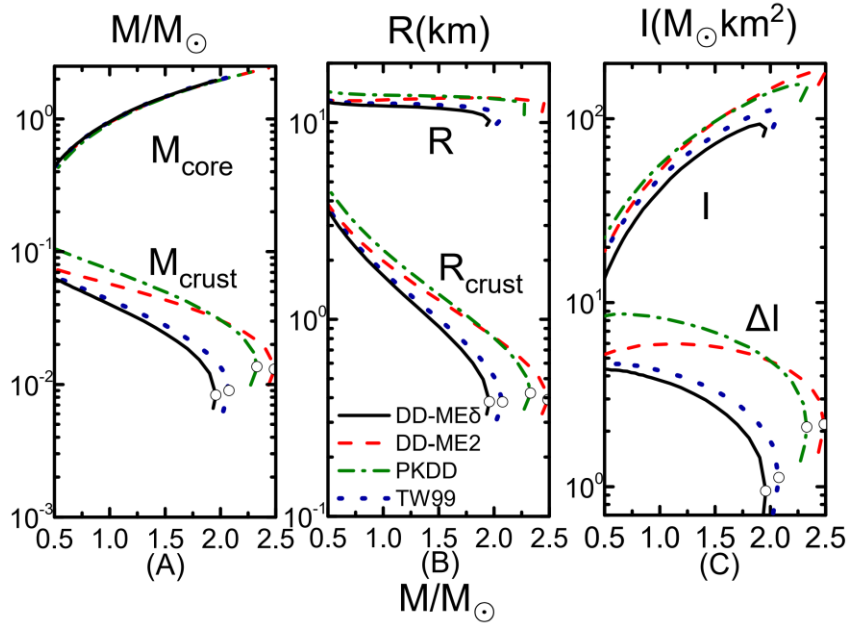
C.J. Xia, BYS, T. Maruyama, W.H.Long, A. Li, PRC 105 (2022) 045803
C.J. Xia, T. Maruyama, A. Li, BYS, WHL, Y.X. Zhang, CTP 74 (2022) 095303



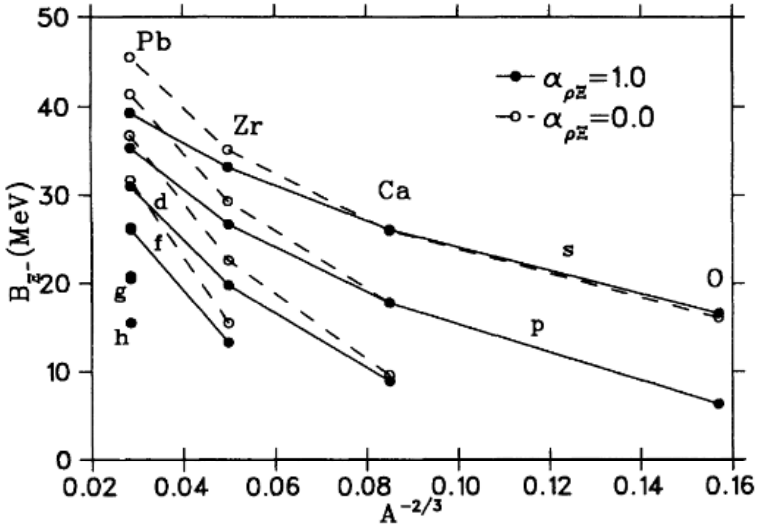
Effects of Isovector Scalar Meson



B. Liu et al., PRC 65 (2002) 045201



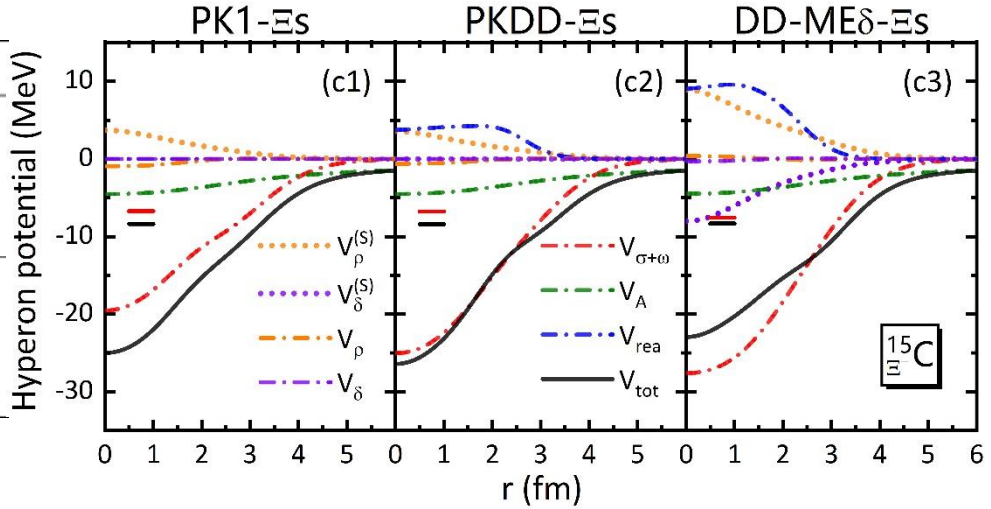
Z. Qian, R. Y. Xing and BYS, Sci. Chin. PMA 61 (2018) 082011



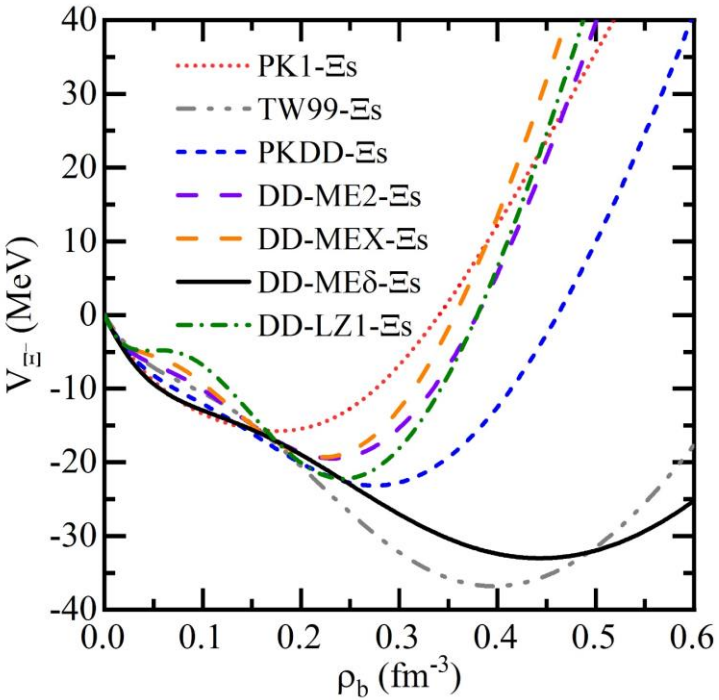
J. Mareš, B. K. Jennings, PRC 49 (1994) 2472

RMF-Ξs	$^{15}_{\Xi^-_s}$C	$^{15}_{\Xi^-_p}$C
PK1	8.000	0.951
PKDD	8.000	0.776
DD-MEδ	8.000	1.251
	8.00 ± 0.77	1.13 ± 0.14
Expt. or empirical data		

S. Y. Ding, T. T. Sun, BYS, arXiv:2406.10980



Clear V_{rea} in DD-MEδ



Summary

- The features of nuclear force depend on the density, isospin, nucleon momentum of nuclear matter, which affect the physics related to nuclear structure at different scales.
- Hypernuclei are nuclear many-body systems that include strange degree of freedom baryons (hyperons), as an important way to understand the in-medium effects of baryon-baryon interaction.
- In CDF theory, by adopting density-dependent coupling strengths in the meson exchange picture, the in-medium dependence of nuclear forces can be effectively considered, improving the model's description of some characteristics of nuclear structure.
- In nuclear matter, the different dynamical equilibrium mechanisms between nucleons and hyperons affect the values of coupling constants, which in turn influence the description of the properties of hypernuclei and neutron stars.