Understanding the microscopic origins, density dependence and impact of symmetry energy

Single-nucleon (Lane) potential in isospin-asymmetric nucleonic matter:

A. M. Lane, Nucl. Phys. 35, 676 (1962).

$$U_{n/p}(k,\rho,\delta) = U_0(k,\rho) \pm U_{sym1}(k,\rho)\bullet\delta + U_{sym2}(k,\rho)\bullet\delta^2 + o(\delta^3)$$

$$E_{sym}(\rho) = \frac{1}{3}\frac{\hbar^2 k^2}{2m_0^*}|_{k_F} + \frac{1}{2}U_{sym,1}(\rho,k_F),$$

K.A. Brueckner, J. Dabrowski, Phys. Rev. B 134 (1964) 722.
J. Dabrowski, P. Haensel, Phys. Lett. B 42 (1972) 163;
S. Fritsch, N. Kaiser, W. Weise, Nuclear Phys. A 750 (2005) 259.

Slope: $$L(\rho) = \frac{2}{3}\frac{\hbar^2 k^2}{2m_0^*}|_{k_F} - \frac{1}{6}\left(\frac{\hbar^2 k^3}{m_0^{*2}}\frac{\partial m_0^*}{\partial k}\right)|_{k_F} + \frac{3}{2}U_{sym,1}(\rho,k_F) + \frac{\partial U_{sym,1}}{\partial k}|_{k_F}\cdot k_F + 3U_{sym,2}(\rho,k_F),$$

Neutron-proton effective mass splitting

$$m^*_{n-p} \approx 2\delta\frac{m}{\hbar^2 k_F}\left[-\frac{dU_{sym,1}}{dk} - \frac{k_F}{3}\frac{d^2U_0}{dk^2} + \frac{1}{3}\frac{dU_0}{dk}\right]_{k_F}\left(\frac{m_0^*}{m}\right)^2$$

C. Xu, B.A. Li, L.W. Chen and C.M. Ko, NPA 865, 1 (2011)

The most fundamental but lest known physics underlying the high-density nuclear symmetry energy

Spin-isospin dependence of 3-body and tensor forces, the resulting isospin-dependence of NN short-range correlations and high-momentum tails in the single-nucleon momentum distribution

In the interacting Fermi gas model, the direct term of the symmetry potential:

M.A. Preston and R.K. Bhaduri, Structure of the Nucleus, 1975

Isospin-dependent NN correlations

$$U_{sym}(k_F,\rho) = \frac{1}{4}\rho\int[V_{T1}(r_{ij})f^{T1}(r_{ij}) - V_{T0}(r_{ij})f^{T0}(r_{ij})]d^3r_{ij}$$

Isospin-dependent NN interactions

Isospin dependence of strong interaction

$V_{np}(T_0) \neq V_{np}(T_1)$

Tensor force due to pion and ρ meson exchange MAINLY in the T=0 channel

Bao-An Li et al., PPNP 99, 29 (2018)

Bayesian inferences using a flexible, isospin & momentum-dept. nucleon potential based on Gogny-like EDF incorporating effects of NN short-range correlations

(1) Calibrated by chiral EFT below $2\rho_0$ and experimental nucleon optical potential at ρ_0 from (p,n) and p/n+A

(2) Using combined data from FRIB-FRIB400, RIKEN & FAIR and multimessengers of neutron stars & their mergers

B.A.Li, C.B. Das, S. Das Gupta and C. Gale, NPA 735, 563 (2004)

B.J. Cai and B.A. Li, arXiv:2210.10924

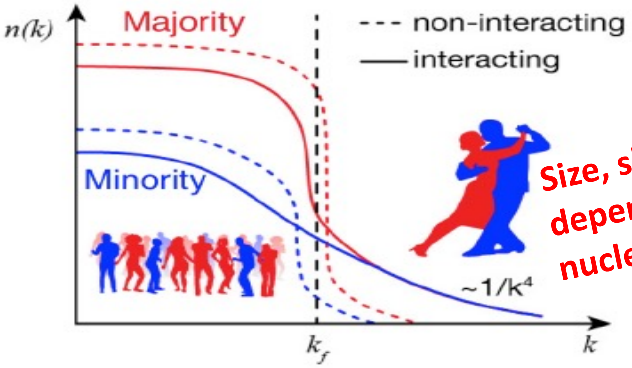
Zero-range 2-body force

Spin-isospin dependence of 3-body force

$$E(\rho,\delta) = E^{\mathrm{kin}}(\rho,\delta) + \frac{A_\ell(\rho_{\mathrm{p}}^2+\rho_{\mathrm{n}}^2)}{2\rho\rho_0} + + \frac{A_{\mathrm{u}}\rho_{\mathrm{p}}\rho_{\mathrm{n}}}{\rho\rho_0} + \frac{B}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma}(1-x\delta^2)$$
$$+ \sum_{J,J'}\frac{C_{J,J'}}{\rho\rho_0}\int \mathrm{d}\mathbf{k}\mathrm{d}\mathbf{k}' f_J(\mathbf{r},\mathbf{k}) f_{J'}(\mathbf{r},\mathbf{k}')\Omega(\mathbf{k},\mathbf{k}'),$$

Finite-range 2-body forces

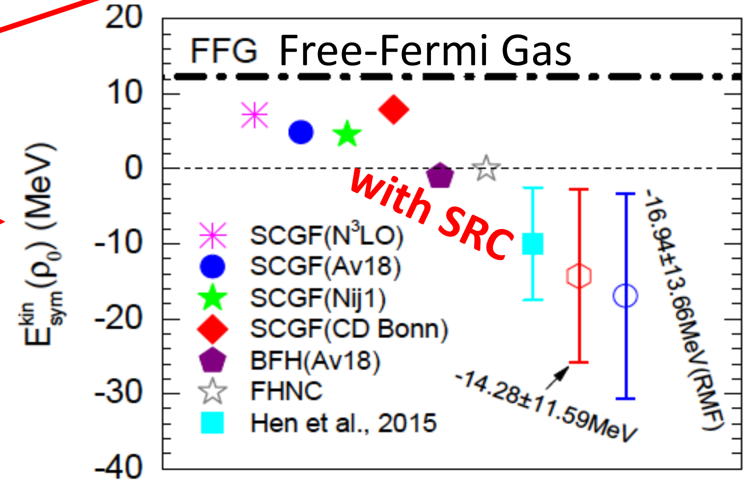
$$\Omega(\mathbf{k},\mathbf{k}') = \left[1+\frac{(\mathbf{k}-\mathbf{k}')^2}{\Lambda^2}\right]^{-1}$$



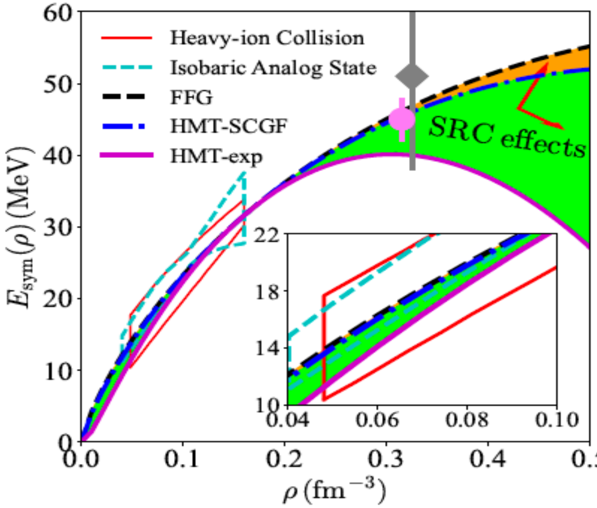
O. Hen et al., Science 346, 614 (2014)

Size, shape, isospin & density dependence of SRC & the nucleon high-momentum tail

Reduced or negative kinetic symmetry energy



O. Hen, B.A. Li, W. Guo, L. Weinstein & E. Piasetzky, PRC 91, 025803 (2015)



(3) Isospin dept. nucleon momentum distribution at ρ_0 calibrated by SRC experiments at JLAB/BNL/GSI

(4) Simulating/emulating heavy-ion reactions using transport models calibrated through the Transport Model Evaluation Project

White Paper1: Dense matter theory for heavy-ion collisions and neutron stars, arXiv:2211.02224

White Paper2: Baryonic Equation of State from Astro Observations and Terrestrial Experiments (in preparation)