Nuclear matter calculations with chiral interactions

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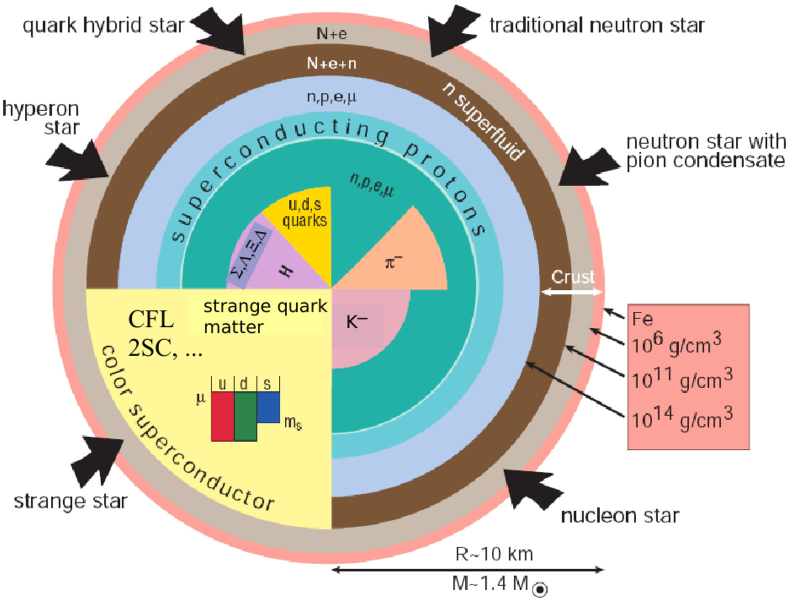
Frascati

27 novembre 2015

- Chiral interactions
- The Brueckner-Hartree-Fock approach in nuclear matter
- Conclusions

Neutron stars



Literature

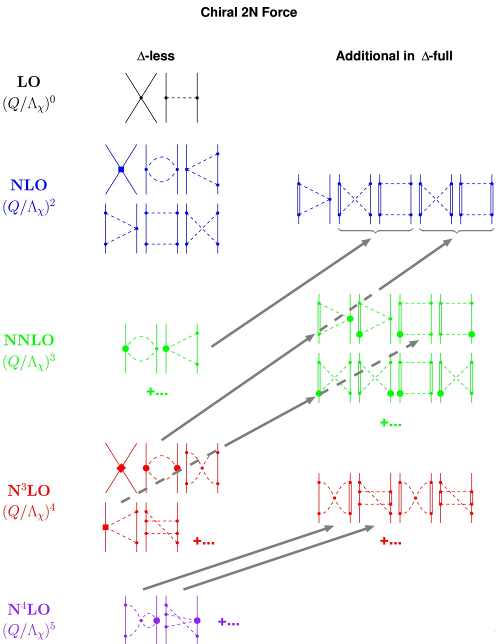
- V_{lowk}-approach:
  K. Hebeler and A. Schwenk, Phys. Rev. C **82**, 014314 (2010).
  K. Hebeler, S. K. Bogner, R. J. Furnstahl, A. Nogga and A. Schwenk, Phys. Rev. C **83**, (2011) 031301(R).
  K. Hebeler, S. K. Bogner, R. J. Furnstahl, A. Nogga and A. Schwenk, Phys. Rev. C **83**, (2011) 031301.

- Green's function:
  A. Carbone, A. Polls and A. Rios Phys. Rev. C **88**, (2013) 044302.

- Monte Carlo:
  S. Gandolfi, A. Lovato, J. Carlson, Kevin E. Schmidt, Phys. Rev. C **90**, 061306 (2014).

- Brueckner-Hartree-Fock:
  D. Logoteta, I. Vidana, I. Bombaci and A. Kievsky, Phys. Rev. C **91**, (2015) 064001.
  M. Kohno, Phys. Rev. C **88**, 064005 (2013).
  F. Sammarruca, L. Coraggio, J.W. Holt, N. Itaco, R. Machleidt, L. E. Marcucci, Phys. Rev. C **91**, 054311 (2015).

- NN potentials: non local N3LO (Idaho-2003), minimal non local N3LOΔ (M. Piarulli-2014 et al.)
- N3LO (Idaho-2003) $\Rightarrow$ in $\mathcal{L}$ included N, π
- N3LOΔ (M. Piarulli-2014 et al.) $\Rightarrow$ in $\mathcal{L}$ included N, π and Δ
- NNN potential: local N2LO (P. Navratil 2007)
- Parameters of NNN force fixed in few body calculations $\Rightarrow$ no free parameters


Chiral 2N Force
Δ-less
Additional in Δ-full
LO
$(Q/\Lambda_\chi)^0$
NLO
$(Q/\Lambda_\chi)^2$
NNLO
$(Q/\Lambda_\chi)^3$
+...
+...
N^{3}LO
$(Q/\Lambda_\chi)^4$
+...
+...
N^{4}LO
$(Q/\Lambda_\chi)^5$
+...

Chiral forces NNN

Chiral 3N Force

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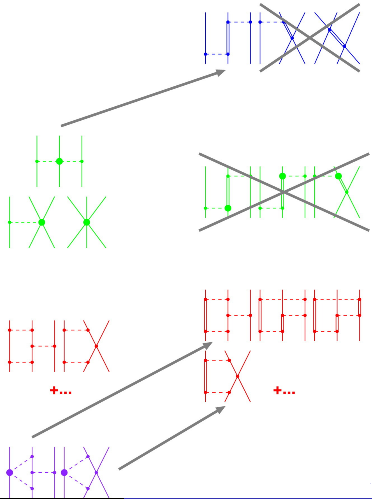
LO $(Q/\Lambda_\chi)^0$		
NLO $(Q/\Lambda_\chi)^2$		
NNLO $(Q/\Lambda_\chi)^3$		
N^{3}LO $(Q/\Lambda_\chi)^4$		
N^{4}LO $(Q/\Lambda_\chi)^5$		



- Starting point: the Bethe-Goldstone equation

$$G(\omega)_{B_1 B_2, B_3 B_4} = V_{B_1 B_2, B_3 B_4} + \sum_{B_i B_j} V_{B_1 B_2, B_i B_j} \times \frac{Q_{B_i B_j}}{\omega - E_{B_i} - E_{B_j} + i\eta} G(\omega)_{B_i B_j, B_3 B_4}$$

$$U_{B_i}(k) = \sum_{B_j} \sum_{\vec{k'}} n_{B_j}(|\vec{k'}|) \times \langle \vec{k}\vec{k'} | G(E_{B_i}(\vec{k}) + E_{B_j}(\vec{k'}))_{B_i B_j, B_i B_j} | \vec{k}\vec{k'} \rangle_{\mathcal{A}}$$

$$E_{B_i}(k) = M_{B_i} + \frac{\hbar^2 k^2}{2 M_{B_i}} + \mathrm{Re}[U_{B_i}(k)]$$

$$\epsilon_{BHF} = \frac{1}{V} \sum_{B_i} \sum_{k \le k_{F_i}} \left[M_{B_i} + \frac{\hbar^2 k^2}{2 M_{B_i}} + \frac{1}{2} U_{B_i}(k) \right]$$

- BHF calculations with NNN forces

NNN forces in the BHF-approach

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$\Downarrow$

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- In r-space:

$$W_{eff}(1,2) = Tr_{\sigma_3\tau_3} \int dx_3 \sum_{cyc} W(1,2,3)\, n(1,2,3)(1-P_{13}-P_{23}) \ \ (A.\ Lovato\ 2011)$$

- In p-space:

$$W_{eff}(1,2) = Tr_{\sigma_3\tau_3} \int dp_3 \sum_{cyc} W(1,2,3)\, n(3)(1-P_{13}-P_{23}) \ \ (J.\ Holt\ 2010)$$

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- Usually for $p-$space average $\Rightarrow$ non local cutoff: $F_\Lambda(p',p) = e^{-(p/\Lambda)^{2n}-(p'/\Lambda)^{2n}}$

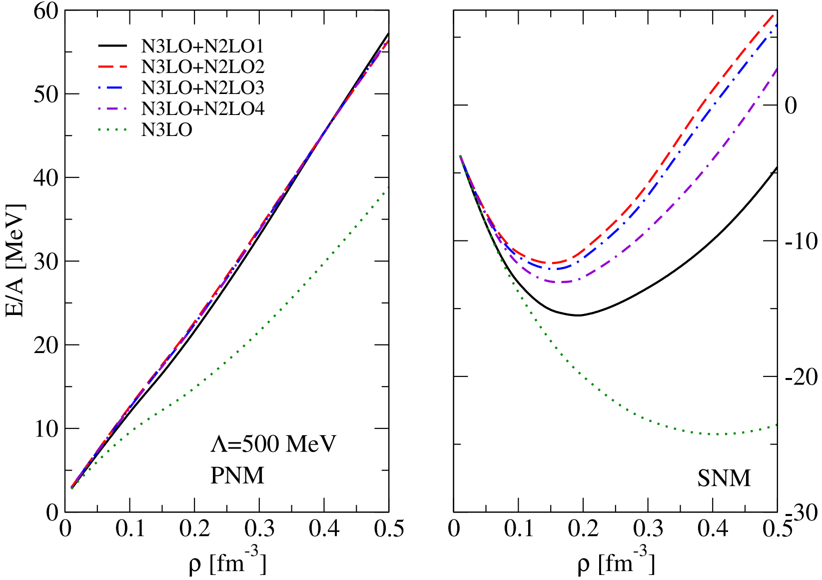
Choice of parameters

- Following: L. E. Marcucci, A. Kievsky, S. Rosati, R. Schiavilla and M. Viviani Phys. Rev. Lett. **108**, (2012) 052502.
  L. Coraggio, J. W. Holt, N. Itaco, R. Machleidt, L. E. Marcucci and F. Sammarruca, Phys Rev. C **89**, (2014) 044321.

$$\Downarrow$$

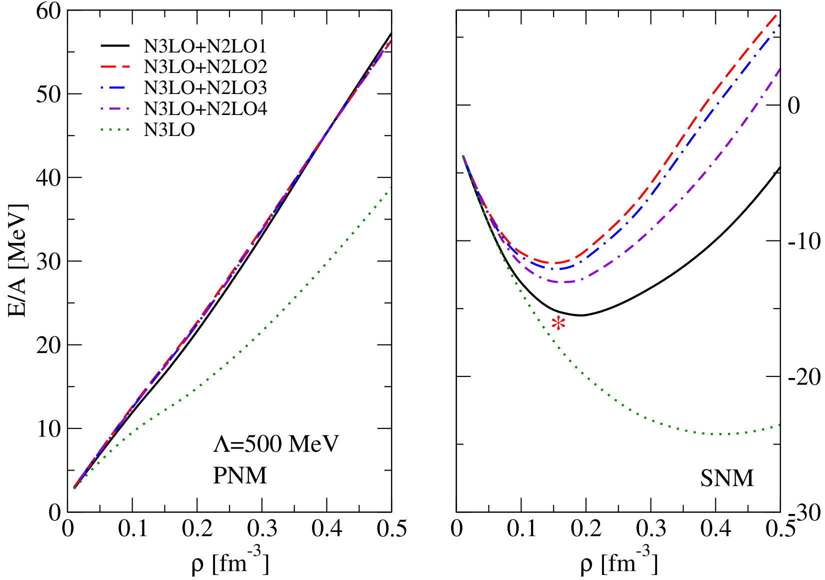
- Low energy constants (c_D, c_E) fixed to reproduce the ^{3}H binding energy + (^{3}H-^{3}He) *GT* transition matrix element.
- In our many-body calculations we use the same cutoff $F_\Lambda(q^2) = e^{-q^4/\Lambda^4}$ employed in the few-body ones $\Rightarrow$ fully consistent calculation.

	c_D	c_E
N2LOL1 ($\Lambda = 500$)	1.00	-0.029
N2LOL2 ($\Lambda = 500$)	-0.20	-0.208
N2LOL3 ($\Lambda = 500$)	-0.04	-0.184
N2LOL4 ($\Lambda = 500$)	0.0	-0.18



N3LO+N2LO1
N3LO+N2LO2
N3LO+N2LO3
N3LO+N2LO4
N3LO
E/A [MeV]
Λ=500 MeV
PNM
SNM
ρ [fm^-3]
ρ [fm^-3]
60
50
40
30
20
10
0
0
-10
-20
-30
0
0.1
0.2
0.3
0.4
0.5

E/A pure and symmetric nuclear matter N3LO+N2LO (r-space average)



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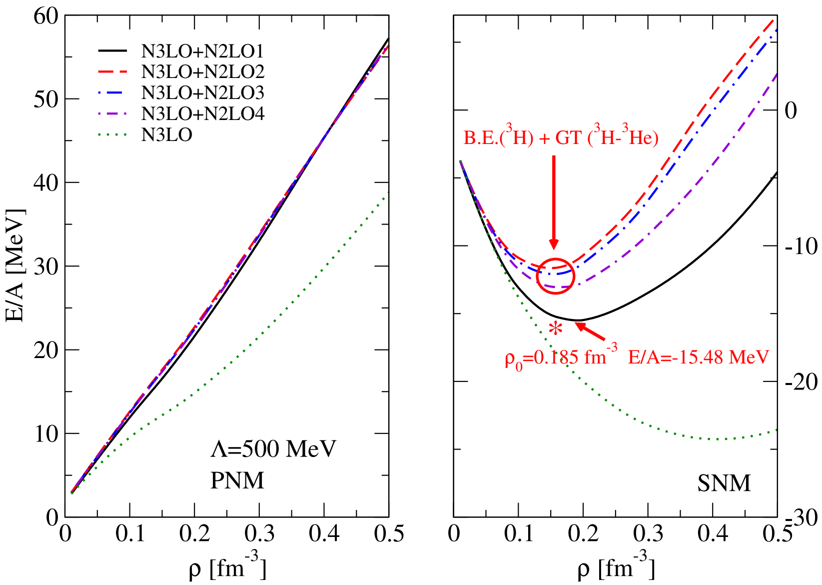

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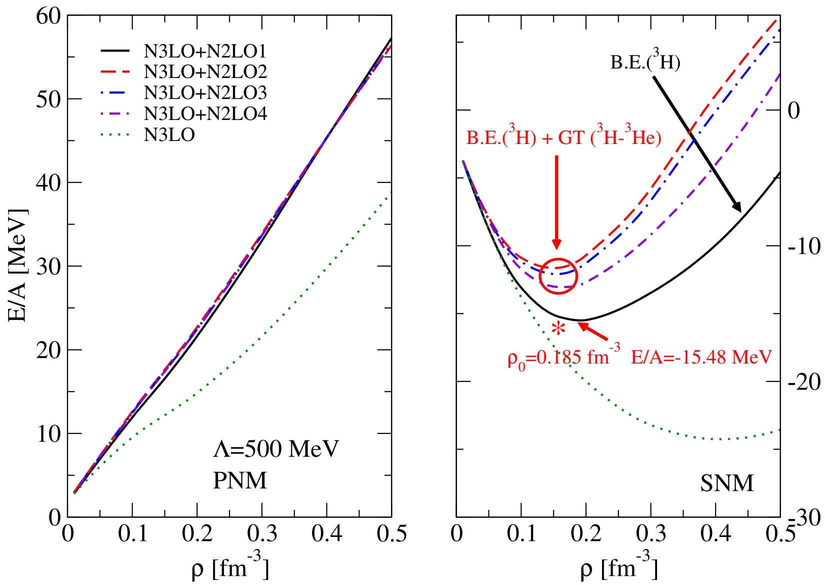
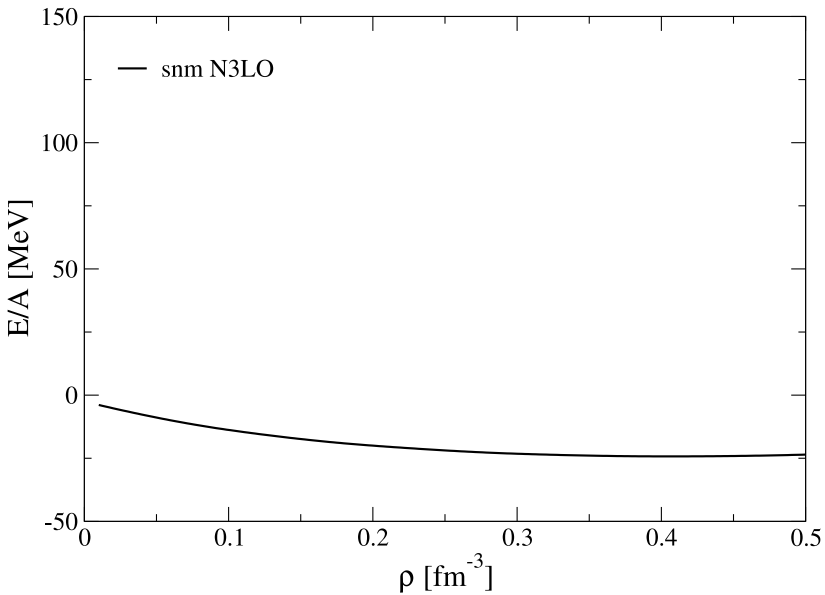
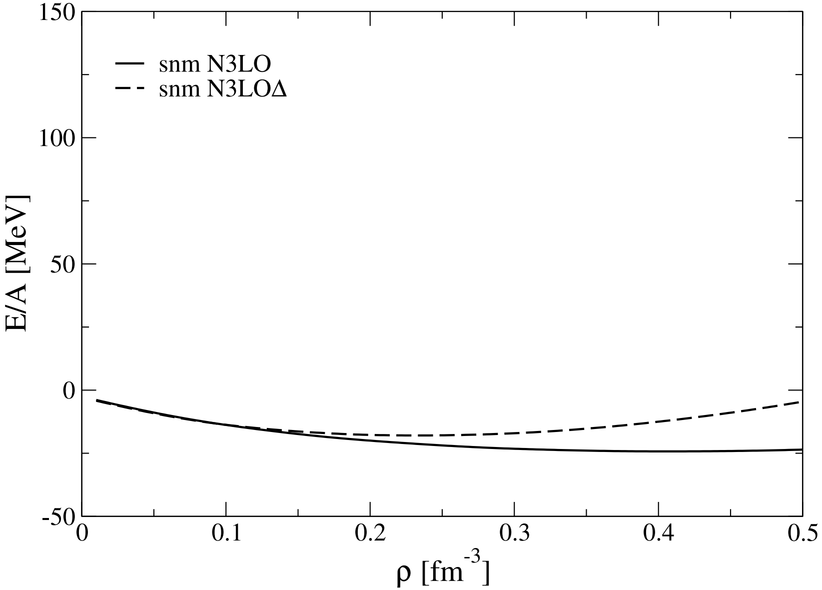
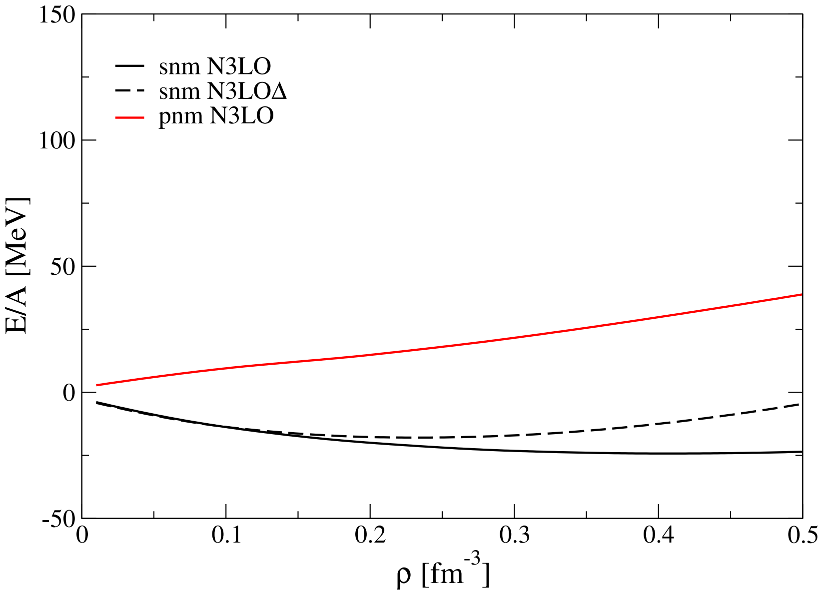


Energy per particle E/A

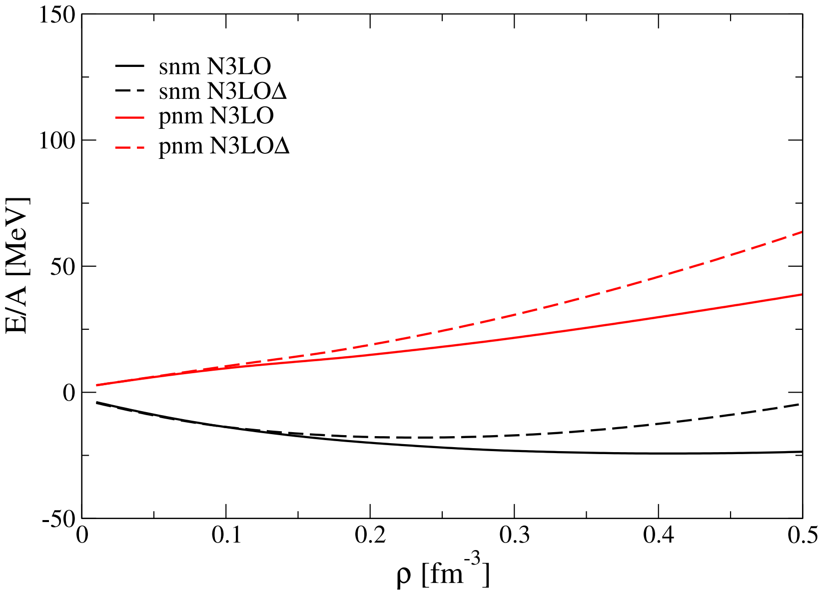


Energy per particle E/A

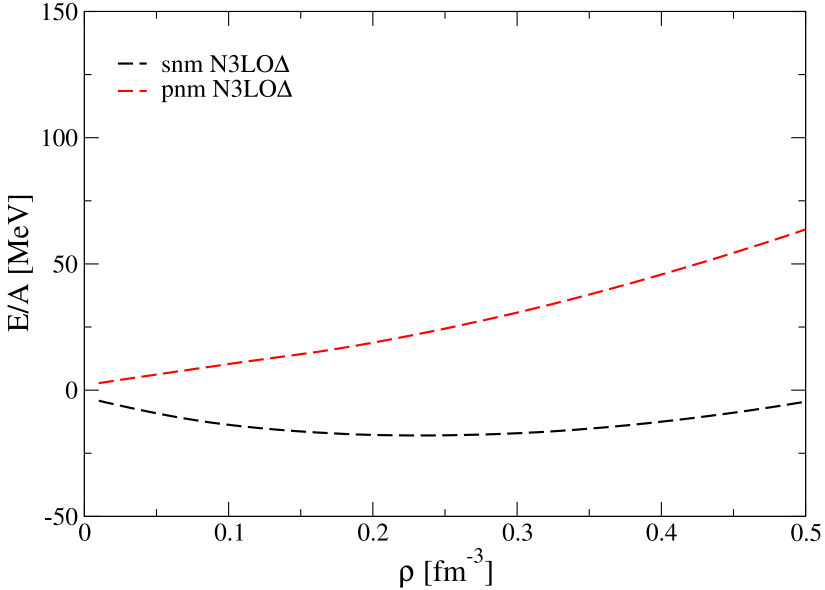



snm N3LO
snm N3LOΔ
pnm N3LO
150
100
50
0
-50
E/A [MeV]
0
0.1
0.2
0.3
0.4
0.5
ρ [fm^-3]

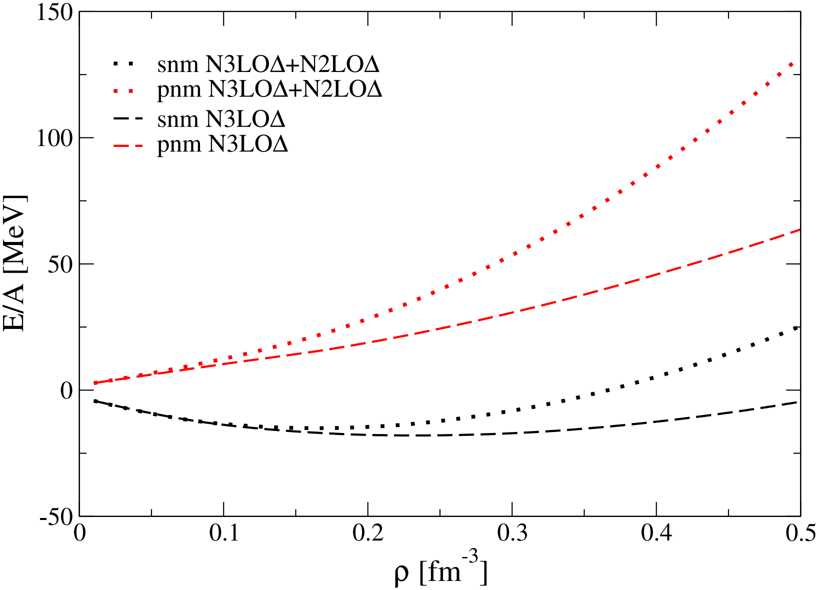
Energy per particle E/A



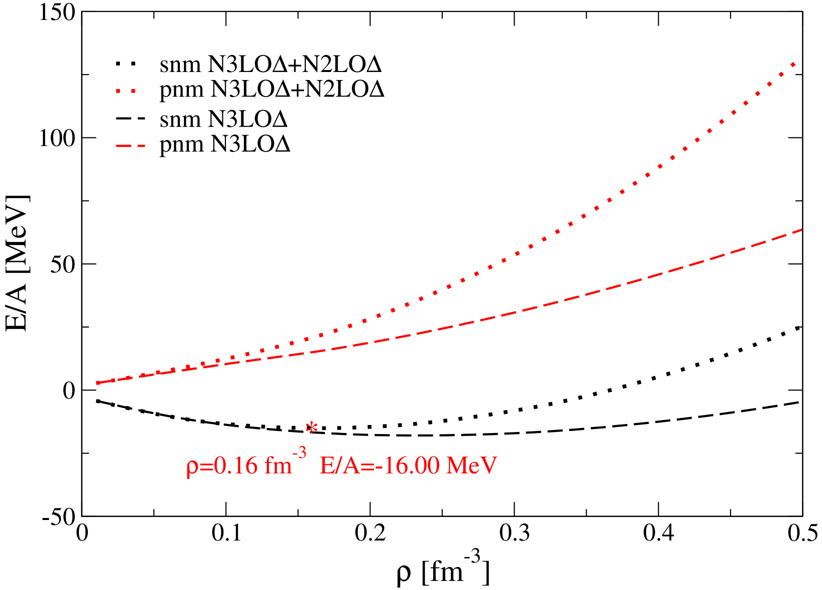
Energy per particle E/A *p*-space average



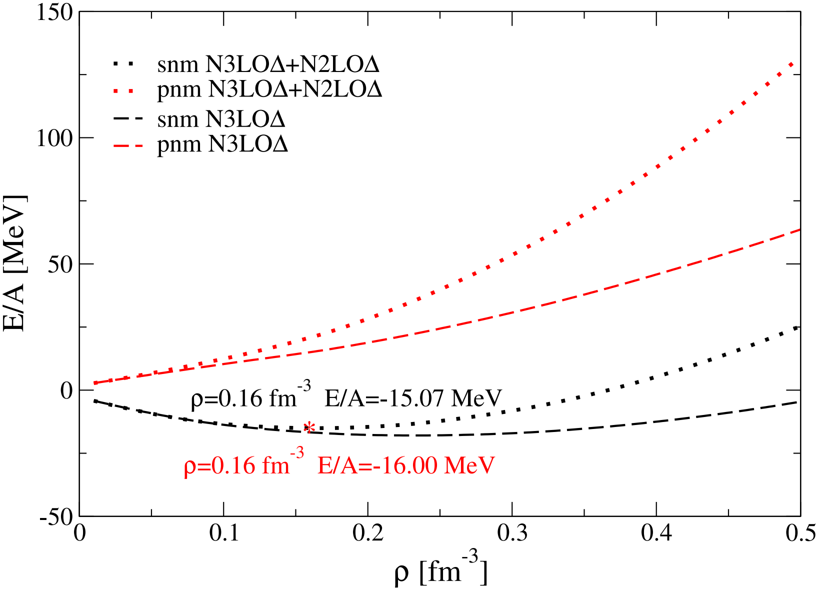
Energy per particle E/A *p-space average*



Energy per particle E/A *p*-space average



Energy per particle E/A *p*-space average



- Microscopic calculations of nuclear matter based on realistic interaction can help us to understand discrepancies between many-body and few-body nuclear physics.
- New generation of interactions based on chiral perturbation theory provide very interesting results.
- Next to do $\Rightarrow$ study of hyperonic matter based on chiral forces.

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- Problem of maximum mass on neutron stars.