

Nuclear matter calculations with chiral interactions

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Pisa

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

- **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:**
L. Coraggio, J. W. Holt, N. Itaco, R. Machleidt, L. E. Marcucci and F. Sammarruca, Phys Rev. C **89**, (2014) 044321.
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: **nonlocal N3LO** (Idaho-2003), **minimal nonlocal N3LO Δ** (M. Piarulli-2014 et al.)
- N3LO (Idaho-2003) \Rightarrow in \mathcal{L} included **N, π**
- N3LO Δ (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**

- Starting point: the **Bethe-Goldstone equation**

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

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

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

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

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- In r-space:

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

- In p-space:

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

- BHF calculations with NNN forces \Rightarrow **too complicated**



- **NNN** force is reduced to a **NN** density dependent one
- In **r-space**:

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

- In **p-space**:

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

- Usually for **p-space** average \Rightarrow **nonlocal cutoff**:

$$F_{\Lambda}(p', p) = e^{-(p/\Lambda)^{2n} - (p'/\Lambda)^{2n}}$$

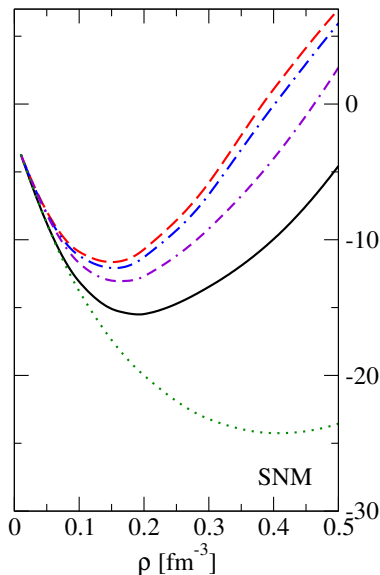
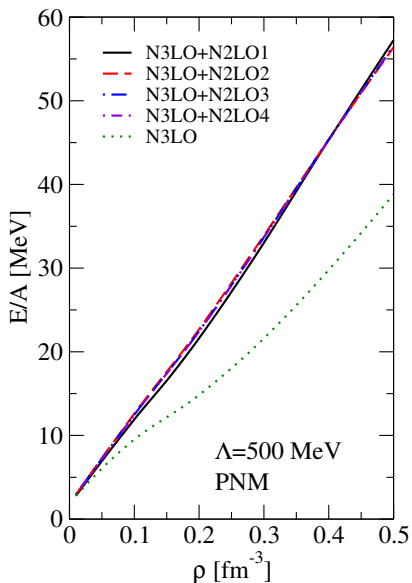
- Following: L. E. Marcucci, A. Kievsky, S. Rosati, R. Schiavilla and M. Viviani Phys. Rev. Lett. **108**, (2012) 052502.
L. Coraggio, J. W. Holt, N. Itaco, R. Machleidt, L. E. Marcucci and F. Sammarruca, Phys Rev. C **89**, (2014) 044321.



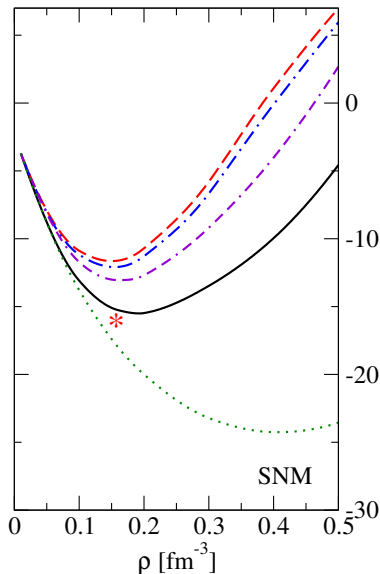
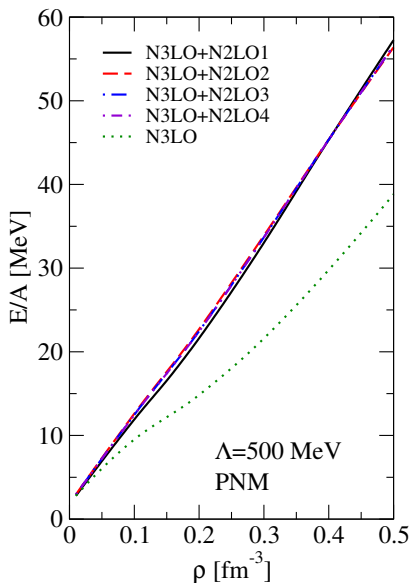
- Low energy constants (c_D, c_E) fixed to reproduce the ${}^3\text{H}$ binding energy + (${}^3\text{H}$ - ${}^3\text{He}$) GT transition matrix element.
- In our many-body calculations we use the same cutoff $F_\Lambda(q^2) = e^{-q^4/\Lambda^4}$ employed in the few-body ones \Rightarrow fully consistent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

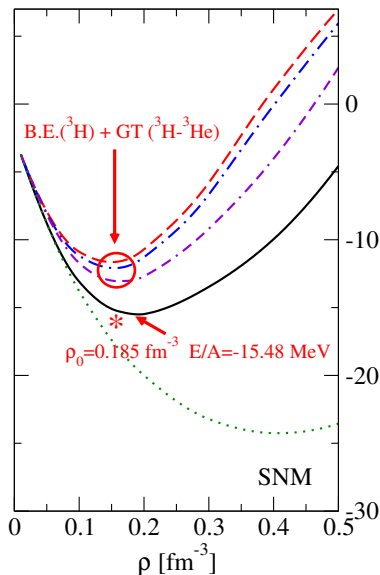
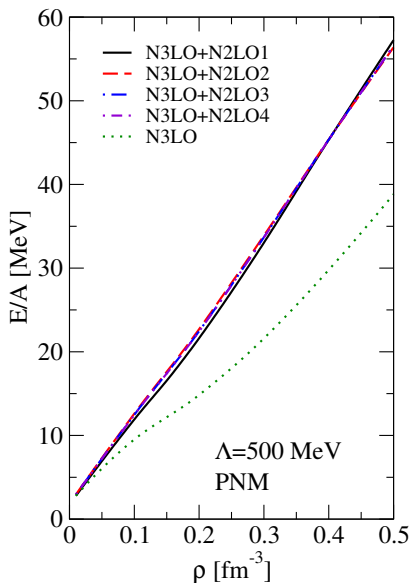
E/A pure and symmetric nuclear matter N3LO+N2LO (*r-space average*)



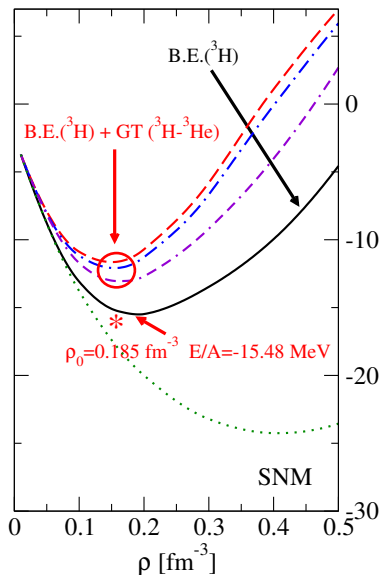
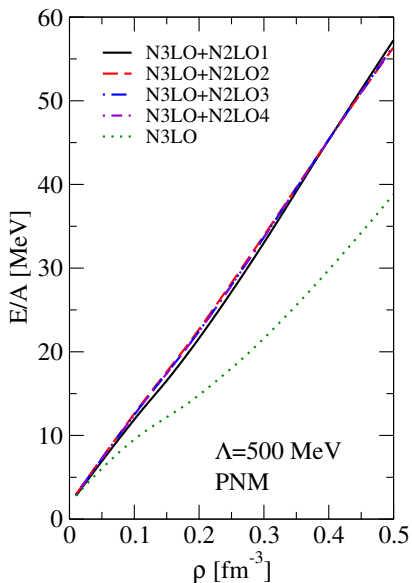
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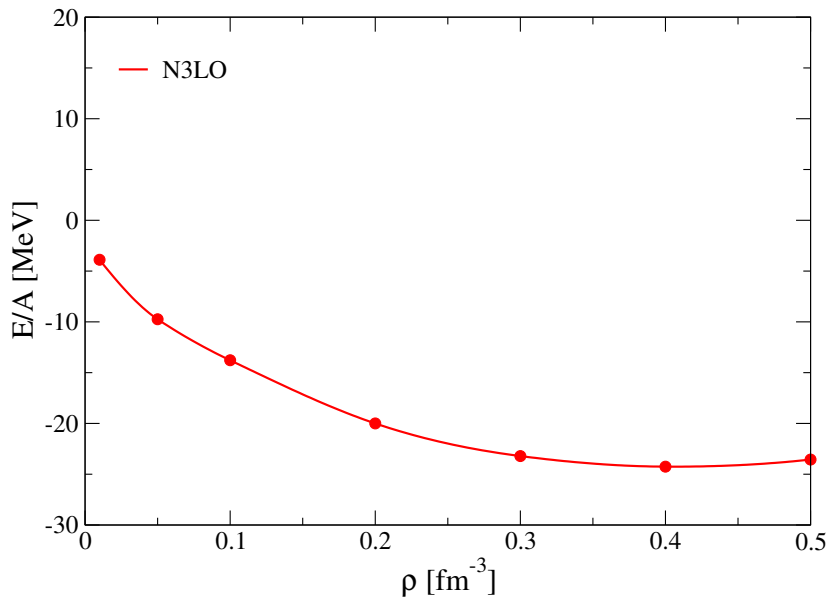


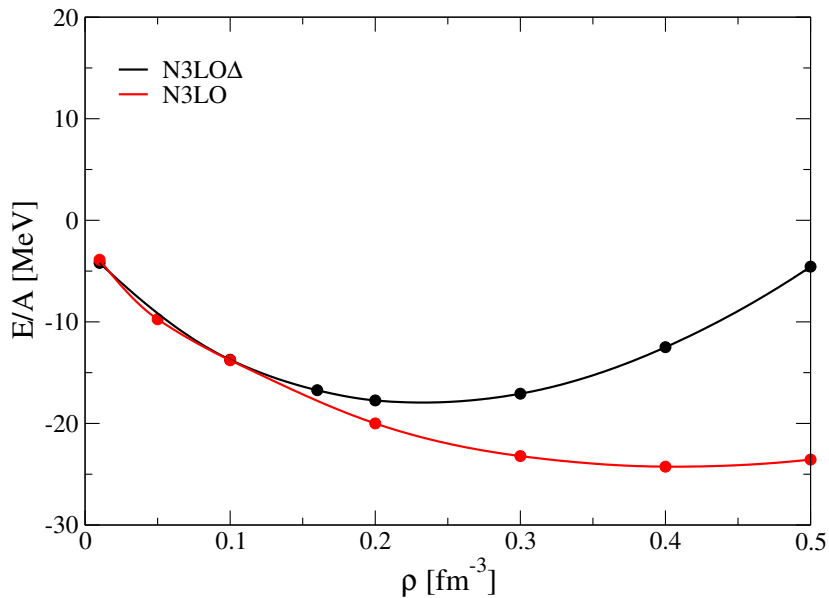
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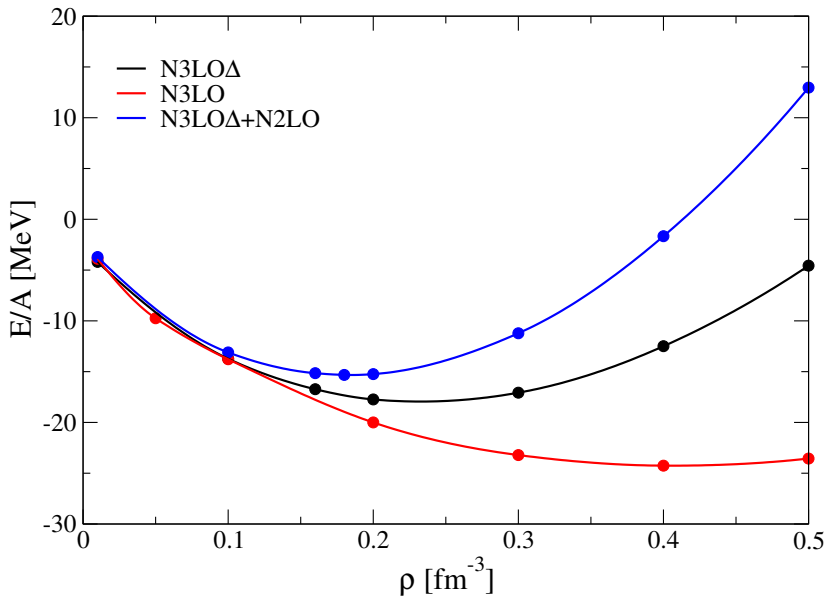
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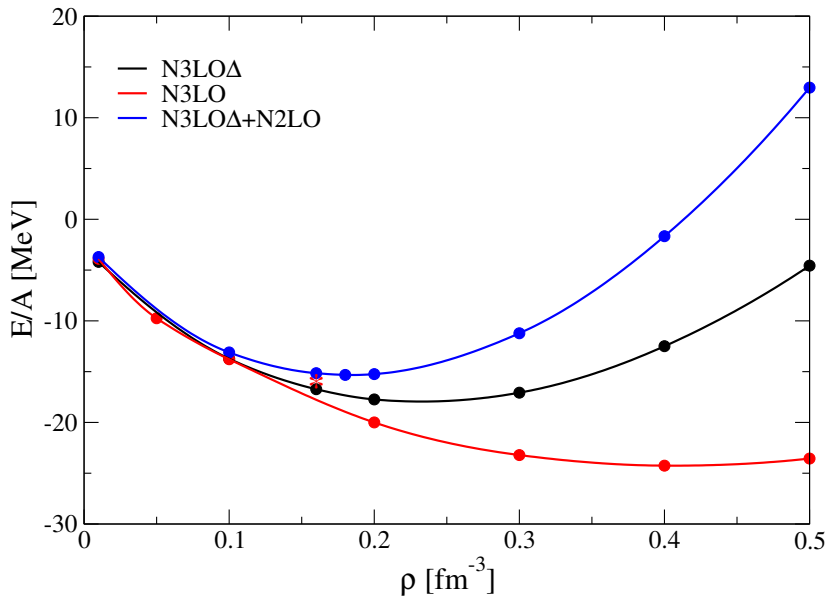




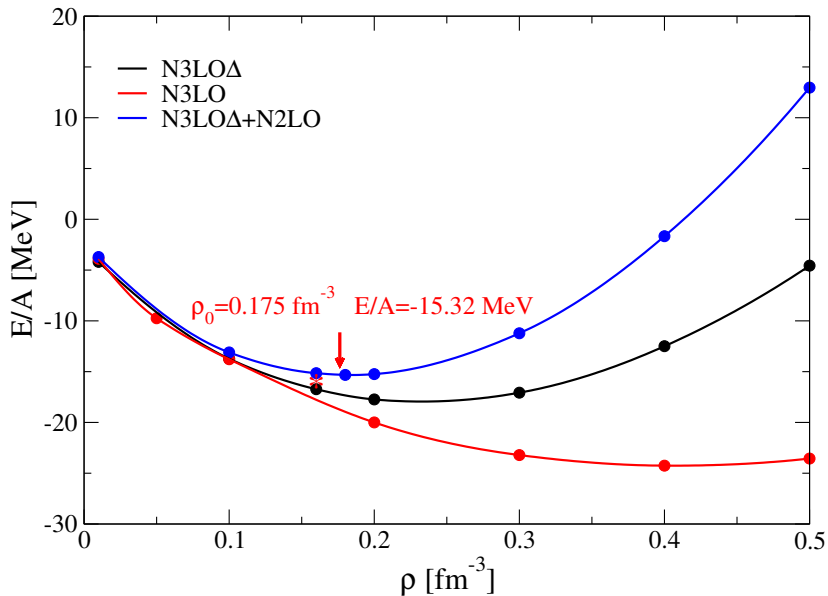
E/A symmetric nuclear matter; ρ -space average



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- **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**.



- Problem of maximum mass on **neutron stars**.