Dense matter equation of state with improved nuclear physics

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Annecy - 12/10/2021

Impact of chiral EFT interactions and experimental nuclear masses on the neutron star crust

Confronting
Chiral EFT
and
Skyrme models
on NS crust predictions

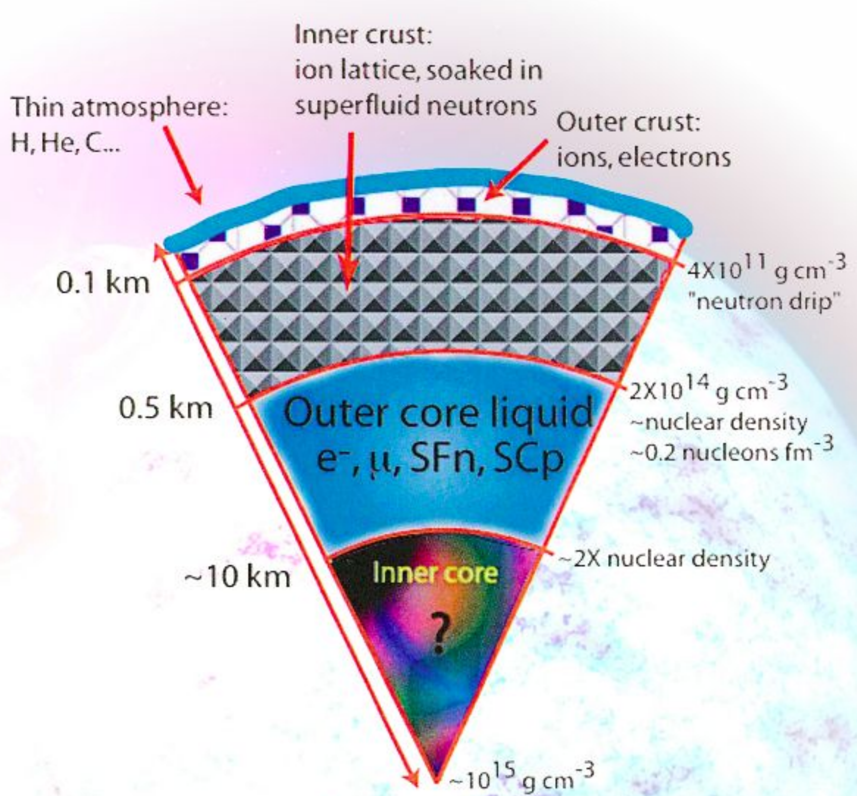
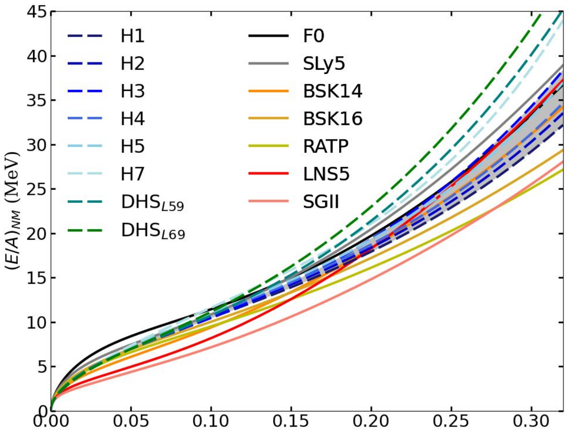
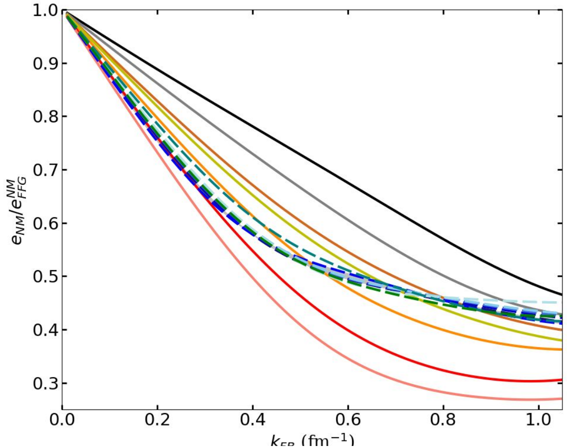


Fig. from Arzoumanian et. al. (2009) arXiv:0902.3264

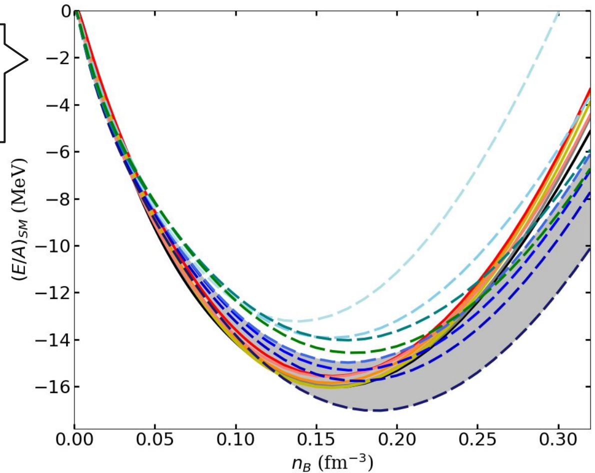
Homogeneous matter

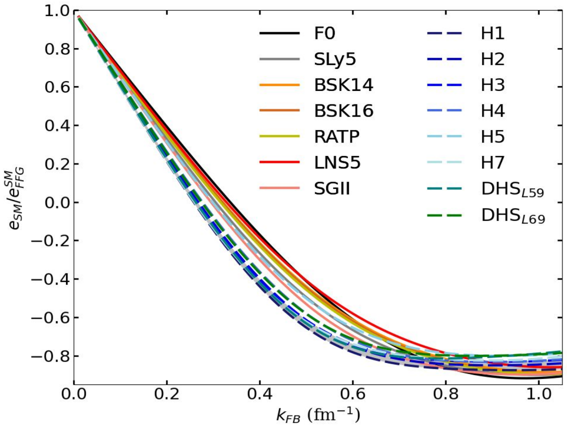




neutron matter

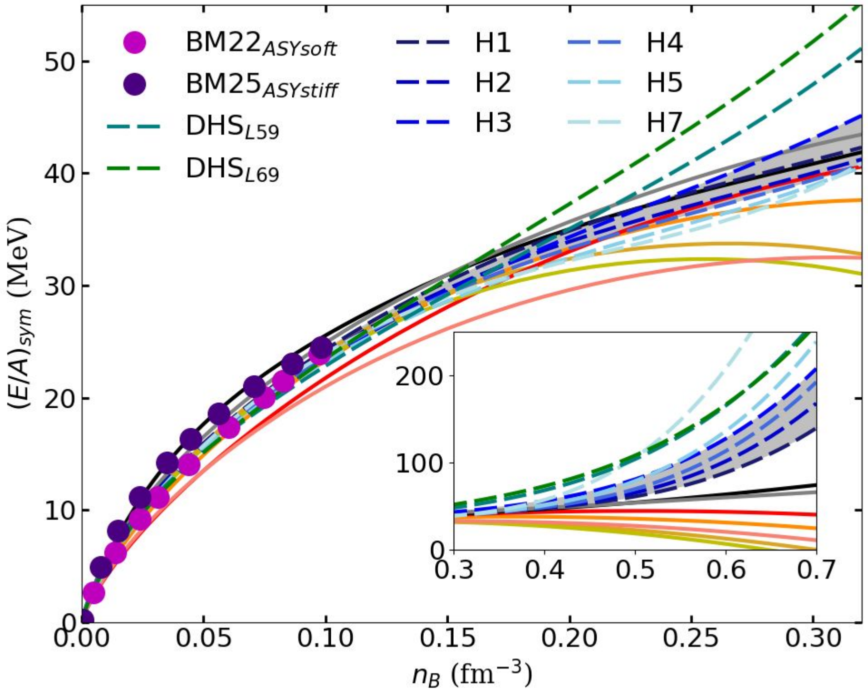
symmetric matter

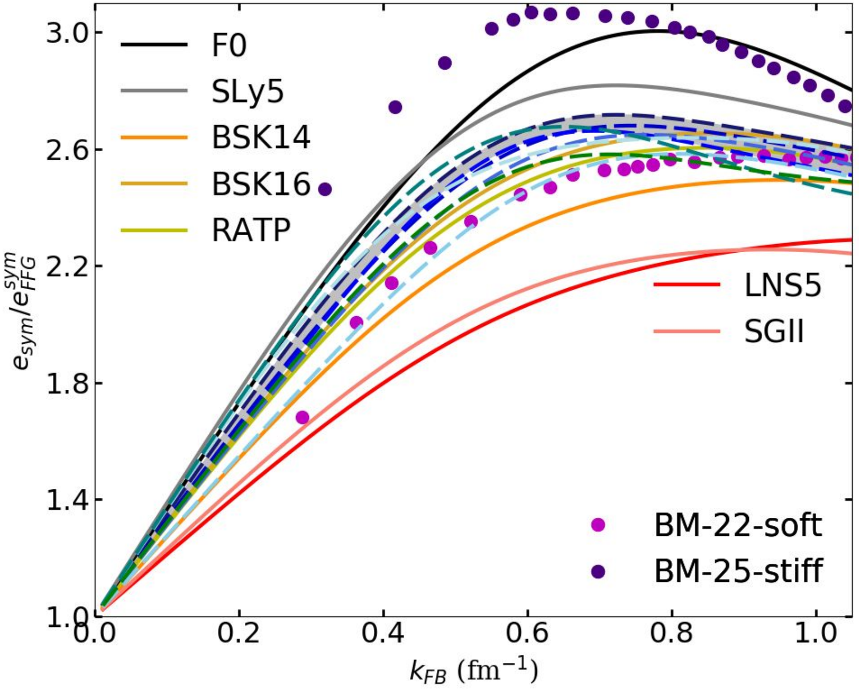




Homogeneous matter

Symmetry energy: $e_{sym} = e_{NM} - e_{SM}$



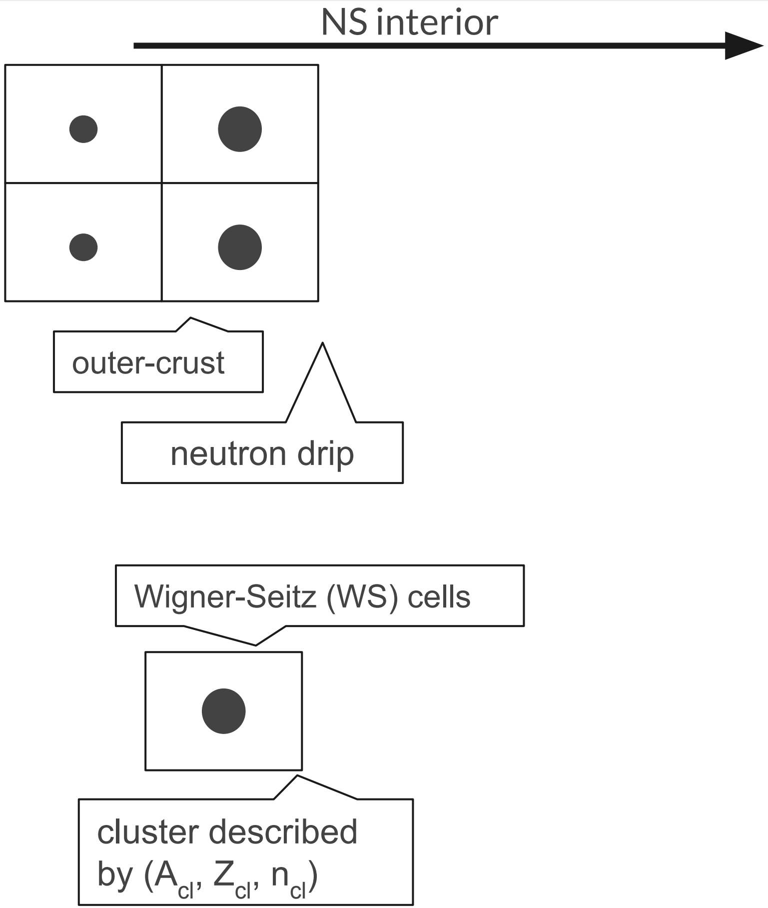


Finite size effects / nuclei description

Volume fraction occupied by nuclei:

$$u = \frac{V_{cl}}{V_{WS}}$$

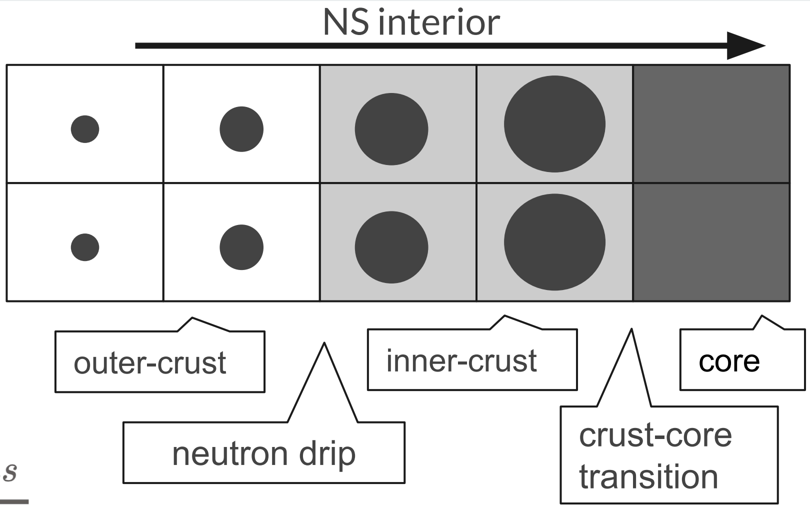
$$u = \frac{n_B}{n_{cl}}$$

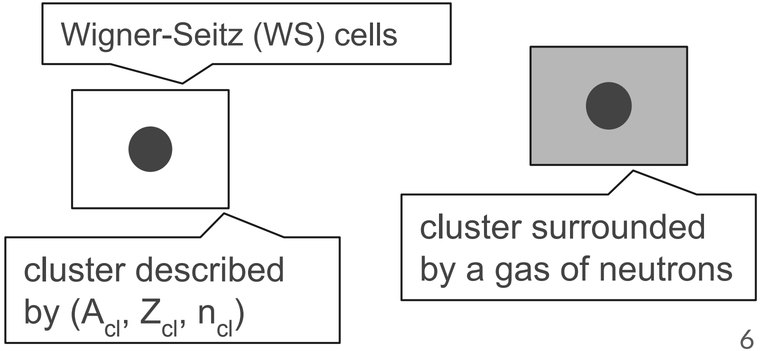


Finite size effects / nuclei description

Volume fraction occupied by nuclei: $u = \frac{V_{cl}}{V_{WS}}$

$$u = \frac{n_B - n_{gas}}{n_{cl} - n_{gas}}$$

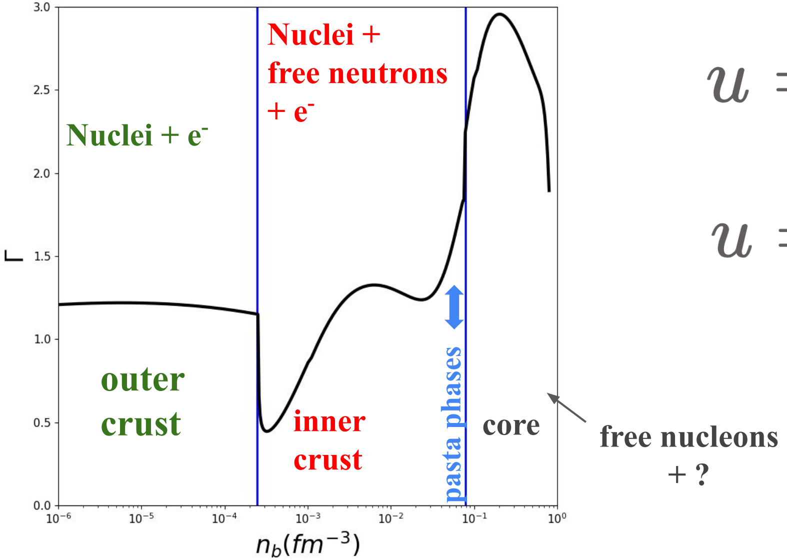




Finite size effects / nuclei description

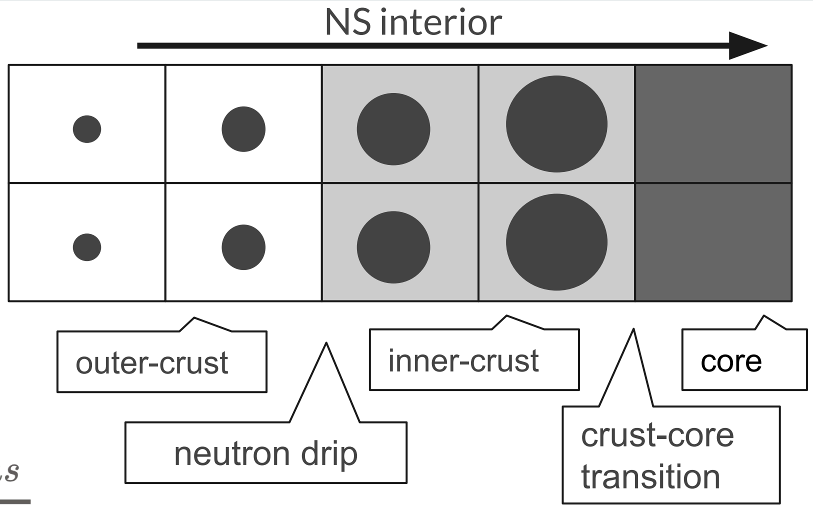
Unified EoS = same nuclear interaction to describe:

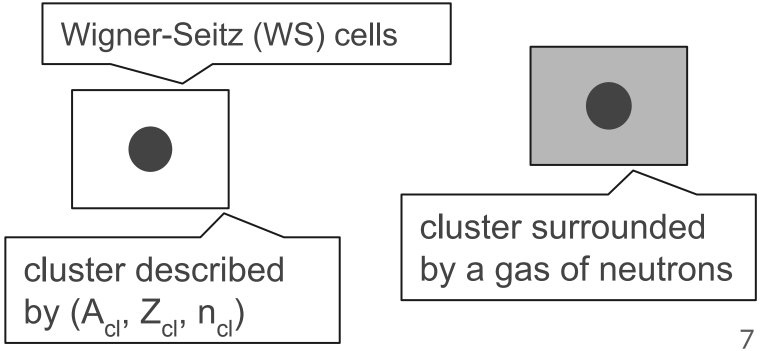
1. Bulk contribution in the cluster (A_{cl}, Z_{cl});
2. Neutron gas;
3. Homogeneous matter (core).



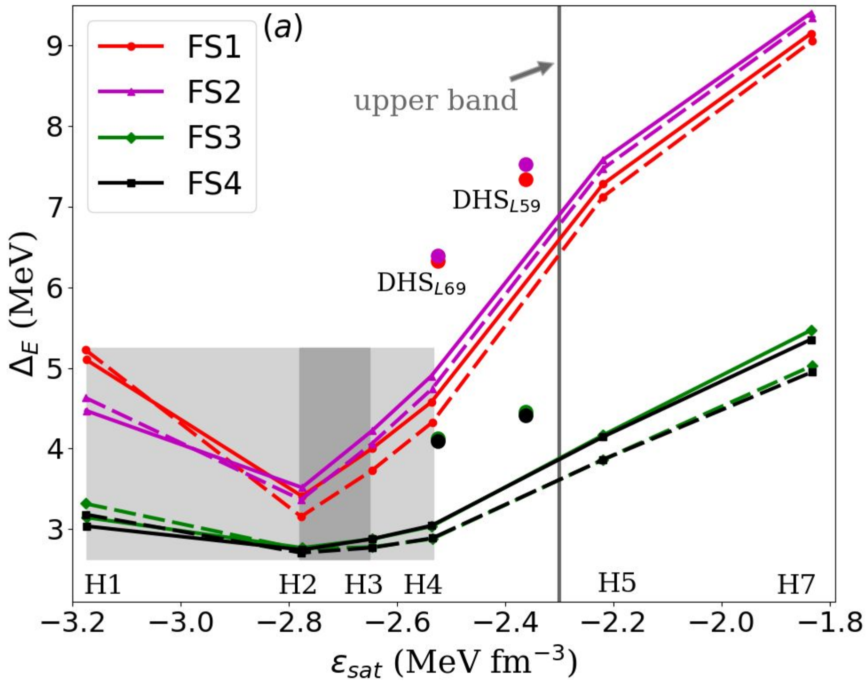
$$u = \frac{V_{cl}}{V_{WS}}$$

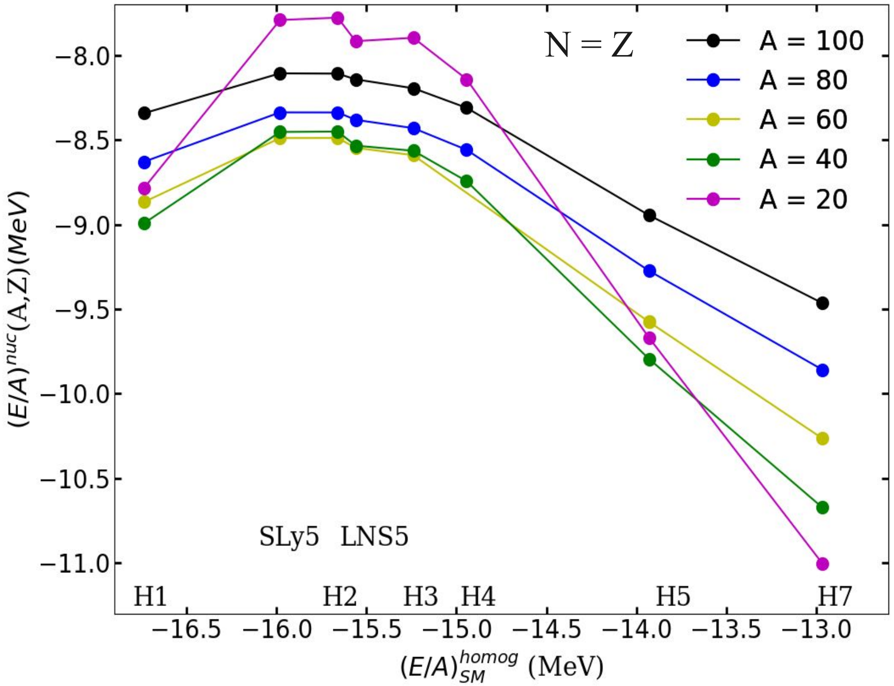
$$u = \frac{n_B - n_{gas}}{n_{cl} - n_{gas}}$$



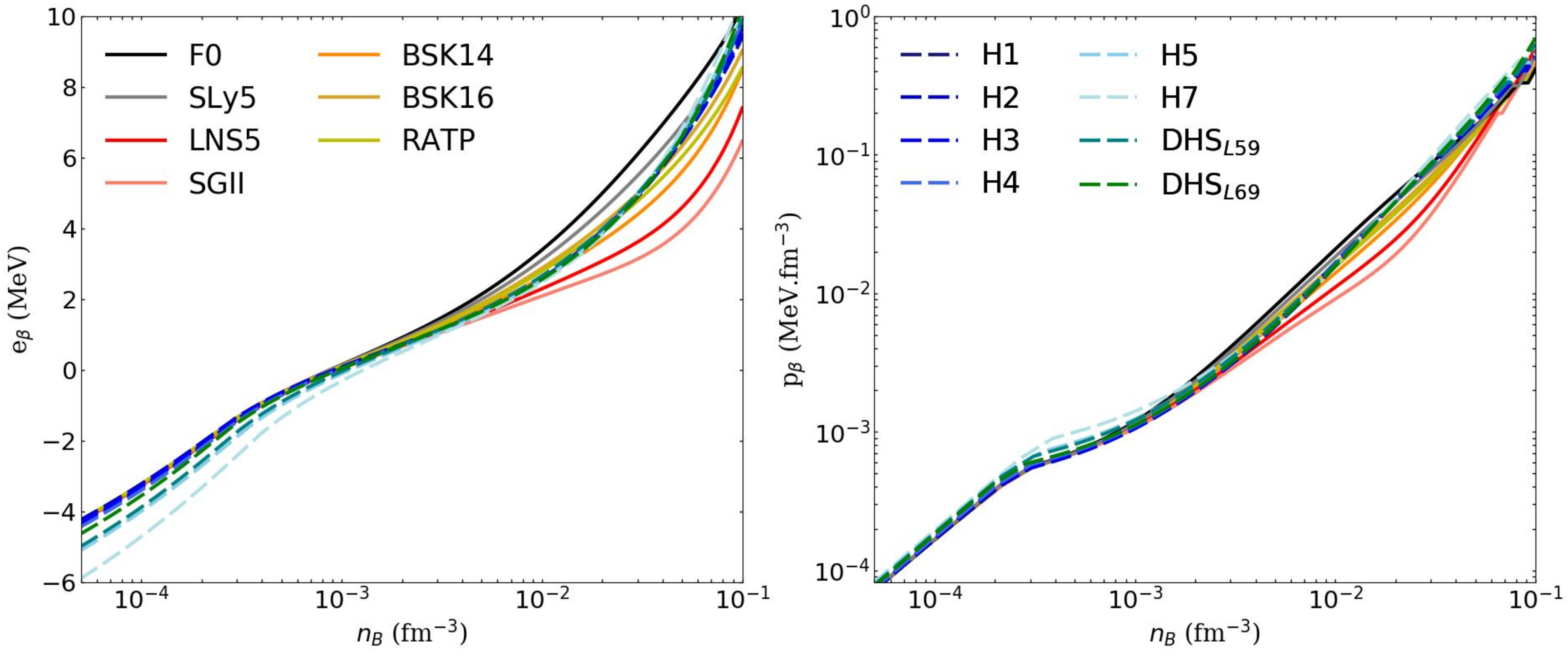


Confronting CLDM against experimental nuclear masses

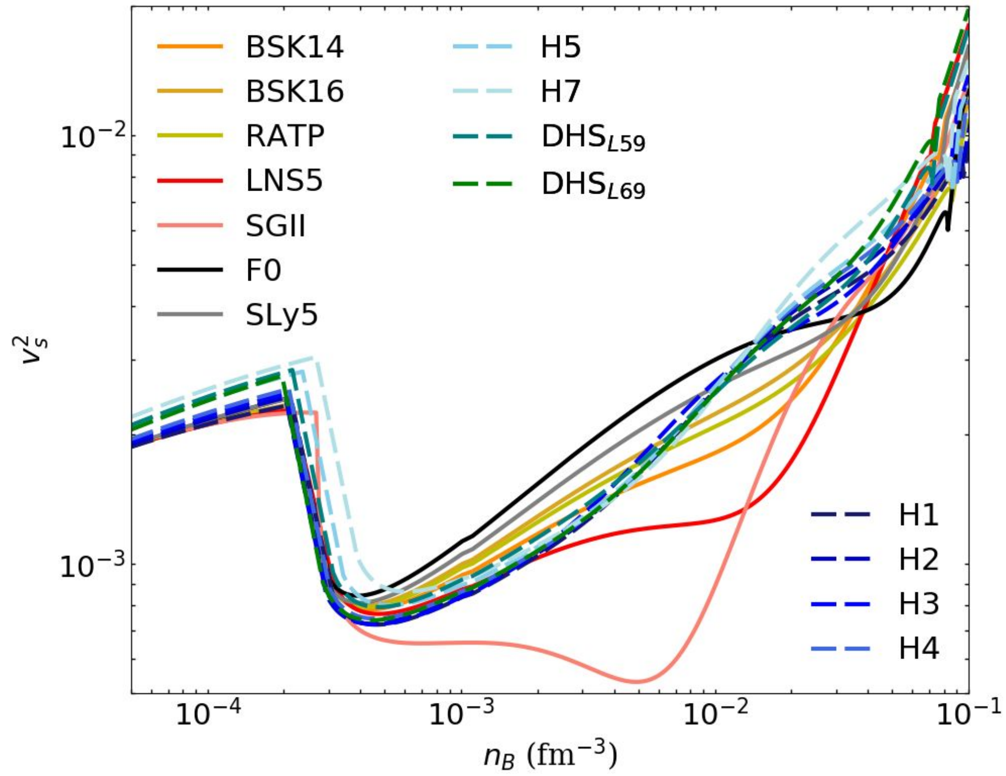


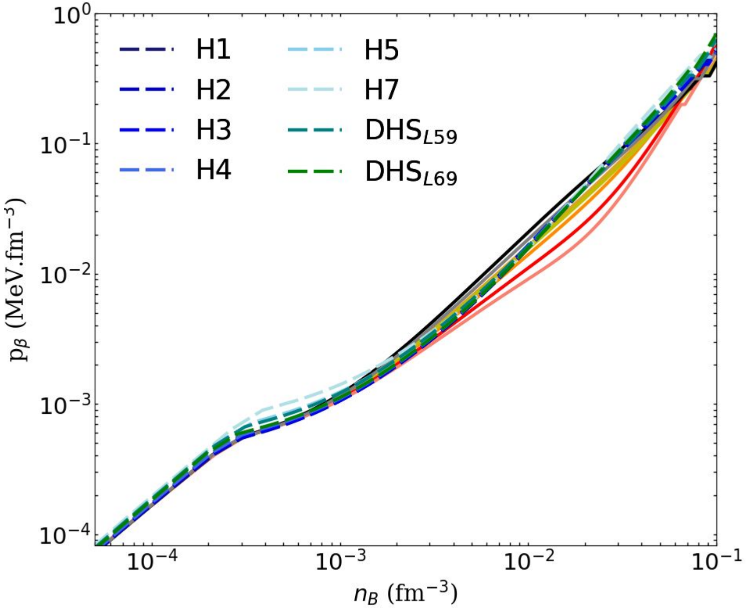


NS crust properties: chiral Hamiltonians and Skyrme comparison

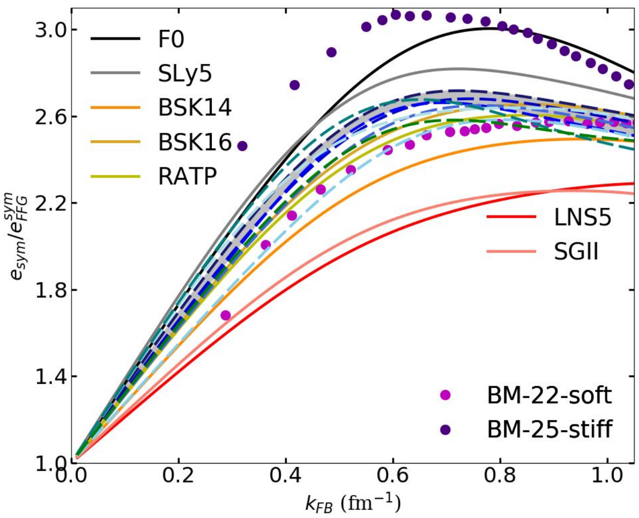


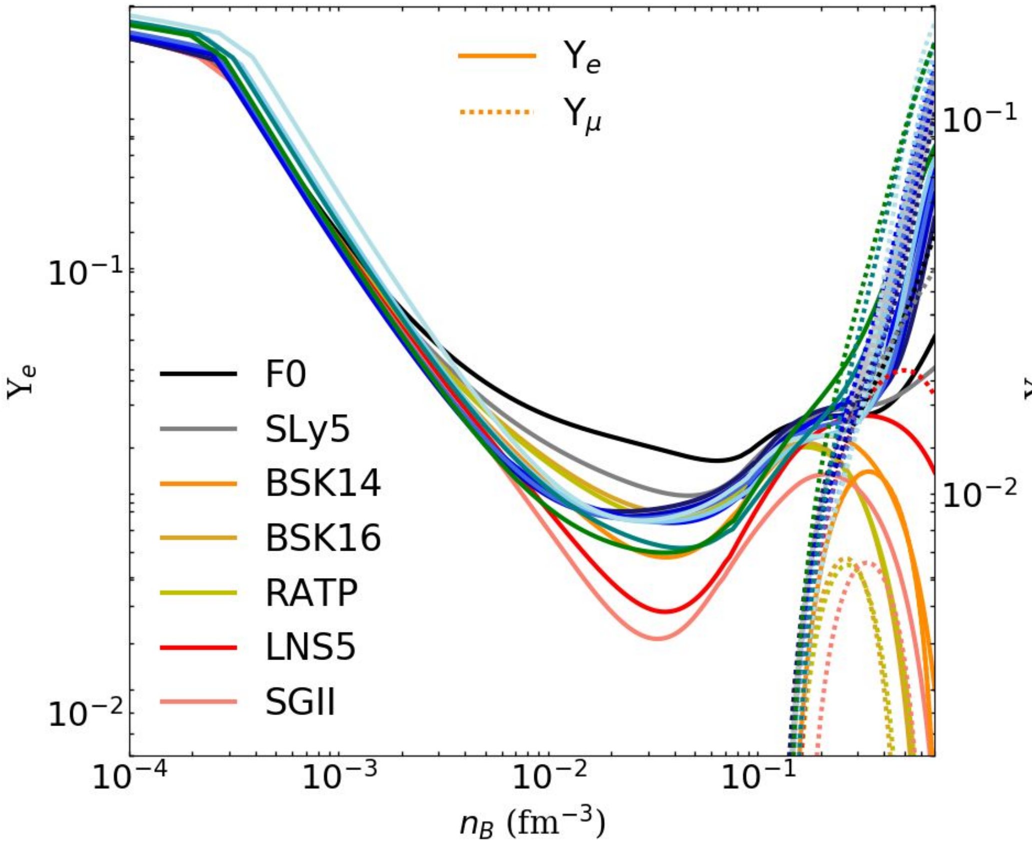
NS crust properties: chiral Hamiltonians and Skyrme comparison





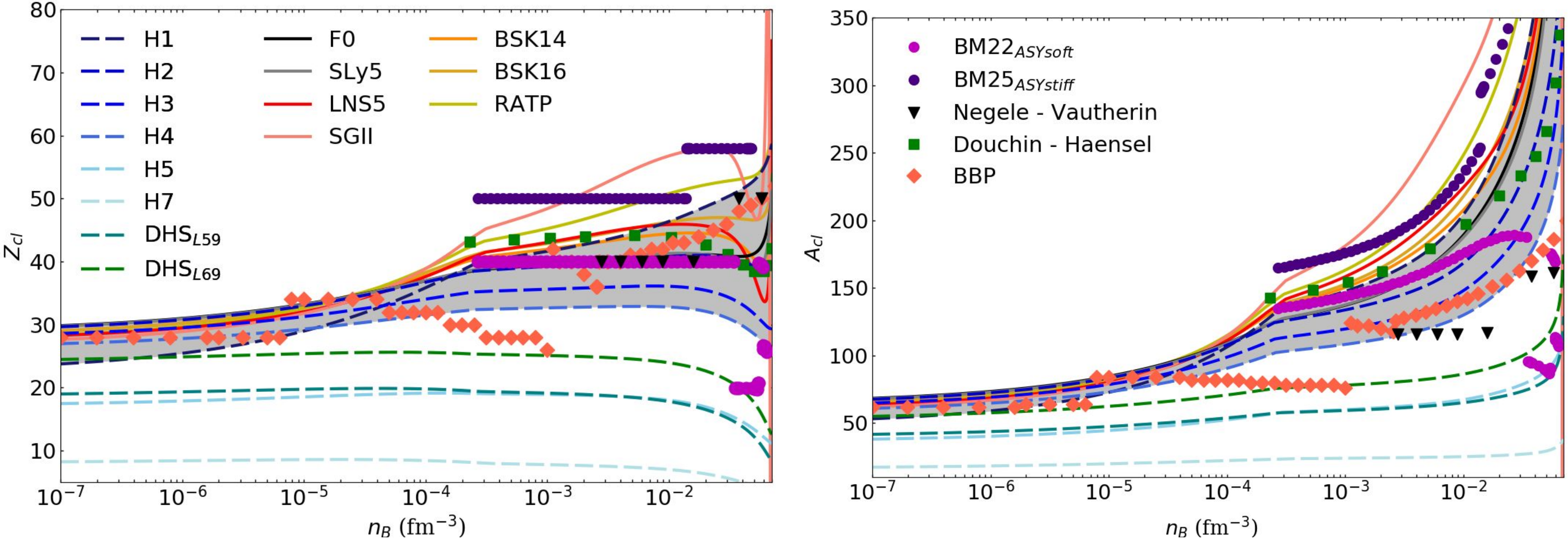
NS crust properties: chiral Hamiltonians and Skyrme comparison





NS crust properties: comparison with previous works

Composition



SUMMARY

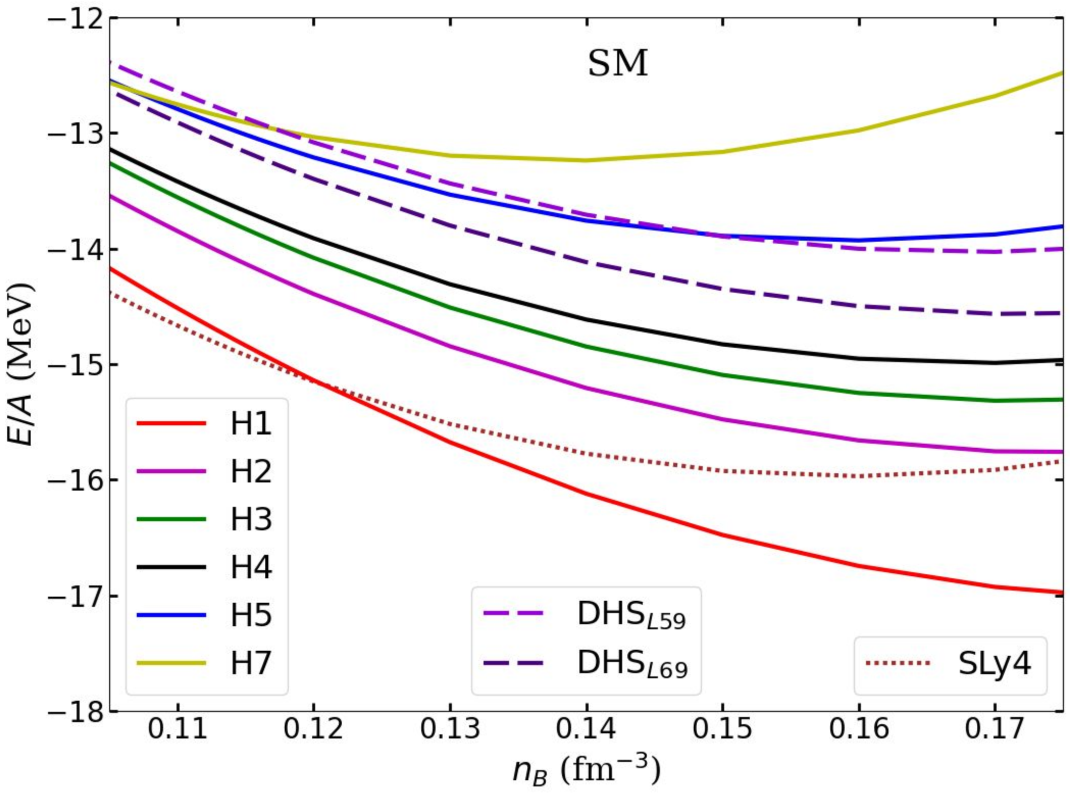
- We adjusted the nucleon meta-model to many-body calculations based on chiral EFT interactions.
- Confronted the CLDM to experimental nuclear masses.
- Predicted NS crust properties.

Main results:

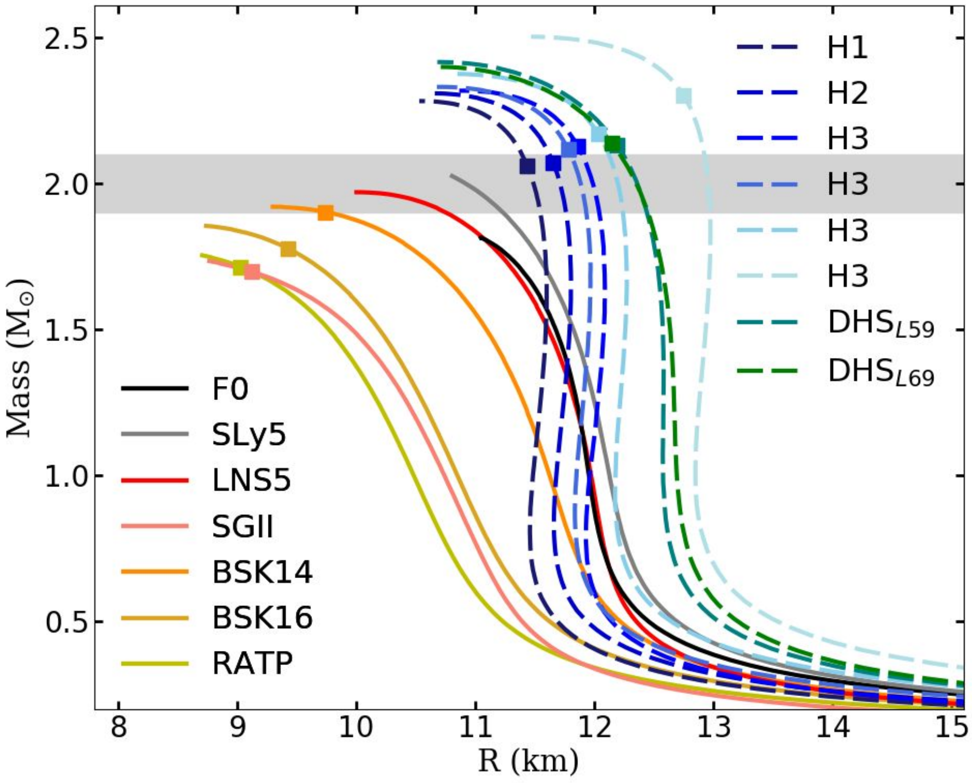
- Clusters mass (A), charge (Z), and asymmetry, are mostly determined by ***symmetric matter*** properties close to saturation density and are therefore mainly constrained by ***experimental nuclear masses.***

- Energy per particle, pressure, sound speed and electron fraction, are mostly influenced by low-density predictions in ***neutron matter***, where *chiral EFT and phenomenological forces substantially differ*.

References at arXiv: 2109.11857 and arXiv: 2110.00441
soon EoSs available at ComPOSE


SM
E/A (MeV)
n_B (fm^{-3})
−12
−13
−14
−15
−16
−17
−18
0.11
0.12
0.13
0.14
0.15
0.16
0.17
H1
H2
H3
H4
H5
H7
DHS$_{L59}$
DHS$_{L69}$
SLy4

Neutron star masses and radii



Meta-model[1] (MM)

$$e_{MM}(n,\delta) = k + v + v^{low,n}$$

kinetic energy

potential: series expansion around saturation

low order correction

- Parameters of the series are the **empirical parameters** of nuclear matter.
- Can be easily compared with nuclear **experiments**.

- We can also *fit the model to any existing model.*
- Here we consider calculations generated by many-body perturbation theory (MBPT) based on chiral NN and 3N interactions[2].

1. J. Margueron, R. Casali and F. Gulminelli. PRC, 97. 025805 (2018)
2. C. Drischler, K. Hebeler and A. Schwenk. PRC 93,054314 (2016)

Homogeneous matter

$$E_{sat}(n) = E_{sat} + \frac{1}{2}K_{sat}x^2 + \frac{1}{6}Q_{sat}x^3 + \frac{1}{24}Z_{sat}x^4$$

$$x = \frac{n - n_{sat}}{3n_{sat}}$$

$$E_{sym}(n) = E_{sym} + L_{sym}x + \frac{1}{2}K_{sym}x^2 + \frac{1}{6}Q_{sym}x^3 + \frac{1}{24}Z_{sym}x^4$$