NOVEL LOW-RESOLUTION INTERACTIONS FOR AB INITIO METHODS

Pierre Arthuis

[Arthuis, Hebeler, Schwenk, arxiv:2401.06675]

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Low-energy ab initio nuclear theory

A-body system with:

Z protons

N neutrons

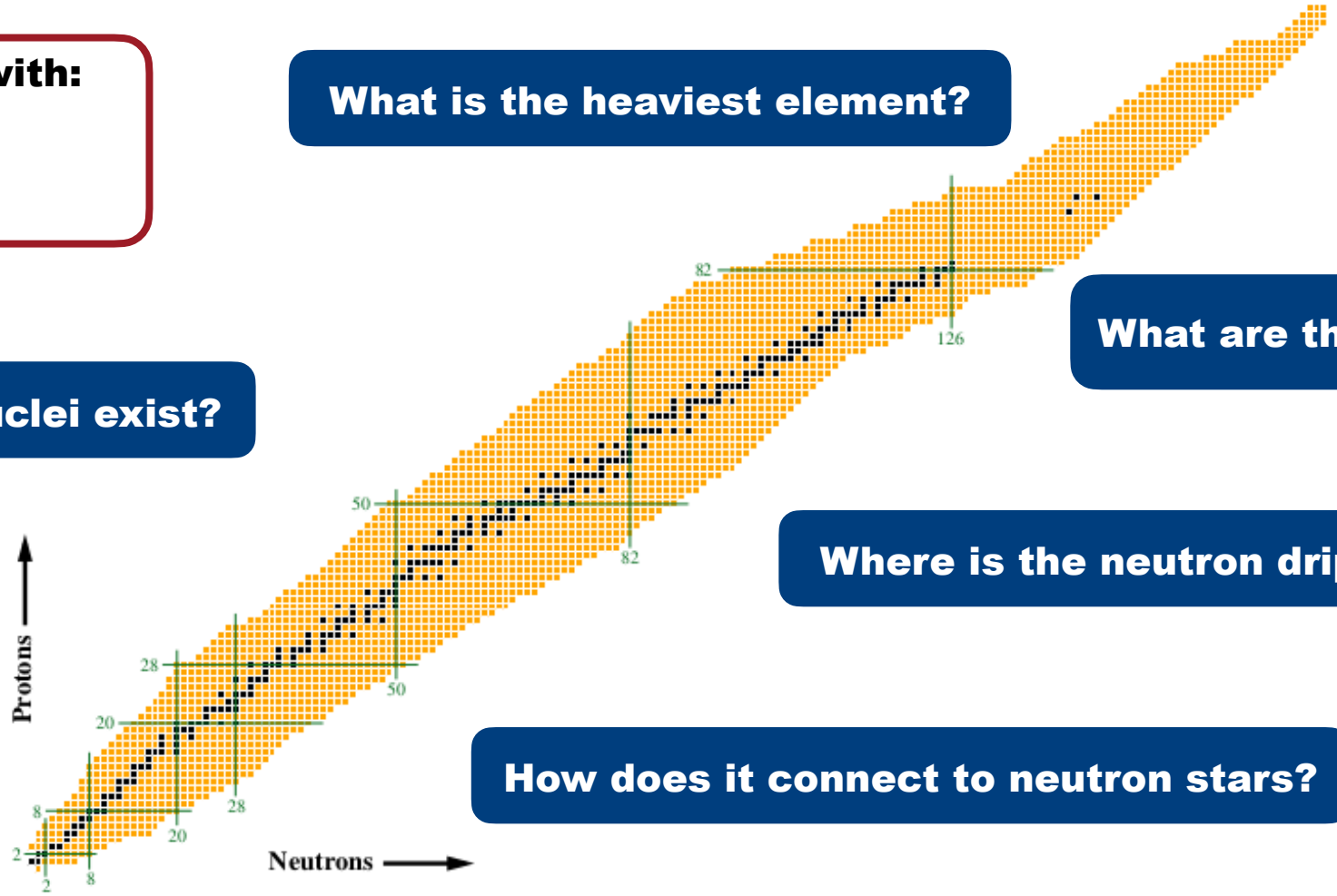
What is the heaviest element?

What are the magic numbers?

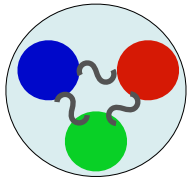
How many nuclei exist?

Where is the neutron dripline?

How does it connect to neutron stars?

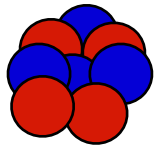


Ab initio many-body scheme



Particle physics

No direct application of
quantum chromodynamics
(Lattice QCD only for few nucleons)



Nuclear theory

Interactions anchored in Effective Field Theory

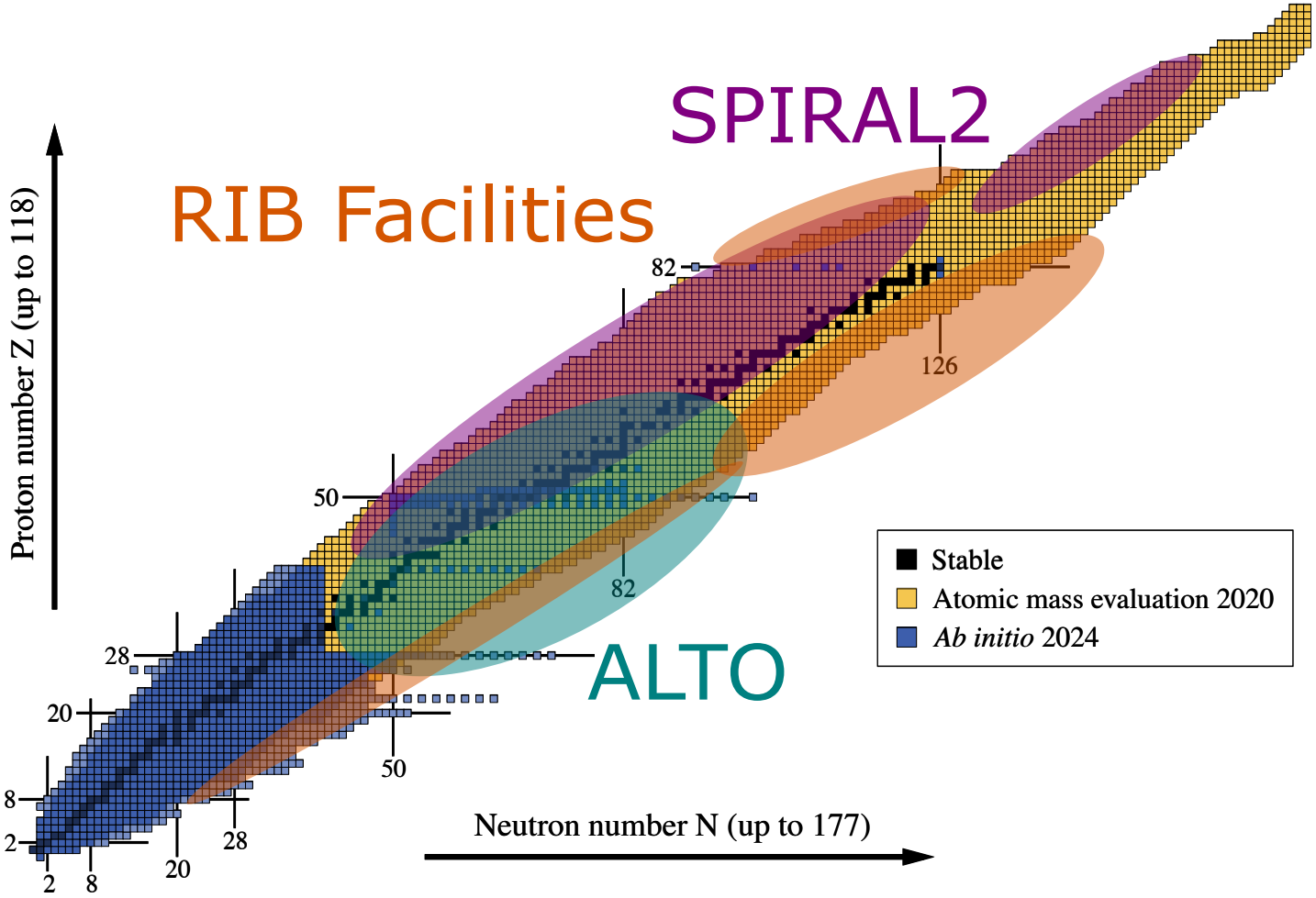
A-body Schrödinger equation

$$H\,|\Psi^{A}\rangle = E^{A}\,|\Psi^{A}\rangle$$

Obtain a description that is:

- Consistent
- Systematic
- Accurate enough
- From inter-nucleon interactions
- Rooted in quantum chromodynamics

A look at experimental facilities



Adapted from B. Bally

New era of shared effort

Heaver nuclei

More exotic nuclei

In-Medium Similarity Renormalization Group

Continuous operator transformation

$$H(s) = U(s)H(0)U^{\dagger}(s)$$

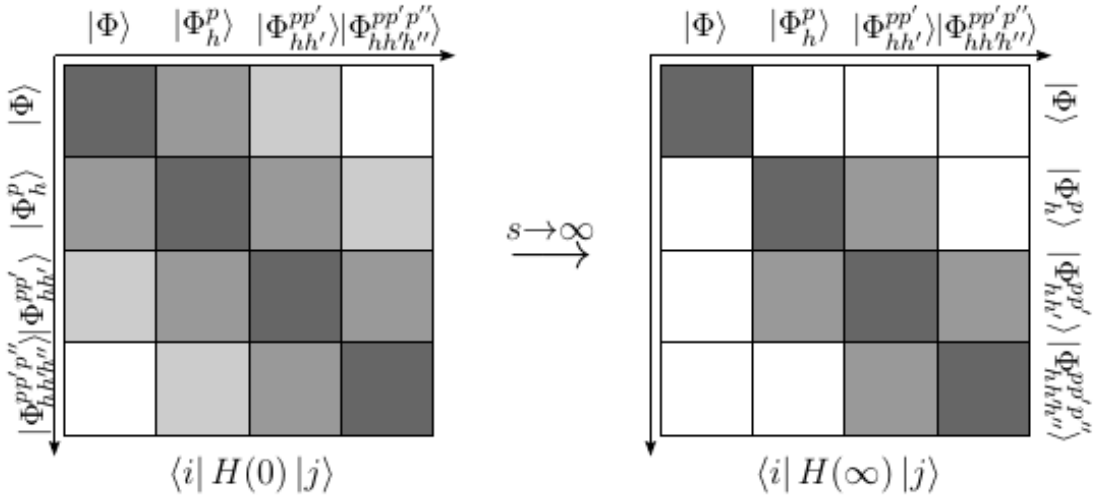
IMSRG flow equation

$$\frac{dH(s)}{ds} = \left[\eta(s), H(s)\right]$$

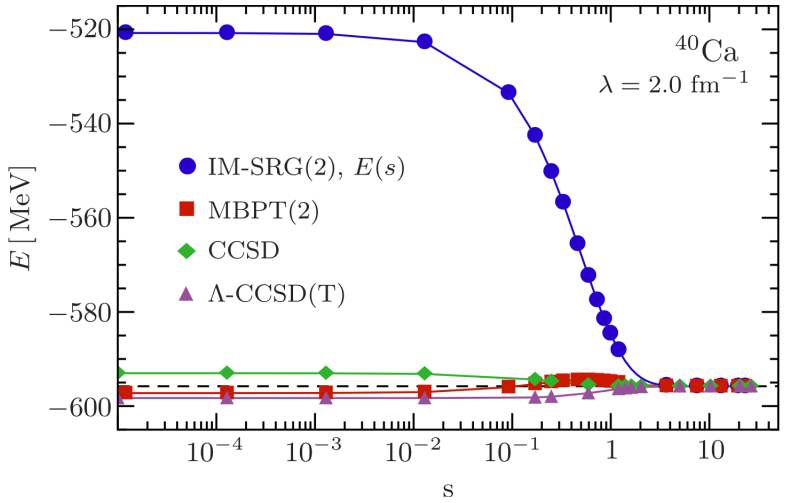
Decouple the reference state from excitations

- Correlations absorbed in the evolved reference state
- Other operators (radii, etc.) evolved jointly

IMSRG(2) = Typically a few % accuracy



[Hergert *et al.*, *J.Phys.Conf.Ser.* 1041 (2018)]



[Hergert *et al.*, *Phys. Rep.* 621 (2016)]

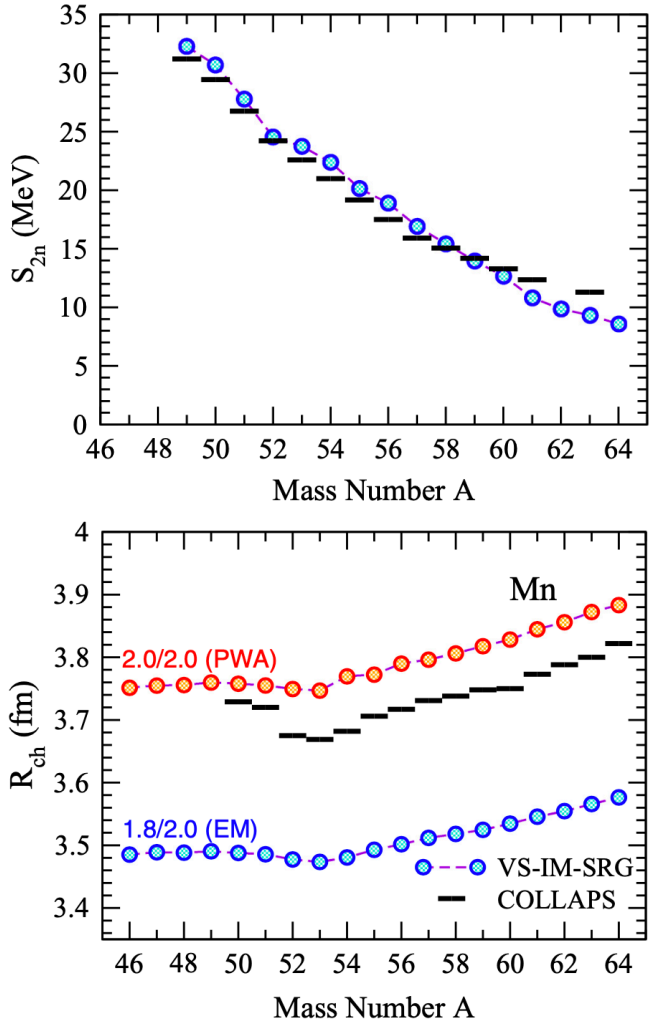
Why low-resolution interactions?

Sufficient to describe bulk properties of nuclei

- Better convergence properties through softened interaction
- Proved successful for binding energies with the 1.8/2.0 (EM)
  [Hebeler *et al.*, *PRC* **83** (2011)]

Revisit the 1.8/2.0 approach

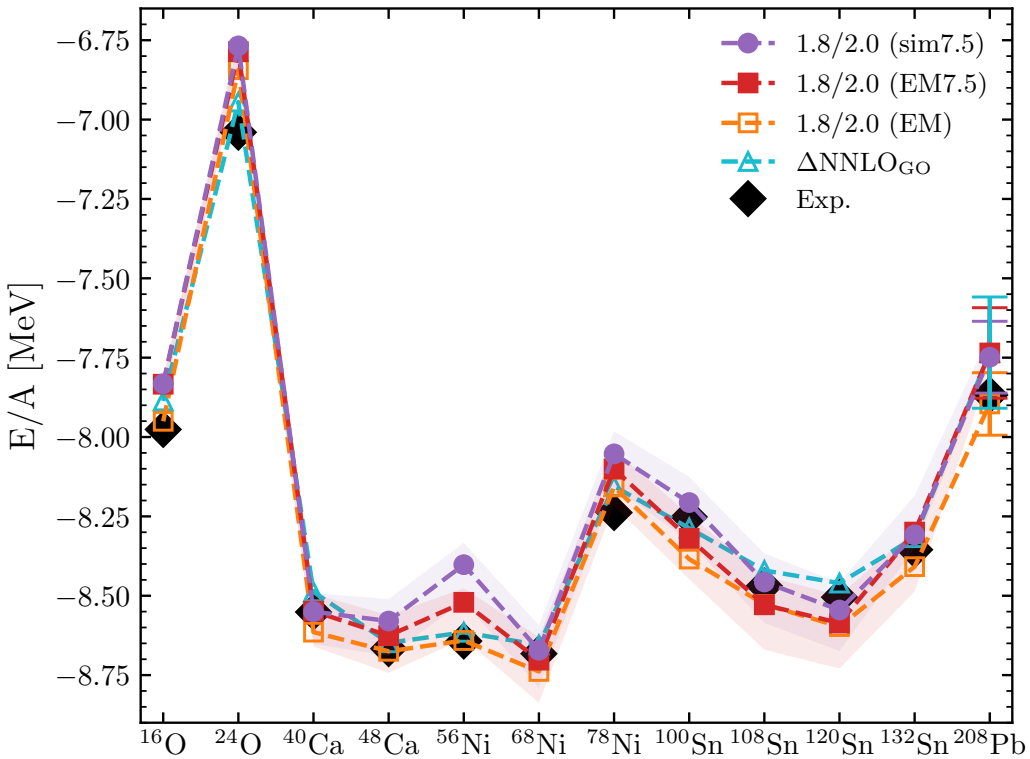
- Goal: Obtain good description of binding energy and radii
- Target: From light to heavy systems

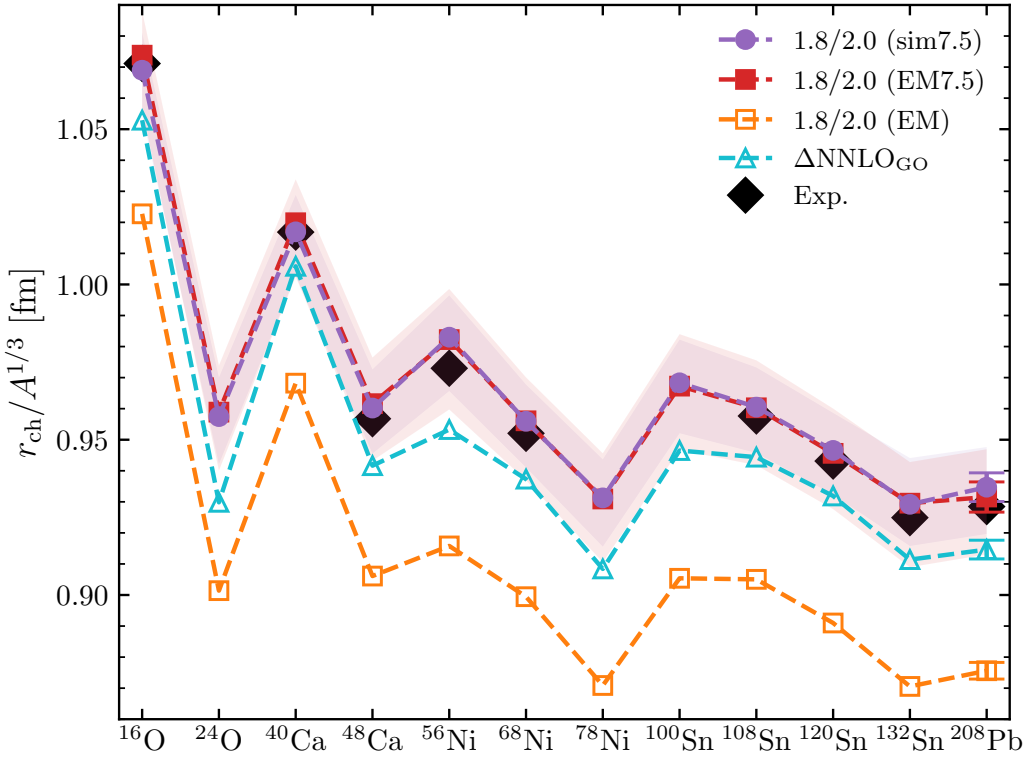


[Simonis *et al.*, *PRC* **96** (2017)]

Ground-state accuracy towards heavy systems

[Arthuis, Hebeler, Schwenk, arxiv:2401.06675]





Binding energy

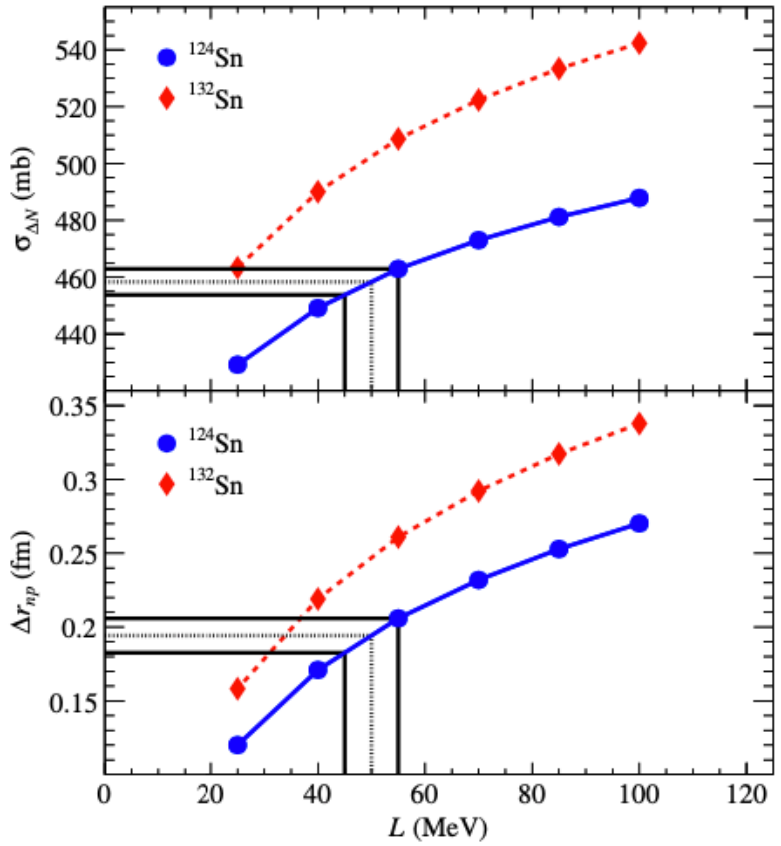
- Reasonable reproduction of experimental values
- Slight improvement for heavy systems w.r.t. 1.8/2.0 (EM)

Charge radius

- Quasi-exact reproduction over complete mass range
- Excellent combined reproduction of charge and mass

Neutron skins and heavy systems

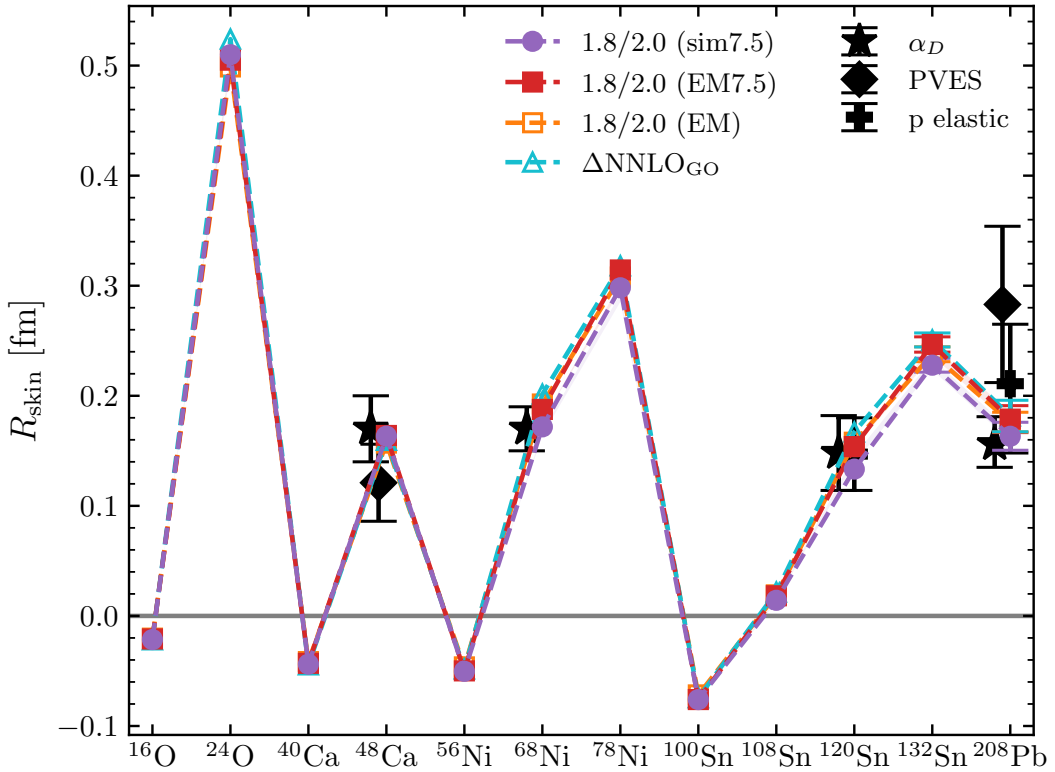
[Arthuis, Hebeler, Schwenk, arxiv:2401.06675]



[Aumann *et al.*, *PRL* 119 (2017)]

Neutron removal off Sn isotopes @ R3B/GSI

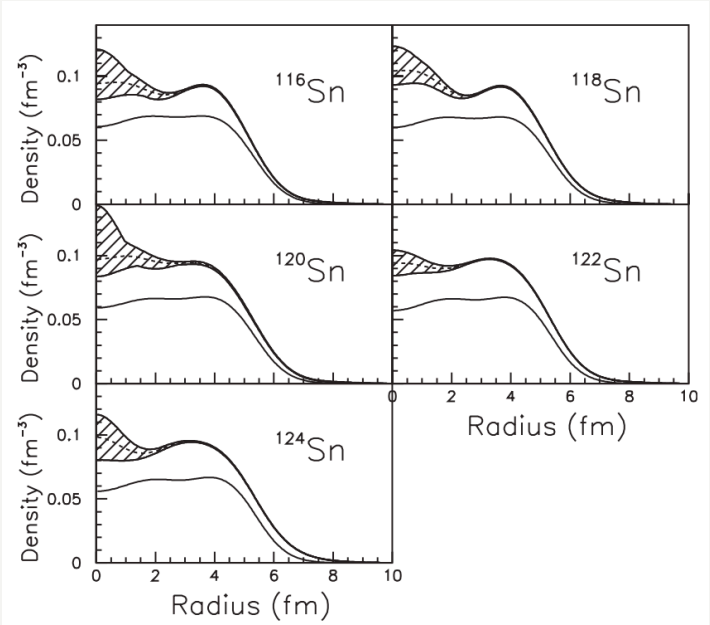
- Access L through the cross-section, need for theory input
- L correlated to neutron skin too: Great test case



On neutron skins

[Arthuis, Hebeler, Schwenk, arxiv:2401.06675]

Evolution w.r.t. isospin

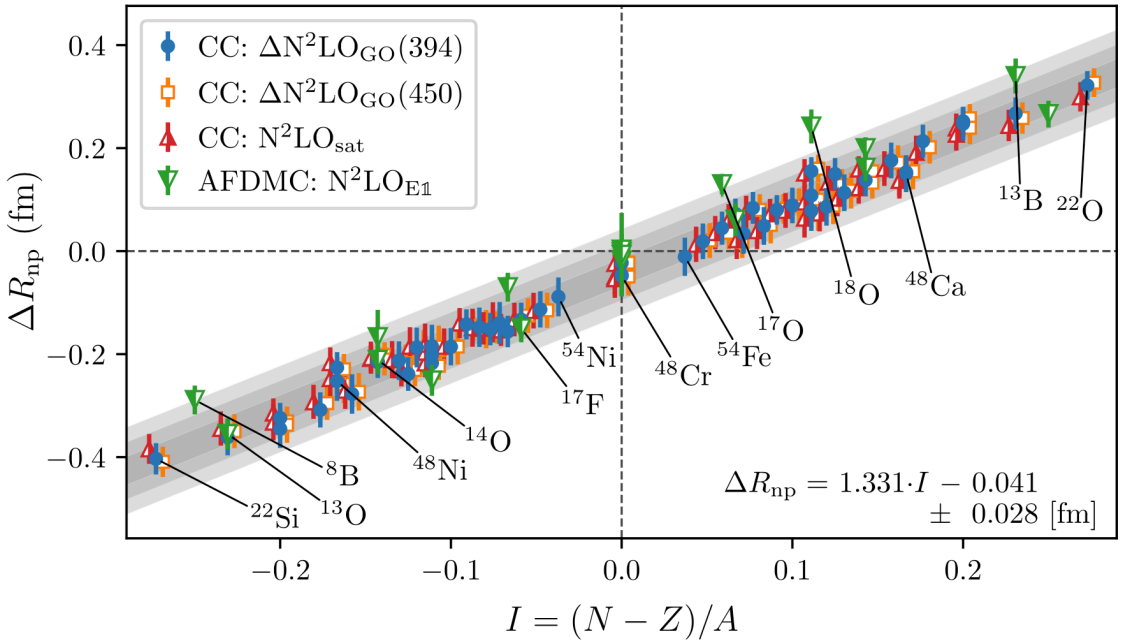


[Terashima *et al.*, *PRC* **77** (2008)]

Liquid droplet model

$$R_{\text{skin}} \propto \frac{2r_0}{3} \frac{S_S}{S_V + S_S A^{-1/3}} \frac{\text{N} - \text{Z}}{\text{A}}$$

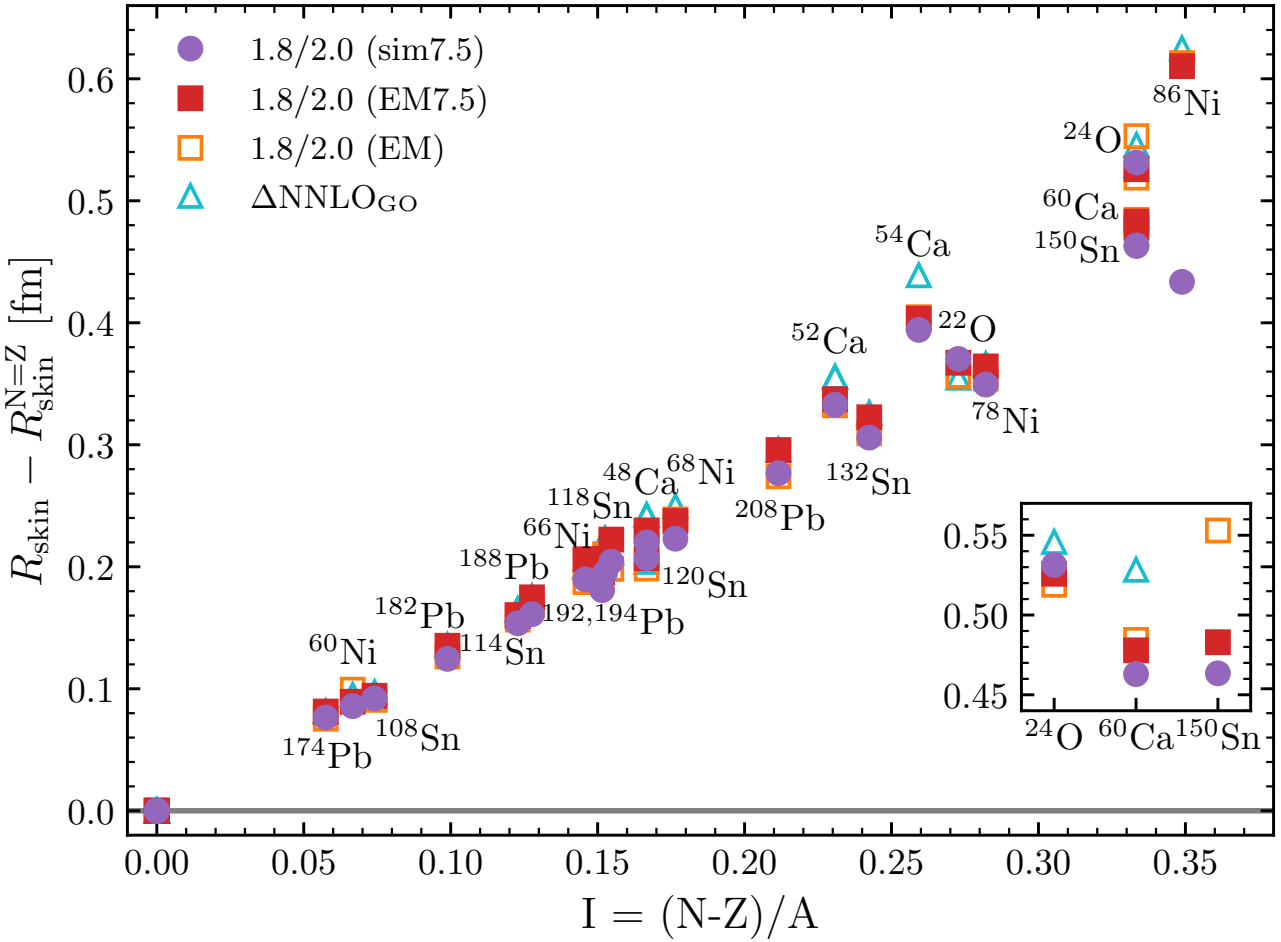
Linear relation confirmed on *ab initio* basis



[Novario *et al.*, *PRL* **130** (2023)]

Neutron skins in neutron-rich isotopes

[Arthuis, Hebeler, Schwenk, arxiv:2401.06675]



Evolution w.r.t. isospin

- Linear dependance confirmed in valley of stability
- Neutron-rich nuclei exhibit stronger dependence
- Highlight importance of interaction

Good physics cases to explore

Strongly correlated with ΔR_{ch}^{mirror}

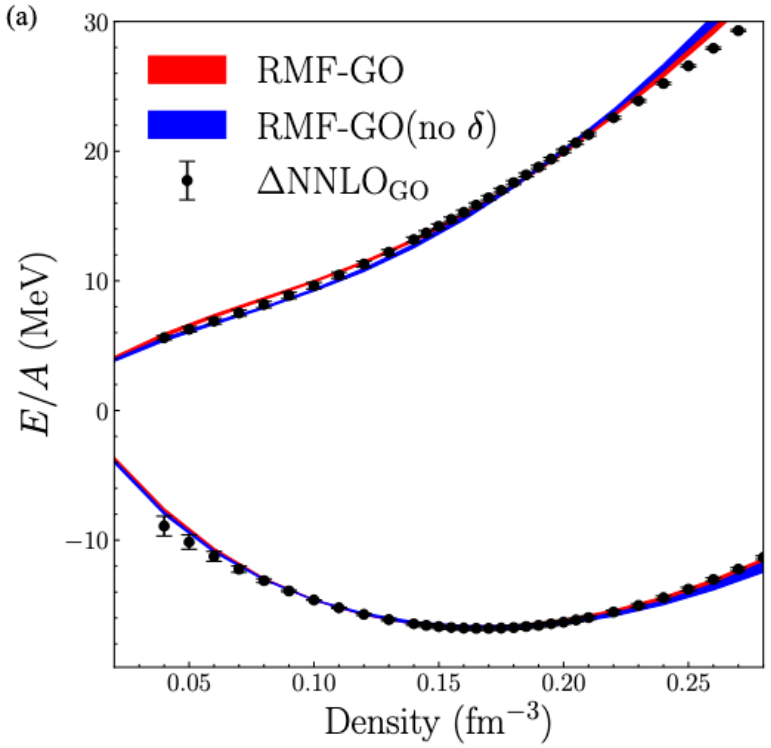
[N. Koak, B.Sc. Thesis (2024)]

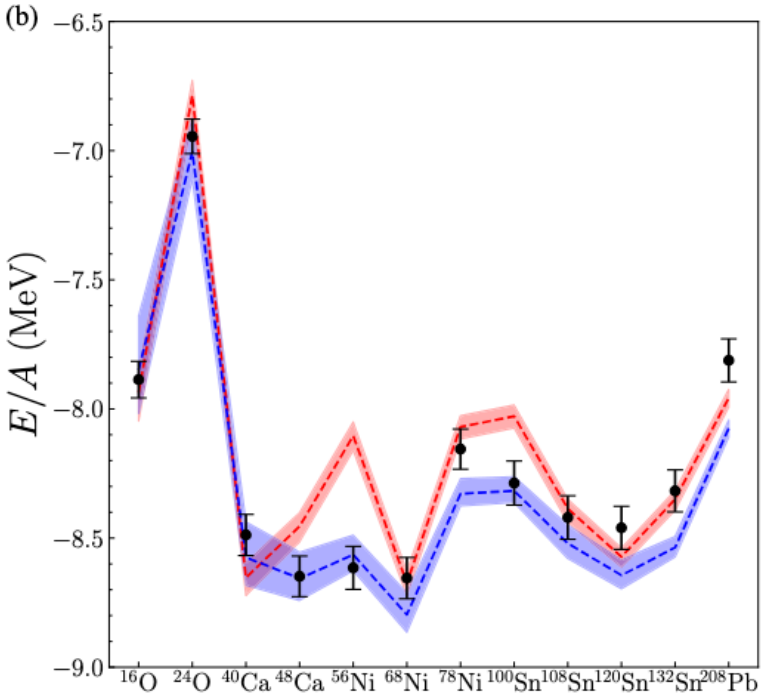
Ab initio results as pseudodata for RMF fits

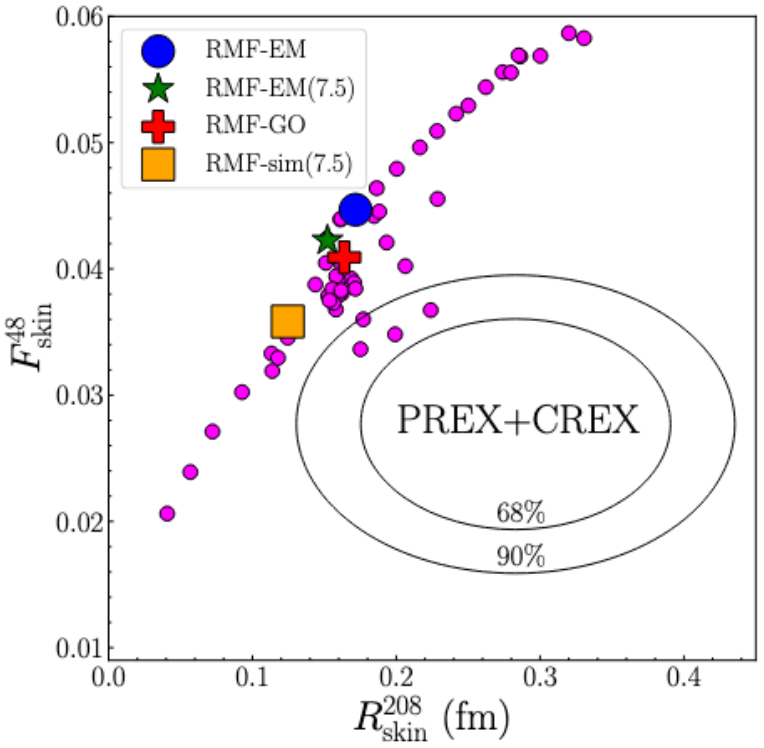
[Reed, Heinz, Arthuis, Tews, Schwenk, *PRC* **112** (2025)]

Can chiral forces inform RMF?

- Trial of two possible Lagrangian parametrisations
- New line of research to be explored more







Conclusion and outlook

Novel accurate interactions over the nuclear chart

- Very good reproduction of binding energy, radii, neutron skins

Neutron skin dependence on isospin

- Enhanced dependance on system at the most neutron-rich
- Neutron-rich nuclei to be more accessible with new RIB facilities

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