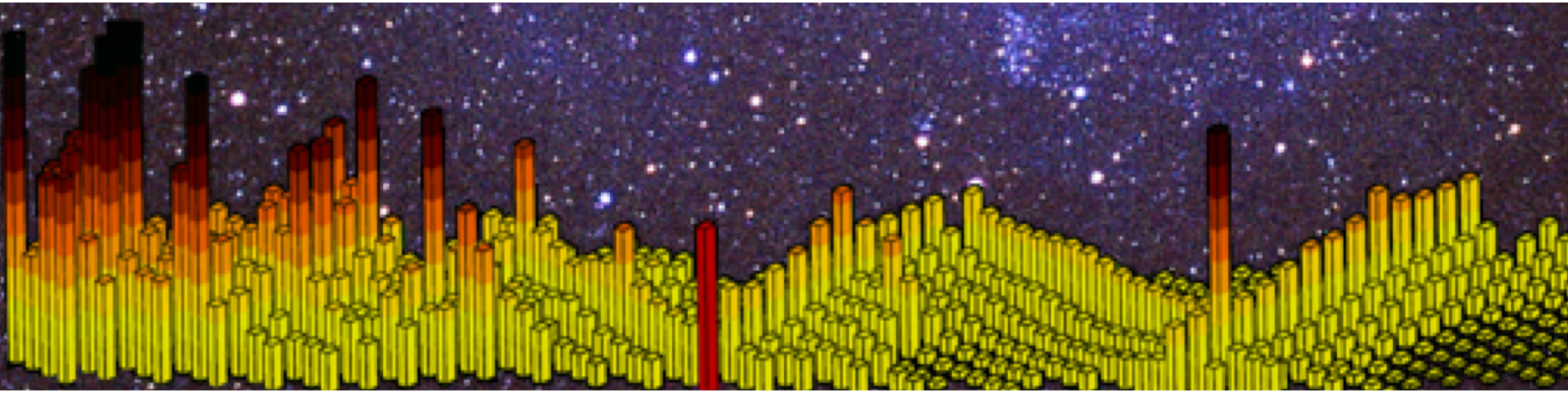
A04: Strong interactions and structure of medium-mass nuclei

Robert Roth and Achim Schwenk

TECHNISCHE UNIVERSITÄT DARMSTADT

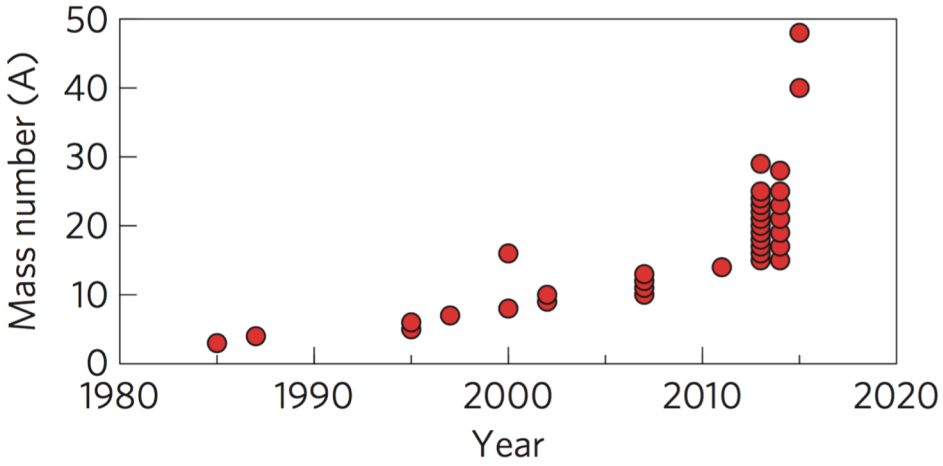


SFB Workshop, March 27, 2019

DFG SFB 1245

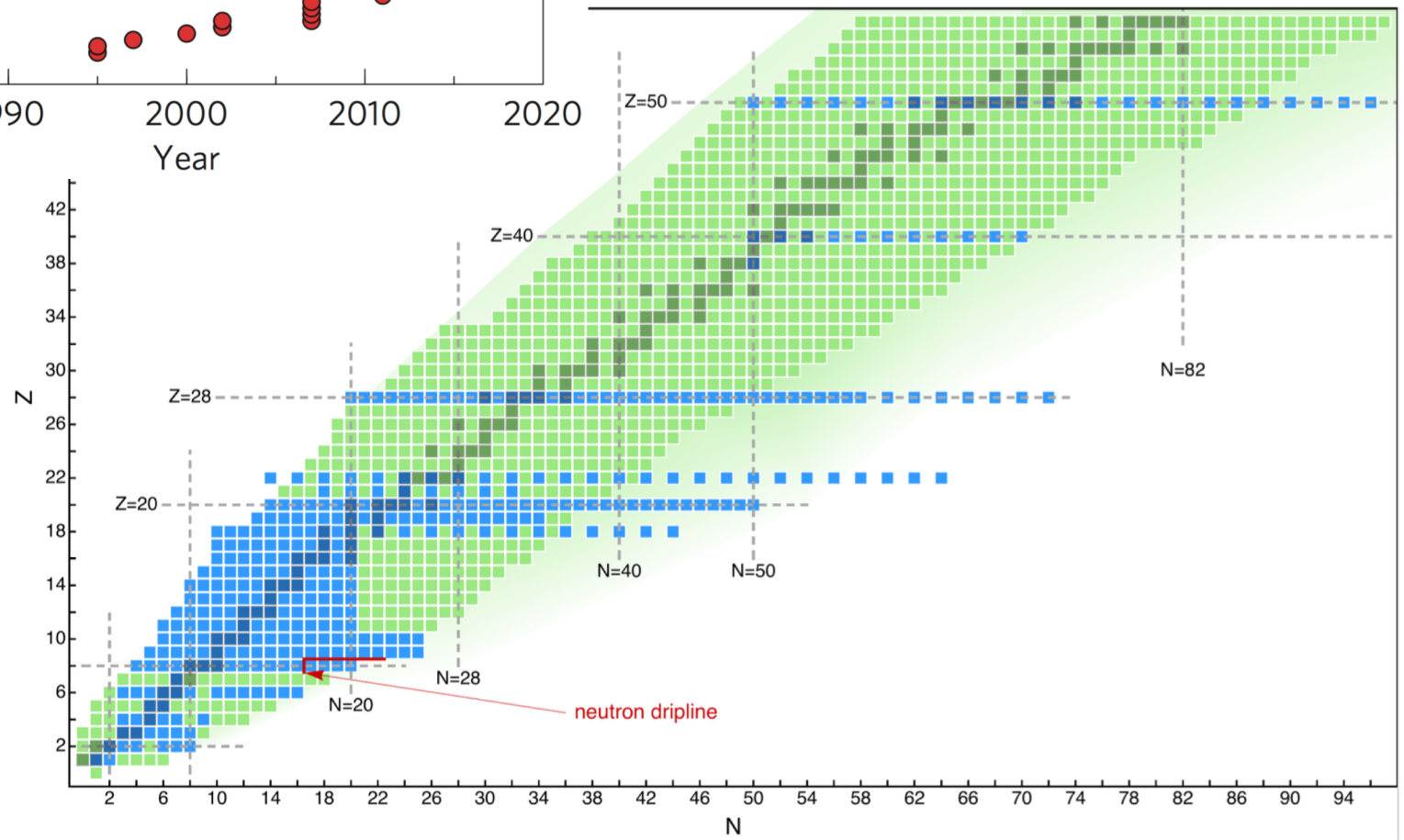
Progress in ab initio calculations of nuclei

dramatic progress in last 5 years to access nuclei up to A ~ 50



from Hagen et al., Nature Phys. (2016)

from Hergert et al., Phys. Rep. (2016)



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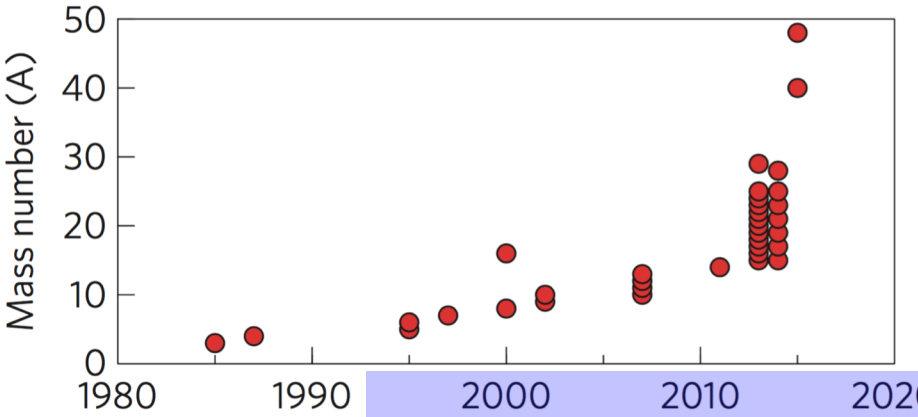

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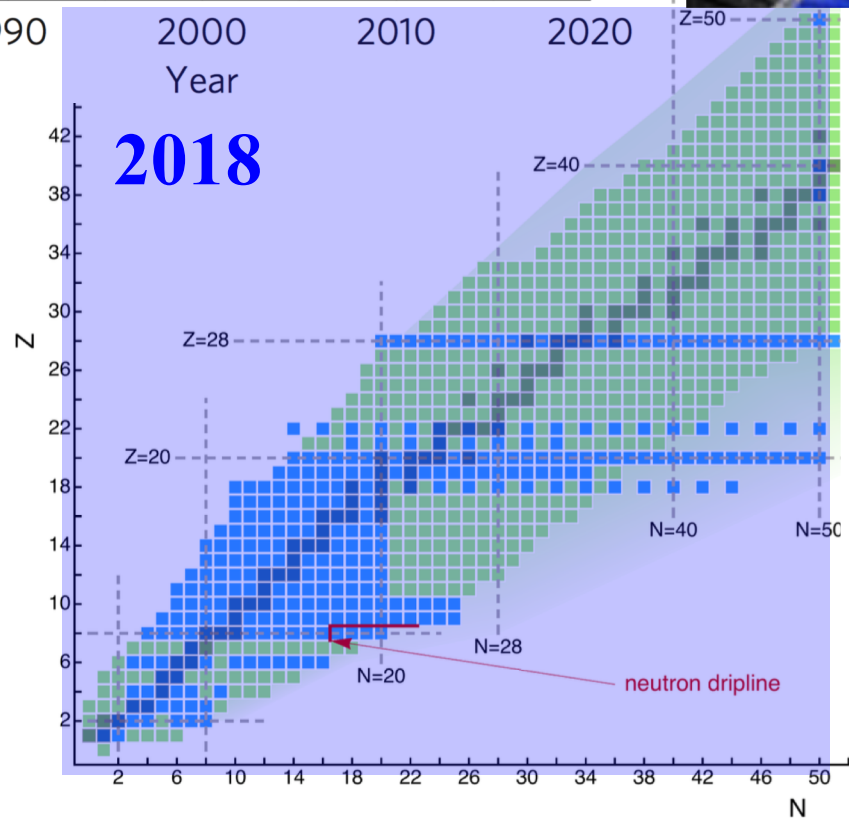
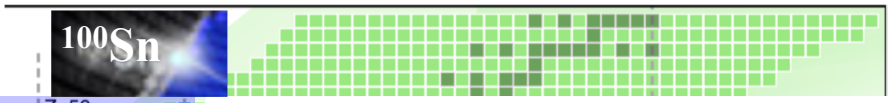


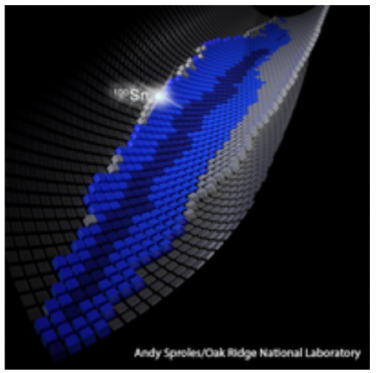


Editors' Suggestion

Structure of the Lightest Tin Isotopes

T. D. Morris, J. Simonis, S. R. Stroberg, C. Stumpf, G. Hagen, J. D. Holt, G. R. Jansen, T. Papenbrock, R. Roth, and A. Schwenk

Phys. Rev. Lett. **120**, 152503 (2018) – Published 12 April 2018

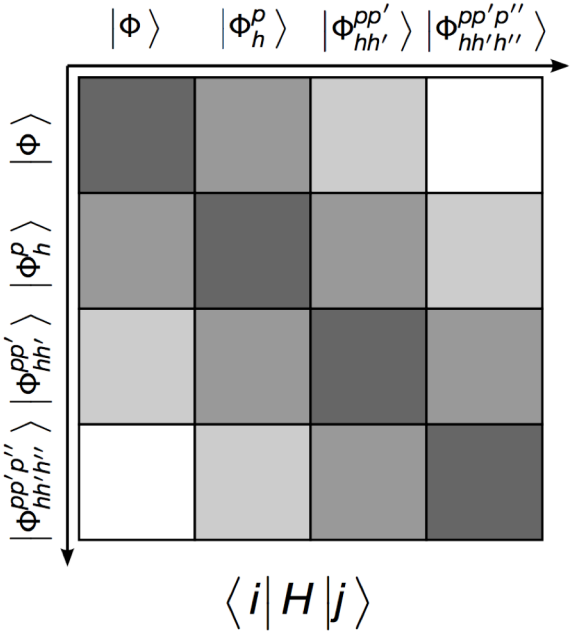


Ab-inito calculations of ^{100}Sn with $N = Z = 50$ predict it to be doubly magic.

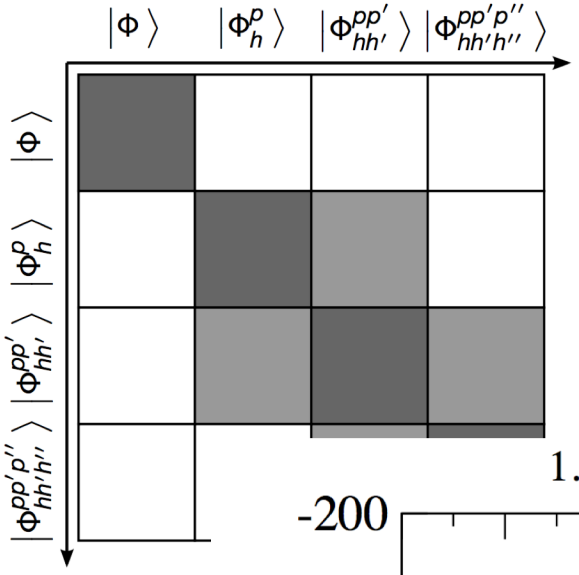
In-medium similarity renormalization group (IMSRG)

flow equations to decouple higher-lying particle-hole states

Tsukiyama, Bogner, AS, PRL (2011), Hergert et al., Phys. Rep. (2016)



IM-SRG

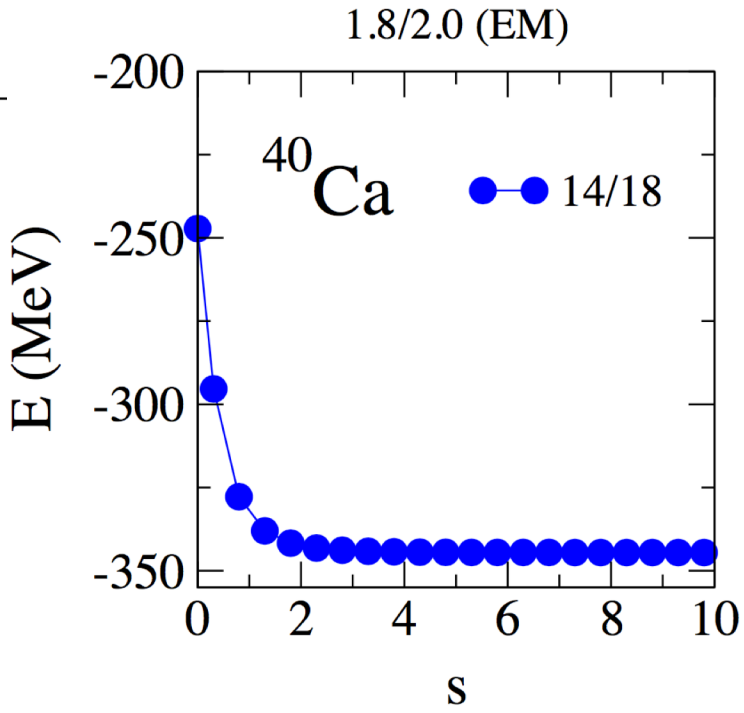


s = 0

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

$$\frac{d}{ds}H(s) = [\eta(s), H(s)]$$

with generator $\eta = [H^d(s), H^{od}(s)]$



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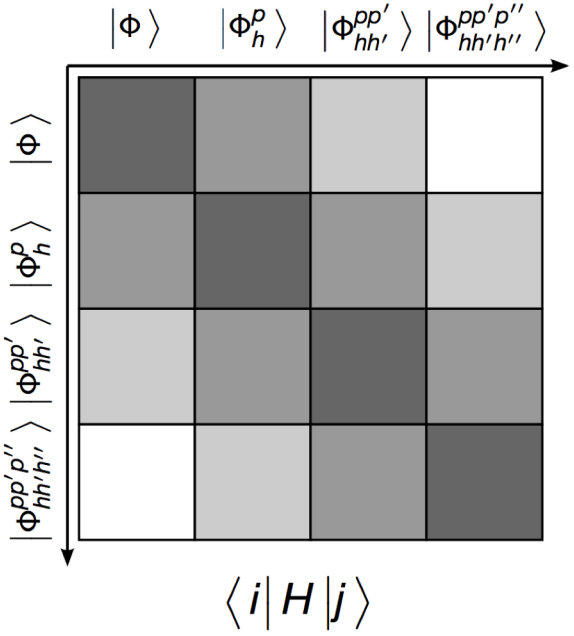
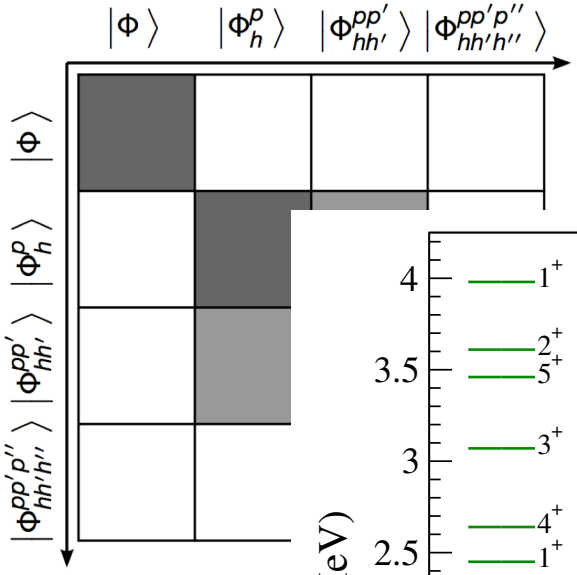


IM-SRG

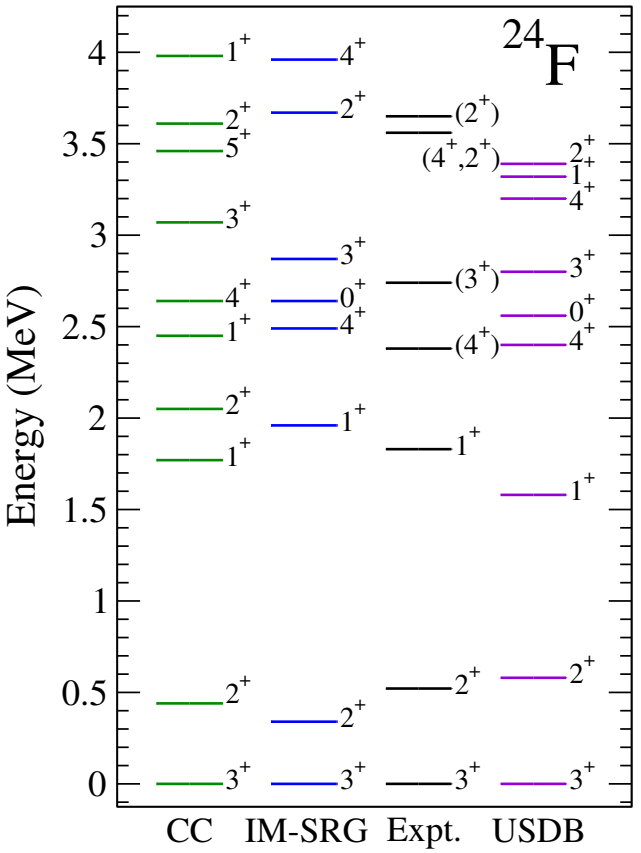


$$H(s) = U(s)H(0)U^{\dagger}(s)$$

valence-space IMSRG: decouple valence space to derive nonpert. shell-model interactions

Tsukiyama et al., PRC (2012); Bogner et al., PRL (2014);

+ ensemble normal ordering Stroberg et al., PRL (2016)

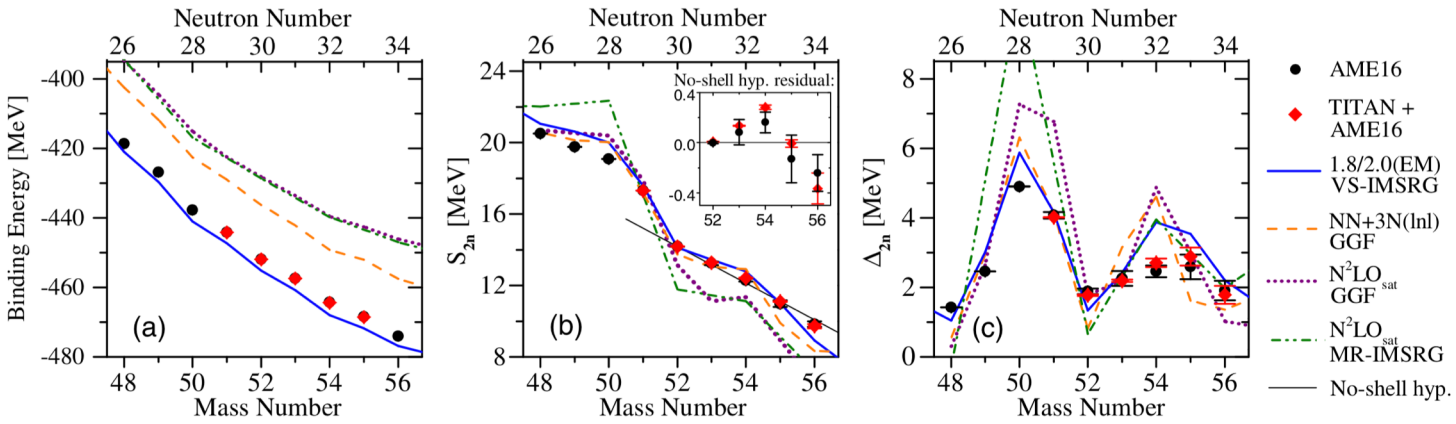


Cáceres et al., PRC (2015)

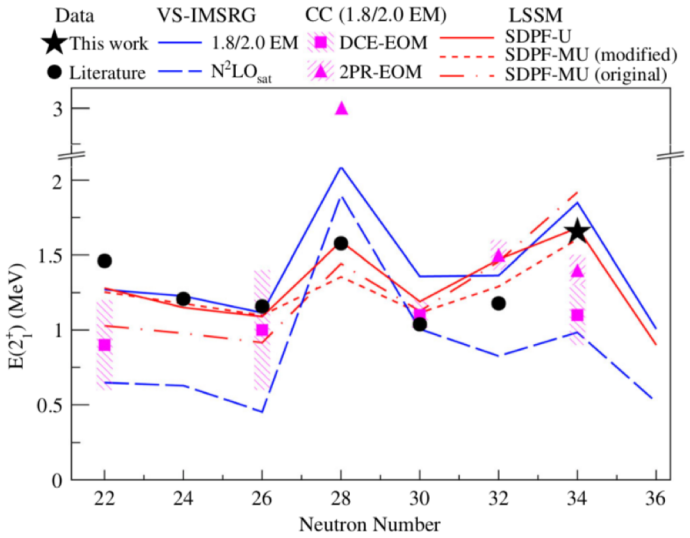
Valence-space IMSRG highlights

joint collaborations with TITAN, ISOLTRAP, R3B, GANIL, RIKEN,…
for F, Ar, Ti, Cr based on NN+3N with good saturation properties

PHYSICAL REVIEW LETTERS **120,** 062503 (2018)

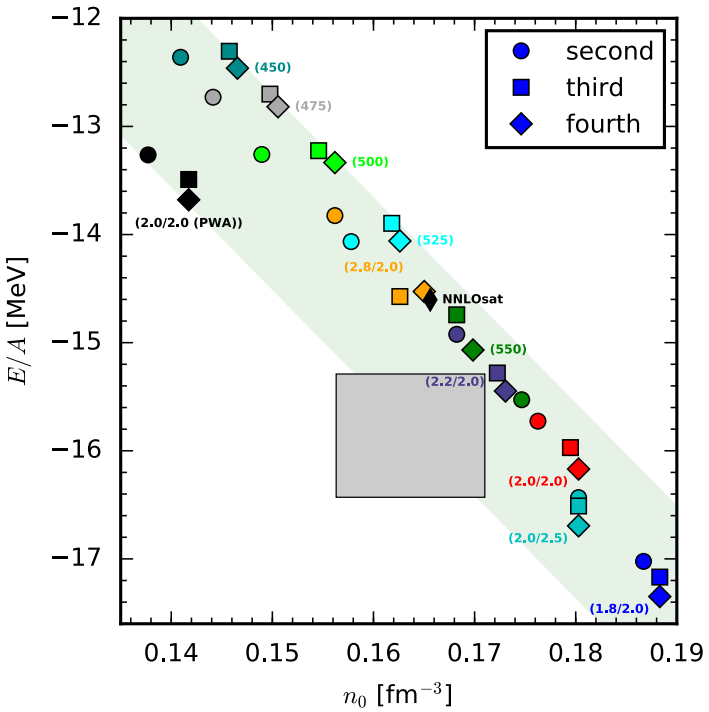


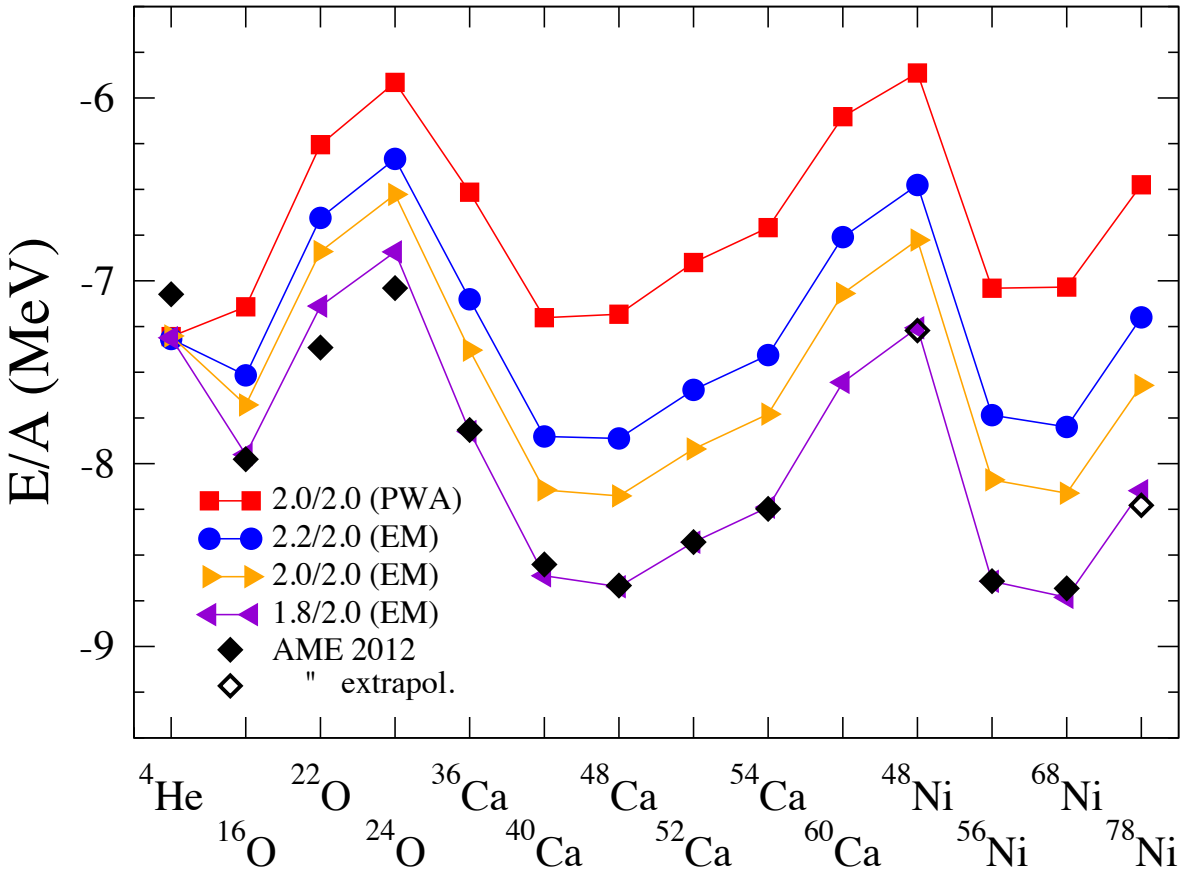
ERS **122,** 072502 (2019)



Importance of saturation for nuclear forces Simonis, Stroberg et al. (2017)

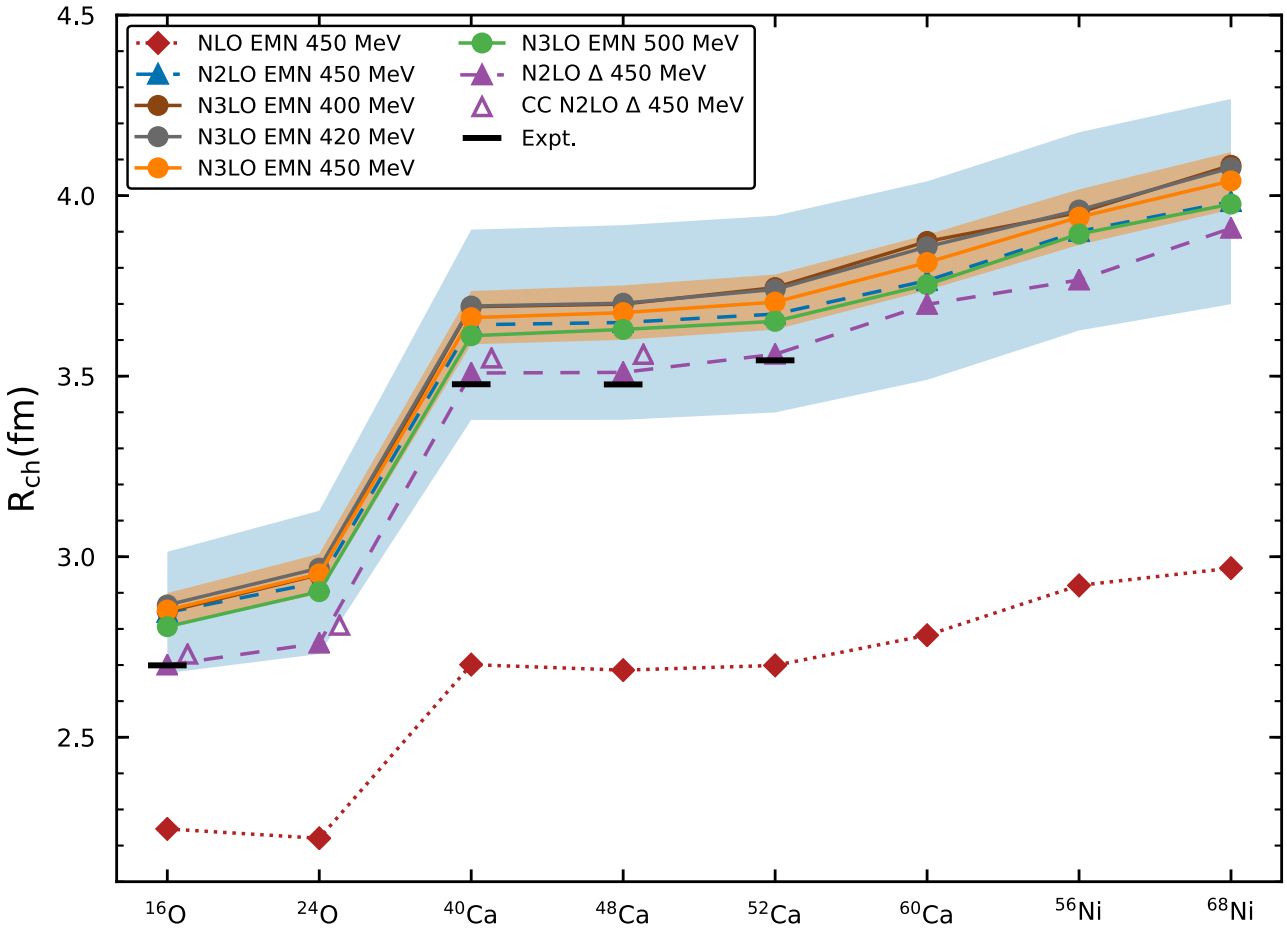
IMSRG calculations of closed shell nuclei follow nuclear matter saturation trends

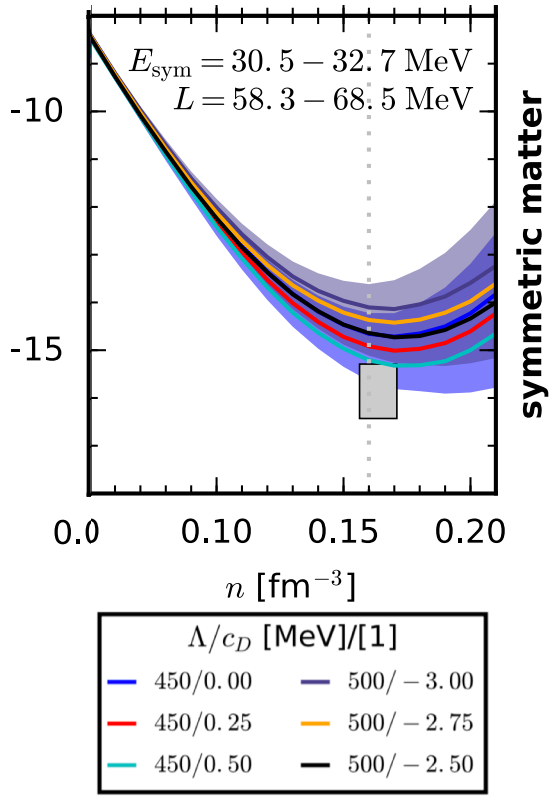




First N^{3}LO results for medium-mass nuclei Hoppe, Simonis et al.

NLO, N^{2}LO, N^{3}LO (EMN 450) with EFT uncertainty bands



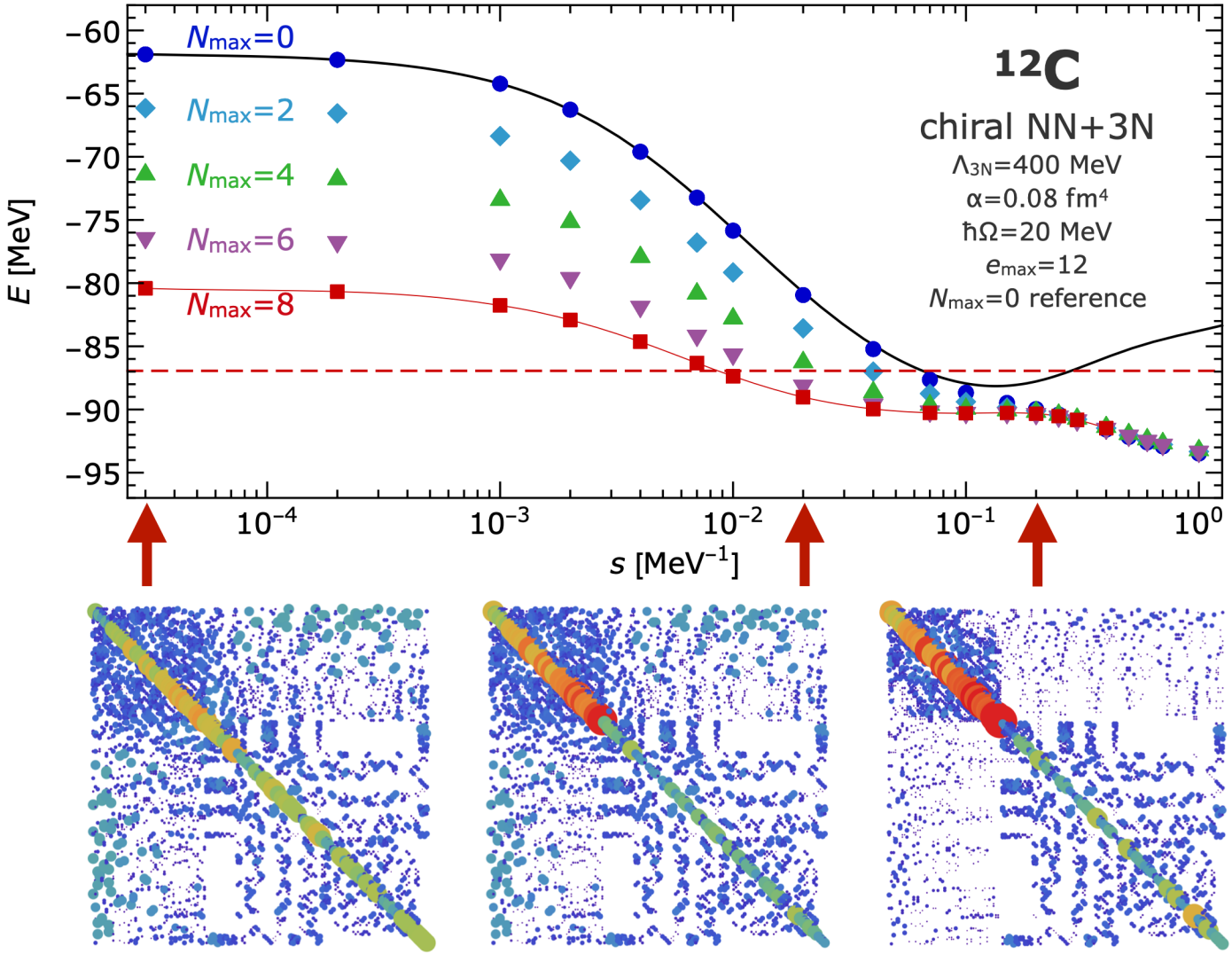


bands overlap and at N^{3}LO cutoff variation is within band

radii in better agreement, larger than expected from saturation point

In-Medium NCSM

Gebrerufael, Vobig, Hergert, Roth; PRL 118, 152503 (2017)



multi-reference IM-SRG evolution to decouple small-N_{max} reference space

+

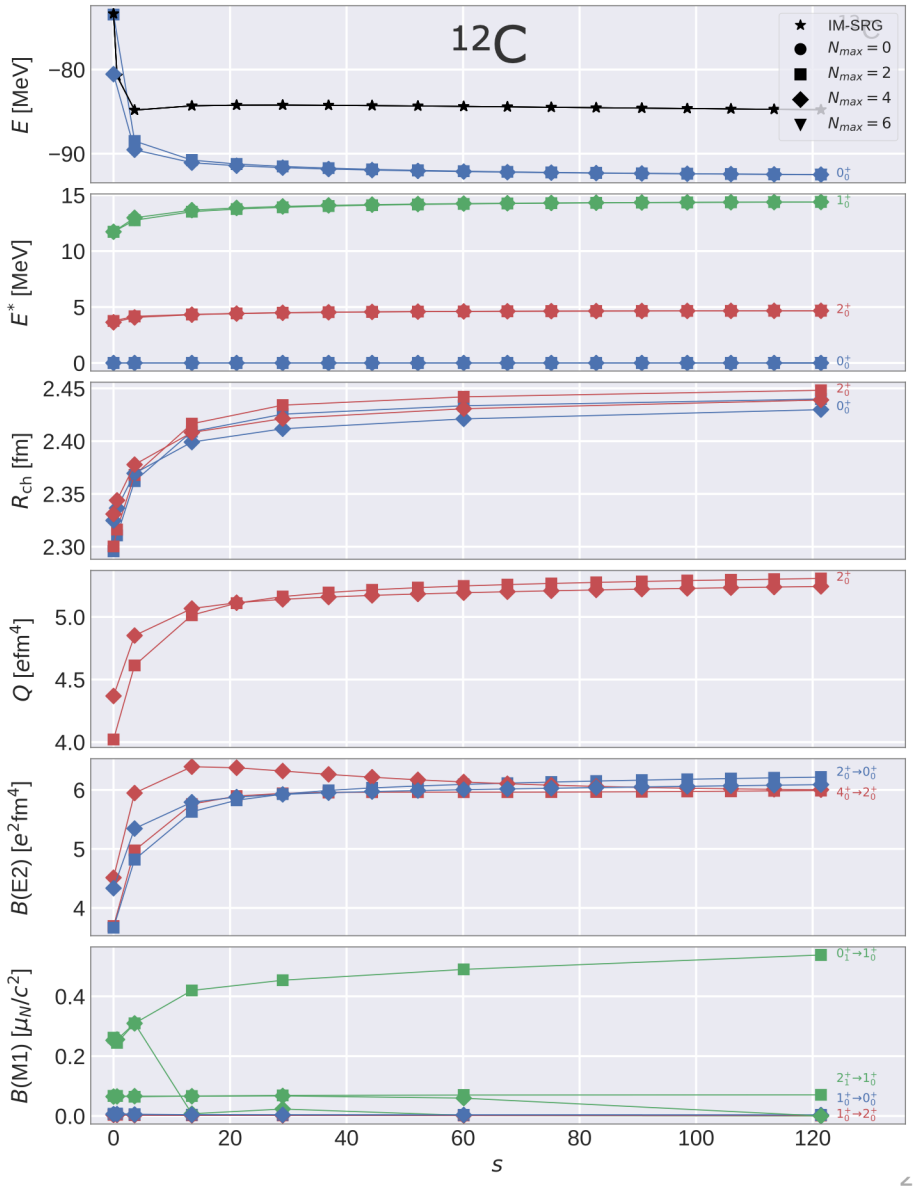
NCSM calculation with evolved Hamiltonian

=

converged energies in small-N_{max} spaces

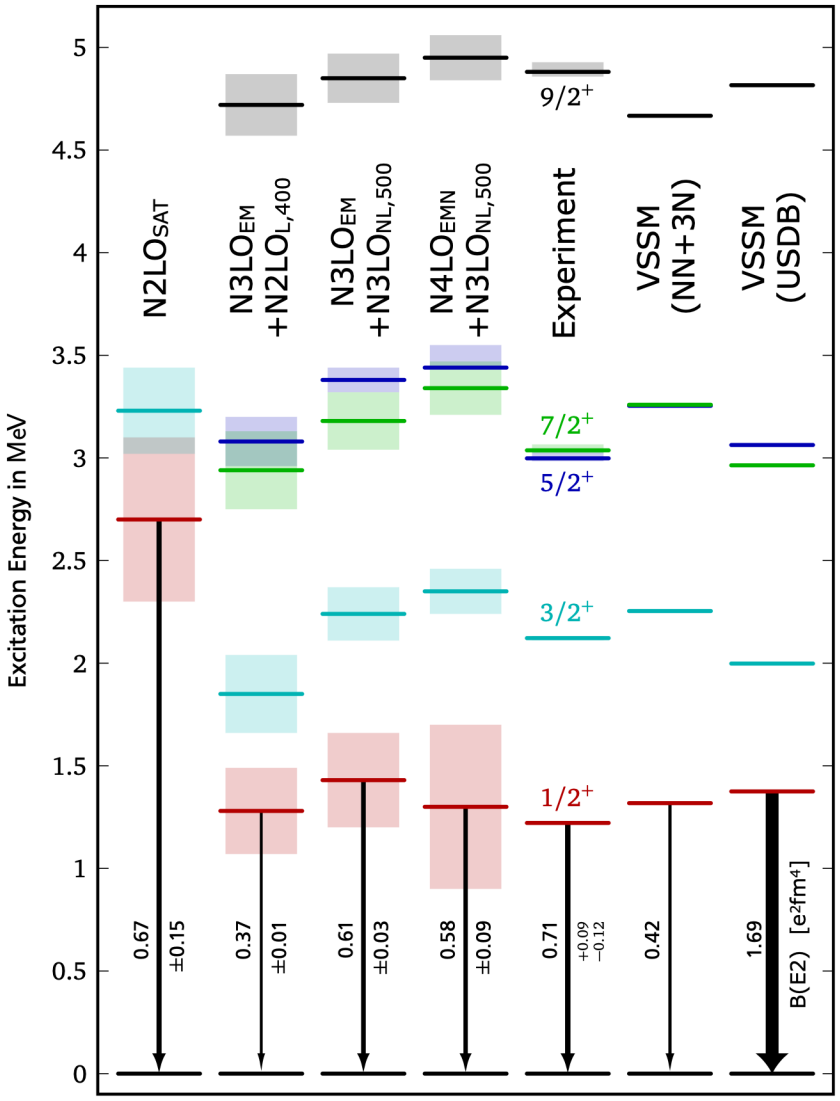
In-Medium NCSM: Developments

- initial formulation for even-A nuclei and energy observables
- implementation of alternative Magnus-formulation of flow equations
- reformulation of generator to suppress induced many-body terms
- extension to odd-A nuclei via a particle attachment or removal scheme
- extension to consistent transformation of non-scalar operators



^{21}O: Collaboration with A03

Heil, Petri, Vobig et al., in preparation



- application of IM-NCSM with particle attachment/removal and electromagnetic operators
- prediction of low-lying spectrum plus complete set of B(E2) and B(M1) transition strengths
- different improved chiral NN+3N interactions
- quantification of many-body uncertainties

PhD Theses: Sebastian Heil & Klaus Vobig

joint paper: in preparation

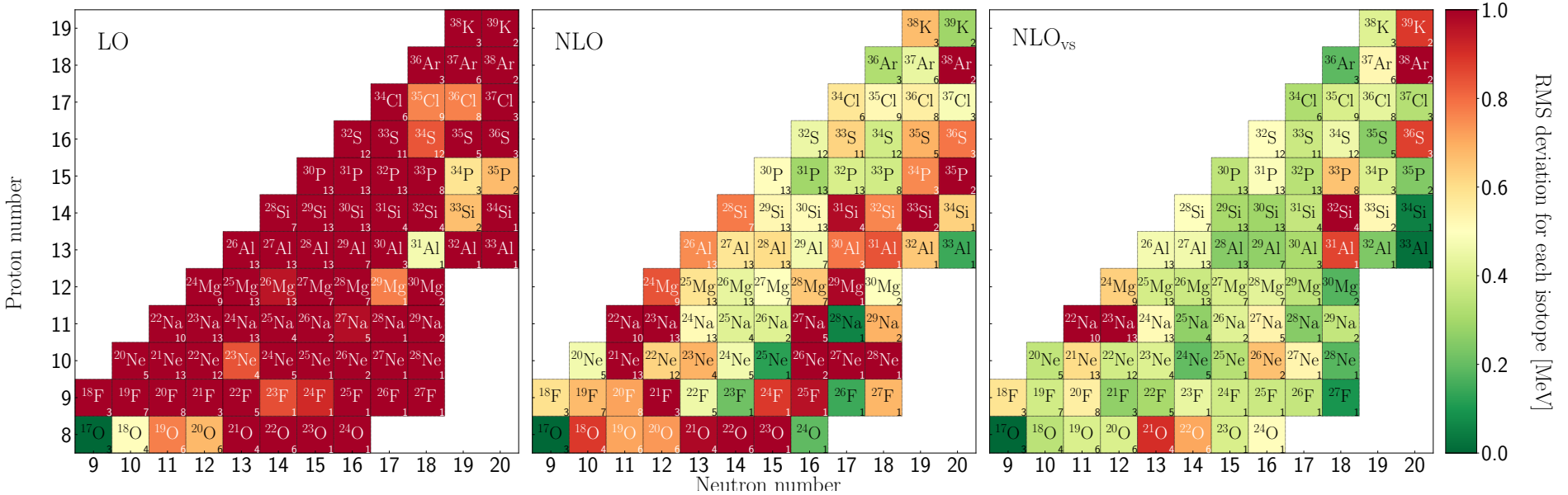
Chiral shell model interactions

use chiral EFT interactions as basis and fit in sd shell directly

Huth, Durant et al., PRC (2018)

includes new valence-space (vs) operators

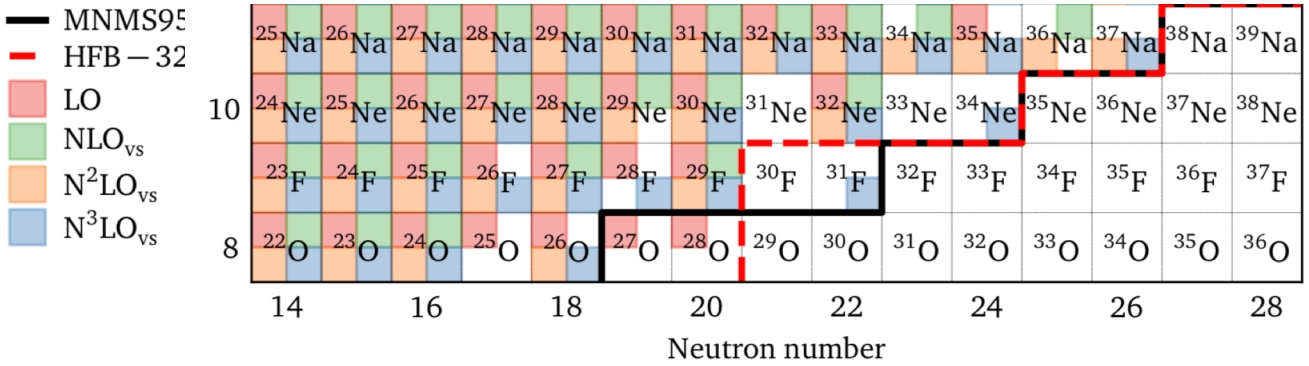
all LECs turn out natural



explore dripline

in sdf$_{7/2}$ space

Huth et al.



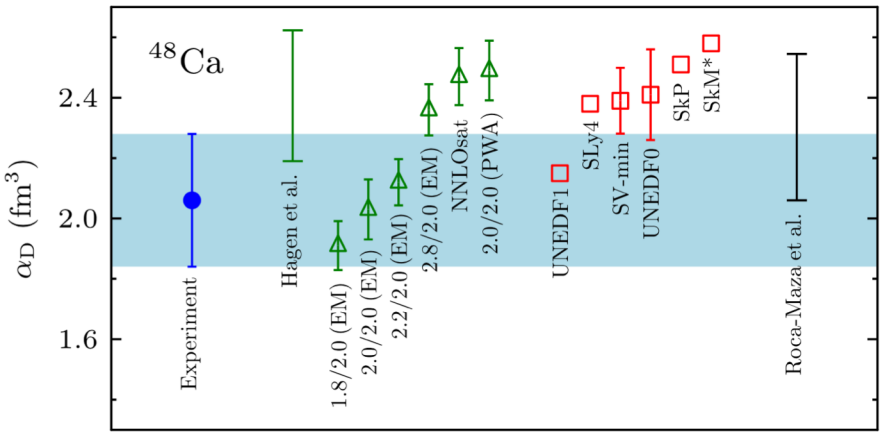
Electric Dipole Polarizability of ^{48}Ca and Implications for the Neutron Skin

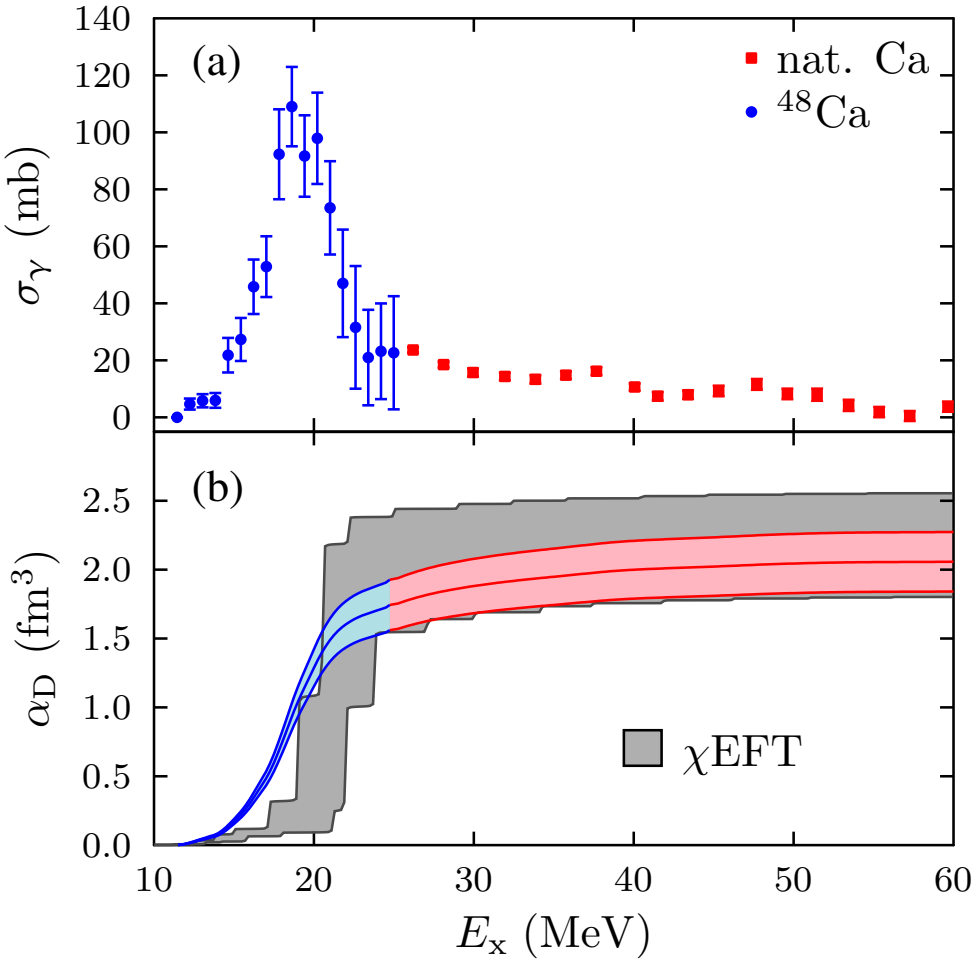
J. Birkhan,[1] M. Miorelli,[2,3] S. Bacca,[2,4] S. Bassauer,[1] C. A. Bertulani,[5] G. Hagen,[6,7] H. Matsubara,[8,9] P. von Neumann-Cosel,[1,*] T. Papenbrock,[6,7] N. Pietralla,[1] V. Yu. Ponomarev,[1] A. Richter,[1] A. Schwenk,[1,10,11] and A. Tamii[8]

from photo-absorption cross section, measured at Osaka up to 25 MeV

good agreement with chiral EFT predictions

theory comparison gives $R_{skin} = 0.14\text{-}0.20$ fm



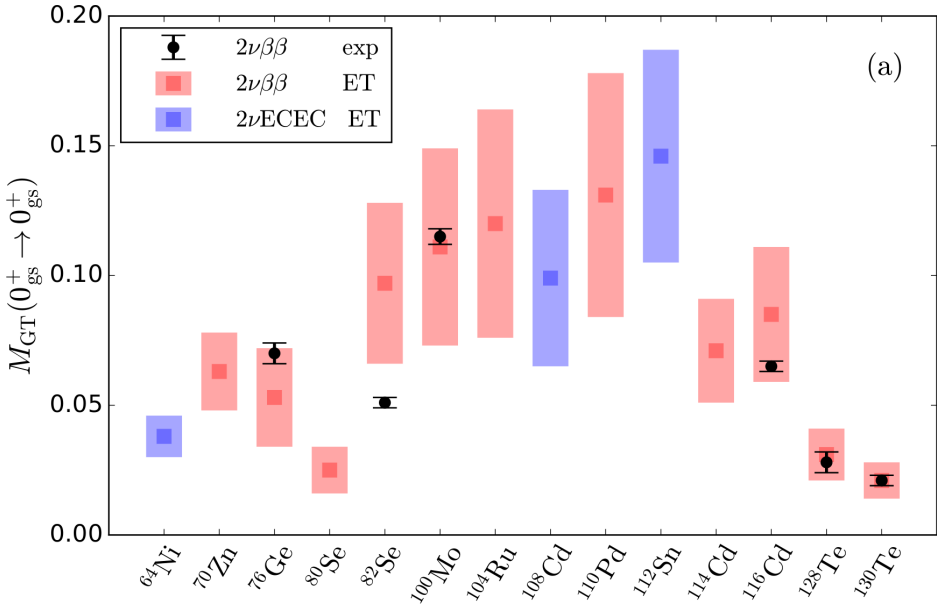


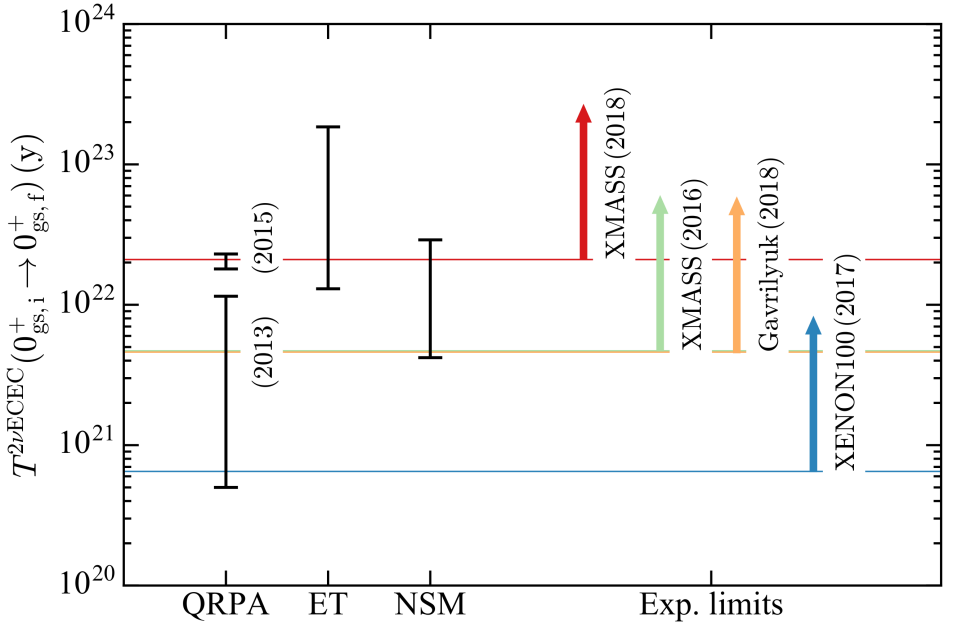
Effective theory for heavy nuclei Coello Perez et al., PRC 2018, arXiv:1809.04443

near spherical nuclei based on phonons + nucleons/holes

Gamow-Teller transitions for single and double-beta decay at LO in effective theory

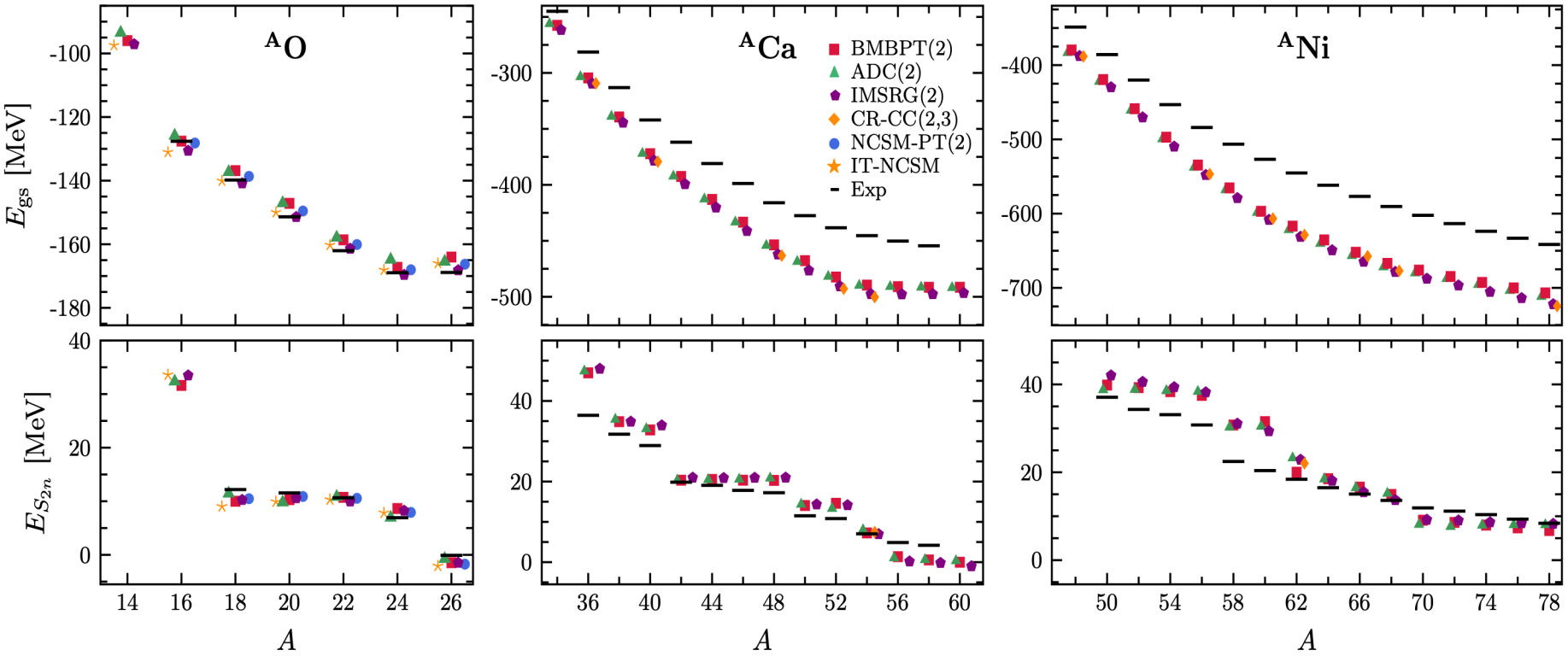
first prediction (ET and shell model) for double electron capture of ^{124}Xe





Bogoliubov MBPT

Tichai, Arthuis, Duguet, et al.; PLB 786, 195 (2018)



- perturbative methods for "rapid characterization" of new NN+3N interactions
- first implementation and benchmark of low-order Bogoliubov MBPT
- good agreement with other many-body method at a fraction of the cost

A04 Publications

19 publications in first period **(8 PRL)**,
1 Editors' suggestion, 2 press releases

- T.D. Morris et al., Structure of the lightest tin isotopes, Phys. Rev. Lett. 120, 152503 (2018).

- E. Gebrerufael et al., Ab initio description of open-shell nuclei: Merging no-core shell model and in-medium similarity renormalization group, Phys. Rev. Lett. 118, 152503 (2017).

- S.R. Stroberg et al., Nucleus-dependent valence-space approach to nuclear structure, Phys. Rev. Lett. 118, 032502 (2017).

- J. Simonis et al., Saturation with chiral interactions and consequences for finite nuclei, Phys. Rev. C 96, 014303 (2017).

A04 People

Postdocs: Toño Coello Perez (LLNL),
Victoria Durant (Mainz)

Doctoral Researchers:

- Victoria Durant, Eskendr Gebrerufael, Lukas Huth, Alexander Tichai; at present: Klaus Vobig, Jan Hoppe

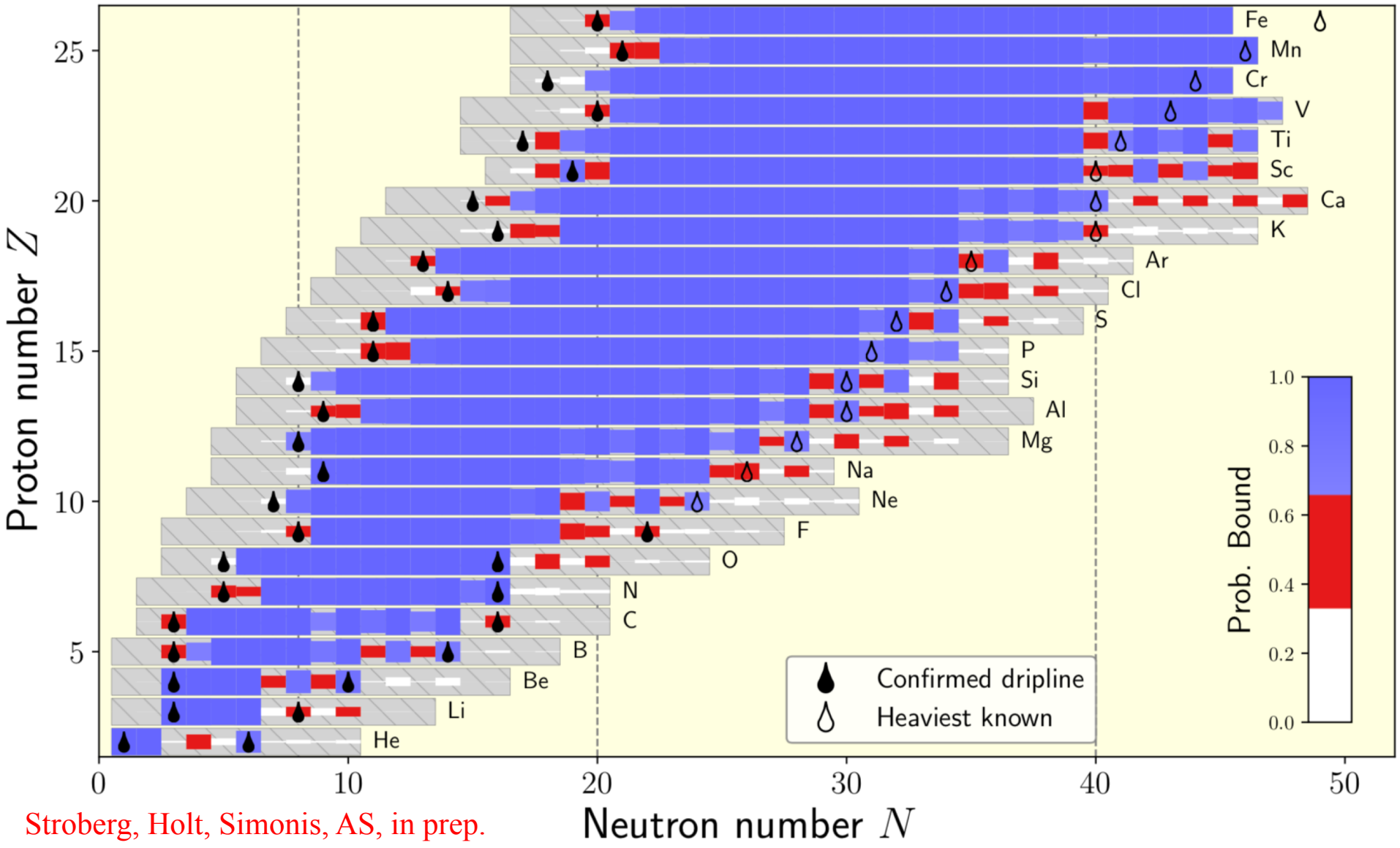
Master Theses:

- Simon Dentinger, Jan Hoppe, Lars Zurek

Bachelor Theses:

- Catharina Brase, Jan Hoppe, Sulamith Weber, Lars Zurek

Nuclear landscape based on a chiral NN+3N interaction



Stroberg, Holt, Simonis, AS, in prep.

ab initio is advancing to global theories, limitations due to input NN+3N

Future plans: IMSRG developments

- extend the IM-SRG to include normal-ordered higher-body contributions, new normal ordering for heavier nuclei
- systematic IM-SRG exploration of the connection between medium-mass nuclei and nuclear matter properties
- develop accurate interactions for medium-mass and heavy nuclei (with B05)
- exploration of density-matrix expansions based on chiral EFT interactions to develop new energy-density functionals
- support key SFB experiments for structure and electroweak observables (A03, A06, A08, B02, B04)

Future Plans: In-Medium NCSM

Developments

- development and implementation of lowest-order corrections for the induced normal-ordered three-body terms in the In-Medium NCSM
- exploration of alternative references spaces and decoupling patterns, e.g., full 2p2h reference spaces instead of N_{max}-truncated spaces
- combination of the In-Medium NCSM with the Lanczos strength-function method for the description of collective excitations

Applications

- complete study of spectroscopy and electromagnetic properties of oxygen isotopic chain using consistent chiral NN+3N interactions from A02
- extension to the spectroscopy of neutron-rich fluorine and neon isotopes
- study of radii, moments, and B(E2) transitions of even and odd isotopes up into the mass A~60 regime (calcium, iron, nickel) for project A03
- exploratory study of collective excitation in the sd-shell

A04 Summary

19 publications in first period **(8 PRL)**
1 Editors' suggestion, 2 press releases

Joint publications with **A02, A03, A06, B01, B04, B05**

Excellent people!

IMSRG future is bright!