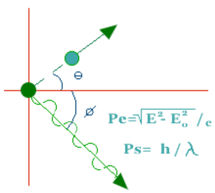
CREX and PREX: Insights from a combined theoretical/experimental approach

Heaven and Earth INT workshop 7/12/2022

Washington University in St. Louis



DOM activities: Wim Dickhoff
Bob Charity
Lee Sobotka
Louk Lapikas (e,e'p)
Henk Blok (e,e'p)
Kazuyuki Ogata (p,2p)
Kazuki Yoshida (p,2p)
Hossein Mahzoon (Ph.D.2015)
Mack Atkinson (Ph.D. 2019)
Natalya Calleya (Grad)
Cole Pruitt (Ph.D. 2019)
Bob Wiringa
Maria Piarulli
Arnau Rios

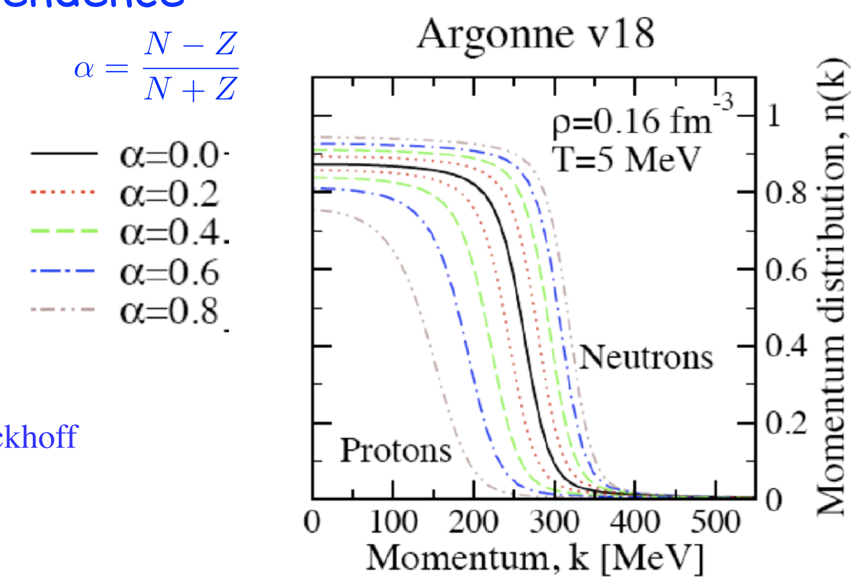
- Motivation —> meaningful link between nuclei and neutron stars
- Green's functions/propagator method
  - vehicle for ab initio calculations —> matter & finite nuclei
    —> Illustrate importance of NN tensor force —> asymmetric matter
  - as a framework to link data at positive and negative energy (and to generate predictions for exotic nuclei as well as neutron skins)
    —> Dispersive optical model (DOM <- started by Claude Mahaux)
- Neutron skin in ^{48}Ca and ^{208}Pb —> PREX II, CREX
- Ground-state energy and EOS —> saturation properties
- Conclusion and outlook

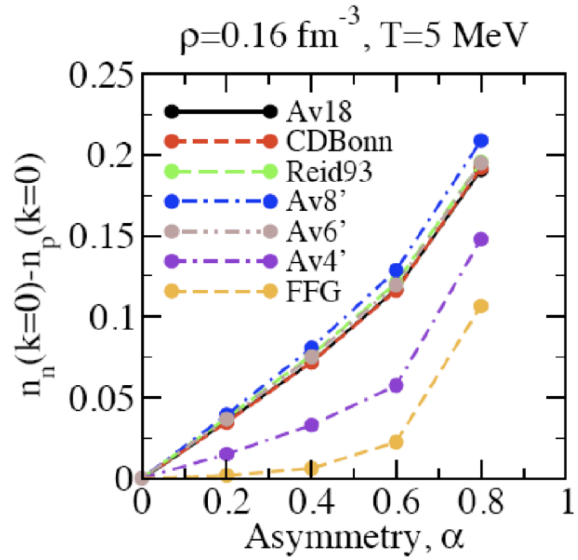
Example momentum distribution SCGF asymmetric matter

- Asymmetry dependence

$$\alpha = \frac{N - Z}{N + Z}$$

SCGF:
self-consistent
Green's functions
for SRC and tensor effects



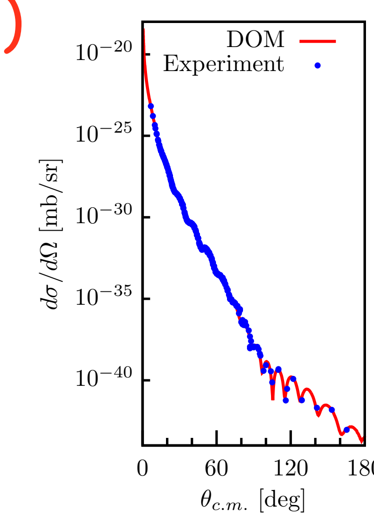


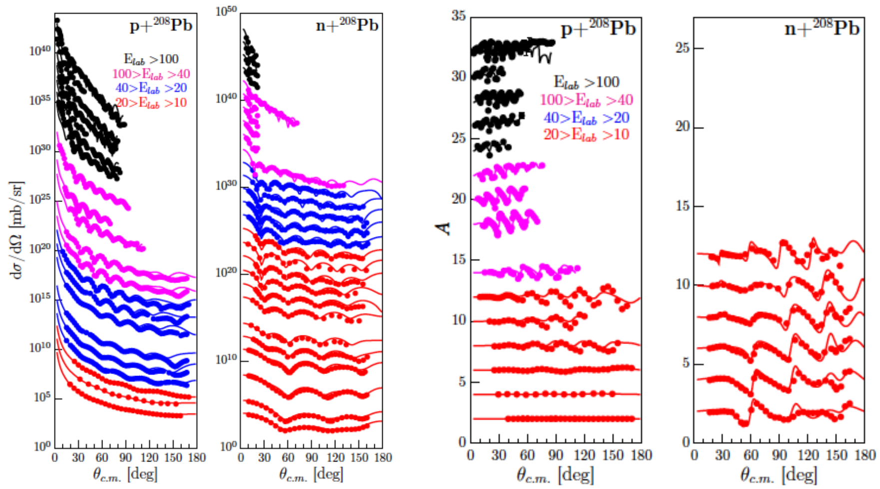
A. Rios, A. Polls, and W. H. Dickhoff
Phys. Rev. C89, 044303 (2014)
Phys. Rev. C79, 064308 (2009)

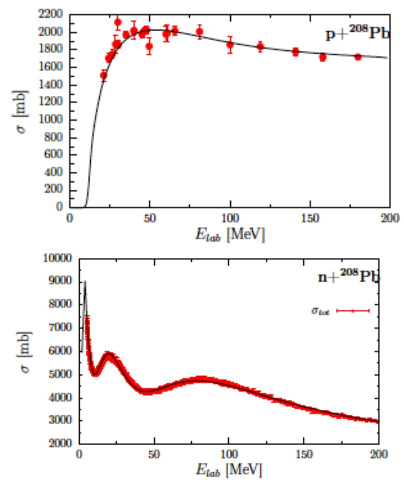
- Incorporates/represents np dominance <—> influence of tensor force
- So more correlations for minority species
- S-wave pairing at low density well constrained; P-wave pairing less so at high density PNM
- EOS available as a function of T and asymmetry (and several V_{NN} + V_{NNN})

Dispersive Optical Model (St. Louis group)

- Mahaux & Sartor 1991 —> Washington University group since 2006
- Use experimental data to constrain the nucleon self-energy while linking structure and reaction domain using dispersion relations







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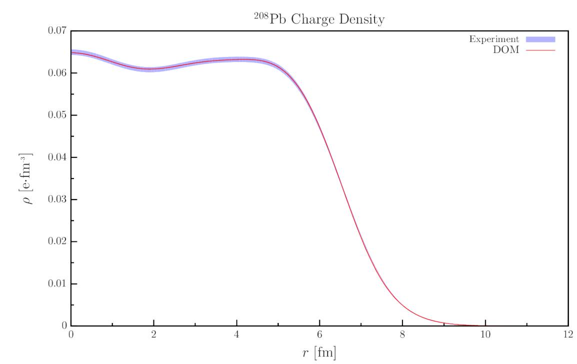


Indirectly:

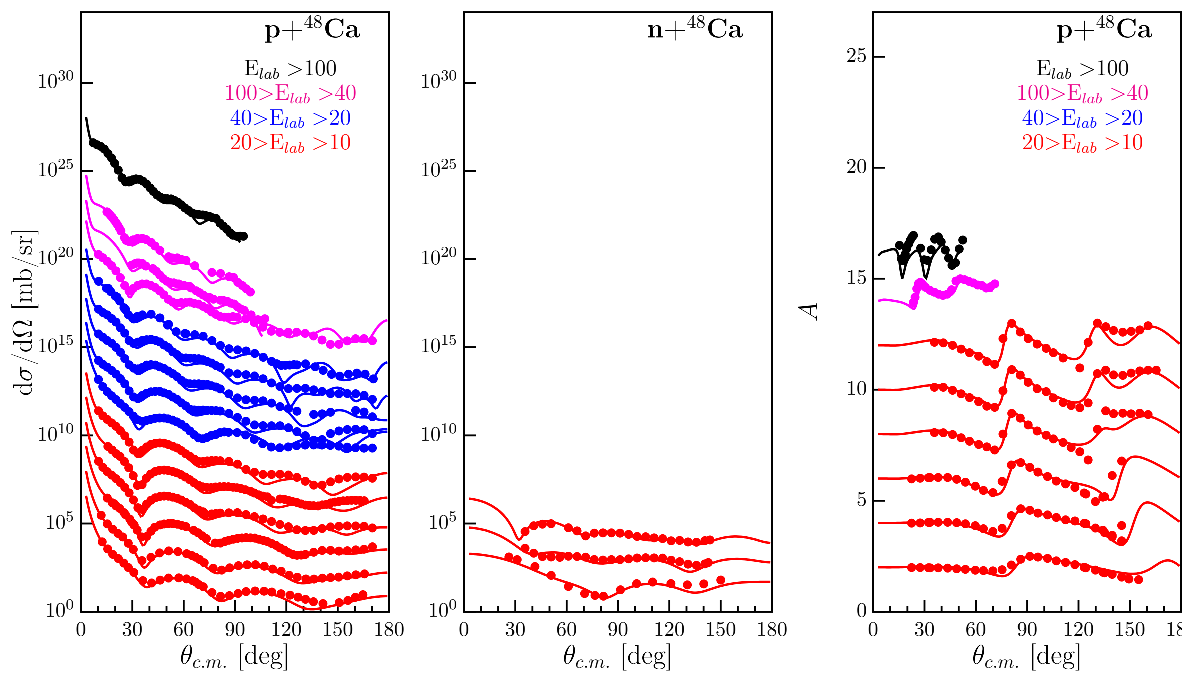
- Predict neutron distribution —> skin

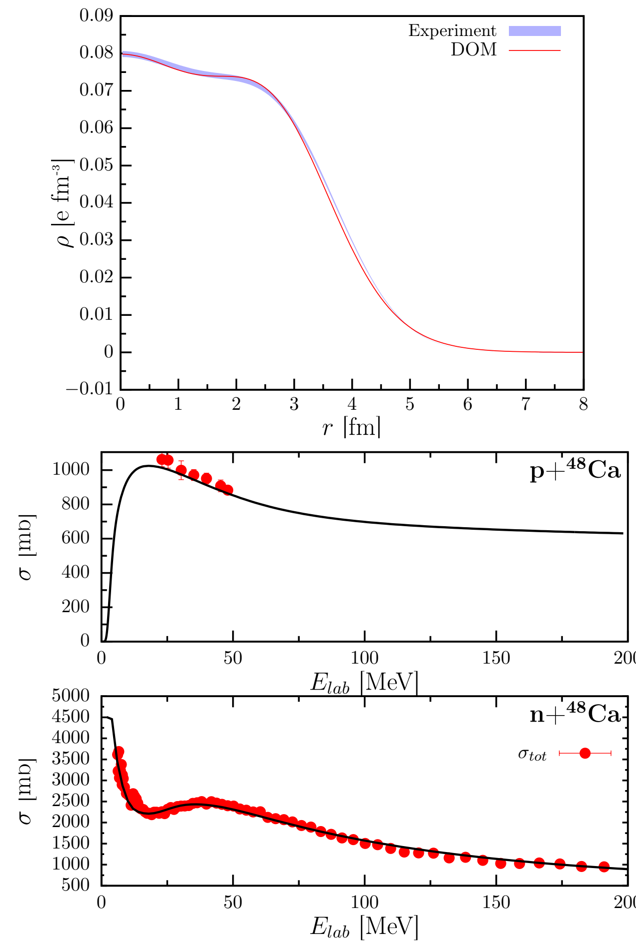
M. C. Atkinson, M. H. Mahzoon, M. A. Keim, B. A. Bordelon, C. D. Pruitt, R. J. Charity, and W. H. Dickhoff
Phys. Rev. C 101, 044303 (2020), 1-15. [arXiv:1911.09020]

DOM

^{48}Ca

- Allows prediction of neutron properties

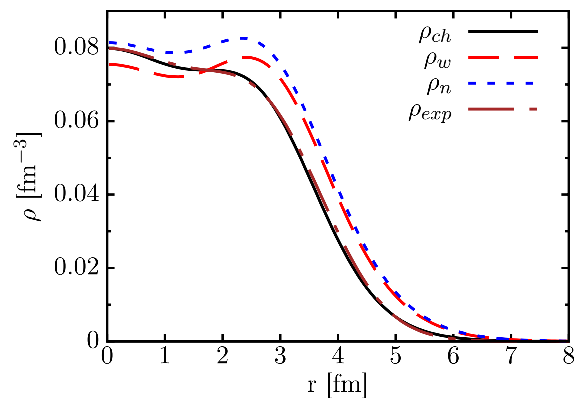




M. C. Atkinson and W. H. Dickhoff
Phys. Lett. B 798, 135027 (2019), 1-6.

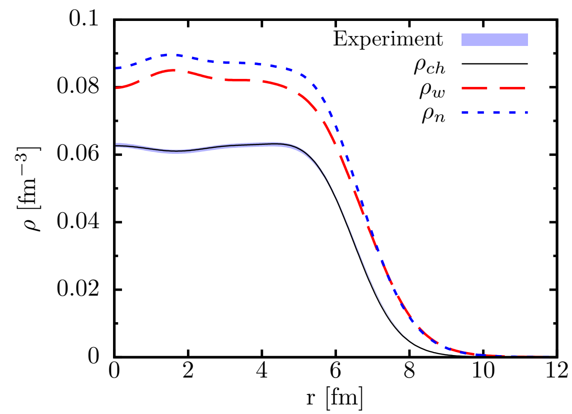
Neutron skins in ^{48}Ca and ^{208}Pb from DOM predictions

- DOM 2017



M. H. Mahzoon, M. C. Atkinson, R. J. Charity, and W. H. Dickhoff
Phys. Rev. Lett. **119,** 222503 (2017), 1-5.

- DOM 2020



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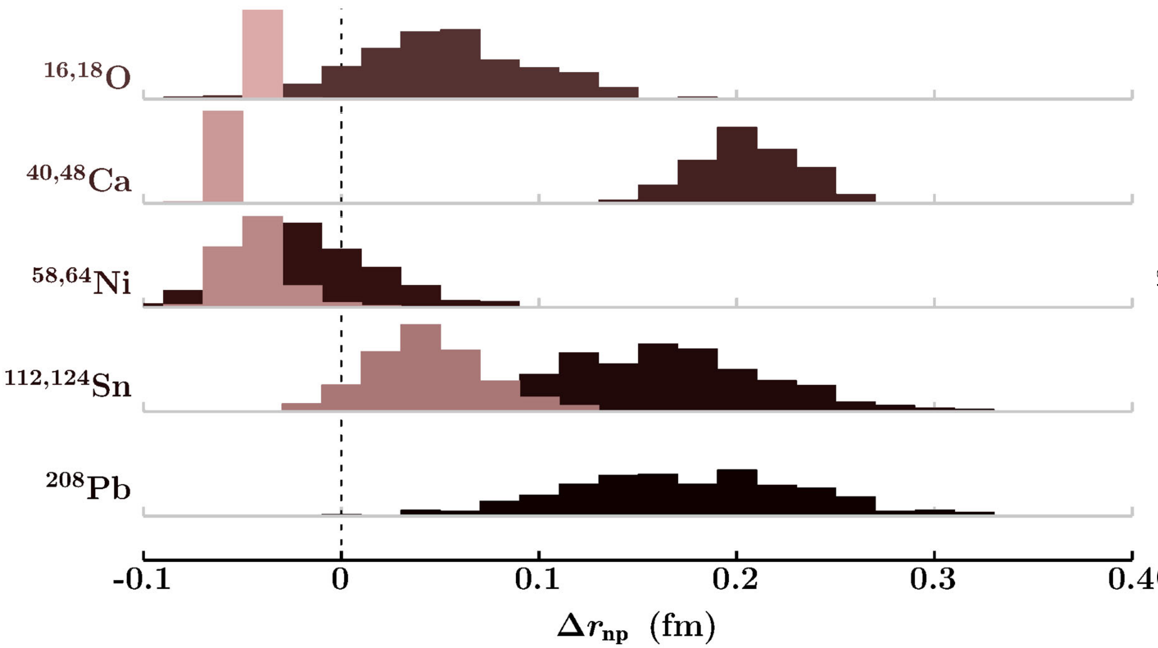
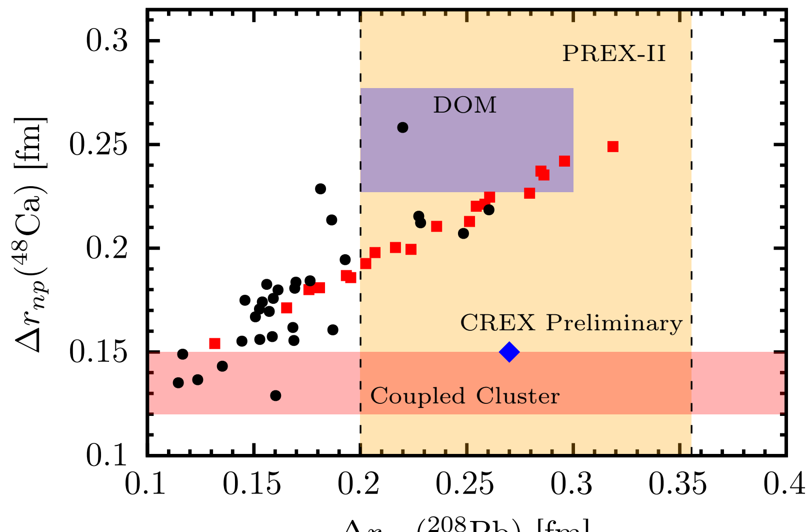
DOM

MCMC and standard DOM prediction of neutron skins

- Markov Chain Monte Carlo



Standard



l., PRC **101**, 044303 (2020)

TABLE I. Neutron skins (Δr_{np}), in fm, from this work. The 16th, 50th, and 84th percentile values of the skin distribution are reported as 50^{84}_{16}.

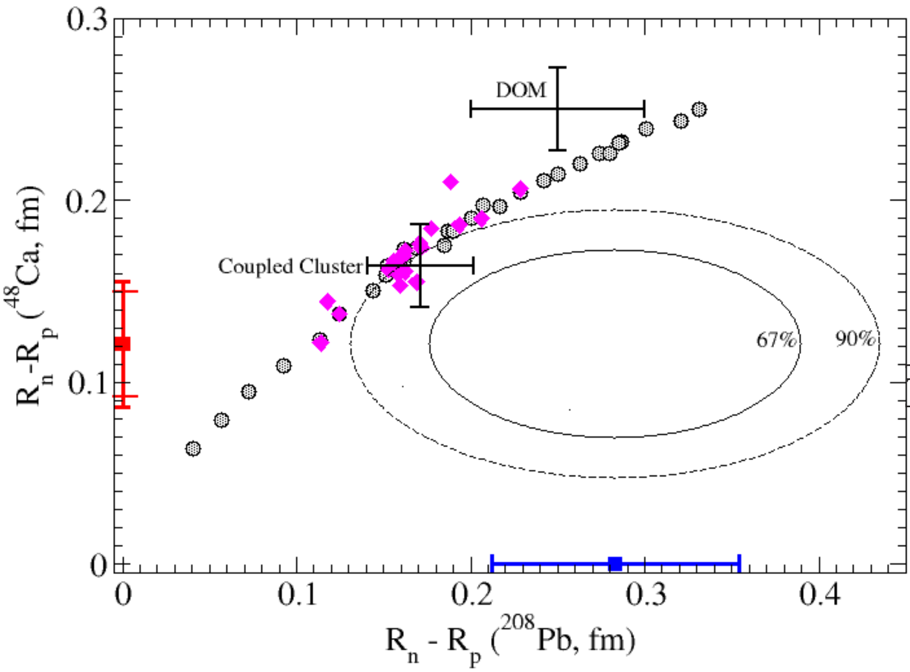
^{16}O	^{18}O	^{40}Ca	^{48}Ca	^{58}Ni	^{64}Ni	^{112}Sn	^{124}Sn	^{208}Pb
$-0.025^{-0.023}_{-0.027}$	$0.06^{0.11}_{0.02}$	$-0.051^{-0.048}_{-0.055}$	$0.22^{0.24}_{0.19}$	$-0.03^{-0.02}_{-0.05}$	$-0.01^{0.03}_{-0.04}$	$0.05^{0.08}_{0.02}$	$0.17^{0.23}_{0.12}$	$0.18^{0.25}_{0.12}$

C. D. Pruitt, R. J. Charity, L. G. Sobotka, M. C. Atkinson, and W. H. Dickhoff
Phys. Rev. Lett. 125, 102501 (2020), 1-6.

DOM

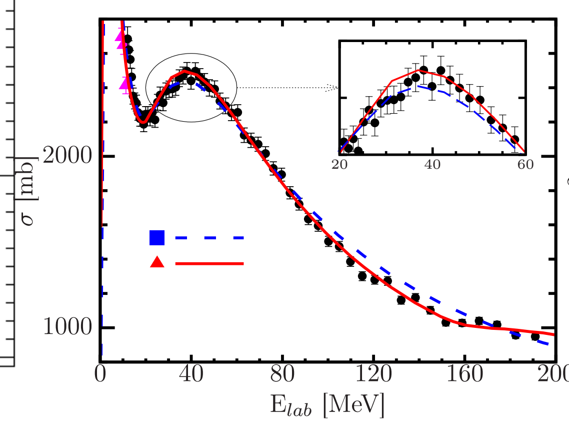
CREX surprise

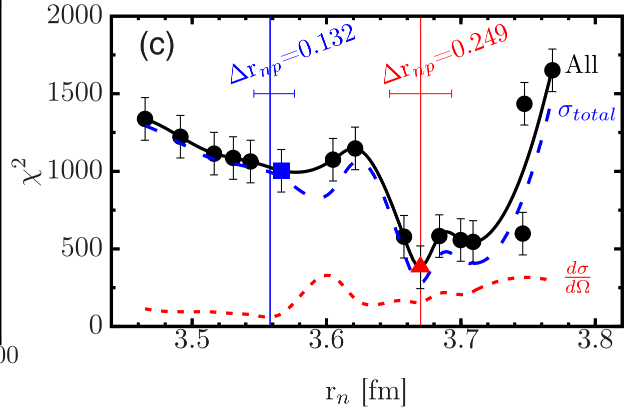
Precision Determination of the Neutral Weak Form Factor of ^{48}Ca
(The CREX Collaboration)



Mean field description cannot accommodate both

How about DOM?





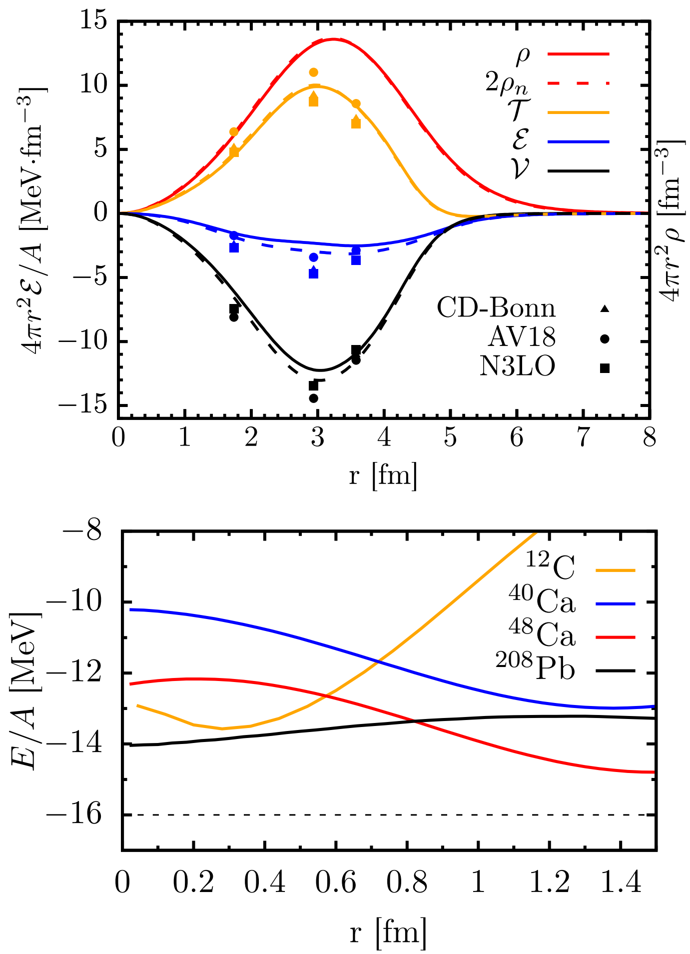
Phys. Rev. Lett. **119**, 222503 (2017)

- But…

DOM

Binding at saturation of symmetric matter

- Maybe 16 MeV binding is not needed!

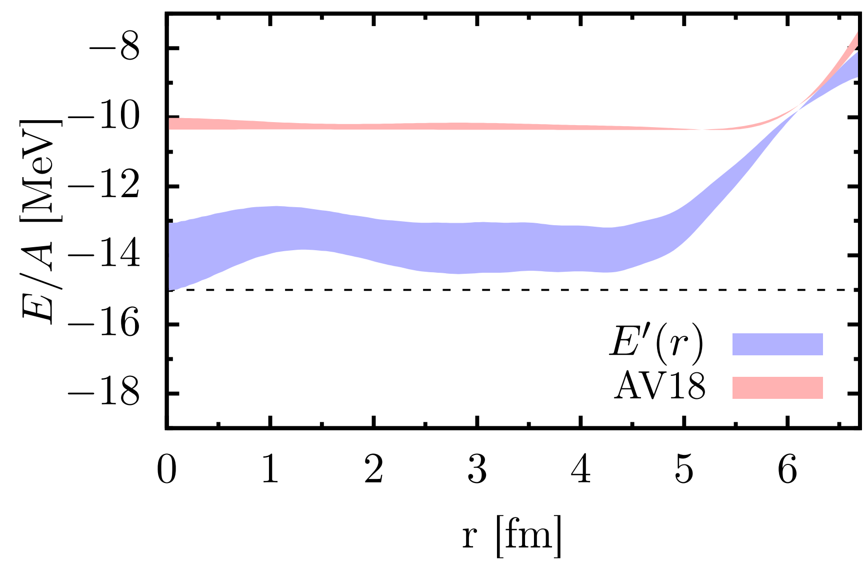


PHYSICAL REVIEW C **102**, 044333 (2020)

Editors' Suggestion

Reexamining the relation between the binding energy of finite nuclei and the equation of state of infinite nuclear matter

M. C. Atkinson[1,2,*] W. H. Dickhoff[1] M. Piarulli,[1] A. Rios[3] and R. B. Wiringa[4]



Neutron skins and EOS

Conclusions

- Ab initio Green's function method at finite T —> asymmetric matter <—> tensor force
- Asymmetric matter: Minority species more correlated quantitatively determined by tensor force
- Pairing gaps relevant for cooling scenarios

- Empirical Green's function method —> DOM
- DOM describes lots of data and can predict hard to access experimental data —> neutron skin
- DOM suggests that some reexamining of nuclear saturation properties might be in order: 16 MeV at saturation may be too large

- DOM should be extended to describe response functions simultaneously