Induced Hyperon-Nucleon-Nucleon Interactions and the Hyperon Puzzle

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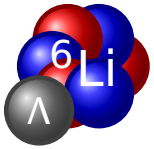
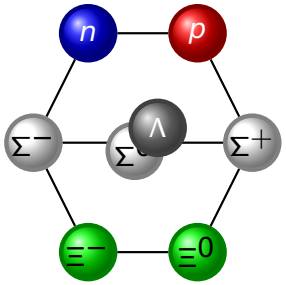
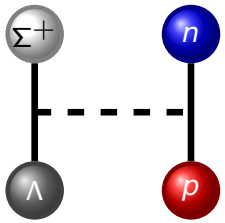
Motivation

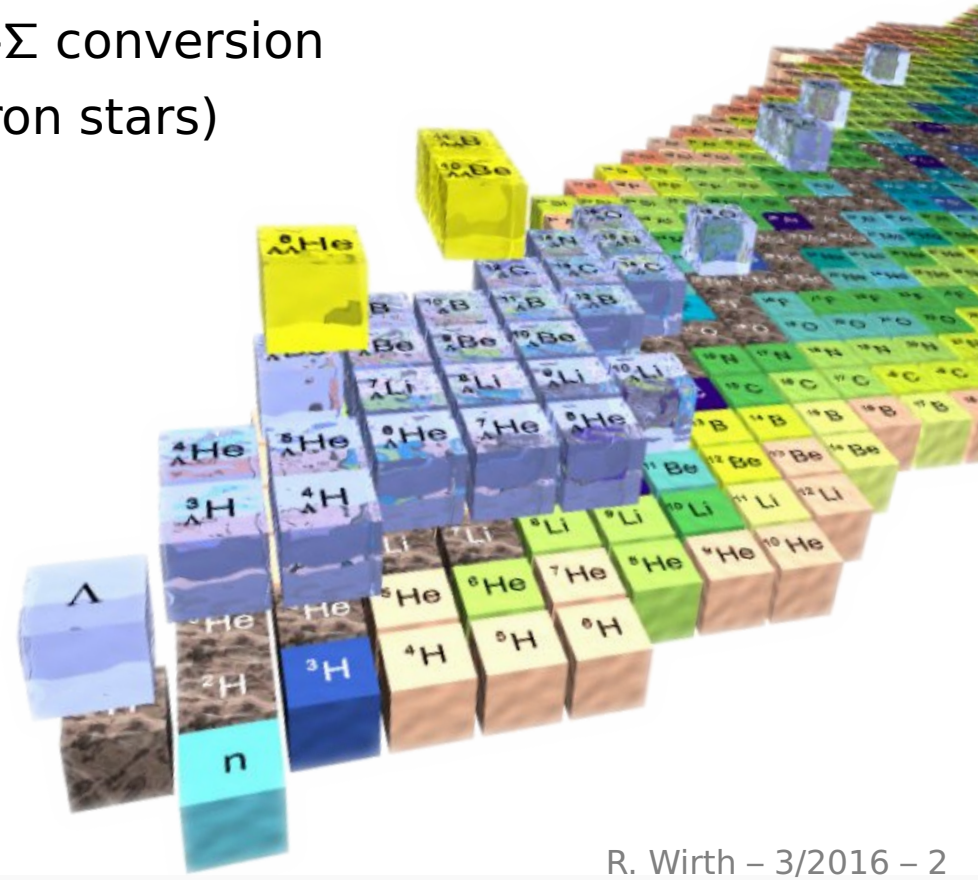






Why hypernuclei?

- Uncertainties in nuclear Hamiltonian under control
- Add new dimension to the nuclear chart
- New effects, e.g. Λ-Σ conversion
- Astrophysics (neutron stars)



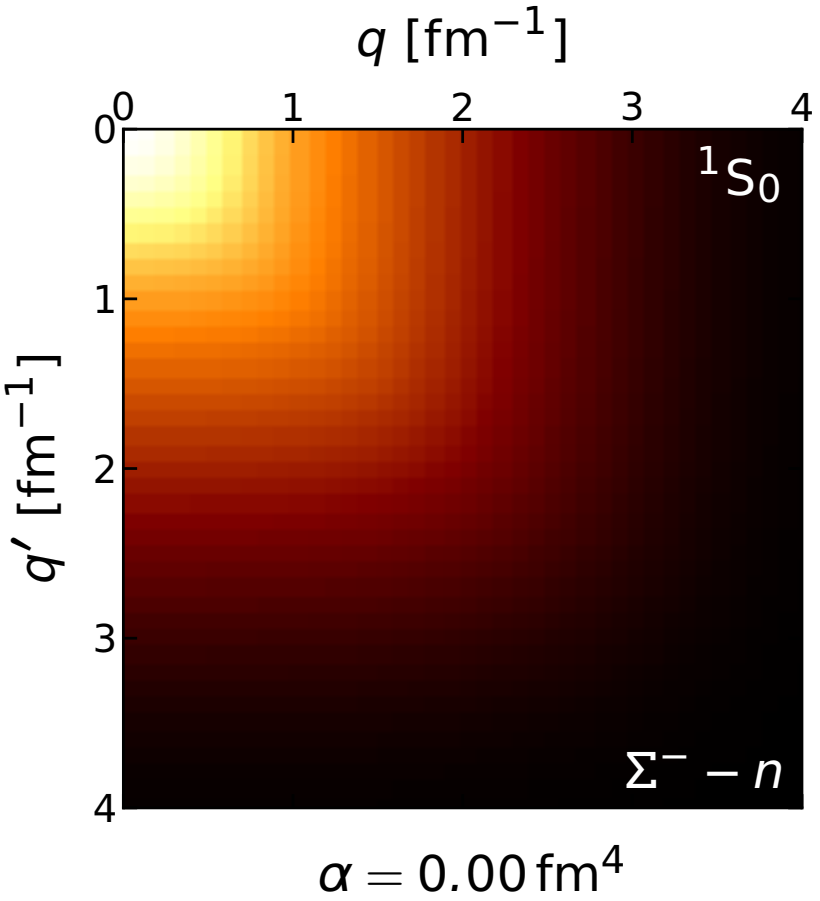
Hypernuclear Hamiltonian

$$\boldsymbol{H} = \Delta\boldsymbol{M} + \boldsymbol{T}_{\text{int}} + \boldsymbol{V}_{\text{NN}} + \boldsymbol{V}_{\text{3N}} + \boldsymbol{V}_{\text{YN}}$$

- NN: chiral N^{3}LO
  Entem & Machleidt
  Phys. Rev. C **68**, 041001(R) (2003)
  $\Lambda_{\text{NN}} = 500\,\text{MeV}$
- 3N: chiral N^{2}LO
  Navrátil
  Few-Body Syst. **41**, 117 (2007)
  $\Lambda_{\text{3N}} = 500\,\text{MeV}$
- YN: chiral LO
  Polinder, Haidenbauer & Meißner
  Nucl. Phys. A **779**, 244 (2006)
  $\Lambda_{\text{YN}} = 600\,\text{MeV}, 700\,\text{MeV}$

NN+3N yields quantitative description of *p*-shell nuclei

Similarity Renormalization Group



$$\partial_\alpha \boldsymbol{H}(\alpha) = [\boldsymbol{\eta}(\alpha), \boldsymbol{H}(\alpha)]$$

$$\boldsymbol{\eta}(\alpha) = m_N^2 [\boldsymbol{T}_{\mathrm{int}}, \boldsymbol{H}(\alpha)]$$

- Up to 6 coupled channels
- Decouples high and low momenta
  $\Rightarrow$ Improved N_{max} convergence
- BUT: Induced many-body terms
  $\Rightarrow$ Assess via α-dependence
- Induced YNN terms sizable

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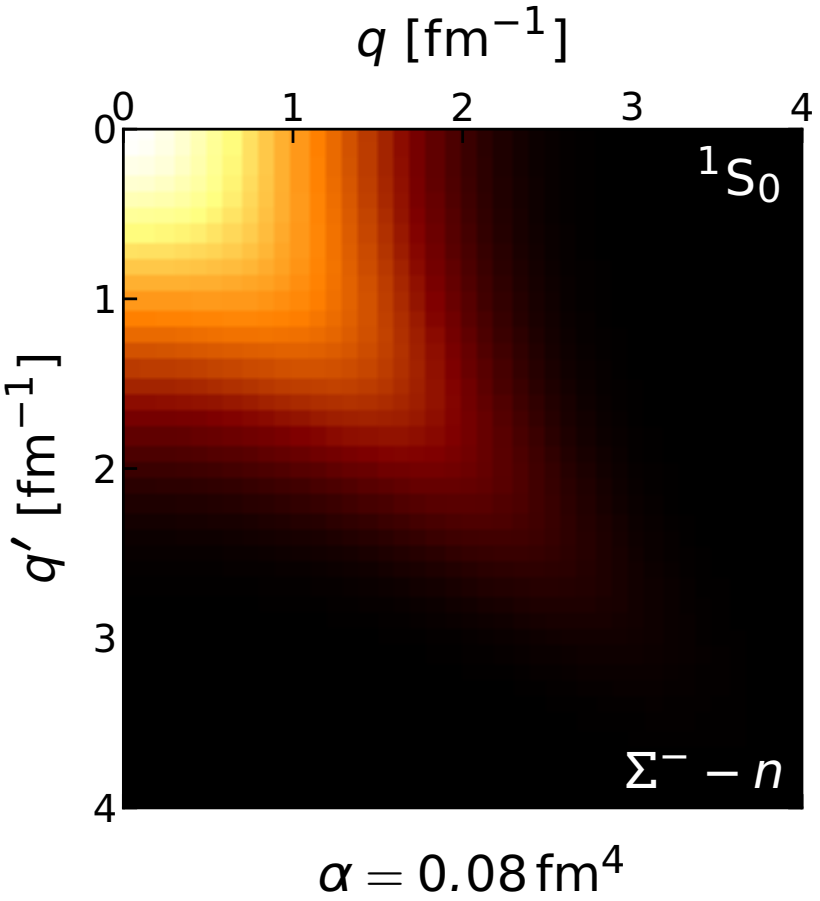

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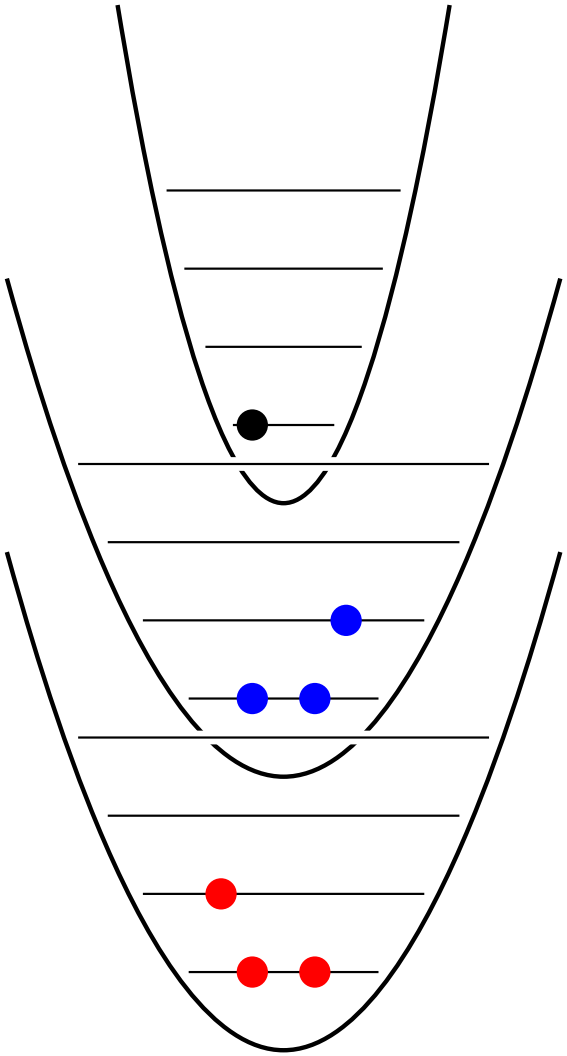
Importance-Truncated No-Core Shell Model



- A-body Slater determinants from HO states

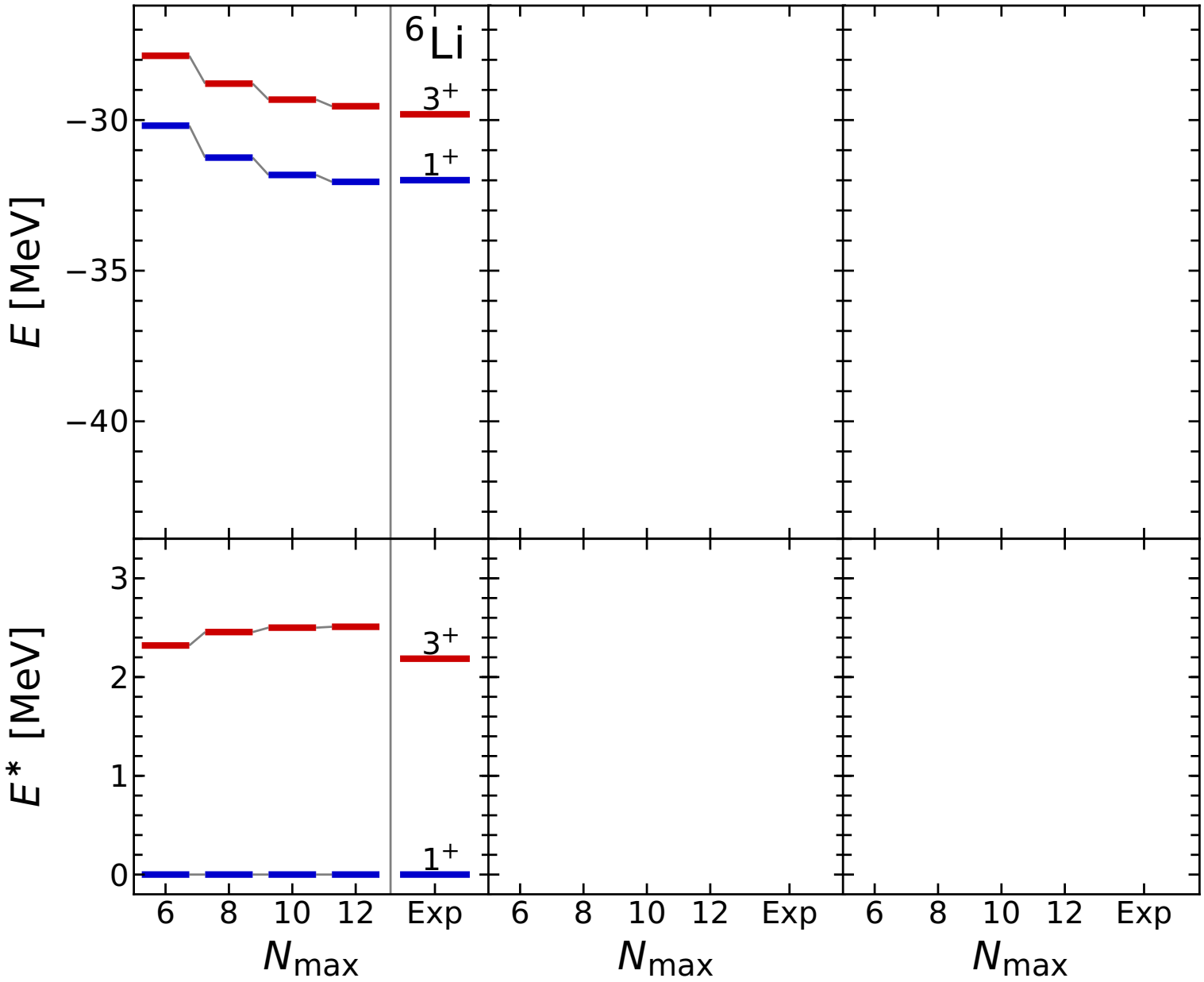
$$|s_1 s_2 \cdots s_A\rangle\,, \quad s_i \equiv |e(l\tfrac{1}{2})j\chi\rangle_i$$

- Λ-Σ conversion, e.g.

$$|pn\Lambda\rangle\,, |pp\Sigma^-\rangle\,, |nn\Sigma^+\rangle \in \mathcal{M}(^{3}_{\Lambda}\mathrm{H})$$

- Impose $N_{\max}$ truncation
- Importance truncation:
  discard irrelevant states + *a posteriori* extrapolation
- Diagonalize Hamilton matrix
  $\Rightarrow$ Energies & wave functions

$^{7}_{\Lambda}$Li — Energies and Spectra



Bare YN

Evolved YN

$\alpha = 0.08\,\mathrm{fm}^4$

$\hbar\Omega = 20\,\mathrm{MeV}$

$\Lambda_{\mathrm{YN}} = 700\,\mathrm{MeV}$

Nucleonic parent reproduced

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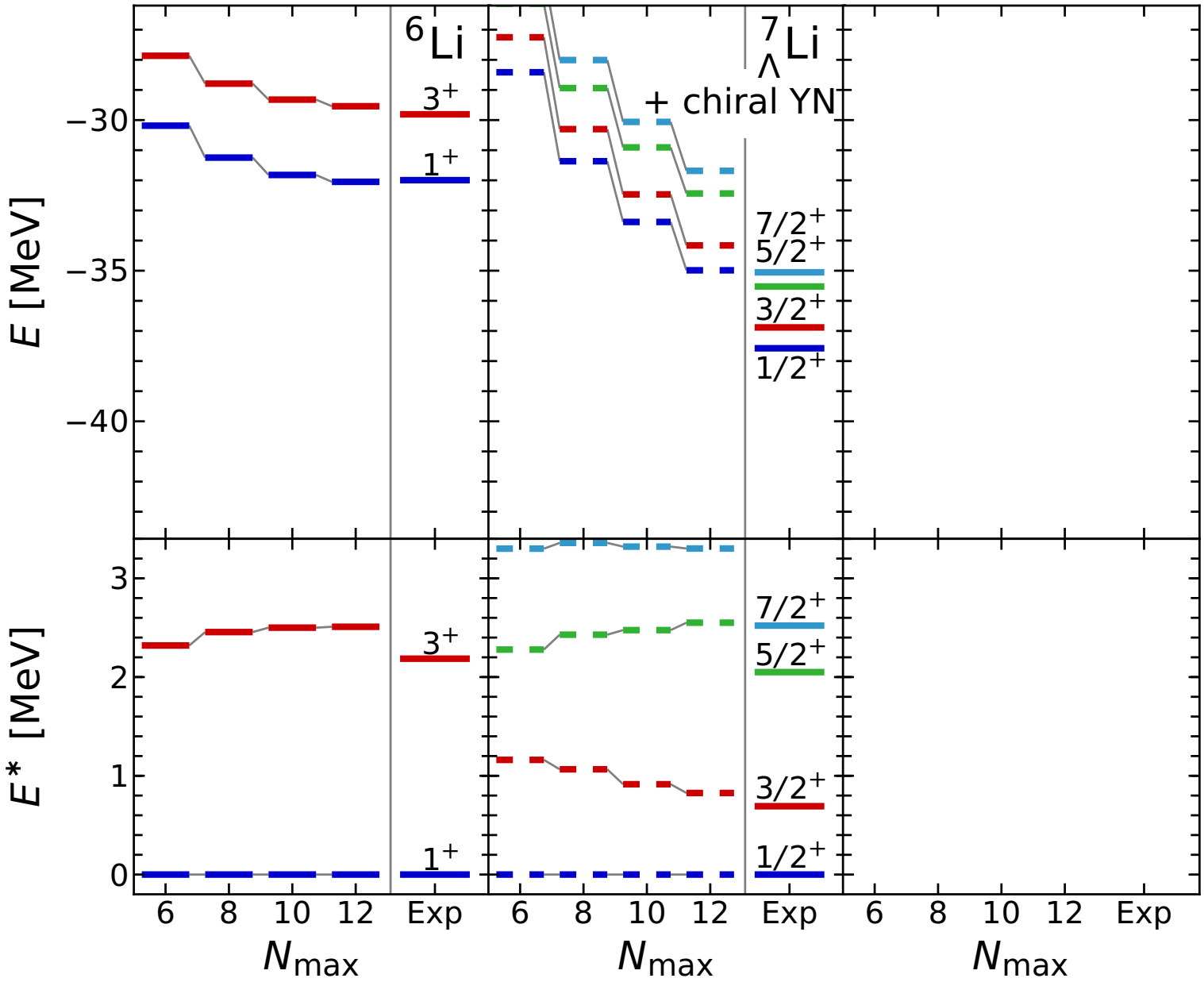

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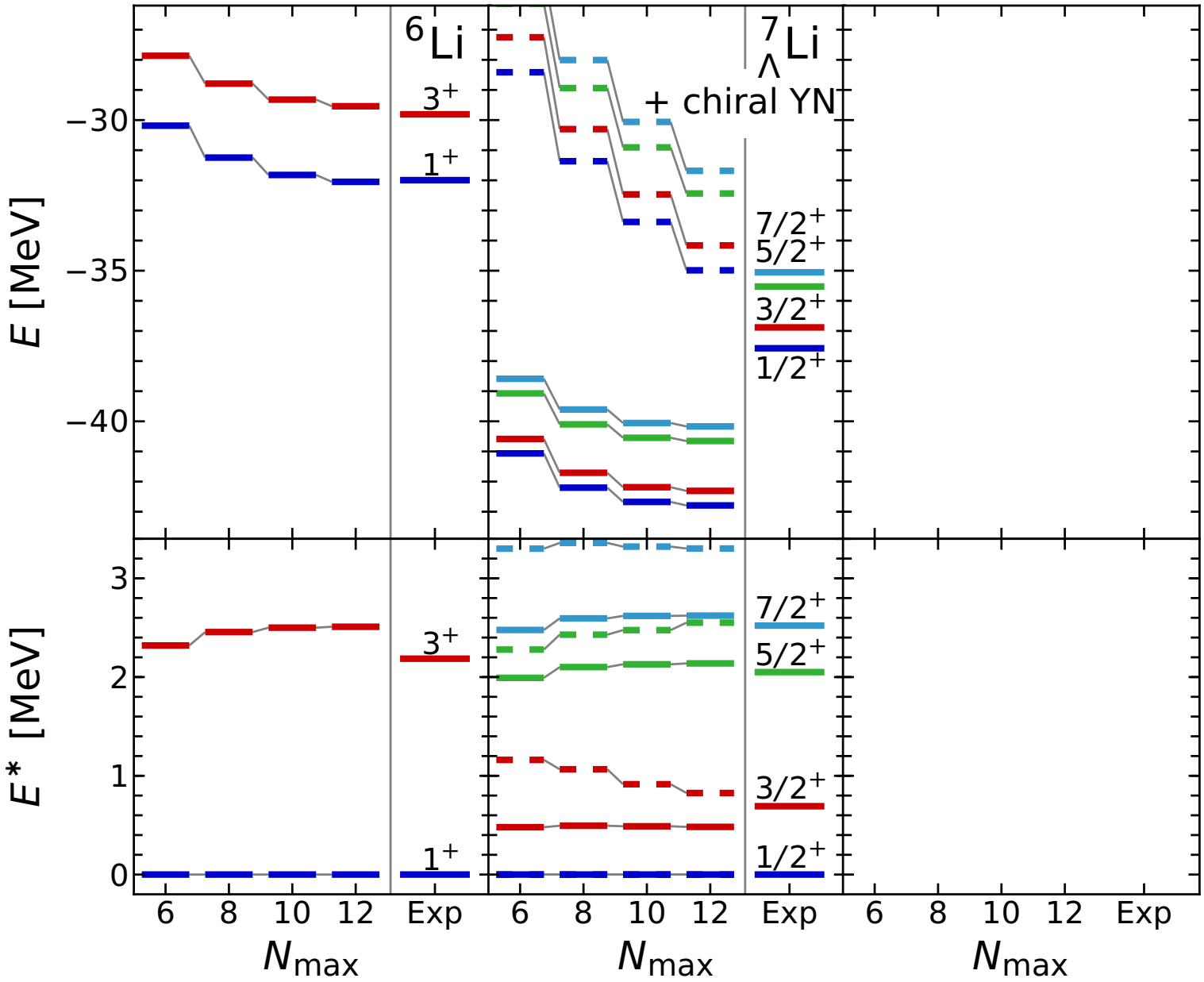

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Evolved YN overbinds

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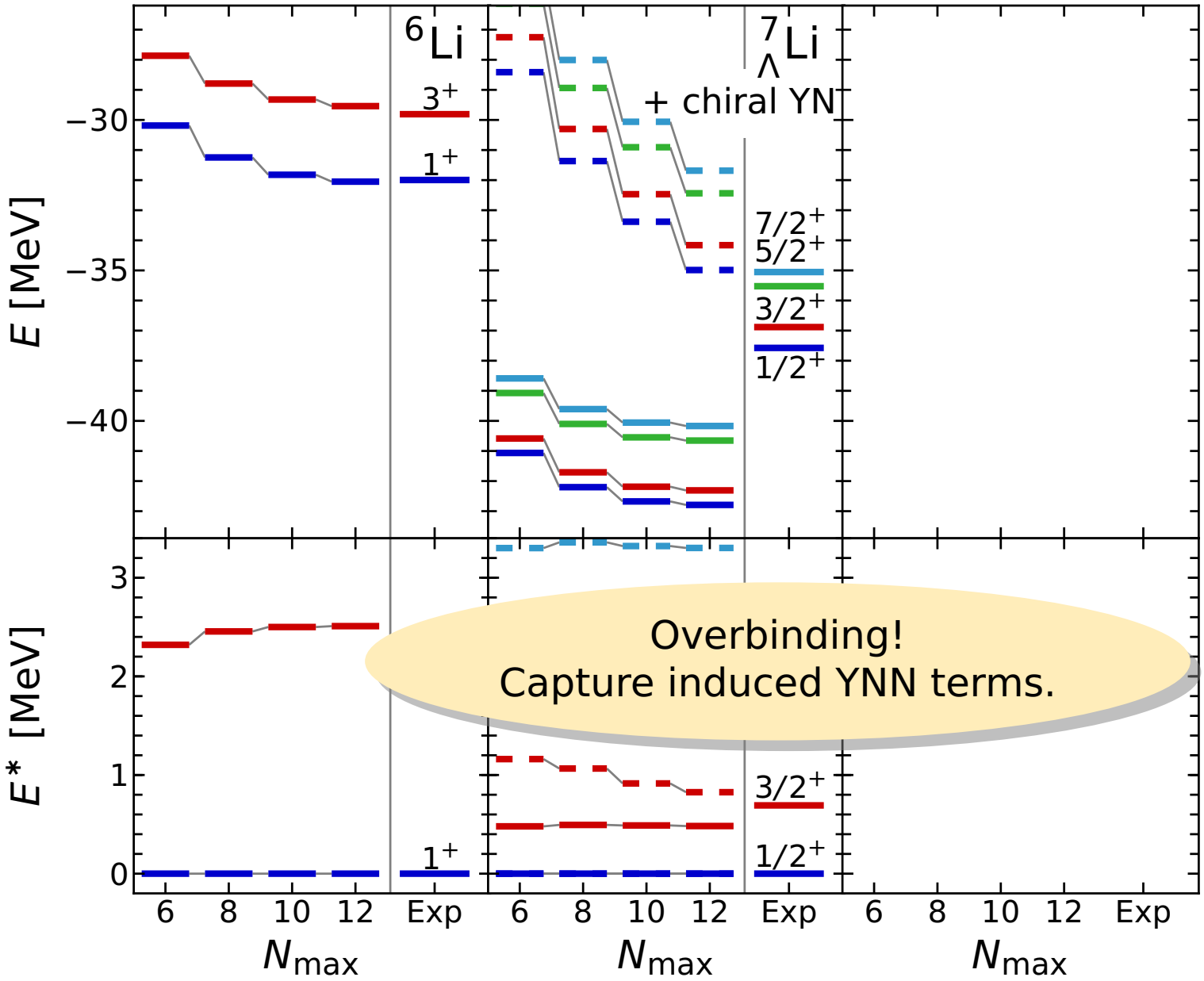

Overbinding!
Capture induced YNN terms.

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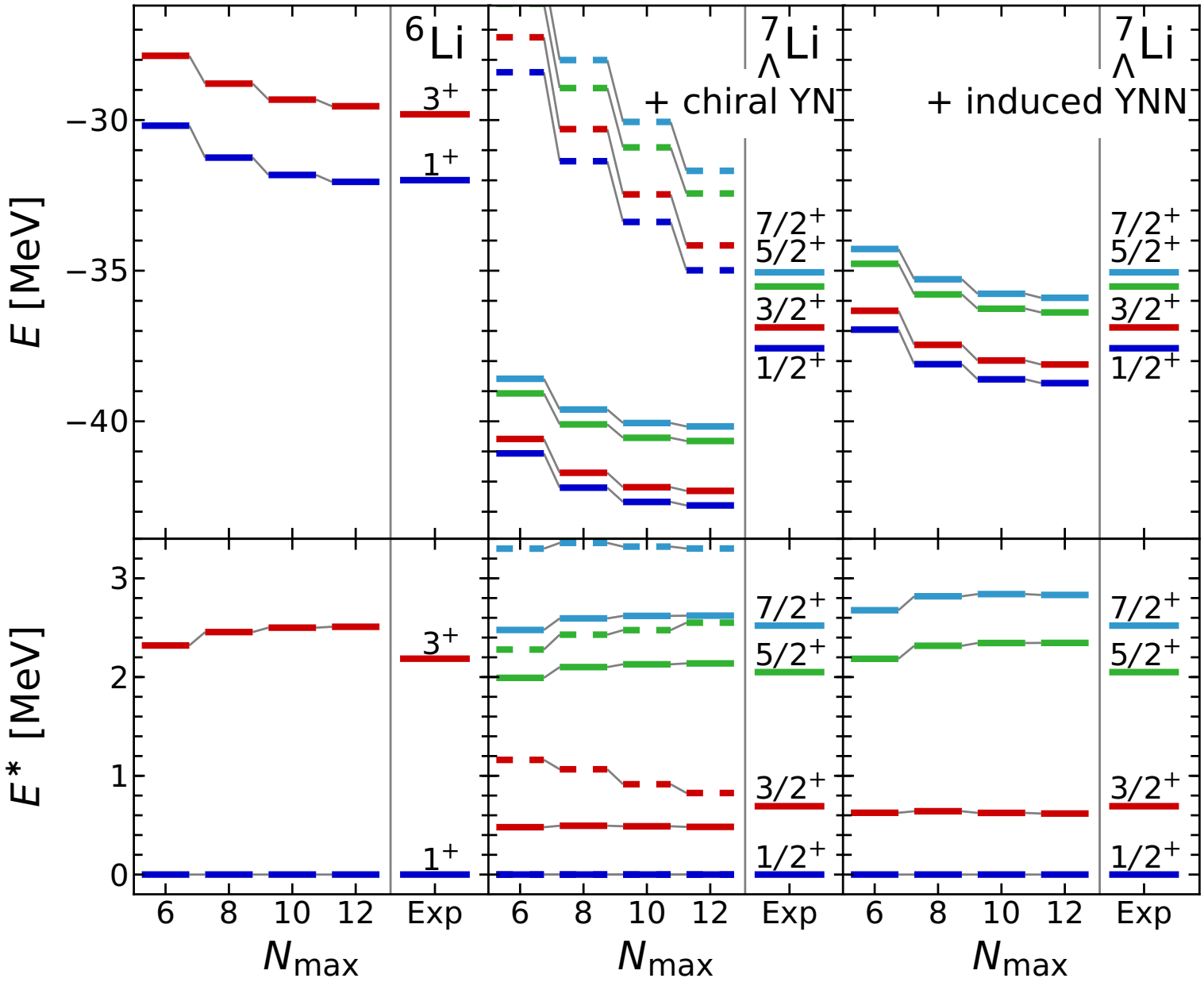

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Nucleonic parent reproduced

Slow convergence of bare YN

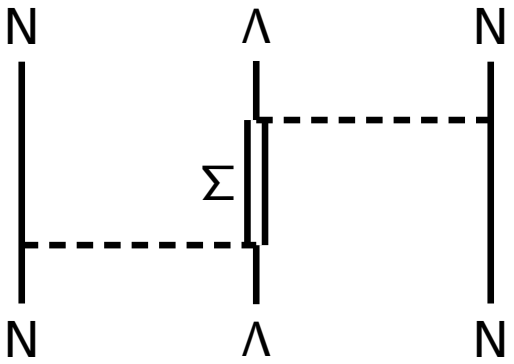
Evolved YN overbinds

Induced YNN improves agreement

Origin of the Induced YNN Terms

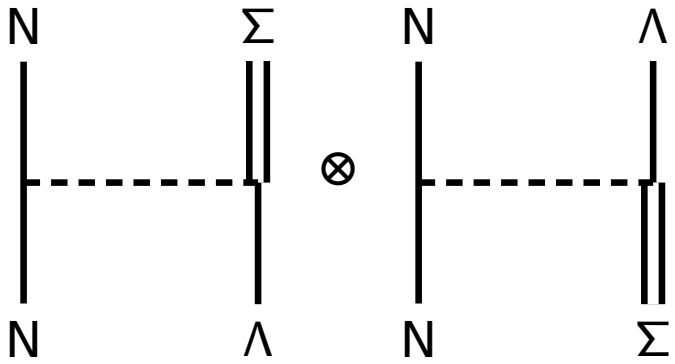
- Two-body evolution suppresses Λ-Σ conversion
- Mechanism for inducing YNN?

Λ-only scheme



Three-Body Force

ΛΣ scheme



Two-Body Force

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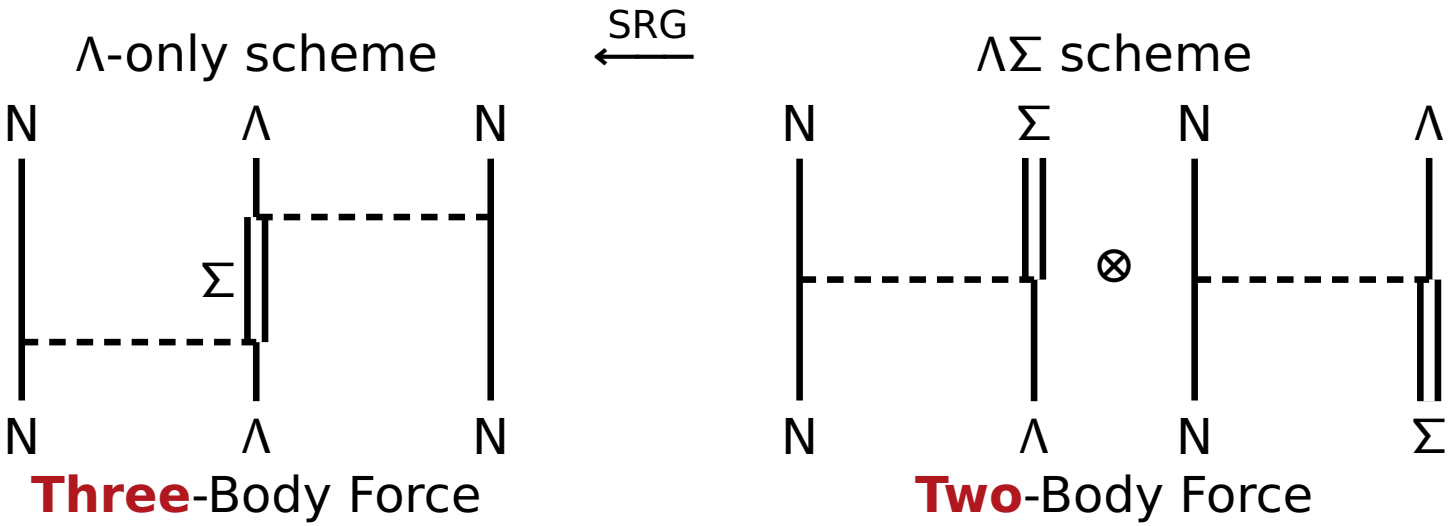
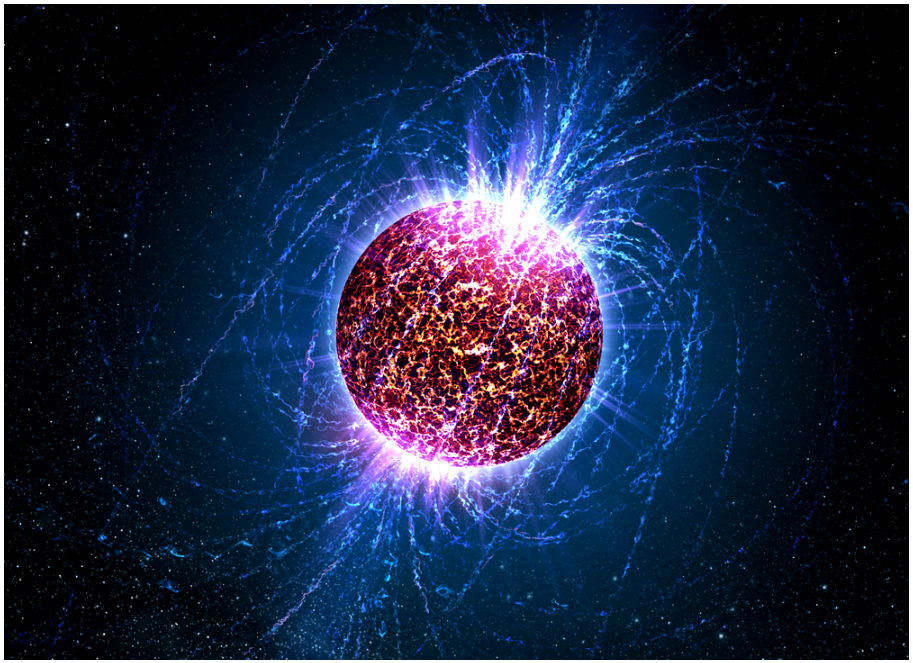
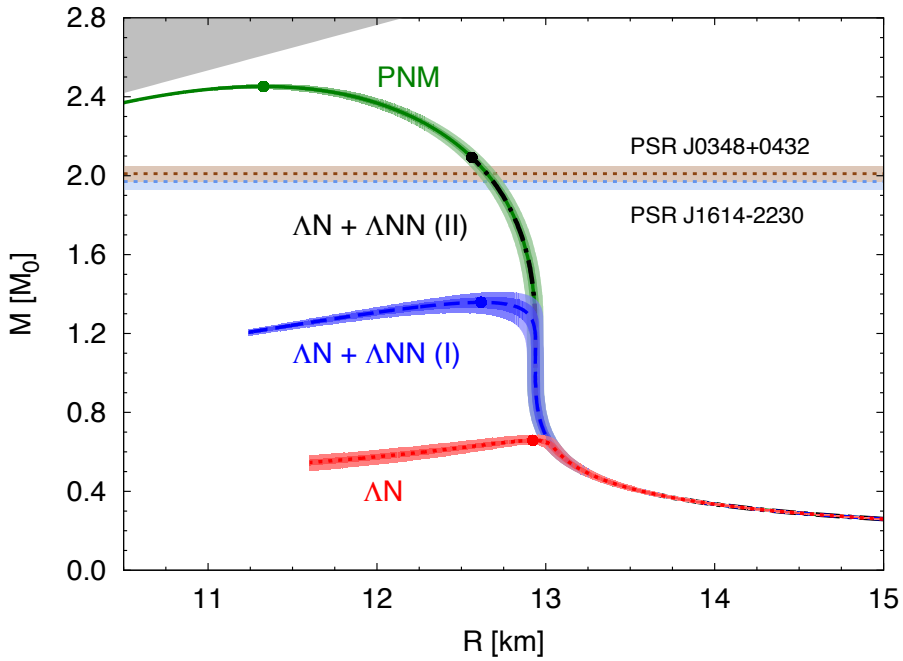


⇒ Use SRG to transform from ΛΣ to Λ-only scheme:
Strong induced YNN terms

Implications for Neutron Star Structure

Neutron Stars — The Hyperon Puzzle

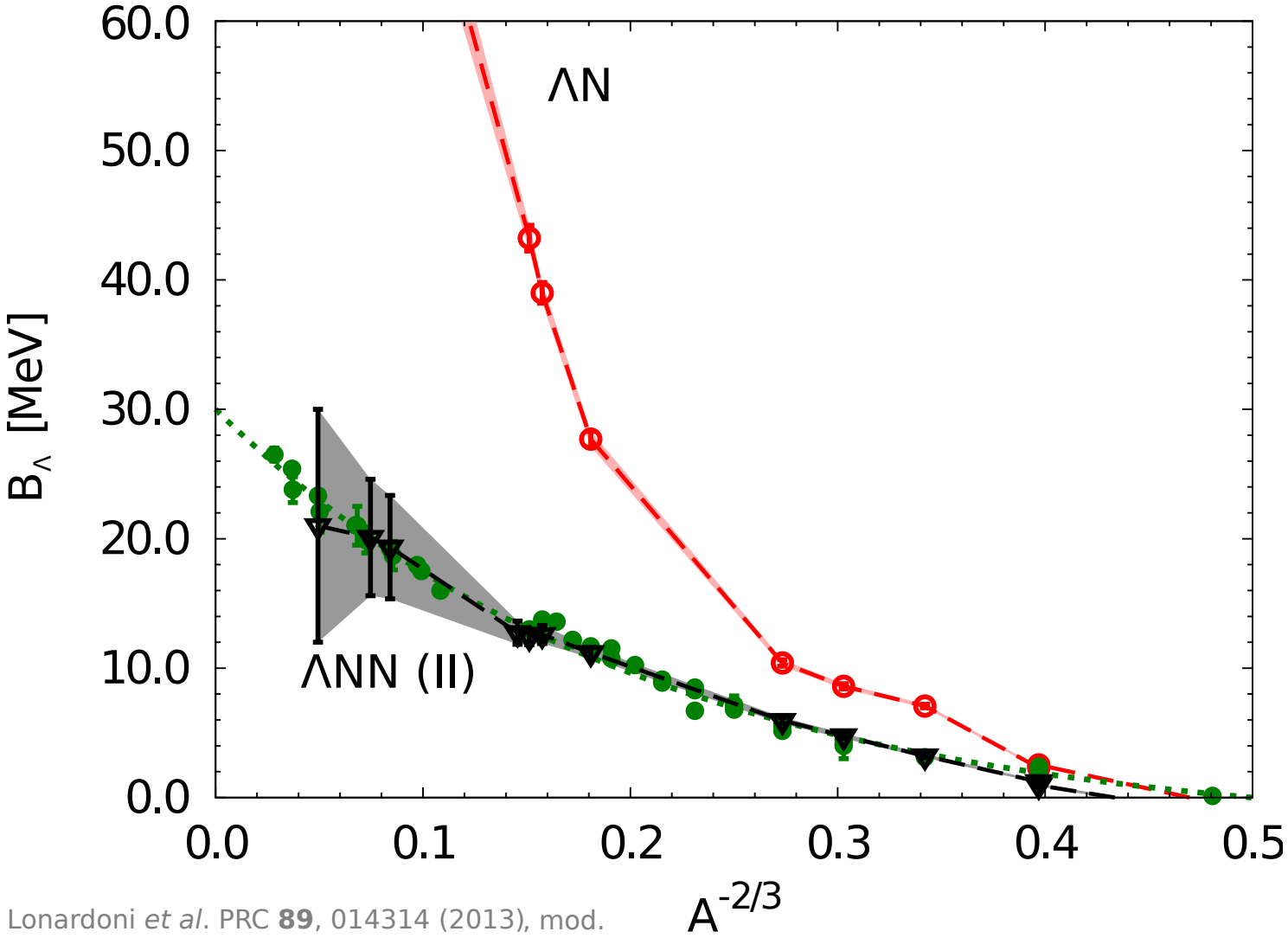




- Expect hyperon production at high densities
- Neutron matter → Strange matter: Add Λ and ΛN interaction
- But: EoS softens too much ⇒ Excluded by $2M_\odot$ NS
- One solution: Add **surprisingly strong** repulsive ΛNN force. **Why?**

The Hyperon Puzzle — Three-Body Forces

What if we treat Λ-Σ conversion consistently?



Lonardoni *et al*. PRC **89**, 014314 (2013), mod.

The Hyperon Puzzle — Three-Body Forces

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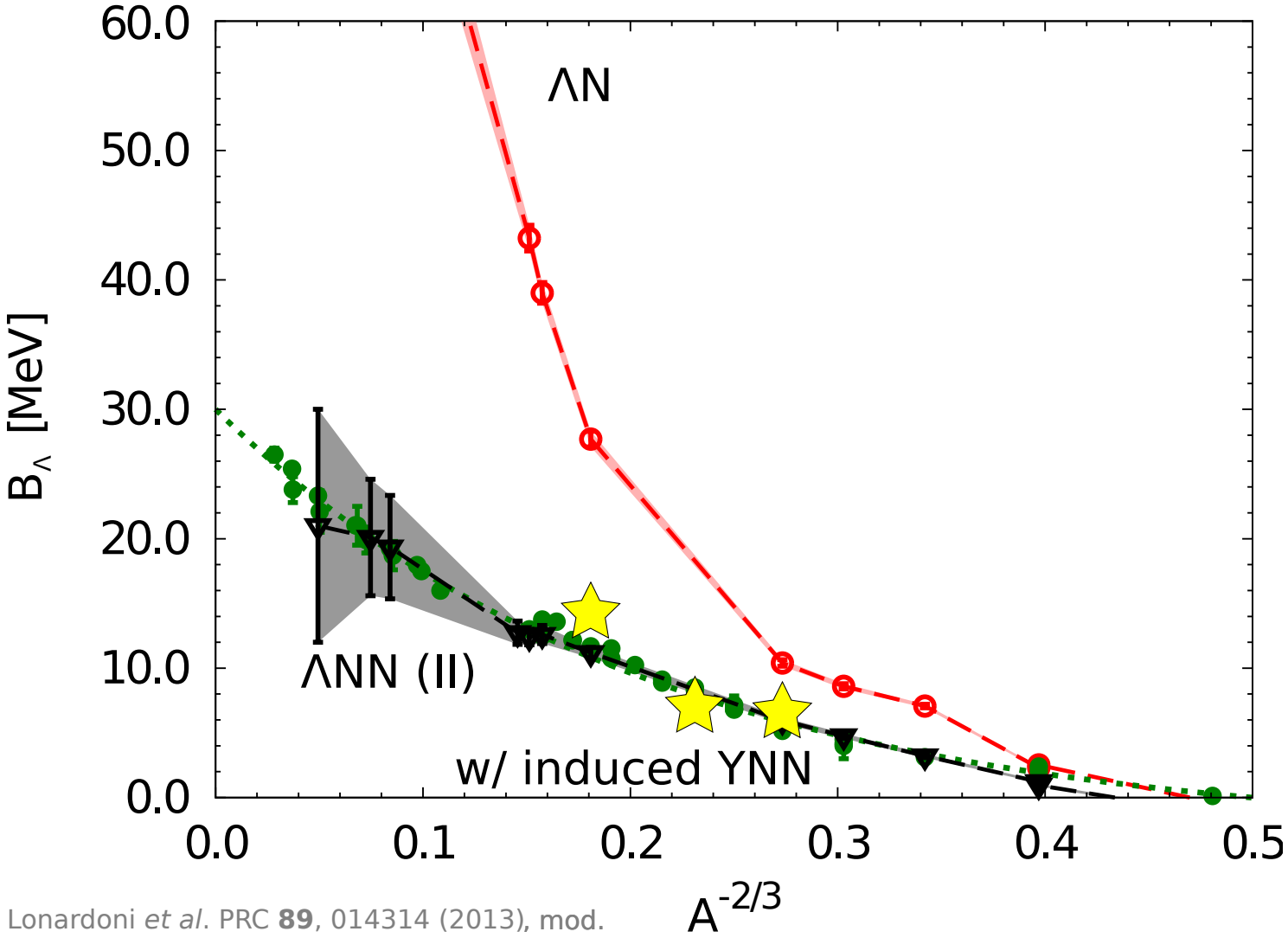

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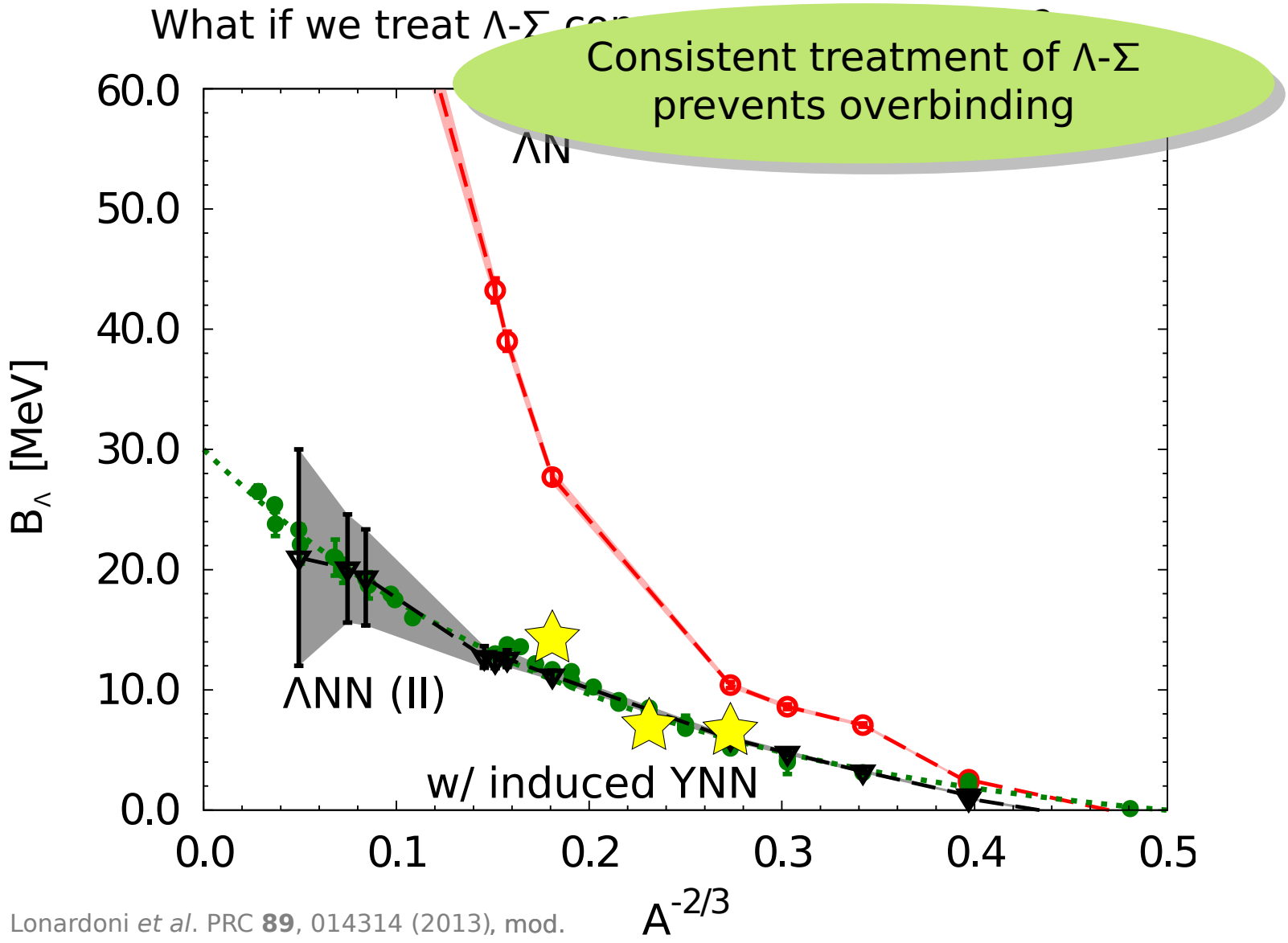

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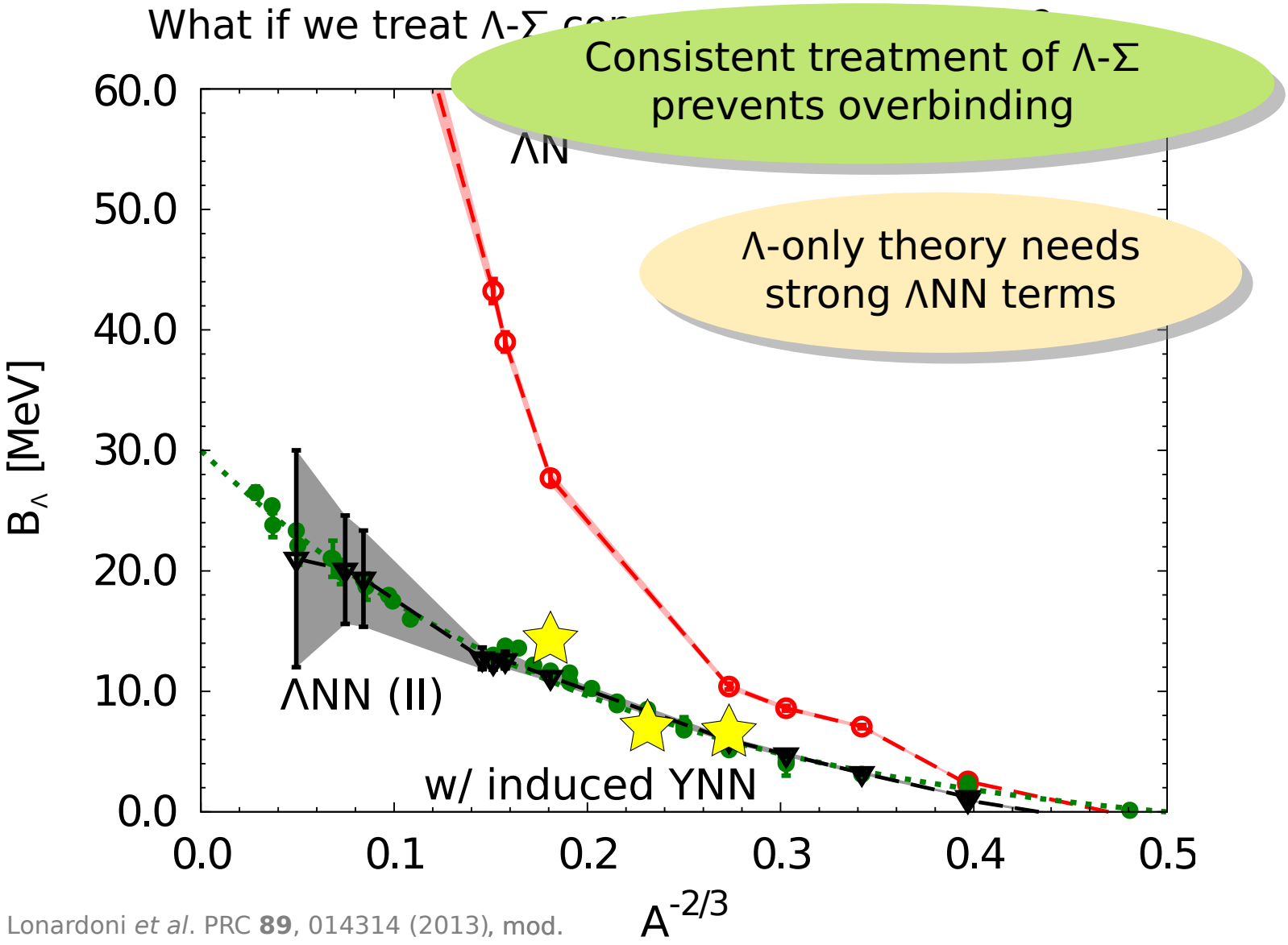

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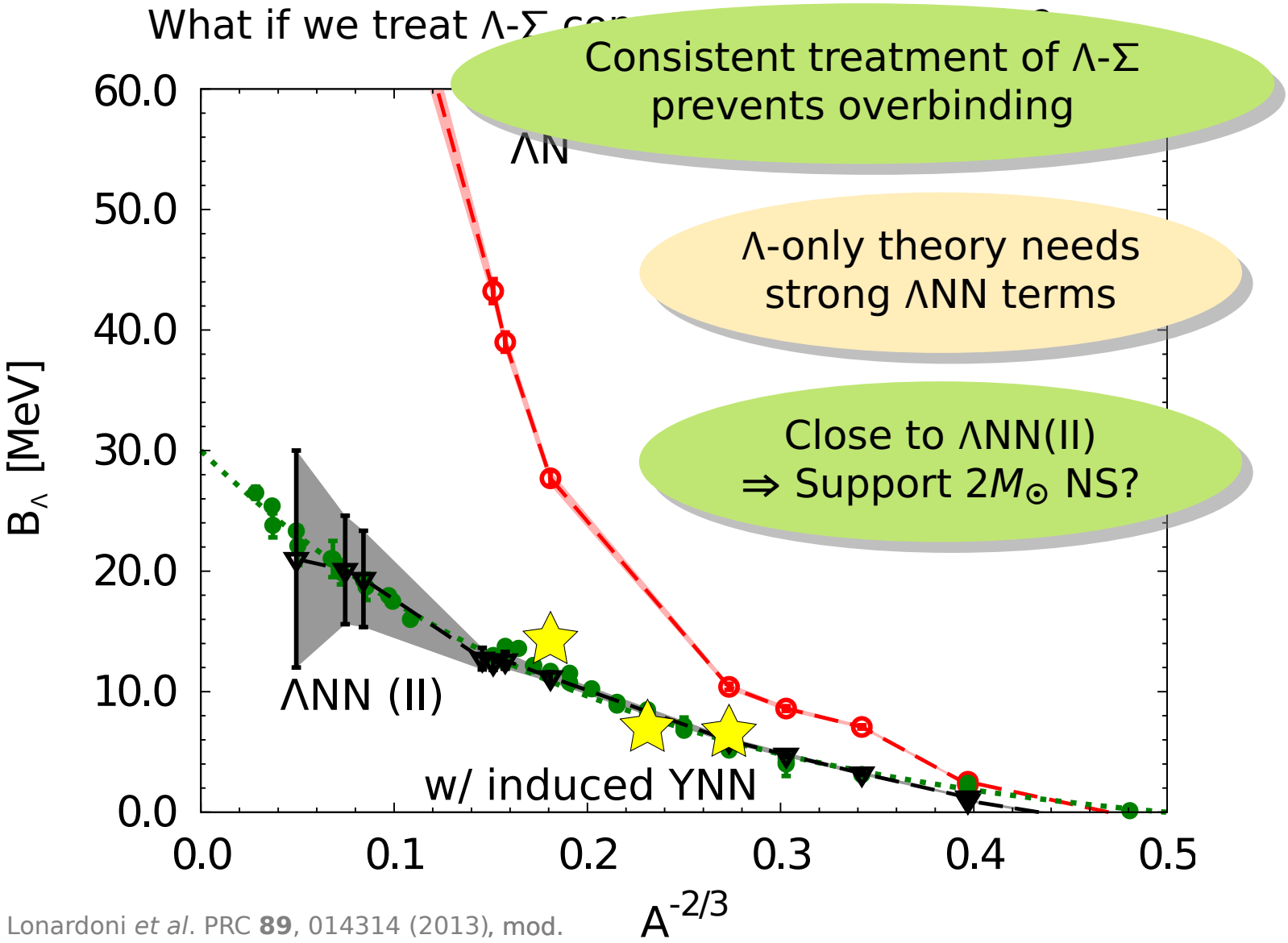

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Summary & Outlook

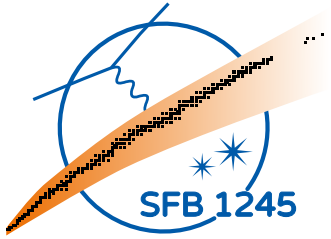
- SRG-induced YNN must be accounted for
  ⇒ Good reproduction of data
- Induced YNN driven by suppression of Λ-Σ conversion
  ⇒ Integrating out (high-energy) Σ d.o.f. generates many-body forces
- Scheme-dependence of the Hyperon Puzzle
  ⇒ Size of three-body forces depends on choice of d.o.f.
  ⇒ SRG as a tool to transform between schemes

- Analyze interaction: NLO, LEC variation at LO
- Build systematics: more *p*-shell hypernuclei
- Calculate matter with induced three-body terms

Epilog

- **Thanks to my group**
  - S. Alexa, S. Dentinger, E. Gebrerufael, T. Hüther, L. Kreher, L. Mertes, **R. Roth**, S. Schulz, H. Spiess, C. Stumpf, A. Tichai, R. Trippel, K. Vobig
    Institut für Kernphysik, TU Darmstadt

- **Thank you for your attention!**



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