Study of nuclei north-east or ⁴⁸Ca with realistic effective hamiltonians

Luigi Coraggio

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- ► T. T. S. Kuo (SUNY at Stony Brook)
- \blacktriangleright L. C. (INFN)

Why to study neutron-rich nuclei above doubly-closed 48 Ca?

- \triangleright To investigate the evolution of the spectroscopic properties of neutron-rich isotopic chains
- \triangleright To ascertain if modern realistic shell-model potentials are able to reproduce the onset/disappearance of the $N = 40$ collectivity

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N. Itaco, L. C., A. Covello, and A. Gargano, J. Phys.: Conf. Ser. **336***, 012008 (2011)*

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Excitation energies of the $J^{\pi} = 2^{+}_{1}$ $_1^+$ states

See for example A. Gade et al., Phys. Rev. C **81** 051304 ([201](#page-3-0)[0\)](#page-5-0)

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A main issue: what should be the shell-model hamiltonian to be employed for this calculation?

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H = \sum_j \epsilon_j \hat{N}_j + \sum_{abcd} V_{abcd} a_a^{\dagger} a_b^{\dagger} a_c a_d
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More precisely: what are the single-particle energies ϵ_i and the two-body matrix elements *Vabcd* to be used?

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Common procedure: ϵ_i and V_{abcd} are derived from the experimental data of the nuclei of the region under investigation, the drawback consists of a loss of predictive power

Microscopic approach (ours): we derive the shell-model hamiltonian from first principles, starting from realistic nucleon-nucleon forces

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There are a plenty of *V_{NN}*s on the market: most of the modern ones reproduce quite well the physics of the two-nucleon system

The trouble with realistic *V*_{*NN*}s is the strong short-range repulsion

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It is necessary to handle the short-range repulsion

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Old way: to resort to the calculation of the Brueckner *G*-matrix of the input V_{NN} and use *G*-matrix vertices in the perturbative expansion of $H_{\rm eff}$

New approaches:

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New approaches:

- \triangleright to renormalize the V_{NN} integrating out the high-momentum components of the potential - the *V*low−^k approach
- \triangleright to employ a realistic potential derived from the chiral perturbation theory and defined only for low momenta - the so-called $N³$ LOW potential (see L.C., A. Covello, A. Gargano, N. Itaco, D. Entem, T. T. S. Kuo, and R. Machleidt, Phys. Rev. C **75** 024311 (2007))

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A very useful way to derive H_{eff} is the time-dependent perturbative approach as developed by Kuo and his co-workers in the 1970s (see *T. T. S. Kuo and E. Osnes, Lecture Notes in Physics vol. 364 (1990))* In this approach the effective hamiltonian *H*_{eff} is expressed as

- \blacktriangleright The integral sign represents a generalized folding operation
- \triangleright The Q -box is a collection of irreducible valence-linked Goldstone

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Q-box diagrams and all effective operators (electric quadrupole transitions, magnetic dipole transitions, ...) up to third order in perturbation theory.

We calculate the Pade approximant $[2|1]$ of the \hat{Q} -box, in order to obtain a better estimate of the value to which the perturbation series should converge

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[2|1] = V_{Qbox}^0 + V_{Qbox}^1 + V_{Qbox}^2 (1 - (V_{Qbox}^2)^{-1} V_{Qbox}^3)^{-1} ,
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The sum at all orders of this class of diagrams makes results independent from the choice of the unperturbed hamiltonian $H_0 = T + U = \sum_i (p_i^2/2M + M\omega^2 r_i^2/2)$ and is equivalent to employ a Hartree-Fock basis

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Q-box perturbative expansion: 1-body diagrams

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Q-box perturbative expansion: 2-body diagrams

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L.C., A. Covello, A. Gargano, N. Itaco, and T. T. S. Kuo, to be publish[ed](#page-29-0) in Annal[s of](#page-0-0) [Ph](#page-0-1)[ysi](#page-0-0)[cs](#page-0-1) [\(2](#page-31-0)[0](#page-29-0)[12\)](#page-30-0)

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Test: $6Li$ first excited states with $N³LO$ potential

[European Radioactive Ion Beam Conference 2012](#page-0-0) "Eurorib'12"

Input V_{NN} **: we derive a** V_{low-k} **with a cutoff momentum** $\Lambda = 2.6$ **fm⁻¹** from the high-precision *NN* CD-Bonn potential.

- \triangleright We consider ⁴⁸Ca a closed core, our chosen model space is spanned by the four neutron SP orbitals $2p_{3/2}$, $2p_{1/2}$, $1f_{5/2}$, $0g_{9/2}$ and proton SP
- \triangleright We derive H_{eff} calculating the Padè approximant [2|1] of the *Q*-box.
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Convergence properties of theoretical SP energies and TBME

Red spectrum: experimental data

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Results: the heavy calcium isotopes

Results: the titanium isotopes

Results: the chromium isotopes

Results: the iron isotopes

Results: the nickel isotopes

- \blacktriangleright The agreement of our results with many experimental data testifies the reliability of our V_{eff}
- No need of $T = 1$ monopole corrections
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Results including ν 1*d*_{5/2} orbital in the model space

Chromium isotopes

Results including ν 1*d*_{5/2} orbital in the model space

Results including $\pi 1p_{3/2}$ and $\nu 1d_{5/2}$ orbital in the model space

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