Nuclear Collective Excitations Using Correlated Realistic Interactions

P. Papakonstantinou, N. Paar, R. Roth, H. Hergert, A. Zapp

Institute of Nuclear Physics, TU Darmstadt, Germany

1.Nuclear response and mean-field theory

- The collective states of medium-mass and heavy nuclei can be tackled only within simple many-body spaces: Hartree-Fock (-Bogolyubov), (Quasi-particle) RPA, ...
- An appropriate "effective interaction" has to be used – mostly phenomenological: Skyrme energy functionals, covariant energy functionals.
- To enhance predictive power one needs to start from realistic interactions instead.

2.What is a correlated realistic interaction?

- From a realistic nucleon-nucleon interaction, e.g., Argonne V18, Bonn, etc, a phase-shift equivalent correlated interaction V_{UCOM} can be obtained within the Unitary Correlation Operator Method (UCOM).
- Because the short-range correlations are treated by the UCOM, the many-body method needs to describe only the state-dependent long-range correlations.
- Thus, V_{UCOM} can be used as a universal effective interaction for calculations within simple Hilbert spaces.

3.Short-Range Correlations - UCOM

- Short-range correlations, tensor and central, are described by a state-independent unitary correlation operator $C = C_\Omega C_r$
- Correlated states $|\tilde{\Psi}\rangle = C|\Psi\rangle$ vs correlated operators $\tilde{O} = C^\dagger O C$:

$$\langle\tilde{\Psi}|O|\tilde{\Psi}'\rangle = \langle\Psi|C^\dagger O C|\Psi'\rangle = \langle\Psi|\tilde{O}|\Psi'\rangle$$

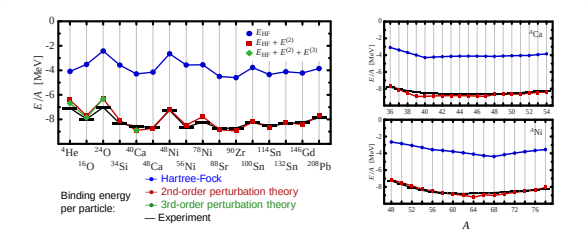
- C is given in a closed operator form. Parameters are determined by energy minimization in two-body space. Range of tensor correlator C_Ω is constrained, because the tensor interaction between two nucleons in a nucleus is screened.
- Correlated NN interaction:

$$\tilde{H} = C^\dagger(T+V)C = \tilde{T}^{[1]} + \tilde{T}^{[2]} + \tilde{V}^{[2]} + \tilde{T}^{[3]} + \tilde{V}^{[3]} + \cdots \approx T + V_{\mathrm{UCOM}}$$

- Tensor correlator range fixed using no-core shell model calculations for the energy of ^{4}He, ^{3}H (experimental point on the Tjon line).
- For this value, contributions from the missing 3-body force and the omitted 3-body terms of the cluster expansion effectively cancel each other.

4.Long-Range Correlations

- Long-range correlations *have to* be described by the many-body state: Hartree-Fock will not be enough.
- They are, however, perturbative:

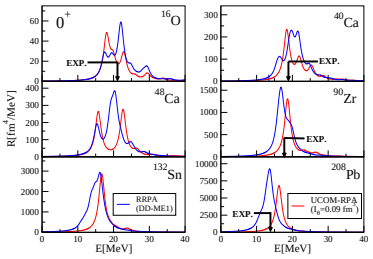


- The cancellation among missing 3-body terms holds for all masses and isospins - but not for all observables e.g. radii.
- A simple zero-range 3-body force is under construction, to account for the missing effects.

5.Results within standard, extended and second RPA + correlated Argonne V18

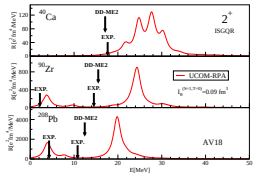
Self-consistent HF+RPA

- Vibration creation operators are written as linear combinations of ph configurations
- Standard, self-consistent HF+RPA - RPA vacuum approximated by Hartree-Fock ground state



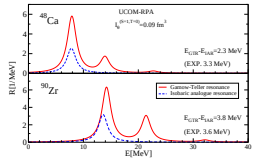
- Good description of Giant Monopole Resonance

Realistic value of nuclear-matter incompressibility



- Energy of Giant Dipole and Quadrupole Resonances overestimated

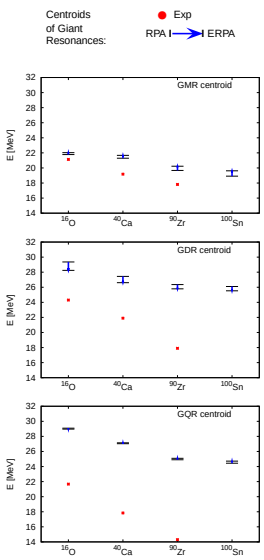
Value of nucleon effective mass too small



- Gamow-Teller States
- Isobaric Analog States
- ... to be continued

"Extended" RPA

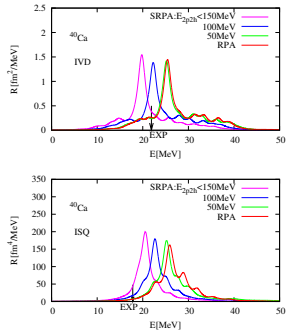
- Renormalized ph excitations are built on the true RPA vacuum
- Effect of explicit ground-state correlations



Small effect on centroids of Giant Resonances

Second RPA

- Include coupling to $2p2h$ states
- Effect of extended model space
- Preliminary results
  - no coupling amongst $2p2h$ states introduced so far
  - truncation of $2p2h$ space at higher energies is needed



Additional configurations are important

Work supported by the **DFG** under contract SFB 634

Visit us for more: http://crunch.ikp.physik.tu-darmstadt.de/tnp