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 \( V_{\text{UCOM}} \) 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, \( V_{\text{UCOM}} \) 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 \( C = C_1 C_2 \).
- Correlated states \( |\Psi\rangle = C |\Psi\rangle \) vs correlated operators \( \hat{O} = C^\dagger \hat{O} C \):
  \[ \langle \hat{O} | C | \Psi\rangle = |\Psi\rangle (C^\dagger \hat{O} C) = \langle \Psi | \hat{O} \Psi \rangle \]
- \( C \) is given in a closed operator form. Parameters are determined by energy minimization in two-body space. Range of tensor correlator \( C_{12} \) is constrained, because the tensor interaction between two nucleons in a nucleus is screened.
- Correlated NN interaction:
  \[ \hat{H} = C(T + V)C = \hat{T}^{(1)} + \hat{T}^{(2)} + \hat{V}^{(1)} + \hat{V}^{(2)} + \ldots \approx T + V_{\text{UCOM}} \]
- Tensor correlator range fixed using no-core shell model calculations for the energy of \(^{4}\text{He}, \ ^{1}\text{H} \) (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
- 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
- Controls of Giant Resonance
- Good description of Giant Resonance
- 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

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