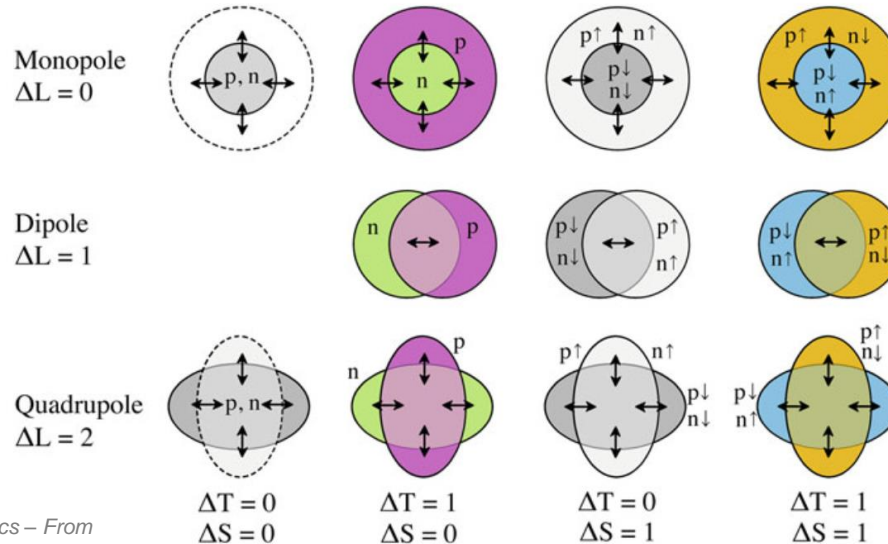


Consistent Description of Collective Excitations in the In-Medium (S)RPA

Michelle Müller



A. Obertelli and H. Sagawa. *Modern Nuclear Physics – From Fundamentals to Frontiers*. 2021.

(Second-Order) Random-Phase Approximation

- investigation of collective excitations
- exact ground state contains correlations

RPA

excited states are given by 1p1h
(de-)excitations of ground state



SRPA

natural extension of RPA to
2p2h (de-)excitations

(S)RPA Transition Strengths

- main focus: calculation of **(S)RPA transition strengths**
- usually: application of one-body transition matrix elements
- extension of strength calculations to two-body contributions
 - possibility to involve *free-space* or *in-medium SRG evolved EM operator*
- calculation of SRPA transition strengths with two-body operator also leads to non-vanishing 2p2h contributions

Comparison of the Methods

HF-(S)RPA

- (S)RPA in Hartree-Fock basis
- ground-state correlations treated in (S)RPA formalism
- strength calculation usually via one-body matrix elements

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IM-(S)RPA

- input: IM-SRG evolved Hamiltonian
- ground-state correlations taken care of by IM-SRG
- strength calculation usually via one-body matrix elements

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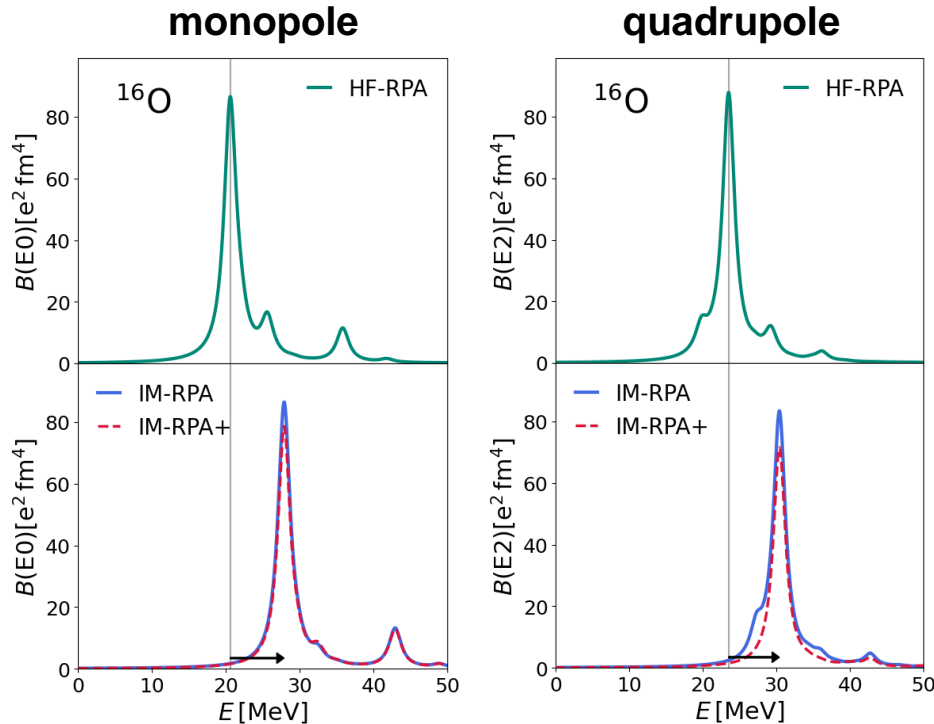
IM-(S)RPA

- input: IM-SRG evolved Hamiltonian
- ground-state correlations taken care of by IM-SRG
- strength calculation usually via one-body matrix elements

IM-(S)RPA+

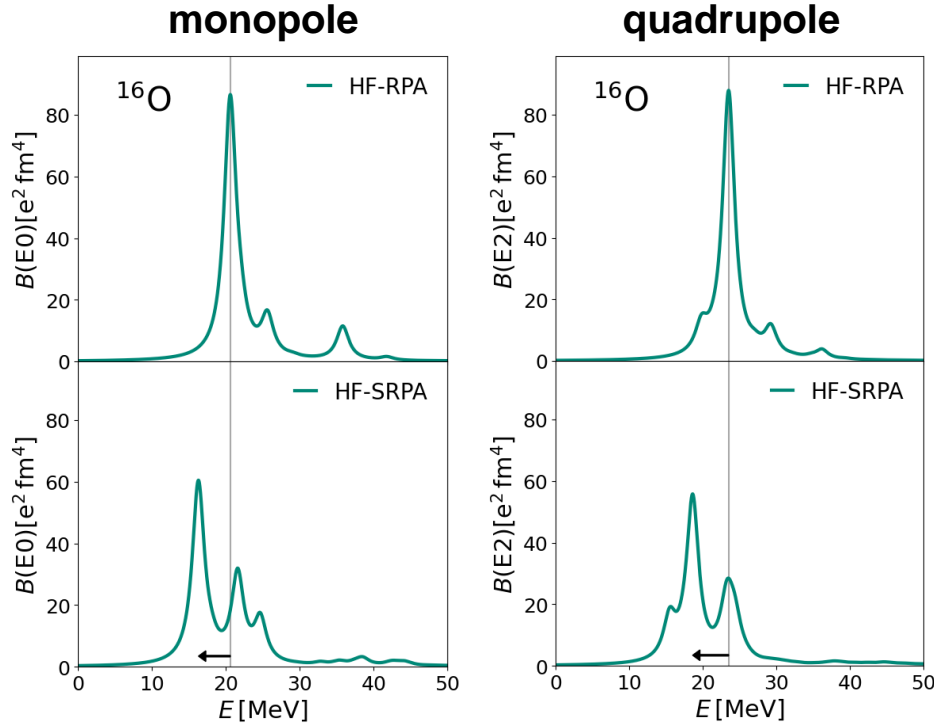
- input: IM-SRG evolved Hamiltonian and IM-SRG evolved EM operator
- strength calculation via one- and two-body matrix elements
- consistent description

(S)RPA Transition Strengths



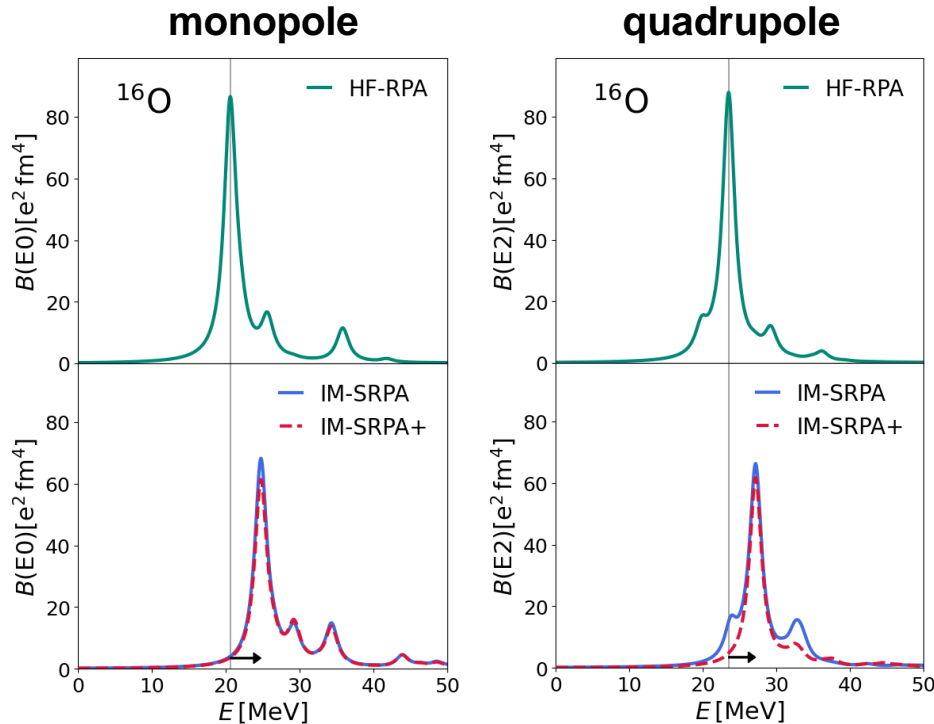
- **HF-RPA \rightarrow IM-RPA:**
shift to higher energies
- **IM-RPA \rightarrow IM-RPA+:**
small changes in strength,
energies unaltered

(S)RPA Transition Strengths



- **HF-RPA \rightarrow HF-SRPA:**
shift to smaller energies

(S)RPA Transition Strengths

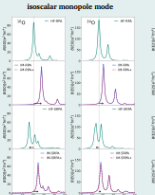
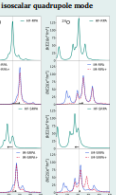


- **HF-SRPA \rightarrow IM-SRPA:**
compensation of shift to smaller energies
- **IM-SRPA \rightarrow IM-SRPA+:**
small changes in strength, energies unaltered

Consistent Description of Collective Excitations in the In-Medium (S)RPA



Michelle Müller, Laura Moritz, Robert Ruth

Motivation	(Second-Order) Random-Phase Approximation	In-Medium (S)RPA
<ul style="list-style-type: none"> investigating collective excitations provides insight into nuclear properties, e.g. deformation, incompressibility or dipole polarizability RPA and SRPA are methods to investigate collective excitations in nuclear theory the calculation of (S)RPA transition strengths allows for a direct comparison to experimental data the extension of strength calculations to contributions of two-body matrix elements results in a complete description for SRPA IM-(S)RPA: applying an In-Medium SRG evolved Hamiltonian in the (S)RPA calculations includes correlations in contrast to the (S)RPA in a Hartree-Fock basis (HF-(S)RPA) consistent description by additionally incorporating IM-SRG evolved electromagnetic (EM) operators 	<ul style="list-style-type: none"> RPA and SRPA are standard tools to describe collective excitations (S)RPA ground state contains particle-hole (ph) excitations of reference state excited states are given by ph (de-)excitations of (S)RPA ground state $\alpha\rangle = Q_2^\dagger \text{SRPA}\rangle$, $Q_2^\dagger \text{SRPA}\rangle = \alpha$ → RPA: restriction to 1p1h (de-)excitations $(Q_2^\dagger)^\dagger = \sum_{i,j} (x_{ij}^\dagger a_i^\dagger a_j - x_{ij} a_i^\dagger a_j)$ → SRPA: natural extension of RPA to 2p2h (de-)excitations $(Q_2^\dagger)^\dagger = (Q_2^\dagger)^\dagger + \sum_{i,j,k,l} (y_{ijkl}^\dagger a_i^\dagger a_j^\dagger a_k a_l - y_{ijkl}^\dagger a_i^\dagger a_j^\dagger a_k a_l)$ (S)RPA written as eigenvalue problem → (S)RPA matrix equations $\begin{pmatrix} A & B \\ -B^\dagger & -A \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} = \lambda \begin{pmatrix} x \\ y \end{pmatrix}$ solving the eigenvalue problem yields (S)RPA amplitudes and eigenenergies, which are crucial for the calculation of transition strengths 	<ul style="list-style-type: none"> In-Medium Similarity Renormalization Group (IM-SRG) decouples reference state from its ph excitations [2] Fermi gap widens for IM-SRG in contrast to HF while the spacing within particle states and within hole states almost remains constant [1] (S)RPA formalism depends on ph excitation energies → IM-(S)RPA: with matrix elements of an IM-SRG evolved Hamiltonian as input in (S)RPA, eigenenergies are shifted to higher energies in SRPA, usually a pathological shift to lower energies is found in contrast to RPA [3, 4] → implementing an IM-SRG evolved Hamiltonian compensates this shift consistent description by additional input of matrix elements of IM-SRG evolved EM operators: IM-(S)RPA+
<h3>Two-Body Contributions to Transition Strength</h3> <ul style="list-style-type: none"> calculation of (S)RPA transition strengths usually by application of one-body transition matrix elements one-body operators are not able to connect the ground state with a 2p2h excited state → comparison of one-body transition matrix elements is identical for RPA and SRPA since all 2p2h contributions vanish for the SRPA → complete description of SRPA transition strengths by additionally including matrix elements containing a two-body operator \hat{F} $\langle \text{SRPA} \hat{F} \alpha \rangle = \sum_{i,j,k,l} \langle \alpha \hat{F} ij \rangle \langle ij \hat{F} \alpha \rangle + \sum_{i,j,k,l} \langle \alpha \hat{F} ijkl \rangle \langle ijkl \hat{F} \alpha \rangle$ 1p1h $\sum_{i,j,k,l} \langle \alpha \hat{F} ijkl \rangle \langle ijkl \hat{F} \alpha \rangle + \sum_{i,j,k,l} \langle \alpha \hat{F} ijkl \rangle \langle ijkl \hat{F} \alpha \rangle$ 2p2h in practical applications, the matrix elements are angular momentum coupled (not shown here for brevity) two-body matrix elements also allow for the inclusion of IM-SRG evolved EM operators into the IM-(S)RPA strength calculations 	<h3>(S)RPA Transition Strengths</h3> <ul style="list-style-type: none"> isobaric transition strengths for the nuclei ^{16}O and ^{40}Ca using an SRG evolved chiral NN+3N interaction [5] ($\tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5 = \tau_6 = \tau_7 = \tau_8 = \tau_9 = \tau_{10} = 12$ and $\ell_{\text{max}} = 10$) <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>isobaric monopole mode</p>  </div> <div style="text-align: center;"> <p>isobaric quadrupole mode</p>  </div> </div>	
<h3>Outlook</h3> <ul style="list-style-type: none"> implementing an IM-SRG evolved E1 operator into IM-(S)RPA+ calculating invector transition strengths for all modes for IM-(S)RPA+ and comparing the results with the other methods testing for various closed-shell nuclei calculating the dipole polarizability for HF- and IM-(S)RPA and comparing the results with experimental data 	<ul style="list-style-type: none"> RPA → SRPA: shift to lower energies HF-(S)RPA → IM-(S)RPA: shift to higher energies for SRPA, the shift to lower energies is compensated by inclusion of IM-SRG IM-(S)RPA → IM-(S)RPA+ <ul style="list-style-type: none"> eigenenergies unaltered small changes in transition strength → significant changes for E2 transition strength applying SRG evolved matrix elements would leave plots visibly unchanged 	

Thank you for your attention!

➔ more details on my poster

References: [1] D. Tjebk, Collective Excitations with Chiral NN+3N Interactions, *Non-Relativistic Effective and Many-Body Theories*, 2023, 10.1007/978-3-031-20985-0_10. [2] J. G. Messineo et al., Phys. Rev. C 81, 044301 (2010). [3] J. G. Messineo et al., Phys. Rev. C 84, 044301 (2011). [4] J. G. Messineo et al., Phys. Rev. C 84, 044301 (2011). [5] J. G. Messineo et al., Phys. Rev. C 84, 044301 (2011).