Spurious states in second RPA and multiphonon calculations

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Outline

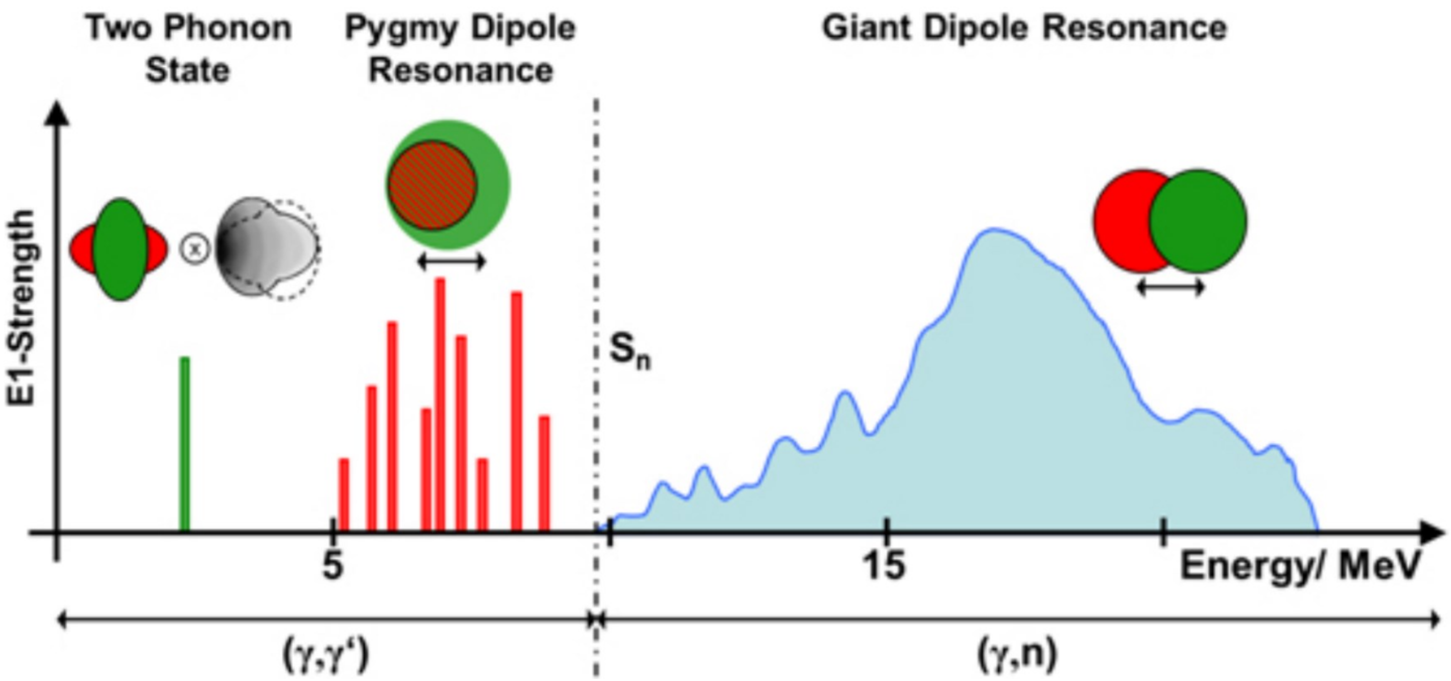
- Second RPA(TDA)
- Equation of motion phonon method (EMPM)
- Spurious center-of-mass states in SRPA/STDA and EMPM

Dipole strength in nuclei

- Giant dipole resonance (GDR) → universal collective mode observed across the entire nuclide chart
- Low-energy dipole strength (Pygmy dipole resonance (PDR))
  → concentrated around the neutron separation energy
  → correlation between the neutron excess and the low-energy dipole strength
- nuclear polarizability ↔ neutron skin thickness

Theoretical tools (microscopic):

RPA → gross properties (energy centroids, total strength)
„beyond“ RPA („complex“ configurations) → fragmentation, spreading widths



Overview of methods accounting for „complex“ configurations

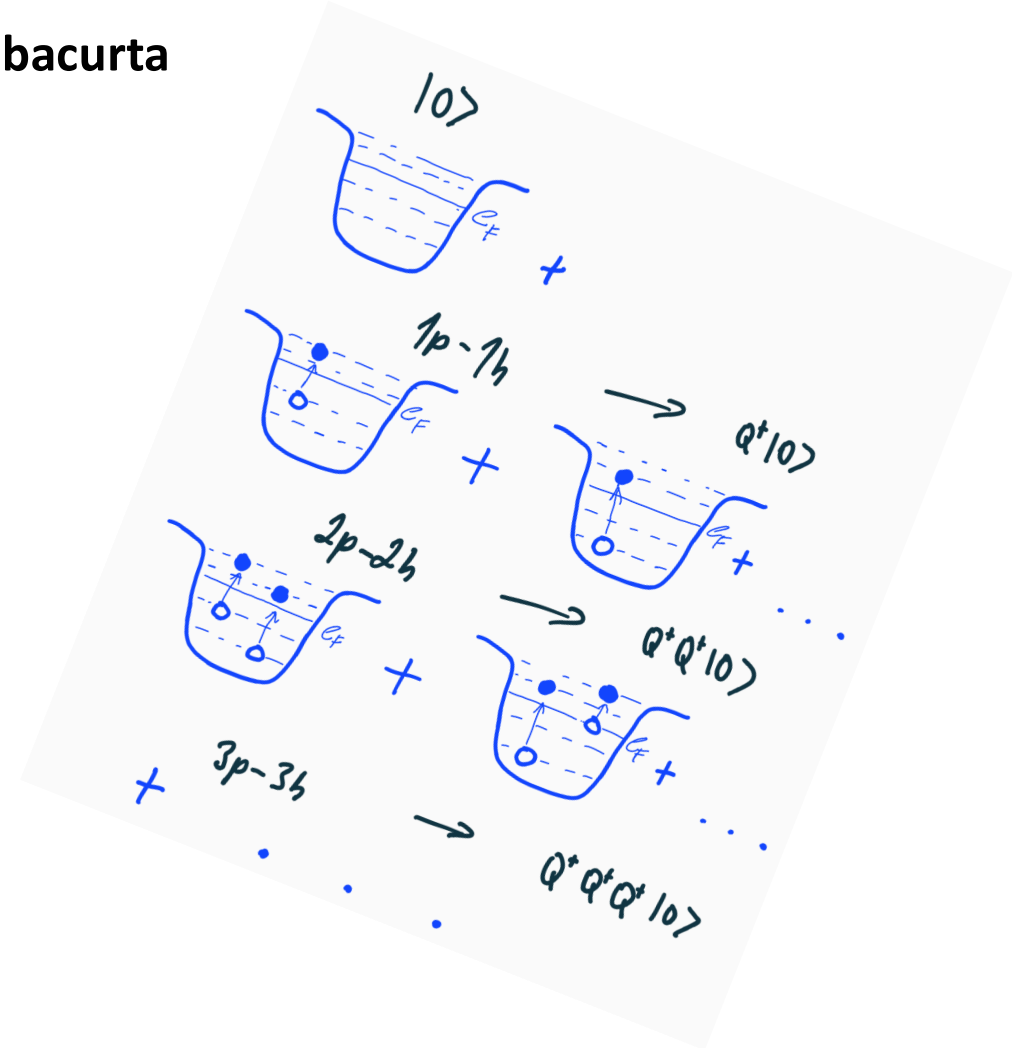
- **SRPA**: RPA + *2p-2h*
  SSRPA: Skyrme and Gogny effective interaction: → **D. Gambacurta**
  finite range „realistic“ interactions: P. Papakonstantinou

- **ETTFS:** Kamerdzhiev *1p-1h x RPA phonon*
- **(R)QTBA**: Litvinova, Tselyaev
  relativistic DFT: (*1p-1h) x RPA phonon, 2qp x QRPA phonon*
  EOM: 2qp x 2phonon → **E. Litvinova**

- **QPM** : *1+2+3 Q(RPA) phonons*
  → **N. Tsoneva**

- **LIT – Coupled-cluster:** → **S. Bacca**
- **Large-scale Shell model**: → **K. Seija** (1+3 $\hbar\omega$ model space)

- **Equation of motion phonon method (EMPM)**



RPA/TDA and SRPA/STDA

- mean-field → optimisation of single-particle basis → refference state (HF vacuum) $|HF\rangle$
- excited states → superpositions of elementary *1p-1h, 2p-2h* … excitations

collective excitations → phonons

$$[\boldsymbol{H_{intr}}, \boldsymbol{Q_\nu^\dagger}]|0\rangle = \hbar\omega_\nu \boldsymbol{Q_\nu^\dagger}|0\rangle$$

$$|\nu\rangle = \boldsymbol{Q_\nu^\dagger}|0\rangle, \quad \boldsymbol{Q_\nu}|0\rangle=0$$

- **RPA (Random Phase Approximation) :** *1p-1h* model with ground state correlations ($|0\rangle \neq |HF\rangle$)

$$\boldsymbol{Q}_\nu^{+(RPA)} = \sum_{ph} X_{ph}^{\boldsymbol{\nu}} \boldsymbol{a}_p^\dagger \boldsymbol{a}_h - Y_{ph}^{\boldsymbol{\nu}} \boldsymbol{a}_h^\dagger \boldsymbol{a}_p$$

- **TDA (Tamm-Dancoff Approximation):** *1p-1h* model without ground state correlations ($|0\rangle = |HF\rangle$,$Y_{ph}^{\boldsymbol{\nu}} = 0$)
- **SRPA** (Second RPA): a straightforward extension of RPA accounting for 2p-2h configurations

$$\boldsymbol{Q}_\nu^{+(SRPA)} = \sum_{ph} (X_{ph}^{\boldsymbol{\nu}\,(1)} \boldsymbol{a}_p^\dagger \boldsymbol{a}_h - Y_{ph}^{\boldsymbol{\nu}\,(1)} \boldsymbol{a}_h^\dagger \boldsymbol{a}_p) + \sum_{p_1p_2h_1h_2} (X_{p_1p_2h_1h_2}^{\boldsymbol{\nu}\,(2)} \boldsymbol{a}_{p_1}^\dagger \boldsymbol{a}_{p_2}^\dagger \boldsymbol{a}_{h_1} \boldsymbol{a}_{h_2} - Y_{p_1p_2h_1h_2}^{\boldsymbol{\nu}\,(2)} \boldsymbol{a}_{h_2}^\dagger \boldsymbol{a}_{h_1}^\dagger \boldsymbol{a}_{p_2} \boldsymbol{a}_{p_1})$$

- **STDA** (Second TDA): ($Y_{ph}^{\boldsymbol{\nu}\,(1)} = 0, Y_{ph}^{\boldsymbol{\nu}\,(2)} = 0$)

Second RPA (SRPA)

Matrix form

$$\left(\begin{array}{cc|cc} \boldsymbol{A} & \boldsymbol{A}_{12} & \boldsymbol{B} & \boldsymbol{B}_{12} \\ \boldsymbol{A}_{21} & \boldsymbol{A}_{22} & \boldsymbol{B}_{21} & \boldsymbol{B}_{22} \\ \hline -\boldsymbol{B}^* & -\boldsymbol{B}^*_{12} & -\boldsymbol{A}^* & -\boldsymbol{A}^*_{12} \\ -\boldsymbol{B}^*_{21} & -\boldsymbol{B}^*_{22} & -\boldsymbol{A}^*_{21} & -\boldsymbol{A}^*_{22} \end{array}\right) \left(\begin{array}{c} \boldsymbol{X}^{\nu\,(1)} \\ \boldsymbol{X}^{\nu\,(2)} \\ \hline \boldsymbol{Y}^{\nu\,(1)} \\ \boldsymbol{Y}^{\nu\,(2)} \end{array}\right) = \hbar\omega_{\boldsymbol{\nu}}^{SRPA} \left(\begin{array}{c} \boldsymbol{X}^{\nu\,(1)} \\ \boldsymbol{X}^{\nu\,(2)} \\ \hline \boldsymbol{Y}^{\nu\,(1)} \\ \boldsymbol{Y}^{\nu\,(2)} \end{array}\right)$$

Quasiboson approximation

C. Yannouleas, Phys. Rev. C ***35****, 1159 (1987)*

$$(\boldsymbol{A})_{ph\,,p\prime h\prime} \approx \langle HF| \left[\boldsymbol{a}_h^\dagger \boldsymbol{a}_p\,, [\boldsymbol{H}_{\boldsymbol{intr}}\,, \boldsymbol{a}_{p\prime}^\dagger \boldsymbol{a}_{h\prime}]\right] |HF\rangle$$

$$(\boldsymbol{B})_{ph\,,p\prime h\prime} \approx -\langle HF| \left[\boldsymbol{a}_h^\dagger \boldsymbol{a}_p\,, [\boldsymbol{H}_{\boldsymbol{intr}}\,, \boldsymbol{a}_{h\prime}^\dagger \boldsymbol{a}_{p\prime}]\right] |HF\rangle$$

$$(\boldsymbol{A}_{12})_{ph\,,\ p_1p_2h_1h_2} \approx \langle HF| \left[\boldsymbol{a}_h^\dagger \boldsymbol{a}_p\,, [\boldsymbol{H}_{\boldsymbol{intr}}\,, \boldsymbol{a}_{p_1}^\dagger \boldsymbol{a}_{p_2}^\dagger \boldsymbol{a}_{h_2} \boldsymbol{a}_{h_1}]\right] |HF\rangle$$

$$(\boldsymbol{A}_{22})_{p_1h_1p_2h_2\,,\,p_1'h_1'p_2'h_2'} \approx \langle HF| \left[\boldsymbol{a}_{h_1}^\dagger \boldsymbol{a}_{h_2}^\dagger \boldsymbol{a}_{p_1} \boldsymbol{a}_{p_2}, \left[\boldsymbol{H}_{\boldsymbol{intr}}\,, \boldsymbol{a}_{p_2'}^\dagger \boldsymbol{a}_{p_1'}^\dagger \boldsymbol{a}_{h_2'} \boldsymbol{a}_{h_1'}\right]\right] |HF\rangle$$

For 2-body Hamiltonian and HF reference state → QBA → $\boldsymbol{B}_{12}, \boldsymbol{B}_{21}, \boldsymbol{B}_{22}$ =0
No explicit mixing between $|HF\rangle$ and $|2p2h\rangle$, g.s. correlations induced via $\boldsymbol{B}$

$\boldsymbol{B} = 0 \ \rightarrow Y_{ph}^{\boldsymbol{\nu}\,(1)}, Y_{p_1p_2h_1h_2}^{\boldsymbol{\nu}\,(2)} = 0$ STDA → diagonalisation in *1p-1h + 2p-2h* model space

Stability of SRPA solutions investigated in *P. Pakakonstantinou, Phys. Rev. C 90, 024 305 (2014)*

Equation-of-motion Phonon method (EMPM)

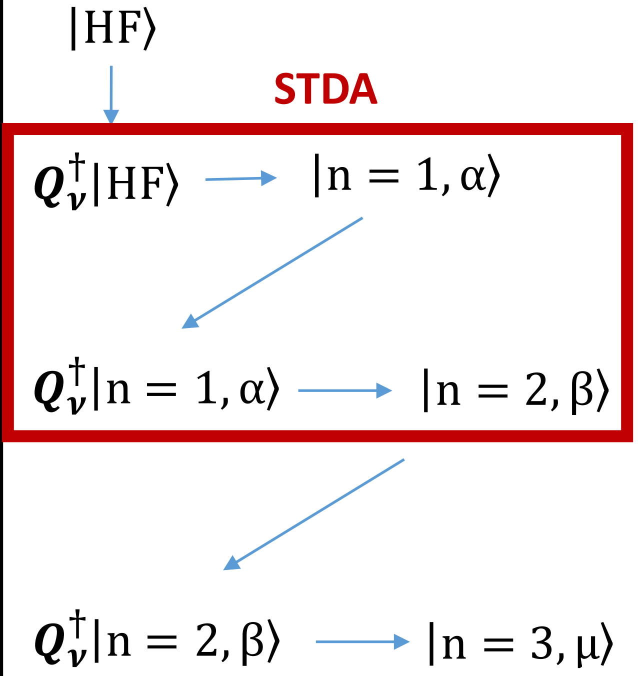
- partitioning of the model space into *n*-phonon (*np-nh*) subspaces

$$\boldsymbol{H_{intr}} = \sum_{n,\alpha} E_\alpha^n |n,\alpha\rangle\langle n,\alpha| + \sum_{nn',\alpha\alpha'} |n',\alpha'\rangle\langle n',\alpha'|\boldsymbol{H_{intr}}|n,\alpha\rangle\langle n,\alpha|$$

$$\langle n,\beta|\boldsymbol{H_{intr}}|n,\alpha\rangle = E_\alpha^n \delta_{\alpha\beta}$$

n-phonon subspace

$E_0^{(0)}$	0	H_{02}	0
0	E_1^1 E_2^1 $\ddots$	H_{12}	0
H_{20}	H_{21}	E_1^2 E_2^2 $\ddots$	H_{23}
0	0	H_{32}	E_1^3 E_2^3 E_3^3 $\ddots$



- fermionic structure of states fully taken into account
- all parts of interaction included
- off-diagonal blocks describe coupling between subspaces

$\langle 1|\ \boldsymbol{H_{intr}}\ |3\rangle \sim \langle 0|\ \boldsymbol{H_{intr}}\ |2\rangle$

- removal of CM contamination in each *n*-phonon subspace

Equation-of-motion Phonon method (EMPM)

- expansion of many-body states into a basis of multiphonon states: $|\mathrm{HF}\rangle$, $\boldsymbol{Q}_\nu^\dagger|\mathrm{HF}\rangle$, $\boldsymbol{Q}_\nu^\dagger|1,\alpha\rangle$, $\boldsymbol{Q}_\nu^\dagger|2,\beta\rangle$ … , where $\boldsymbol{Q}_\nu^\dagger$ are TDA phonons → basis similar to QPM
- iterative construction of the Hamiltonian in phonon subspaces
- J-coupled scheme

$$\langle n-1,\alpha|\boldsymbol{H_{intr}}|n-1,\alpha'\rangle = E_\alpha^{n-1}\delta_{\alpha\alpha'}$$

↓

$$\langle n,\beta|\left[\boldsymbol{H_{intr}},\boldsymbol{Q}_\nu^\dagger\right]|n-1,\alpha\rangle = (E_\beta^n - E_\alpha^{n-1})\langle n,\beta|\boldsymbol{Q}_\nu^\dagger|n-1,\alpha\rangle$$

↓

$$\langle n,\beta|\boldsymbol{H_{intr}}|n,\beta'\rangle = E_\beta^n\delta_{\beta\beta'} \qquad |n,\beta\rangle = \sum_{\nu\alpha} C_{\nu\alpha}^{\beta(n)*}\boldsymbol{Q}_\nu^\dagger|n-1,\alpha\rangle$$

generalized eigenvalue problem in a **overcomplete nonorthogonal basis** $\boldsymbol{Q}_\nu^\dagger|\boldsymbol{n-1,\alpha}\rangle$

D. Bianco, F.K. et al., Phys. Rev. C ***85****, 014313 (2012)*

Equation-of-motion Phonon method (EMPM)

generalized eigenvalue problem in **redundant nonorthogonal basis**

$$(\boldsymbol{A}^{(n)}\ \boldsymbol{D}^{(n)})\ C = E\ \boldsymbol{D}^{(n)}\ C$$

$$(A^{(n)}D^{(n)})_{\nu\alpha,\nu'\alpha'} = \langle n-1,\alpha|\boldsymbol{Q}_\nu \boldsymbol{H}_{intr}\ \boldsymbol{Q}^\dagger_{\nu'}|n-1,\alpha'\rangle \qquad D^{(n)}_{\nu\alpha,\nu'\alpha'} = \langle n-1,\alpha|\boldsymbol{Q}_\nu\ \boldsymbol{Q}^\dagger_{\nu'}|n-1,\alpha'\rangle$$

Generalization of TDA matrix $A^{(n)}_{\nu\alpha,\nu'\alpha'} = (E^{n-1}_\alpha + E^1_\nu) + \mathcal{V}^{(n)}_{\nu\alpha,\nu'\alpha'}$

Overlap matrix $D^{(n)}_{\nu\alpha,\nu'\alpha'} = \delta_{\alpha\alpha'}\delta_{\nu\nu'} + \sum_\beta X^{\alpha\,(n-1)}_{\nu'\beta} X^{\alpha'(n-1)}_{\nu\beta} - \sum_{\substack{(ij)=(p_1p_2)\\(h_1h_2)}} \rho^{(n-1)}_{\alpha\alpha'}(ij)\rho^{(1)}_{\nu\nu'}(ij)$

Phonon amplitudes

$$X^{\alpha\,(n-1)}_{\nu\beta} = \langle n-1,\alpha|\ \boldsymbol{Q}^\dagger_\nu|n-2,\beta\rangle = \sum_{\nu'\beta'} D^{(n-1)}_{\nu\beta,\nu'\alpha'} C^{\alpha(n-1)}_{\nu'\beta'}$$

pp,hh phonon densities

$$\rho^{(n-1)}_{\alpha\alpha'}(pp') = \langle n-1,\alpha|\ \boldsymbol{a}^\dagger_p \boldsymbol{a}_{p'}|n-1,\alpha'\rangle$$
$$\rho^{(n-1)}_{\alpha\alpha'}(hh') = \langle n-1,\alpha|\ \boldsymbol{a}^\dagger_h\ \boldsymbol{a}_{h'}|n-1,\alpha'\rangle$$

Equation-of-motion Phonon method (EMPM)

1-phonon - *n*-phonon interaction

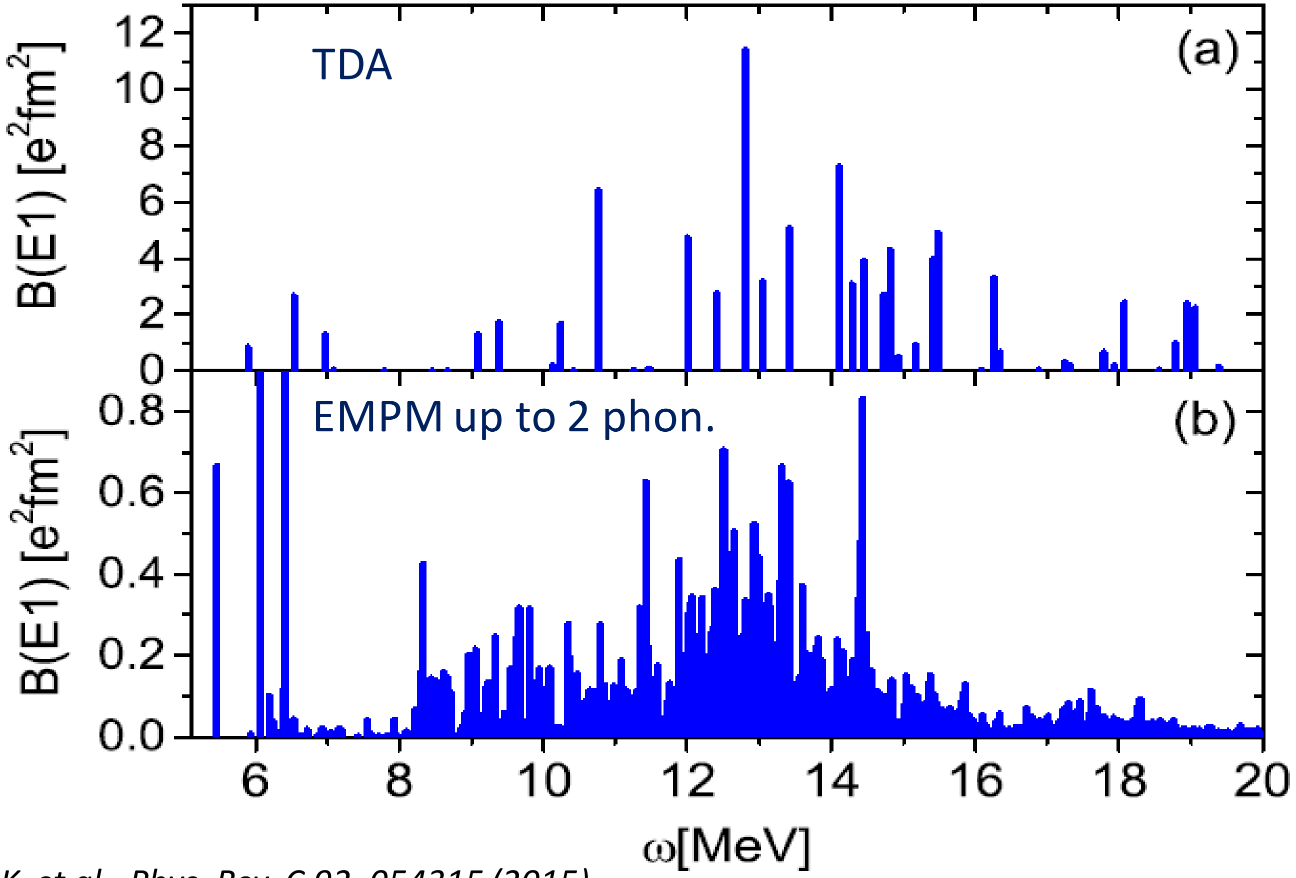
$$\mathcal{V}^{(n)}_{\nu\alpha,\nu'\alpha'} = \sum_{pp'} V^{phon}_{\nu\nu'}(pp')\rho^{(n-1)}_{\alpha\alpha'}(pp') + \sum_{hh'} V^{phon}_{\nu\nu'}(hh')\rho^{(n-1)}_{\alpha\alpha'}(hh')$$

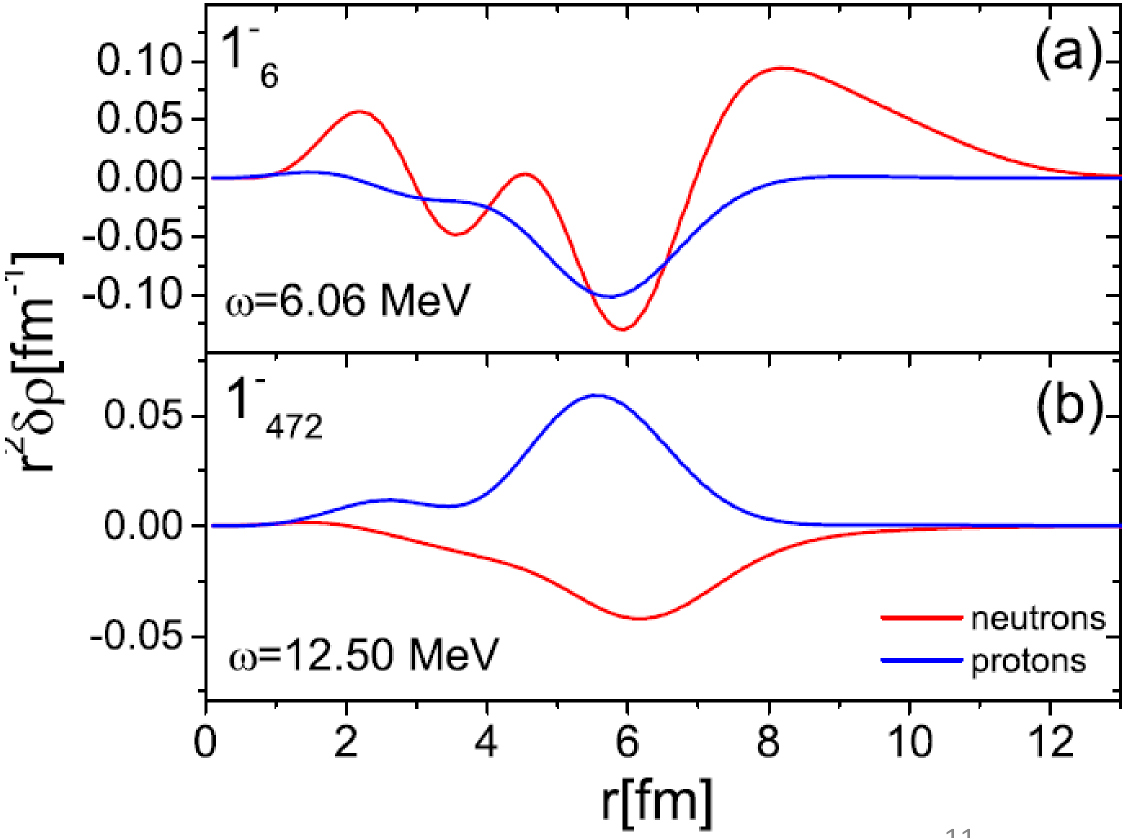
$$V^{phon}_{\nu\nu'}(pp') \sim \sum_{\substack{(ij)=(p_1p_2)\\(h_1h_2)}} V_{pip'j}\rho^{(1)}_{\nu\nu'}(ij) \qquad V^{phon}_{\nu\nu'}(hh') \sim \sum_{\substack{(ij)=(p_1p_2)\\(h_1h_2)}} V_{hih'j}\rho^{(1)}_{\nu\nu'}(ij)$$

$$V_{ijkl} =< ij|\boldsymbol{V}|kl >$$

Dipole strength in ^{208}Pb within EMPM

- calculation with $NNLO_{opt}$ potential (*A. Ekstrom et al., Phys. Rev. Lett. 110, 192502 (2013)*) + phenomenological correction
- model space truncation → 2 phonon states $[Q_1^+ \times Q_2^+]^{1-}$ → TDA phonons with $E_\lambda < 30$ MeV
- Pygmy character of particular states around 6-7 MeV
- fragmentation of the E1 strength into many transitions



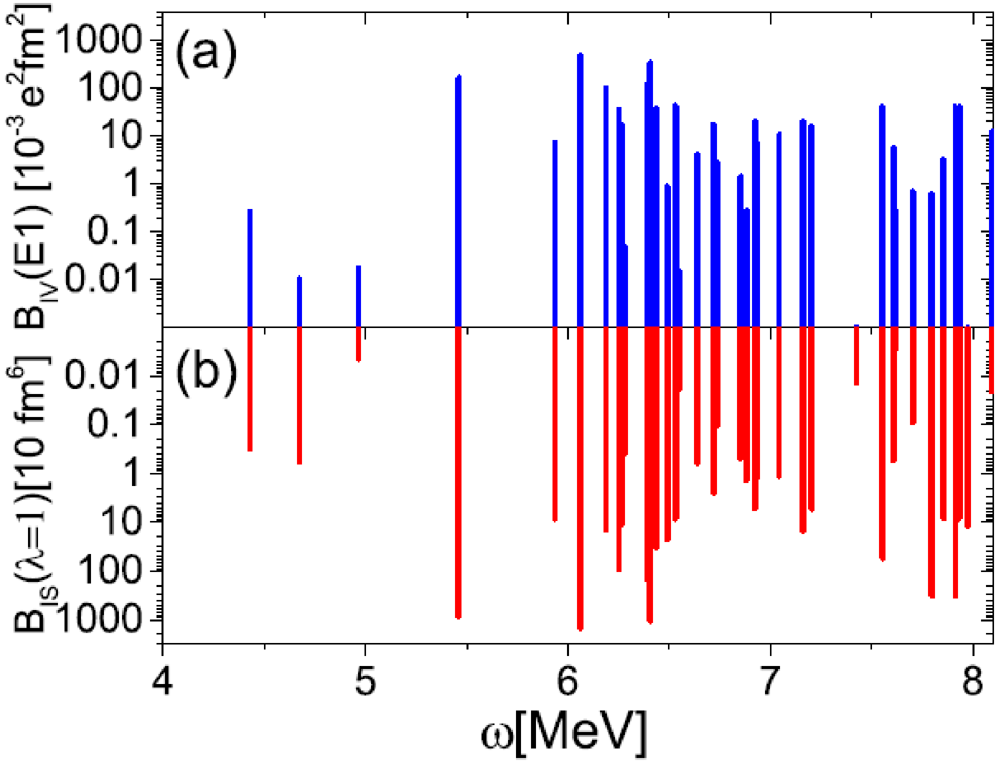


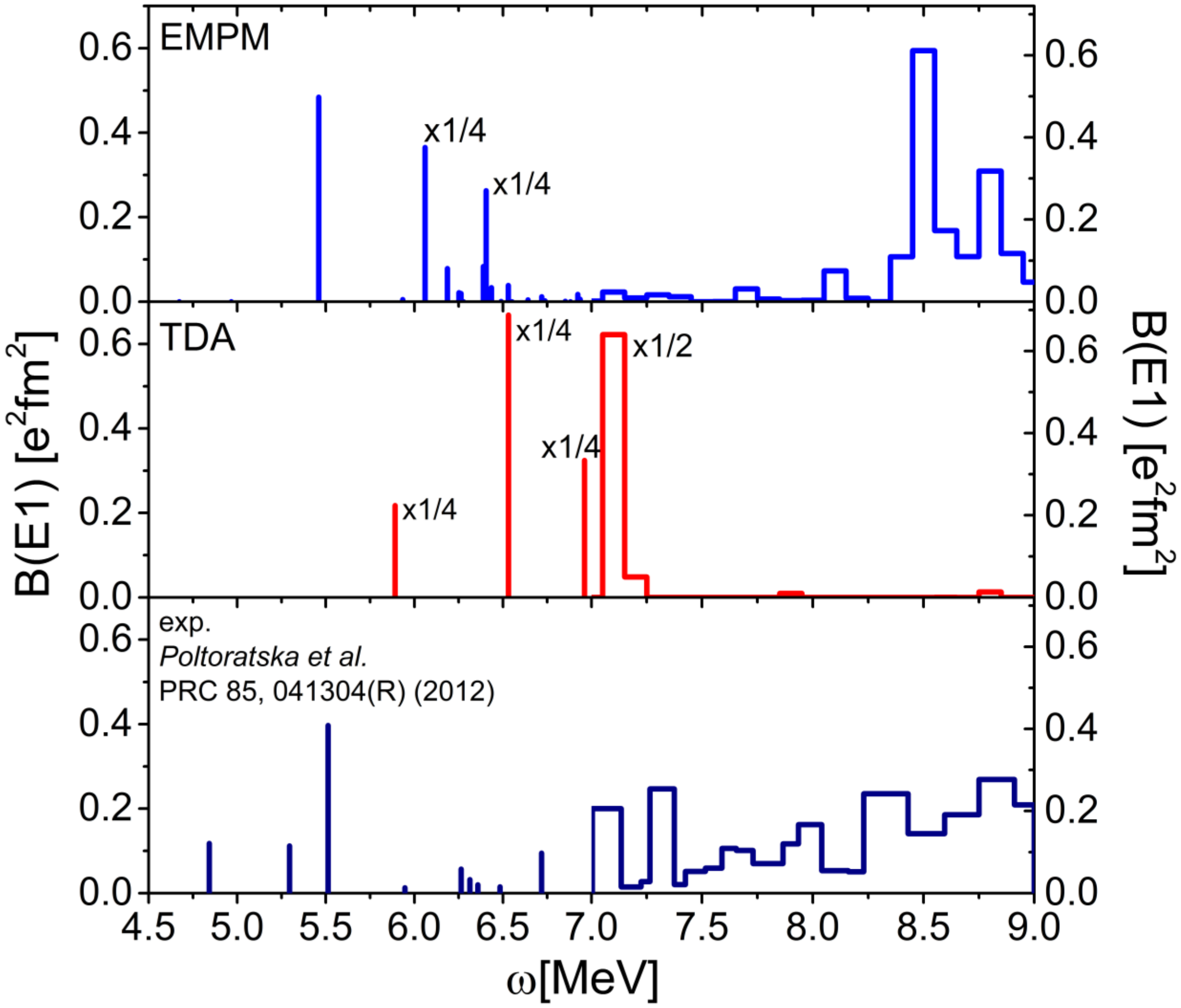
F.K. et al., Phys. Rev. C 92, 054315 (2015)

Dipole transitions in ^{208}Pb within EMPM

- EMPM predicts strength in the region 7-9 MeV, TDA/RPA does not.
- density of states reasonable but lowest states too strong

Possible improvement → suppression of 1phonon components due to the <1|H|3> phonon coupling





F.K. et al., Phys. Rev. C 92, 054315 (2015)

EMPM for odd systems

Odd nucleus: valence particle (hole) + even-even closed-shell core

→ **particle(hole)-phonon coupling**

densities, energies, amplitudes calculated for even-even core within EMPM

- diagonalization of Hamiltonian in nonorthogonal overcomplete basis → particle x *n*-phonon

$\boldsymbol{a_p^+|HF\rangle}$
$\boldsymbol{a_p^+|n=1,\alpha\rangle}$
$\boldsymbol{a_p^+|n=2,\beta\rangle}$

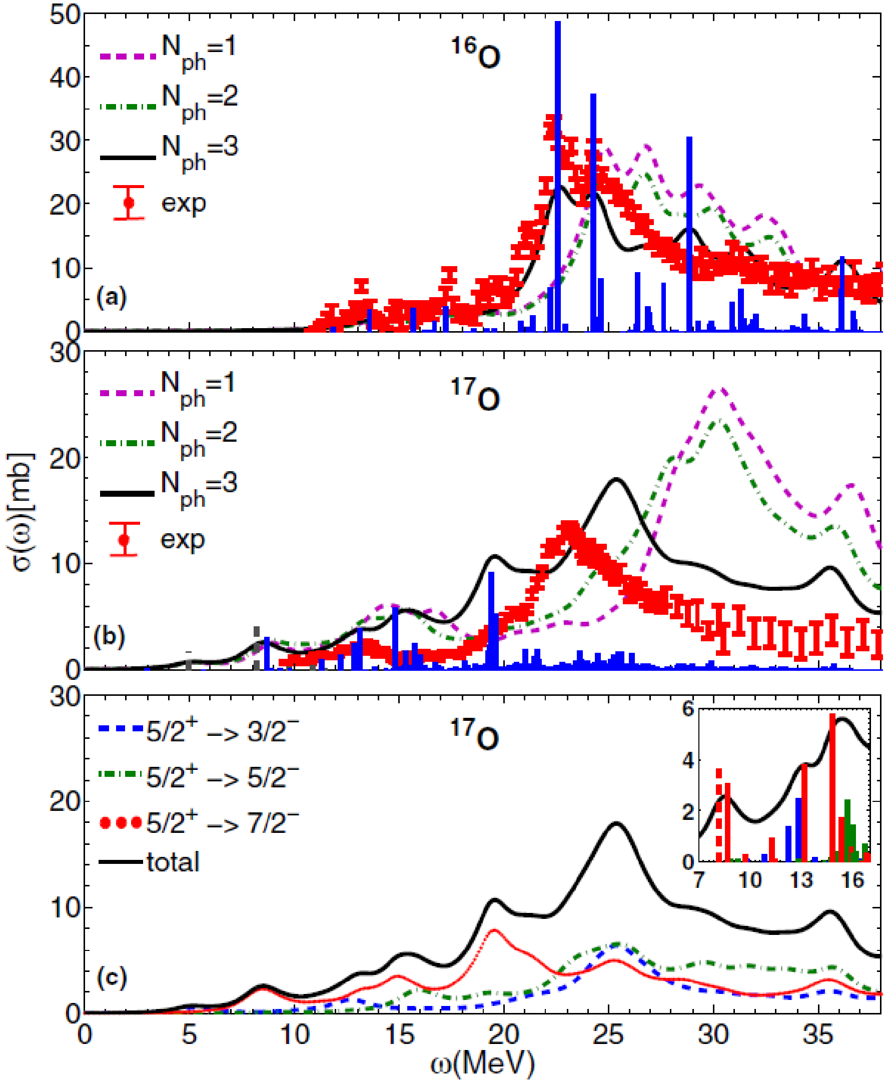
$$\langle n,\alpha|[\boldsymbol{H_{intr}},\boldsymbol{a_p^+}]|n,\nu\rangle = (E_\nu^n - E_\alpha^n)\langle n,\alpha|\boldsymbol{a_p^+}|n,\nu\rangle$$

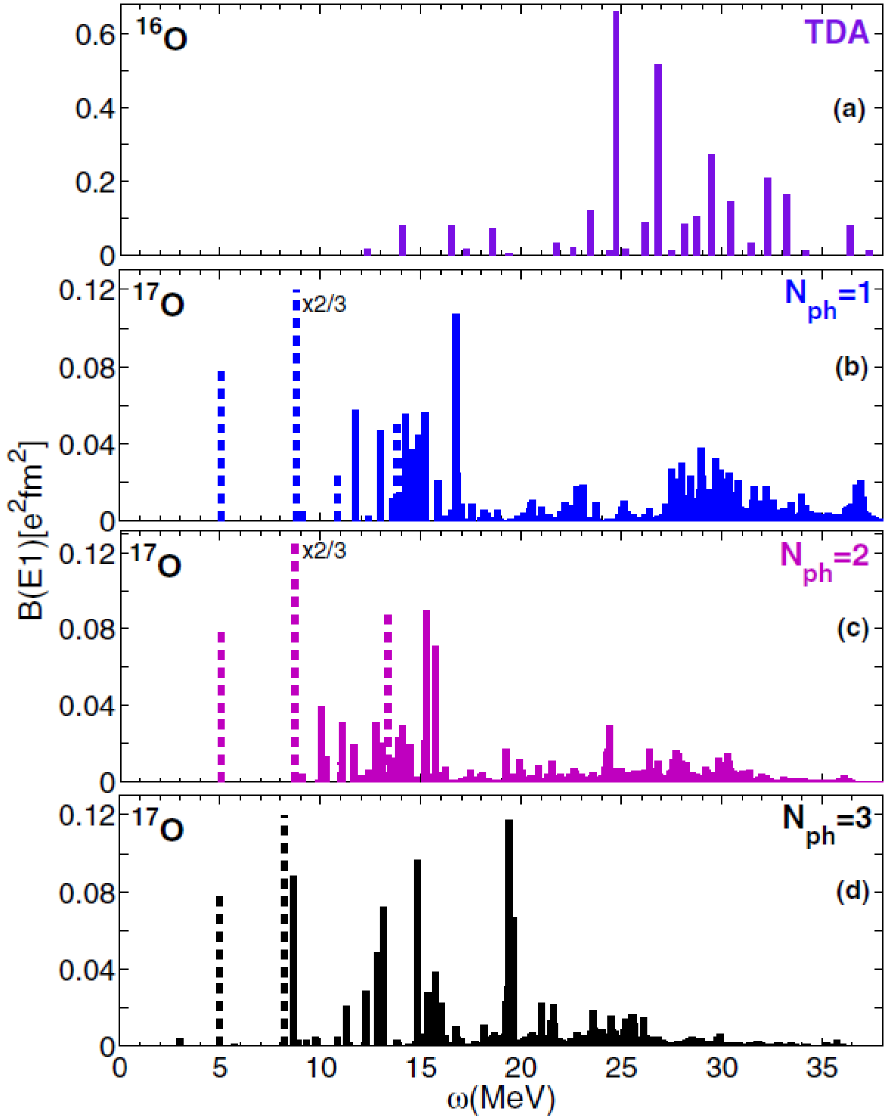
n-phonon state of even-even core

particle - *n*-phonon eigenstate of odd-even nucleus

EMPM: particle-phonon coupling

- exact treatment computationally demanding → 3-phonon subspace - diagonal approximation
- <1|H|2> phonon coupling weaker than <1|H|3>





G. De Gregorio, F.K.,N. Lo Iudice and P. Veselý, Phys. Rev. C 95, 034327 (2017), Phys. Rev. C 97, 034311 (2018)

CM problem in microscopic nuclear models

CM problem is inherently present in all microscopic calculations (except few methods)

Some approaches avoid the CM problem

- ***few body systems*** - Jacobi coordinates – feasible just for the lightest systems
- ***Ab-initio No-core shell model (NCSM)***

  exact factorization of intrinsic and CM function in **HO sp. basis only** (complete set of N_{max} basis states)

Plethora of ***approximative methods*** developed for more or less specific situations

some examples:

- **Shell model**: *G.H. Gloeckner, R.D. Lawson, Phys. Lett B **53**, 313 (1974)*
- **RPA**: *F. Dönau, Phys. Rev. Lett. **94**, 092503 (2005)*
- **Nuclear level densities**: *M. Horoi and V. Zelevinsky Phys. Rev. Lett. **98**, 262503 (2007)*
- **Coupled-cluster**: *G. Hagen, T. Papenbrock, and D.J. Dean Phys. Rev. Lett. **103**, 062503 (2009)*
- **QRPA**: *A. Repko, J. Kvasil, V. O. Nesterenko, Phys. Rev. C**99**,044307 (2019)*
- **EMPM:** *G. De Gregorio, F. Knapp, N. Lo Iudice, P. Veselý, Phys. Lett. B **821**, 136636 (2021)*
- **ERPA, TBA**: *V. Tselyaev, arXiv:2209.06935 [nucl-th] (2022)*
- …

A note about CM correction in the Hartree-Fock approximation

Hartree-Fock (HF) approximation for a many-body Hamiltonian with 2-body interaction

$$\boldsymbol{H} = \sum_{i=1}^{A} \frac{\boldsymbol{p}_i^2}{2m} + \sum_{i<j}^{A} \boldsymbol{V}_{ij}^{(2)} \quad = \boldsymbol{H}_{intr} + \boldsymbol{T}_{CM} \qquad \boldsymbol{T}_{CM} = \frac{\boldsymbol{P}^2}{2Am}$$

CM subtraction → intrinsic Hamiltonian important to get spurious states close to zero energy

$$\boldsymbol{H}_{intr} \equiv \boldsymbol{H} - \boldsymbol{T}_{CM} = \frac{1}{A} \sum_{i<j} \frac{(\boldsymbol{p}_i - \boldsymbol{p}_j)^2}{2m} + \sum_{i<j}^{A} \boldsymbol{V}_{ij}^{(2)} \quad = \left(1 - \frac{1}{A}\right) \sum_{i=1}^{A} \frac{\boldsymbol{p}_i^2}{2m} + \sum_{i<j}^{A} \left(\boldsymbol{V}_{ij}^{(2)} - \frac{\boldsymbol{p}_i \cdot \boldsymbol{p}_j}{Am}\right)$$

- single-particle wave functions **depend** on the form of $\boldsymbol{H}_{intr}$ (2-body or (1+2)-body) but **HF energy does not!**
  Khadkikar, Kamble, Nucl. Phys A225, 352 (1974)., Jaqua et al, Phys. Rev. C46, 2333(1992)

- many-body perturbation corrections and RPA energies **depend on the choice of $\boldsymbol{H}_{intr}$**
  (residual interaction not included consistently)

- if the residual interaction is fully taken into account results (e. g. in exact diagonalisation) results are **the same**!

Spurious states in RPA

- mean-field → symmetry breaking → **existence of spurious solutions**

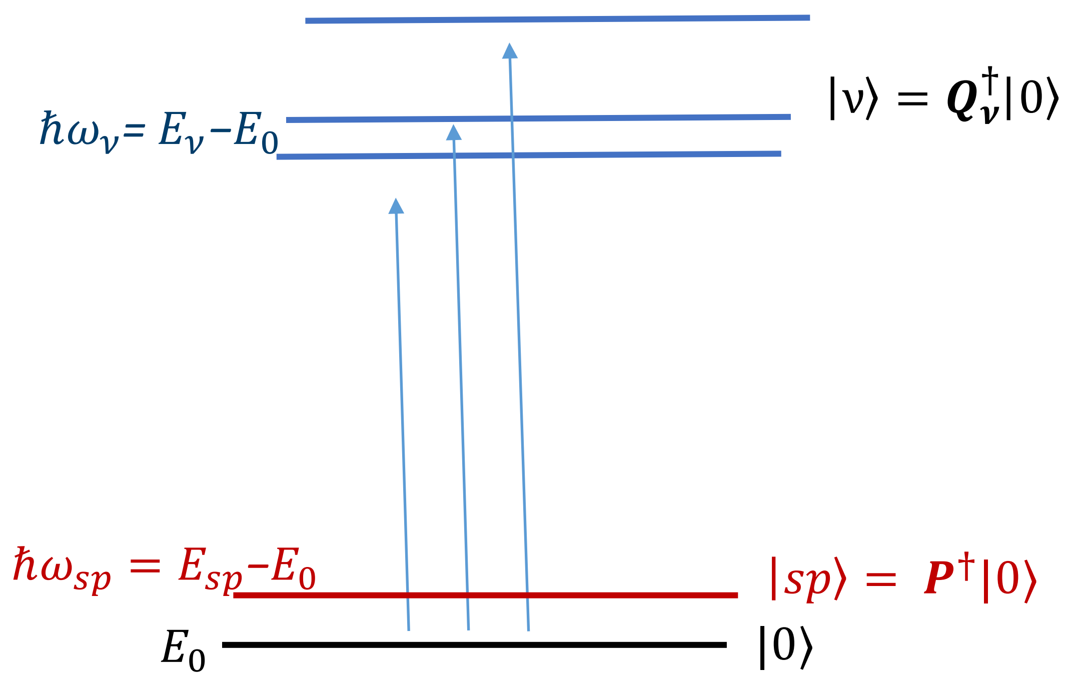
$\hbar\boldsymbol{\omega_{sp}} = \mathbf{0}$ in **RPA,** $\hbar\boldsymbol{\omega_{sp}} \neq \mathbf{0}$ in **TDA**

→ separation is far from perfect in many **RPA** calculations (finiteness of the model space) → mixing with physical states

Center-of-mass (CM) motion → contamination of low-lying dipole states

CM motion treatment in TDA and EMPM

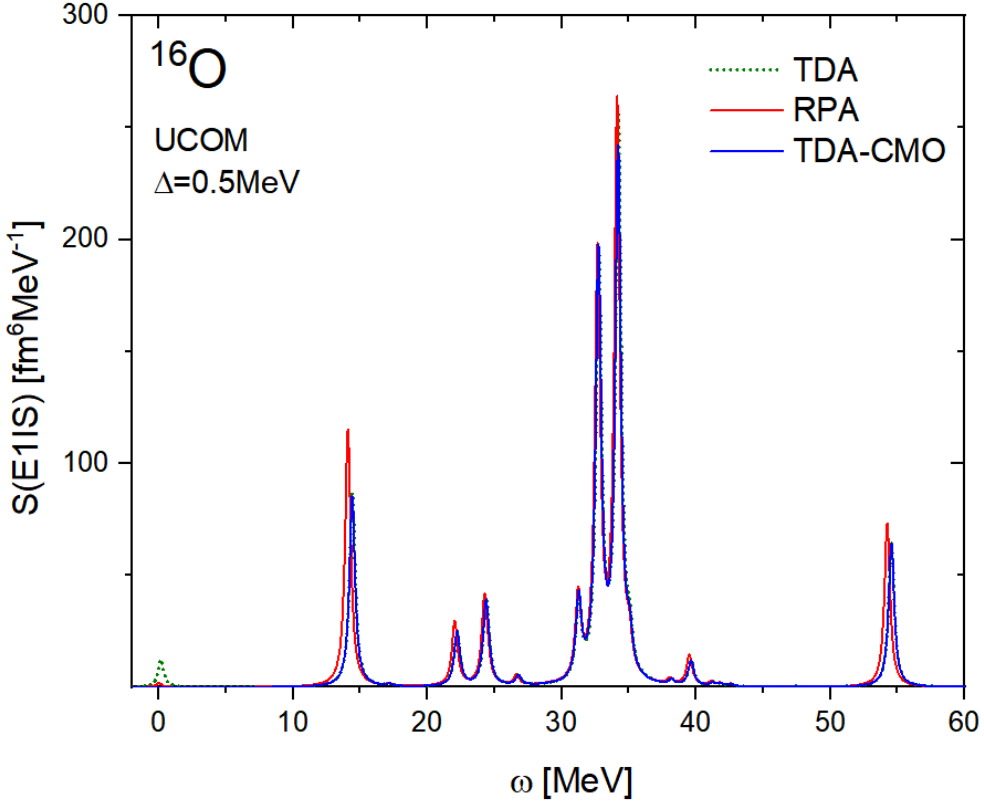
1. we construct 1-phonon basis $\{|\alpha\rangle\}$ orthogonal to the CM mode $\boldsymbol{P}^{\dagger}|0\rangle \leftrightarrow \langle\alpha|\boldsymbol{P}^{\dagger}|0\rangle$=0

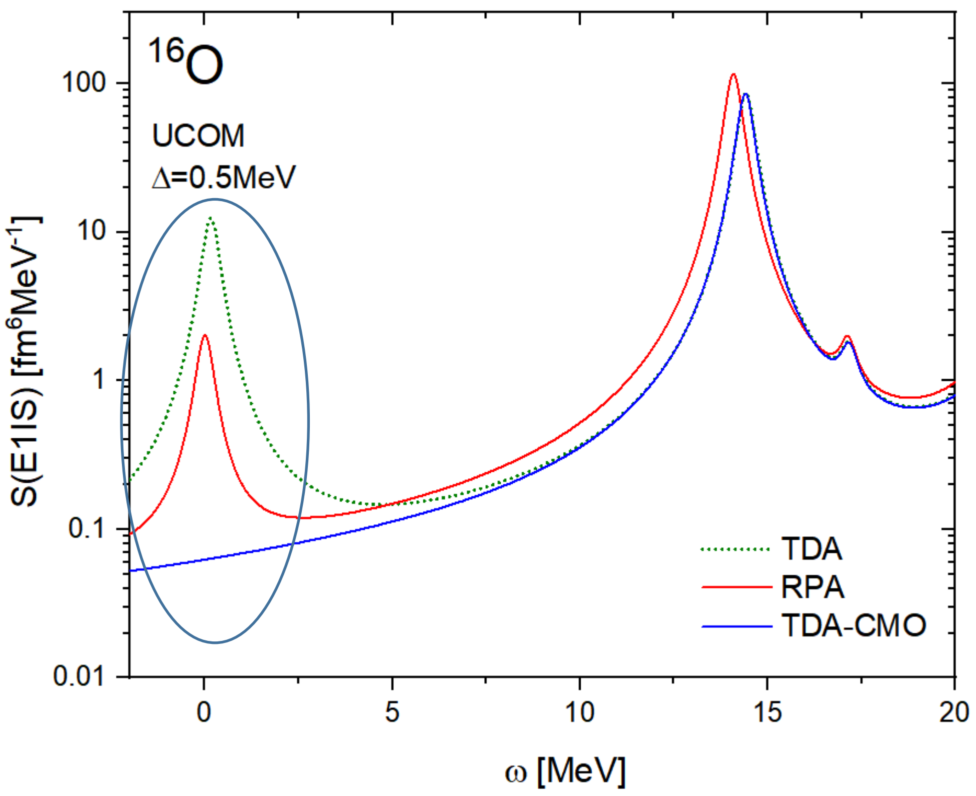


CM problem in 1-phonon models (RPA/TDA)

- closed-shell nuclei: CM mode contaminates $J^{\pi}=1^{-}$ excitation spectrum
- RPA: subtraction of CM contribution from transition operators only
  → wave functions contain CM admixtures, which are small if $\hbar\omega_{CM} << \hbar\omega_{\nu}$

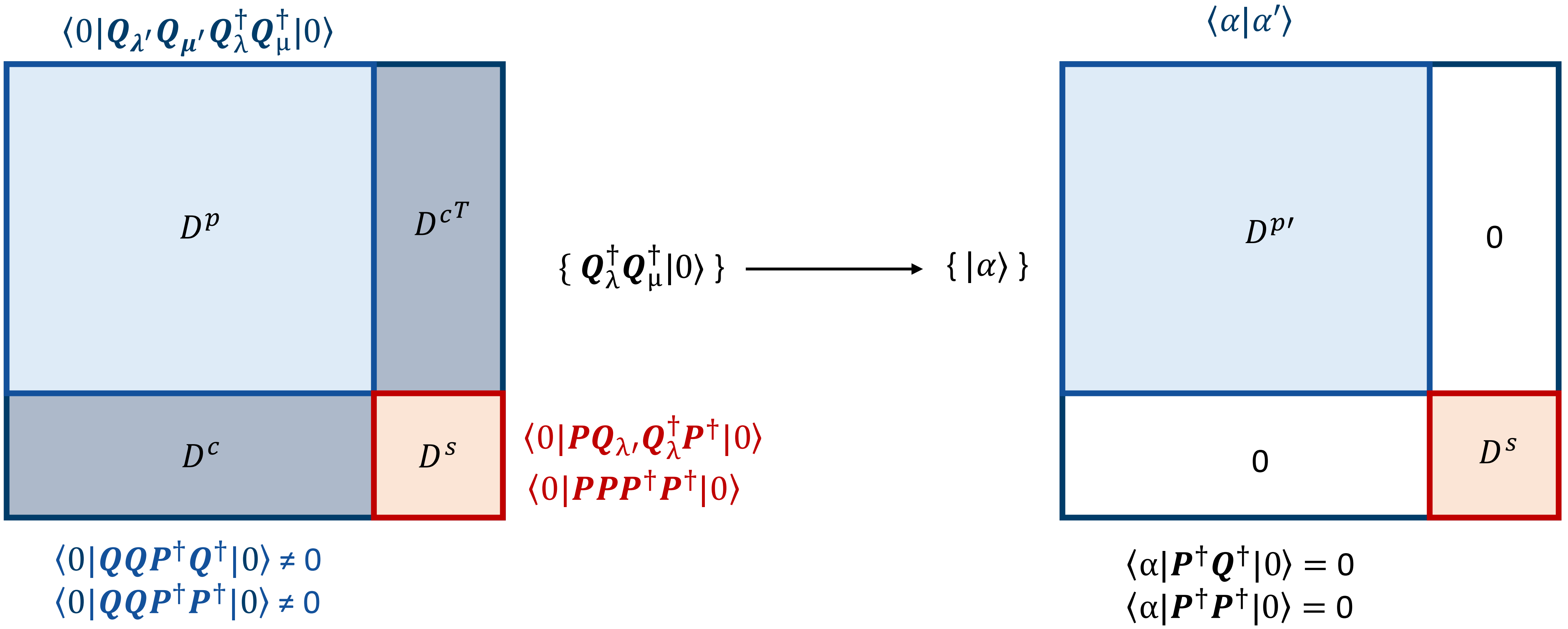
E1 transitions $\quad M(\mathrm{E1IS}) \sim e\sum_{i=1}^{A}(r_i^3 - \frac{5}{3} < r_i^2 >)\,Y_{1M} \quad M(\mathrm{E1IV}) \sim e\frac{N}{A}\sum_{i=1}^{Z} r_i Y_{1M} - e\frac{Z}{A}\sum_{i=1}^{N} r_i Y_{1M}$





Elimination of spurious states in EMPM for n>1

- advantage of phonon basis → we know source of the spuriosity
- construction of spurious-free basis decoupled from spurious subspace (for *n>1*)



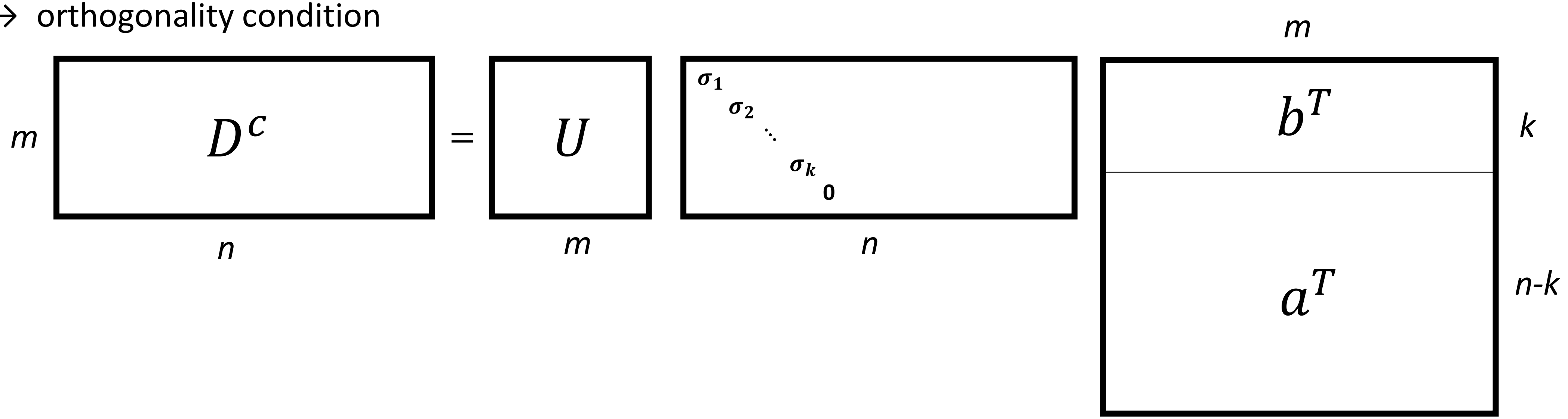
→ **singular value decomposition (SVD) of the overlap submatrix D^{c}**

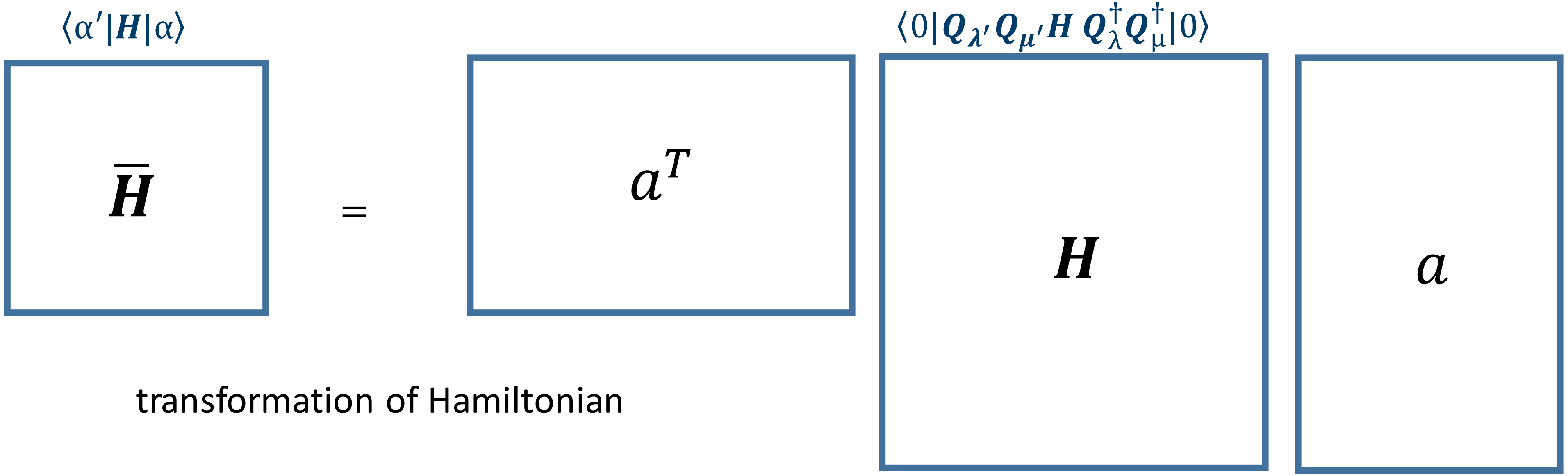
→ diagonalization of $\boldsymbol{H}_{intr}$ in spurious-free basis

Elimination of spurious states in EMPM

- SVD of real *m* x *n* matrix $\boldsymbol{D^c}$: $\boldsymbol{D^c} = \boldsymbol{U\Sigma V^T}$, where $\boldsymbol{U}$ and $\boldsymbol{V}$ are orthogonal matrices
- Right singular vectors $\boldsymbol{V}$ corresponding to zero singular values span the null space(kernel) of $\boldsymbol{D^c}$

  $\boldsymbol{D^c}a = 0 \leftrightarrow$ orthogonality condition





transformation of Hamiltonian

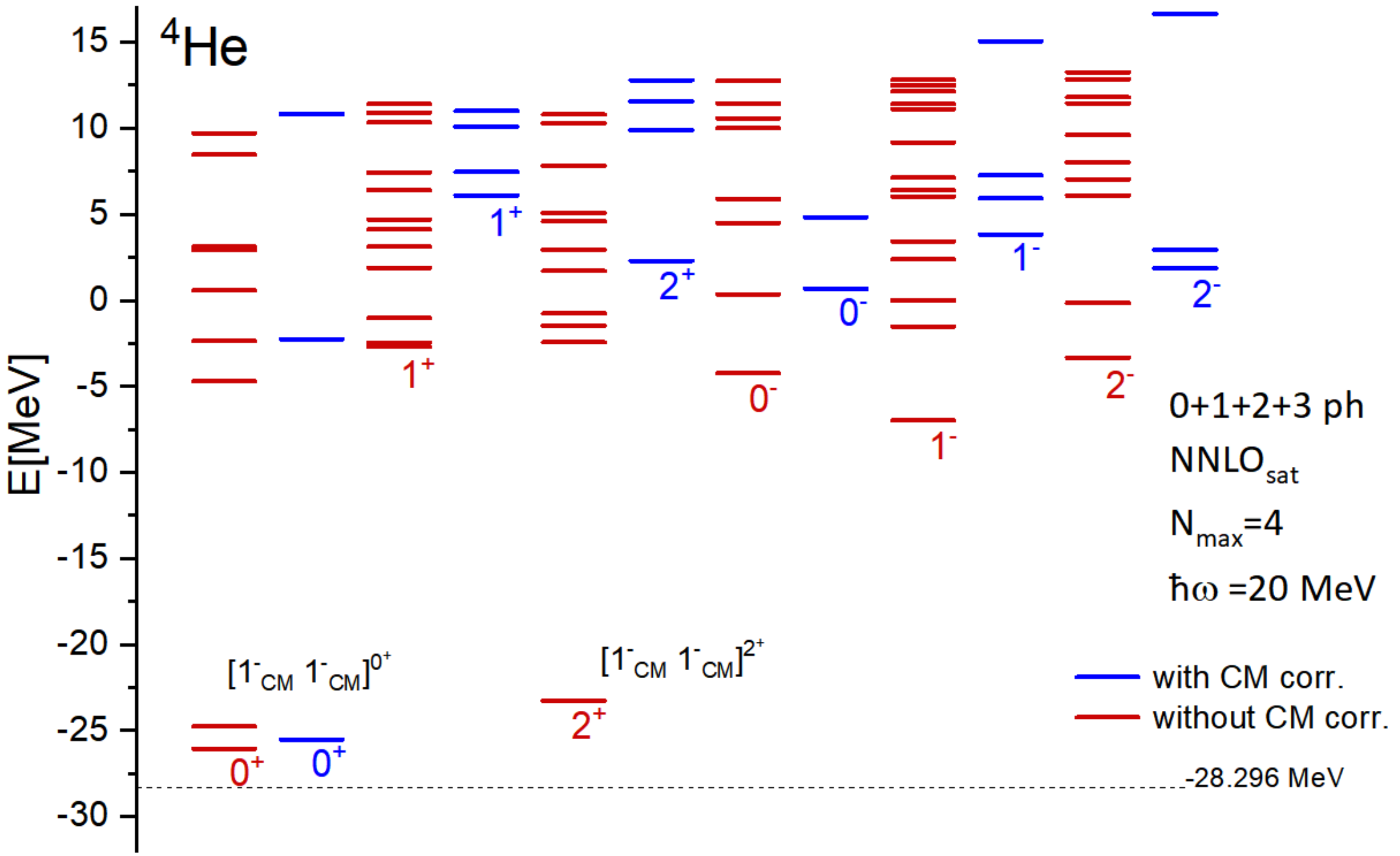
Test of SVD-CMO

Spectrum of ^{4}He calculated up to 3-phonons

G. De Gregorio, F. K. et al., Phys. Lett. B ***821****, 136636 (2021)*

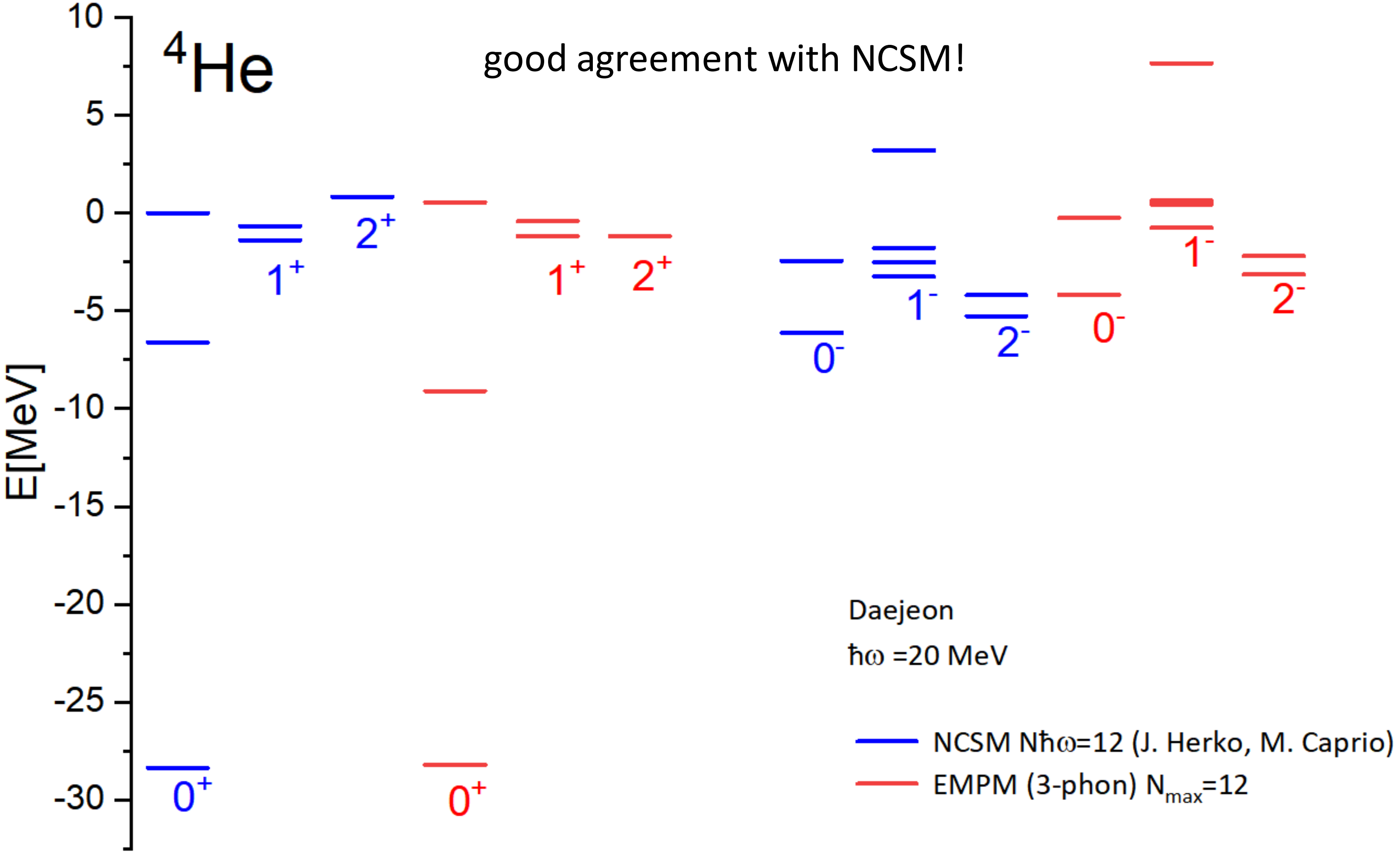
G. De Gregorio, F. K. et al., Phys. Rev. C ***105****, 024326 (2022)*

- spurious states for all spins and both parities
- is the removal procedure correct and effective? → comparison with NCSM



EMPM-CMO vs. NCSM

- NCSM and EMPM model spaces are different (HF vs HO sp. basis, phonon vs. $N\hbar\omega$ truncation)
- approximative calculation of 3-phon. subspace in EMPM (we neglected the interaction between 3-phon. states)

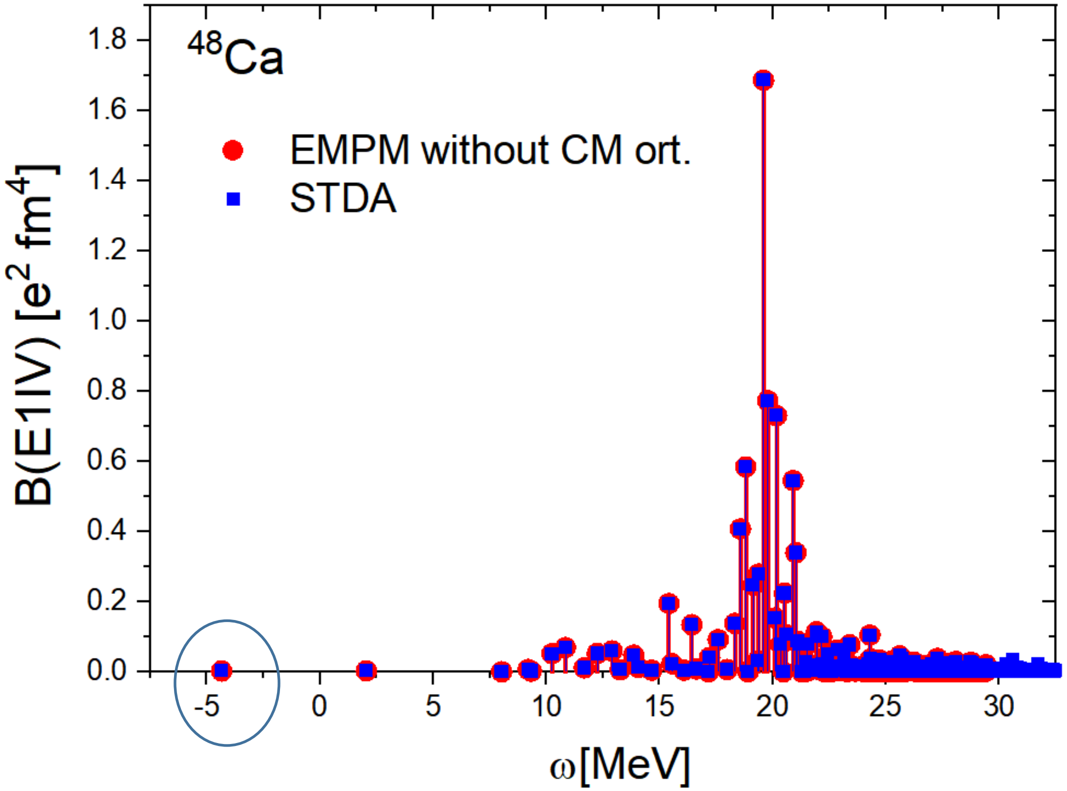


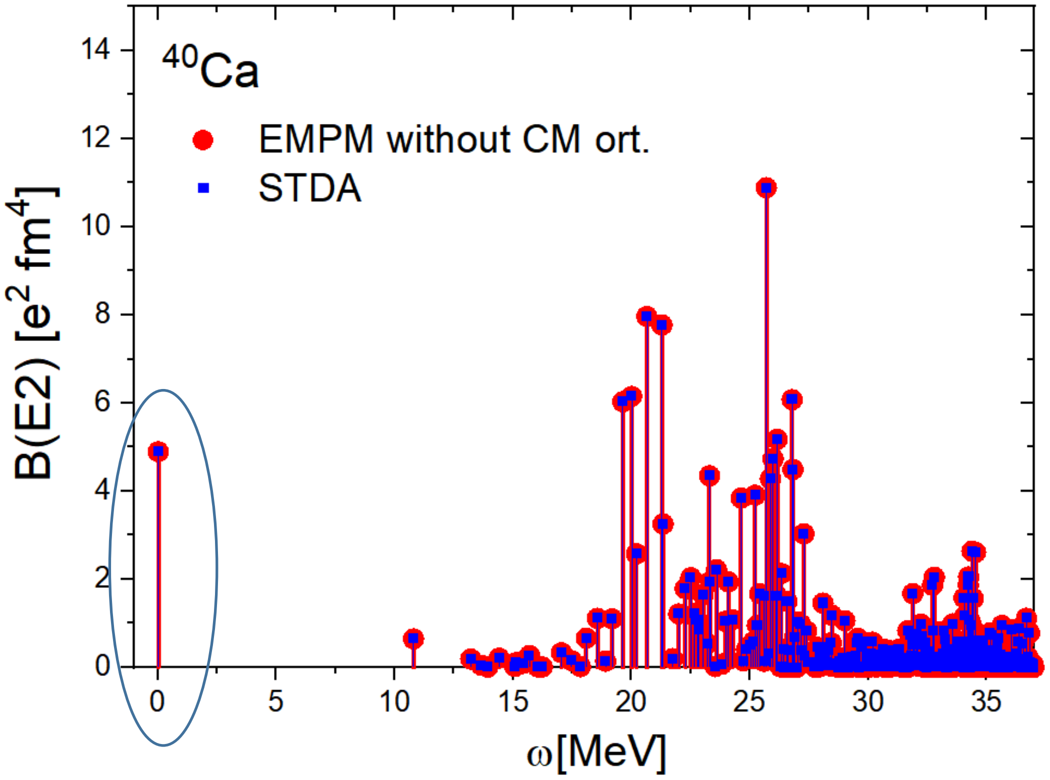
EMPM-CMO vs. EMPM/STDA/SRPA

→ independent benchmark with large-scale SRPA/STDA calculations

→ electric responses in ^{16}O,^{40}Ca,^{48}Ca with UCOM potential

P. Papakonstantinou and R. Roth, Phys. Rev C 81, 024317 (2010)





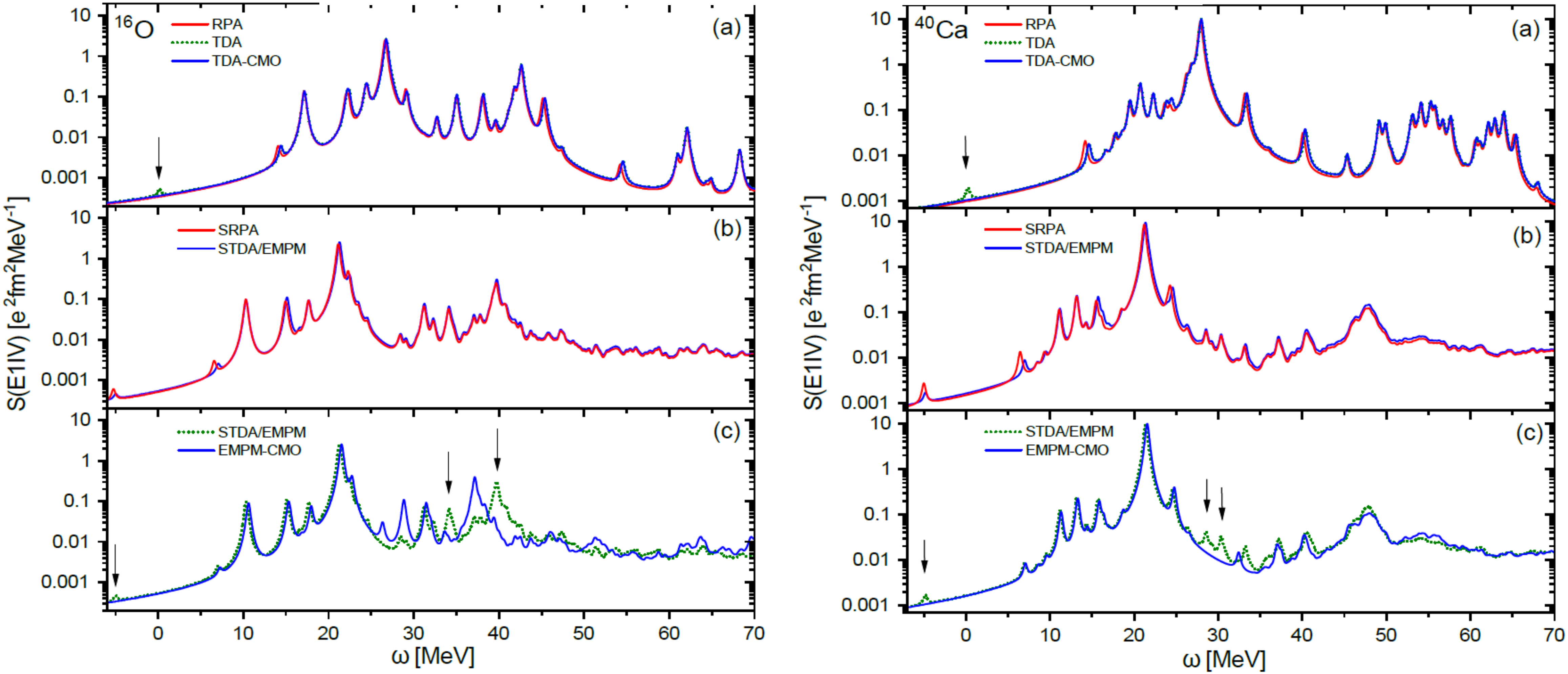
→ **EMPM** (1+2 phonon without CMO) **and STDA are equivalent (numerical „proof“)** in complete model space (no truncation of *2p-2h* or 2-phonon basis) for all multipolarities

→ **the same spurious states in STDA and EMPM**

EMPM-CMO vs. EMPM/STDA/SRPA

What is the effect of CMO on strength distributions?

$$S(E\lambda,\omega) = \sum_f B(E\lambda, i \to f)\delta(\omega - \omega_f) \approx \sum_f B(E\lambda, i \to f)\rho_\Delta(\omega - \omega_f)$$



F. Knapp, P. Papakonstantinou et al., in preparation

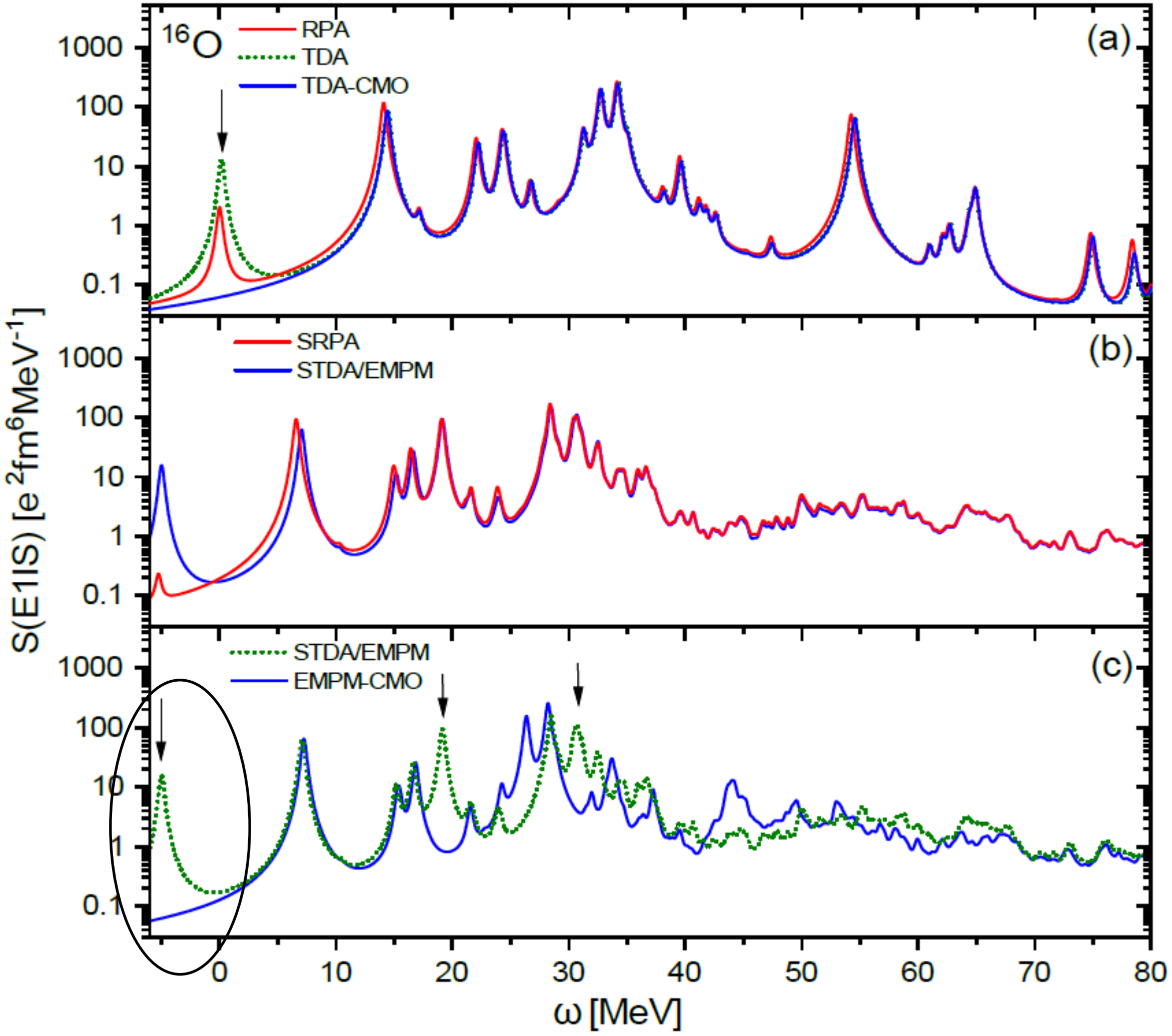
EMPM-CMO vs. EMPM/STDA/SRPA

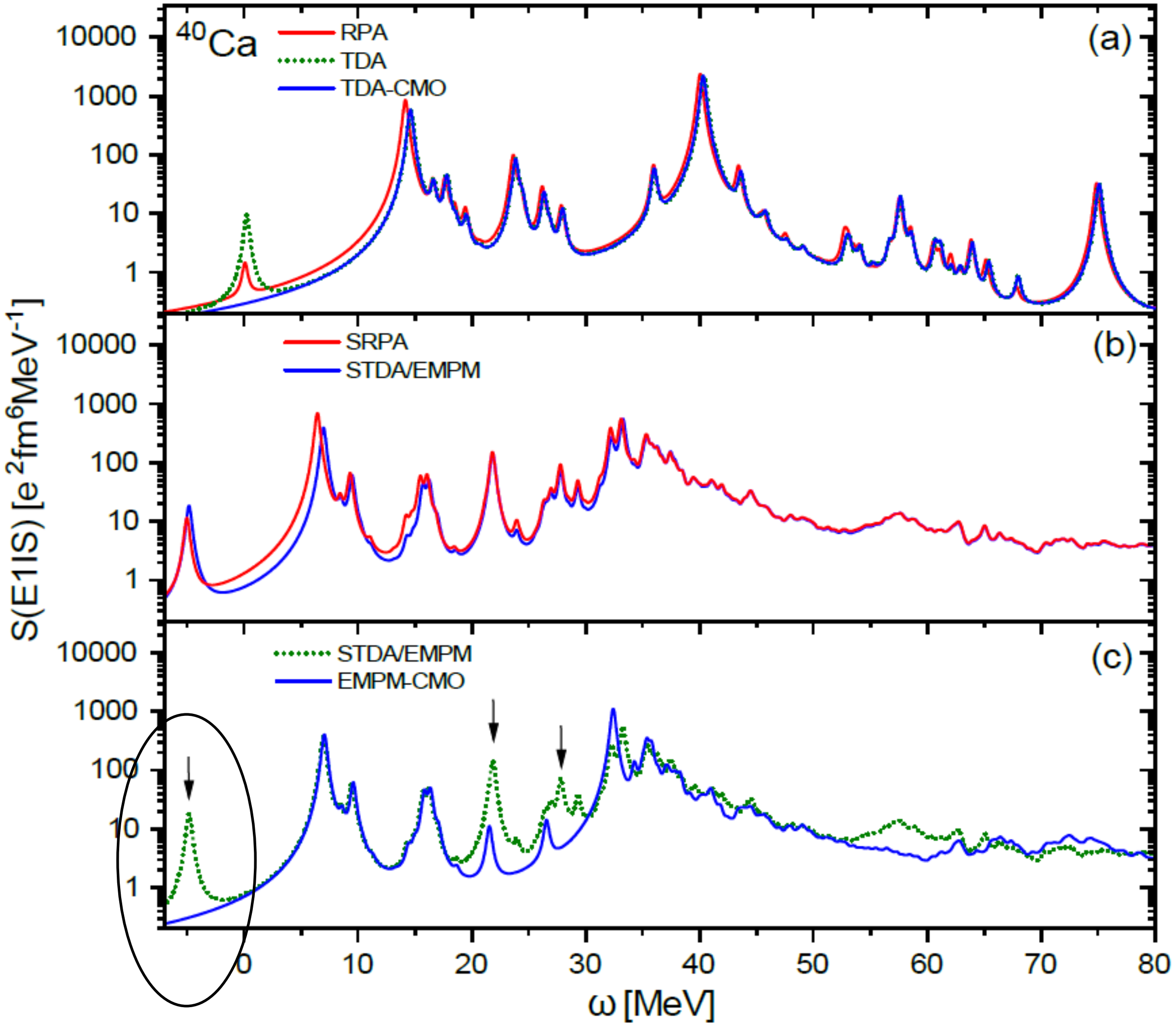
Isoscalar E1 sensitive to CM spurious states

EMPM-CMO: contribution from CM correction of the transitions operator is 0

STDA/EMPM states with negative energy disappear

$$M(\mathbf{E1IS}) \sim e\sum_{i=1}^{A}\left(r_i^3 - \frac{5}{3} < r_i^2 >\right) Y_{1M}$$





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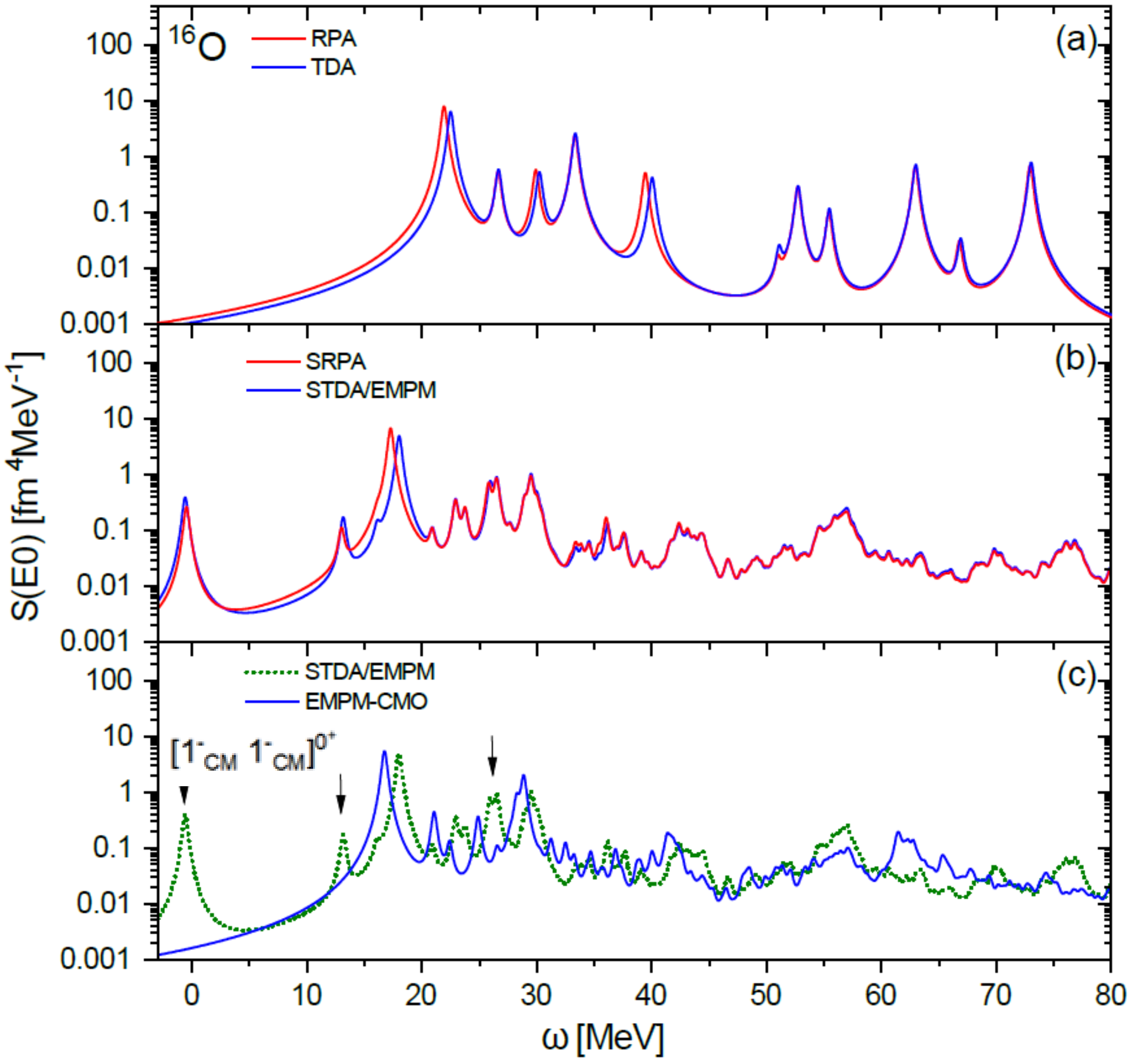
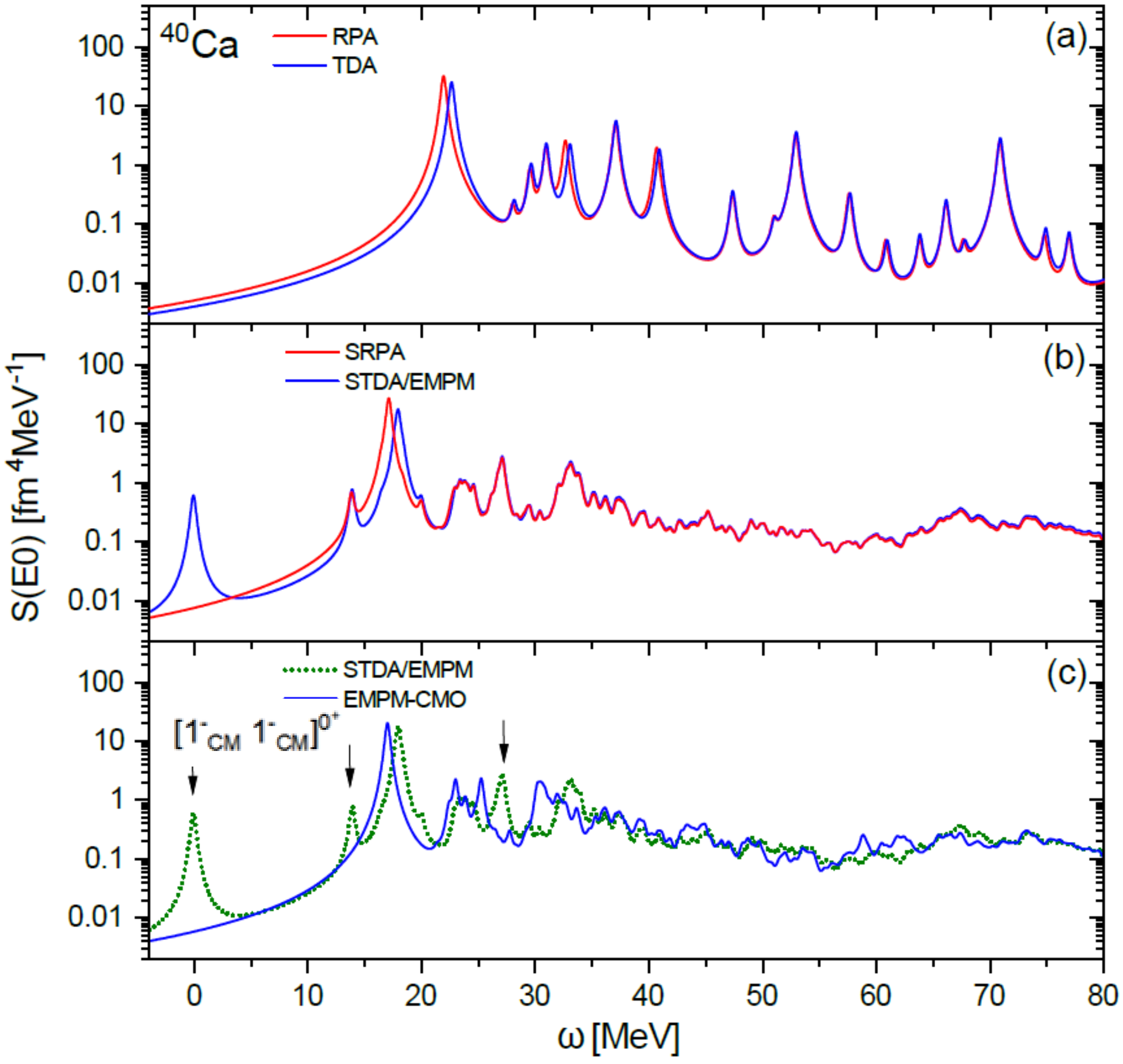
EMPM-CMO vs. EMPM/STDA/SRPA

(Not?) surprisingly the E0 response is affected as well.





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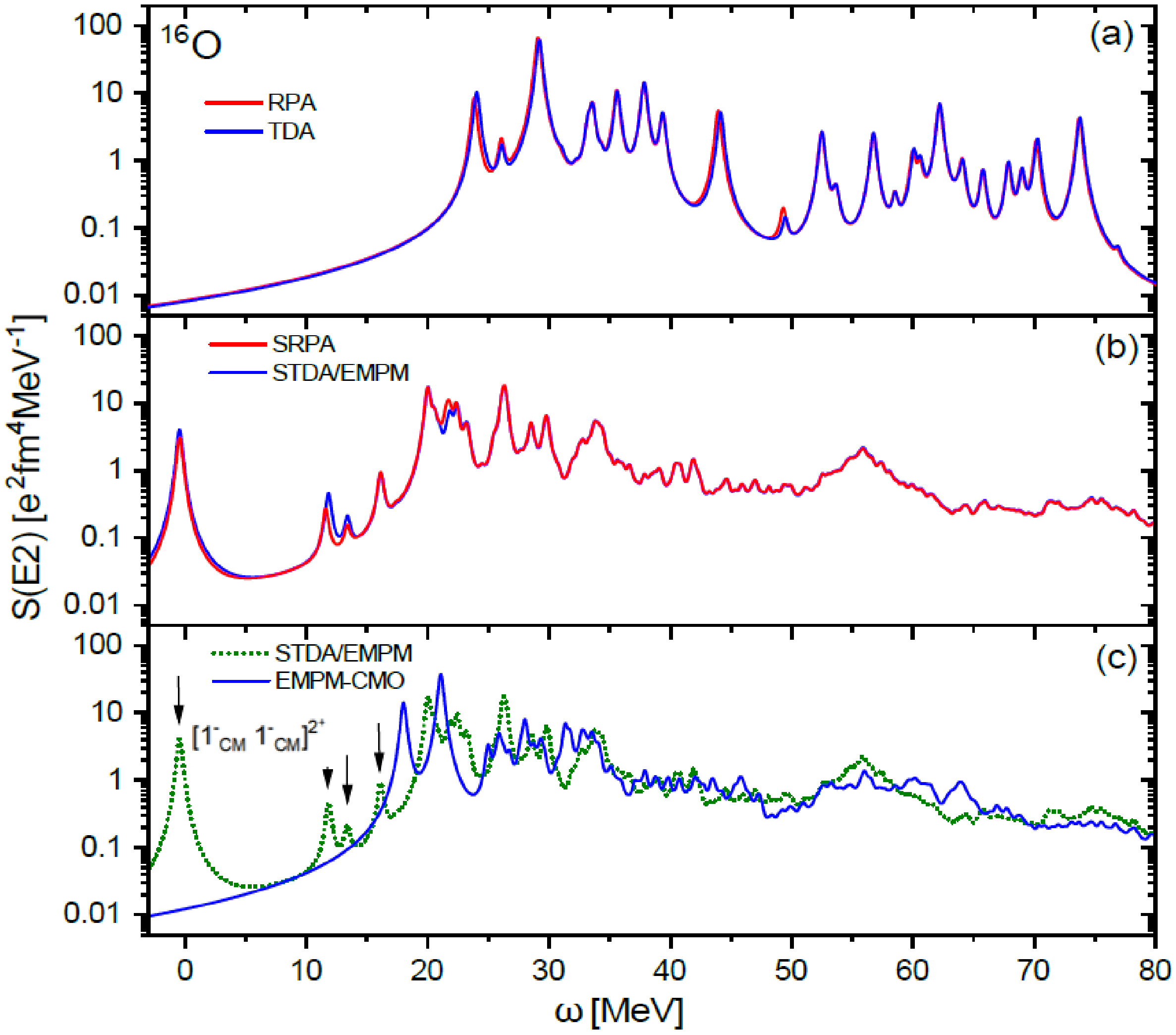
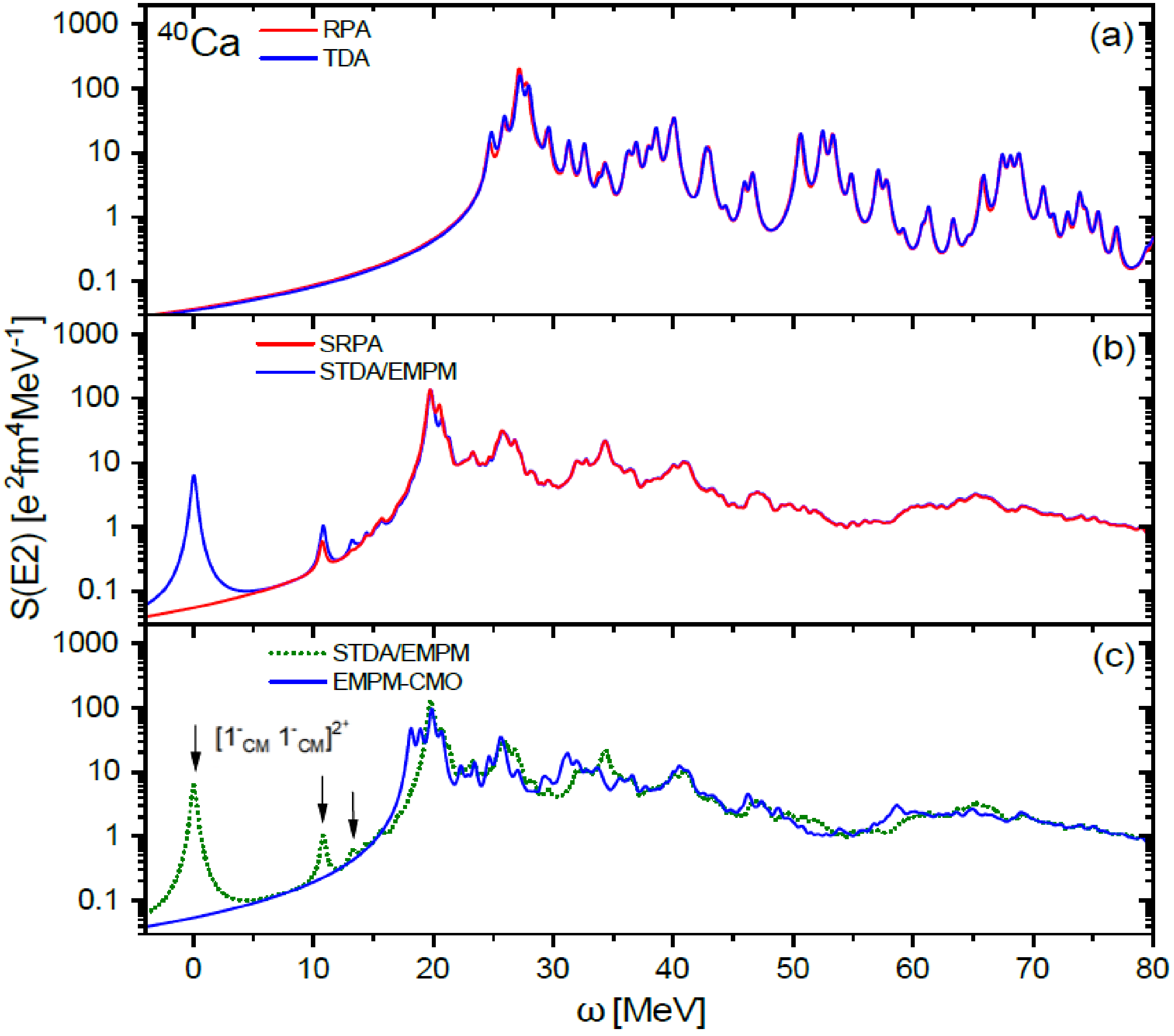
… and so the E2





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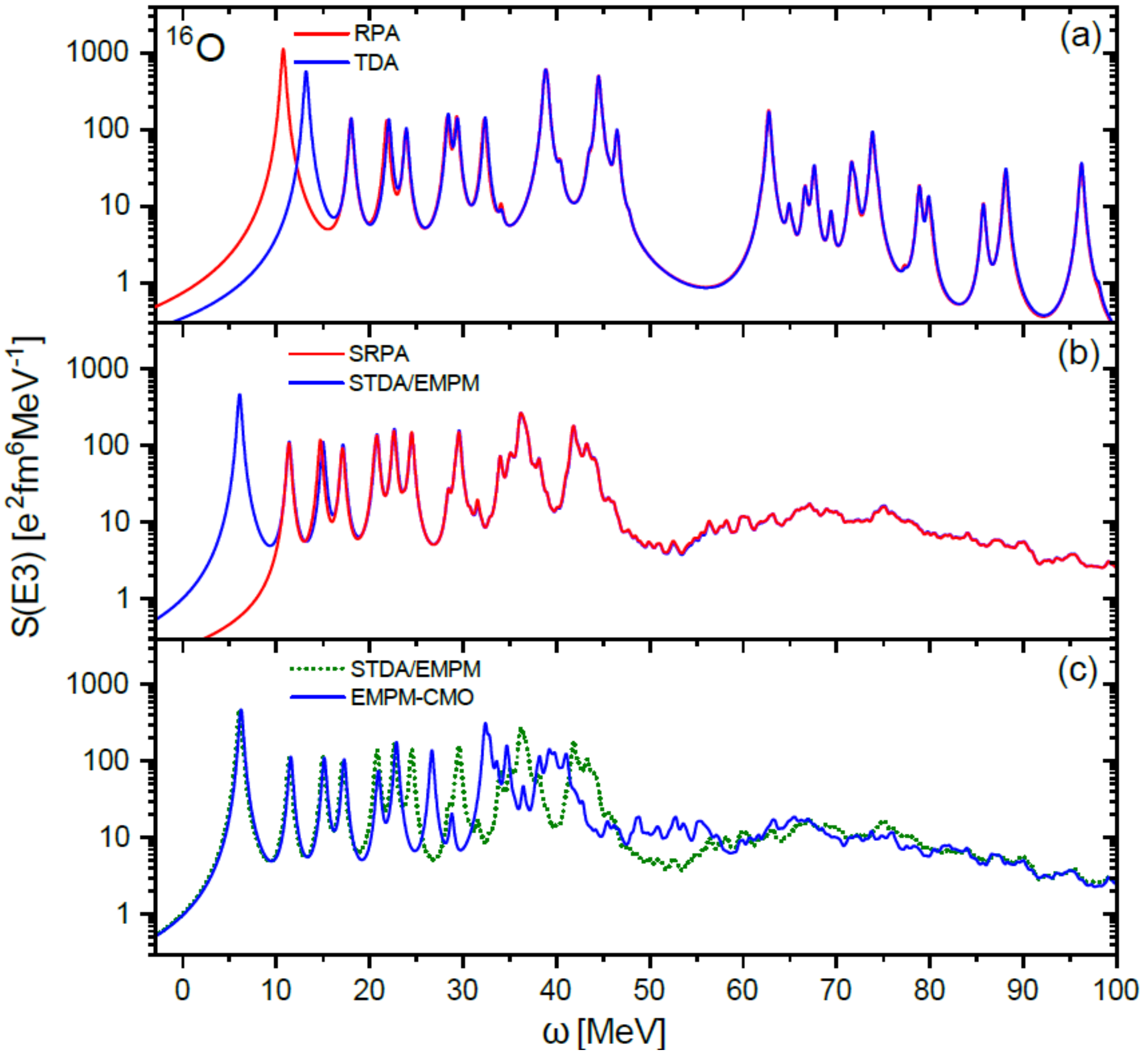
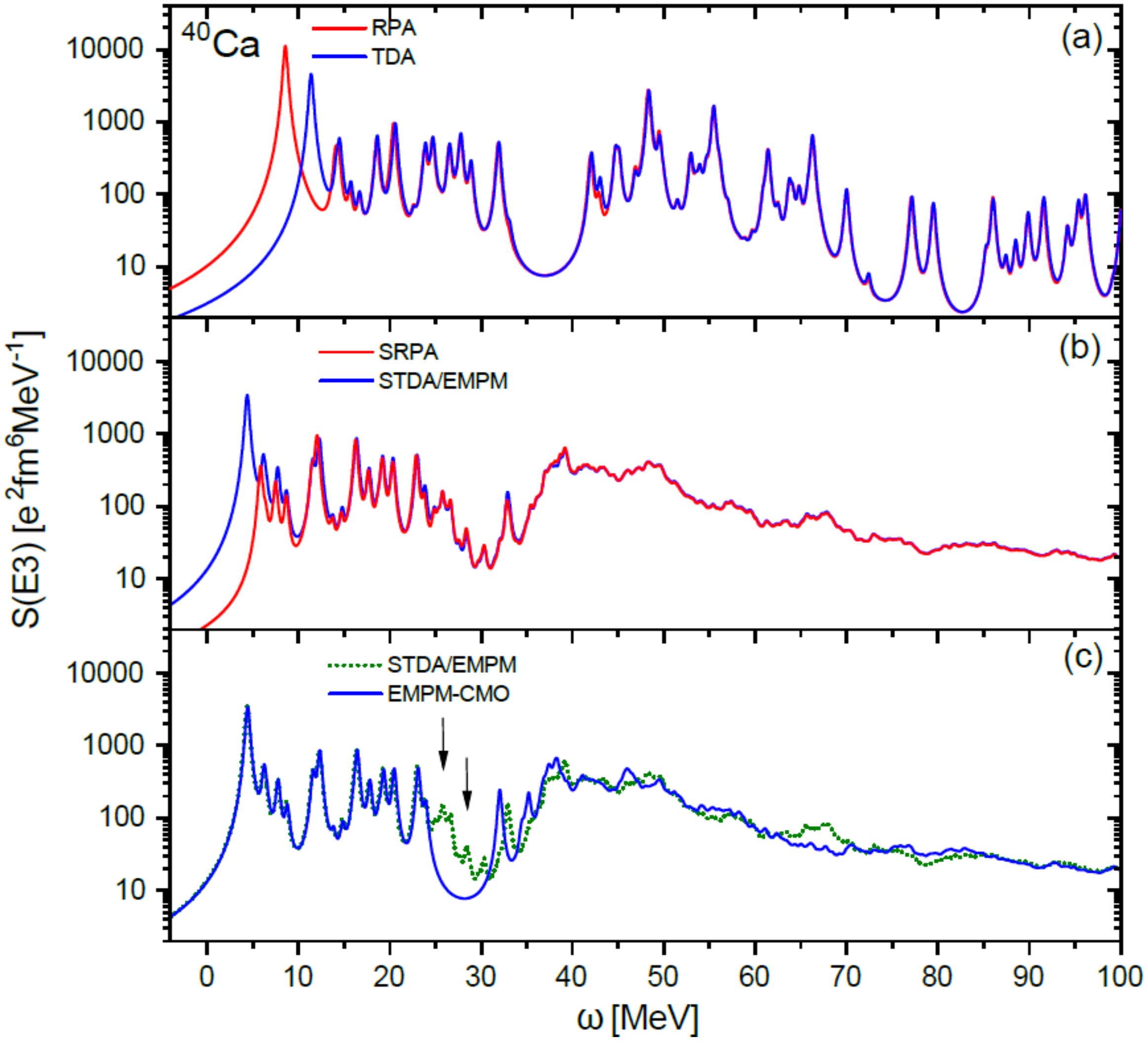
EMPM-CMO vs. EMPM/STDA/SRPA

E3 is the only response where SRPA/STDA differ significantly, but only in low-energy part

Lowest peak disappears from SRPA response because it corresponds to imaginary solution of SRPA





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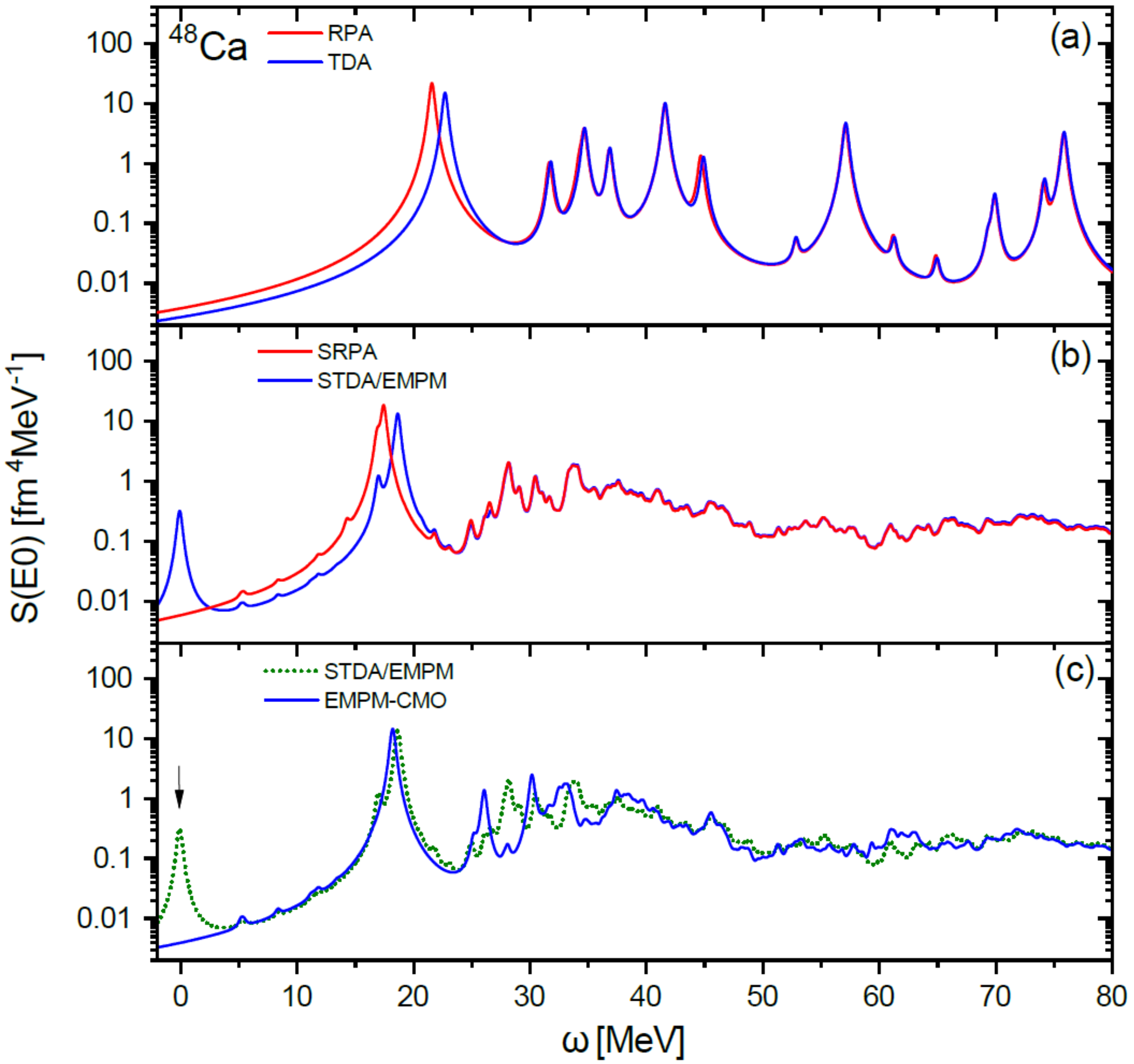
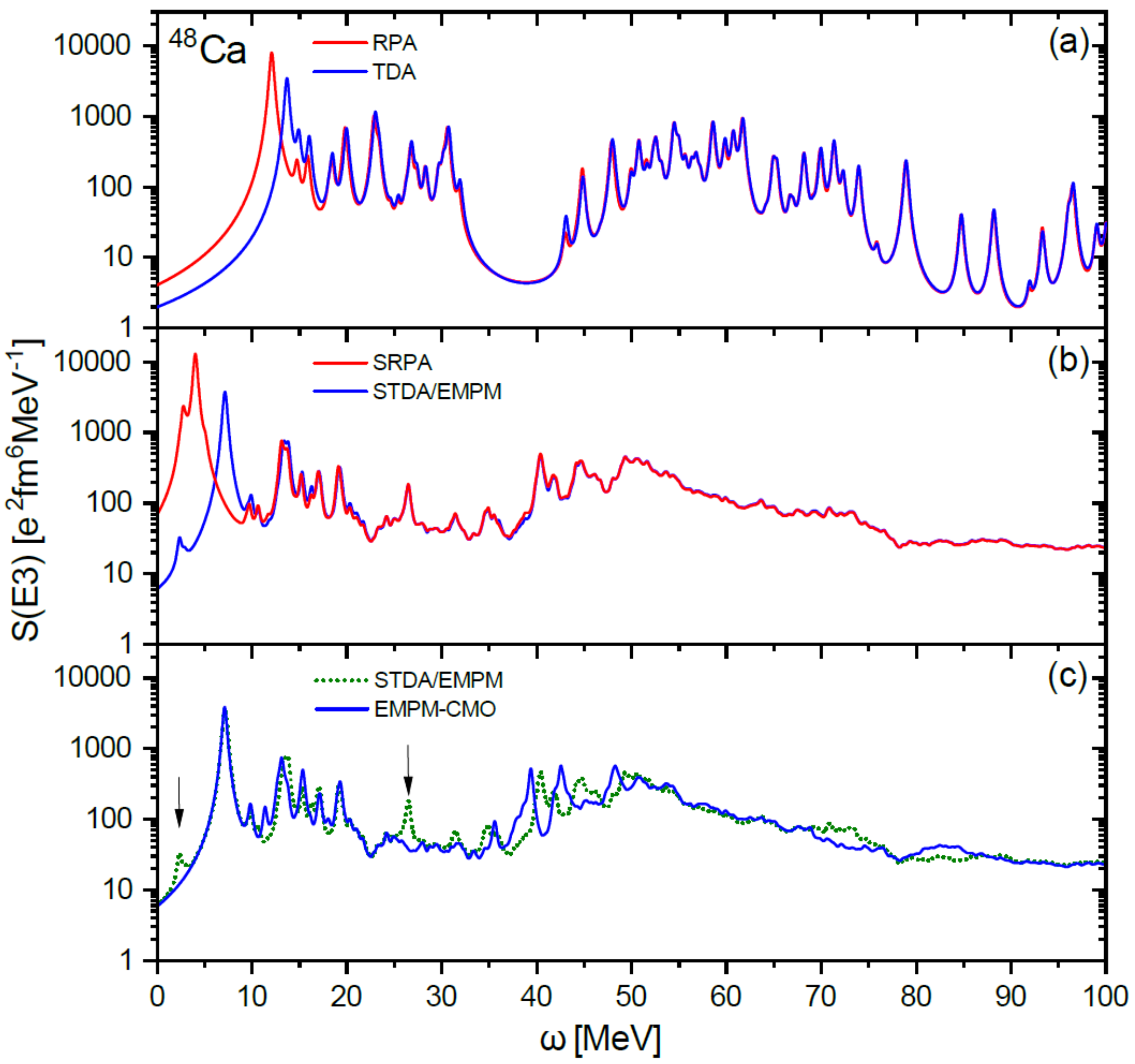
EMPM-CMO vs. EMPM/STDA/SRPA

One more example for N≠Z nucleus





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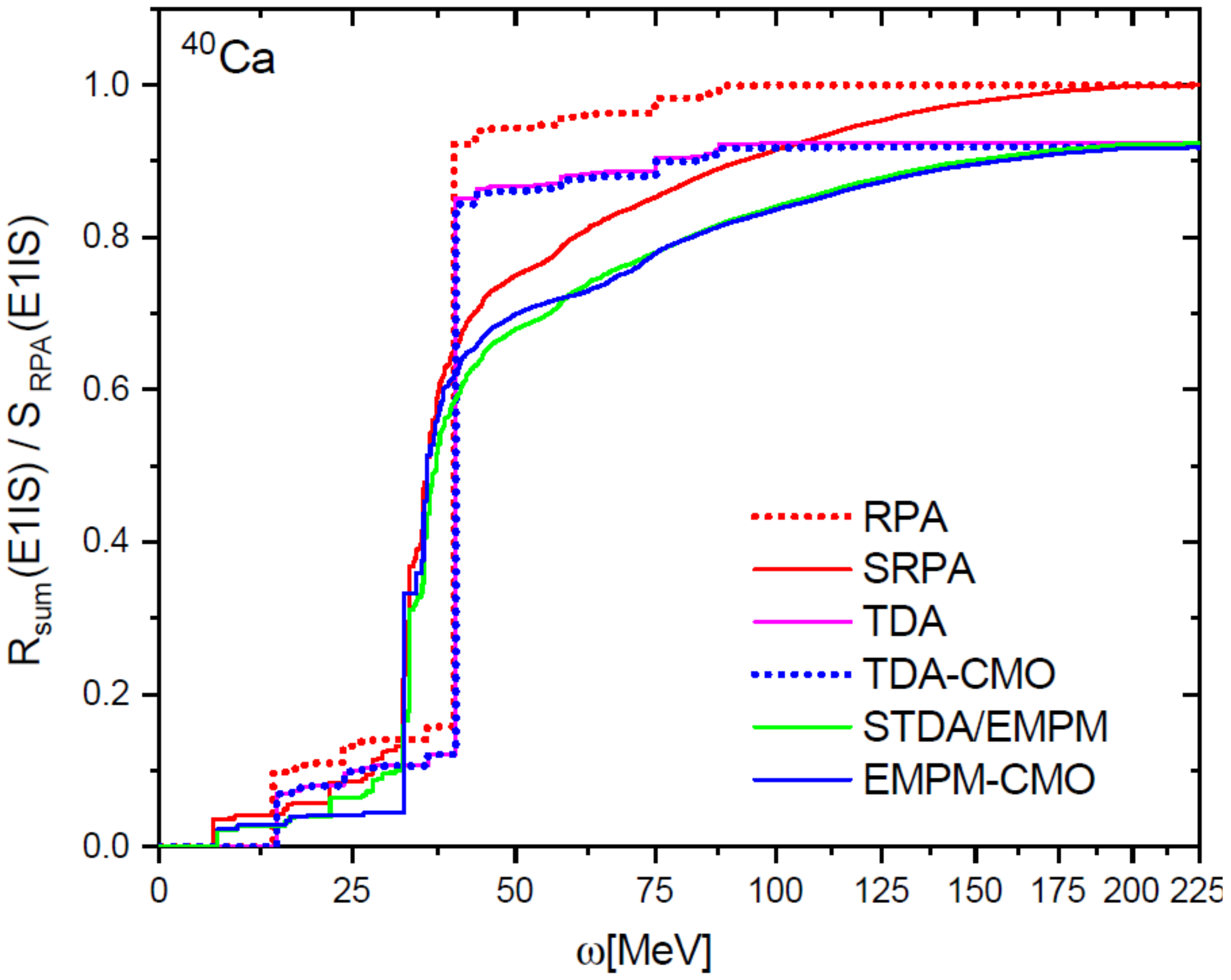
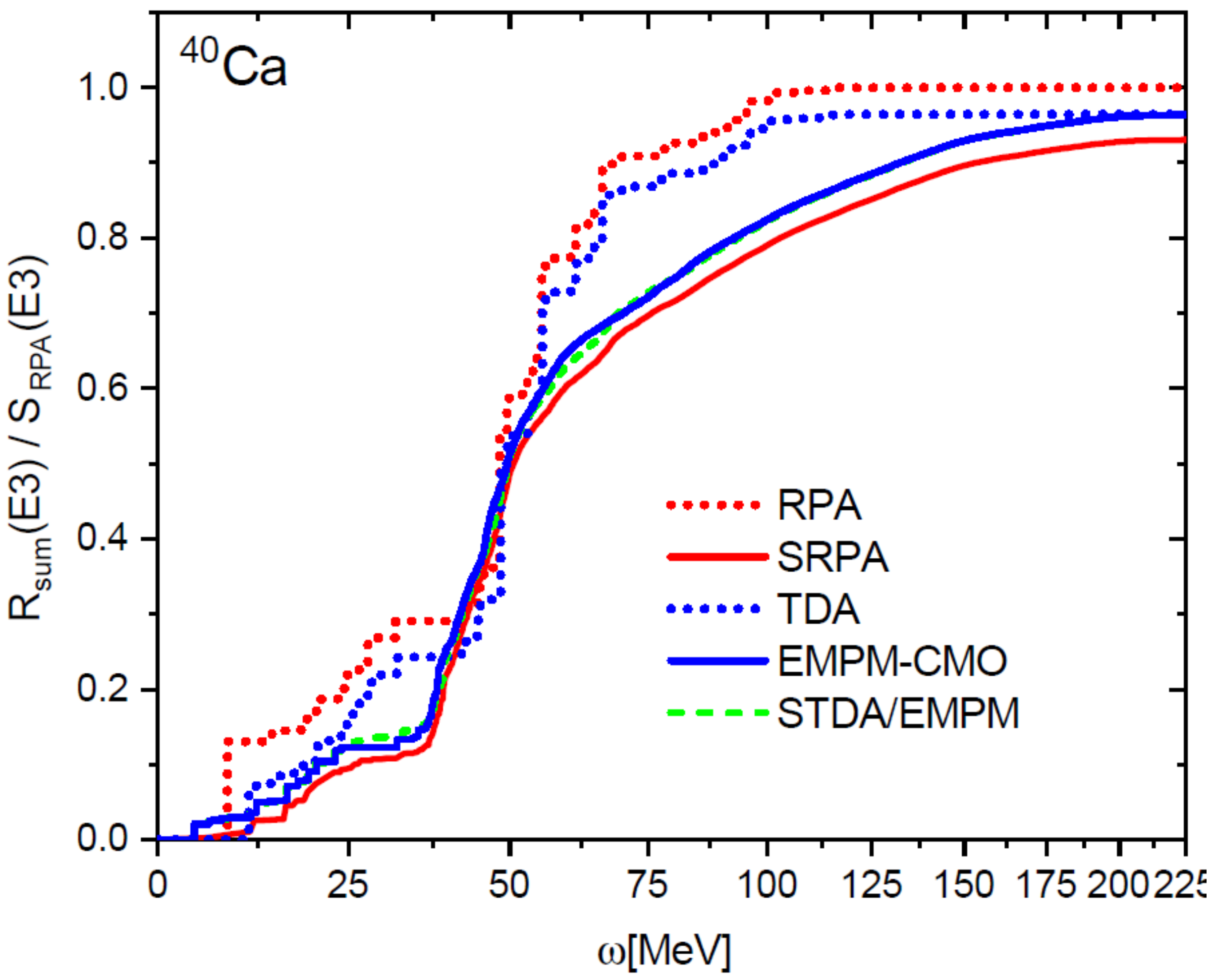
EMPM-CMO vs. EMPM/STDA/SRPA

- Total e.w. sum is the same in SRPA and RPA only **if there are no new imaginary solutions in SRPA**
- Total e.w. sum is the same in EMPM/STDA and EMPM-CMO



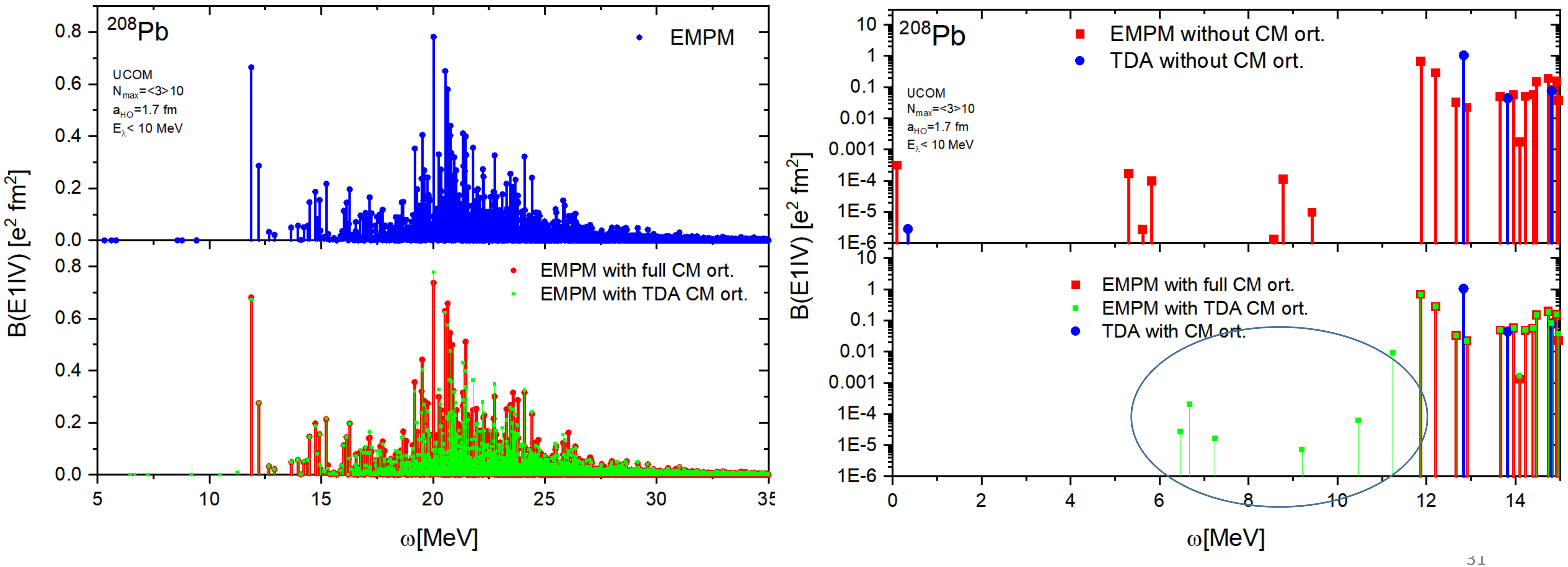


EMPM-CMO vs. EMPM/STDA/SRPA

- Does it have an impact on the low-lying dipole strength?

→ preliminary calculation in restricted model space in ^{208}Pb

- We can effectively eliminate CM in TDA only, and no significant spurious strength appears in E1IV response
- Still we see **fake states in the low-lying dipole spectrum** which disappear if we apply CMO



Conclusions & Prospects

CM problem studied within microscopic approaches SRPA, STDA and EMPM

- effective procedure for the elimination of CM contamination within EMPM from nuclear spectra and responses was developed

- numerical equivalence of EMPM and STDA, and close relation to SRPA was demonstrated
- **spurious solutions in SRPA** → existence of fake states especially in the low-energy part of spectra (no obvious solution how to avoid them)

Prospects:

- Effect of CMO within EMPM for odd systems (odd nuclei with one valence particle)
- CM contamination of low-lying dipole strength in heavy systems (effect on the Pygmy resonance)
- spurious modes connected with particle number violation

→quasiparticle SQRPA/SQTDA/QEMPM

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