Hartree-Fock and RPA for Axially Deformed Nuclei with Realistic Interactions

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21. März 2012

Outline

Basics

Interaction

Unitarily transformed interaction, based on realistic AV18 NN interaction

- suitable for restricted Hilbert spaces
- tamed short-range correlations
- improved convergence behavior
- conservation of phase shifts
- phenomenological 3-body contact term - one parameter

Many body method

Hartree-Fock and Random Phase Approximation (RPA) with axial deformation

- spherical Harmonic Oscillator basis, truncated at $e = 2\,n + l \leq 14,\ l \leq 10$
- HF variation over n,l,j,m_j - m_j and parity of l are good quantum numbers (m_j is usually reffered to as k)
- exact angular momentum projection
- approximative variation after projection with β constraint

RPA Formalism for Axially Deformed Nuclei

Vibration creation operator

$$\hat{Q}^{\dagger}_{\omega} = \sum_{ph} X^{\omega}_{ph}\, \hat{a}^{\dagger}_{p}\hat{a}_{h} - \sum_{ph} Y^{\omega}_{ph}\, \hat{a}^{\dagger}_{h}\hat{a}_{p}$$

$$\hat{Q}_{\omega}|\mathrm{RPA}\rangle = 0 \qquad , \qquad \hat{Q}^{\dagger}_{\omega}|\mathrm{RPA}\rangle = |\omega\rangle$$

ph selection rules

$$\pi_p - \pi_h = \pi_\omega$$

$$|m_p - m_h| = |m_\omega|$$

Quasi-Boson-Approximation

$$\langle\mathrm{RPA}|\hat{H}\,\hat{Q}^{\dagger}_{\omega}|\mathrm{RPA}\rangle \to \langle\mathrm{HF}|[\hat{H}, \hat{Q}^{\dagger}_{\omega}]|\mathrm{HF}\rangle$$

RPA equations in $ph-$space

$$\begin{pmatrix} A & B \\ -B^* & -A^* \end{pmatrix} \begin{pmatrix} X^{\nu} \\ Y^{\nu} \end{pmatrix} = \hbar\omega_{\nu} \begin{pmatrix} X^{\nu} \\ Y^{\nu} \end{pmatrix}$$

$$A_{ph,p'h'} = \delta_{pp'}\delta_{hh'}(e_p - e_h) + H_{hp',ph'} \quad , \quad B_{ph,p'h'} = H_{hh',pp'}$$

RPA Transition Amplitudes

Unprojected transition amplitudes

$$(\mathsf{RPA}\|\hat{T}^{\lambda}\|\omega) = \sum_{\mu,ph} \left(X_{ph}^{\omega} + (-1)^{K_{ph}} Y_{ph}^{\omega}\right) \langle h|\hat{T}_{\mu}^{\lambda}|p\rangle$$

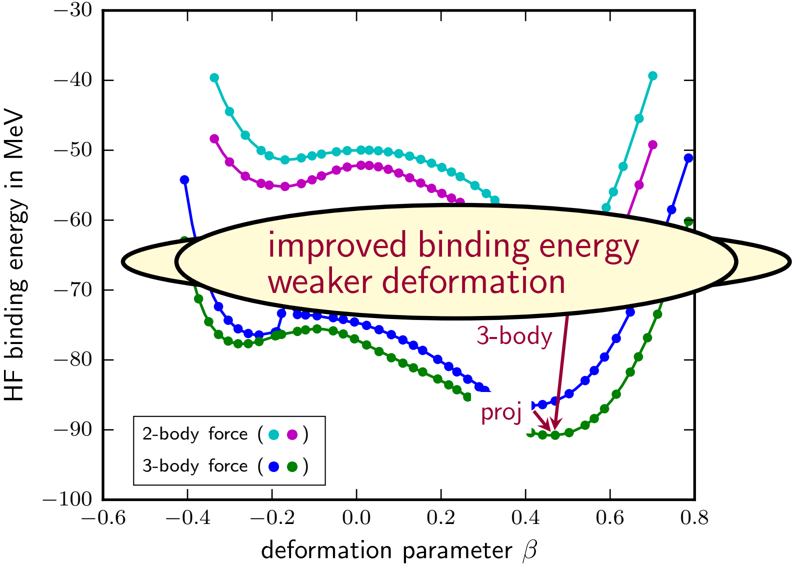
Projected transition amplitudes

$$(\mathsf{RPA}\|\hat{T}^{\lambda}\|\omega) = (2\,J_0+1)\,N_0\,N_\omega\,(-1)^{J_0-K_0} \sum \begin{pmatrix} J_0 & \lambda & J_\omega \\ -K_0 & \mu & K_0-\mu \end{pmatrix}$$

no additional approximations for
angular momentum projection

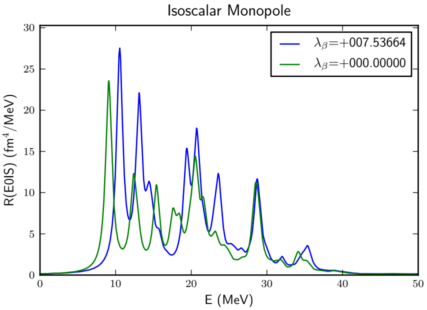
$$\hat{P}_{MK}^{J} = \frac{2\,J+1}{2} \int_{-1}^{1} d_{MK}^{J}(\beta)\,\mathrm{e}^{i\beta J_y}\,\mathrm{d}\cos(\beta)$$

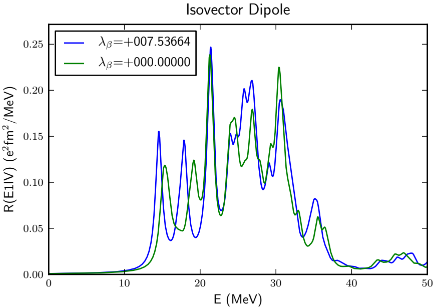
HF Ground State - ^{20}Ne

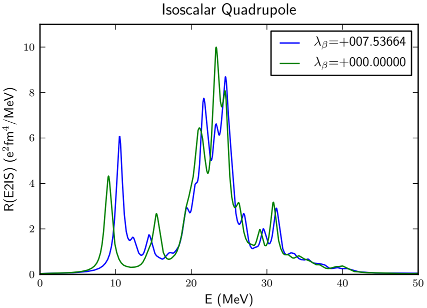


Effect of HF angular momentum projection - ^{20}Ne

- energy of peaks is shifted
- smaller effect on peak height

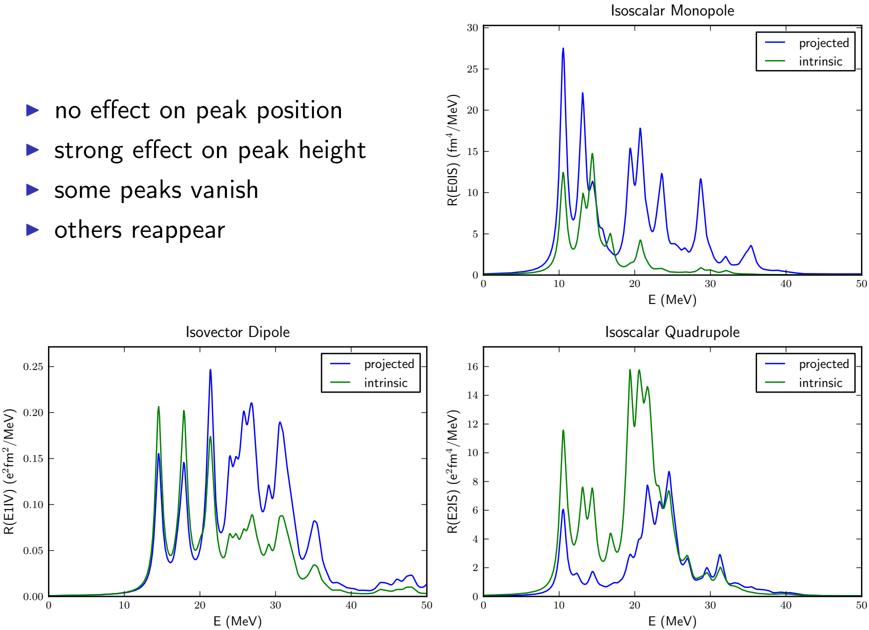






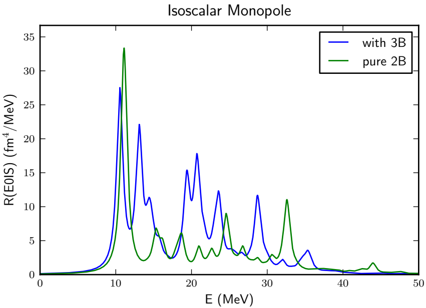
Effect of RPA angular momentum projection - ^{20}Ne

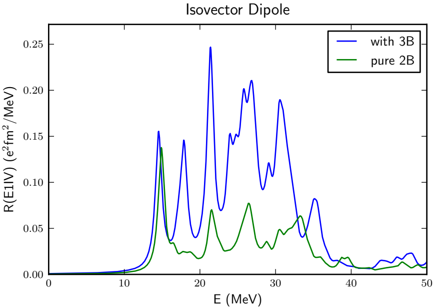
- no effect on peak position
- strong effect on peak height
- some peaks vanish
- others reappear

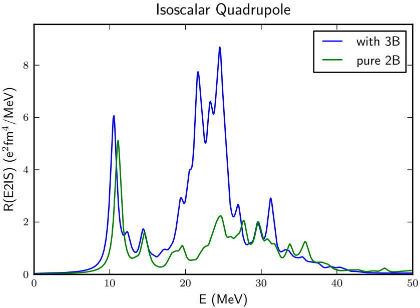


Effect of 3-body forces - ^{20}Ne

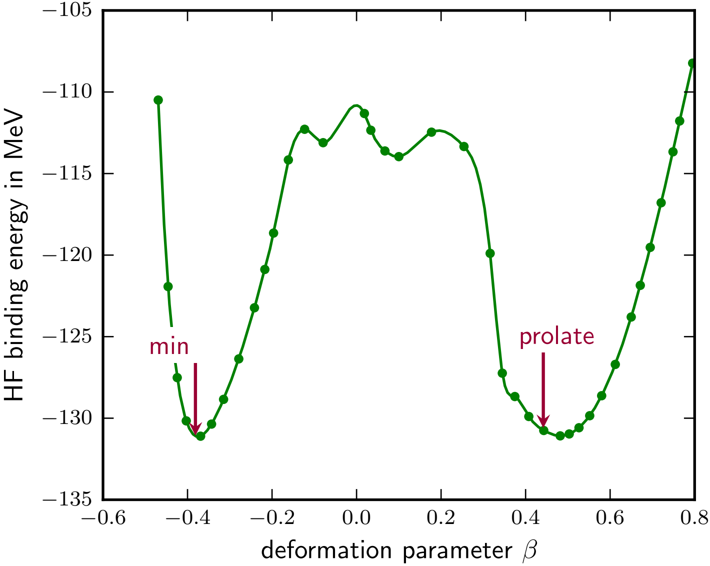
- peak structure changes completely
- only very few features stable





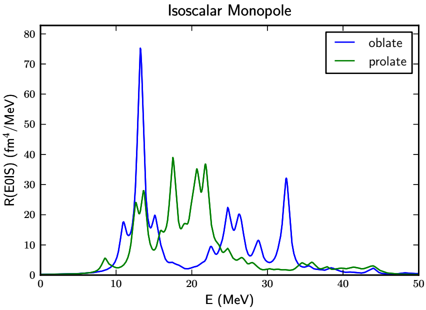


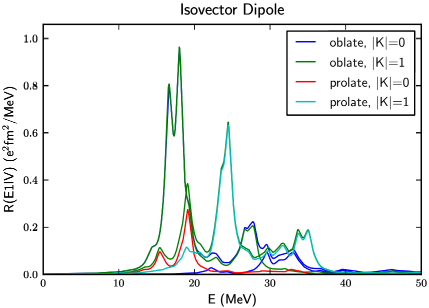
HF Ground State - ^{28}Si

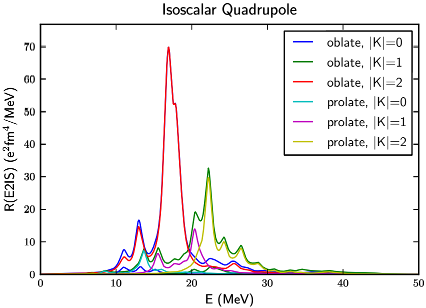


Effect of prolate and oblate deformation - ^{28}Si

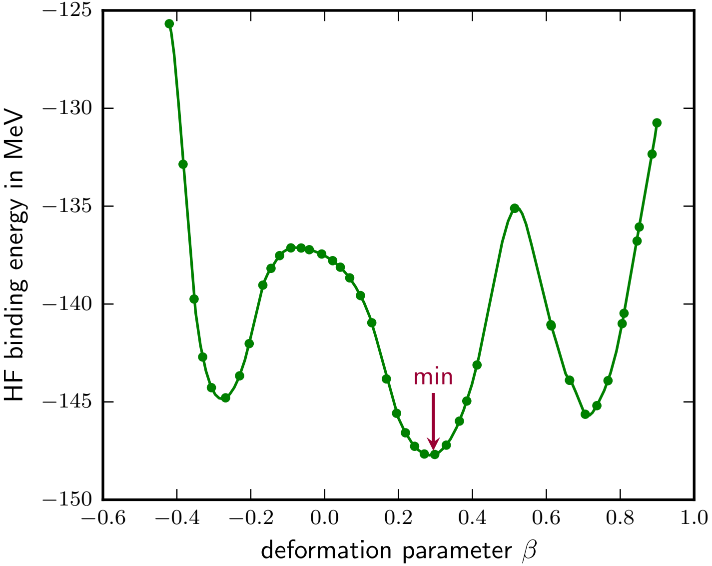
- no recognizable similarity
- oblate:
  K$=$ 1 low, K$=$ 0 high
- problate:
  K$=$ 0 low, K$=$ 1 high





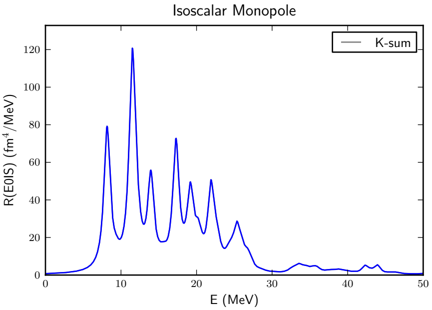


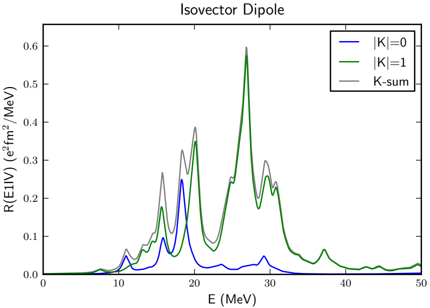
HF Ground State - ^{32}S

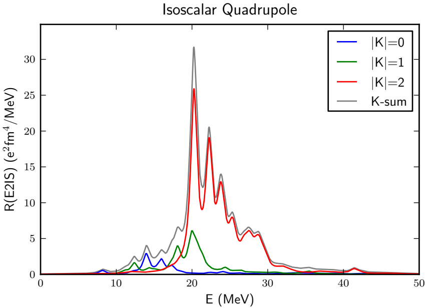


K contributions - ^{32}S

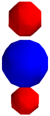
- regions are dominated by single K
- K defines the shape of the oscillation

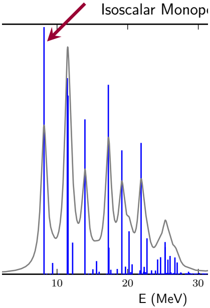


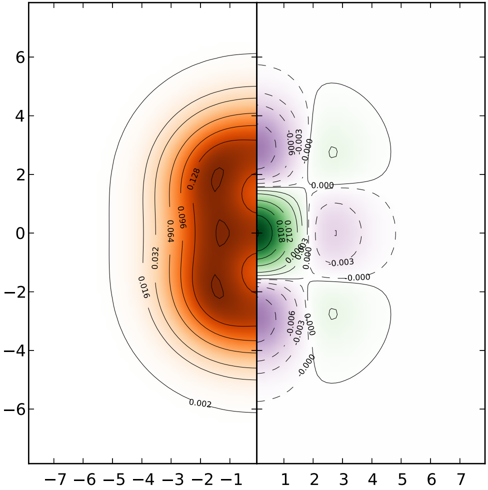




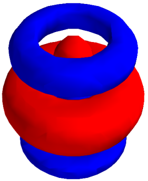
Transition densities - ^{32}S $\quad J = 0 \quad K = 0 \quad E = 8.2\text{MeV}$

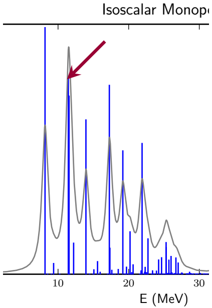


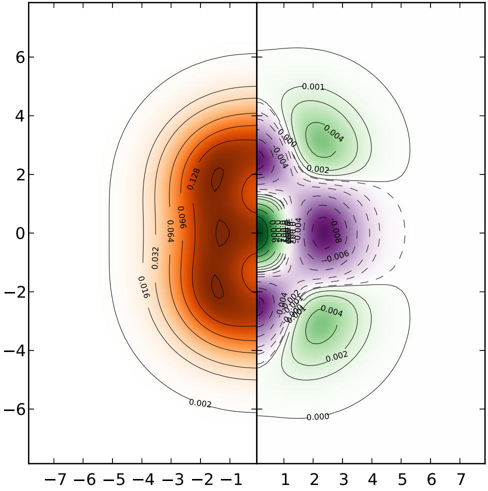




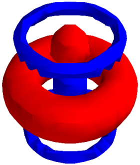
Transition densities - ^{32}S $J = 0$ $K = 0$ $E = 11.5$MeV

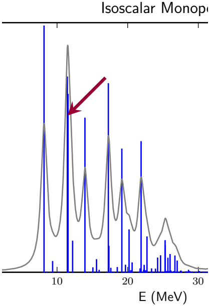


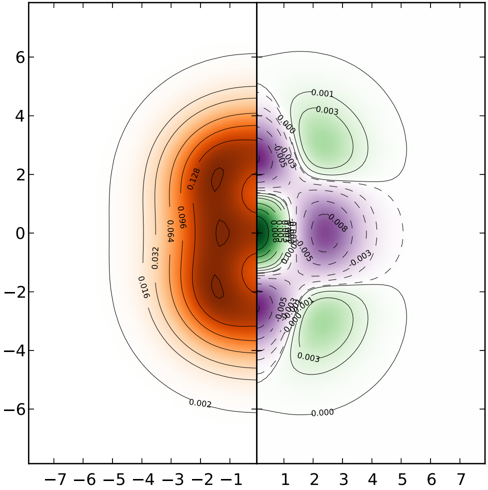




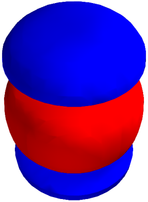
Transition densities - ^{32}S $J = 0$ $K = 0$ $E = 11.6$MeV

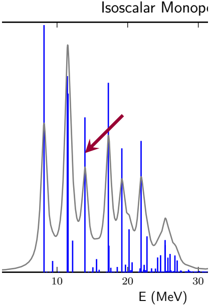


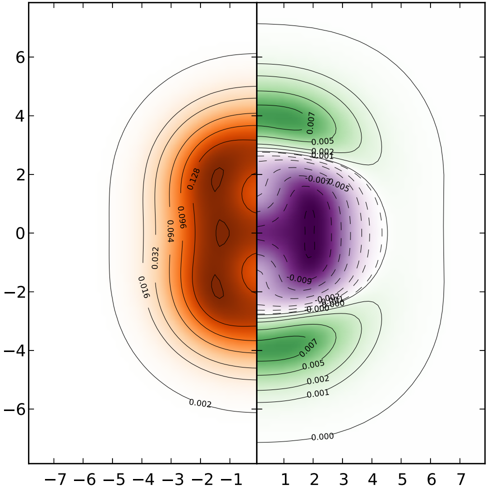




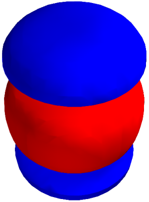
Transition densities - ^{32}S J = 0 K = 0 E = 13.9MeV

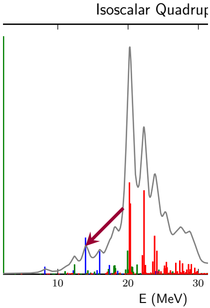


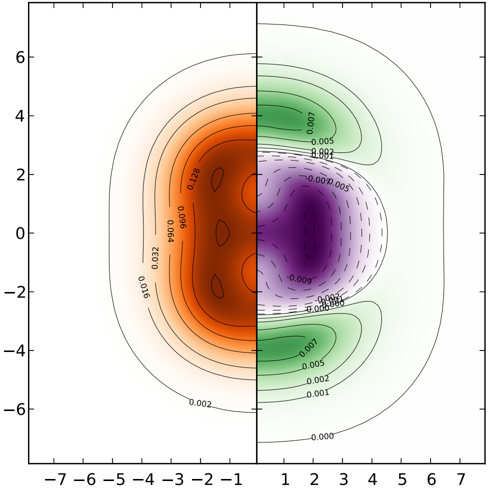




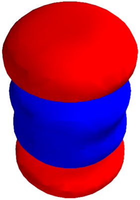
Transition densities - ^{32}S $J = 2$ $K = 0$ $E = 13.9$MeV

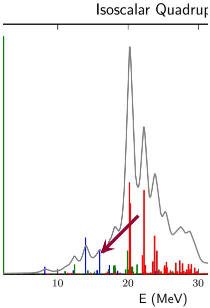


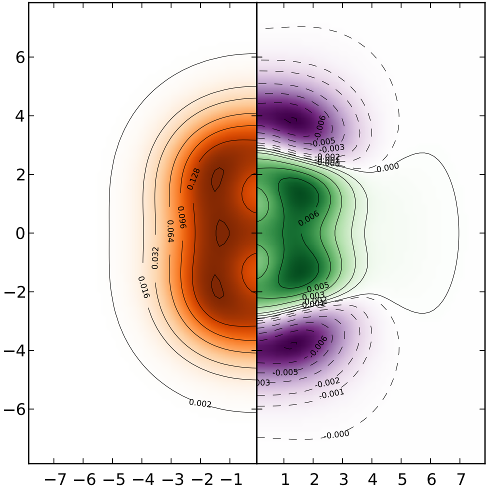




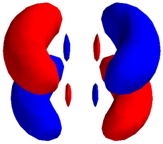
Transition densities - ^{32}S $J = 2$ $K = 0$ $E = 16.0\text{MeV}$

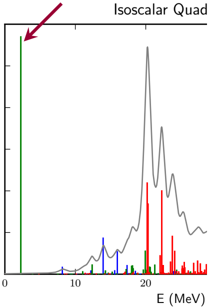


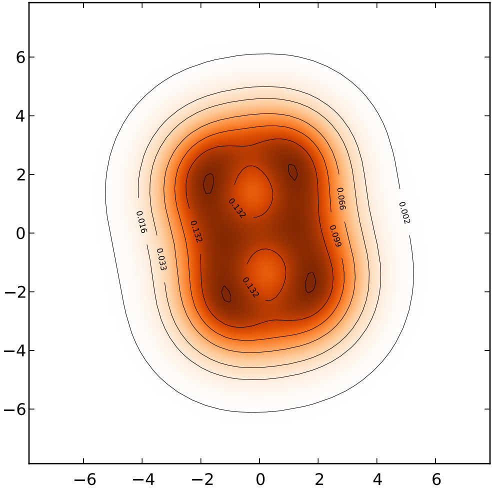




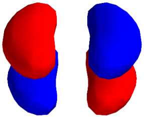
Transition densities - ^{32}S $J = 2$ $K = 1$ $E = 2.3$MeV

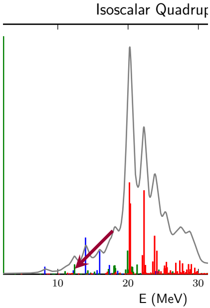


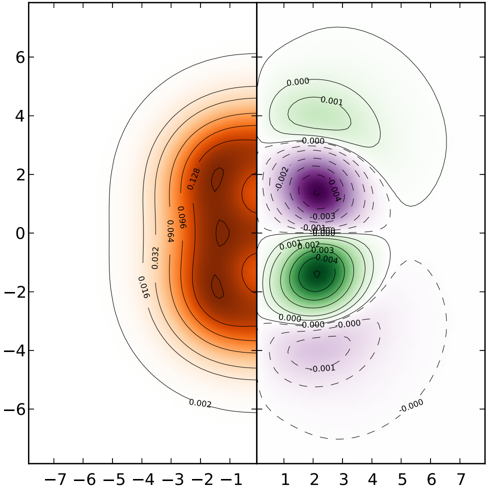




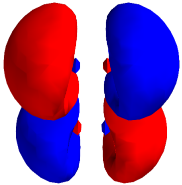
Transition densities - ^{32}S $J = 2$ $K = 1$ $E = 12.4\mathrm{MeV}$

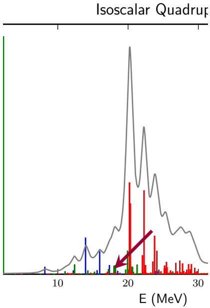


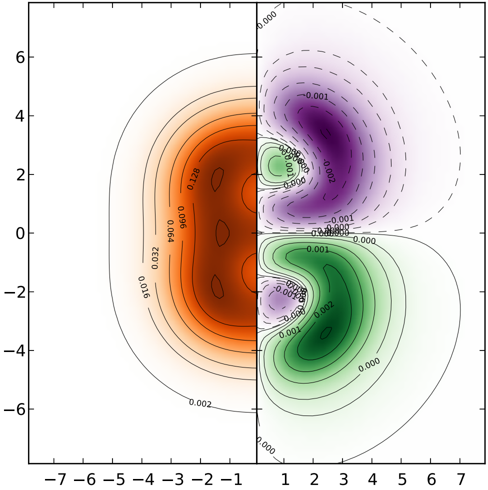




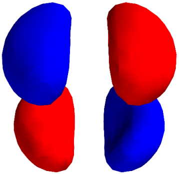
Transition densities - ^{32}S $J = 2$ $K = 1$ $E = 18.0$MeV

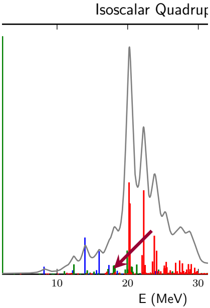


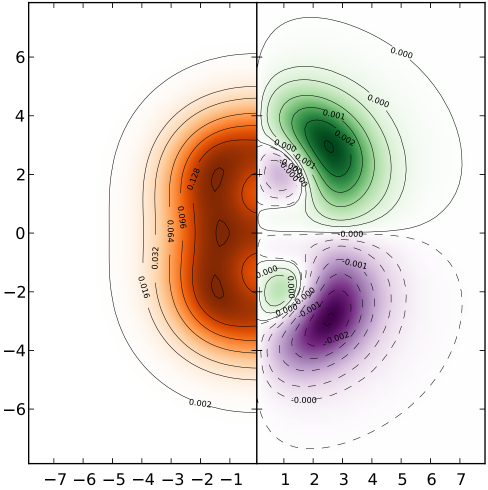




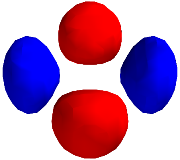
Transition densities - ^{32}S $J = 2$ $K = 1$ $E = 18.1$MeV

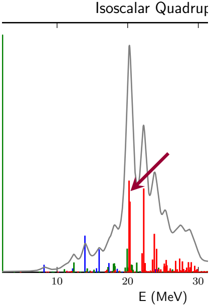


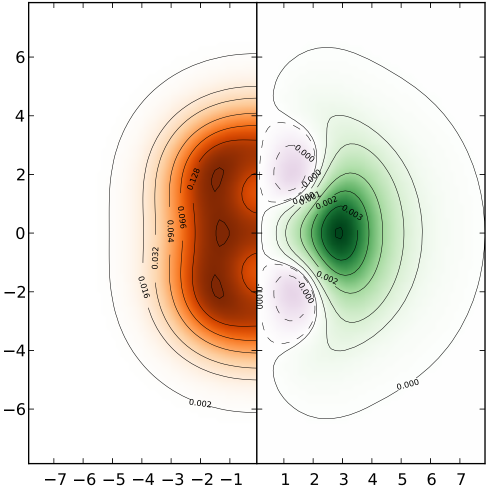




Transition densities - ^{32}S   J = 2   K = 2   E = 20.2MeV







Acknowledgement

TNP++ Group

S. Binder, A.Calci, E. Gebrerufael, A. Günther, H. Krutsch, J. Langhammer, S. Reinhardt, C. Stumpf, R. Trippel, R. Wirth and R. Roth

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HIC for FAIR Helmholtz International Center

Deutsche Forschungsgemeinschaft DFG

LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz

Bundesministerium für Bildung und Forschung