Shell model description of dipole strength at low energy

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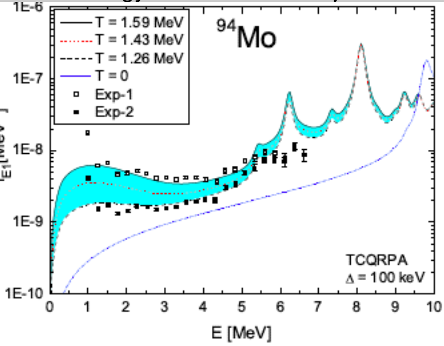
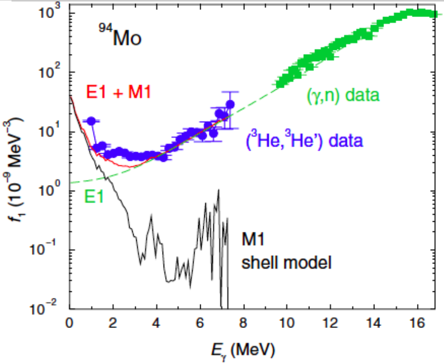
Overview & Motivation

Low energy enhancement of γ-SF



E. Litvinova and N. Belov, Phys. Rev. C88 (2013) 031302R

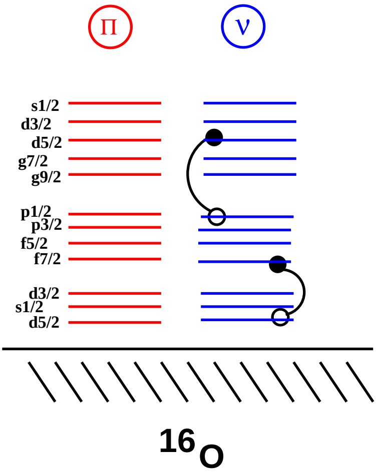
- Thermal continuum QRPA calculations
- Enhancement due to transitions between thermally unblocked s.p. states and the continuum
- Note the difference between $T = 0$ (ground state) and $T > 0$ (excited state) E1 strength distribution



R. Schwengner et al., PRL111 (2013) 232504

- Shell model transitions between a large amount of states
- Enhancement due to the M1 transitions between states in the region near the quasicontinuum
- A general mechanism to be found throughout the nuclear chart

SM calculations in *sd* – *pf* – *gds* valence space



	fp	1p-1h
^{48}Cr	1.963.461	165.821.912
^{56}Fe	345.400.174	23.194.461.394

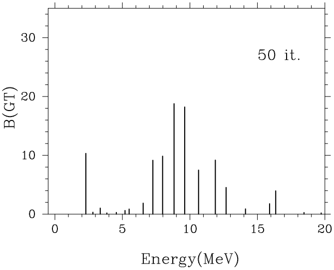
- Full *fp*-calculations for positive parity states
- Full $1\hbar\omega$ calculations for negative parity states- all 1p-1h excitations from *sd* and to *gds* shells
- $H_{SM} =$ $\sum_i \varepsilon_i c_i^\dagger c_i + \sum_{i,j,k,l} V_{ijkl} c_i^\dagger c_j^\dagger c_l c_k + \beta_{c.m.} H_{c.m.}$
- **60 states per spin and parity** $S_{M1/E1} = \langle B(M1/E1)\rangle \rho(E_i)$ (60×5000 iterations...)
- or Lanczos SF method with 500 iterations for upward $S_{M1/E1}$

Downward and upward strength calculations

γ-decay (RSF)

- calculate desired number of low lying states using standard SM diagonalization techniques
- obtain the averages and radiative strength functions from relations:

$$f_{M1/E1}(E_\gamma) = 16\pi/9(\hbar c)^3 S_{M1/E1}(E_\gamma)$$
$$S_{M1/E1} = \langle B(M1/E1)\rangle \rho_i(E_i)$$



photoabsorption (PSF)

- use Lanczos Strength Function method with a large number of iterations:

$$S = |\hat{O}|\psi_i\rangle| = \sqrt{\langle\psi_i|\hat{O}^2|\psi_i\rangle}$$

The operator $\hat{O}$ does not commute with H and $\hat{O}|\psi_i\rangle$ is not necessarily the eigenstate of the Hamiltonian. But it can be developed in the basis of energy eigenstates:

$$\hat{O}|\psi_i\rangle = \sum_f S(E_f)|E_f\rangle,$$

where $S(E_f) = \langle E_f|\hat{O}|\psi_i\rangle$ is microscopic **strength function**.
If we carry Lanczos procedure using $|O\rangle = \hat{O}|\psi_i\rangle$ as initial vector then H is diagonalized to obtain eigenvalues $|E_f\rangle$ and after N iterations we have also the strength distribution.

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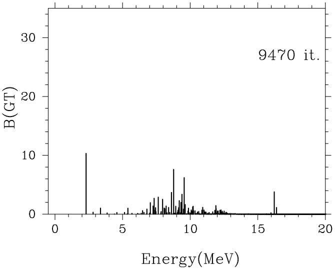

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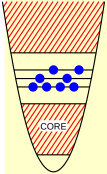
Large scale shell model framework



- define valence space
- $H_{\text{eff}}\Psi_{\text{eff}} = E\Psi_{\text{eff}}$

$\rightsquigarrow$ INTERACTIONS

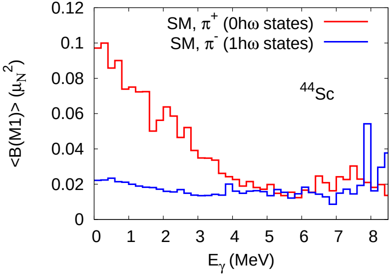
- build and diagonalize Hamiltonian matrix

$\rightsquigarrow$ CODES

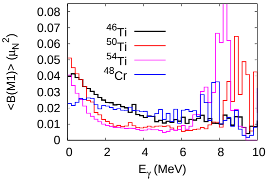
Strasbourg shell model codes (E. Caurier, RMP77, 2005, 427)

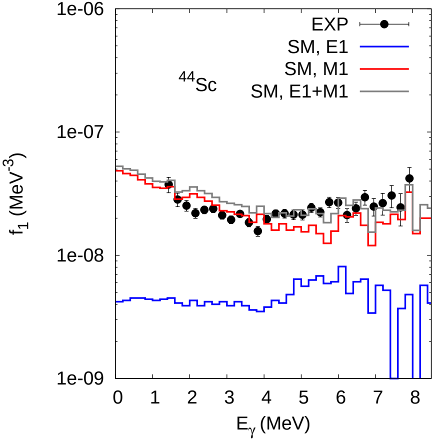
NATHAN	ANTOINE
j-coupled basis	m-scheme basis
large number of non-zero ME	sparse matrices
smaller dimensions tractable	larger dimensions tractable
good quantum number: J can get many states of the same J	good quantum number: M numerical problems to get many states of the same J
used in the present calculations ideal for description of γ-decay downward strength (RSF)	used in the present calculations ideal for description of photoabsorption upward strength (PSF)

Dipole strength in ^{44}Sc: theory vs exp



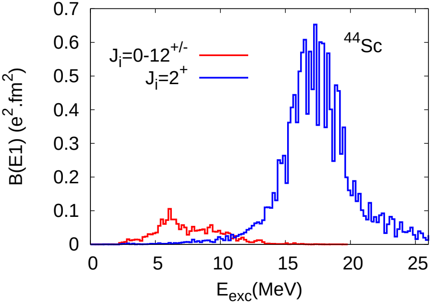
- No enhancement of the 1$\hbar\omega$ M1 strength due to the complexity of wave functions (comparable to that of deformed nuclei)



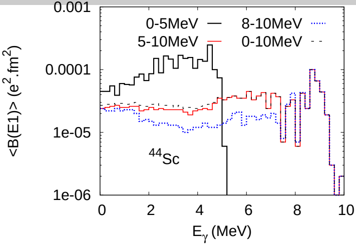


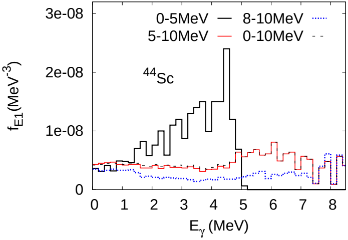
-all states below $S_n \sim$10MeV
-86642 M1 matrix elements
-65670 E1 matrix elements
KS, submitted

Dipole strength in ^{44}Sc: E1 part



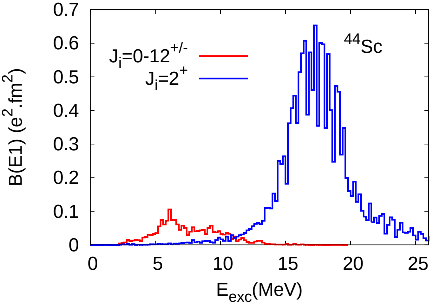
low energy part: 65670 E1 matrix elements
higher energy part: LSF with 500 iterations
$(J_i = 2^+ \rightarrow 1^-, 2^-, 3^-)$

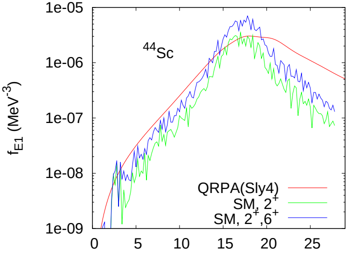


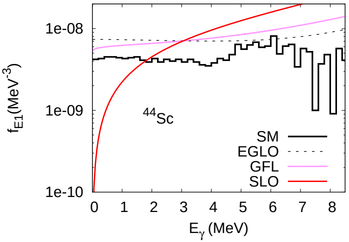


- Behaviour of the E1 strength at low energy independent on spin range and energy cut-off

Comparison to other models

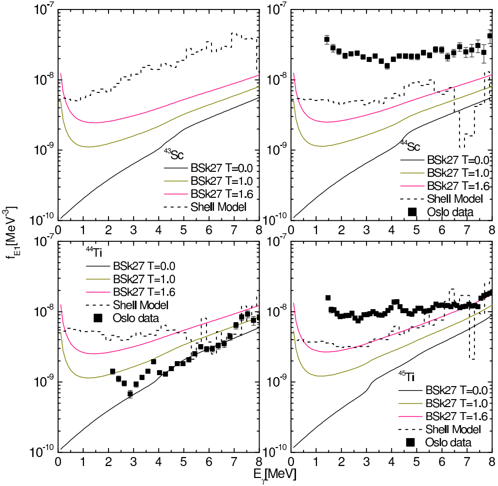






- Reasonable agreement between QRPA and SM PSF up to 15MeV $\rightarrow$ for higher energies, $3\hbar\omega$ excitations should be included in SM
- Microscopic SM strength has a non-zero limit for $E_\gamma = 0$. Consistent with EGLO model.

Low energy E1 strength in SM & QRPA models



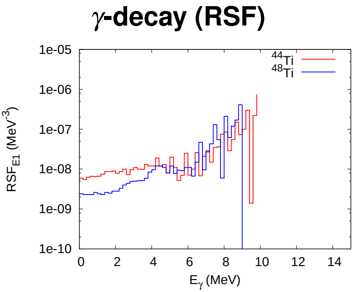
QRPA from S. Goriely, priv. comm.

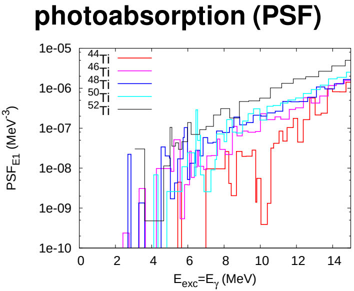
- QRPA describes formally photoabsorption from the ground state
- correction term is added to take into account collisions of quasiparticles:

$$\Gamma'(E) = \Gamma(E)(1 + \alpha \frac{4\pi T^2}{EE_{GDR}})$$

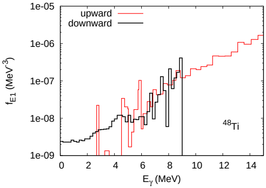
- the upbend of QRPA strength is not consistent with low energy strength from shell model
- shell model is the only microscopic tool that gives the downward strength

Downward vs upward strength: E1



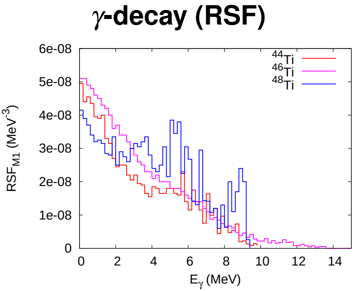


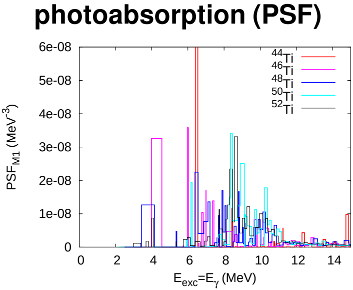
☞Decay to all available states adds a broad component to the strength function with a non-zero $E_\gamma = 0$ limit.



RSF=PSF of the g.s. only
for higher transition energies

Downward vs upward strength: M1



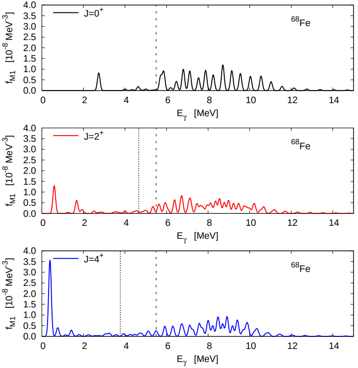


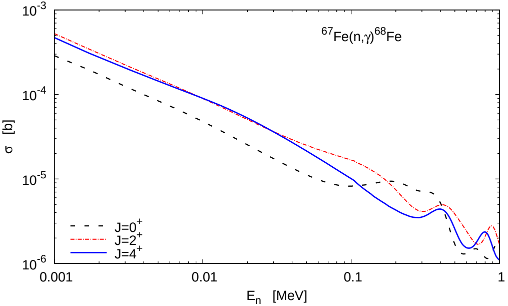
☞Decay to all available states can produce an enhancement effect at low energy.

Impact of the realistic M1 fragmentation on the neutron capture cross sections

M1 microscopic strength functions in iron chain (^{53}Fe-^{70}Fe) and impact on (n,γ) cross sections

H.-P. Loens K. Langanke, G. Martinez-Pinedo and KS, EPJ A48 (2012) 48





- Using SF of excited states instead of that of 0^+ leads to larger cross sections

Outlook: A word on shell model calculations

☞SM is a powerful tool that can be used in many mass regions. Nevertheless, to get the proper physics, large valence spaces and time-consuming calculations are necessary.

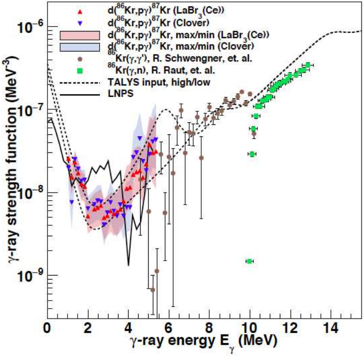
A valence space can be adequate to describe some properties and completely wrong for others:

^{48}Cr	$(f_{7/2})^8$	$(f_{7/2}p_{3/2})^8$	$(fp)^8$
$Q(2^+)(e.fm^2)$	0.0	-23.3	-23.8
$E(4^+)/E(2^+)$	1.94	2.52	2.26
$B(E2;2^+\rightarrow)(e^2.fm^4)$	77	150	216
B(GT)	0.90	0.95	3.88

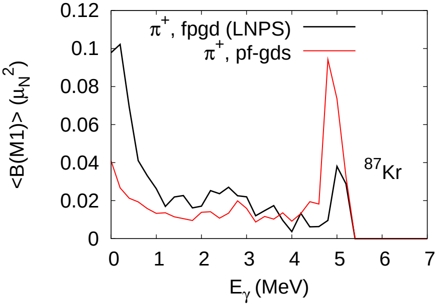
The GT (magnetic) properties require model spaces that include all spin-orbit partners.

Some effects can be incorporated via renormalization of the magnetic operator (quenching), but some other cannot ...

B(M1) in ^{87}Kr: model space dependence



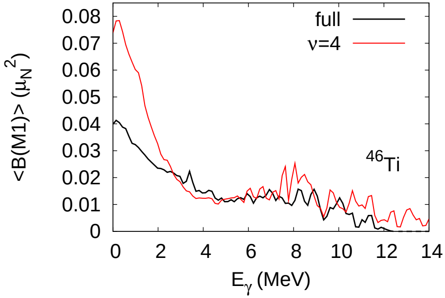
from V. W. Ingeberg talk

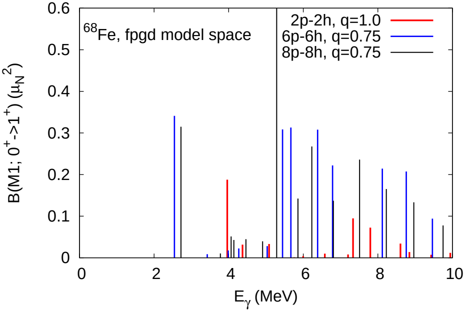


fpgd model space: full *pf*-shell for protons, 2p-2h excitations from $p_{3/2}, f_{5/2}$ to $p_{1/2}, g_{9/2}, d_{5/2}$ neutron orbits

pf – *gds* model space: full *pf*-shell for protons, 2p-2h excitations from $g_{9/2}$ to $d_{5/2}, s_{1/2}, d_{3/2}, g_{7/2}$ neutron orbits

Outlook: M1 strengths and correlations within the model space





☞Not enough correlations $\rightarrow$ too much enhancement, not enough strength at low energy...

Summary

- The large-scale shell model can describe both, upward and downward M1/E1/E2... strengths. Employed in model spaces encompassing the necessary degrees of freedom can give a valuable insight into physics mechanisms behind the low-energy behavior of calculated strengths.
- M1 dipole strength functions show an upbend for the low γ-energies. However, the mixing destroys the enhancement.
- No enhancement of the $1\hbar\omega$ M1 is present for the same reason. More complexity of the wave function $\rightarrow$ less probability for the upbend.
- E1 dipole strength functions do not show the low energy upbend. Given the nature of the E1 operator, one can expect no much upbend throughout the nuclear chart $\rightarrow$ to be verified in very neutron-rich nuclei.
- Shell model E1 strength at low energy exhibits different trend from QRPA approaches with a flat, non-zero $E_\gamma = 0$ limit. Consistent with EGLO model.
- Systematic, reliable SM calculations needed to characterize the regions where the enhancement should be present and the evolution of strengths in neutron-rich nuclei.

Effective Hamiltonian

- Interaction from V_{lowk} based on the CD-Bonn potential
- Monopole corrections to fix the s.p. and s.h. energies
- *pf*-shell TBME from the LNPS fit (PRC82, 054301, 2010)
- Good reproduction of low lying levels in considered nuclei and accurate position of the first 1p-1h states
- Quenching of 0.75 on magnetic spin operator
- Accurate reproduction of known magnetic moments of $f_{7/2}$-shell nuclei