Structure of low-lying octupole states in the mass 160 region

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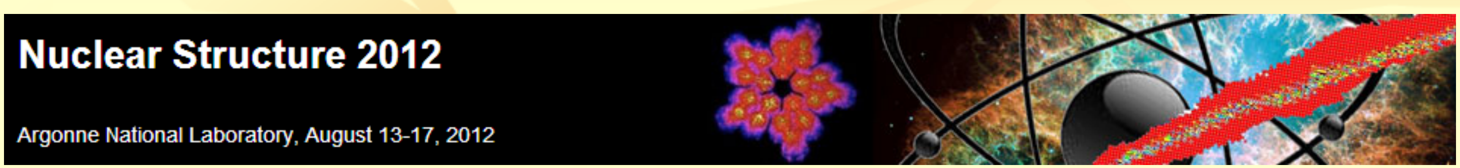
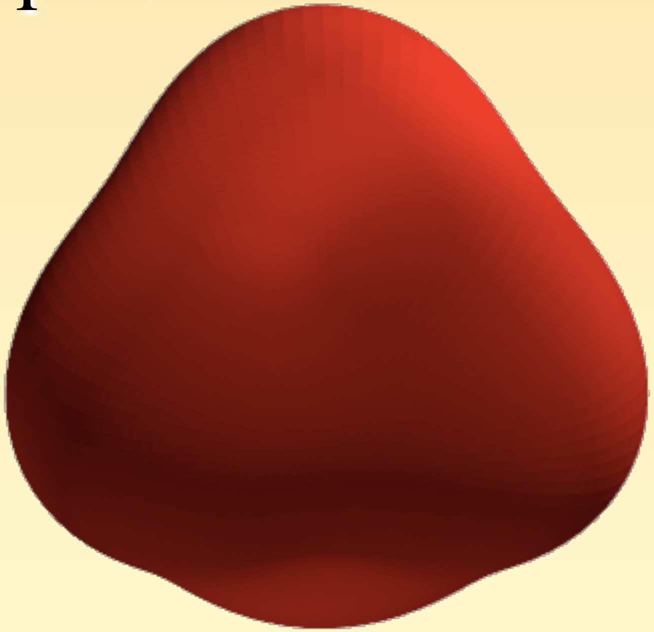


Low spin negative parity bands in mass 160 region

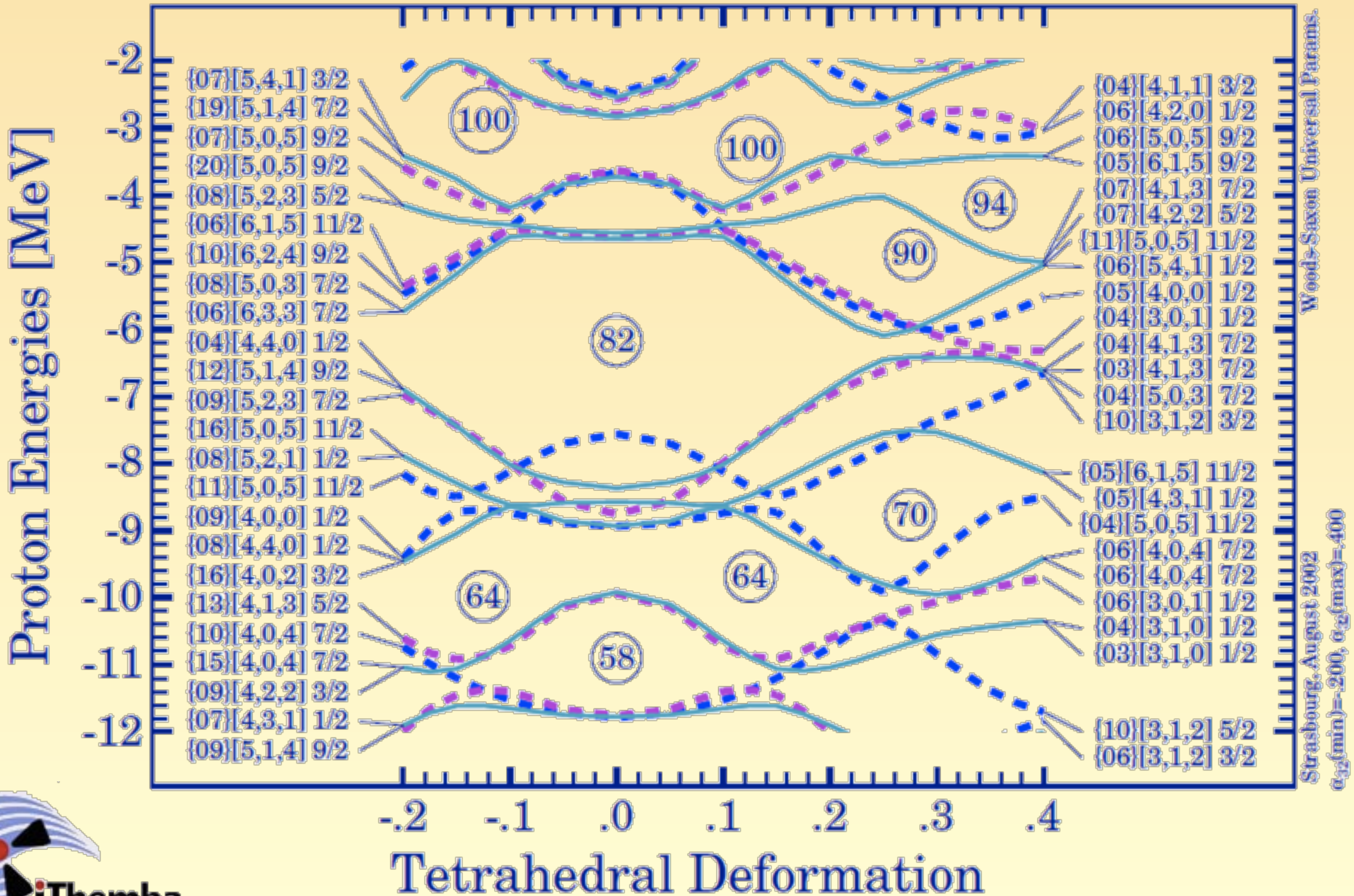
- Experiments show existence of np bands at fairly low excitation energy (< 1 MeV)
- Negative parity – 'octupole' bands from Y_{3m}
- Possibly tetrahedral (Jerzy Dudek)?

Theoretical prediction

- "Tetrahedral" nucleus implies Y_{32} contribution and also vanishing of other octupole terms.
- Additionally, $\alpha_{20} = 0$
- Calculations by Dudek suggest that nuclei with a tetrahedral deformation at a low excitation may exist in periodic table.



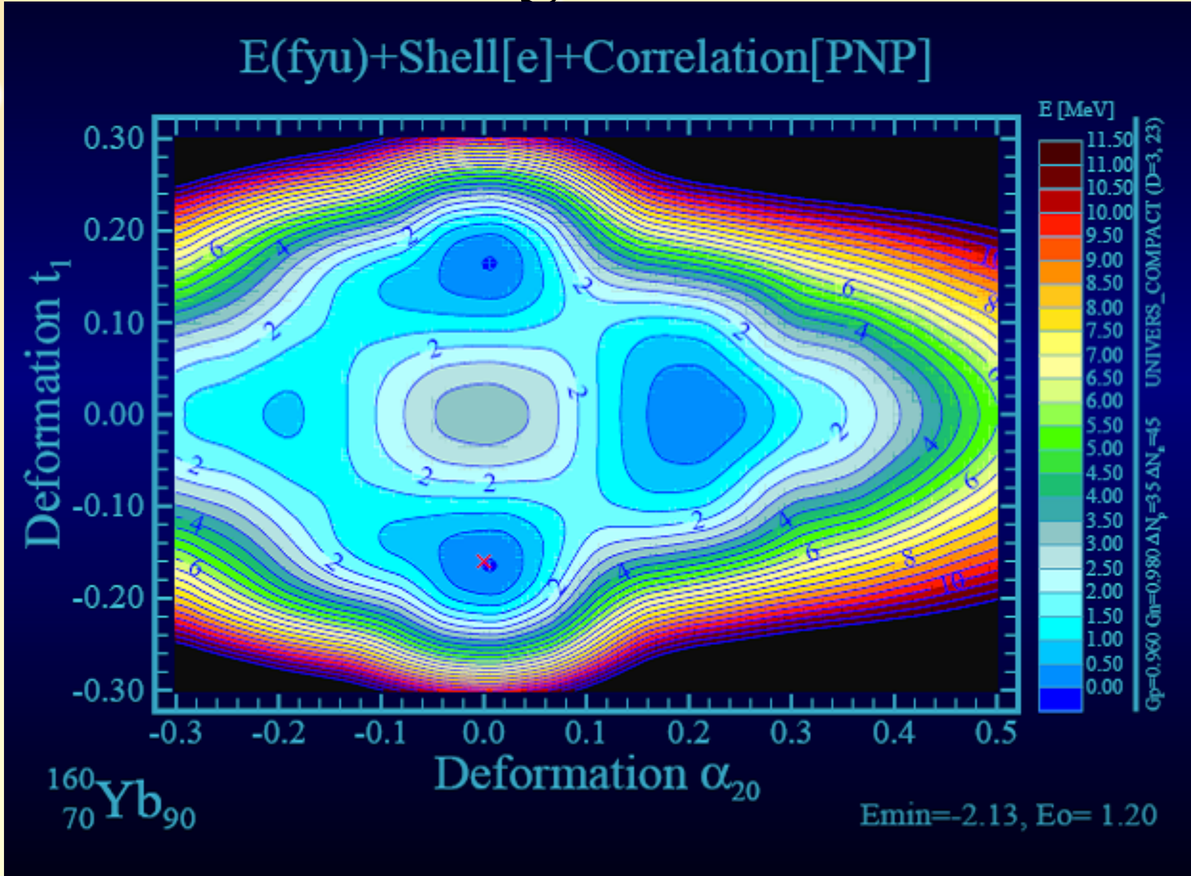
Where to find them?



Study "doubly-magic" nuclei

- Shell-gaps exist at 64 and 70, then 90 and 94
- One focus area is the A~160 region:

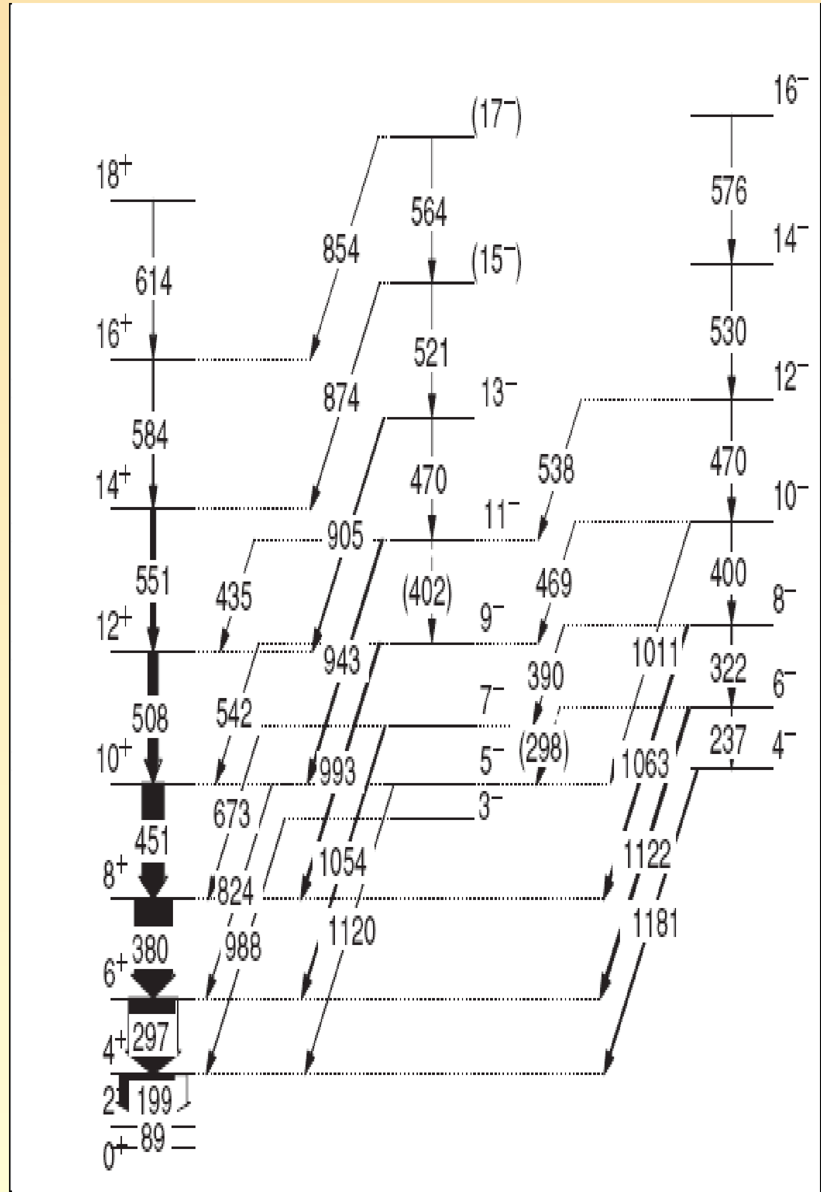
^{154,156}Gd, ^{160}Yb



- Minimum at non-zero Y_{32}, and zero Y_{20}.

Experimental signature – ^{156}Gd ?

- Odd negative parity bands have lack if in-band E2 transitions below spin 9.
- B(E2)/B(E1) discrepancy in signature partner bands.
- Suppression of E2 rates?
  - **Tetrahedral candidates**
- But has Partner!!



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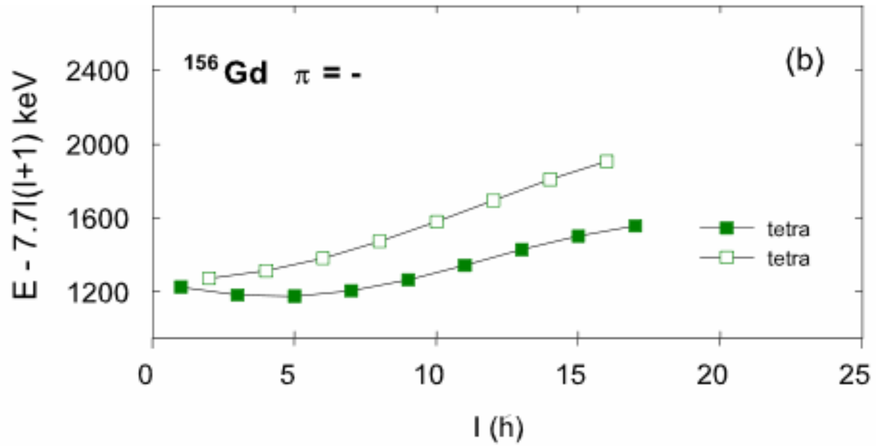
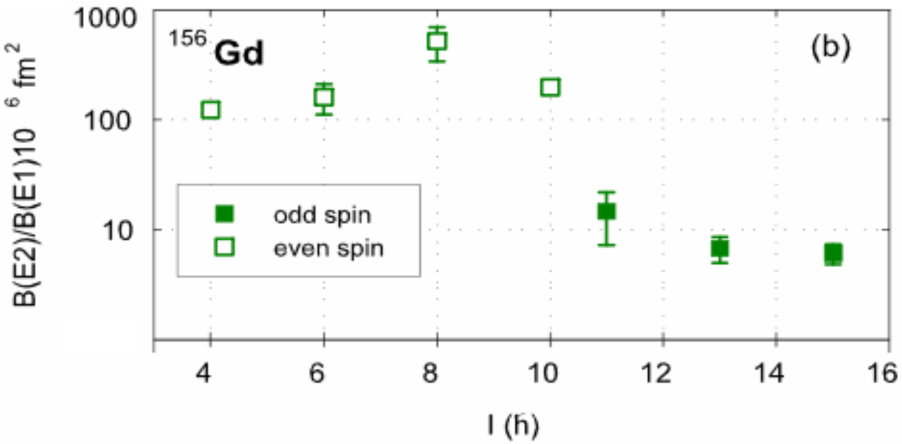
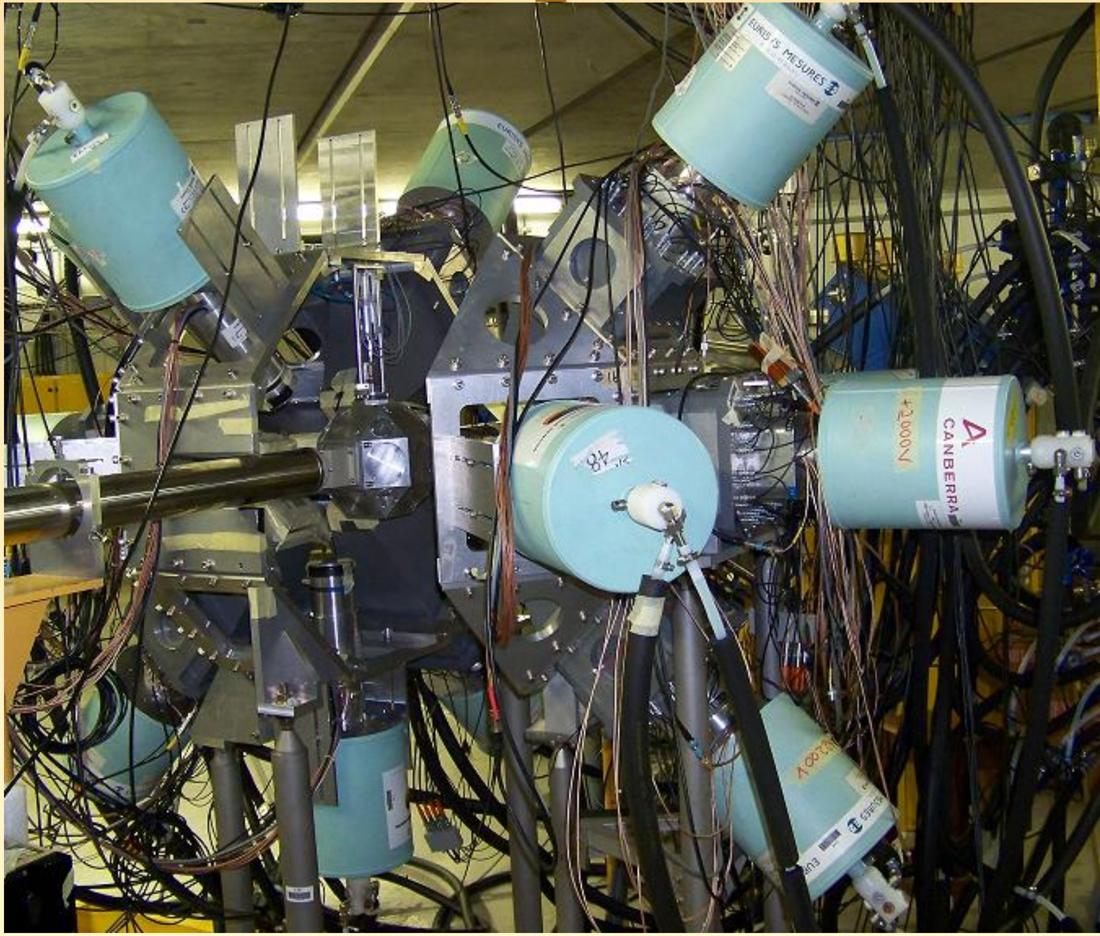
- Big difference between B(E2)/B(E1) values for the two signatures
- Due to big difference in B(E2) (α=1 tetrahedral)
- Or: big difference in B(E1)?





AFRODITE setup

- K = 200 SSC
- HPGe γ detectors
- Array of 9 clovers and up to 8 LEPS
- Collect 10^9 γγ coincidence events / weekend.



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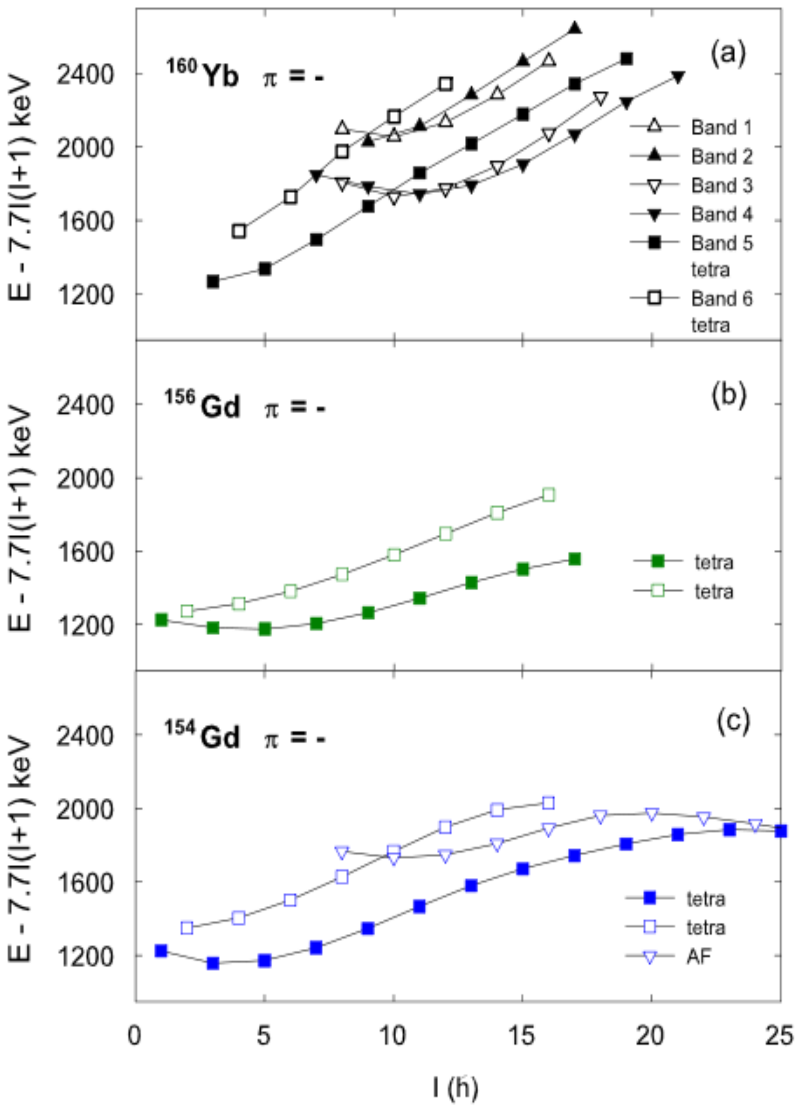
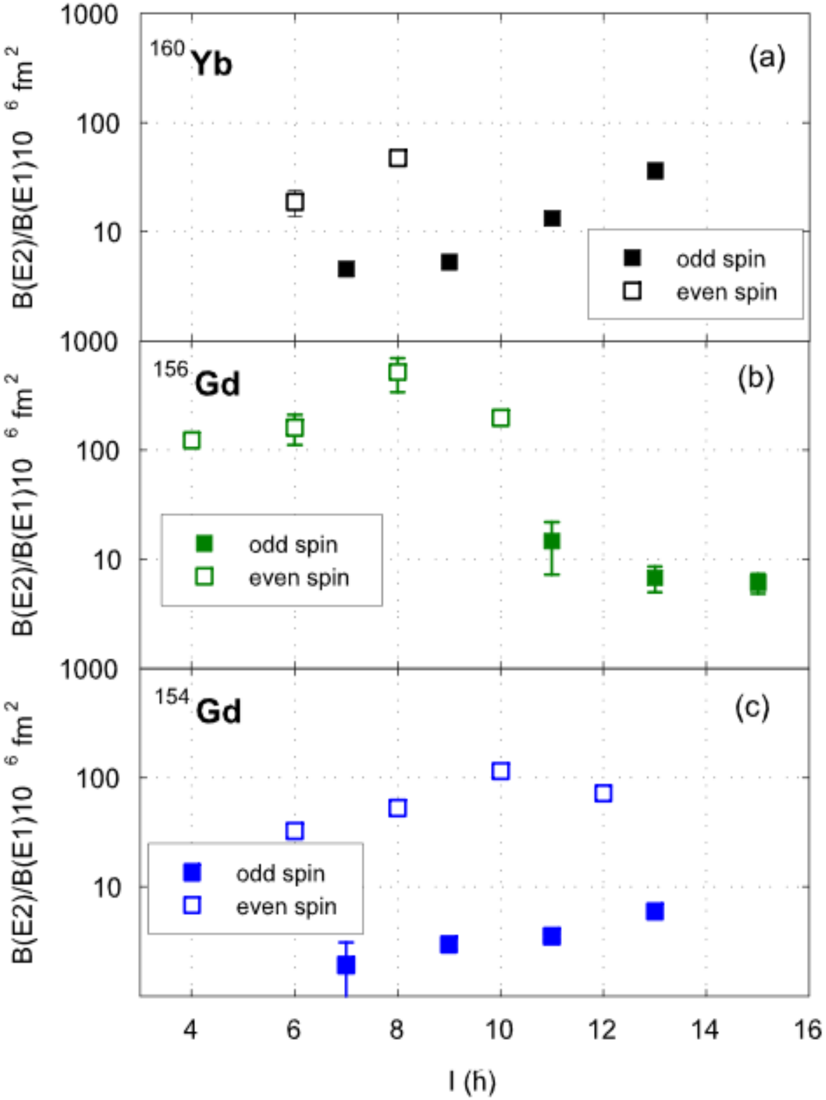
Recent experiments at iThemba

- At iThemba ran several experiments to search for low-lying states in N=88,90,92 nuclei:
  - ^{152}Sm(^{12}C,4n)^{160}Er at 62 MeV
  - ^{156}Gd(α,2n)^{158}Dy at 27 MeV
  - ^{147}Sm(^{12}C,3n)^{156}Er
  - ^{147}Sm(^{16}O,3n)^{160}Yb
  - ^{154}Sm(α,4n)^{154}Gd

Early Results from iThemba





Analysis of ^{160}Yb

- Transitions in π− bands found down to spin 4
- Band mixing calculations suggest a non-zero quadrupole moment – not tetrahedral.

PRL **104,** 022501 (2010) PHYSICAL REVIEW LETTERS week ending 15 JANUARY 2010

Nonzero Quadrupole Moments of Candidate Tetrahedral Bands

R. A. Bark,[1] J. F. Sharpey-Schafer,[2] S. M. Maliage,[1,2] T. E. Madiba,[1,2] F. S. Komati,[1,2] E. A. Lawrie,[1] J. J. Lawrie,[1] R. Lindsay,[2] P. Maine,[1,2] S. M. Mullins,[1] S. H. T. Murray,[1] N. J. Ncapayi,[1] T. M. Ramashidza,[1,2] F. D. Smit,[1] and P. Vymers[1,2]

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(Received 2 September 2009; published 11 January 2010)

Negative-parity bands in the vicinity of ^{156}Gd and ^{160}Yb have been suggested as candidates for the rotation of tetrahedral nuclei. We report the observation of the odd and even-spin members of the lowest energy negative-parity bands in ^{160}Yb and ^{154}Gd. The properties of these bands are similar to the proposed tetrahedral band of ^{156}Gd and its even-spin partner. Band-mixing calculations are performed and absolute and relative quadrupole moments deduced for ^{160}Yb and ^{154}Gd. The values are inconsistent with zero, as required for tetrahedral shape, and the bands are interpreted as octupole vibrational bands. The failure to observe the in-band $E2$ transitions of the bands at low spins can be understood using the measured $B(E1)$ and $B(E2)$ values.

^{156}Gd lifetimes

- ^{156}Gd(n,n'γ)
- In 2010 found to have quadrupole moment inconsistent with tetrahedral deformation

Bands are NOT tetrahedral

PRL **104,** 222502 (2010) PHYSICAL REVIEW LETTERS week ending 4 JUNE 2010

Ultrahigh-Resolution γ-Ray Spectroscopy of ^{156}Gd: A Test of Tetrahedral Symmetry

M. Jentschel,[1] W. Urban,[1,2] J. Krempel,[1] D. Tonev,[3] J. Dudek,[4] D. Curien,[4] B. Lauss,[5] G. de Angelis,[6] and P. Petkov[3]

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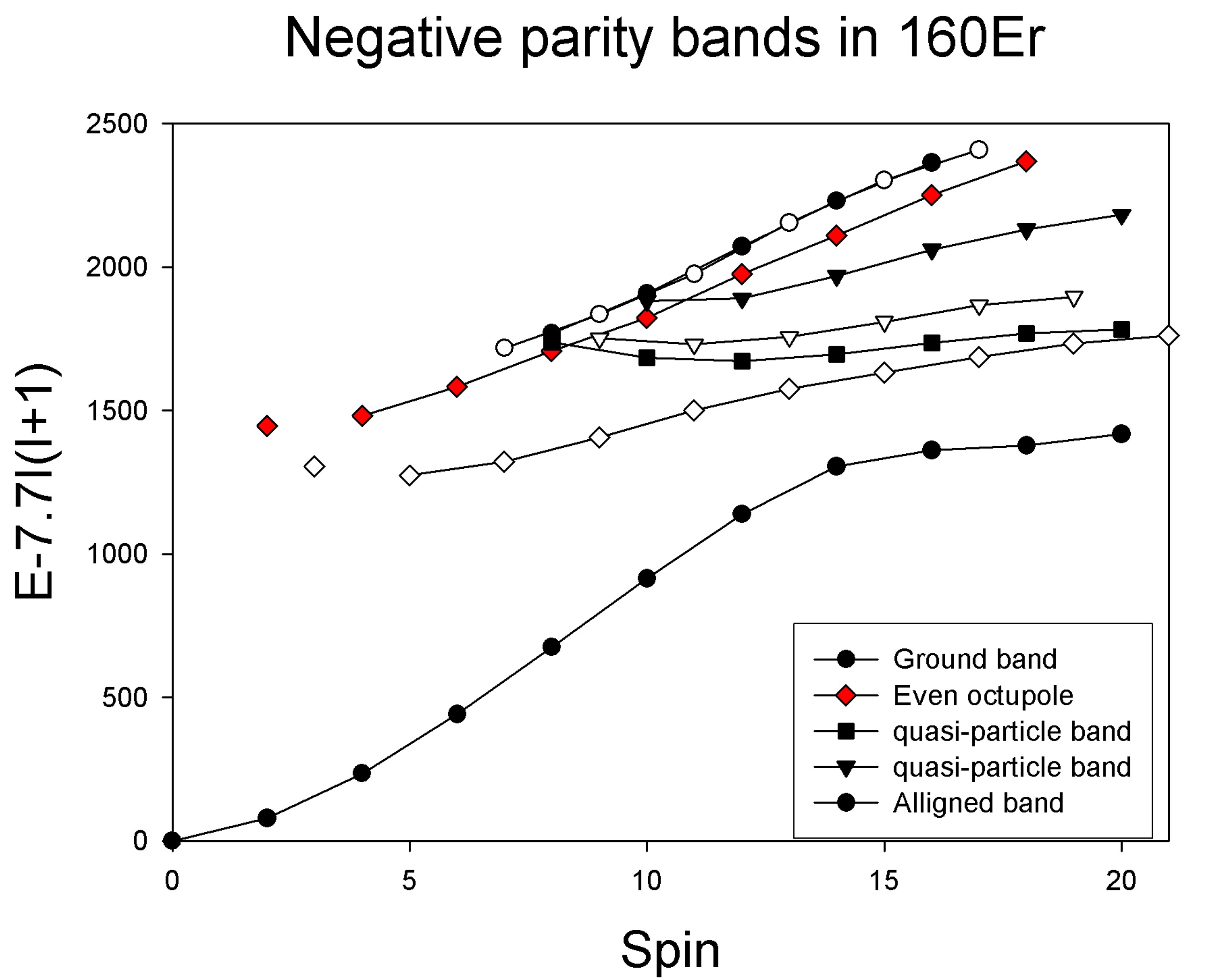
[2]*Faculty of Physics, University of Warsaw, ul. Hoża 69, PL-00-681 Warsaw, Poland*
[3]*Institute for Nuclear Research and Nuclear Energy, BAS, BG-1784 Sofia, Bulgaria*
[4]*Departement de Recherches Subatomiques, Institut Pluridisciplinaire Hubert Curien, DRS-IPHC, 23 rue du Loess, BP 28, F-67037 Strasbourg, France*
[5]*Paul Scherrer Institut, CH-5232 Villigen-PSI, Switzerland*
[6]*Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy*

(Received 26 February 2010; published 4 June 2010)

^{160}Er bands


Negative parity bands in 160Er
E-7.7I(I+1)
Spin
2500
2000
1500
1000
500
0
0
5
10
15
20
Ground band
Even octupole
quasi-particle band
quasi-particle band
Alligned band

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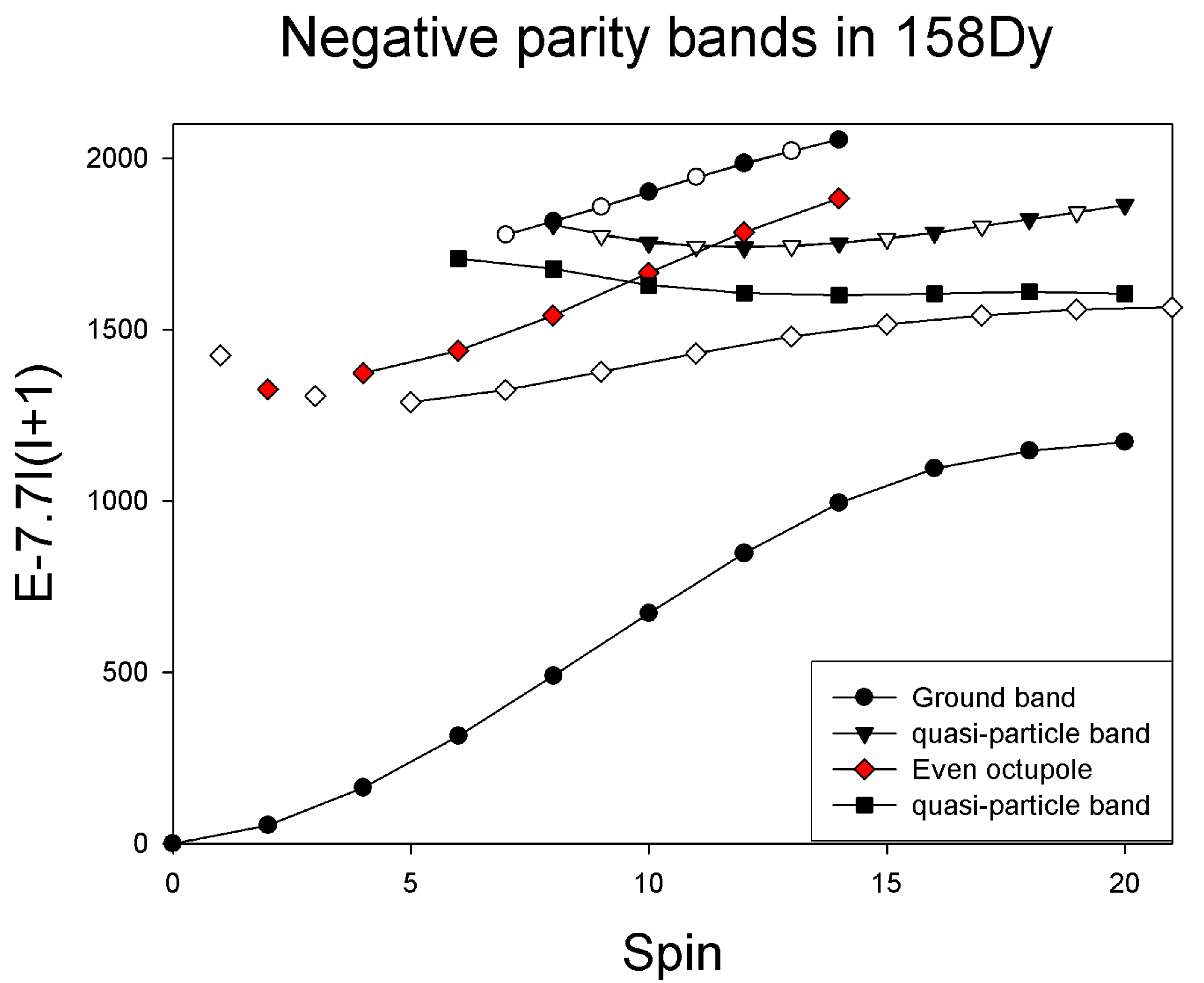
^{158}Dy bands



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Branching ratios for low spins

- Choice in E2 in-band or E1 going to yrast, the observed branching ratio (hist. counts):

$$\lambda = \frac{P_\gamma(\mathrm{E2}, I \rightarrow I-2)}{P_\gamma(\mathrm{E1}, I \rightarrow I-1)} \sim \frac{E_\gamma(\mathrm{E2}, I \rightarrow I-2)^5}{E_\gamma(\mathrm{E1}, I \rightarrow I-1)^3}$$

- If E1 constant, the 238keV (7^- to 5^-) transition 5 times less likely than the 315keV (9^- to 7^-).
- The 5^- to 3^- transition is 125keV, 30 times weaker than 7^- to 5^- peak: cannot be observed.

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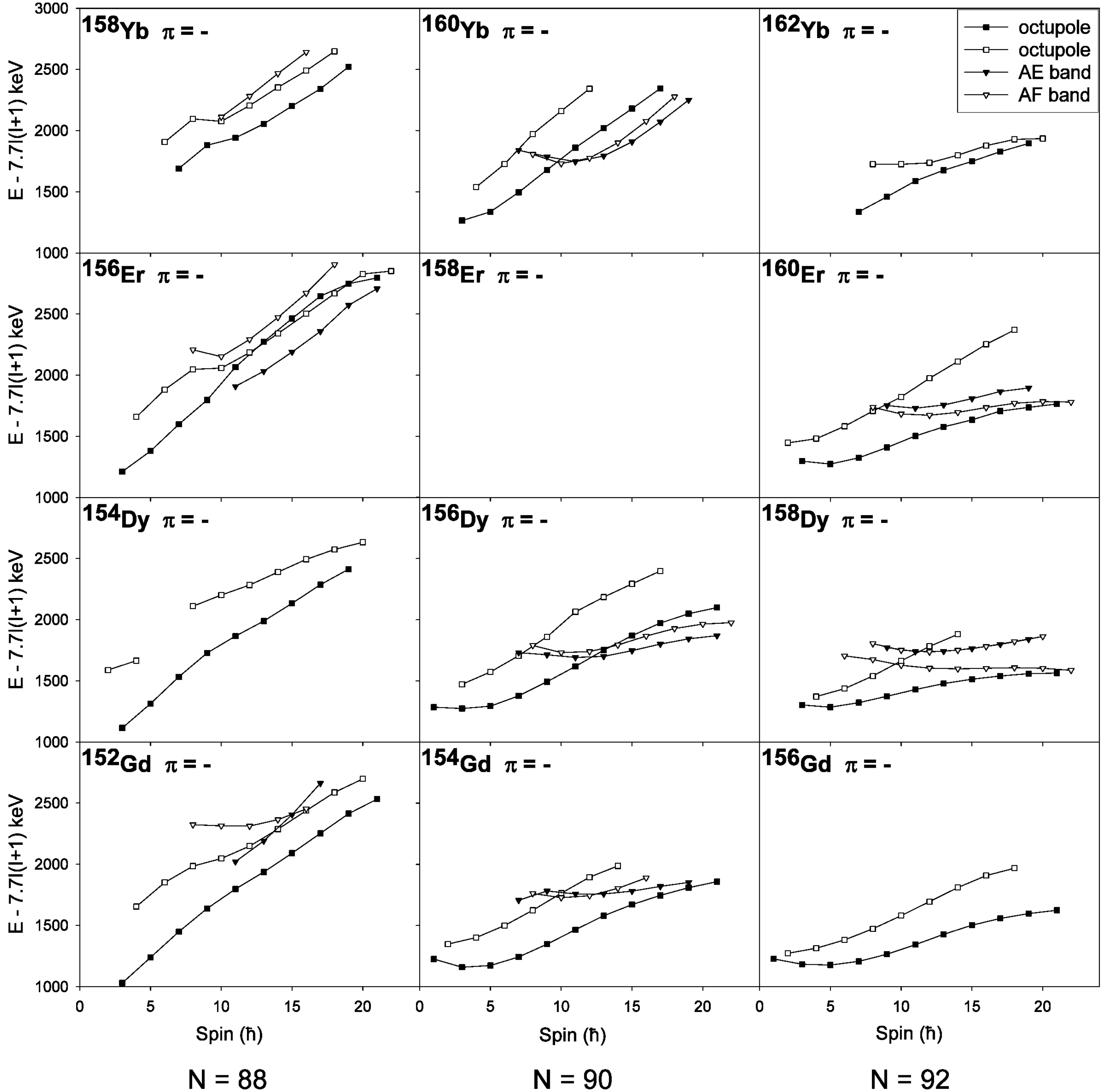
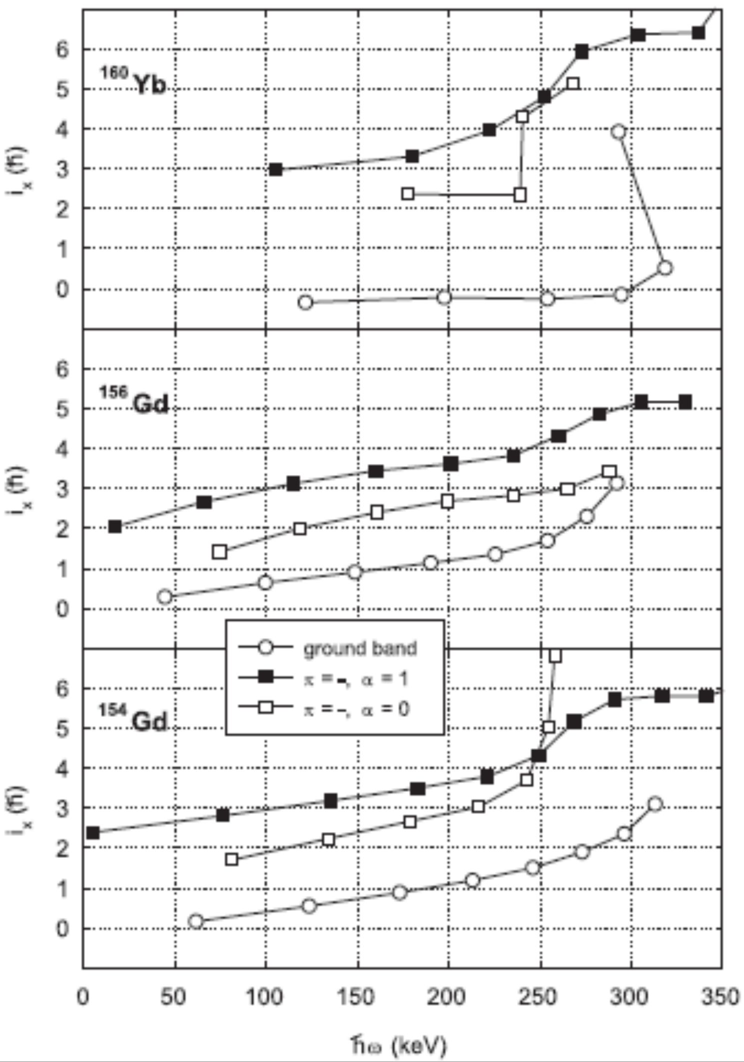

158Yb π = -
160Yb π = -
162Yb π = -
octupole
octupole
AE band
AF band
156Er π = -
158Er π = -
160Er π = -
154Dy π = -
156Dy π = -
158Dy π = -
152Gd π = -
154Gd π = -
156Gd π = -
E - 7.7I(I+1) keV
Spin (ħ)
N = 88
N = 90
N = 92

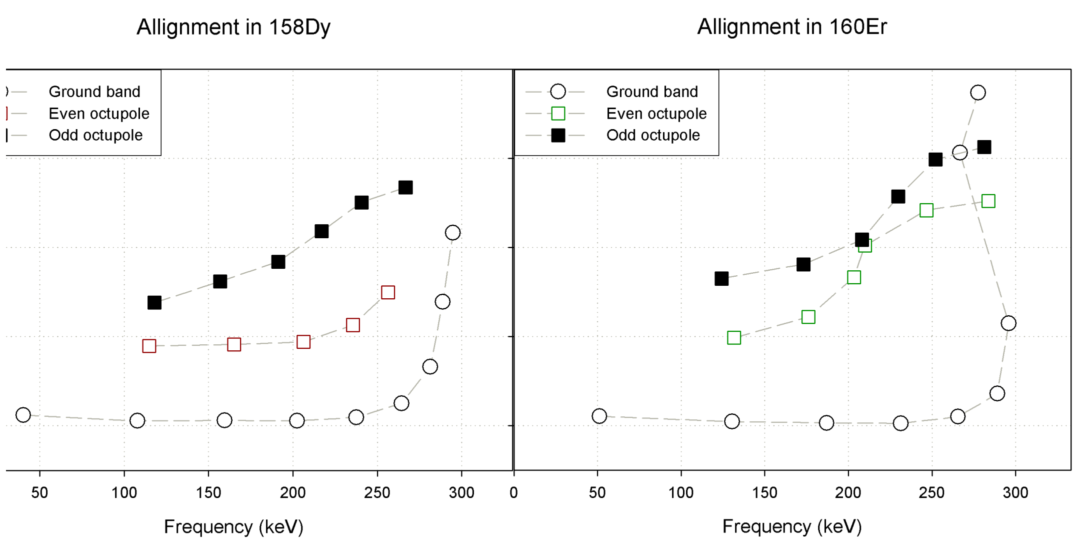
Experimental Alignments



Aligned octupole Bands:

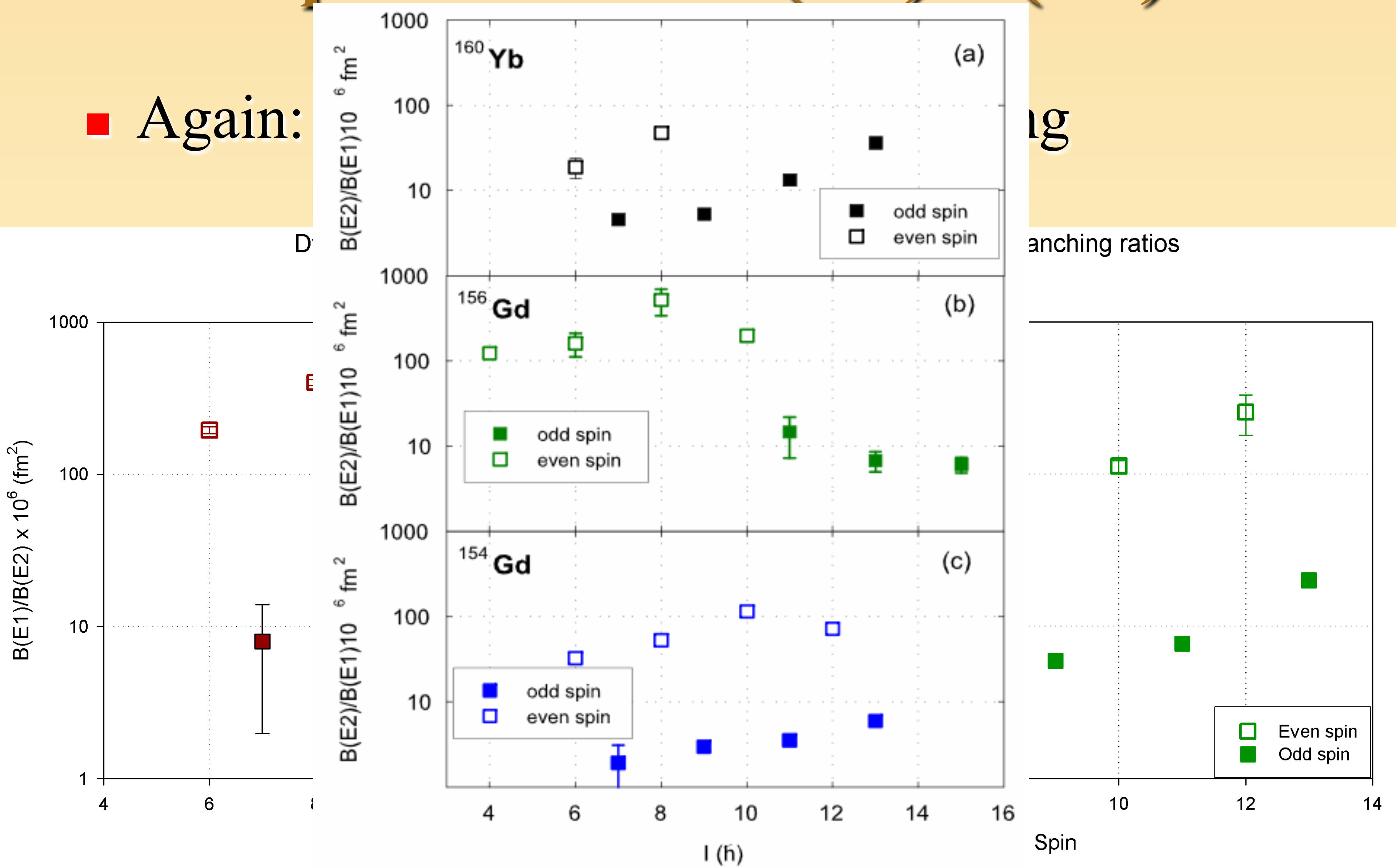
α = 0; 2 hbar

α = 1; 3 hbar



Experimental B(E2)/B(E1):

- Again: ng



B(E1)'s different. Why?

- The odd spin 'octupole' bands in the region systematically show stronger out-of-band transitions.

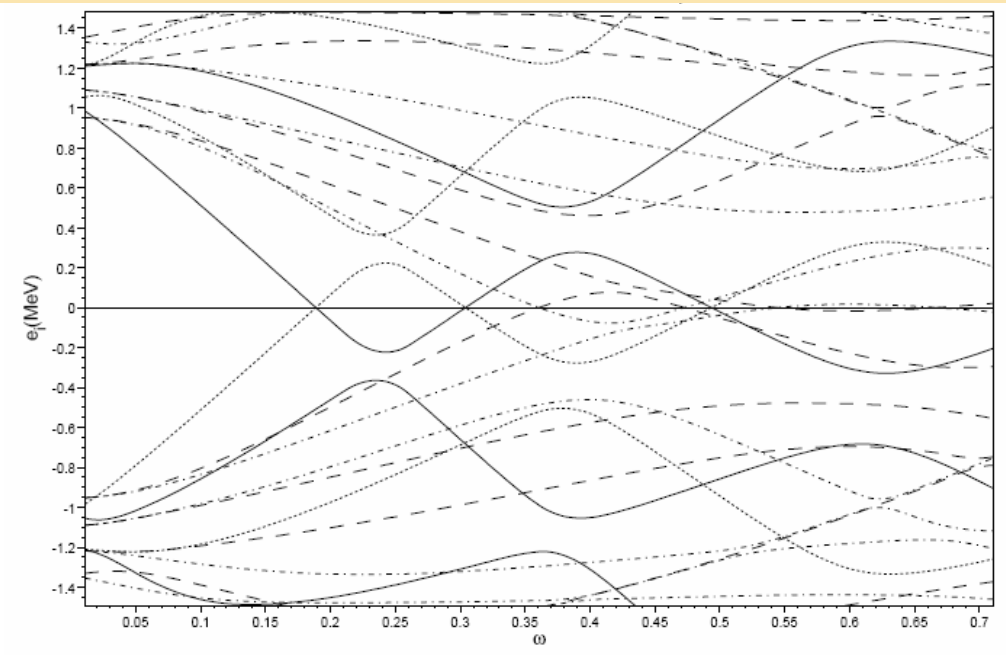
- Try to find a physical reason for the staggering of out-of-band B(E1) strengths.

Random Phase Approximation

- Take output of TAC:
- Hamiltonian:

$$H_{RPA} = h_{2qp} - \frac{1}{2}\sum_{i,t} \kappa_{it}(\hat{Q}_{it})^2$$

- Good signature for multipoles of form:



$$\hat{Q}_{lms} = \frac{1}{2}(\hat{Q}_{lm} + s \cdot \hat{Q}^*_{lm})$$

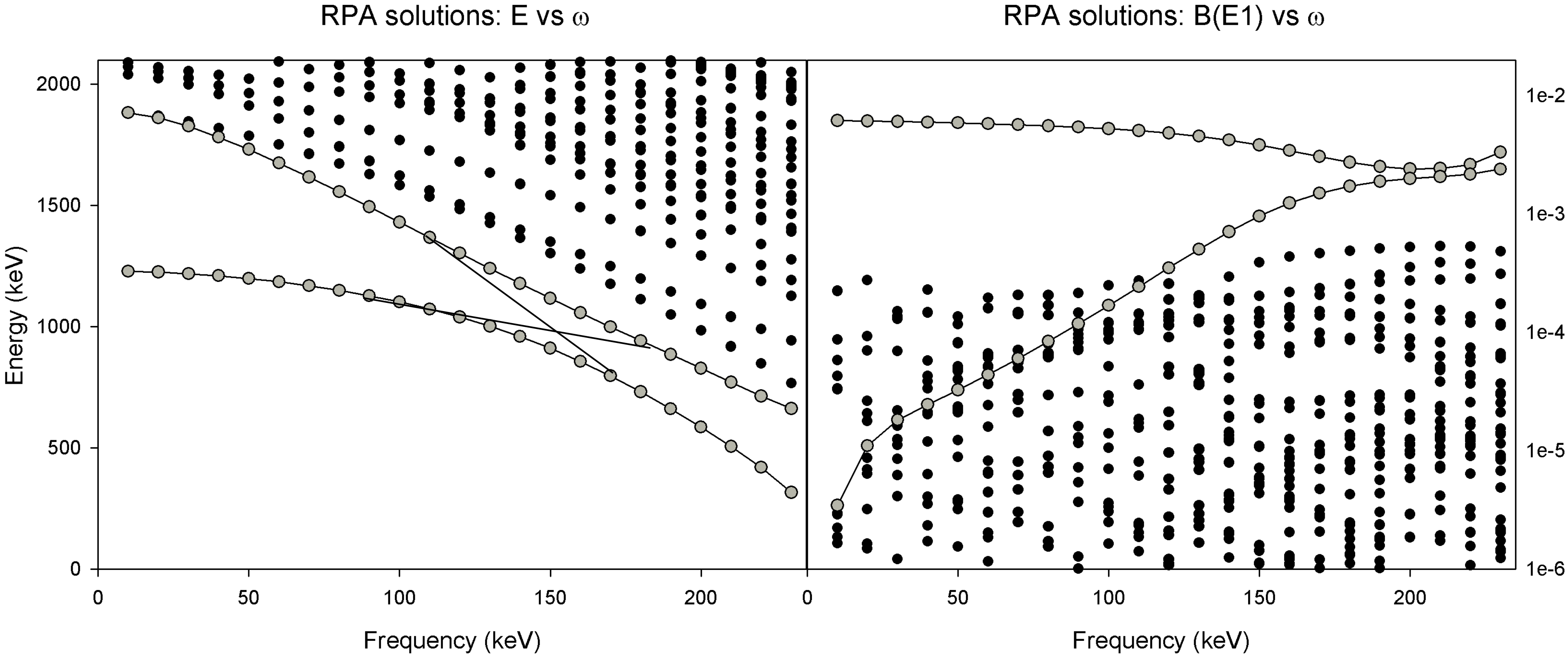
$$\hat{R}_x \hat{Q}_{lms} = (-1)^{l+m} \cdot s\,\hat{Q}_{lms}$$

Random Phase Approximation

- The RPA model takes cranking output and models interactions between quasiparticles:
  - Tilted Axis Cranking performed around a chosen axis (in this case *x*)
  - Quadrupole deformation taken from Möller-Nix
  - Single fit to octupole interaction strength κ, for each signature for an experimental data point
  - Run over multiple ω values
    - The RPA calculations done in intrinsic frame, as all states are excitations vacuum (yrast)

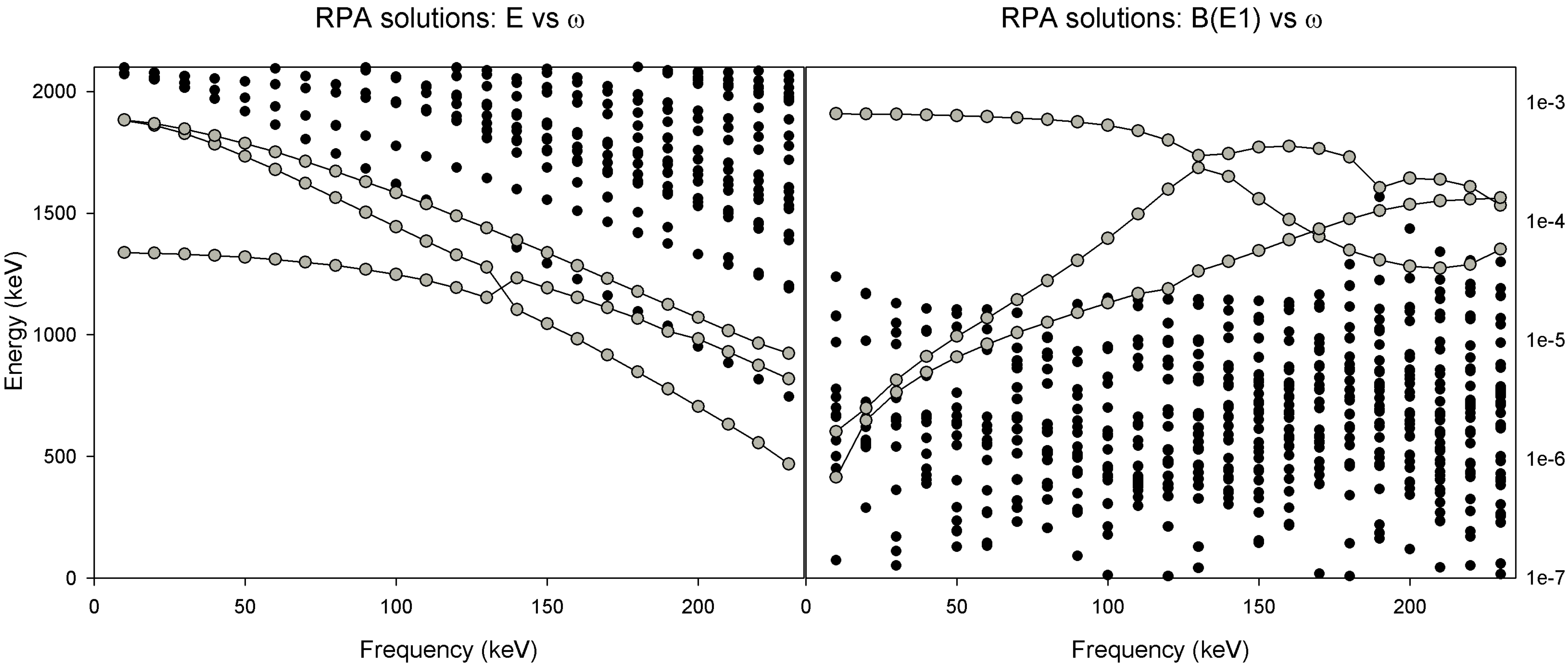
RPA calculations on ^{158}Dy, α=1

- Run the codes – band crossings must be dealt with through E/B(E1) continuity:

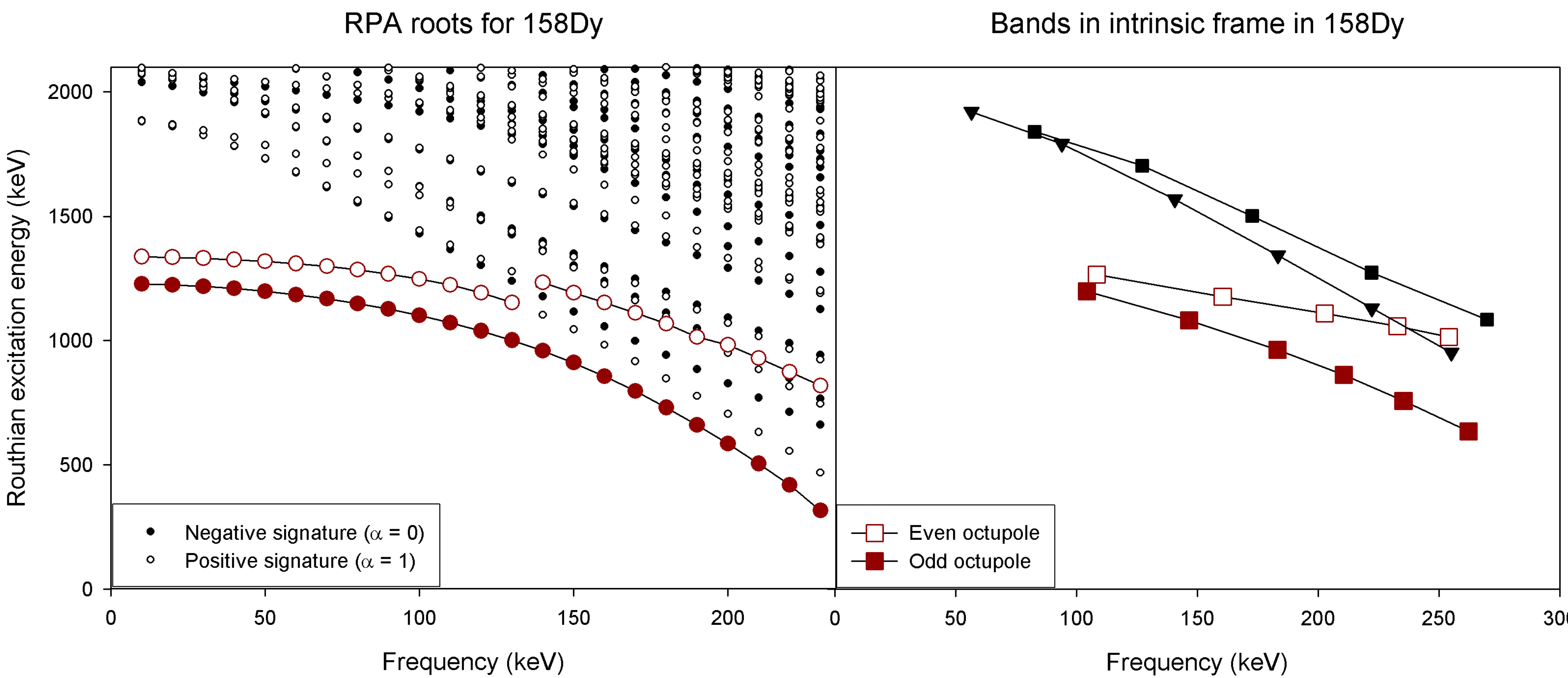


RPA calculations on ^{158}Dy, $\alpha=0$

- For both signatures…

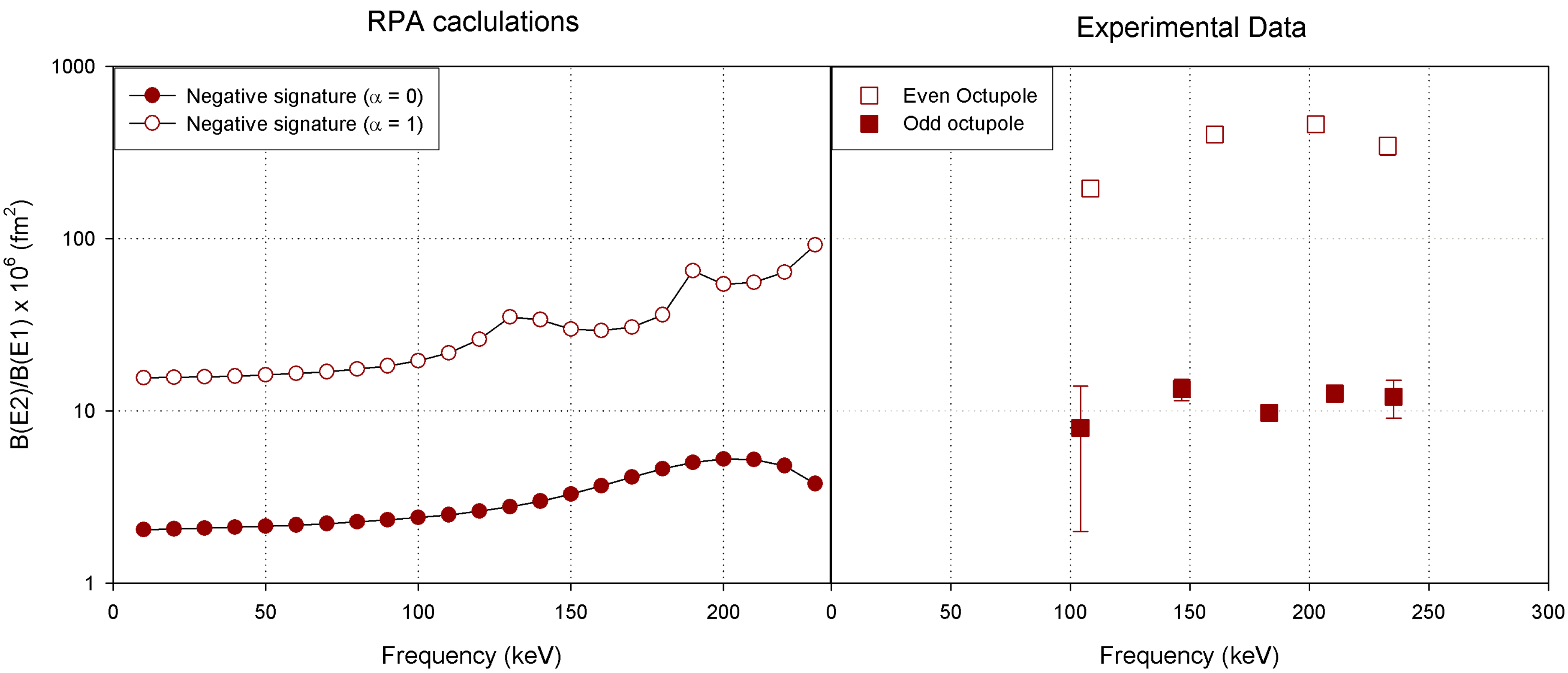


^{158}Dy: RPA-Experiment

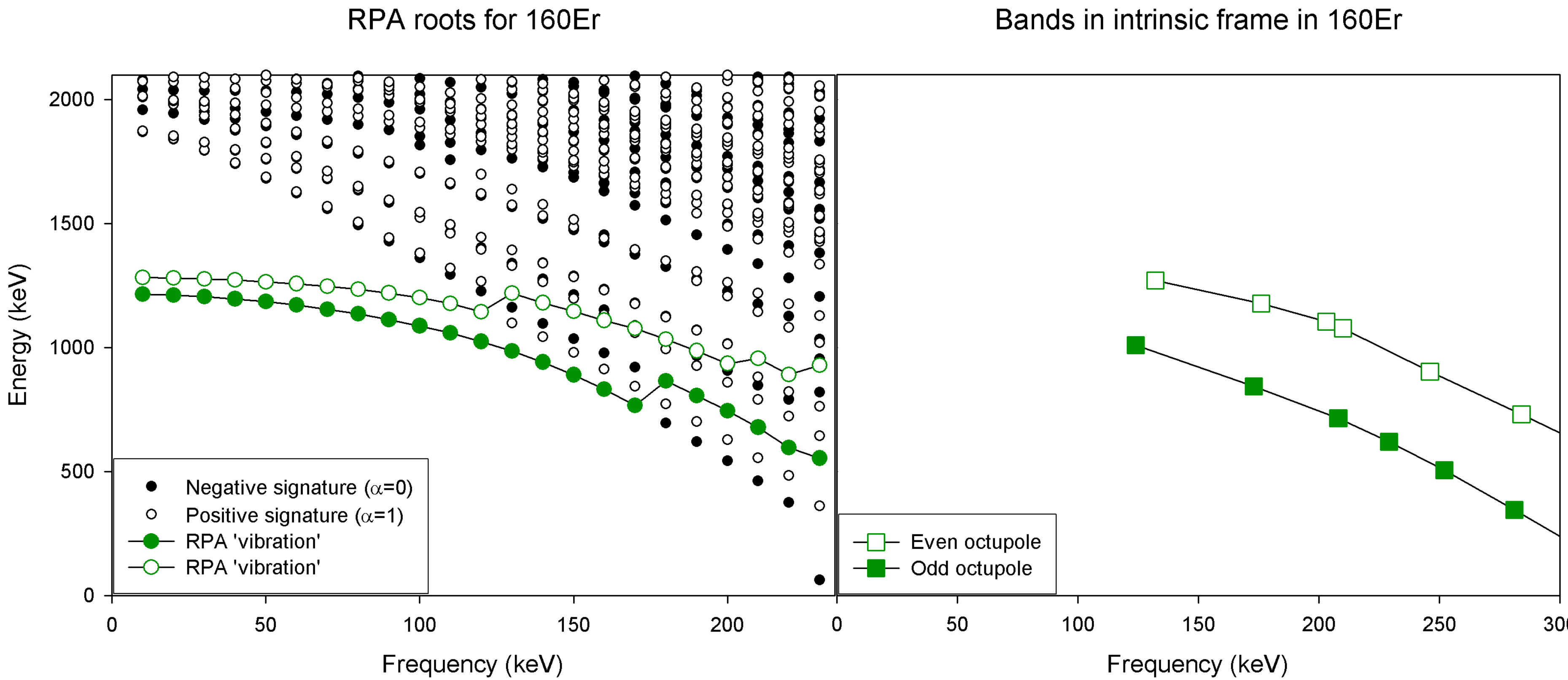


Pretty decent agreement!

^{158}Dy: RPA-Experiment



^{160}Er: RPA-Experiment



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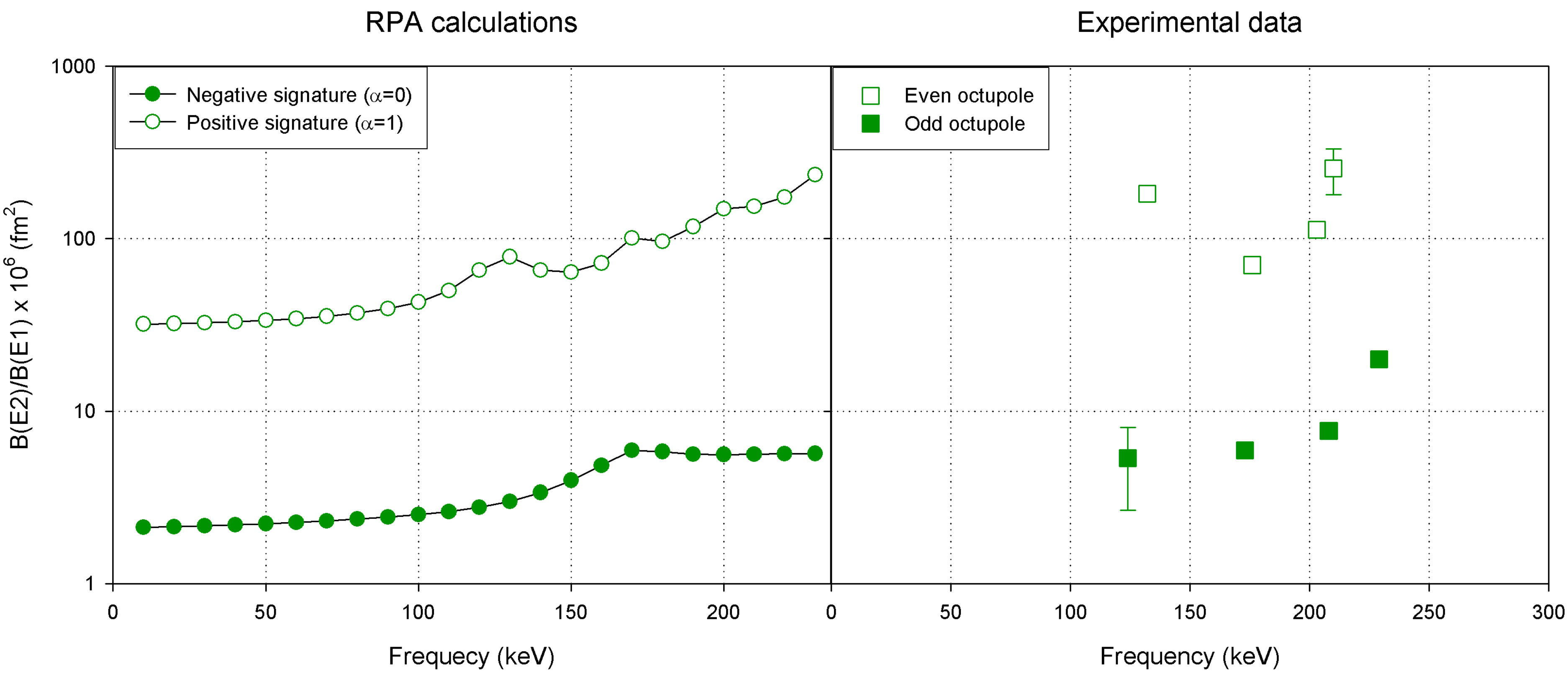
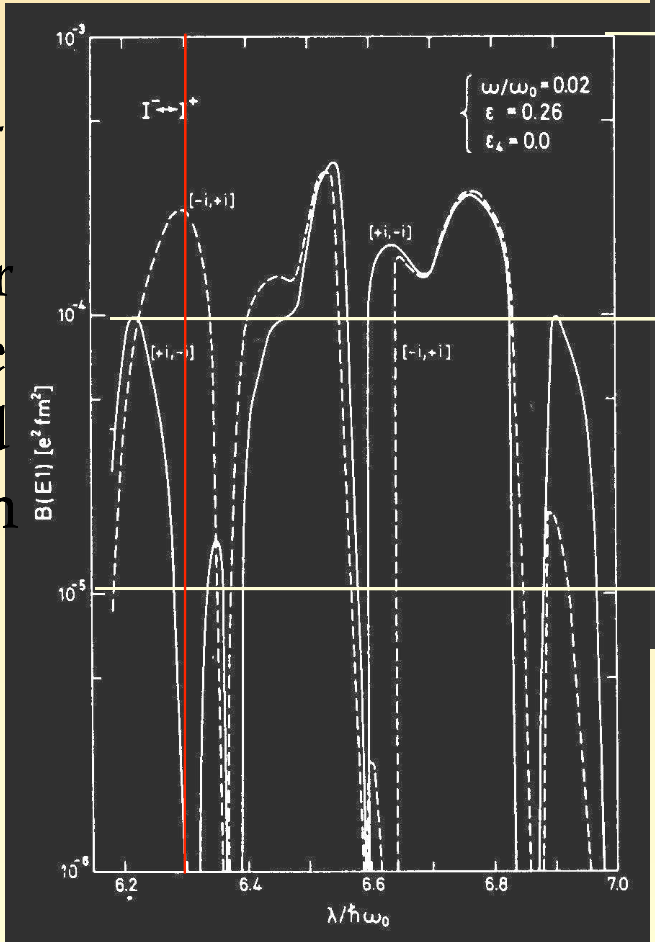
^{160}Er: RPA-Experiment

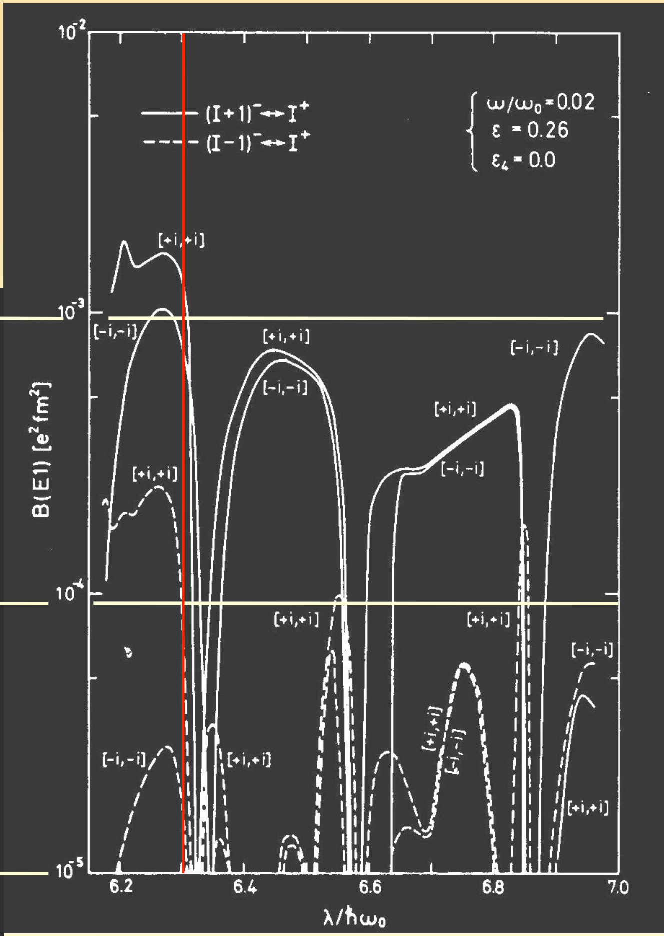


2QP BANDS
Hamamoto & Sagawa

$$B(E1; I \rightarrow I\text{-}1) > B(E1; I \rightarrow I)$$

"This relation can be understood by considering the fact that it is most efficient for a single-particle state with strongly aligned spin to emit a photon in the direction of the alignment."





Conclusion

- Negative parity bands are aligned octupole bands
- RPA
  - Qualitatively good agreement with data
  - Systematically consistent behaviour
- Signature dependent B(E1) strengths consistent with 2QP staggering

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Thanks to:

Fritz Dönau[1], Rob Bark[2], David Aschman[3], Pradip Datta[2], Tsepho Dinoko[2], Stefan Frauendorf[4], Toafiq Ibrahim[2], Elena Lawrie[2], Kobus Lawrie[2], Siya Majola[2], Simon Mullins[2], John Sharpey-Schafer[2]

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[3] University of Cape Town

[4] University of Notre Dame

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- Nice place to do physics: