Multiple octupole bands and shape change in ^{221}Th

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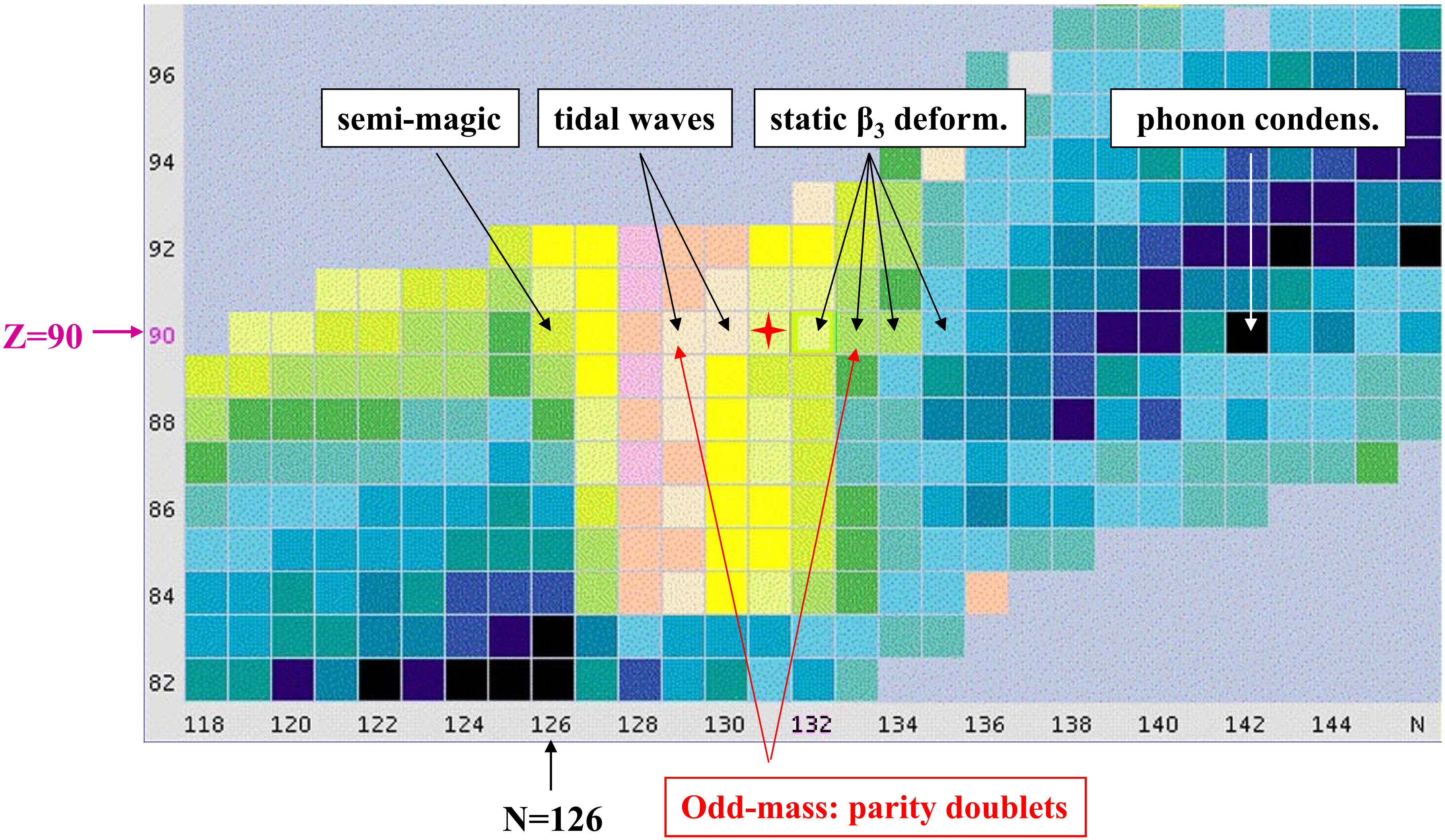


Outline

I. Introduction (long)

II. Experiment and level-scheme construction

III. Discussion

IV. Conclusions

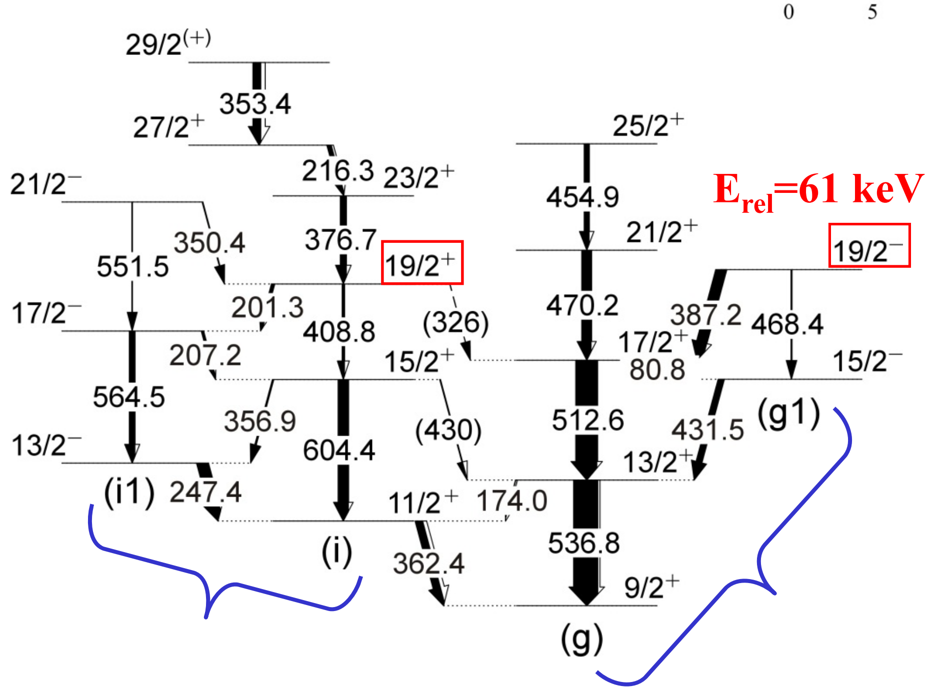
"Degeneracy" plot: $E_{rel} = E(s=+i) - E(s=-i)$

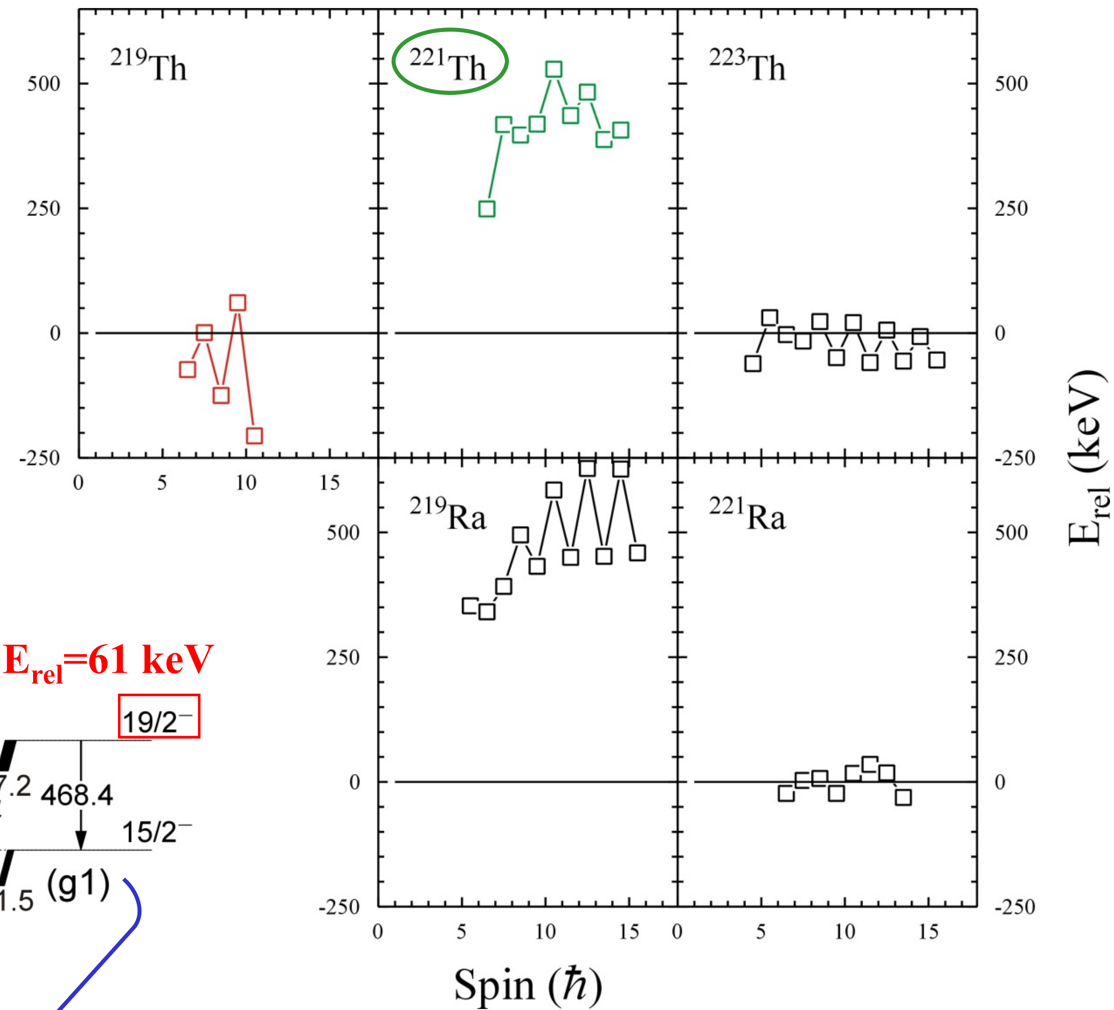
^{219}Th

Simplex structure s=+i (**g** and **g1**).

Simplex structure s=-i (**i** and **i1**).

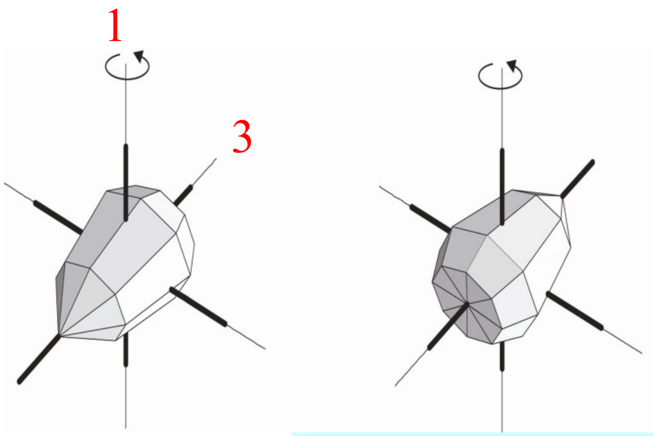
Both are energetically nearly degenerate.





Near degeneracy seems the rule.

Reflection-asymmetric shape ($\beta_3 \neq 0$)



R=exp(-iπI)	Half-turn around axis 1	**No**
X	Mirror symmetry w.r.t. a plane containing axis 1 and not axis 3	**No**
S=PR^{-1}	Mirror symmetry w.r.t. a plane containing axes 1 and 3 (P:parity)	**Yes**

Spin selection rules: half-integer spin

S = P exp(iπI) = P cos(πI) + P i sin(πI)

S = -i I^P = 1/2$^-$, 5/2$^-$, 9/2$^-$, … and 3/2$^+$, 7/2$^+$, 11/2$^+$,…

S = +i I^P = 1/2$^+$, 5/2$^+$, 9/2$^+$, … and 3/2$^-$, 7/2$^-$, 11/2$^-$,…

The simplex S fixes the spin for a given parity!

Parity doublets (*S. Frauendorf*)

Energy degeneracy indicates that S represents a broken symmetry.

"Bad" simplex implies a rotation that is not about a principal axis (analog high-K bands).

The odd particle tilts the rotational axis w.r.t. the 1-axis.

$^{219}Th_{129}$

$(g_{9/2})^3$ K=3/2

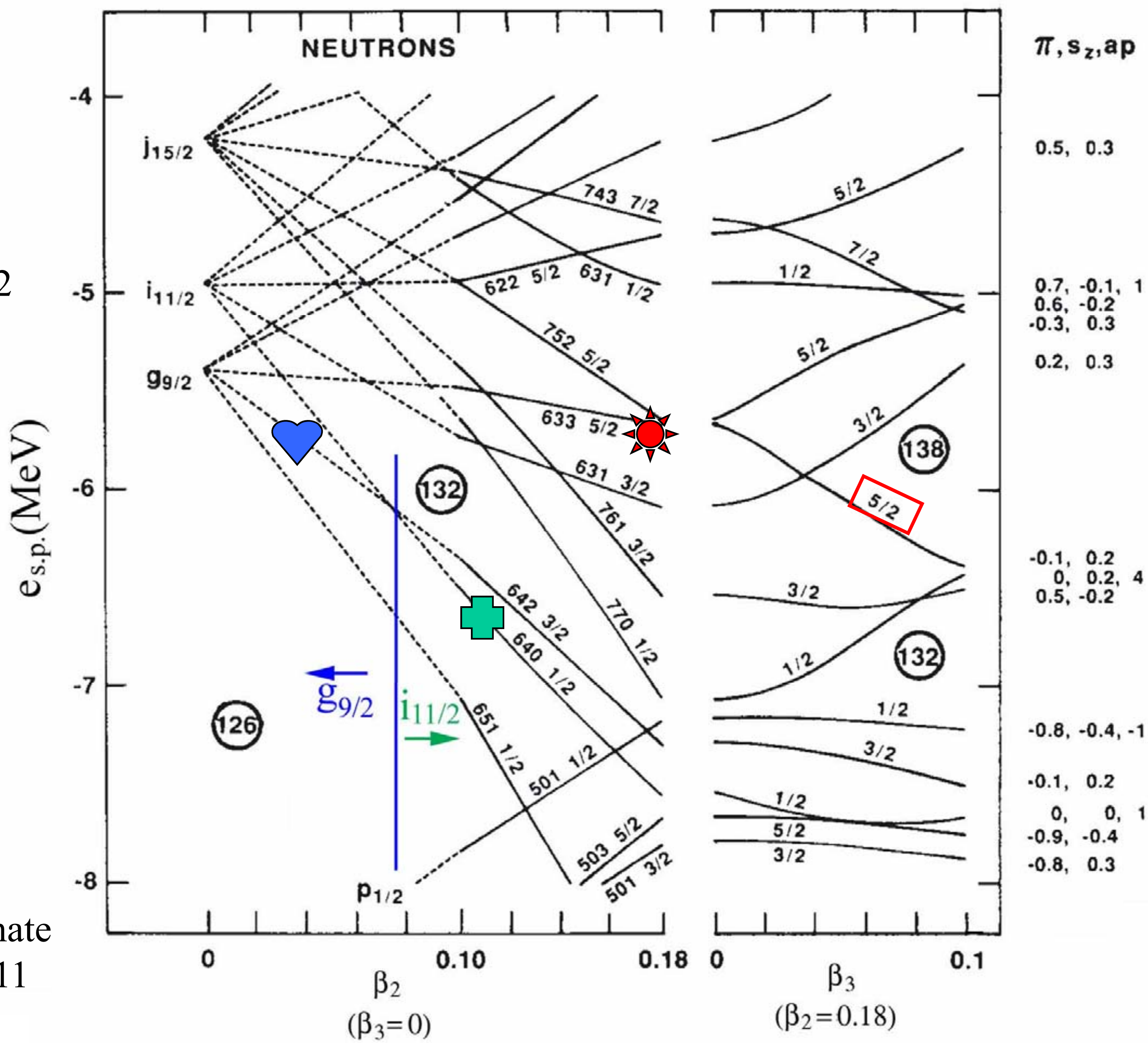
$^{221}Th_{131}$

$i_{11/2}(g_{9/2})^4$ K=1/2

$^{223}Th_{133}$

$(i_{11/2})^2(g_{9/2})^5$
K=5/2

G. A. LEANDER AND Y. S. CHEN PRC 37 (1988)



Grodzins estimate for ^{221}Th: β_2=.11

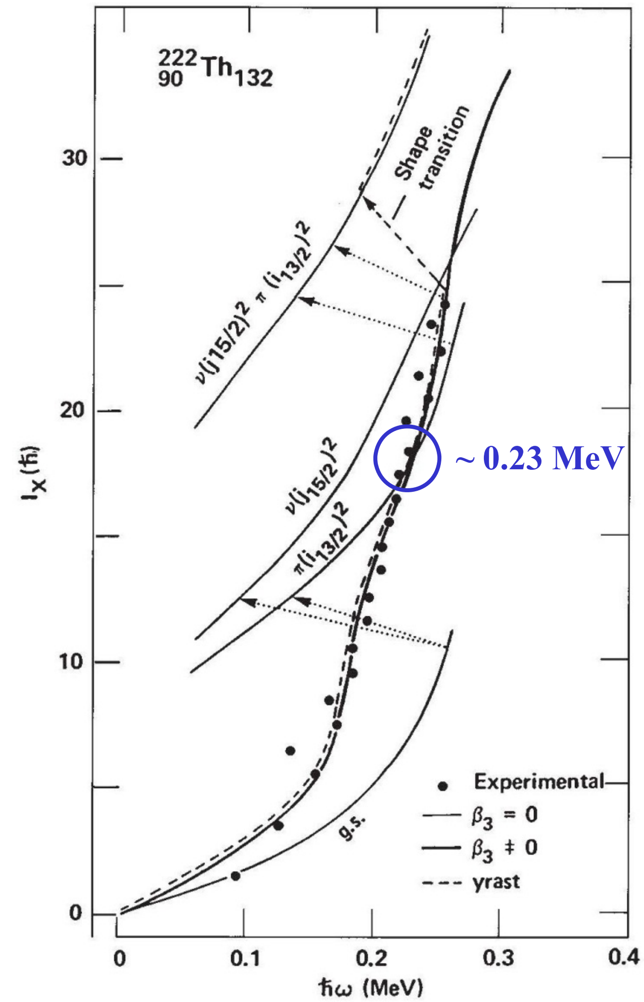
Related paper: ***Cwiok & Nazarewicz, NPA 529 (1991)***

^{221}Th - Issues

- Delineation of the non-yrast structure.
- Subtle differences between Th and Ra isotones (role of **proton $i_{13/2}$** orbital).
- Feeding of octupole bands.

<u>Theoretical calculations</u>
Nazarewicz et al., NPA 467 (1987)

<u>^{222}Th experimental check</u>
Smith et al., PRL 75 (1995)

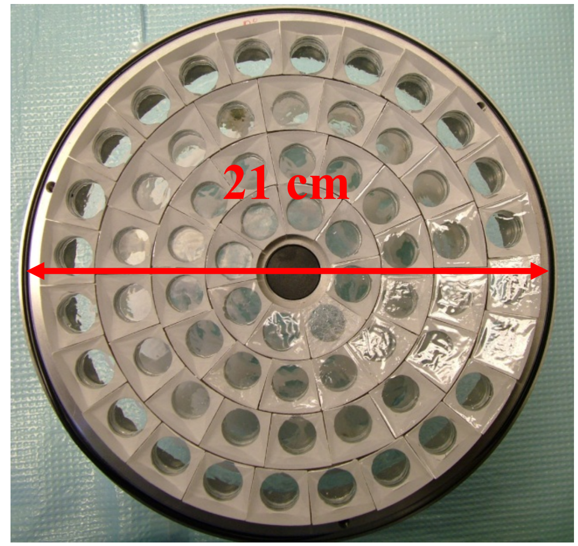


II. Experiment and level-scheme construction

$^{18}O + ^{207}Pb \rightarrow ^{225}Th^*$ Experiment

Channel of interest	**$^{221}Th + 4n$**
Beam energy	**96 MeV (ATLAS)**
Beam intensity	6 pnA
Beam period	247.5 ns (3:1 sweeping)
Target thickness	0.47 mg/cm^2
E_{kin}	3.9 - 7.4 MeV (^{221}Th)
Flight path	**23.2 cm (target - ring 3)**
ToF residues	91 - 126 ns
ToF scattered beam	7 ns
Trigger condition	**Gammasphere ∩ Hercules**
Other	hardware veto

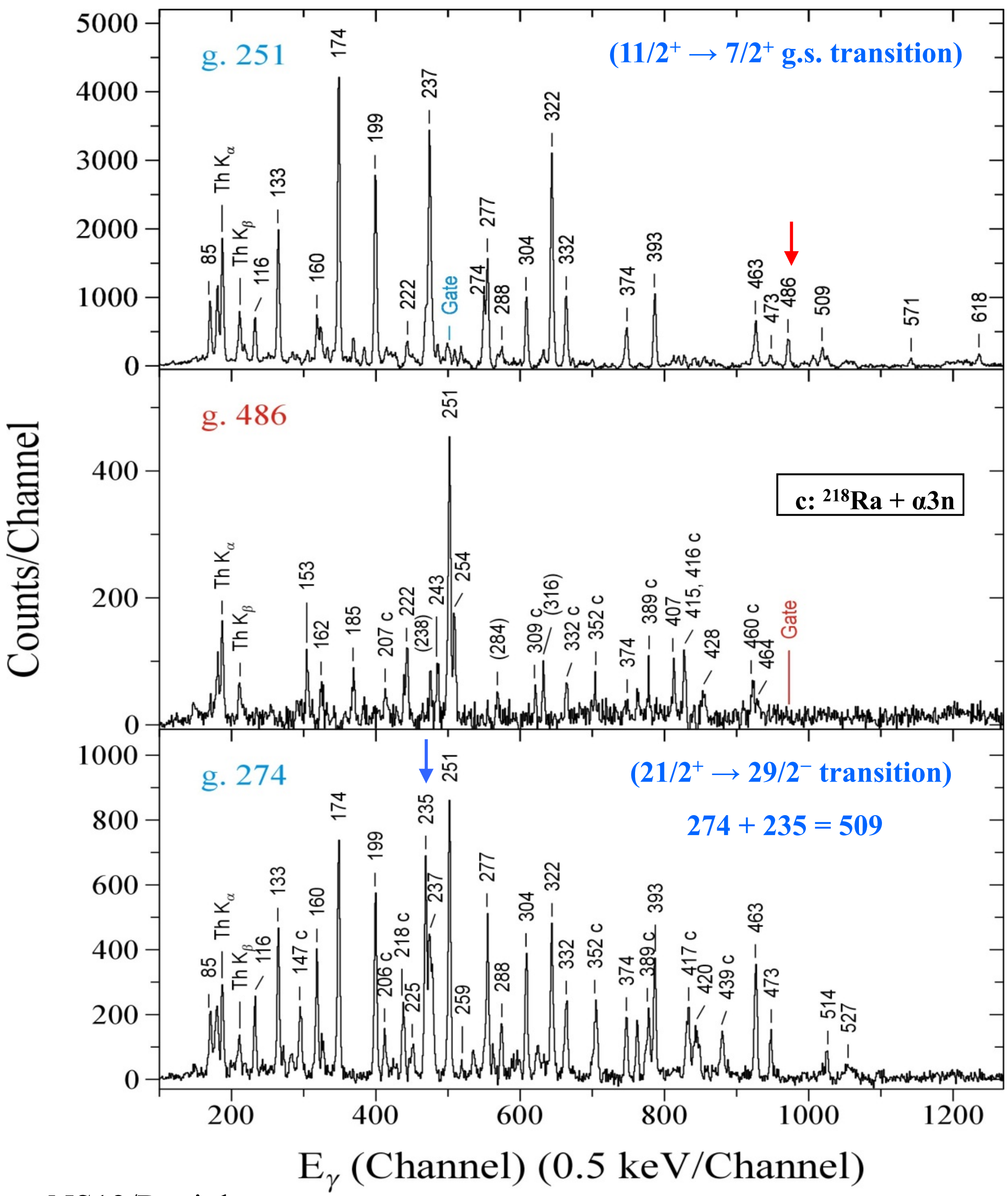
HERCULES (64 dets.)

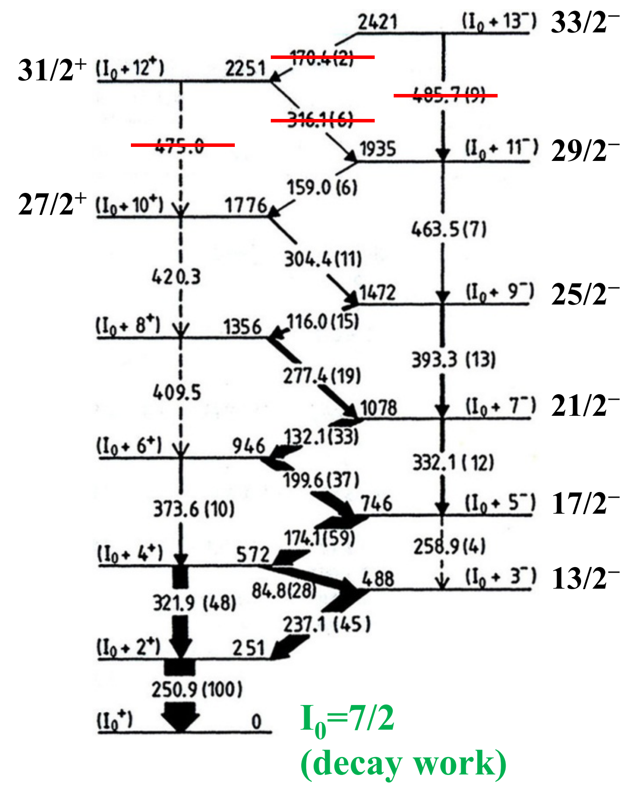


θ = 4.1° - 26.8° (nominal)
6.6° - 26.8° (present expt.)
Measure ToF, pulse height, residue direction
Compatible w/ 98 GS detectors

Light-Thorium spectroscopy is traditionally done with a “filter” to reduce the fission background (e.g. Dahlinger et al., NPA 484 [1988]).

^{221}Th
Sample residue-gated γ-γ coincidence spectra





^{221}Th

^{18}O + ^{207}Pb (4n channel)
E_{lab}= 96 MeV

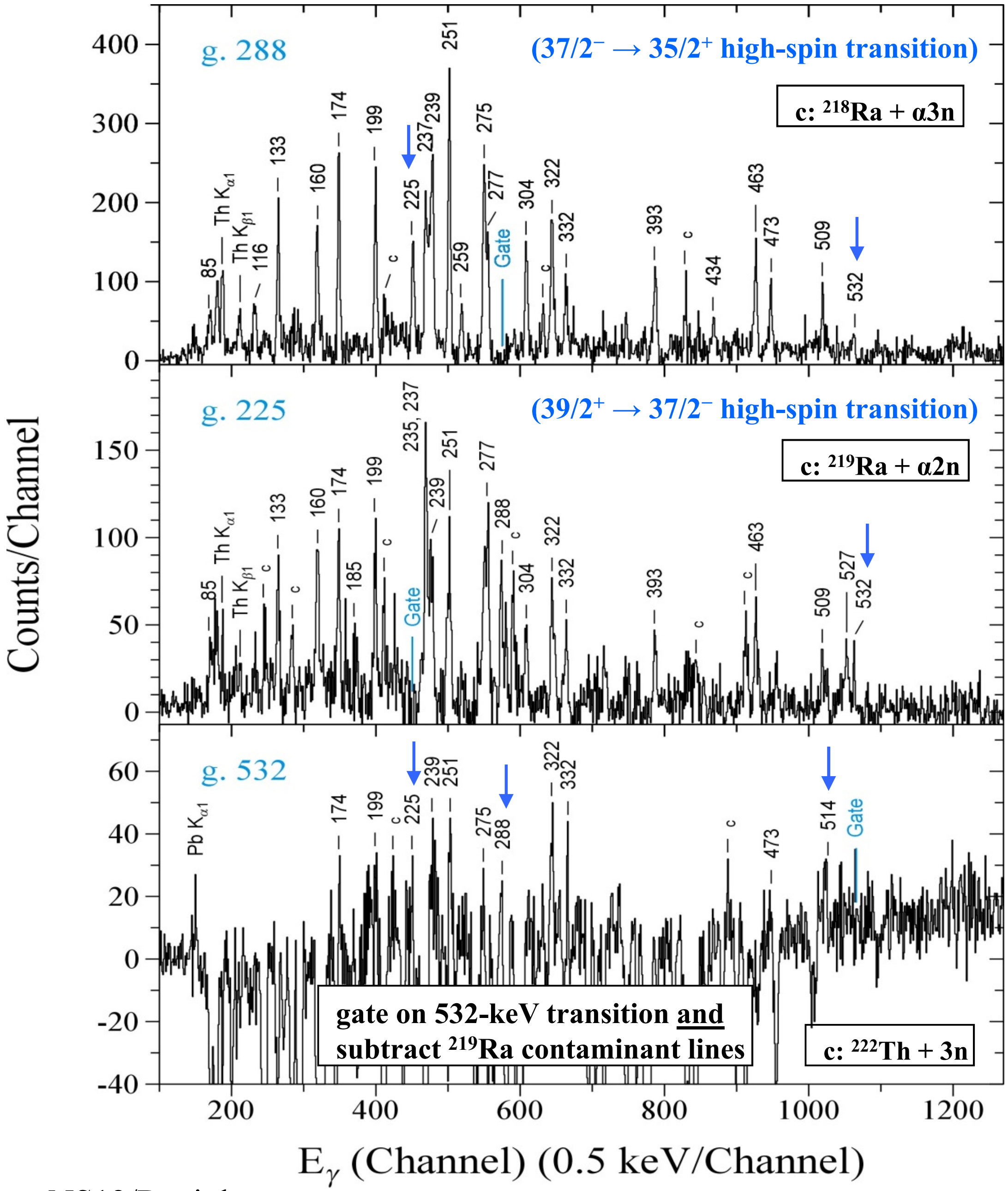
yrast
S=-i

off-yrast
(S=+i)

E.g. 13/2^{+} vs. 13/2^{-}
E_{rel}=250 keV

Intensity difference:
about factor of 5

Previous work:
Dahlinger et al. NPA 484 (1988)

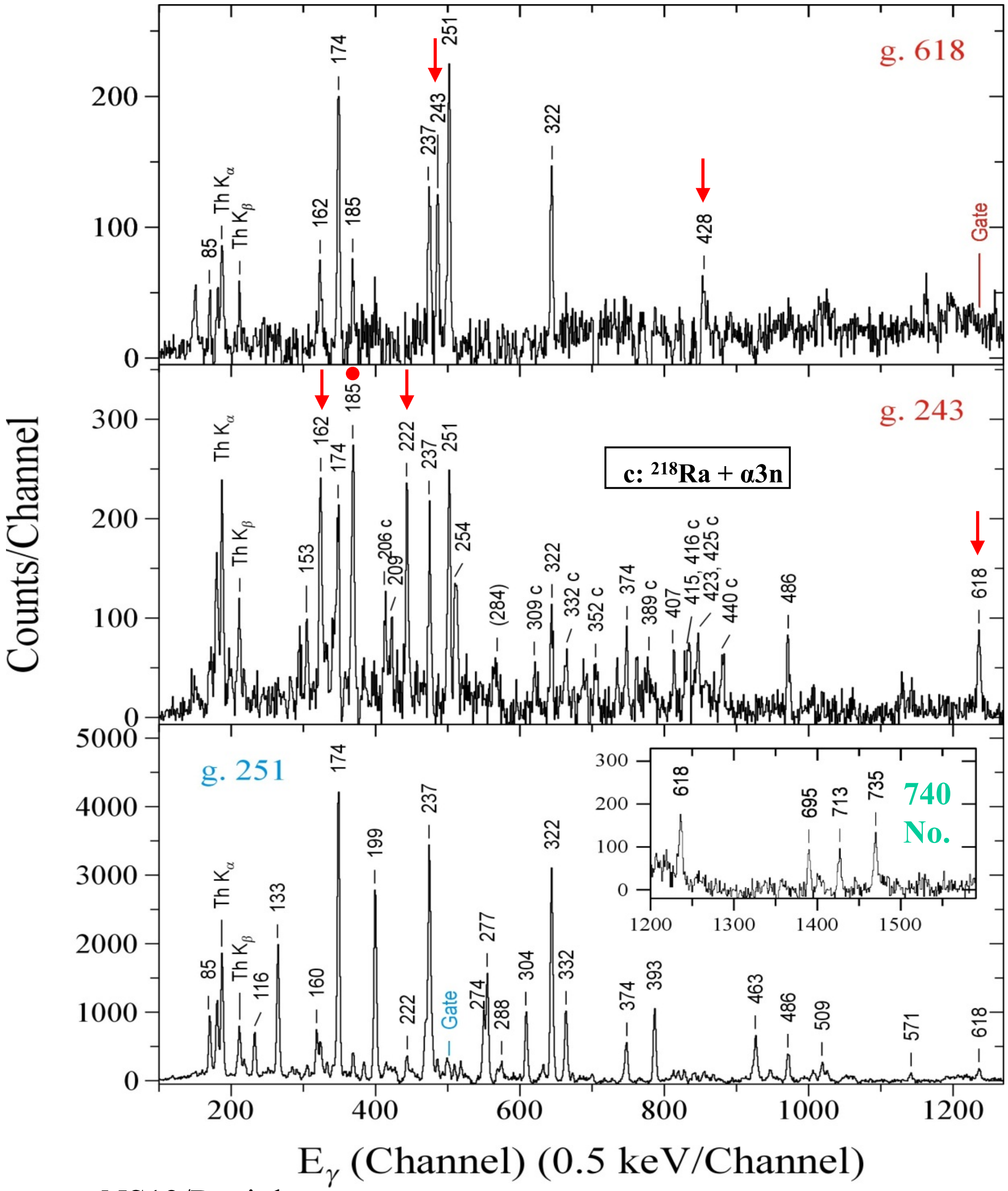


I ≥ 39/2: crossing w/ other structure

I ≥ 31/2: deviation from I vs. ħω behavior of ^{219}Ra (N=131 isotone)

^{221}Th

partial level scheme (yrast)



^{221}Th

Side-band assignments

γ-angular distribution (dipole vs. E2)

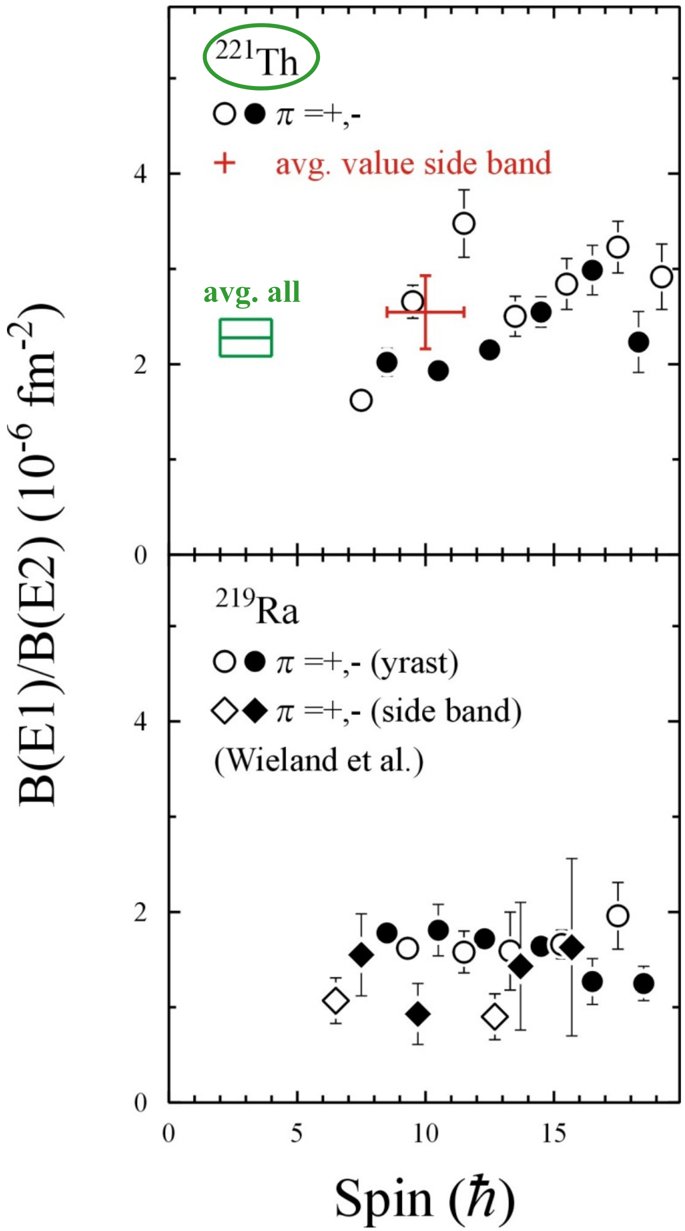
total-intensity (E1 assignment for low-energy dipoles)

coincidence considerations (parity assignment)

No 740

partial level scheme (side band b1-b2)

III. Discussion

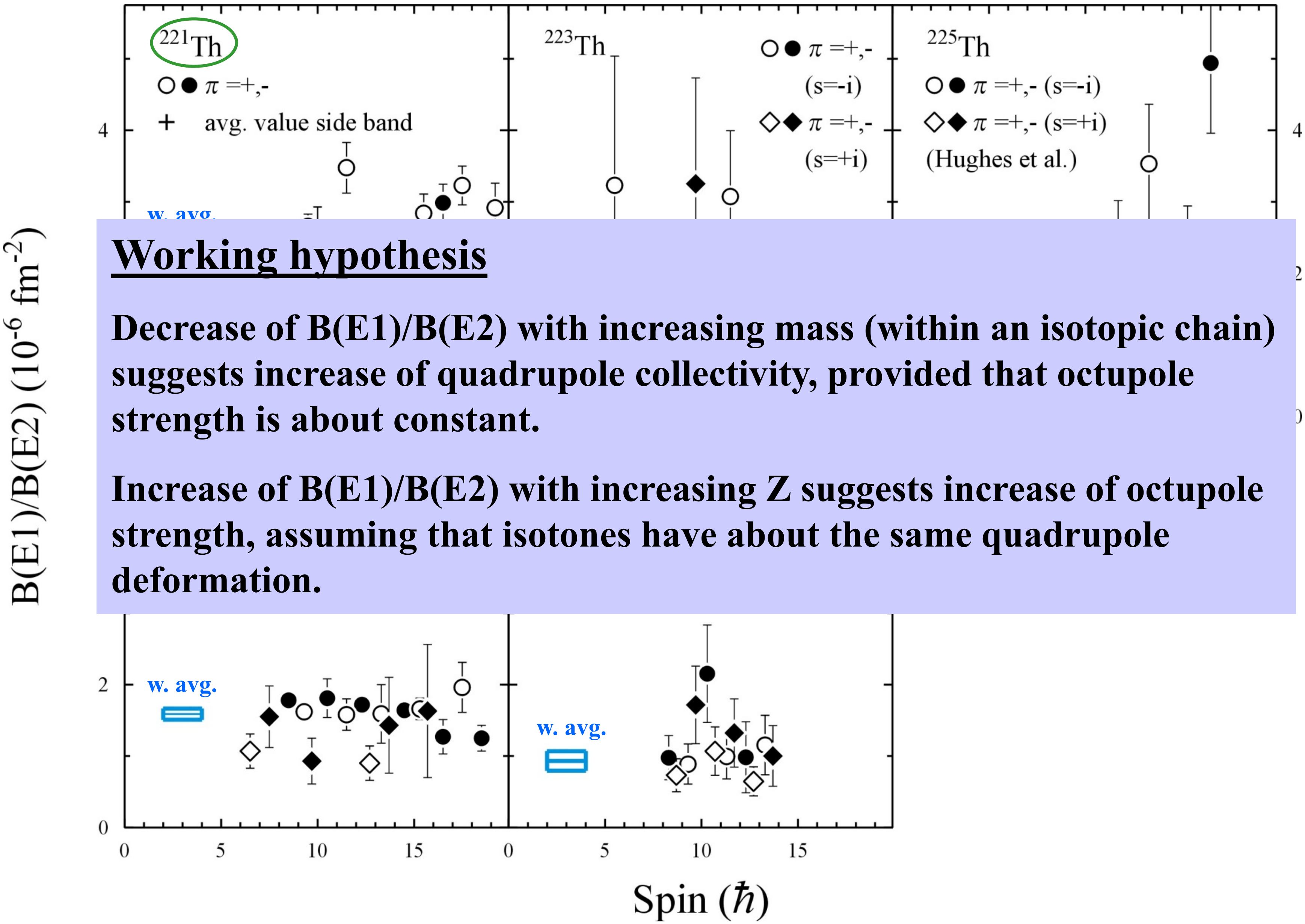


$B(E1)/B(E2) = 2.3 \cdot 10^{-6}$ fm^{-2}

$B(E2) = 3.5 \cdot 10^{3}$ e^{2}fm^4 (estimate)

$B(E1) \sim 7 \cdot 10^{-3}$ e^{2}fm^2 = $3 \cdot 10^{-3}$ W.u.

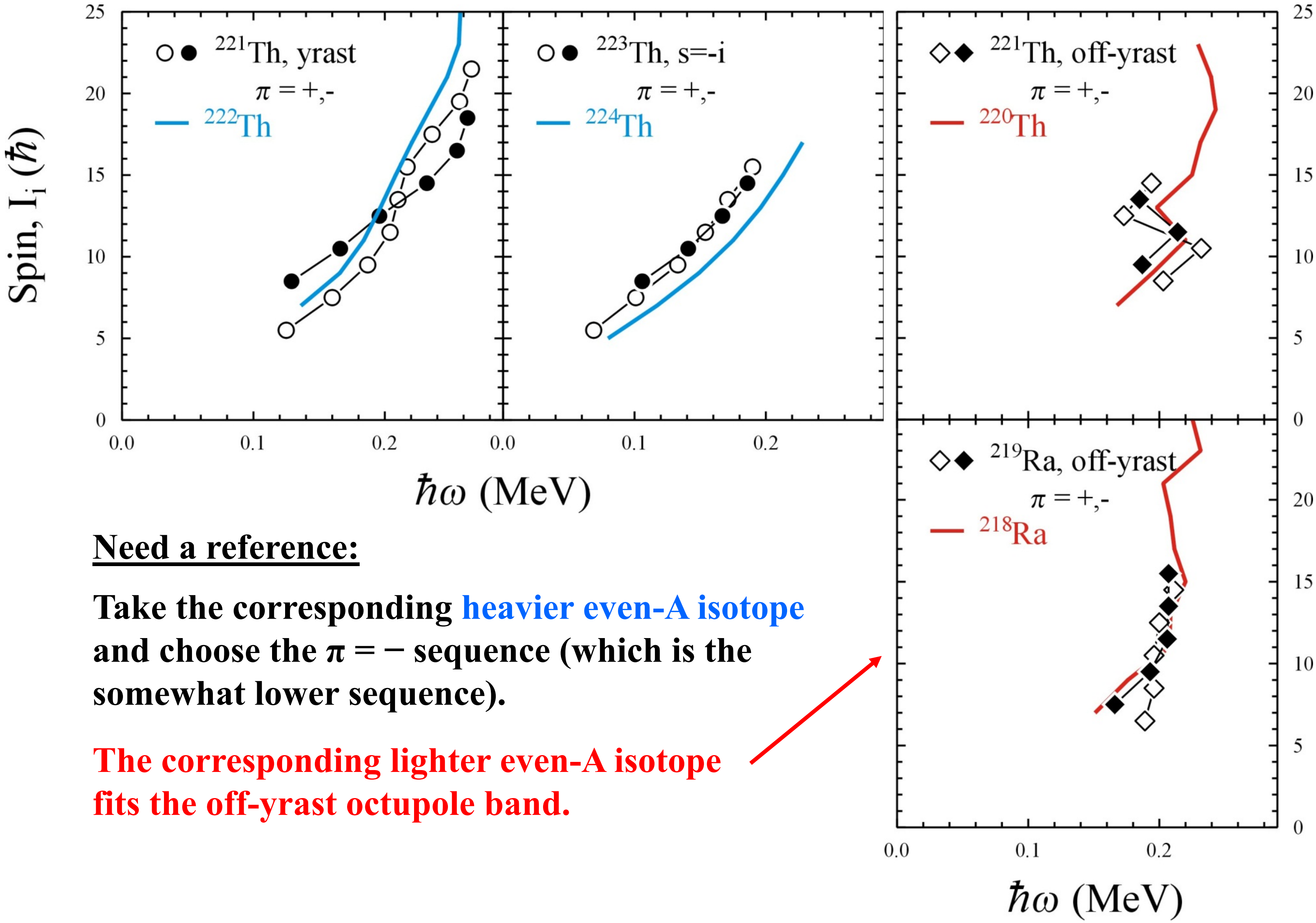
$$\frac{B(E1)}{B(E2)} = 0.7708 \cdot 10^{-6} \cdot \frac{T_\gamma(E1)}{T_\gamma(E2)} \cdot \frac{E_\gamma^5}{E_\gamma^3} \quad [fm^{-2}]$$



Working hypothesis

Decrease of B(E1)/B(E2) with increasing mass (within an isotopic chain) suggests increase of quadrupole collectivity, provided that octupole strength is about constant.

Increase of B(E1)/B(E2) with increasing Z suggests increase of octupole strength, assuming that isotones have about the same quadrupole deformation.



Need a reference:

Take the corresponding heavier even-A isotope and choose the π = − sequence (which is the somewhat lower sequence).

The corresponding lighter even-A isotope fits the off-yrast octupole band.

IV. Conclusions

1. Octupole correlations provide a good example, how the symmetry of the mean field dictates the spin-parity sequence of the level scheme. The much weaker off-yrast structure also forms an alternating-parity band, even though it is not rotational like.

2. At ~20 $\hbar$ ($I^{\pi} = 39/2^{+}$) and $\hbar\omega \sim 0.25$ MeV, the octupole band becomes less favorable. For ^{222}Th, a high-spin crossing with a structure based on a pair of rotation aligned $i_{13/2}$ protons (and of $j_{15/2}$ neutrons) is predicted. Suitable for this scenario is also ^{221}Th – the smaller quadrupole deformation helps. Could it trigger new Nilsson-Strutinsky type calculations?

Co-workers

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Theoretical help

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