Octupole Correlations in Positive-Parity States of the Rare Earths and Actinides

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Bonn-Cologne Graduate School of Physics and Astronomy

CGS 2014
Dresden (Germany)

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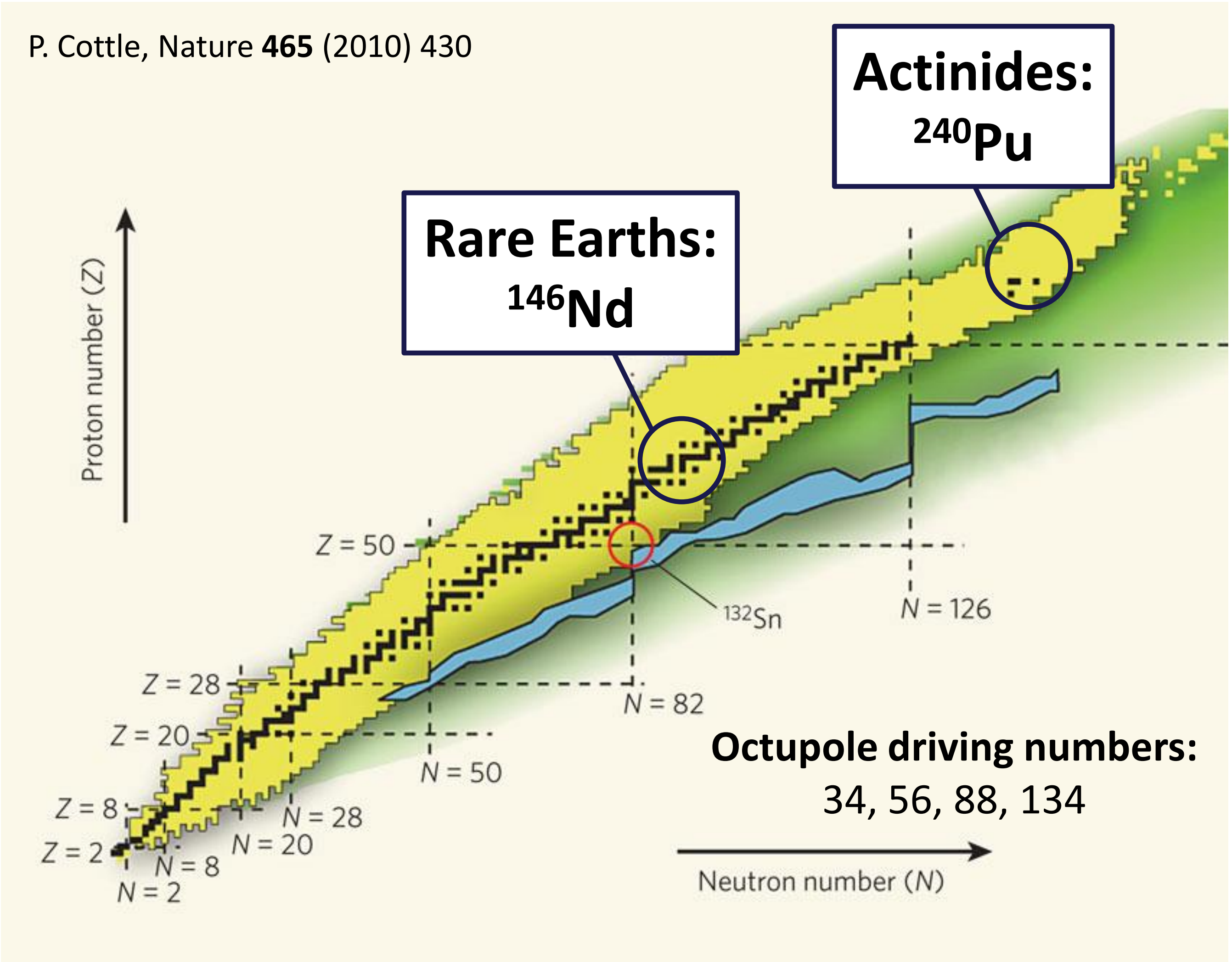
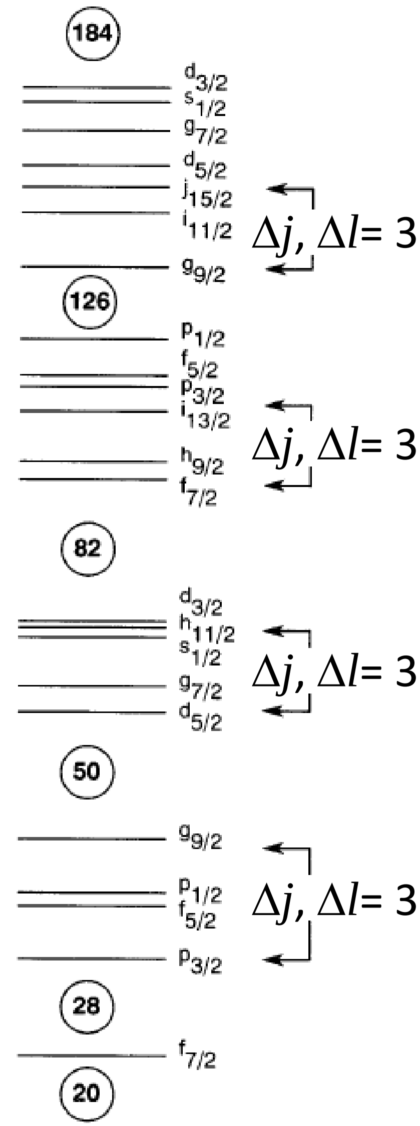
*Supported by the Bonn-Cologne Graduate School of Physics and Astronomy

Octupole Correlations in Atomic Nuclei

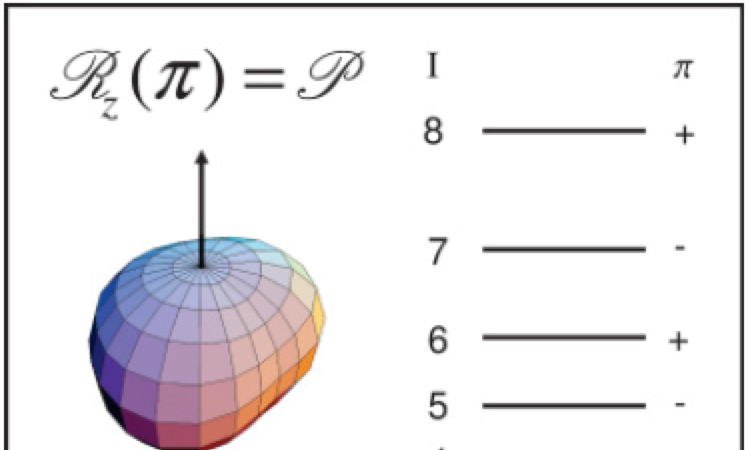




P.A. Butler, W. Nazarewicz, Rev. Mod. Phys. **68** (1996) 349

Alternating-Parity Bands in the Actinides

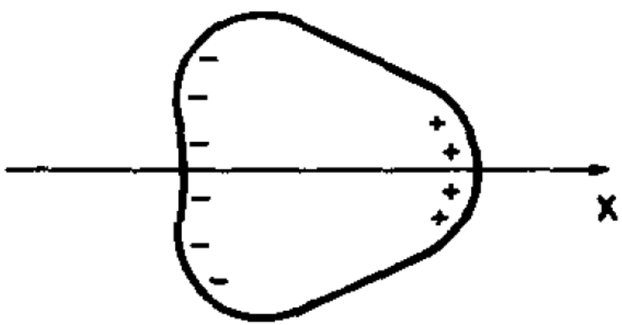
Theory



S. Frauendorf, PRC **77** (2008) 021304(R)

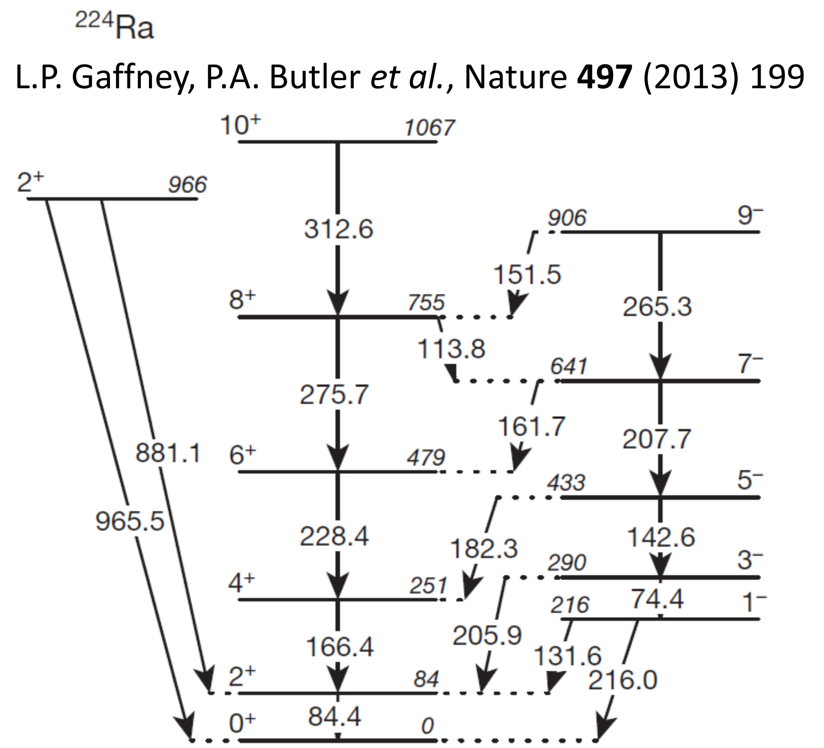
E1 Transitions

$\rightarrow T(E1) \sim D_0 \sim \beta_2\beta_3$



F. Iachello, PLB **160** (1985) 1

Experiment



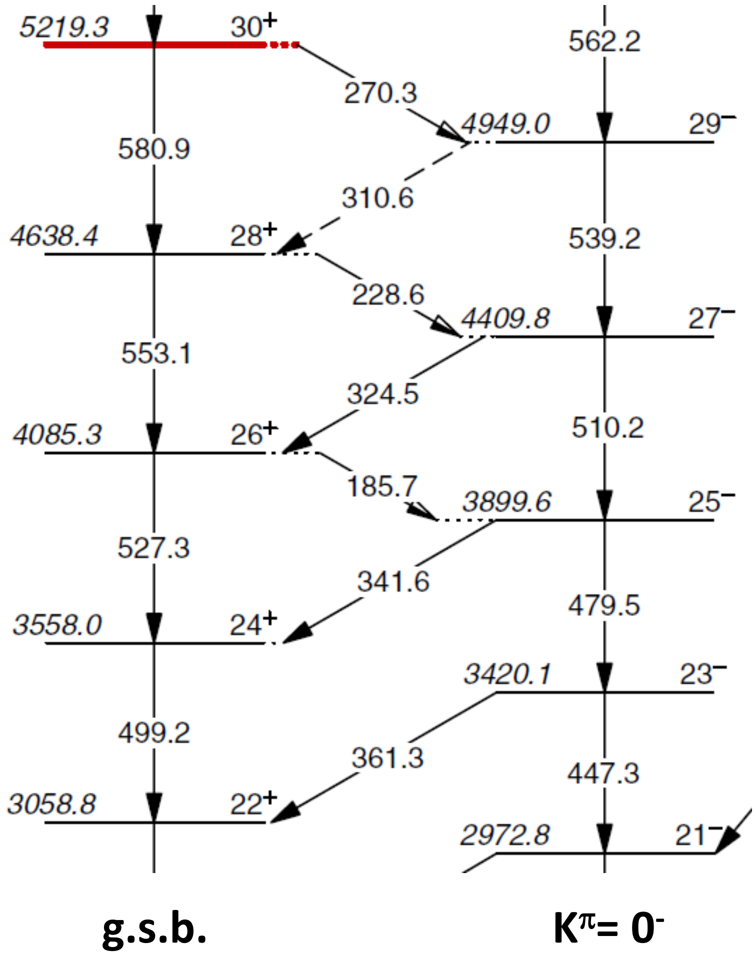
L.P. Gaffney, P.A. Butler *et al.*, Nature **497** (2013) 199

Static octupole deformation in ^{224}Ra

Talk by M. Scheck, Session 29, Fr, 11:30

Octupole Correlations in ^{240}Pu

^{240}Pu @ Gammasphere, Argonne National Laboratory



Experiment

- Build-up of an alternating-parity band at J ≥ 20
- Induced intrinsic dipole moment D_0 = 0.2 efm (e.g. light Th-isotopes 0.2 – 0.3 efm)

X. Wang *et al.*, PRL **102** (2009) 122501
I. Wiedenhöver *et al.*, PRL **83** (1999) 2143

Octupole Correlations in ^{240}Pu

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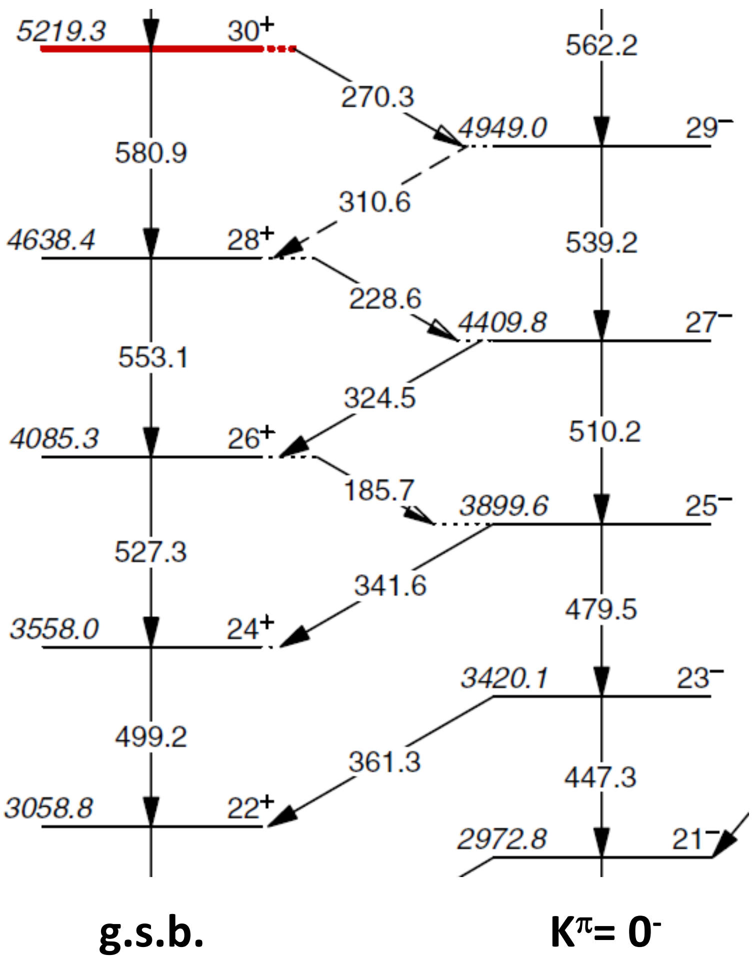


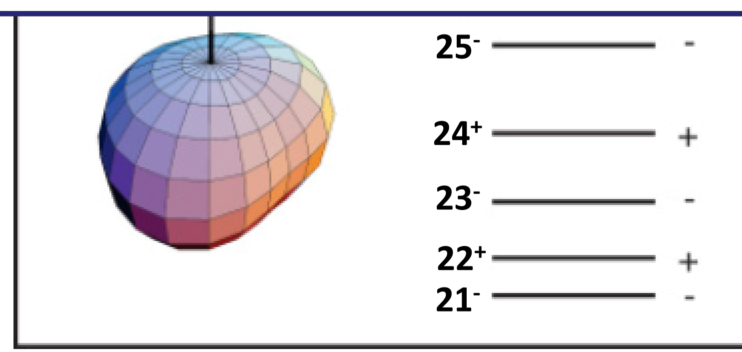
X. Wang *et al.*, PRL **102** (2009) 122501
I. Wiedenhöver *et al.*, PRL **83** (1999) 2143

Experiment

- Build-up of an alternating-parity band at $J \geq 20$
- Induced intrinsic dipole moment D_0 = 0.2 efm (e.g. light Th-isotopes 0.2 – 0.3 efm)

Octupole deformation might set in at high spin

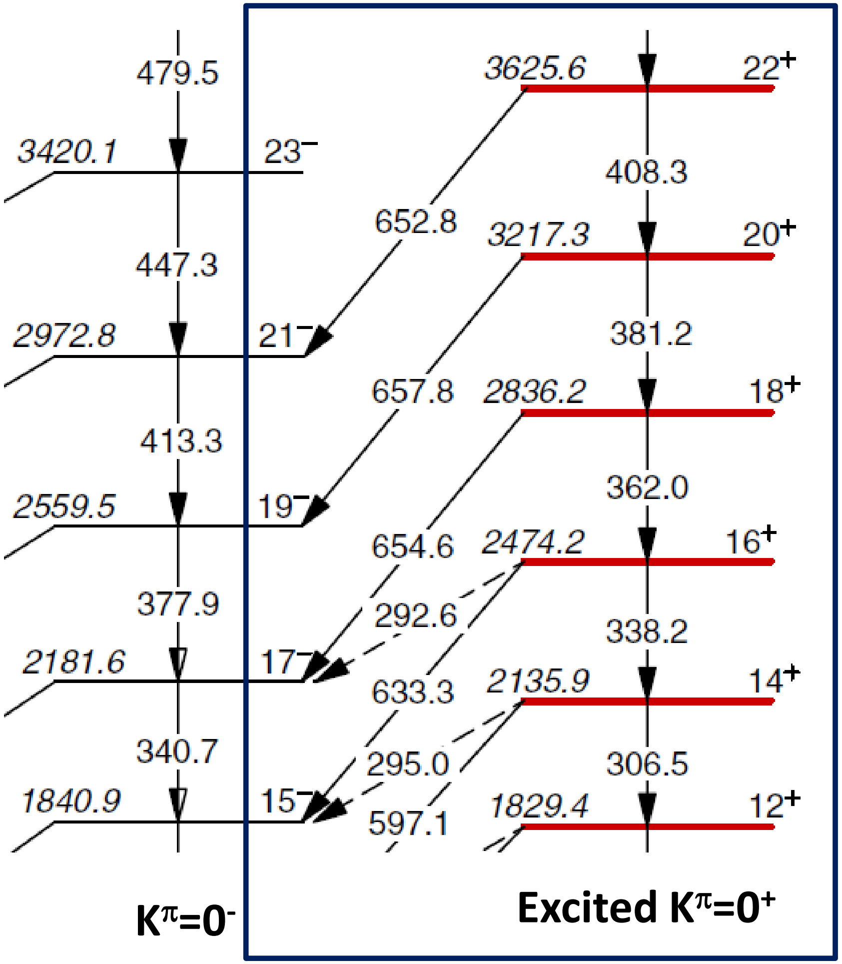
R.V. Jolos *et al.*, PRC **86** (2012) 024319



S. Frauendorf, PRC **77** (2008) 021304(R)

Octupole Correlations in ^{240}Pu

^{240}Pu @ Gammasphere, Argonne National Laboratory



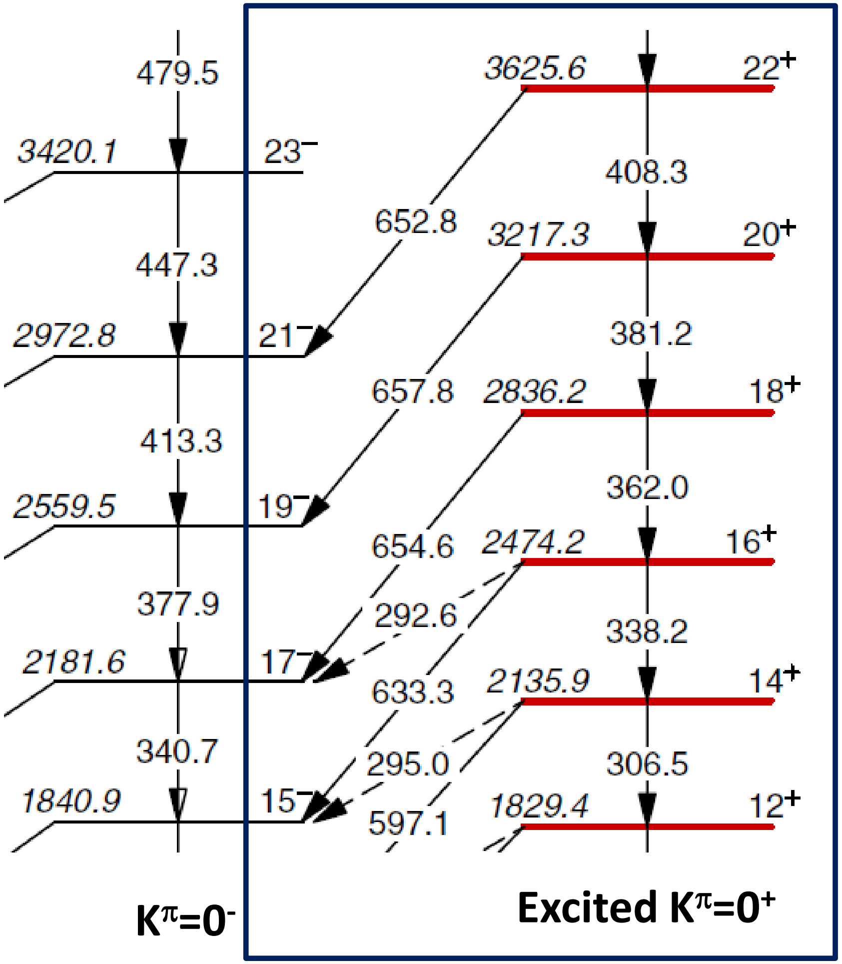
X. Wang *et al.*, PRL **102** (2009) 122501
I. Wiedenhöver *et al.*, PRL **83** (1999) 2143

Experiment

- Observation of an additional $K^{\pi}= 0^{+}$ rotational band up to highest spins
  - → Exclusive decay to $K^{\pi}= 0^{-}$ one-octupole phonon band
  - → Enhanced *E1* transitions of ~ 2 mW.u.

Octupole Correlations in ^{240}Pu

^{240}Pu @ Gammasphere, Argonne National Laboratory



X. Wang *et al.*, PRL **102** (2009) 122501
I. Wiedenhöver *et al.*, PRL **83** (1999) 2143

Experiment

- Observation of an additional $K^\pi = 0^+$ rotational band up to highest spins
  - → Exclusive decay to $K^\pi = 0^-$ one-octupole phonon band
  - → Enhanced *E1* transitions of ~ 2 mW.u.

Theory

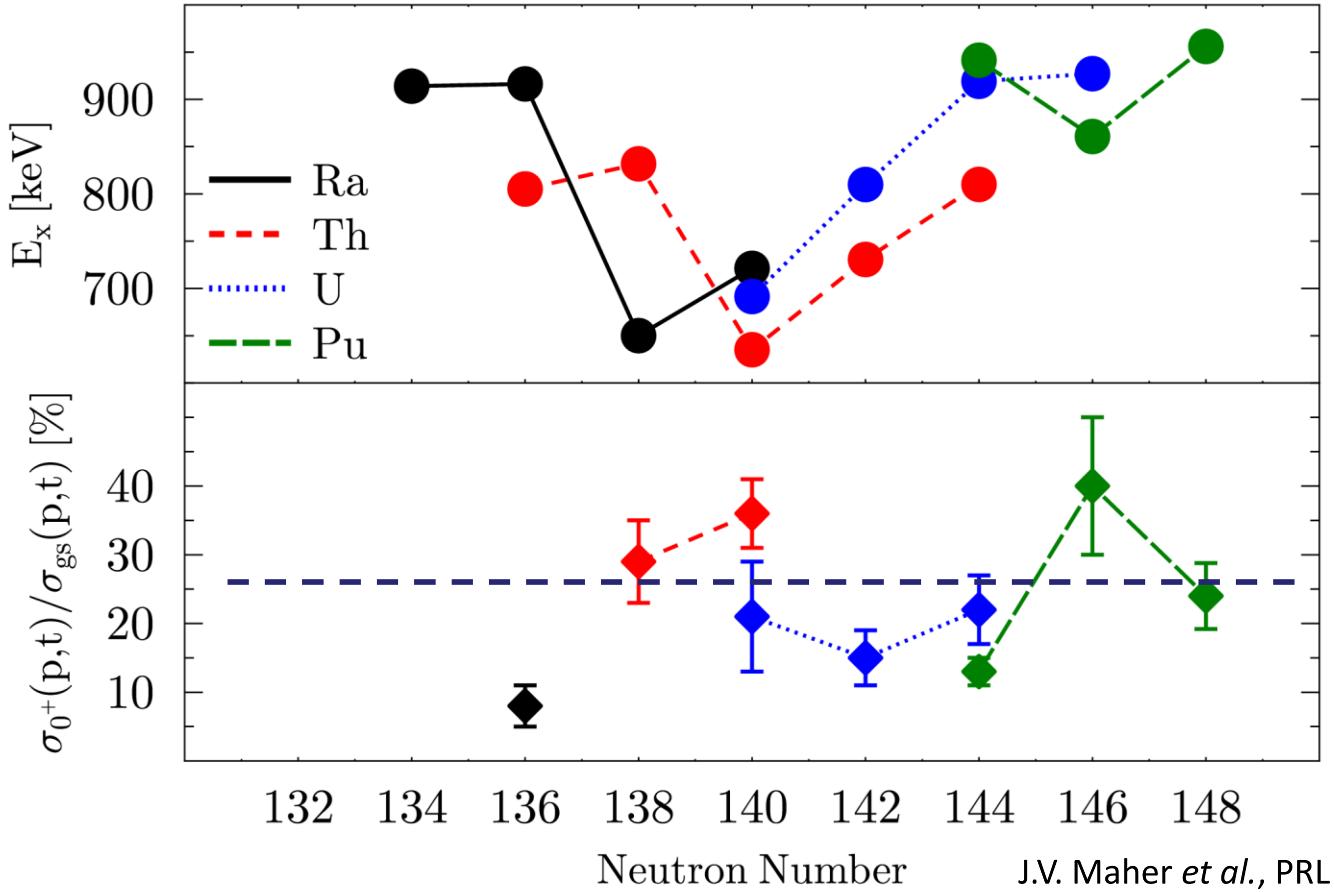
- $K^\pi = 0_2^+$ is double-octupole phonon band

$$\left(3^- \otimes 3^-\right)_{0^+}$$

First Excited 0^+ States in the Actinides

Uniformly strong (p,t) population of first-excited 0^+ states

$\rightarrow$ Collective excitation?

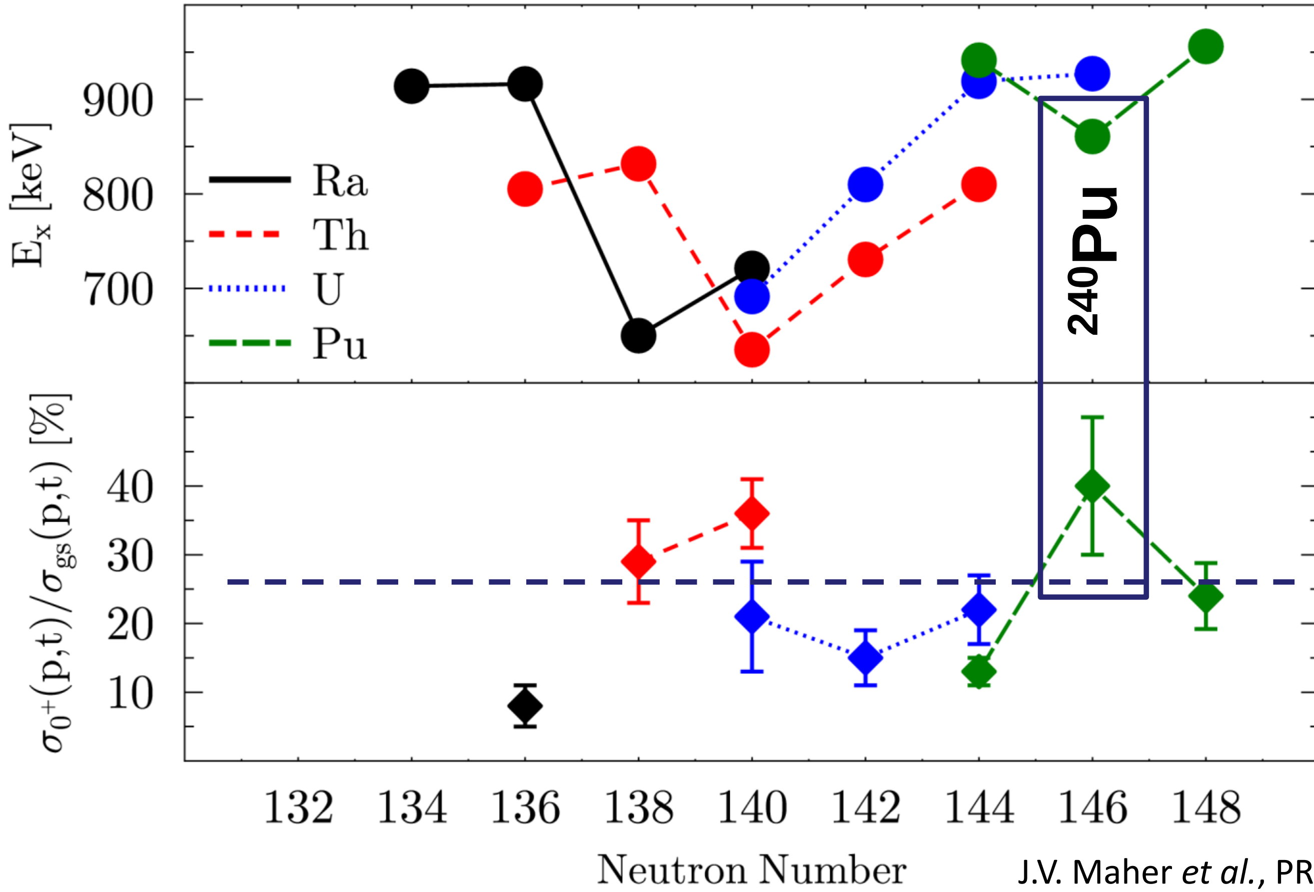


J.V. Maher *et al.*, PRL **25** (1970), 302;
J.V. Maher *et al.*, PRC **5** (1972), 1380;
A.M. Friedman *et al.*, PRC **9** (1974) 760

First Excited 0⁺ States in the Actinides

Uniformly strong (p,t) population of first-excited 0⁺ states

→ Collective excitation?



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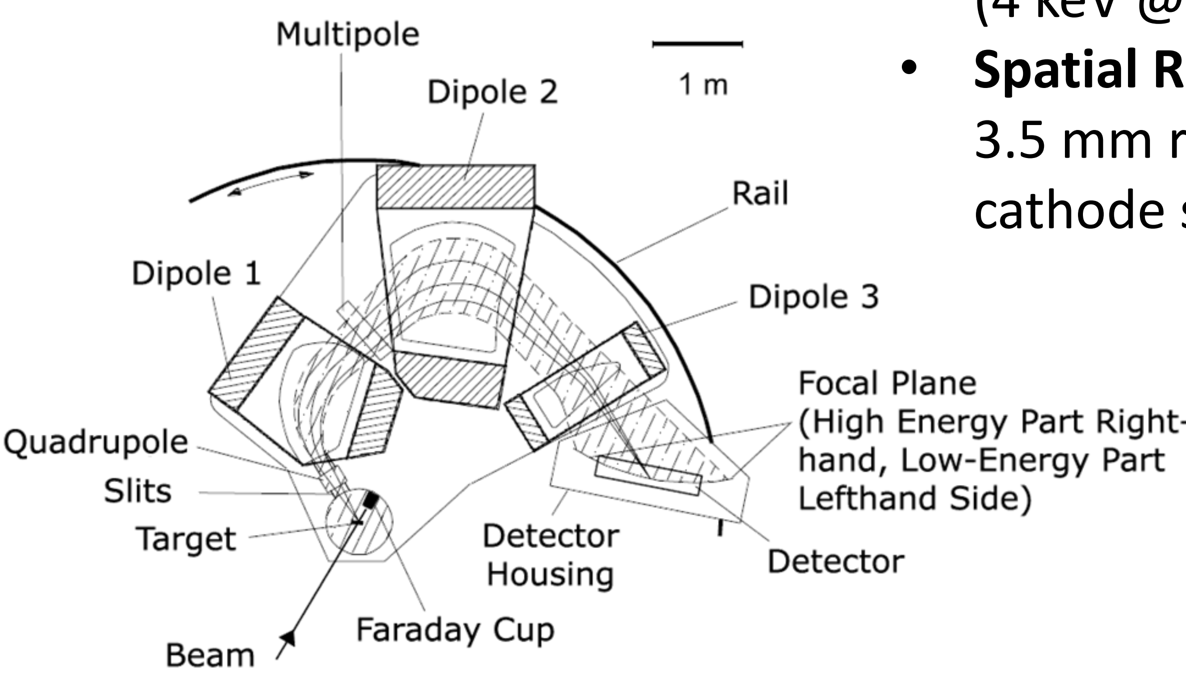
Experimental Setup

Experiment: Two-neutron transfer reaction (p,t) to populate low-spin states in ^{240}Pu (E_p= 24 MeV)

Q3D @ MLL, Munich



- **Particle-Energy Resolution:**
  $\Delta E/E = 2 \times 10^{-4}$
  (4 keV @ E_t= 20 MeV)
- **Spatial Resolution:**
  3.5 mm repetition length, 255 cathode strips (length: 1 m)

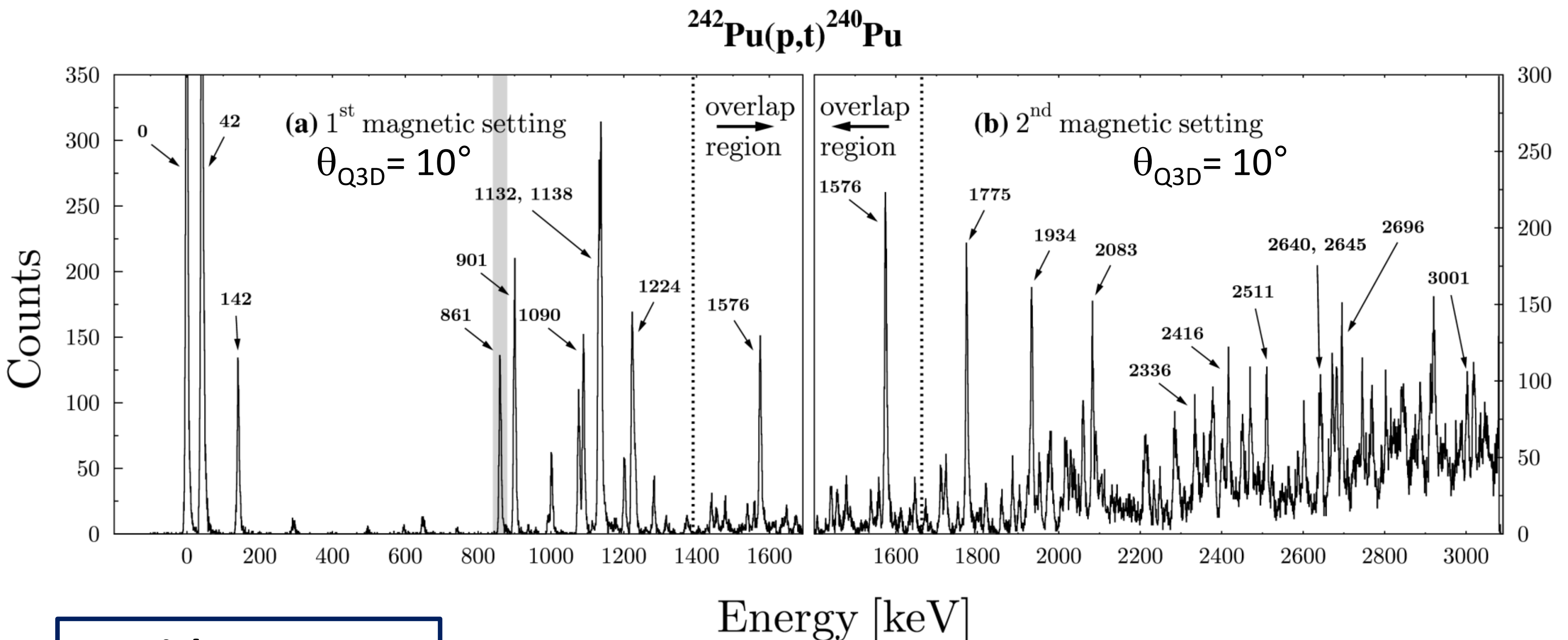
Target:
120 µg/cm^2 ^{242}Pu (99.93%, $T_{1/2}$= 3.75 x 10^5 a) on a 25 µg/cm^2 carbon backing (provided by Oak Ridge National Laboratory)

Excited States in $^{242}Pu(p,t)^{240}Pu$

2 magnetic settings of Q3D to cover the focal plane of 1.8 m

→ Excitation energies up to 3 MeV could be measured

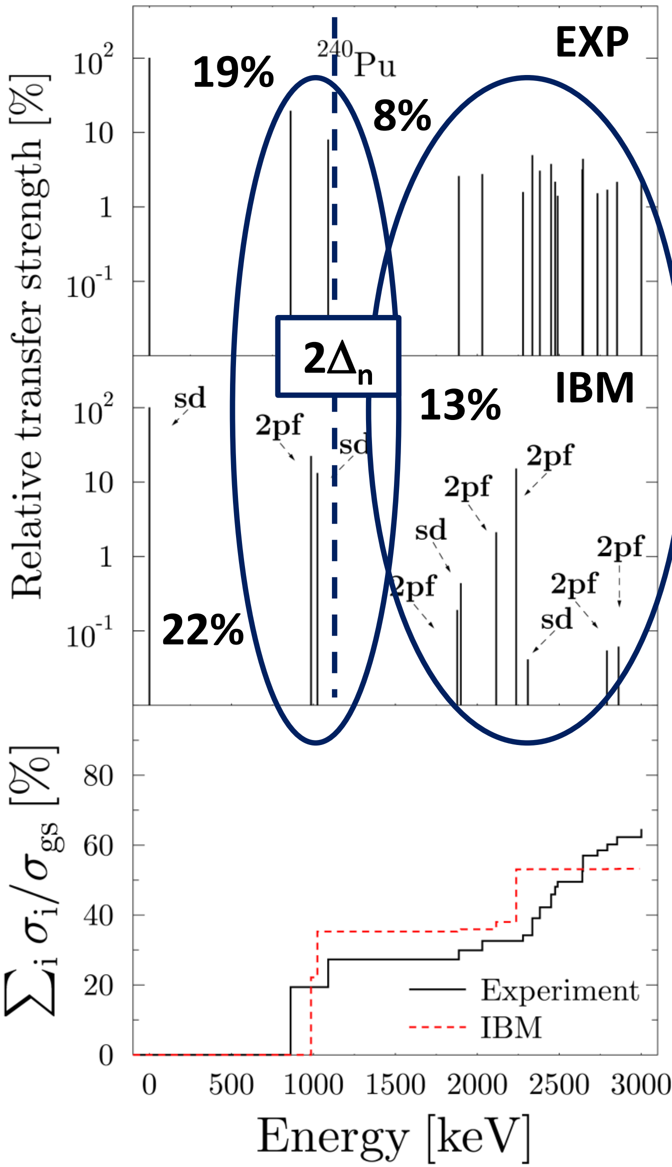
→ Observation of 208 excited states ($J^{\pi}=0^{+} - 6^{+}$)



Particle Spectrum

M. Spieker *et al.*, PRC **88** (2013) 041303(R)

Experimental Results and IBM Calculations



Experiment

- 17 (21) $J^\pi=0^+$ states excited up to E_x= 3 MeV
- Two firmly assigned 0^+ states below $2\Delta_n$
- 2nd 0^+ state 19% of g.s. transfer strength

spdf IBM theory

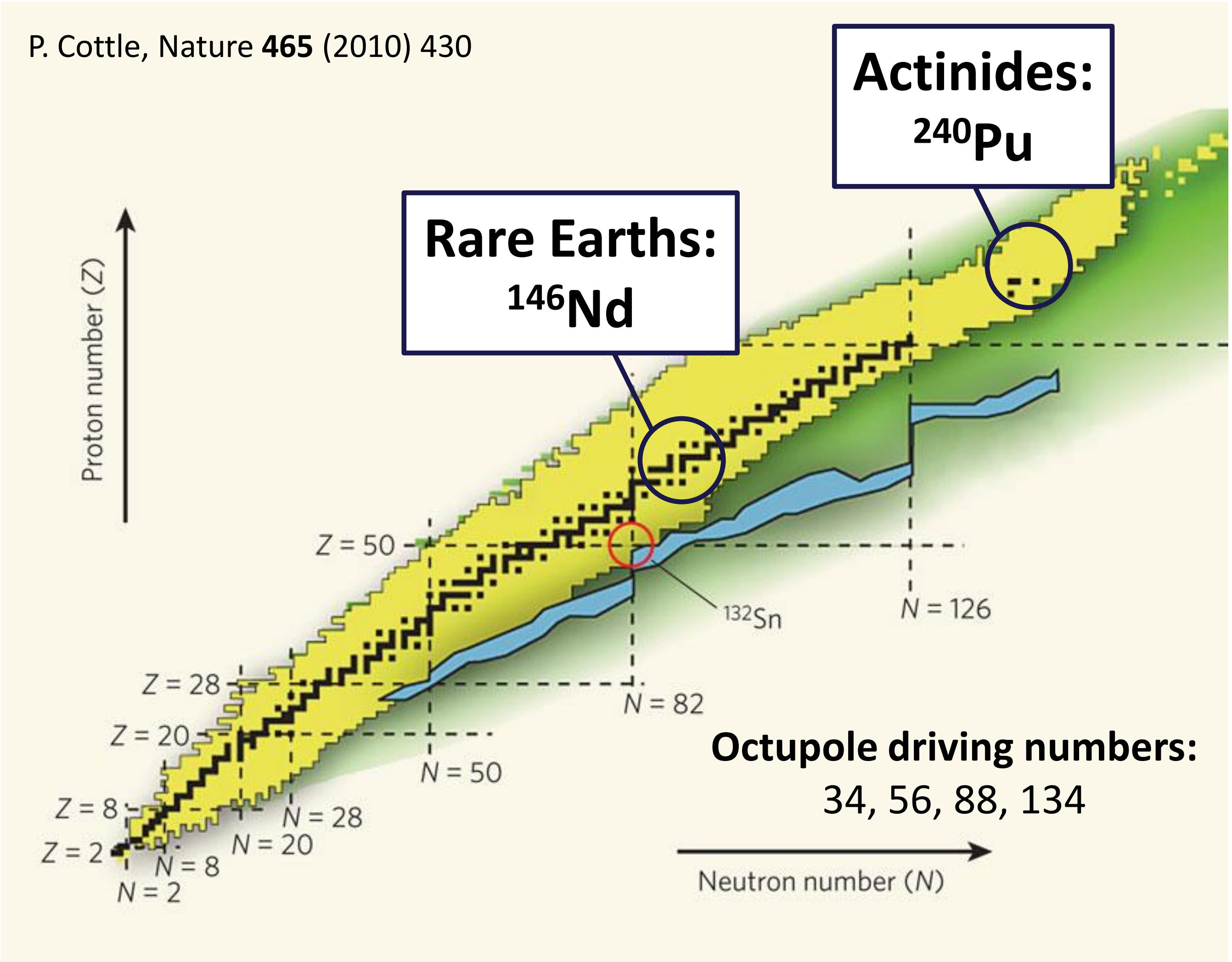
- 10 $J^\pi=0^+$ states with non-vanishing transfer strength predicted (12 in total)
- Two 0^+ states below $2\Delta_n$ predicted
- 2nd 0^+ state 22% of g.s. transfer strength

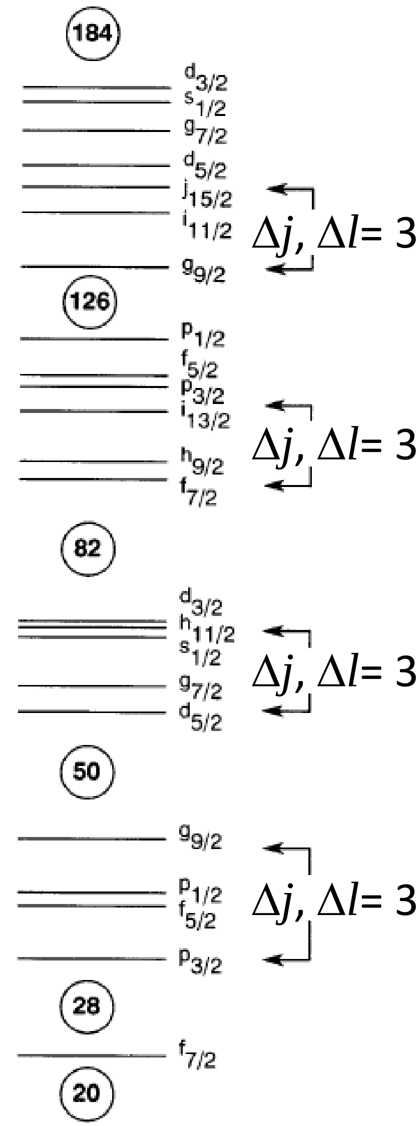
Conclusion

- Double-octupole structure predicted
- Two groups of excited states
- Correct prediction of transfer strength
- Stronger fragmentation observed

M. Spieker *et al.*, PRC **88** (2013) 041303(R)

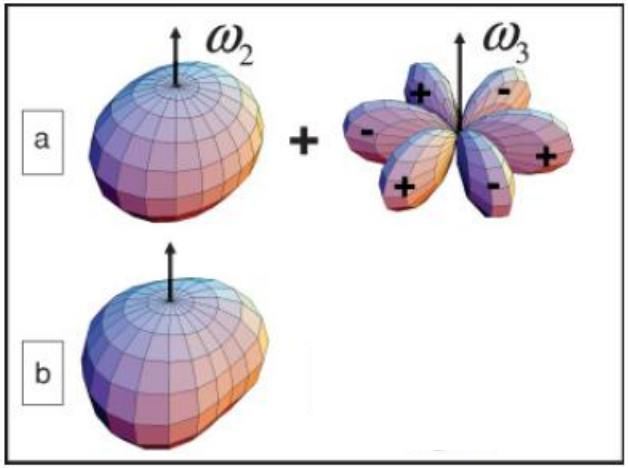
Octupole Correlations in Atomic Nuclei





P.A. Butler, W. Nazarewicz, Rev. Mod. Phys. **68** (1996) 349

Octupole-Phonon Condensation [1]



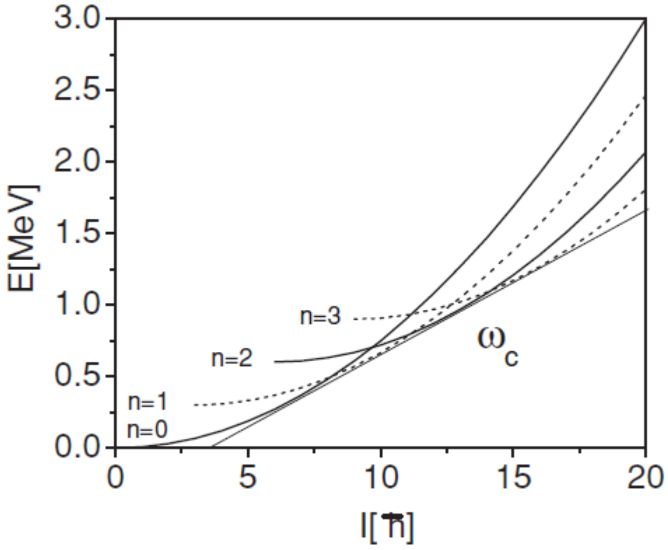
[1] S. Frauendorf, PRC **77** (2008) 021304(R)

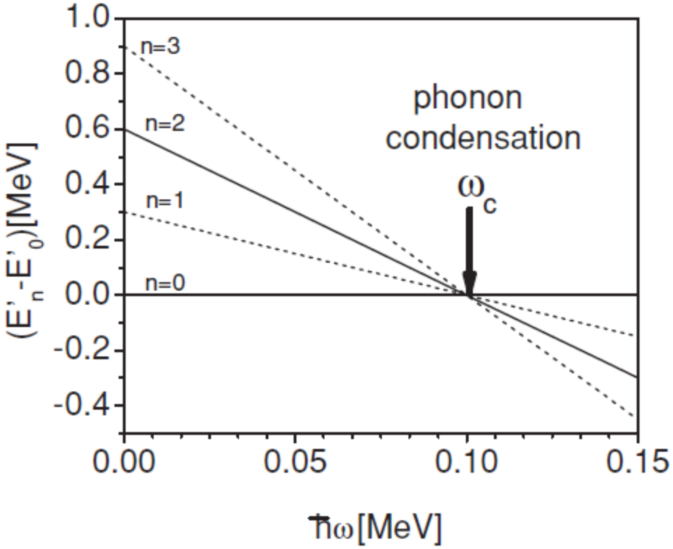
- Synchronization of rotating quadrupole shape (ω_2) and octupole wave (ω_3) at ω_c

→ Octupole-phonon condensation
→ Rotating heart/pear shape

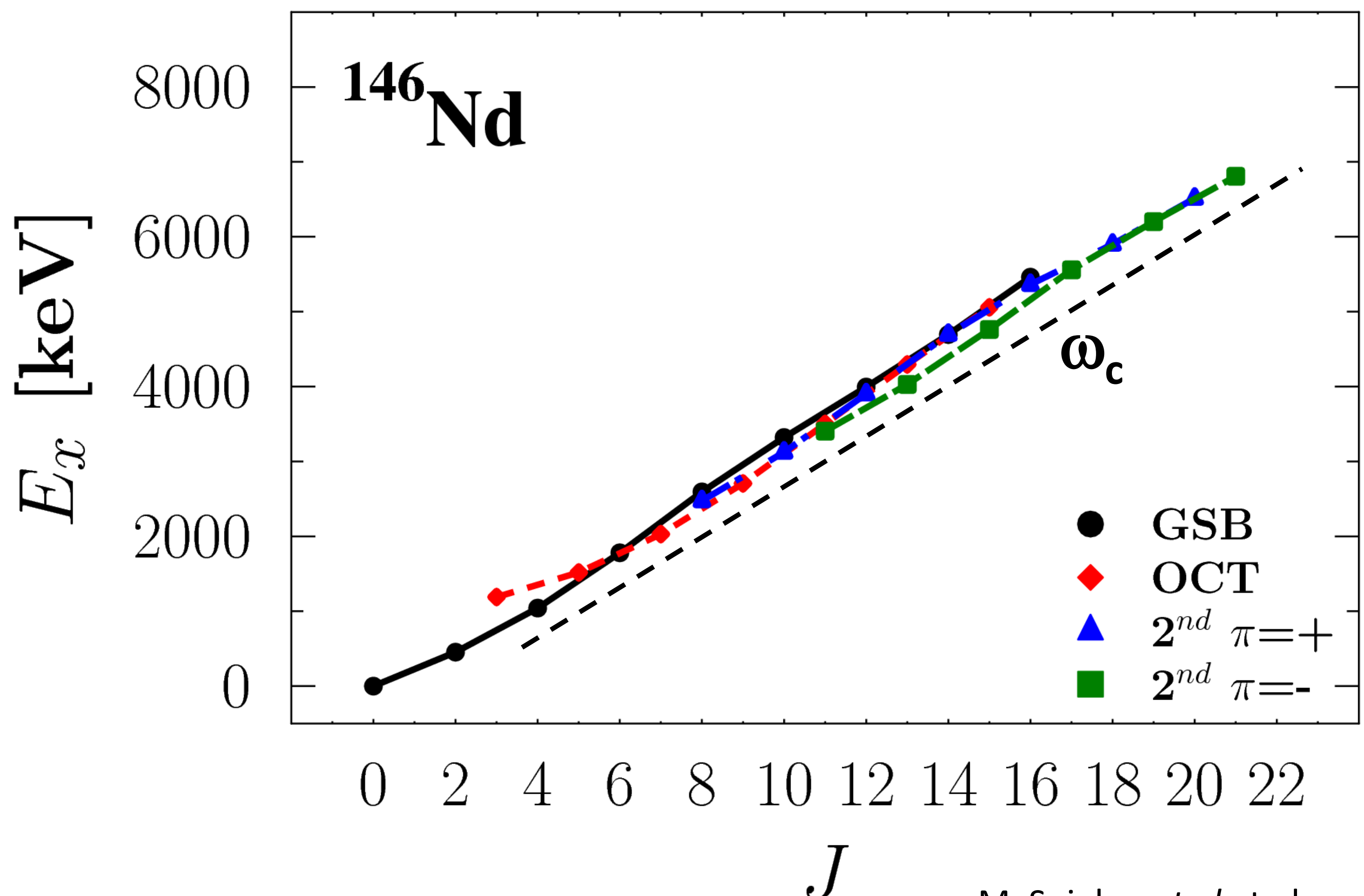
Signatures:

- Common tangent of E(J) for n-phonon bands
- n-phonon bands cross at ω_c



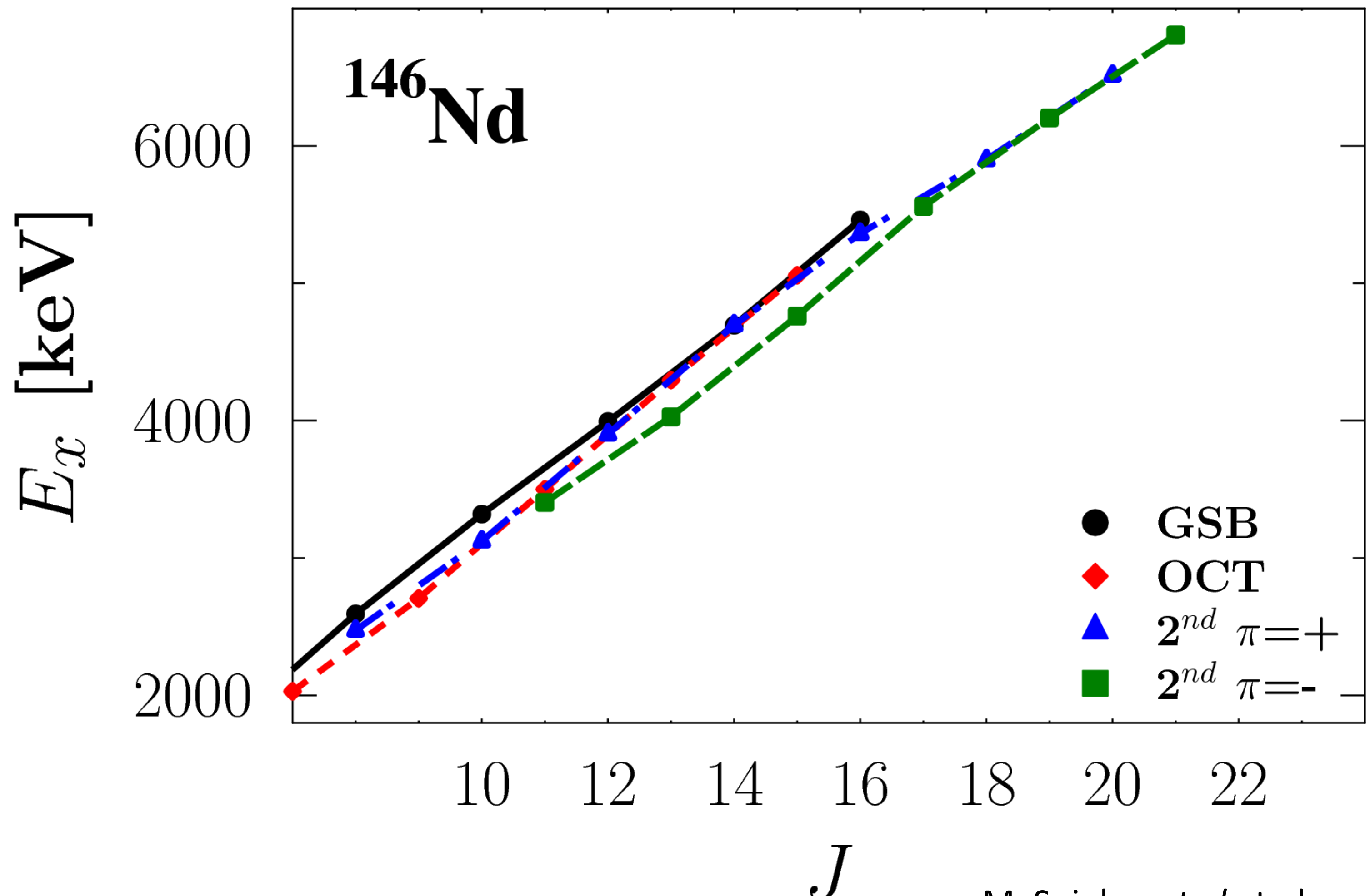


Octupole-Phonon Condensation in ^{146}Nd?



M. Spieker *et al.*, to be published
Data compiled from ENSDF

Octupole-Phonon Condensation in ^{146}Nd?



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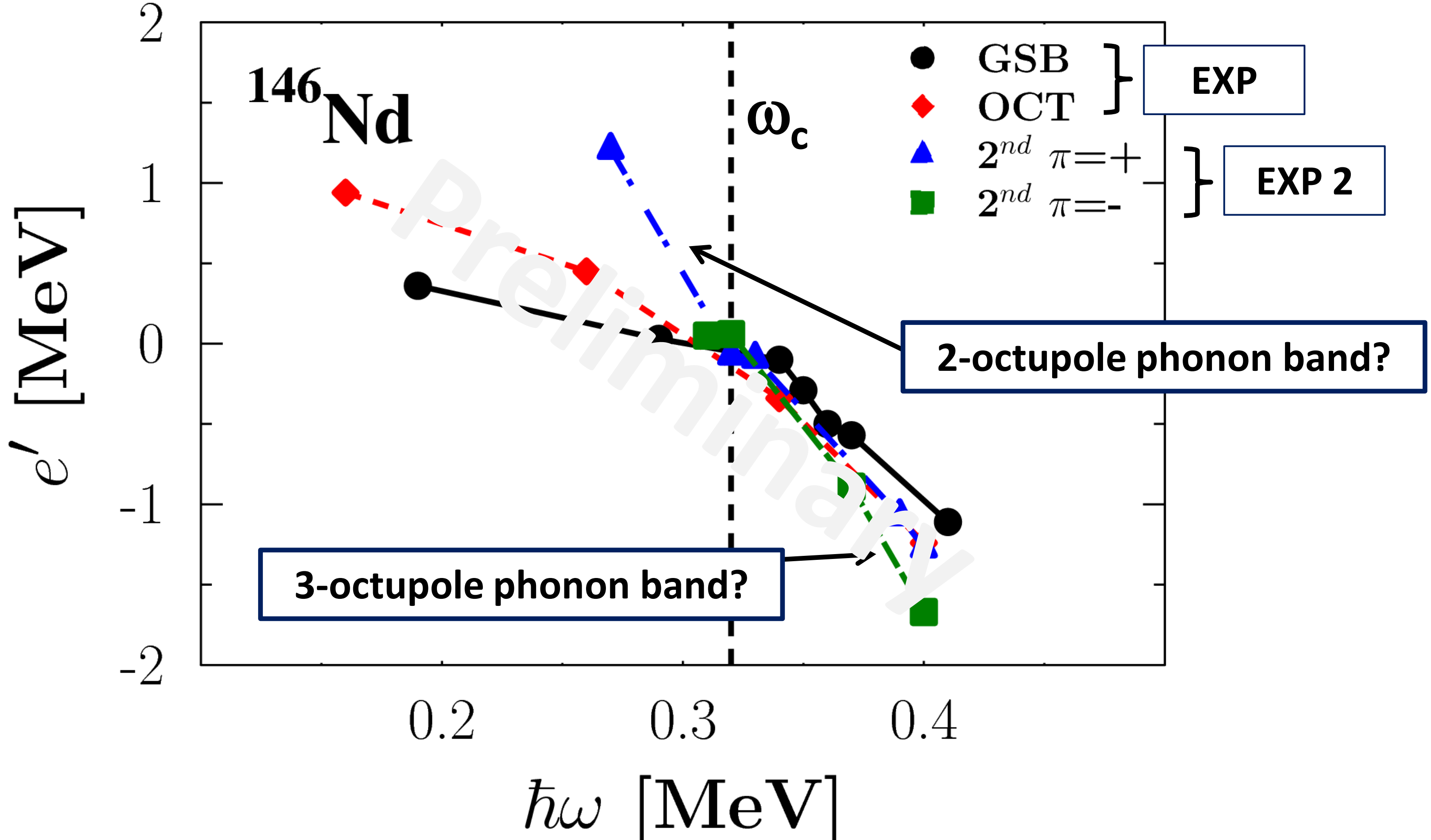
Octupole-Phonon Condensation in ^{146}Nd?

Routhians in ^{146}Nd

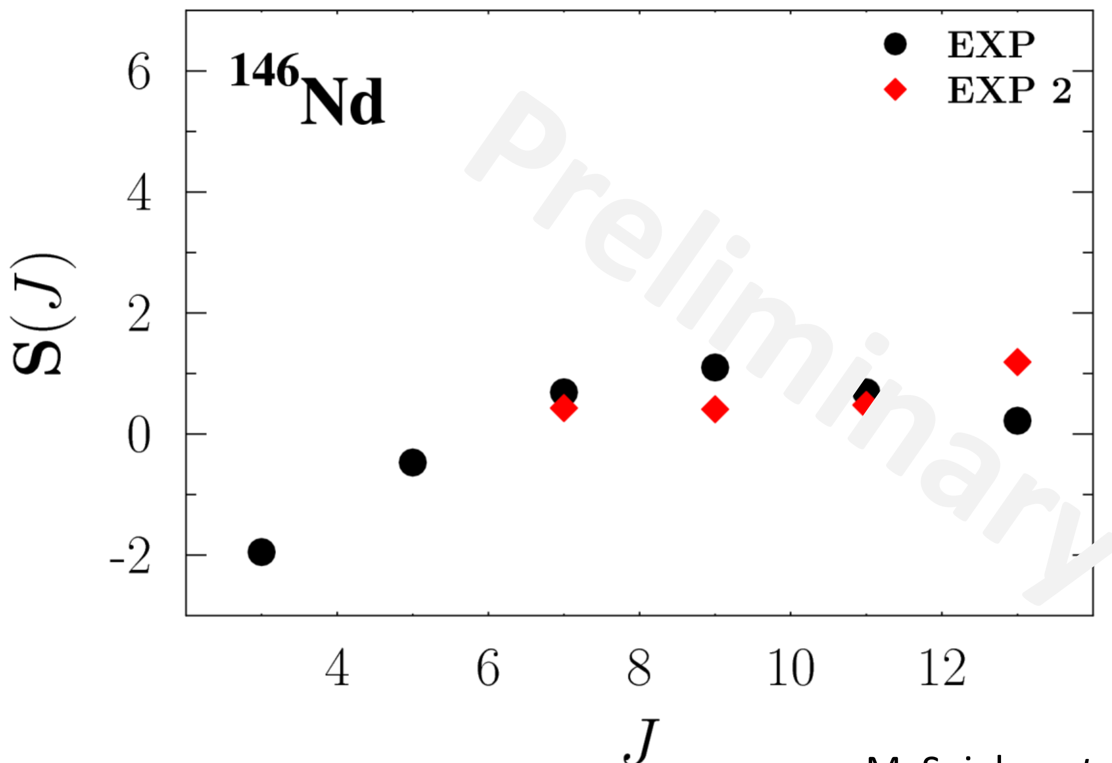


M. Spieker *et al.*, to be published
Data compiled from ENSDF

Multiphonon-Octupole Excitations in ^{146}Nd?

Signature Splitting:

$$S(J) = \frac{[E_{J+1} - E_J] - [E_J - E_{J-1}]}{E_{2_1^+}}$$



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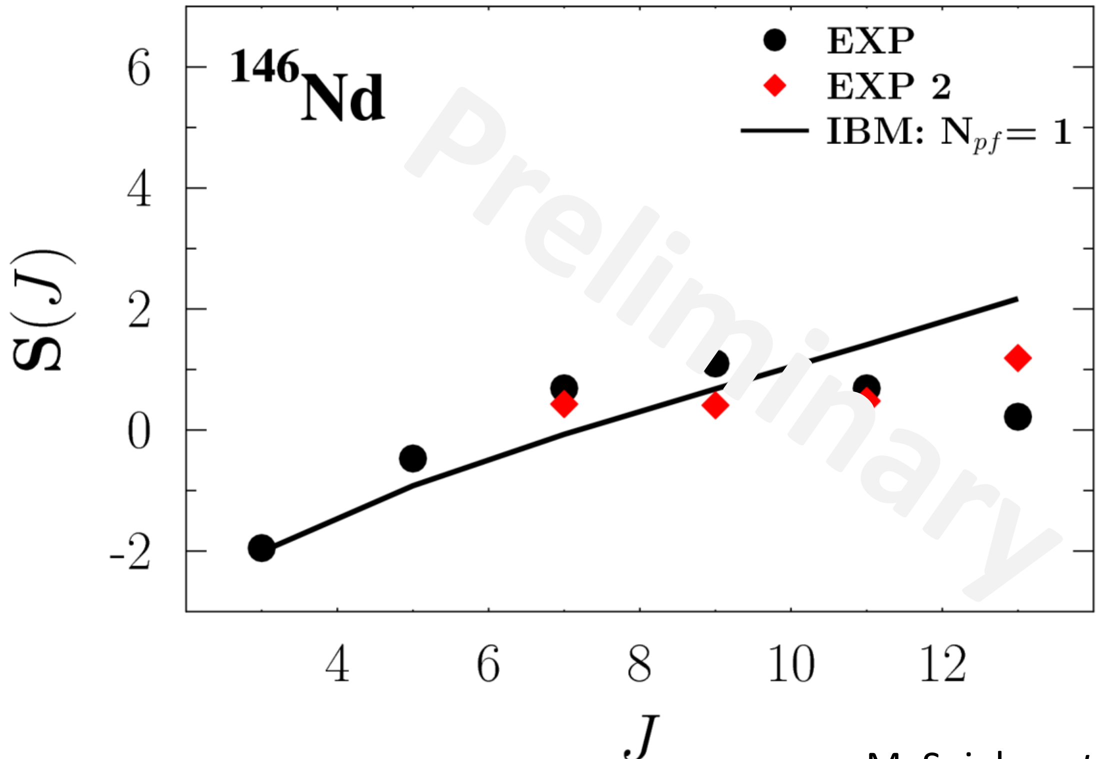

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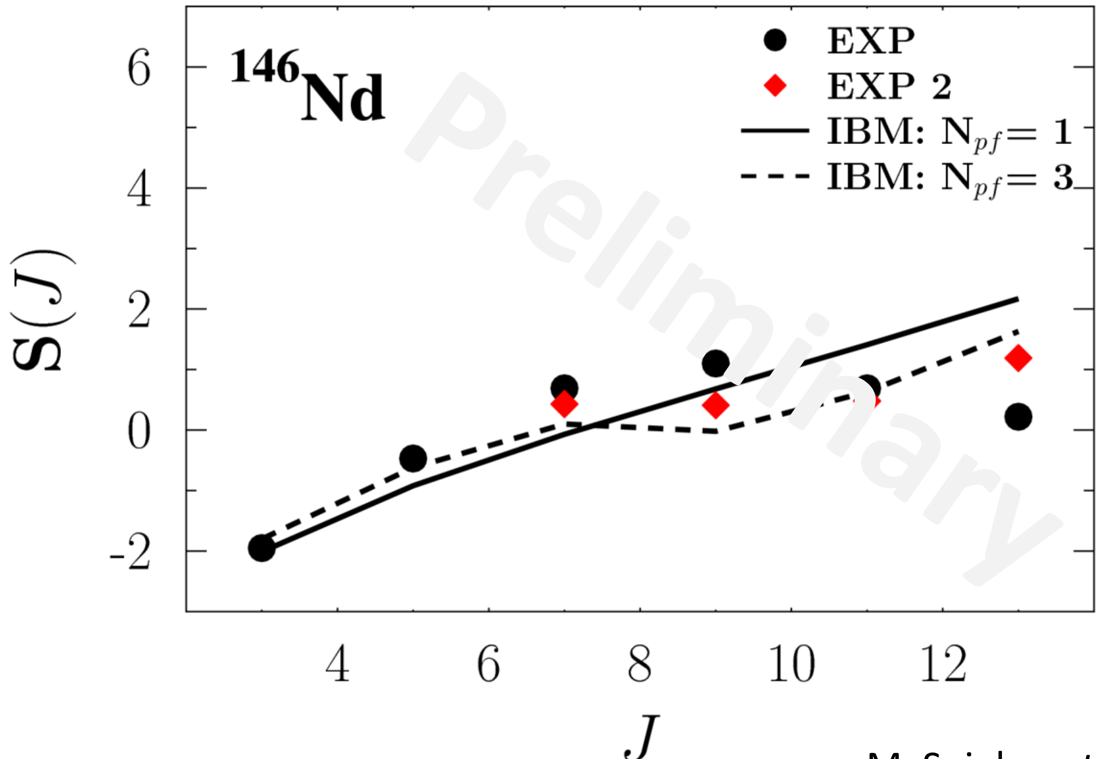
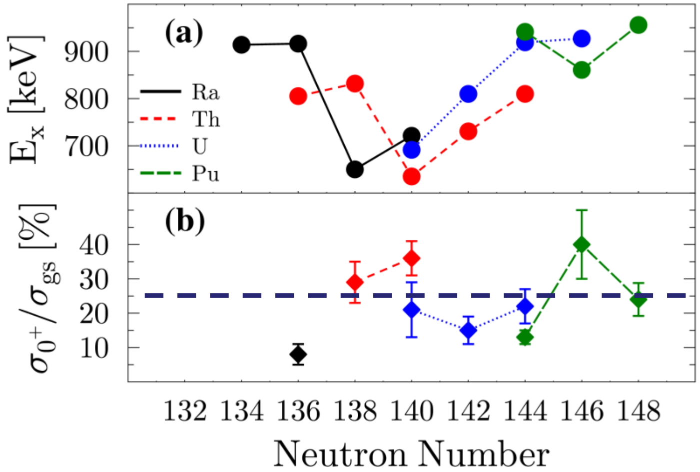


M. Spieker *et al.*, to be published
Data compiled from ENSDF

Summary

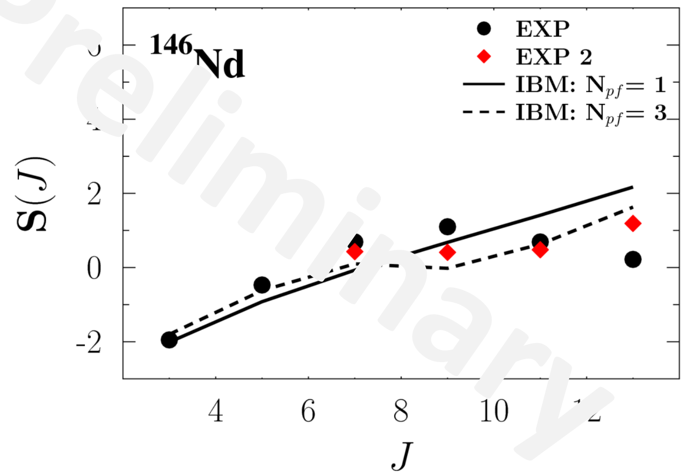
Experiment

- **$^{242}Pu(\textit{p,t})^{240}Pu$ @ Q3D, MLL Munich**
  - → 200 excited states observed
  - → 20 excited $J^{\pi}=0^{+}$ states up to 3 MeV
- **^{146}Nd**
  - → Occurrence of additional π=+ and π=- bands (Routhians cross!)
  - → Change in Yrast structure



Theory

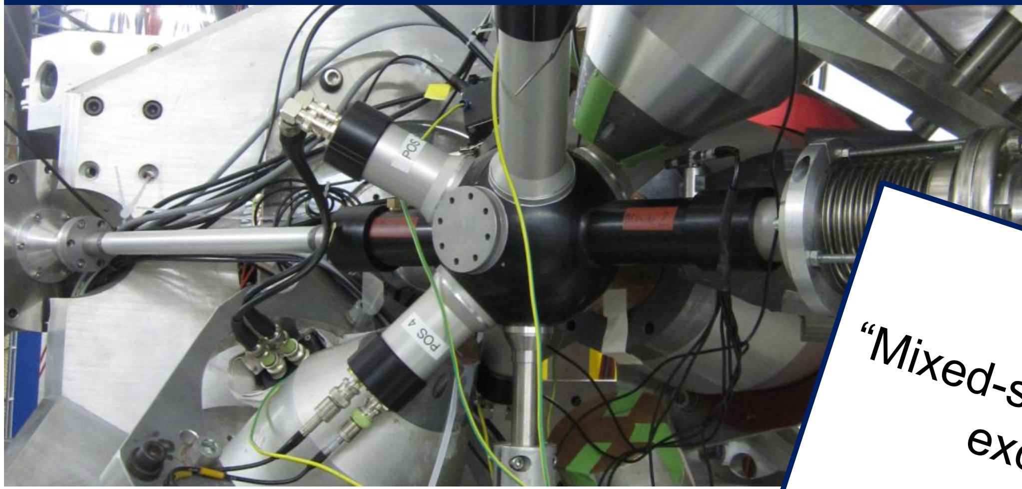
- **Double-octupole states predicted in IBM and other theoretical models**
  - → Octupole structure essential to describe different experimental observables in rare earths and actinides, e.g., *E1* strength, *B(E1)/B(E2)* ratios

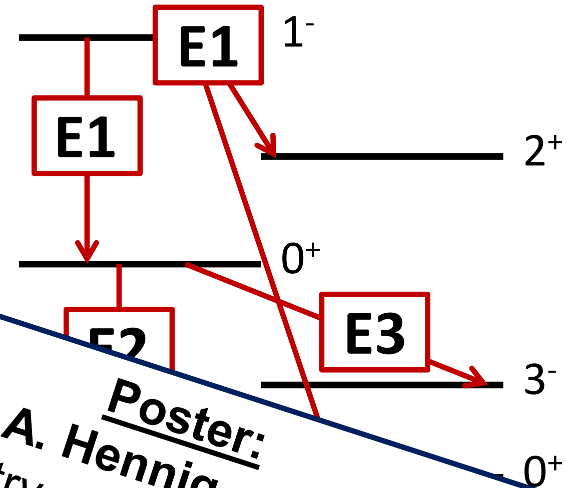


How do double-octupole states effect basic nuclear properties, e.g., octupole deformation, Yrast structure?

Outlook

SONIC@HORUS, Cologne





Poster:
A. Hennig *et al.*
"Mixed-symmetry octupole and hexadecapole excitations in the N=52 isotones"
S. Pickstone *et al.*
"Pygmy Dipole Resonance in (p,p'γ) and (d,pγ) experiments with SONIC@HORUS"

Study of decay propert
particle-γ coinciden

- **Gate on excitation energy in particle spectrum (SONIC)**
  - → Decay of specific state can be studied selectively (HORUS)
- **DSAM measurements possible with SONIC@HORUS**
  - → Lifetimes can be determined without any feeding contributions due to selective gate on excited state