The Search for Tetrahedral Shapes in Nuclei

Atlas Workshop

Lee Riedinger and Daryl Hartley

August 8, 2009

Use of stable and radioactive beams and Gammasphere to search for tetrahedral shapes

- **Nuclei around N = 90 with stable beams**
- **Nuclei around Z = 90 with stable beams**
- **Nuclei around Z = 40 with radioactive beams**
- **Part of the *Tetranuc* collaboration:**
  - **Theory effort led by Jerzy Dudek at Strasbourg**
  - **Experimental effort led by Dominique Curien in Europe**
  - **Experiments at Cape Town in South Africa - Robert Bark and John Sharpey Schafer**
  - **Our experimental effort focused on Gammasphere**
- **Each project has other goals beyond things tetrahedral**

Predicted bands based on tetrahedral shapes

PRL **97,** 072501 (2006) PHYSICAL REVIEW LETTERS week ending 18 AUGUST 2006

Island of Rare Earth Nuclei with Tetrahedral and Octahedral Symmetries: Possible Experimental Evidence

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Nuclear Tetrahedral Symmetry: Possibly Present throughout the Periodic Table

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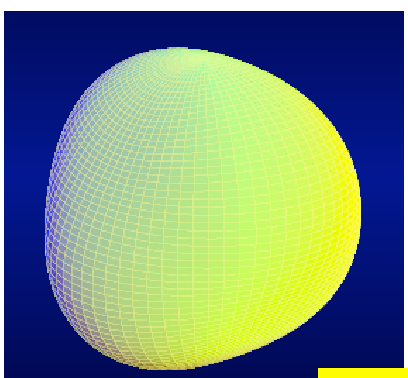
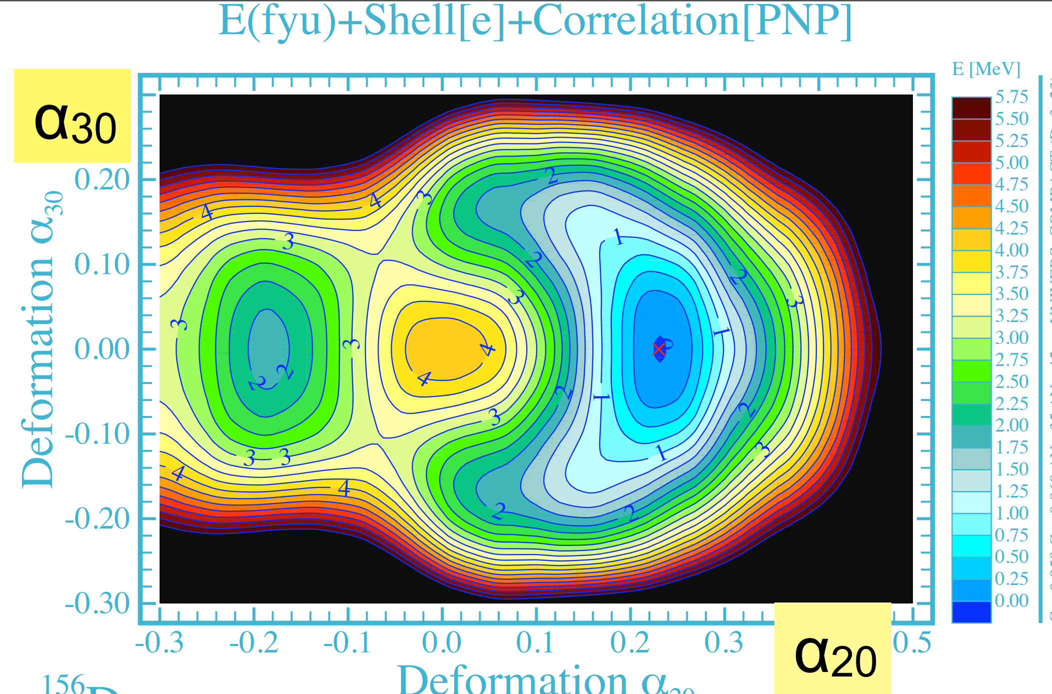
More than half a century after the fundamental, spherical shell structure in nuclei had been established, theoretical predictions indicated that the shell gaps comparable or even stronger than those at spherical shapes may exist. Group-theoretical analysis supported by realistic mean-field calculations indicate that the corresponding nuclei are characterized by the T_d^D ("double-tetrahedral") symmetry group. Strong shell-gap structure is enhanced by the existence of the four-dimensional irreducible representations of T_d^D; it can be seen as a *geometrical* effect that does not depend on a particular realization of the mean field. Possibilities of discovering the T_d^D symmetry in experiment are discussed.

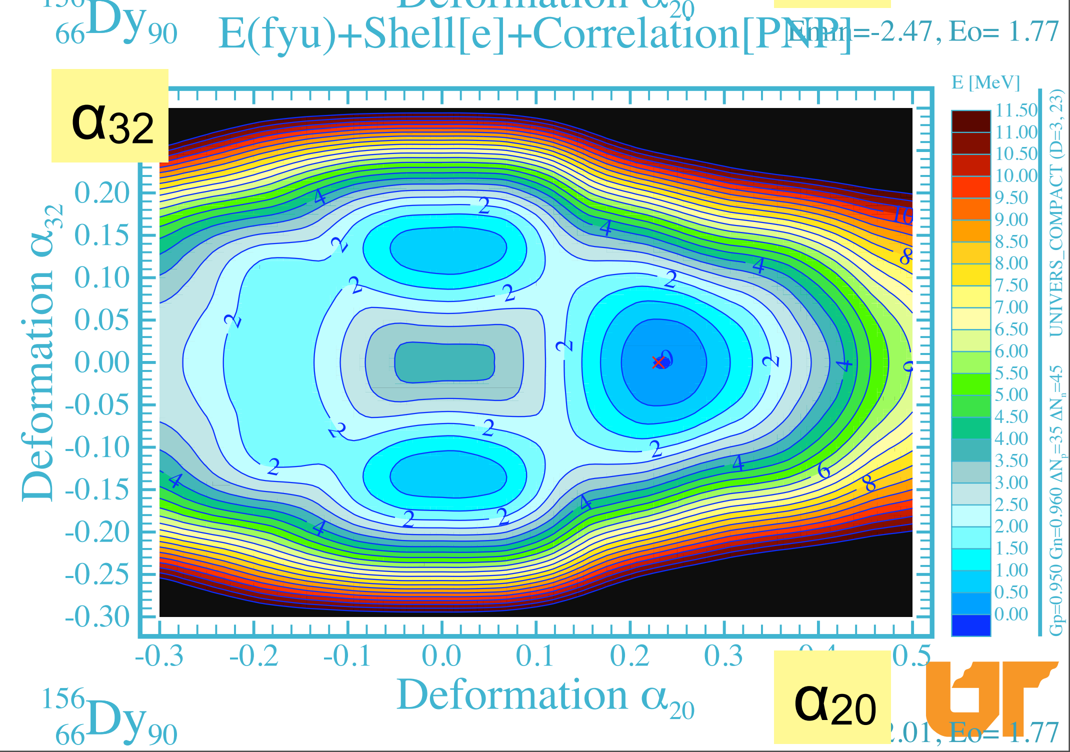


Pyramid-like shapes with rounded edges and corners

Dudek calculations for ^{156}Dy

- **Strong tetrahedral deformations are predicted around 'magic numbers': 32, 40, 56, 64, 70, 90, 132 - 136**
- **Top figure - do not see a minimum develop for non-zero α_{30}**
- **Bottom figure - a minimum develops for non-zero α_{32}**



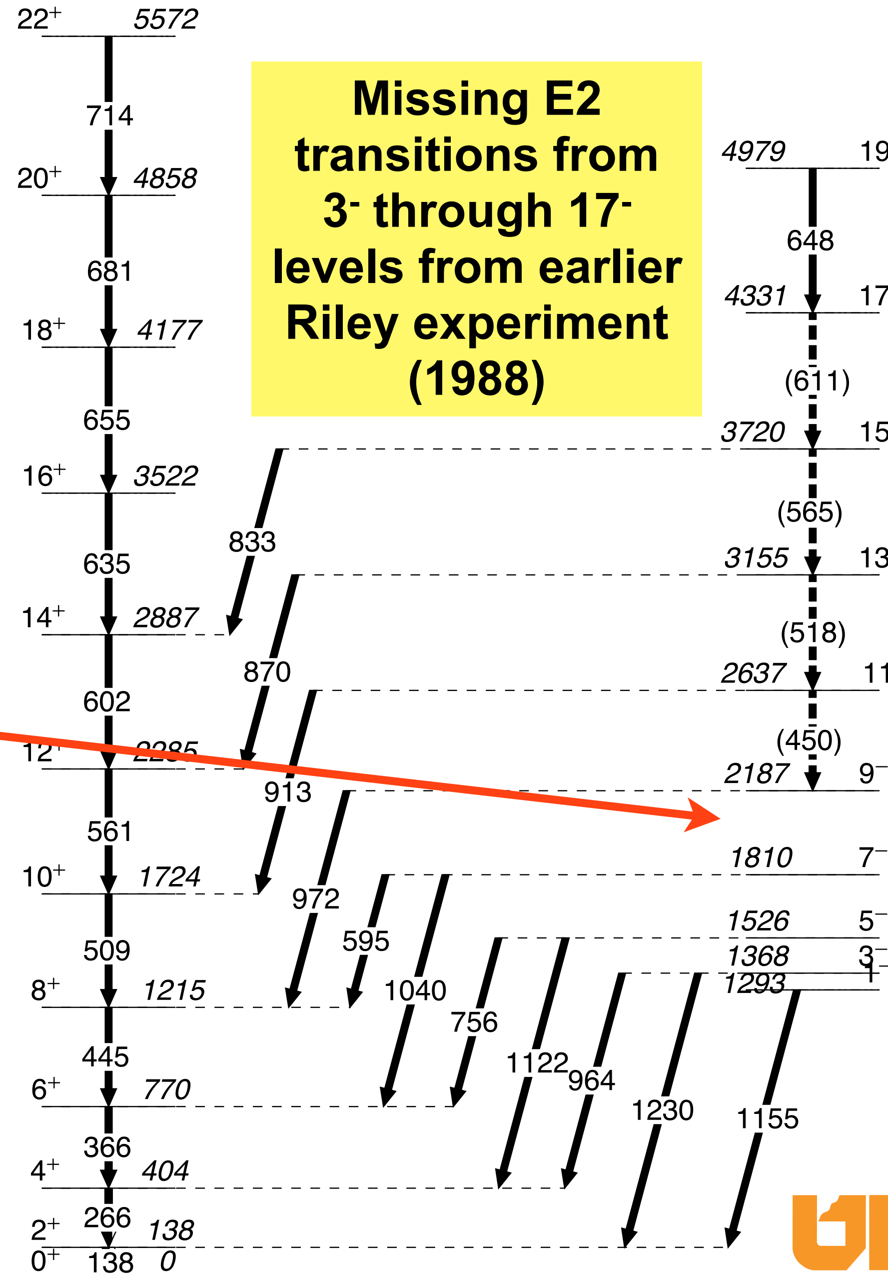


November Gammasphere measurement of ^{156}Dy

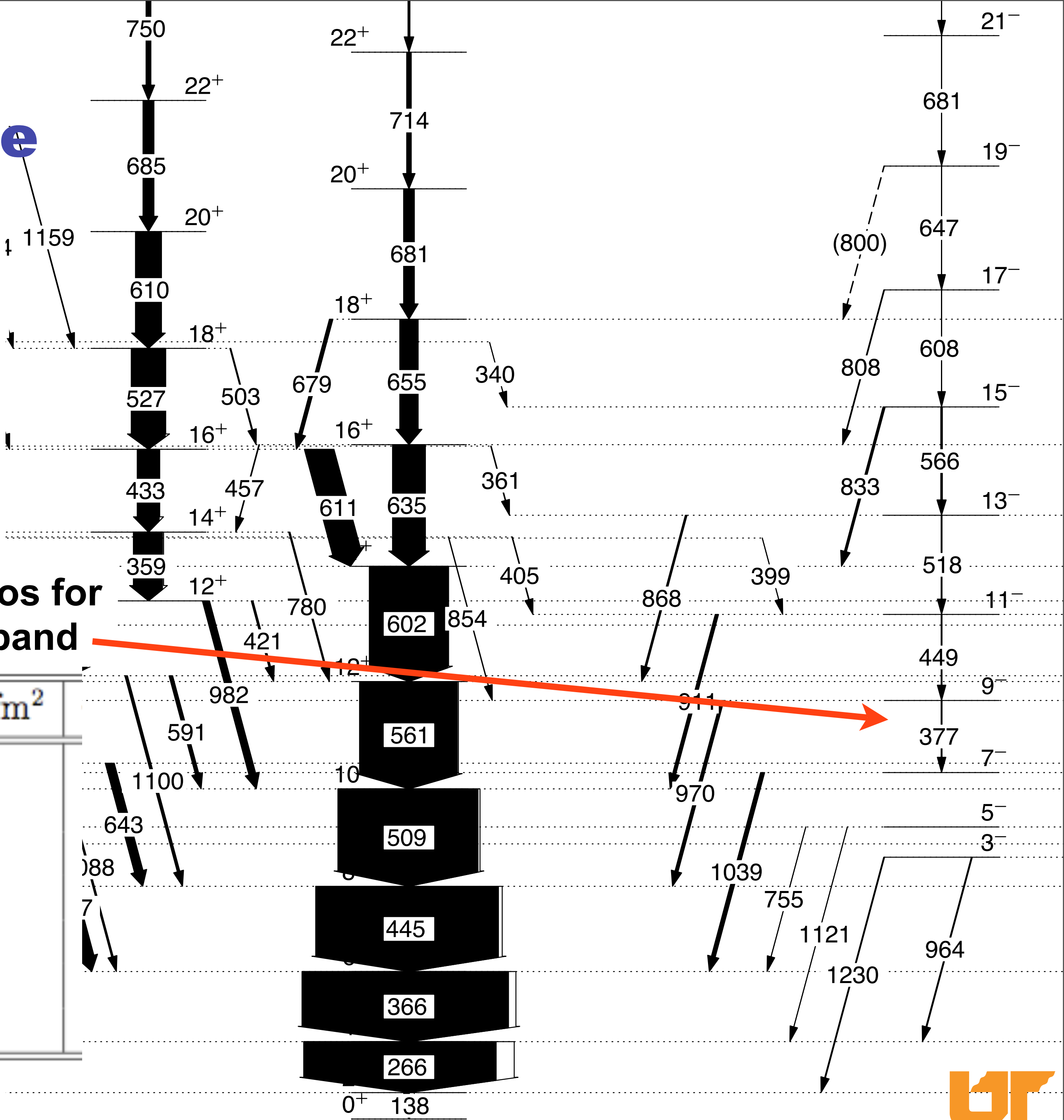
- Used ^{148}Nd(^{12}C,4n) reaction so that we did not bring in too much angular momentum
- Ran for three days to get excellent data
- Looked for weak transitions in this K = 0 negative-parity band
- Looked for levels and transitions in the higher lying K = 1 negative-parity band, below I = 9

^{156}Dy

Missing E2 transitions from 3^- through 17^- levels from earlier Riley experiment (1988)



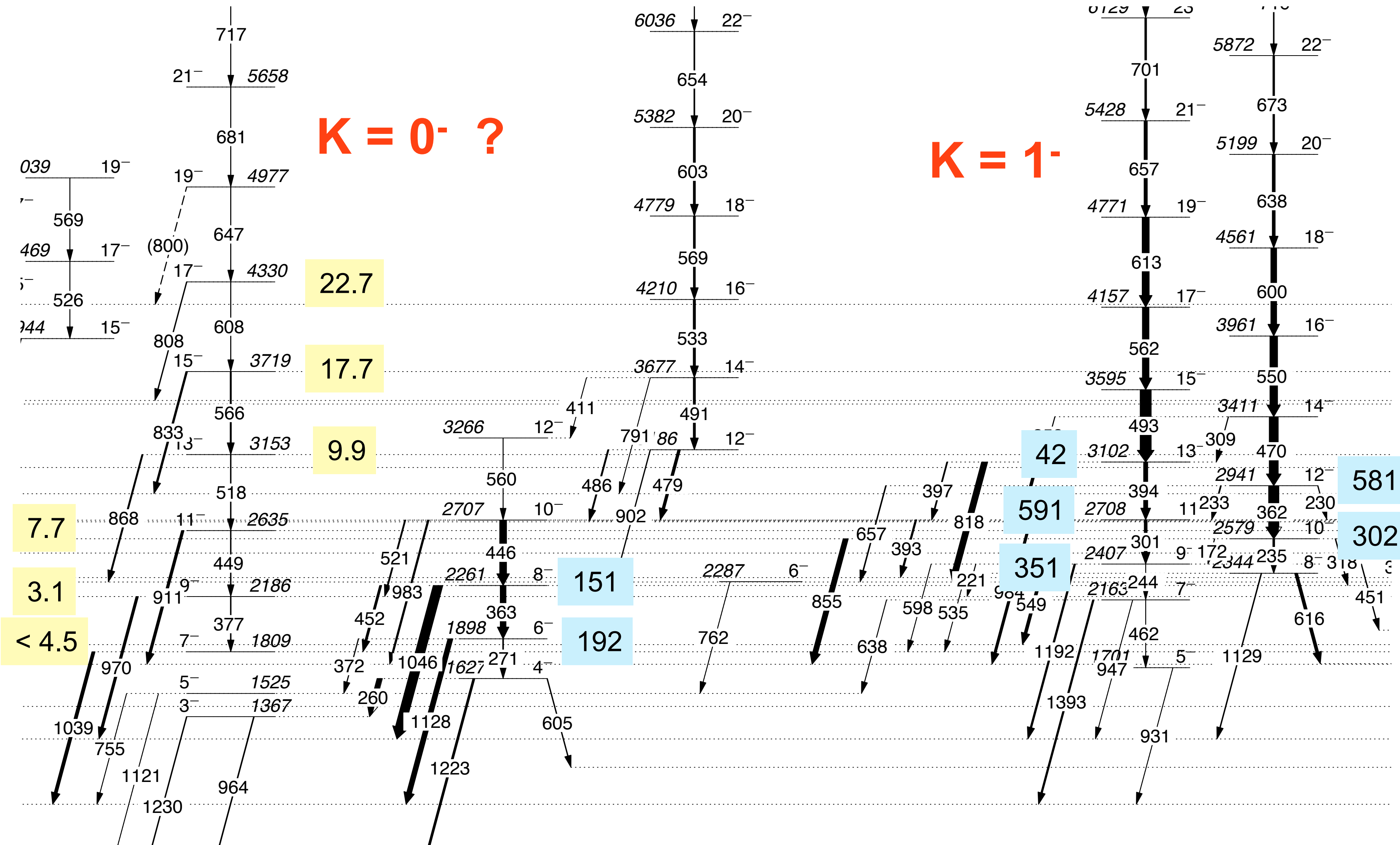
Successful Gammasphere run on ^{156}Dy



Measured branching ratios for lowest negative-parity band

I	$B(E2)/B(E1) \times 10^6$ fm^2
17	22.7
15	17.7
13	9.86
11	7.73
9	3.06
7	< 4.5
5	< 642

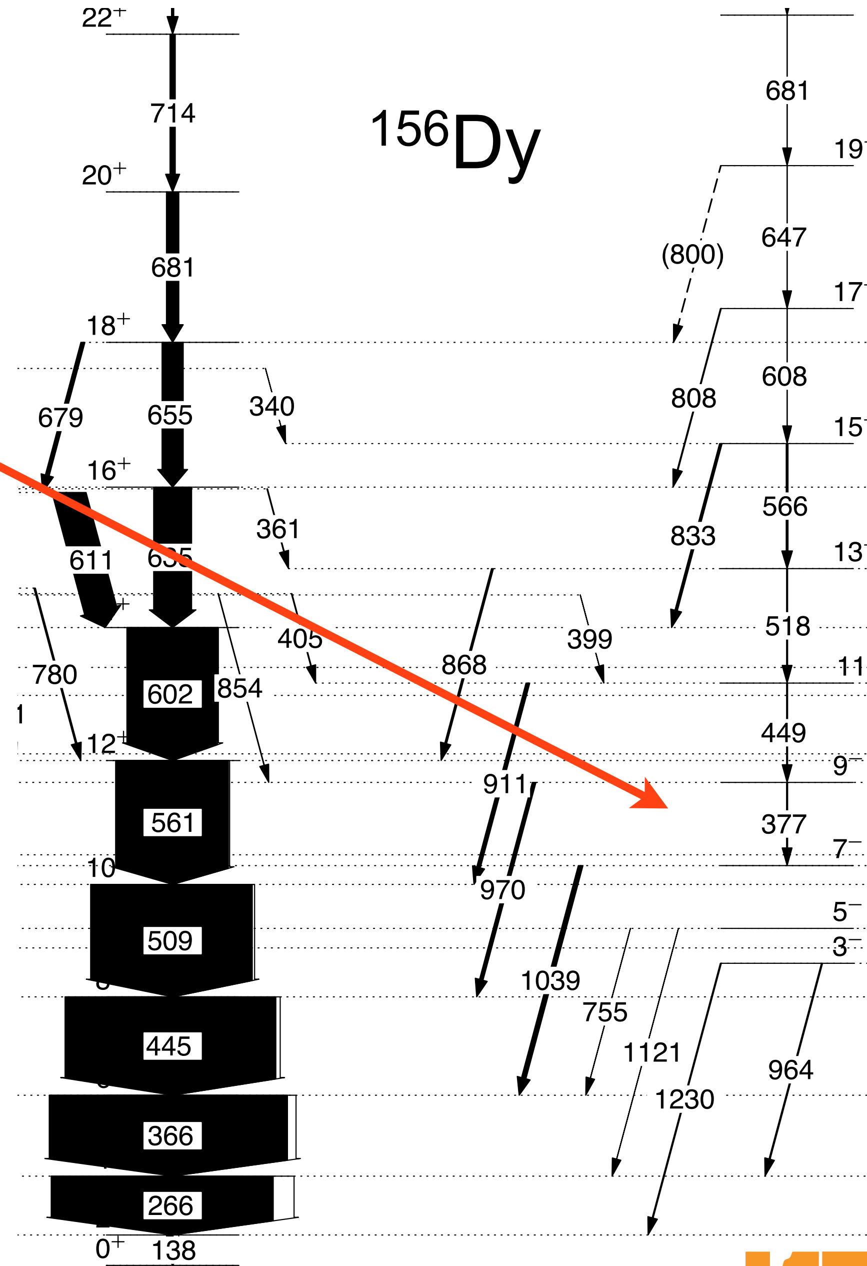
The B(E2)/B(E1) ratios are much larger in the K = 1 negative-parity band in ^{156}Dy



B(E2)/B(E1) values in units of 10^6 fm^2

Next step - measure lifetimes

- **September Gammasphere experiment is scheduled with the $^{25}Mg(^{136}Xe,5n)^{156}Dy$ reaction**
- **Question is whether the B(E2)/B(E1) ratios are small due to small B(E2) (tetrahedral shape) or large B(E1) (octupole vibration)**
- **The lifetime of the state will vary greatly depending on whether Q_t is normal or reduced**



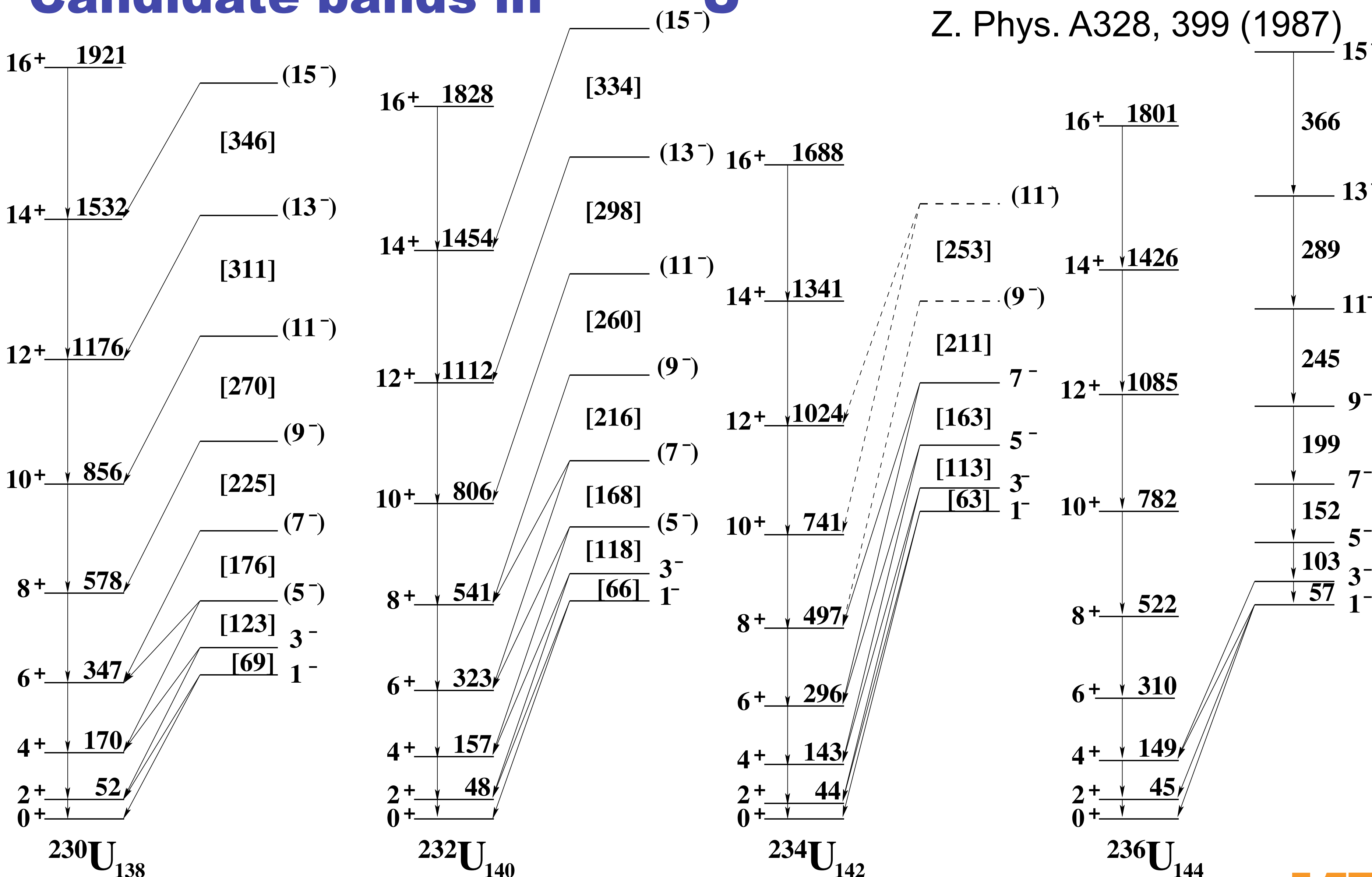
Secondary goals of this project:

- **Understand family of negative-parity bands - may not actually be a low lying K = 0^- structure**
- **Look for "second vacuum" family of bands, as in other N = 90 nuclei**

Search for tetrahedral shapes near Z = 90

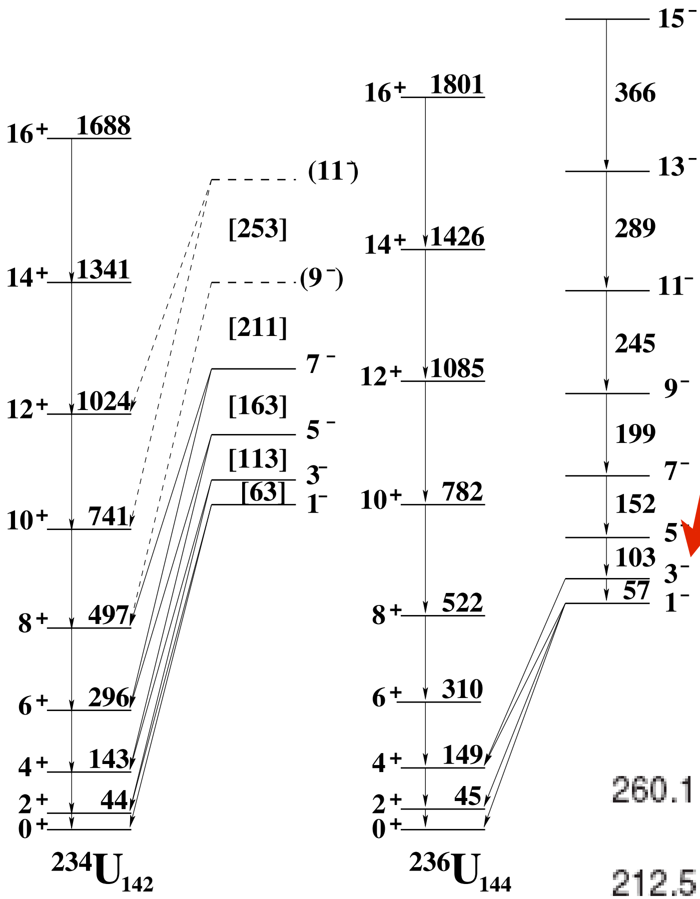
Candidate bands in $^{230-234}U$

Z. Phys. A328, 399 (1987)

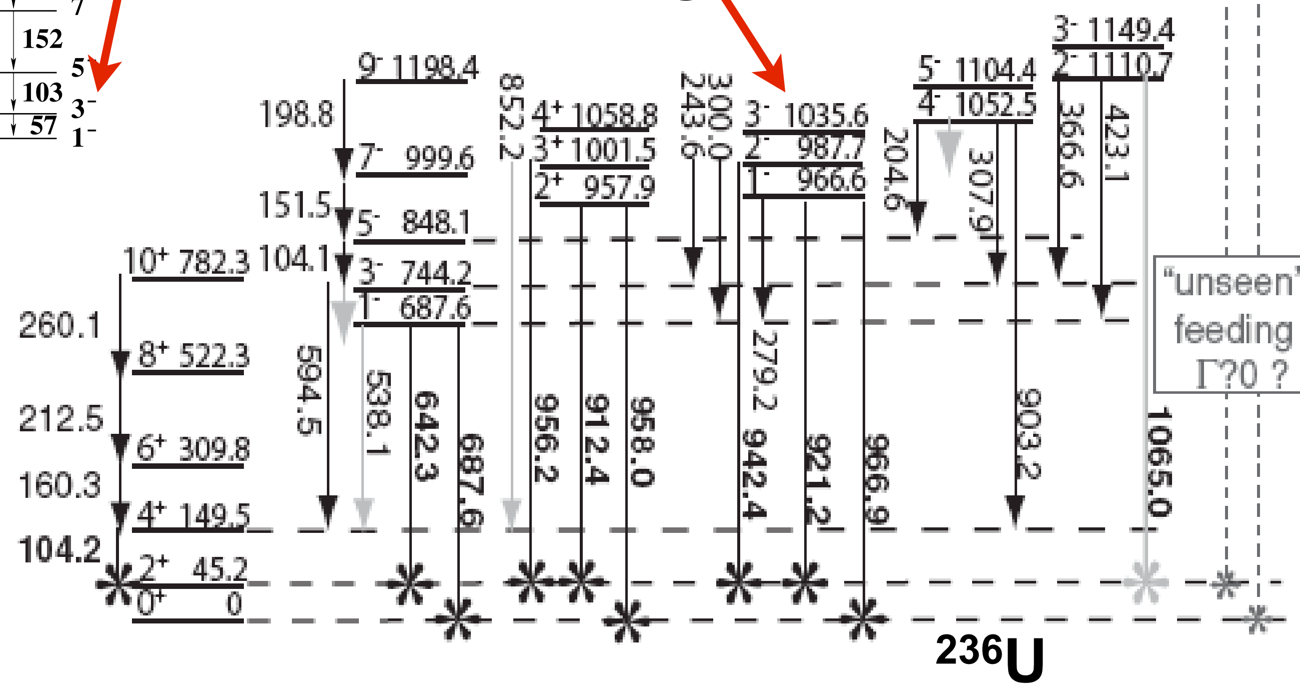


$^{231}Pa(p,2n)$ $^{230}Th(\alpha,2n)$ $^{232}Th(\alpha,2n)$ $^{236}U(d,pn)$

Propose to do multi-step Coulomb excitation of $^{234,236}U$ with Gammasphere



- This lowest 1⁻ band in ^{236}U is different than those in other U - too low in energy and few E1s
- Second 1⁻ band may be analogous tetrahedral candidate
- Look for 'missing' E2s in coulexc

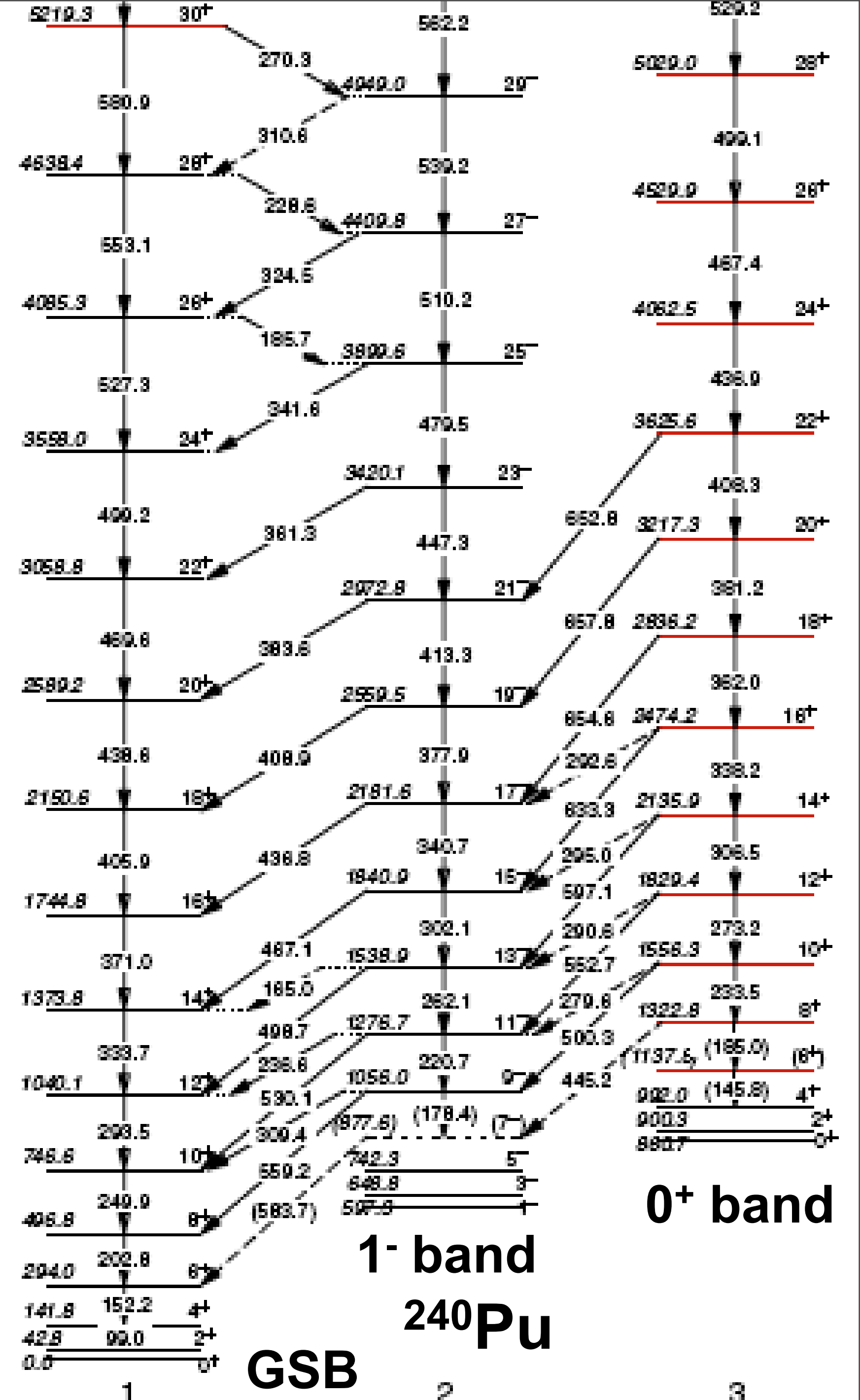


Secondary goal of this project: search for K = 0⁺ two-phonon octupole band

Allmond et al., PRC 79, 054610 (2009)
Relative ^{235}U(n, γ) and (n, f) cross sections from ^{235}U(d,pγ) and (d,pf)

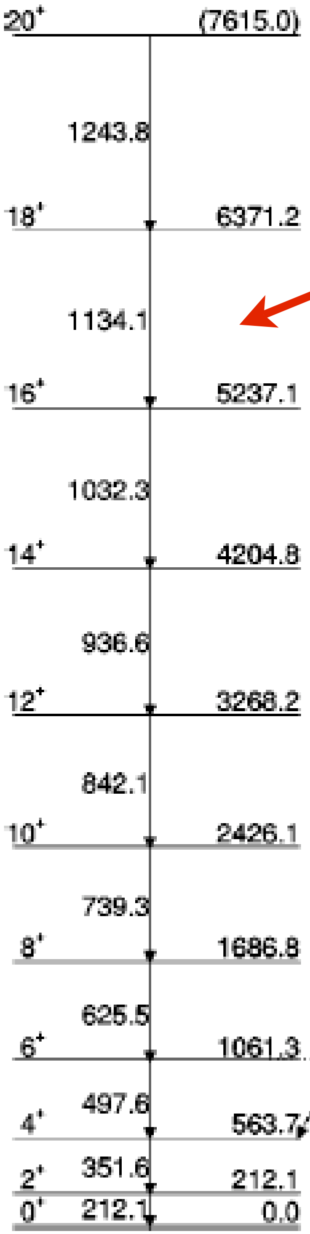
Recent Gammasphere work on ^{240}Pu

- See strong E1 lines from 1^- band to GSB
- Also see strong E1 lines from 0^+ band to 1^-band
- Explanation is that these are a family of octupole phonons
- Question is whether there is a similar 0^+ band in ^{232,234,236}U
  - 0^+_β found at 691 keV in ^{232}U and 810 keV in ^{234}U by Janssens et al. - PLB156, 163 (85)

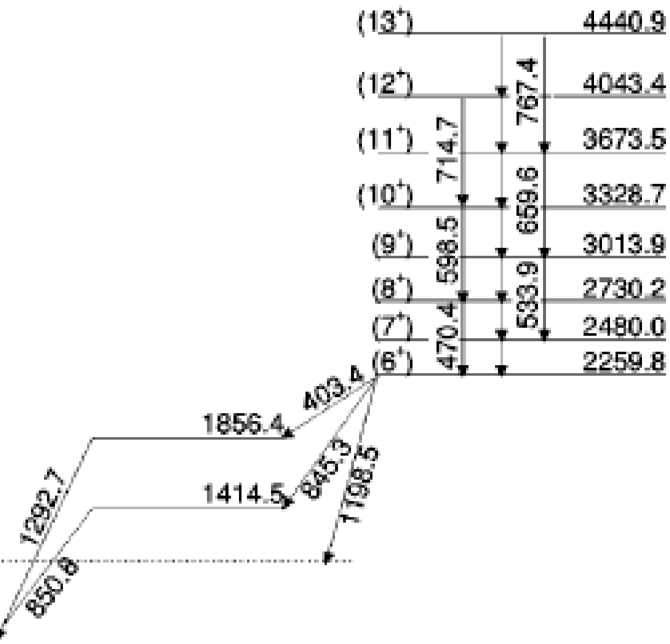


Wang et al., PRL 102, 122501 (2009)

Possible tetrahedral shape in ^{100}Zr



- ^{100}Zr: Z = 40, N = 60 - magic numbers
- ^{238}U(α,f) expt. - Gammasphere plus Chico - 2004
- Ground state is prolate with a 2 QP sideband
- Gammasphere spontaneous fission work - spherical 0^+ at 331 keV with structure on top of it - 2006



- Propose doing a Caribu experiment - coulex of a ^{100}Zr beam, to hunt for tetrahedral bands associated with the prolate ground-state configuration

Hua et al., PRC 69, 014317 (2004)

^{100}Zr experiment

Secondary goal: measure matrix elements important for understanding shape coexistence

Hwang et al., PRC 74, 017303 (2006) - spontaneous fission experiment inside Gammasphere