Variety of shapes and a complex shape coexistence in ^{187}Tl

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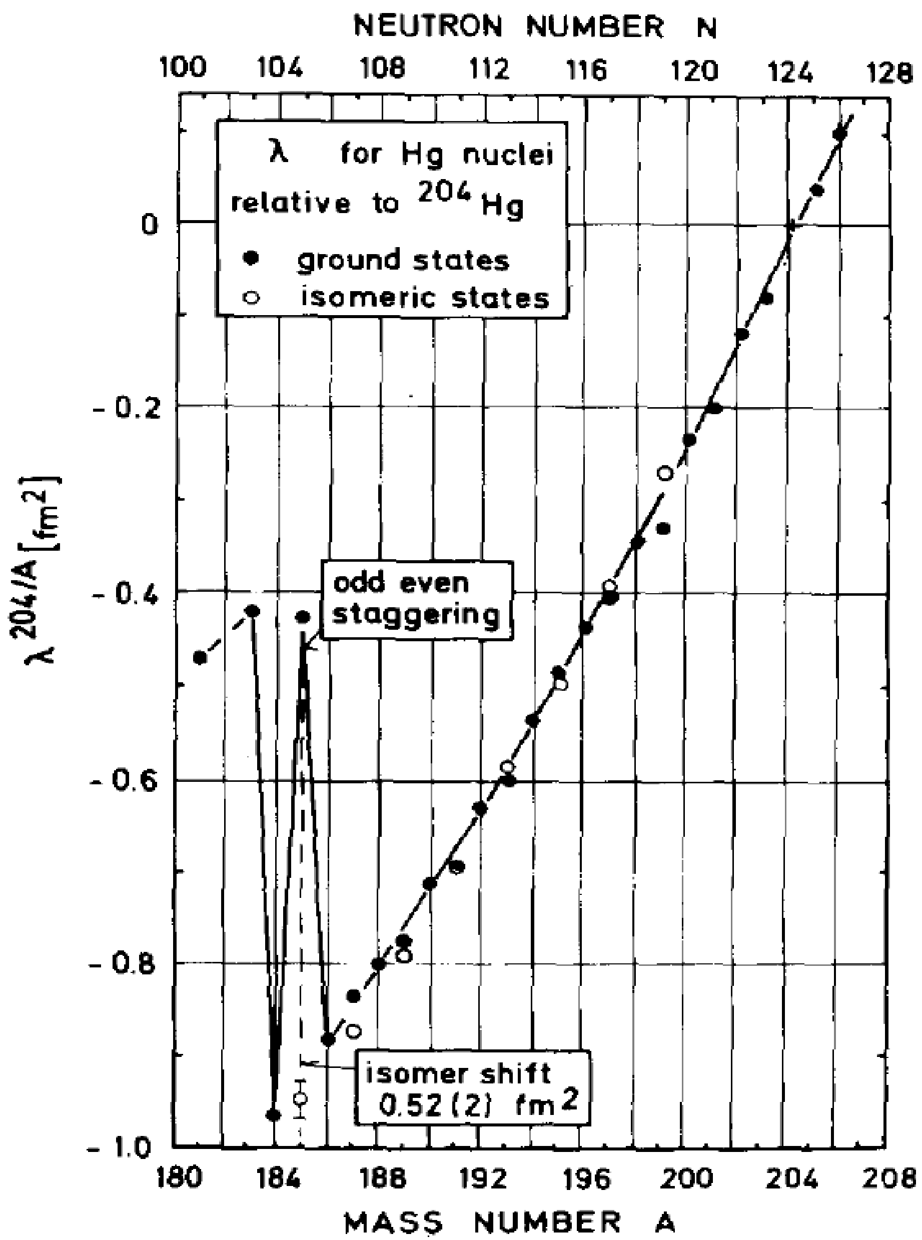
Albert Lee: ANU PhD thesis (2013)

Partial results in Lee et al, EPJ Web of Conf. 35 (2012) 06002

Shape coexistence near Z=82: Hg nuclei



Original evidence for shape coexistence in Hg-Pb region came from laser spectroscopy.

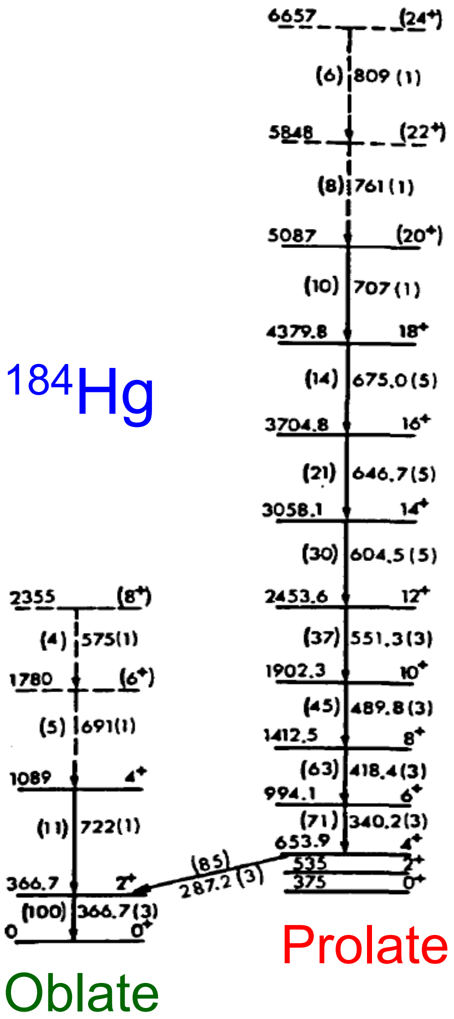
Odd-even staggering of $\delta\langle r^2 \rangle$

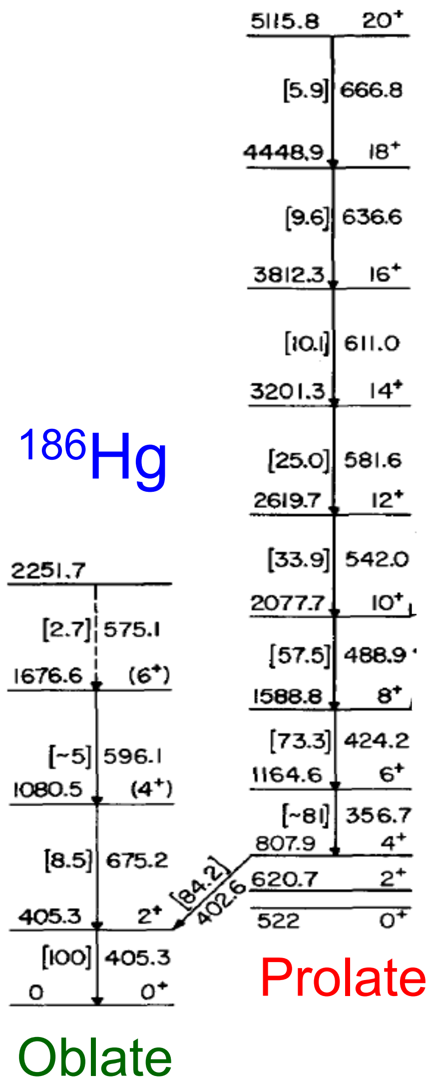
P. Dabkiewicz et. al. ,
Phys. Lett. B **82** (1979) 199-203

$1/2^{-}$[521] (prolate) ground state for ^{185}Hg

Excited (oblate) isomer in ^{185}Hg continues trend from heavier isotopes

Even-A Hg isotopes: coexisting bands

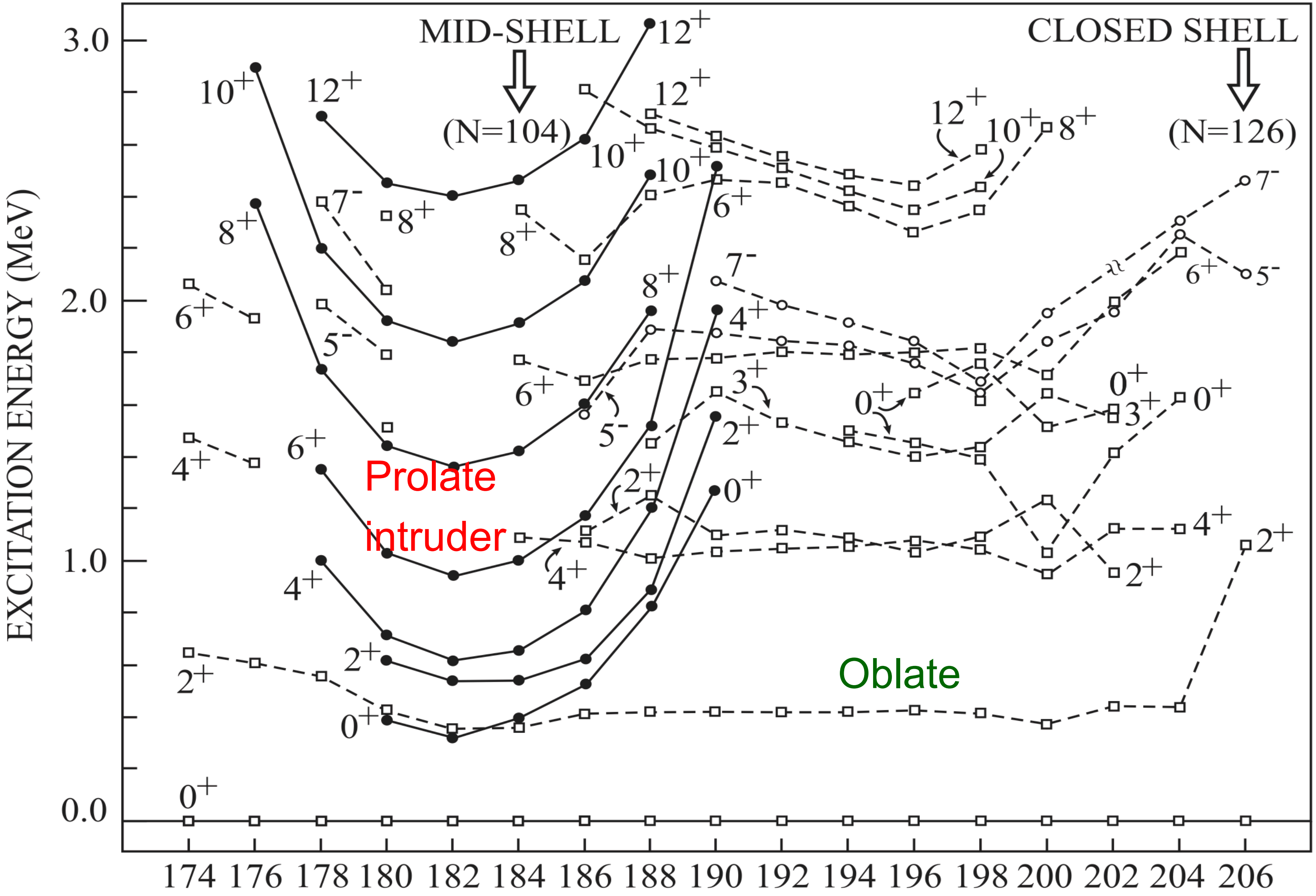




W. C. Ma et. al., Phys. Lett. ***167****B (1986) 277*

R. V. F. Janssens et. al., Phys. Lett. ***131****B (1983) 35*

Comprehensive even-A Hg systematics

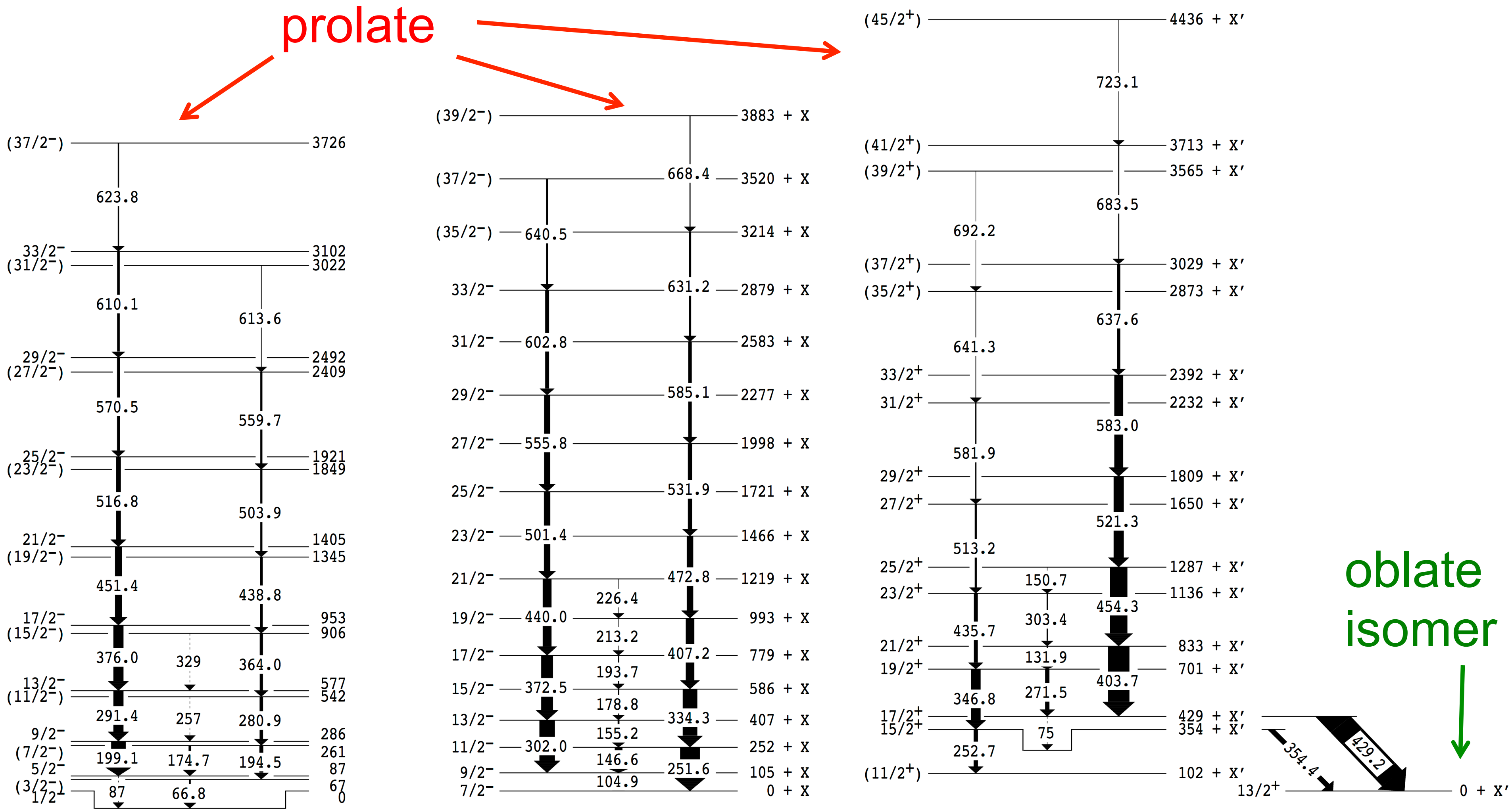


Heyde and Wood, RMP 83 (2011) 1467

Oblate ground state band

Prolate intruder around mid-shell

Odd-A Hg nuclei: not as well studied



1/2-[521]

7/2-[514]

"9/2+[624]"

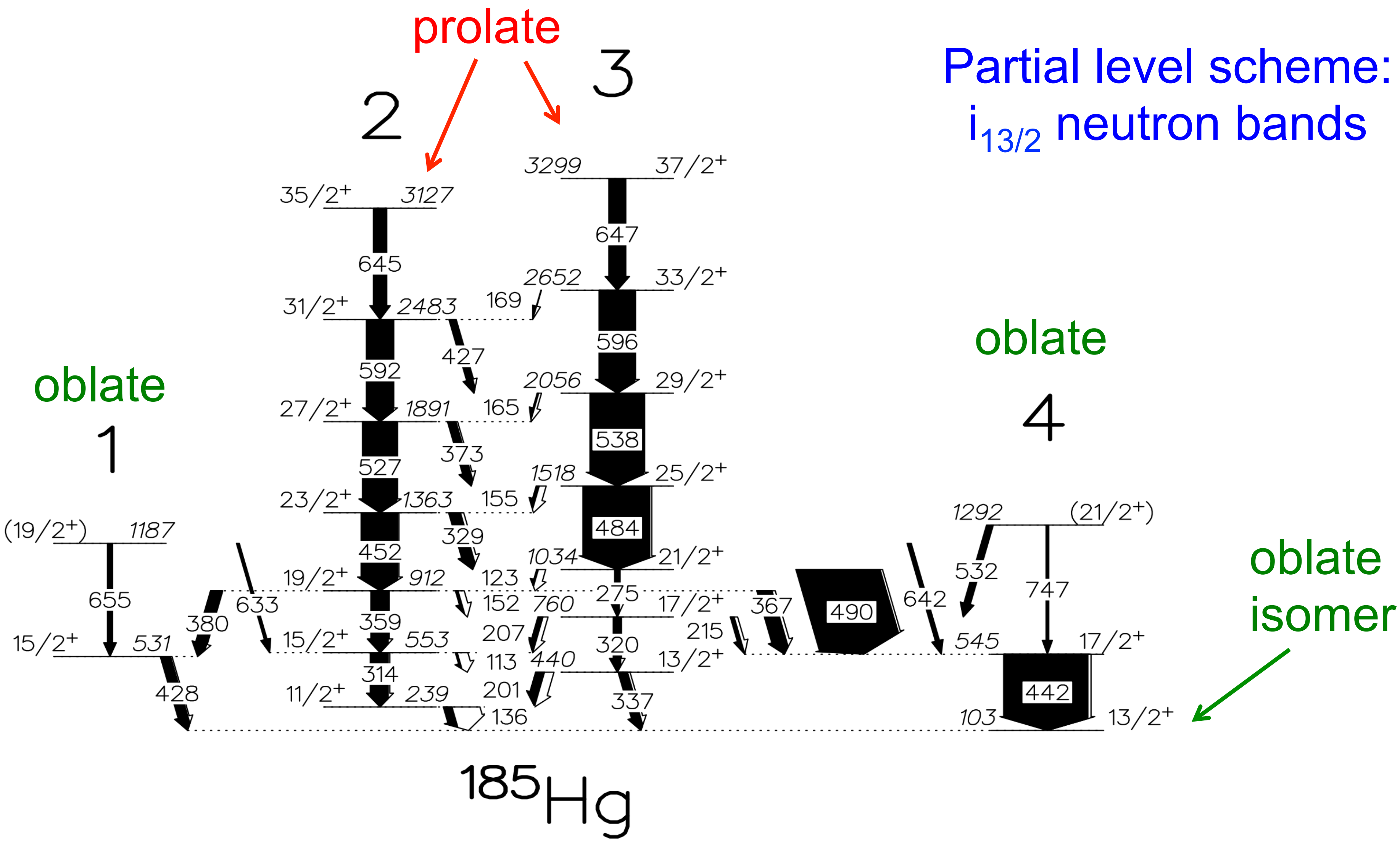
Ground state Q, J and μ from laser spec

^{183}Hg

Lane et al, NPA A 589 (1995) 129-159

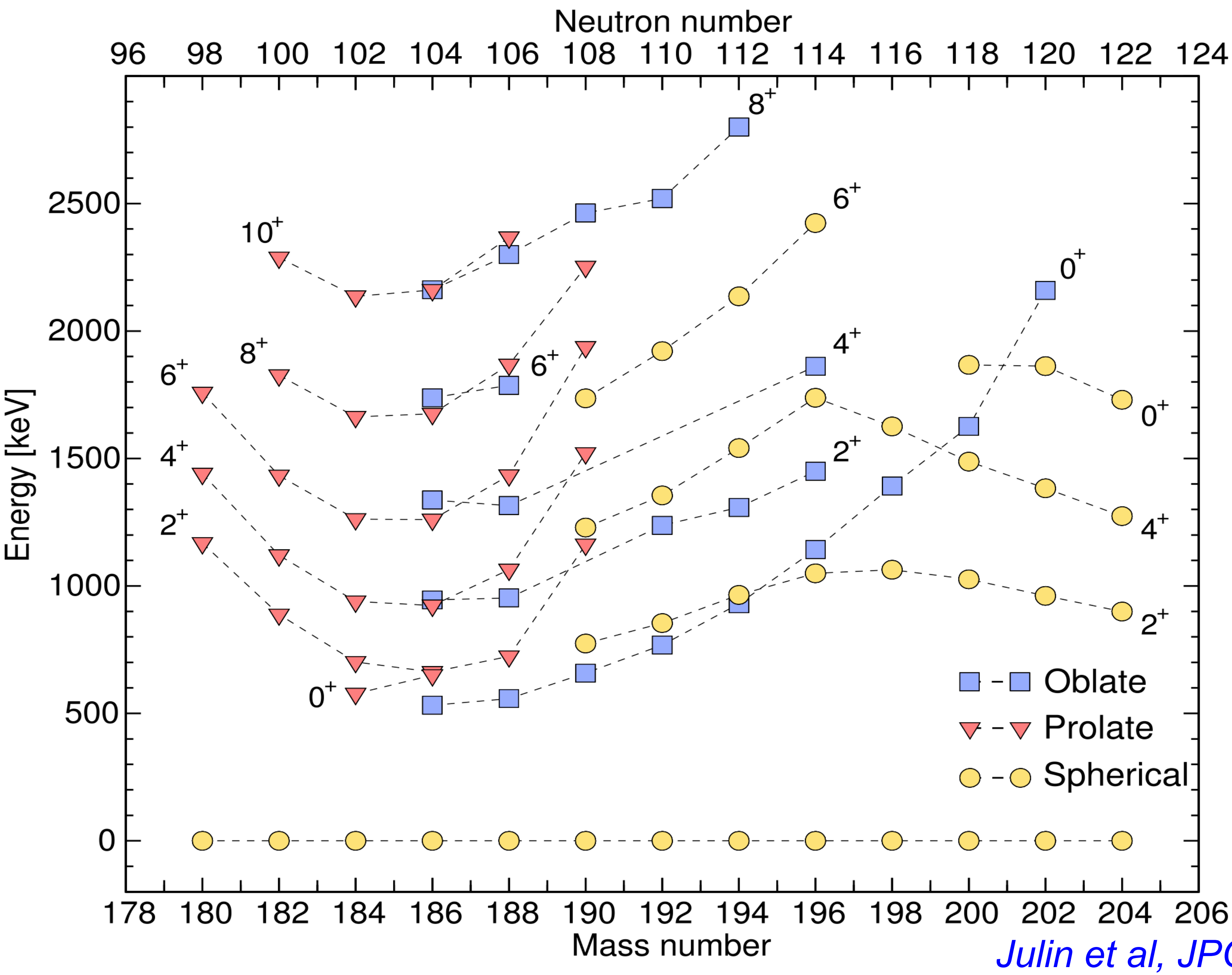
Odd-A Hg nuclei: not as well studied

Partial level scheme: $i_{13/2}$ neutron bands



Original scheme from Hannachi et al, ZPA 330 (1988) 15.
Present scheme from Lane et al, should be published

Neighbouring even-A Pb systematics



Julin et al, JPG 43 (2016) 024004

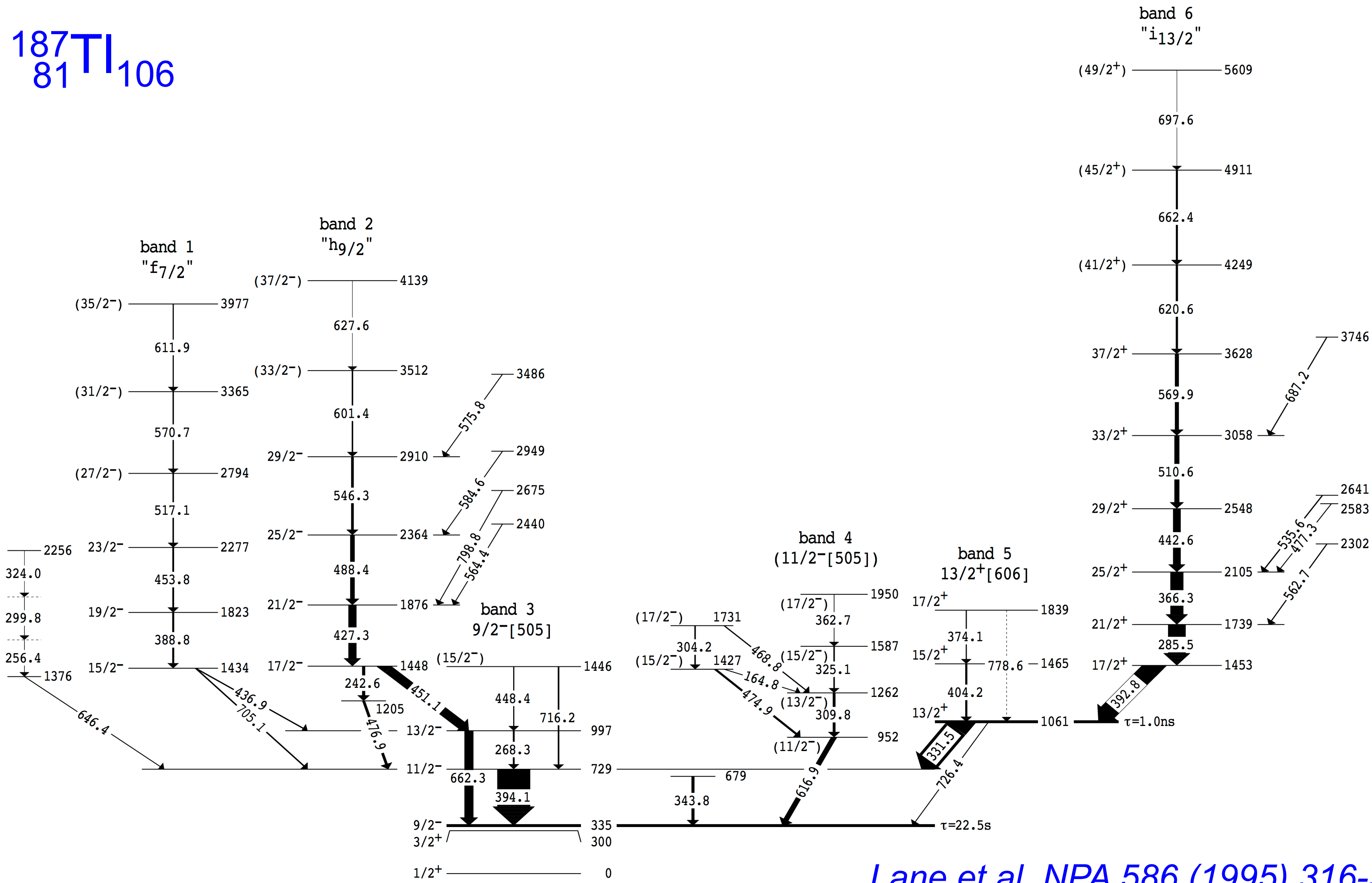
Z=82 => Spherical gs

Prolate and **oblate** intruder bands around mid-shell

What about $_{81}$Tl between Hg and Pb?

Odd-Tl nuclei: triple shape coexistence

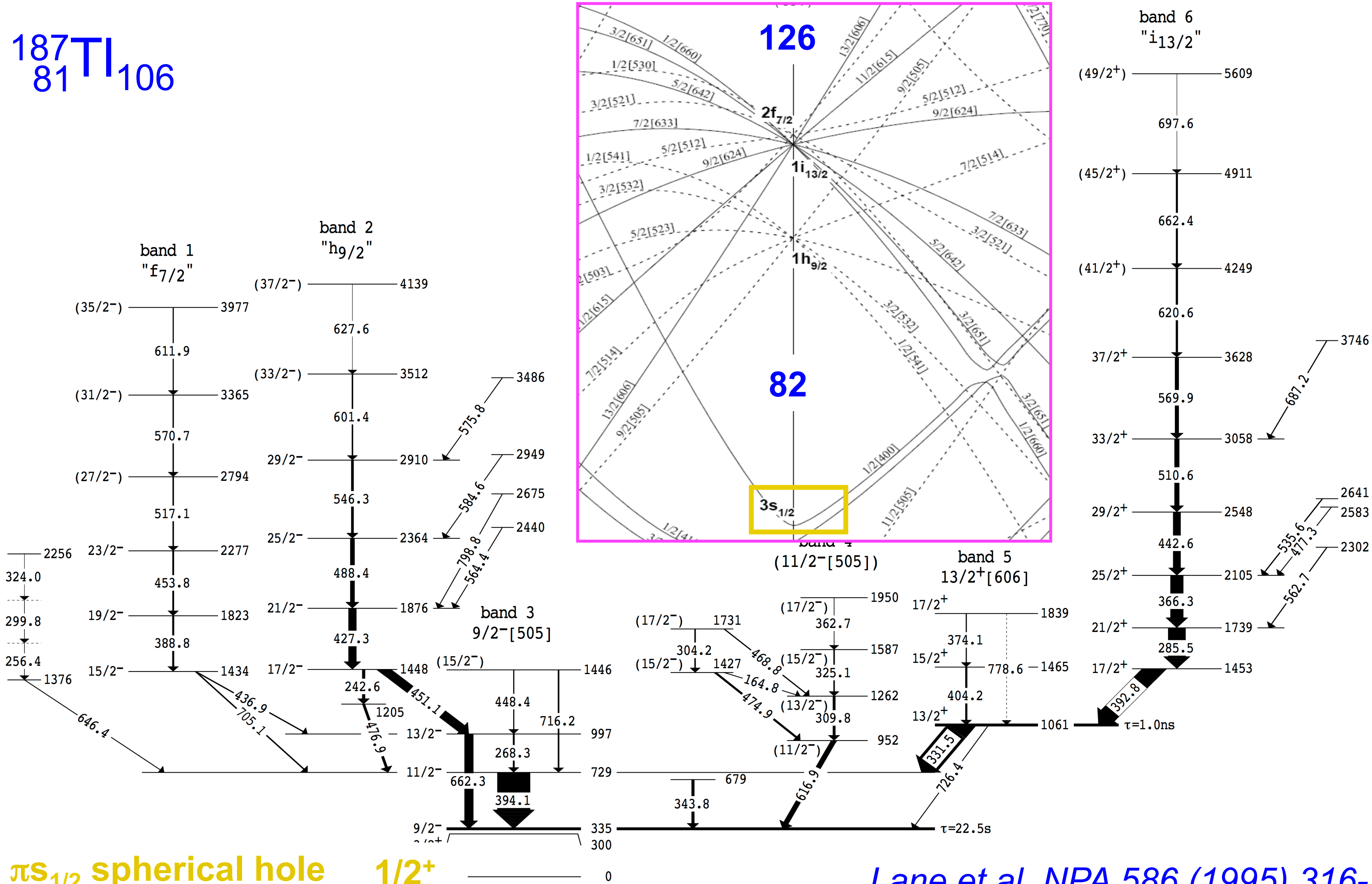
$^{187}_{81}Tl_{106}$



Lane et al, NPA 586 (1995) 316-350

Odd-Tl nuclei: triple shape coexistence

$^{187}_{81}Tl_{106}$



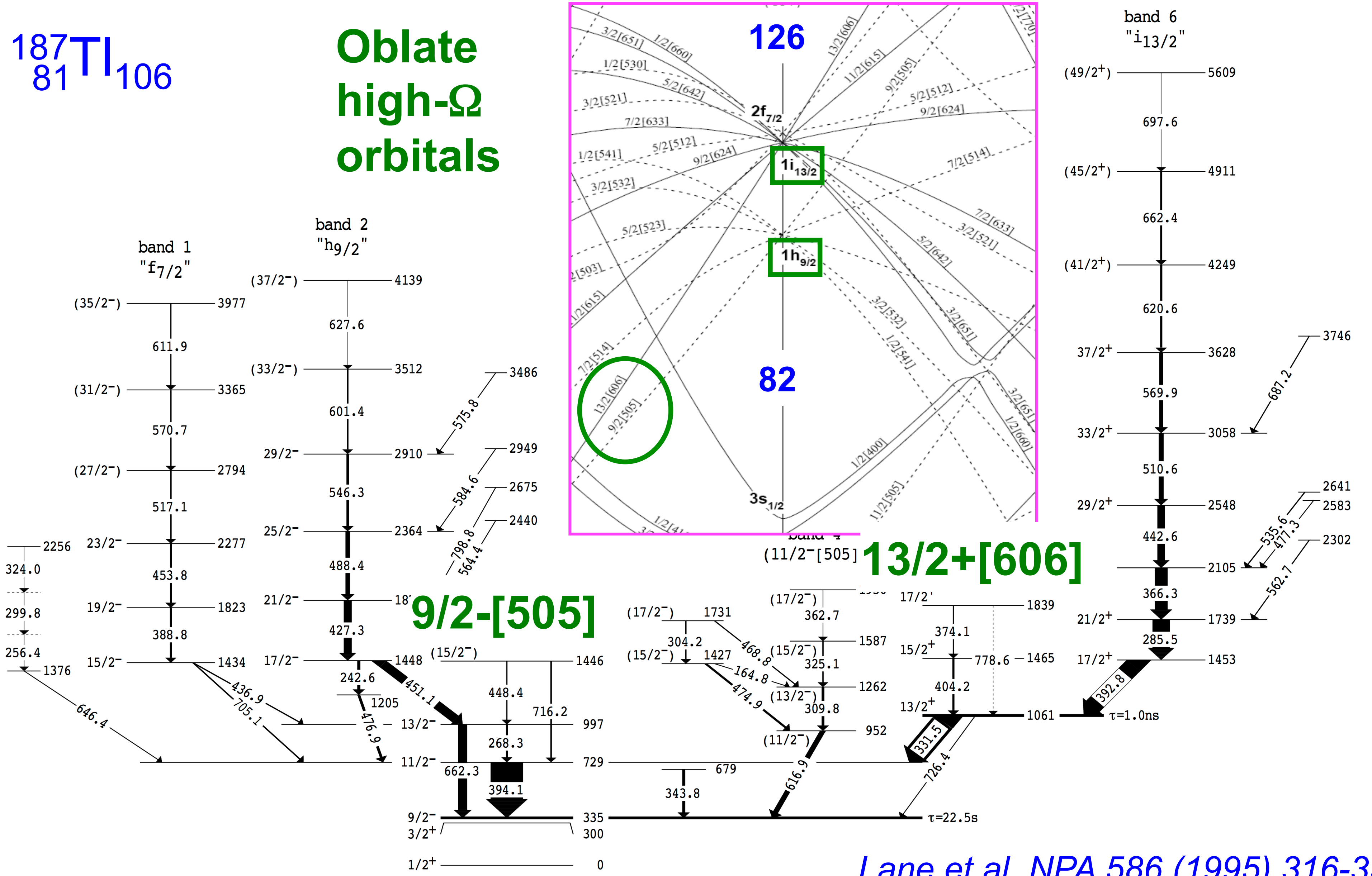
πs1/2 spherical hole 1/2+

Lane et al, NPA 586 (1995) 316-350

Odd-Tl nuclei: triple shape coexistence

$^{187}_{81}Tl_{106}$

Oblate high-Ω orbitals

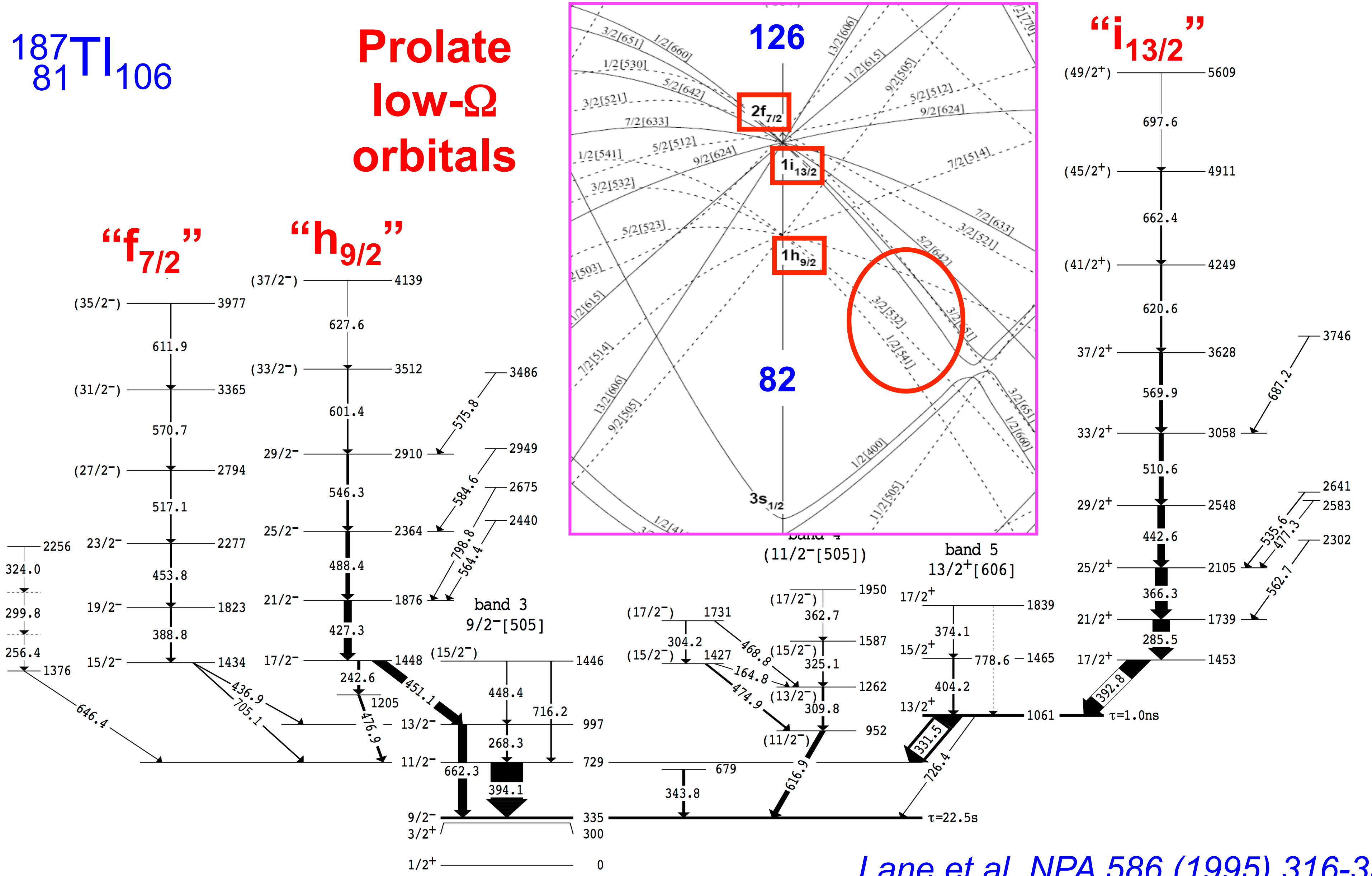


Lane et al, NPA 586 (1995) 316-350

Odd-Tl nuclei: triple shape coexistence

$^{187}_{81}Tl_{106}$

Prolate low-Ω orbitals

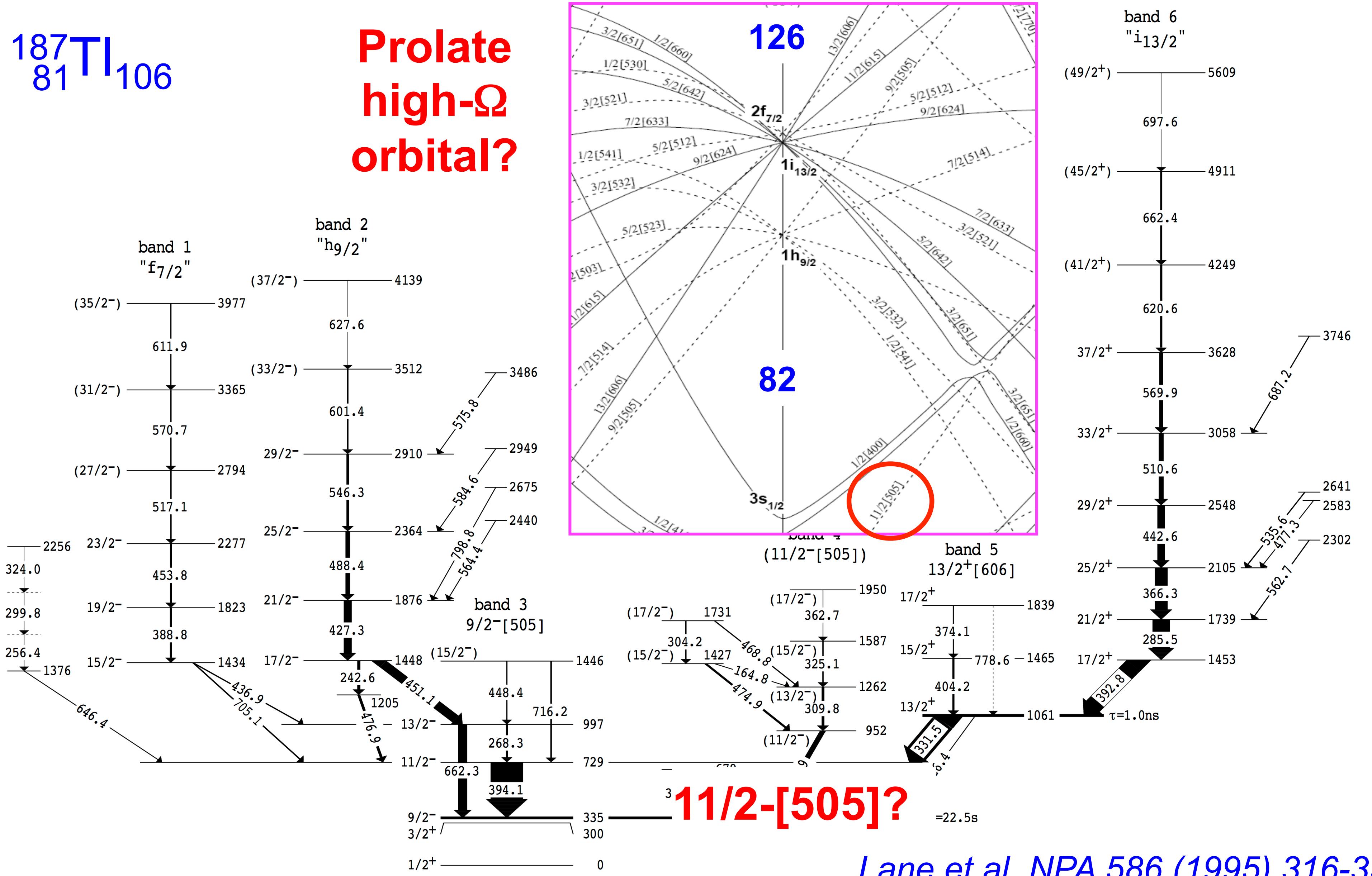


Lane et al, NPA 586 (1995) 316-350

Odd-Tl nuclei: triple shape coexistence

$^{187}_{81}Tl_{106}$

Prolate high-Ω orbital?



11/2-[505]?

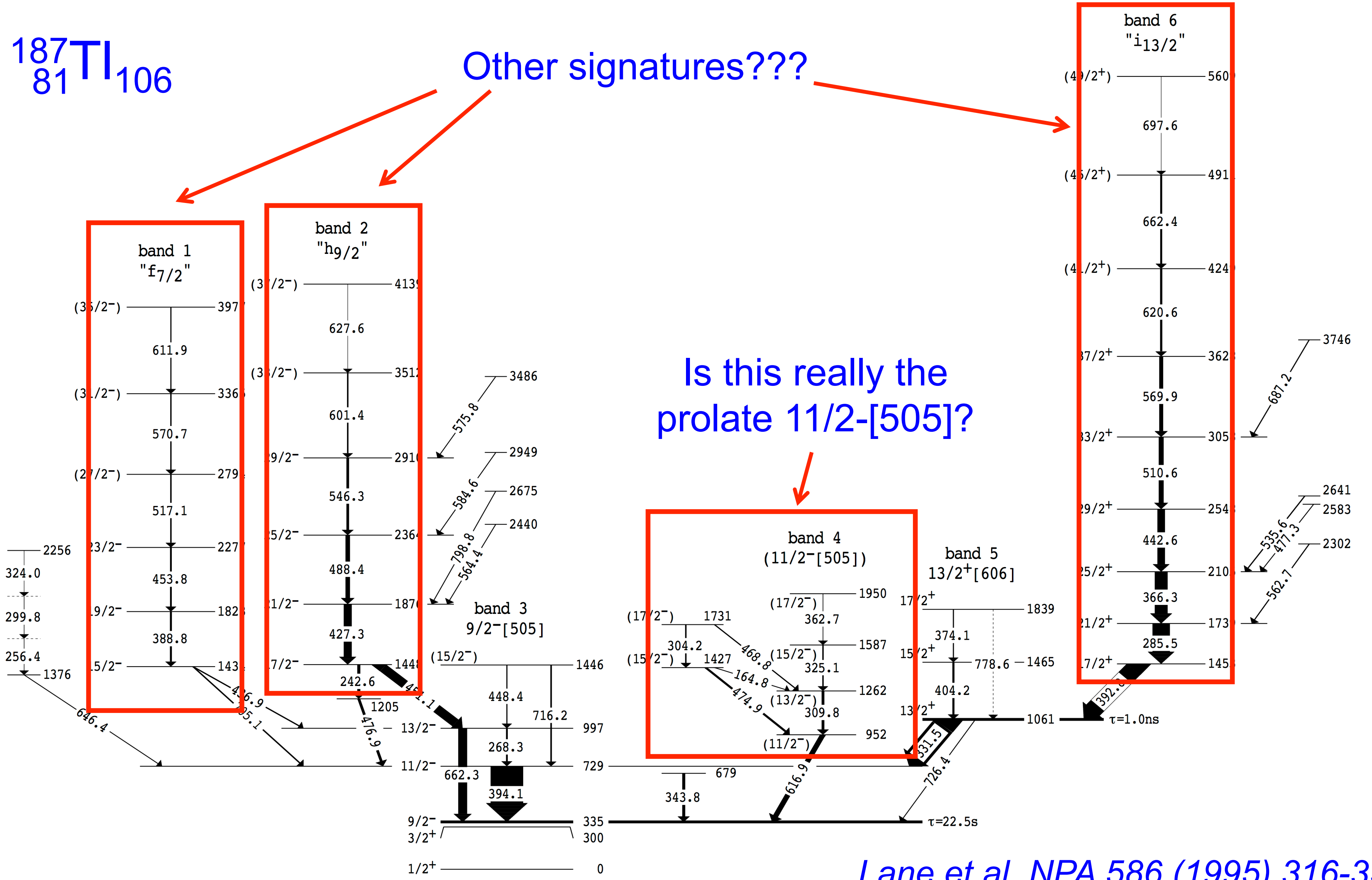
Lane et al, NPA 586 (1995) 316-350

Open questions

$^{187}_{81}Tl_{106}$

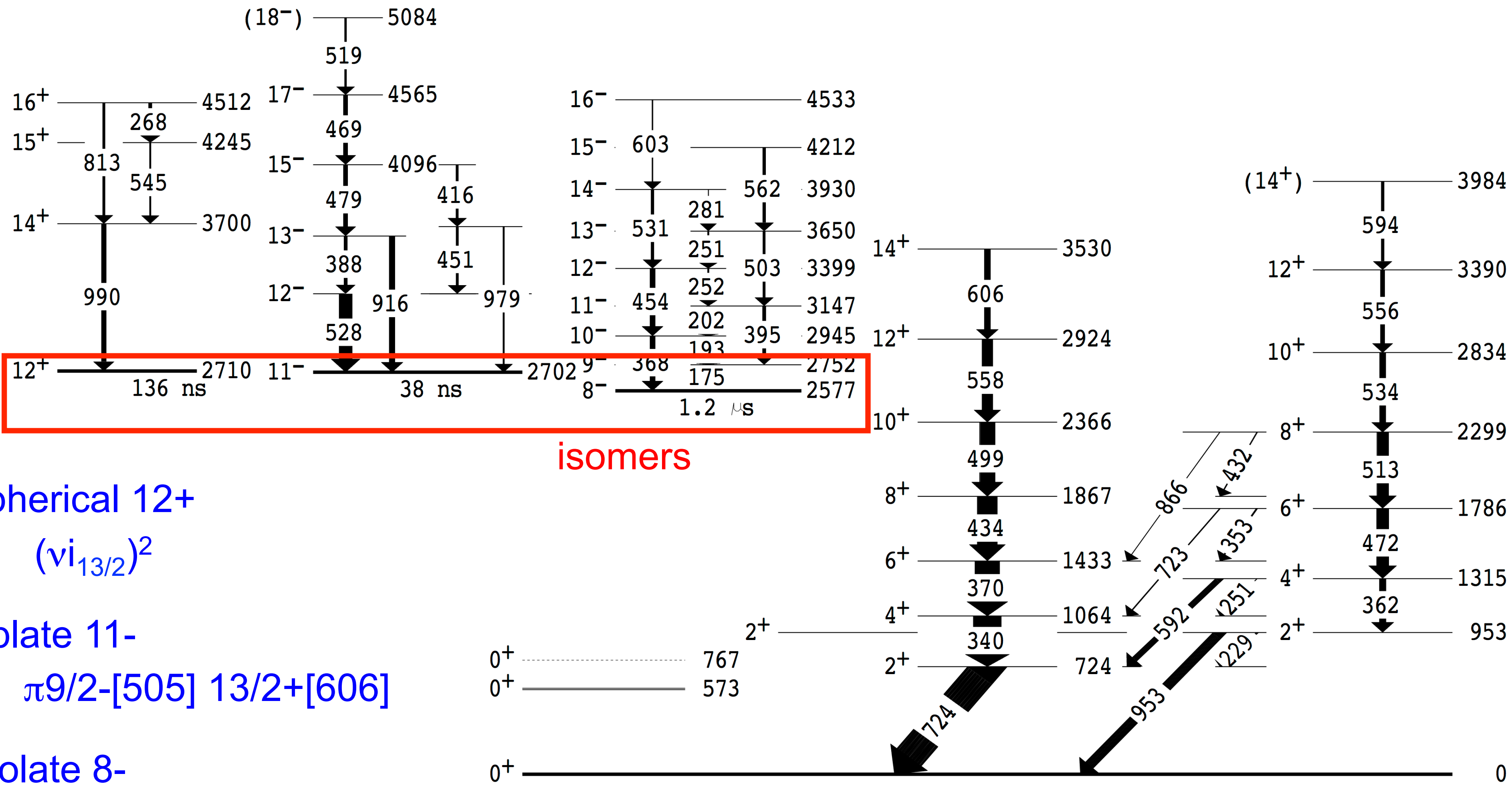
Other signatures???

Is this really the prolate 11/2-[505]?



Lane et al, NPA 586 (1995) 316-350

What about mqp isomers?



Spherical 12+

$(\nu i_{13/2})^2$

Oblate 11-

π9/2-[505] 13/2+[606]

Prolate 8-

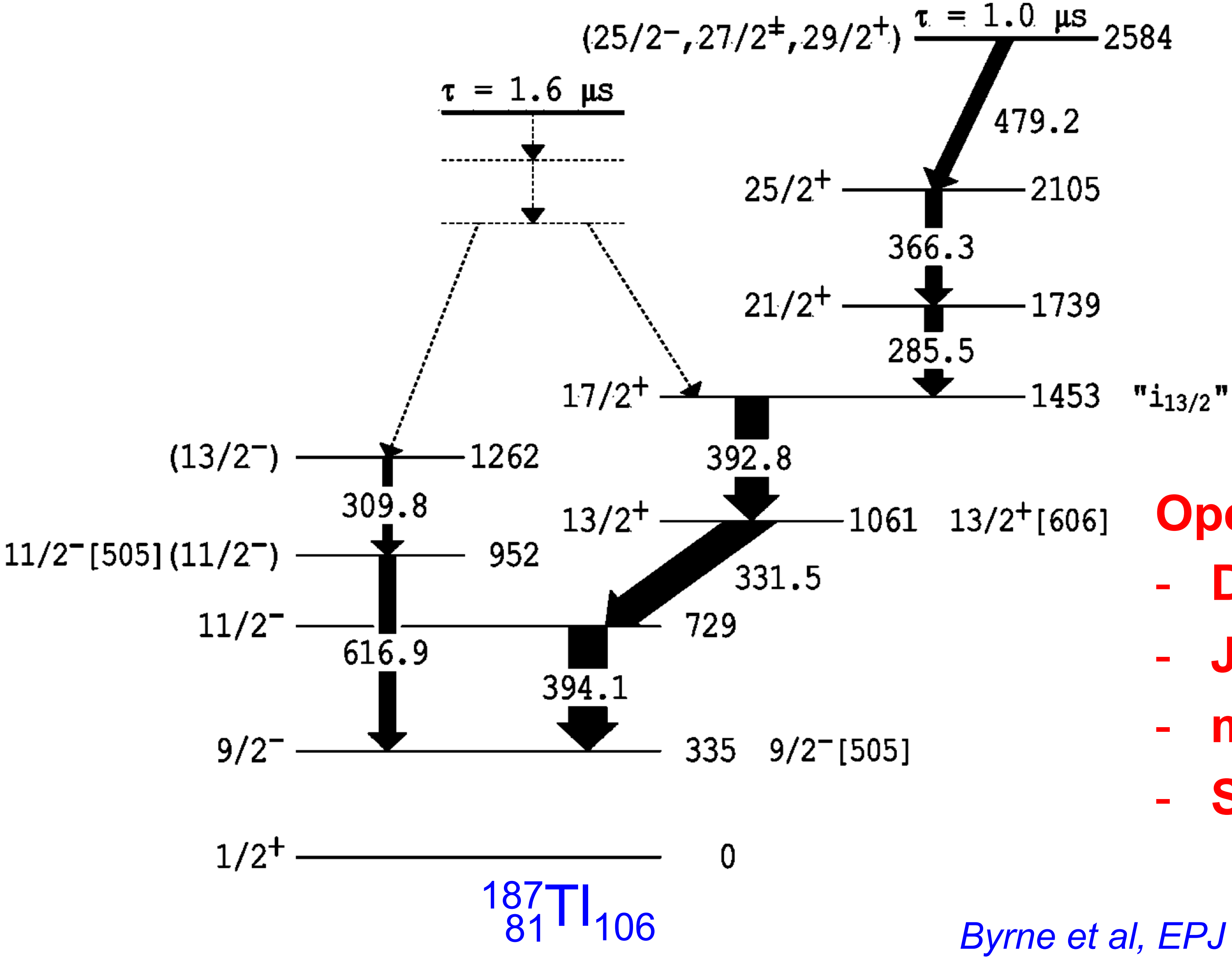
ν9/2+[624] 7/2-[514]

$^{188}_{82}Pb_{106}$

Unique identification – contrast with 0+ states

Dracoulis et al, PRC 69 (2004) 054318

Multiparticle isomers in ^{187}Tl



Open questions:

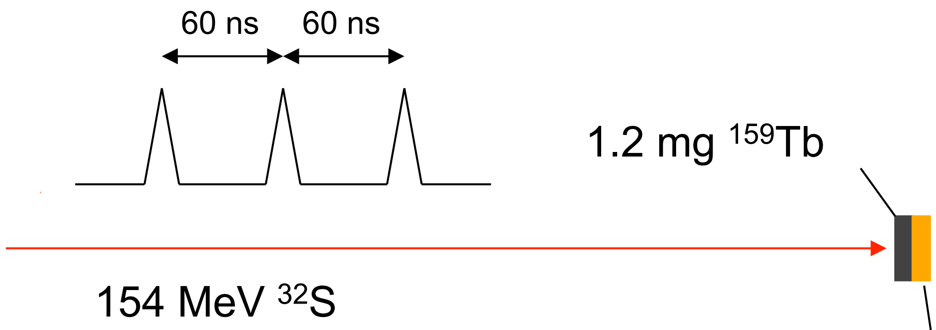
- **Decay links?**
- **J^{π} ?**
- **mqp structure?**
- **Shapes?**

Byrne et al, EPJ A 7 (2000) 41-44.

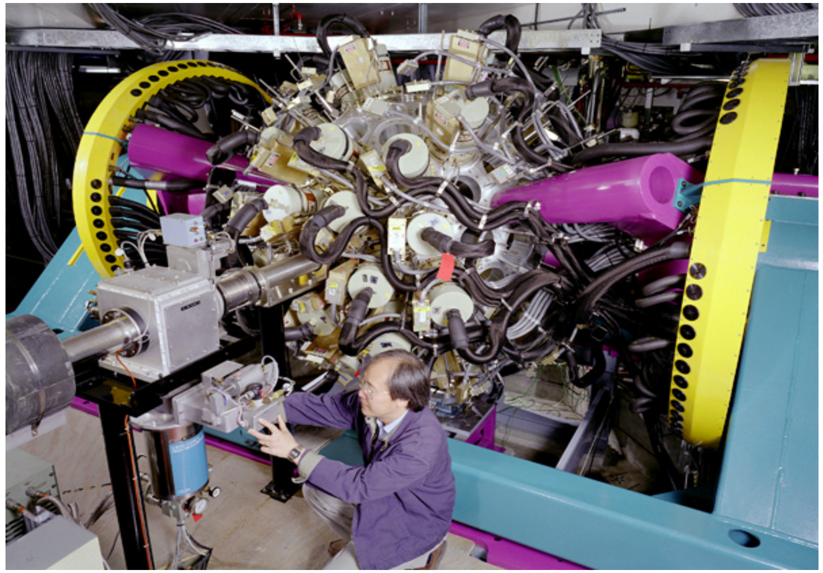
Experiment with Gammasphere at LBNL

Lawrence Berkeley National Lab, USA, 2001

- $^{159}Tb(^{32}S,4n)^{187}Tl$



4.5 mg ^{197}Au

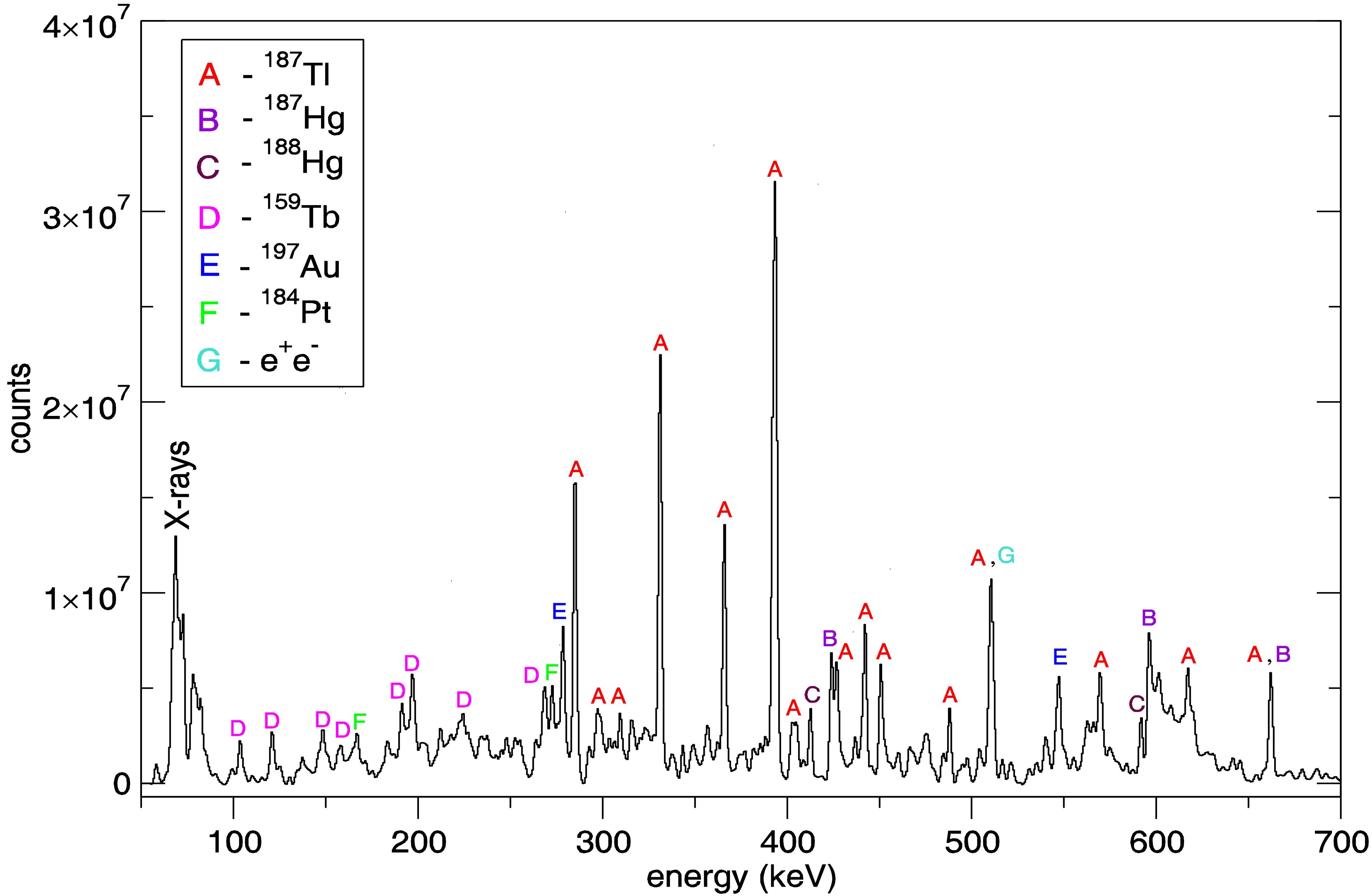


Data Analysis

- 1.2 x 10^9 events recorded from threefold γ-rays or higher

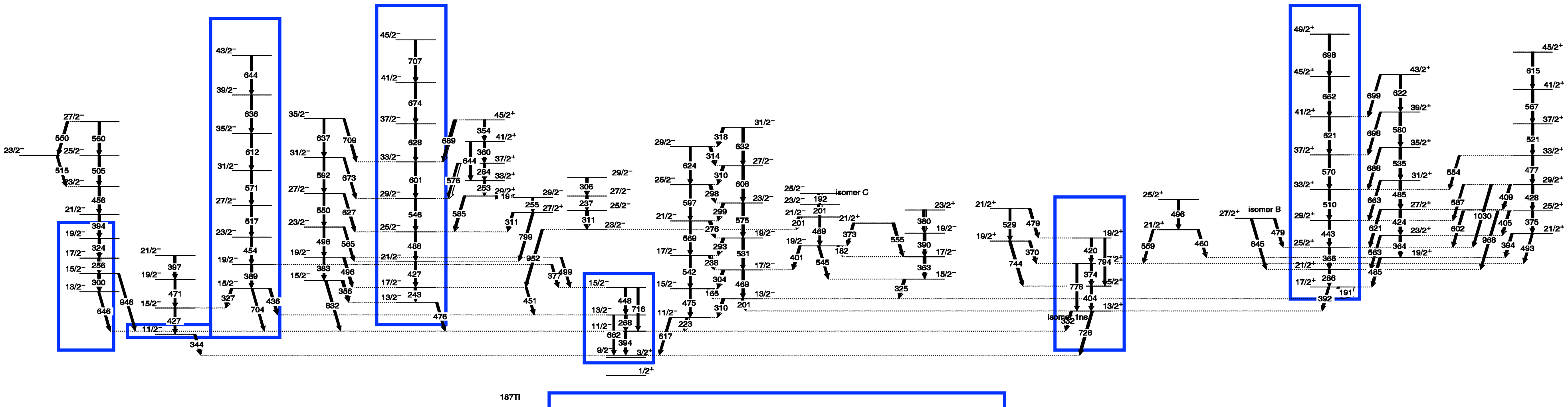
- Time coincidence overlap of +/- 700 ns

Total projection of in-beam gamma-rays



Australian National University

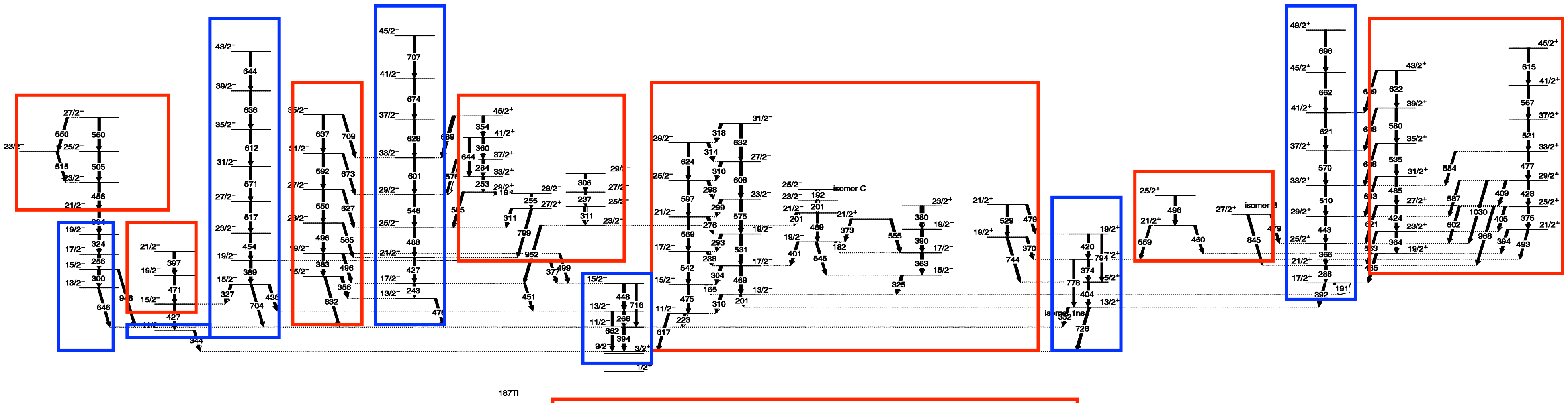
New level scheme for ^{187}Tl



Prior level scheme

Australian National University

New level scheme for ^{187}Tl

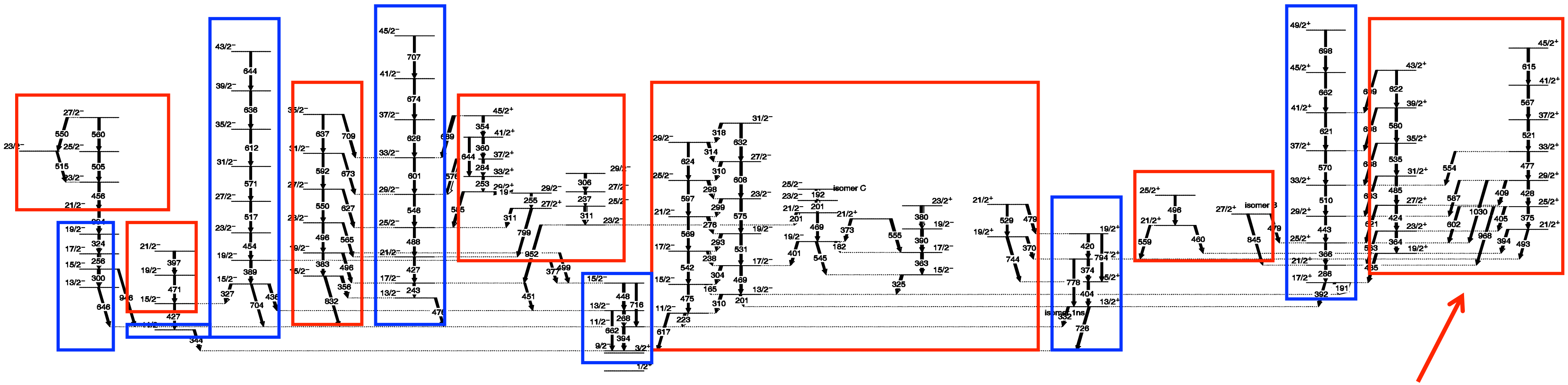


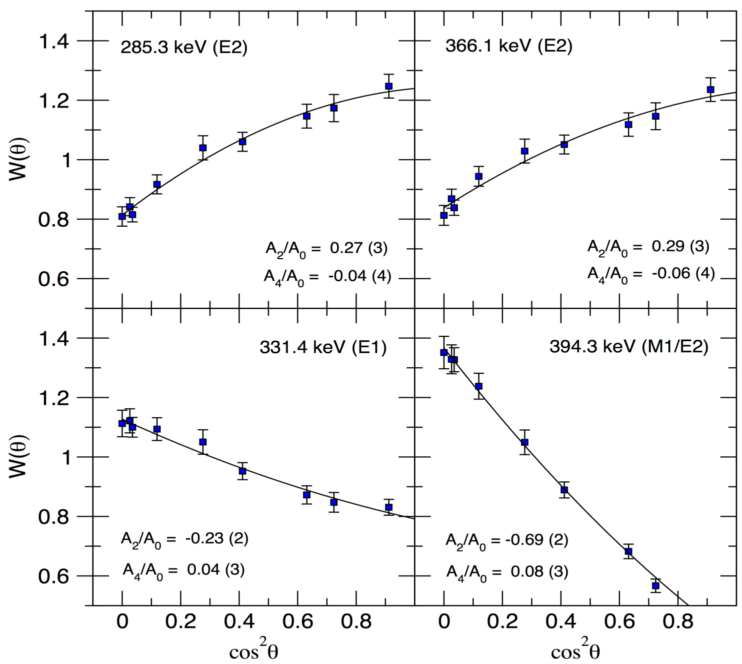
~ 120 new γ-rays

~ 70 new levels

Australian National University

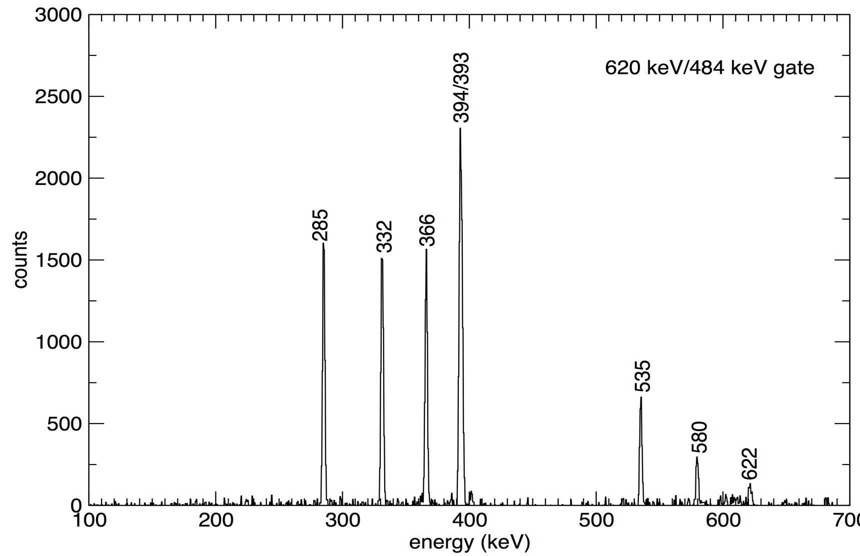
New level scheme for ^{187}Tl



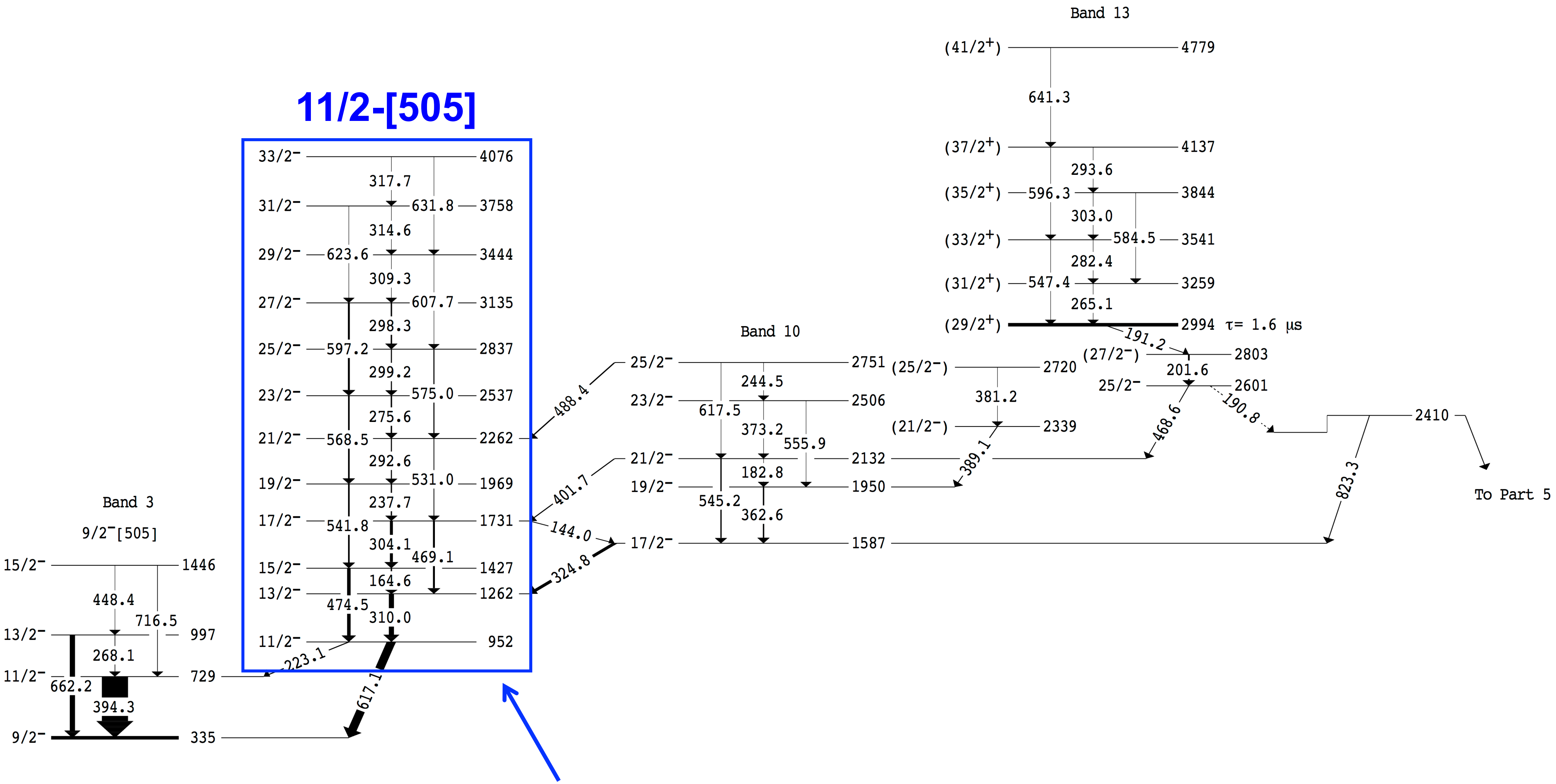


Angular distributions for Jπ assignments

γγγ coincidences with high statistics to find new structures

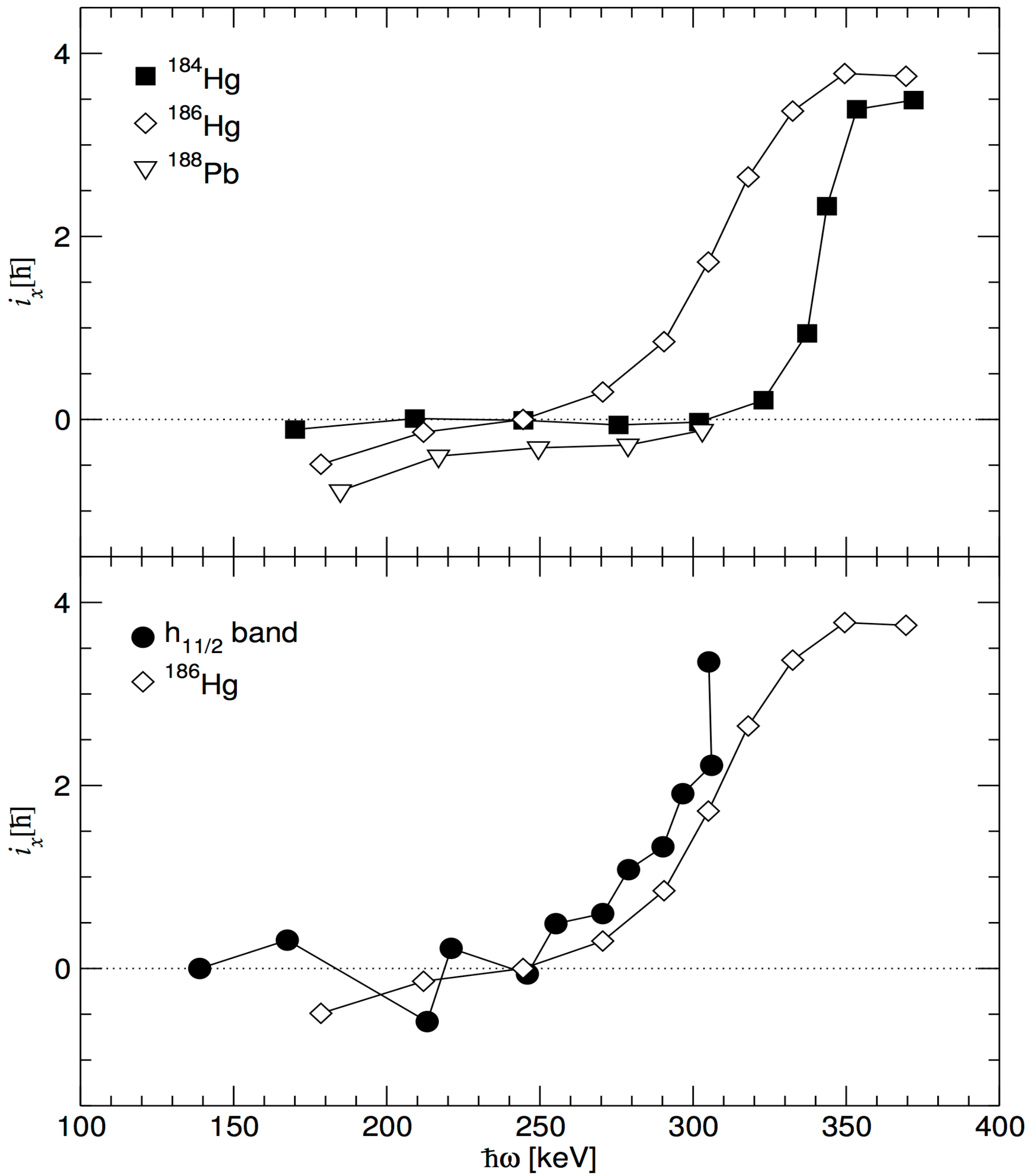


Level scheme for ^{187}Tl: Part 2 of 5



Previously irregular 11/2-[505] band is now well-established.

Triaxial to prolate shape change



- Reference chosen to produce i_x=0 for prolate bands in nearby even-even nuclei.
- $i_{13/2}$ neutron alignments are evident.

- Comparison of 11/2-[505] band to the prolate ^{186}Hg core.
- Signature splitting decreases as neutrons align.
- Triaxial to prolate shape change (Frauendorf, PLB 125 (1983) 245).
- Also in nearby Ir isotopes (e.g. Schuck et al., NPA 325 (1979) 421).

PES calculations for 1qp states in ^{187}Tl

PES calculations by Furong Xu and his student D.X. Dong.

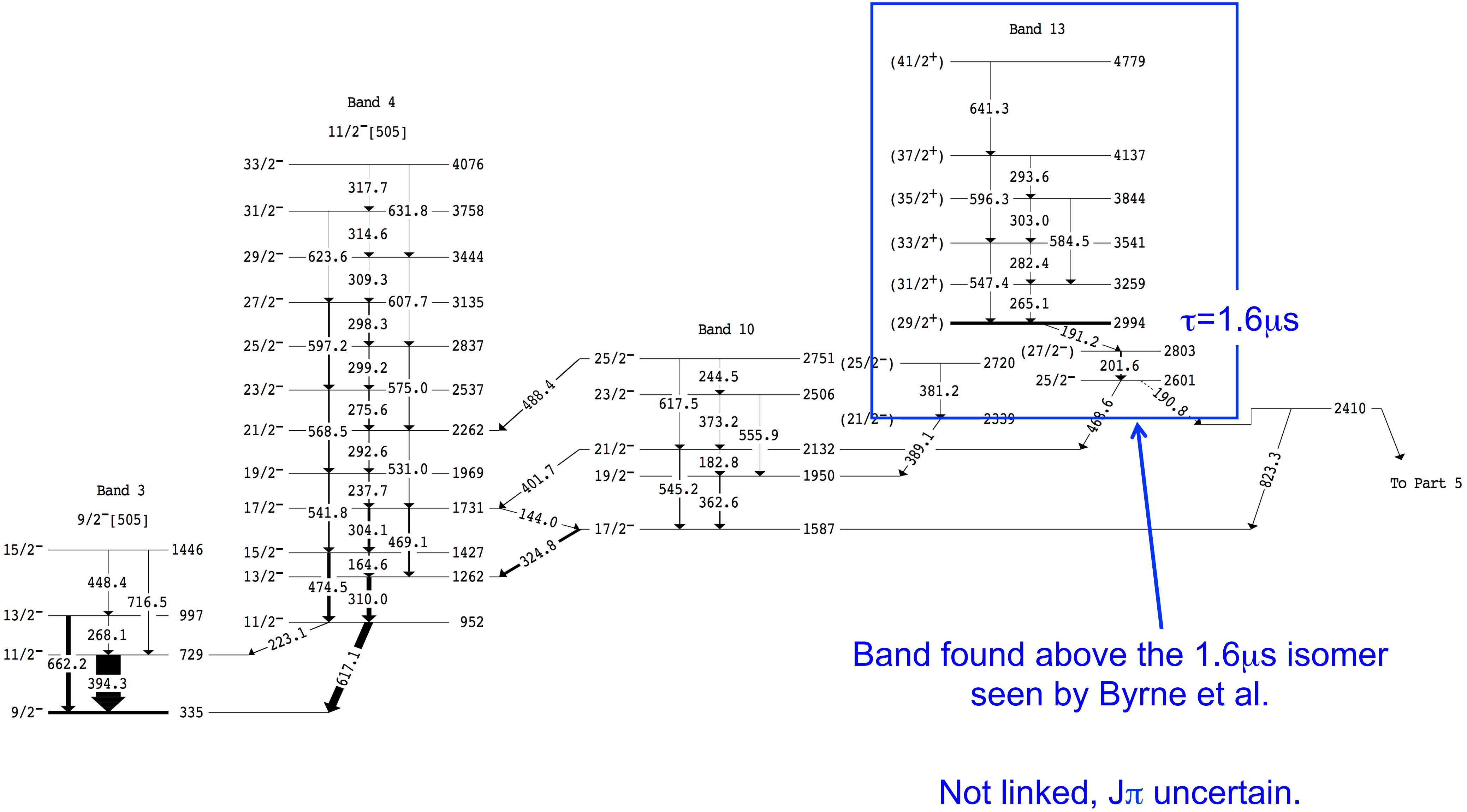
Methodology described in Xu et al., Phys. Lett. B 435 (1998) 257

K^π	shape	Configuration	E_{calc} (keV)	E_{expt} (keV)	β_2	β_4	γ
$\frac{1}{2}^+$	oblate	$\pi\frac{1}{2}^+[400]$	0	0	0.081	0.003	-60^0
$\frac{13}{2}^+$	oblate	$\pi\frac{13}{2}^+[606]$	964	1061	0.191	0.016	-60^0
$\frac{9}{2}^-$	oblate	$\pi\frac{9}{2}^-[505]$	126	335	0.168	-0.004	-60^0
$\frac{11}{2}^-$	(prolate)	$\pi\frac{11}{2}^-[505]$	902	952	0.220	-0.024	-18^0
$\frac{1}{2}^-$	prolate	$\pi\frac{1}{2}^-[530]$	862	$\sim 1069^a$	0.258	-0.021	0^0
$\frac{3}{2}^-$	(prolate)	$\pi\frac{3}{2}^-[532]$	836	$\sim 967^a$	0.240	-0.017	14^0
$\frac{1}{2}^+$	(prolate)	$\pi\frac{1}{2}^+[660]$	1158	$\sim 1239^b$	0.269	-0.015	-13^0
$\frac{1}{2}^-$	(prolate)	$\pi\frac{1}{2}^-[541]$	805		0.186	-0.015	20^0

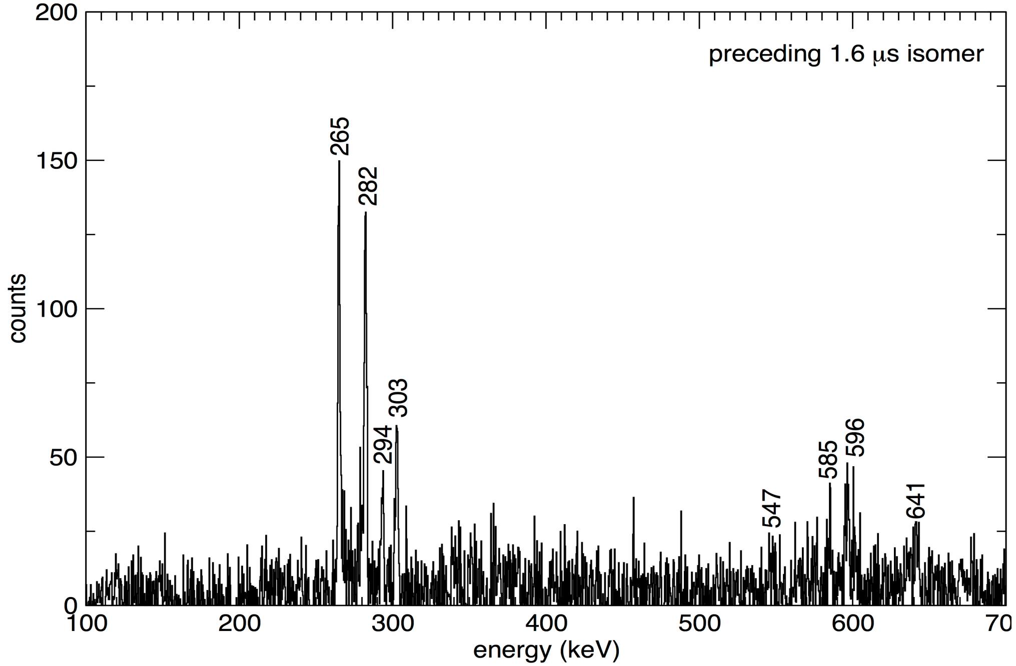
Energy predictions are generally in good agreement with experiment.

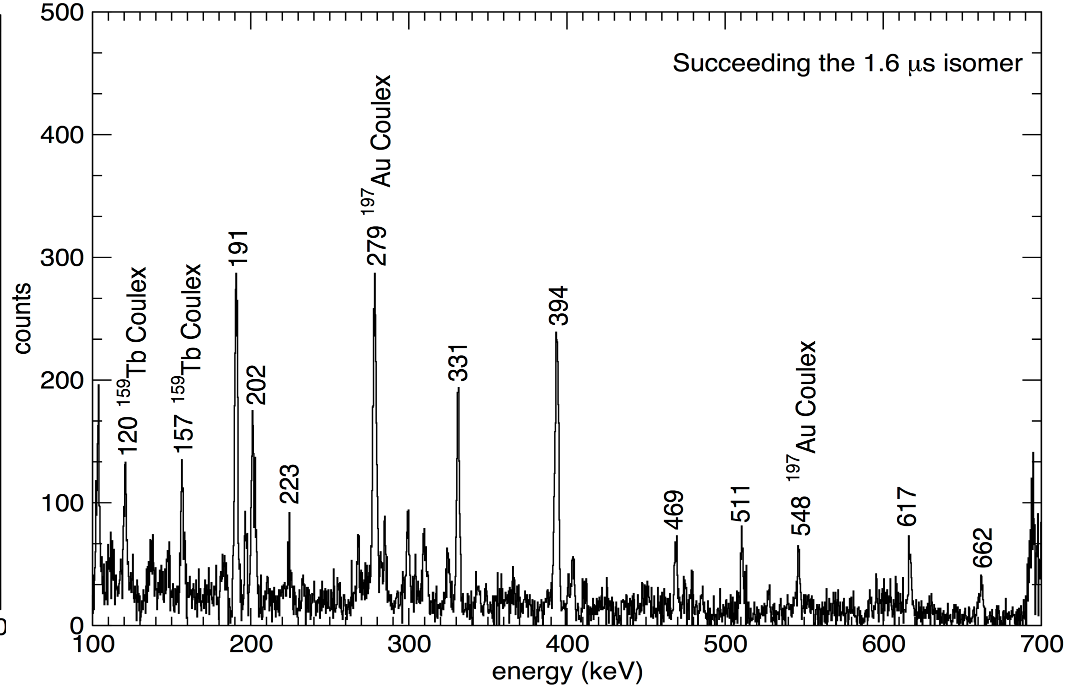
11/2-[505] state is predicted to be triaxial at the bandhead.

Level scheme for ^{187}Tl: Part 2 of 5



Time correlation issues



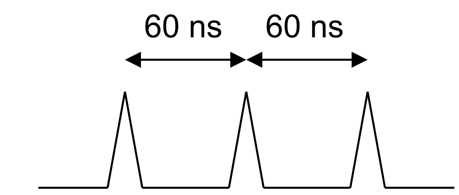


Sum of gates in a matrix of pairs of gamma-rays that precede pairs of double gates below the 1.6μs isomer.

Establishes the band feeding isomer

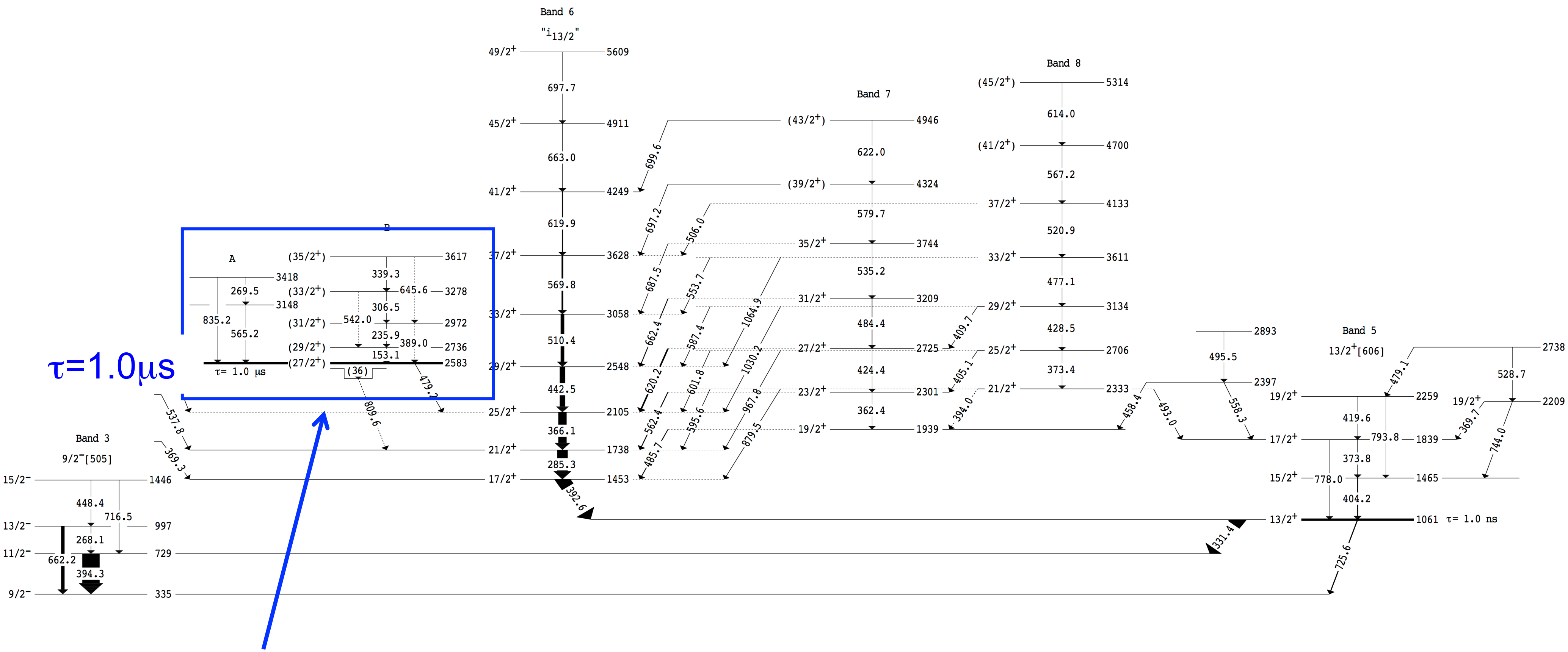
Poor statistics above isomer means that projecting the decays out of the isomer gives a very dirty spectrum.

Cannot establish complete decay pattern



Exacerbated by short pulsing from cyclotron and the low energy time walk extending across multiple prompt peaks.

Level scheme for ^{187}Tl: Part 3 of 5



Band found above the 1.0μs isomer seen by Byrne et al.

Again not linked, Jπ uncertain.

Can we understand the multi-quasiparticle structure of these isomers?

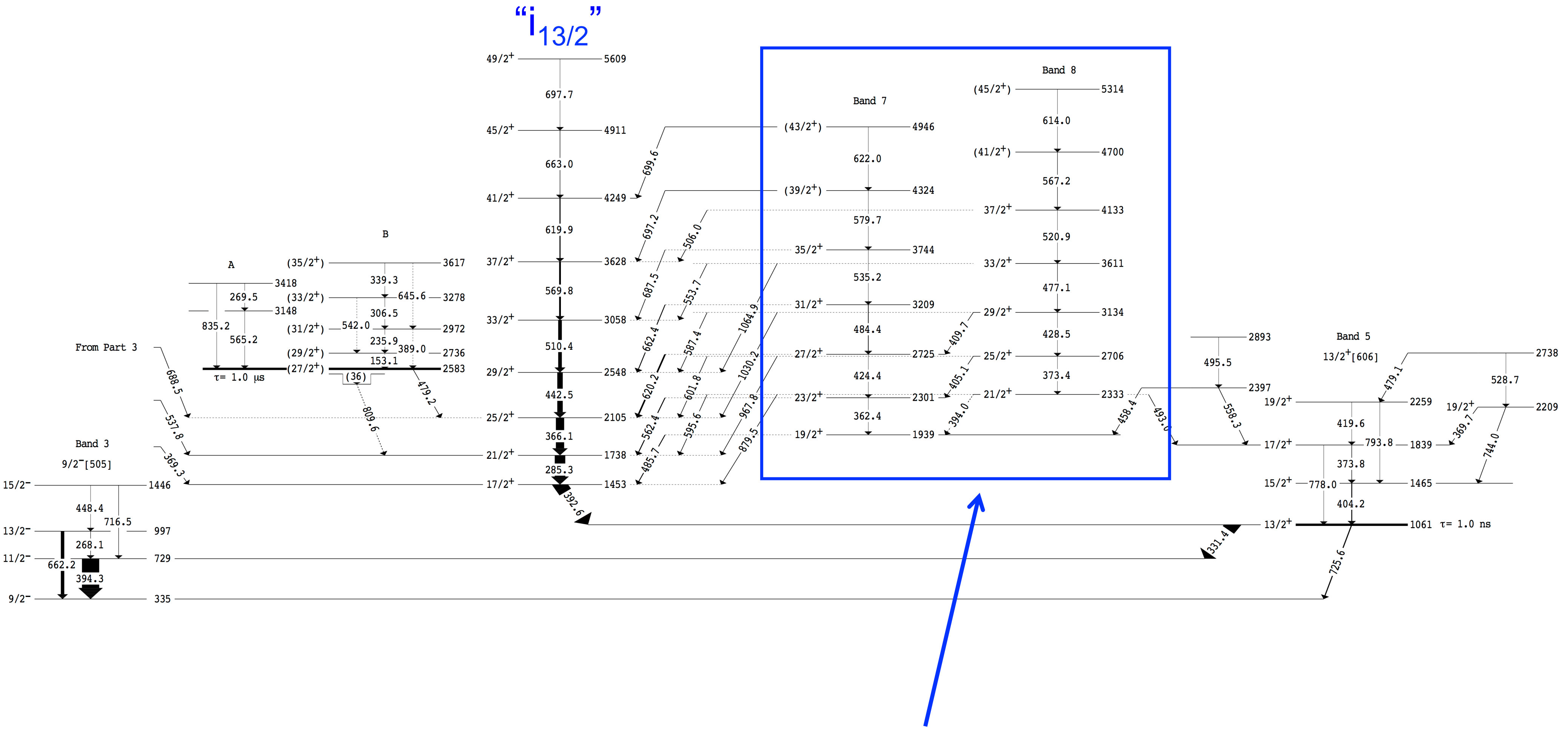
PES calculations for 3qp states in ^{187}Tl

K^π	shape	Configuration	E_{calc} (keV)	β_2	β_4	γ
$\frac{27}{2}^+$	(prolate)	$\pi\frac{11}{2}^-[505] \otimes 2\nu\{\frac{7}{2}^-[514] \otimes \frac{9}{2}^+[624]\}$	2148	0.233	-0.010	-12^0
$\frac{25}{2}^-$	(prolate)	$\pi\frac{11}{2}^-[505] \otimes 2\nu\{\frac{7}{2}^-[514] \otimes \frac{7}{2}^-[503]\}$	2596	0.212	-0.002	-22^0
$\frac{25}{2}^+$	(prolate)	$\pi\frac{11}{2}^-[505] \otimes 2\nu\{\frac{5}{2}^-[512] \otimes \frac{9}{2}^+[624]\}$	2422	0.231	-0.010	-12^0
$\frac{27}{2}^-$	(prolate)	$\pi\frac{11}{2}^-[505] \otimes 2\nu\{\frac{7}{2}^+[404] \otimes \frac{9}{2}^+[624]\}$	2308	0.215	-0.009	19^0
$\frac{21}{2}^+$	oblate	$\pi\frac{9}{2}^-[505] \otimes 2\nu\{\frac{3}{2}^-[512] \otimes \frac{9}{2}^+[624]\}$	2026	0.165	-0.007	-59^0
$\frac{23}{2}^+$	oblate	$\pi\frac{9}{2}^-[505] \otimes 2\nu\{\frac{5}{2}^-[503] \otimes \frac{9}{2}^+[624]\}$	2061	0.166	-0.009	-60^0
$\frac{25}{2}^+$	oblate	$\pi\frac{9}{2}^-[505] \otimes 2\nu\{\frac{11}{2}^+[615] \otimes \frac{5}{2}^-[503]\}$	2499	0.157	-0.008	-60^0
$\frac{29}{2}^+$	oblate	$\pi\frac{13}{2}^+[606] \otimes 2\nu\{\frac{7}{2}^+[633] \otimes \frac{9}{2}^+[624]\}$	2751	0.188	-0.009	-61^0
$\frac{25}{2}^-$	oblate	$\pi\frac{9}{2}^-[505] \otimes 2\nu\{\frac{7}{2}^+[633] \otimes \frac{9}{2}^+[624]\}$	1717	0.173	0.000	-60^0
$\frac{27}{2}^-$	(oblate)	$\pi\frac{13}{2}^+[606] \otimes 2\nu\{\frac{3}{2}^-[512] \otimes \frac{11}{2}^+[615]\}$	3492	0.171	-0.005	-92^0
$\frac{27}{2}^+$	oblate	$\pi\frac{13}{2}^+[606] \otimes 2\nu\{\frac{9}{2}^+[624] \otimes \frac{5}{2}^+[642]\}$	2992	0.191	0.012	-60^0
$\frac{27}{2}^-$	oblate	$\pi\frac{9}{2}^-[505] \otimes 2\nu\{\frac{7}{2}^+[633] \otimes \frac{11}{2}^+[615]\}$	2236	0.164	-0.002	-60^0
$\frac{29}{2}^-$	oblate	$\pi\frac{9}{2}^-[505] \otimes 2\nu\{\frac{9}{2}^+[624] \otimes \frac{11}{2}^+[615]\}$	2356	0.157	0.000	-60^0

Range of 3qp states predicted at low energies with multiple shapes.

Limited spectroscopic information precludes association with specific isomers at present. More data is required.

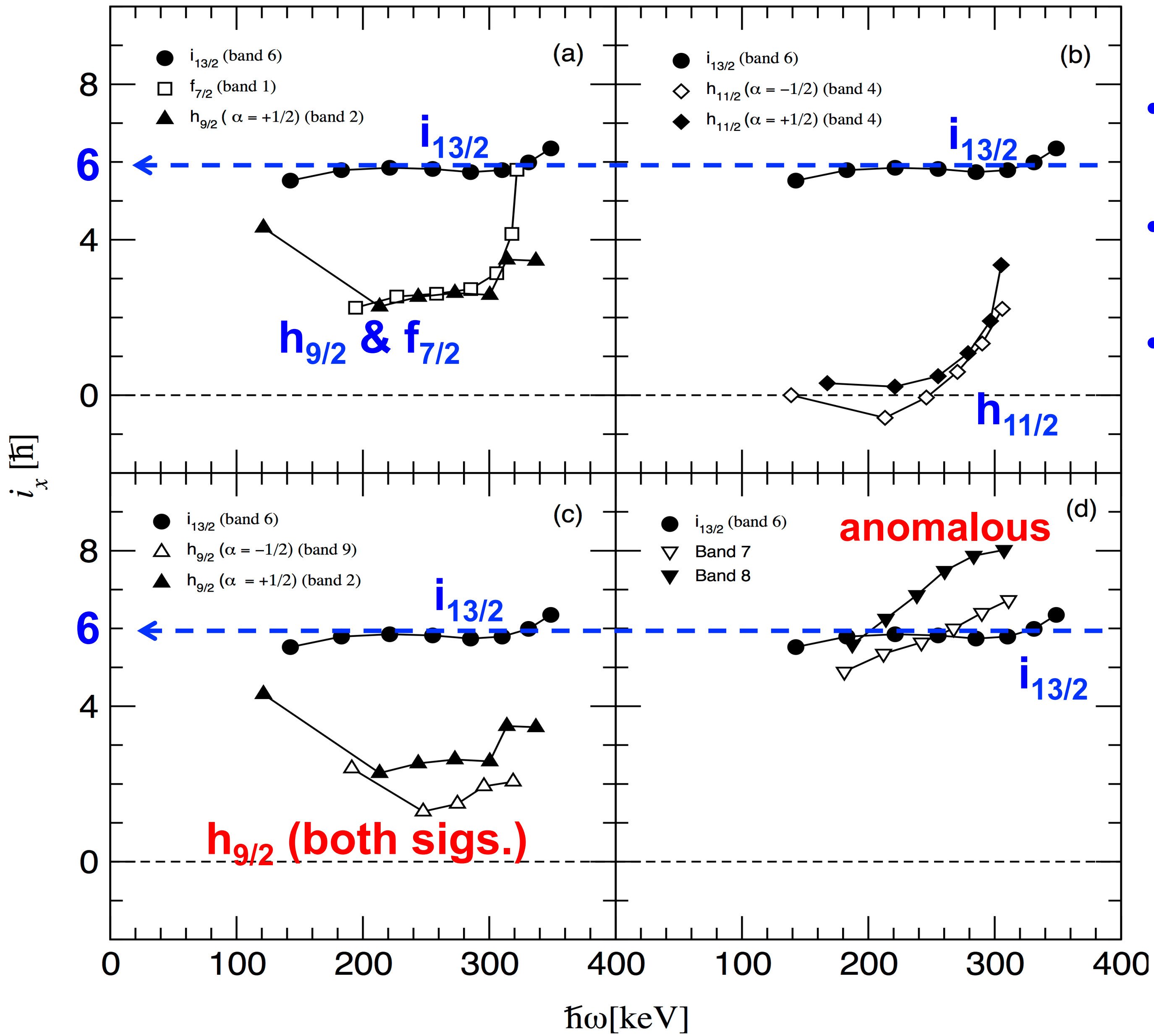
Level scheme for ^{187}Tl: Part 3 of 5



Expect only one signature partner to the $i_{13/2}$ band.

But we observe two bands feeding!?!?

Alignments for single-proton bands

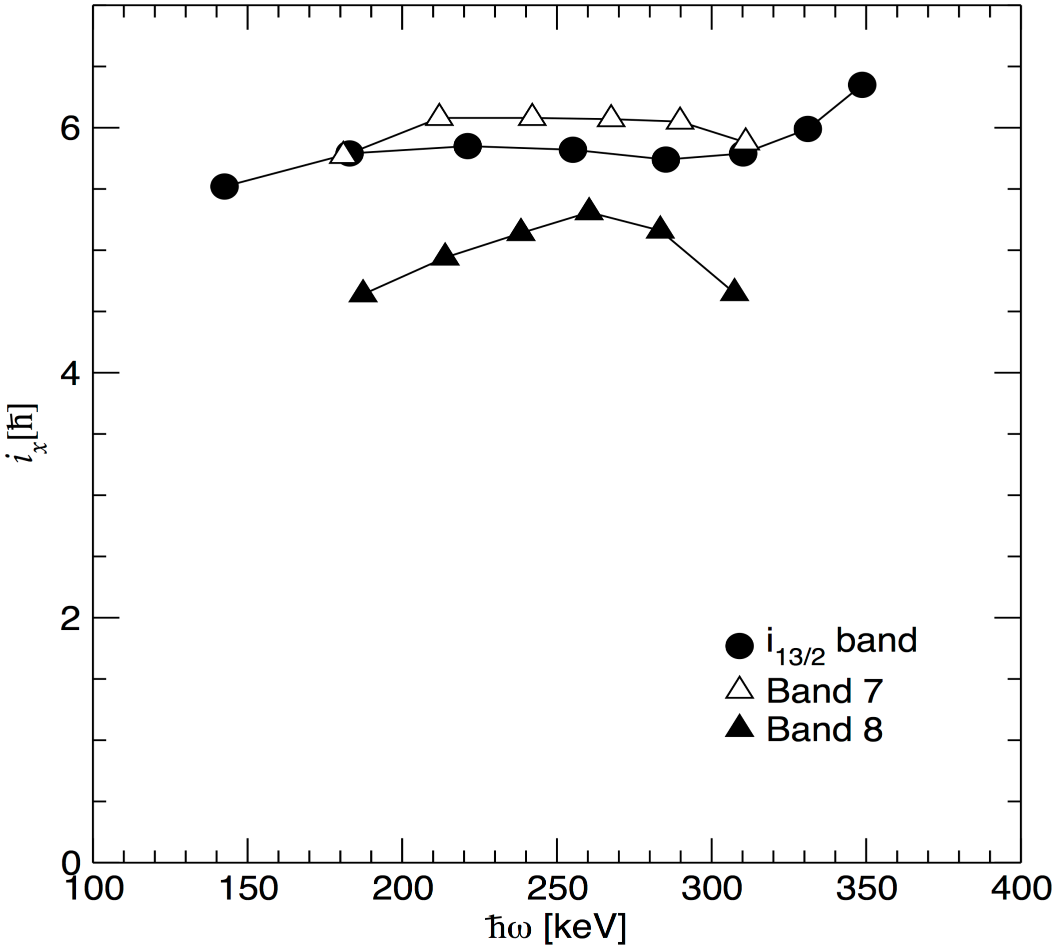


- Fully aligned low-Ω protons have i_x~j
- Unfavoured signatures have i_x~j-1
- High-Ω bands have i_x~0

Issues:

- $h_{9/2}$ protons are not fully aligned (only 3 and 2 hbar)
- Neither of the new positive parity bands are a signature partner to the known $i_{13/2}$ band.
- Signature partners to each other.

Explanation: Enhanced deformation?



Choose a reference so that the new bands have i_x~6 and 5 hbar.

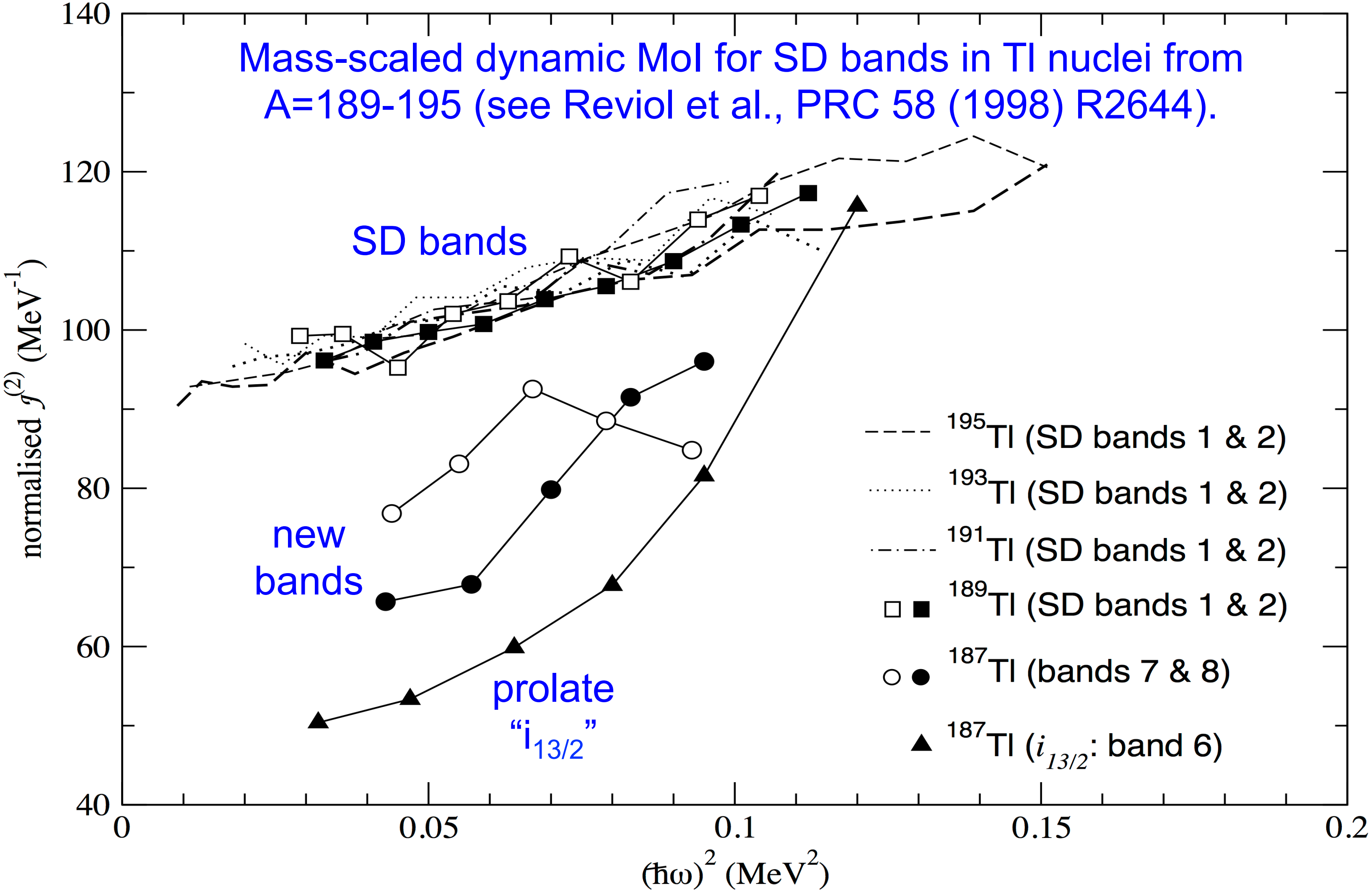
From this Harris reference we can evaluate a moment of inertia. Then, knowing that:

$$\beta_2 \propto \sqrt{\Im_{eff(\hbar\omega\sim0.2)}}$$

we can evaluate the ratio of the deformations to estimate that:

$$\frac{\beta(\text{new bands})}{\beta(\text{“}i_{13/2}\text{”})} \sim 1.43$$

Gradual development of SD shape?



New bands in ^{187}Tl appear to sit between the normal prolate deformed shape and the super-deformed shape

Conclusions

- Odd nuclei have a richer spectrum than the even cases – potentially a better probe for examples of shape coexistence and a better test for theoretical models?
- New results for ^{187}Tl provide evidence for spherical, prolate, oblate and triaxial shapes.
- New isomer bands in ^{187}Tl may provide only the second examples of shape-coexisting, multi-quasiparticle states in this region. New spectroscopic information is required to finalise the interpretation.
- A possible fifth shape may be present in the form of enhanced deformation bands, intermediate between the normal and superdeformed shapes.