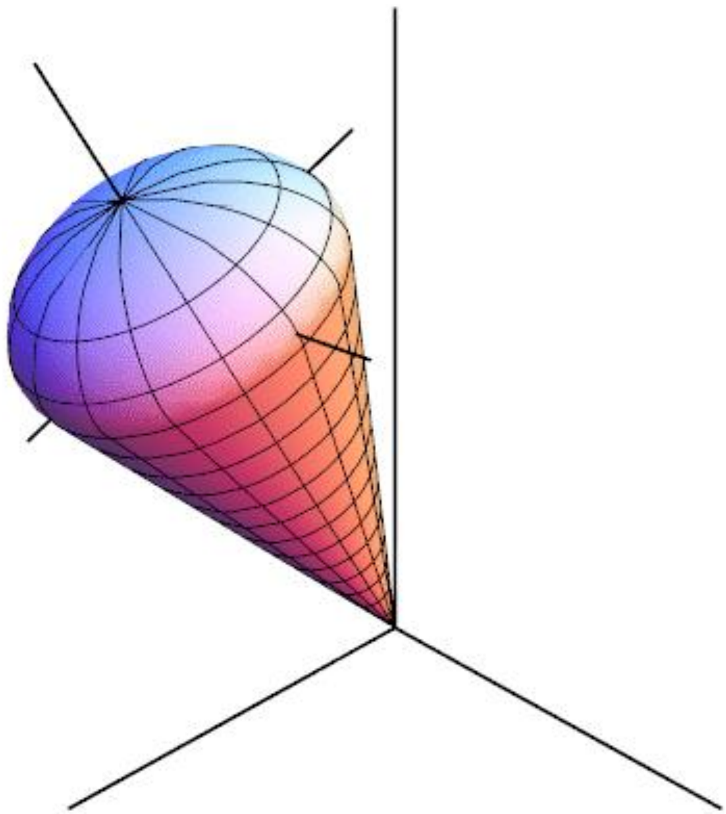
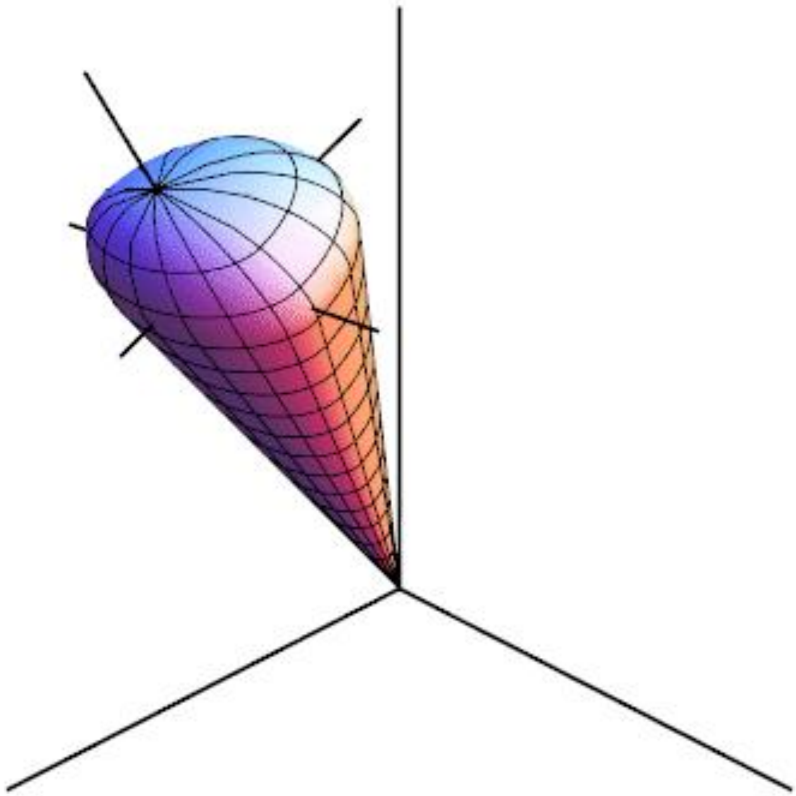
Spinning Triaxial Nuclei Wobble: Sometimes Transverse, At Others Longitudinal

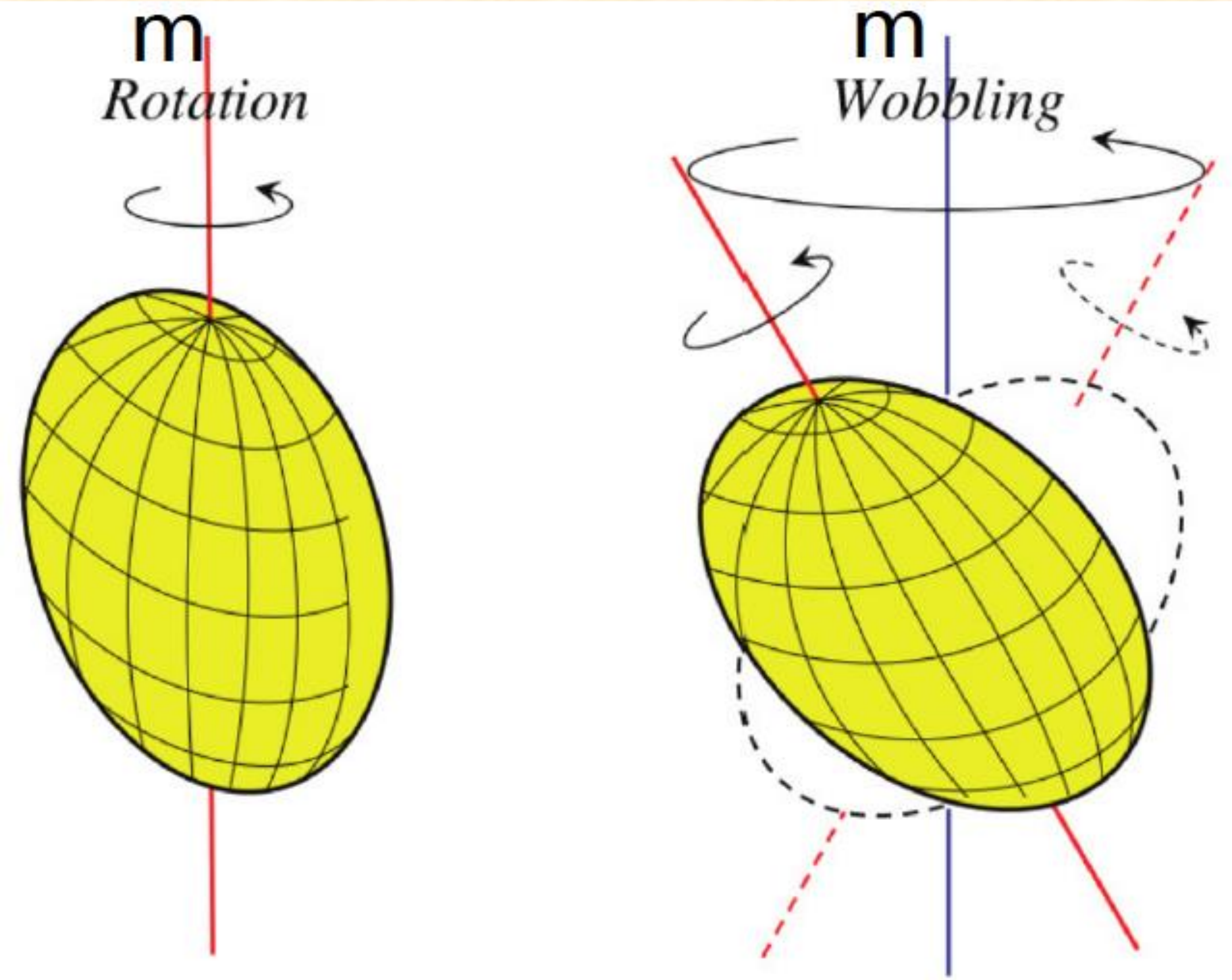
U. Garg
University of Notre Dame

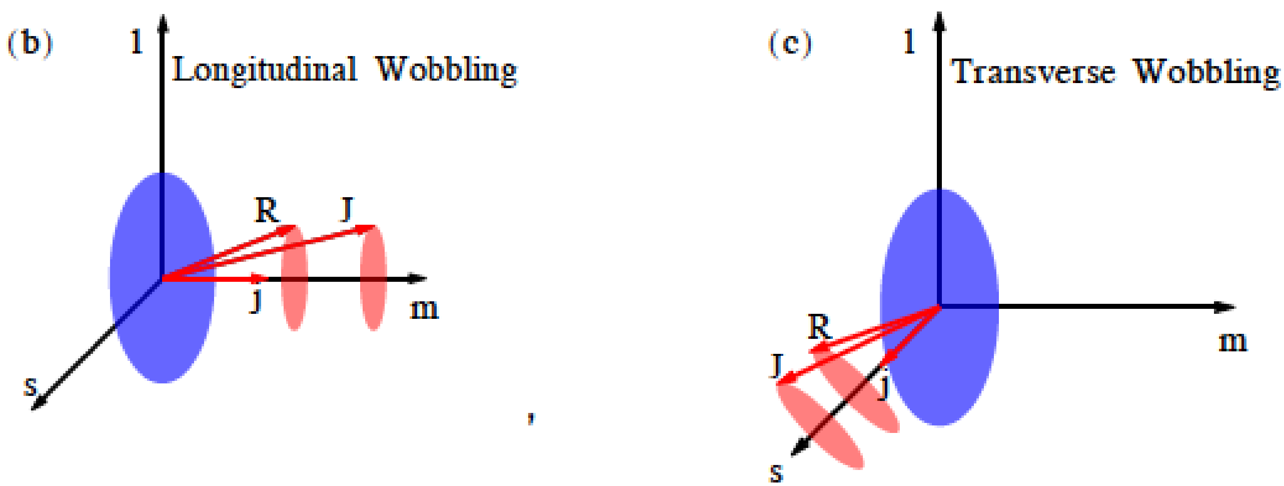
Supported in part by the National Science Foundation

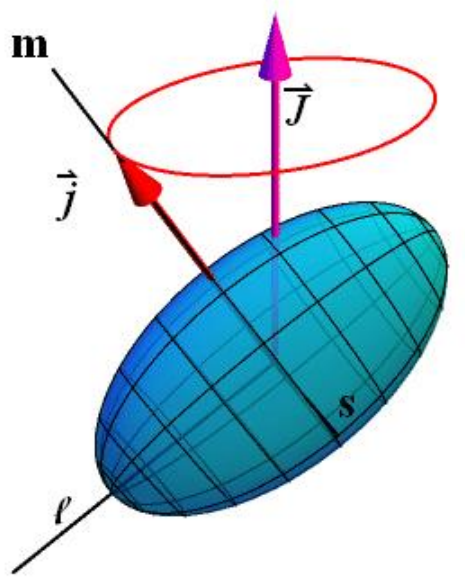
SPIN-2016, 09/27/2016



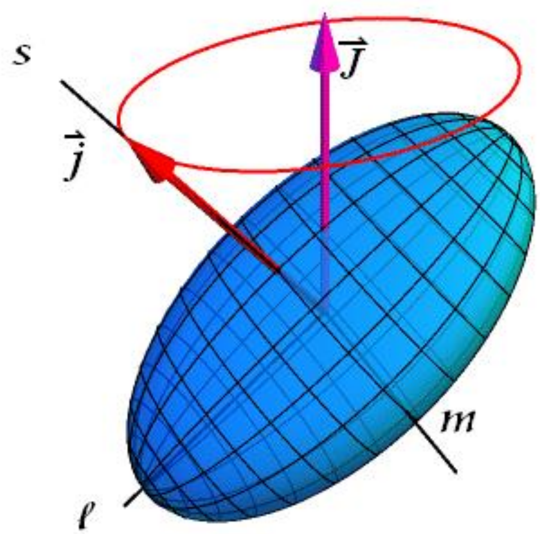


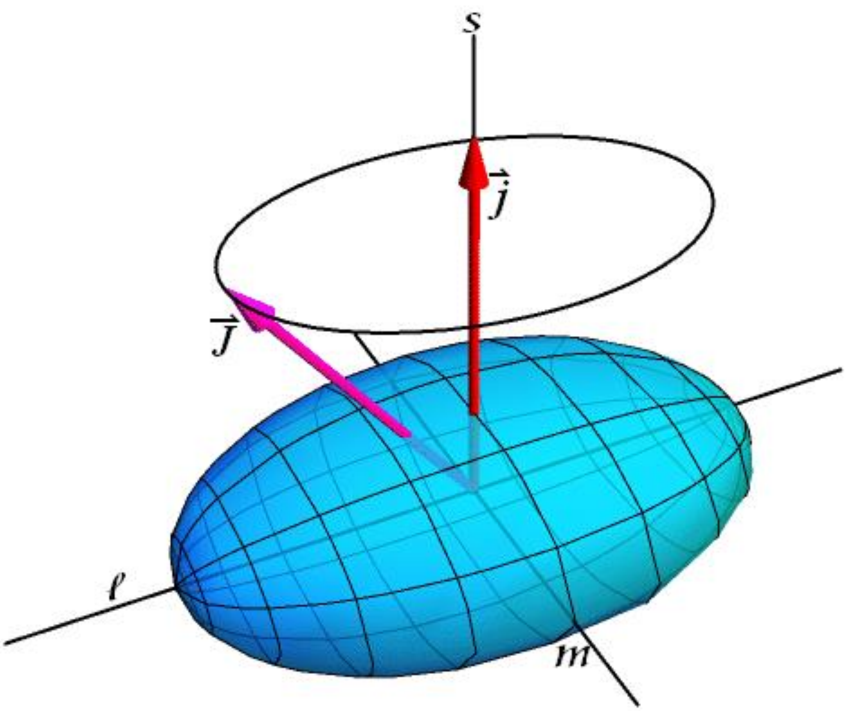

m
Rotation
m
Wobbling


(b)
1
Longitudinal Wobbling
R
J
j
m
s
(c)
1
Transverse Wobbling
R
J
j
m
s



m
$\vec{J}$
$\vec{j}$
s
ℓ

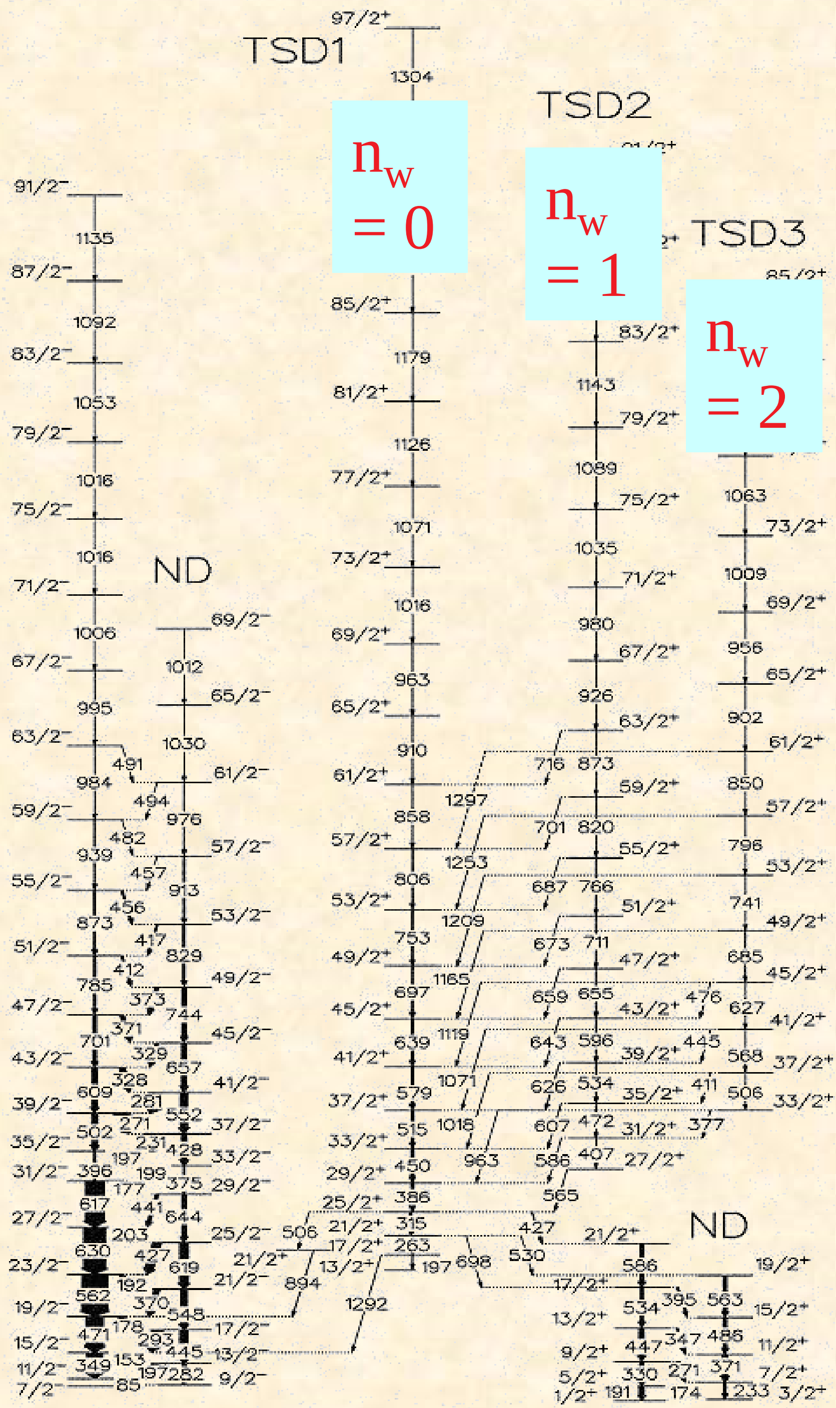

s
J
j
m
ℓ


s
$\vec{j}$
$\vec{J}$
ℓ
m

Wobbling bands (TSD) are generally considered as one of the best signatures of nuclear triaxiality. Another is, of course, chirality.

Triaxiality in nuclei had been a longstanding prediction of theory, but had proved very difficult to establish experimentally.

The best example of wobbling has been seen in the Lu nuclei.



^{163}Lu

“Wobbler Bands”

- Rotational bands corresponding to $n_\omega = 0, 1, 2, \ldots\ldots$
- Transitions from $n_{\omega+1} \rightarrow n_\omega$ [“one way” and $\Delta n_\omega = +1$]
- Interband transitions are $\Delta J = 1$, $E2$

Wobbling frequency, defined by:

$E_{wobb} = E\ (I, n_\omega=1) - [E\ (I+1, n_\omega=0) + E\ (I-1, n_\omega=0)]/2$

$$\hbar\omega_w = \frac{j}{\mathcal{J}_3}\left[\left(1+\frac{J}{j}\left(\frac{\mathcal{J}_3}{\mathcal{J}_1}-1\right)\right)\left(1+\frac{J}{j}\left(\frac{\mathcal{J}_3}{\mathcal{J}_2}-1\right)\right)\right]^{1/2}$$

"Longitudinal " wobbler:

Odd-particle aligned with the axis with maximum moment of inertia (the "medium axis)

$\mathfrak{I}_3 > \mathfrak{I}_2\ ;\ \mathfrak{I}_3 > \mathfrak{I}_1$

$\rightarrow E_\omega$ increases with J

S. Frauendorf and F. Dönau, Phys. Rev. C 89, 014322 (2014)

Wobbling frequency, defined by:

$E_{wobb} = E\,(I, n_\omega{=}1) - [E\,(I{+}1, n_\omega{=}0) + E\,(I{-}1, n_\omega{=}0)]/2$

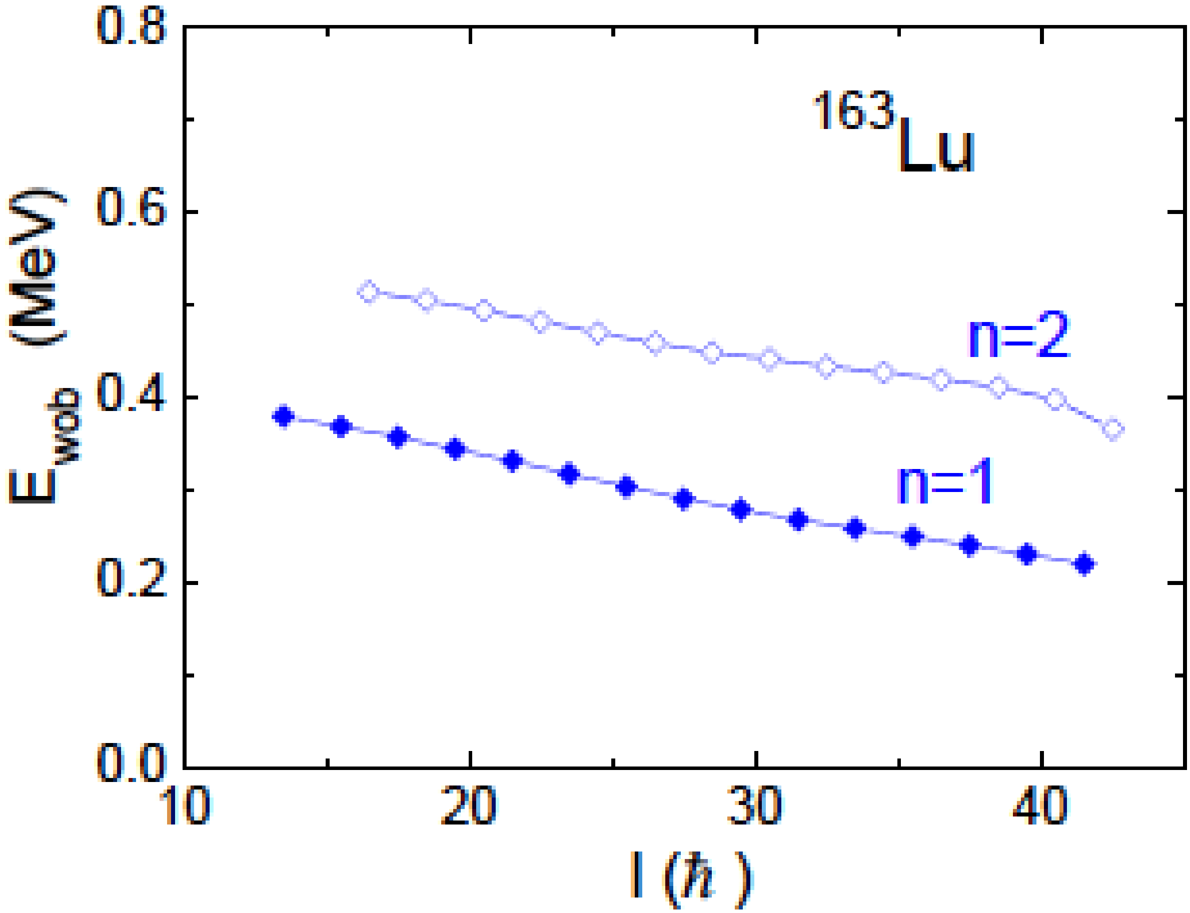
$$\hbar\omega_w = \frac{j}{\mathcal{J}_3}\left[\left(1+\frac{J}{j}\left(\frac{\mathcal{J}_3}{\mathcal{J}_1}-1\right)\right)\left(1+\frac{J}{j}\left(\frac{\mathcal{J}_3}{\mathcal{J}_2}-1\right)\right)\right]^{1/2}$$

“Transverse“ wobbler:
Odd-particle aligned with the “small” axis

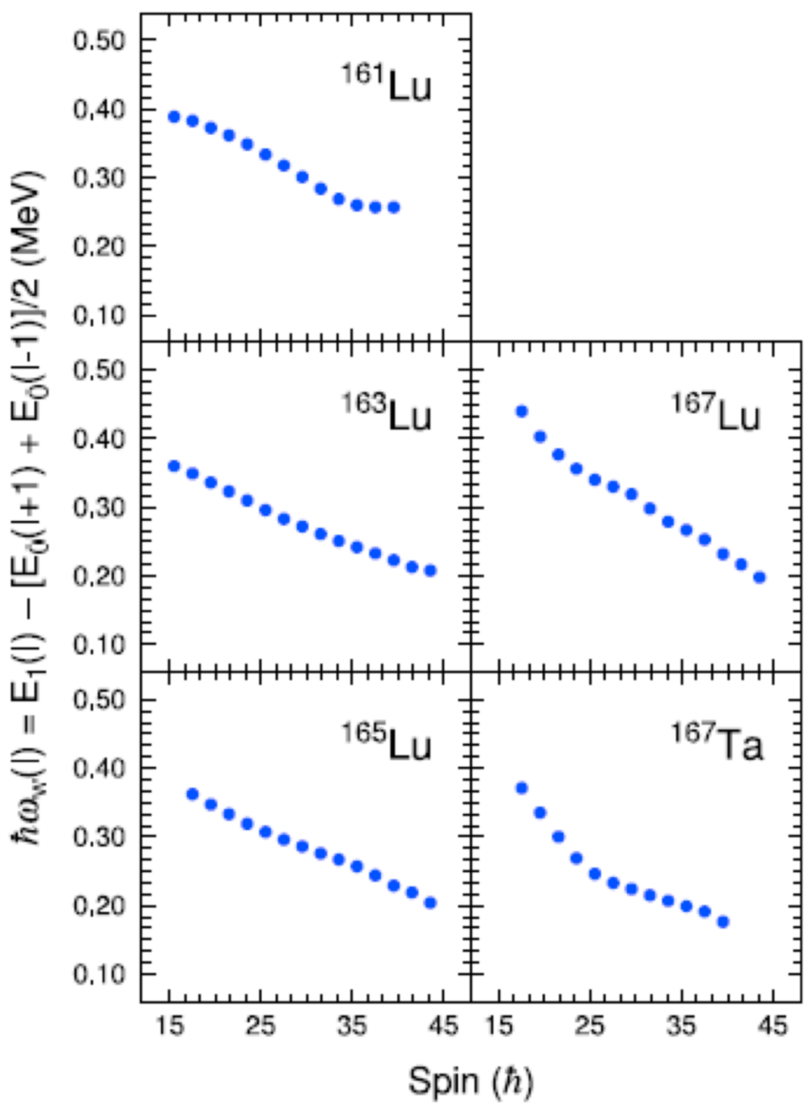
$\Im_3 < \Im_2$; $\Im_3 > \Im_1$

$\rightarrow$ E_ω decreases with J

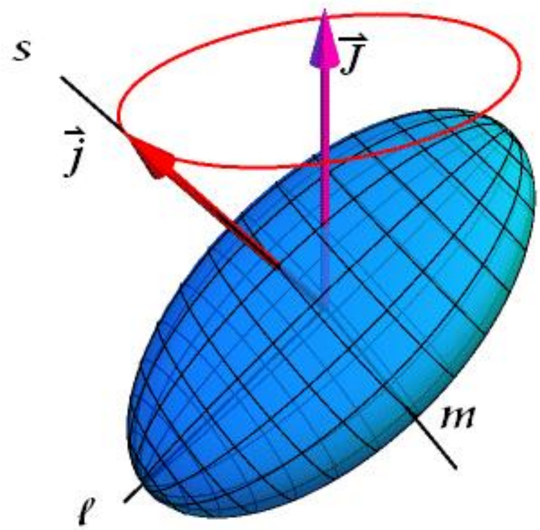
reaching 0 at $J_c = j\,\Im_2/(\Im_2 - \Im_3)$



"Standard" wobbler would have increasing E_{wobb}!

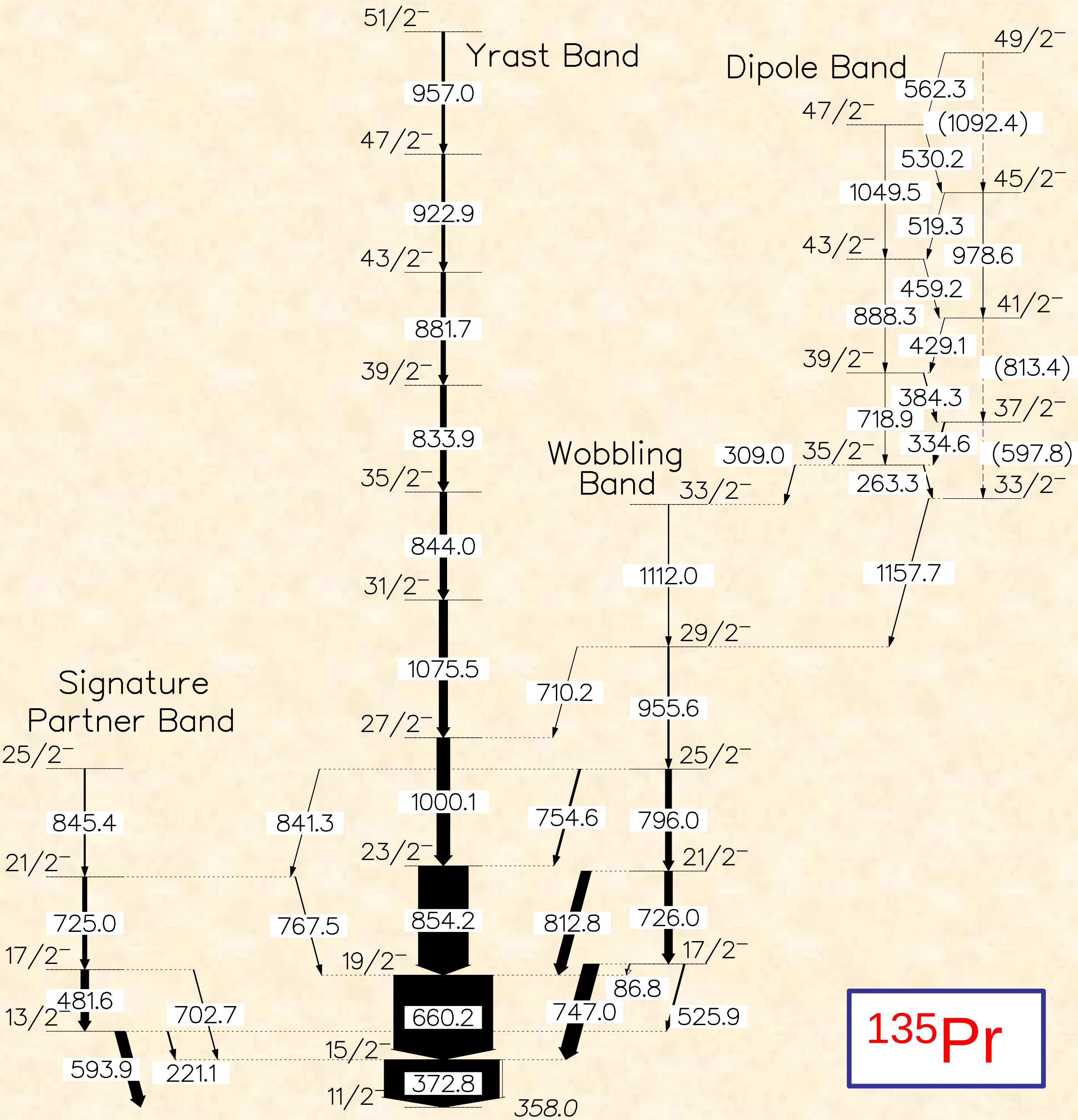


^{161}Lu
^{163}Lu
^{167}Lu
^{165}Lu
^{167}Ta
$\hbar\omega_w(I) = E_1(I) - [E_0(I+1) + E_0(I-1)]/2$ (MeV)
0.50
0.40
0.30
0.20
0.10
15
25
35
45
Spin ($\hbar$)

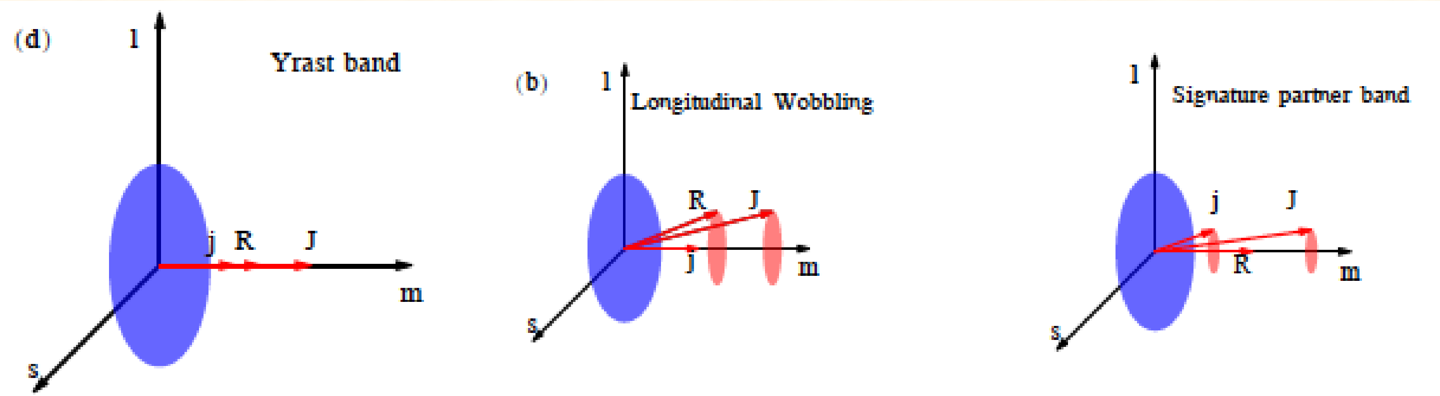


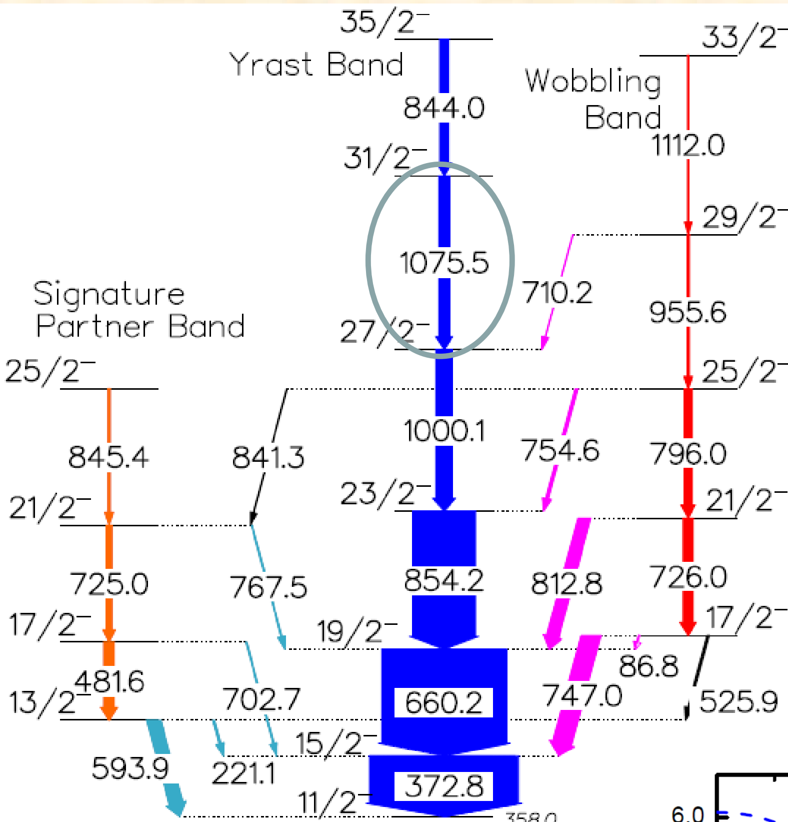
s
j
J
m
ℓ

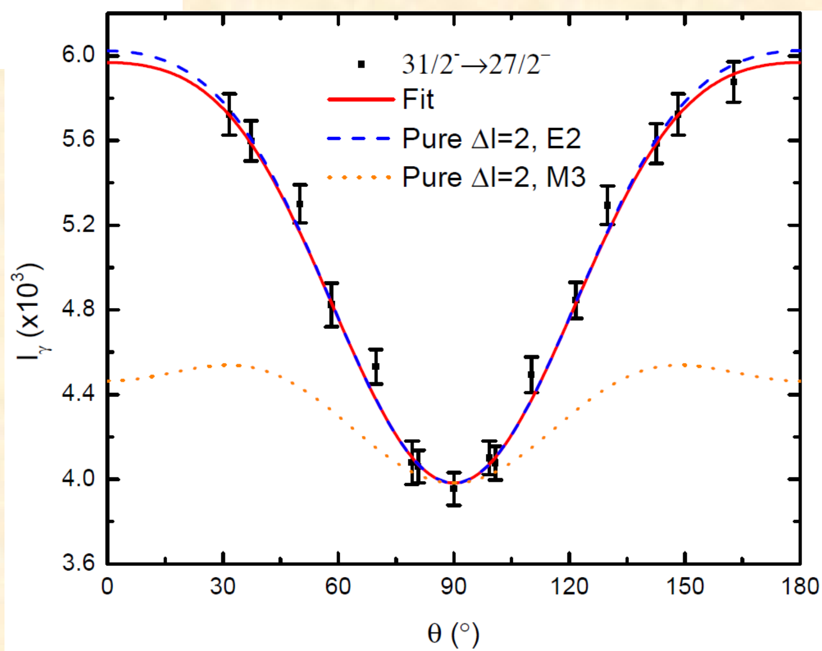
^{123}Sb (^{16}O, 4n)^{135}Pr @ 80 MeV
Gammasphere at ATLAS
(100 CSGe detectors)
γ–γ–γ coincidences
angular correlations

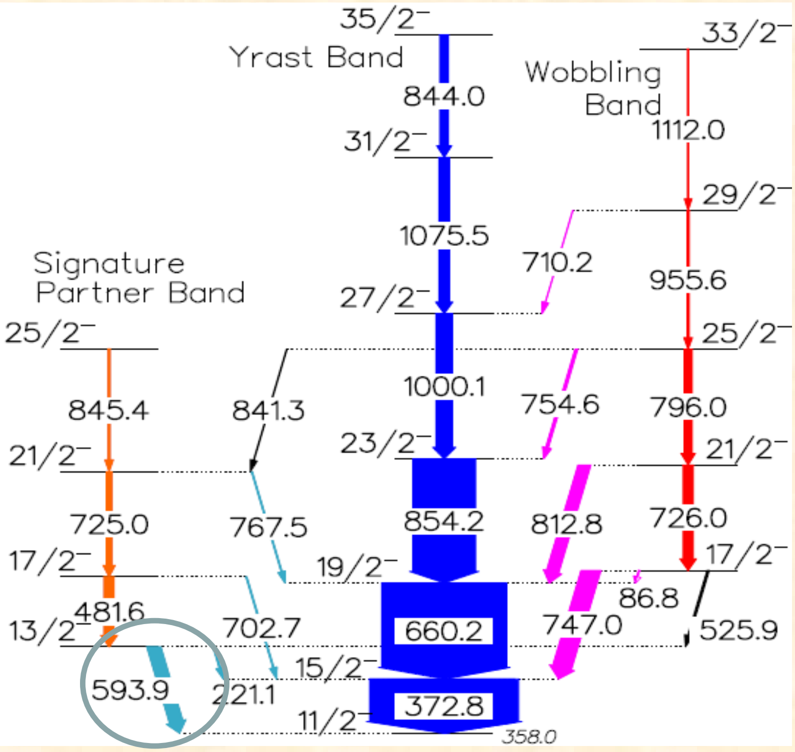


J. T. Matta *et al*., Phys. Rev. Lett. 114, 082501 (2015)


(d)
l
Yrast band
j
R
J
m
s
(b)
l
Longitudinal Wobbling
R
J
j
m
s
l
Signature partner band
j
J
R
m
s

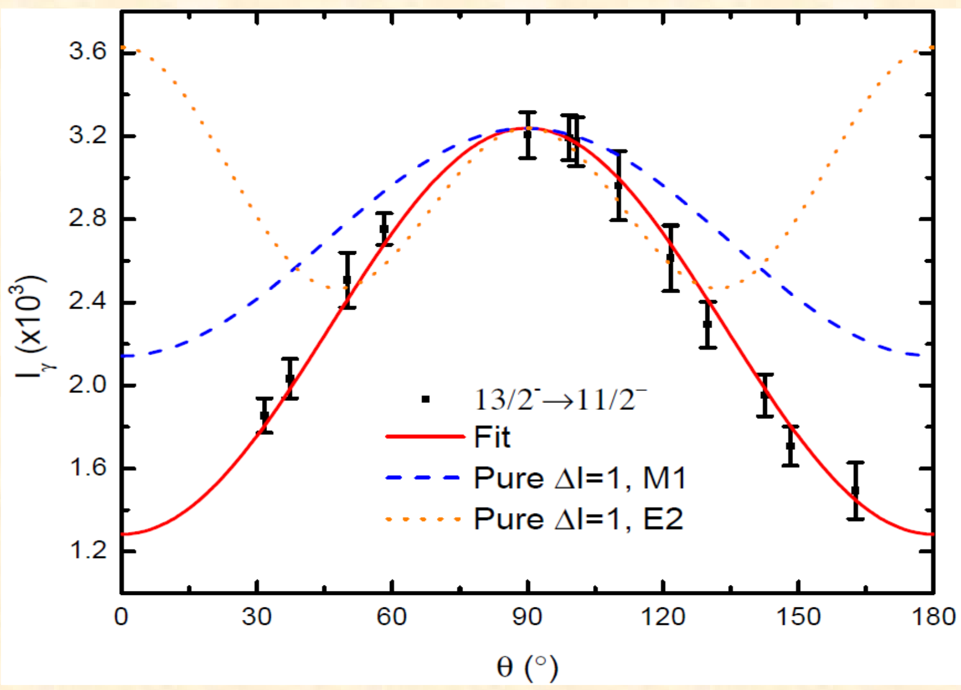

Yrast Band
Wobbling Band
Signature Partner Band
35/2⁻
844.0
31/2⁻
1075.5
27/2⁻
1000.1
23/2⁻
854.2
19/2⁻
660.2
15/2⁻
372.8
11/2⁻
358.0
33/2⁻
1112.0
29/2⁻
955.6
25/2⁻
796.0
21/2⁻
726.0
17/2⁻
710.2
754.6
812.8
747.0
86.8
525.9
25/2⁻
845.4
21/2⁻
725.0
17/2⁻
481.6
13/2⁻
593.9
841.3
767.5
702.7
221.1

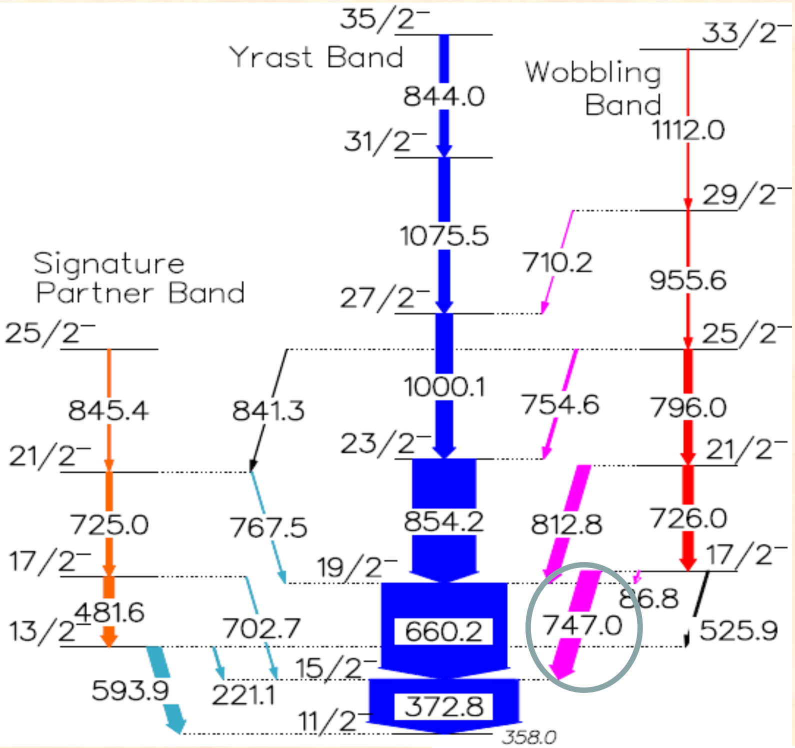

31/2⁻→27/2⁻
Fit
Pure ΔI=2, E2
Pure ΔI=2, M3
Iγ (x10³)
θ (°)



$\delta = -0.16 \pm 0.04$

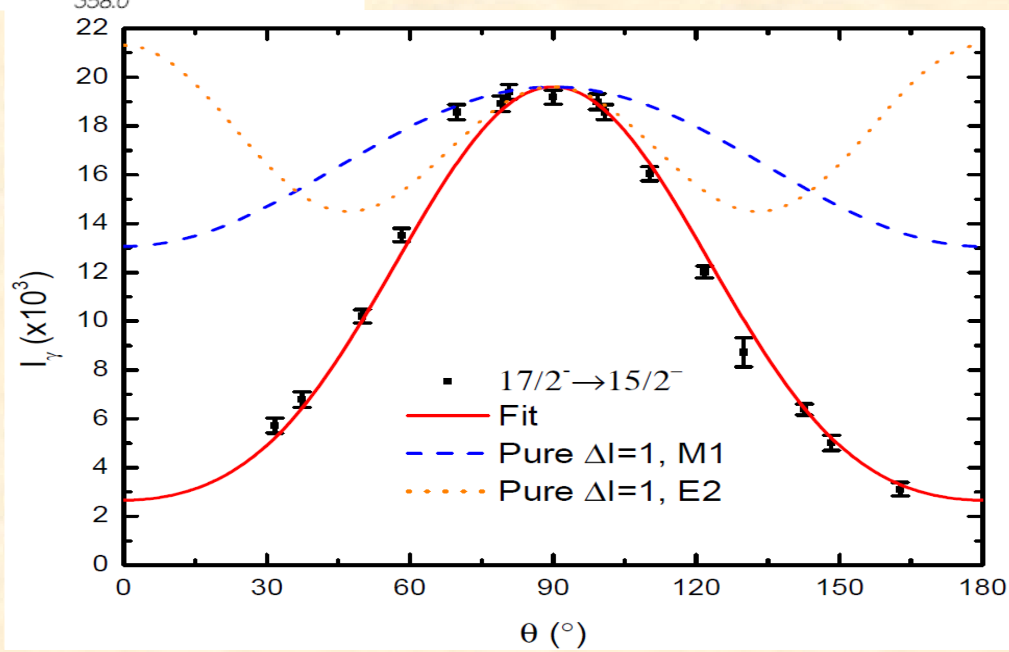
$E2\% = 2.4 \pm 1.2$

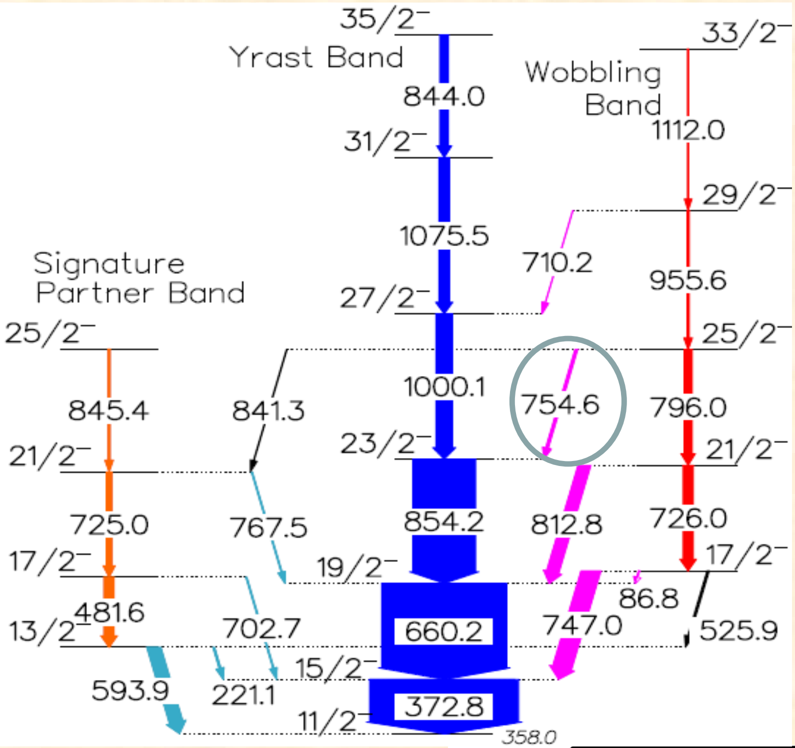




$\delta = -1.24 \pm 0.13$

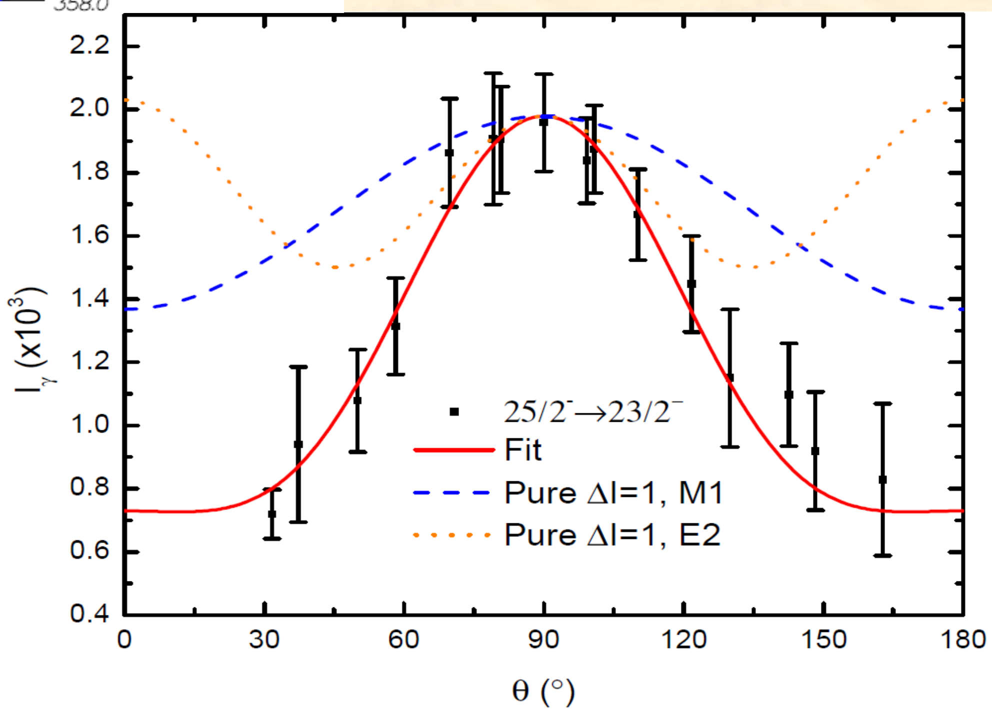
$E2\% = 60.6 \pm 5.1$





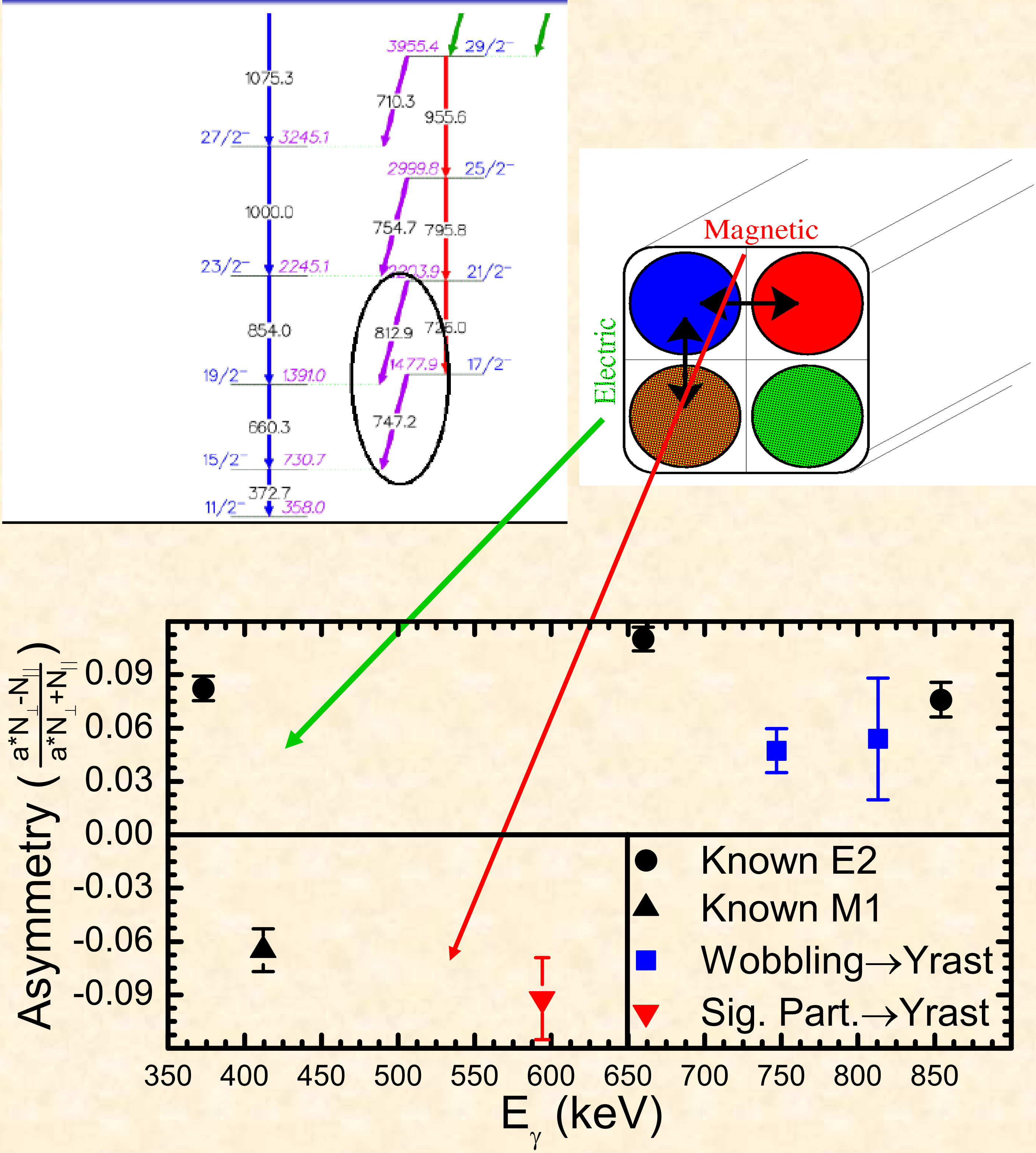
$\delta = -2.38 \pm 0.37$

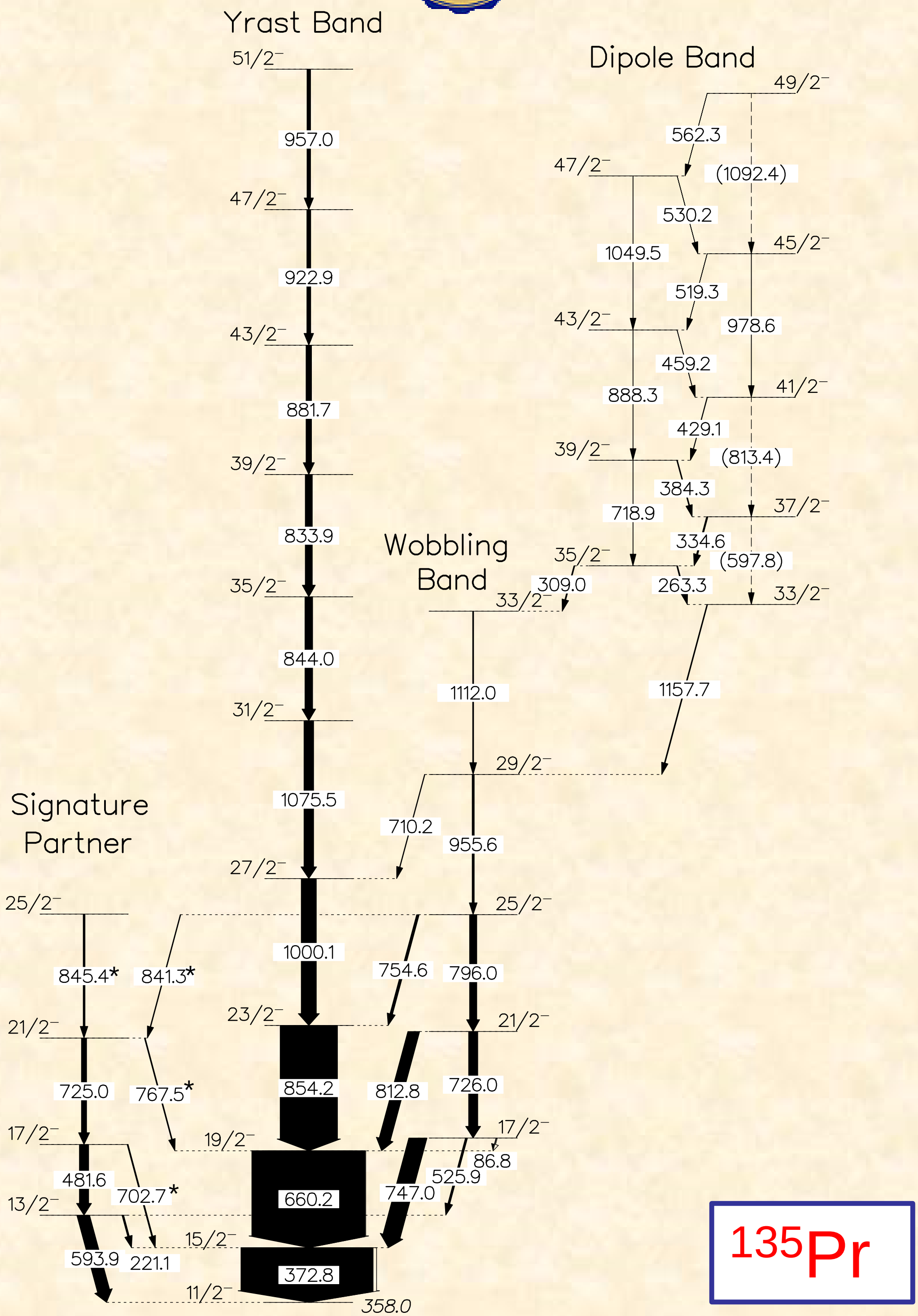
$E2\% = 85.0 \pm 4.0$

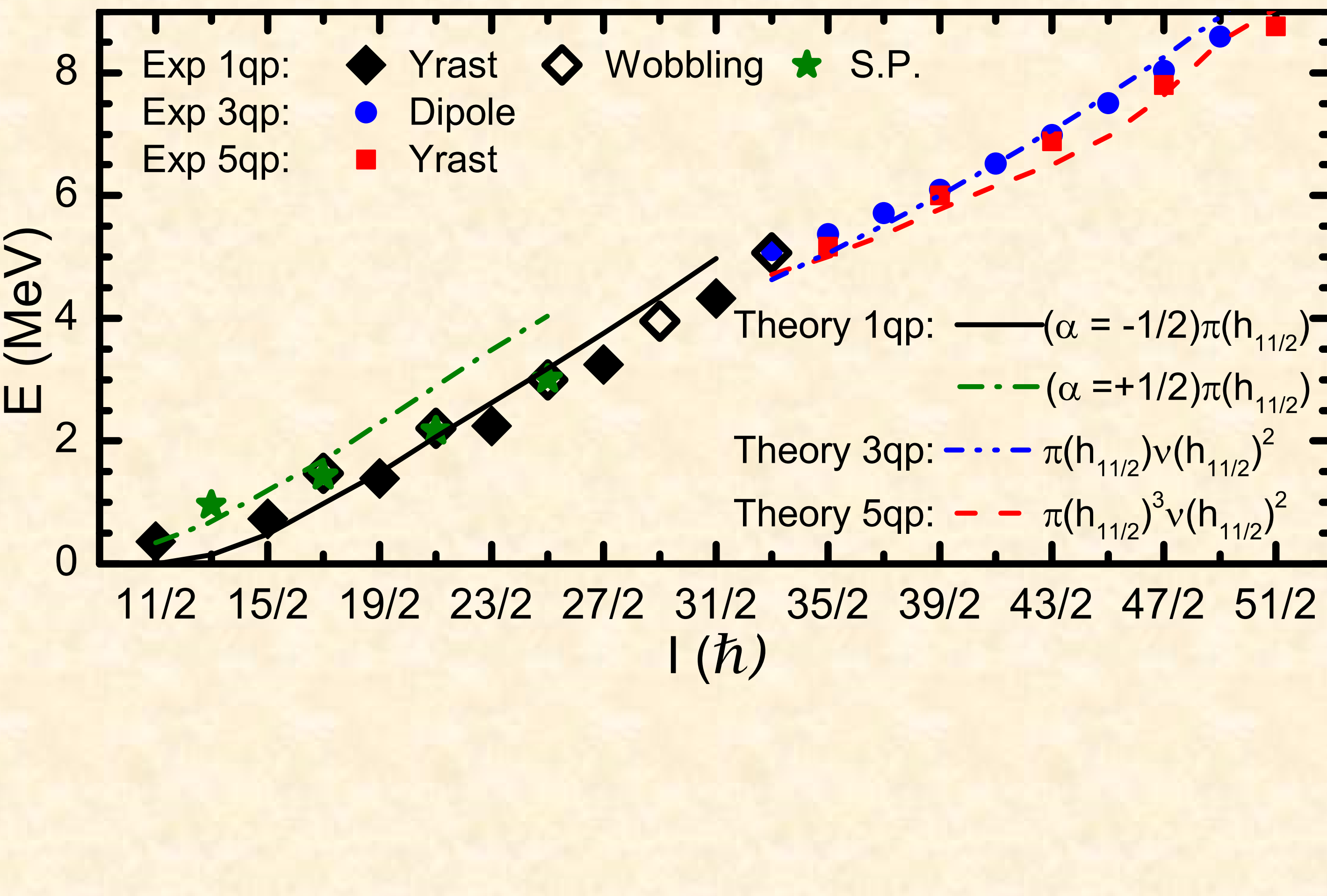


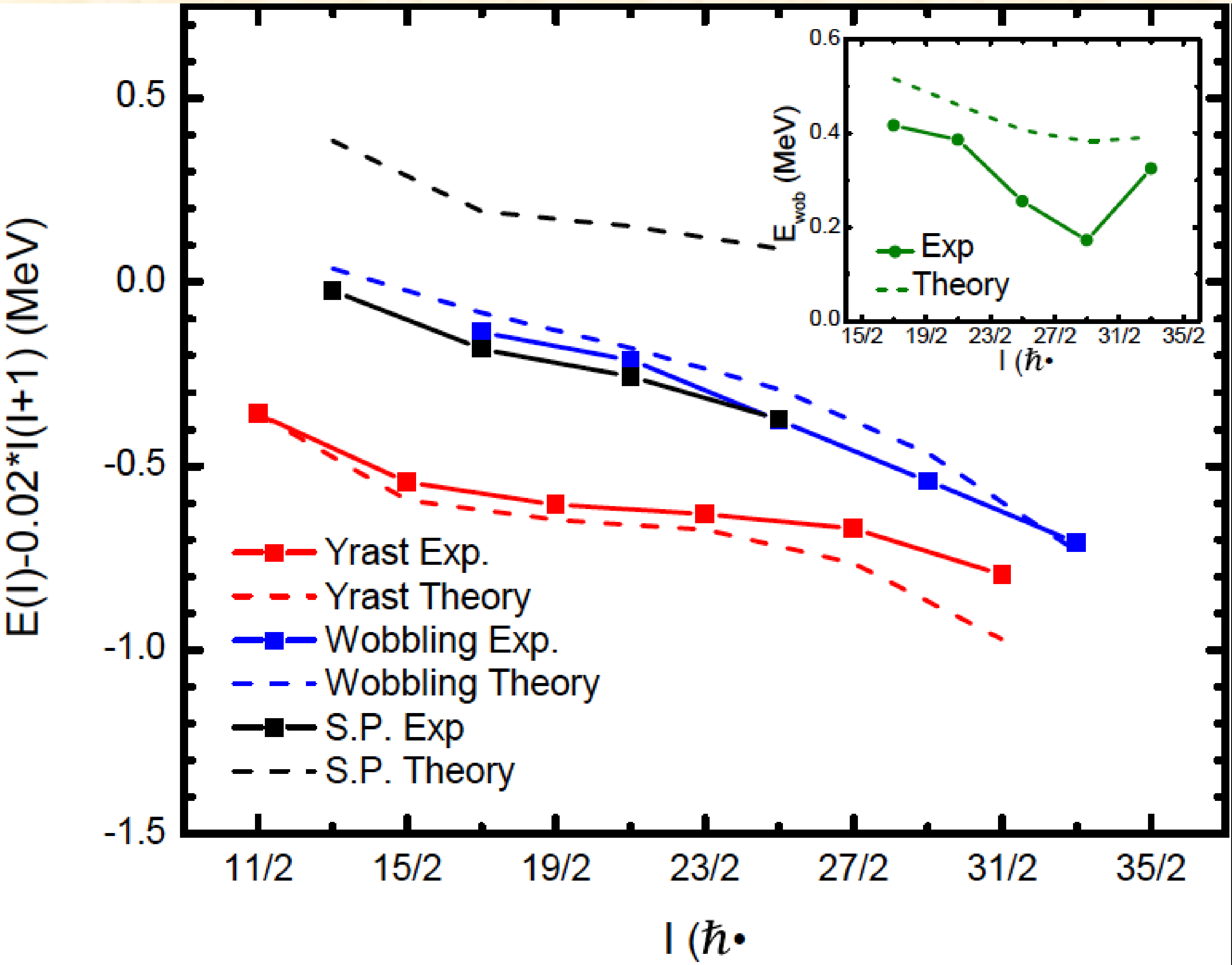
INGA @ TIFR
20 CS “clover” detectors
polarization measurements

Polarization Asymmetries




Yrast Band
Dipole Band
Wobbling Band
Signature Partner
51/2⁻
47/2⁻
43/2⁻
39/2⁻
35/2⁻
31/2⁻
27/2⁻
23/2⁻
19/2⁻
15/2⁻
11/2⁻
957.0
922.9
881.7
833.9
844.0
1075.5
1000.1
854.2
660.2
372.8
358.0
49/2⁻
47/2⁻
45/2⁻
43/2⁻
41/2⁻
39/2⁻
37/2⁻
35/2⁻
33/2⁻
562.3
(1092.4)
530.2
1049.5
519.3
978.6
459.2
888.3
429.1
(813.4)
384.3
718.9
334.6
(597.8)
263.3
309.0
1157.7
33/2⁻
29/2⁻
25/2⁻
21/2⁻
17/2⁻
1112.0
955.6
710.2
796.0
754.6
726.0
812.8
747.0
525.9
86.8
25/2⁻
21/2⁻
17/2⁻
13/2⁻
845.4*
841.3*
725.0
767.5*
481.6
702.7*
593.9
221.1
135Pr


Exp 1qp: Yrast Wobbling S.P.
Exp 3qp: Dipole
Exp 5qp: Yrast
Theory 1qp: $(\alpha = -1/2)\pi(h_{11/2})$
$(\alpha = +1/2)\pi(h_{11/2})$
Theory 3qp: $\pi(h_{11/2})\nu(h_{11/2})^2$
Theory 5qp: $\pi(h_{11/2})^3\nu(h_{11/2})^2$
E (MeV)
0
2
4
6
8
11/2
15/2
19/2
23/2
27/2
31/2
35/2
39/2
43/2
47/2
51/2
I ($\hbar$)



E(I)-0.02*I(I+1) (MeV)
0.5
0.0
-0.5
-1.0
-1.5
11/2
15/2
19/2
23/2
27/2
31/2
35/2
I (ħ)
Yrast Exp.
Yrast Theory
Wobbling Exp.
Wobbling Theory
S.P. Exp
S.P. Theory
E_wob (MeV)
0.6
0.4
0.2
0.0
15/2
19/2
23/2
27/2
31/2
35/2
I (ħ)
Exp
Theory

- ✓Measurements of level energies, angular distributions, and polarizations of the associated γ rays, have established a "wobbler" sequence in ^{135}Pr.

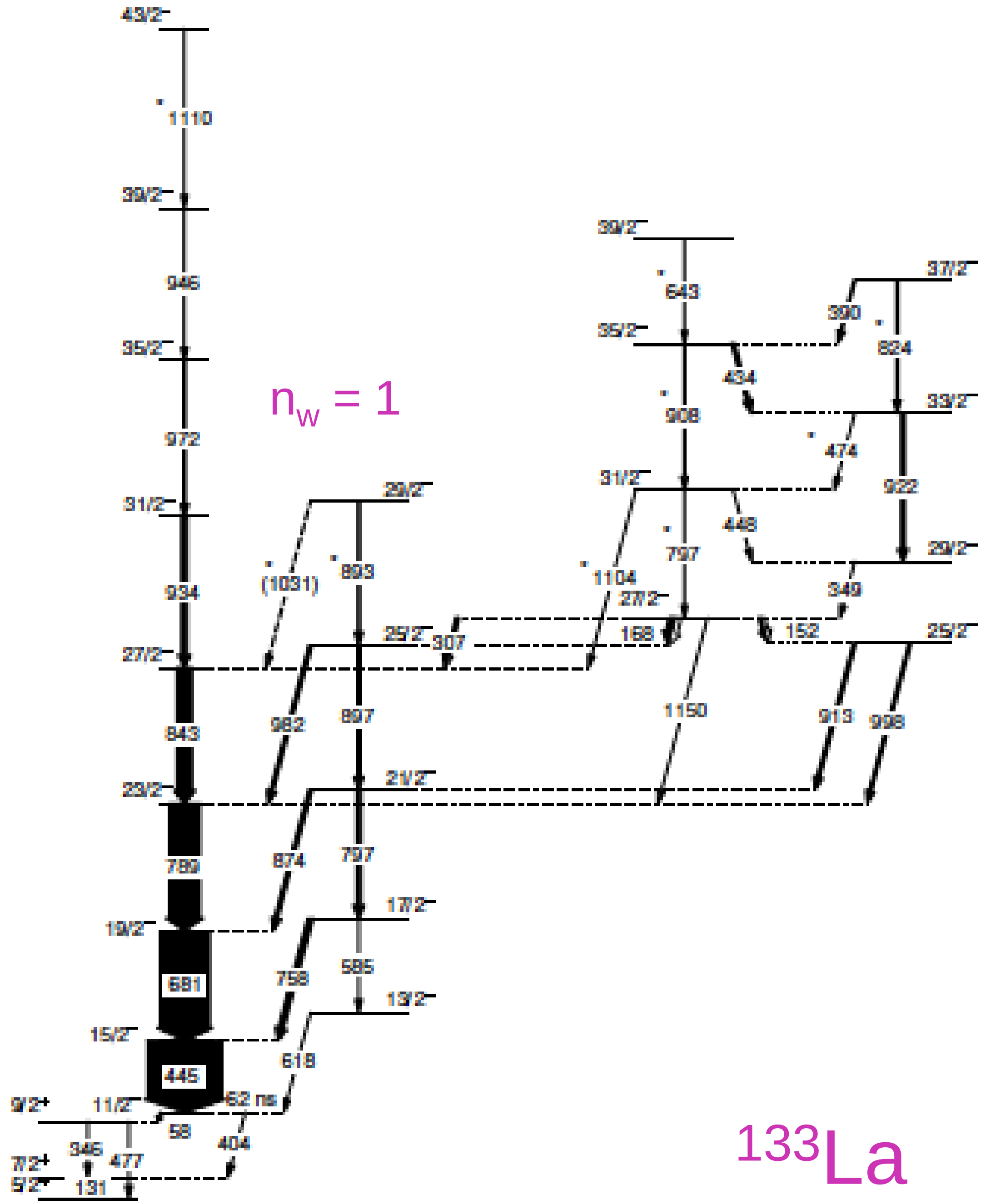
  First observation of wobbling in any nuclei away from A~160 region.

- ✓ Comparison with calculations in QTR model establishes the observed structure as corresponding to a "transverse wobbler"

- ✓ The transmutation of the transverse wobbler into a longitudinal wobbler and then to a magnetic rotation structure is observed in line with theoretical predictions.

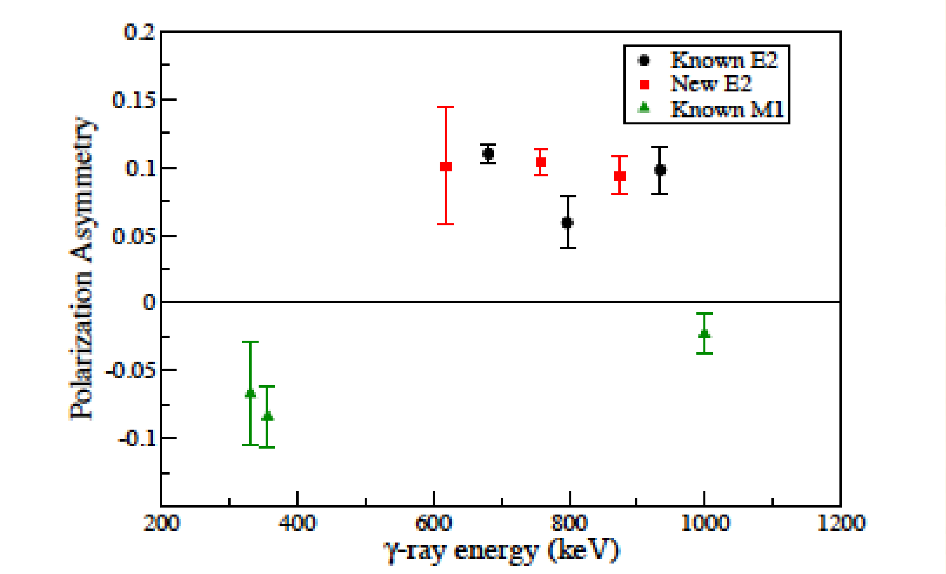
  Clear indications of gradual change of the rotational axis from "short" into a planar geometry akin to magnetic rotation.

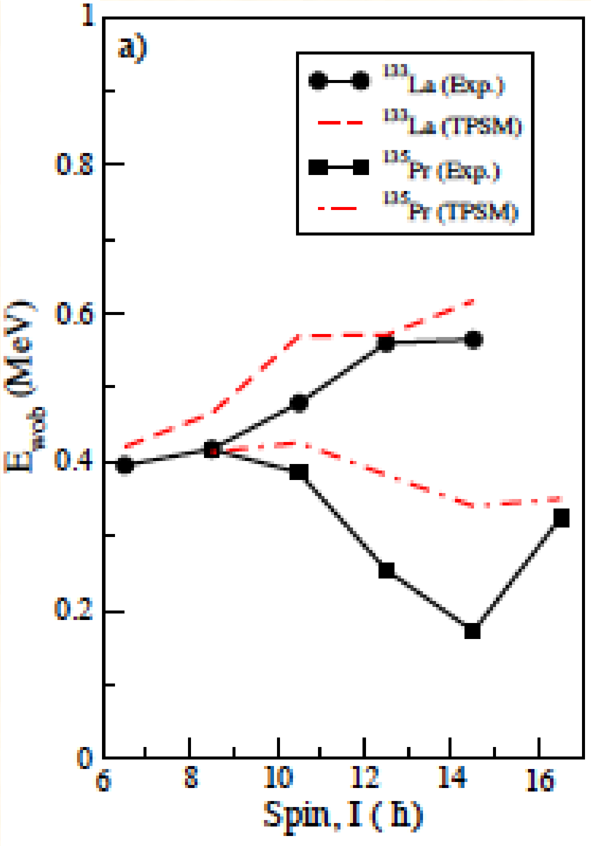
J. T. Matta *et al*., Phys. Rev. Lett. 114, 082501 (2015)


43/2⁻
1110
39/2⁻
946
35/2⁻
972
31/2⁻
934
27/2⁻
843
23/2⁻
789
19/2⁻
681
15/2⁻
445
11/2⁻
9/2⁺
7/2⁺
5/2⁺
346
477
131
58
62 ns
404
618
13/2⁻
585
758
17/2⁻
797
874
21/2⁻
897
982
25/2⁻
893
(1031)
29/2⁻
307
168
1104
27/2⁻
1150
797
31/2⁻
908
35/2⁻
643
39/2⁻
434
448
152
349
474
390
37/2⁻
824
33/2⁻
922
29/2⁻
25/2⁻
913
998

$n_w = 1$

^{133}La





^{133}La $n_\omega = 1$ band

Courtesy of R. Palit, TIFR, Mumbai

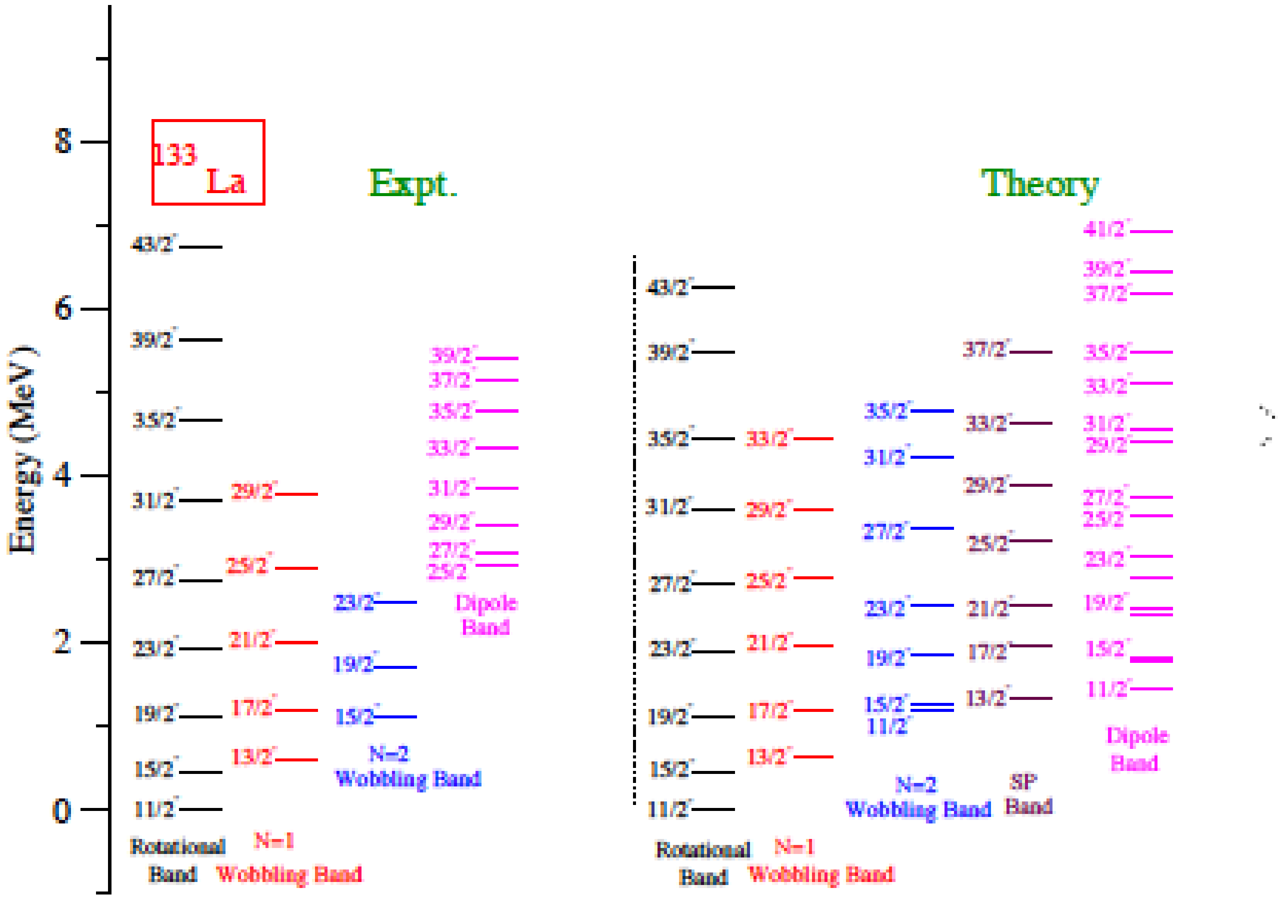
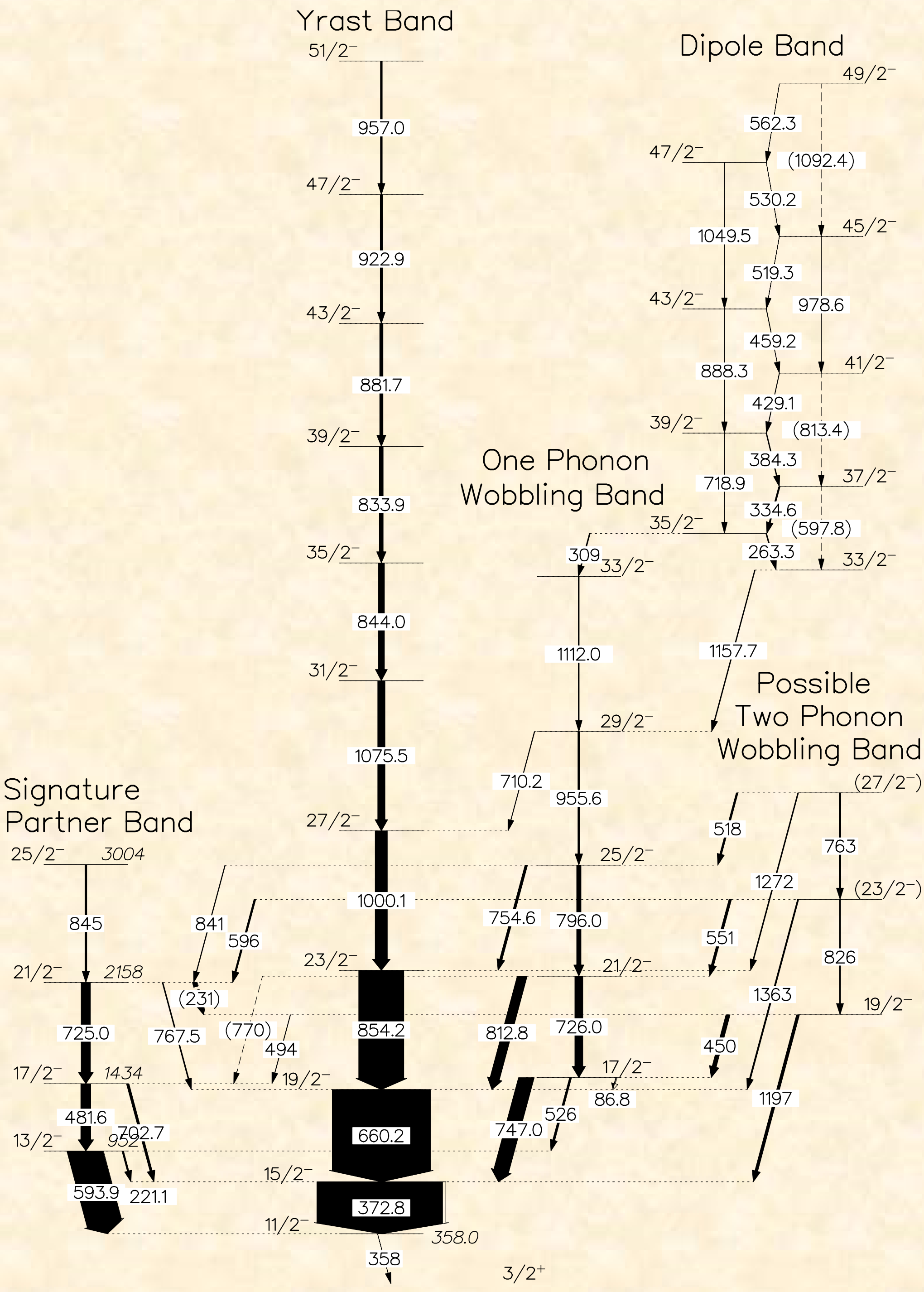
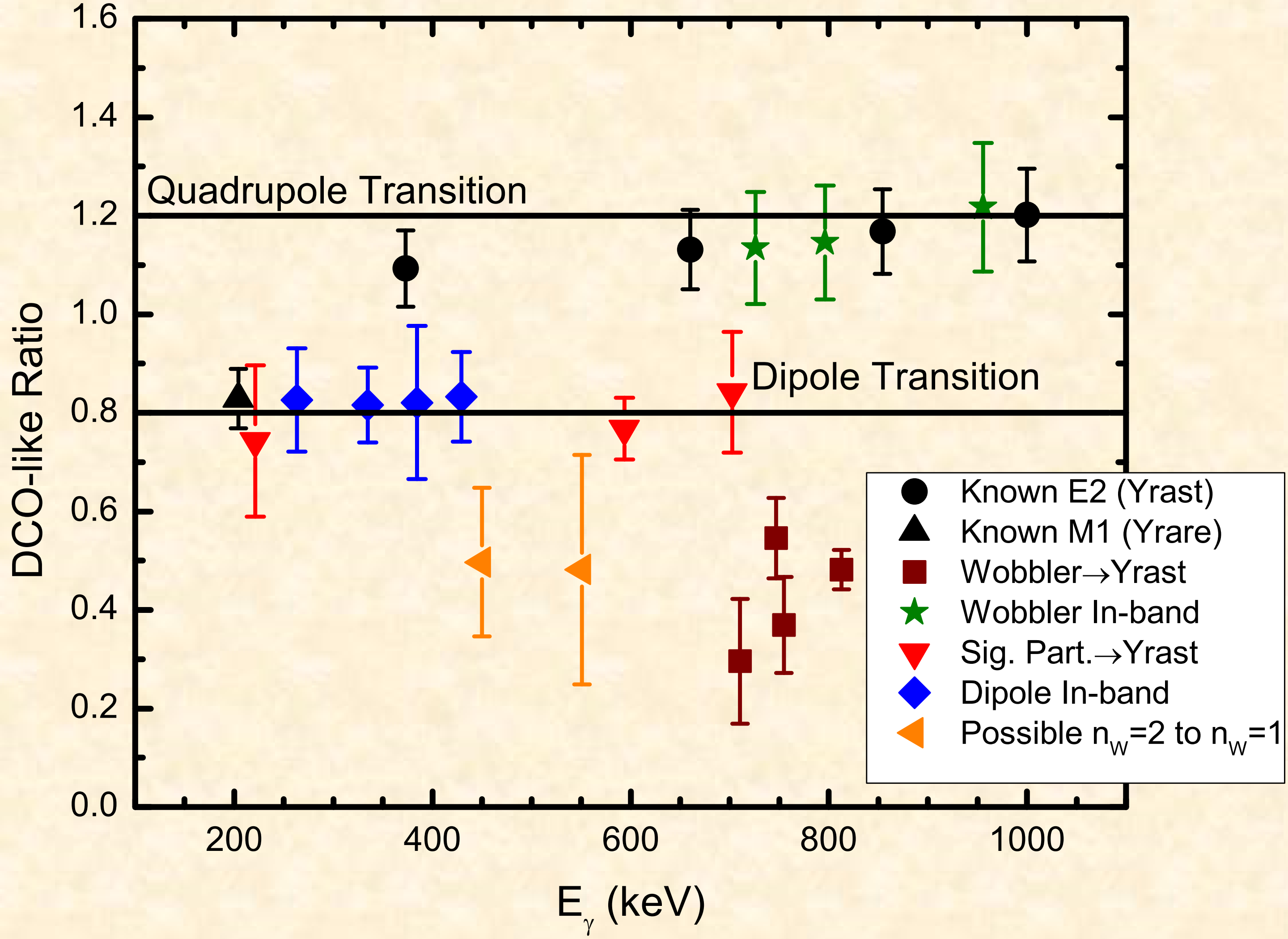


FIG. 7. Comparision of experimental levels with TPSM calculations.

Calculations from J. Sheikh *et al.*
Courtesy of R. Palit, TIFR, Mumbai


Yrast Band
Dipole Band
One Phonon Wobbling Band
Possible Two Phonon Wobbling Band
Signature Partner Band
51/2⁻
957.0
47/2⁻
922.9
43/2⁻
881.7
39/2⁻
833.9
35/2⁻
844.0
31/2⁻
1075.5
27/2⁻
1000.1
23/2⁻
854.2
19/2⁻
660.2
15/2⁻
372.8
11/2⁻
358.0
358
3/2⁺
49/2⁻
562.3
(1092.4)
47/2⁻
530.2
1049.5
45/2⁻
519.3
978.6
43/2⁻
459.2
888.3
41/2⁻
429.1
39/2⁻
(813.4)
384.3
718.9
37/2⁻
334.6
35/2⁻
(597.8)
263.3
33/2⁻
309
33/2⁻
1112.0
1157.7
29/2⁻
710.2
955.6
25/2⁻
796.0
21/2⁻
726.0
17/2⁻
86.8
754.6
812.8
747.0
526
(27/2⁻)
518
1272
763
(23/2⁻)
551
826
1363
19/2⁻
450
1197
25/2⁻
3004
845
21/2⁻
2158
841
596
(231)
725.0
767.5
(770)
494
17/2⁻
1434
481.6
702.7
13/2⁻
952
593.9
221.1



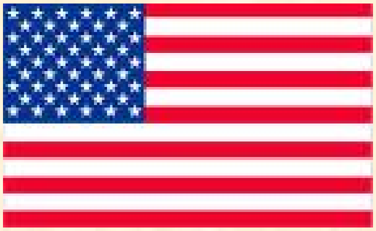
Quadrupole Transition
Dipole Transition
DCO-like Ratio
E$_\gamma$ (keV)
Known E2 (Yrast)
Known M1 (Yrare)
Wobbler→Yrast
Wobbler In-band
Sig. Part.→Yrast
Dipole In-band
Possible n$_W$=2 to n$_W$=1

J. T. Matta
W. Lin
U. G.
S. Frauendorf
A.D. Ayangeakaa
D. Patel
R. Palit, J. Sethi, S. Saha, T. Trivedi
S. S. Ghugre, R. Raut, A. K. Sinha
S. Ray
P. V. Madhusudhana Rao
S. Mukhopadhyay
M. P. Carpenter, R. V. F. Janssens
F. G. Kondev, T. Lauritsen
D. Seweryniak, C. J. Chiara, S. Zhu
C. Petrache
D. H. Hartley
F. Dönau
J. A. Sheikh, G. H. Bhat

I S N A P

धन्यवाद

Thanks!



How to speak to a Different Physics Community

- Use no jargon
- Don't overwhelm with detail
- Use animal pictures, to keep audience attention.

The Question Kitten

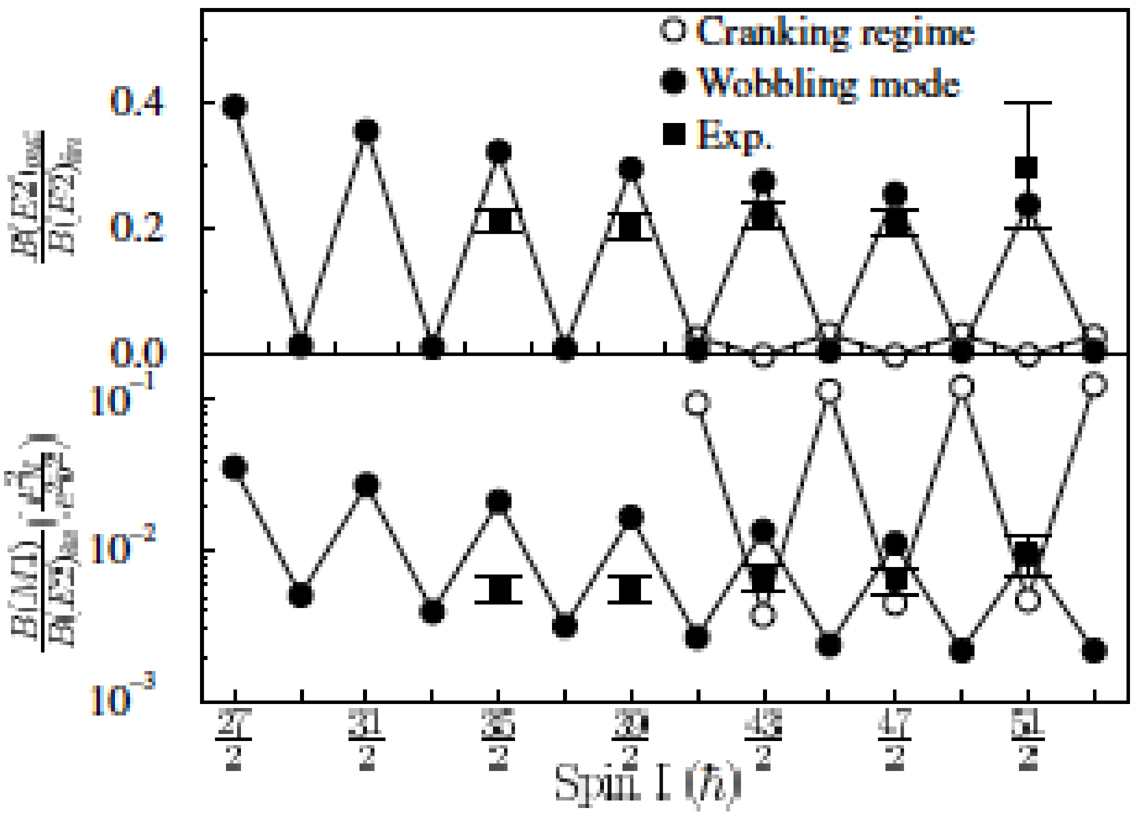
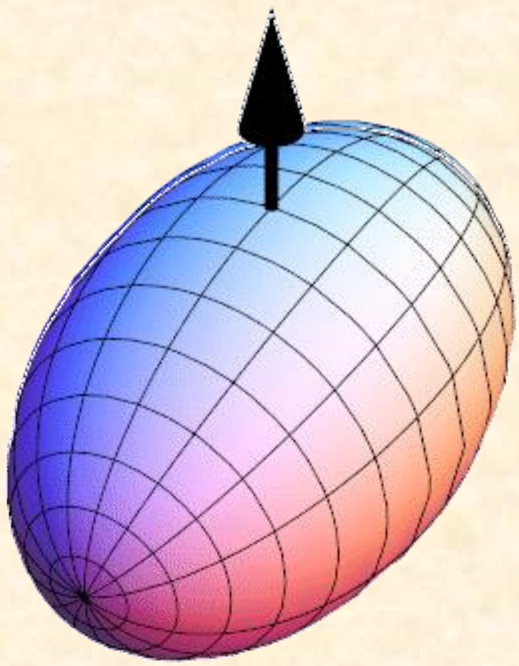
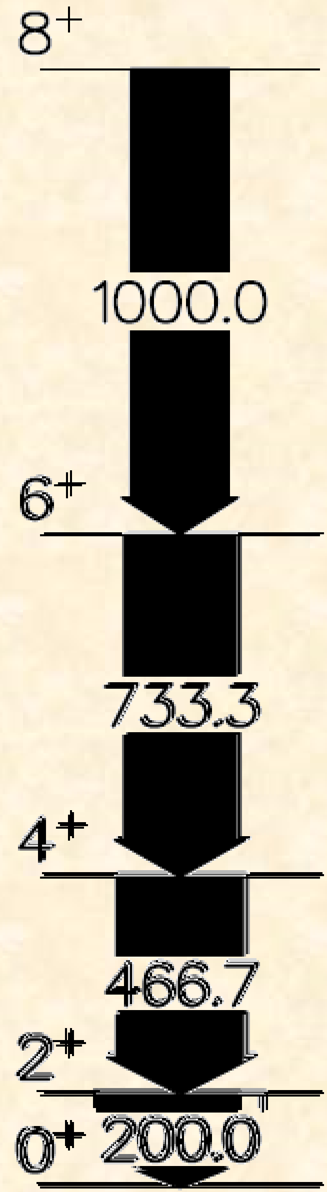


FIG. 5. Experimental and calculated electromagnetic properties of the connecting transitions.




8+
1000.0
6+
733.3
4+
466.7
2+
0+
200.0

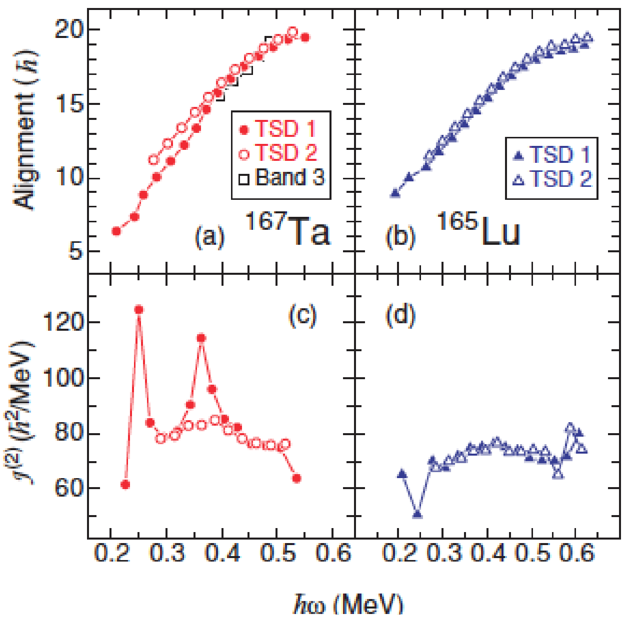


FIG. 3. (Color c
TSD 1 ($\pi i_{13/2}$) and
Harris parameters [
were used as a refer
bands in (c) ^{167}Ta ar

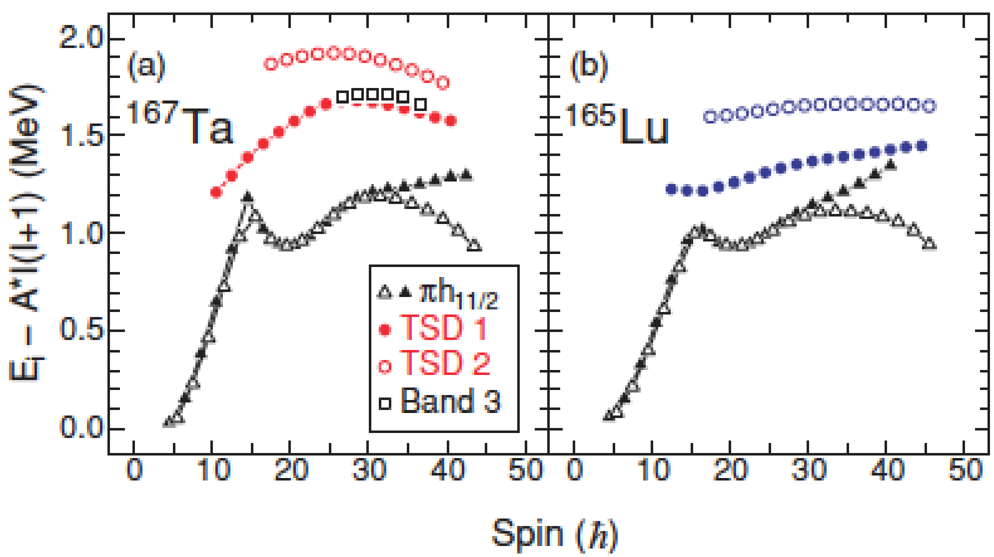


FIG. 4. (Color online) Excitation energy minus a rigid-rotor reference for denoted bands in (a) ^{167}Ta and its isotone (b) ^{165}Lu [5]. The inertia parameter A was set to $0.007\,\mathrm{MeV}/\hbar^2$. The $\pi h_{11/2}$ bands are shown for both nuclei as they are the energetically lowest structures.