Chirality and wobbling: new achievements and perspectives

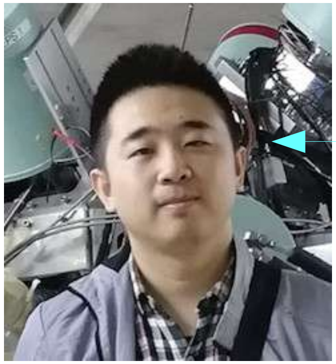
Three successful experiments

RITU + JUROGAM II – 2016 (B. F. Lv)

^{135}Nd, ^{136}Nd, ^{137}Nd – multiple chiral bands

^{135}Nd – Wobbling at low spin **NO**

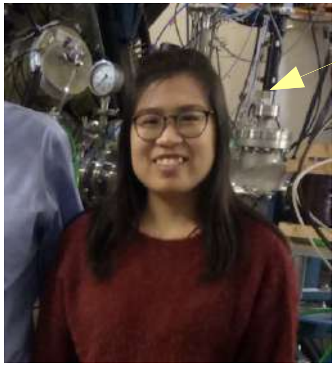
^{136}Nd – Wobbling 2qp at high spin **YES** (F.Q. Chen)



GALILEO + EUCLIDES + N WALL – 2017 (S. Guo)

^{130}Ba – Wobbling 2qp **YES** (Q. B. Chen, Y. X. Liu)

^{131}Ba – chiral bands+octupole correlations



MARA + JUROGAM III – 2019 (K. K. Zheng)

^{119}Cs – electric revolving chirality

^{119}Cs – prolate-oblate shape coexistence

^{119}Ba – neutron 1-qp configurations

^{118}Cs – isomers at the proton-drip line

JUROGAM II + RITU, $^{40}Ar+^{100}Mo \rightarrow Nd$
20 pnA (1 week, October 2016)

JUROGAM II

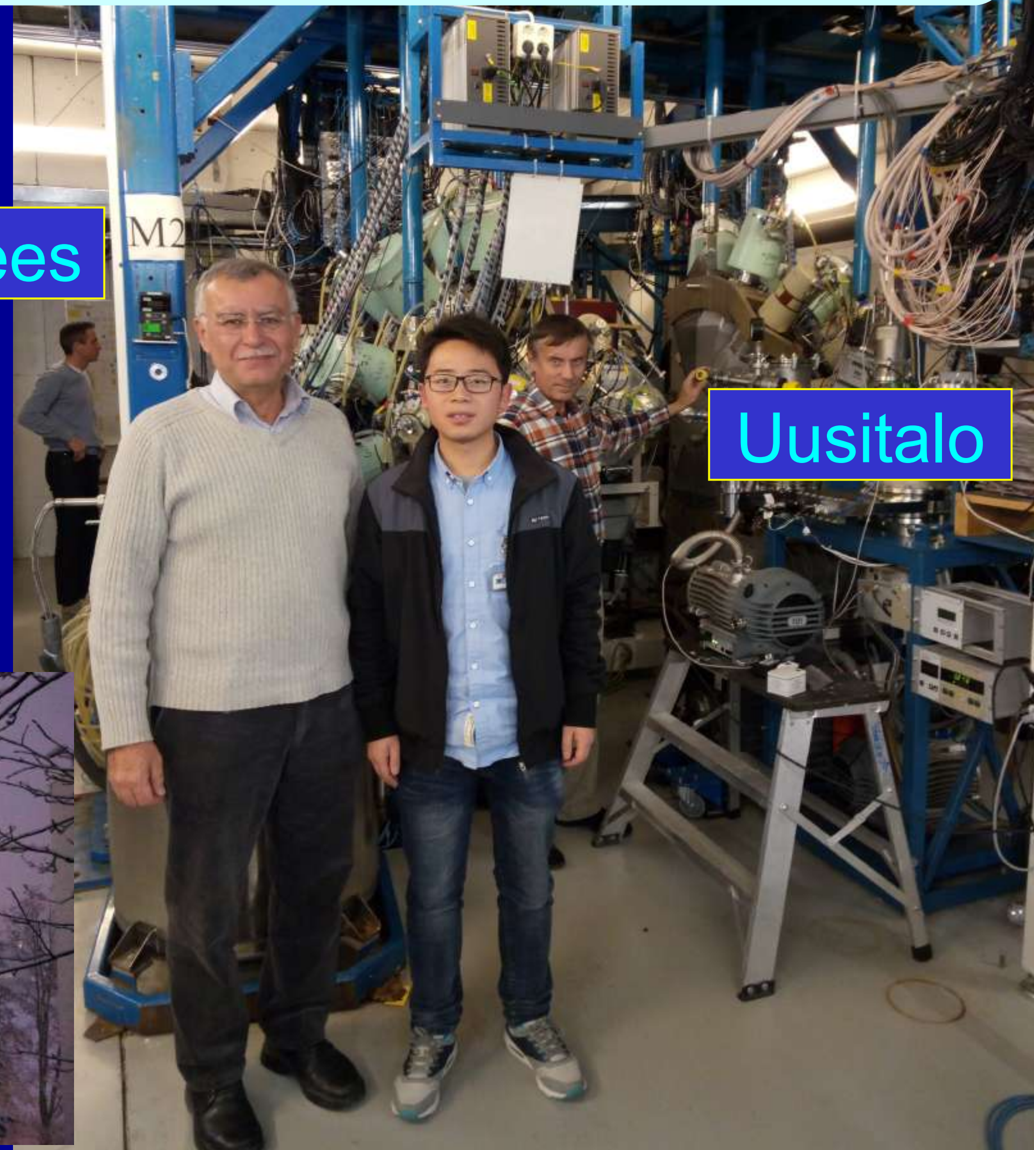
24 Clovers HPGe

15 Coaxial HPGe

39 BGO shields

$\varepsilon_{tot} = 4\ \%$

RITU



Greenlees

Uusitalo

MARA + JUROGAM 3,
$^{64}Zn+^{58}Ni \rightarrow$ Cs, Ba, LA (3 days, May 2019)

MARA

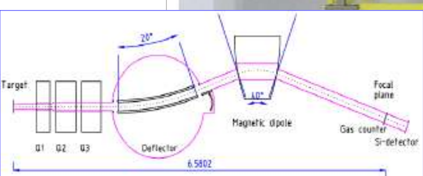
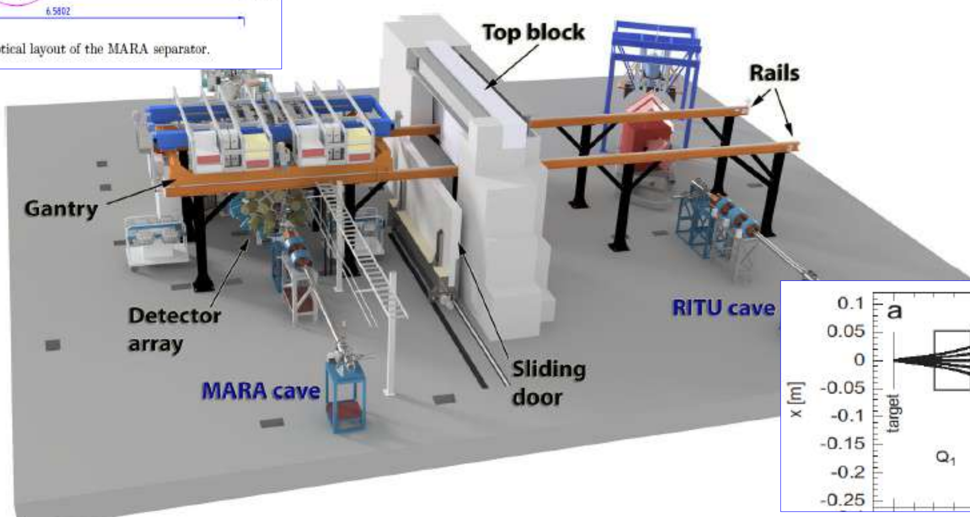
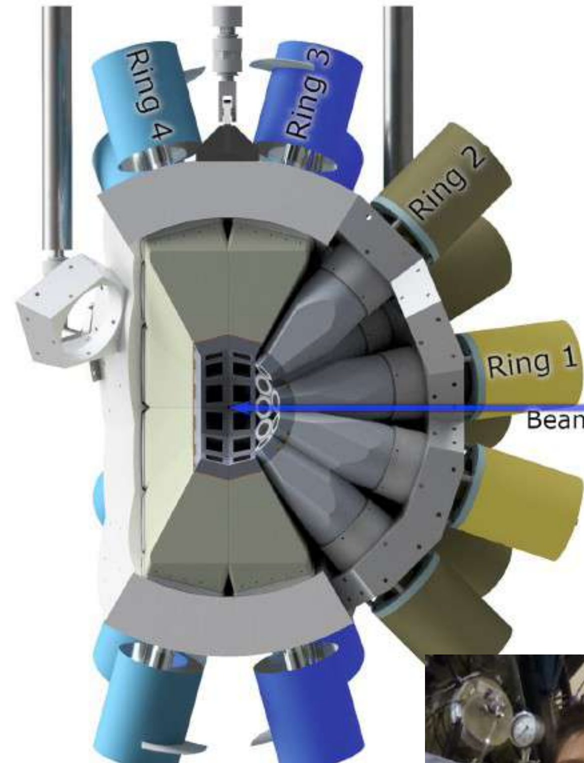
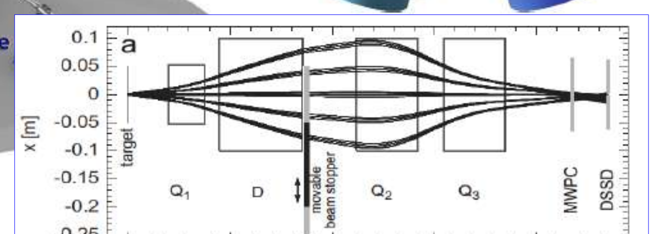


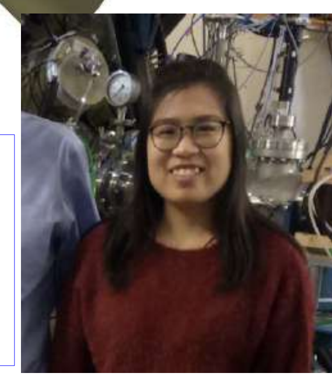
Fig. 1. Ion-optical layout of the MARA separator.



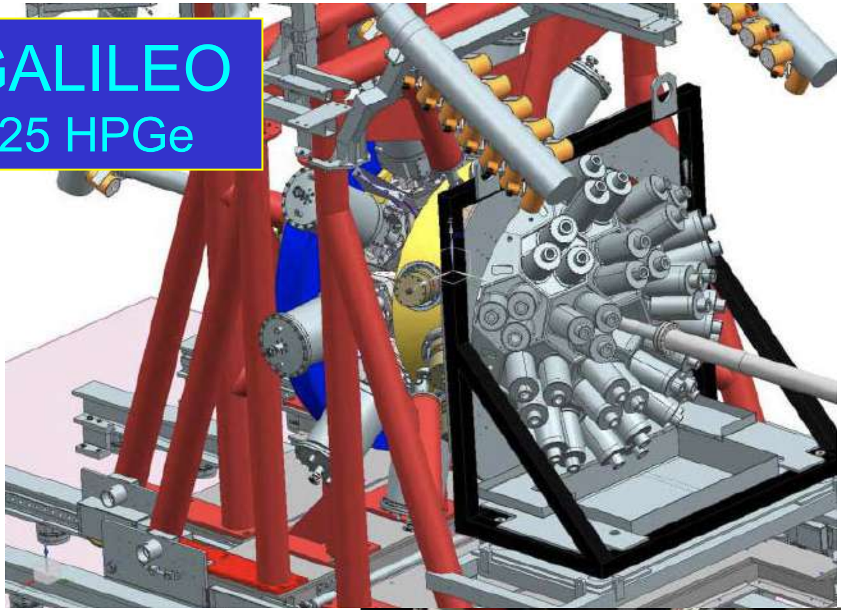
JUROGAM 3

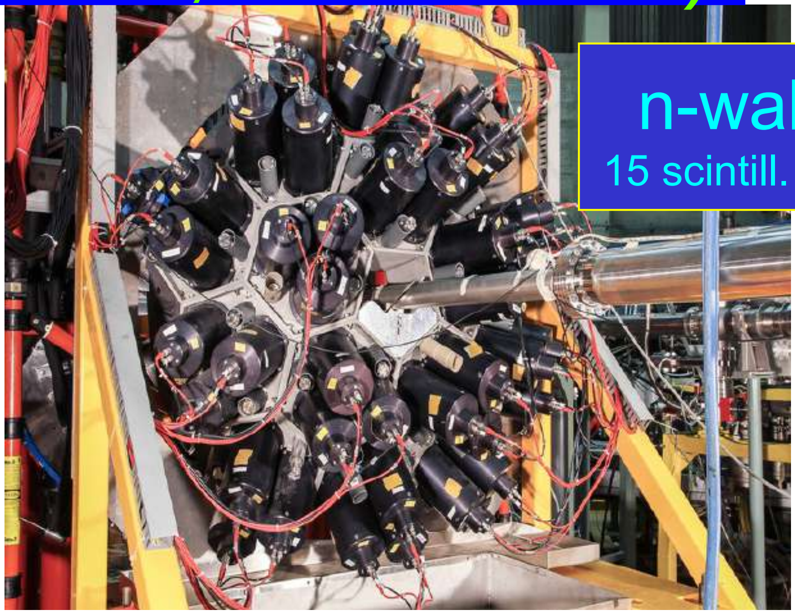






GALILEO + EUCLIDES + n wall, $^{13}C+^{122}Sn \rightarrow$ Ba (1 week, March 2017)

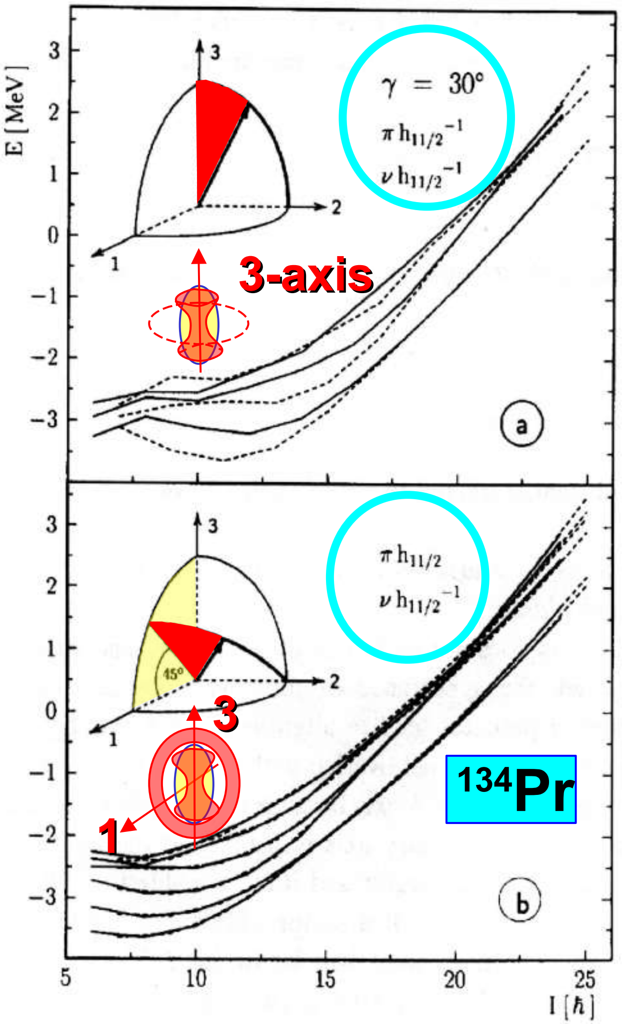




Chirality

Triaxiality

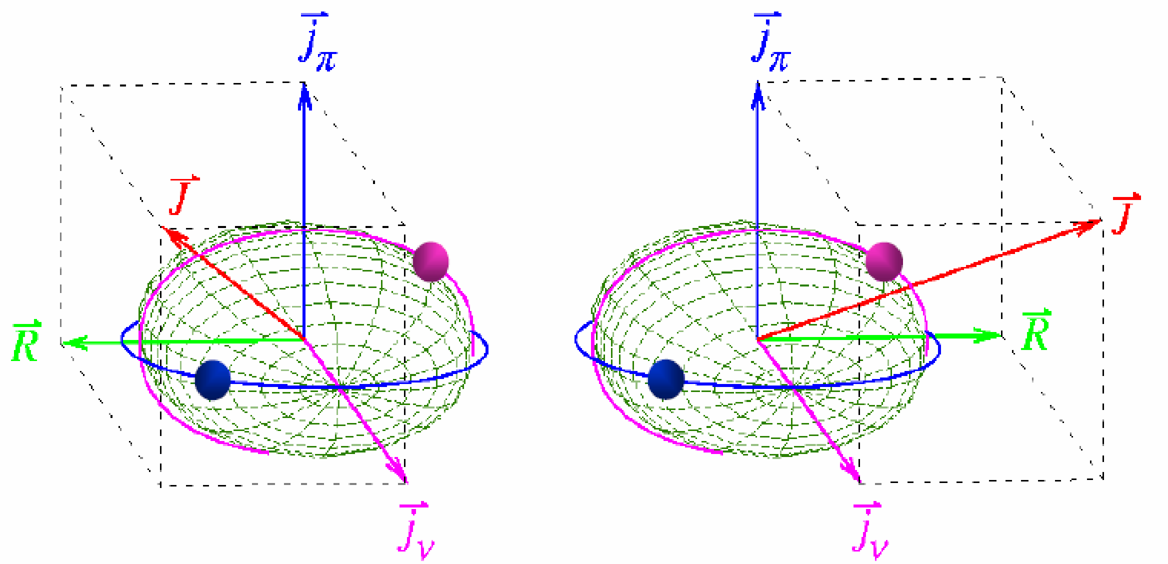
Frauendorf & Meng, NPA 617, 1997



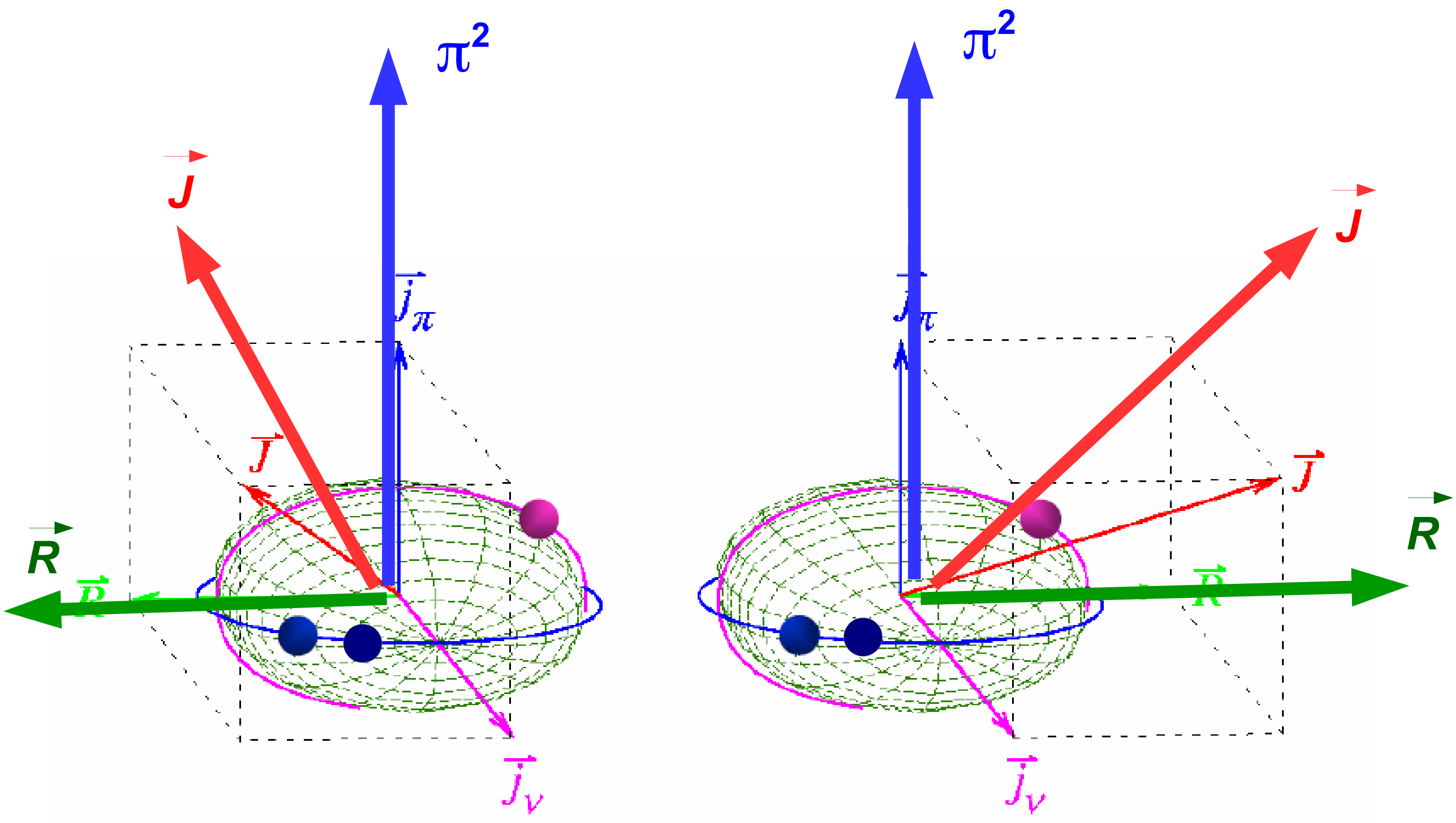
C.P. et al, NPA 597, 1996

Chiral Geometry in Nuclei

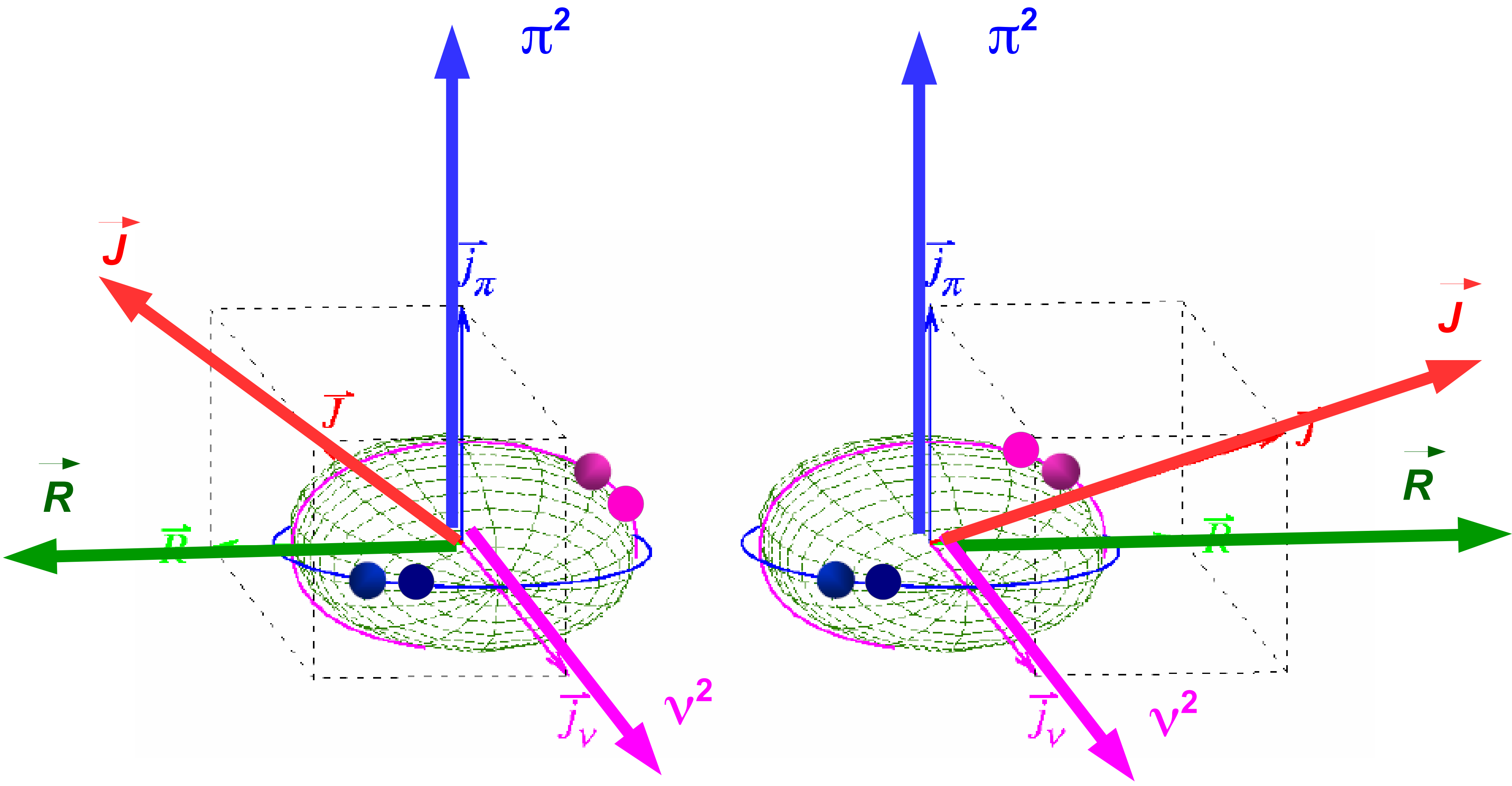
Mutually orthogonal coupling of three angular momenta in odd-odd nuclei



Chirality in odd-even nuclei: 3-qp configurations



Chirality in even-even nuclei: 4-qp configurations



Y. X. Luo, et al. - PLB 670 (2009) 307

^{110,112}Ru - Many of the experimental findings can be explained by microscopic calculations that combine the TAC mean-field with RPA but a simple geometrical explanation is not apparent.

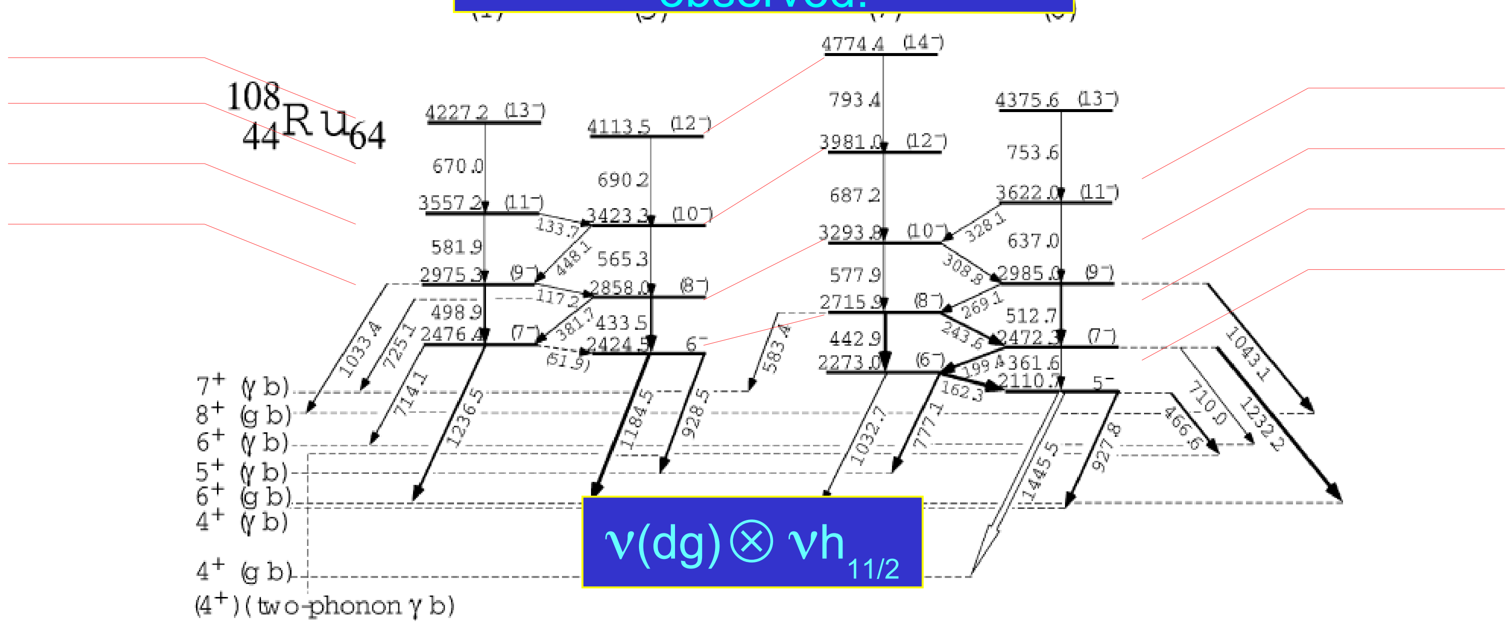
The lowest configuration is obtained by exciting a neutron from the highest $h_{11/2}$ level to the low-lying mixed $d_{5/2} – g_{7/2}$ levels.

The tendency to chirality comes about from the interplay of all the neutrons in the open shell, and we could not find a simple partition.

No chiral partner observed!

No interband transtions observed!

No chiral partner observed!



Five chiral doublets in one nucleus: apotheosis of chirality in ^{136}Nd

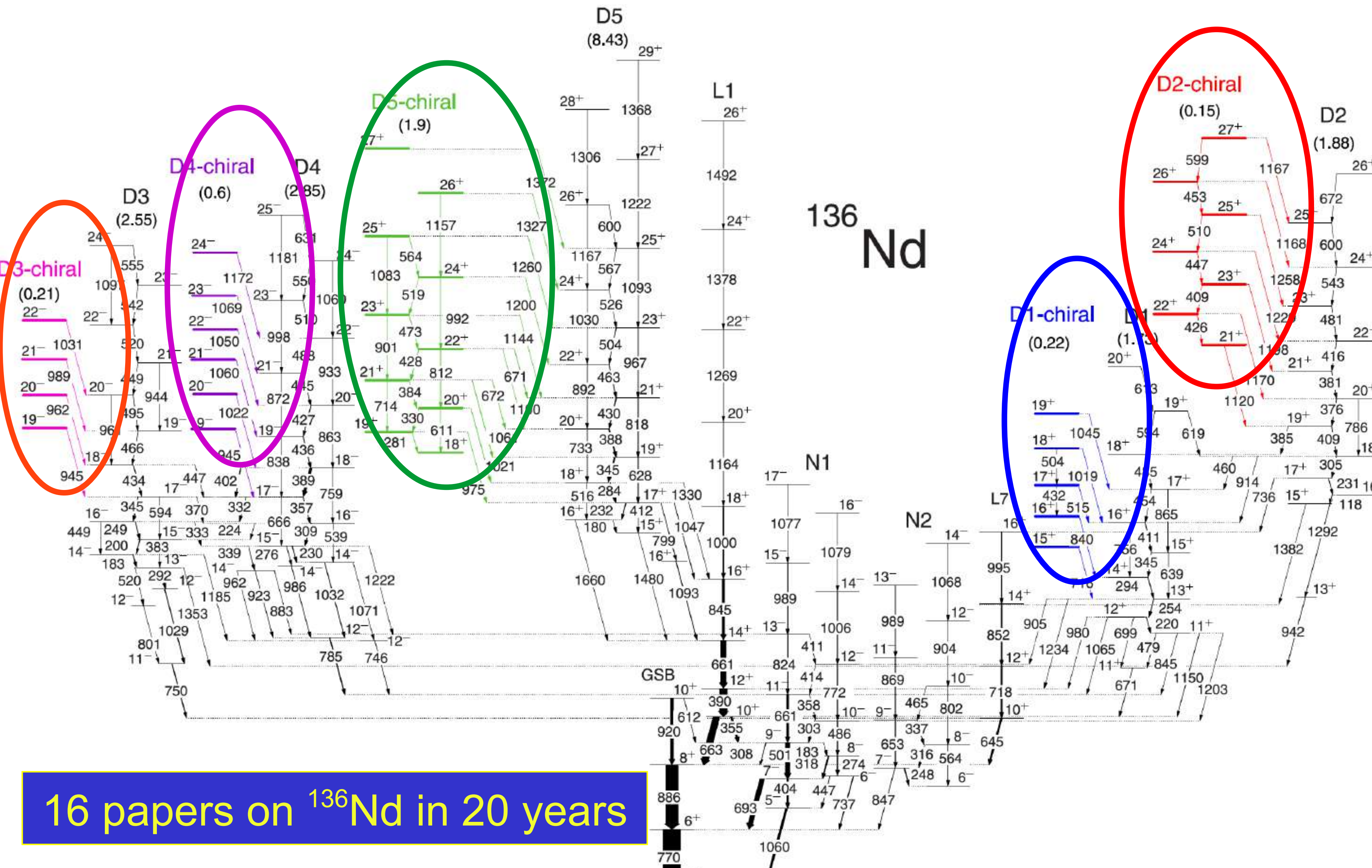
CP, B.F. Lv, et al.

PRC 97 (2018) 041304(R)

Breaking two pairs of nucleons and placing them in orbitals with orthogonal angular momenta lead to much more combinations than in odd-odd nuclei.

The challenge is to identify the very weakly populated 4-qp bands!

Ultimate chirality: clear evidence in even-even nuclei

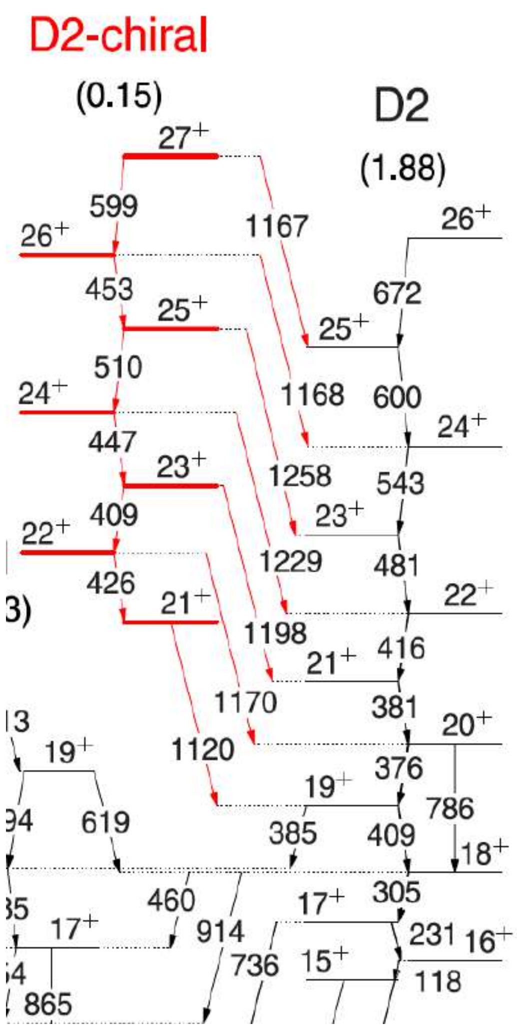


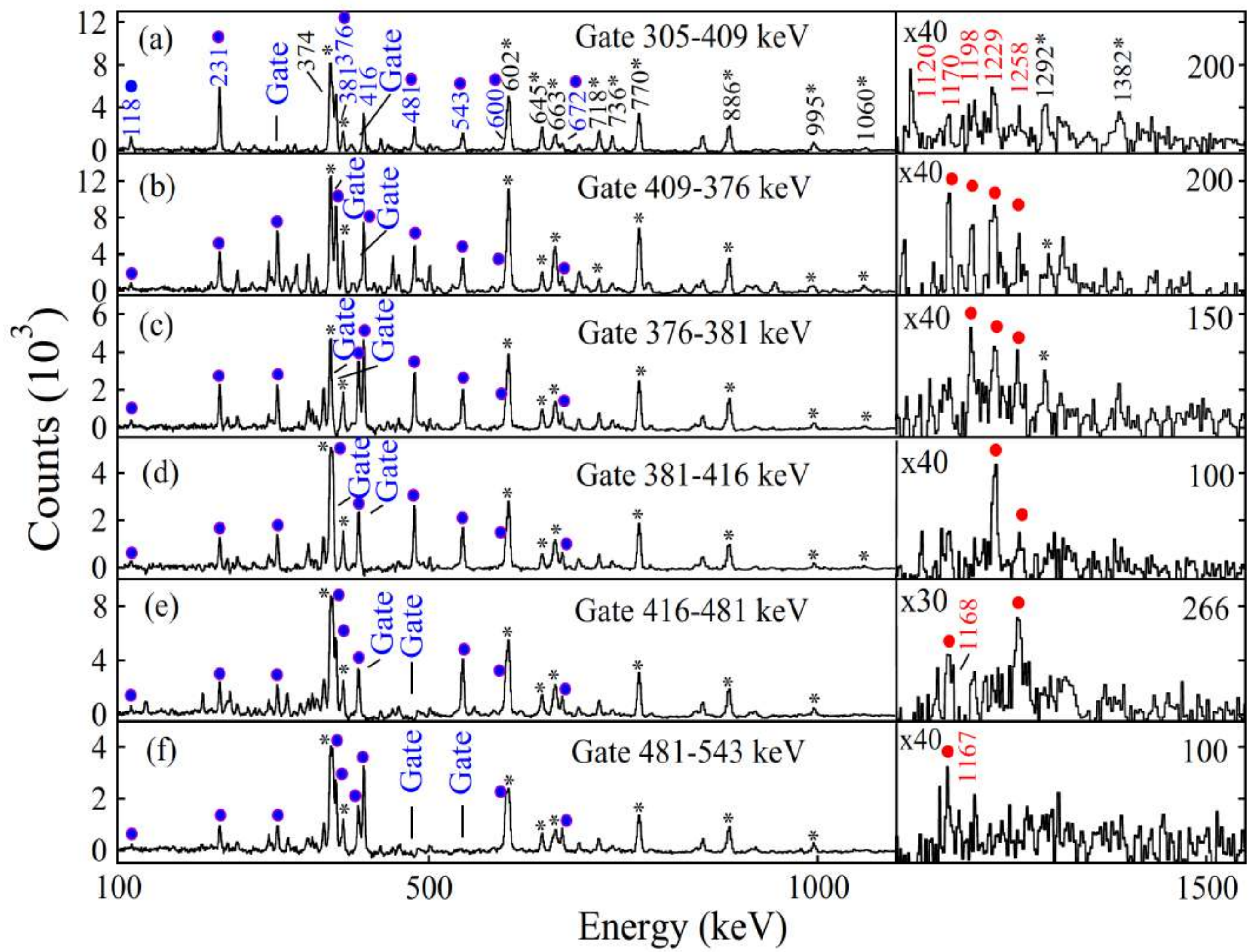
16 papers on ^{136}Nd in 20 years

CP, B.F. Lv et al, PRC 97 (2018) 041304(R)

^{136}Nd – D2 chiral doublet

$\pi\, h^3\, (dg)^{-1} \otimes \nu\, h^{-1} (sd)^{-1}$ (3 particles+3 holes)

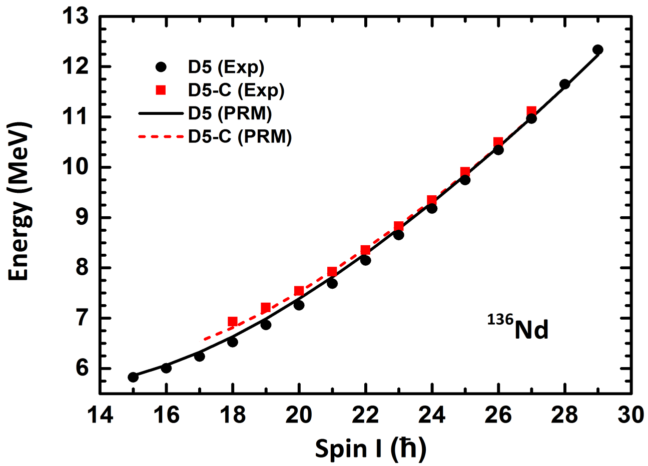


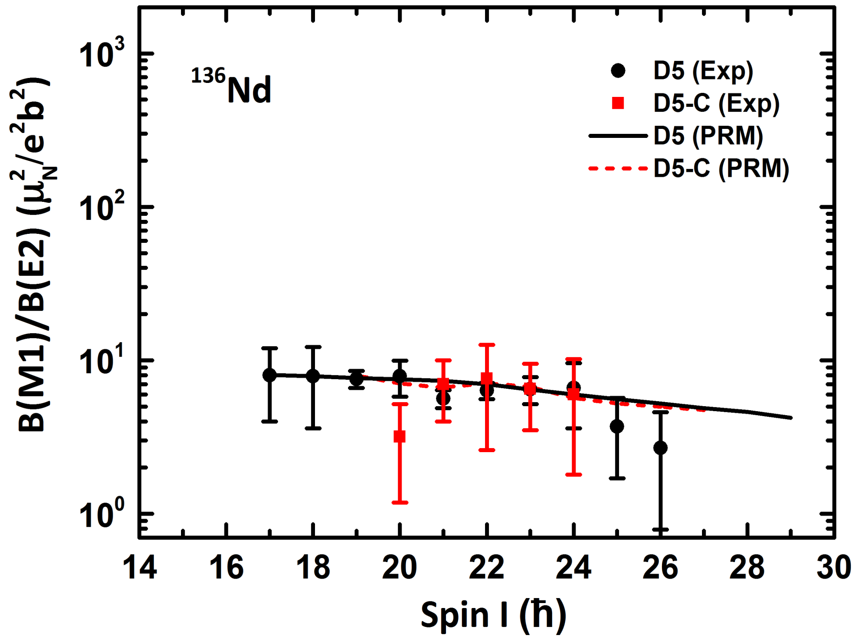


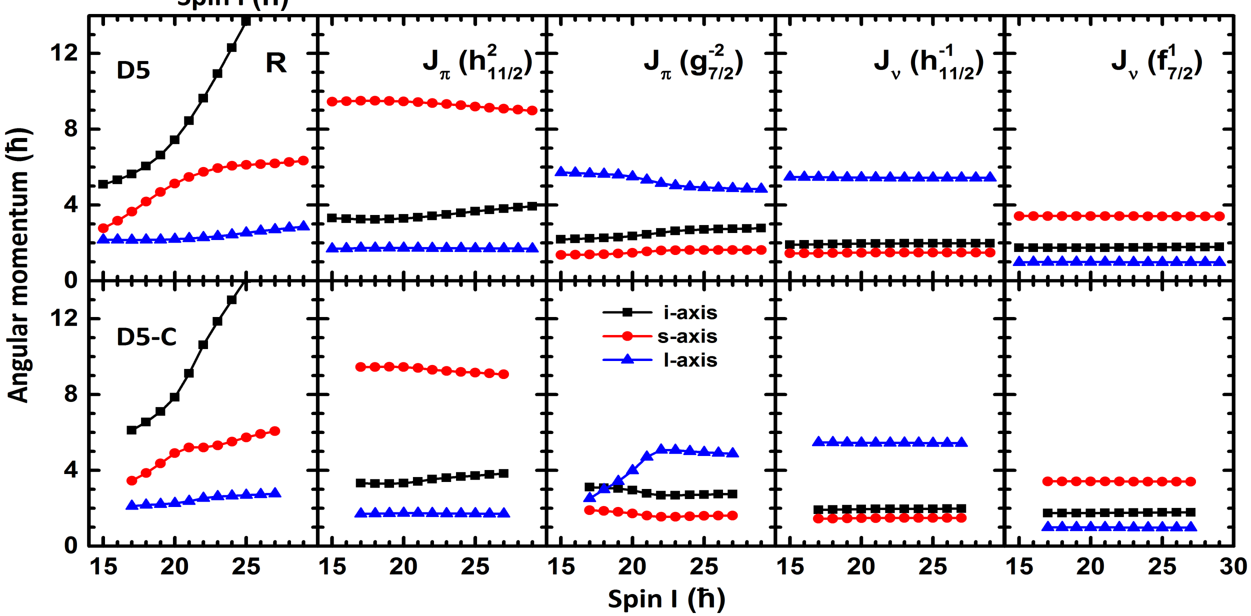
^{136}Nd – chiral doublet D5 (I=2%)

Numerical details

- Configuration: $\pi\,(1h_{11/2})^2\,(1g_{7/2})^{-2}\,\nu\,(1h_{11/2})^{-1}\,(1f_{7/2})^1$
- Deformation: ($\beta = 0.26$, $\gamma = 23.0^o$)
- Irr. MOI: $\Im = 40$ MeV
- Coriolis attenuation factor: 0.93



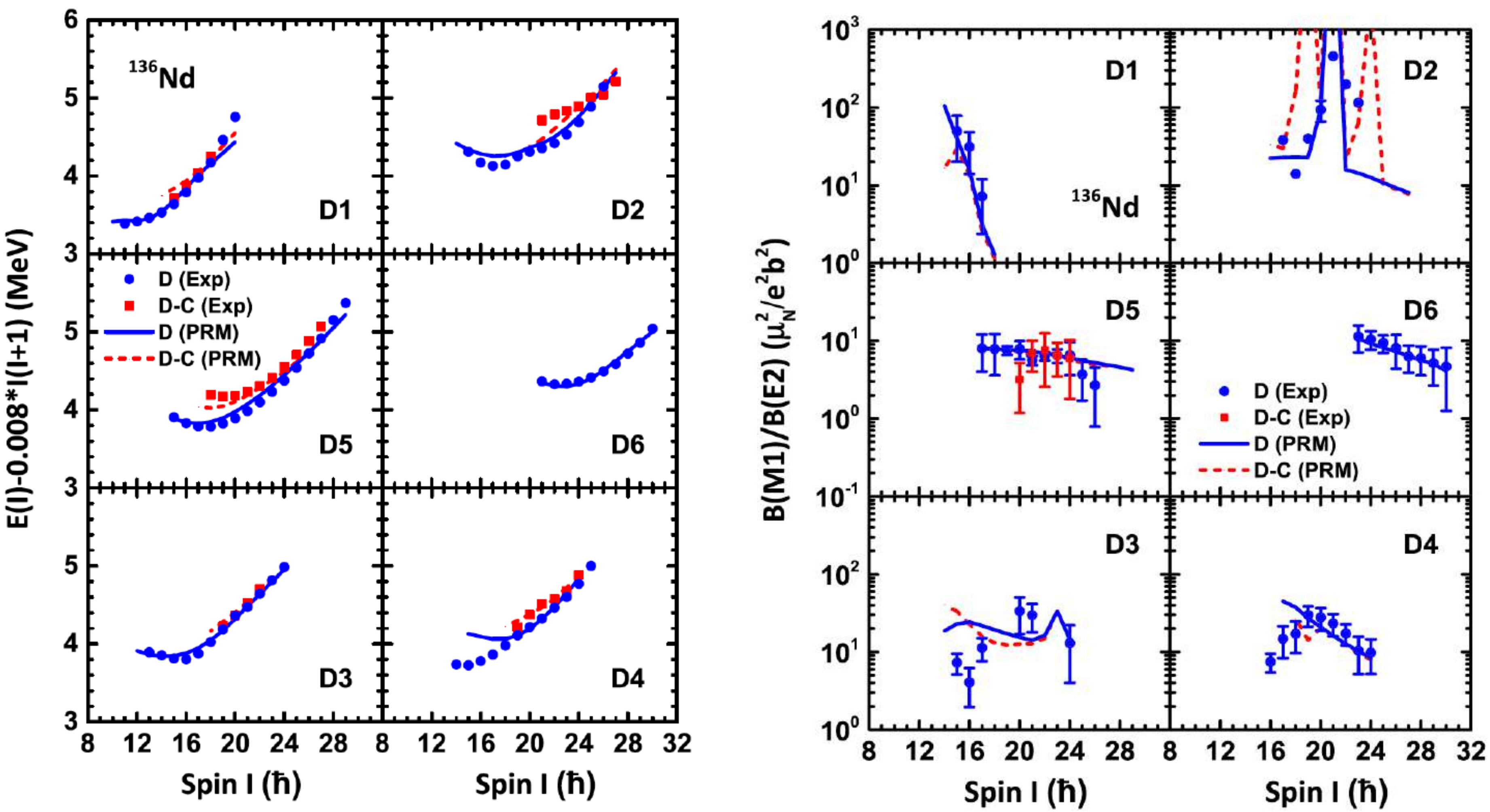




Multiple chiral doublets in four-j shells particle rotor model: Five possible chiral doublets in $^{136}_{60}Nd_{76}$

Q.B. Chen [a], B.F. Lv [b], C.M. Petrache [b], J. Meng [c,d,e,*]

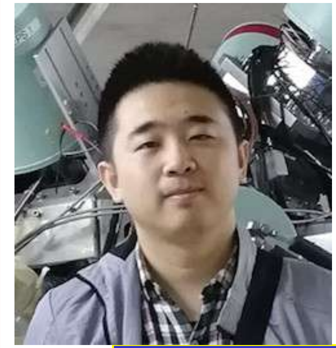
Physics Letters B 782 (2018) 744–749

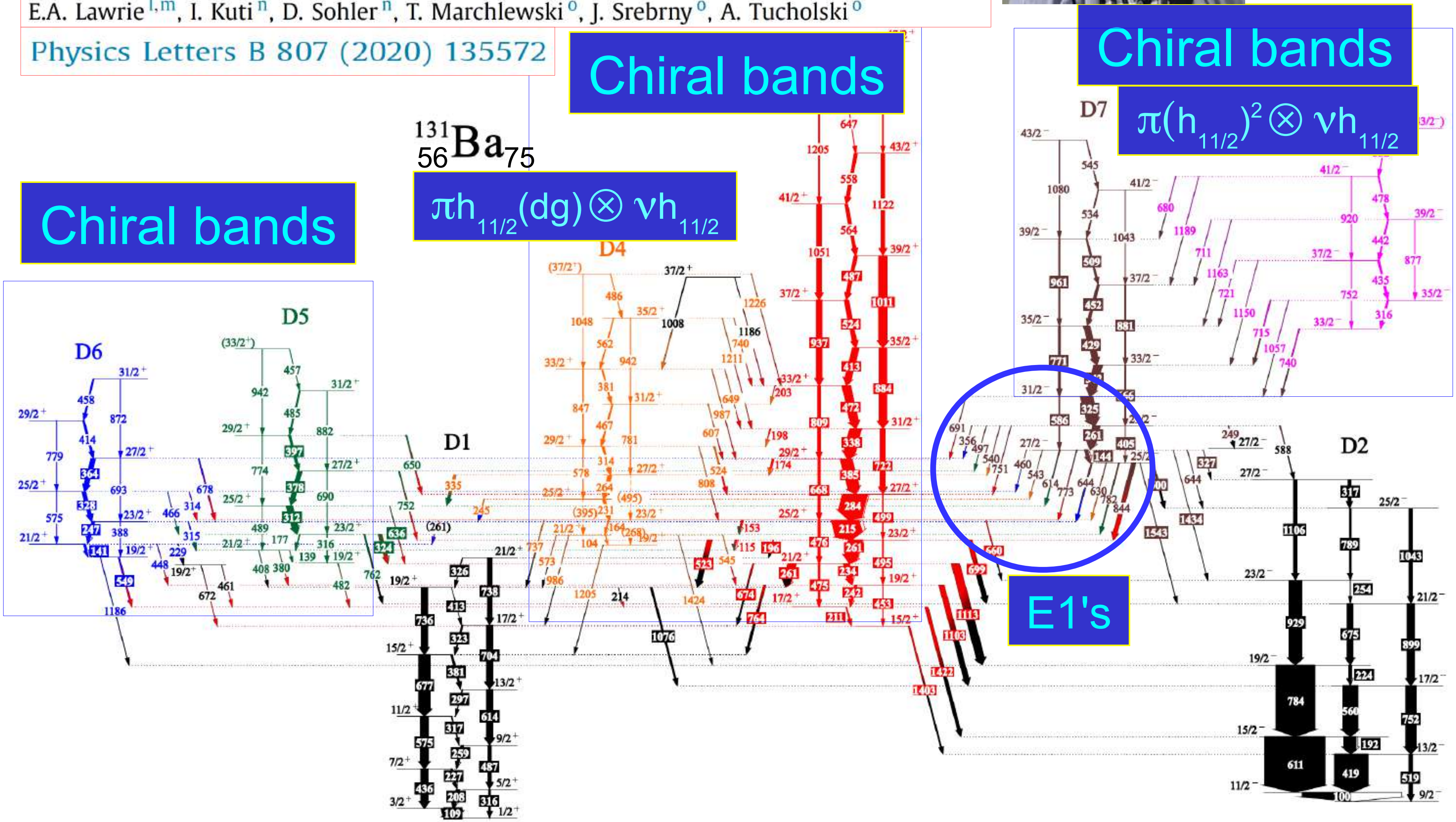


Evidence for pseudospin-chiral quartet bands in the presence of octupole correlations

S. Guo [a,b,*], C.M. Petrache [c,*], D. Mengoni [d,e], Y.H. Qiang [a], Y.P. Wang [f], Y.Y. Wang [f], J. Meng [f,g], Y.K. Wang [f], S.Q. Zhang [f], P.W. Zhao [f], A. Astier [c], J.G. Wang [a,b], H.L. Fan [a], E. Dupont [c], B.F. Lv [c], D. Bazzacco [d,e], A. Boso [d,e], A. Goasduff [d,e], F. Recchia [d,e], D. Testov [d,e], F. Galtarossa [h,i], G. Jaworski [h], D.R. Napoli [h], S. Riccetto [h], M. Siciliano [h], J.J. Valiente-Dobon [h], M.L. Liu [a,b], G.S. Li [a,b], X.H. Zhou [a,b], Y.H. Zhang [a,b], C. Andreoiu [j], F.H. Garcia [j], K. Ortner [j], K. Whitmore [j], A. Ataç-Nyberg [k], T. Bäck [k], B. Cederwall [k], E.A. Lawrie [l,m], I. Kuti [n], D. Sohler [n], T. Marchlewski [o], J. Srebrny [o], A. Tucholski [o]

Physics Letters B 807 (2020) 135572





Selection rules of electromagnetic transitions for chirality-parity violation in atomic nuclei

Yuanyuan Wang [a], Xinhui Wu [a], Shuangquan Zhang [a], Pengwei Zhao [a], Jie Meng [a, b, c]

ELSEVIER
Science Bulletin
Volume 65, Issue 23, 15 December 2020, Pages 2001-2006

Multiple chiral doublet bands with octupole correlations in reflection-asymmetric triaxial particle rotor model

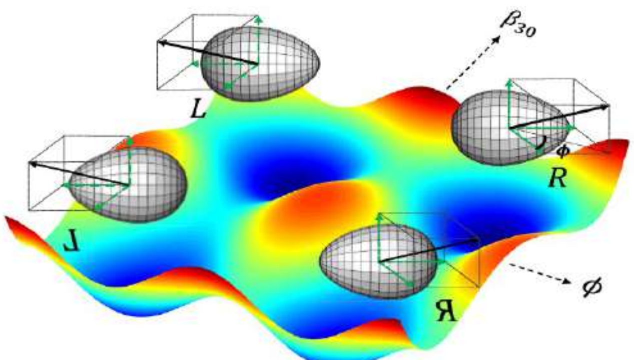
Y.Y. Wang (王媛媛)[a], S.Q. Zhang (张双全)[b], P.W. Zhao (赵鹏巍)[b], J. Meng (孟杰)[b,a,c,*]

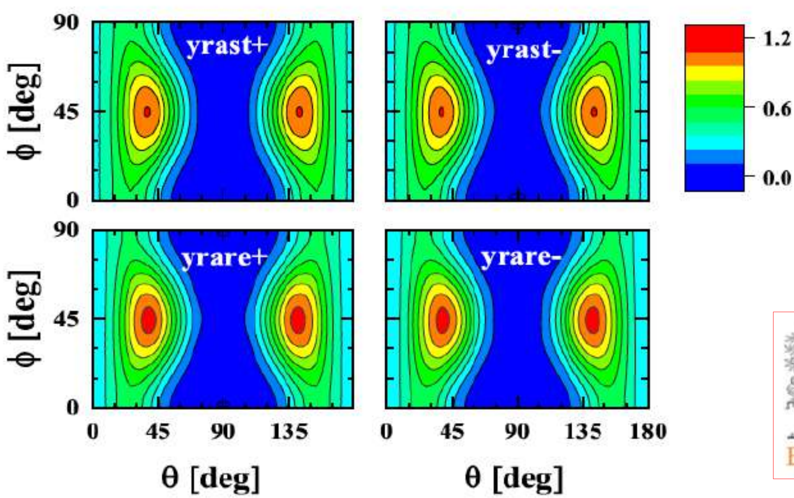
Physics Letters B 792 (2019) 454–460

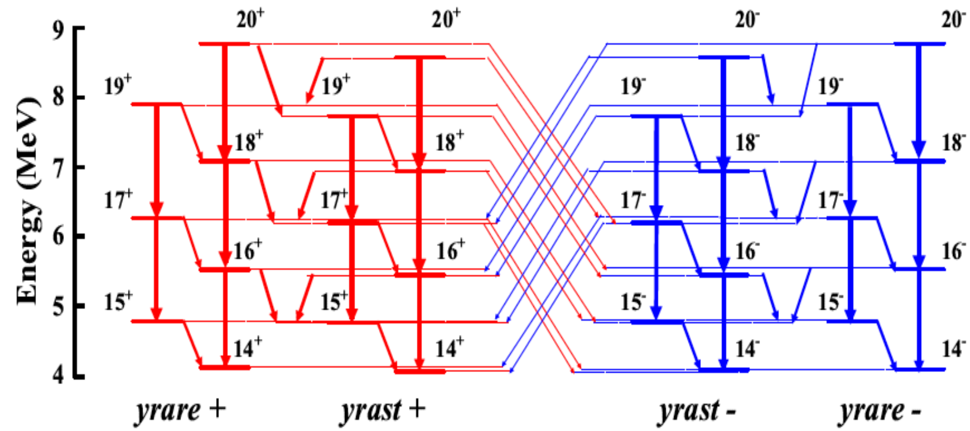
New quantum numbers

Chiture $\mathcal{A}$, similar to signature $\mathcal{R}$

Chiplex $\mathcal{B}=\mathcal{A}\mathcal{P}$, similar to simplex $\mathcal{S}=\mathcal{R}(\pi)\mathcal{P}$







Robustness of chiral symmetry in atomic nuclei with reflection-asymmetric shapes

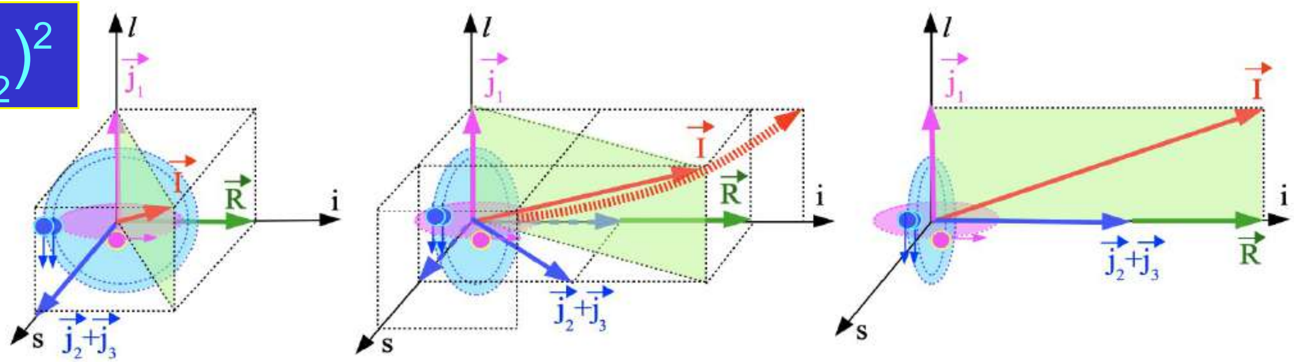
Costel Marian Petrache

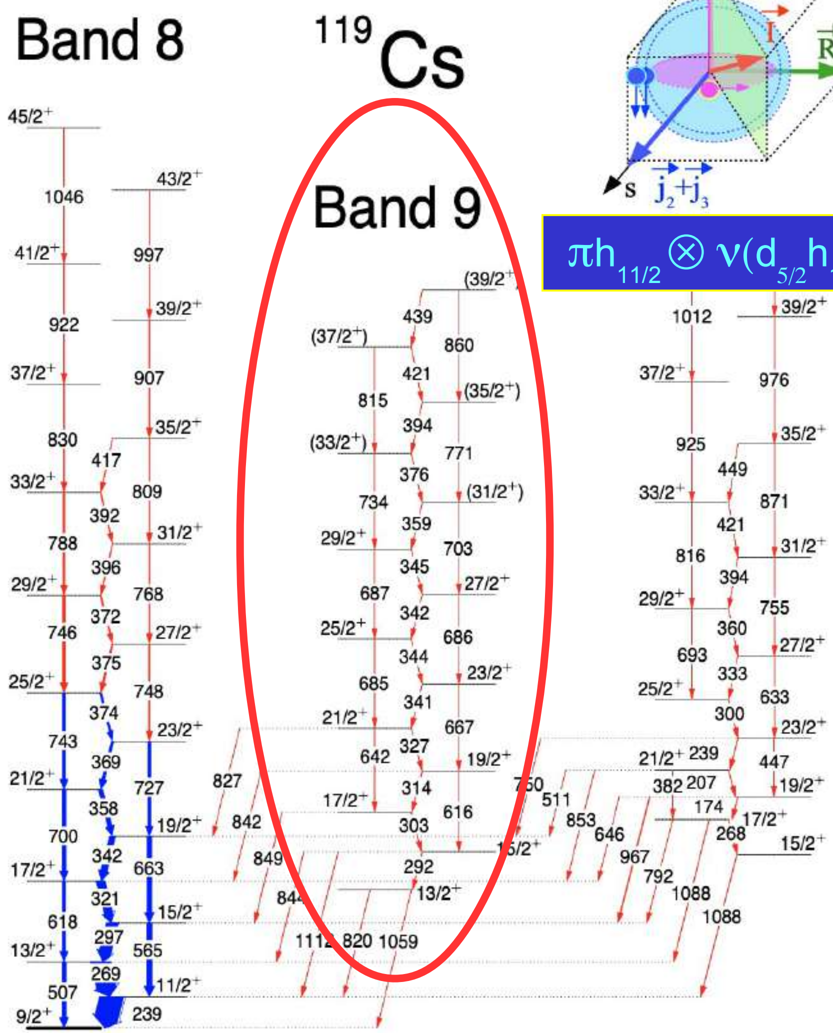
ELSEVIER
Science Bulletin
Volume 65, Issue 23, 15 December 2020, Pages 1956-1957

Electric revolving *chirality* at the limits

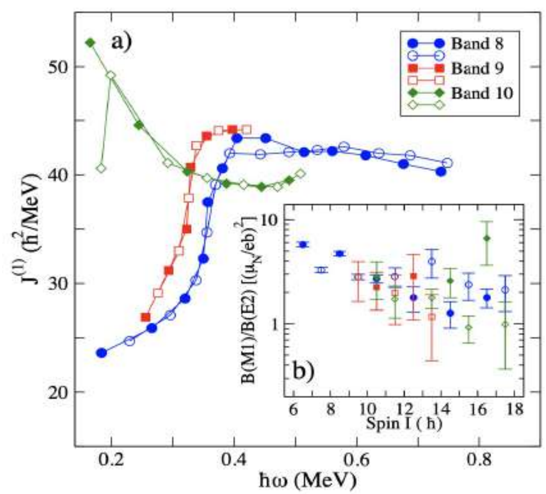
3D rotation (bottom) → 3D rotation (revolving) → 2D rotation (top)

$\pi[404]9/2^{+} \otimes \pi(h_{11/2})^2$



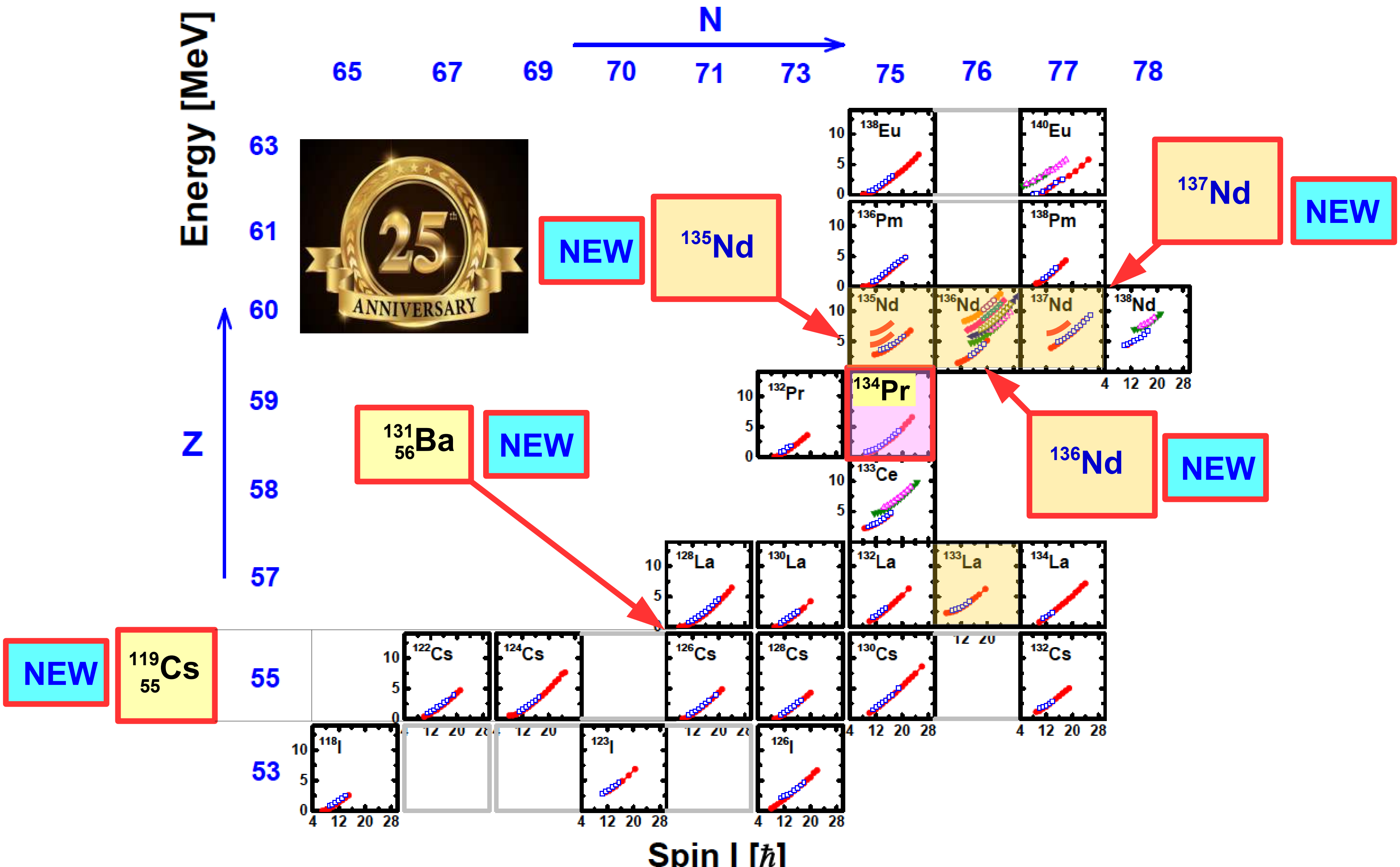


$\pi h_{11/2} \otimes \nu(d_{5/2} h_{11/2})$



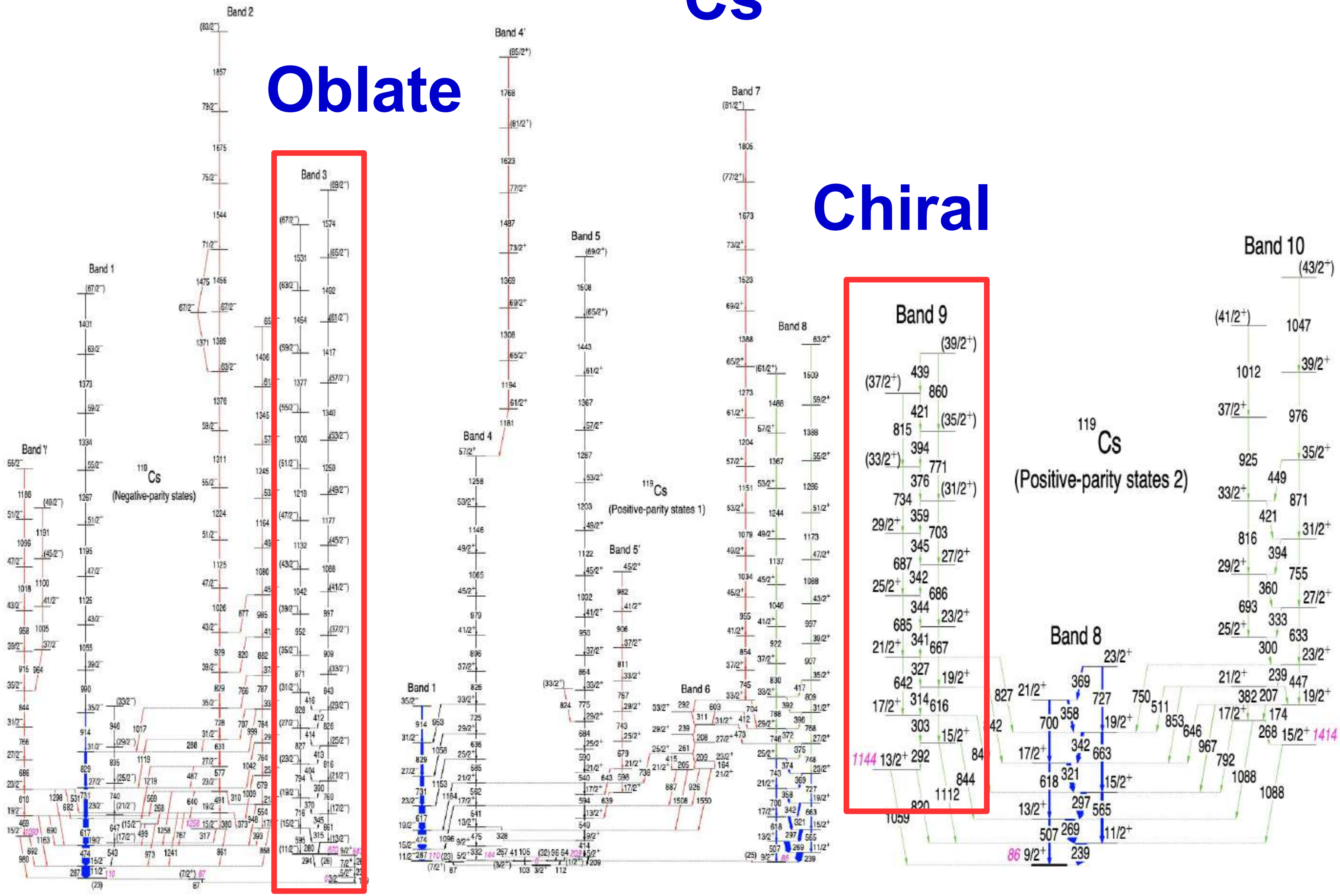
Submitted to PRL

New chiral bands in A=130 region



B.W. Xiong, Y.Y. Wang, ADNDT 125 (2018) 193: Nuclear chiral bands data tables

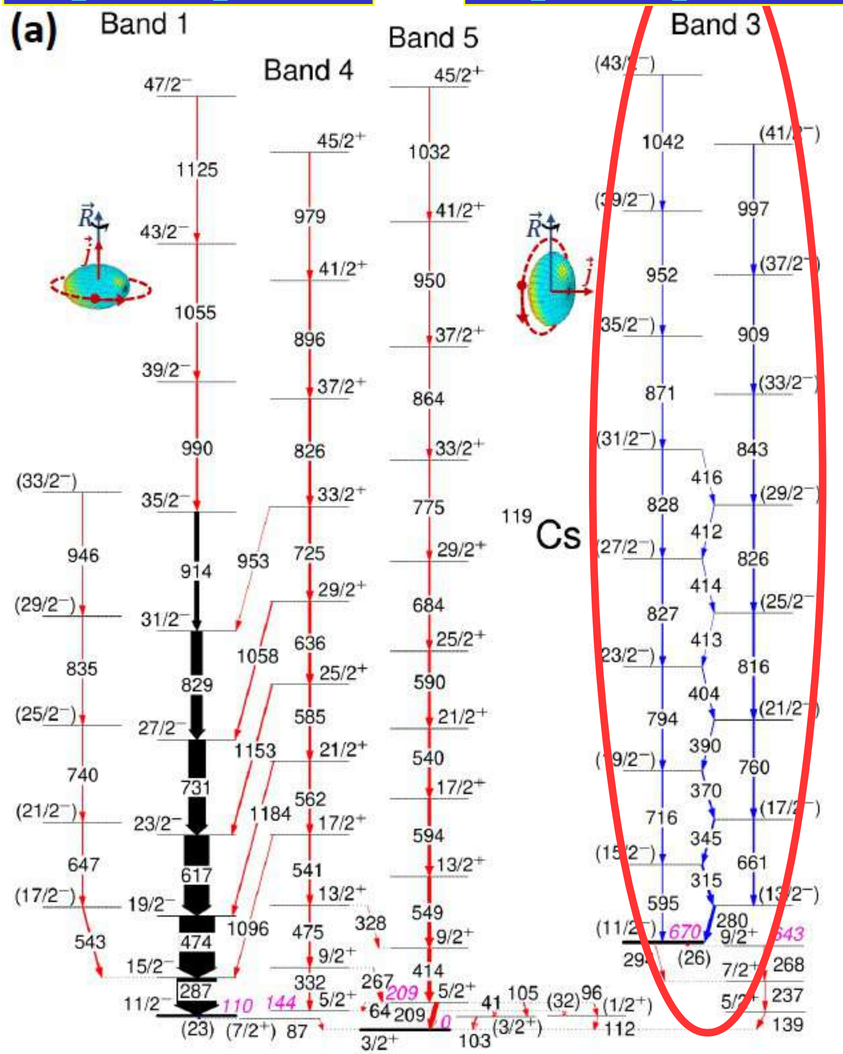
^{119}Cs



Oblate
Chiral
Band 1
Band 2
Band 3
Band 4
Band 4'
Band 5
Band 5'
Band 6
Band 7
Band 8
Band 9
Band 10
Band γ
119Cs (Negative-parity states)
119Cs (Positive-parity states 1)
119Cs (Positive-parity states 2)

Oblate-prolate coexistence at the limits

π[541]3/2⁻ π[505]11/2⁻



TAC-CDFT

submitted to PLB

PNC-CSM

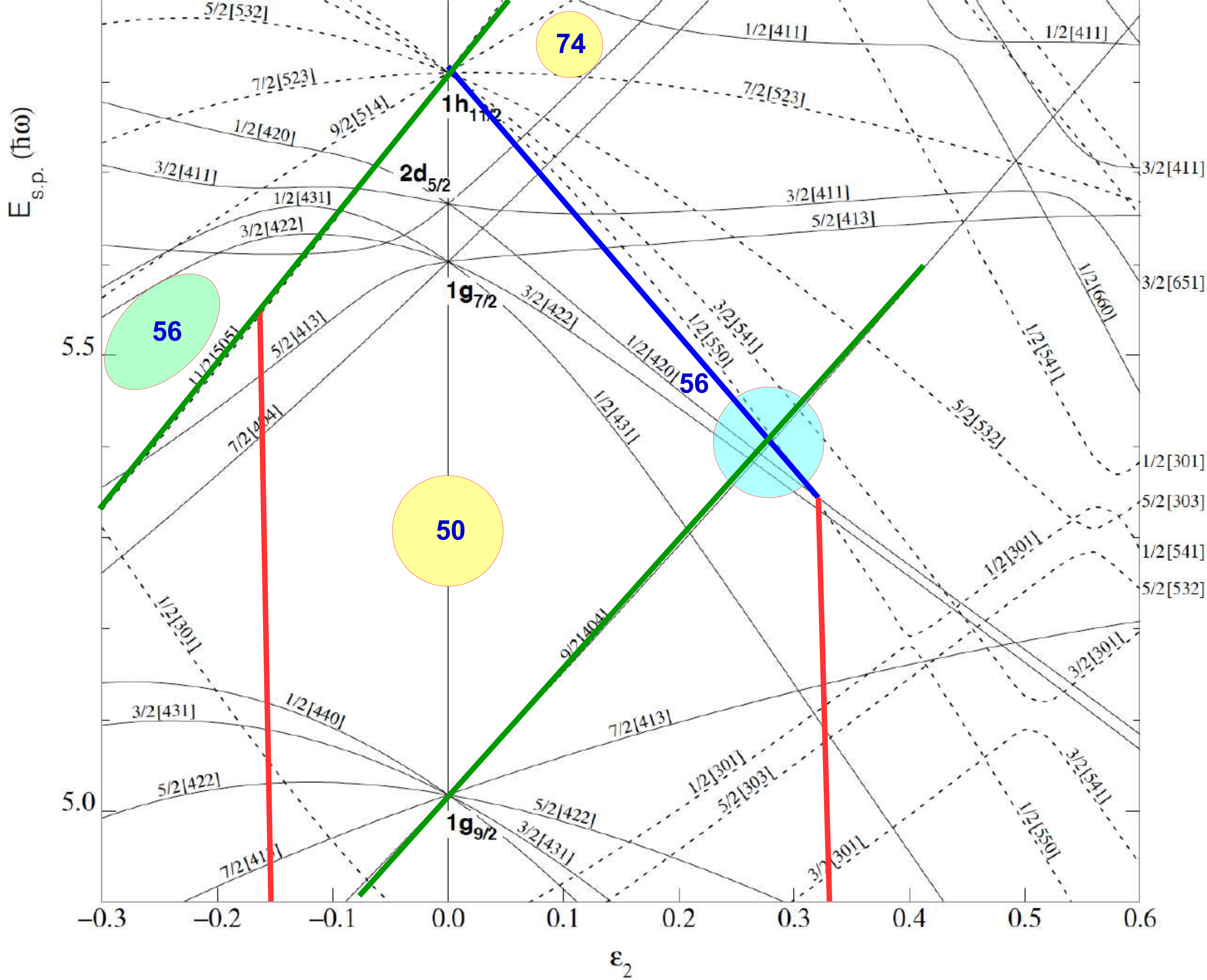


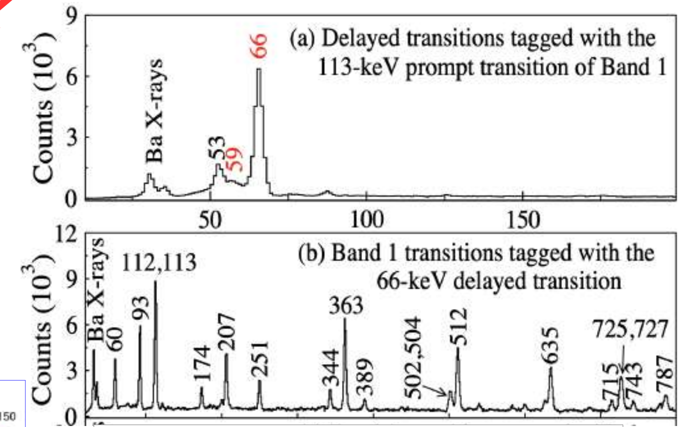
Figure 11. Nilsson diagram for protons, $50 \leq Z \leq 82$ ($\varepsilon_4 = \varepsilon_2^2/6$).

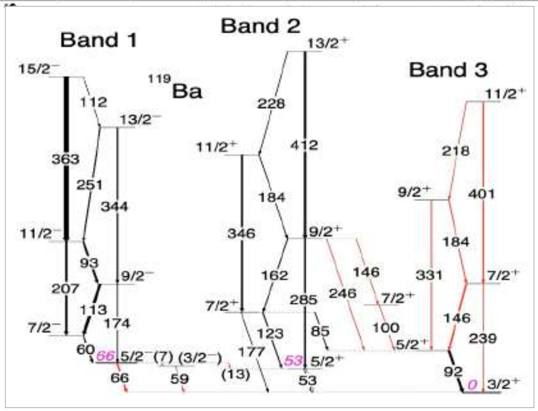
Isomerism
at the proton drip line

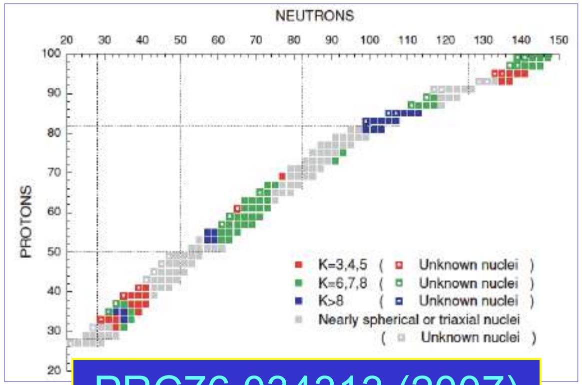
^{119}Cs $\pi[541]3/2^-$

^{119}Ba $\nu[532]5/2^-$

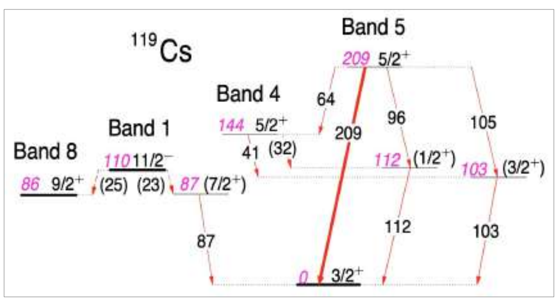
^{118}Cs
$\pi[541]3/2^-$
$\nu[532]5/2^-$

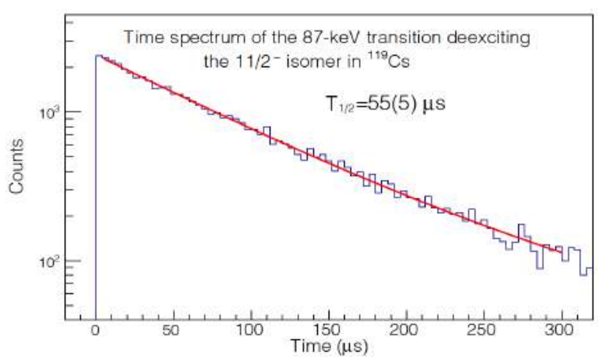


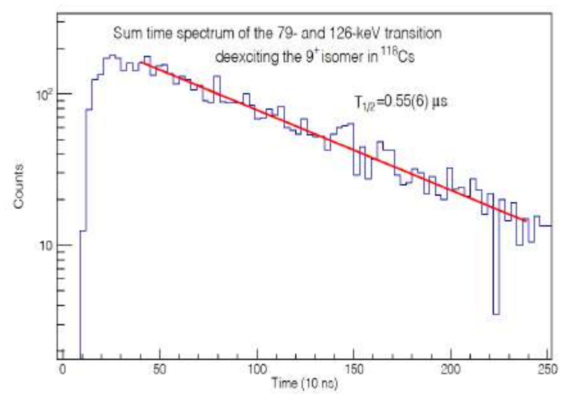


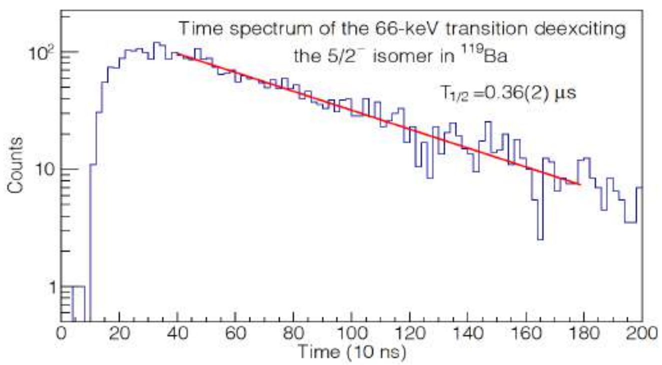


PRC76,034313 (2007)









Wobbling outside of the A=160 mass region

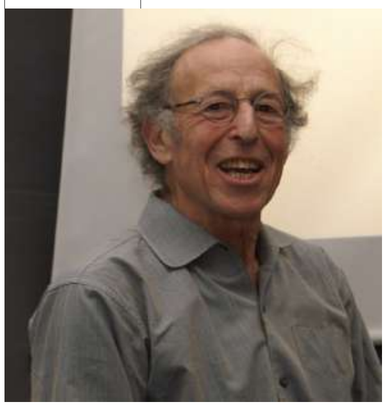
- low-spin 1-qp bands: NO
- high-spin 1,2-qp bands: YES

Wobbling bands ■ theoretical predictions and calculations

1975, Bohr-Mottelson, Chapter 4,
States with large I ($I^2 >> I_2^2+I_3^2$)

$$E(I, n_{\mathrm{wobb}}) = \frac{I(I+1)}{2\mathcal{J}_x} + \hbar\omega_{\mathrm{wobb}}\left(n_{\mathrm{wobb}} + \frac{1}{2}\right)$$

1975 — 2001 — 2020

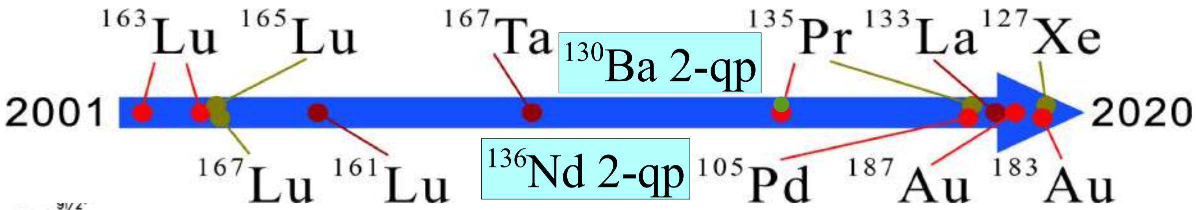




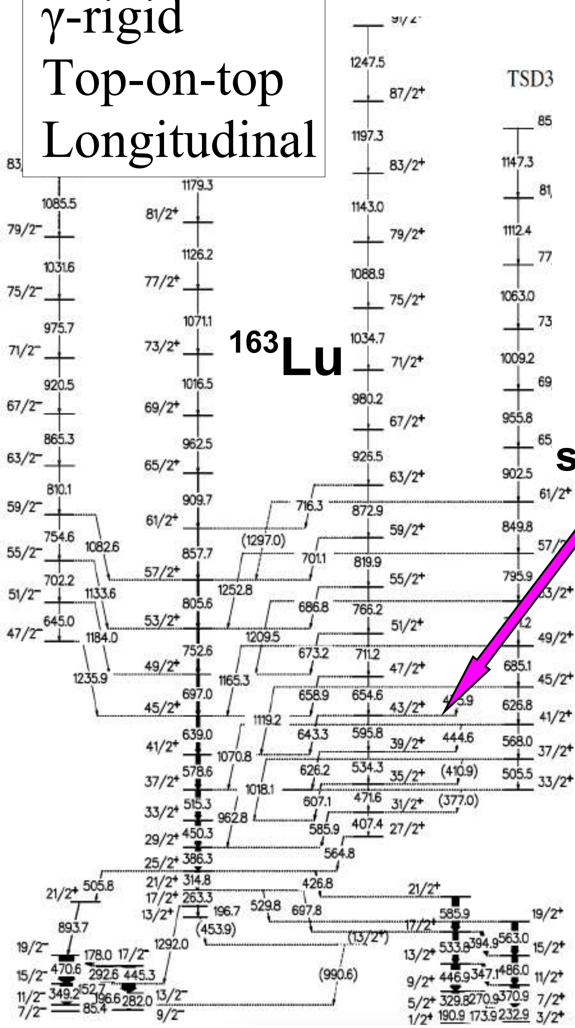


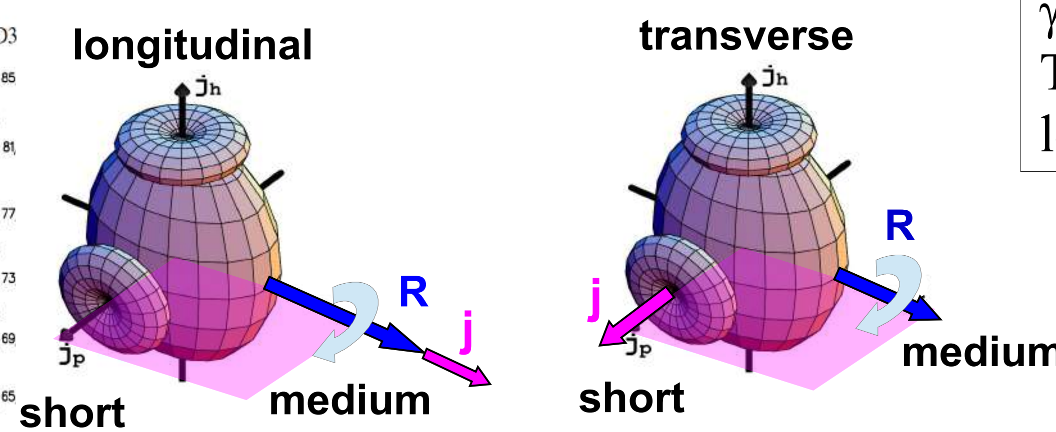

Reported wobbling bands

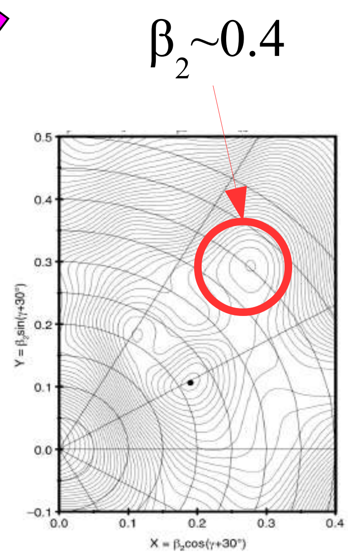
High spins
Large β_2
γ-rigid
Top-on-top
Longitudinal

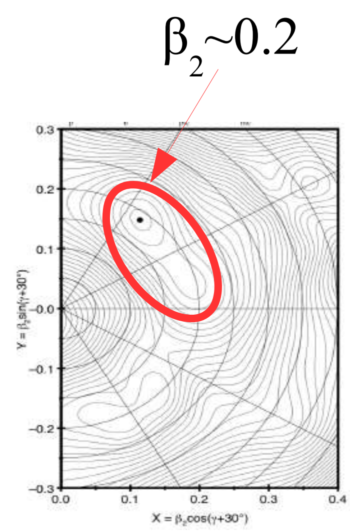


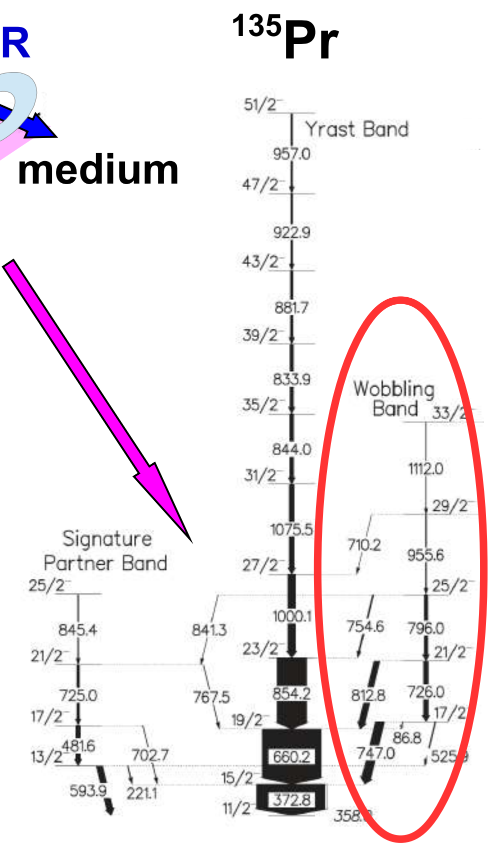
Low spins
Moderate β_2
γ-soft
Transverse or longitudinal







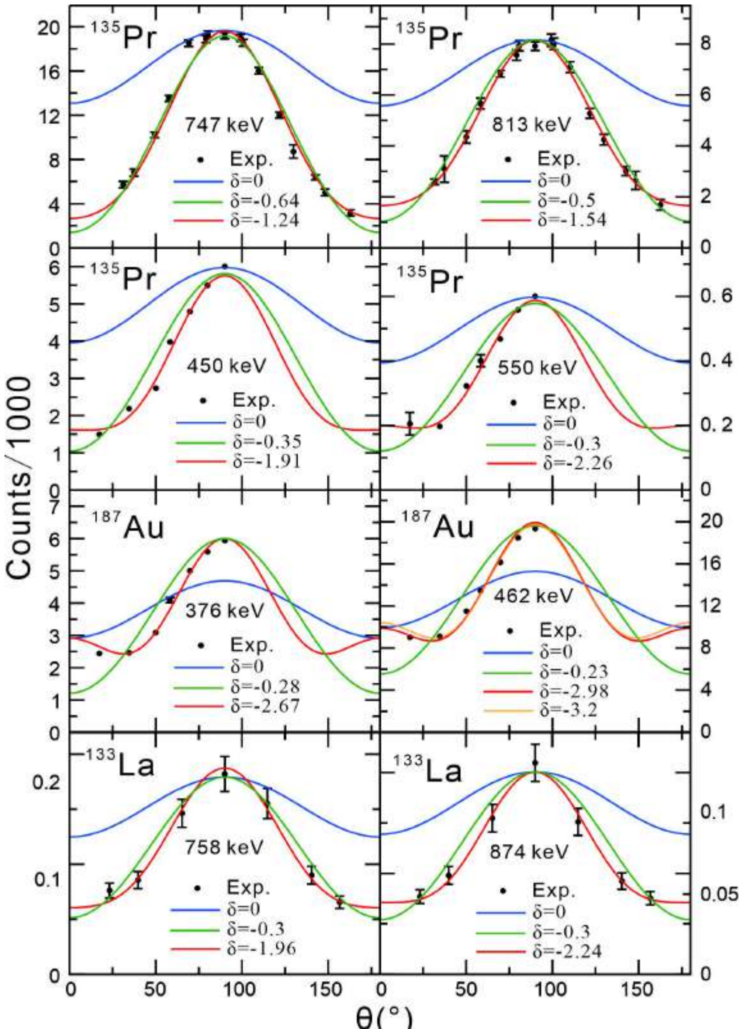




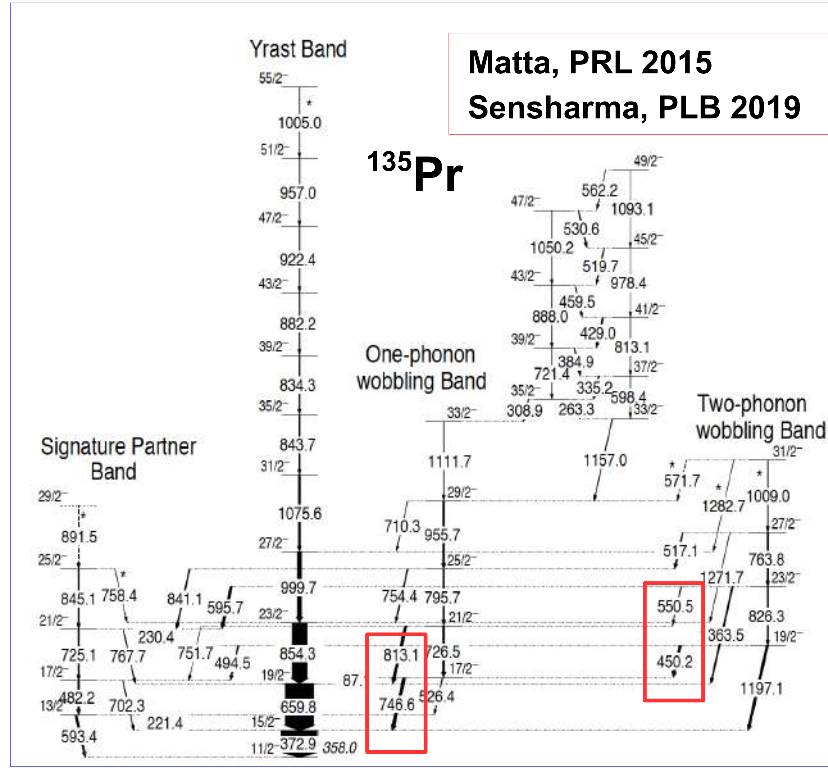
No wobbling at low spin !

Not easy to extract convincing mixing ratios from angular distributions of transitions with 10% relative intensities!

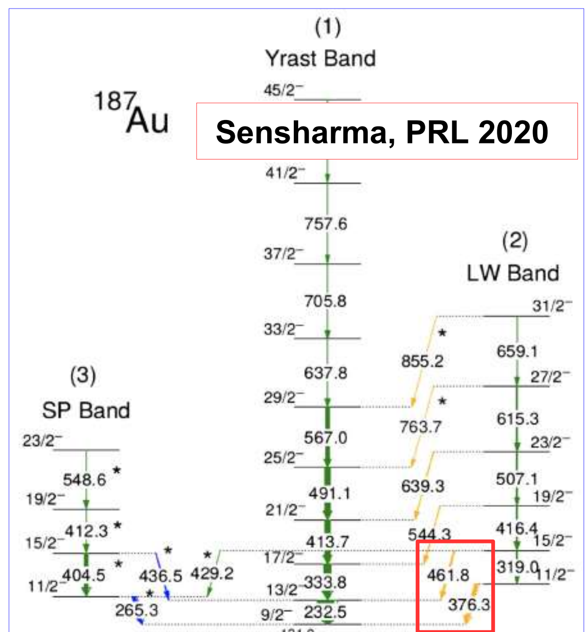
Polarization asymmetry has very large errors for weak transitions!



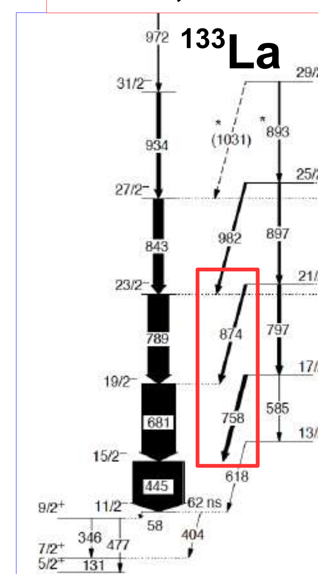
Matta, PRL 2015
Sensharma, PLB 2019



Sensharma, PRL 2020



Biswas, EPJA 2019



No wobbling at low spins, high risk of misinterpretation

PHYSICAL REVIEW C **101**, 034306 (2020)

Tilted precession and wobbling in triaxial nuclei

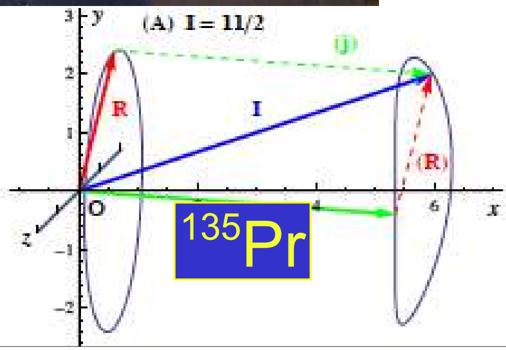
E. A. Lawrie[1,2,*] O. Shirinda[1,†] and C. M. Petrache[3,‡]

The wobbling approximation is valid if the rotational angular momenta around the two axes with lower MoI is small [16]:

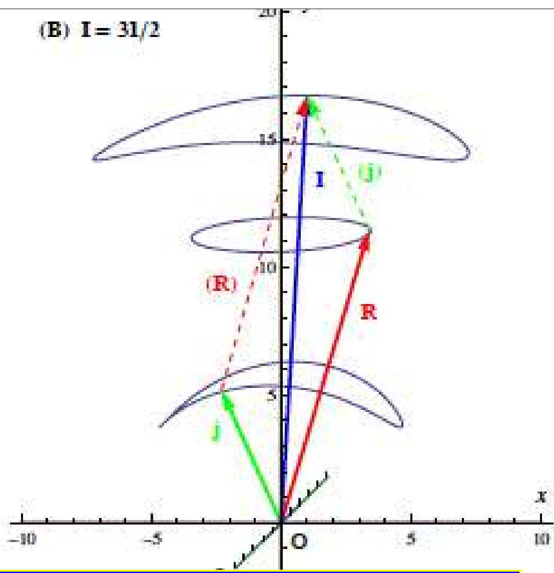
$$I_2^2 + I_3^2 \ll I^2, \quad (15)$$

a condition that can be rewritten as

$$f(n, I) = (2n+1)\frac{(A_2 + A_3 - 2A_1)}{2I\sqrt{(A_2 - A_1)(A_3 - A_1)}} \ll 1. \quad (16)$$

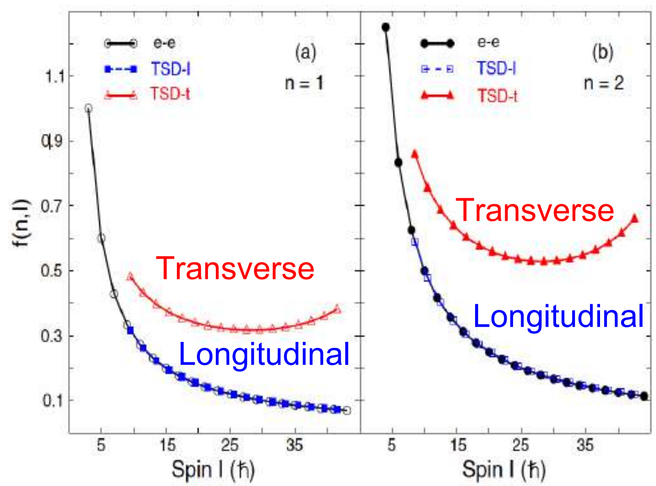


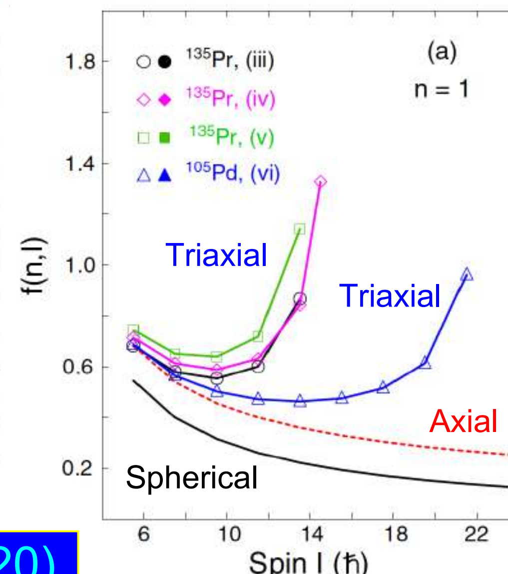
Revolving towards the medium axis
No stable transverse geometry !!!



Tanabe, PRC 95 (2017)

$A_1 = 1, A_2 = 4$, and $A_3 = 4$ are used





Lawrie, PRC 101 (2020)

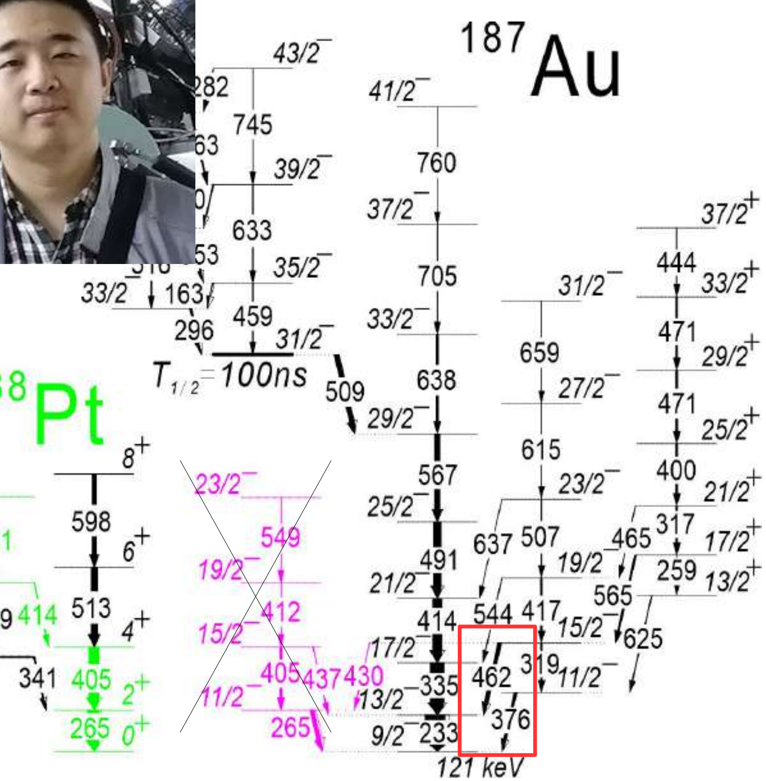
PHYSICAL REVIEW LETTERS **124,** 052501 (2020)

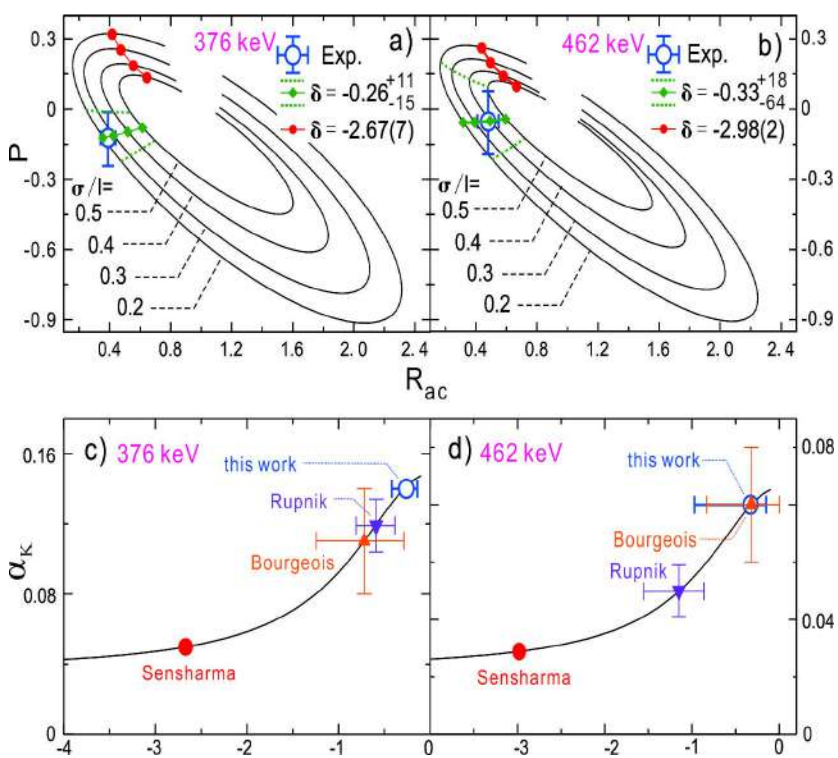
Editors' Suggestion | Featured in Physics

No wobbling in ^{187}Au !

Longitudinal Wobbling Motion in ^{187}Au

N. Sensharma,[1] U. Garg,[1] Q. B. Chen,[2] S. Frauendorf,[1] D. P. Burdette,[1] J. L. Cozzi,[1] K. B. Howard,[1] S. Zhu,[10] M. P. Carpenter,[3] P. Copp,[3] F. G. Kondev,[3] T. Lauritsen,[3] J. Li,[3] D. Seweryniak,[3] J. Wu,[3] A. D. Ayangeakaa,[4] D. J. Hartley,[4] R. V. F. Janssens,[5,6] A. M. Forney,[7] W. B. Walters,[7] S. S. Ghugre,[8] and R. Palit[9]

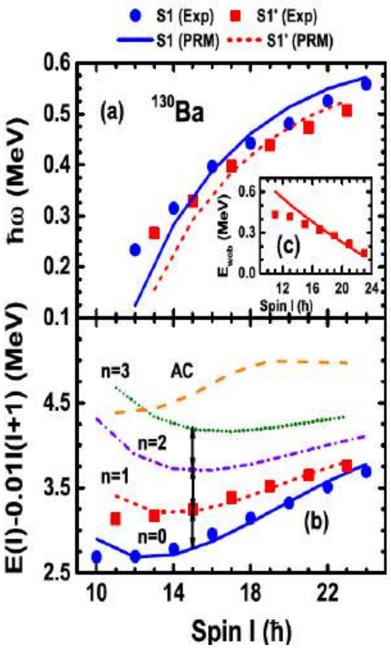




PHYSICAL REVIEW C 100, 061301(R) (2019)

Transverse wobbling in an even-even nucleus ^{130}Ba

Q. B. Chen[1,*], S. Frauendorf,[2,†] and C. M. Petrache[3,‡]



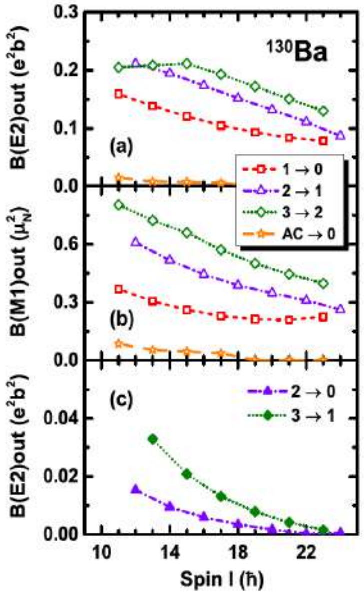
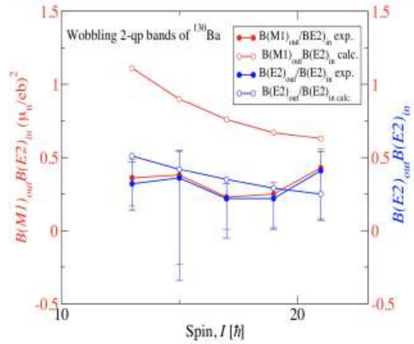
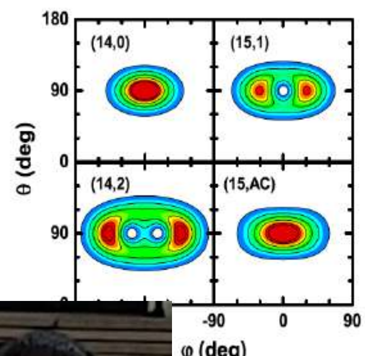
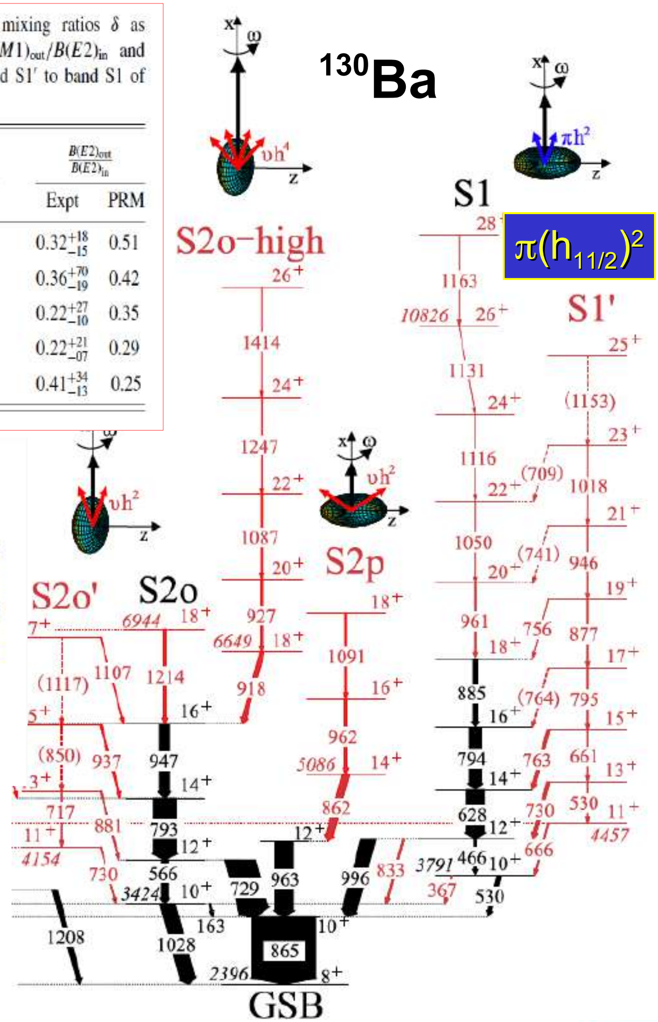


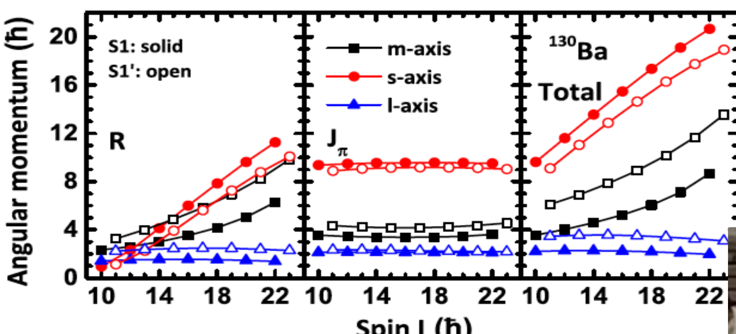
TABLE I. Experimental and theoretical mixing ratios δ as well as the transition probability ratios $B(M1)_{out}/B(E2)_{in}$ and $B(E2)_{out}/B(E2)_{in}$ for the transitions from band S1′ to band S1 of ^{130}Ba.

I (ħ)	δ Expt	δ PRM	$\frac{B(M1)_{out}}{B(E2)_{in}}(\frac{\mu_N^2}{e^2b^2})$ Expt	$\frac{B(M1)_{out}}{B(E2)_{in}}(\frac{\mu_N^2}{e^2b^2})$ PRM	$\frac{B(E2)_{out}}{B(E2)_{in}}$ Expt	$\frac{B(E2)_{out}}{B(E2)_{in}}$ PRM
13	-0.58^{+13}_{-13}	−0.67	0.36^{+19}_{-13}	1.11	0.32^{+18}_{-15}	0.51
15	-0.62^{+10}_{-10}	−0.68	0.38^{+61}_{-16}	0.90	0.36^{+70}_{-19}	0.42
17	-0.62^{+10}_{-10}	−0.68	0.23^{+22}_{-09}	0.76	0.22^{+27}_{-10}	0.35
19	−0.60	−0.66	0.25^{+23}_{-08}	0.67	0.22^{+21}_{-07}	0.29
21	−0.60	−0.63	0.43^{+35}_{-13}	0.63	0.41^{+34}_{-13}	0.25









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Two quasiparticle wobbling in the even-even nucleus ^{130}Ba

Y.K. Wang[a], F.Q. Chen[b], P.W. Zhao[a,*]

Physics Letters B 802 (2020) 135246

Diversity of shapes and rotations in the γ-soft ^{130}Ba nucleus: First observation of a t-band in the $A = 130$ mass region

C.M. Petrache[a,*], P.M. Walker[b], S. Guo[c,d,*], Q.B. Chen[e], S. Frauendorf[f], Y.X. Liu[g], R.A. Wyss[h], D. Mengoni[i], Y.H. Qiang[c], A. Astier[a], E. Dupont[a], R. Li[a], B.F. Lv[a], K.K. Zheng[a], D. Bazzacco[i], A. Boso[i], A. Goasduff[i], F. Recchia[i], D. Testov[i], F. Galtarossa[j], G. Jaworski[j], D.R. Napoli[j], S. Riccetto[j], M. Siciliano[j,k], J.J. Valiente-Dobon[j], M.L. Liu[c,d], X.H. Zhou[c,d], J.G. Wang[c], C. Andreoiu[l], F.H. Garcia[l], K. Ortner[l], K. Whitmore[l], T. Bäck[h], B. Cederwall[h], E.A. Lawrie[m], I. Kuti[n], D. Sohler[n], J. Timár[n], T. Marchlewski[o], J. Srebrny[o], A. Tucholski[o]

Microscopic investigation on the existence of transverse wobbling under the effect of rotational alignment: the ^{136}Nd case

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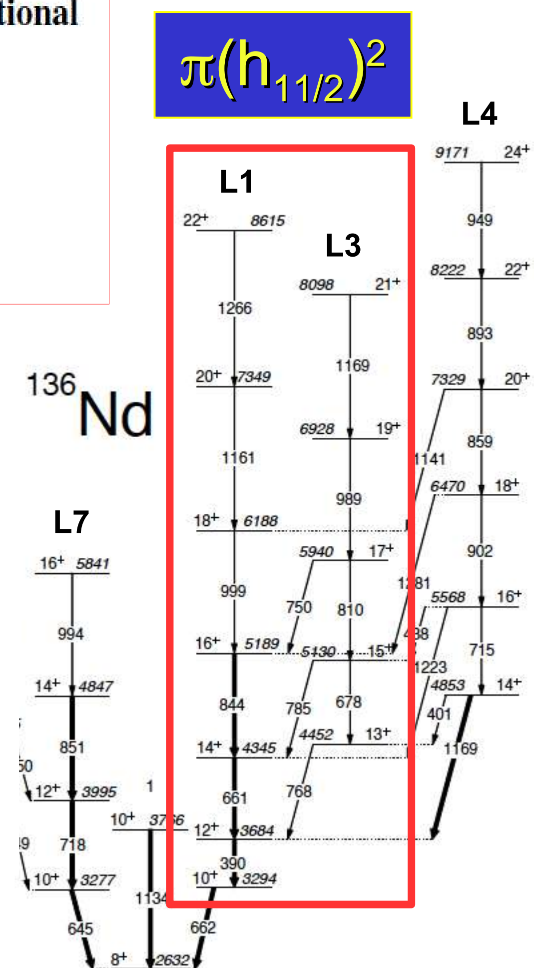
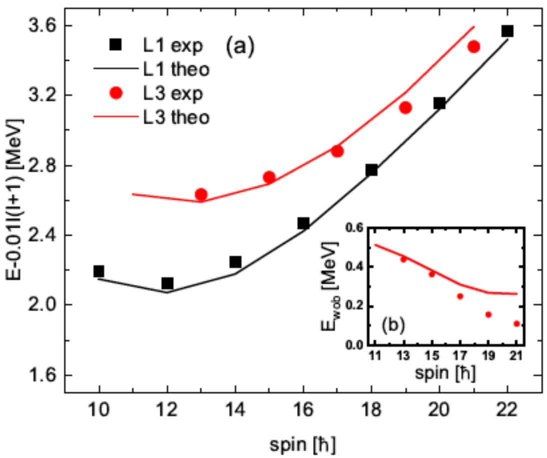
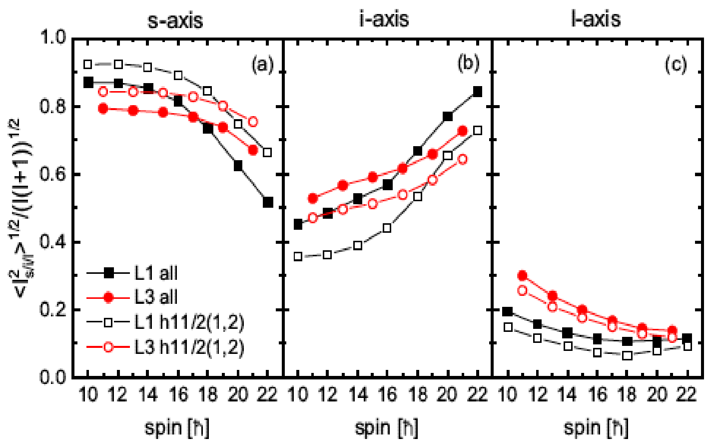
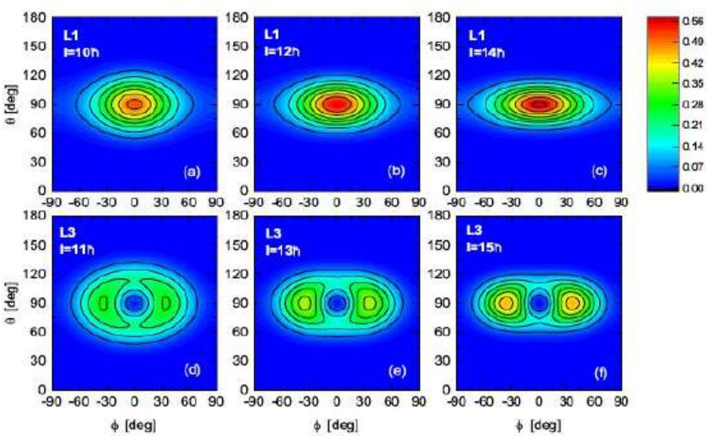
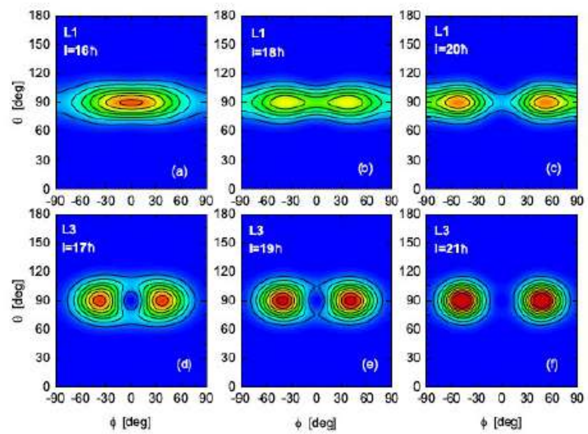
(Dated: November 11, 2020)











Risk of misinterpretation of low-spin bands in odd-even nuclei as wobbling bands instead of Tilted Precession (TiP) bands

Wobbling at low spins? => NO: not supported by experiment and by theory

^{135}Pr – no wobbling (1 PLB & 1 PRL submitted)

^{187}Au – no wobbling (1 PLB submitted)

Tilted Precession at low spin in general – PRC 101, 034306 (2020)

Tilted Precession at low spin in ^{135}Nd – PRC 103, 044308 (2021)

2-qp wobbling at high spins => YES

2-qp wobbling in ^{130}Ba – PRC 100, 061301(R) (2019)

2-qp wobbling in ^{136}Nd – PRC submitted

Challenges and perspectives for chiral and wobbling bands, and shape coexistence

Chirality

New types of chiral motion.

Robustness of chirality against other broken symmetries.

Wobbling

- Consolidate the experimental results, which at present are NOT conclusive, but only SUGGEST the possible existence of low-spin wobbling bands!
- Measurement of mixing ratios with very high precision, therefore high statistics, which imply long beam times and/or very high efficiency setups.

Shape coexistence – new regions, global view

Thank you !