CWAN’23 Chirality and Wobbling in Atomic Nuclei
July 10-14, 2023 Huizhou, China

Collective multiple chiral and wobbling bands in transitional systems

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Outline

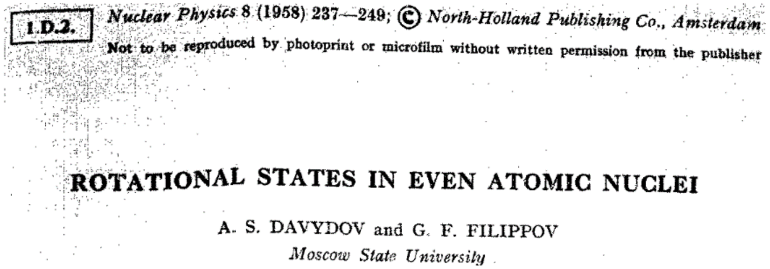
I. Motivation: Triaxiality and Transitional (Critical point) structures

II. T(4) critical point symmetry

III. An example

IV. Conclusion

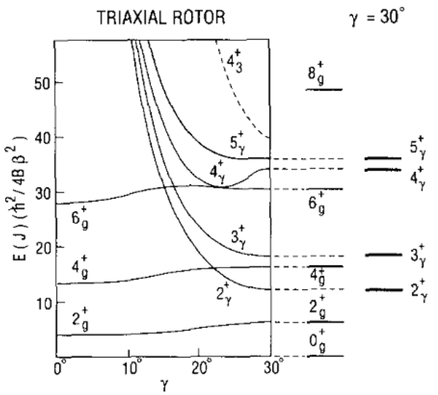
Triaxiality



I.D.2. Nuclear Physics 8 (1958) 237—249; © North-Holland Publishing Co., Amsterdam

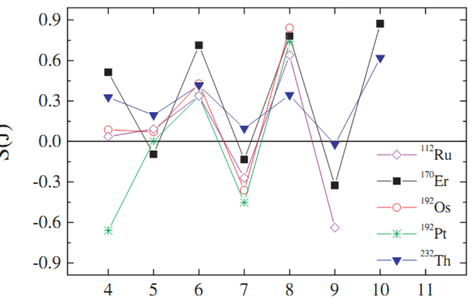
ROTATIONAL STATES IN EVEN ATOMIC NUCLEI

A. S. DAVYDOV and G. F. FILIPPOV
Moscow State University



$$\frac{\{E(J_\gamma^+)-E[(J-1)_\gamma^+]\}-\{E[(J-1)_\gamma^+]-E[(J-2)_\gamma^+]\}}{E(2_1^+)}$$

minima at odd J



PHYSICAL REVIEW C 76, 024306 (2007)

ggering in γ-band energies and the transition between different structural symmetries in nuclei

E. A. McCutchan,[1,*] Dennis Bonatsos,[2,†] N. V. Zamfir,[3,‡] and R. F. Casten[1,§]

γ rigid mode

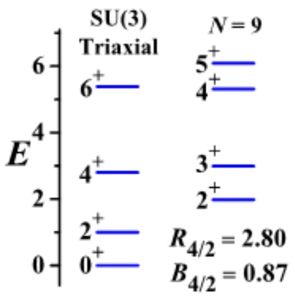
Even

Odd

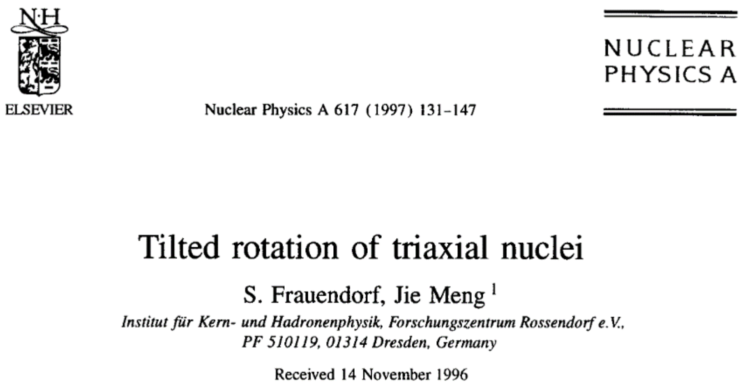
$$H=\sum_{k=1}^{3}\frac{R_k^2}{2J_k}$$

$$J_k=J\sin^2\left(\gamma-\frac{2k\pi}{3}\right)$$

New feature for triaxiality



Physics Letters B 834 (2022) 137443



ELSEVIER
Nuclear Physics A 617 (1997) 131–147
NUCLEAR PHYSICS A

Tilted rotation of triaxial nuclei

S. Frauendorf, Jie Meng [1]
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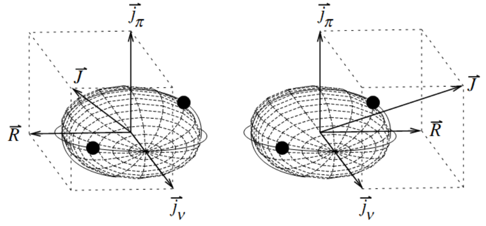
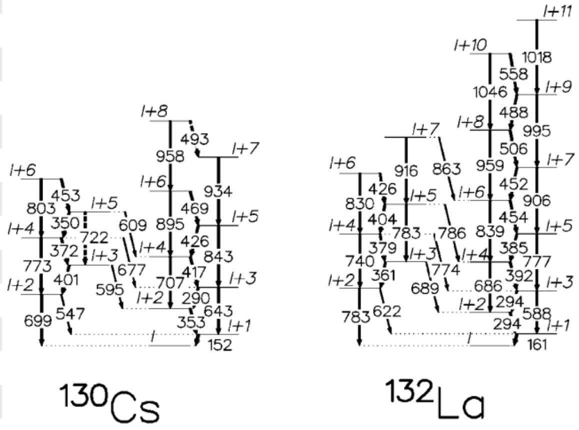
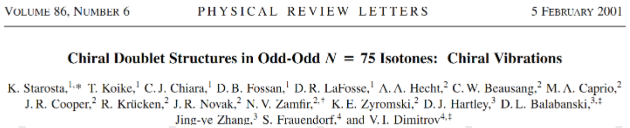
Received 14 November 1996





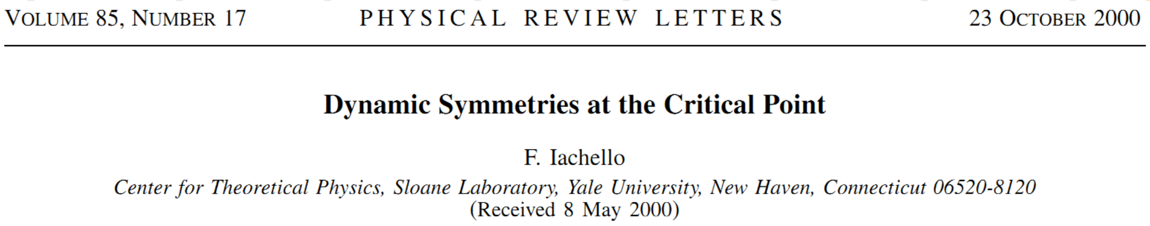


VOLUME 86, NUMBER 6 PHYSICAL REVIEW LETTERS 5 FEBRUARY 2001

Chiral Doublet Structures in Odd-Odd $N = 75$ Isotones: Chiral Vibrations

K. Starosta,[1,*] T. Koike,[1] C. J. Chiara,[1] D. B. Fossan,[1] D. R. LaFosse,[1] A. A. Hecht,[2] C. W. Beausang,[2] M. A. Caprio,[2] J. R. Cooper,[2] R. Krücken,[2] J. R. Novak,[2] N. V. Zamfir,[2,†] K. E. Zyromski,[2] D. J. Hartley,[3] D. L. Balabanski,[3,‡] Jing-ye Zhang,[3] S. Frauendorf,[4] and V. I. Dimitrov[4,‡]

Critical point structure



VOLUME 85, NUMBER 17 PHYSICAL REVIEW LETTERS 23 OCTOBER 2000

Dynamic Symmetries at the Critical Point

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(Received 8 May 2000)

$$u(\beta) = \beta^2 + \eta[(1-\beta^2)^2 + \chi\beta^3]$$

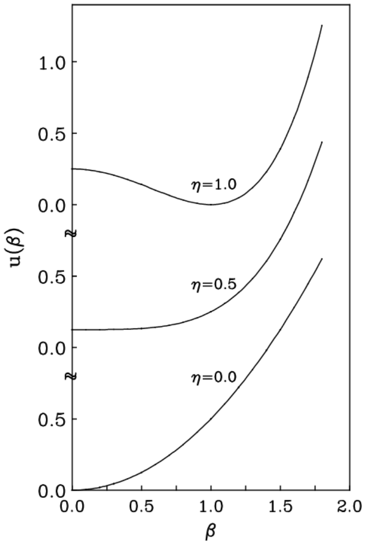
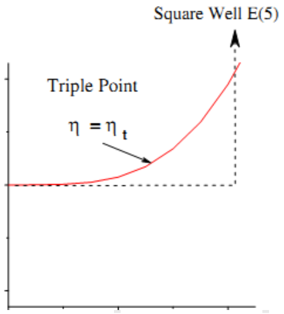


FIG. 2. Potential energy surfaces for the U(5)-SO(6) shape phase transitions obtained from the interacting boson model Hamiltonian by the method of "group" coherent states.

β Soft mode



R.F. Casten / Progress in Particle and Nuclear Physics 62 (2009) 183–209

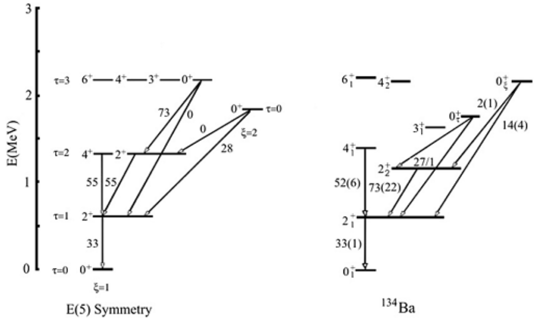


Fig. 19. Low-lying levels of *E*(5) (from Ref. [29]) compared with the data for ^{134}Ba. Based on Ref. [35].

Even

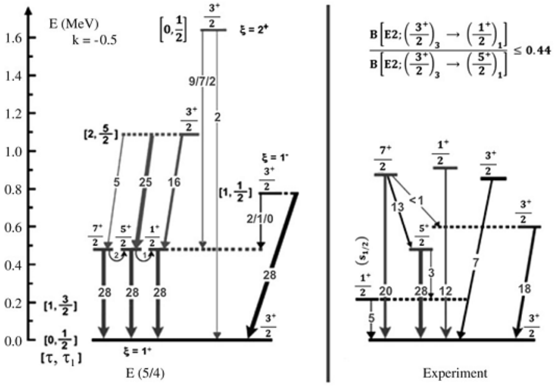


Fig. 20. Comparison of *E*(5/4) with the low-lying levels and transitions in ^{135}Ba. Based on Ref. [85].

Odd A

Nuclear Shape Phase Transition and CPS models

$$H = -\frac{\hbar^2}{2B}\left[\frac{1}{\beta^4}\frac{\partial}{\partial\beta}\beta^4\frac{\partial}{\partial\beta} + \frac{1}{\beta^2\sin3\gamma}\frac{\partial}{\partial\gamma}\sin3\gamma\frac{\partial}{\partial\gamma} - \frac{1}{4\beta^2}\sum_{\kappa}\frac{Q_\kappa^2}{\sin^2(\gamma-\frac{2}{3}\pi\kappa)}\right] + V(\beta,\gamma).$$

$$V(\beta,\gamma) = V(\beta) + V(\gamma)$$

$$V(\beta) = \begin{cases} 0, & \beta \le \beta_W, \\ \infty, & \beta > \beta_W, \end{cases} \qquad V(\gamma) = \frac{1}{2}C(\gamma-\gamma_e)^2$$

Critical point symmetry (CPS)

E(5) , X(5), Iachello, PRL 85,3580 (2000); PRL87,052502 (2001)

Z(5), Bonatsos, et al., PLB 588,172(2004)

T(5), Zhang, et al., PLB 751,423(2013)

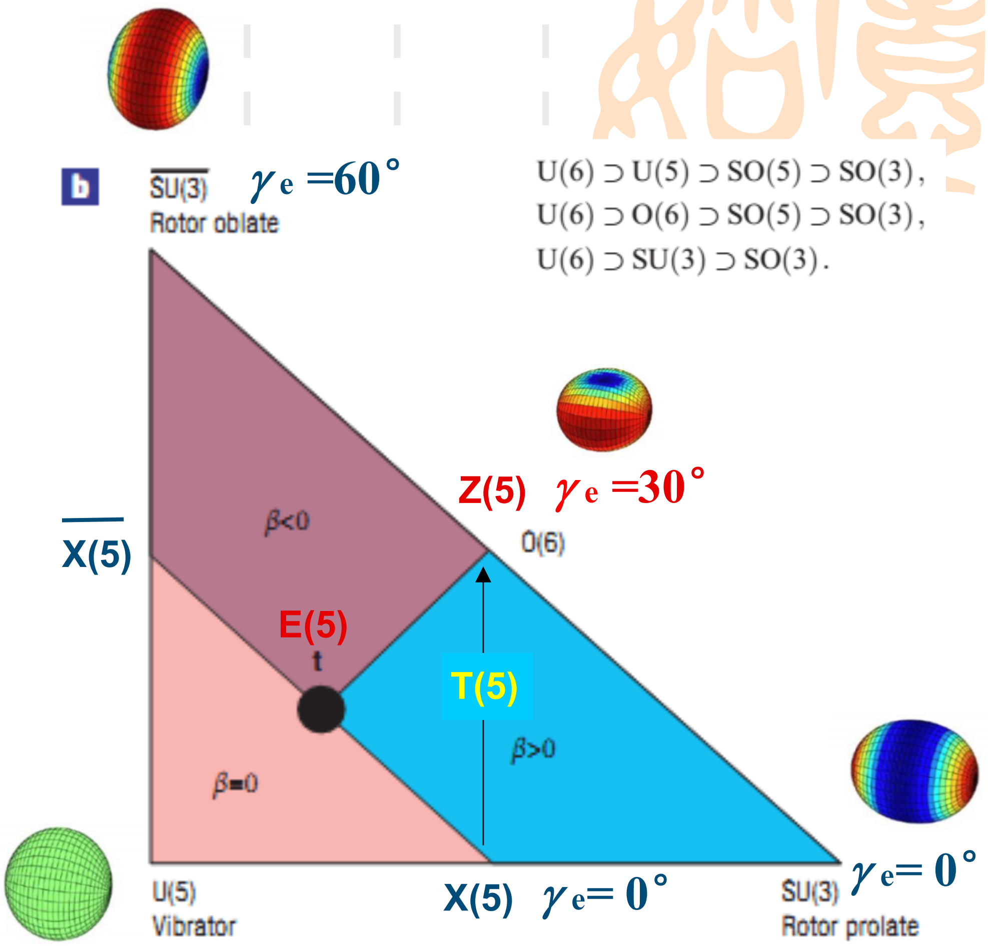
…

γ rigid solutions

X(4), R. Budaca, A.I. Budaca, PLB 759,349(2016)

X(3), Z(4), Bonatsos, et al., 621,102(2005); PLB 632,238(2006)

T(4), Zhang, et al., PRC 96.034323(2017)

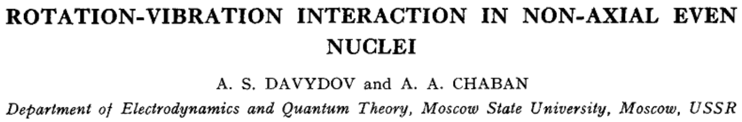


$$\mathrm{U}(6) \supset \mathrm{U}(5) \supset \mathrm{SO}(5) \supset \mathrm{SO}(3),$$
$$\mathrm{U}(6) \supset \mathrm{O}(6) \supset \mathrm{SO}(5) \supset \mathrm{SO}(3),$$
$$\mathrm{U}(6) \supset \mathrm{SU}(3) \supset \mathrm{SO}(3).$$

R. F. Casten, Nat. Phys. **2**, 811 (2006).

Triaxial critical point symmetry

----- A bridge between "β-soft" QPT and "γ-rigid" Triaxiality



ROTATION-VIBRATION INTERACTION IN NON-AXIAL EVEN NUCLEI

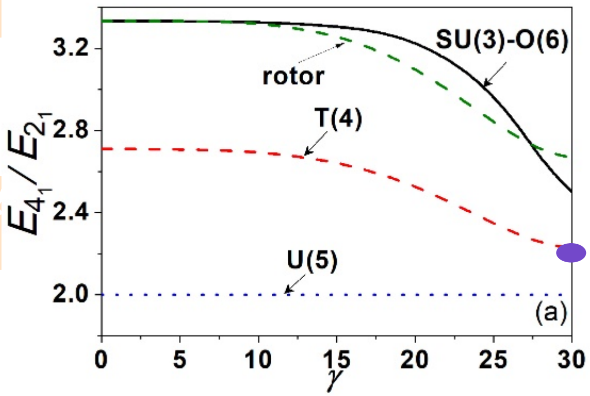
A. S. DAVYDOV and A. A. CHABAN

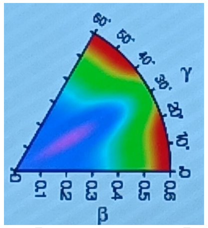
Department of Electrodynamics and Quantum Theory, Moscow State University, Moscow, USSR

T(4), YZ, Pan, Liu, et al., PRC 96,034323(2017)

$$H=-\frac{\hbar^2}{2B}\left[\frac{1}{\beta^3}\frac{\partial}{\partial\beta}\beta^3\frac{\partial}{\partial\beta}-\frac{1}{4\beta^2}\sum_k\frac{L'^2_k}{\sin^2\left(\gamma-\frac{2}{3}k\pi\right)}\right]$$
$$+U(\beta),$$

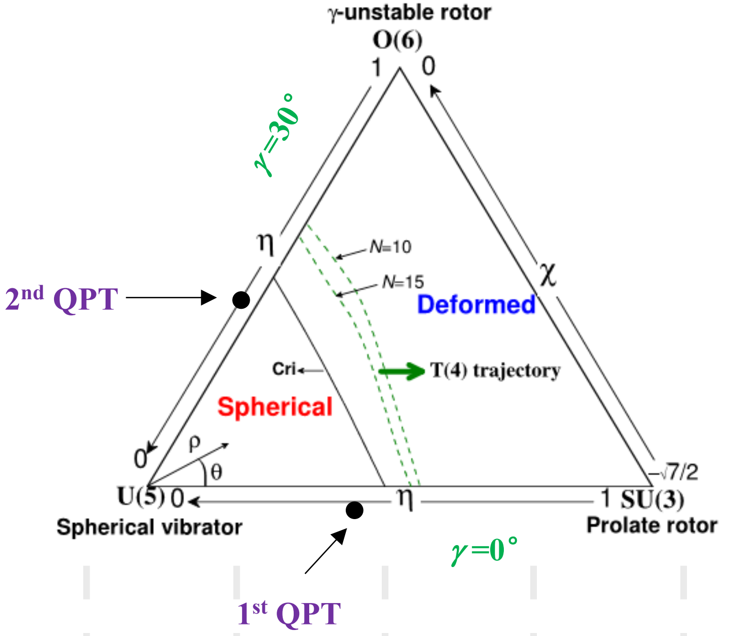
$$U(\beta)=\begin{cases}0, & \beta\leqslant\beta_W\\ \infty, & \beta>\beta_W\end{cases}$$





T(4) CPS = An exactly solvable β-soft rotor

J. Phys. G: Nucl. Part. Phys. **46** (2019) 045101 (12pp)



$$\mathrm{U}(6)\supset\mathrm{U}(5)\supset\mathrm{SO}(5)\supset\mathrm{SO}(3),$$
$$\mathrm{U}(6)\supset\mathrm{O}(6)\supset\mathrm{SO}(5)\supset\mathrm{SO}(3),$$
$$\mathrm{U}(6)\supset\mathrm{SU}(3)\supset\mathrm{SO}(3).$$

For example: one control parameter $\gamma\sim9^\circ-27^\circ$:
Nd150, Yb160, Xe126, Pd108, Xe128, Zn62

T(4) CPS for odd systems

Core + particle coupling formulas: $\hat{H} = \hat{H}_{\mathrm{T(4)}} + \hat{H}_{\mathrm{sp}}$

1 Core: $$\hat{H}_{\mathrm{T(4)}} = -\frac{\hbar^2}{2B}\left[\frac{1}{\beta^3}\frac{\partial}{\partial\beta}\beta^3\frac{\partial}{\partial\beta} - \frac{1}{4\beta^2}\frac{1}{4}\sum_k \frac{\hat{L}_k^2}{\sin^2(\gamma - \frac{2}{3}k\pi)}\right] + U(\beta),$$

$$U(\beta) = \begin{cases} 0, & \beta \leqslant \beta_W \\ \infty, & \beta > \beta_W \end{cases}$$

$$\hat{I} = \hat{L} + \hat{j}_{\mathrm{p}} + \hat{j}_{\mathrm{n}}$$

2 Particle: $$\hat{H}_\sigma = \hat{H}_0 + kr^2\beta\left[\cos(\gamma)Y_{20} + \frac{\sin(\gamma)}{\sqrt{2}}(Y_{22} + Y_{2-2})\right]$$

Single-*j*: $$\begin{aligned}\hat{H}_{\mathrm{sp}} &= \hat{H}_{\mathrm{p}} + \hat{H}_{\mathrm{n}} \\ &= E_0 + \sum_{\sigma=\mathrm{p,n}} C_\sigma\left\{\left[\hat{j}^2_{\sigma 3} - \frac{j_\sigma(j_\sigma+1)}{3}\right]\cos(\gamma) \right. \\ &\quad \left. + \frac{1}{2\sqrt{3}}\left[\hat{j}^2_{\sigma+} + \hat{j}^2_{\sigma-}\right]\sin(\gamma)\right\},\end{aligned}$$

$$C_\sigma = \pm\frac{195}{2j_\sigma(j_\sigma+1)}A^{-1/3}\bar{\beta} \qquad \bar{\beta} \equiv \langle\beta\rangle$$

3 Eigenvalue equation : $\hat{H}\Psi = E\Psi$

$$\left[R + \hat{h}_{\mathrm{sp}}\right]\varphi(\theta_i, a_{\mathrm{p}}, a_{\mathrm{n}}) = r\varphi(\theta_i, a_{\mathrm{p}}, a_{\mathrm{n}})$$

$$R \equiv \sum_{k=1}^{3}\left.\frac{\hat{L}_k^2}{4\sin^2(\gamma - \frac{2}{3}k\pi)}\right|_{\gamma\simeq\gamma_e} \qquad \hat{h}_{\mathrm{sp}} = 2B\beta^2\hat{H}_{\mathrm{sp}}/\hbar^2$$

$$\frac{d^2F}{dz^2} + \frac{1}{z}\frac{dF}{dz} + \left[1 - \frac{v^2}{z^2}\right]F = 0 \qquad v_s = \sqrt{r_s + 1}$$

4 Solution:

$$\Psi = \frac{1}{\beta}F(\beta)\varphi(\theta_i, a_{\mathrm{p}}, a_{\mathrm{n}}) \qquad E = \frac{\hbar^2}{2B\beta_W^2}x^2_{\xi,s}$$

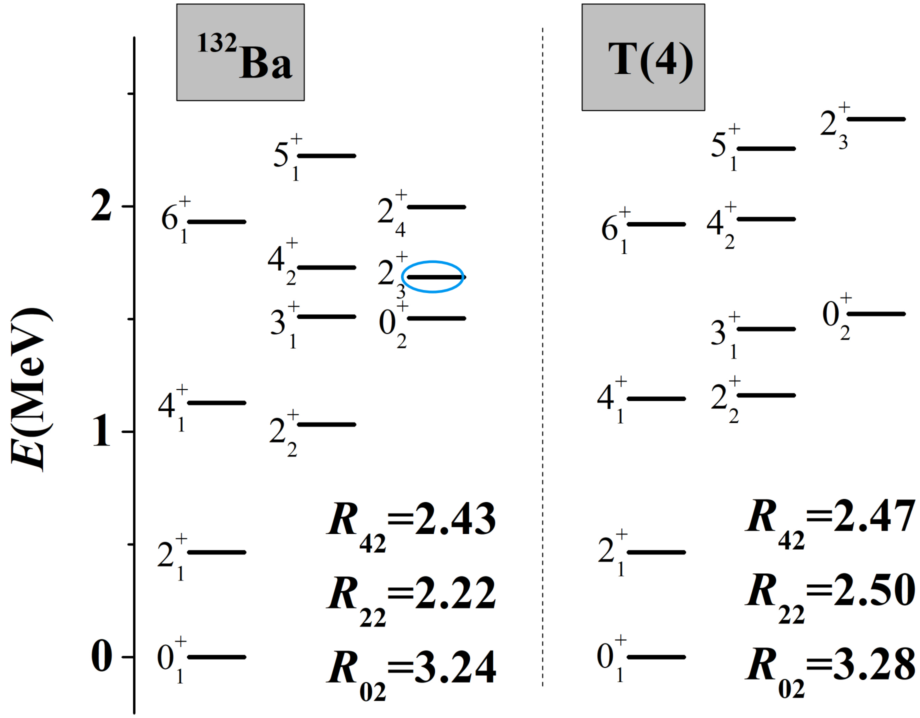
"*x*" is the zeros of the Bessel functions, which generate the representation basis for the Euclidean group, like in the other CPS models.

The other extensions:

1, odd-odd by T(4) →T(5): **Science China, Phys. Mech. Astron. 64,122011 (2021)**

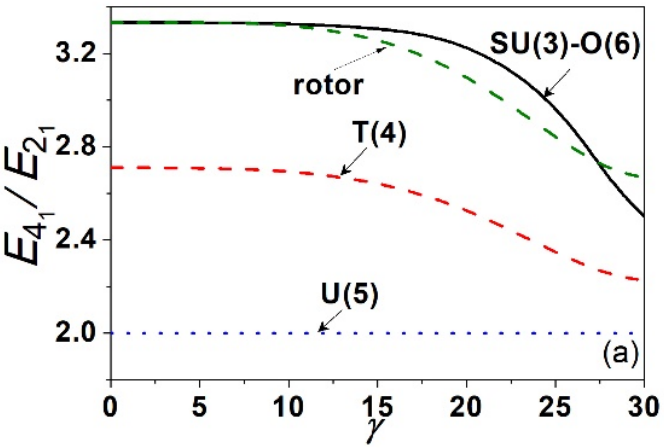
2, odd-A by $\hat{H}_{\mathrm{sp}}=\hat{H}_0$: **Nucl. Phys. A 987, 90 (2019)**

An example : even-even core fixing the parameters



R_{42}=2.43
R_{22}=2.22
R_{02}=3.24

R_{42}=2.47
R_{22}=2.50
R_{02}=3.28



R42 **≥ 2.66**
For irrotational flow rotor

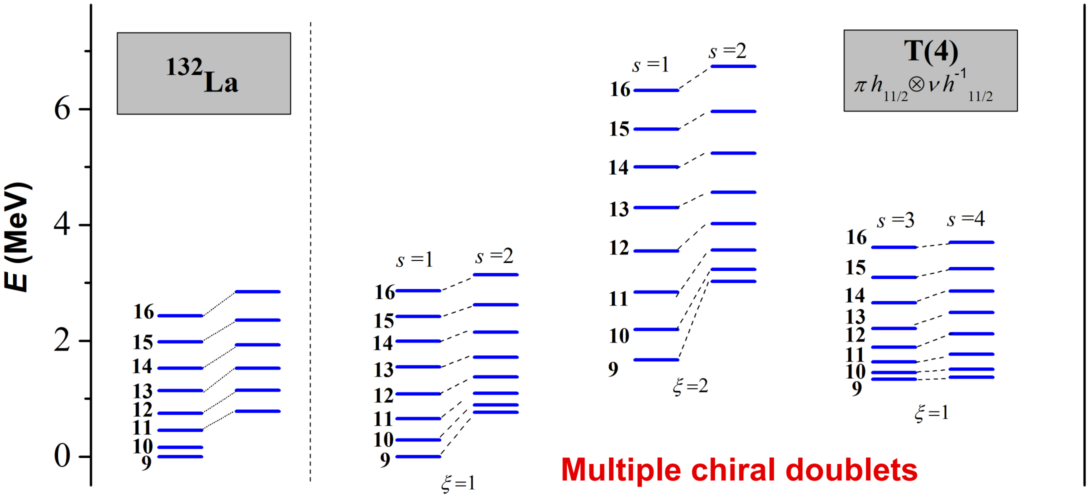
Nuclear Physics A 697 (2002) 75–91

All parameters: $B = 170\text{MeV}^{-1}, \beta_w = 0.255, \gamma = 22^\circ$

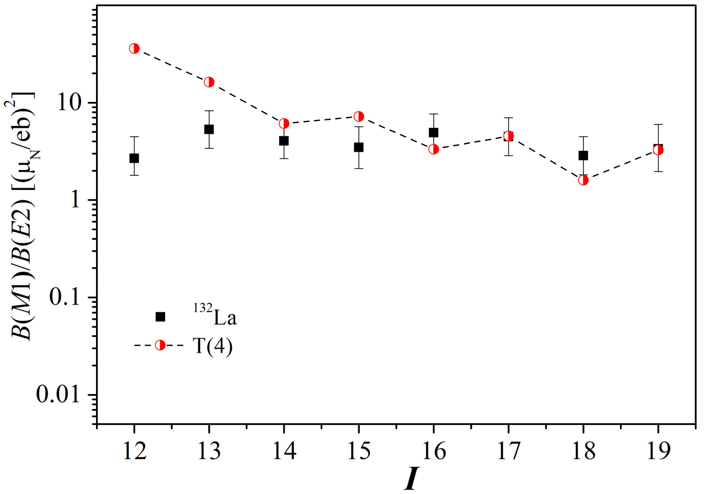
$$\Downarrow$$

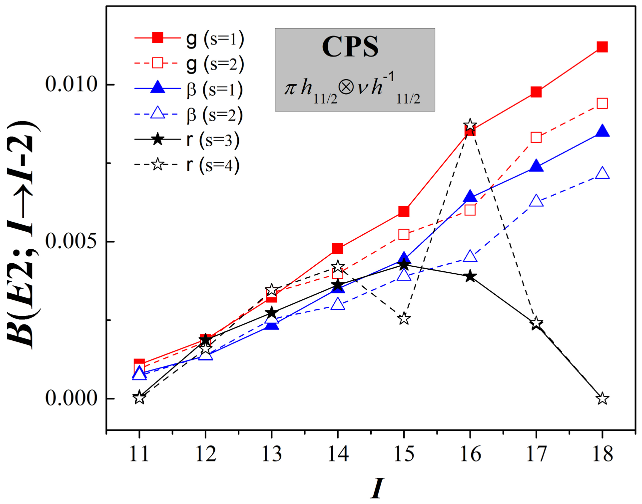
Average β deformation: $\bar{\beta}=0.17$

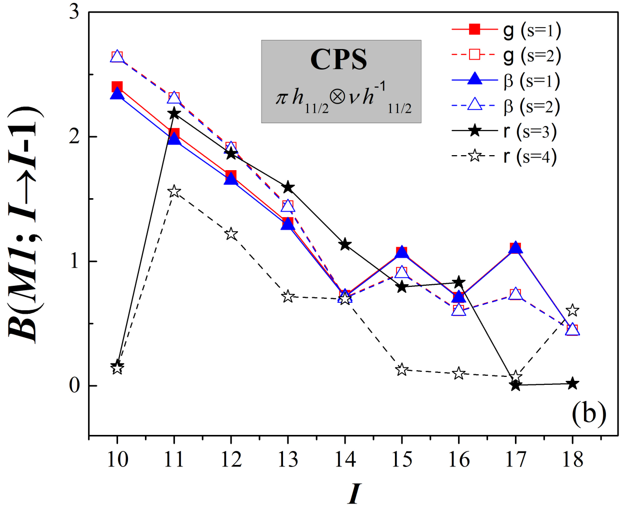
An example: odd-odd with particle + hole configuration



Multiple chiral doublets







β vibration of chiral doublets

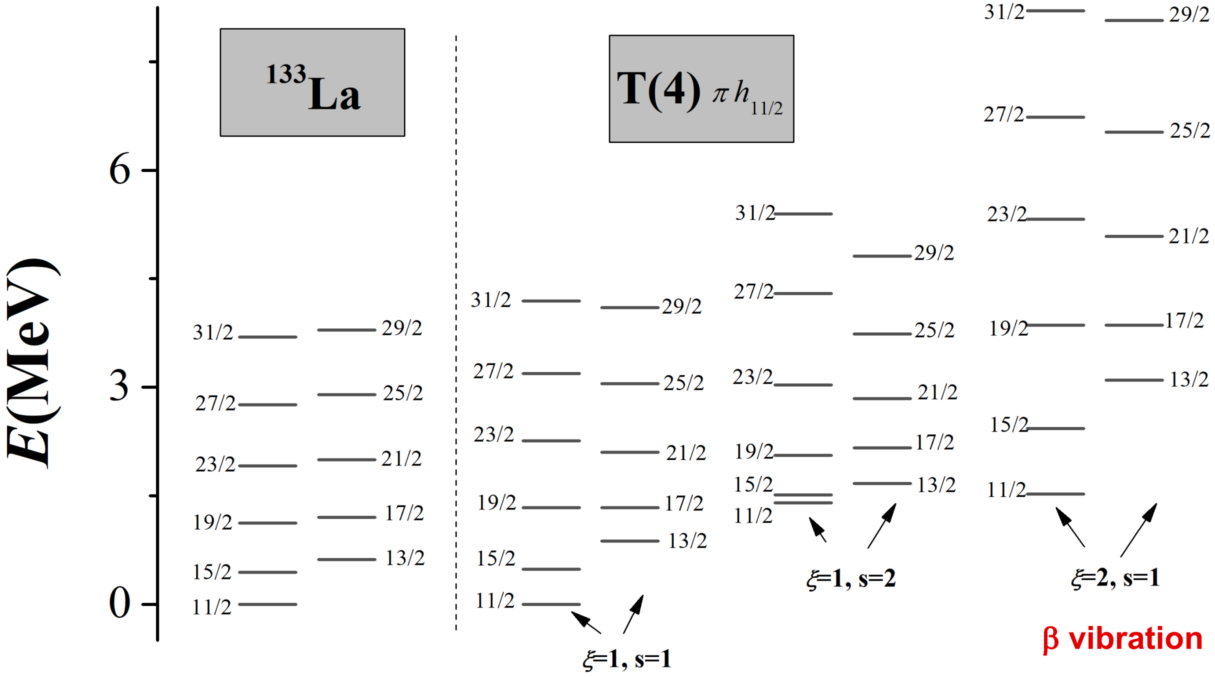
$$\hat{Q}_{2\mu} = \mathcal{D}^{2*}_{\mu 0}\hat{Q}'_{20} + \left(\mathcal{D}^{2*}_{\mu 2} + \mathcal{D}^{2*}_{\mu -2}\right)\hat{Q}'_{22}$$

$$\hat{T}^{M}_{u} = \sqrt{\frac{3}{4\pi}}\frac{e\hbar}{2Mc}\left[(g_{\mathrm{p}} - g_R)\hat{j}_{\mathrm{p}u} + (g_{\mathrm{n}} - g_R)\hat{j}_{\mathrm{n}u}\right]$$

β + γ vibration:

ZY, B. Qi, S.Q. Zhang
Science China-Phys. Mech. Astron
(2021) 64:122011

An example: odd A with one particle configuration



β vibration

Multiple wobbling bands

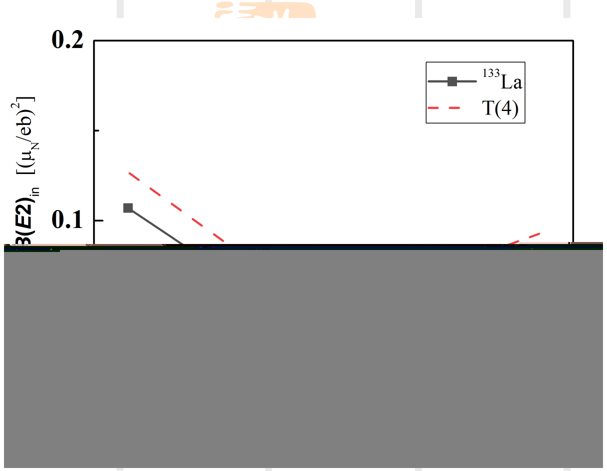
Eur. Phys. J. A (2019) **55**: 159
DOI 10.1140/epja/i2019-12856-5

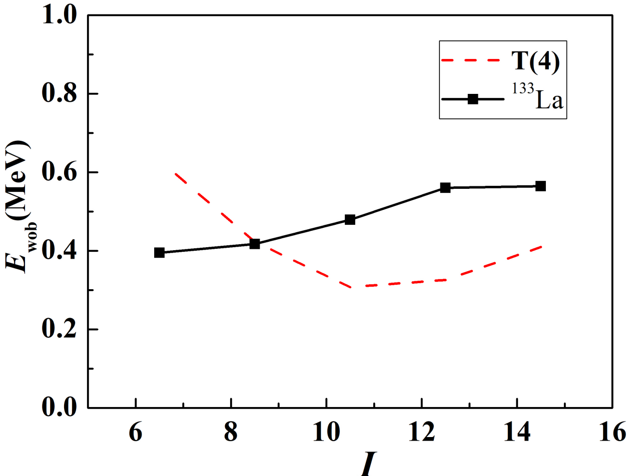
THE EUROPEAN PHYSICAL JOURNAL A

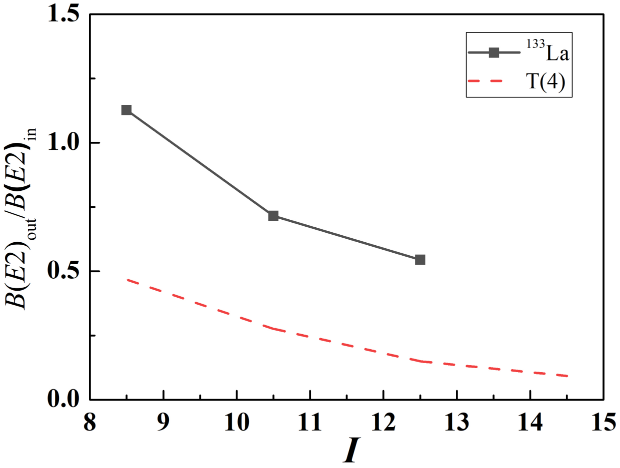
Regular Article – Experimental Physics

Longitudinal wobbling in ^{133}La

S. Biswas[1], R. Palit[1,a], S. Frauendorf[2], U. Garg[2], W. Li[2], G.H. Bhat[3,4], J.A. Sheikh[3,4], J. Sethi[1], S. Saha[1], Purnima Singh[1], D. Choudhury[1], J.T. Matta[2], A.D. Ayangeakaa[2], W.A. Dar[3], V. Singh[5], and S. Sihotra[5]







Conclusion

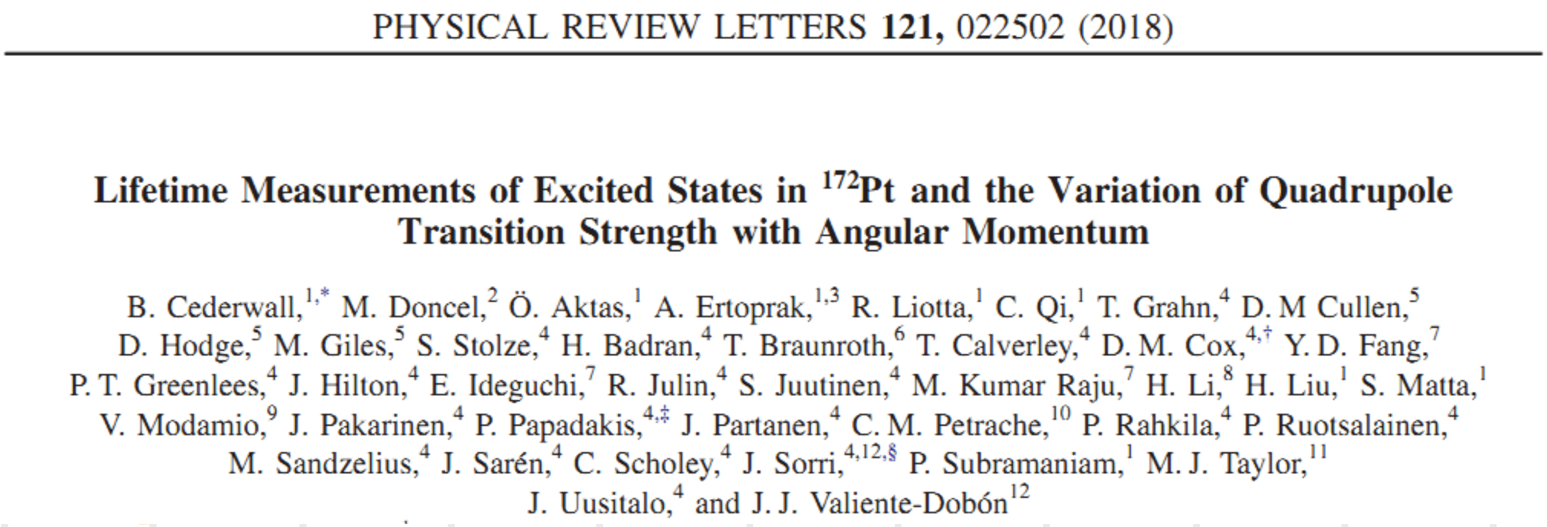
A) The CPS method is extended to present a unified description of even and odd mass nuclei through the core-coupling scheme, by which a link between language of shape transition and chiral/wobbling is provided.

B) It seems that beta-soft cannot affect the basic features of chiral and wobbling-like modes induced by gamma-rigid triaxiality.

C) Within the present collective model, collective vibration of the chiral and wobbling bands are allowed.

Thank You!

Neutron-deficient nuclei: Normal and Abnormal



PHYSICAL REVIEW LETTERS **121,** 022502 (2018)

Lifetime Measurements of Excited States in ^{172}Pt and the Variation of Quadrupole Transition Strength with Angular Momentum

B. Cederwall,[1,*] M. Doncel,[2] Ö. Aktas,[1] A. Ertoprak,[1,3] R. Liotta,[1] C. Qi,[1] T. Grahn,[4] D. M Cullen,[5] D. Hodge,[5] M. Giles,[5] S. Stolze,[4] H. Badran,[4] T. Braunroth,[6] T. Calverley,[4] D. M. Cox,[4,†] Y. D. Fang,[7] P. T. Greenlees,[4] J. Hilton,[4] E. Ideguchi,[7] R. Julin,[4] S. Juutinen,[4] M. Kumar Raju,[7] H. Li,[8] H. Liu,[1] S. Matta,[1] V. Modamio,[9] J. Pakarinen,[4] P. Papadakis,[4,‡] J. Partanen,[4] C. M. Petrache,[10] P. Rahkila,[4] P. Ruotsalainen,[4] M. Sandzelius,[4] J. Sarén,[4] C. Scholey,[4] J. Sorri,[4,12,§] P. Subramaniam,[1] M. J. Taylor,[11] J. Uusitalo,[4] and J. J. Valiente-Dobón[12]

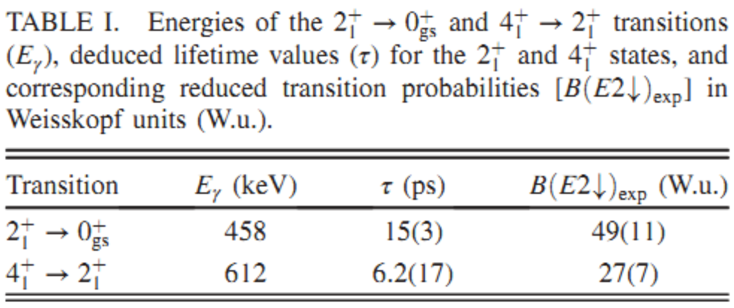
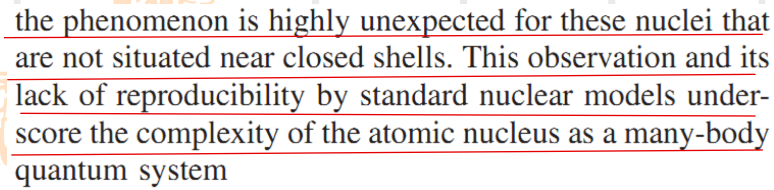


TABLE I. Energies of the $2_1^+ \to 0_{gs}^+$ and $4_1^+ \to 2_1^+$ transitions (E_γ), deduced lifetime values (τ) for the 2_1^+ and 4_1^+ states, and corresponding reduced transition probabilities [$B(E2\downarrow)_{exp}$] in Weisskopf units (W.u.).

Transition	E_γ (keV)	τ (ps)	$B(E2\downarrow)_{exp}$ (W.u.)
$2_1^+ \to 0_{gs}^+$	458	15(3)	49(11)
$4_1^+ \to 2_1^+$	612	6.2(17)	27(7)

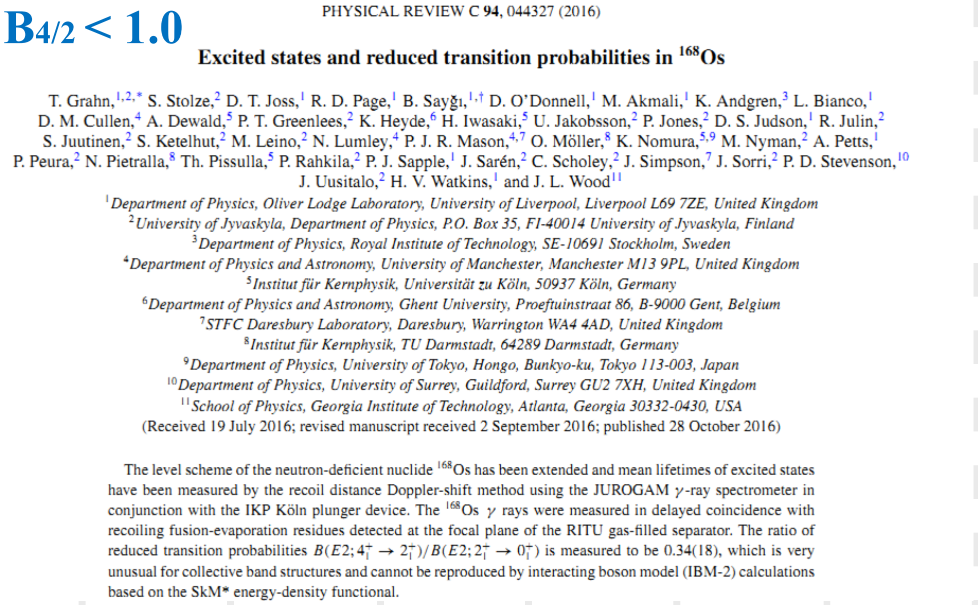
$R_{4/2}$=2.34

$B_{4/2}$=0.55(19)



the phenomenon is highly unexpected for these nuclei that are not situated near closed shells. This observation and its lack of reproducibility by standard nuclear models underscore the complexity of the atomic nucleus as a many-body quantum system

Anomalous $B_{4/2} < 1.0$



PHYSICAL REVIEW C **94**, 044327 (2016)

Excited states and reduced transition probabilities in ^{168}Os

T. Grahn,[1,2,*] S. Stolze,[2] D. T. Joss,[1] R. D. Page,[1] B. Sayğı,[1,†] D. O'Donnell,[1] M. Akmali,[1] K. Andgren,[3] L. Bianco,[1]
D. M. Cullen,[4] A. Dewald,[5] P. T. Greenlees,[2] K. Heyde,[6] H. Iwasaki,[5] U. Jakobsson,[2] P. Jones,[2] D. S. Judson,[1] R. Julin,[2]
S. Juutinen,[2] S. Ketelhut,[2] M. Leino,[2] N. Lumley,[4] P. J. R. Mason,[4,7] O. Möller,[8] K. Nomura,[5,9] M. Nyman,[2] A. Petts,[1]
P. Peura,[2] N. Pietralla,[8] Th. Pissulla,[5] P. Rahkila,[2] P. J. Sapple,[1] J. Sarén,[2] C. Scholey,[2] J. Simpson,[7] J. Sorri,[2] P. D. Stevenson,[10]
J. Uusitalo,[2] H. V. Watkins,[1] and J. L. Wood[11]
[1]*Department of Physics, Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, United Kingdom*
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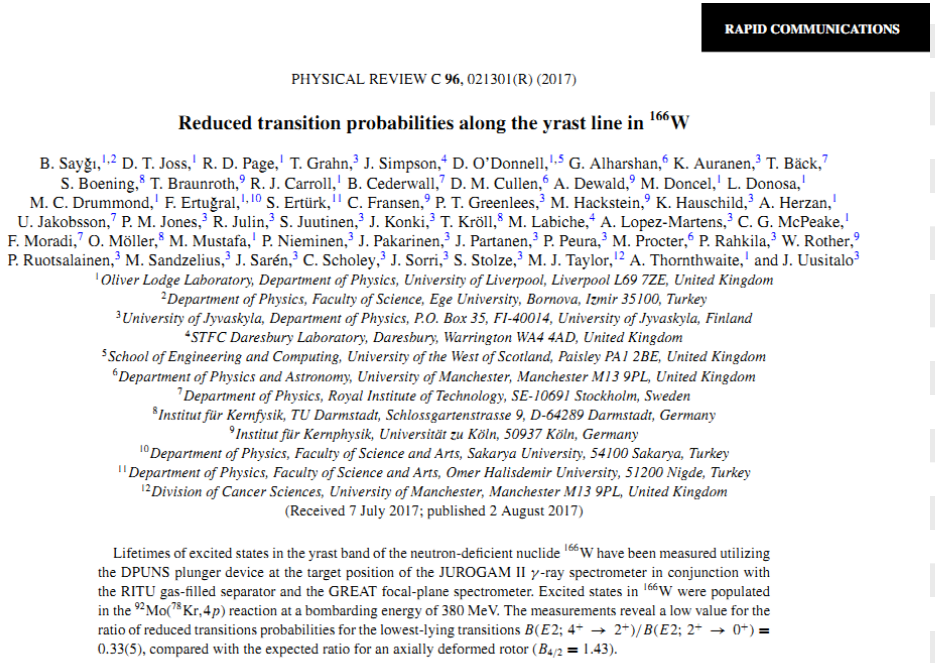
The level scheme of the neutron-deficient nuclide ^{168}Os has been extended and mean lifetimes of excited states have been measured by the recoil distance Doppler-shift method using the JUROGAM γ-ray spectrometer in conjunction with the IKP Köln plunger device. The ^{168}Os γ rays were measured in delayed coincidence with recoiling fusion-evaporation residues detected at the focal plane of the RITU gas-filled separator. The ratio of reduced transition probabilities $B(E2;4_1^+ \rightarrow 2_1^+)/B(E2;2_1^+ \rightarrow 0_1^+)$ is measured to be 0.34(18), which is very unusual for collective band structures and cannot be reproduced by interacting boson model (IBM-2) calculations based on the SkM* energy-density functional.



RAPID COMMUNICATIONS

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Reduced transition probabilities along the yrast line in ^{166}W

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Lifetimes of excited states in the yrast band of the neutron-deficient nuclide ^{166}W have been measured utilizing the DPUNS plunger device at the target position of the JUROGAM II γ-ray spectrometer in conjunction with the RITU gas-filled separator and the GREAT focal-plane spectrometer. Excited states in ^{166}W were populated in the ^{92}Mo(^{78}Kr,$4p$) reaction at a bombarding energy of 380 MeV. The measurements reveal a low value for the ratio of reduced transitions probabilities for the lowest-lying transitions $B(E2;\, 4^+ \rightarrow 2^+)/B(E2;\, 2^+ \rightarrow 0^+) = 0.33(5)$, compared with the expected ratio for an axially deformed rotor ($B_{4/2} = 1.43$).

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$B(E2)$ anomalies in the yrast band of ^{170}Os

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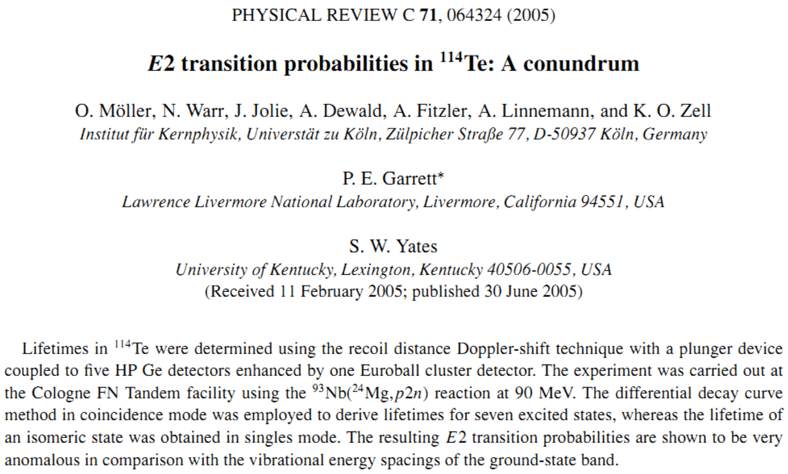
Background: The neutron-deficient osmium isotopic chain provides a great laboratory for the study of shape evolution, with the transition from the soft triaxial rotor in ^{168}Os to the well-deformed prolate rotor in ^{180}Os, while shape coexistence appears around $N = 96$ in ^{172}Os. Therefore, the study of the Os isotopic chain should provide a better understanding of shape changes in nuclei and a detailed scrutiny of nuclear structure calculations. In this paper, the lifetimes of the low-lying yrast states of ^{170}Os have been measured for the first time to investigate the shape evolution with neutron number.
Purpose: Lifetimes of excited states in the ground-state band of ^{170}Os are measured to investigate the shape evolution with neutron number in osmium isotopes and compare with state-of-the-art calculations.
Methods: The states of interest were populated via the fusion-evaporation reaction ^{142}Nd(^{32}S, $4n$) at a bombarding energy of 170 MeV at the ALTO facility from IPN (Orsay, France). Lifetimes of the 2_1^+ and 4_1^+ states in ^{170}Os were measured with the recoil-distance Doppler-shift method using the Orsay universal plunger system.
Results: Lifetimes of the two first excited states in ^{170}Os were measured for the first time. A very small $B(E2;4_1^+ \rightarrow 2_1^+)/B(E2;2_1^+ \rightarrow 0_1^+) = 0.38(11)$ was found, which is very uncharacteristic for collective nuclei. These results were compared to state-of-the-art beyond-mean-field calculations.
Conclusions: Although theoretical results give satisfactory results for the energy of the first few excited states in ^{170}Os and the $B(E2;2_1^+ \rightarrow 0_1^+)$ they fail to reproduce the very small $B(E2;4_1^+ \rightarrow 2_1^+)$, which remains a puzzle.



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$E2$ transition probabilities in ^{114}Te: A conundrum

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Lifetimes in ^{114}Te were determined using the recoil distance Doppler-shift technique with a plunger device coupled to five HP Ge detectors enhanced by one Euroball cluster detector. The experiment was carried out at the Cologne FN Tandem facility using the ^{93}Nb(^{24}Mg,$p2n$) reaction at 90 MeV. The differential decay curve method in coincidence mode was employed to derive lifetimes for seven excited states, whereas the lifetime of an isomeric state was obtained in singles mode. The resulting $E2$ transition probabilities are shown to be very anomalous in comparison with the vibrational energy spacings of the ground-state band.