Exotic rotations, triaxiality and shape coexistence in A=130-140 nuclei

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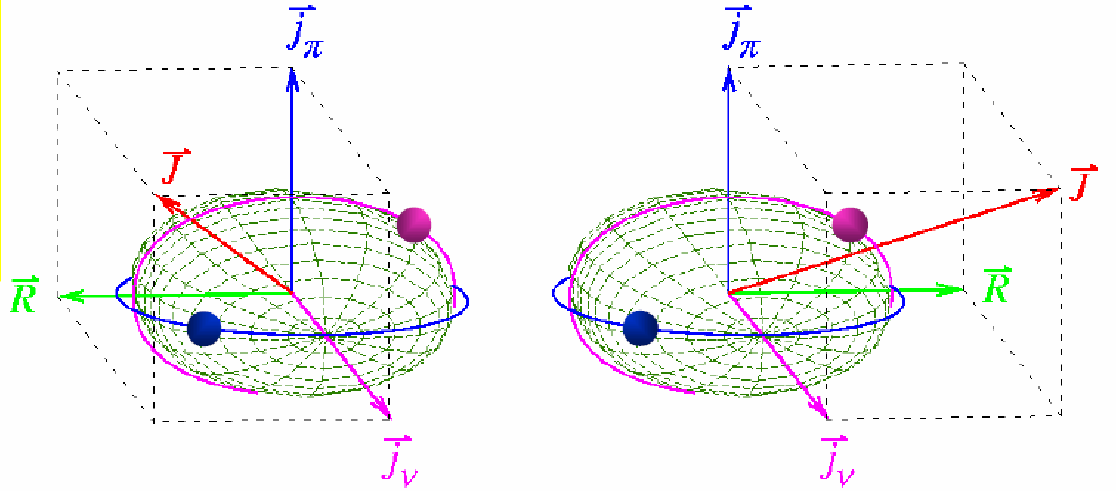
1. Wobbling mode - one example and preliminary results

2. Which rotation axis for a triaxial nucleus ?

Chiral mode
- vibration (^{134}Pr)
- multiple (^{133}Ce)

Chiral Geometry in Nuclei

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



Wobbling mode
- longitudinal (^{163}Lu)
- transverse (^{135}Pr)

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

$$\hbar\omega_{\mathrm{wobb}} = \hbar\omega_{\mathrm{rot}}\sqrt{\frac{(\mathcal{J}_x - \mathcal{J}_y)(\mathcal{J}_x - \mathcal{J}_z)}{\mathcal{J}_y \mathcal{J}_z}}$$

$$\hbar\omega_{\mathrm{rot}} = \frac{I}{\mathcal{J}_x}$$

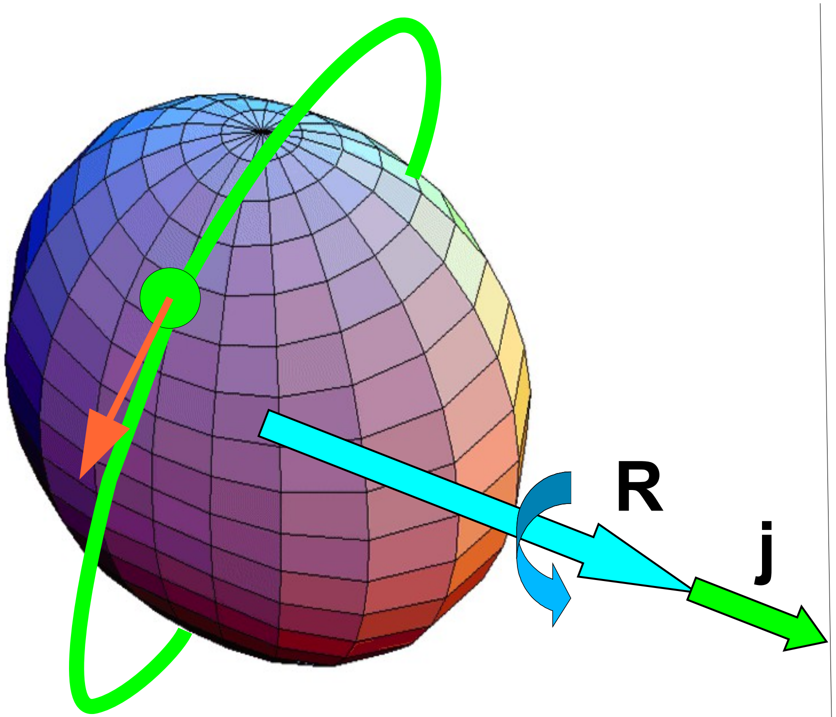
1. The wobbling mode

PHYSICAL REVIEW C 89, 014322 (2014)

Transverse wobbling: A collective mode in odd-A triaxial nuclei

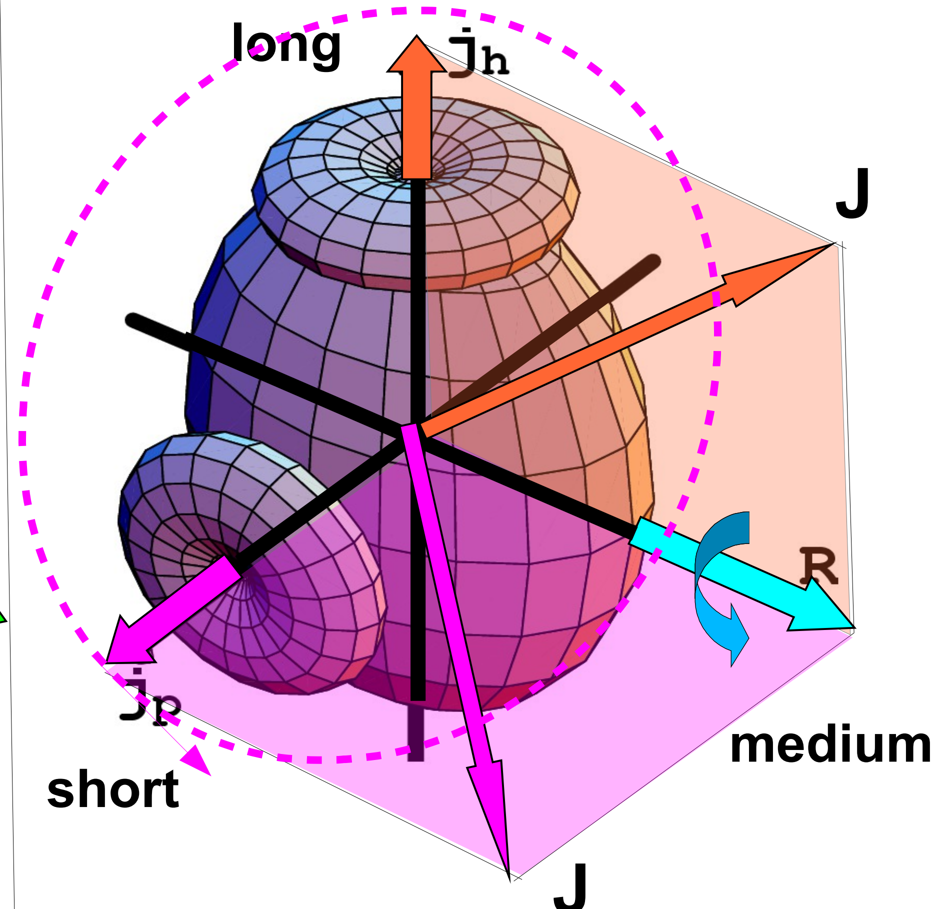
S. Frauendorf[1,*] and F. Dönau[2,†]

Longitudinal wobbler



$$\Im_3 \rightarrow \Im_3' = \frac{\Im_3 \omega + j}{\omega} = \Im_3 + \frac{j}{\omega} \Rightarrow \hbar \omega_{rot} = \frac{I}{\Im_3'}$$

Transverse wobbler



Wobbling mode

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

$$\hbar\omega_{wobb} = \frac{\hbar^2 J}{\mathcal{J}_3}\sqrt{\frac{(\mathcal{J}_3 - \mathcal{J}_1)(\mathcal{J}_3 - \mathcal{J}_2)}{\mathcal{J}_1 \mathcal{J}_2}}$$ → **Simple** wobbler (even-even)

$$\hbar\omega_{wobb} = \frac{\hbar^2 j}{\mathcal{J}_3}\sqrt{\left[1 + \frac{J}{j}\left(\frac{\mathcal{J}_3}{\mathcal{J}_1} - 1\right)\right]\left[1 + \frac{J}{j}\left(\frac{\mathcal{J}_3}{\mathcal{J}_2} - 1\right)\right]}$$ → **Longitudinal** wobbler, **Transverse** wobbler

Longitudinal wobbling $\mathfrak{I}_3 > \mathfrak{I}_1, \mathfrak{I}_2$ — ω_{wobb} **increases with J**

Transverse wobbling
- $\mathfrak{I}_2 > \mathfrak{I}_3 > \mathfrak{I}_1$ **odd particle**
- $\mathfrak{I}_3 < \mathfrak{I}_1, \mathfrak{I}_2$ **odd hole**

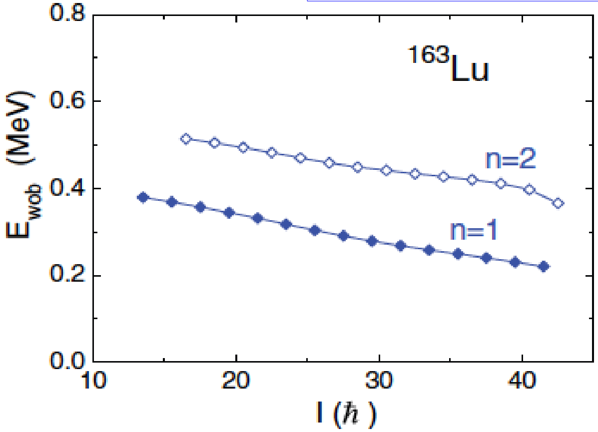
ω_{wobb} **decreases with J**

Fitted QTR MoI for ^{135}Pr	$\mathcal{J}_m, \mathcal{J}_s, \mathcal{J}_l = 7.4,\ 5.6,\ 1.8\hbar^2/\text{MeV}$	$\mathcal{J}_m/\mathcal{J}_s/\mathcal{J}_l = 1/0.75/0.24$
TAC MoI for ^{135}Pr	$\mathcal{J}_m, \mathcal{J}_s, \mathcal{J}_l = 19,\ 8,\ 3\,\hbar^2/\text{MeV}$	$\mathcal{J}_m/\mathcal{J}_s/\mathcal{J}_l = 1/0.42/0.16$
RPA MoI for ^{138}Nd	$\mathcal{J}_x, \mathcal{J}_y, \mathcal{J}_z = 35, 20, 8\ \hbar^2/MeV$	$\mathcal{J}_x/\mathcal{J}_y/\mathcal{J}_z = 1/0.57/0.23$

Wobbling frequency

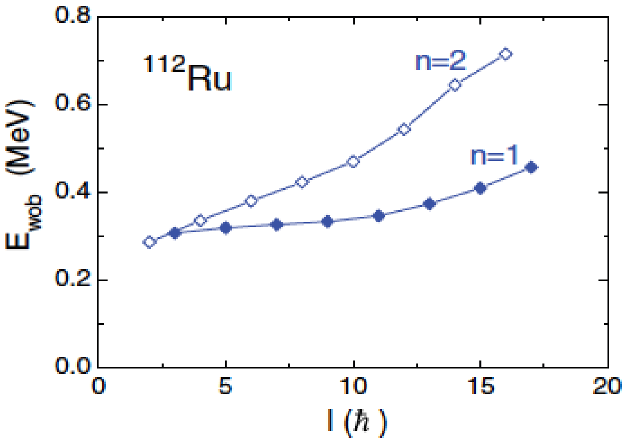
Wobbling frequency is experimentally defined by:

$$E_{wobb} = E(I, n_w = 1) - \frac{E(I+1, n_w=0) + E(I-1, n_w=0)}{2}$$



ω_{wobb} **decreases with J => transverse wobbler**

Originally interpreted as longitudinal wobbler !



ω_{wobb} **increases with J => simple wobbler**

Frauendorf and Dönau, PRC 89 (2014)

PRL 114, 082501 (2015) PHYSICAL REVIEW LETTERS week ending 27 FEBRUARY 2015

Transverse Wobbling in ^{135}Pr

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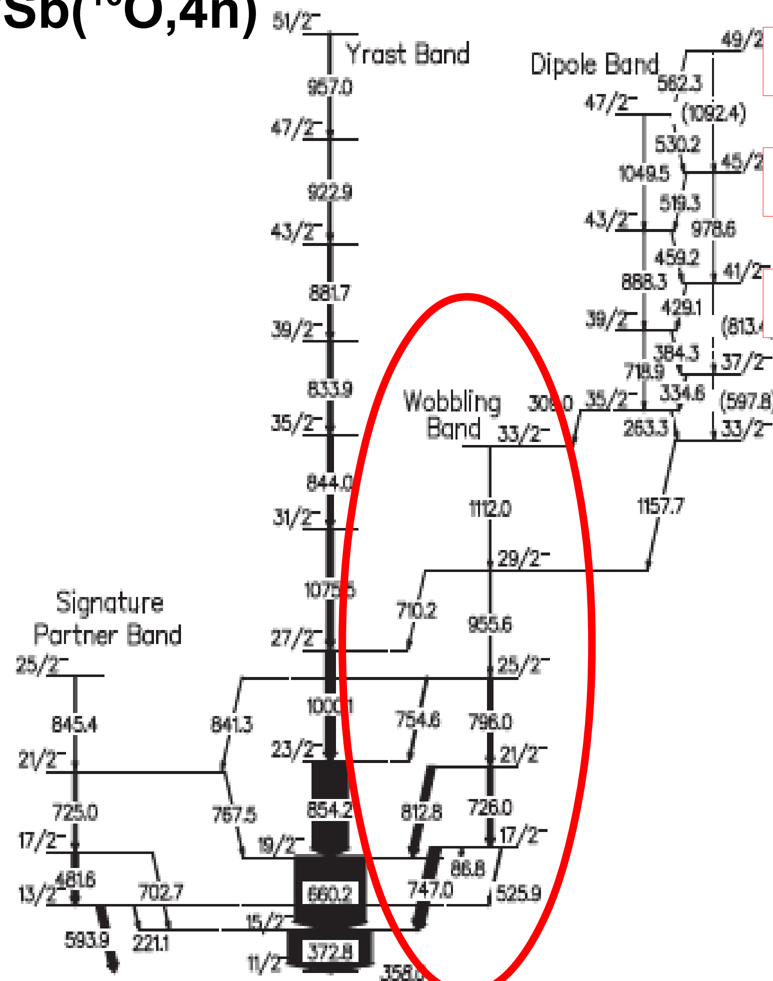
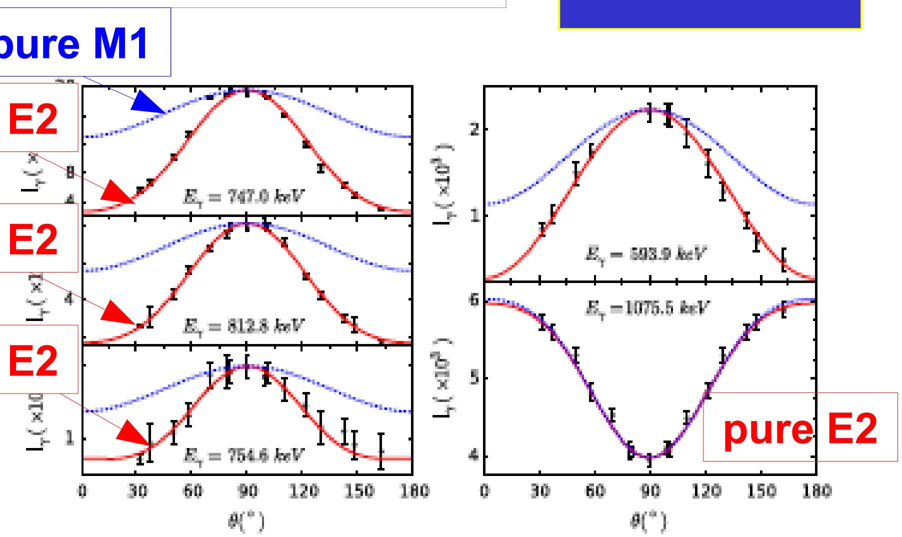
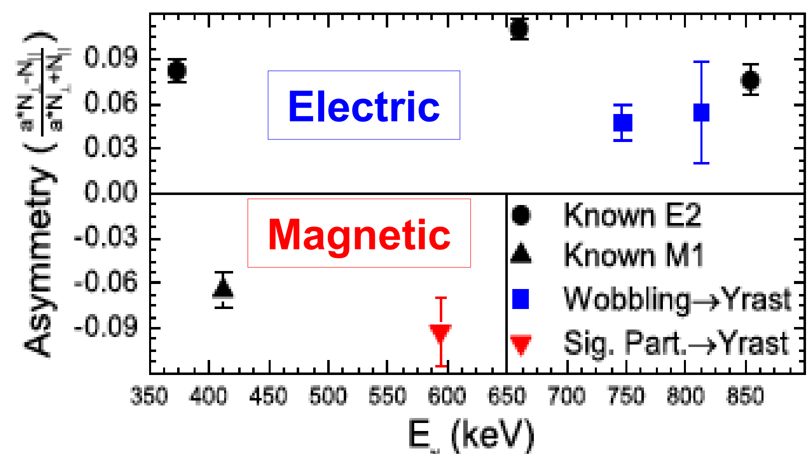
^{135}Pr

^{123}Sb(^{16}O,4n)





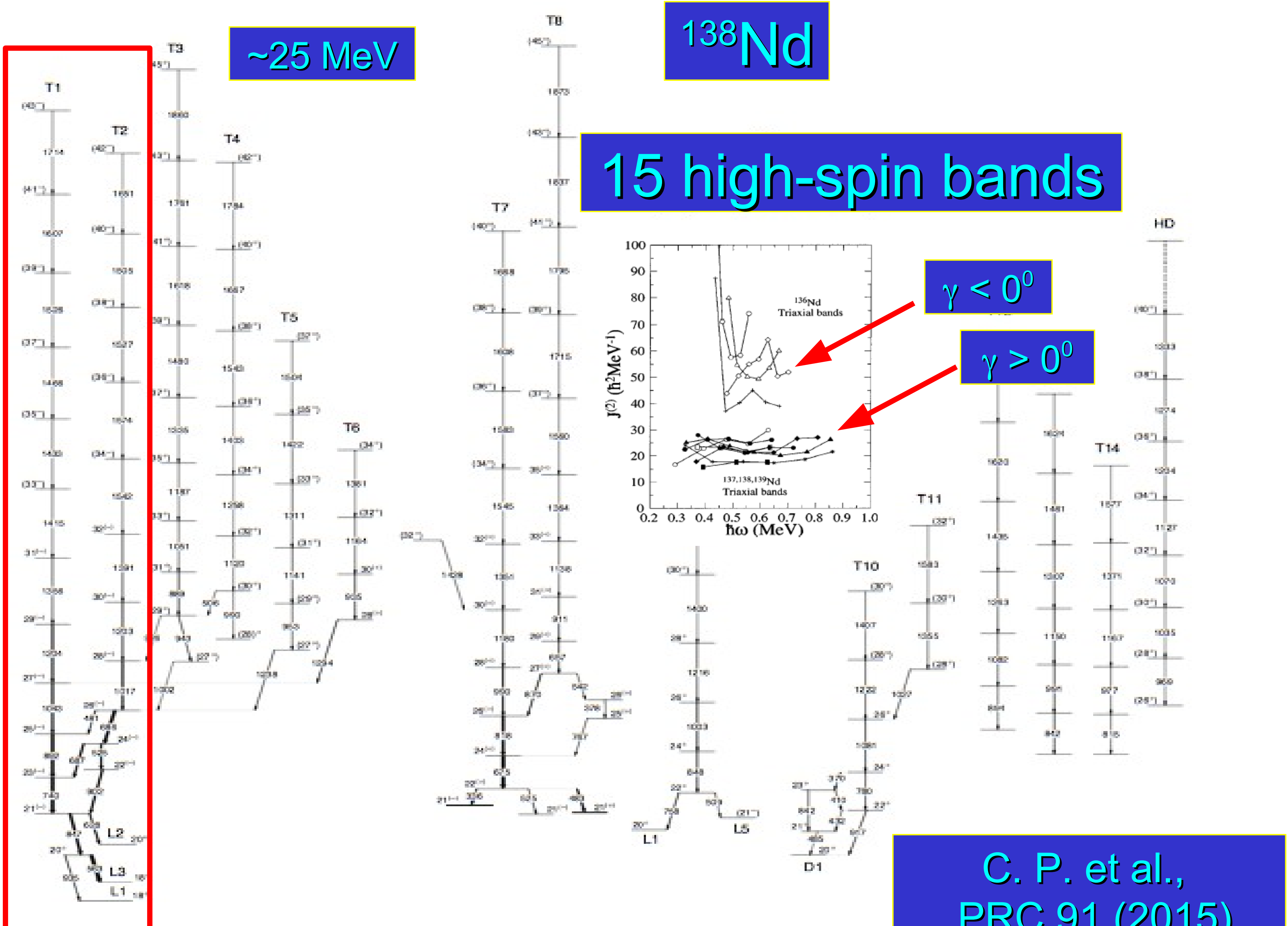


Conclusions, perspectives for wobbling, chirality

Many questions wait an answer :

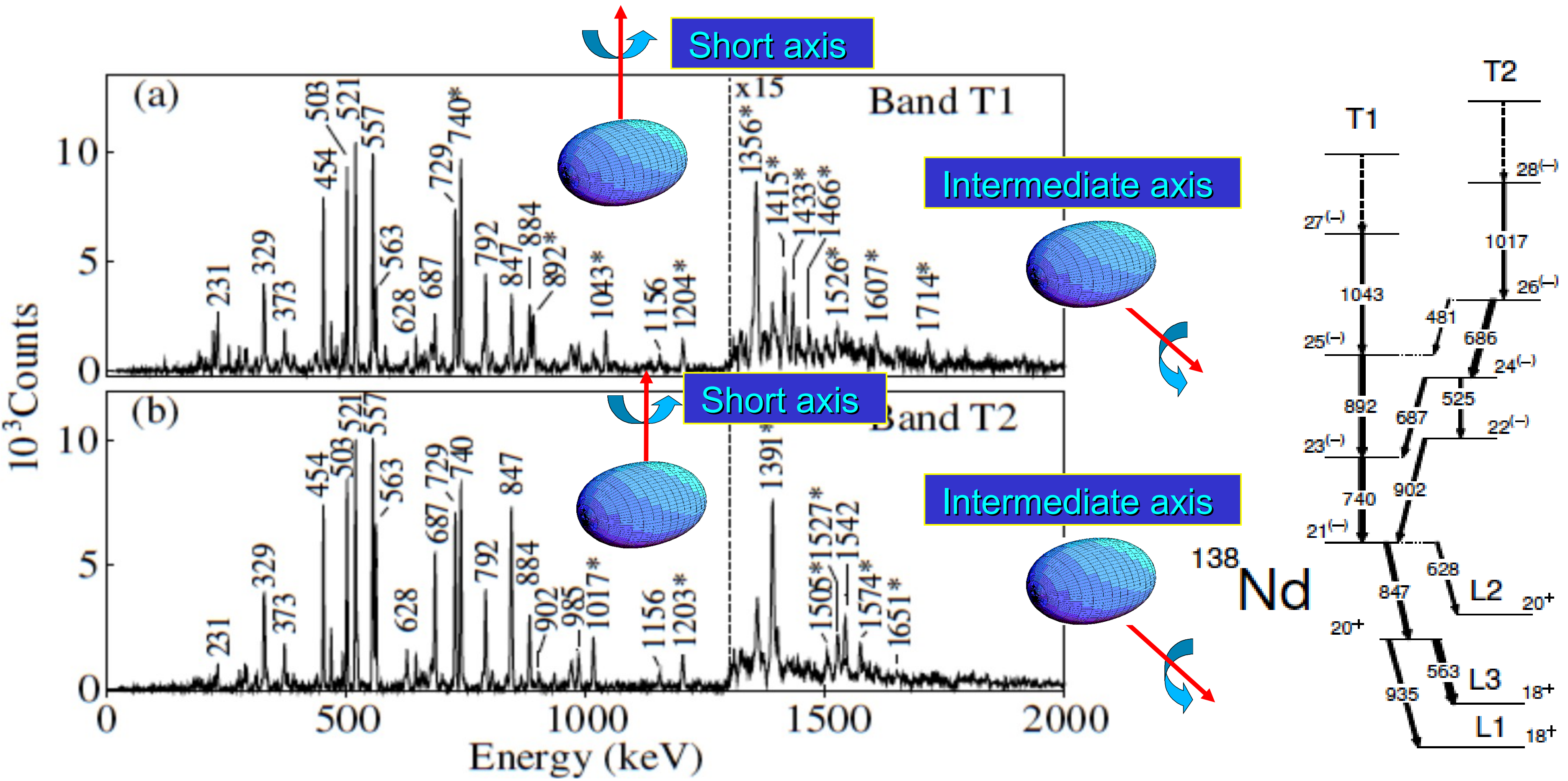
- transverse wobbling in other nuclei with A=130-140
- transverse wobbling in other mass regions
- transverse wobbling in excited configurations
- precise measurement of mixing ratios
- precise measurement of transition probabilities

2. Which rotation axis for a triaxial nucleus ?



~25 MeV
138Nd
15 high-spin bands
γ < 0^0
γ > 0^0
C. P. et al.,
PRC 91 (2015)
T1
T2
T3
T4
T5
T6
T7
T8
T10
T11
T14
HD
L1
L2
L3
L5
D1
J^(2) (ħ^2MeV^-1)
ħω (MeV)
136Nd
Triaxial bands
137,138,139Nd
Triaxial bands

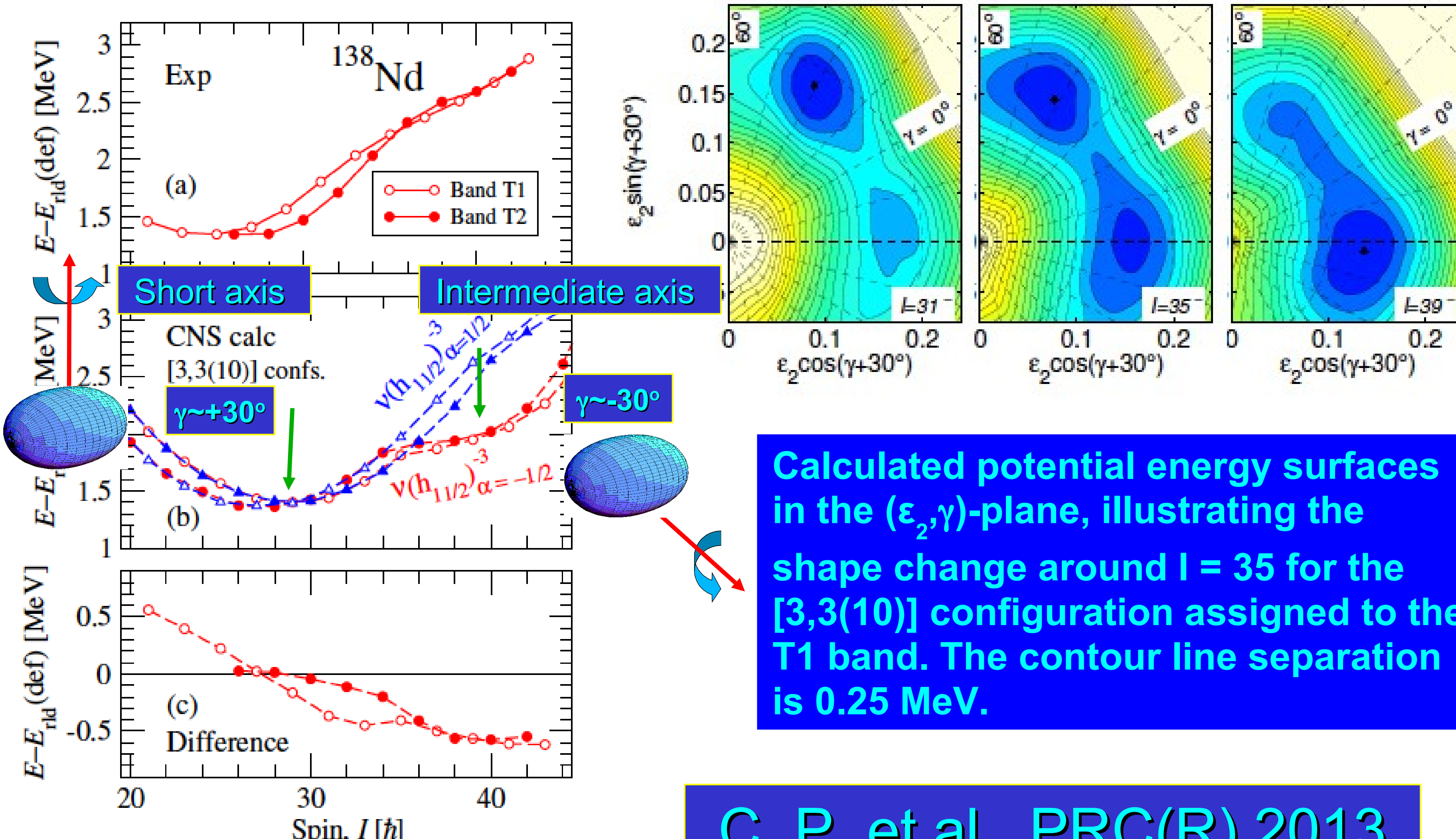
Switch of rotation from short to intermediate axis at high spin in ^{138}Nd



C. P. et al., PRC(R) 2013

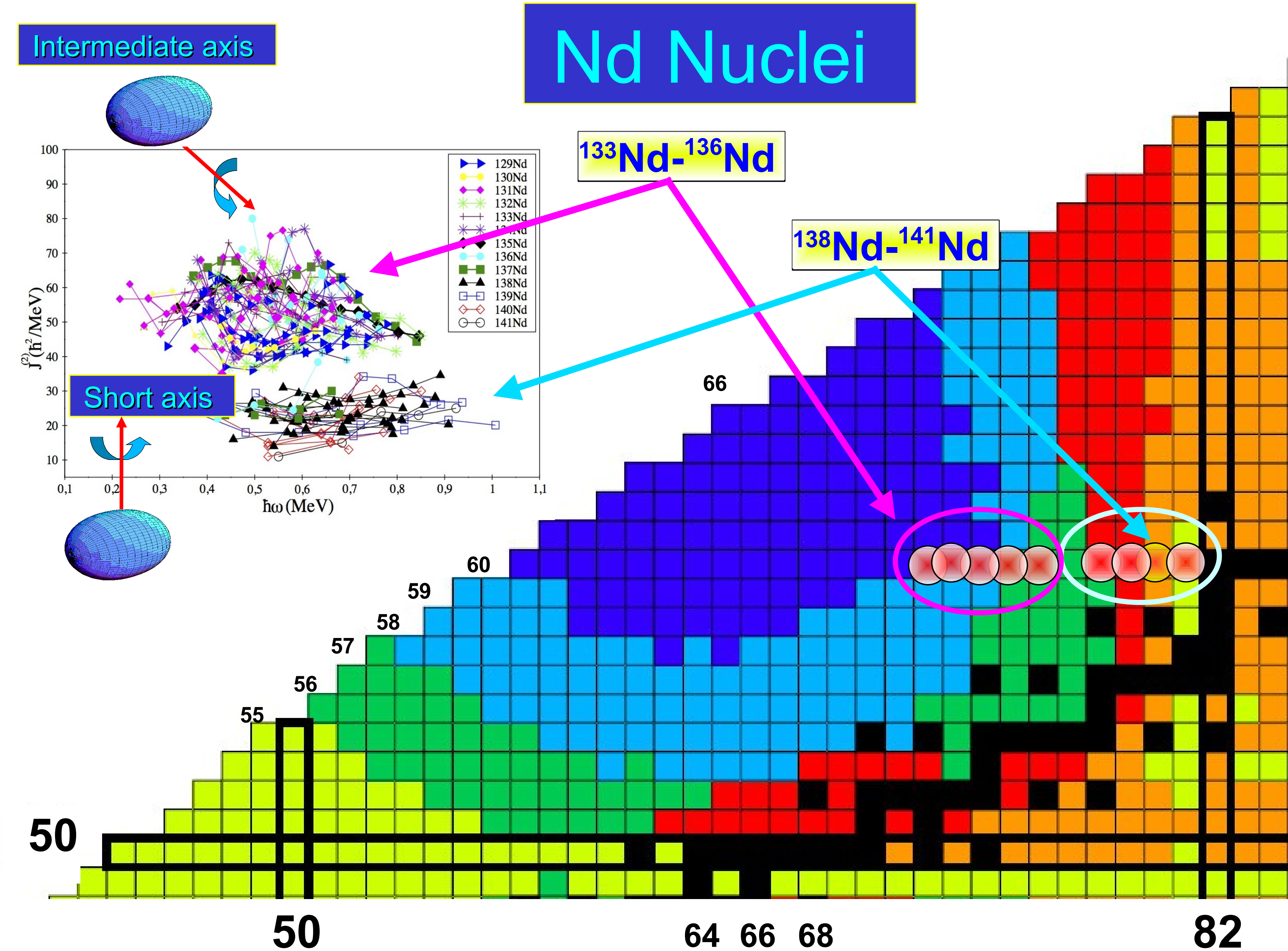
Existence of triaxial shapes with $\gamma > 0^o$ and $\gamma < 0^o$

CNS calculations for ^{138}Nd – I. Ragnarsson



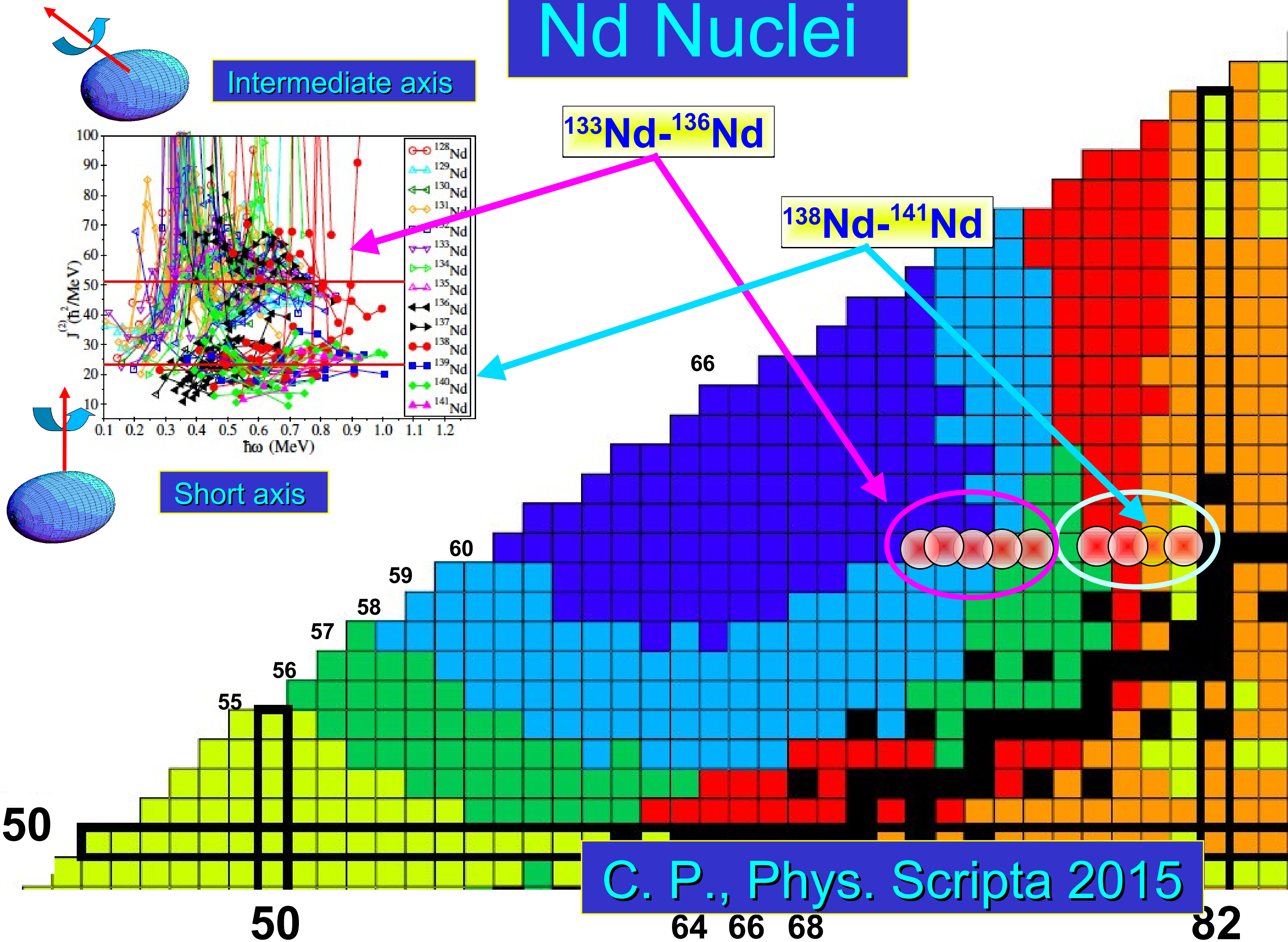
Calculated potential energy surfaces in the (ε_2,γ)-plane, illustrating the shape change around I = 35 for the [3,3(10)] configuration assigned to the T1 band. The contour line separation is 0.25 MeV.

C. P. et al., PRC(R) 2013



Nd Nuclei
Intermediate axis
Short axis
133Nd-136Nd
138Nd-141Nd
129Nd
130Nd
131Nd
132Nd
133Nd
135Nd
136Nd
137Nd
138Nd
139Nd
140Nd
141Nd
J(2)(ħ2/MeV)
ħω (MeV)
100
90
80
70
60
50
40
30
20
10
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
1,1
66
60
59
58
57
56
55
50
50
64
66
68
82

Nd Nuclei



C. P., Phys. Scripta 2015

Conclusions, perspectives for triaxiality, shape coexistence and rotation axis

Many questions wait an answer :

- why a sudden change of the rotation axis in the A=130-140 nuclei – a simple explanation is missing !
- how the collective and single-particle excitations contribute to the rotation at high spins
- which is the mechanism inducing the shape coexistence of spherical-triaxial-superdeformed shapes at high spins

Collaborators

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Institute of Modern Physics, China – Guo Song

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LTH Lund, Sweden – I. Ragnarsson

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