

# Unusual Octupole Shape Deformation Terms and K-Mixing

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# The region of n-rich $Z \sim 42$ to 44

- Clearly a region of triaxial nuclear shapes
- Low-lying quasi-gamma bands,  $2^+$
- Hence, extensive K-mixing
- Strong E1 transitions from odd-parity bands
- Hence, some octupole shape interference with quadrupole shape terms.

# Theoretical shape calculations

- Many theoretical calculations over decades support prevalence of triaxiality.
- Peter Möller et al. recently published energy lowering calculations of even-even ground states by inclusion of  $Y_2^2$  for hundreds of nuclei.
- The neutron-rich Mo and Ru fission products show the greatest  $Y_2^2$  lowering.

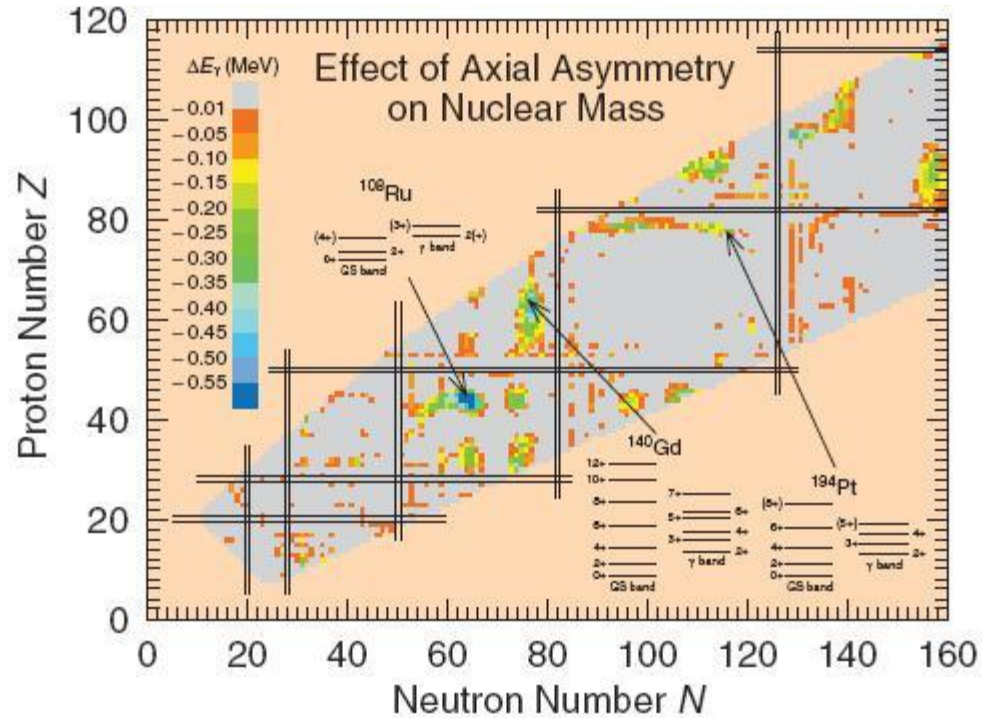


FIG. 2 (color). Calculated lowering of the nuclear ground-state energy when axial symmetry is broken, relative to calculations limited to axially symmetric shapes only. Near the center of each of the three regions of axially asymmetric nuclei accessible to experiment, we show a measured spectrum [16]. All three spectra exhibit characteristic  $\gamma$  bands. This can be thought of as a necessary condition:  $\gamma$  bands should be present when the shapes are axially asymmetric.

*Peter Möller et al*

*in*

*Global Calculation of Ground-State Axial Shape Asymmetry of Nuclei*

# Samples of E1 branching— $^{112}\text{Ru}$

- Previous talk of Dr. Luo emphasized the odd-parity chiral partner bands and arguments for chirality in e-e Ru nuclei.
- Here I call attention to their E1 branching out to ground and quasi-gamma band in competition with collective E2 intraband transitions.
- E1 strengths only 3 or 4 orders of magnitude less than Weisskopf single-particle—as strong as found in Ba & Ra pear-shaped nuclear regions.

# Octupole shape terms

- It is the presence of the unique high- $j$  orbital of opposite parity in most major shells of the spin-orbit shell model that gives rise to E3 shape collectivity and enhancement of low-energy E3 gamma transitions.
- Low-energy E1 transitions are weak because the high- $j$  orbital differs in  $j$  by greater than 1 from other orbitals in shell.

# Low-energy E1 “enhancement”

- Nuclei with both quadrupole and octupole vibrational modes or deformation can enable E1's to the extent that the quadrupole-octupole cross-term is different for the protons and the neutrons. (Related to spurious center-of-mass motion in the shell model.)

# Deduction from “enhanced” E1s

- If enhanced E1s are found between bands in nuclei with quadrupole deformation, it means that octupole collectivity is also present.
- The absence of E1s, however, does not mean the absence of octupole collectivity, since it may only denote similarity of deformation of protons and neutrons.



# Some triaxial-shape-theory studies

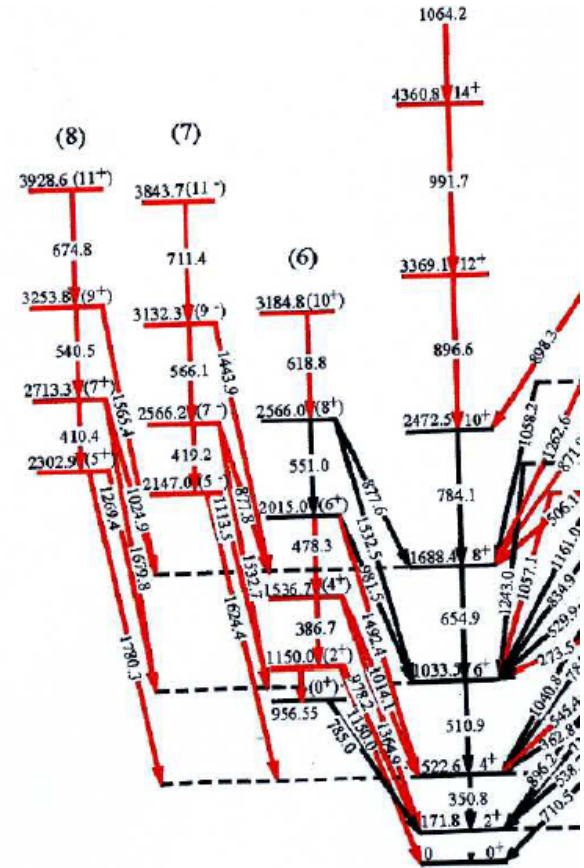
- J. Skalski, S. Mizutori, and W. Nazarewicz, Nucl. Phys. A 617, 282 (1997)
- D. Troltenier, J.P. Draayer, B.R.S. Babu, J.H. Hamilton, A.V. Ramayya, V.E. Oberacker, Nucl. Phys. A 601 (1996)
- J. Äystö, et al., Nucl. Phys. A 515, 165 (1990)

# Shape terms in the Mo-Ru region

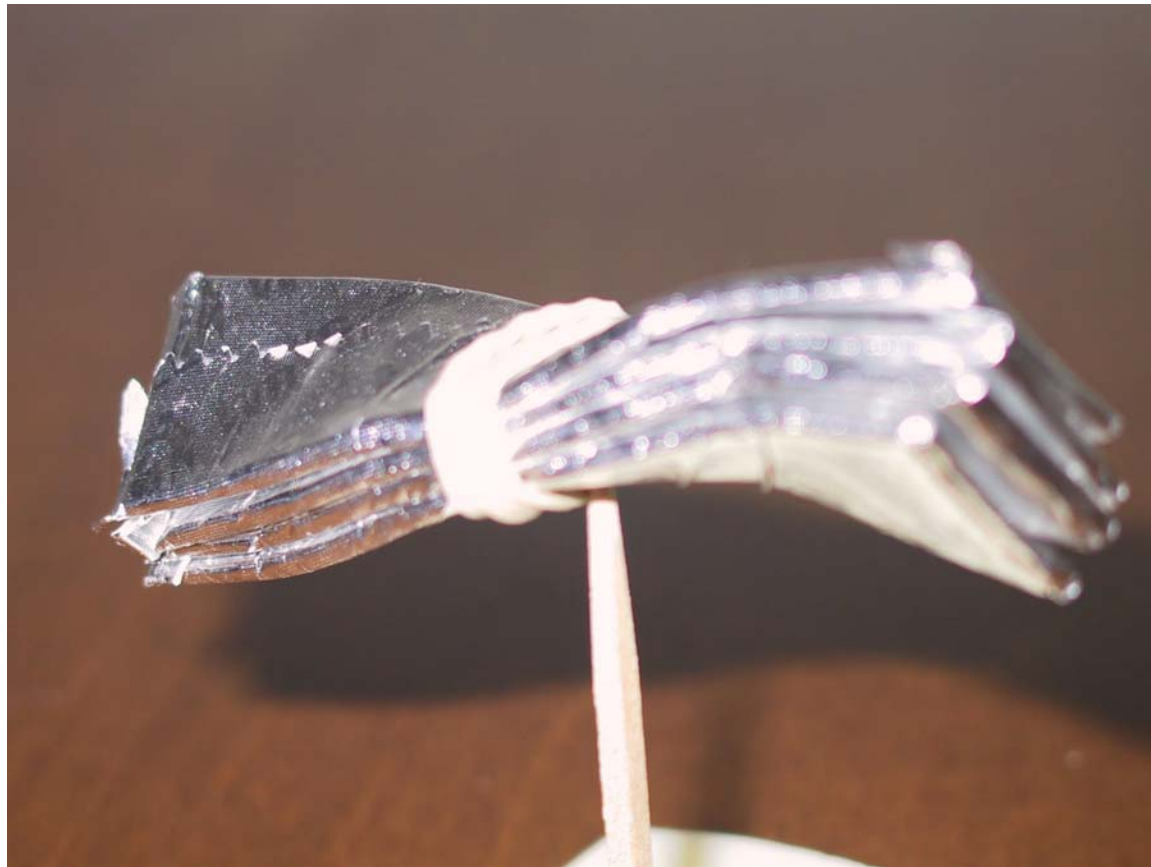
- Low-lying 1- and 2-phonon quasi-gamma bands mean triaxiality— $Y_{2,0}$  and  $Y_{2,2}$
- E1 transition rates 3 or 4 orders of magnitude below Weisskopf single-proton values—comparable to Ba and Ra regions—mean E3 collectivity.
- Nilsson diagrams suggest  $Y_{3,2}$  octupole

# $^{106}\text{Mo}$ partial level scheme

- Bands (7) & (8) seem to be E2 cascades.  
Band (8) is odd parity  
Red transitions and levels added by our GANDS collaboration.
- Puzzle suggesting rotation about 2-fold symmetry axis



“Propellor” shape of nucleus with  $Y_2^0, Y_2^2, Y_3^2$  shape terms (Mo/Ru region ?). Note 2-fold rotational symmetry on all 3 principal axes but parity violation. Has distinct left- and right-handed forms (chirality)

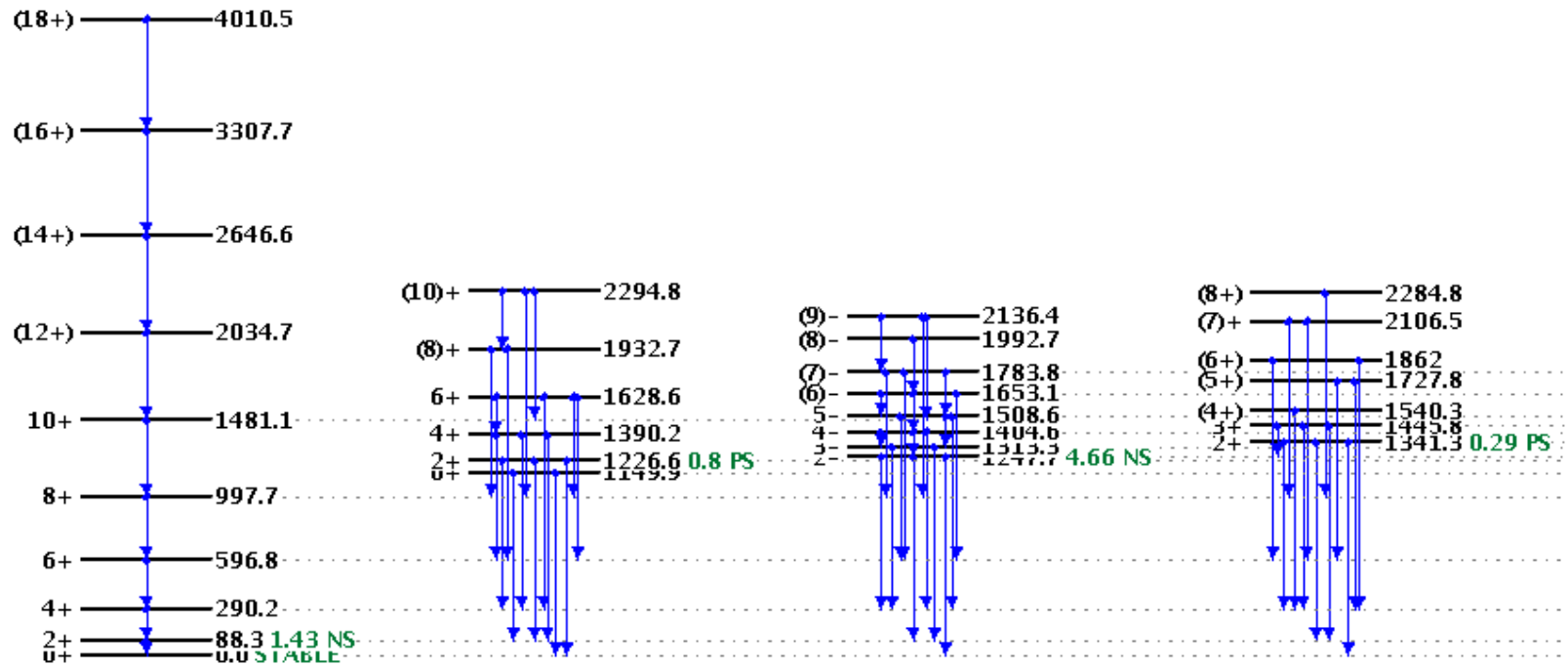


# The Hf-W-Os region

- What are similarities and differences from Mo-Ru region?
- Quasi-gamma bands  $2+$  not low lying.
- Evidently, little K-mixing near bandheads and extensive K-mixing in upper ground band.
- $2-$  bands with enhanced  $E3$  decay and lifetimes.

# $^{176}\text{Hf}$ partial level scheme

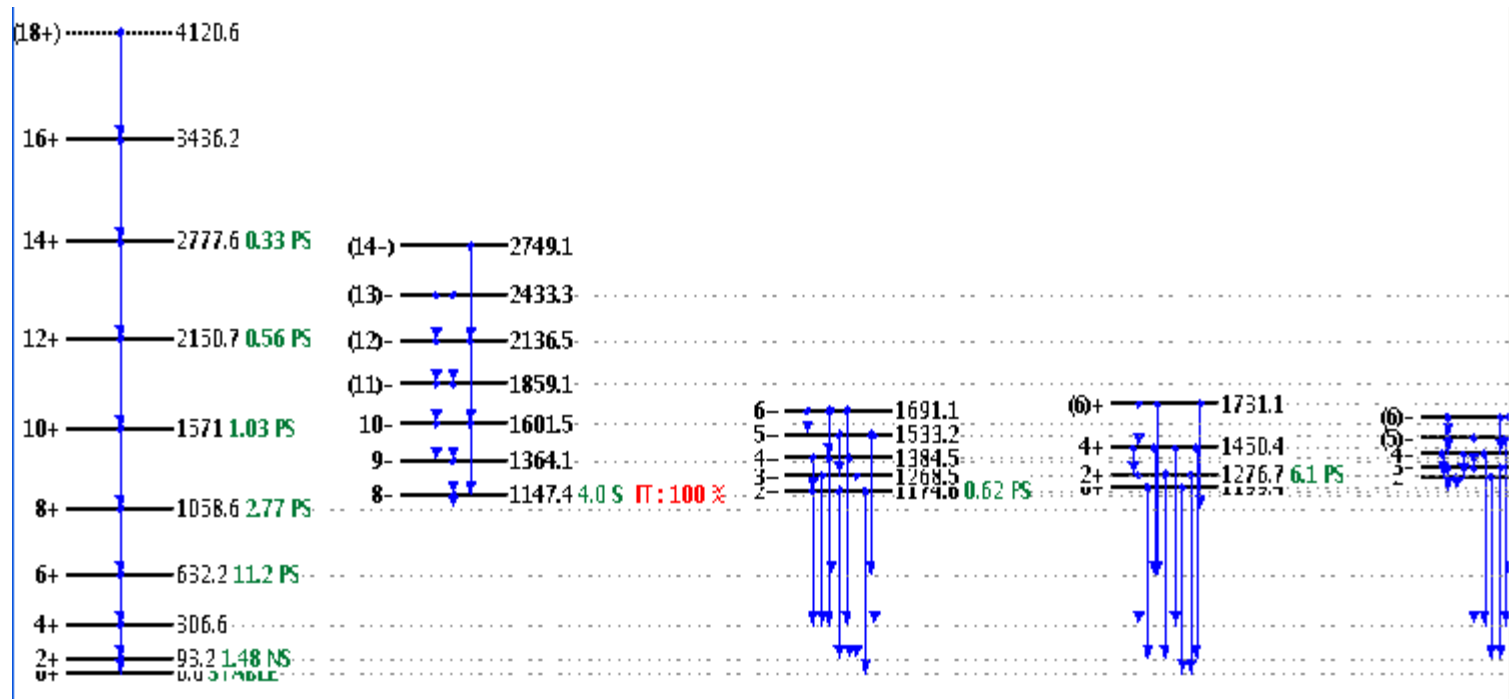
Note E1 branching out of levels of 2- band



# $^{178}\text{Hf}$ partial level scheme

Note E1 branching out of levels of 2- band

No low-lying gamma band—difference from Mo/Ru

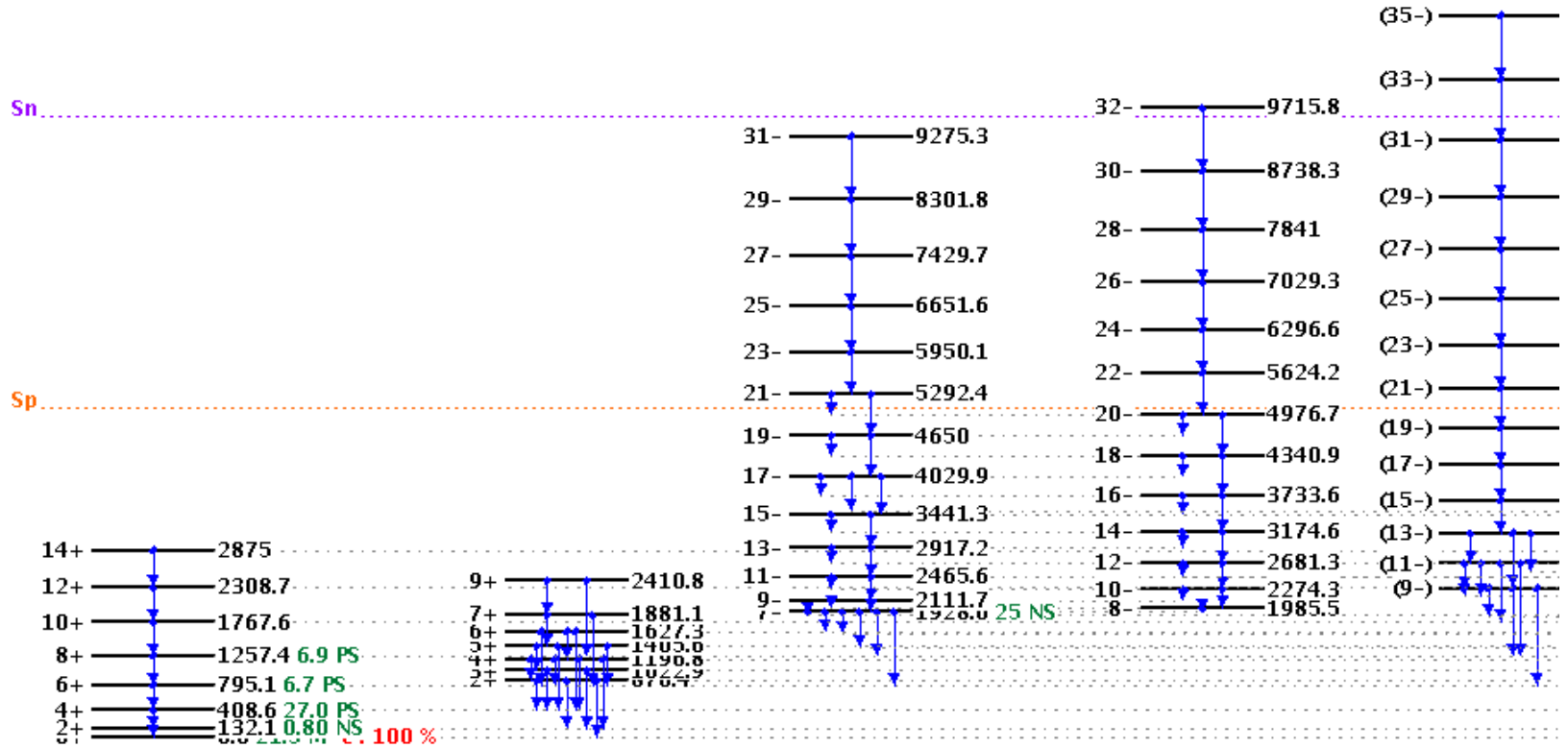


# E3 strength from $2^-$ in $^{176}\text{Hf}$

- 1247.7-keV  $2^-$  level has 4.66 ns half life
- Main transition to  $2^+$  is 20% E3, small M2, and mostly E1.
- E3 is 20 x Weisskopf single-proton strength
- E1 is  $10^{-7}$  x Weisskopf
- ENSDF refs. 1972Lo03
- $\Omega = 5/2, 7/2, 9/2$  Nilsson orbitals

# $^{180}\text{Os}$ Partial level scheme

Note competitive branching out of 9- band



Frauendorf's REVIEWS OF MODERN PHYSICS, VOLUME 73, APRIL 2001. Note the rotational band patterns from rotational symmetries and parity violation.

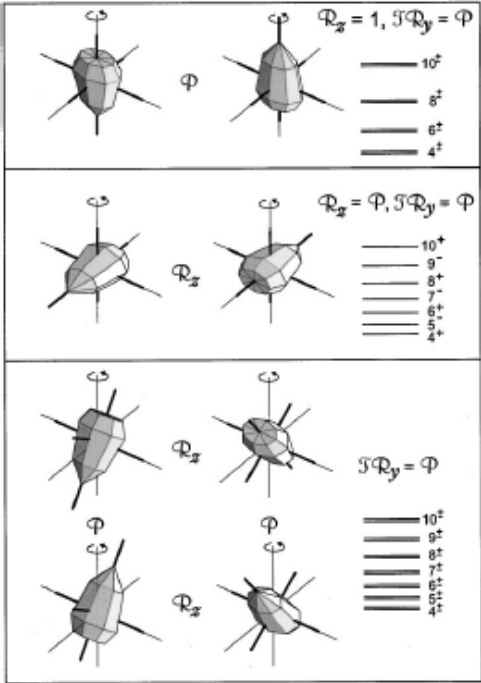
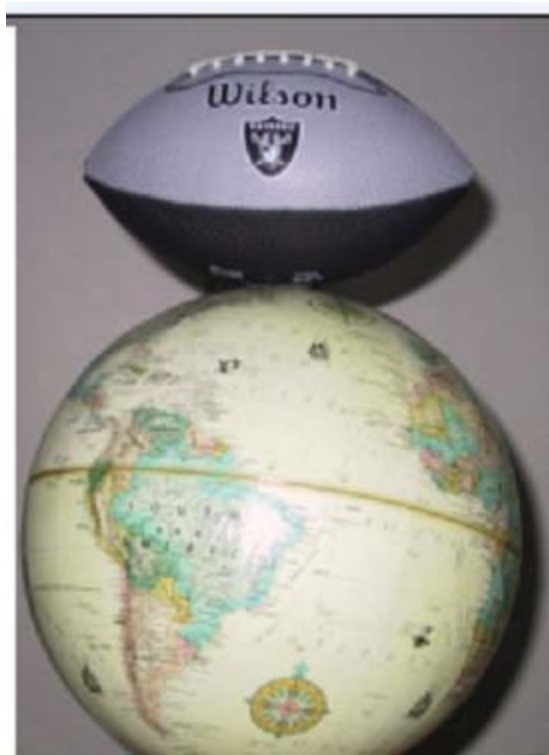


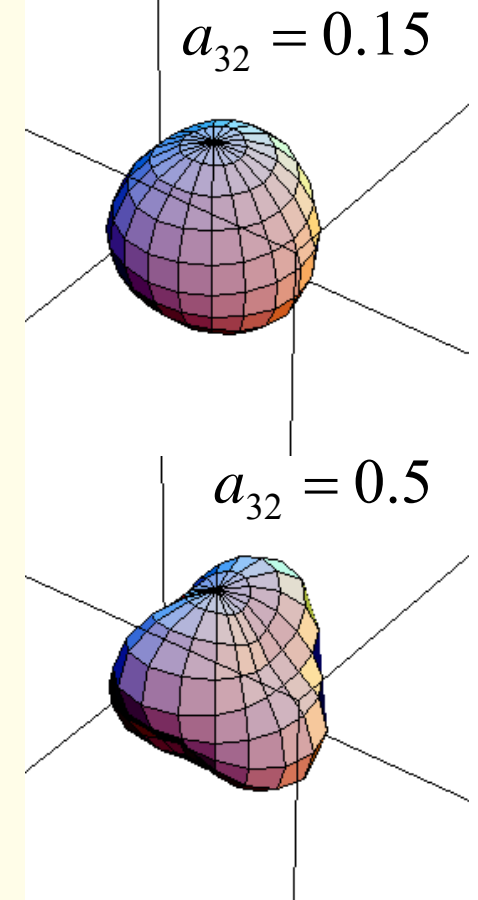
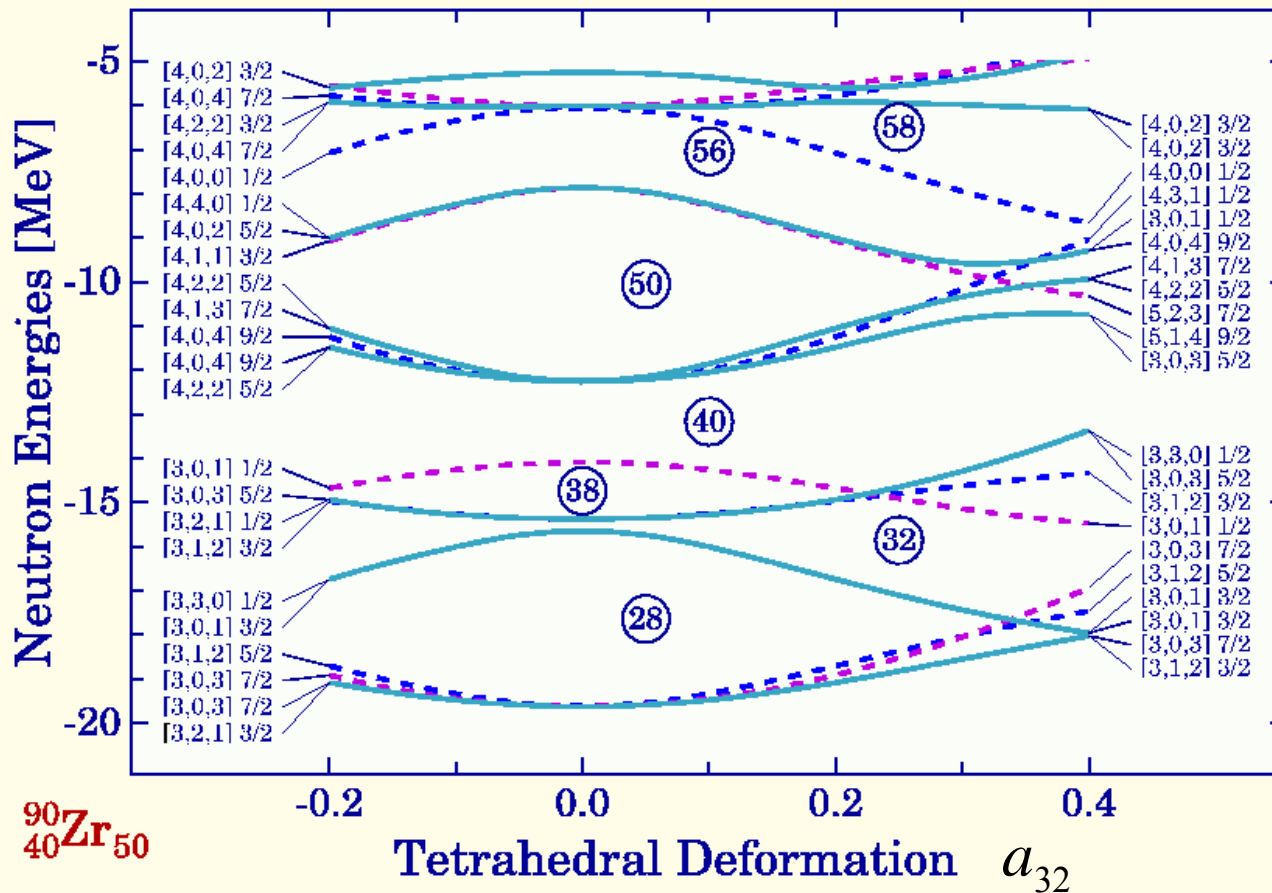
FIG. 27. The discrete symmetries of the mean field of a rotating nucleus with two symmetry planes. See caption of Fig. 9.

FIG. 28

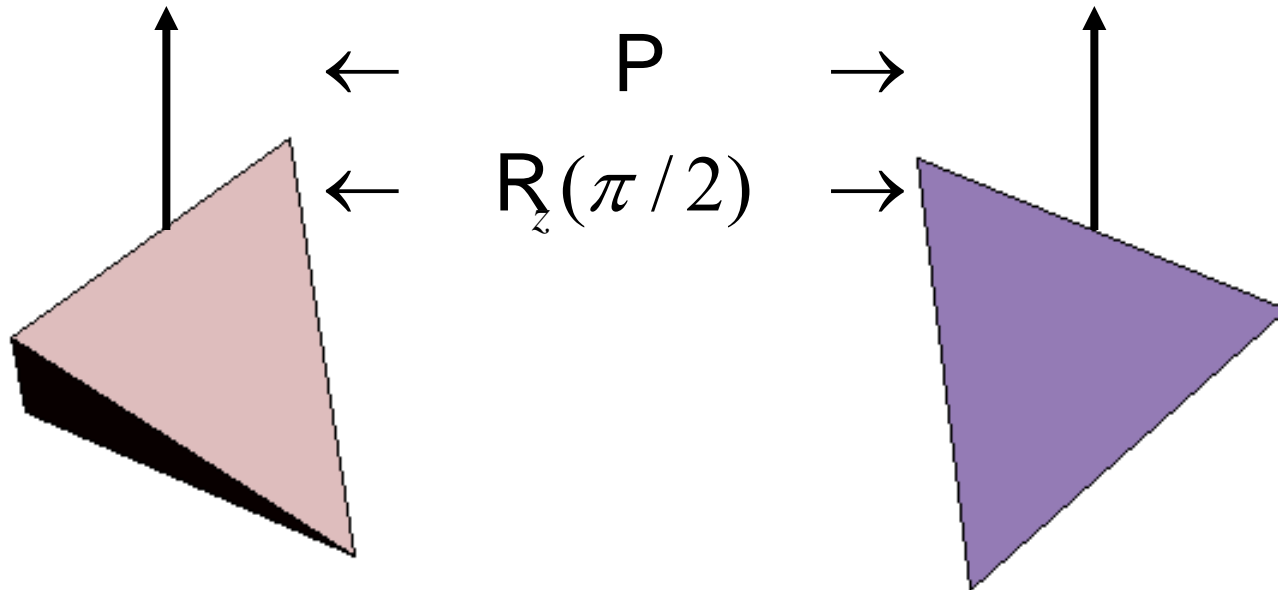
Possible shape mode for higher spins in Hf | W | Os region  
Spherical doubly closed shell  $^{132}\text{Sn}$  below  
Prolate cluster from mid  $f_{7/2}$  shells (22 to 26 protons or neutrons)



# Tetrahedral shapes—pure $Y_2^2$



J. Dudek et al. PRL 88 (2002) 252502



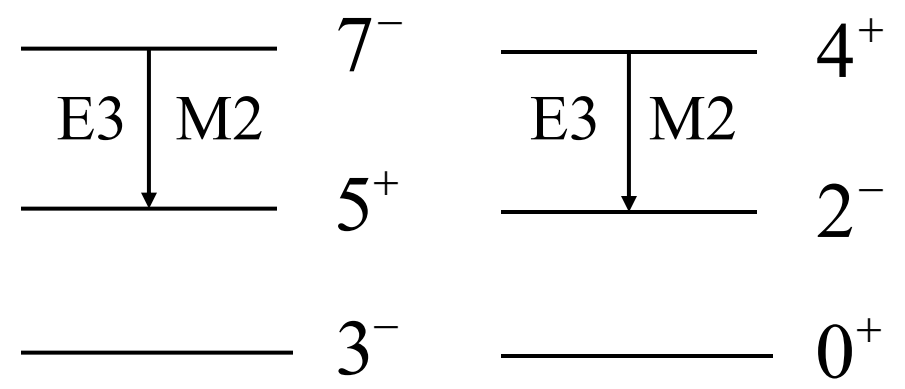
$R_z(\pi) = 1$  signature  $\alpha$

$I = \alpha + 2n$

$D = PR_z(\pi/2) = 1$

$D|> = e^{-i\pi\delta} |>$  doublet  $\delta = \frac{\alpha}{2}, \frac{\alpha}{2} + 1$

parity  $\pi = (-)^{I/2 - \delta}$



# SUMMARY 1

- E1 branching above bandheads signals octupole-quadrupole shape interference
- K-mixing broken by Coriolis,  $Y_2^2$ ,  $Y_3^2$
- Twisted-pack-of-gum nuclear shape has right- and left-handed forms, another mode for chiral doubling
- This shape has 2-fold rotational symmetry for all 3 principal axes.

# Summary 2

- Most likely for  $Y_2^0, Y_2^2, Y_3^2$  shapes is neutron-rich Mo-Ru region.
- Most likely for  $Y_2^0, Y_3^2$  only is beta-stable Hf-W region, though data and cluster model hint at possibility at higher spins of spherical  $^{132}\text{Sn}$  core with equatorially-tangent prolate spheroid.
- Need for heavy-ion, xn transfer reaction studies to complement existing work.