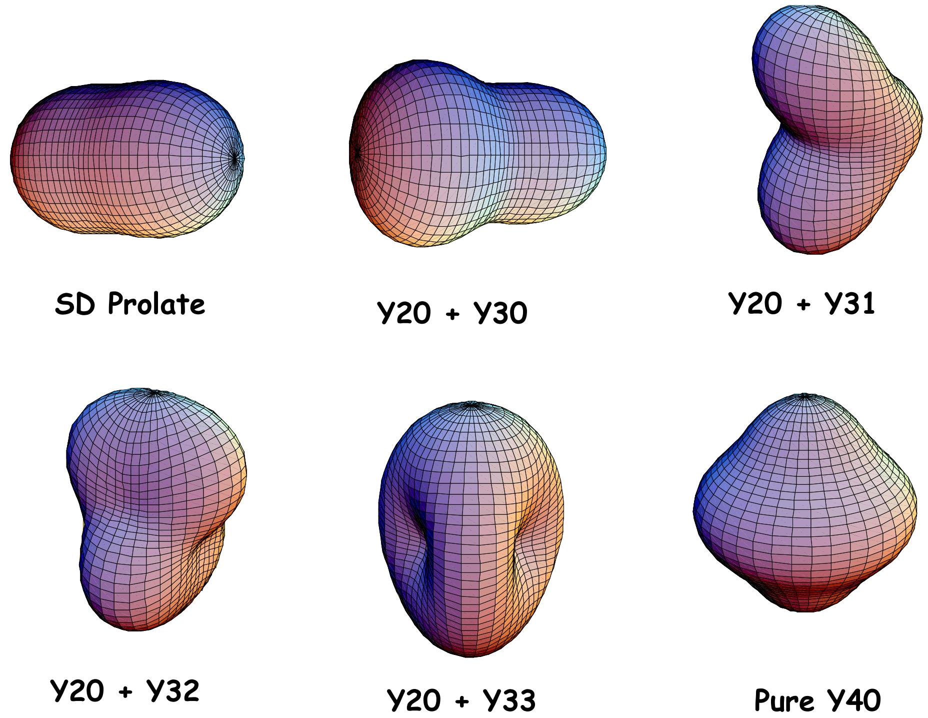
SPES-LOI: *Search for Exotic-Octupole deformation effects in n-rich Ce-Xe-Ba Nuclei*

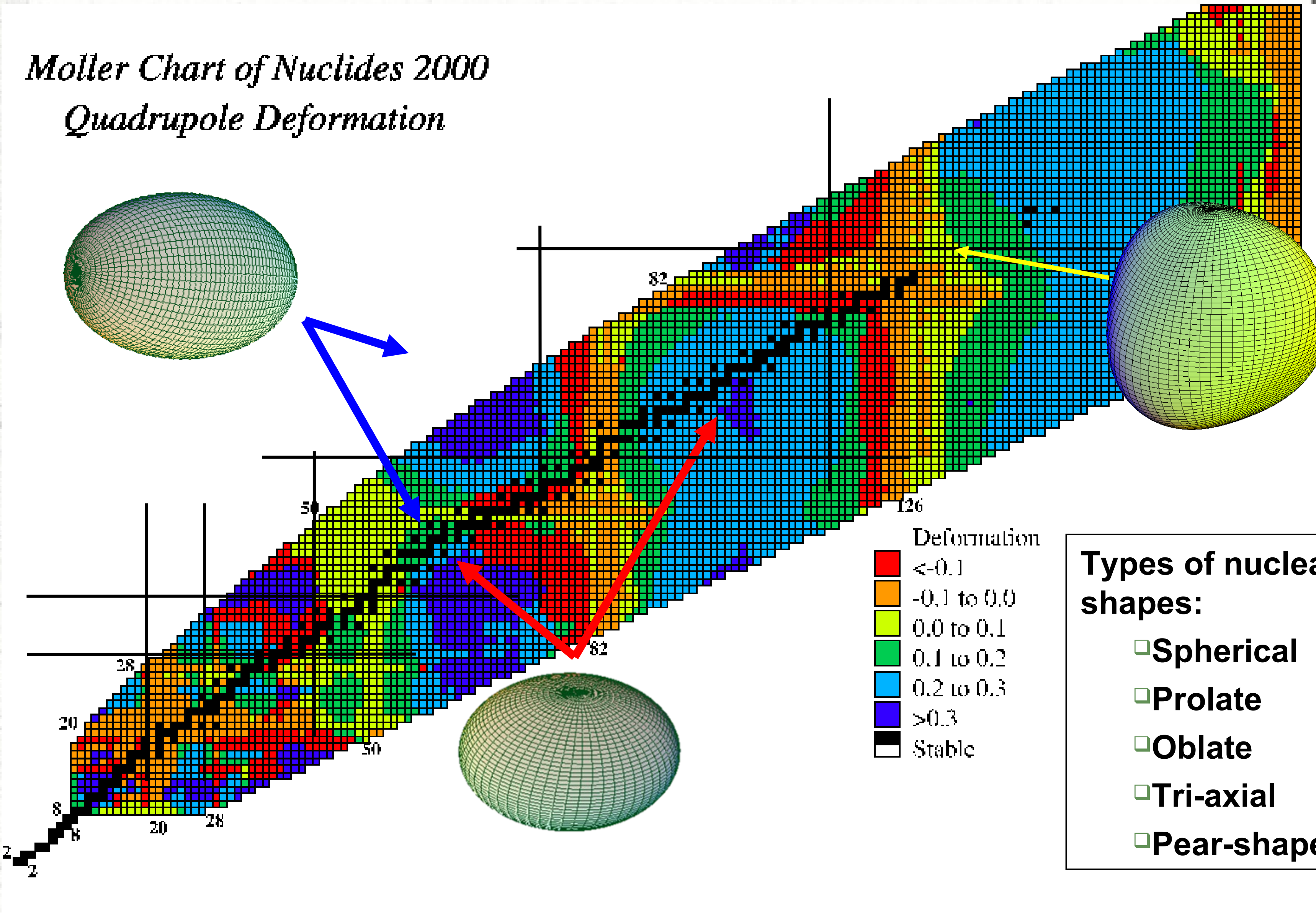


Spokesperson: E. Sahin*, G. de Angelis**

**University of Oslo, Norway*

***INFN, Laboratori Nazionali di Legnaro, Italy*

Standard Nuclear Shapes

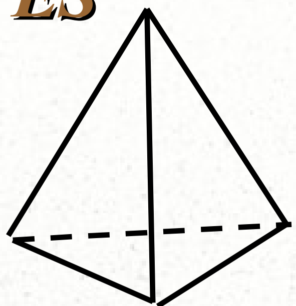


Types of nuclear shapes:

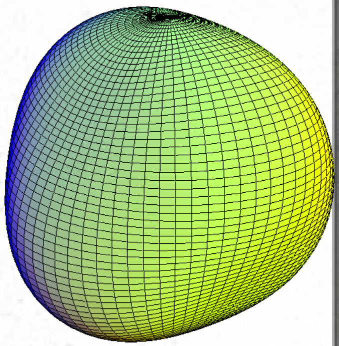
- **Spherical**
- **Prolate**
- **Oblate**
- **Tri-axial**
- **Pear-shape**

EXOTIC SHAPES

- Parameterization of the shape symmetries:

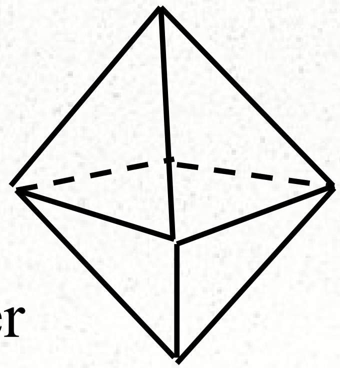


tetrahedron

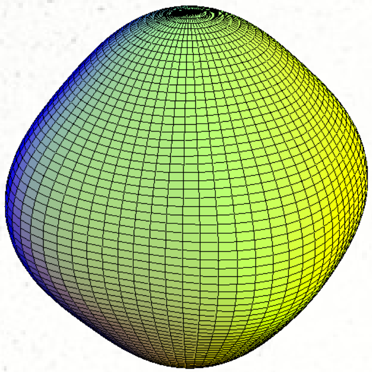


$$R(\theta,\varphi) = R_0 c(\alpha)\left[1 + \sum_{\lambda}\sum_{\mu=-\lambda}^{+\lambda} \alpha_{\lambda\mu} Y_{\lambda\mu}(\theta,\varphi)\right]$$

- Tetrahedral: $\alpha_{32} \neq 0$
- Octahedral: $\alpha_{40}, \alpha_{44} \neq 0$
- Other possibilities involving higher order multipoles $\alpha_{\lambda\mu}$

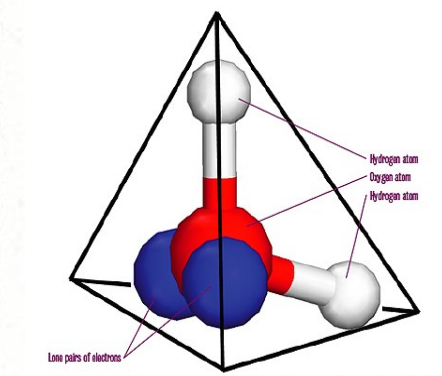


octahedron

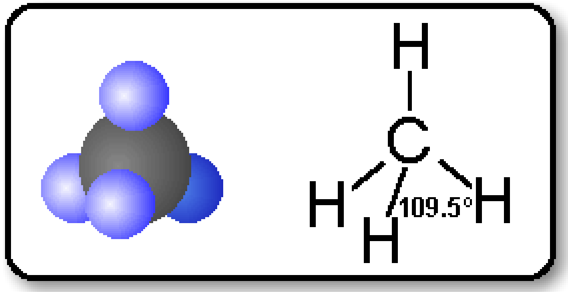


J. Dudek, A. Góźdź and N. Schunck
Act. Phys. Pol. **B34** 2491 (2003)

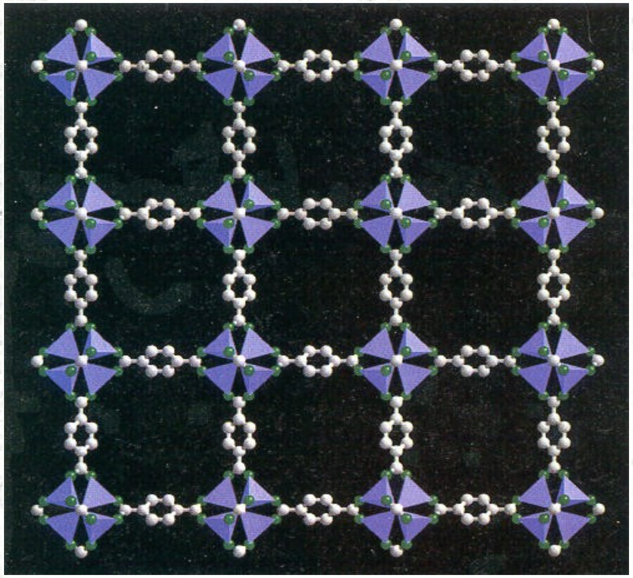
Molecular Structures of Organic/Inorganic Compounds, Metal Clusters: Point Symmetries



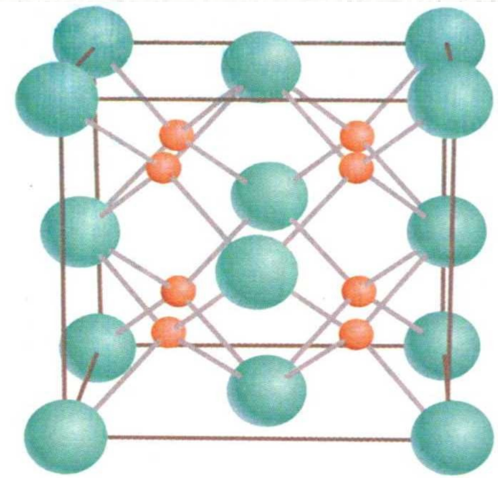
Water: The oxygen atom has two remaining pairs of electrons. These lone electron pairs and the hydrogen atoms are as far apart as possible, creating a tetrahedral arrangement. The oxygen lies at the centre of a tetrahedron



Methane is the simplest hydrocarbon molecule present in natural gas. This molecule provides the basis for the tetrahedral geometries at each carbon in a hydrocarbon chain.



Synthetic inorganic-organic compound with ZnO4 tetrahedral clusters linked by C6H4-C-O2 “struts” (Li, Nature, 1999). 1.29 nm spacing between centers of adjacent clusters.



Face-centered-cubic (fcc) crystal structure of PuO_2 (Pu atoms in green, O atoms in red).

- C_1 Point Group
- C_i Point Group
- C_s Point Group
- C_n Point Groups
- C_{nv} Point Groups
- C_{nh} Point Groups
- D_n Point Groups
- D_{nh} Point Groups
- D_{nd} Point Groups
- S_n Point Groups
- Tetrahedral Point Groups
- Octahedral Point Groups
- Icosahedral Point Groups
- Spherical Point Group

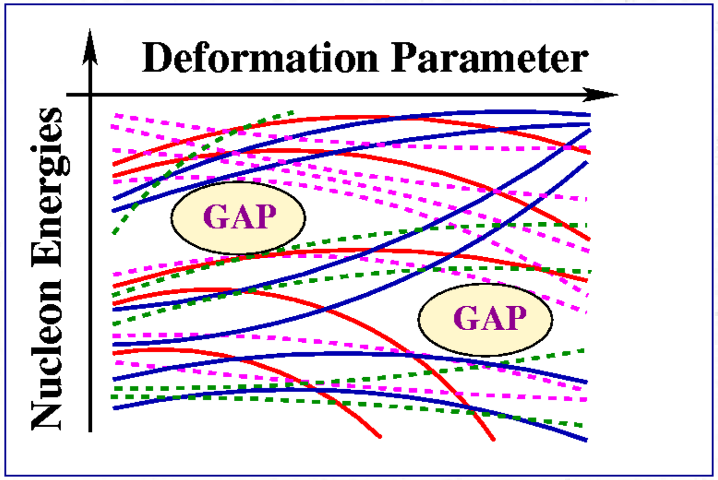
Point Groups and Level Degeneracy

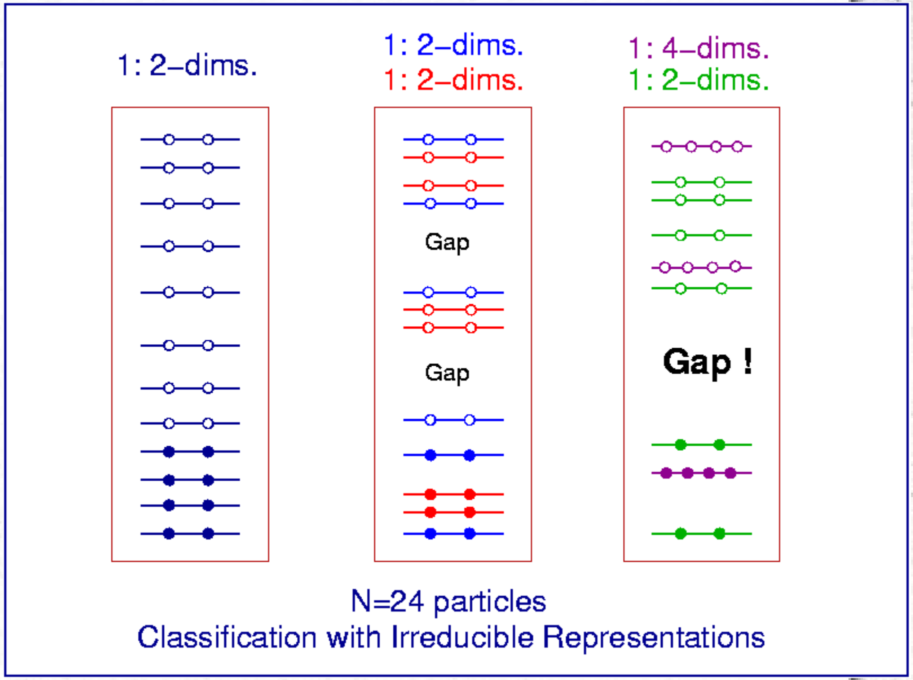
Survey of the properties of a few point groups

Properties	High Symmetries		'Usual' Symmetries
(or observables)	Tetrahedral	Octahedral	D_2^D ('tri-axial')
No. Sym. Elemts.	48	96	8
Parity	NO	YES	YES
Degeneracies	4, 2, 2	$\underbrace{4,2,2}_{\pi=+}$ $\underbrace{4,2,2}_{\pi=-}$	$\underbrace{2}_{\pi=+}$ $\underbrace{2}_{\pi=-}$
Quantum Numbers	3	$3+3+2\,(\pi=\pm)$	$2\ \ (\pi=\pm)$

Point Symmetries and Nuclear Stability

- **Shell Gaps**
  ⇒ Stable configurations
- In nuclei:
  Higher degeneracies ⇒
  Larger shell gaps

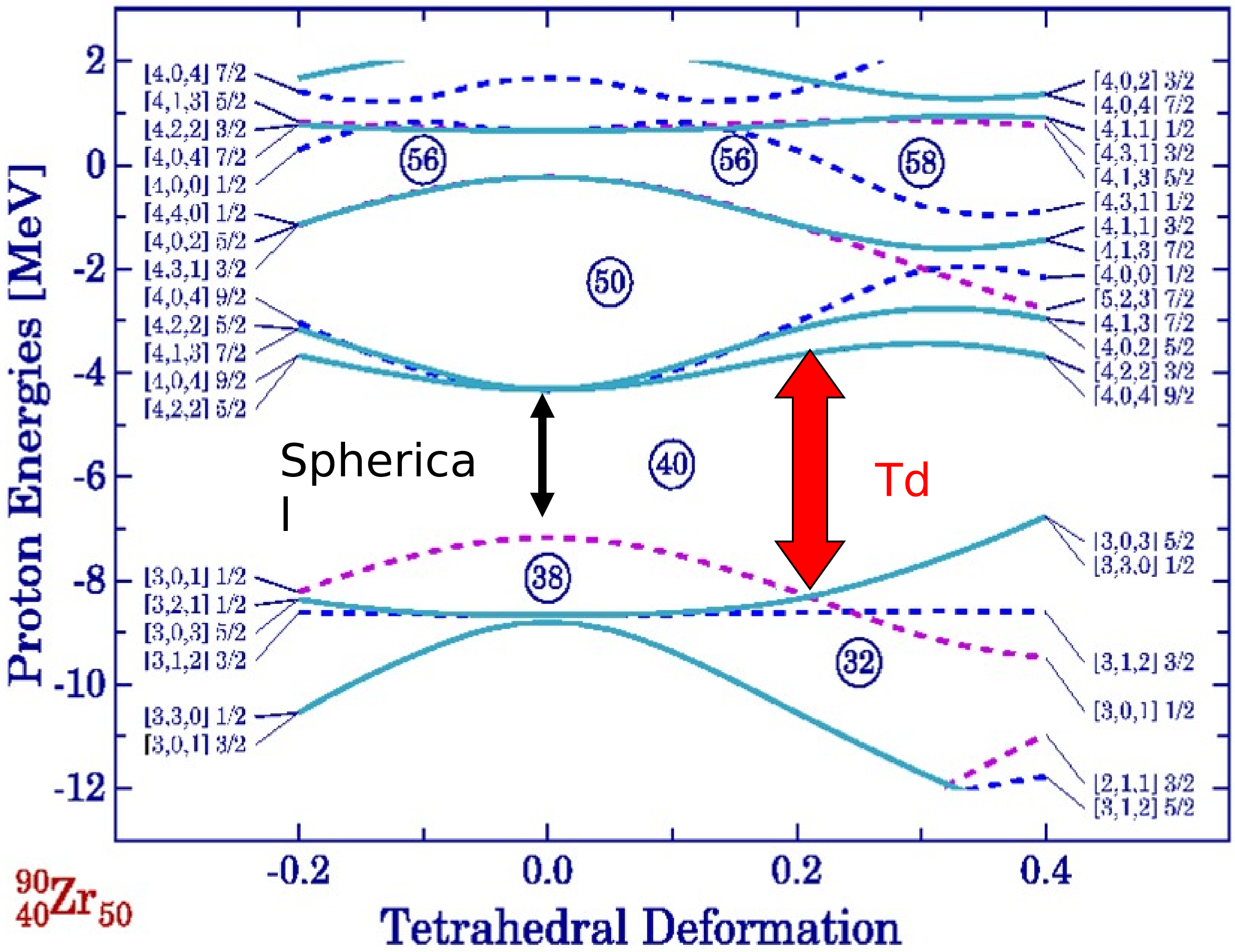




J. Dudek, A. Góźdź, N. Schunck and M. Miskiewicz
Phys. Rev. Lett. **88** 252502 (2002)

Degeneracies are a direct consequence of the underlying point symmetry of the shape

Tetrahedral Shell Gaps



J. Dudek, A. Góźdź and N. Schunck
Act. Phys. Pol. **B34** 2491 (2003)

Tetrahedral Magic Numbers

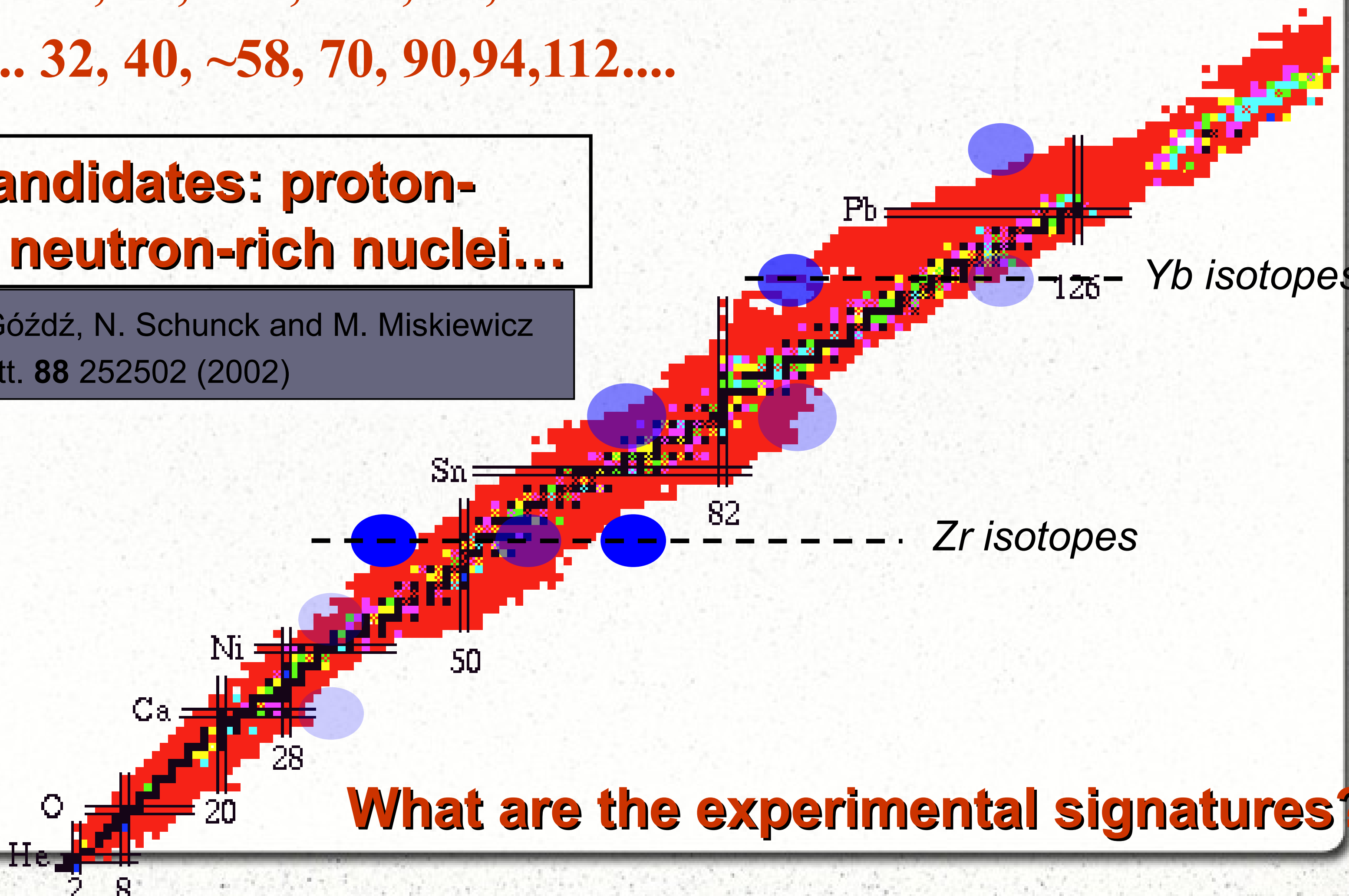
- From a WS potential:

$Z = \ldots 32, 40, \sim 56, \sim 64, 70, \sim 90\ldots$

$N = \ldots 32, 40, \sim 58, 70, 90, 94, 112\ldots.$

Best candidates: proton-rich or neutron-rich nuclei…

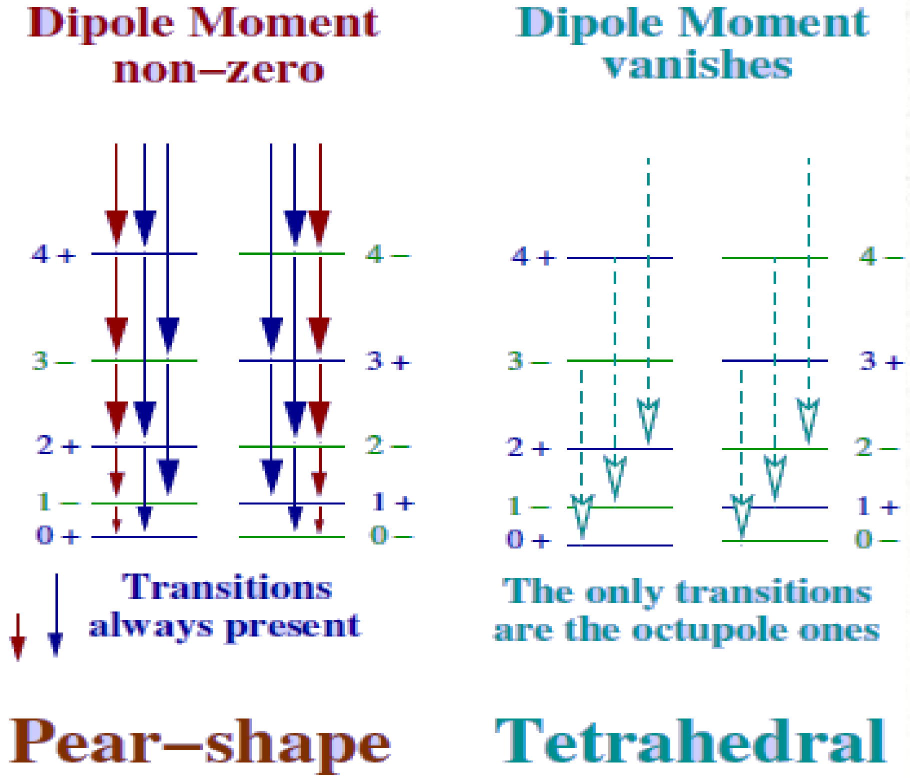
J. Dudek, A. Góźdź, N. Schunck and M. Miskiewicz
Phys. Rev. Lett. **88** 252502 (2002)



What are the experimental signatures?

Ideal Case: Extreme-Symmetry limit Q2=0 & Q1=0

Tetrahedral symmetry is compatible with the presence of some non-zero quadrupole moment if the so-called **zeropoint motion** is taken into consideration. Moreover, the tetrahedral component in the nuclear mean field can very well give rise to the `tetrahedral oscillations' of the nuclear ground-states leading to the K = 2- bands in full analogy to the K = 2+ bands (the well known gamma-bands) with the strong quadrupole moments present in both cases.



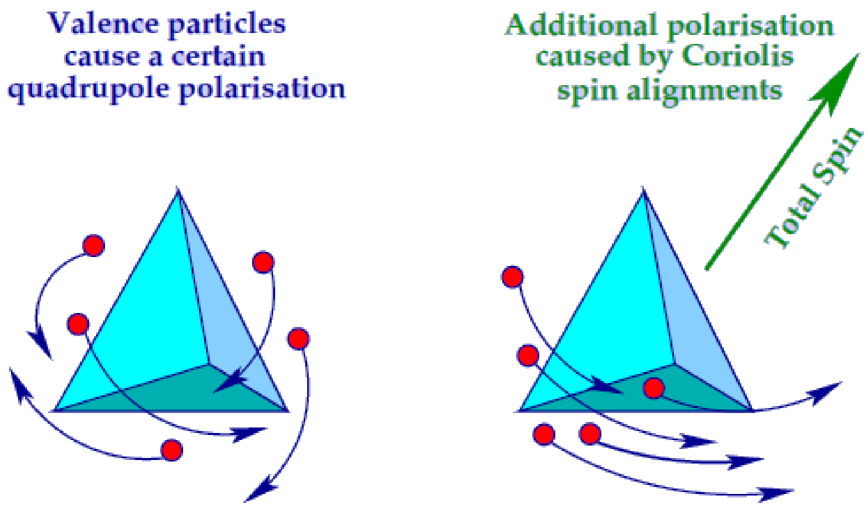
Dobrowolski A. et al., 2011 Int. J. Mod. Phys. E 20 500

Ideal static-THS picture needs to be modified when we wish to address the problem of radiation

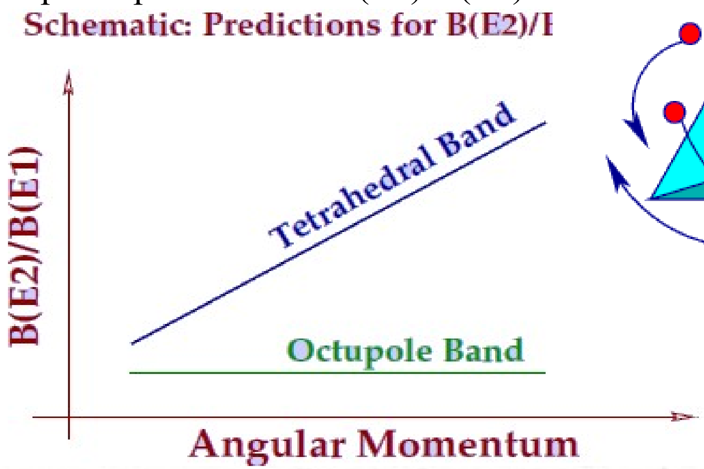
It is known that at reduced transition probabilities B(E1) and B(E3) comparable, the E1-decay is 10E12 more probable !!

Therefore it will be necessary to look into problems of partial symmetry breaking in the case of the two high-rank symmetries

Spin-alignment will cause additional quadrupole polarization



Spin dependence on B(E2)/B(E1)



Experimental signatures required for confirmation of THD

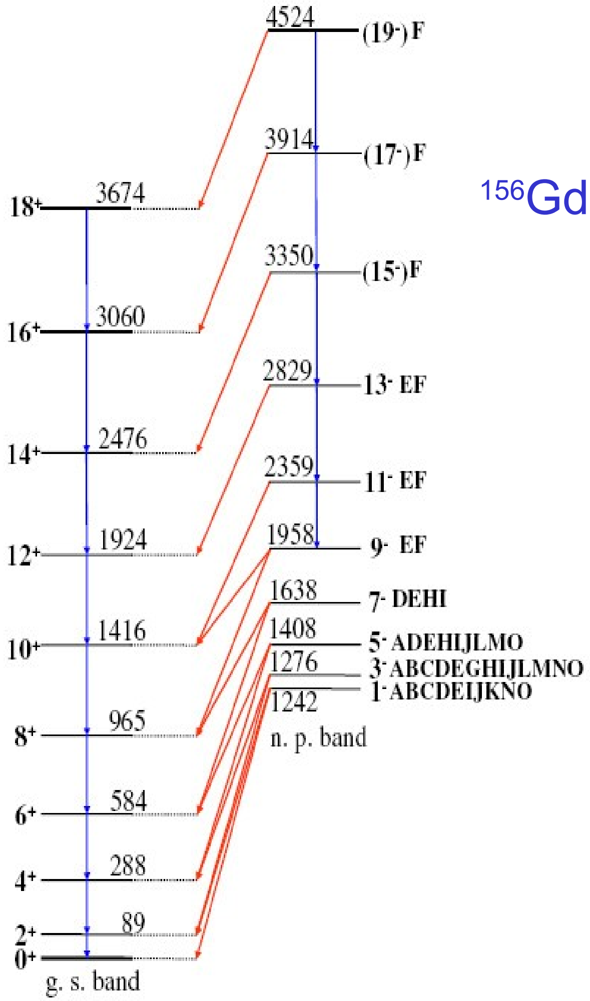
Focus on the negative parity band
→ Octupole character
Close-lying levels
→ 4-fold degeneracy
Very weak intra-band E2
→ angular-momentum-induced
quadrupole moments

1) Precise branching ratios B(E2)/B(E1)
2) Large B(E3) matrix elements

3) Look for missing E2 intraband in

low-lying states

4)Find quadrupole moments

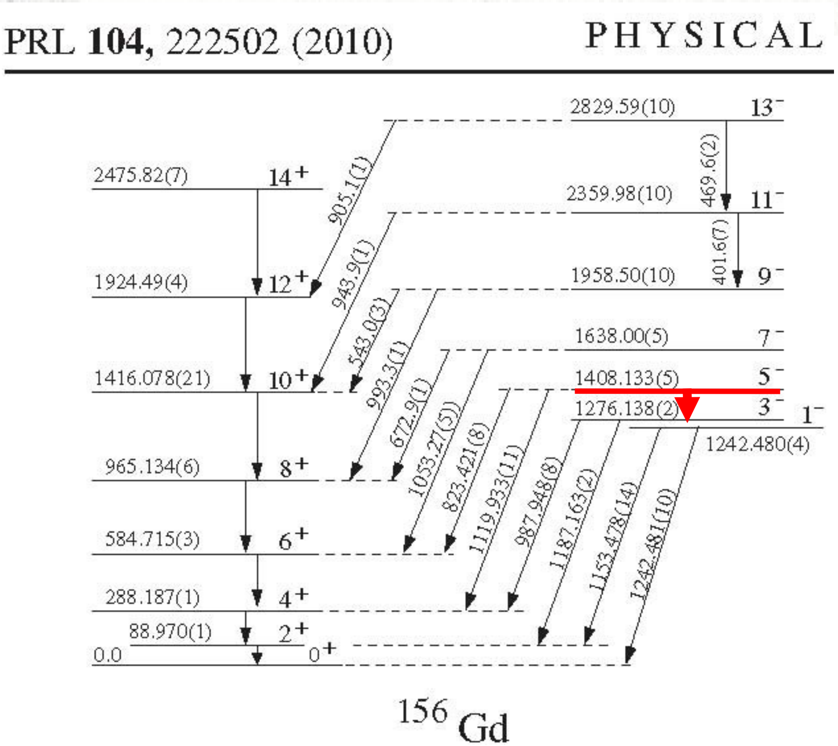


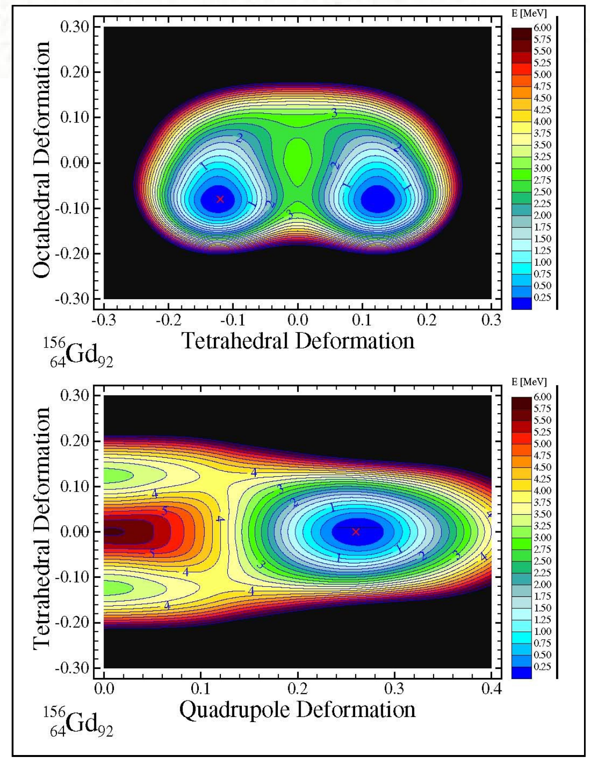
J. Dudek et al., PRL 97 (2006)

PRL **104,** 222502 (2010) PHYSICAL REVIEW LETTERS week ending 4 JUNE 2010

Ultrahigh-Resolution γ-Ray Spectroscopy of ^{156}Gd: A Test of Tetrahedral Symmetry

M. Jentschel,[1] W. Urban,[1,2] J. Krempel,[1] D. Tonev,[3] J. Dudek,[4] D. Curien,[4] B. Lauss,[5] G. de Angelis,[6] and P. Petkov[3]





Intensity of the 132 keV $5^- \rightarrow 3^-$ γ ray
Lifetime of the 5^- level at 1.408 MeV
GRID method

$B(E2\ 5^- \rightarrow 3^-) = 293\ (+61-134)$ W.U.
$B(E2\ 2^+ \rightarrow 0^+) = 186.1(20)$ W.U.

$\beta_{5^-} = 0.35(15)$
$\beta_{2^+} = 0.3378(18)$

$Q_{5^-} = 7.1\ (+0.7-1.6)$ b
$Q_{2^+} = 6.83\ (37)$ b

PRL 104, 222502 (2010) PHYSICAL REVIEW LETTERS week ending 4 JUNE 2010

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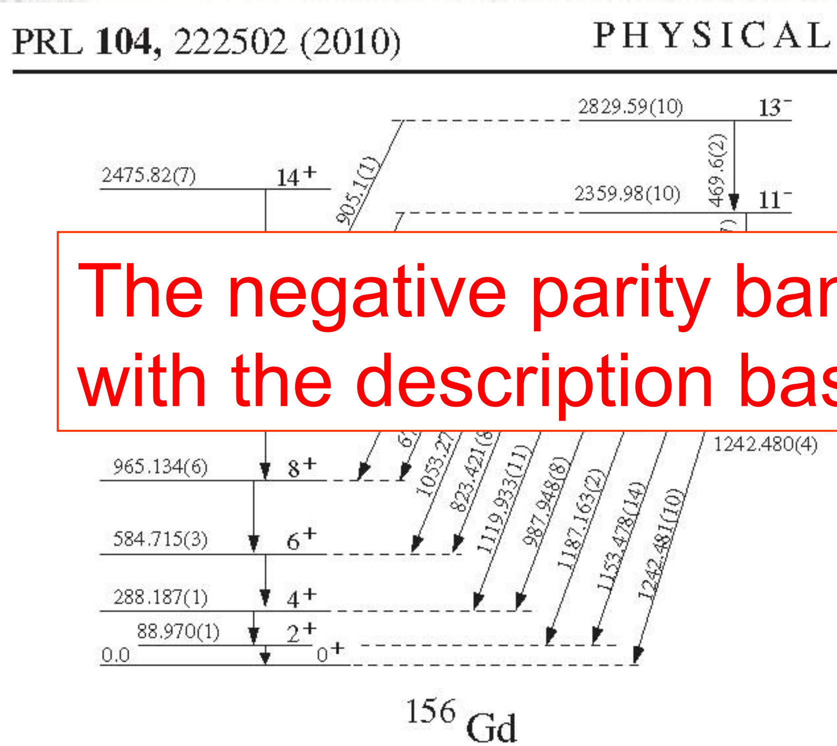

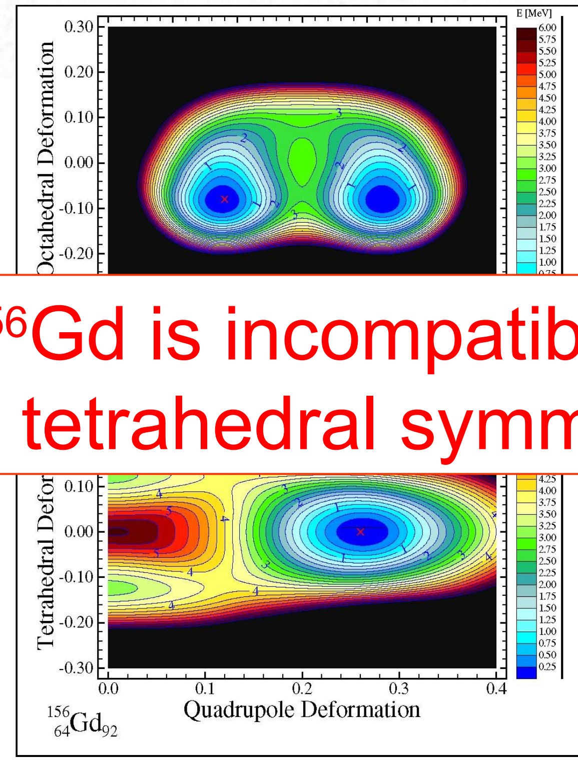

The negative parity band in ^{156}Gd is incompatible with the description based on tetrahedral symmetry

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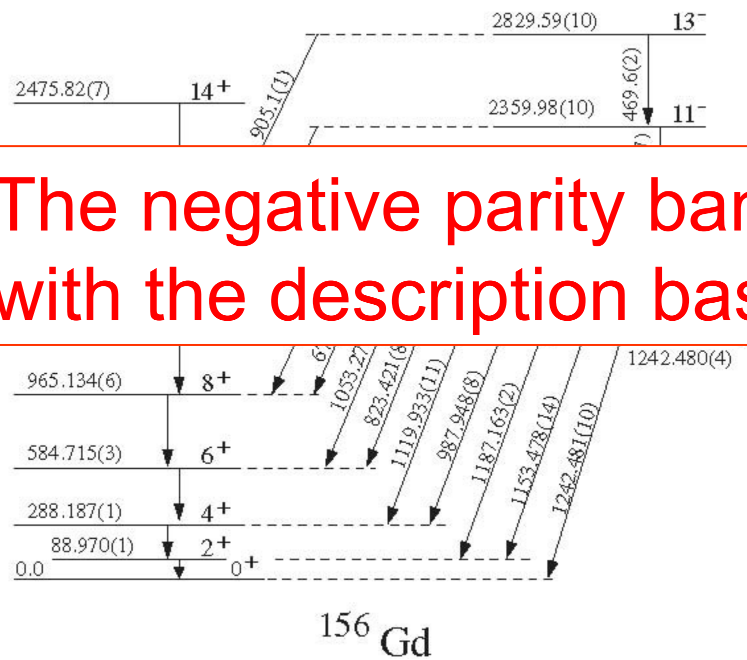
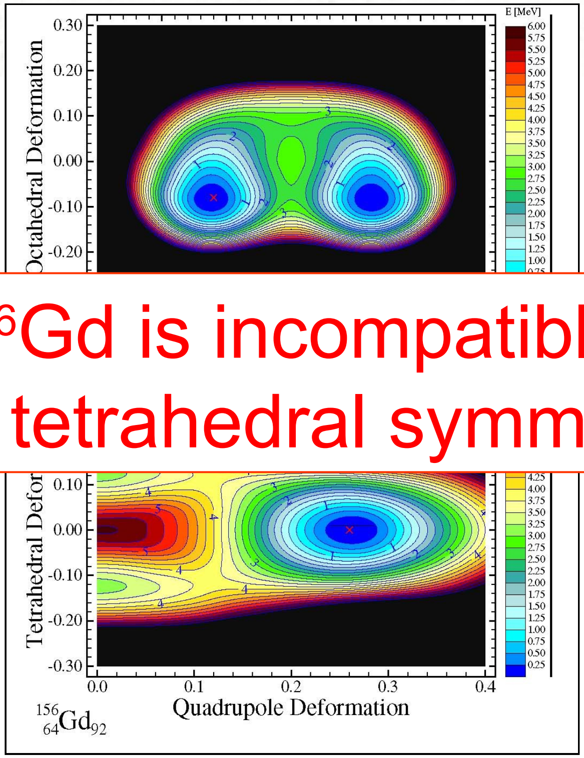
PRL 104, 222502 (2010) PHYSICAL





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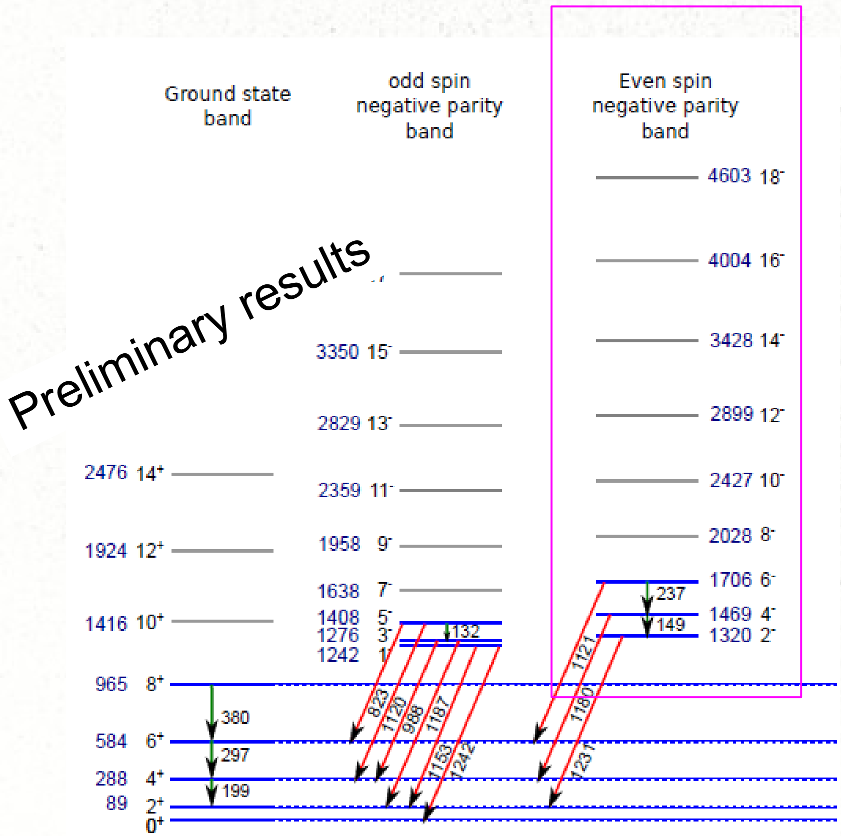
EXILL Campaign at ILL

$$^{155}\mathrm{Gd}(\mathrm{n},\gamma)^{156}\mathrm{Gd}$$



even-spin negative parity band interpreted as the signature partner band of the one with the odd spins

Courtesy of M. Jentschel and J. Dudek et al.

EXILL Campaign at ILL

PRL **112,** 152501 (2014) PHYSICAL REVIEW LETTERS week ending 18 APRIL 2014

Evidence for Tetrahedral Symmetry in ^{16}O

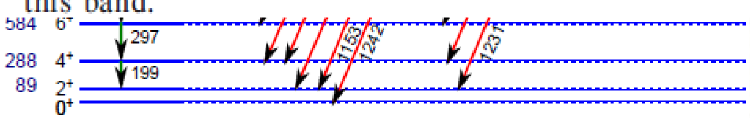
R. Bijker[1] and F. Iachello[2]

[1]*Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Apartado Postal 70-543, 04510 México, Distrito Federal, Mexico*

[2]*Center for Theoretical Physics, Sloane Laboratory, Yale University, New Haven, Connecticut 06520-8120, USA*

(Received 30 January 2014; published 14 April 2014)

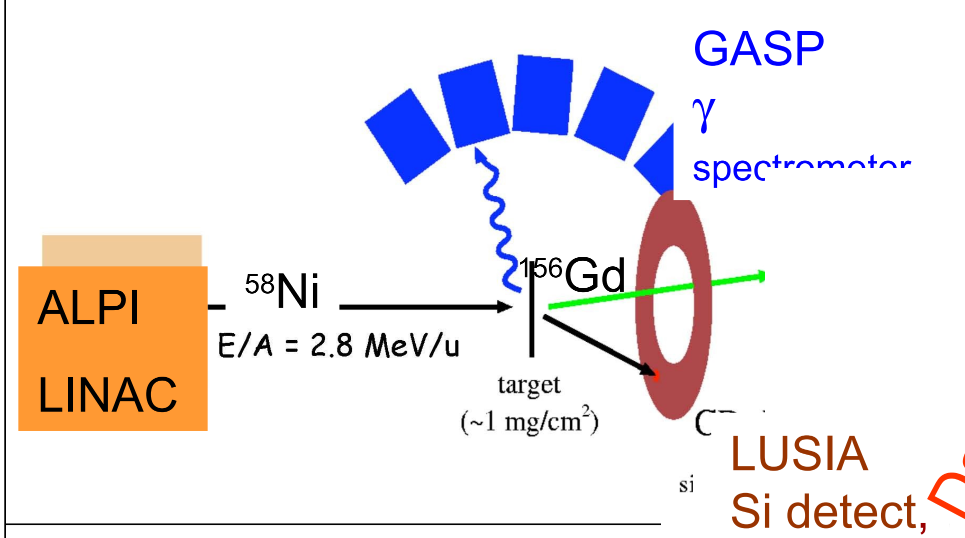
We derive the rotation-vibration spectrum of a 4α configuration with tetrahedral symmetry $\mathcal{T}_d$ and show evidence for the occurrence of this symmetry in the low-lying spectrum of ^{16}O. All vibrational states with A, E, and F symmetry appear to have been observed as well as the rotational bands with $L^P = 0^+, 3^-, 4^+, 6^+$ on the A states and part of the rotational bands built on the E, F states. We derive analytic expressions for the form factors and $B(EL)$ values of the ground-state rotational band and show that the measured values support the tetrahedral symmetry of this band.



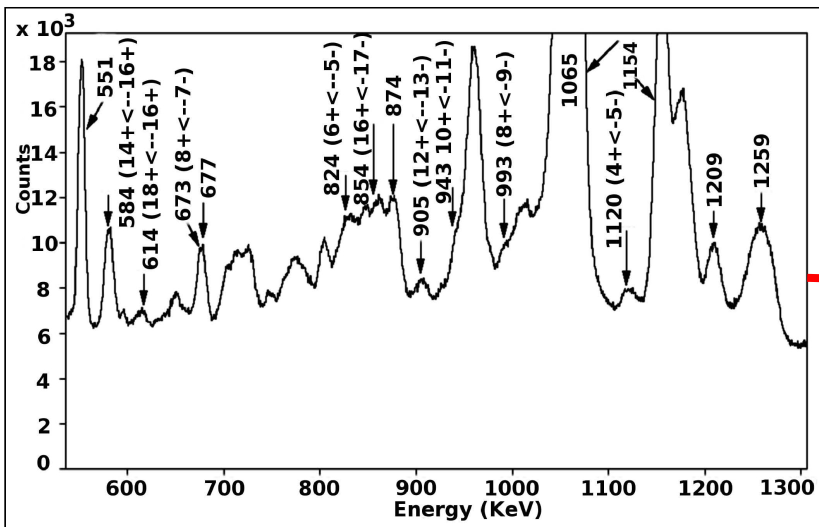
Courtesy of M. Jentschel and J. Dudek et al.

Electromagnetic transition matrix elements and quadrupole moment (with sign) accessible by low energy Coulomb excitation at LNL

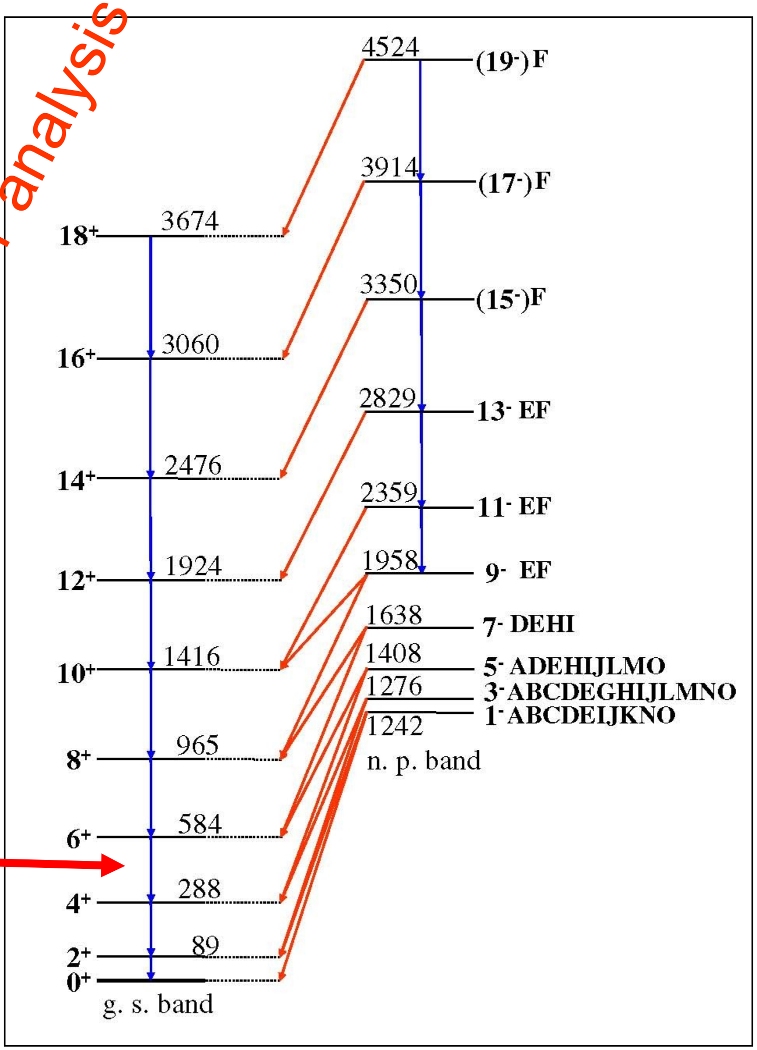
Rajesh Pratap Singh et al.
IUAC Delhi, India



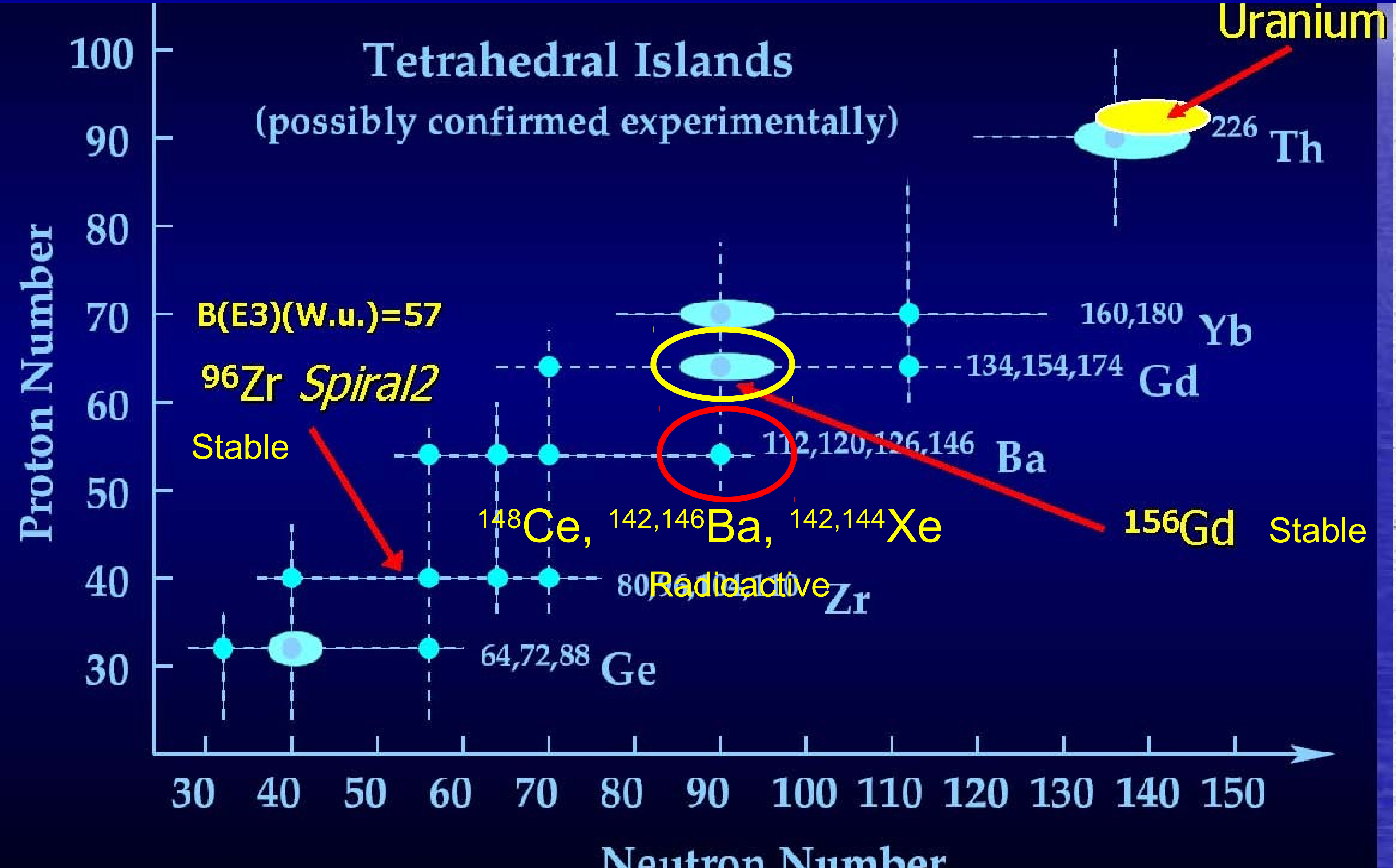
Data under analysis



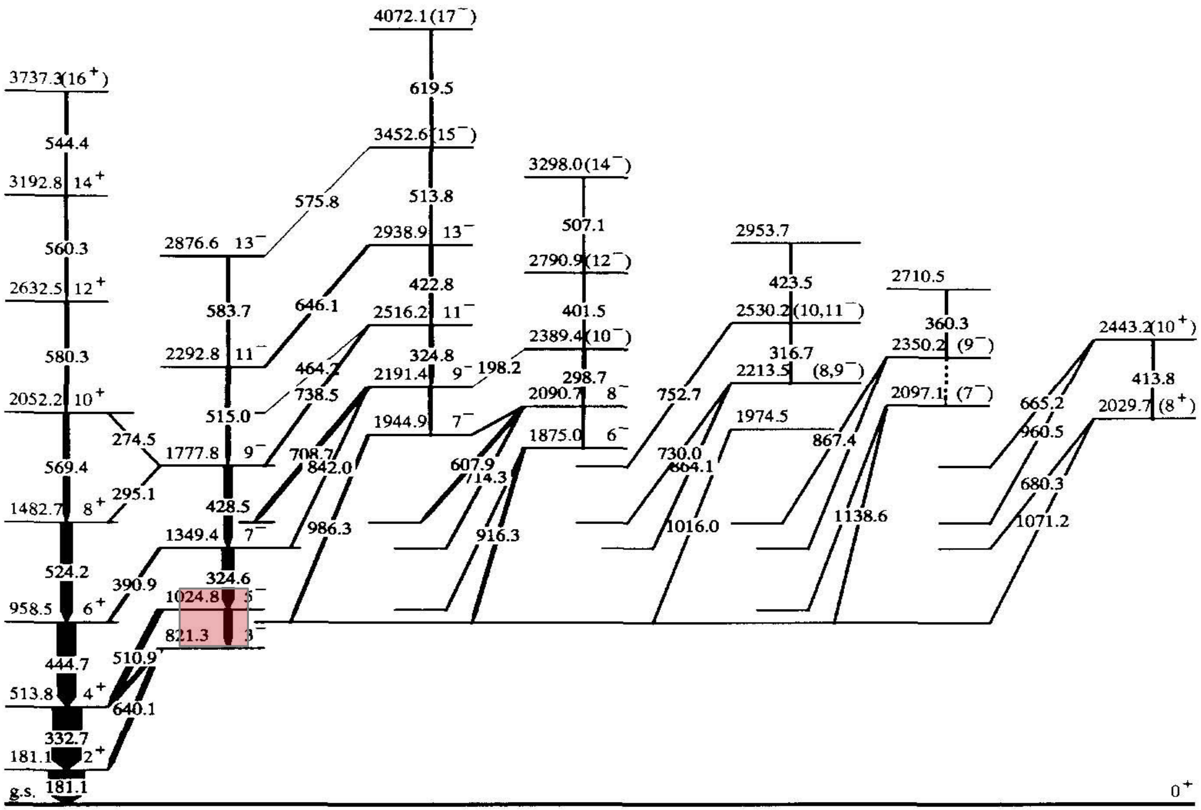
Gate



AIM of the LOI: Transition matrix elements and Q-moments of the exotic octupole bands from Coulex for the n-rich Ce, Ba, Xe nuclei. SPES intensities ~ 105-107 pps



Excited states of the Z=56 N=90 ^{146}Ba nucleus. The negative parity band is a candidate for tetrahedral symm



^{146}Ba

1) To determine the quadrupole moment and precise values for B(E2)/B(E1) values for the expected tetrahedral bands from the angular dependence of the population on the relevant states on the E1 and E2 matrix elements. It is expected that the Q2 moment should decrease with decreasing spin.
2) To look for the expected E3 and/or E1 transitions between the positive and negative parity band members of this family.
3) To search for the other members of this family of bands.

Proposed experiment:

Coulomb excitation of the quadrupole and octupole structures

We propose to populate the above mentioned bands in ^{144,146}Ba and ^{142,144}Xe nuclei through Coulomb excitation using the following beams:

^{142,144,146}Ba and ^{10,1442,144}Xe at an energy of 550 MeV & ^{58}Ni target of about 1 mg/cm^2.

TRACE or SPIDER for the scattered beam particles

GALILEO gamma ray spectrometer for the gamma events

The cross-section for the population of the negative parity band (based on the 3^- state) we are interested in is estimated to be about 2.5 10^{-3} barn using the GOSIA calculations

Nucleus	Beam intensity after re-acceleration (particle/s)	Number of nuclei per day	Number of gamma-particle events per day
^{142}Ba	$1.87\text{x}10^8$	$4\text{x}10^5$	$6\text{x}10^4$
^{144}Ba	$1.14\text{x}10^6$	2550	380
^{140}Xe	$1.34\text{x}10^7$	$3\text{x}10^4$	4500
^{142}Xe	$7.49\text{x}10^5$	1700	250

Table 1: Estimated rates for the ^{142,144}Ba, ^{140,142}Xe nuclei. It has been assumed that the branching ratio E3/E1 is of about 50%, the efficiency for the GALILEO array about 6% and that for the particle detector TRACE about 50% in the rate estimation.

THANKS!!!