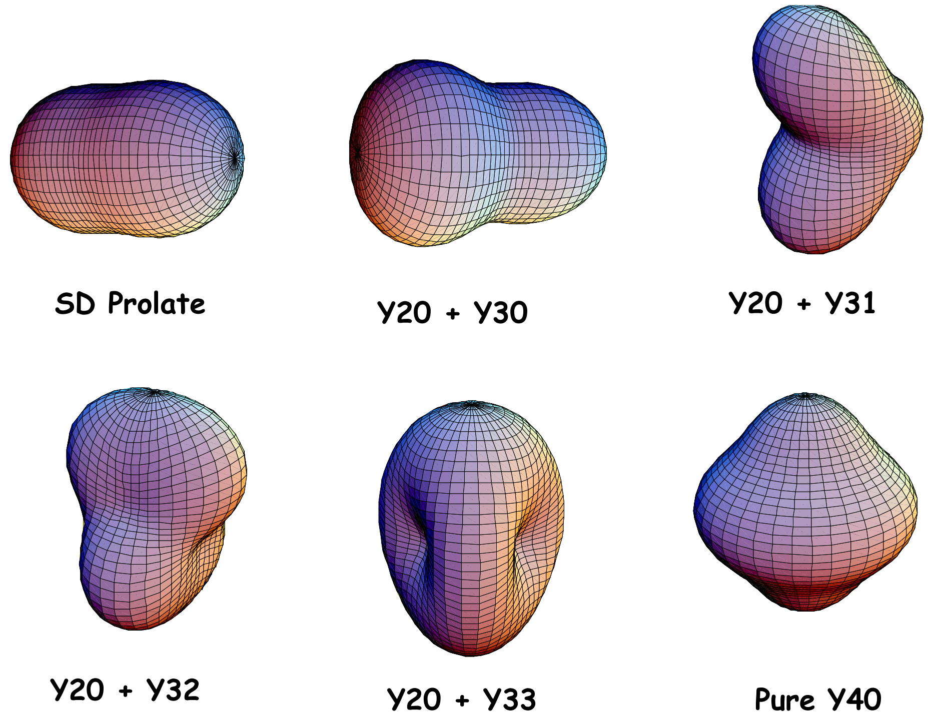
SPES-LOI: Search for Exotic-Octupole deformation effects in n-rich Ce-Xe-Ba Nuclei



Spokesperson: E. Sahin, D. Curien, J. Dudek, M. Zielinska, G. de Angelis
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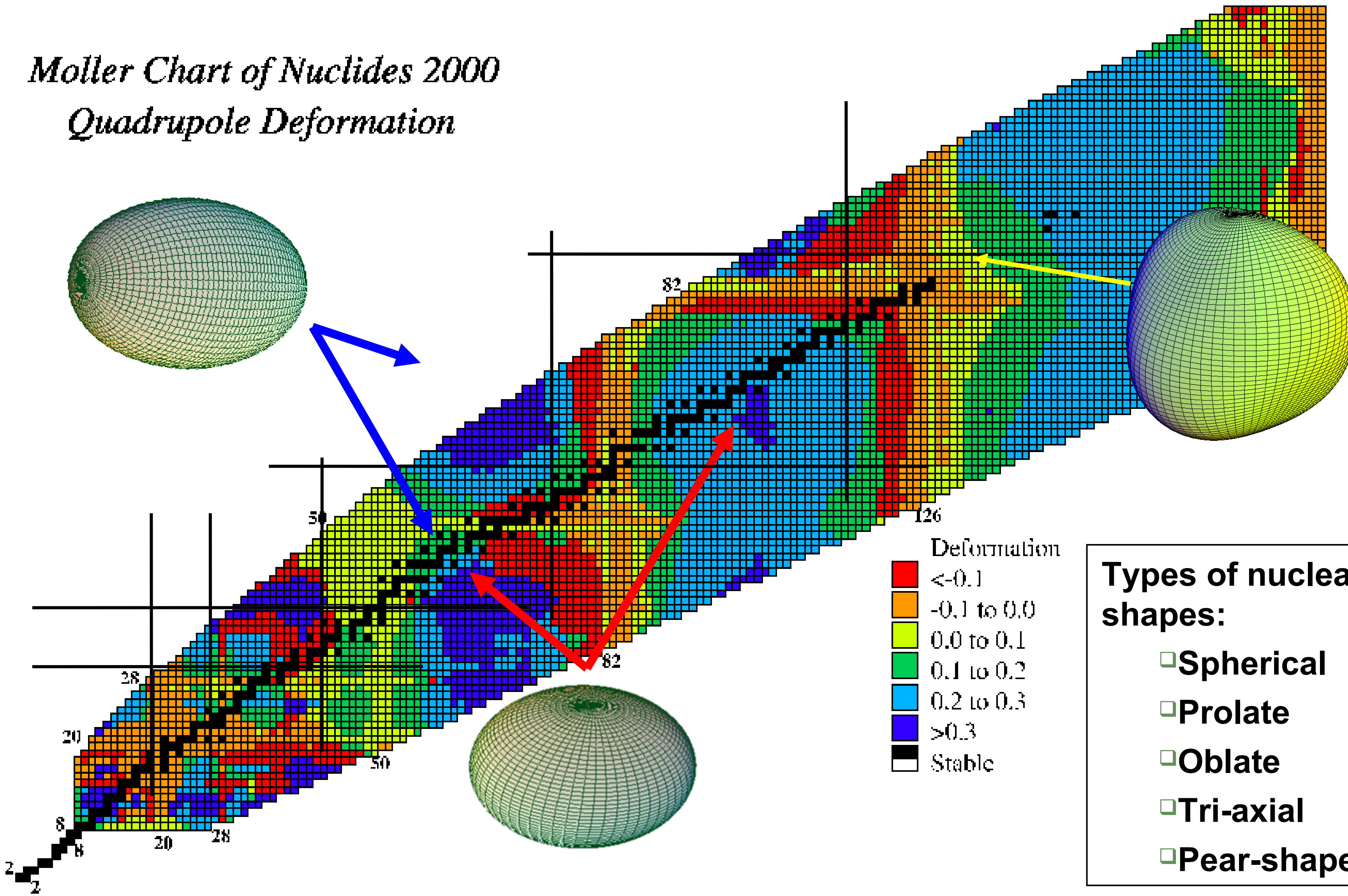
Inter University Accelerator Center, Delhi, India
Bulgarian Accedemy of Science, Sofia, Bulgaria

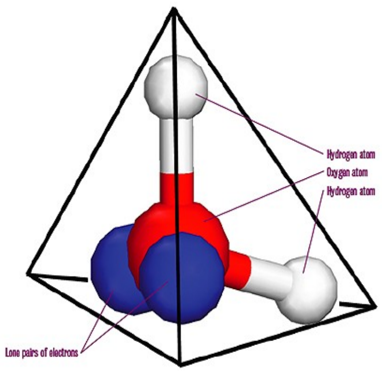
Standard Nuclear Shapes



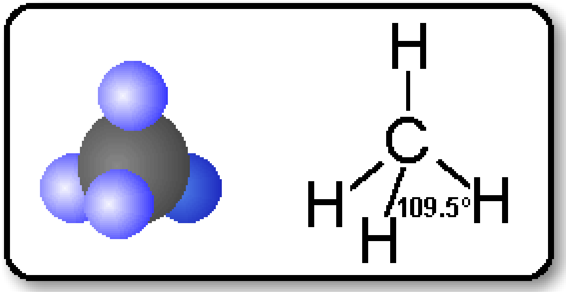
Types of nuclear shapes:

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

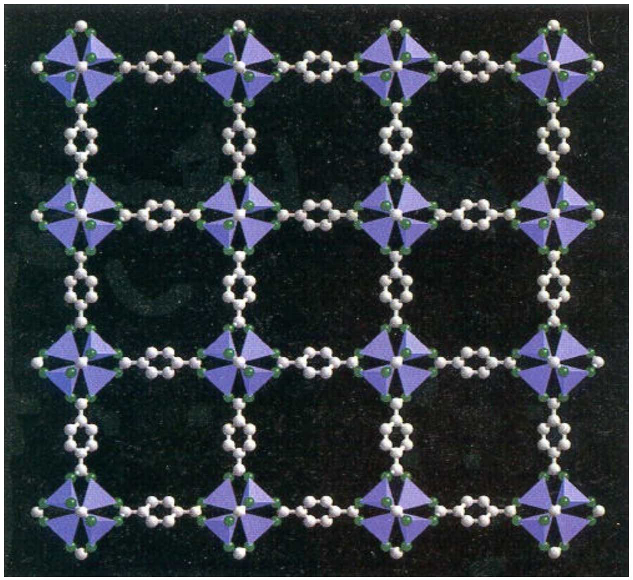
Molecular Structures of Organic/Inorganic Compounds, Metal Clusters: Point Symmetries



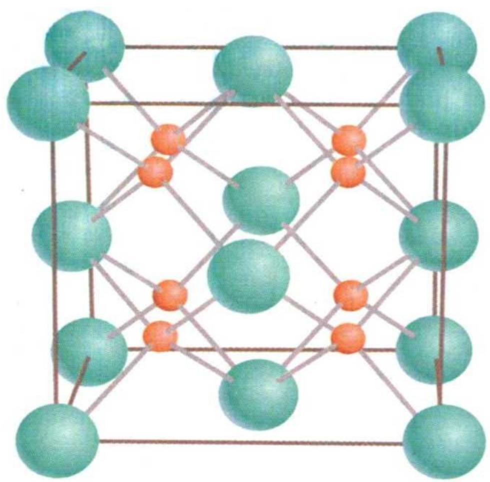
Water: The oxygen atom has two remaining pairs of electrons. These lone electron pairs and the hydrogen atoms are as far apart as possible, creating a tetrahedral arrangement. The oxygen lies at the centre of a tetrahedron



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.

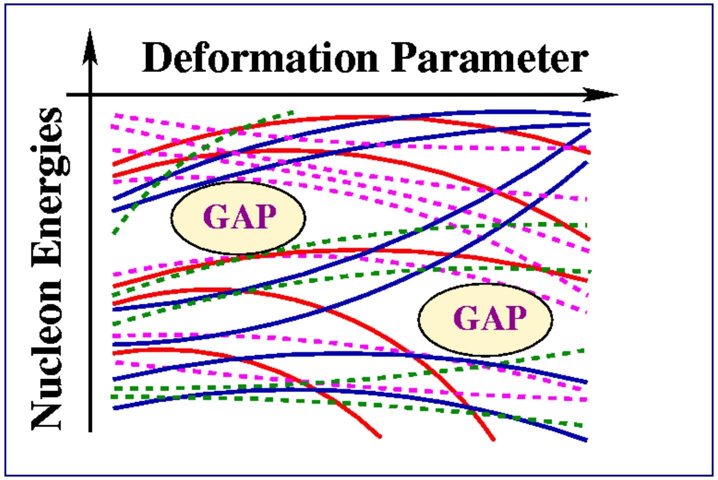


Face-centered-cubic (fcc) crystal structure of PuO_2 (Pu atoms in green, O atoms in red).

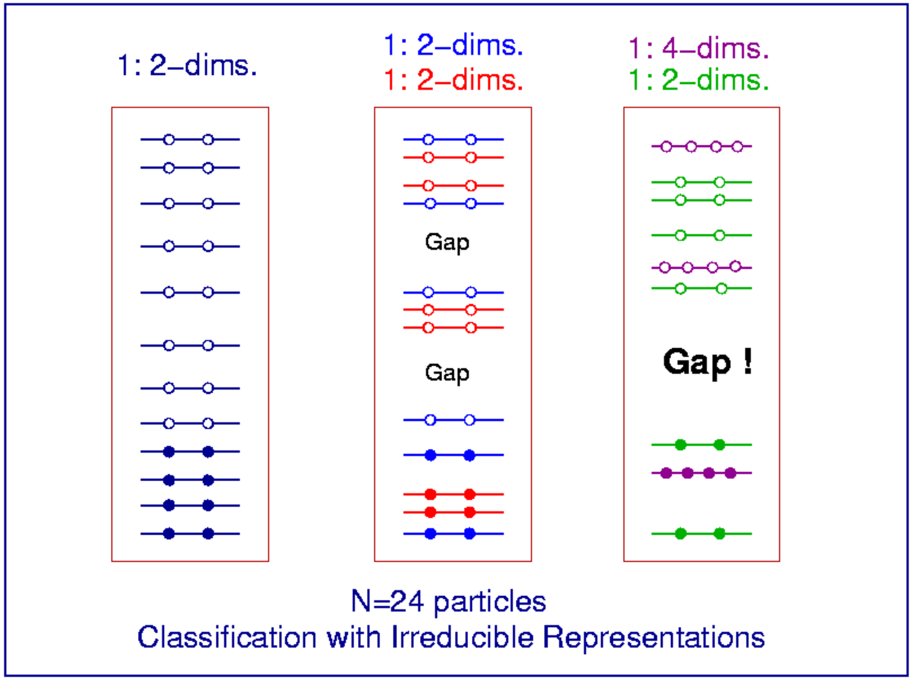
- C_1 Point Group
- C_i Point Group
- C_s Point Group
- C_n Point Groups
- C_{nv} Point Groups
- C_{nh} Point Groups
- D_n Point Groups
- D_{nh} Point Groups
- D_{nd} Point Groups
- S_n Point Groups
- Tetrahedral Point Groups
- Octahedral Point Groups
- Icosahedral Point Groups
- Spherical Point Group

Point Symmetries and Nuclear Stability

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



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

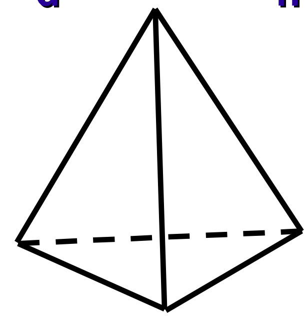
Point Groups and Level Degeneracy

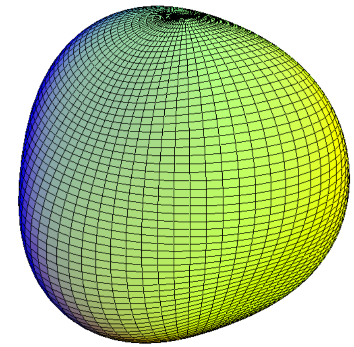
Properties	High symmetries			Low symmetries
Type	Spherical	**Tetrahedral**	**Octahedral**	Any other…
Number of Symmetry Elements	∞	**48**	**96**	…
New Degeneracies	2j + 1	**4, 2, 2**	**4, 2, 2** **4, 2, 2**	, 2

Kramers Degeneracy (= time-reversal symmetry)

Survey of the properties of a few point groups

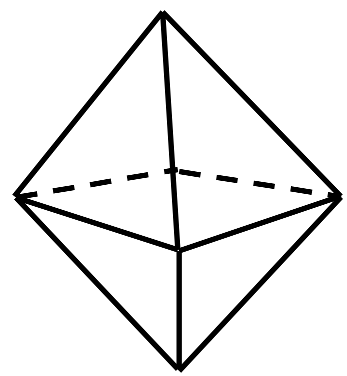
Symmetry Groups T_d and O_h

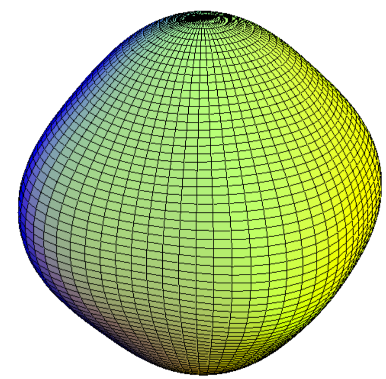




- Parameterization of the shape symmetries:

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

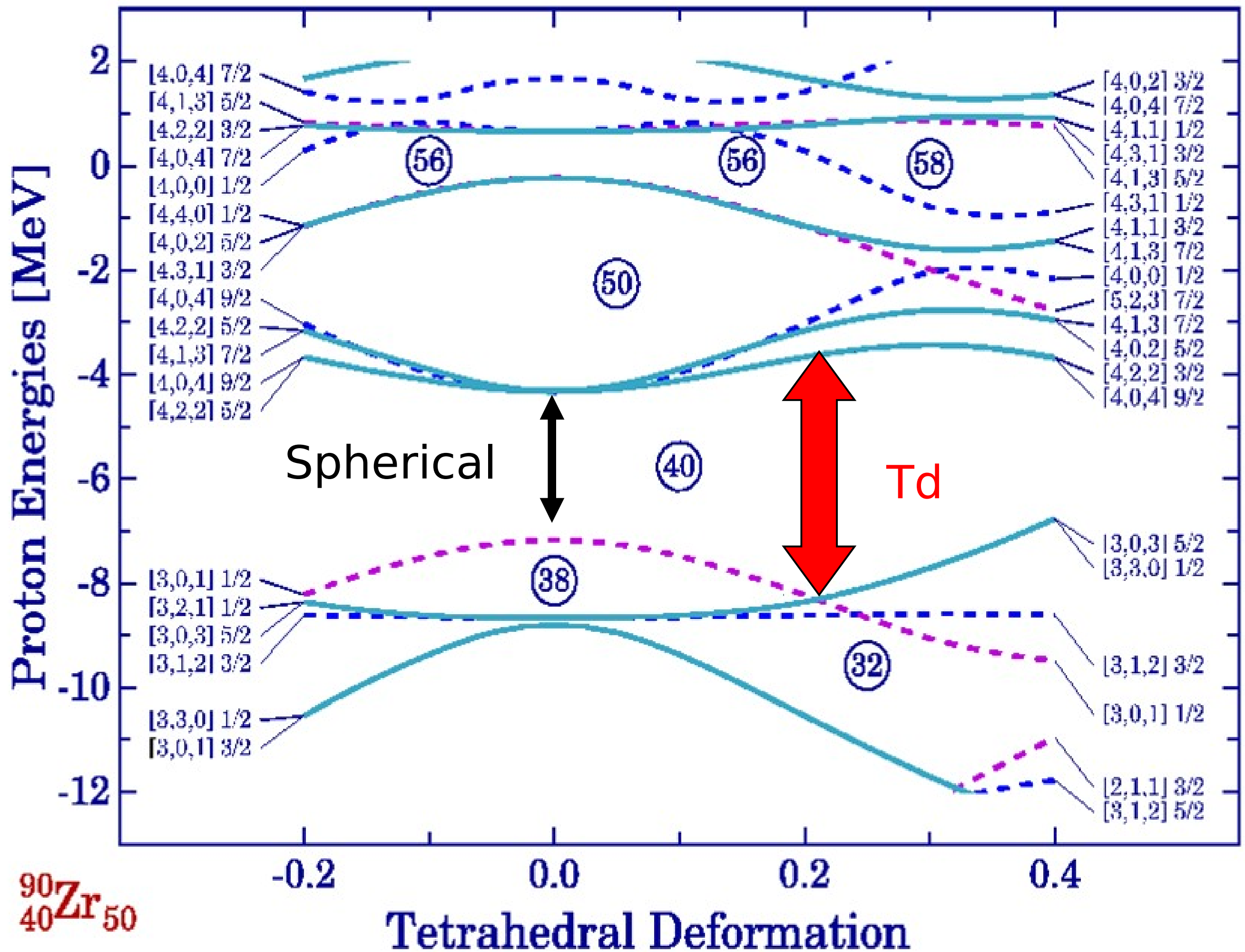




- Tetrahedral: $\alpha_{32} \neq 0$
- Octahedral: $\alpha_{40}, \alpha_{44} \neq 0$
- Other possibilities involving higher order multipoles $\alpha_{\lambda\mu}$

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

Tetrahedral Shell Gaps



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

Tetrahedral Magic Numbers

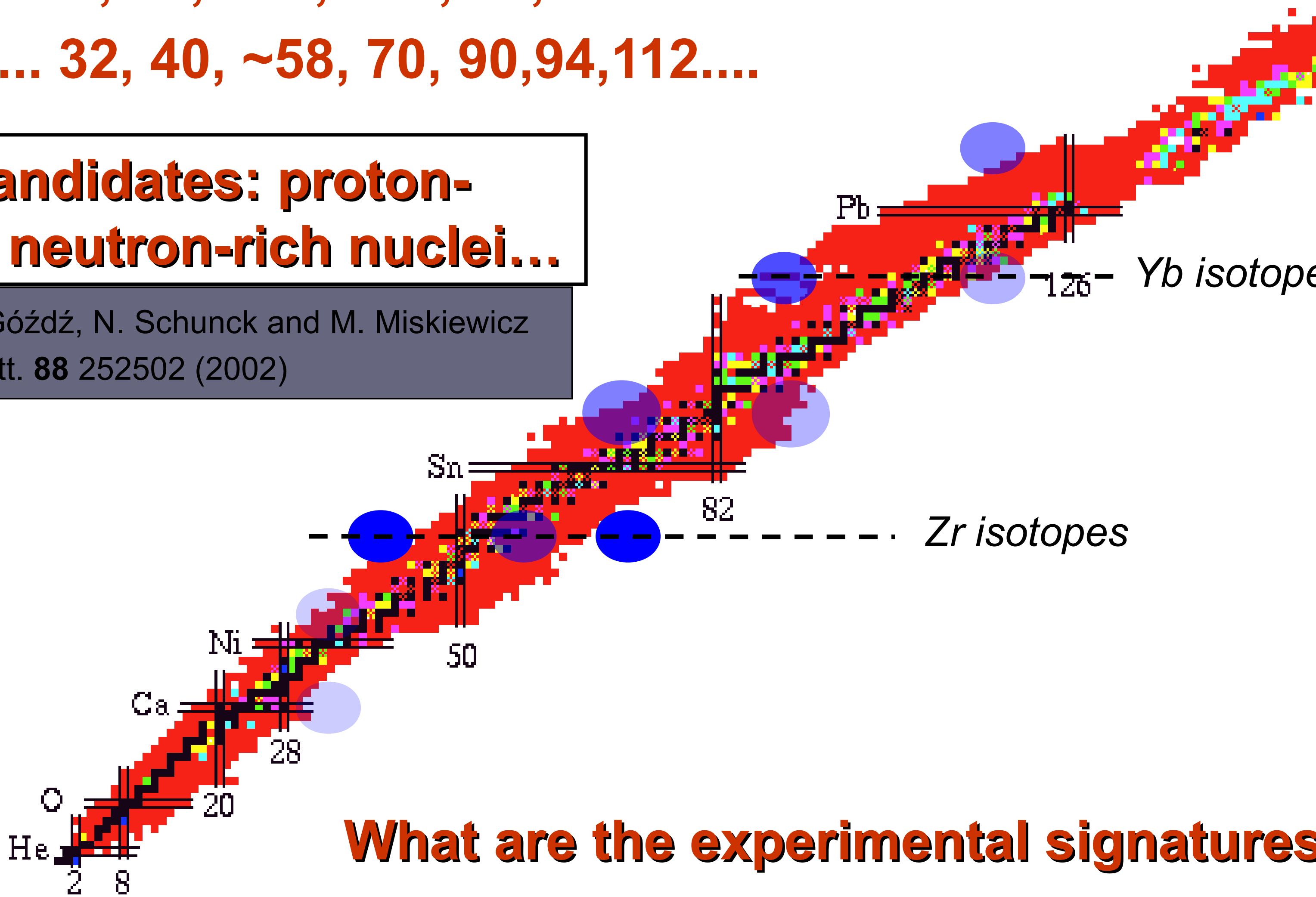
- From a WS potential:

Z = ... 32, 40, ~56, ~64, 70,~90…

N = ... 32, 40, ~58, 70, 90,94,112....

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

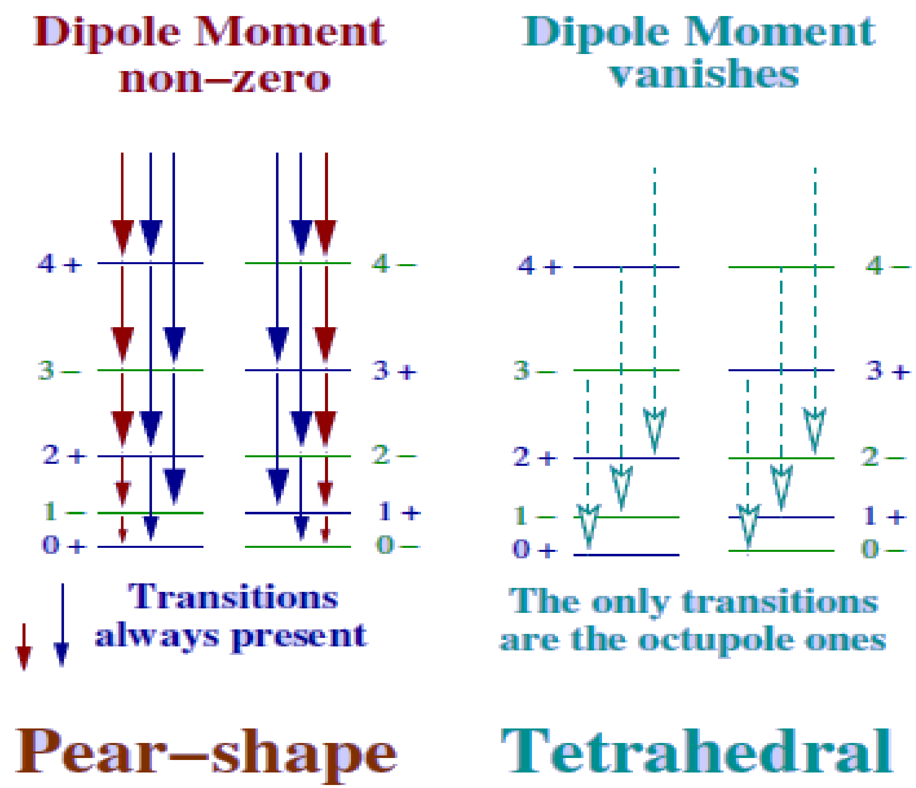
J. Dudek, A. Góźdź, N. Schunck and M. Miskiewicz
Phys. Rev. Lett. **88** 252502 (2002)



What are the experimental signatures?

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

The mechanism of zero-point quadrupole motion about zero-quadrupole deformation

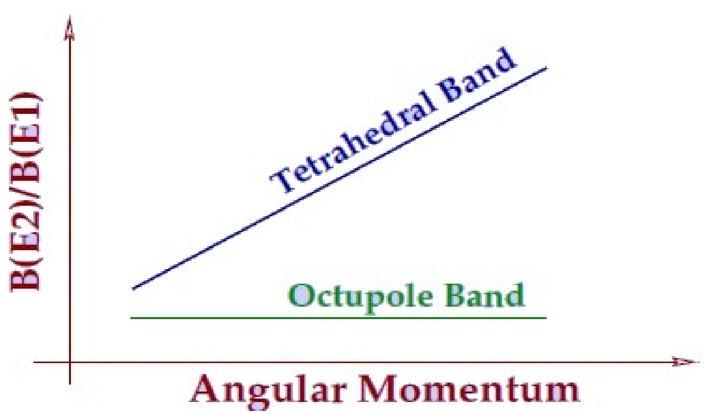


Ideal static-THS picture needs to be modified when we wish to address the problem of radiation

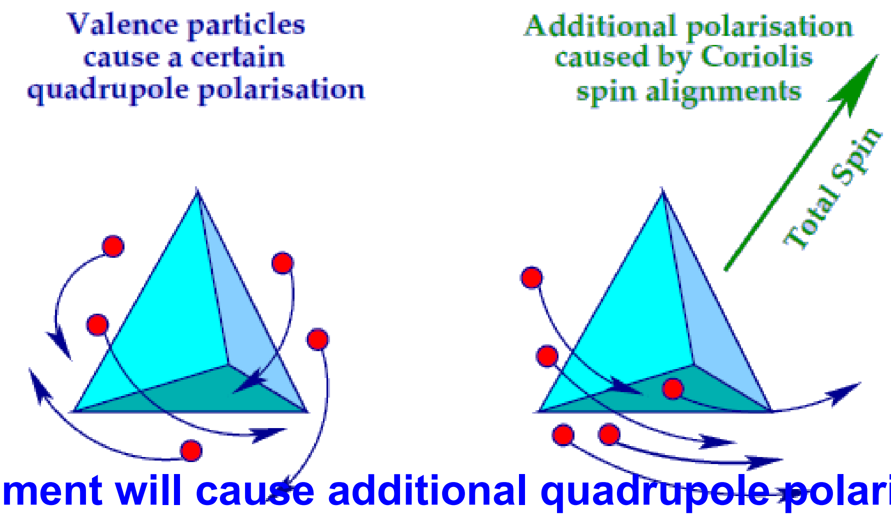
It is known that at reduced transition probabilities B(E1) and B(E3) comparable, the E1-decay is 10E12 more probable !!

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

Schematic: Predictions for B(E2)/B(E1)



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



Spin-alignment will cause additional quadrupole polarization

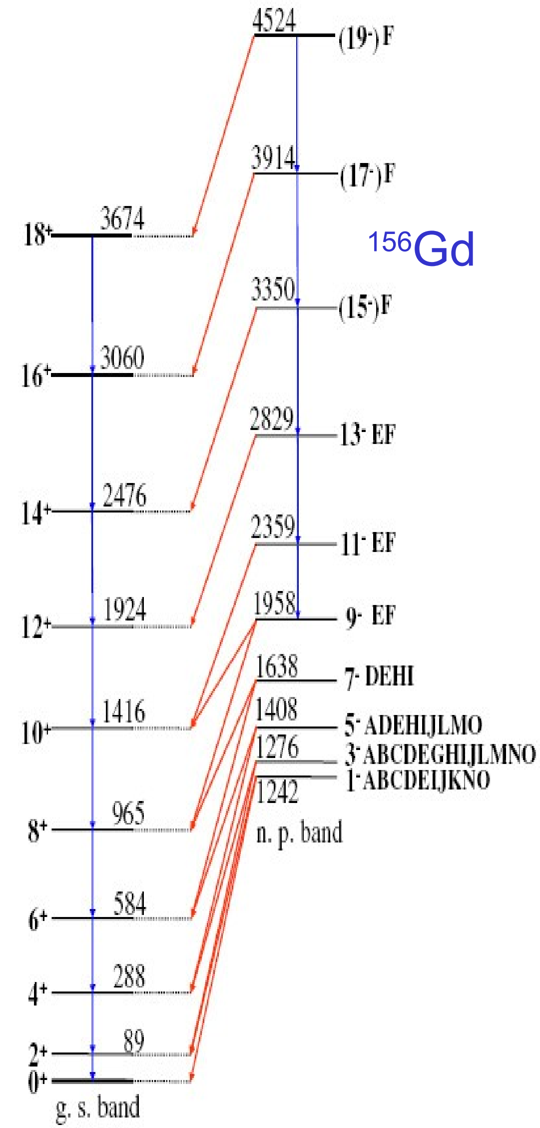
Experimental signatures required for confirmation of THD

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

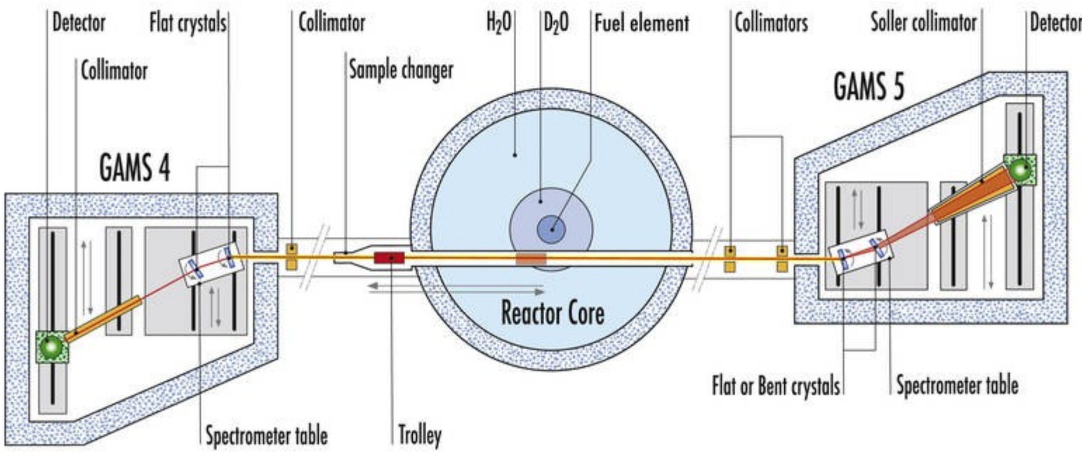
1) Precise branching ratios B(E2)/B(E1)
2) Large B(E3) matrix elements

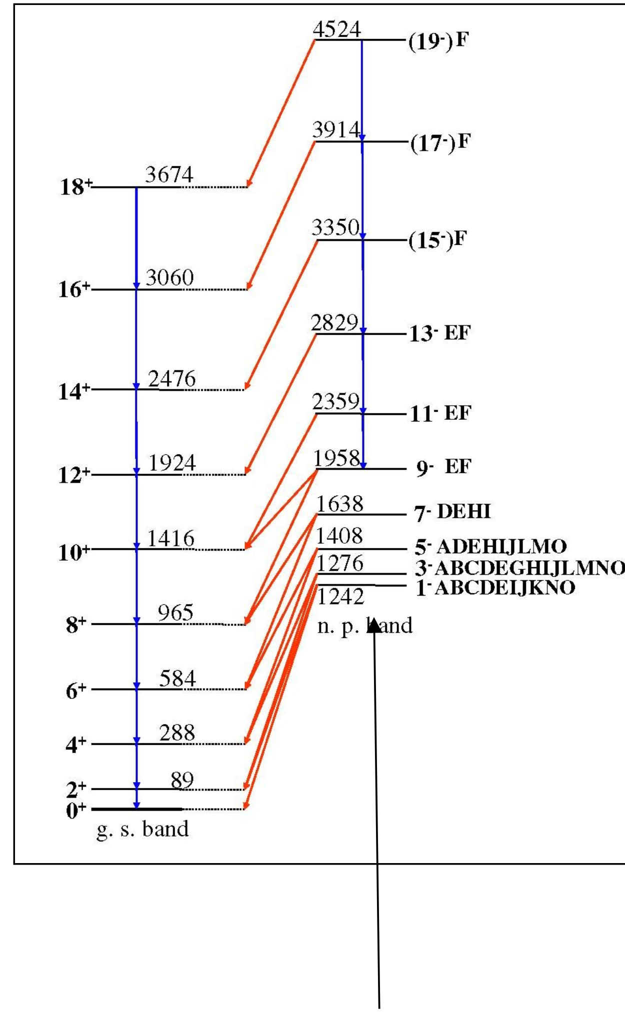
3) Look for missing E2 intraband in low-lying states

)Find quadrupole moments



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





(n,γ) on ^{155}Gd $\rightarrow$ ^{156}Gd

Ultrahigh resolution γ-ray spectroscopy at ILL

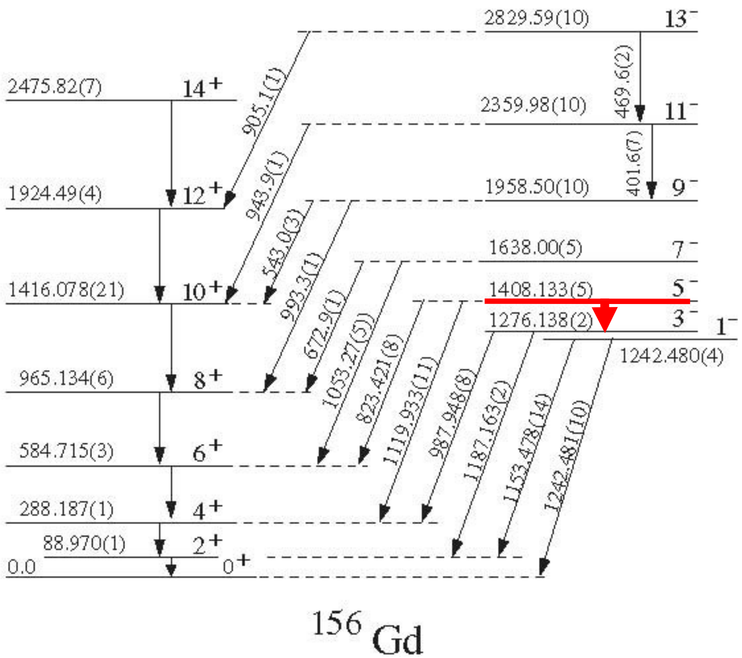
Intensity of the 132 keV 5^- $\rightarrow$ 3^- γ ray

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

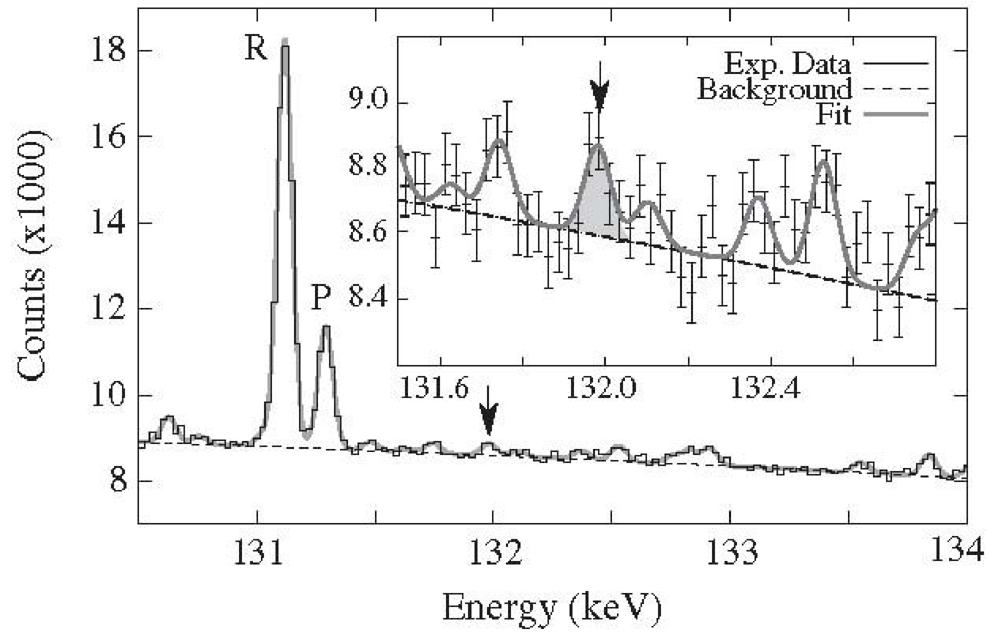
Ultrahigh-Resolution γ-Ray Spectroscopy of ^{156}Gd: A Test of Tetrahedral Symmetry

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]

PRL **104,** 222502 (2010) PHYSICAL



PRL **104,** 222502 (2010) PHYSICAL



Lifetime of the 5⁻ level at 1.408 MeV

Intensity of the 132 keV 5⁻ → 3⁻ γ ray

Quadrupole moment of the 5^- state in ^{156}Gd

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

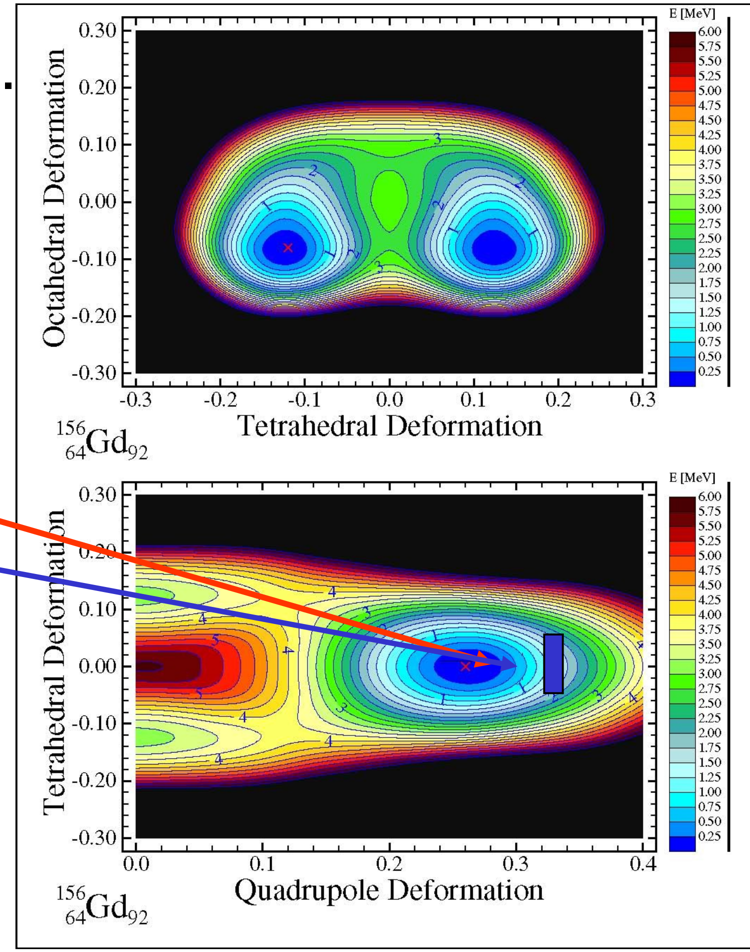
$B(E2\ 2^+ \rightarrow 0^+) = 186.1(20)$ W.U.

$\beta_{5^-} = 0.35(15)$

$\beta_{2^+} = 0.3378(18)$

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

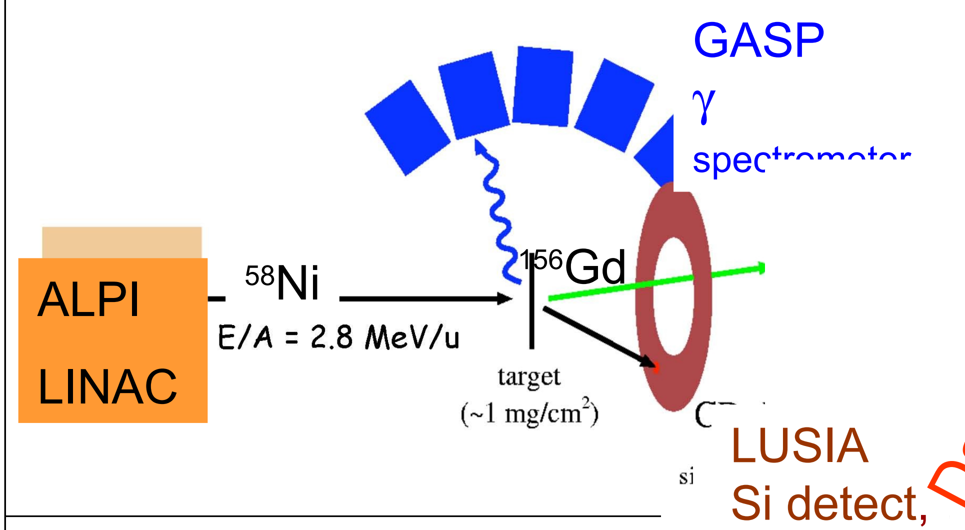
$Q_{2^+} = 6.83\ (37)$ b



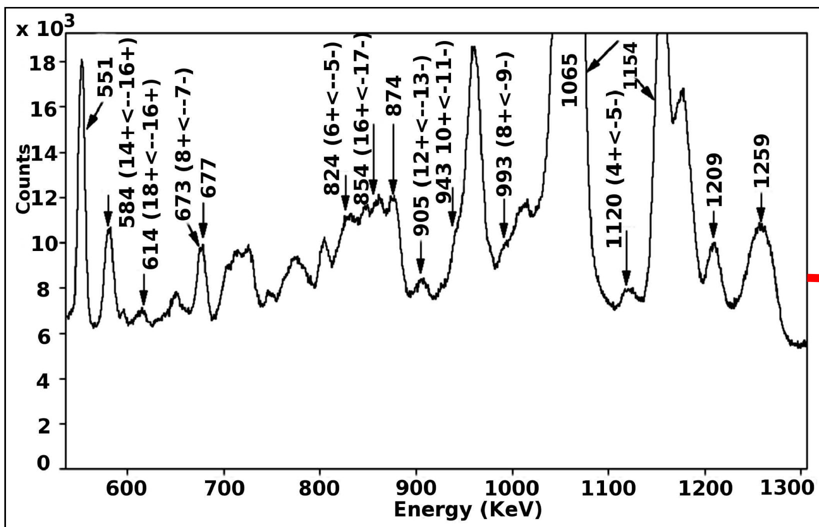
The negative parity band in ^{156}Gd is incompatible with the description based on tetrahedral symmetry

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

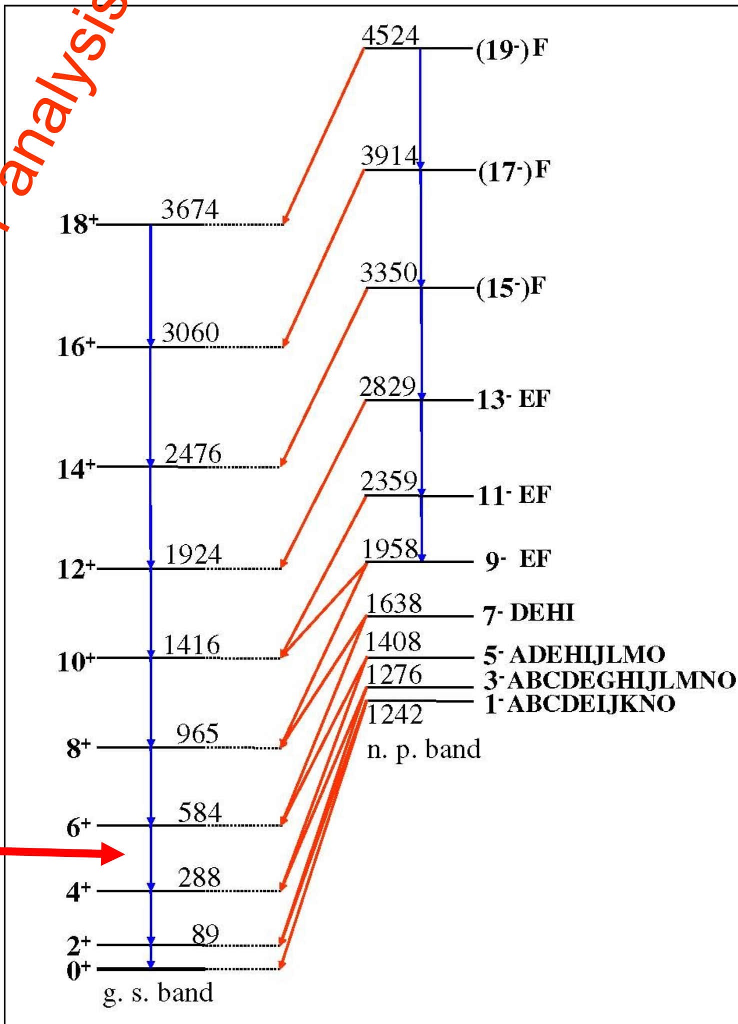
Rajesh Pratap Singh et al.
IUAC Delhi, India



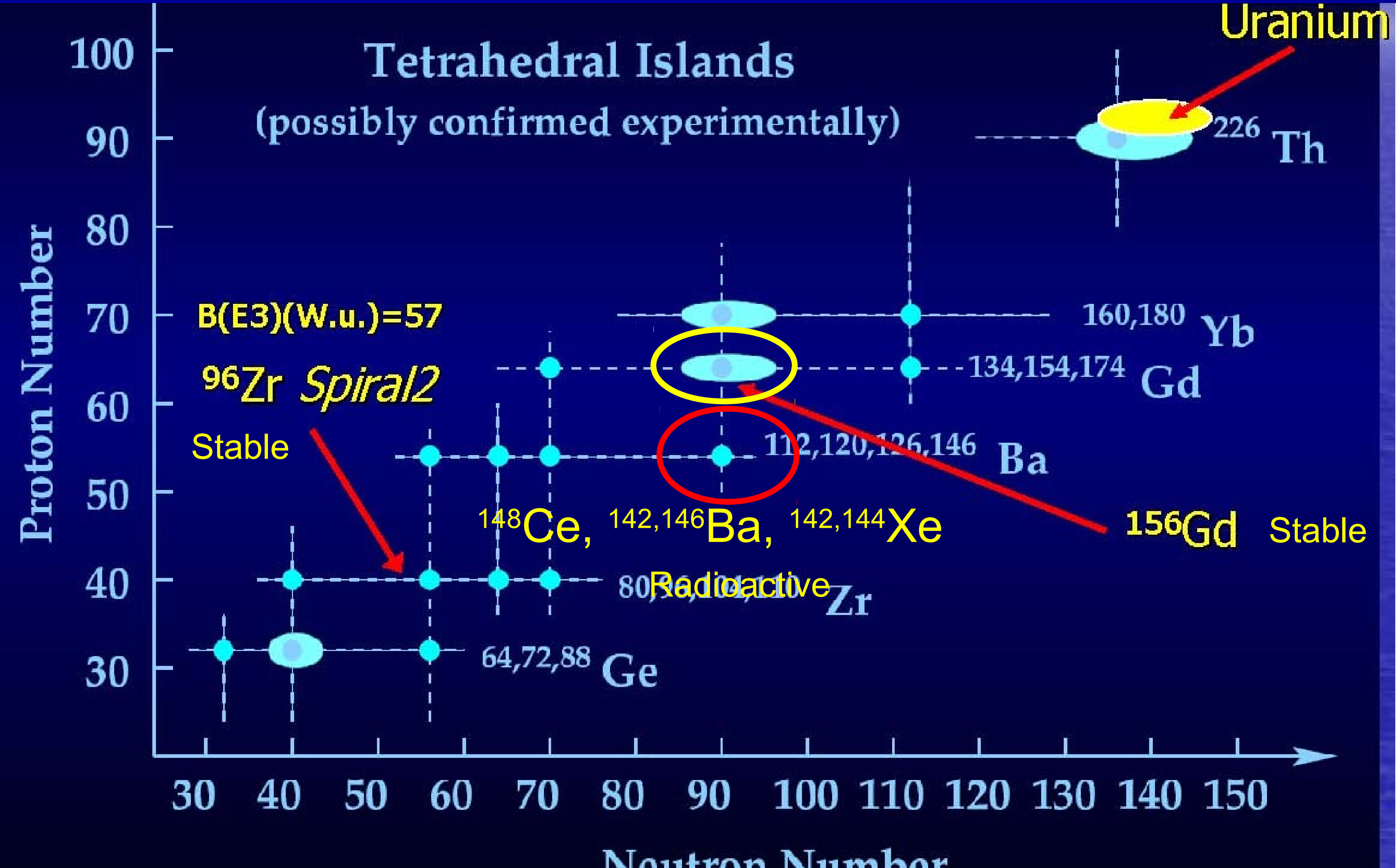
Data under analysis



Gate



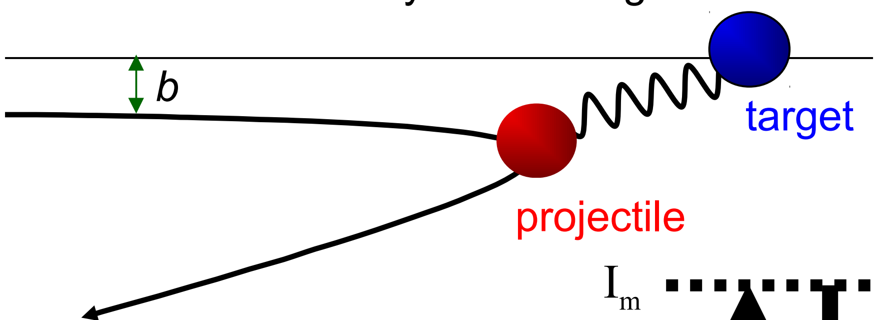
AIM of the LOI: Transition matrix elements and Q-moments of the exotic octupole bands from Coulex for the n-rich Ce, Ba, Xe nuclei. SPES intensities ~ 105-107 pps



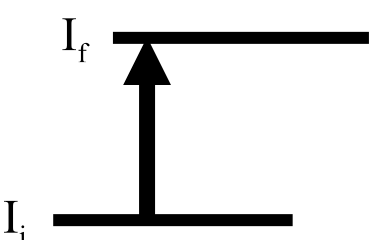
AIM of the LOI: Transition matrix elements and Q-moments (sign) of the exotic octupole bands from reorientation effects for the n-rich Ce, Ba, Xe nuclei.

SPES intensities ~ 10^5-10^7 pps

Nuclear excitation by electromagnetic field acting between nuclei.

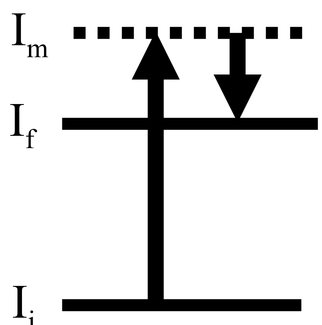


The excitation cross section is a direct measure of the $E\lambda$ matrix elements.



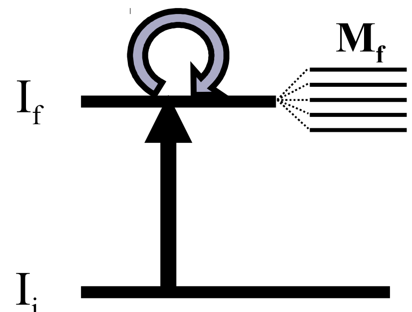
1st order:

$$a^{(1)}_{i\to f} \propto \langle I_f \| M(E2) \| I_i \rangle$$



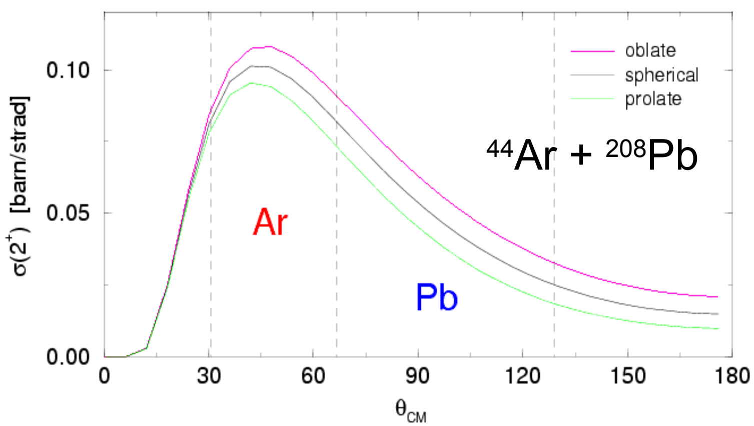
2nd order:

$$a^{(2)}_{i\to f} \propto \langle I_f \| M(E2) \| I_m \rangle \langle I_m \| M(E2) \| I_i \rangle$$



reorientation effect:

$$a^{(2)}_{i\to f} \propto \langle I_f \| M(E2) \| I_f \rangle \langle I_f \| M(E2) \| I_i \rangle$$

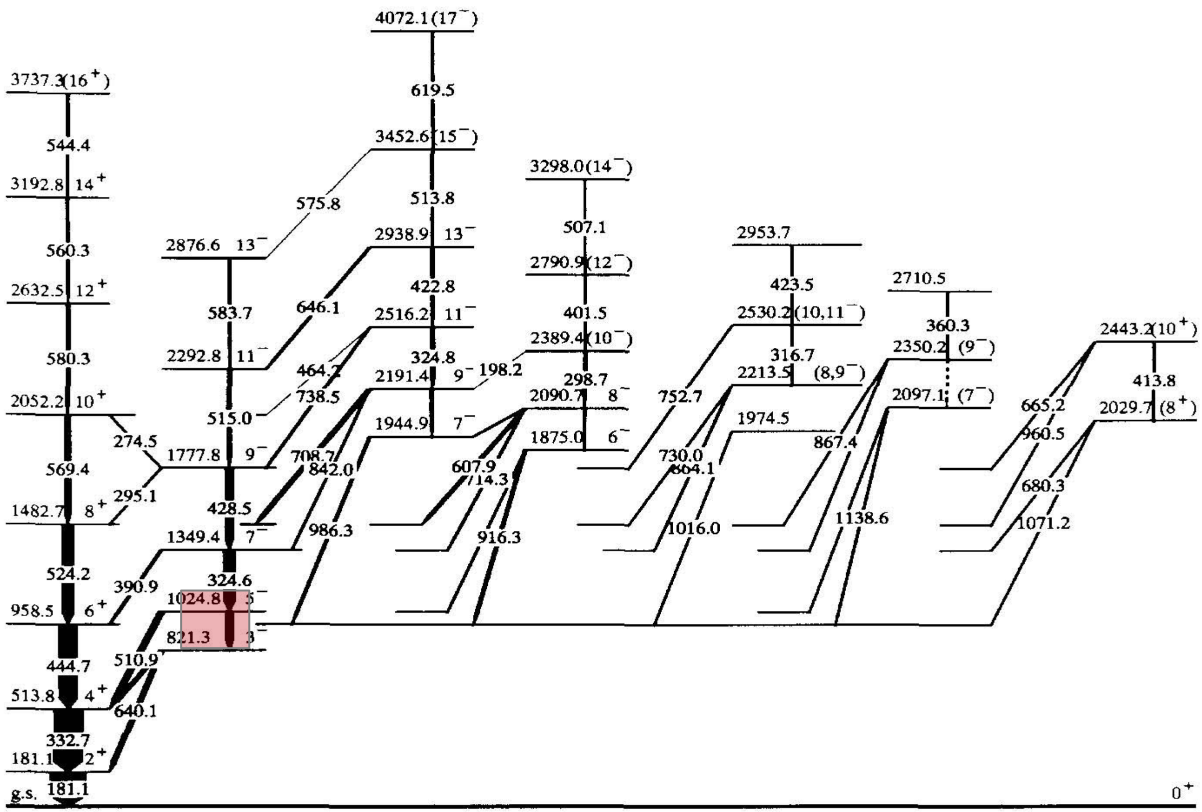


differential Coulomb excitation cross section

⇒ transition probability *B(E2)*

⇒ quadrupole moment Q_s

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



^{146}Ba

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:

^{144,146}Ba and ^{142,144}Xe at an energy of 550 MeV

Impinging on a ^{58}Ni target of about 100 mg/cm^2.

We would use the position sensitive silicon detector TRACE or a Si disk to detect the scattered beam particles in coincidence with the gamma events detected in the GALILEO gamma ray spectrometer.

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

We will suppose 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%.

Assuming a ^{146}Ba intensity of about 1.4 10^4 pps accelerated by the SPES radioactive nuclear beam facility

50 particle-gamma events per day, 1-2 weeks of beam time allowing to extract the B(E3) transition matrix element with an accuracy of about 25%.