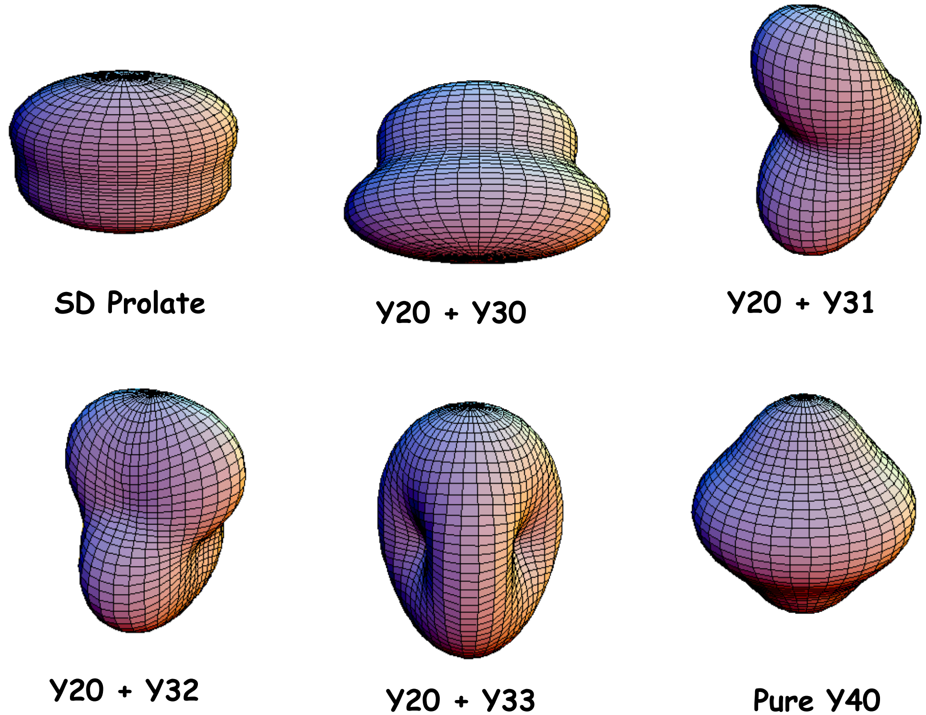
SPES-LOI: Search for Exotic-Octupole deformation effects in n-rich Ce-Xe-Ba Nuclei



Spokesperson: E. Sahin, D. Curien, J. Dudek, M. Zielinska, G. de Angelis

INFN, Laboratori Nazionali di Legnaro, Italy

IPHC Strasbourg, France

University of Warsaw, Poland

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Polish Academi of Science, Crakow, Poland

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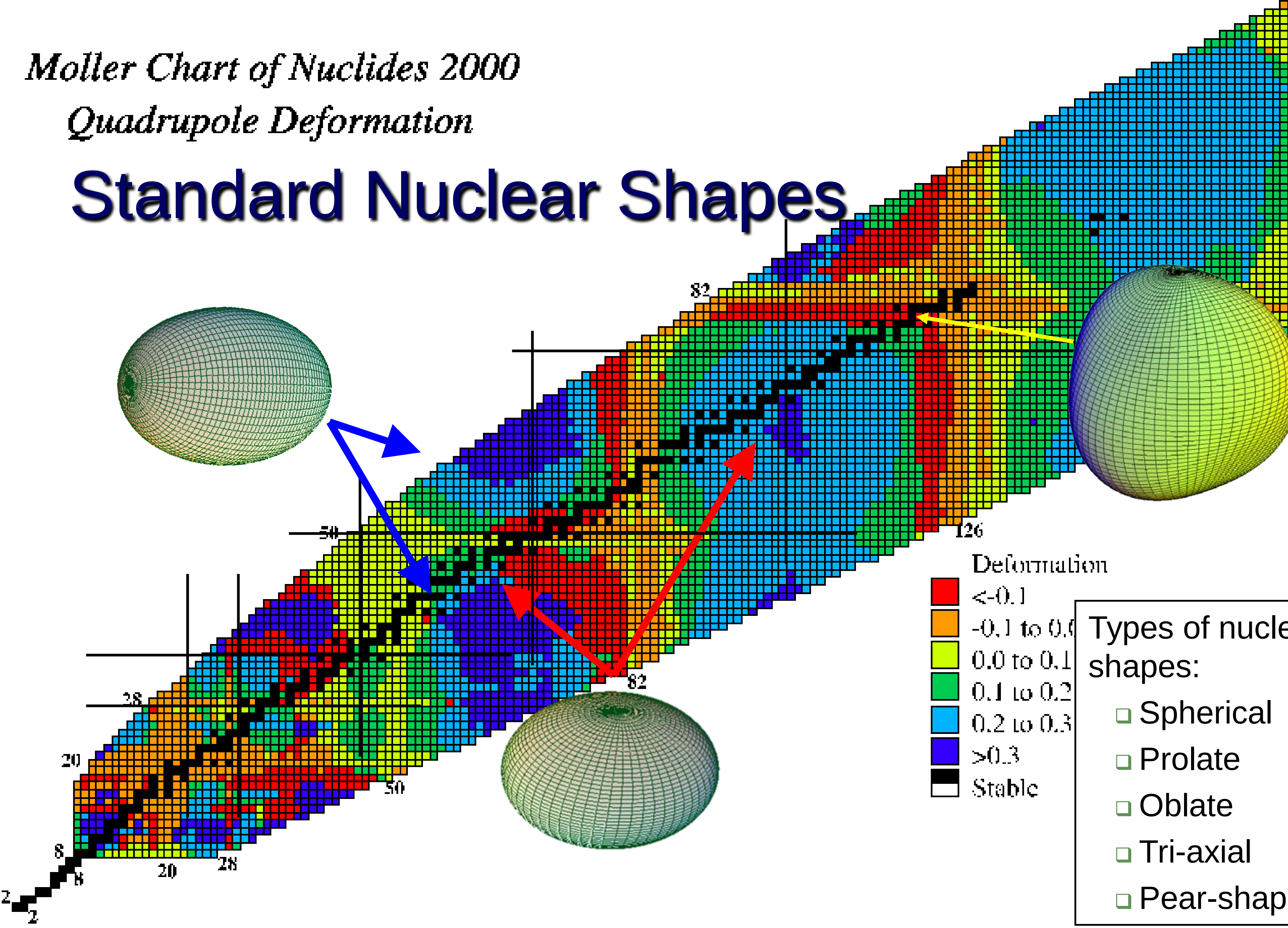
Inter University Accelerator Center, Delhi, India

Bulgarian Accedemy of Science, Sofia, Bulgaria

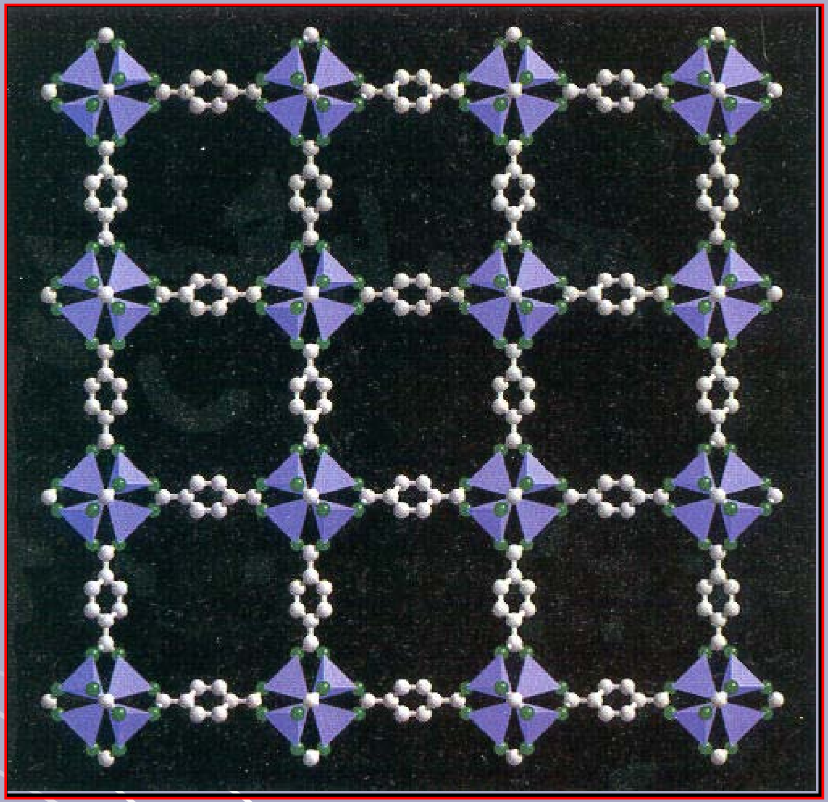
Standard Nuclear Shapes



Types of nucle
shapes:

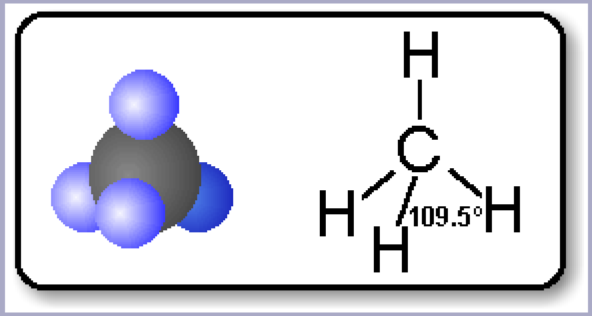
- Spherical
- Prolate
- Oblate
- Tri-axial
- Pear-shap

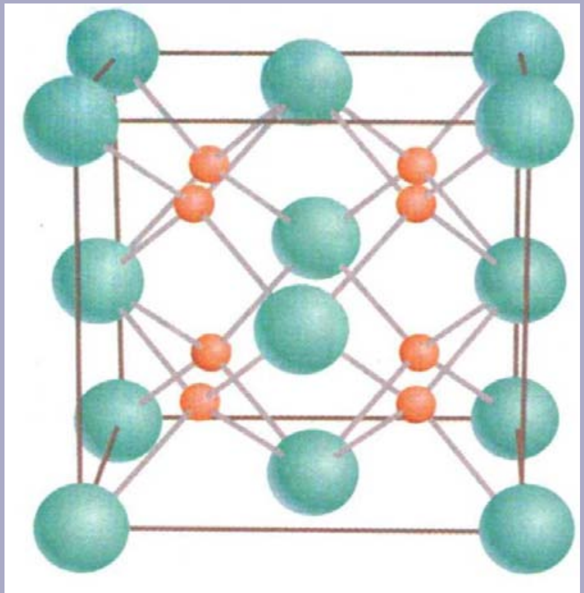
Point Symmetries in the Microscopic World



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.

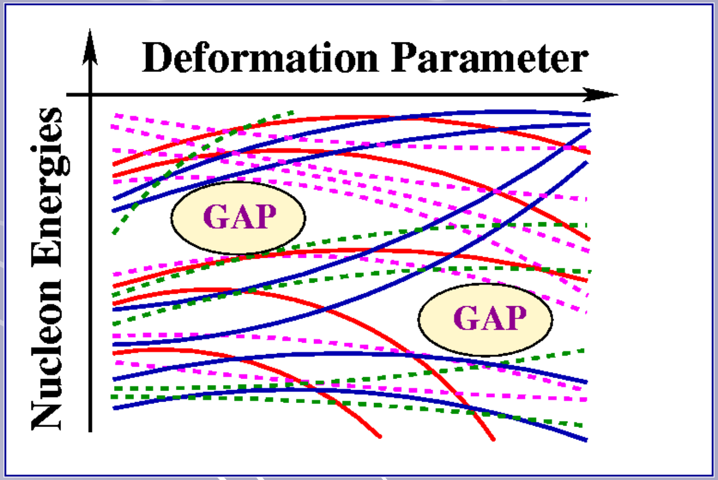


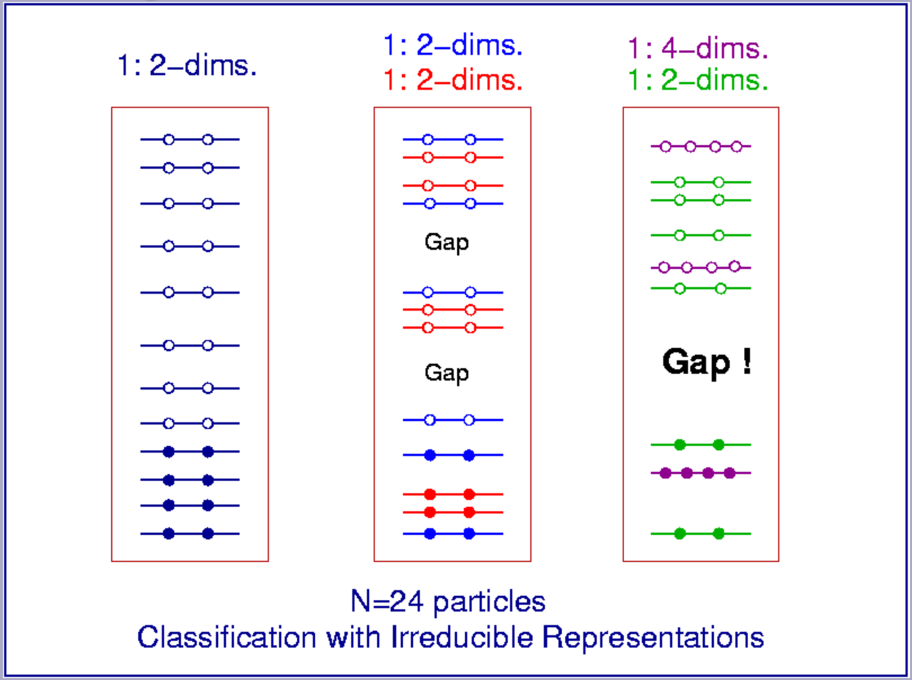


Face-centered-cubic (fcc) crystal structure of PuO_2 (Pu atoms in green, O atoms in red).

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

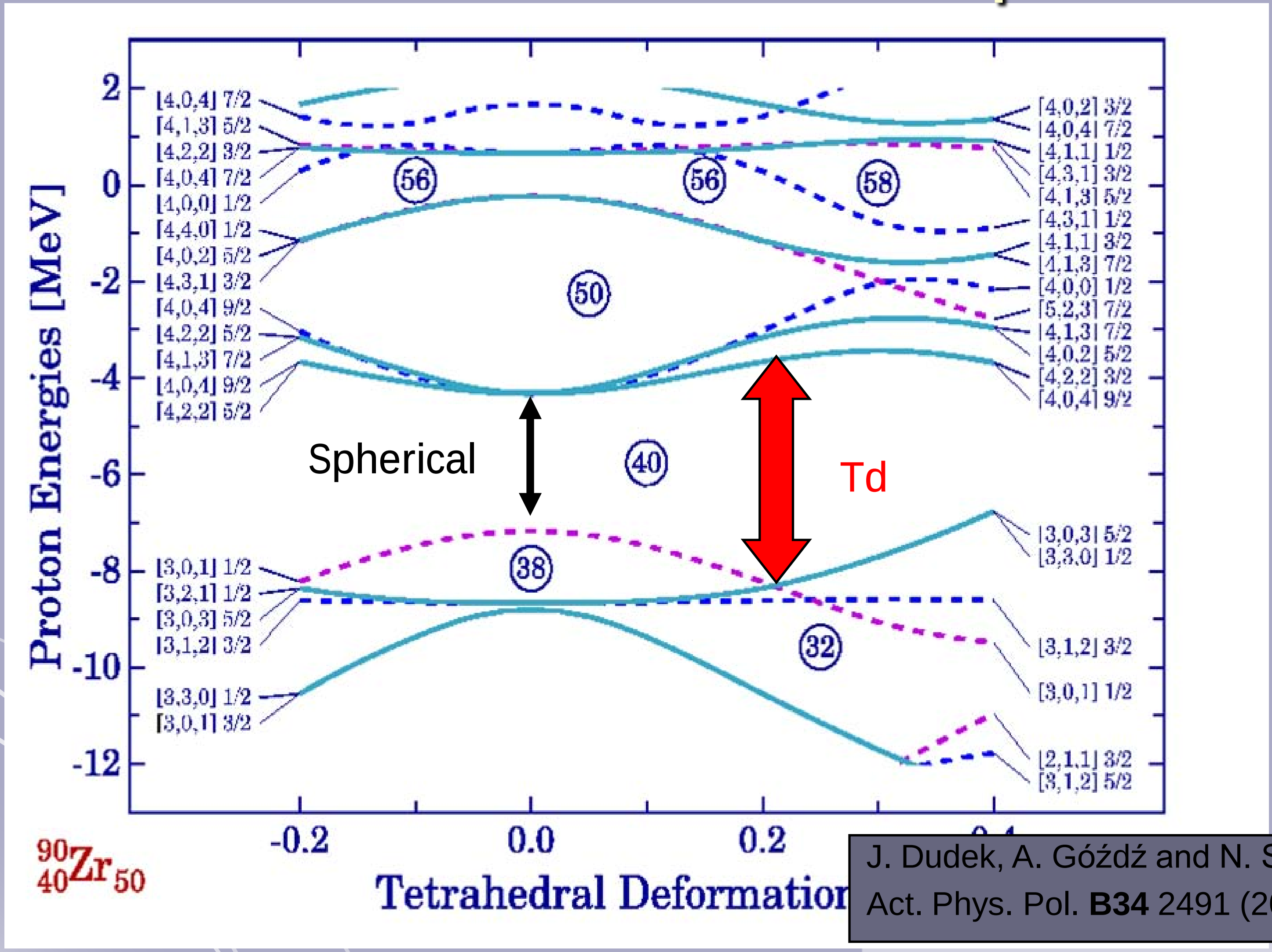
Point Groups and Level Degeneracy

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, 2

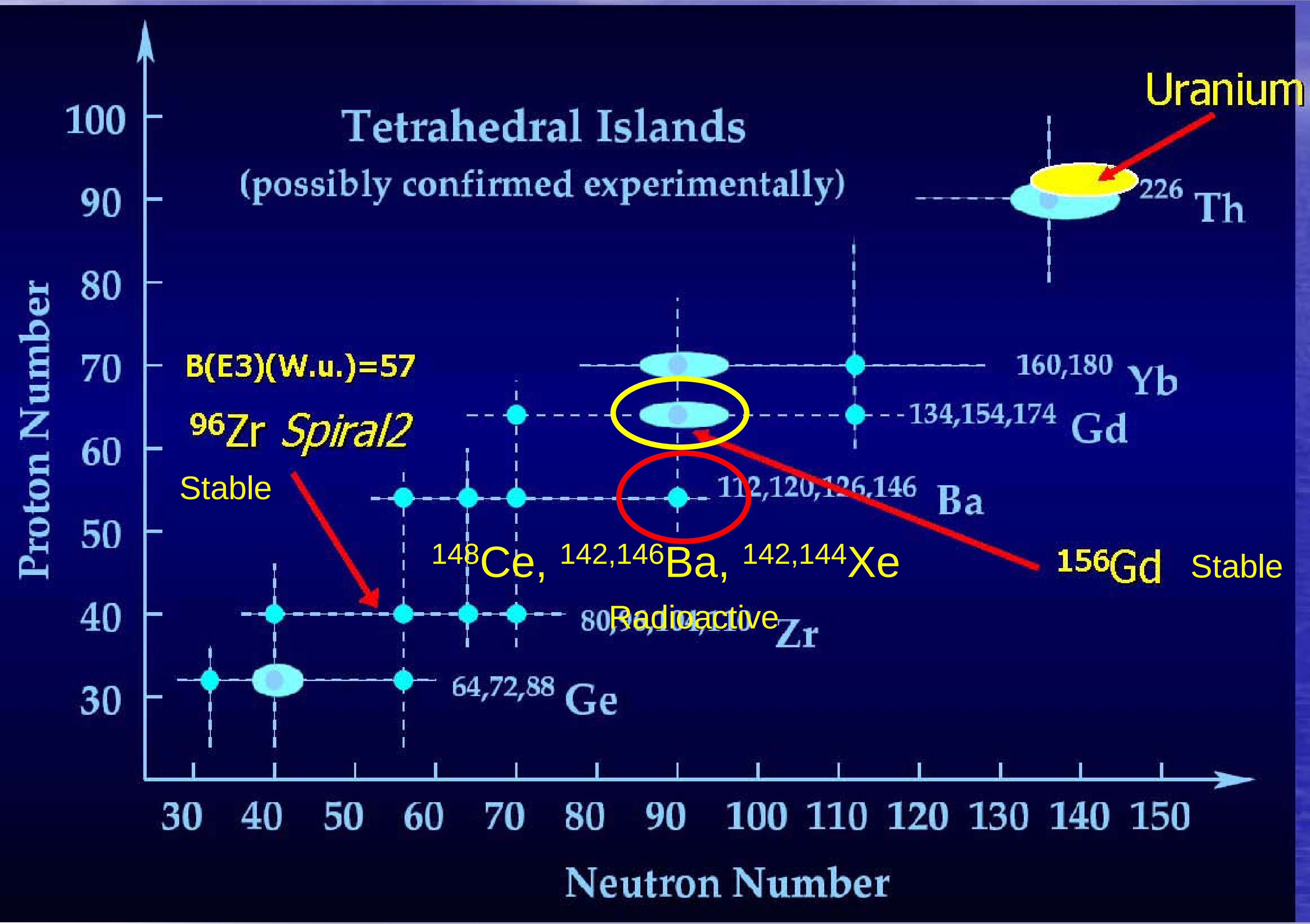
Kramers Degeneracy (= time-reversal symmetry)

Survey of the properties of a few point groups

Tetrahedral Shell Gaps



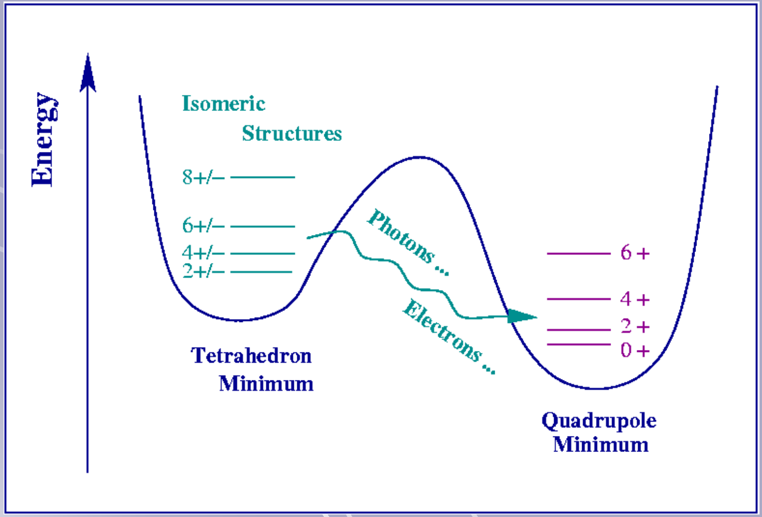
J. Dudek, A. Góźdź and N. Schunck
Act. Phys. Pol. **B34** 2491 (2003)

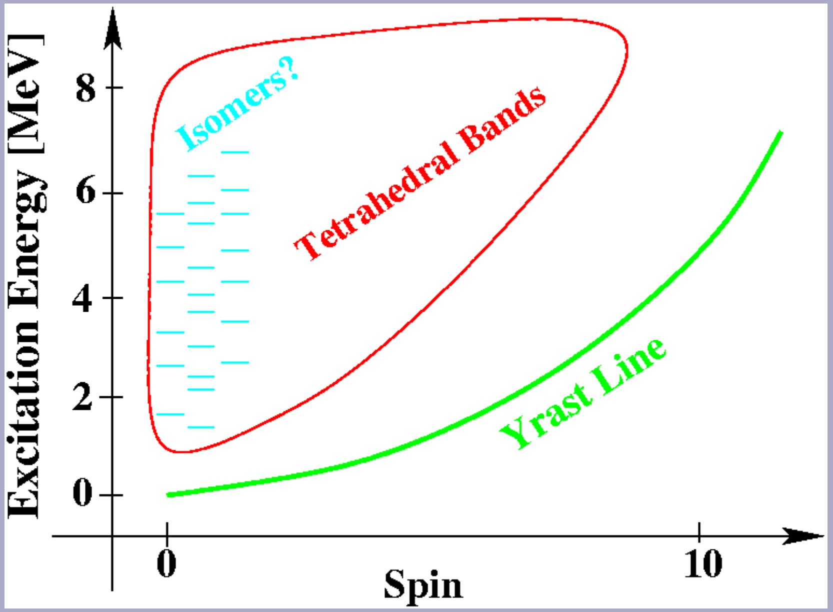


Tetrahedral Islands
(possibly confirmed experimentally)
Uranium
226 Th
160,180 Yb
134,154,174 Gd
112,120,126,146 Ba
Zr
64,72,88 Ge
B(E3)(W.u.)=57
96Zr Spiral2
Stable
148Ce, 142,146Ba, 142,144Xe
Radioactive
156Gd Stable
Proton Number
Neutron Number
100
90
80
70
60
50
40
30
30 40 50 60 70 80 90 100 110 120 130 140 150

Experimental signatures (1/2)

- Stable tetrahedral minimum: **Shape isomer**
- **Low-spin physics**: don't expect I > 10 ħ…
- Vanishing **quadrupole moment Q_2**
- Static **octupole moment Q_3**
- No dipole moment





Schematic illustrations of where to look for tetrahedral states

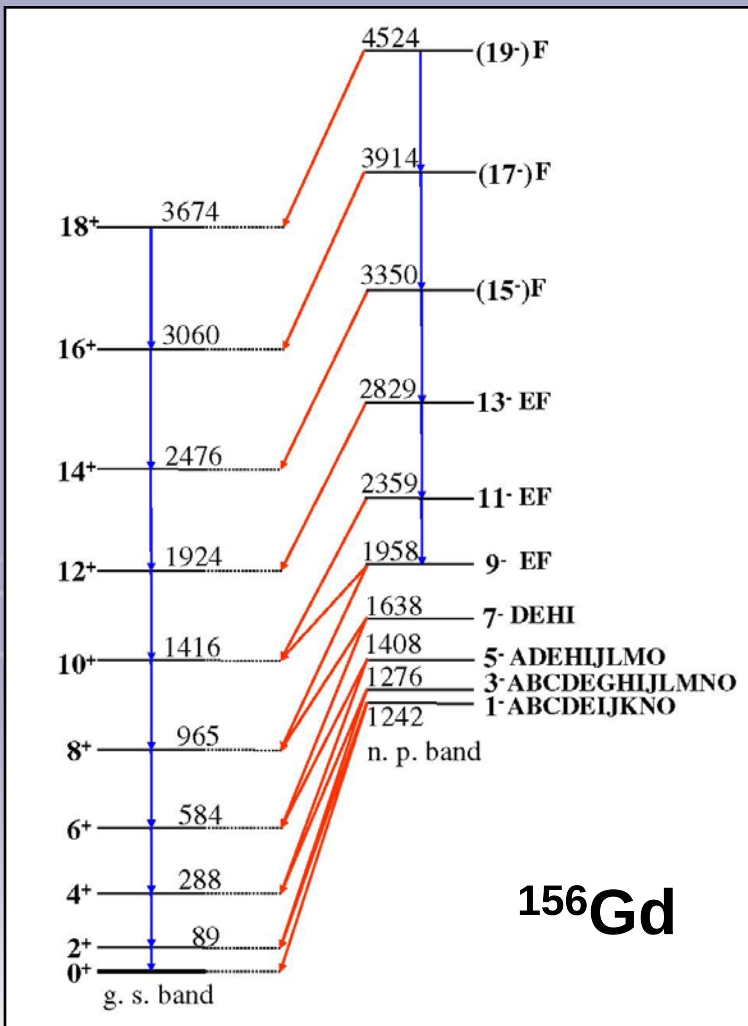
Experimental signatures (2/2)

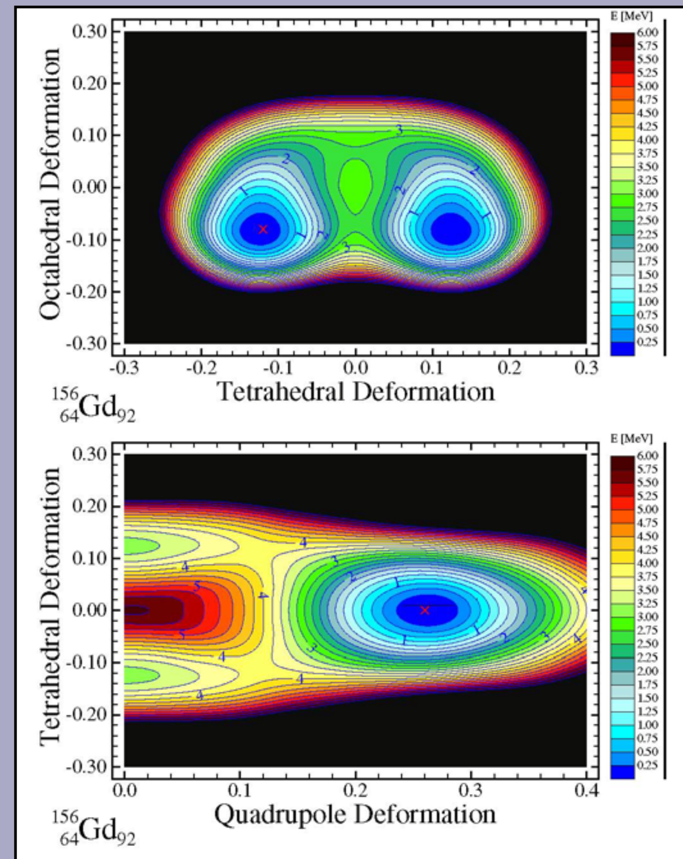
- The **quadrupole moment of a nucleus possessing a an exact T_d symmetry is equal to zero** and therefore also the corresponding **B(E2)** matrix elements have to vanish
- Large **B(E3)** matrix elements
- **B(E1)/B(E2)** ratios

PRL **97,** 072501 (2006) PHYSICAL REVIEW LETTERS week ending 18 AUGUST 2006

Island of Rare Earth Nuclei with Tetrahedral and Octahedral Symmetries: Possible Experimental Evidence

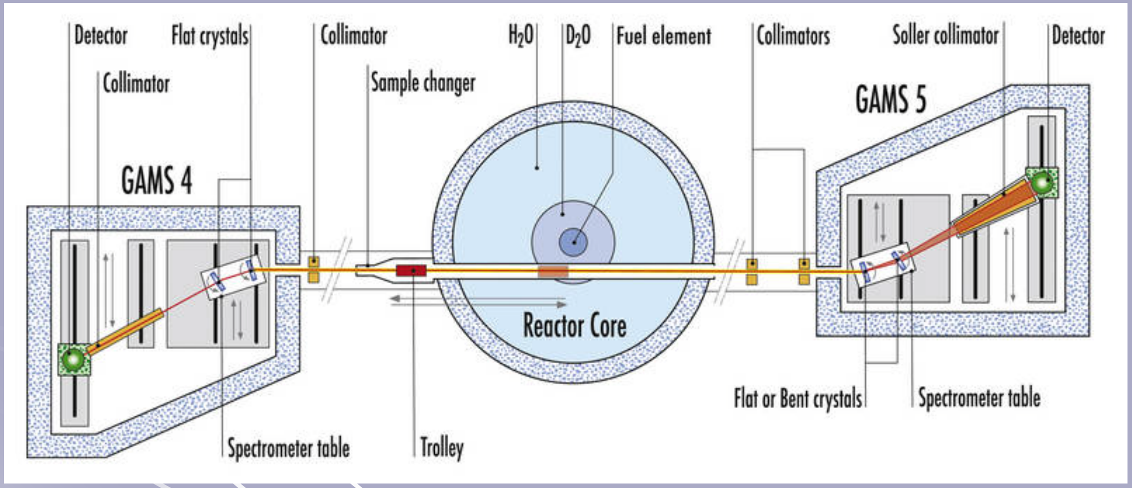
J. Dudek,[1] D. Curien,[2] N. Dubray,[1] J. Dobaczewski,[3] V. Pangon,[1] P. Olbratowski,[3] and N. Schunck[4]

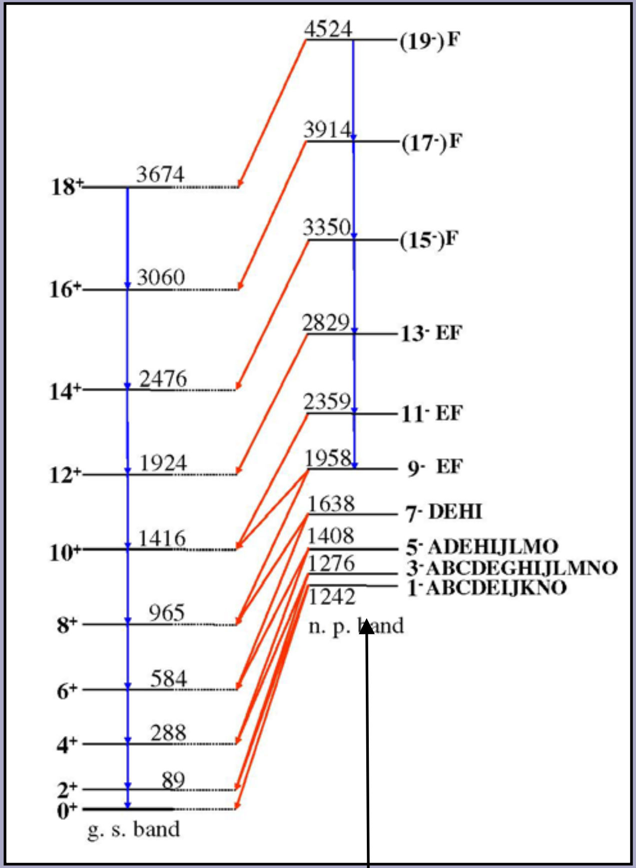




Vanishing E2 inband transitions

Large E1 interband transitions





(n,γ) on ^{155}Gd → ^{156}Gd

Ultrahigh resolution γ-ray spectroscopy at ILL

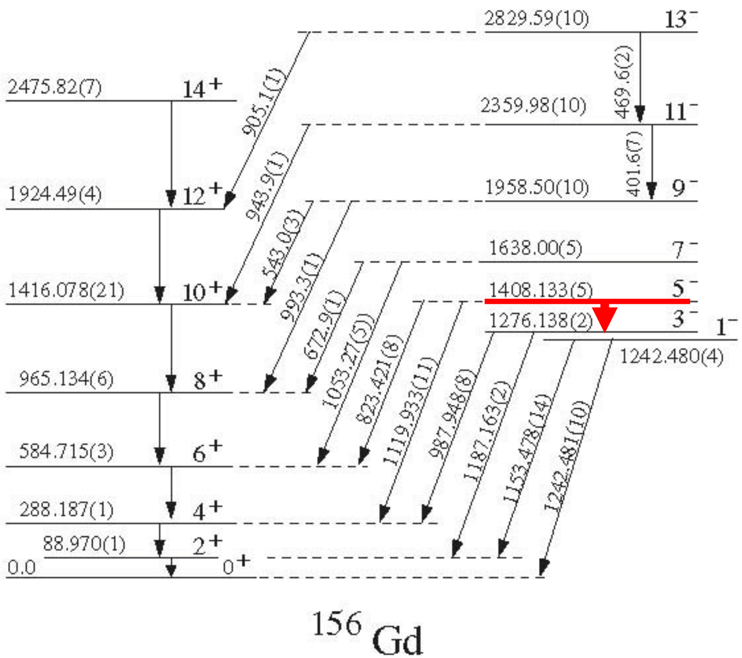
Intensity of the 132 keV 5^- → 3^- γ ray

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

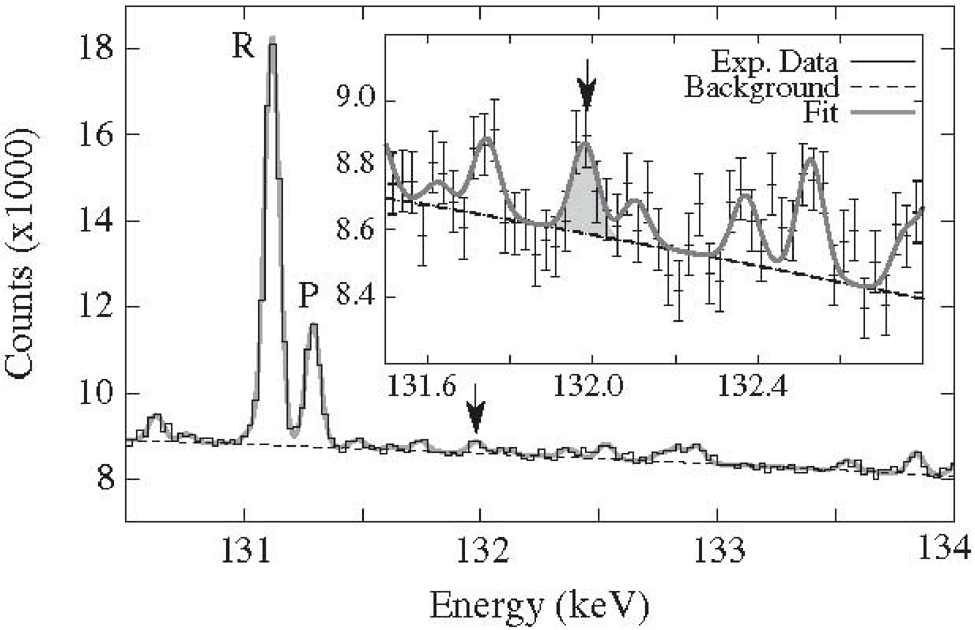
Ultrahigh-Resolution γ-Ray Spectroscopy of ^{156}Gd: A Test of Tetrahedral Symmetry

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



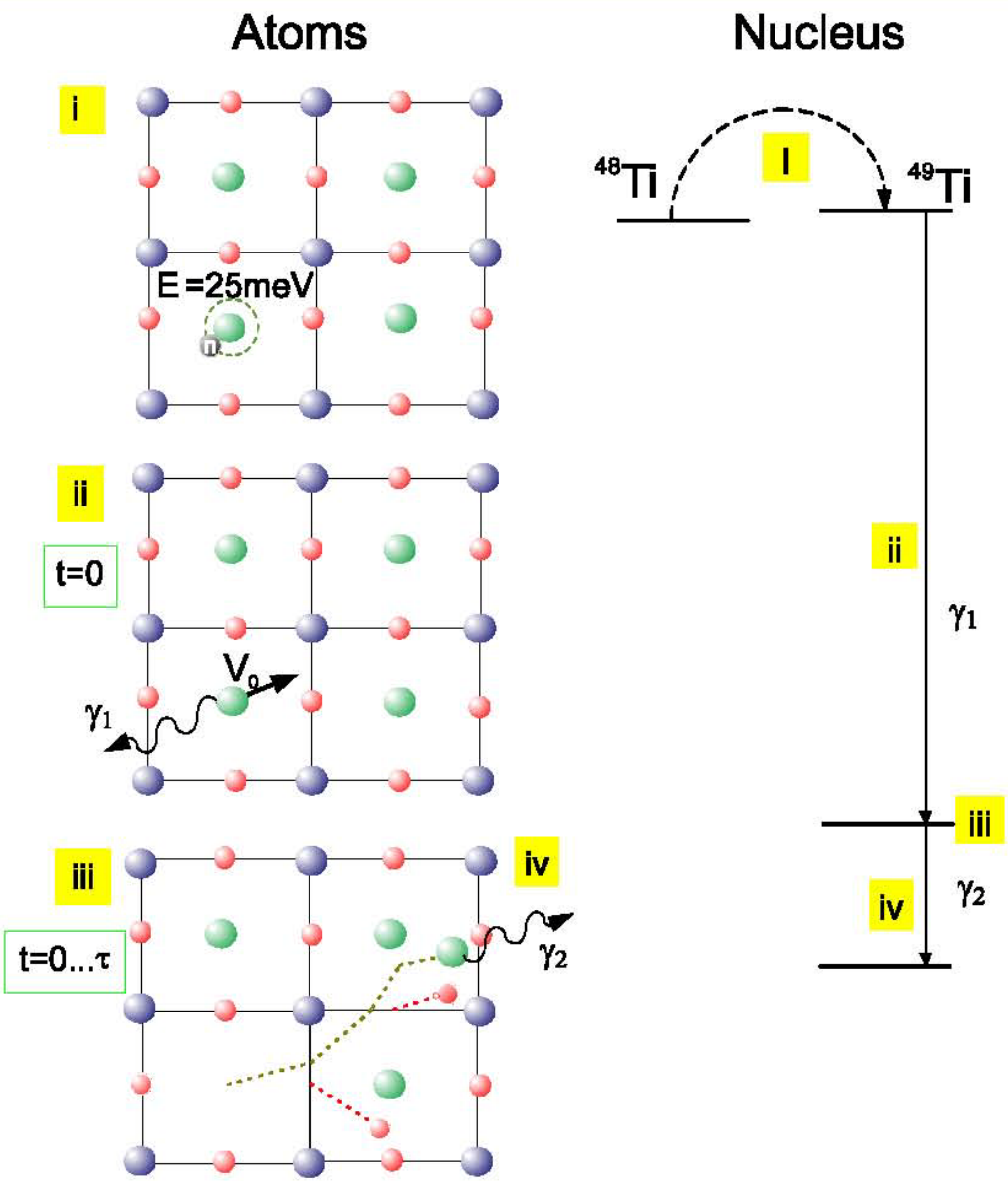
PRL 104, 222502 (2010) PHYSICAL

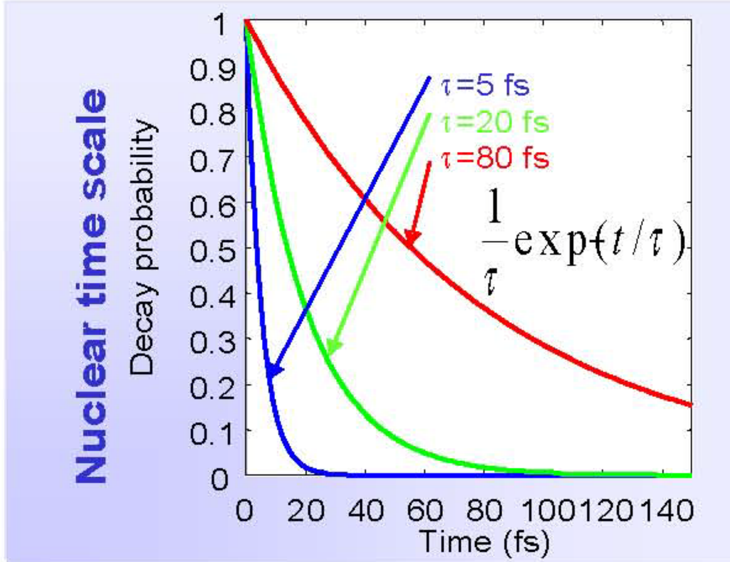


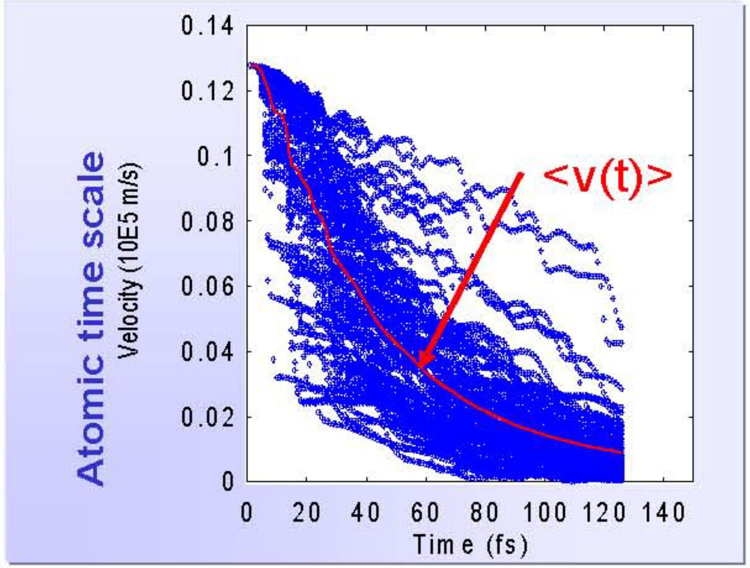
Lifetime of the 5^- level at 1.408 MeV

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

Measuring a lifetime requires clocks







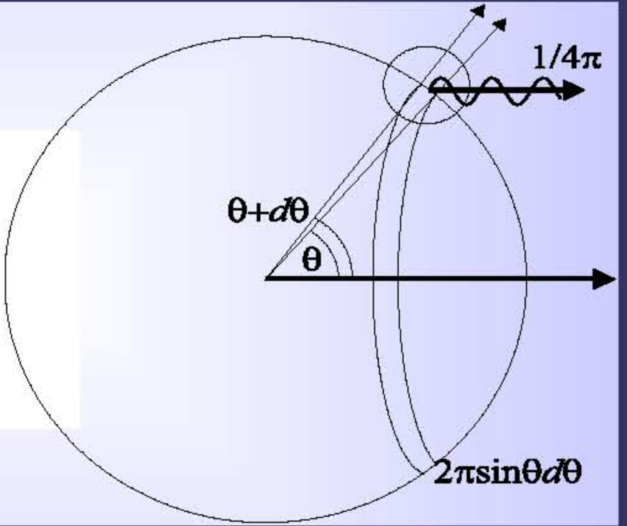
Model of an isotropic slowing down

$$I(E)dE = C\sum_i \int_0^\infty dt \frac{\exp(-t/\tau)dE}{\left[E - E_0\left\{1 + \frac{v_i(t)}{c}\cos\theta_i(t)\right\}\right]^2 + [\Gamma/2]^2}$$

Doppler shift of one photon

Isotropic slowing down:

- $\theta(t) = const$
- $v(\theta_0, t) = v(t)$



$$I(E)dE = \tilde{C}\int_0^\pi d\theta \int_0^\infty dt \frac{\sin(\theta)\exp(-t/\tau)dE}{\left[E - E_0\left\{1 + \frac{v(t)}{c}\cos(\theta)\right\}\right]^2 + [\Gamma/2]^2}$$

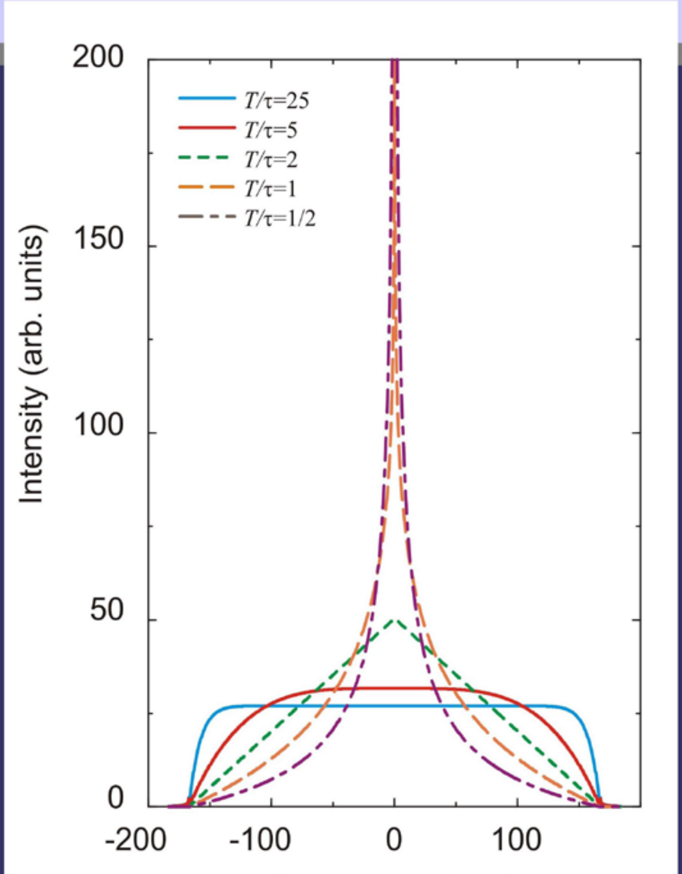
$$= \hat{C}\int_0^\infty \exp(-t/\tau)dt\left[\arctan\frac{\Gamma}{2}\left\{E - E_0\left(1 - \frac{v(t)}{c}\right)\right\} - \arctan\frac{\Gamma}{2}\left\{E - E_0\left(1 + \frac{v(t)}{c}\right)\right\}\right]$$

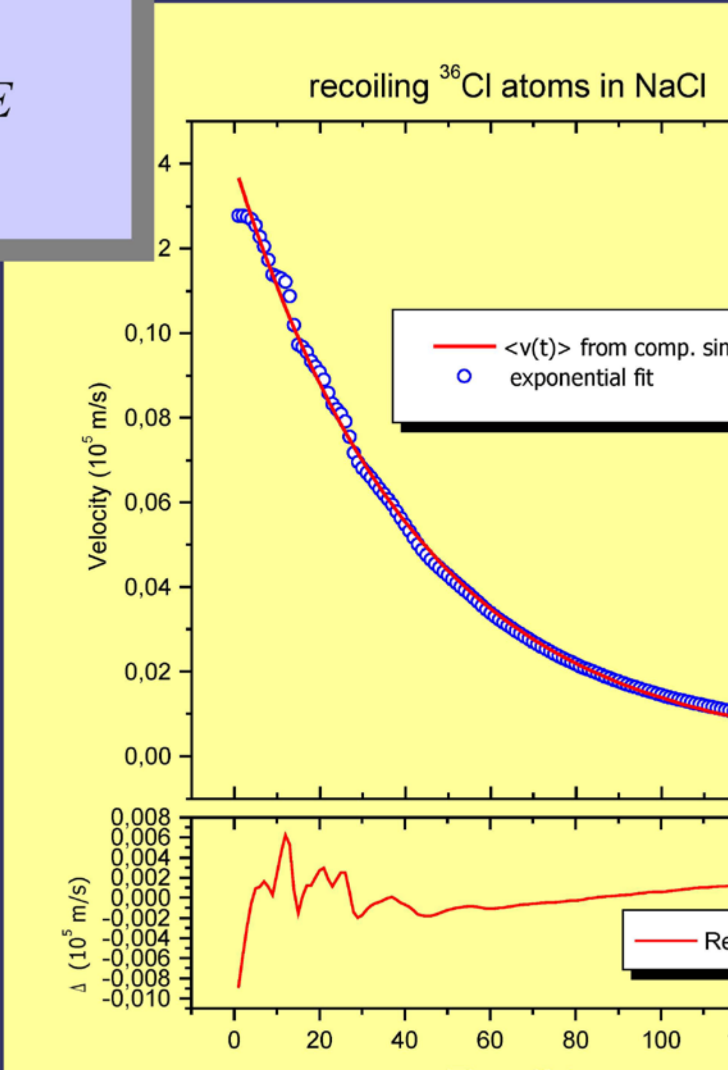
Line profile of an isotropic moving particle

Exponential slowing down model

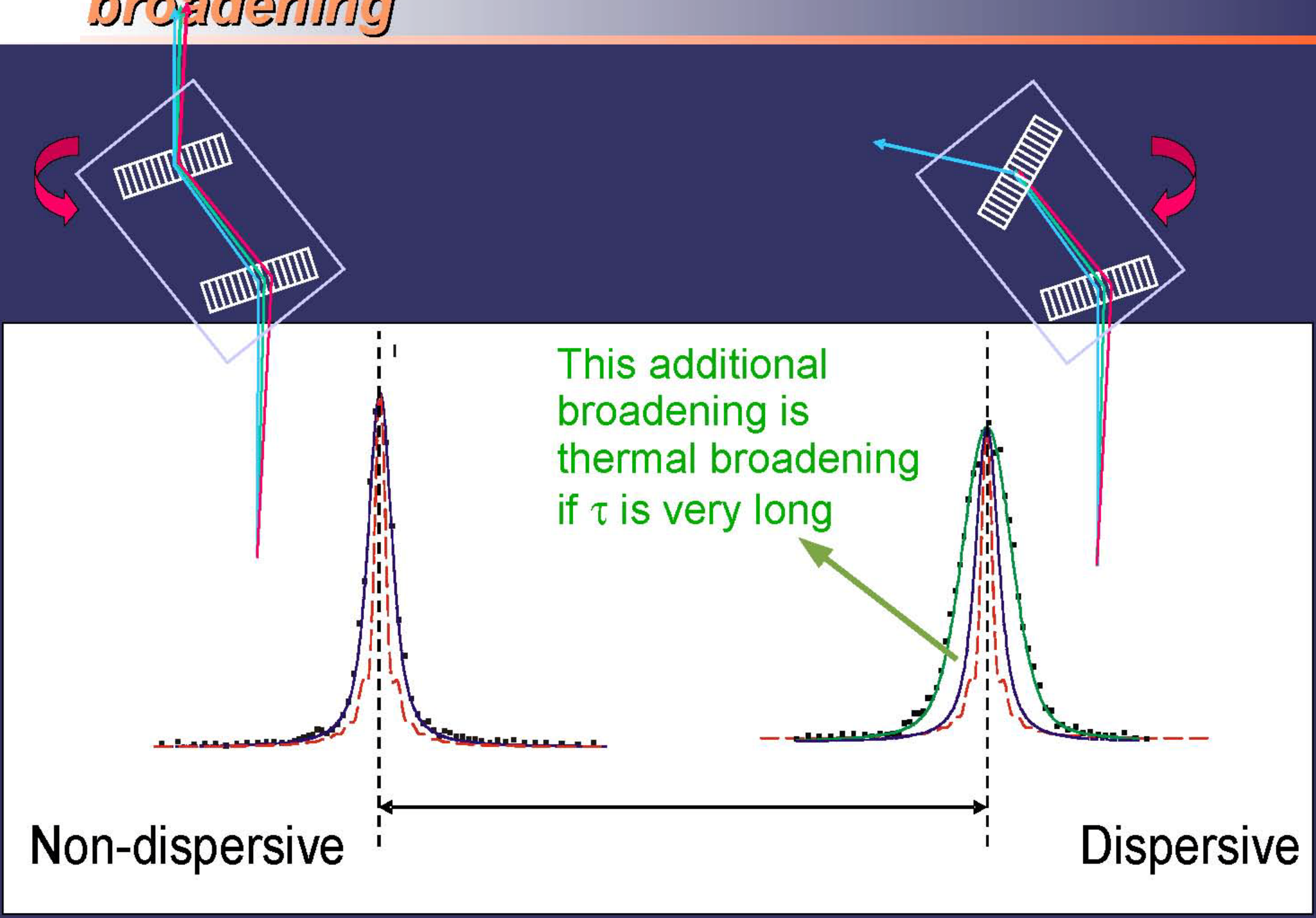
Exponential slowing down: $\mathrm{v}(t) = \mathrm{v}_0 \exp(-t/T)$

$$I(E)dE = \frac{C}{(T/\tau - 1)}\left(\frac{1}{\mathrm{v}_0}\right)^{T/\tau - 1}\left[\mathrm{v}_0^{T/\tau - 1} - \left|c\left(1 - \frac{E}{E_0}\right)\right|^{T/\tau - 1}\right]dE$$

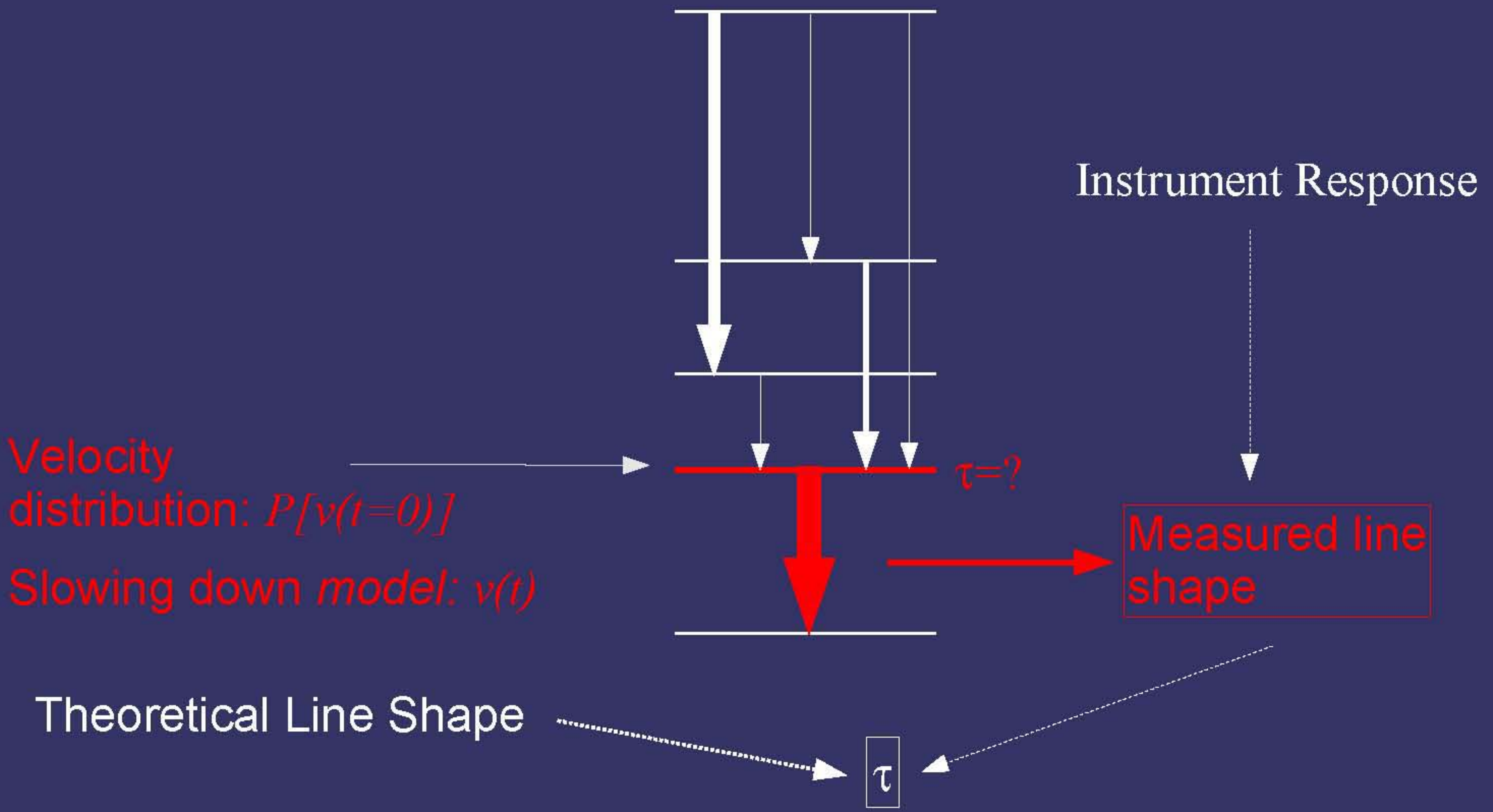




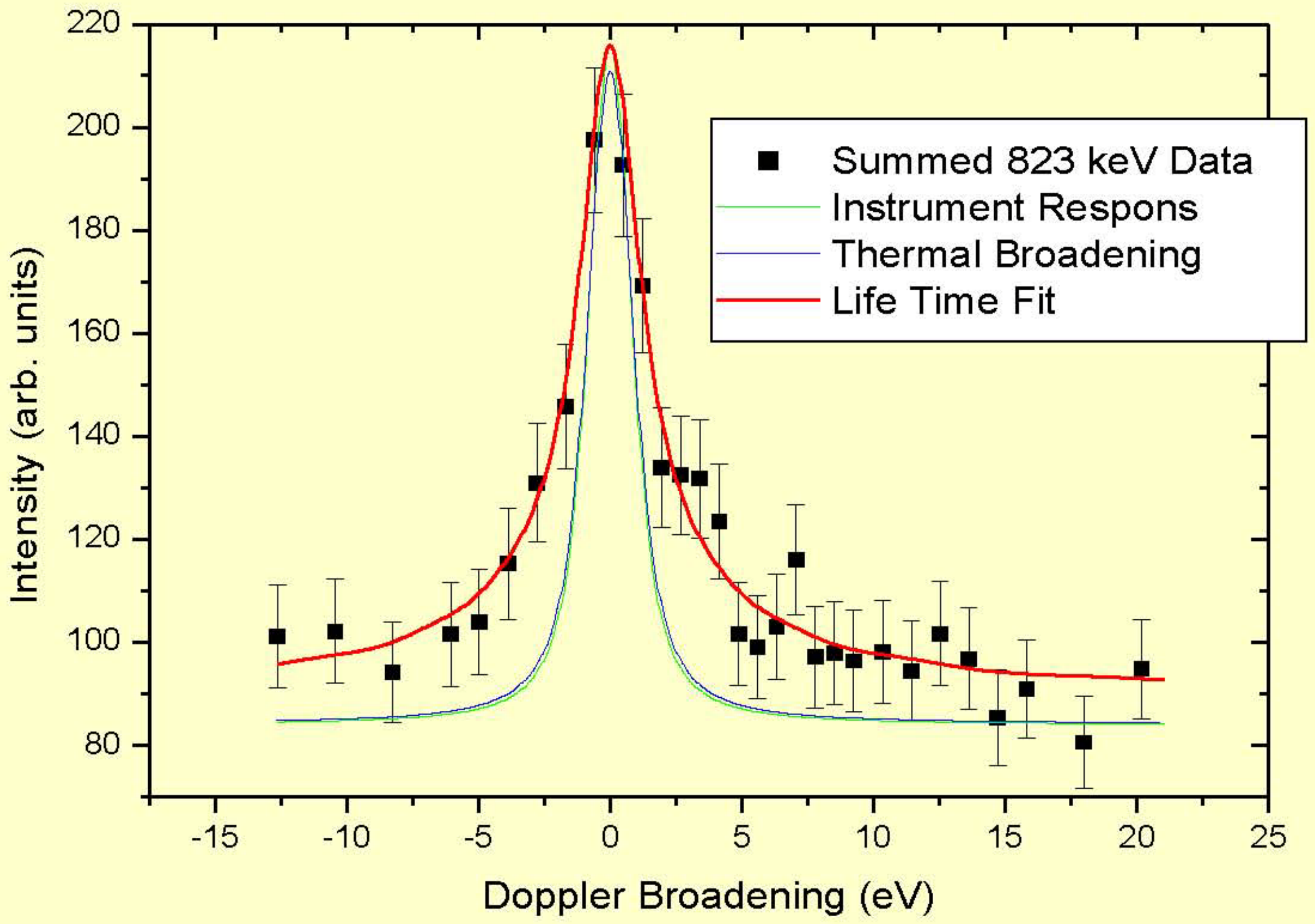
Measuring the temperature via Doppler broadening



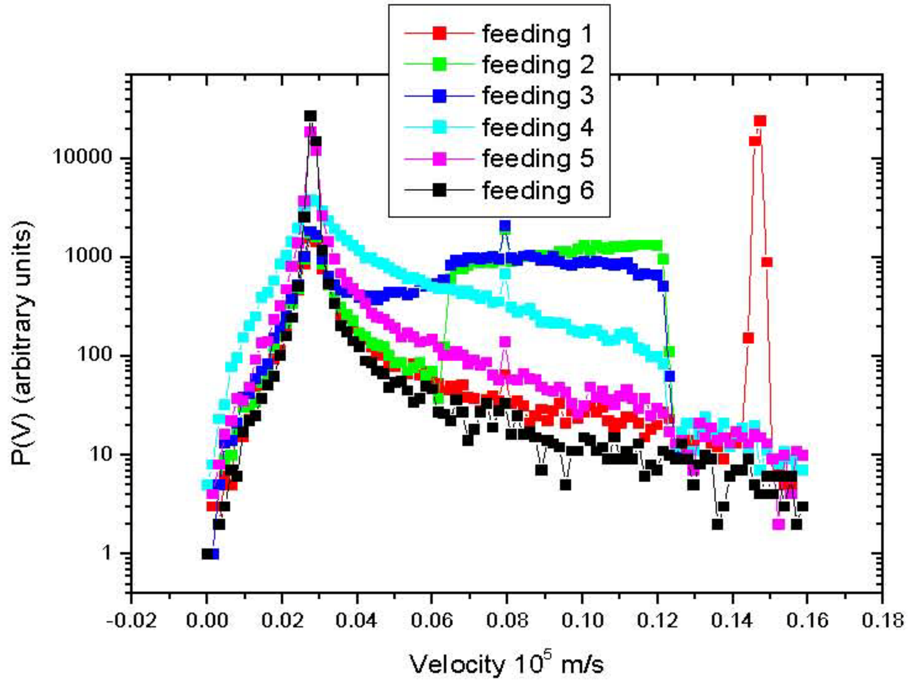
What do we really need to know?



(3,-3) Scan of the 823.421 keV Line

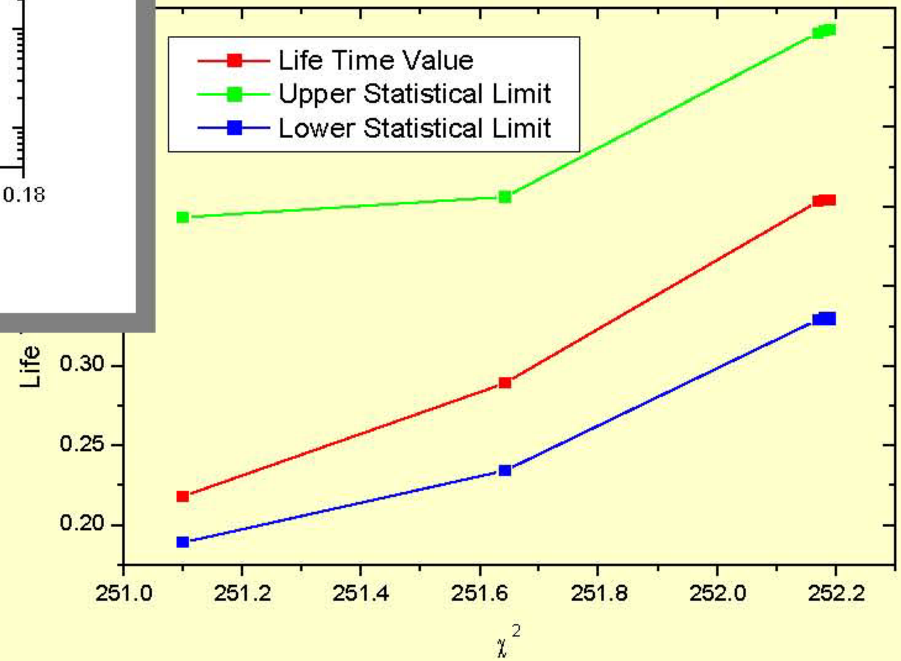


Life Time Results for different Scenarios



τ = 220 (+180 -40)fs

Velocity Distribution for Different Scenarios



Life Times for Different Scenarios

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

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

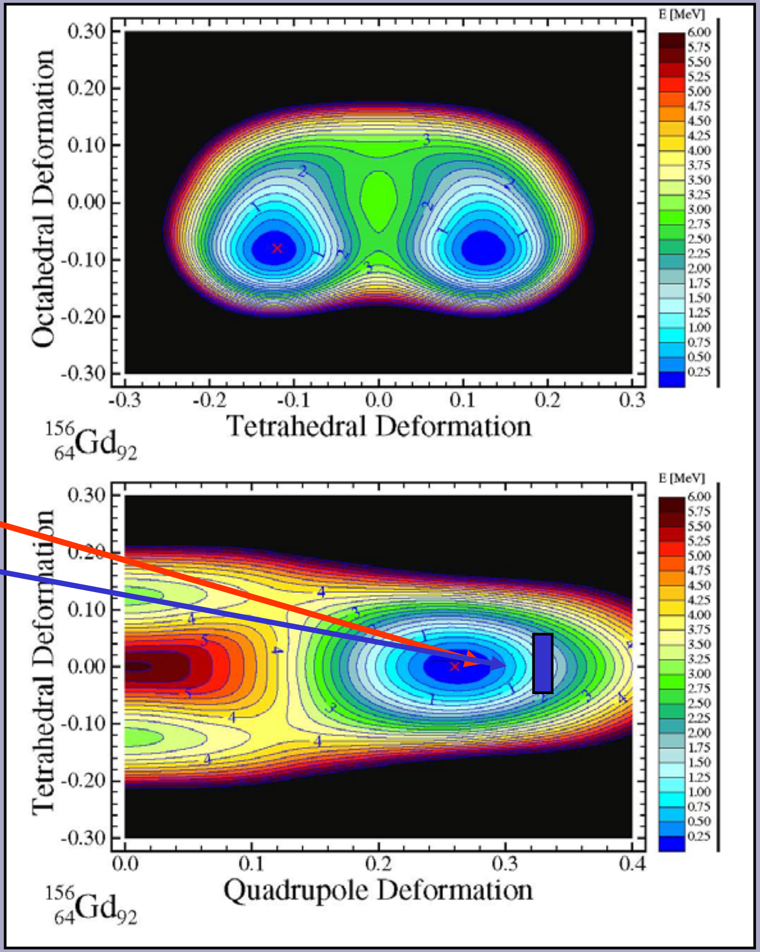
B(E2 $2^+ \rightarrow 0^+$) = 186.1(20) W.U.

β_{5^-} = 0.35(15)

β_{2^+} = 0.3378(18)

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

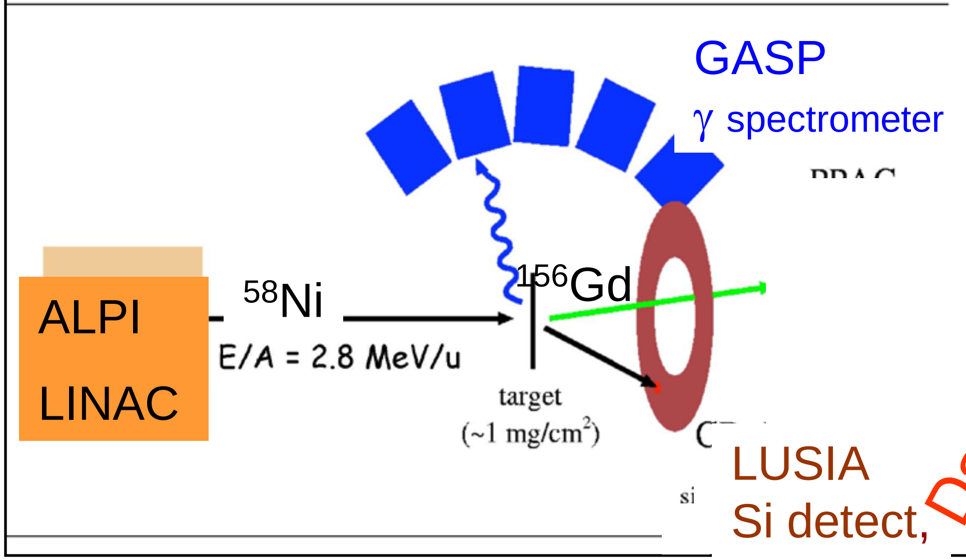
Q_{2^+} = 6.83 (37) b



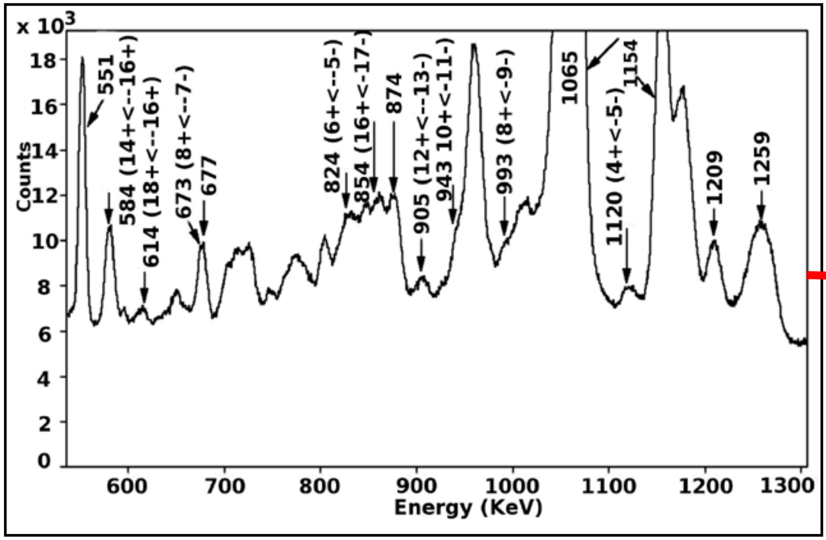
The negative parity band in ^{156}Gd is incompatible with the description based on tetrahedral symmetry

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

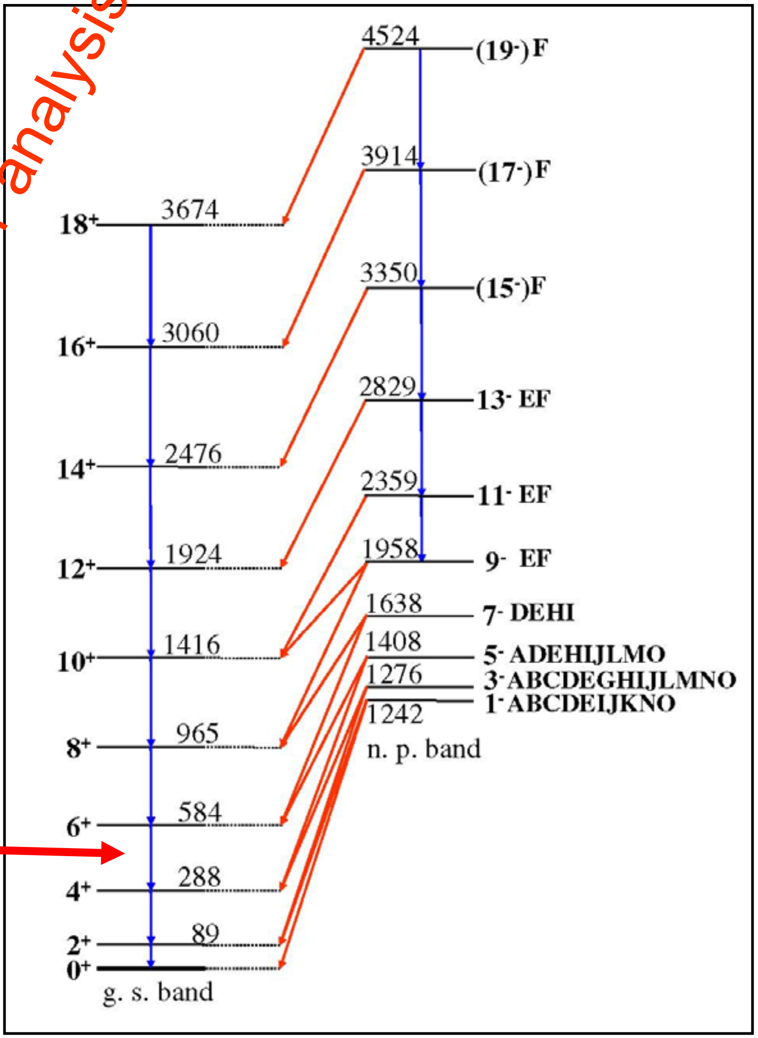
Rajesh Pratap Singh et al.
IUAC Delhi, India



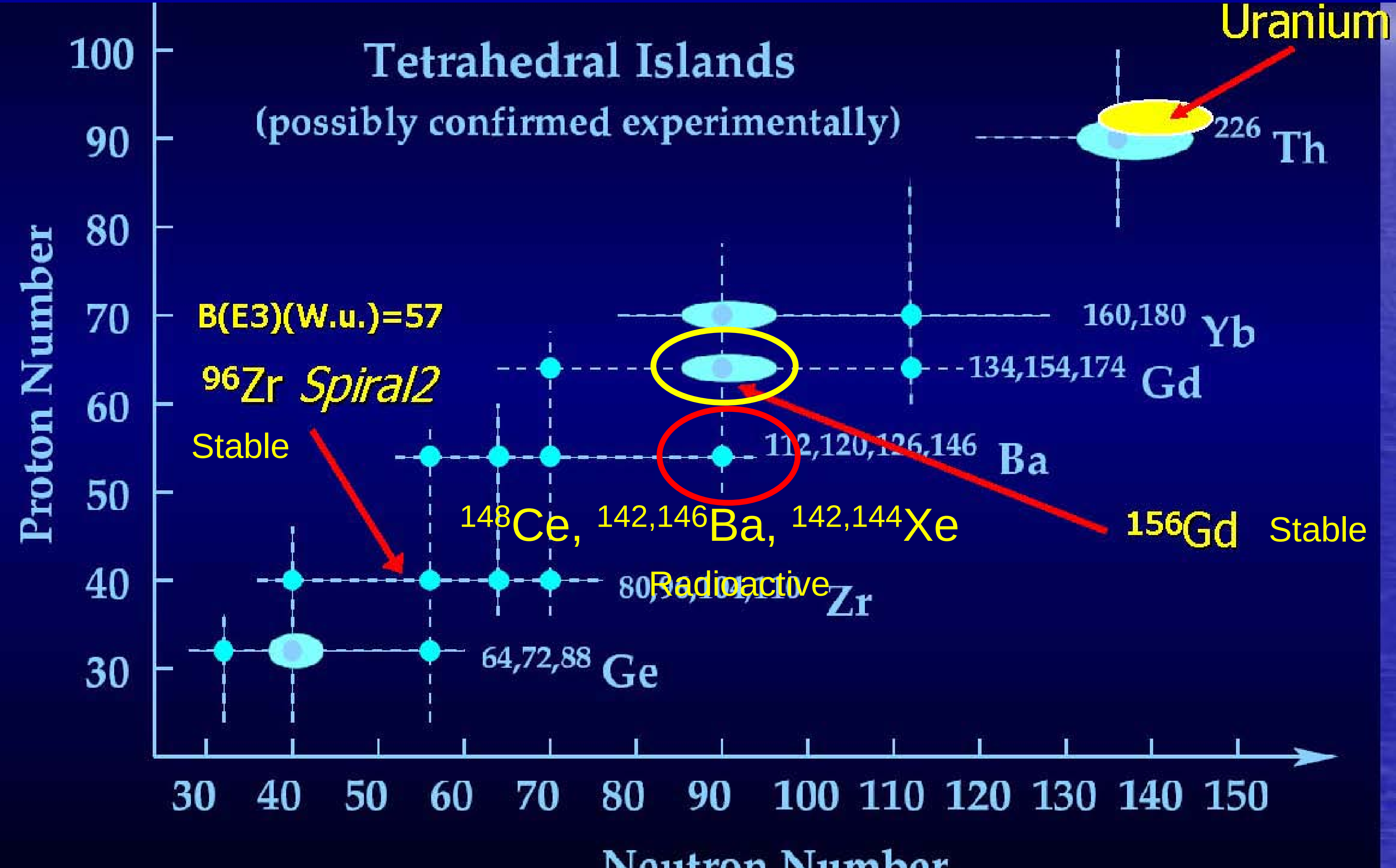
Data under analysis



Gate



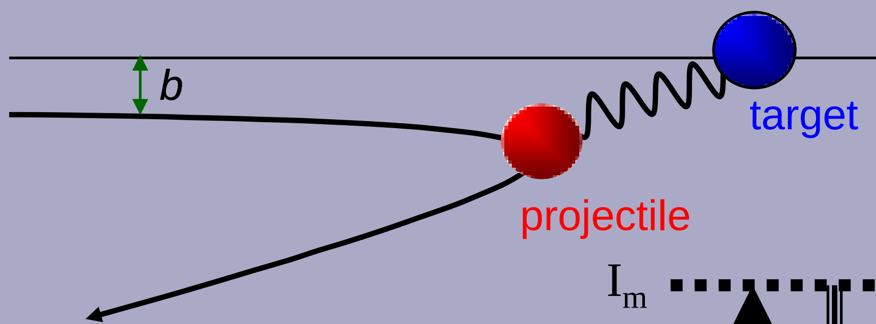
AIM of the LOI: Transition matrix elements and Q-moments of the exotic octupole bands from Coulex for the n-rich Ce, Ba, Xe nuclei. SPES intensities ~ 105-107 pps



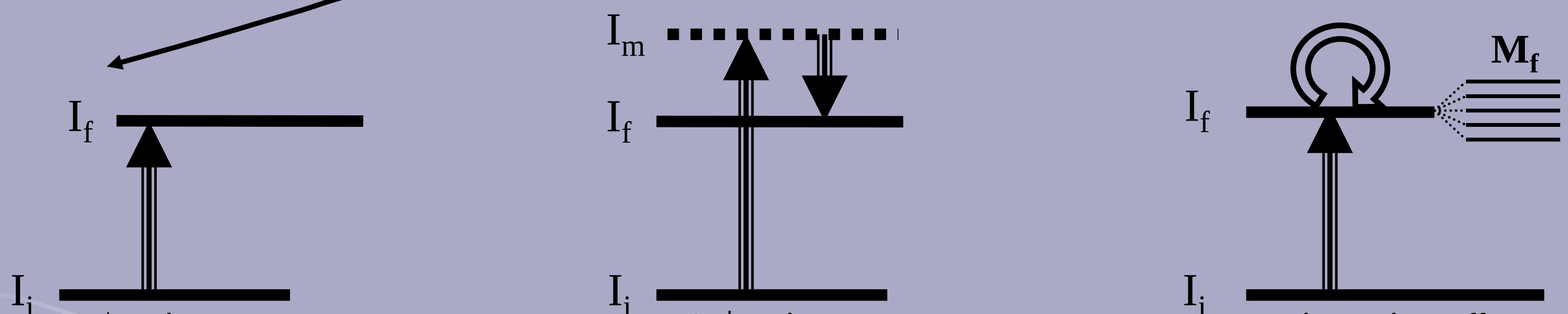
AIM of the LOI: Transition matrix elements and Q-moments (sign) of the exotic octupole bands from reorientation effects for the n-rich Ce, Ba, Xe nuclei.

SPES intensities ~ 10^5-10^7 pps

Nuclear excitation by electromagnetic field acting between nuclei.



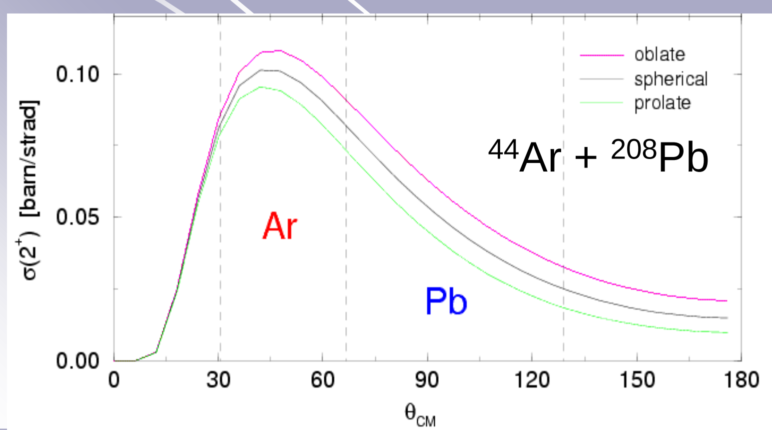
The excitation cross section is a direct measure of the $E\lambda$ matrix elements.



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

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

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



differential Coulomb excitation cross section

$\Rightarrow$ transition probability *B(E2)*

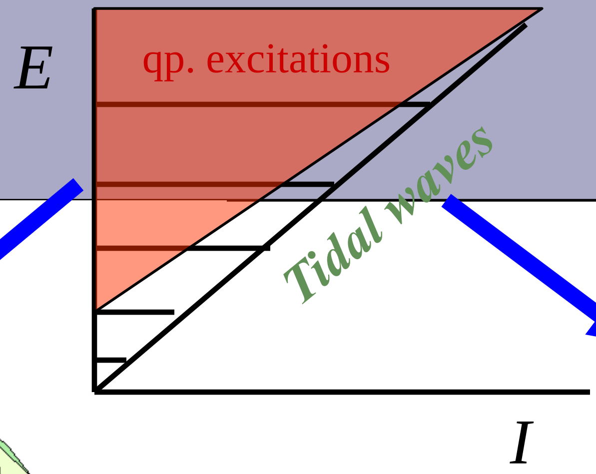
$\Rightarrow$ quadrupole moment Q_s

Set-up presented yesterday by Barbara Mellon

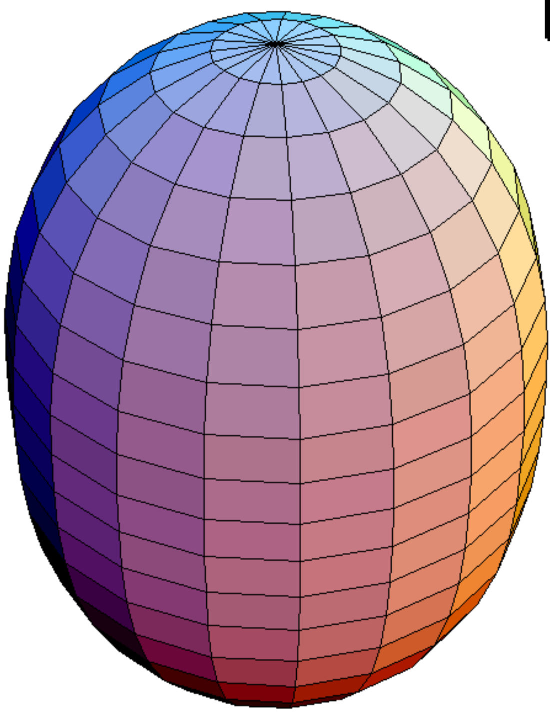
Summary

- **Mean-field Theories** predict **tetrahedral configurations** in **islands of nuclei** throughout the nuclear chart
- **Signature: Vanishing quadrupole moment**
- The best candidates will be found **away from the valley of stability**
- Aim of the LOI: **Coulomb excition of the quadrupole and octupole structures**
- **SPES intensities fine for the n-rich Ce, Ba, Xe**

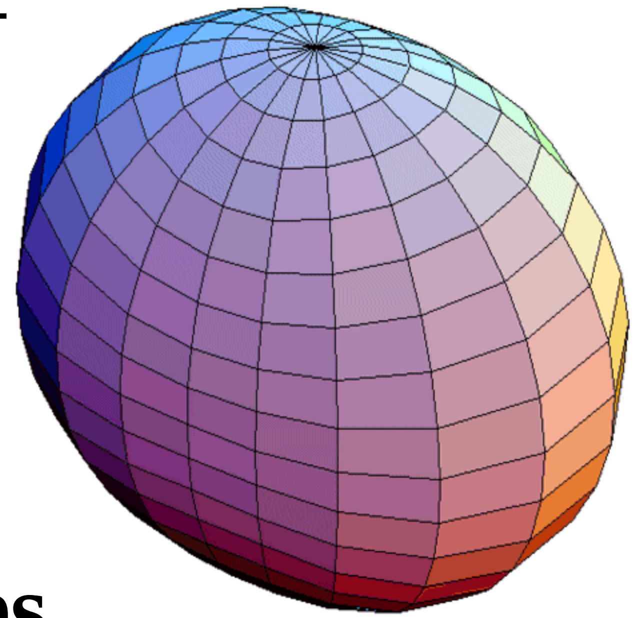
The nuclear tetrahedral symmetry reflects the quantal nature of the nucleus (always competing with the macroscopic, liquid-drop aspects)



$$\omega = \frac{\Omega}{2} \quad E = \omega L_z$$



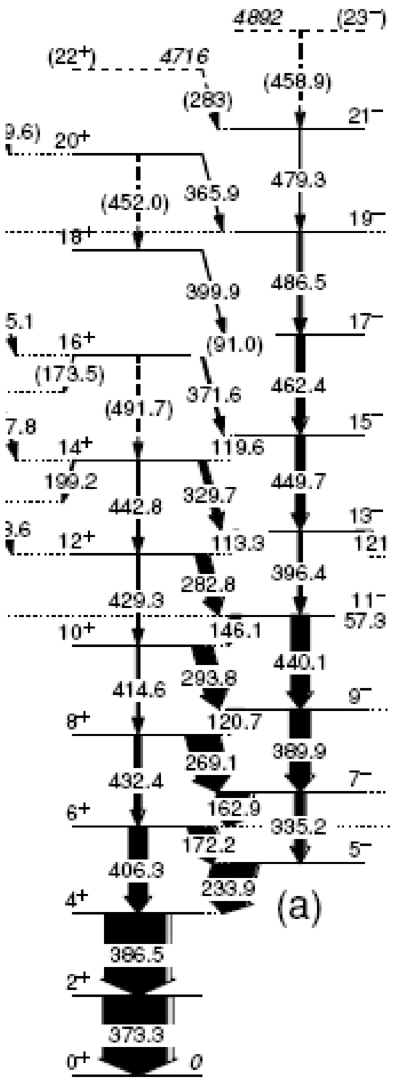
Tidal Waves



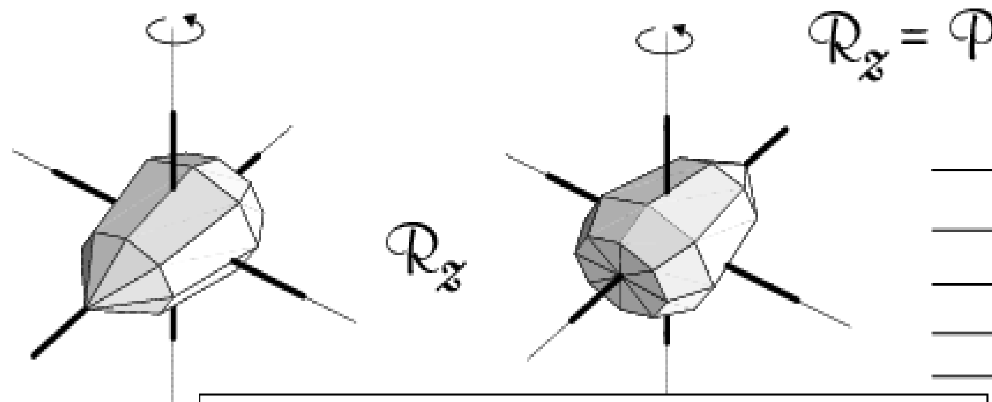
$$R(\vartheta,\varphi,t) =$$
$$R_0[1 + a_0 \cos(\Omega t) Y_{20}(\theta, \varphi = 0)]$$

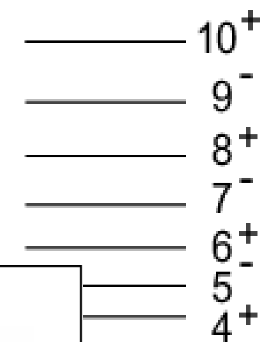
$$R(\vartheta,\varphi,t) =$$
$$R_0[1 + 2a_2 \cos(2\varphi - \Omega t) Y_{22}(\vartheta, \varphi = 0)]$$

Heart-shaped waves - good simplex



$^{220}_{90}\mathrm{Th}_{130}$





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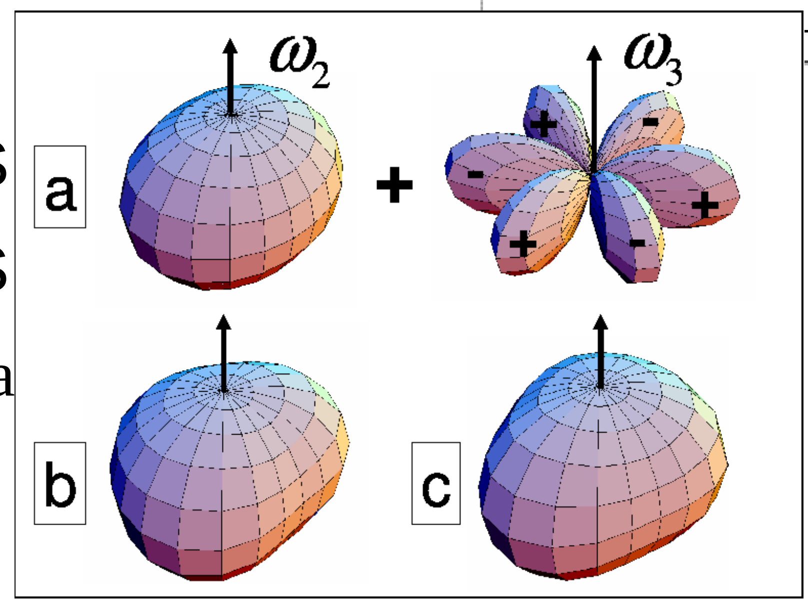

W. Reviol *et al.* Phys. Rev. C74, 044305 (2006)