Probing Multiphonon Excitations in Nearly Spherical Nuclei with Fast Neutrons

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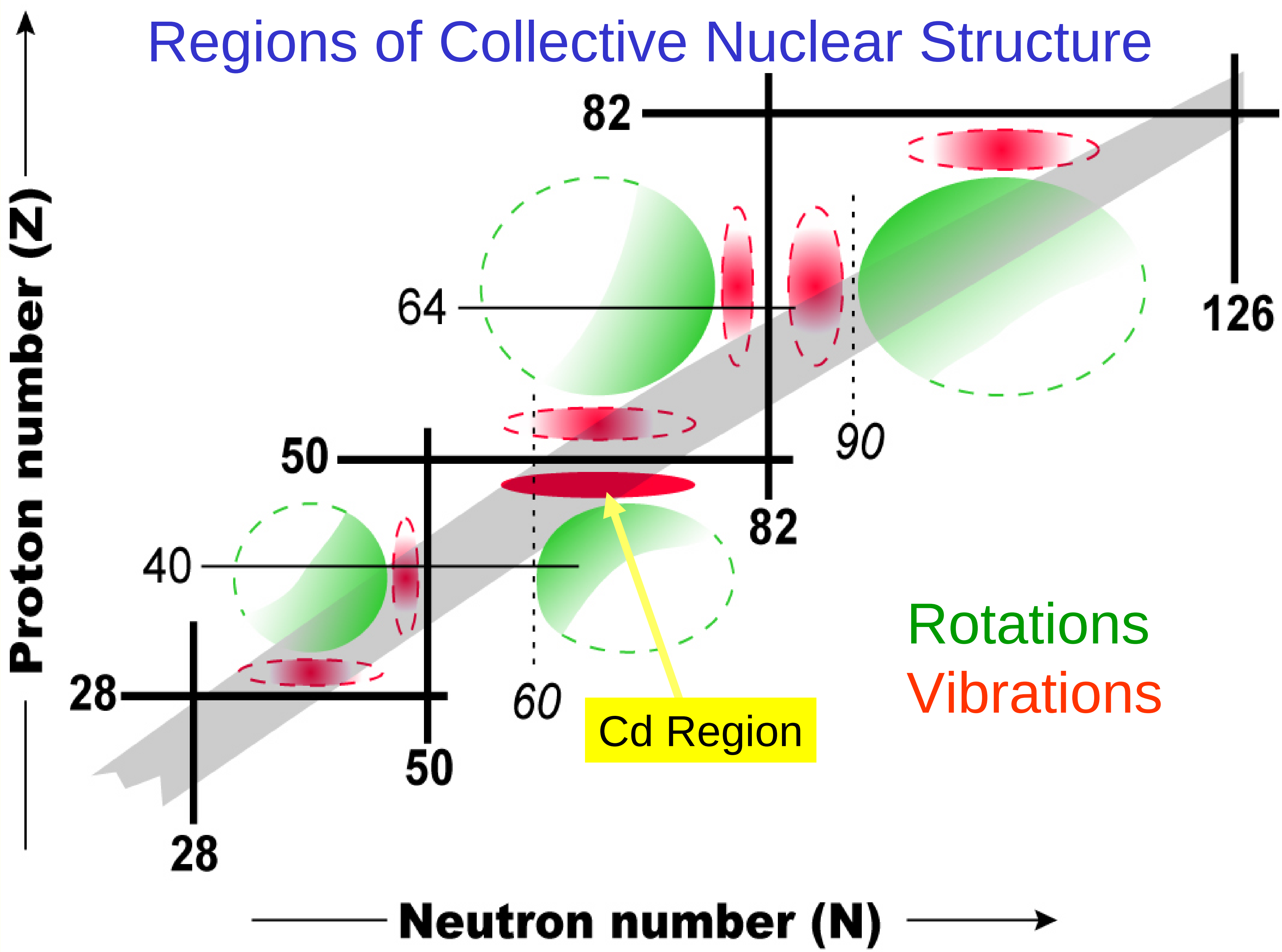
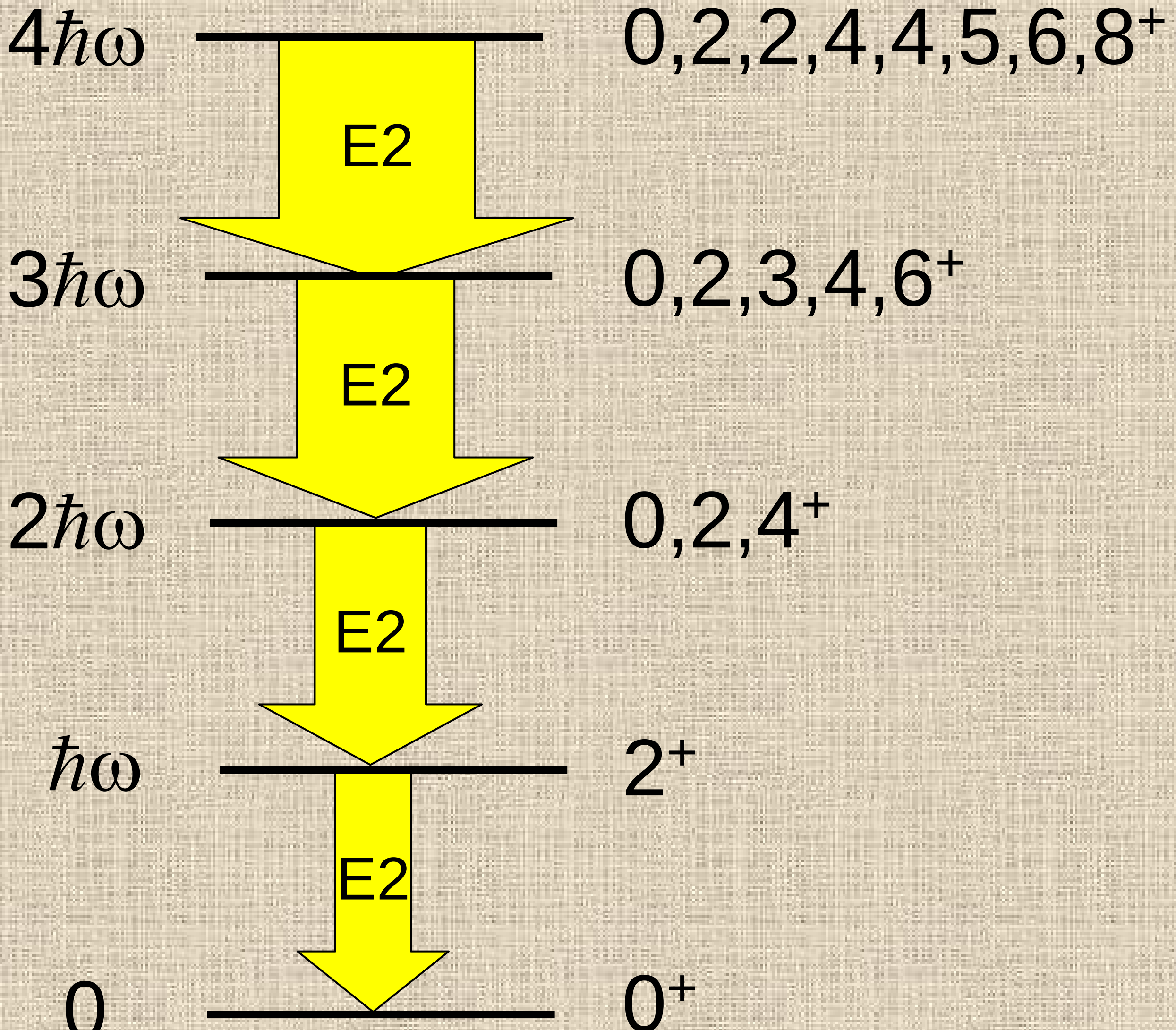
NSF



Regions of Collective Nuclear Structure
82
64
126
90
50
82
40
28
60
Cd Region
50
28
Rotations
Vibrations
Proton number (Z)
Neutron number (N)

$\Delta n = \pm 1$



Quadrupole Vibrations

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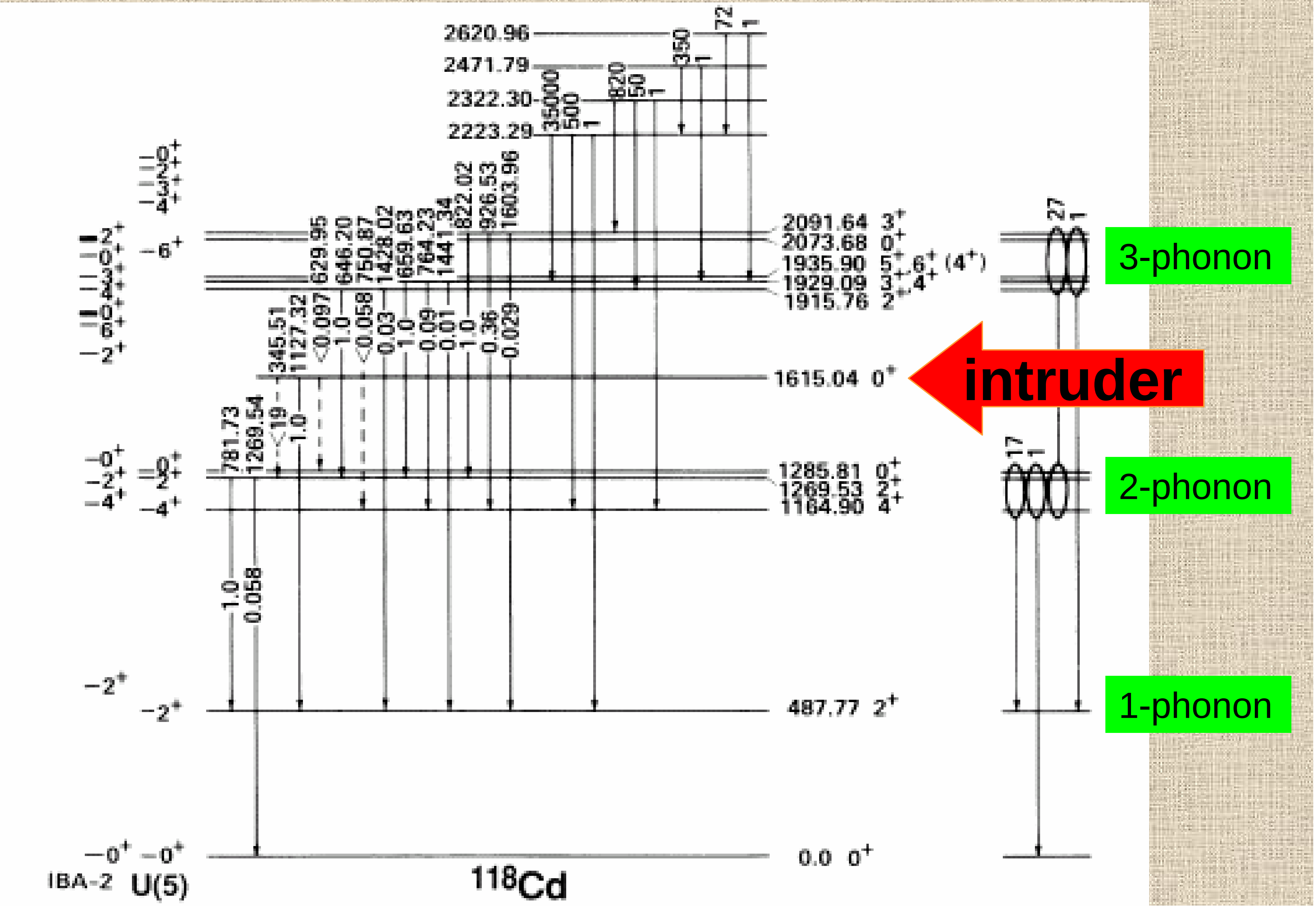
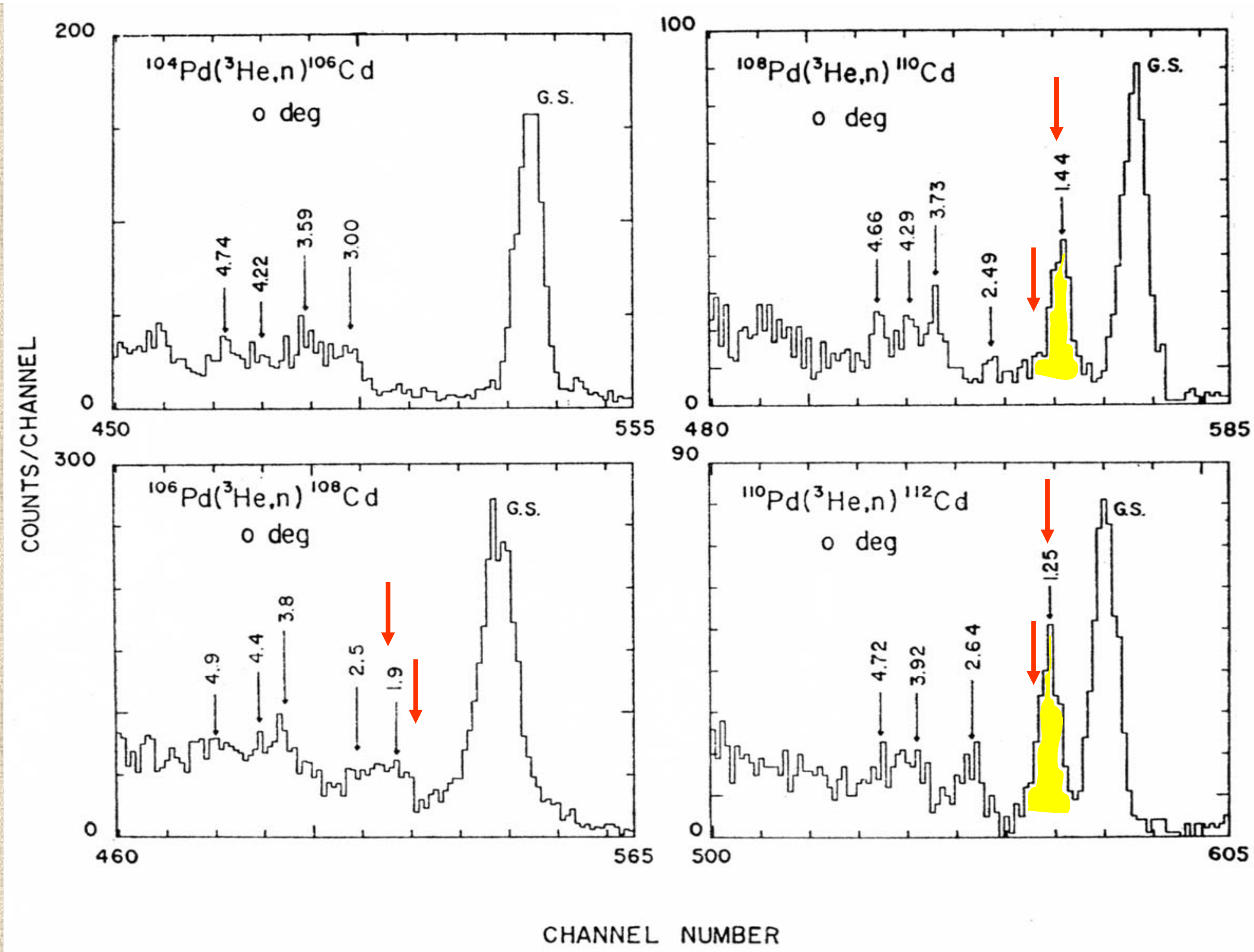
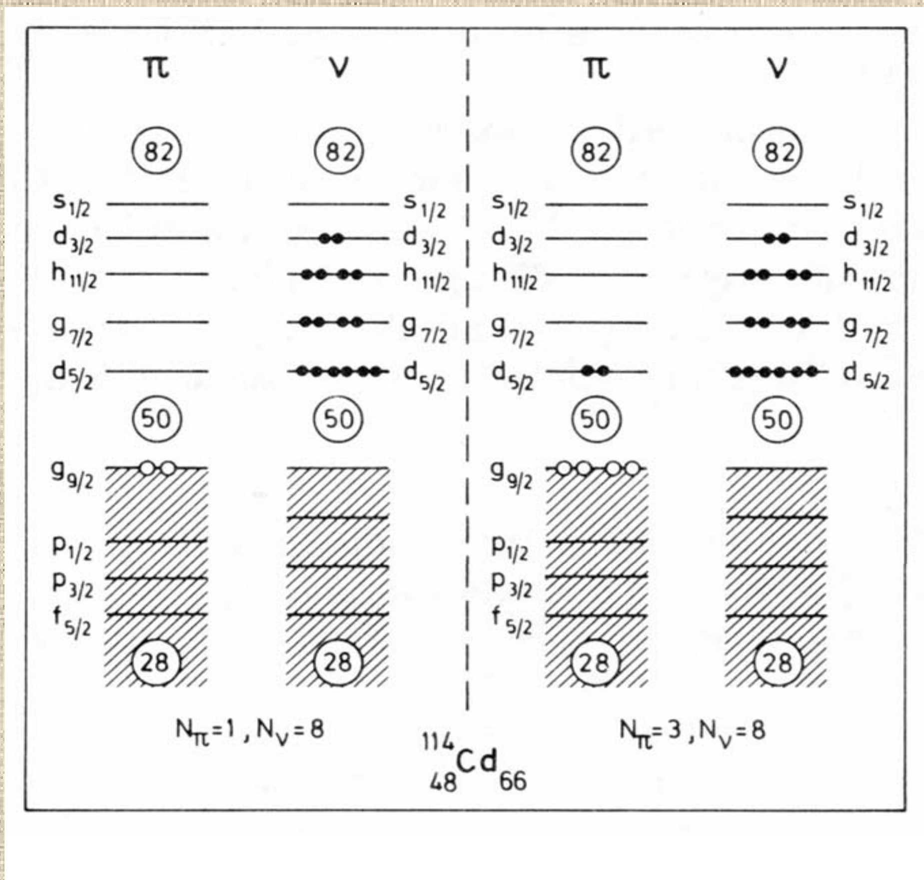
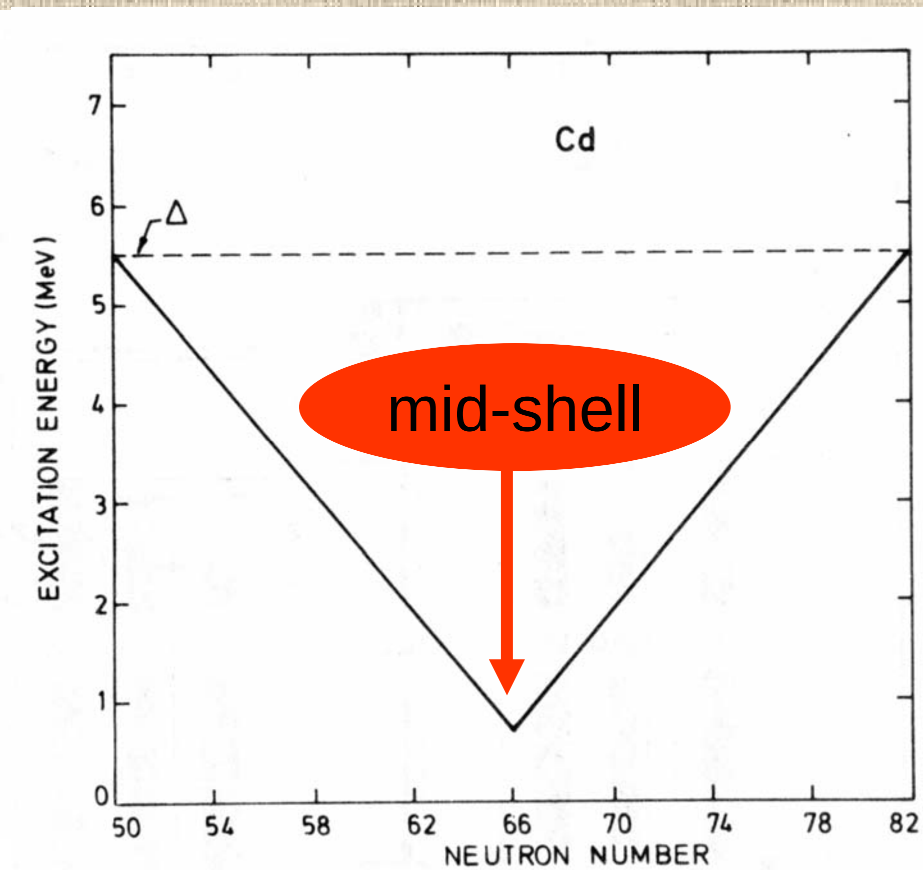




H. W. Fielding, R. E. Anderson, C. D. Zafiratos, D. A. Lind, F. E. Cecil, H. H. Wieman, and W. P. Alford, Nucl. Phys. **A281**, 389 (1977).





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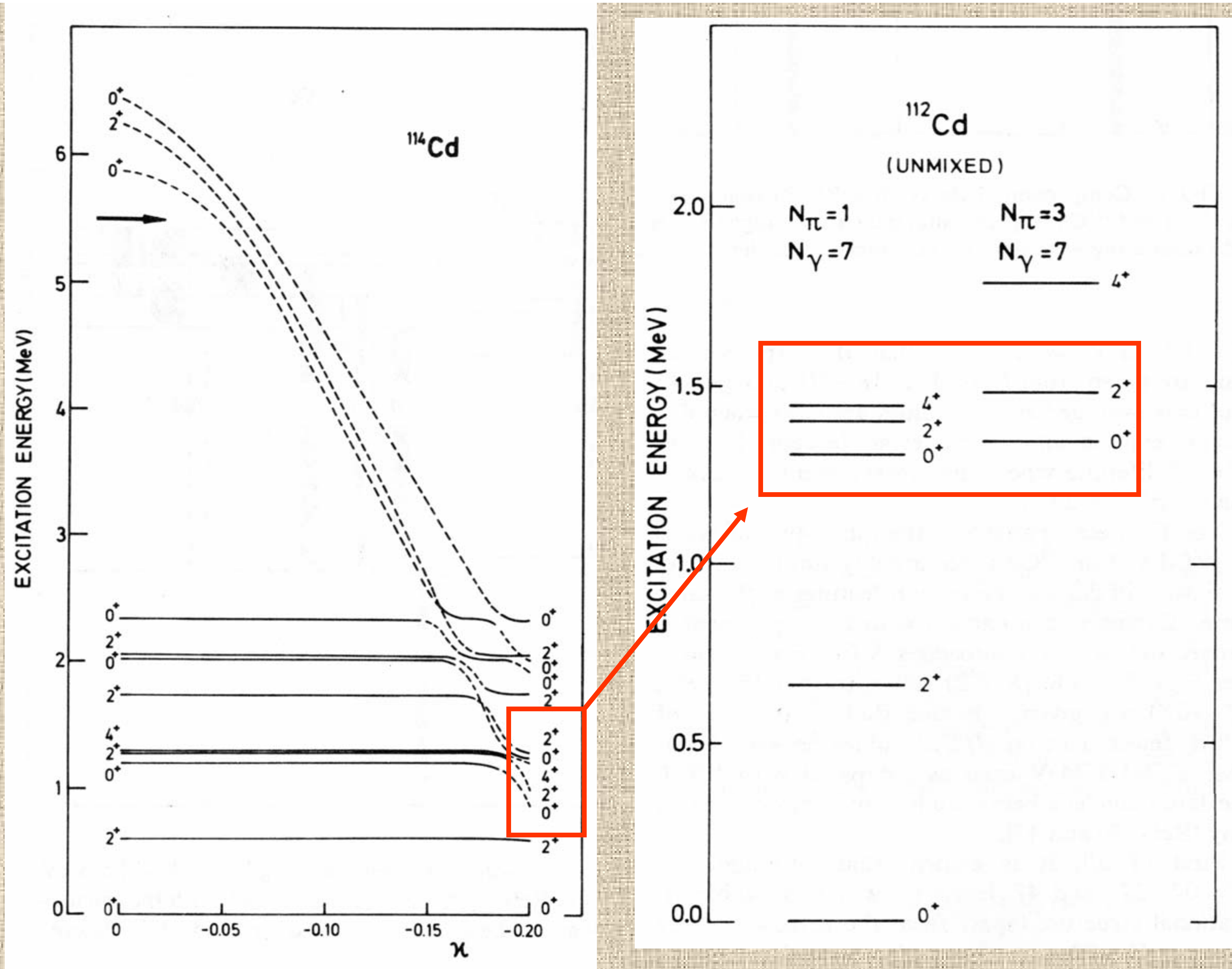
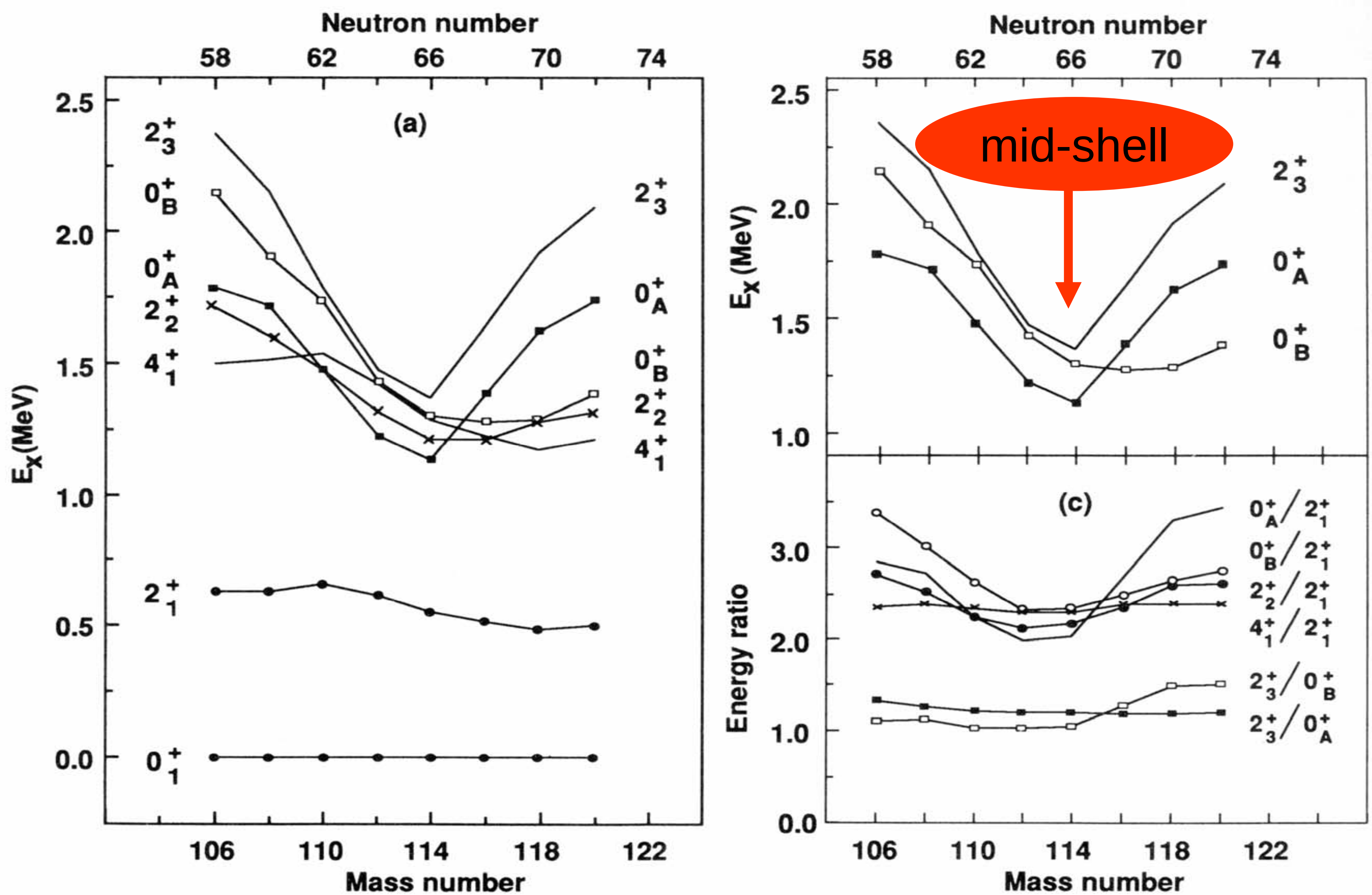
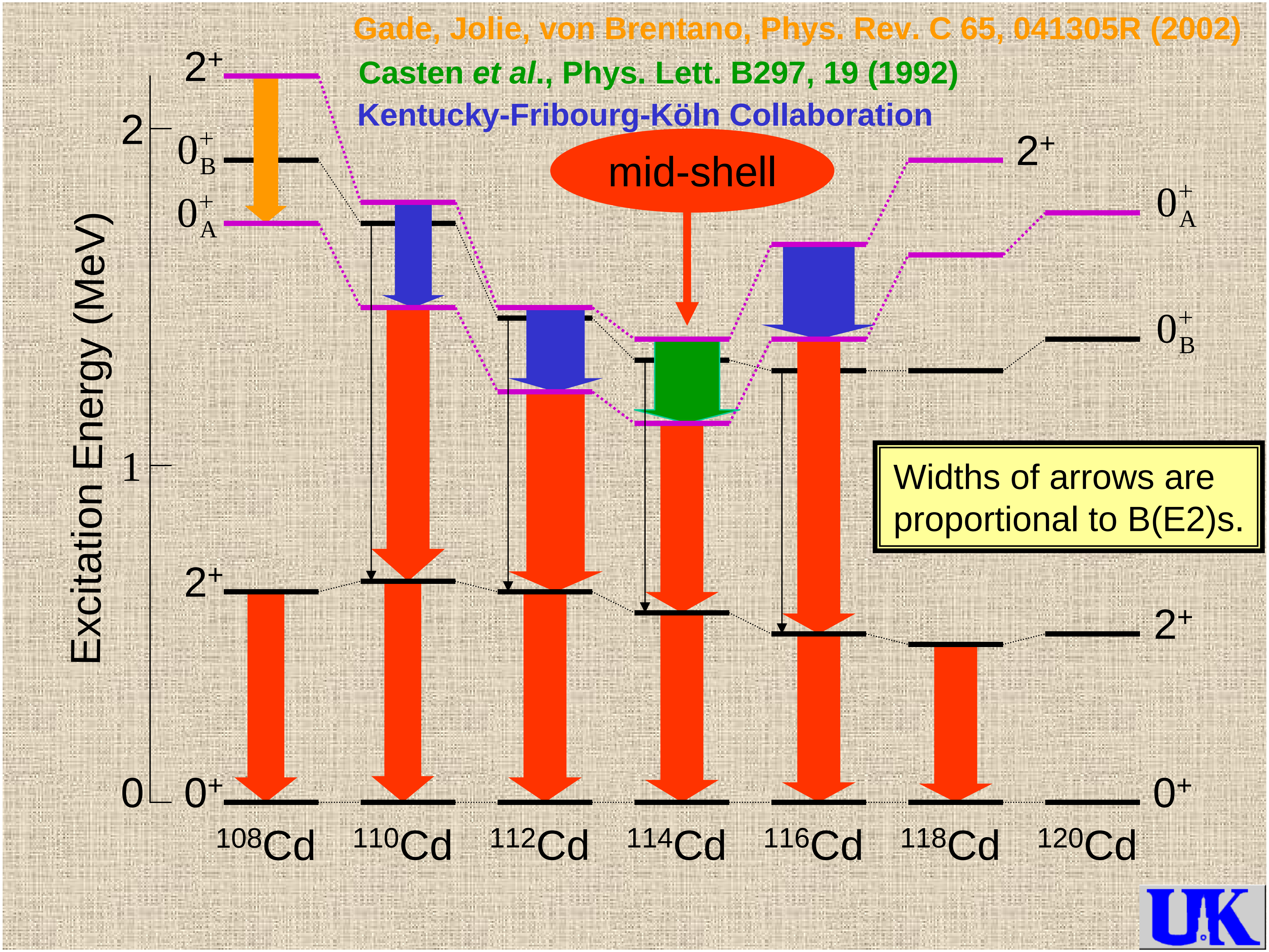


K. Heyde, P. Van Isacker, M. Waroquier, G. Wenes, and M. Sambataro, Phys. Rev. C **25**, 3160 (1982).

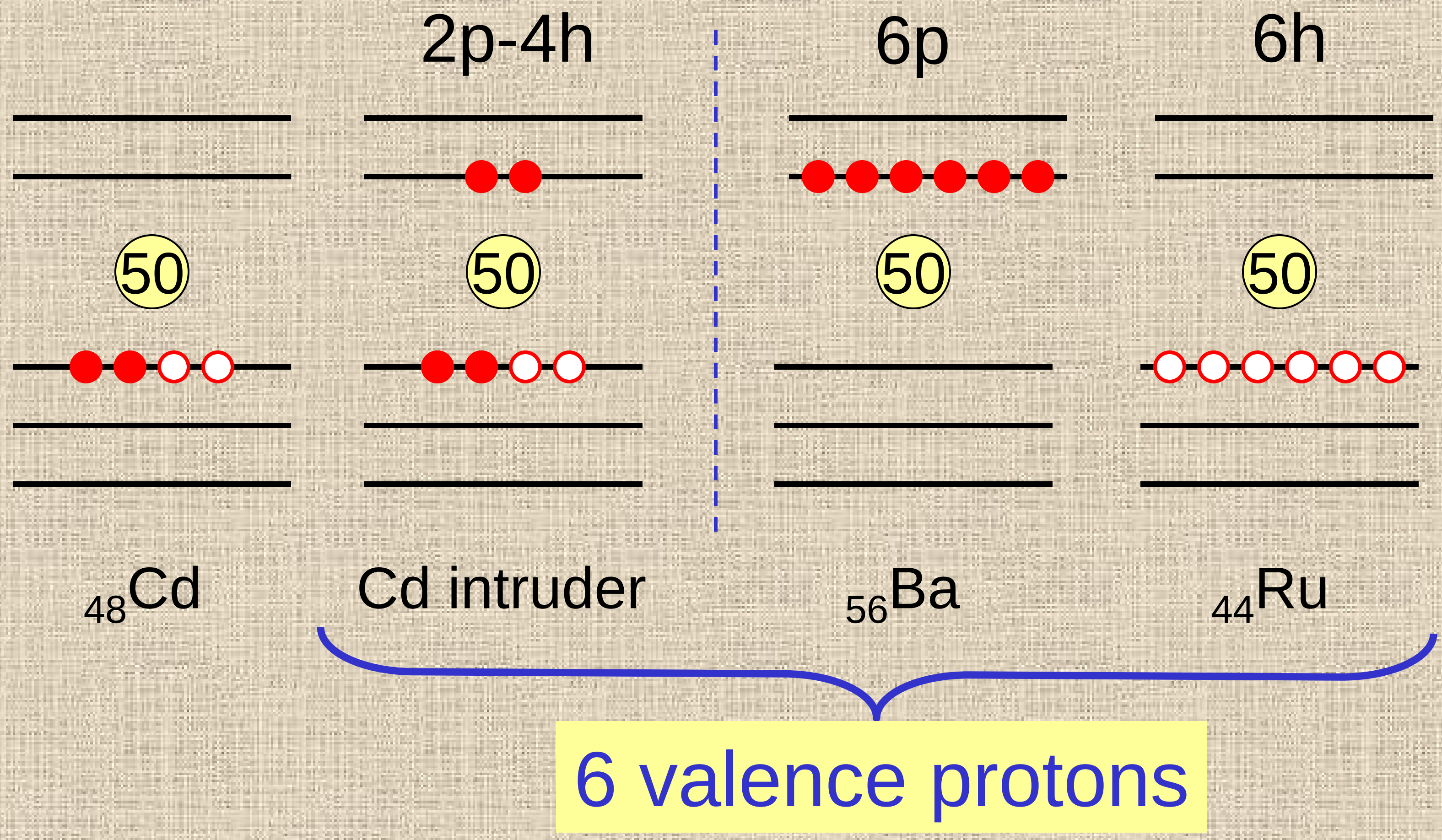


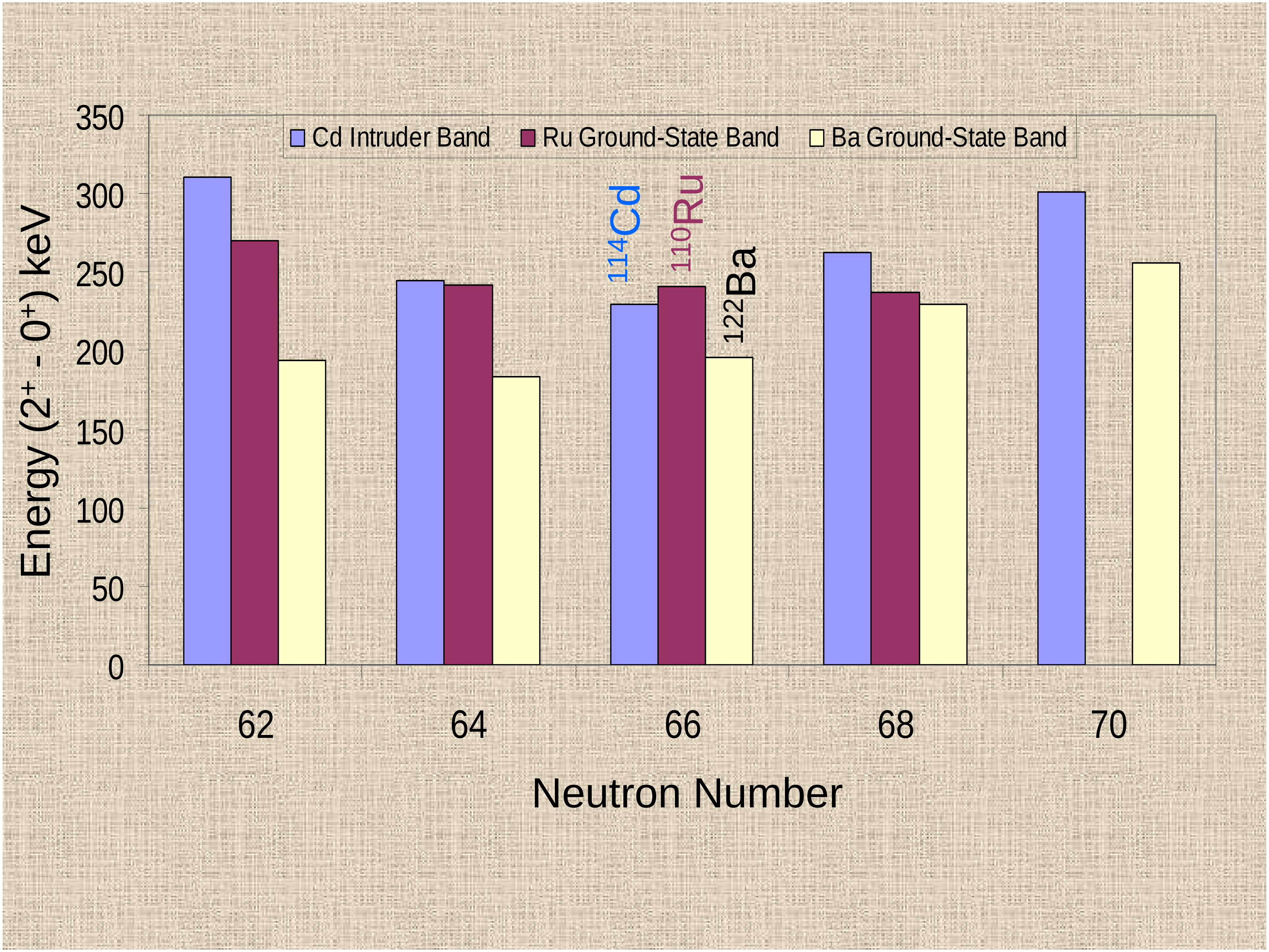
J. Kumpulainen, R. Julin, J. Kantele, A. Passoja, W. H. Trzaska, E. Verho, J. Väärämäki, D. Cutoiu, and M. Ivascu, Phys. Rev. C **45**, 640 (1992).



Gade, Jolie, von Brentano, Phys. Rev. C 65, 041305R (2002)
Casten et al., Phys. Lett. B297, 19 (1992)
Kentucky-Fribourg-Köln Collaboration
mid-shell
Widths of arrows are proportional to B(E2)s.
Excitation Energy (MeV)
2
1
0
2+
0+B
0+A
2+
0+
108Cd
110Cd
112Cd
114Cd
116Cd
118Cd
120Cd

Intruder State Model
Proton Levels





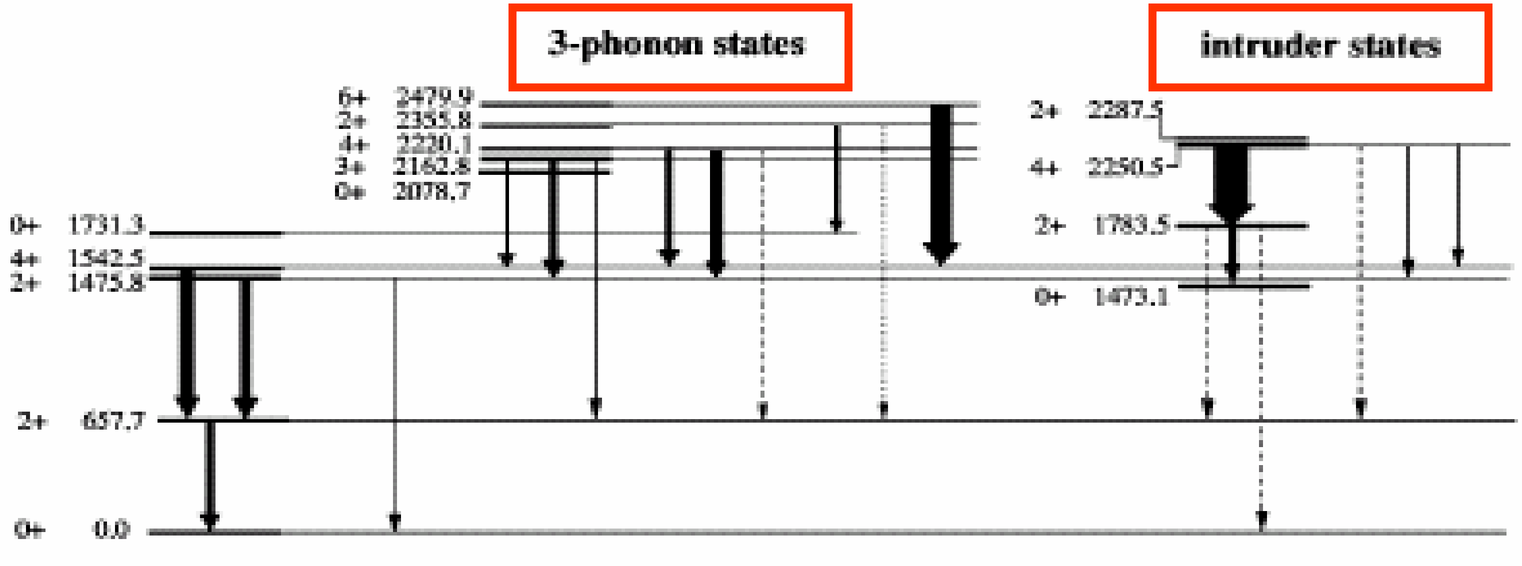
Energy (2+ - 0+) keV
350
300
250
200
150
100
50
0
Cd Intruder Band
Ru Ground-State Band
Ba Ground-State Band
114Cd
110Ru
122Ba
62
64
66
68
70
Neutron Number

B(E2) Values in Six Valence Proton Nuclei*

Neutron Number	Cd Intruder $B(E2;2_3 \rightarrow 0_A)$	Ru $B(E2;2_1 \rightarrow 0_1)$	Ba $B(E2;2_1 \rightarrow 0_1)$
62	23^{+27}_{-18}		
64	56 ±17	58 ± 5	
66	61 ± 8	70 ± 5	154 ± 14
68	86^{+24}_{-30}	75 ± 7	116 ± 6
70			98 ± 16

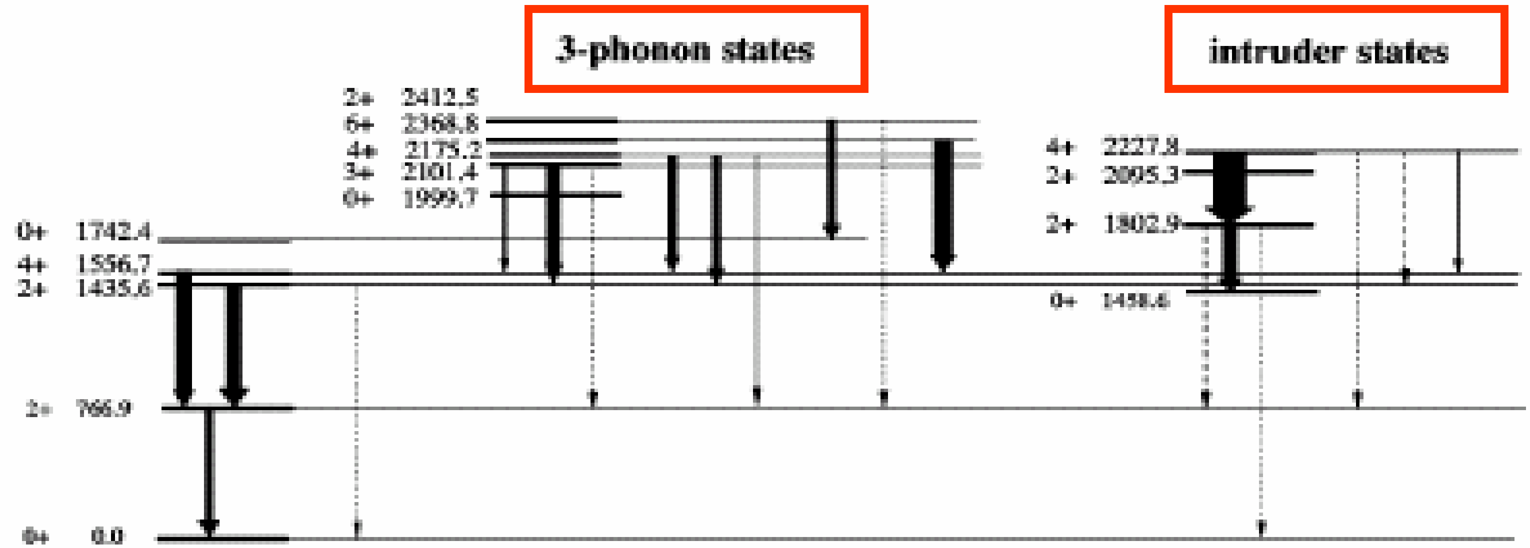
*In Weisskopf units

M. Kadi *et al.*, Phys. Rev. C **68**, 031306R (2003)

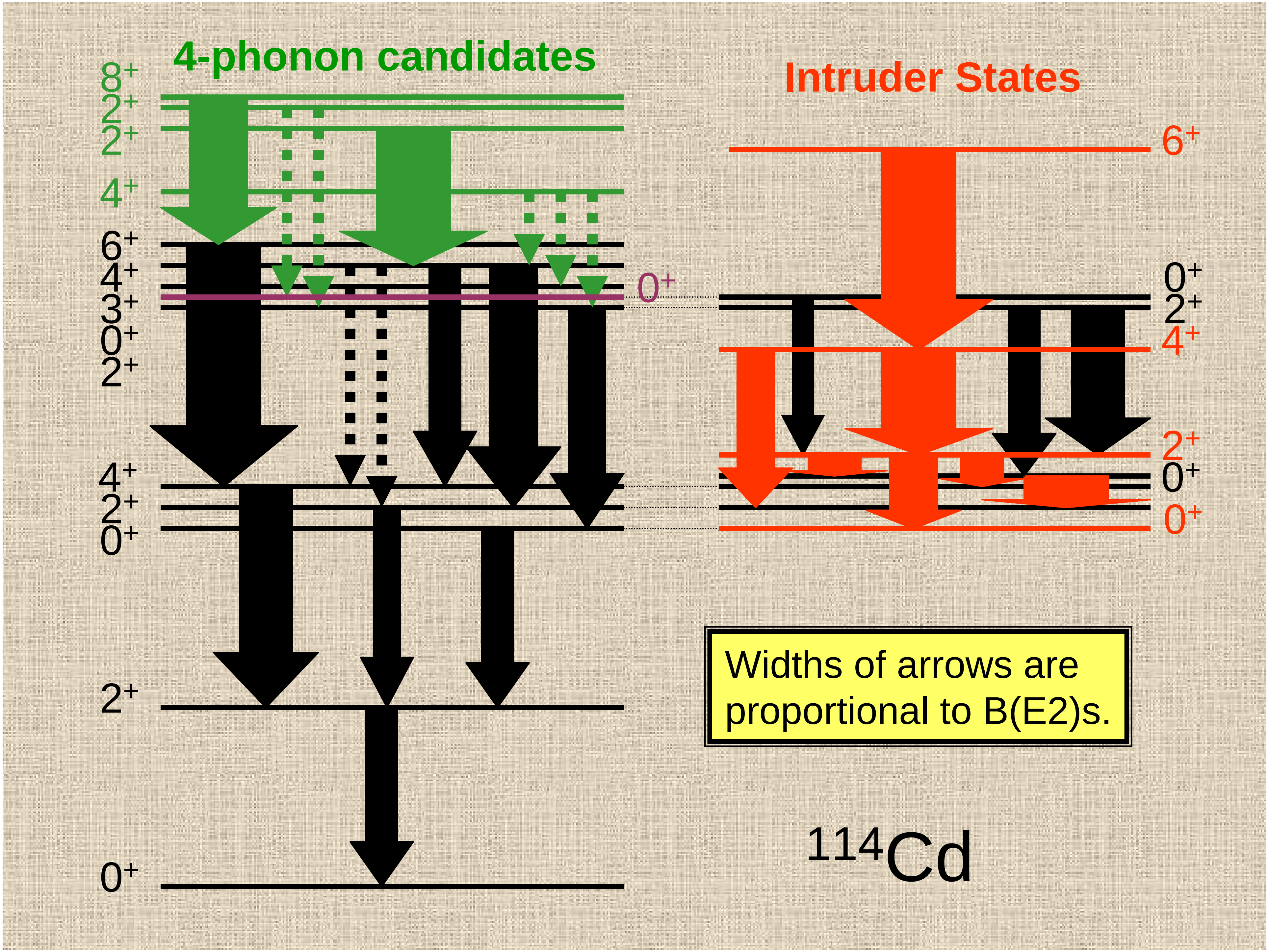


^{110}Cd

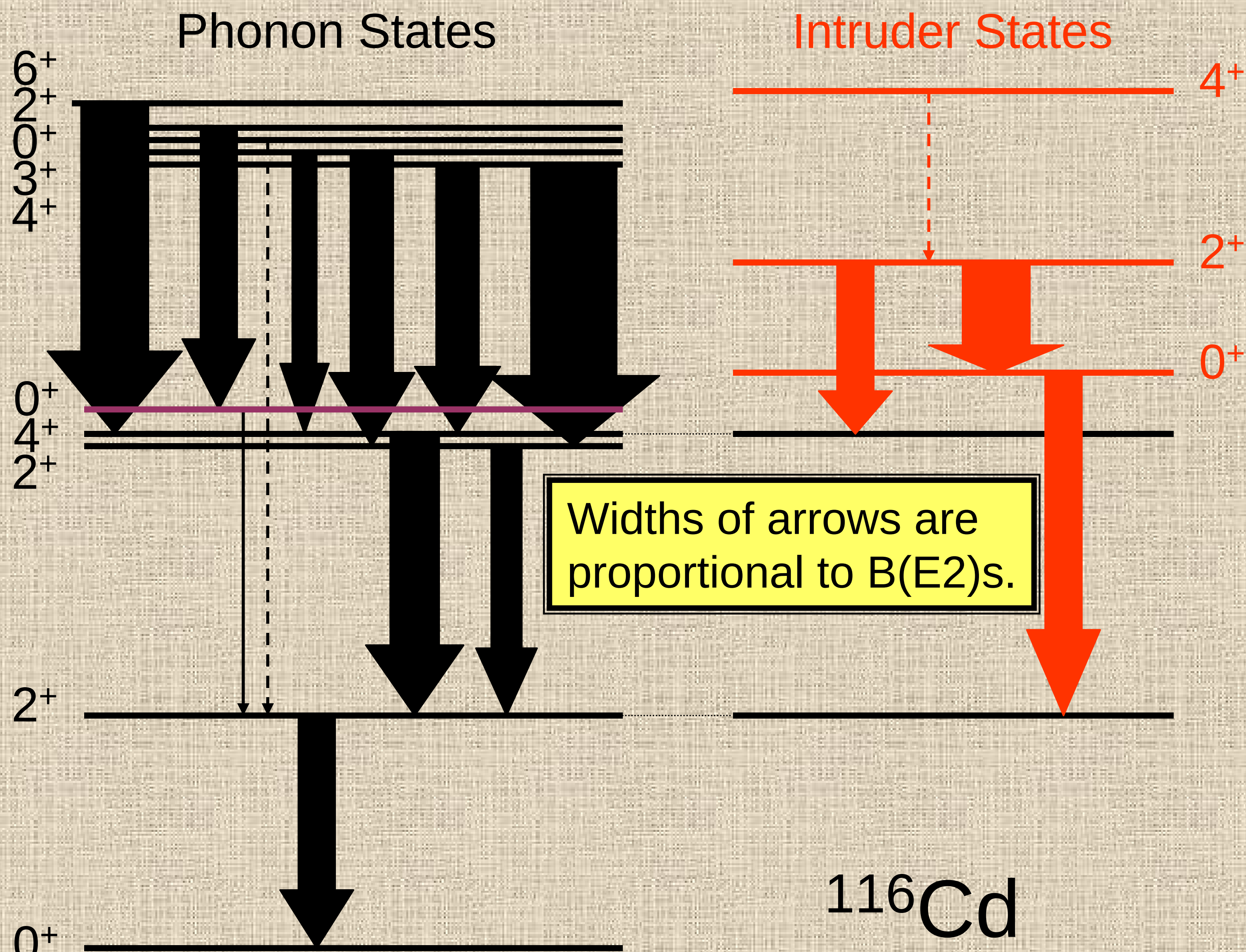
F. Corminboeuf, *et al.*, Phys. Rev. C **63**, 014305 (2000).



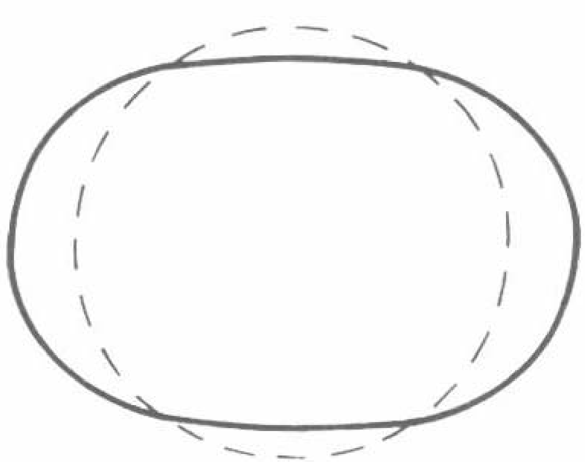
U(5)-O(6)



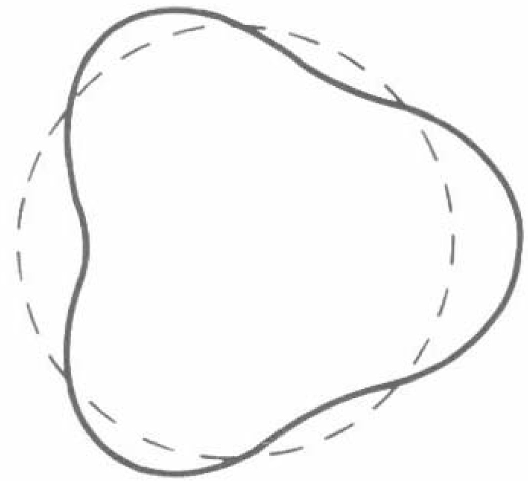
4-phonon candidates
Intruder States
8+
2+
2+
4+
6+
4+
3+
0+
2+
0+
4+
2+
0+
2+
0+
6+
0+
2+
4+
2+
0+
0+
Widths of arrows are proportional to B(E2)s.
114Cd



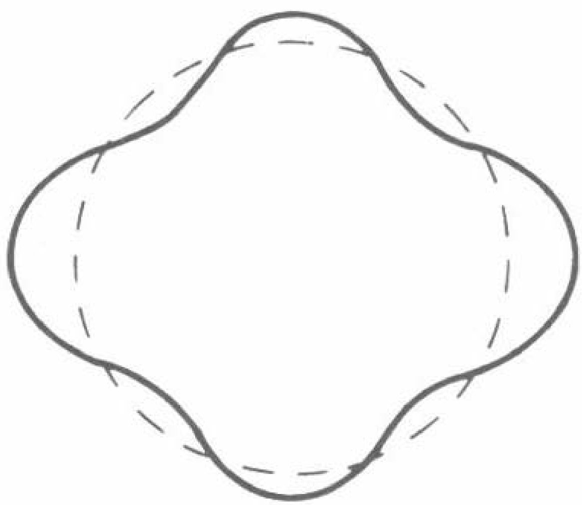
M. Kadi *et al*., Phys. Rev. C **68**, 031306R (2003)



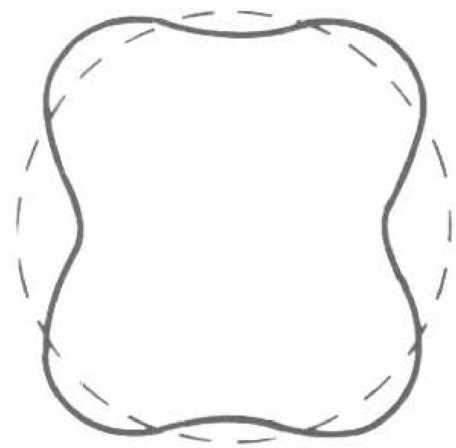
Quadrupole



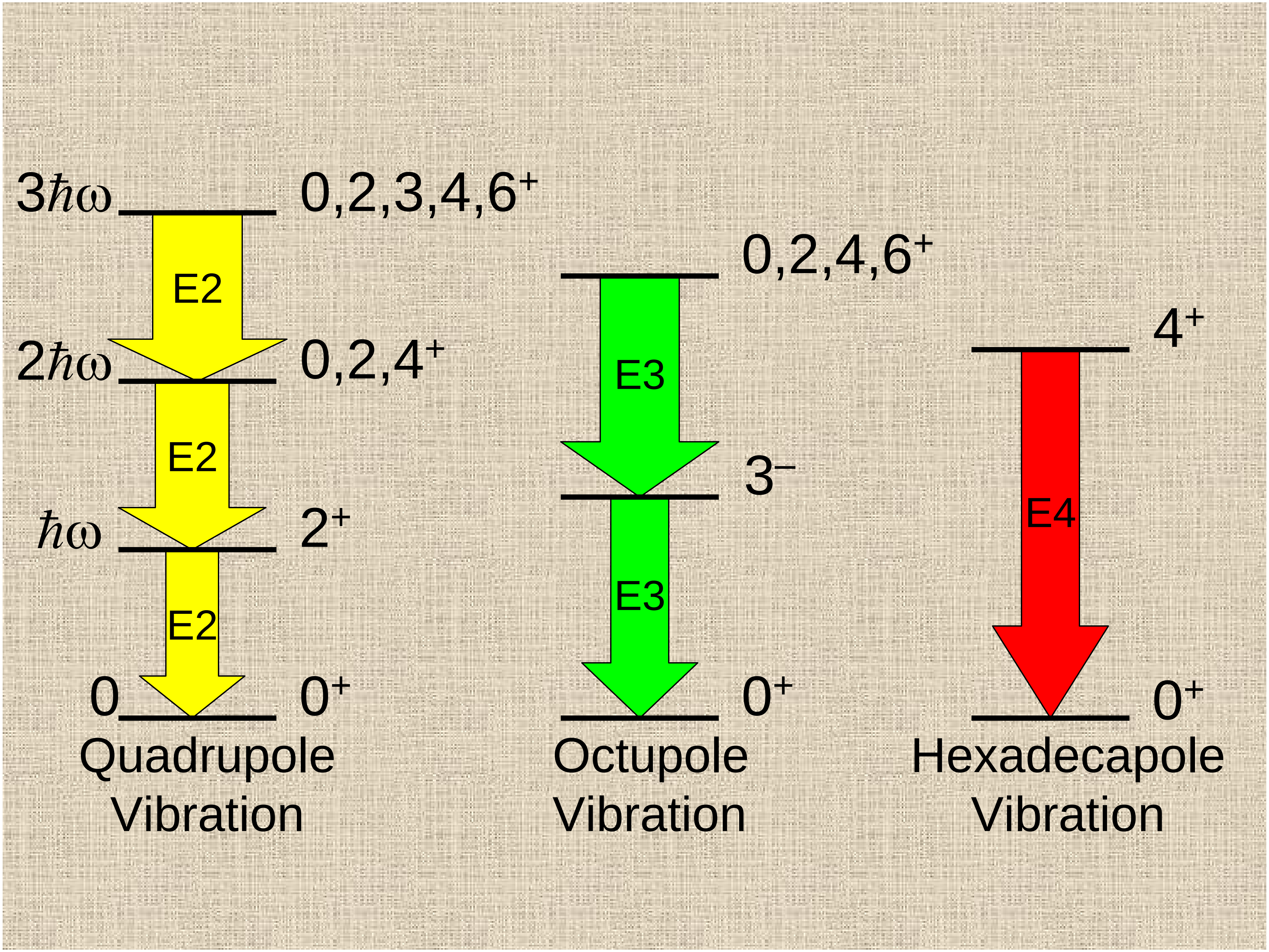
Octupole



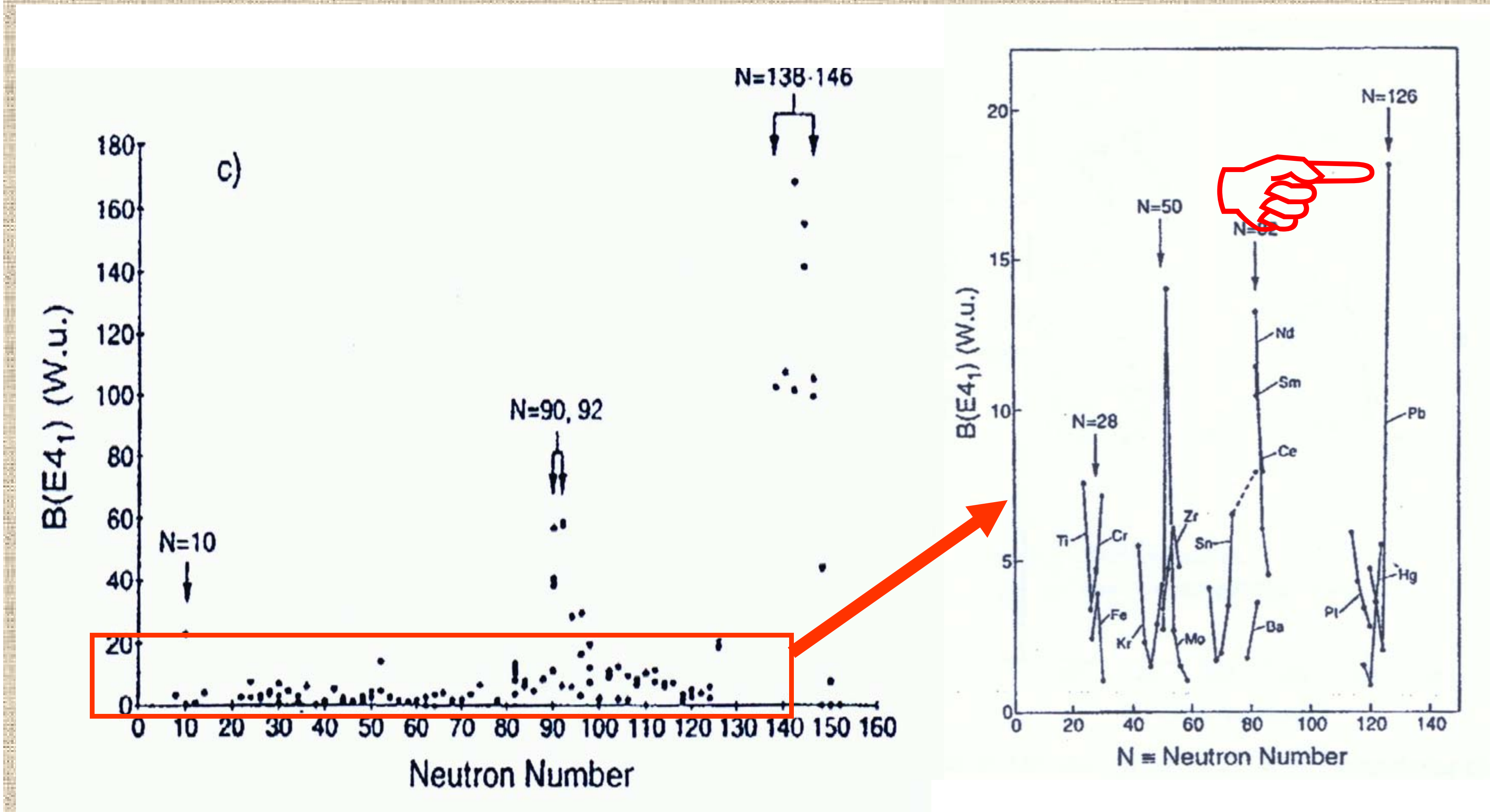
Hexadecapole



Hexadecapole

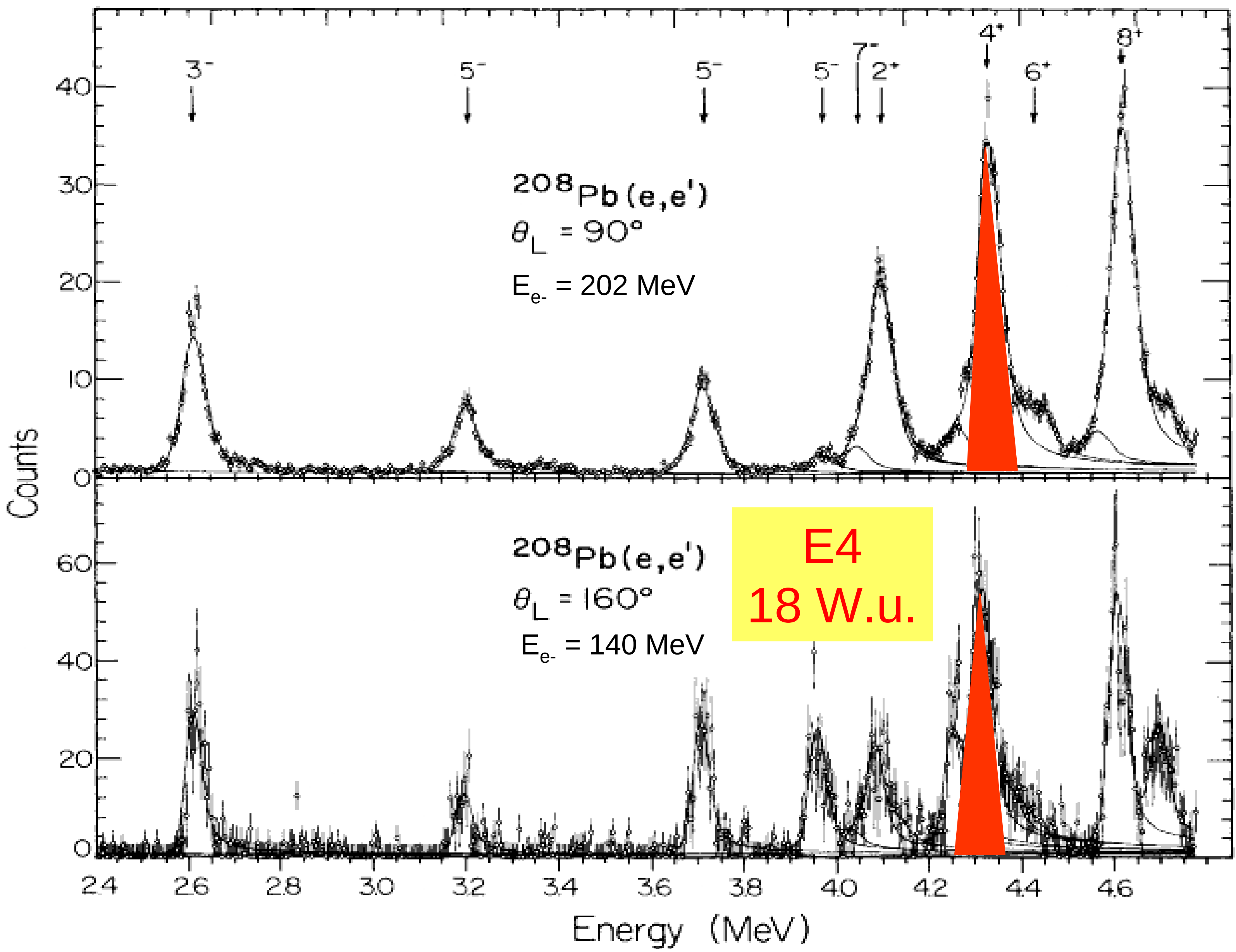

3ħω
0,2,3,4,6+
E2
2ħω
0,2,4+
E2
ħω
2+
E2
0
0+
Quadrupole
Vibration
0,2,4,6+
E3
3−
E3
0+
Octupole
Vibration
4+
E4
0+
Hexadecapole
Vibration

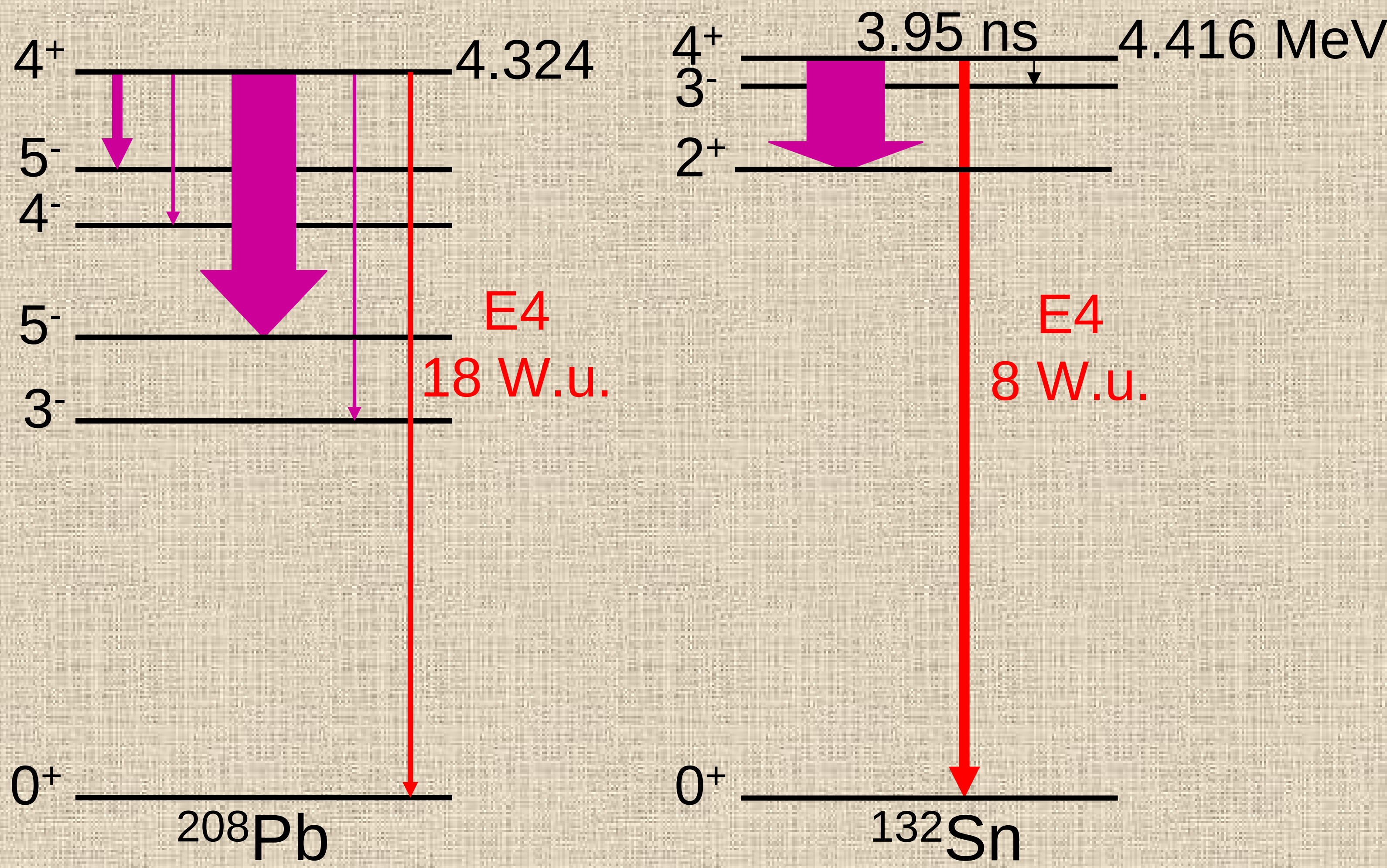
Hexadecapole Excitations



R. K. Sheline, B. Singh, P. C. Sood, and S. Y. Chu, Czech. J. Phys. **49**, 1047 (1999)

J. Heisenberg *et al*., Phys. Rev. C **25**, 2292 (1982).





M. Yeh *et al*.

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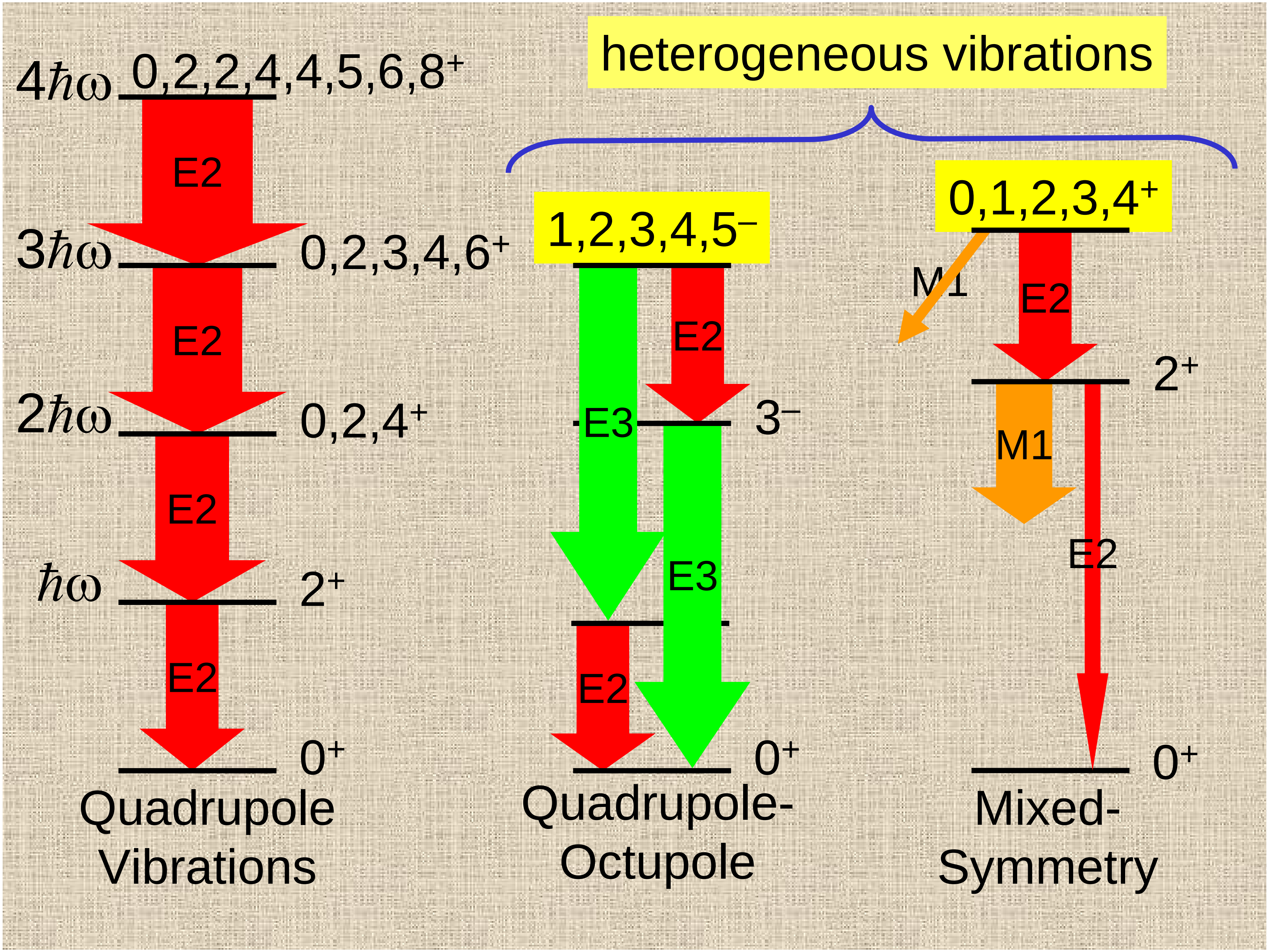
Phys. Scr. **T56**, 79 (1995).

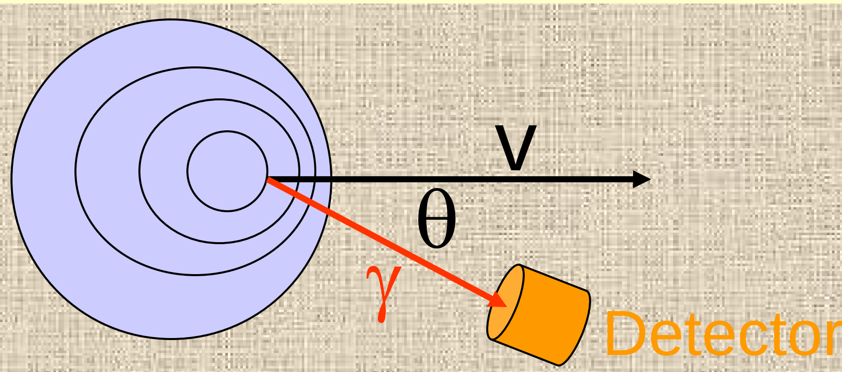


heterogeneous vibrations
4ħω 0,2,2,4,4,5,6,8⁺
3ħω 0,2,3,4,6⁺
2ħω 0,2,4⁺
ħω 2⁺
0⁺
E2
E2
E2
E2
Quadrupole Vibrations
1,2,3,4,5⁻
3⁻
0⁺
E3
E2
E3
E2
Quadrupole-Octupole
0,1,2,3,4⁺
2⁺
0⁺
M1
E2
M1
E2
Mixed-Symmetry

Summary of Vibrations in Nearly Spherical Nuclei

Quadrupole	♦ *complete 3-phonon quintets known* ♦ *intruder interactions understood?* ♦ *4-phonon candidates*
Octupole	♦ *cascades of two E3 transitions* ♦ *possible 2-phonon quartet*
Hexadecapole	♦ *promising, but no 2-phonon*
Quad-Oct	♦ *complete 2-phonon quintets known*
MS-Quad	♦ *2-phonon multiplets emerging*

Doppler-Shift Attenuation Method Following Inelastic Neutron Scattering

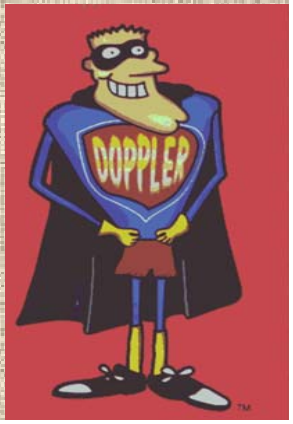


$$E(\theta) = E_\gamma \, (1 + v/c \cos \theta)$$

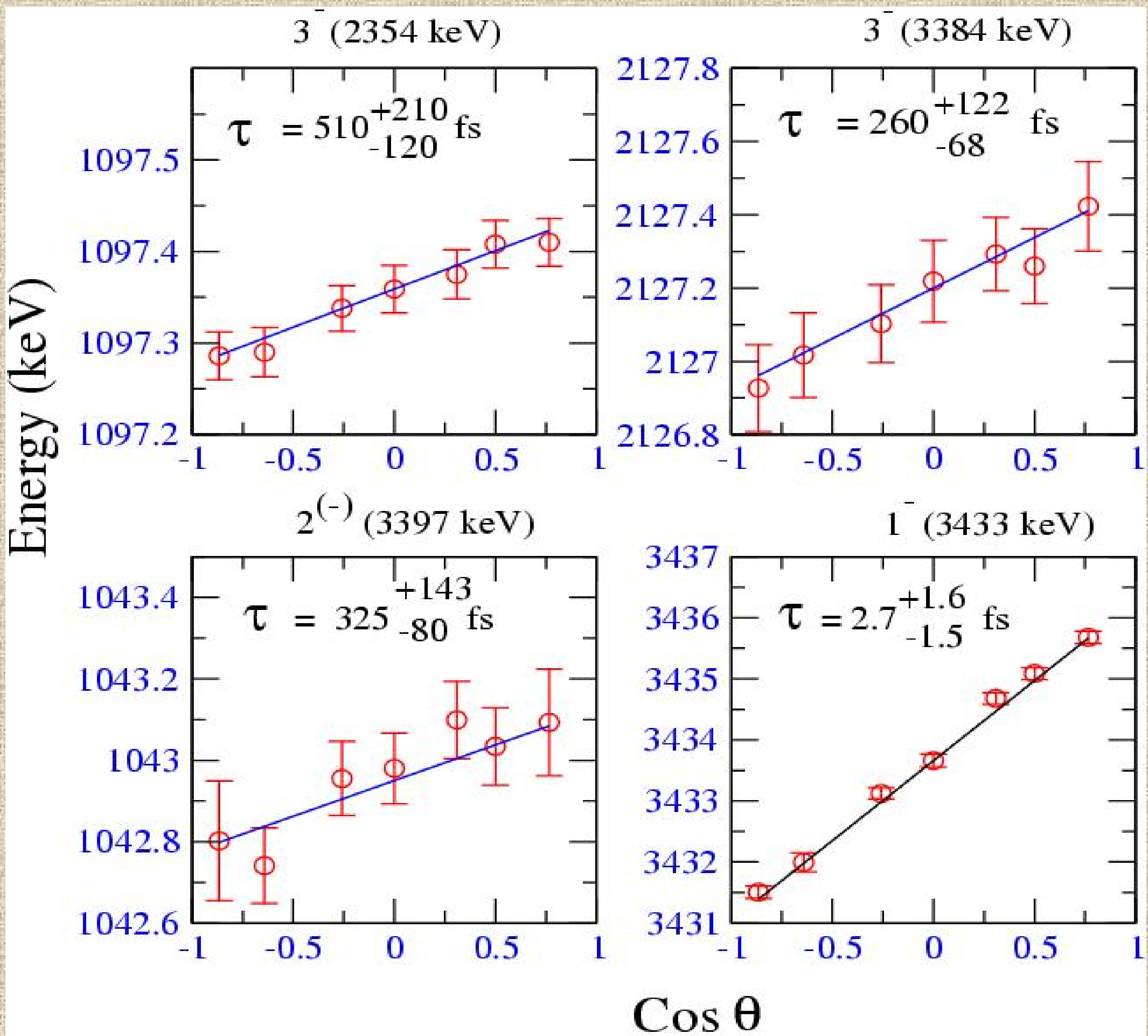
The nucleus is recoiling into a viscous medium.

$$v \rightarrow v(t) = F(t) v_{max}$$

$$E(\theta) = E_\gamma \, (1 + \mathbf{F(\tau)} \, v/c \cos \theta)$$



$E(\theta) = E\gamma\,(1 + F(\tau)\; v/c \cos\theta)$



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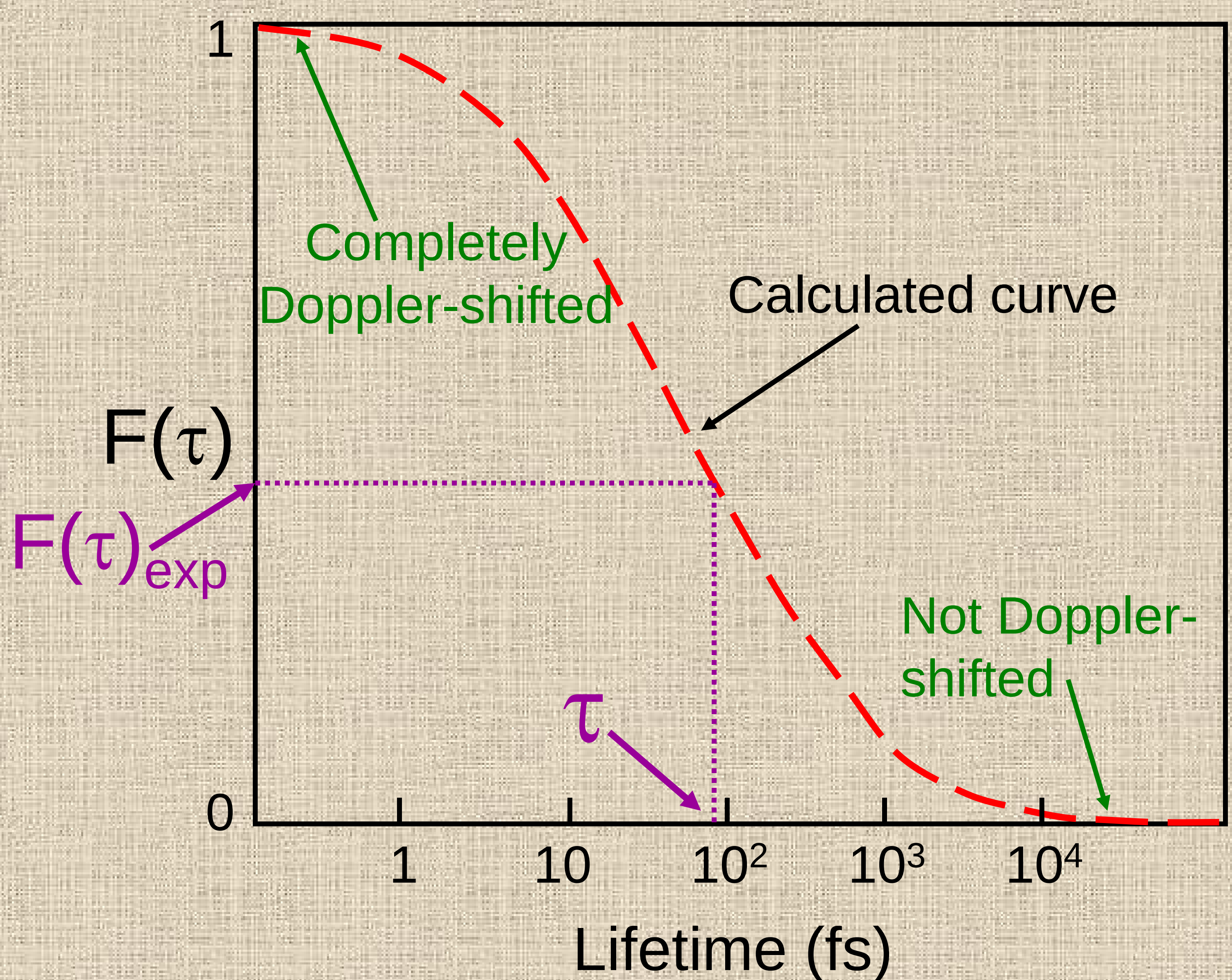


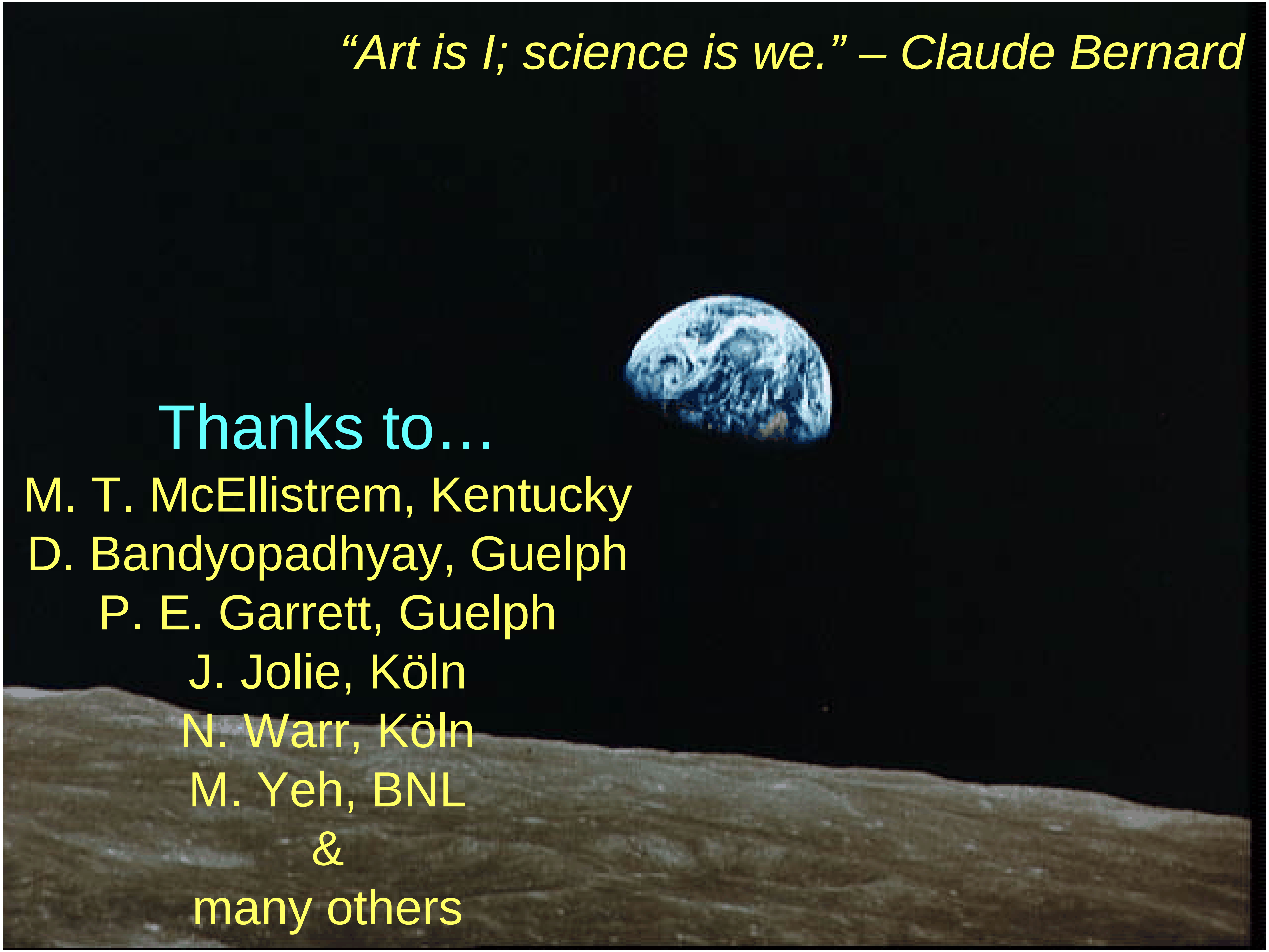
*Inelastic Neutron Scattering**

- ☞ No Coulomb barrier/variable neutron energies
- ☞ Good energy resolution (γ rays detected)
- ☞ Nonselective, but limited by angular momentum
- ☞ Lifetimes by Doppler-shift attenuation method
  (feeding-time problem minimized)
- ☞ Gamma-gamma coincidence measurements
  McGrath *et al.*, Nucl. Instrum. Meth. **A421**, 458 (1999).
- 👎 Limited to stable nuclei
- 👎 Large amounts of enriched isotopes required

*Garrett, Warr, & Yates, J. Res. Natl. Inst. Stand. Technol. **105**, 141 (2000).

Conclusions

- Inelastic neutron scattering is an excellent tool for probing the properties of the low-lying levels of vibrational nuclei and for determining transition rates.
- Three-phonon quadrupole quintets have been identified in a number of nuclei and 4-phonon octets are emerging.
- The coexistence and mixing picture of vibrational and intruder states generally works well in the Cd nuclei, although some details are not yet explained, *e.g.*, 0^+ states.
- Other types of multiphonon excitations, *e.g.*, octupole and heterogeneous, are being characterized.


"Art is I; science is we." – Claude Bernard
Thanks to…
M. T. McEllistrem, Kentucky
D. Bandyopadhyay, Guelph
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J. Jolie, Köln
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many others