Proxy SU(3) for Nuclear Structure

Nuclear Theory Group

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Who are we?

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Spyros Peroulis

Graduate student

Elliott SU(3) Symmetry 1957

Collective motion in the nuclear shell model

I. Classification schemes for states of mixed configurations

BY J. P. ELLIOTT

Atomic Energy Research Establishment, Harwell, Didcot, Berkshire

(*Communicated by Sir John Cockcroft, F.R.S.—Received* 12 *December* 1957)

The first algebraic Nuclear Model with microscopic justification

Elliott’s Breakthrough

Shell Model Space → All the collective observables

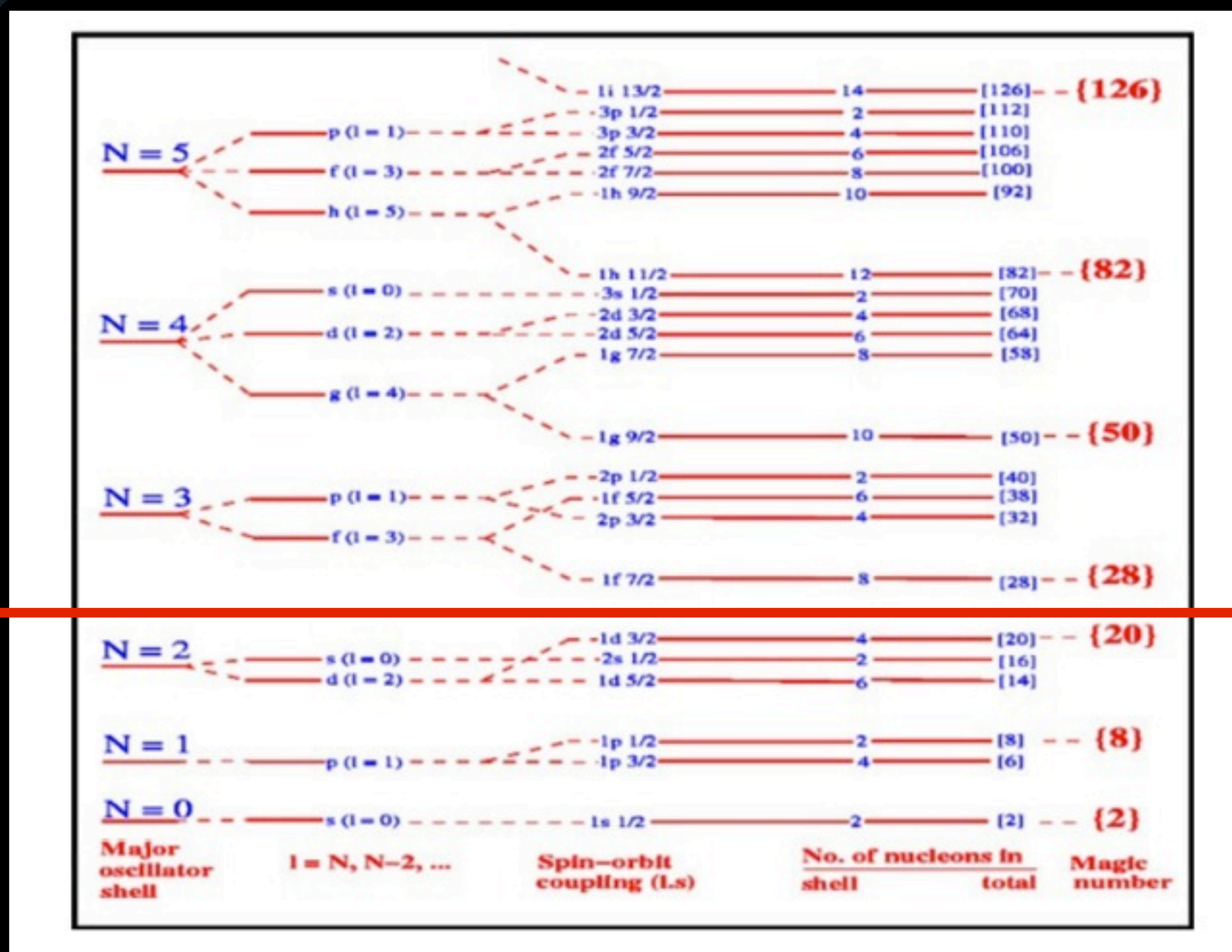
The proxy-SU(3) project

<u>Persons involved</u>: D. Bonatsos, I. E. Assimakis, N. Minkov, A. Martinou, R. F. Casten, R. B. Cakirli, K. Blaum

SU(3) Symmetry

Proxy SU(3)

Elliott SU(3)



Orbitals differing per 1 quantum in the z axis

Emergent Collectivity in Nuclei and Enhanced Proton-Neutron Interactions

D. Bonatsos[1], S. Karampagia[1], R.B. Cakirli[2,3], R.F. Casten[4], K. Blaum[3], L. Amon Susam[2]
[1]*Institute of Nuclear and Particle Physics, National Centre for Scientific Research Demokritos, GR-153 10 Aghia Paraskevi, Attiki, Greece*
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[4]*Wright Nuclear Structure Laboratory, Yale University, New Haven, CT 06520, USA*
(Dated: October 30, 2013)

Phys. Rev. C 2013

The replacement of orbitals

Table 2: Nilsson orbitals for the nucleons between 20 and 50. Due to the ls interaction the $1f_{7/2}$ orbital is excluded from the shell under discussion, while the $1g_{9/2}$ orbital is included. Thus the harmonic oscillator shell 20-40, becomes the nuclear shell 28-50. The 28-50 shell consists of some orbitals with $\mathcal{N} = 3$ and some orbitals with $\mathcal{N} = 4$ quanta [14]. Therefore the Elliott SU(3) symmetry is not valid in the 28-50 shell.

Shell model	$K[\mathcal{N} n_z \Lambda]$	$\|n_z r s \Sigma\rangle$
$1g_{9/2}$	9/2[404]	$\|040+\rangle$
	7/2[413]	$\|130+\rangle$
	5/2[422]	$\|220+\rangle$
	3/2[431]	$\|310+\rangle$
	1/2[440]	$\|400+\rangle$
$2p_{1/2}$	1/2[301]	$\|021-\rangle$
$1f_{5/2}$	5/2[303]	$\|030-\rangle$
	3/2[301]	$\|021+\rangle$
	1/2[310]	$\|111+\rangle$
$2p_{3/2}$	3/2[312]	$\|120-\rangle$
	1/2[321]	$\|210-\rangle$
$1f_{7/2}$	7/2[303]	$\|030+\rangle$
	5/2[312]	$\|120+\rangle$
	3/2[321]	$\|210+\rangle$
	1/2[330]	$\|300+\rangle$

Edited volume on “Nuclear Structure Physics”, to be published by CRC Press/Taylor and Francis Group, USA.

1st Proxy SU(3) Publication

PHYSICAL REVIEW C 95, 064325 (2017)

Proxy-SU(3) symmetry in heavy deformed nuclei

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(Received 17 January 2017; revised manuscript received 2 June 2017; published 27 June 2017)

Background: Microscopic calculations of heavy nuclei face considerable difficulties due to the sizes of the matrices that need to be solved. Various approximation schemes have been invoked, for example by truncating the spaces, imposing seniority limits, or appealing to various symmetry schemes such as pseudo-SU(3). This paper proposes a new symmetry scheme also based on SU(3). This proxy-SU(3) can be applied to well-deformed nuclei, is simple to use, and can yield analytic predictions.
Purpose: To present the new scheme and its microscopic motivation, and to test it using a Nilsson model calculation with the original shell model orbits and with the new proxy set.
Method: We invoke an approximate, analytic, treatment of the Nilsson model, that allows the above vetting and yet is also transparent in understanding the approximations involved in the new proxy-SU(3).
Results: It is found that the new scheme yields a Nilsson diagram for well-deformed nuclei that is very close to the original Nilsson diagram. The specific levels of approximation in the new scheme are also shown, for each major shell.
Conclusions: The new proxy-SU(3) scheme is a good approximation to the full set of orbits in a major shell. Being able to replace a complex shell model calculation with a symmetry-based description now opens up the possibility to predict many properties of nuclei analytically and often in a parameter-free way. The new scheme works best for heavier nuclei, precisely where full microscopic calculations are most challenged. Some cases in which the new scheme can be used, often analytically, to make specific predictions, are shown in a subsequent paper.

DOI: 10.1103/PhysRevC.95.064325

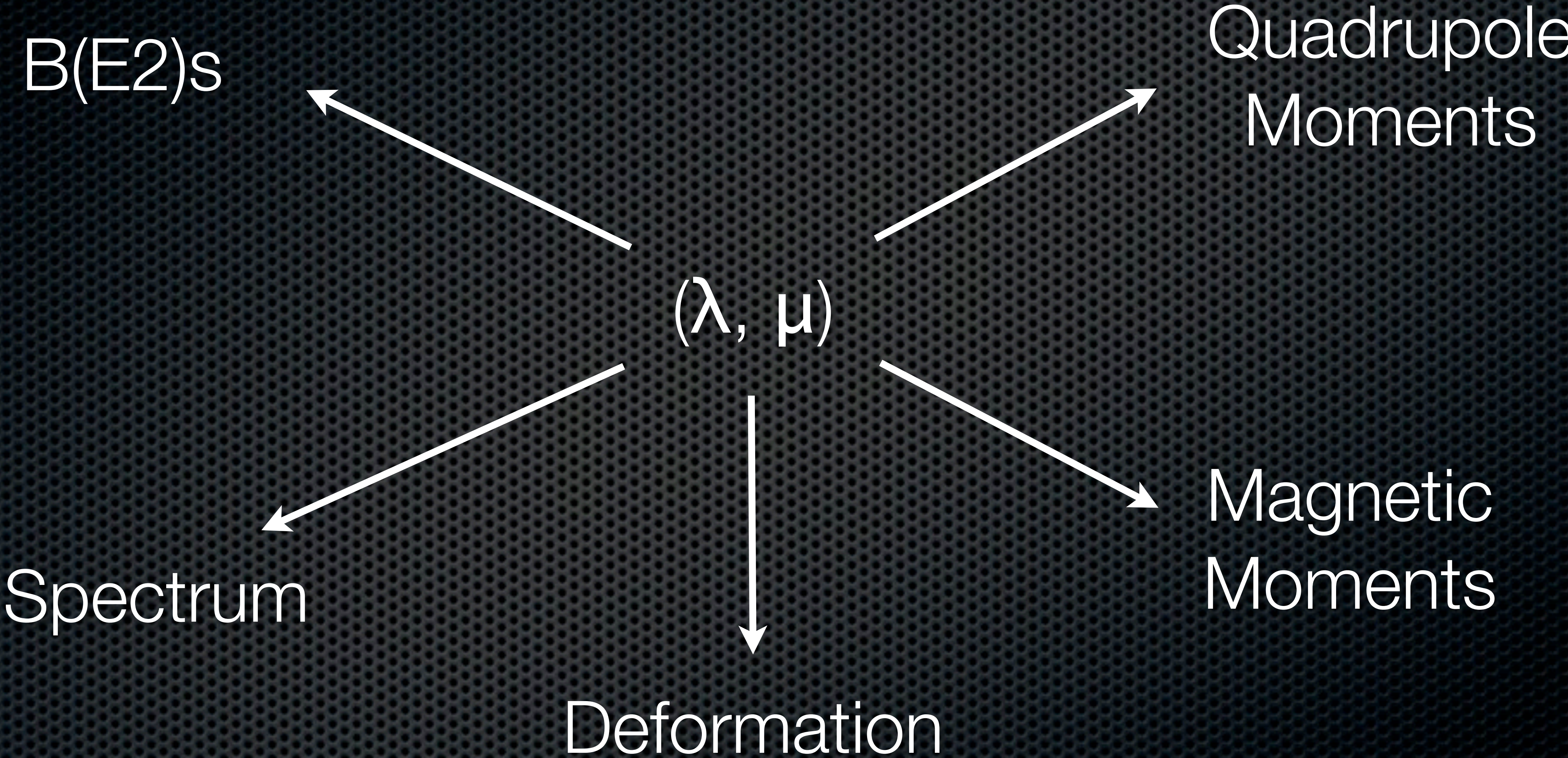
The effect on the Hamiltonian

TABLE V. Same as Table III, but for the H matrix elements with $\epsilon = 0.3$ for Nilsson orbitals in the 50–82 proton shell (upper part) and in the sdg proton shell (lower part). Note again that these calculations use the asymptotic wave functions defined in Sec. III. The deformation comes in only through the linear dependence on epsilon of the diagonal matrix elements of H_{osc}. See Sec. IV A for further discussion.

	$\frac{1}{2}$[400]	$\frac{1}{2}$[411]	$\frac{3}{2}$[402]	$\frac{1}{2}$[420]	$\frac{3}{2}$[411]	$\frac{5}{2}$[402]	$\frac{1}{2}$[431]	$\frac{3}{2}$[422]	$\frac{5}{2}$[413]	$\frac{7}{2}$[404]	$\frac{1}{2}$[550]	$\frac{3}{2}$[541]	$\frac{5}{2}$[532]	$\frac{7}{2}$[523]	$\frac{9}{2}$[514]	$\frac{11}{2}$[505]
1/2[400]	6.28	−0.13	0	0.22	0	0	0	0	0	0	0	0	0	0	0	0
1/2[411]		5.74	0	0.18	0	0	0.27	0	0	0	0	0	0	0	0	0
3/2[402]			6.26	0	0.16	0	0	0.19	0	0	0	0	0	0	0	0
1/2[420]				5.30	0	0	−0.16	0	0	0	0	0	0	0	0	0
3/2[411]					5.61	0	0	−0.13	0	0	0	0	0	0	0	0
5/2[402]						6.00	0	0	−0.09	0	0	0	0	0	0	0
1/2[431]							5.06	0	0	0	0	0	0	0	0	0
3/2[422]								5.27	0	0	0	0	0	0	0	0
5/2[413]									5.56	0	0	0	0	0	0	0
7/2[404]										5.93	0	0	0	0	0	0
1/2[550]											5.88	0	0	0	0	0
3/2[541]												5.81	0	0	0	0
5/2[532]													5.82	0	0	0
7/2[523]														5.90	0	0
9/2[514]															6.06	0
11/2[505]																6.30

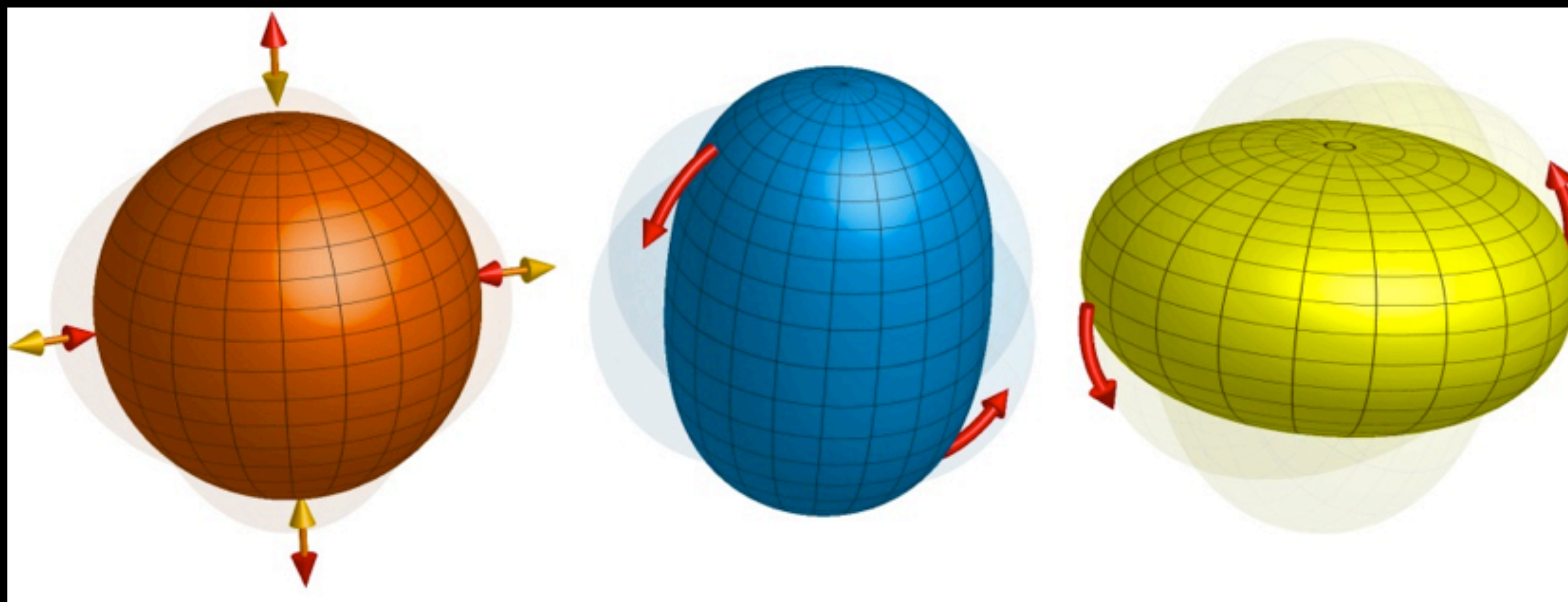
	$\frac{1}{2}$[400]	$\frac{1}{2}$[411]	$\frac{3}{2}$[402]	$\frac{1}{2}$[420]	$\frac{3}{2}$[411]	$\frac{5}{2}$[402]	$\frac{1}{2}$[431]	$\frac{3}{2}$[422]	$\frac{5}{2}$[413]	$\frac{7}{2}$[404]	$\frac{1}{2}$[440]	$\frac{3}{2}$[431]	$\frac{5}{2}$[422]	$\frac{7}{2}$[413]	$\frac{9}{2}$[404]
1/2[400]	6.28	−0.13	0	0.22	0	0	0	0	0	0	0	0	0	0	0
1/2[411]		5.74	0	0.18	0	0	0.27	0	0	0	0	0	0	0	0
3/2[402]			6.26	0	0.16	0	0	0.19	0	0	0	0	0	0	0
1/2[420]				5.30	0	0	−0.16	0	0	0	**0.27**	0	0	0	0
3/2[411]					5.61	0	0	−0.13	0	0	0	**0.27**	0	0	0
5/2[402]						6.00	0	0	−0.09	0	0	0	**0.19**	0	0
1/2[431]							5.06	0	0	0	**0.18**	0	0	0	0
3/2[422]								5.27	0	0	0	**0.22**	0	0	0
5/2[413]									5.56	0	0	0	**0.22**	0	0
7/2[404]										5.93	0	0	0	**0.18**	0
1/2[440]											**5.73**	0	0	0	0
3/2[431]												**5.74**	0	0	0
5/2[422]													**5.82**	0	0
7/2[413]														**5.98**	0
9/2[404]															**6.22**

SU(3) Observables



Literature has been enriched by Pseudo-SU(3) publications

Nuclear Shape



spherical prolate oblate

Parameter free shape predictions

PHYSICAL REVIEW C **95**, 064326 (2017)

Analytic predictions for nuclear shapes, prolate dominance, and the prolate-oblate shape transition in the proxy-SU(3) model

Dennis Bonatsos,[1] I. E. Assimakis,[1] N. Minkov,[2] Andriana Martinou,[1] S. Sarantopoulou,[1] R. B. Cakirli,[3]
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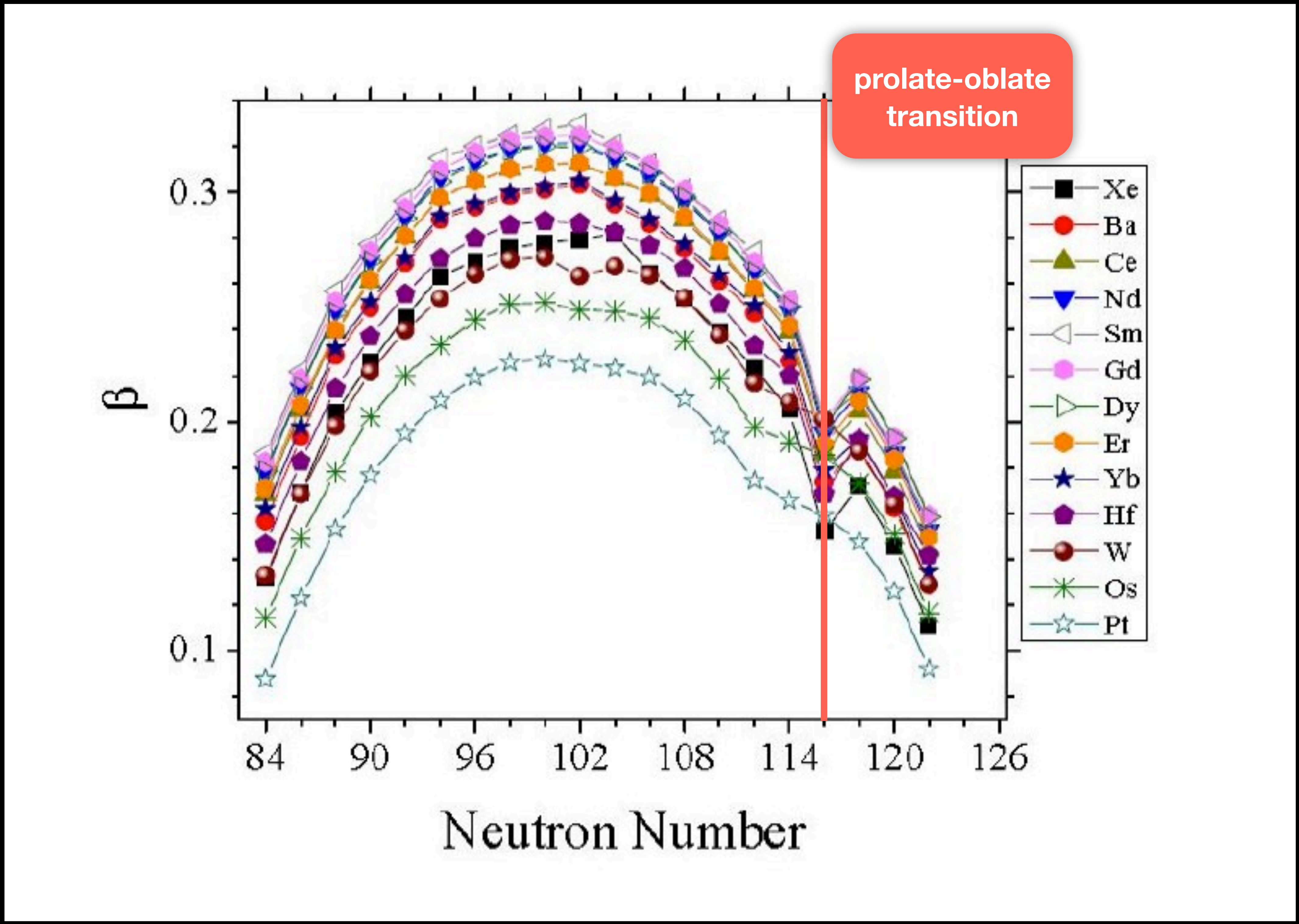
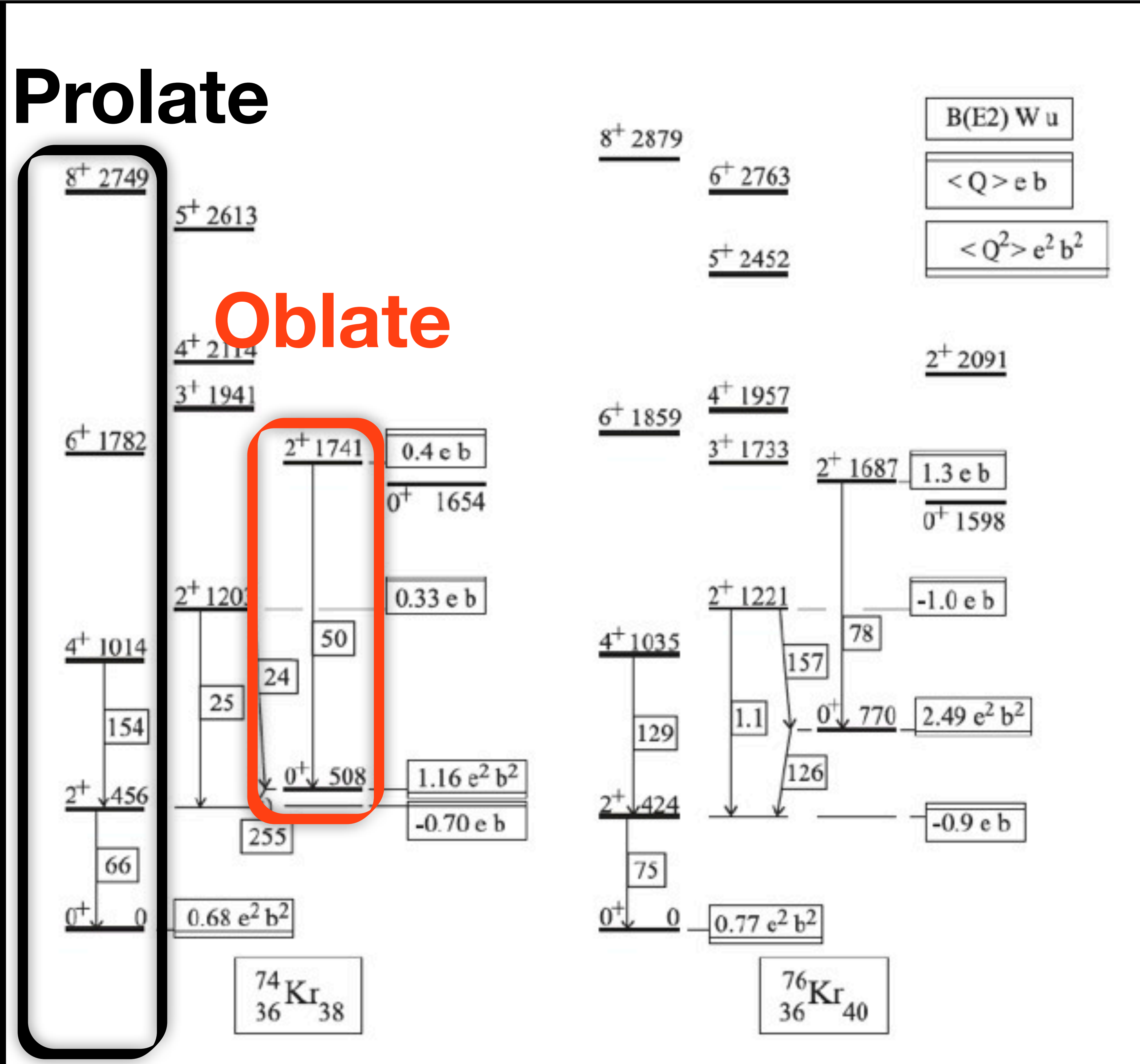
Using a new approximate analytic parameter-free proxy-SU(3) scheme, we make simple predictions of shape observables for deformed nuclei, namely γ and β deformation variables, the global feature of prolate dominance, and the locus of the prolate-oblate shape transition. The predictions are compared with empirical results.

Prolate over oblate dominance



The shape coexistence project

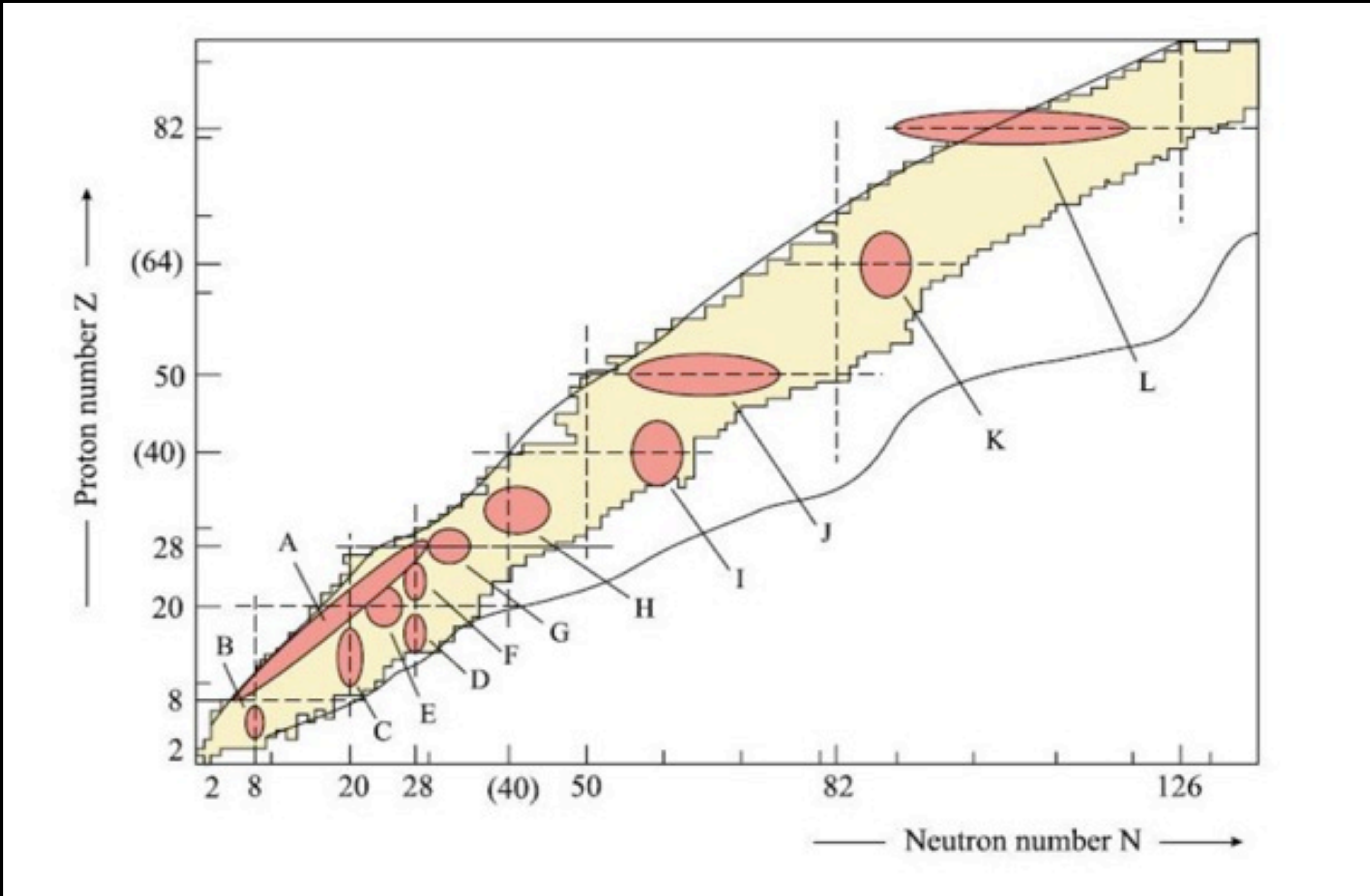
Persons involved: A. Martinou, D. Bonatsos, I.E. Assimakis, S. Peroulis, S. Sarantopoulou, N. Minkov



Manifestation of shape coexistence.

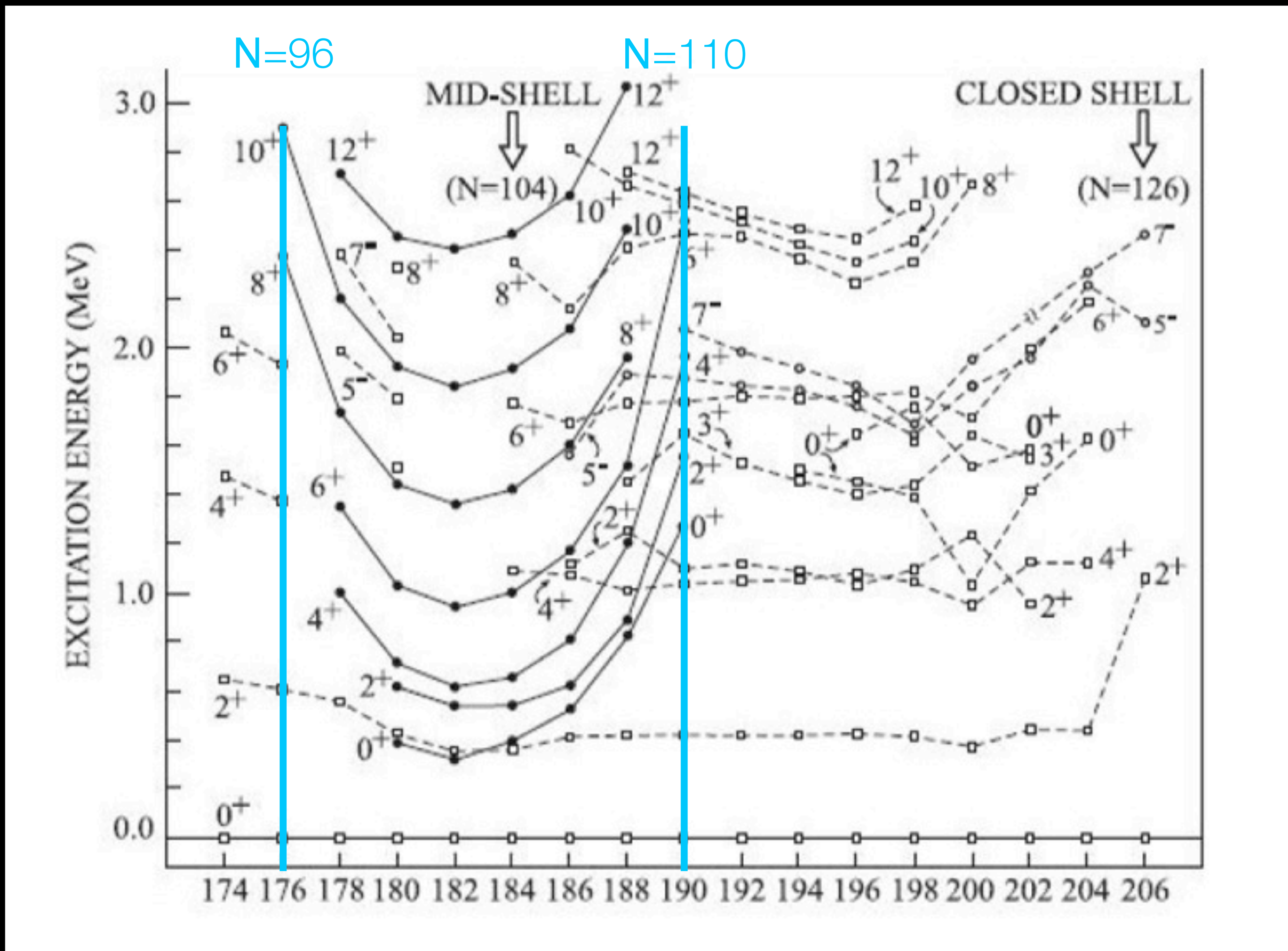
Clement et al. Phys. Rev. C 75, 054313, 2007.

Islands of coexistence



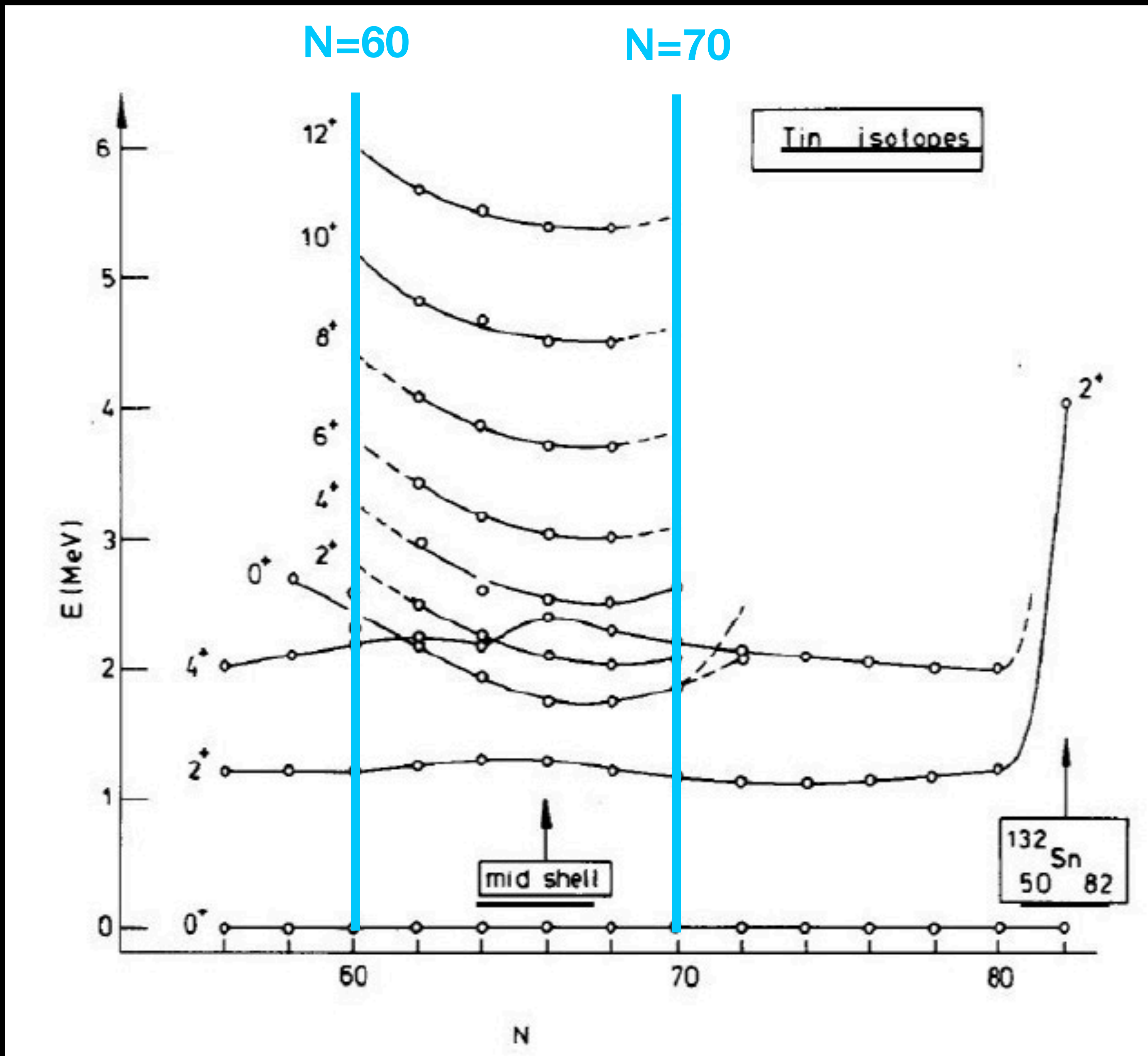
Kris Heyde and J. L. Wood, Rev. Mod. Phys., Vol 83, 2011

Hg isotopes



Why?

Sn isotopes



Why?

J. L. Wood et al., Phys. Rep. 215, Nos 3 & 4, 101-201, 1992.

The collective quadrupole interaction

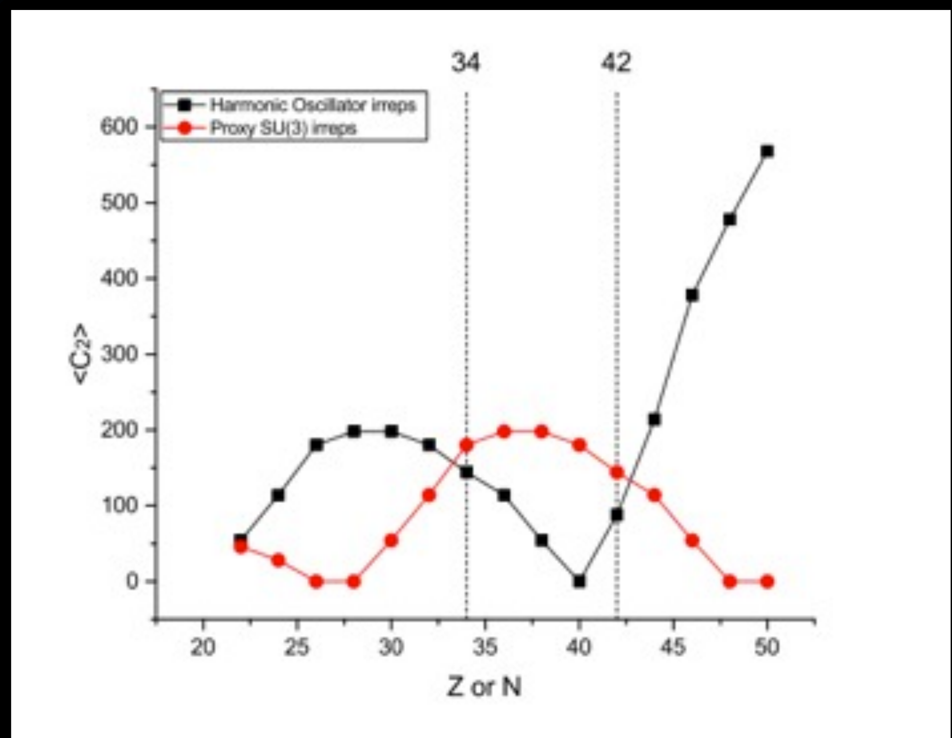
$$Q \cdot Q = 4C_2 - 3L^2,$$
$$C_2 = \lambda^2 + \mu^2 + \lambda\mu + 3(\lambda + \mu),$$
$$\beta^2 = \frac{4\pi}{5(A\bar{r^2})^2}(C_2 + 3)$$

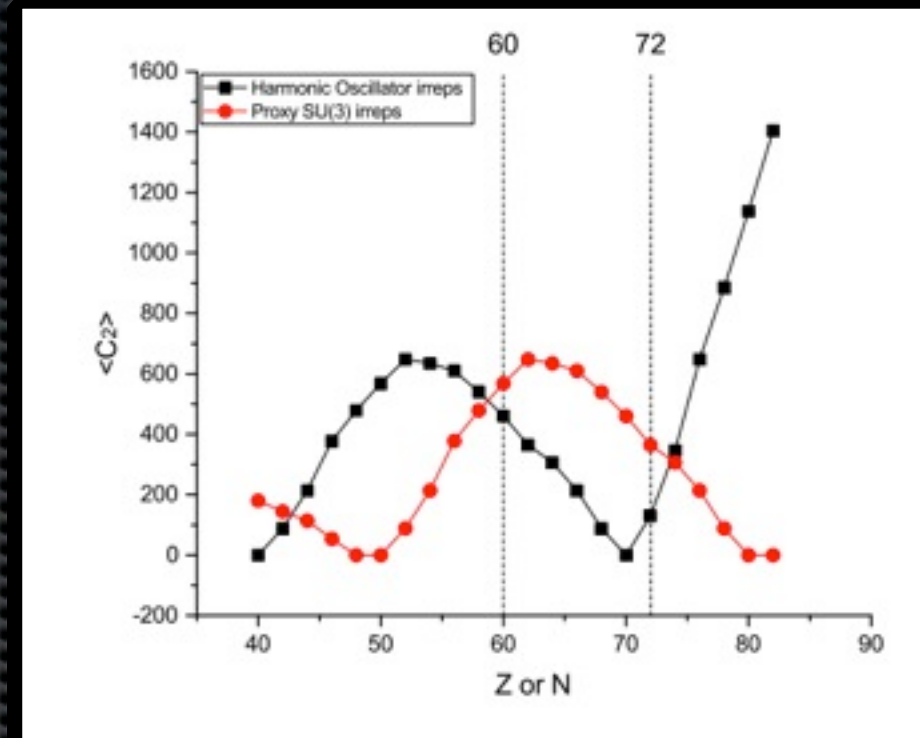
O. Castanos et al., Z. Phys. A, 329, 33-43, (1988).

$$\gamma = \arctan\left(\frac{\sqrt{3}(\mu + 1)}{2\lambda + \mu + 3}\right)$$

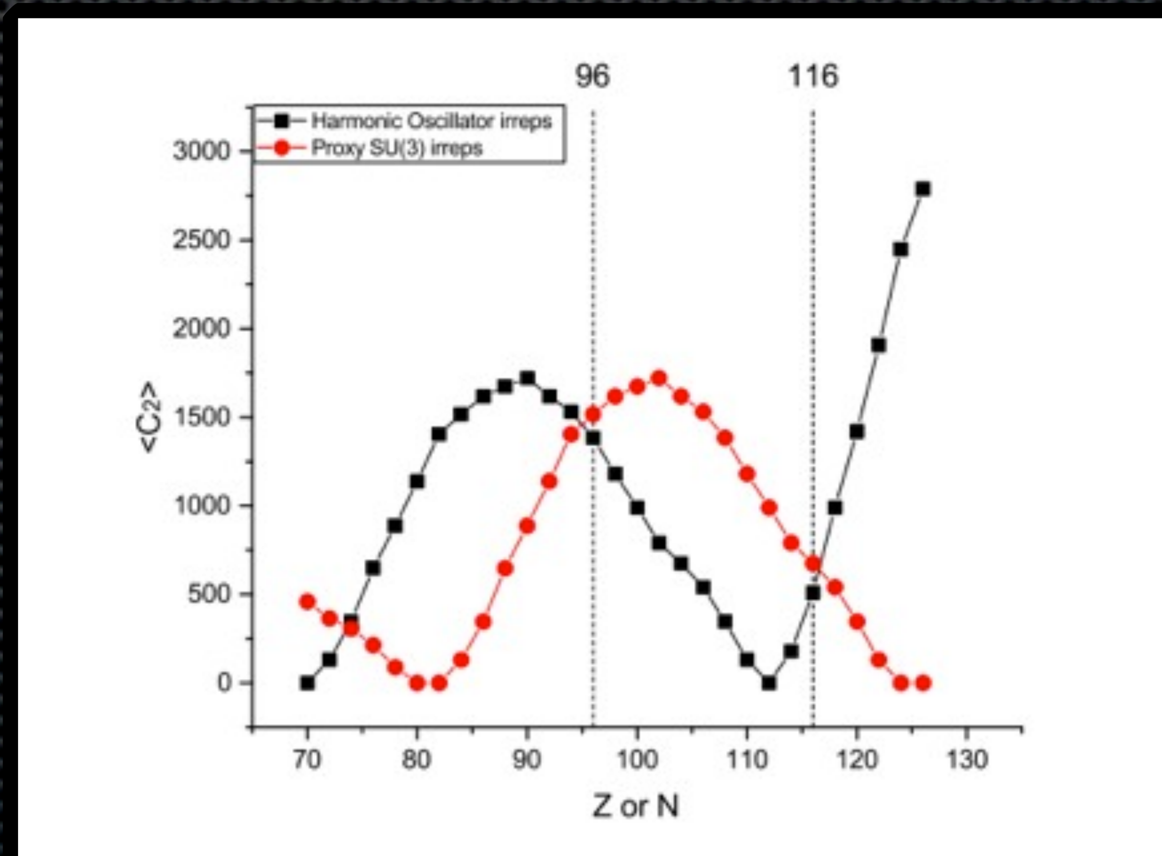
- (λ,μ) are the quantum numbers of SU(3). They depend on the choice of magic numbers. β is the deformation and γ is the angle which distinguishes prolate from oblate.

The islands of coexistence





Invitation for a Review Article in EPJ A



Experiment in 180Hf

IFIN-HH
Proposal for the TANDEM accelerator
experiments 2019

Collectivity and shape coexistence in ^{180}Hf

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I. Asimakis[2], M. Axiotis[2], D. Bonatsos[2], A. Lagoyannis[2], A. Martinou[2], S. Peroulis[1,2],
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[...]
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D. Filipescu[4], I. Gheorghe[4], D.G. Ghiță[4], T. Glodariu[4], R. Lică[4], R. Mărginean[4],
A. Negreț[4], T. Sava[4], L. Stroe[4], S. Toma[4], R. Șuvăilă[4], N.V. Zamfir[4], C.A. Ur[4]

[1] Department of Physics, University of Athens, Greece
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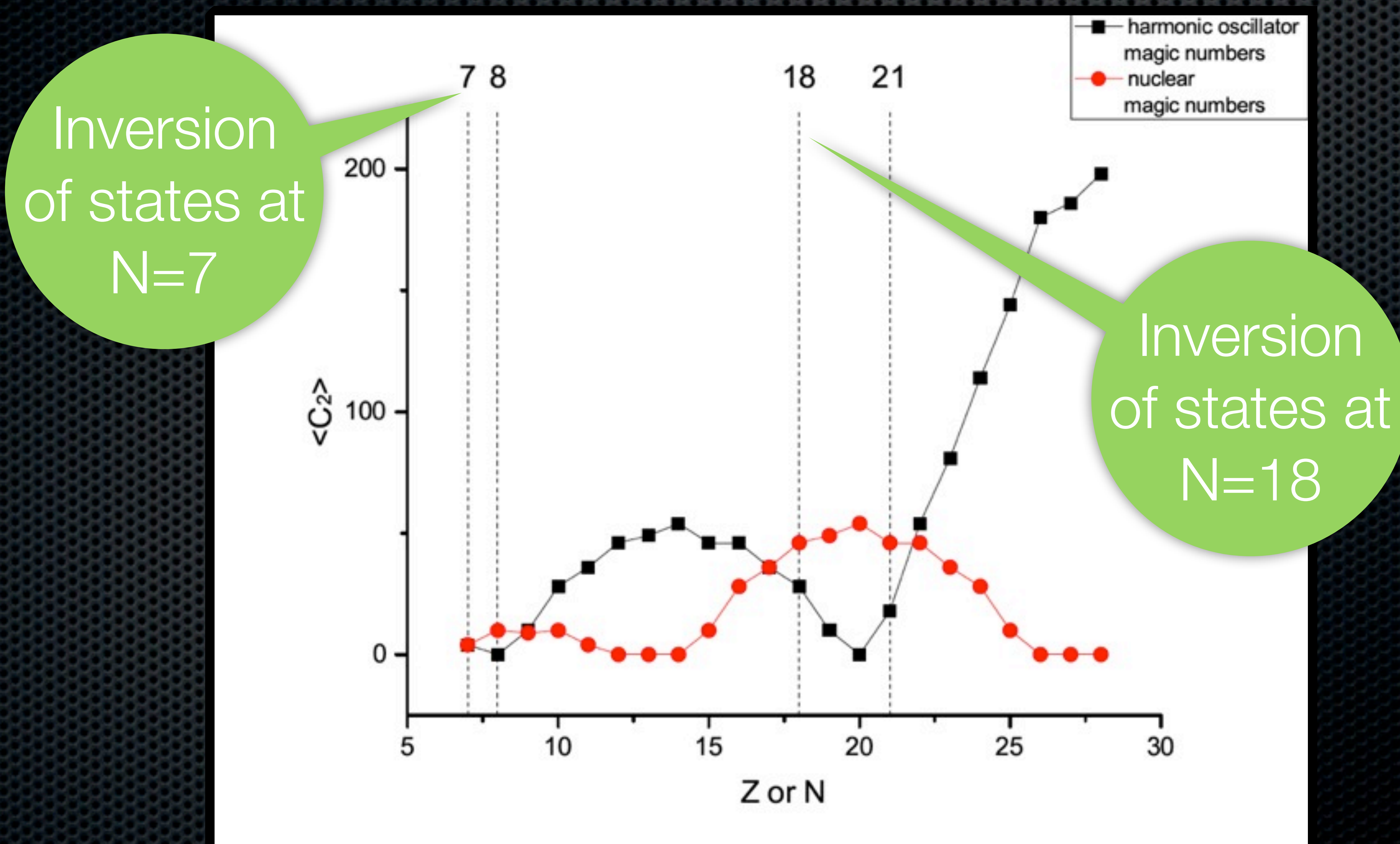
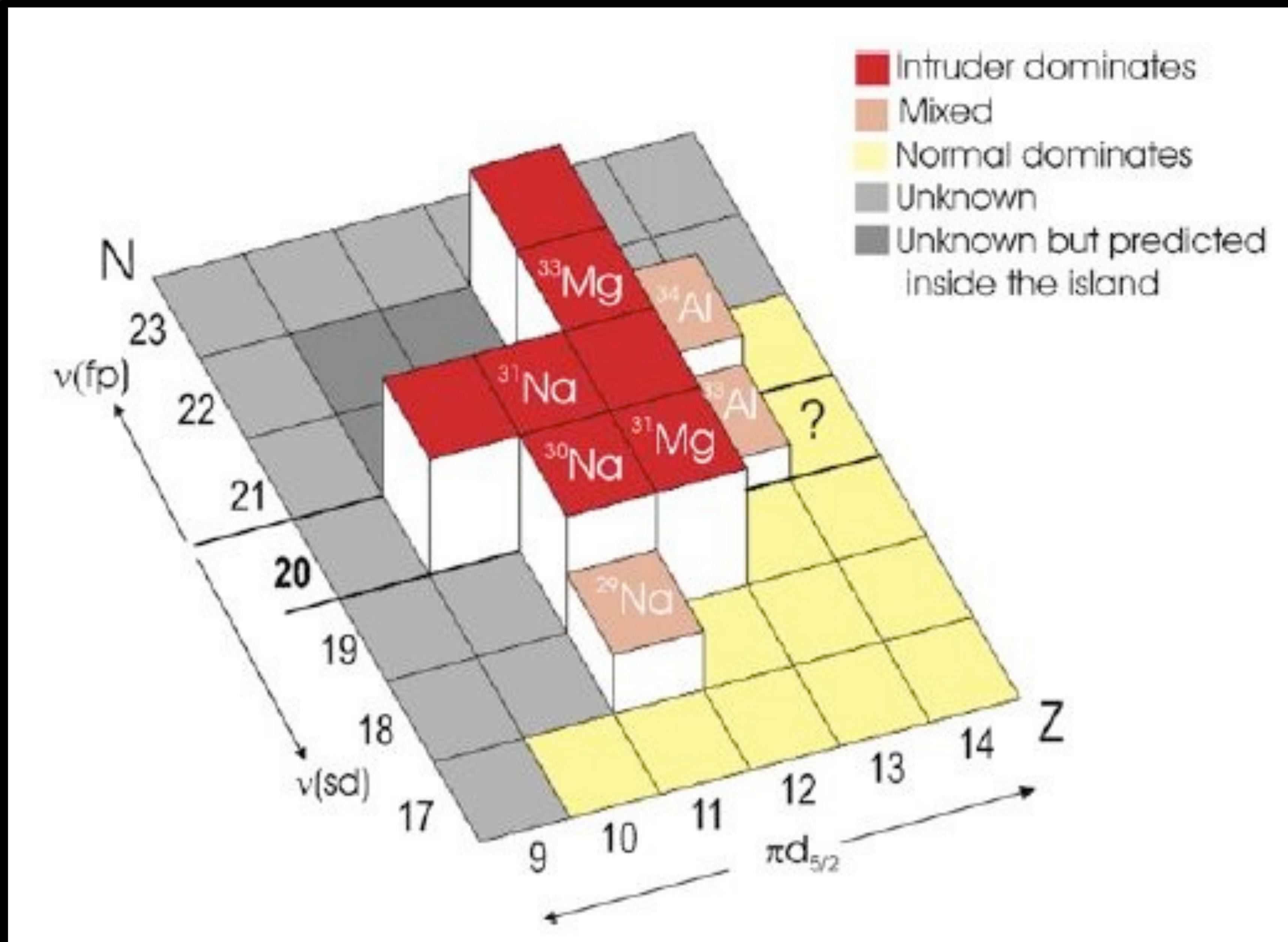
Spokespersons: T.J. Mertzimekis
Contact Person: N. Mărginean

Shape coexistence=portal to the island of inversion



The Evidence

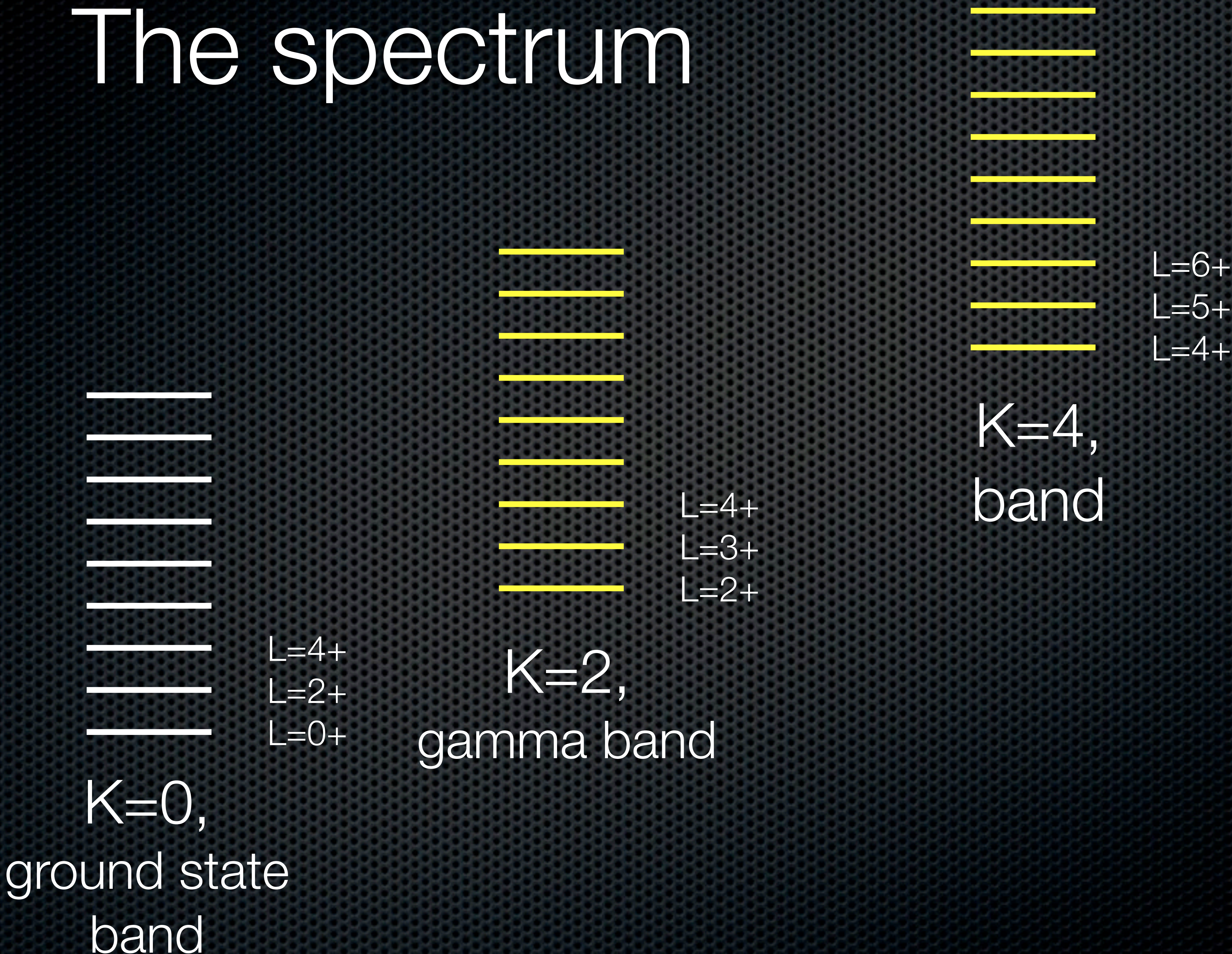


P. Himpe et al., Phys. Lett. B 658, 203-208, 2008.

The nuclear observables project

Persons involved: D. Bonatsos, S. Karambagia, R. F. Casten, N. Minkov, R. B. Cakirli, A. Martinou, I.E. Assimakis, S. Sarantopoulou, S. Peroulis

The spectrum



The SU(3) Hamiltonian

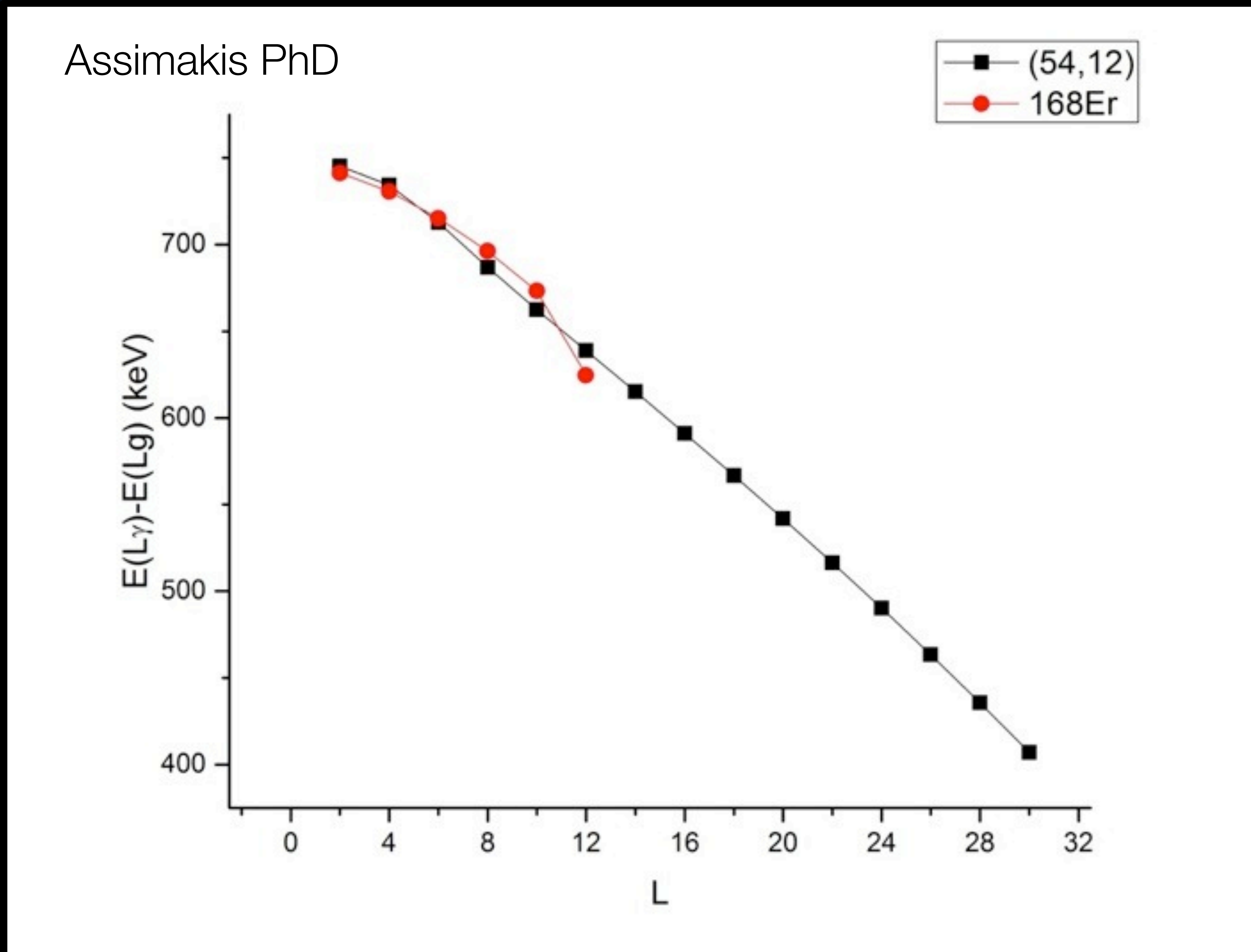
- $H = H_0 - \chi/2\ QQ + c_1\ \Omega$ or Λ

Mean field potential

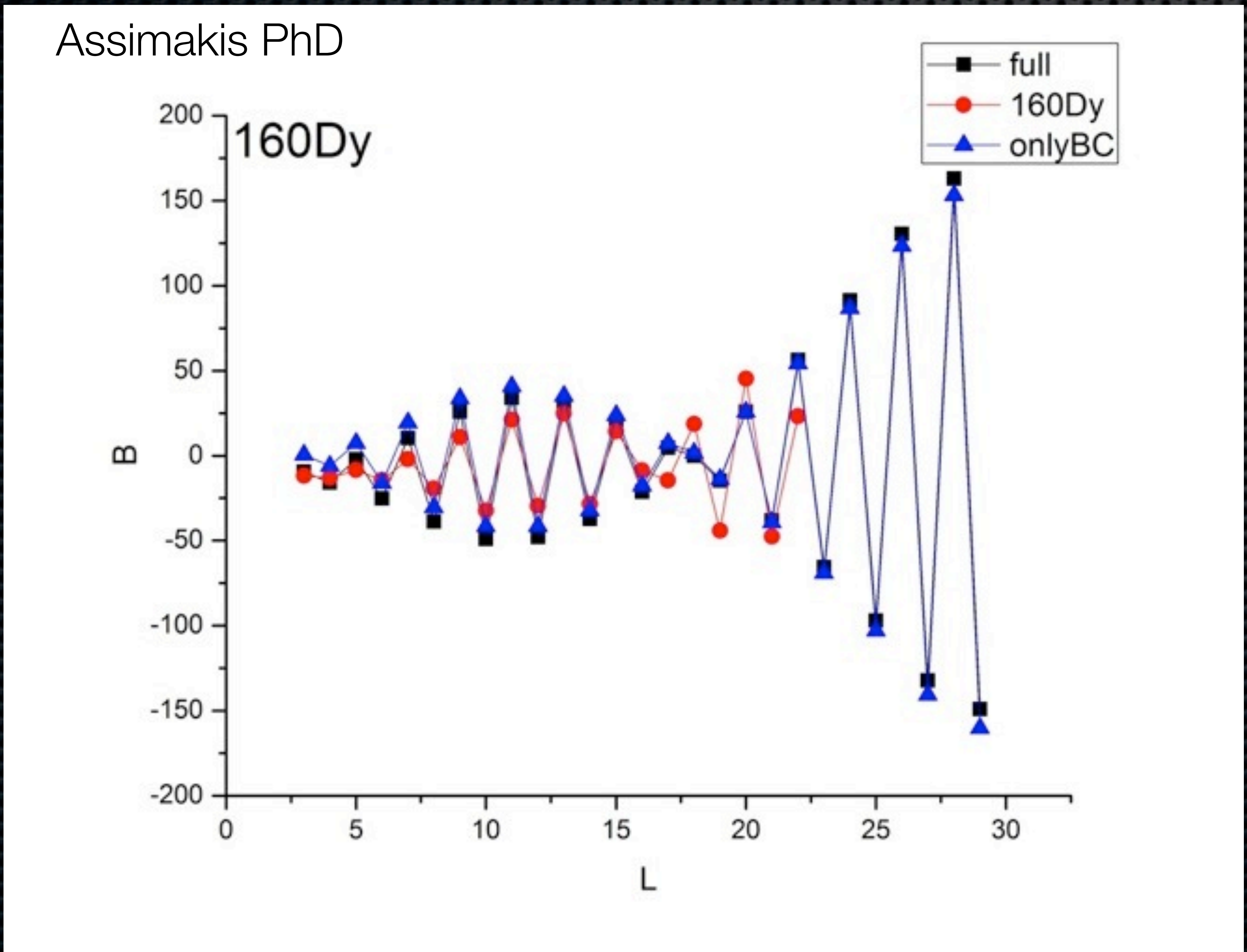
Quadrupole-Quadrupole interaction

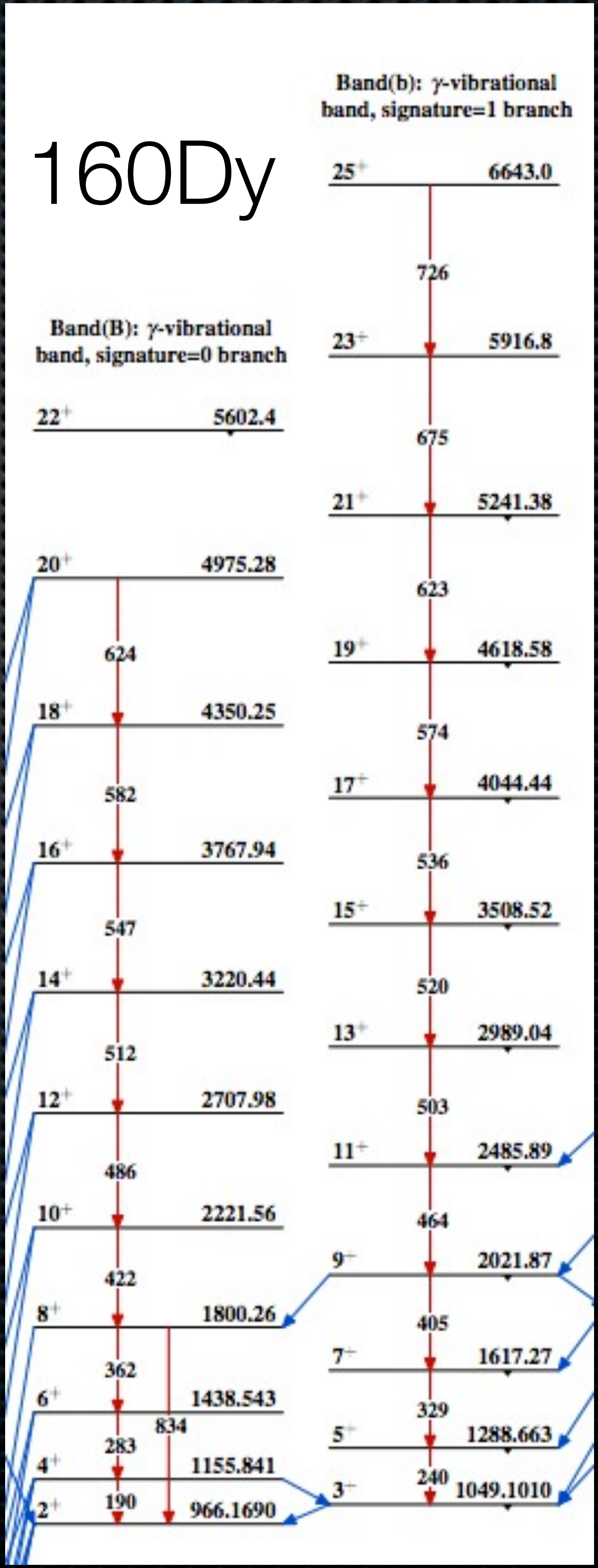
Break the degeneracy between the K bands

$E(L)_{gamma} - E(L)_{ground}$



γ band staggering



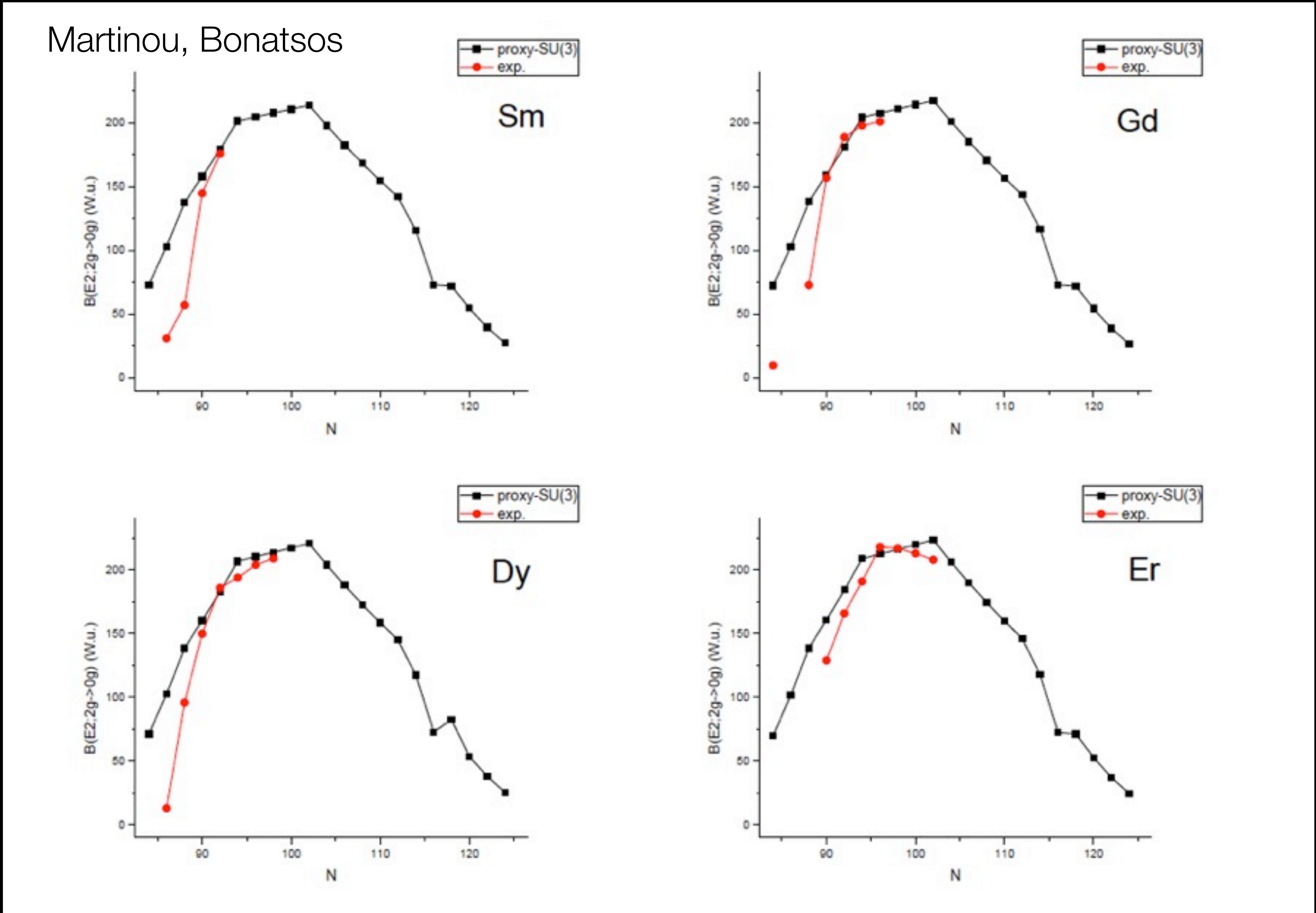


B(E2)s- Transition probabilities

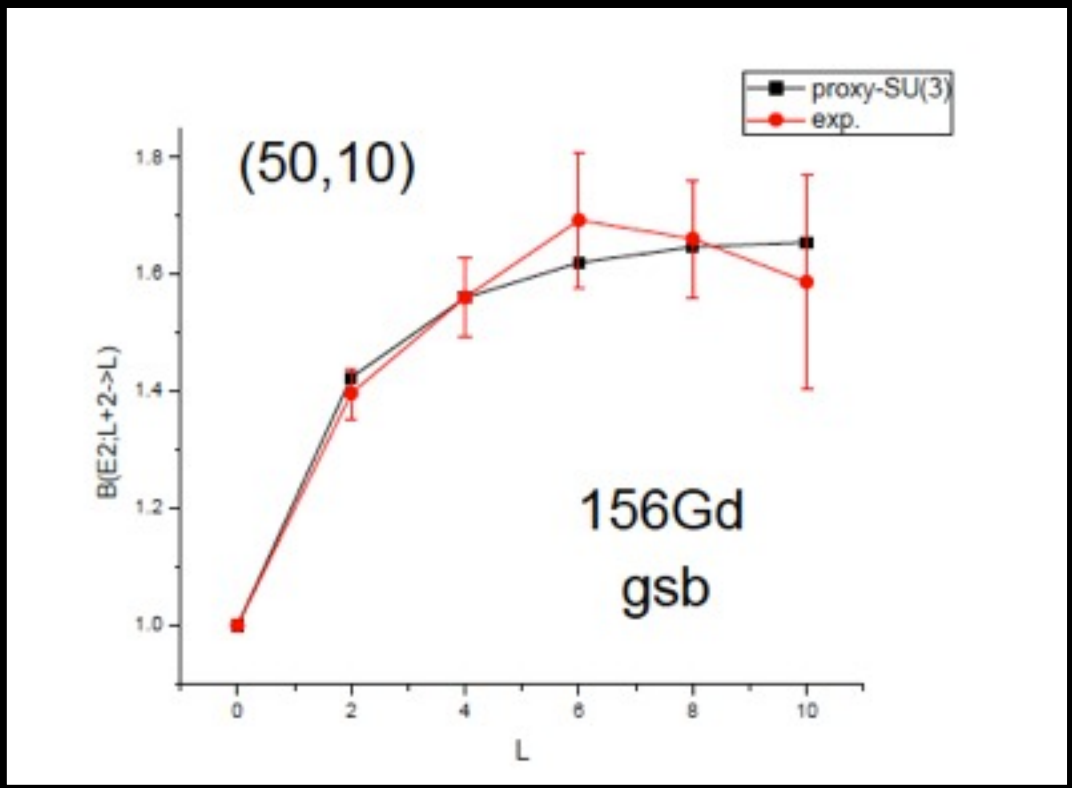
$$B(E2;(\lambda,\mu)KL \to (\lambda,\mu)K'L') = 4C_2^{(\lambda,\mu)}\frac{2L'+1}{2L+1}\left(\langle(\lambda,\mu)KL;(1,1)2||(\lambda,\mu)K'L'\rangle\right)^2.$$

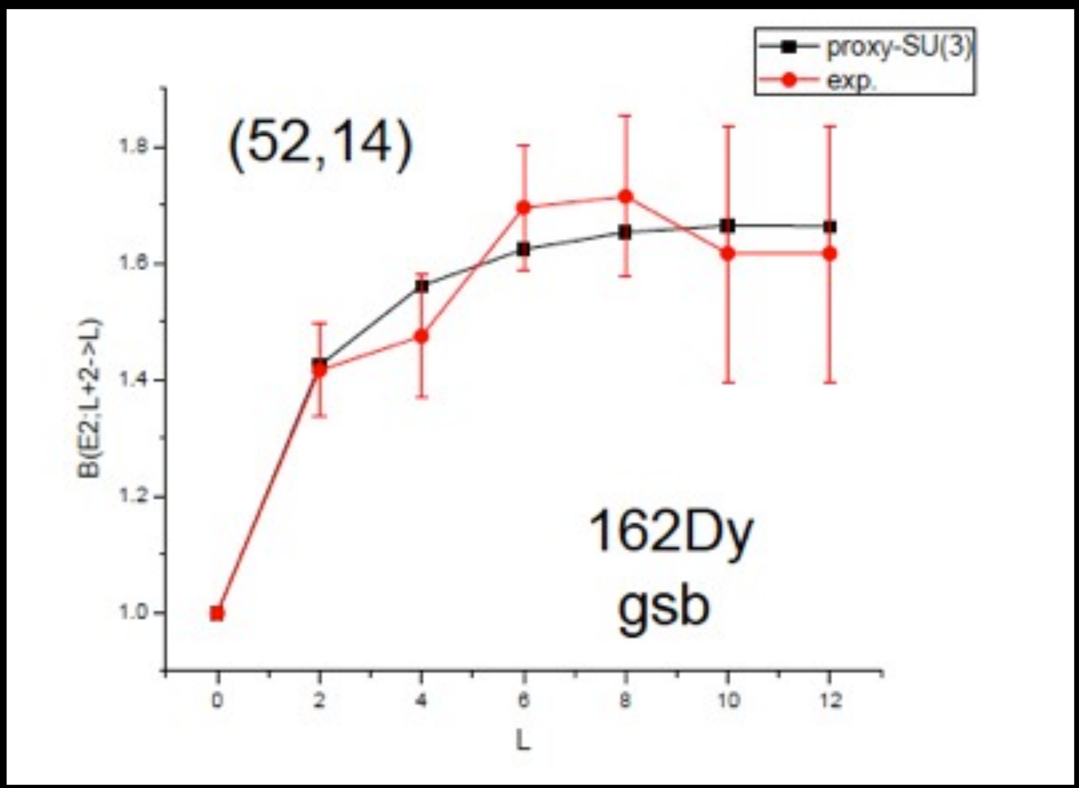
C. Bahri, D. J. Rowe and J.P. Draayer, Comput. Phys. Commun. 159,121 (2004)

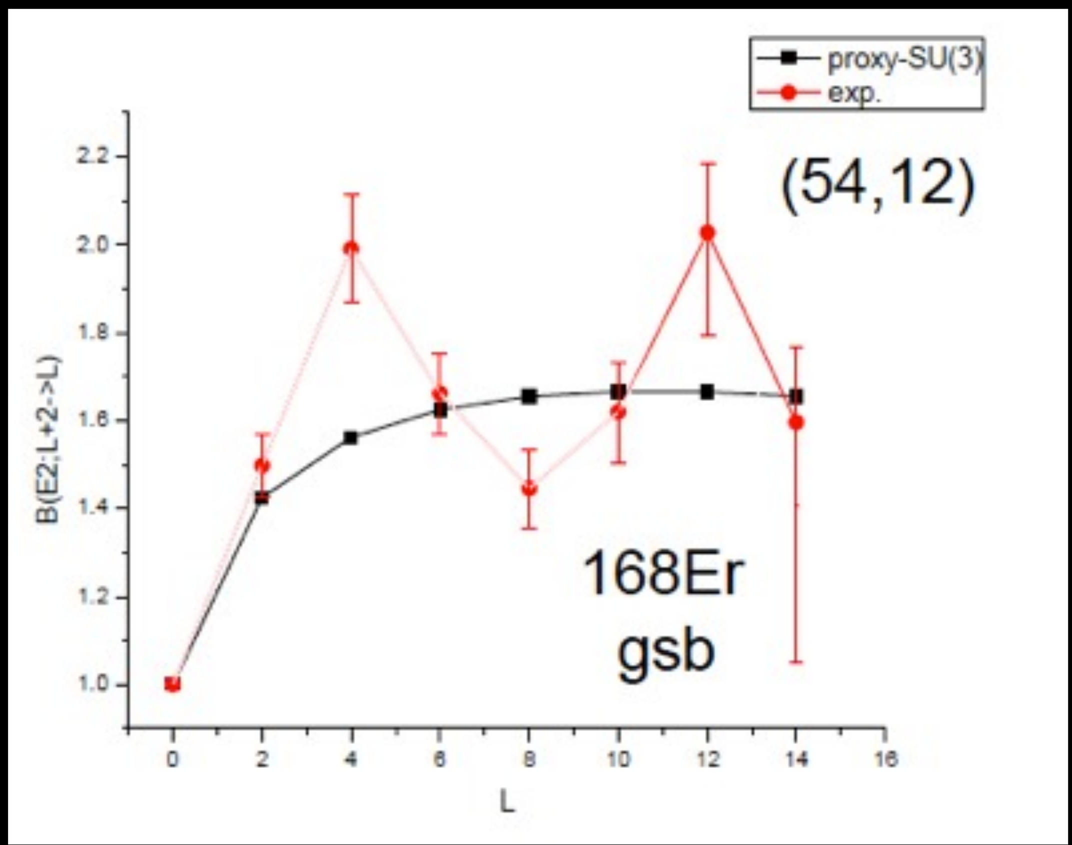
Absolute B(E2)s 2g->0g

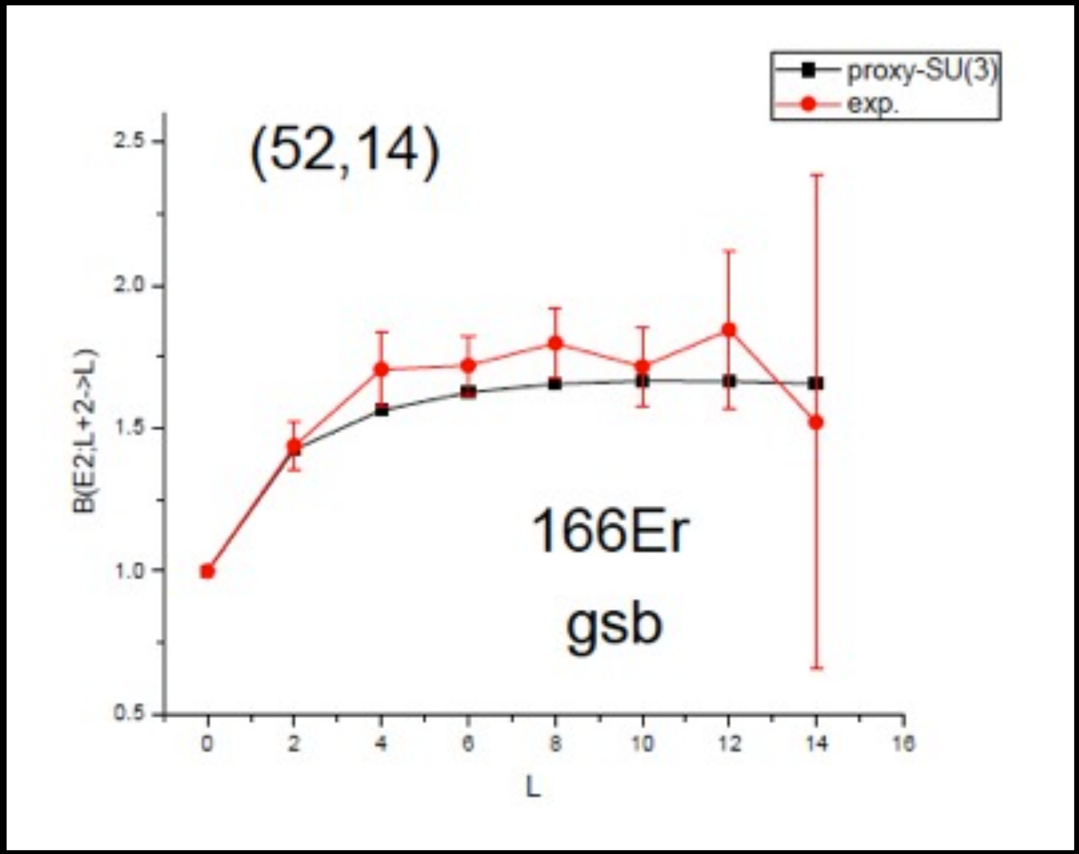


B(E2) ratios within g.s.b. normalized to 2g->0g









Nuclear Lifetimes

$$T_{1/2} = \ln 2 \frac{10^2}{1.23 \Delta E^5 4C_2(\lambda,\mu) < (\lambda,\mu)KL;(1,1)2||(\lambda,\mu)K'L' >^2} sec$$

Rep. Prog. Phys. 79 (2016) 076301 Dracoulis et al.

Table 4. Shape-coexisting two-(quasi)particle states in ^{188}Pb.

I^π	$T_{1/2}$	E^* (keV)	Configuration	shape
8^-	1.2 μs	2577	$\nu 9/2^+[624], 7/2^-[514]$	High-K prolate
11^-	38 ns	2702	$\pi 9/2^-[505], 13/2^+[606]$	High-K oblate
12^+	136 ns	2710	$\nu i_{13/2}^{-2}$	Spherical

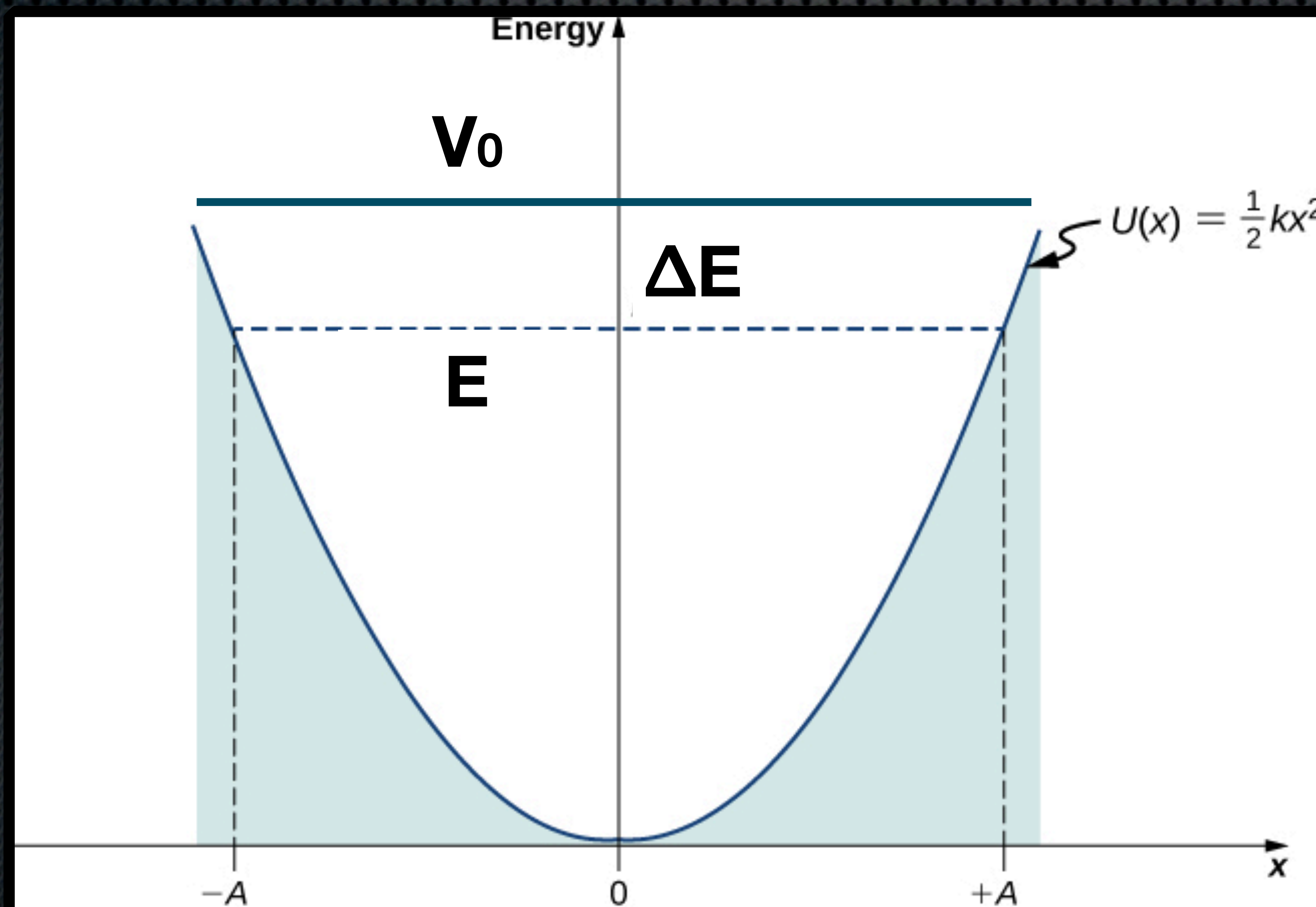
Our value is 134 ns

Group Proposal to Hellenic Foundation for Research and Innovation

The nucleon separation energies project

Persons involved: A. Martinou, S. Sarantopoulou, D. Bonatsos

Two neutron separation energy with Proxy SU(3)



$\Delta E = V_0 - E$

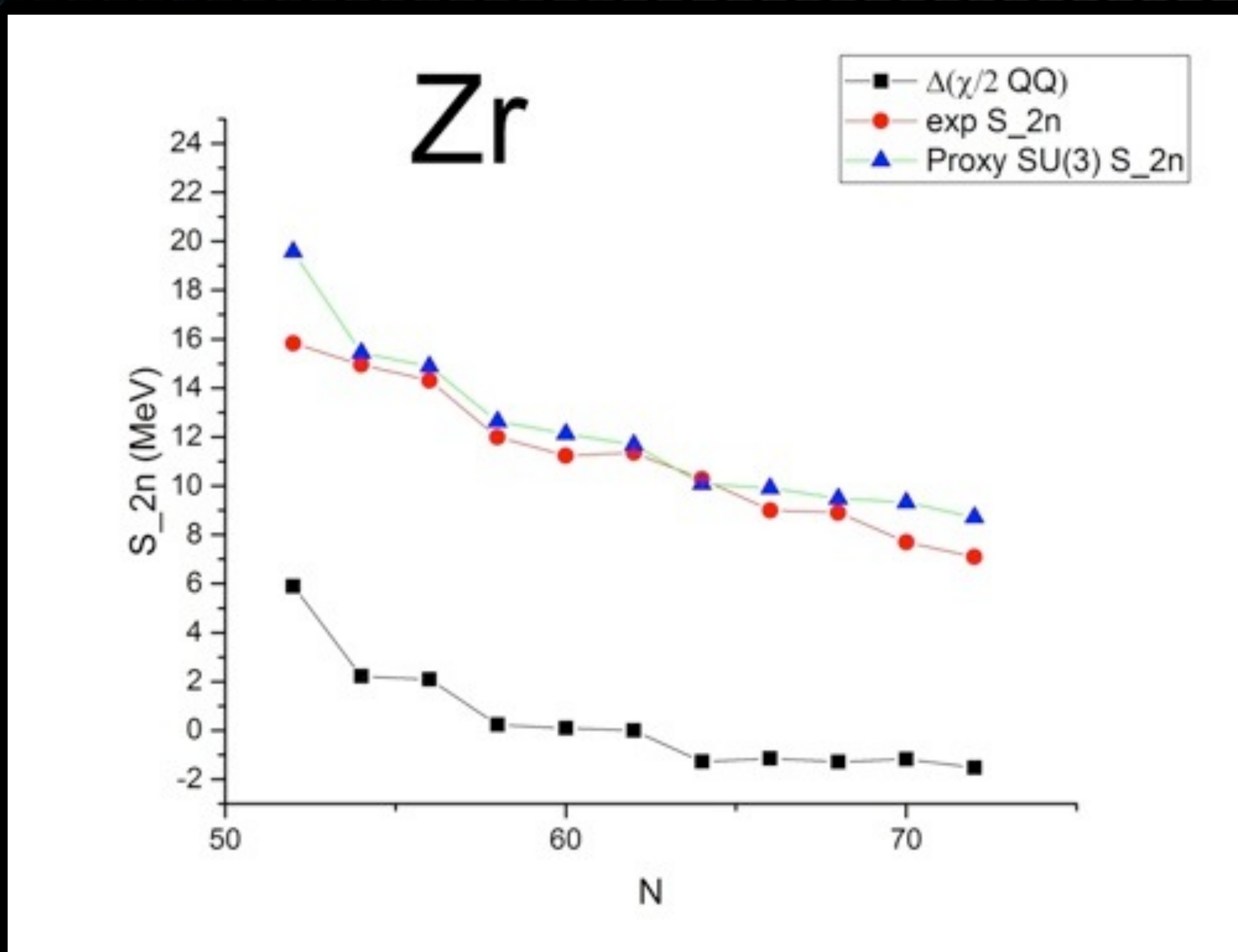
QQ interaction differences

$$\Delta(\chi/2\ QQ)=(\chi/2\ QQ(\lambda,\mu))_{N}-(\chi/2\ QQ(\lambda,\mu))_{N-2}$$

$$\frac{\chi}{2}=\frac{1}{4N_0}$$

Independent of fitting

Parameter free S_{2n}



$S_{2n}=\Delta E+\Delta(\chi/2\ QQ)$

Proposal in Ministry of Development and Investments (ΕΔΒΜ). Grade 95,22%.

The magic numbers project

<u>Persons involved</u>: D. Bonatsos, S. Peroulis, A. Martinou, I.E. Assimakis

Two options

40

20

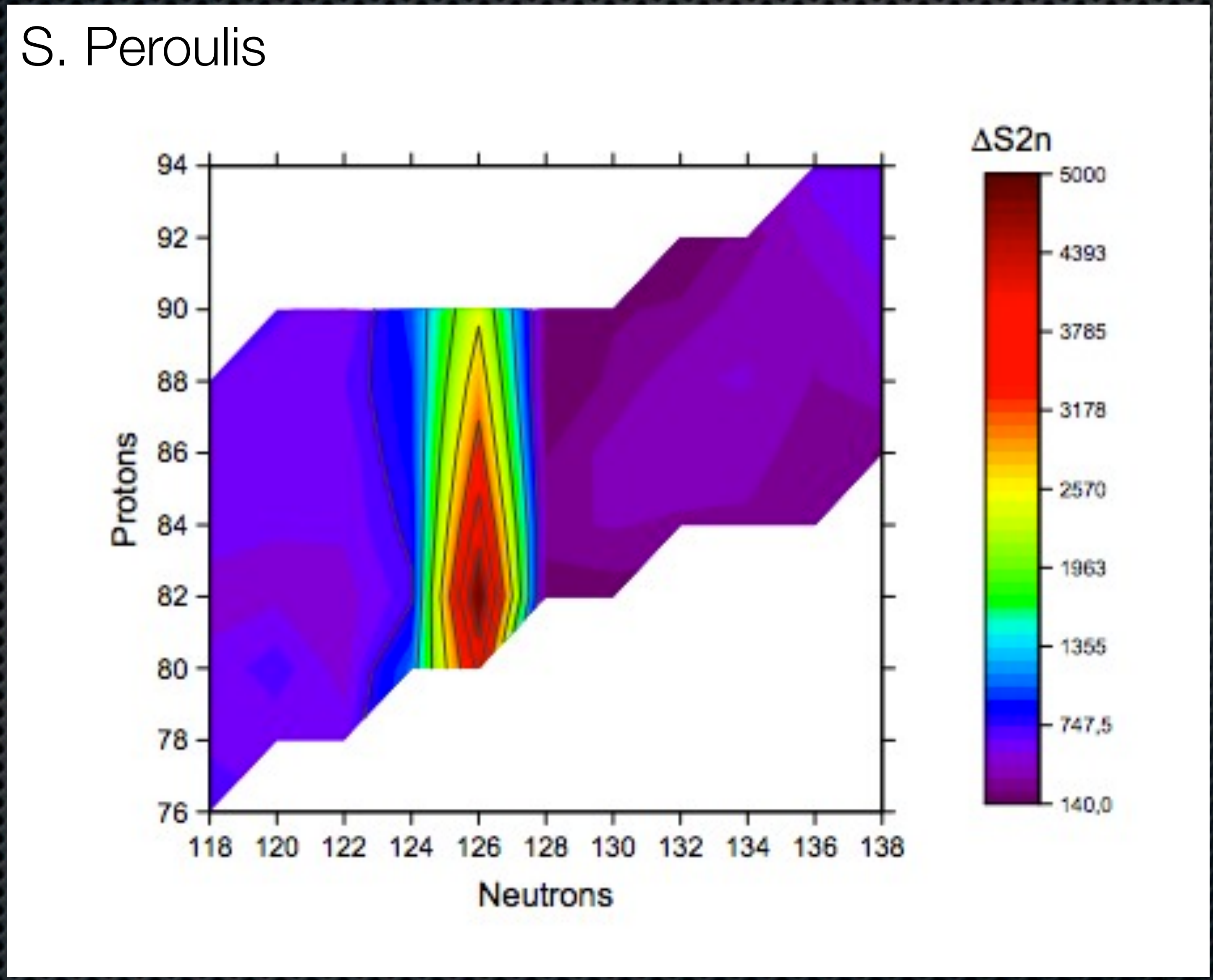
harmonic oscillator magic numbers

50

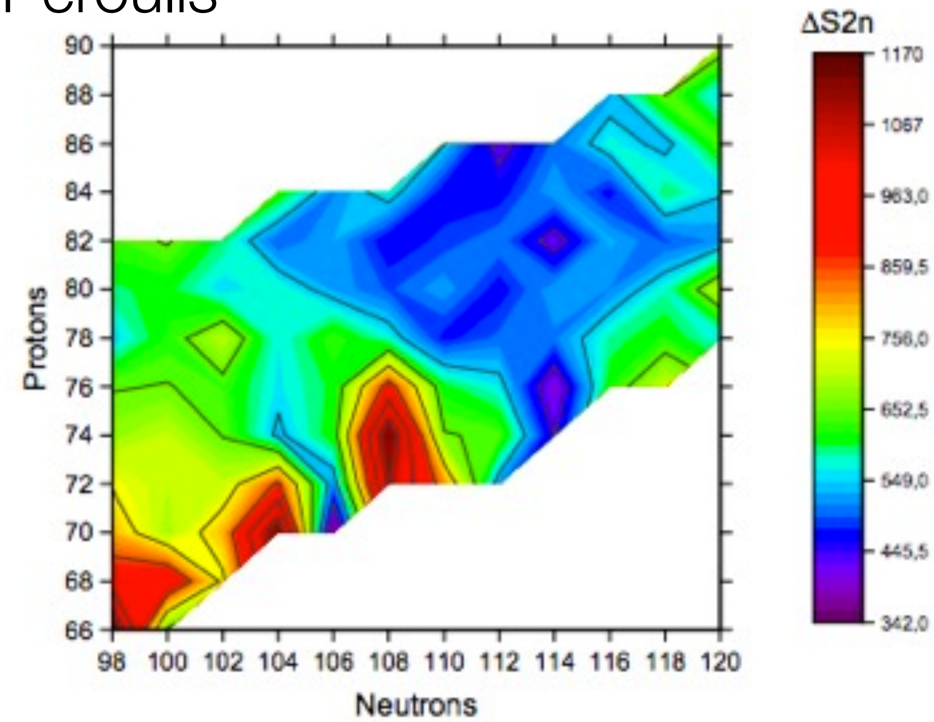
28

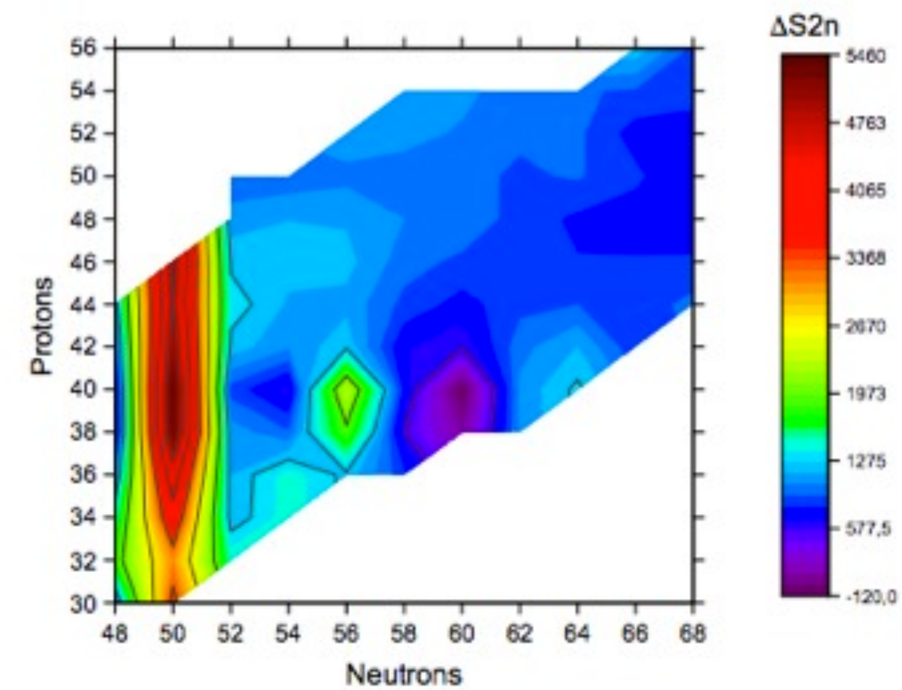
spin-orbit like magic numbers

Major Magic Numbers



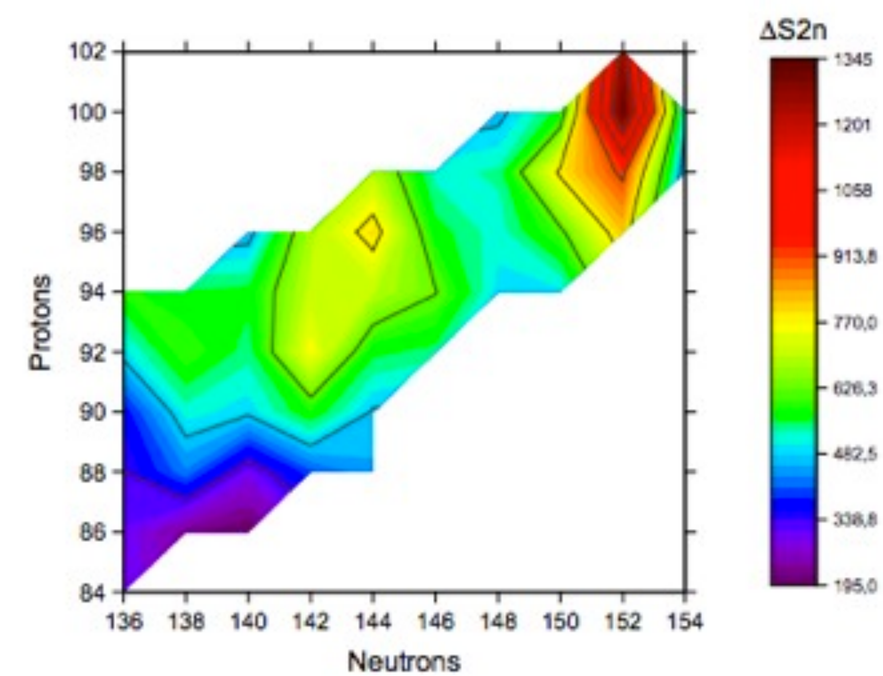
S. Peroulis





(i)

Minor Magic Numbers



Another way to search

Harmonic oscillator magic numbers → $J_1\pi$ → μ_1

Spin-orbit like magic numbers → $J_2\pi$ → μ_2

$J_1\pi$ Exotic odd nuclei $J_2\pi$

μ_1 Compare with data μ_2

Proposal of A. Martinou to State Scholarships Foundation. Grade 93,75%

gSPEC NUSTAR FAIR

27-28 September 2018

Scientific themes

- Nuclear moments
- Nuclear structure of exotic nuclei
- Single-particle/collective excitations
- Neutron-rich nuclei around ^{132}Sn, ^{208}Pb
- Proton-rich nuclei around ^{100}Sn

gSPEC workshop on nuclear moments at GSI/FAIR

Organising committee

R. Lozeva (CSNSM/CNRS)
G. Georgiev (CSNSM/ANU)
J. Gerl (GSI/FAIR)
T. Mertzimekis (U. Athens)
A. Stuchbery (ANU)

Site

University of Milan (Milan, Italy)
together with NUSTAR week
24-27 September 2018

https://indico.in2p3.fr/event/17501/

Funding

- A. Martinou, 7 months Post-Doc position in INPP.
- Proposal of A. Martinou, S. Sarantopoulou in Ministry of Development and Investments (ΕΔΒΜ), Grade 95,22%, 15 months.
- Proposal of A. Martinou to State Scholarships Foundation, grade 93,75%, 24 months.
- Proposal of Group in Hellenic Foundation for Research and Innovation, grade ???, 3 years.

Thank you!