A new approximate nuclear symmetry, Proxy-SU(3), and parameter-free predictions for deformed nuclei

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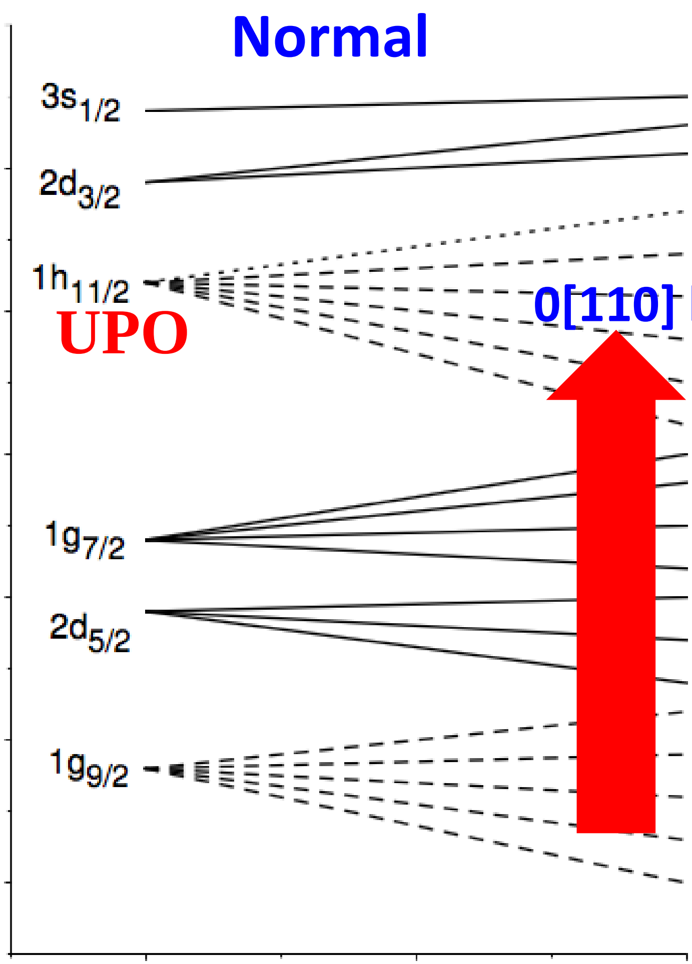
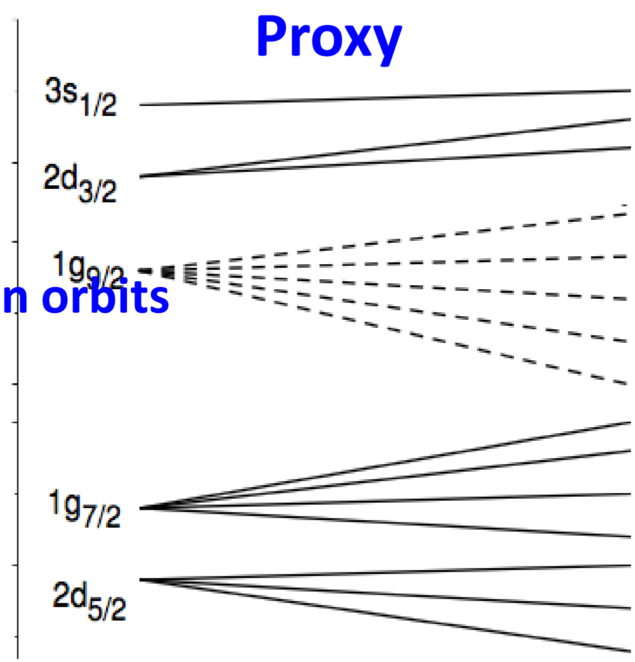
SU(3) (a la Elliott) breaks down in heavy nuclei.

Proxy-SU(3) – Approximate shell model to recover SU(3)





NOW have full set of sdg *l, j*

l =	0	2	4
J =	1/2,	3/2, 5/2	7/2, 9/2

Recovers H.O. → SU(3). Lose one orbit: 30/32 particles

Big problem: Parity issue Spurious matrix elements.

N particles: group is U(N/2) with SU(3) sub-group

G.s.— highest weight irreps labeled by SU(3) quantum numbers: (λ, μ)

Relation of Proxy-SU(3) irrep labels, (λ, μ) to β and γ

$$\beta^2 = \frac{4\pi}{5} \frac{1}{(A\bar{r^2})^2} (\lambda^2 + \lambda\mu + \mu^2 + 3\lambda + 3\mu + 3)$$

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

Note that, if μ>λ, the nucleus is oblate (γ>30 deg.)

Combined (proton + neutron) Proxy-SU(3) irreps: prolate-oblate shapes

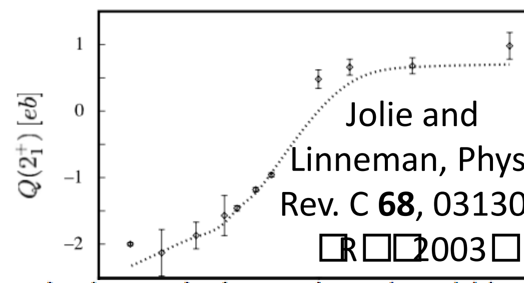
TABLE II: Most leading SU(3) irreps [34, 35] for nuclei with protons in the 50-82 shell and neutrons in the 82-126 shell. Boldface numbers indicate nuclei with $R_{4/2} = E(4_1^+)/E(2_1^+) \geq 2.8$, while * denotes nuclei with $2.8 > R_{4/2} \geq 2.5$, and ** labels a few nuclei with $R_{4/2}$ ratios … any other nuclei with $R_{4/2} < 2.5$. For the rest of th… d) the $R_{4/2}$ ratios are still unknown [47]. Oblate irre…

Predictions using (λ,μ)

			Ba	Ce	Nd	Sm	Gd	Dy	Er	Yb	Hf	W	Os	Pt
		Z	56	58	60	62	64	66	68	70	72	74	76	78
		Z_{val}	6	8	10	12	14	16	18	20	22	24	26	28
N	N_{val}	irrep	(18,0)	(18,4)	(20,4)	(24,0)	(20,6)	(18,8)	(18,6)	(20,0)	(12,8)	(6,12)	(2,12)	(0,8)
88	6	(24,0)	(42,0)*	(42,4)*	(44,4)*									
90	8	(26,4)	**(44,4)**	**(44,8)**	**(46,8)**	**(50,4)**	**(46,10)**	**(44,12)**	(44,10)*	(46,4)*	(38,12)*			
92	10	(30,4)	**(48,4)**	**(48,8)**	**(50,8)**	**(54,4)**	**(50,10)**	**(48,12)**	**(48,10)**	**(50,4)**	(42,12)*			
94	12	(36,0)	(54,0)	(54,4)	**(56,4)**	**(60,0)**	**(56,6)**	**(54,8)**	**(54,6)**	**(56,0)**	**(48,8)**	**(42,12)**	(38,12)*	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**(52,14)**	**(52,12)**	[illegible]	(46,14)	(40,18)	(36,18)*	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**(52,16)**	**(52,14)**	**(54,8)**	[illegible]			
1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**(54,14)**	**(54,12)**	**(56,6)**	[illegible]			
1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**(60,6)**	**(58,8)**	**(58,6)**	**(60,0)**	[illegible]			
1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**(52,16)**	[illegible]	**(54,8)**	[illegible]			
1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(48,20)	**(48,18)**	**(50,12)**	[illegible]			
108	26	(28,12)	(46,12)	(46,16)	(48,16)	(52,12)	(48,18)	(46,20)	(46,18)	**(48,12)**	[illegible]			
110	28	(28,8)	(46,8)	(46,12)	(48,12)	(52,8)	(48,14)	(46,16)	(46,14)	(48,8)	[illegible]			
112	30	(30,0)	(48,0)	(48,4)	(50,4)	(54,0)	(50,6)	(48,8)	(48,6)	(50,0)	**(42,8)**	**(36,12)**	**(32,12)**	(30,8)**
114	32	(20,10)	(38,10)	(38,14)	(40,14)	(44,10)	(40,16)	(38,18)	(38,16)	(40,10)	(32,18)	**(26,22)**	**(22,22)**	(20,18)**
116	34	(12,16)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(24,14	(18,28)*	**(14,28)**	(12,24)**
118	36	(6,18)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18,26	(12,30)	(8,30)*	(6,26)**
120	38	(2,16)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14,24	(8,28)	(4,28)*	(2,24)**

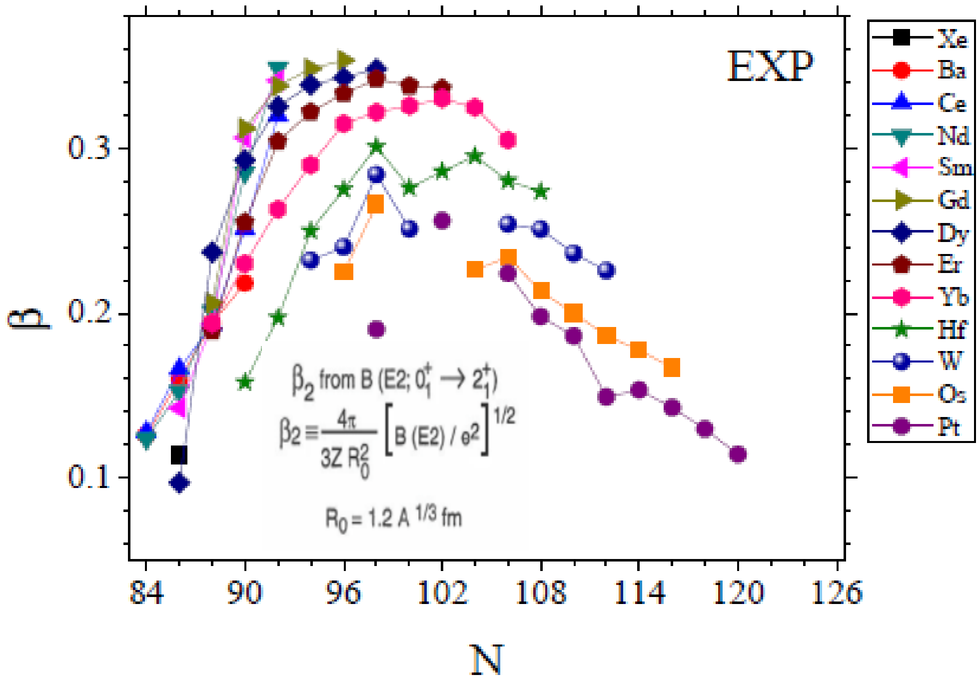
(λ,μ) grow towards mid-shell

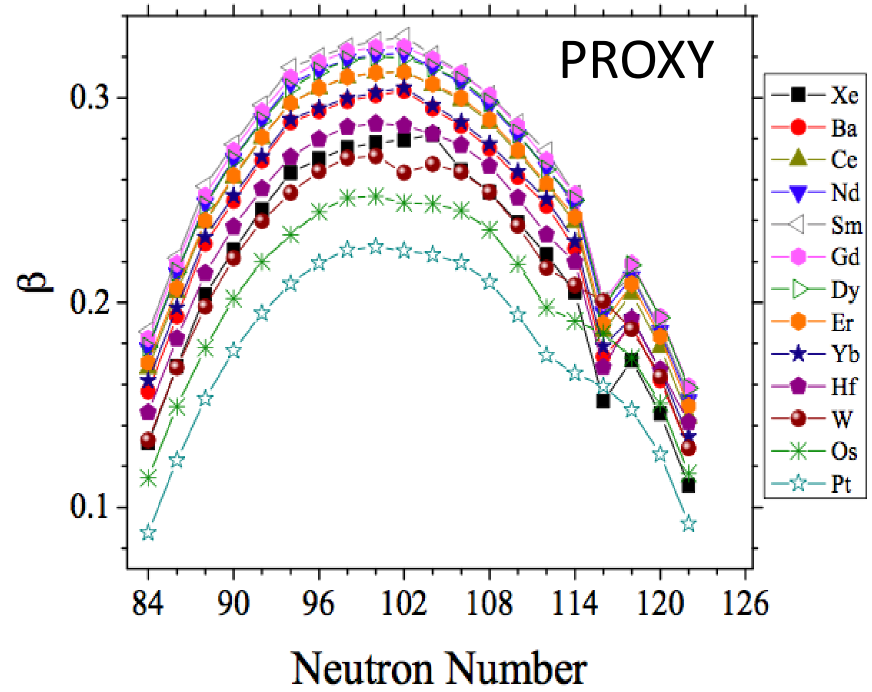
λ >> μ -- prolate



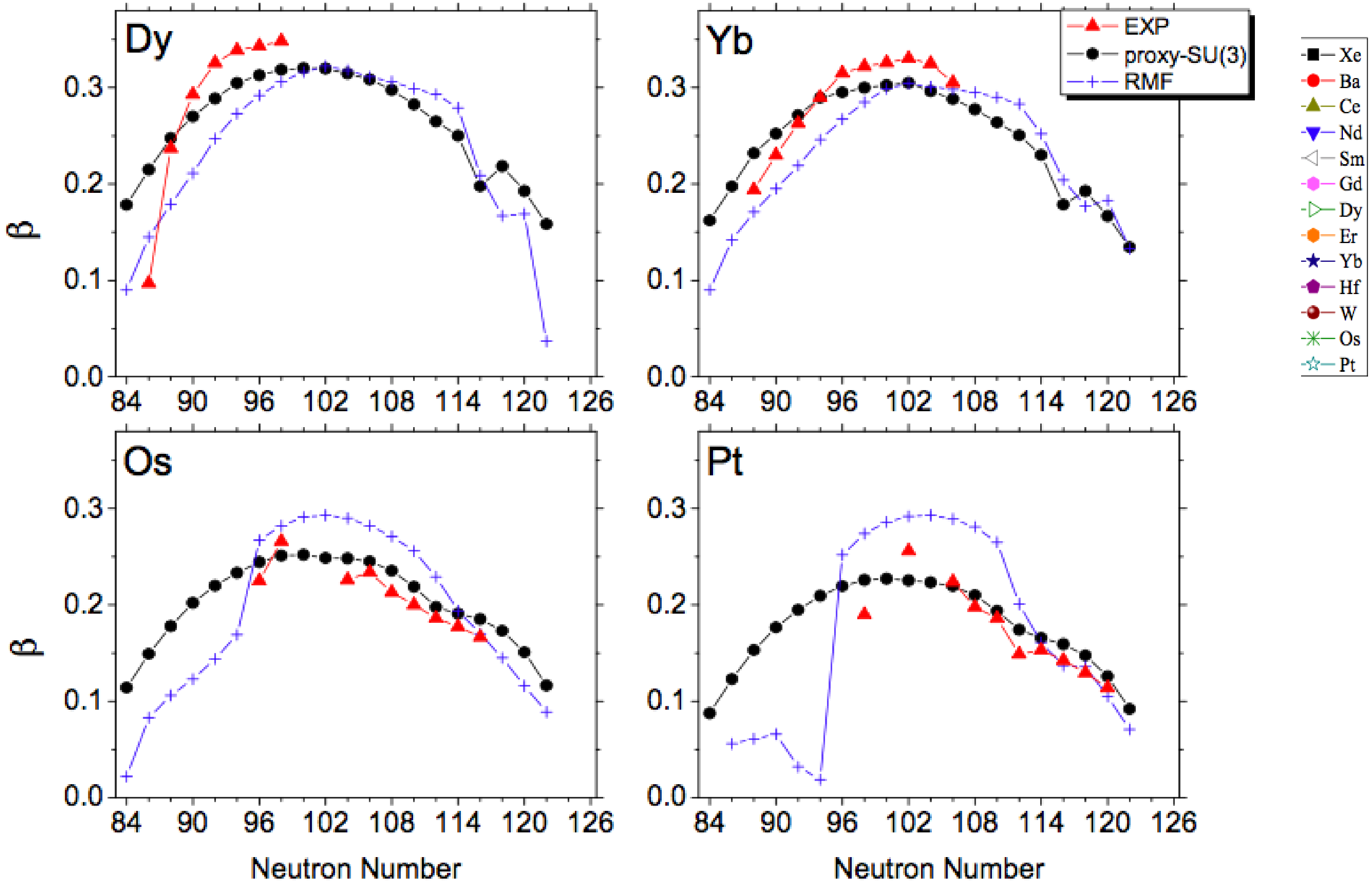
a prolate-to-oblate shape/phase transition occurs at N = 116, λ < μ

Proxy-SU(3) predictions of the β deformation variable

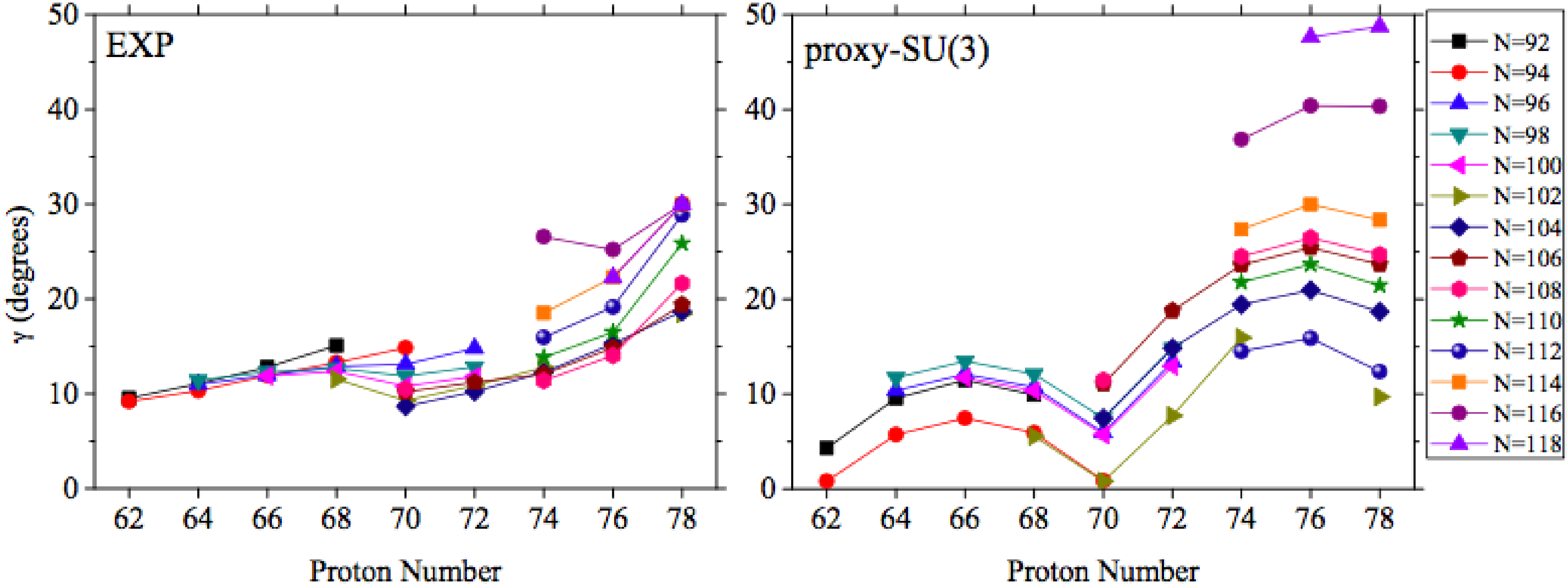




Proxy-SU(3) predictions of the β deformation variable



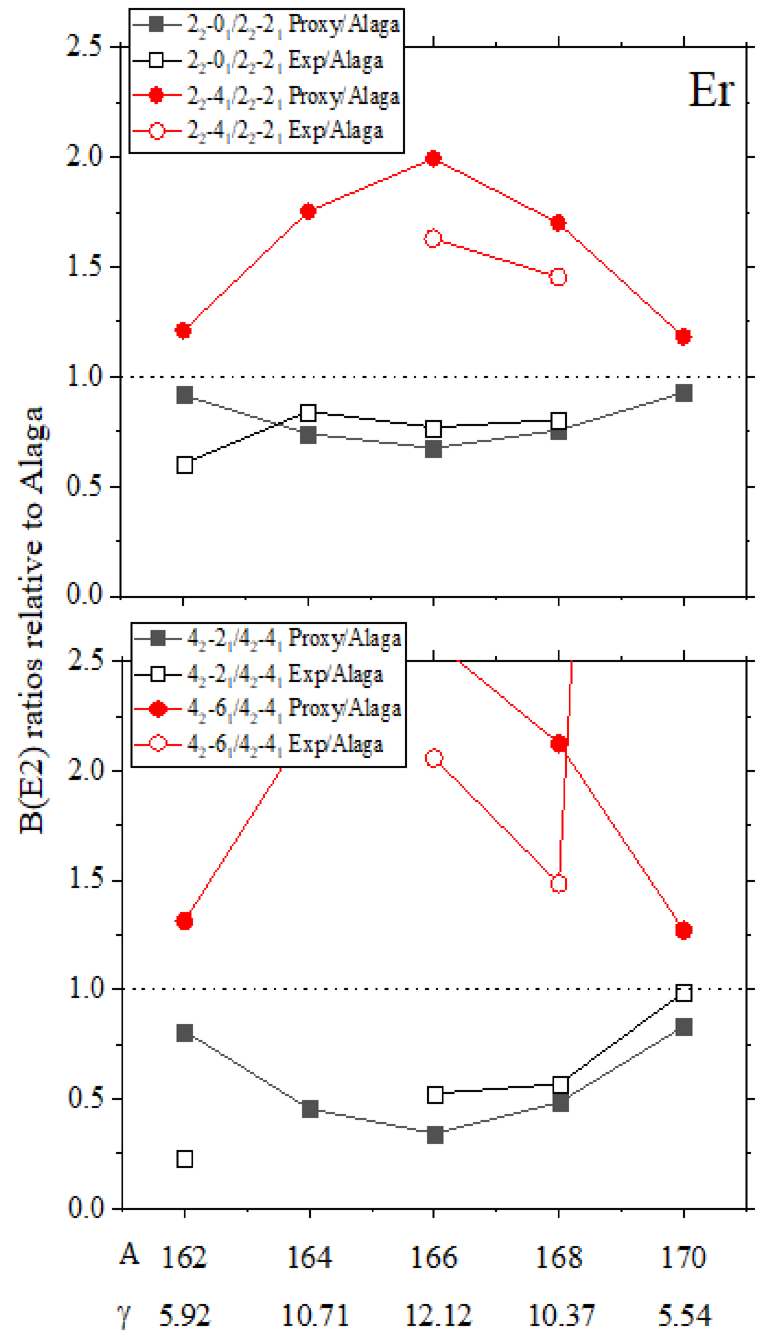
Empirical values and Proxy-SU(3) predictions of γ deformation values



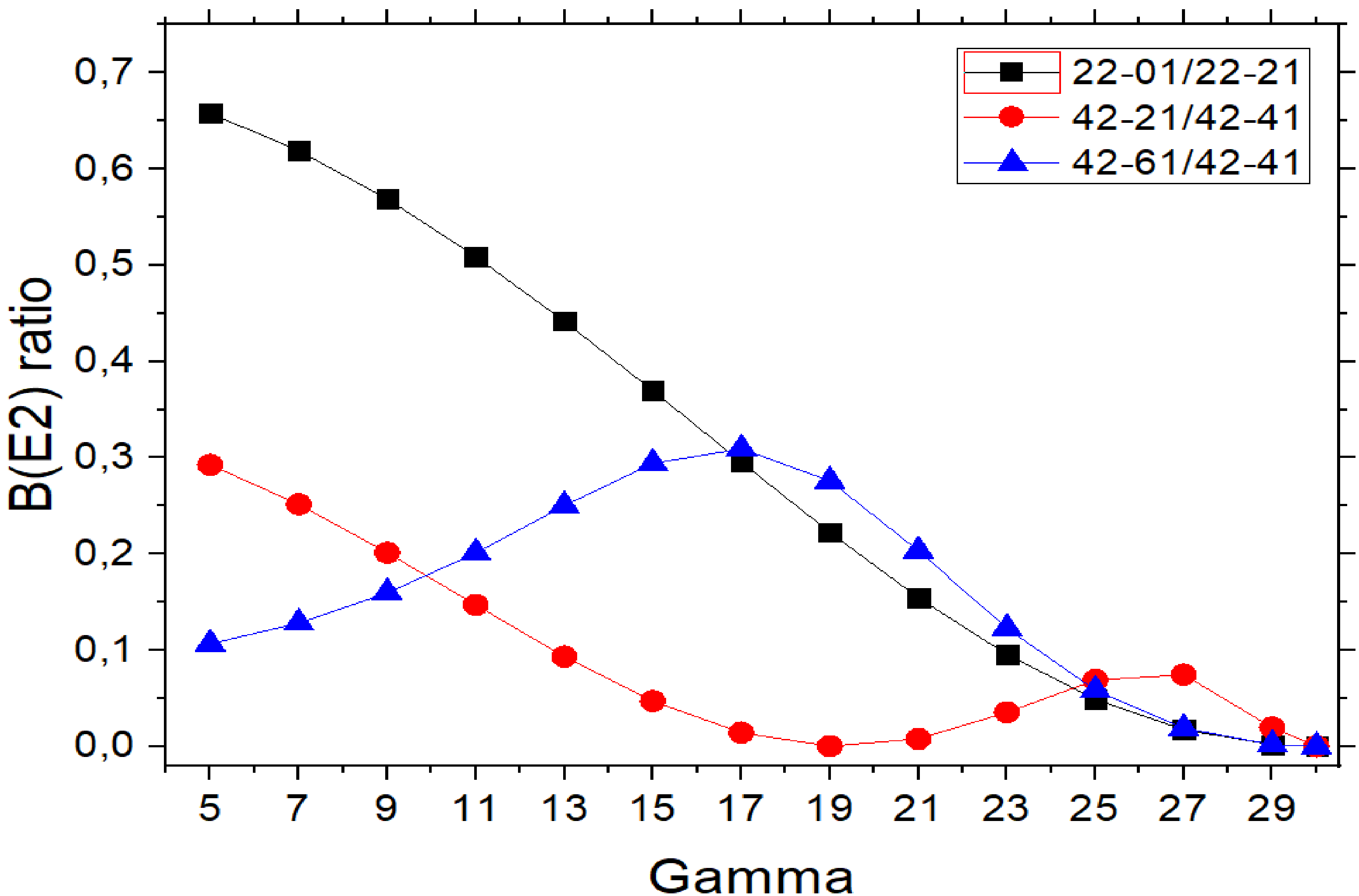
Similar trends: 10-15 deg. rising to ~30 degrees
Oscillations in the predictions: Presumably due to neglect of pairing which would average out predictions over several neutron numbers

Proxy → γ → Davydov → B(E2: γ → ground) values

- **Finite γ is equivalent to bandmixing**
- **Deviations from Alaga rules increase with γ**
- **Spin INcreasing transitions INcrease rel to Alaga**
- **Spin DEcreasing transitions DEcrease rel to Alaga**
- **Er: γ values vary "parabolically". So do predicted Proxy B(E2)s**



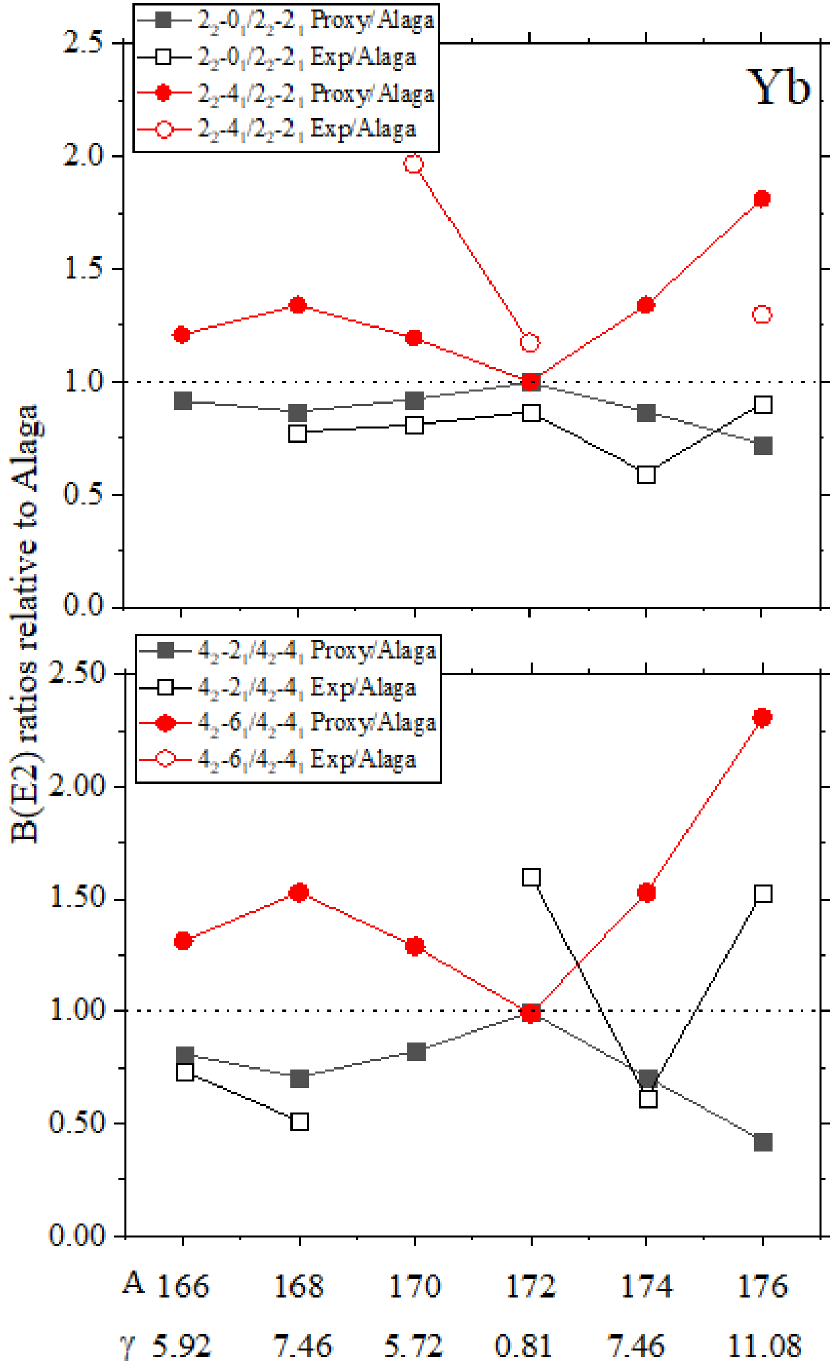
Use Proxy γ in Davydov model to predict B(E2: γ → ground) values: deviations from Alaga rules: Generic behavior of B(E2: γ → ground) values vs γ



Full set of Proxy-Davydov predictions for ^{168}Er

$J_{initial}$	J_{final}	^{168}Er-EXP	Alaga	Proxy	$Z\gamma$=0.035	PDS	CQF
2_γ	0^+	56.2(11)	70	52.9	56.9	64.3	54
	2^+	100	100	100	100	100	100
	4^+	7.3(4)	5	8.5	7.6	6.3	8
3_γ	2^+	100	100	100	100	100	100
	4^+	62.6(14)	40	73	62.9	49.3	69
4_γ	2^+	19.3(4)	34	16.4	20.2	28.1	18
	4^+	100	100	100	100	100	100
	6^+	13.1(12)	8.6	18.7	16	12.5	16
5_γ	4^+	100	100	100	100	100	100
	6^+	123(14)	57.1	147.7	117	79.6	125
6_γ	4^+	11.2(10)	26.9	7.4	11	20.3	9
	6^+	100	100	100	100	100	100
	8^+	37.6(72)	10.6	27.9	23.6	18	20

- **Yb: γ values vary erratically. So do predicted Proxy B(E2)s**



Summary

- **Approximate shell model scheme – physics-motivated orbit substitution – recovers an SU(3) symmetry for heavy deformed nuclei**
- **The Proxy Scheme: simple but with inherent flaws to be assessed**
- **Analytic parameter-free predictions: ground state shapes, prolate-oblate transition. Overall agreement.**
- **γ-band to ground band B(E2)s:**
  Proxy → γ → Davydov → B(E2)s: Relation to bandmixing
- **Improvements (e.g., pairing) and extensions (e.g., higher intrinsic excitations)**

Collaborators

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PR. C 95, 064325(2017): Proxy-SU(3) symmetry in heavy def. nuclei

PR C 95, 064326(2017): Analytic predictions for nuclear shapes, prolate dominance, and the P-O shape transition in the proxy-SU(3) model

B(E2) values, in preparation