Nuclear shape predictions with proxy-SU(3)

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Motivation

- The dominance of prolate (ellipsoidal) over oblate (disk) shapes in the ground states of even-even nuclei is still a puzzling open problem in nuclear structure.
- Comparision of experimental results with proxy SU(3) symmetry for a prolate-to-oblate shape transition in the rare earth region around neutron number N = 116.
- In addition to prolate-oblate, it is interesting challenge to predict nuclear shapes : ! and ! .

- Proxy-SU(3) can predict ! and ! deformation variables

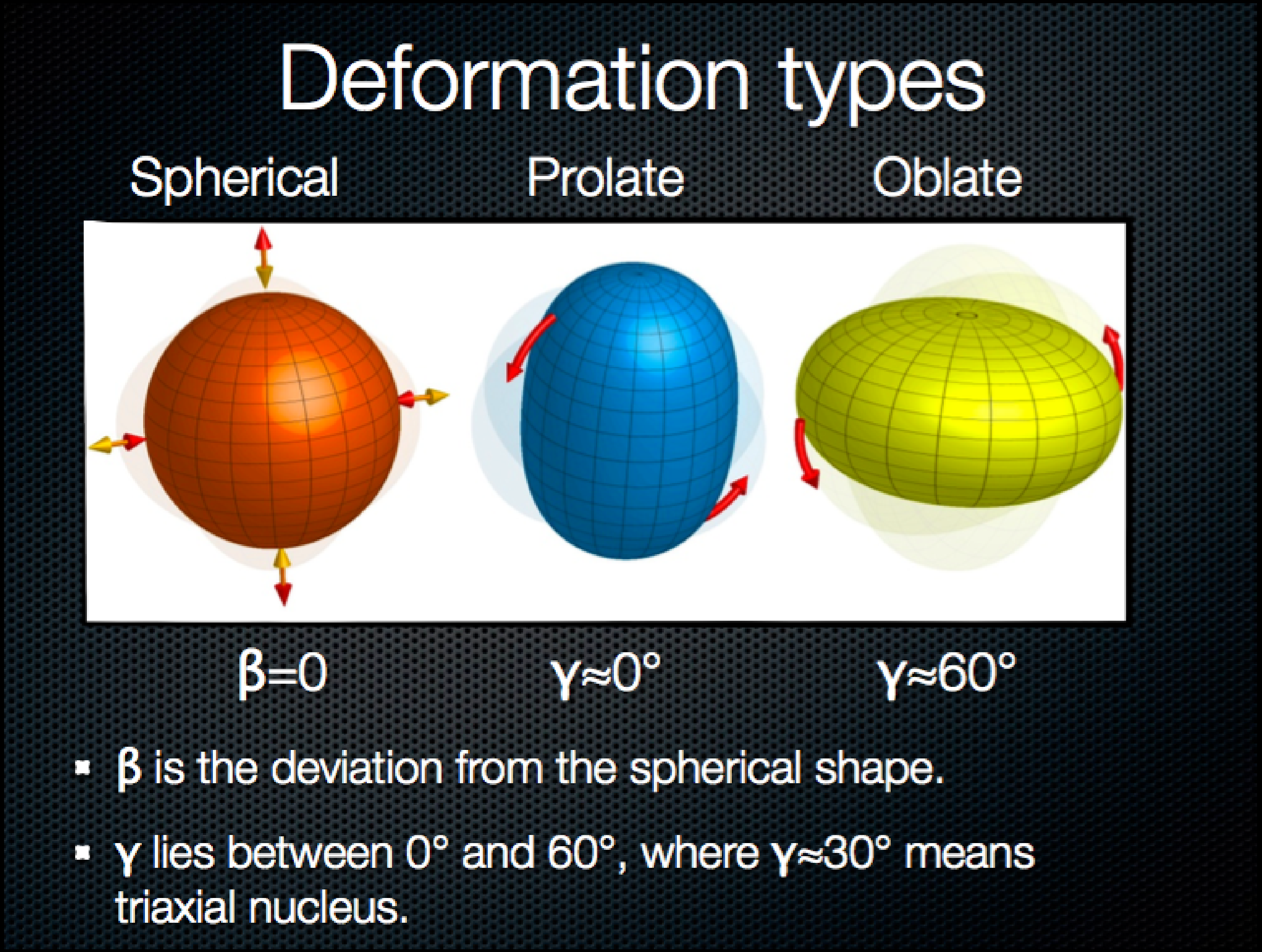


Figure from A.Martinou

Relation of Proxy-SU(3) irrep labels, ! , ! , to ! and ! deformation variables

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

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

! >> 1, ! =0,
! → 0!
! >> 1, ! =! ,
! =30!

Note in particular that,
if ! ! ! ! ! the nucleus is oblate (! ! ! ! ! deg.)
30 ≤ ! ! ≤ 60

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

(! ,! !

			Ba									W	Os	Pt
		Z	56									4	76	78
		Z_{val}	6									4	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)*	[illegible]	(44,4)*									
90	8	(26,4)	**(44,4)**	**(44,8)**	[illegible]	**(50,4)**	**(46,10)**	**(44,12)**	(44,10)*	(46,4)*	(38,12)*			
92	10	(30,4)	**(48,4)**	**(48,8)**	[illegible]	**(54,4)**	**(50,10)**	**(48,12)**	**(48,10)**	**(50,4)**	(42,12)*			
94	12	(36,0)	(54,0)	**(54,4)**	[illegible]	**(60,0)**	**(56,6)**	**(54,8)**	**(54,6)**	**(56,0)**	**(48,8)**	**(42,12)**	(38,12)*	
96	14	(34,6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**(46,14)**	**(40,18)**	(36,18)*	
98	16	(34,8)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**(46,16)**	**(40,20)**	(36,20)*	
100	18	(36,6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**(56,6)**	[illegible]	**(42,18)**	**(38,18)**	(36,14)*
102	20	(40,0)	(58,0)	(58,4)	(60,4)	(64,0)	**(60,6)**	**(58,8)**	**(58,6)**	**(60,0)**	**(52,8)**	**(46,12)**	**(42,12)**	(40,8)*
104	22	(34,8)	(52,8)	(52,12)	(54,12)	(58,8)	(54,14)	[illegible]	**(52,14)**	**(54,8)**	**(46,16)**	**(40,20)**	**(36,20)**	(34,16)*
106	24	(30,12)	(48,12)	(48,16)	(50,16)	(54,12)	(50,18)	[illegible]	**(48,18)**	[illegible]	**(42,20)**	**(36,24)**	**(32,24)**	(30,20)*
108	26	(28,12)	(46,12)	(46,16)	(48,16)	(52,12)	(48,18)	(46,20)	(46,18)	**(48,12)**	**(40,20)**	**(34,24)**	**(30,24)**	(28,20)*
110	28	(28,8)	(46,8)	(46,12)	(48,12)	(52,8)	(48,14)	(46,16)	(46,14)	(48,8)	**(40,16)**	**(34,20)**	**(30,20)**	(28,16)*
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]	[illegible]	(18,28)*	**(14,28)**	(12,24)**
118	36	(6,18)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(12,30)	(8,30)*	(6,26)**
120	38	(2,16)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(8,28)	(4,28)*	(2,24)**

! ! ! ! ! ! -- prolate

a prolate-to-oblate shape transition occurs at N = 116,

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

TABLE III: Same as Table II, but for the most leading SU(3) irreps [34, 35] for nuclei with protons in the 50-82 shell and neutrons in the 50-82 shell.

			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)
56	6	(18,0)	(36,0)	(36,4)	(38,4)	(42,0)	(38,6)	(36,8)	(36,6)	(38,0)	(30,8)	(24,12)	(20,12)	(18,8)
58	8	(18,4)	(36,4)	(36,8)	(38,8)	(42,4)	(38,10)	(36,12)	(36,10)	(38,4)	(30,12)	(24,16)	(20,16)	(18,12)
60	10	(20,4)	(28,4)	(38,8)	(40,8)	(44,4)	(40,10)	(38,12)	(38,10)	(40,4)	(32,12)	(26,16)	(22,16)	(20,12)
62	12	(24,0)	**(42,0)**	(42,4)	(44,4)	(48,0)	(44,6)	(42,8)	(42,6)	(44,0)	(36,8)	(30,12)	(26,12)	(24,8)
64	14	(20,6)	**(38,6)**	**(38,10)**	(40,10)	(44,6)	(40,12)	(38,14)	(38,12)	(40,6)	(32,14)	(26,18)	(22,18)	(20,14)
66	16	(18,8)	**(36,8)**	**(36,12)**	(38,12)	(32,8)	(38,14)	(36,16)	(36,14)	(38,8)	(30,16)	(24,20)	(20,20)	(18,16)
68	18	(18,6)	**(36,6)**	**(36,10)**	**(38,10)**	(42,6)	(38,12)	(36,14)	(36,12)	(38,6)	(30,14)	(24,18)	(20,18)	(18,14)
70	20	(20,0)	(38,0)*	**(38,4)**	**(40,4)**	**(44,0)**	(40,6)	(38,8)	(38,6)	(40,0)	(32,8)	(26,12)	(22,12)	(20,8)
[illegible]										(32,8)	(24,16)	(18, 20)	(14, 20)	(12, 16)
[illegible]										26,12)	(18, 20)	(12, 24)	(8, 24)	(6, 20)
[illegible]										22,12)	(14, 20)	(8, 24)	(4, 24)	(2, 20)
[illegible]										(20,8)	(12, 16)	(6, 20)	(2, 20)	(0, 16)

a prolate-to-oblate shape transition occurs at N = 72, ! ! ! ! !

Z=N=50-82 Shell

Prolate-Oblate Phase Transition In The Hf-Hg region

N	108	108	110	112	112	114	**116**	116	118	118	120
Nucleus	^{180}Hf	^{182}W	^{184}W	^{186}W	^{188}Os	^{190}Os	^{192}Os	^{194}Pt	^{196}Pt	^{198}Hg	^{200}Hg
(λ,μ)	(40,20)	(34,24)	(34,20)	(36,12)	(32,12)	(22,22)	**(14,28)**	(12,24)	(6,26)	(6,18)	(2,16)

prolate

oblate

$\lambda<\mu$

Prolate to Oblate shape phase transition in Os

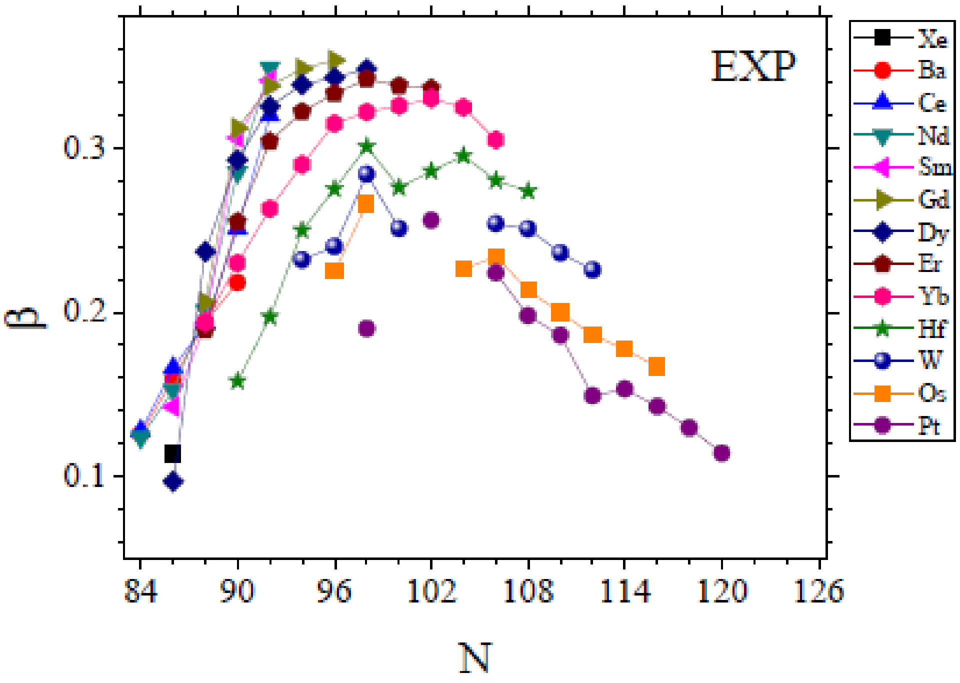
N	96	98	100	102	104	106	108	110	112	114	**116**	118
Nucleus	^{172}Os	^{174}Os	^{176}Os	^{178}Os	^{180}Os	^{182}Os	^{184}Os	^{186}Os	^{188}Os	^{190}Os	^{192}Os	^{194}Os
(λ,μ)	(36,18)	(36,20)	(38,18)	(42,12)	(36,20)	(32,24)	(30,24)	(30,20)	(32,12)	(22,22)	**(14,28)**	(8,30)

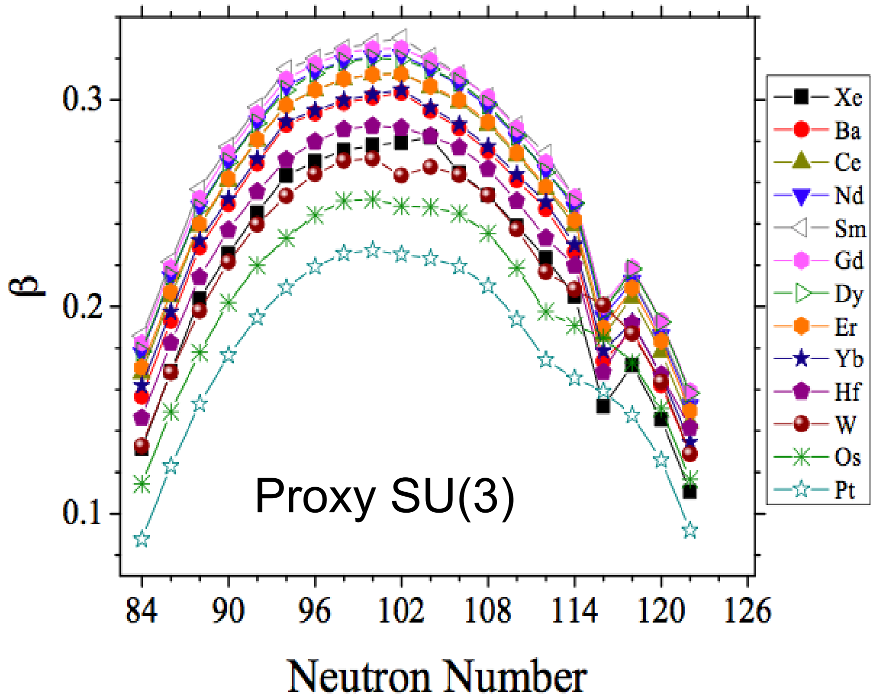
prolate

oblate

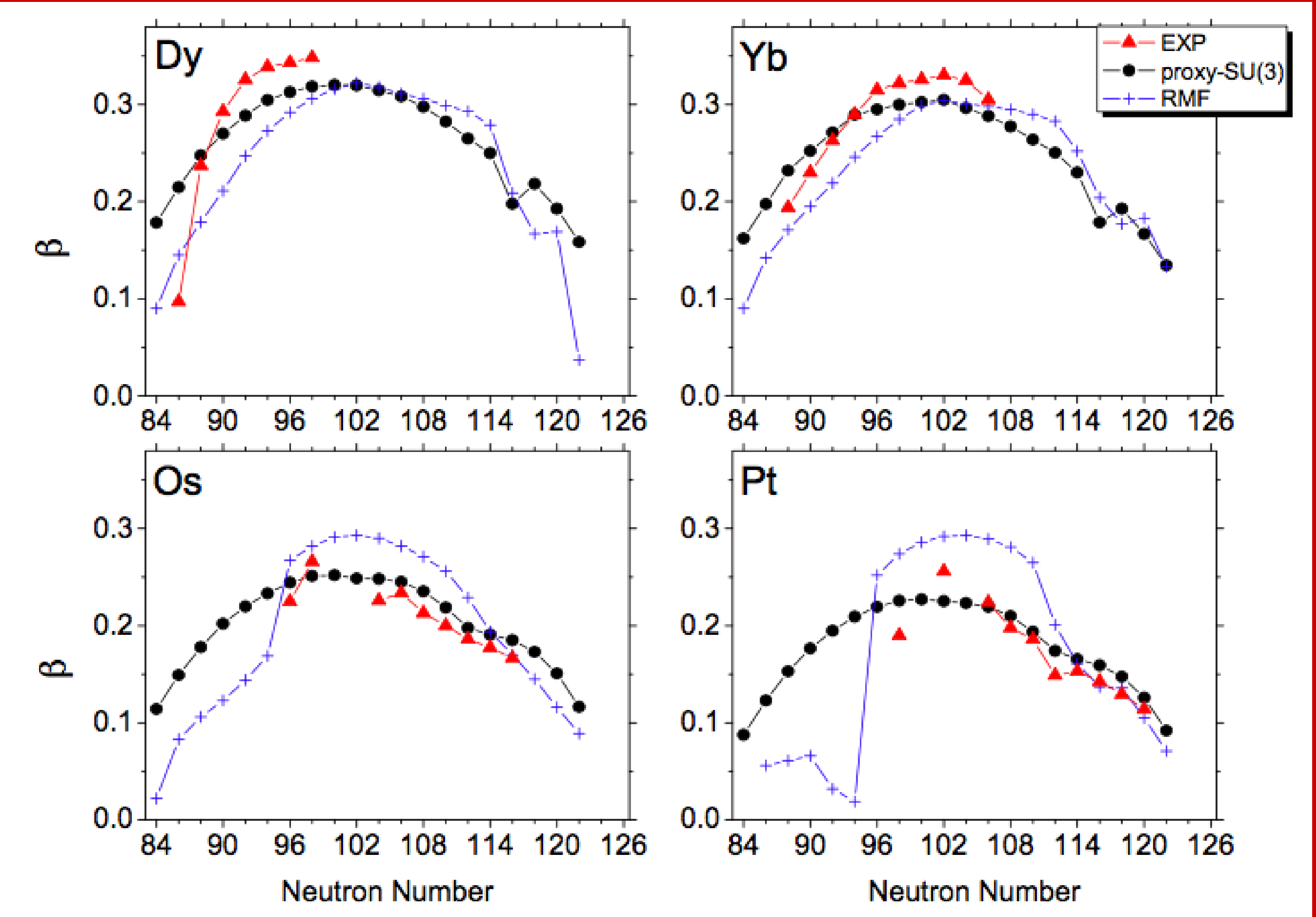
$\lambda<\mu$

Empirical values and Proxy-SU(3) predictions of the ! deformation variable

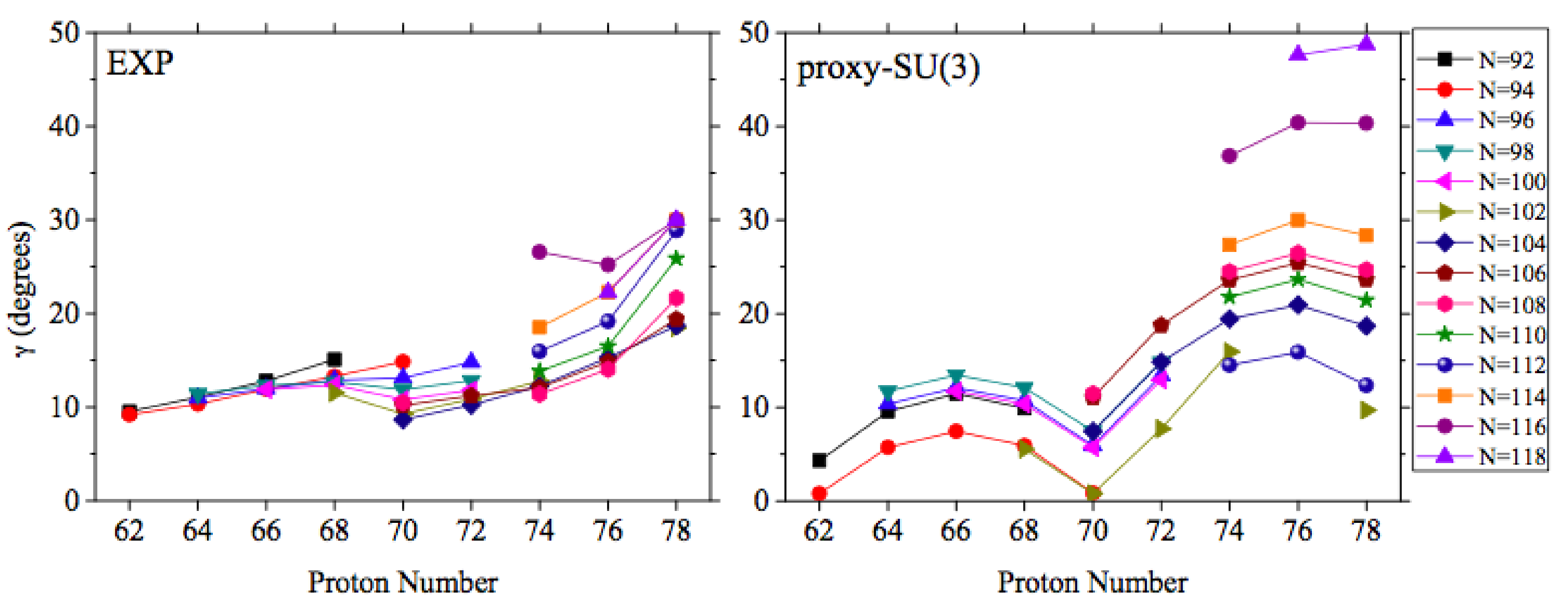




Empirical values and Proxy-SU(3) predictions for the !   deformation variable



Empirical values and Proxy-SU(3) predictions of ! 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

! is only rising at large neutron number N, indicating regions with triaxial shapes.

Conclusions

- The new proxy-SU(3) scheme is a good approximation to the full set of orbits in major shells and yields a reasonable Nilsson diagram for well-deformed nuclei.
- Not trying to claim that proxy-SU(3) is a detailed microscopic calculation but it is a valuable, extremely simple model for well-deformed nuclei.
- The prolate over oblate dominance
- The proxy-SU(3) symmetry suggests N ~ 116 as the point of the prolate-to-oblate shape/phase transition, in agreement with existing exprerimental evidence and microscopic calculations, for the Z=50-82, N=82-126 shells.
- For the Z=N=50-82 shells, a prolate-to-oblate shape/phase transition occurs at N = 72.
- The proxy-SU(3) symmetry provides predictions for the collective variables which are comparable empirical values obtained from B(E2) transition rates and with microscopic calculations where the data are known. Interestingly, there are significant differences in nuclei where these B(E2) values are not yet measured.

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Main references on Proxy SU(3)

Phys. Rev. C95, 064325(2017) Proxy-SU(3) symmetry in heavy deformed nuclei
Phys. Rev. C95, 064326(2017) Analytic predictions for nuclear shapes, prolate dominance, and the prolate-oblate shape transition in the proxy-SU(3) model

Thank you for your attention !