Nuclear level density as a signature of shape phase transitions

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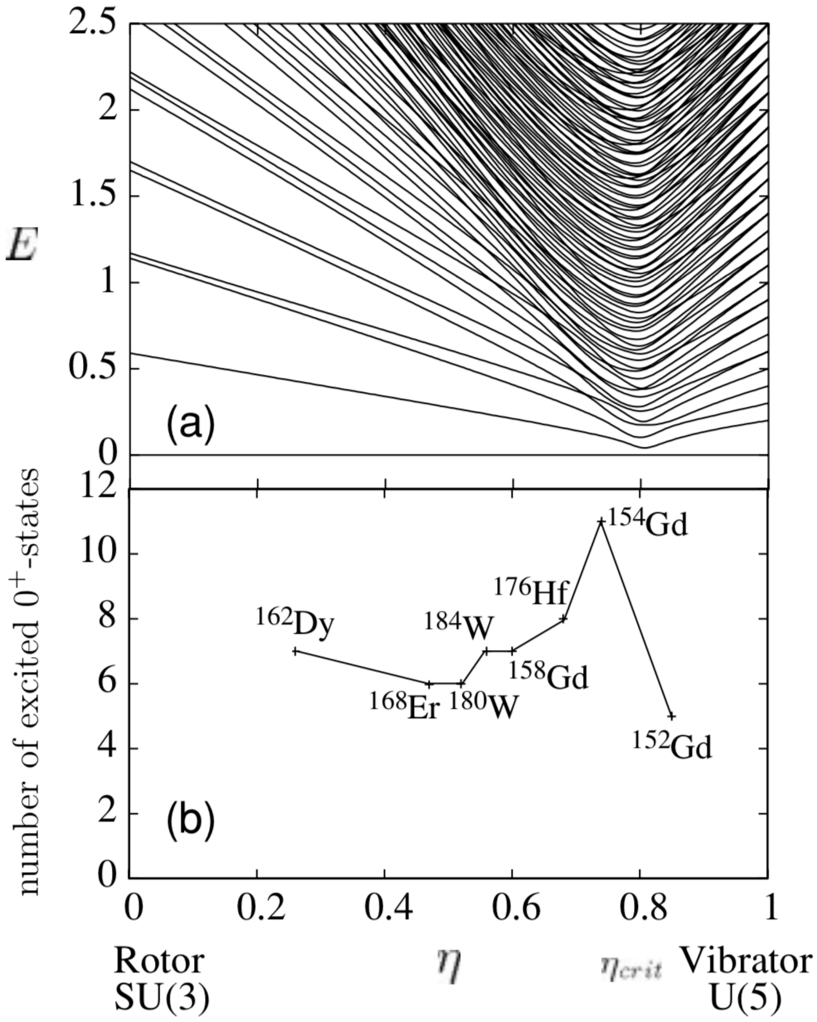


P.Cejnar & J. Jolie,
P.R. E61(2000)6237

0$^+$ states; IBM calculations
N_B = 30

D.A.Meyer et al.,
P.L. B638(2006)44
P.R. C74(2006)044309

Number of exp. 0$^+$ states
up to E_x = 2.5 MeV
(seen with the (p,t) reaction)

Level density

$\rho(E,J) = f(J)\rho(E)$

$\rho(E) = dN(E)/dE = 1/D(E)$

At low exc. energies:
CT or **BSFG** models

$$\rho_{BSFG}(E) = \frac{e^{2\sqrt{a(E-E_1)}}}{12\sqrt{2}a^{1/4}(E-E_1)^{5/4}}$$

(Back-shifted Fermi gas formula)

Larger ***a*** → larger **ρ**

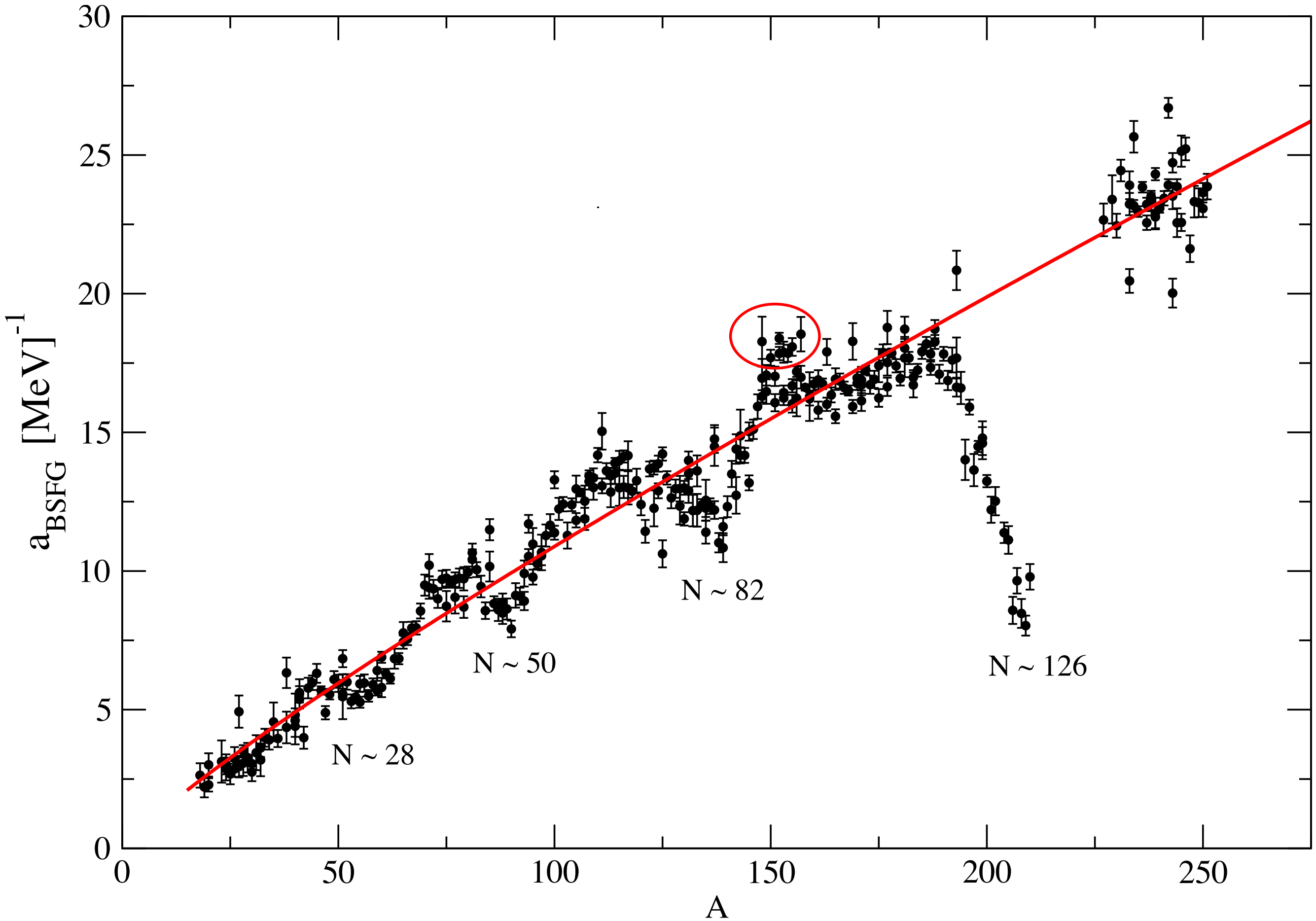
T. Von Egidy & D.Bucurescu, P.R. C80(2009)054310 :

- Empirical ***a*** and ***E_1*** free parameters determined by fits to individual nuclei:

  → experimental levels (*complete level schemes at low energies*)

  → level density at $E_x \approx B_n$ (from *average neutron resonance spacings*)

~300 nuclei between ^{18}F and ^{251}Cf (of the type "stable nucleus + 1 neutron")



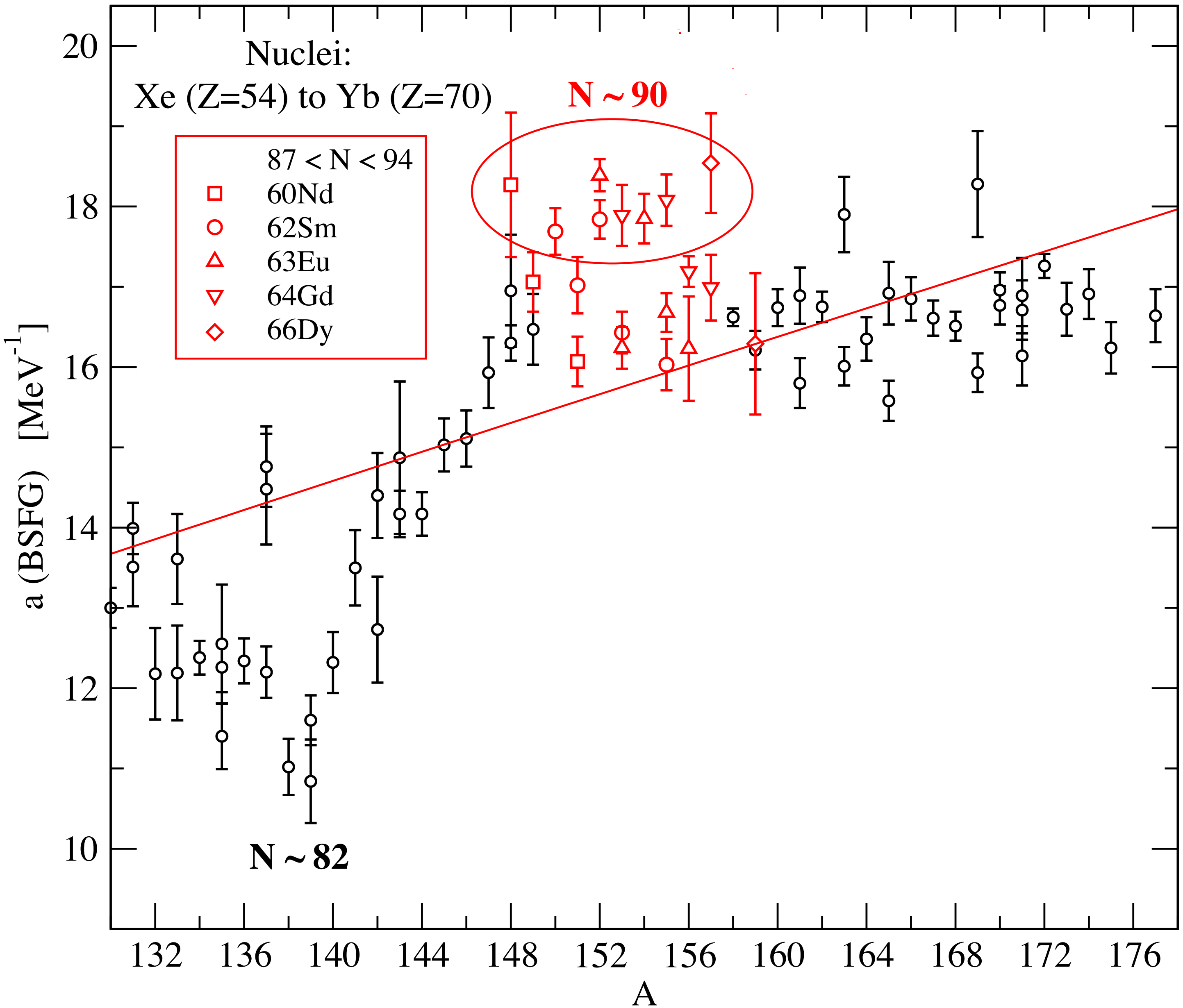
- From correlations between ***a, E*₁** and other quantities, empirical formulas:

$$a = (0.199 + 0.0096S')A^{0.869} \qquad E_1 = -0.381 + 0.5Pa'$$

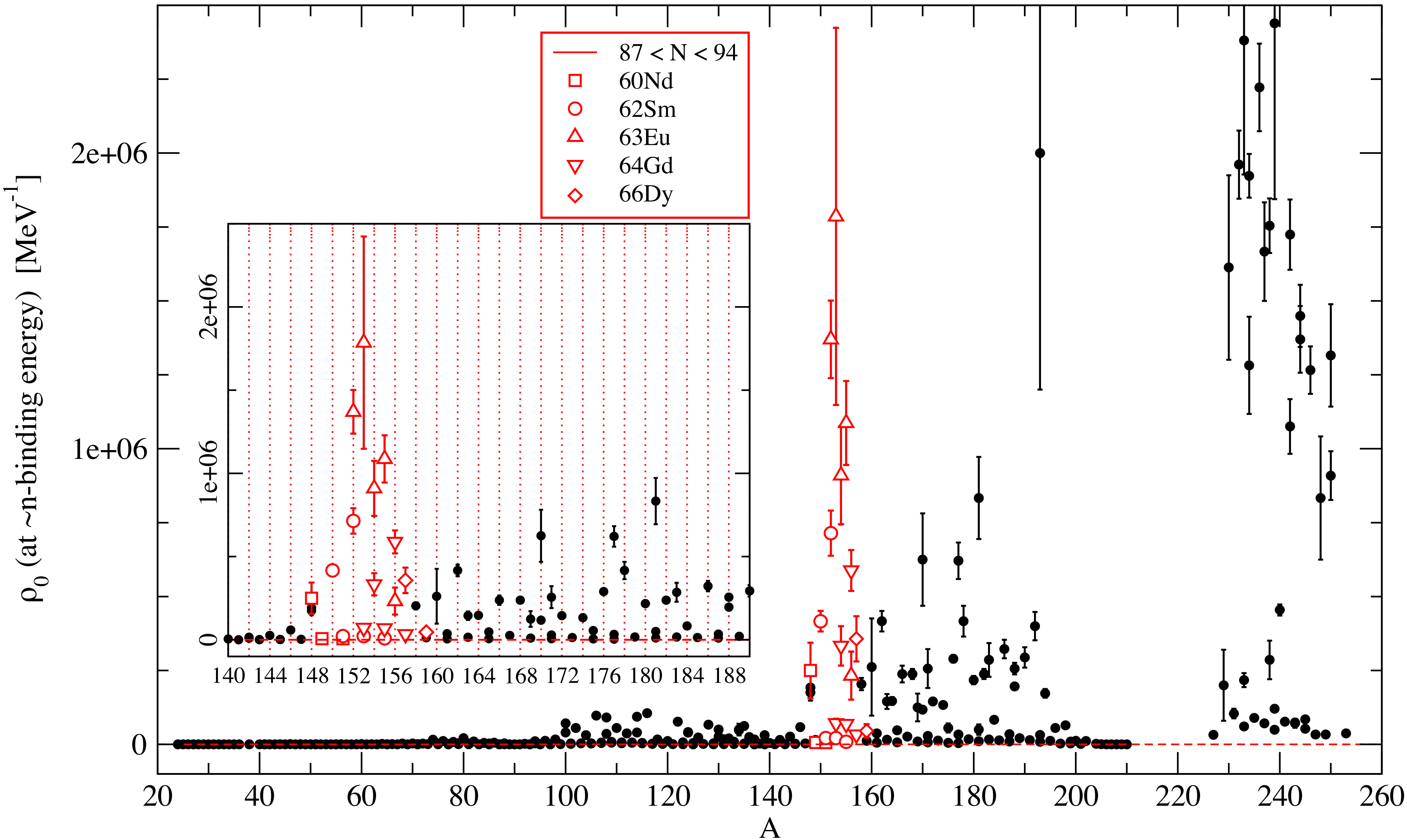
$$S' = S + 0.5Pa' \qquad S = B_{Weizsacker} - B_{exp}$$ (shell correction)

$$Pa' = [2B(Z,N) - B(Z+1,N+1) - B(Z-1,N-1)]/2$$ (deuteron pairing)

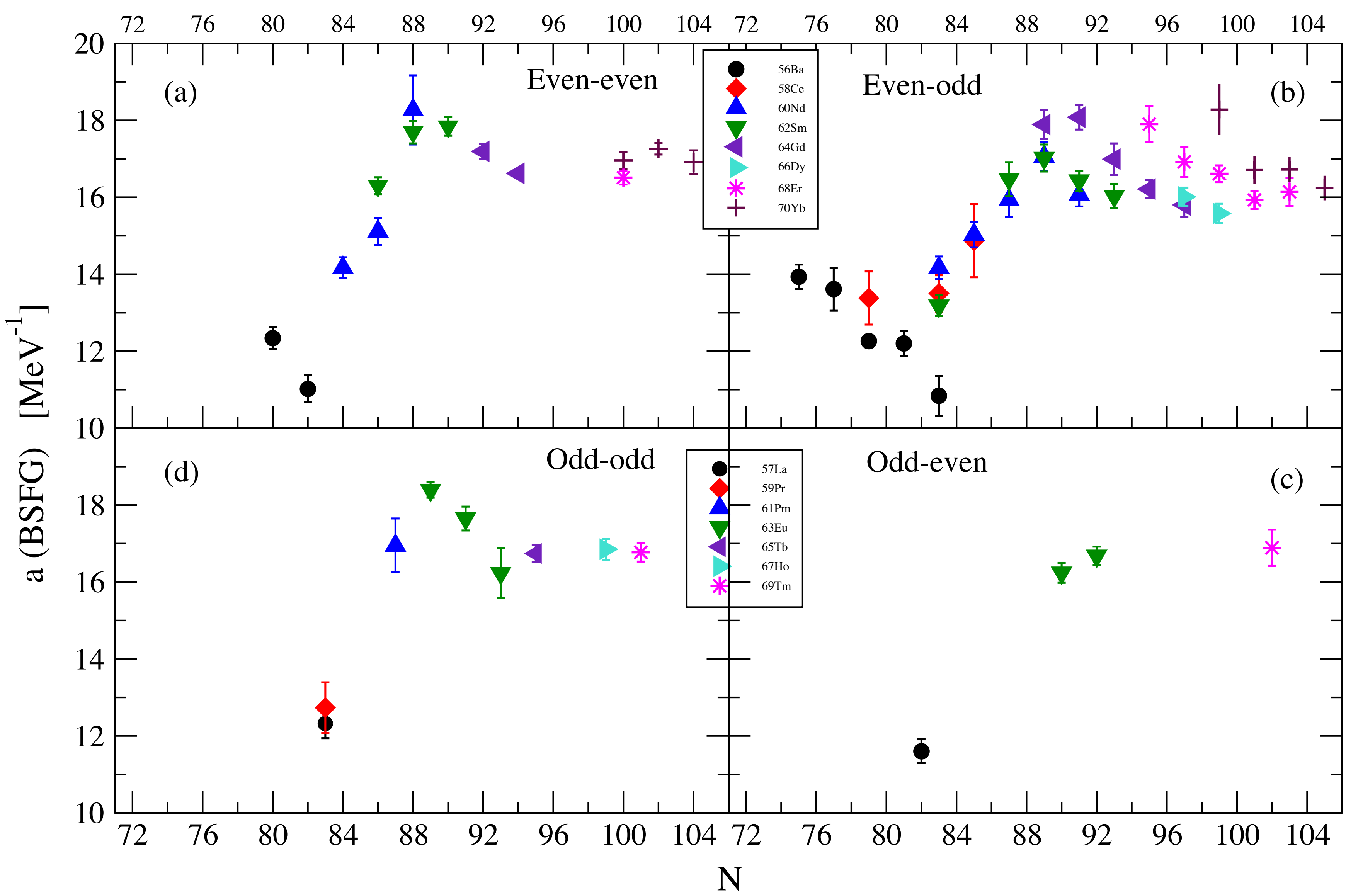
B – binding energy



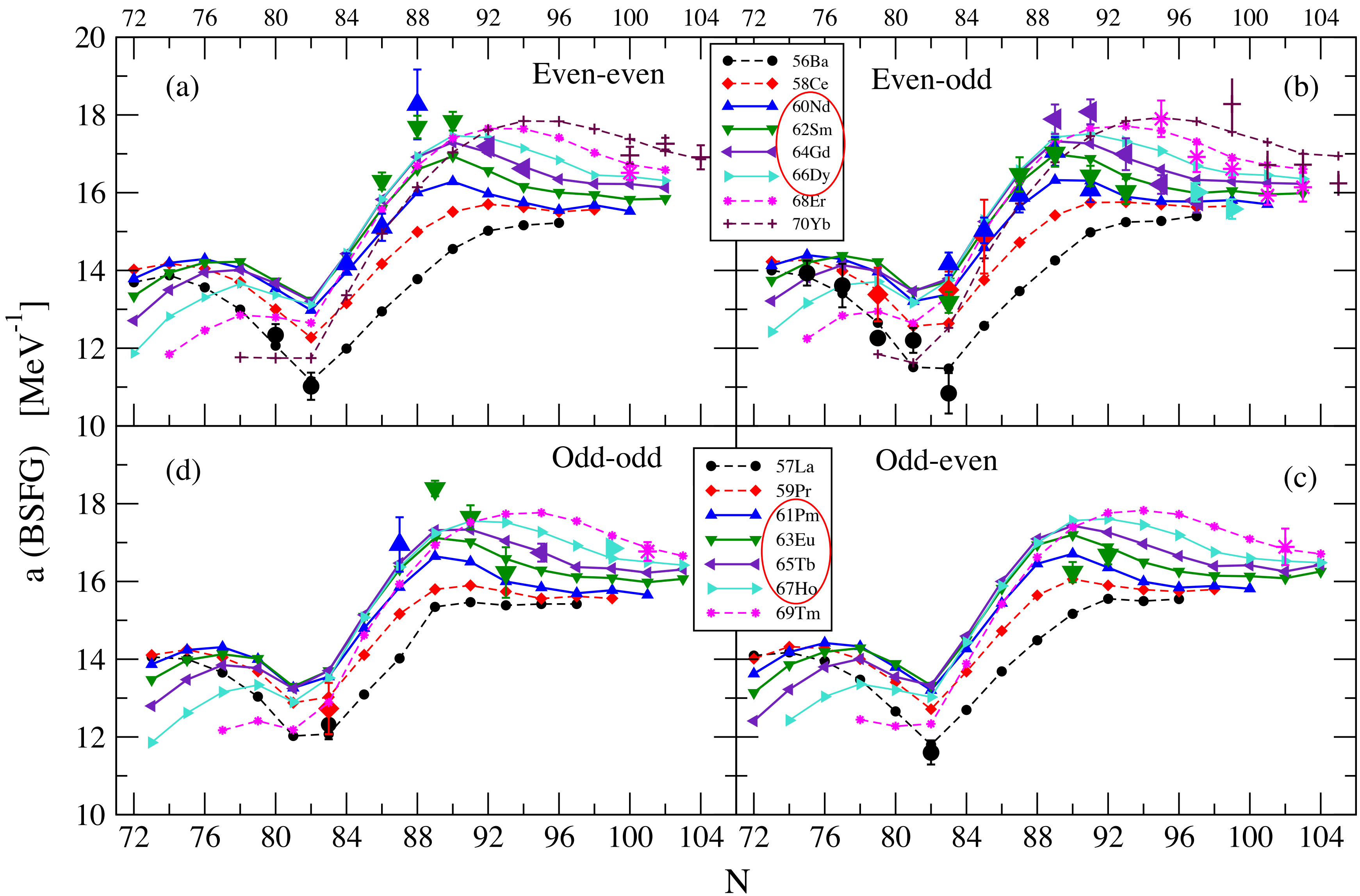
Larger ***a*** → larger **ρ**



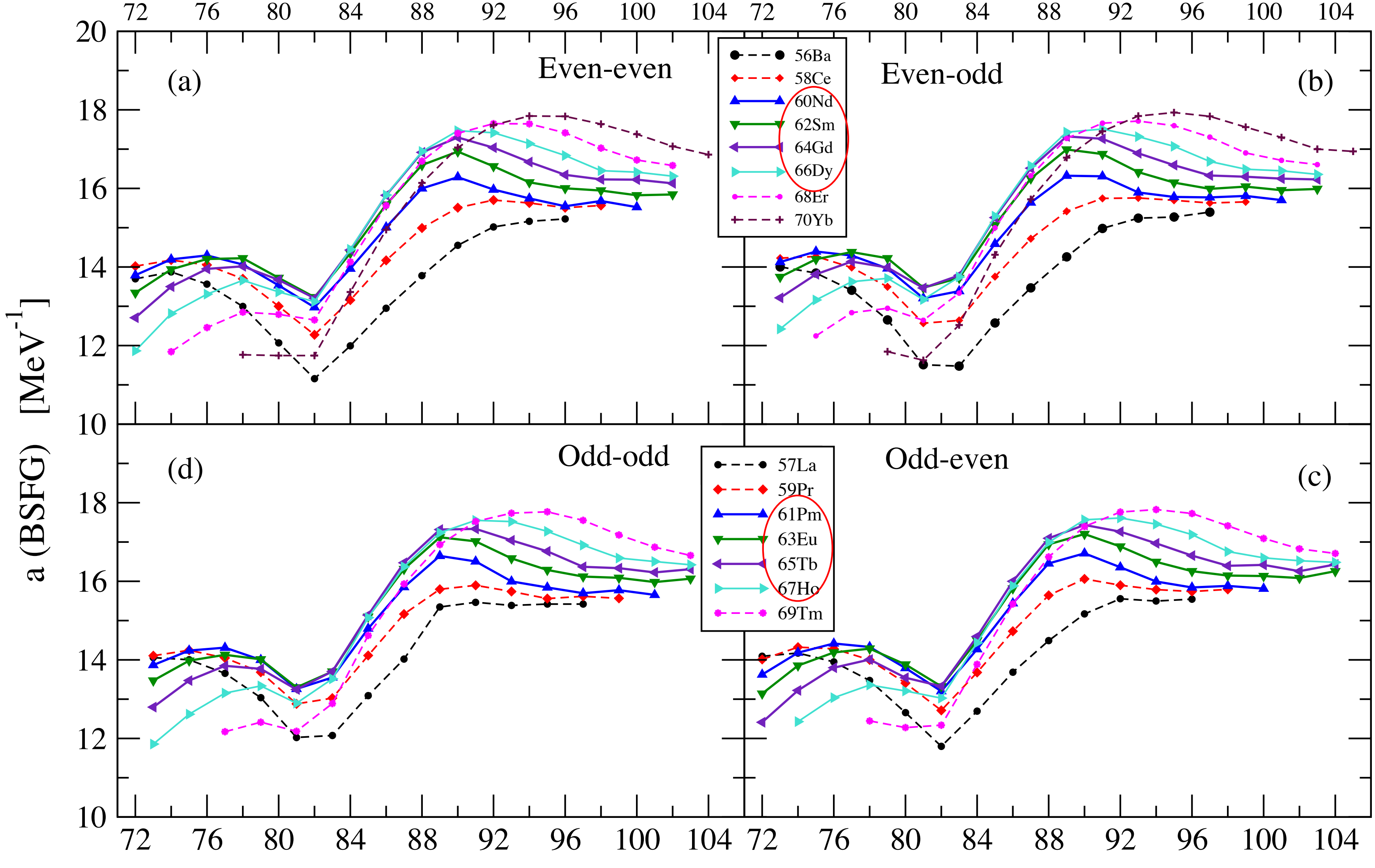
Experimental level density for *s*-wave neutron level resonances (RIPL-3 database)



(a)
Even-even
(b)
Even-odd
(c)
Odd-even
(d)
Odd-odd
56Ba
58Ce
60Nd
62Sm
64Gd
66Dy
68Er
70Yb
57La
59Pr
61Pm
63Eu
65Tb
67Ho
69Tm
a (BSFG) [MeV-1]
N



Big symbols: experimental values (fits to individual nuclei); Curves: empirical formula.



$$a = (0.199 + 0.0096S')A^{0.869}$$

Increased level density at N=90: special nuclear potential well, which is able to accommodate a larger number of levels. "Phase coexistence" of two families of levels at low energy.

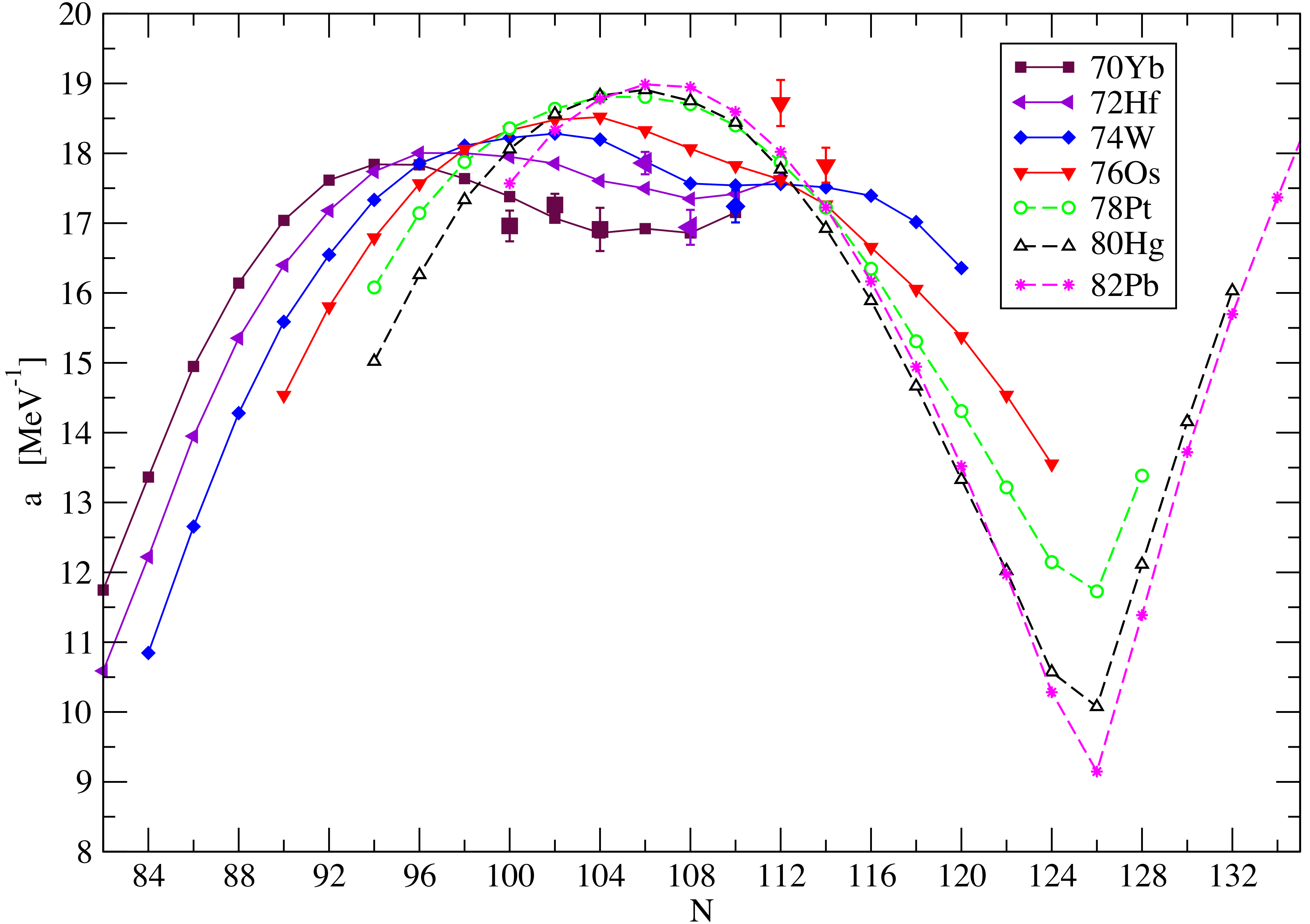
Conclusions

- ✓ The evolution of the *experimental nuclear level density* offers a *good signature for the first order phase shape transition (e.g., **a*** - "effective order parameter"*).*

- ✓ For isotopes with Z = 60 to 67 the level density has a *maximum in the region of the critical point at N=90*. This corroborates earlier findings of increased density of the low-lying 0^+ states and of IBM calculations.

- ✓ This new indicator can be used to investigate SPT in *all types of nuclei: even-even, odd-A and odd-odd*.

- ✓ The increased level density at the critical point: valuable hint to the *nature* of the 1st order SPT from vibrator to axial rotor: it is *consistent with the phase coexistence* phenomenon (due to a broadened - in the deformation space - potential well, with two coexisting, almost degenerated minima separated by a small barrier).

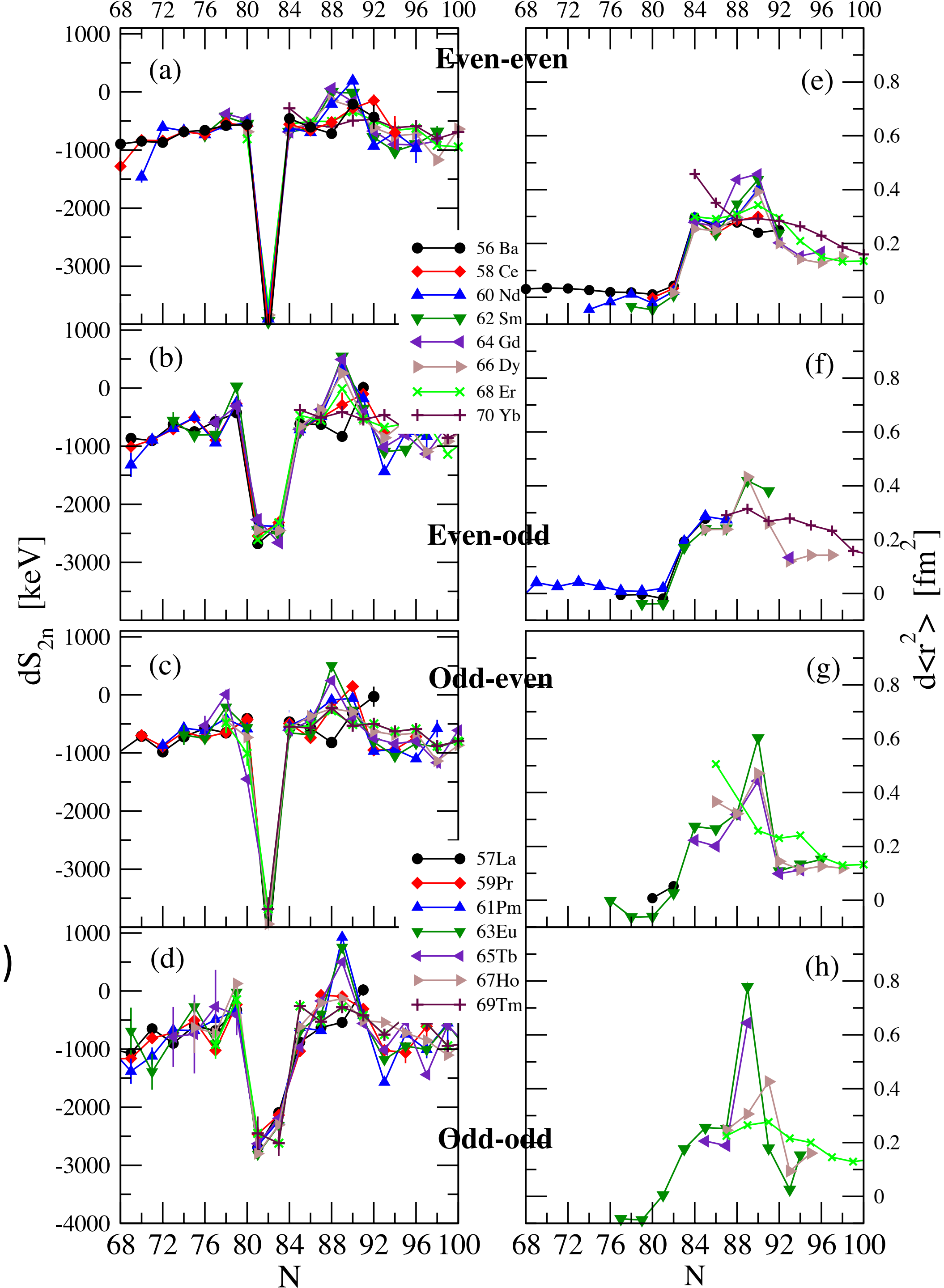


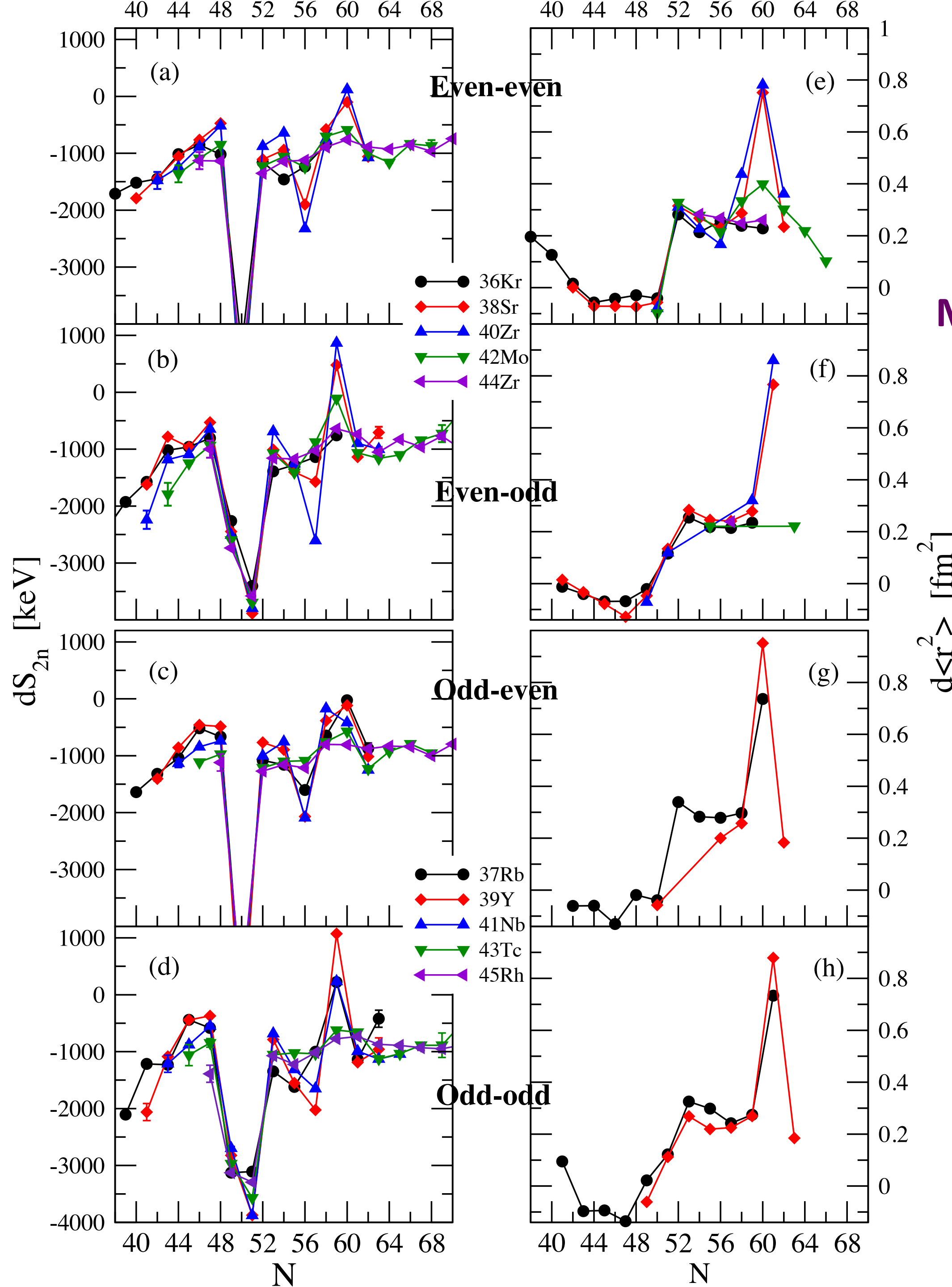
70Yb
72Hf
74W
76Os
78Pt
80Hg
82Pb
a [MeV^{-1}]
N
20
19
18
17
16
15
14
13
12
11
10
9
8
84
88
92
96
100
104
108
112
116
120
124
128
132

Mass ~150

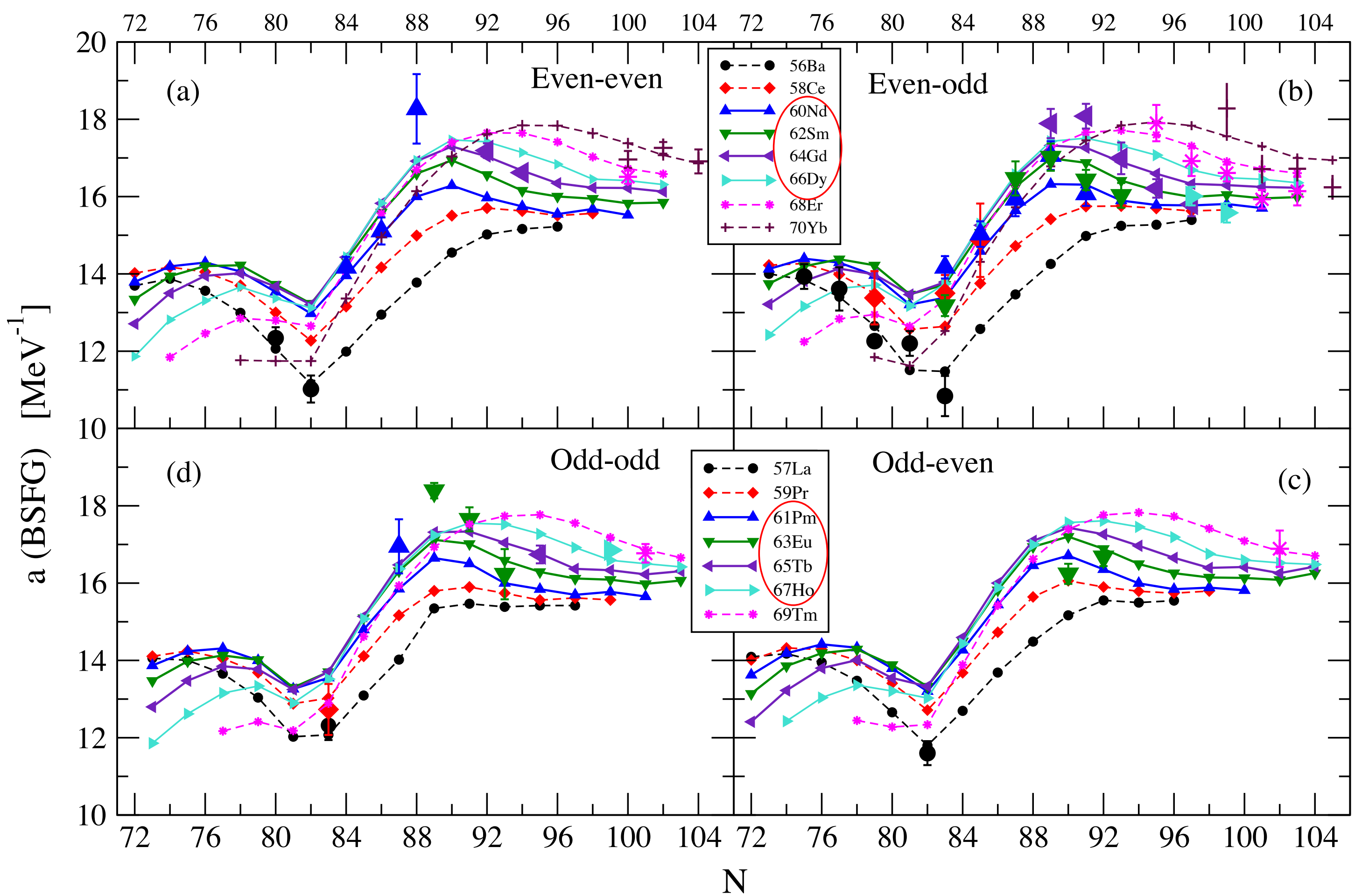
$dS_{2n}(Z,A)=S_{2n}(Z,A+2)-S_{2n}(Z,A)$

$d\langle r^2\rangle(Z,A)=\langle r^2\rangle(Z,A)-\langle r^2\rangle(Z,A-2)$




Even-even
Even-odd
Odd-even
Odd-odd
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
36Kr
38Sr
40Zr
42Mo
44Zr
37Rb
39Y
41Nb
43Tc
45Rh
dS2n [keV]
d<r2> [fm2]
N

Mass ~100



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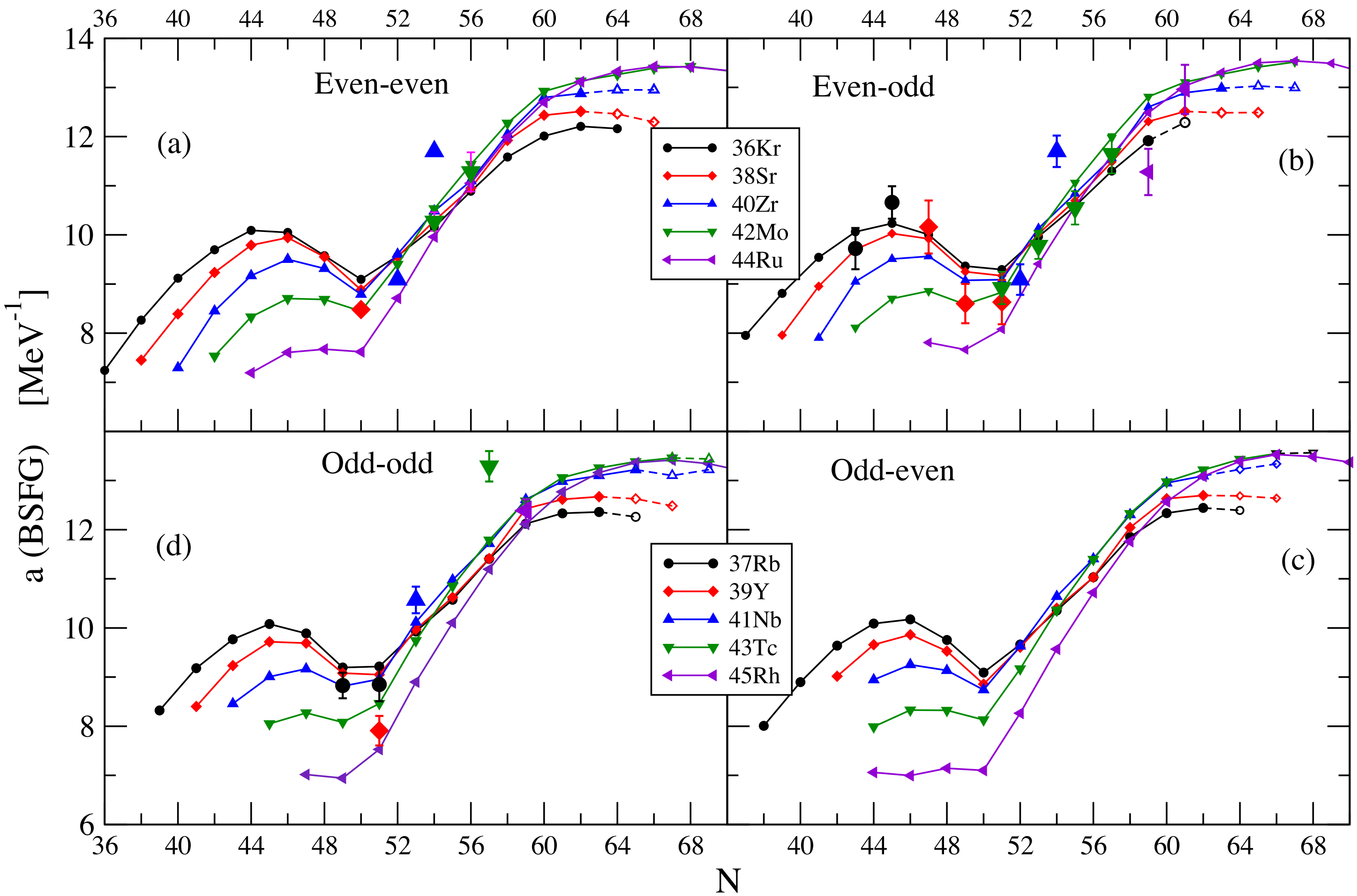
a (BSFG) [MeV^{-1}]
N



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a (BSFG) [MeV^{-1}]
N