MICROSCOPIC DESCRIPTION OF OCTUPOLE DEFORMATIONS IN EVEN-EVEN Xe AND Ba ISOTOPES

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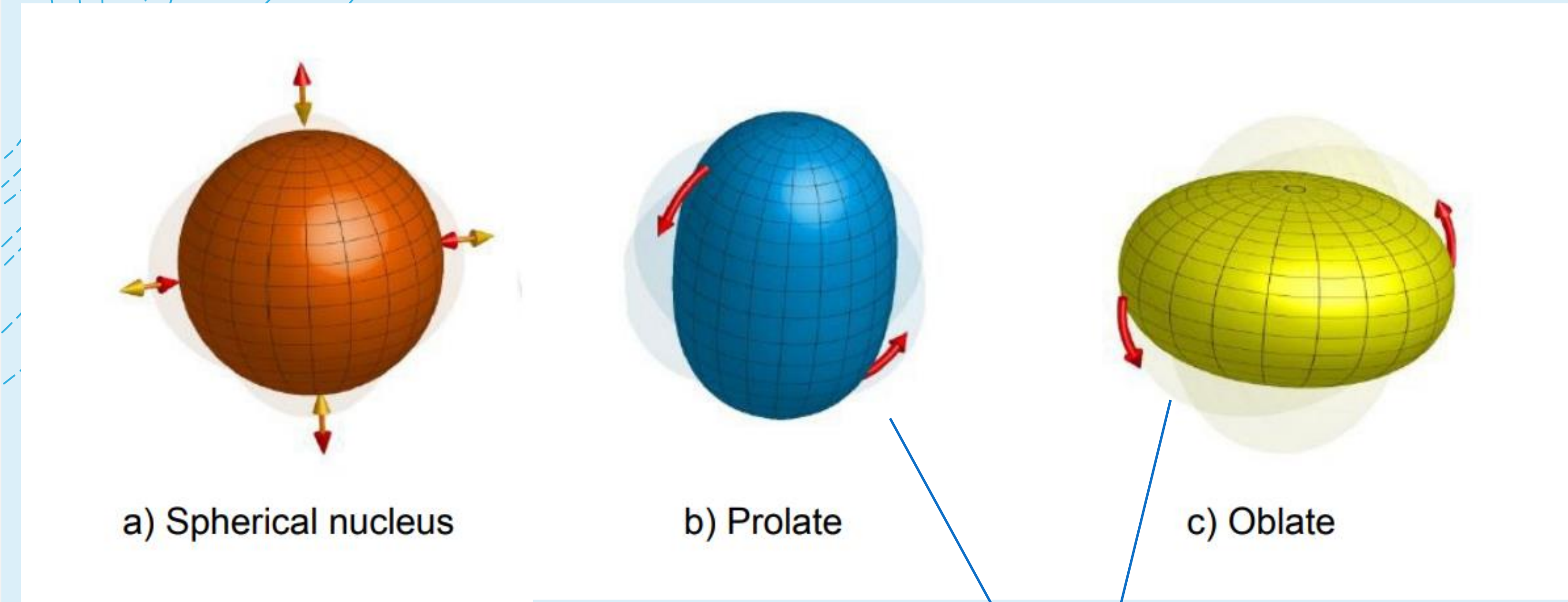
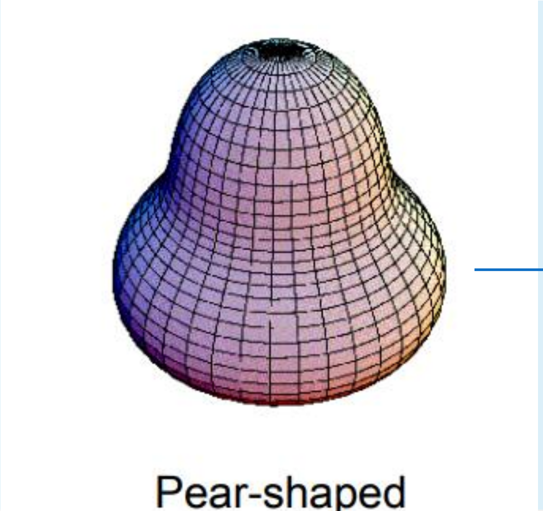
+ 11th of July, 2022

+Introduction:

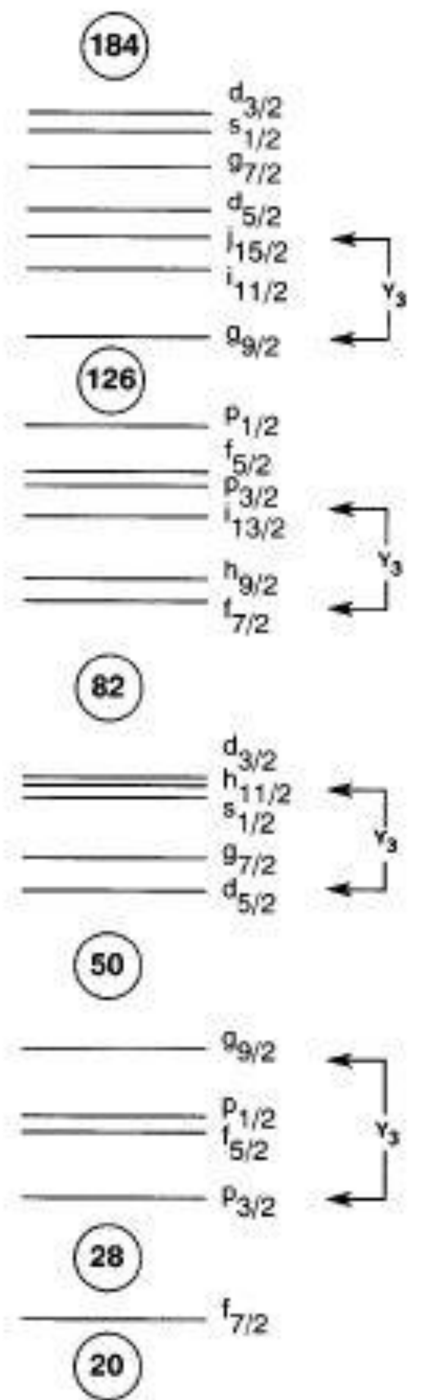
- Octupole deformations: N or Z near 34, 56, 88, 134



Quadrupole deformations



Octupole deformations



+ Introduction:

- The goal: exploration of octupole correlations and intrinsic octupole shapes for even-even Xe (Z=54) and Ba (Z=56) isotopes in the region $N \approx 56$ and $N \approx 88$, calculation of low-lying energy spectra and transition strengths B(E1), B(E2), B(E3)

- Octupole collectivity in the region $N \approx Z \approx 56$ has not been as extensively studied as in actinides $(N \approx 134,\ Z \approx 88)$ and lanthanides $(N \approx 88,\ Z \approx 56)$

- Calculations: SCMF calculations with the DD-PC1 functional

- Extension of SCMF: Quadrupole-octupole collective Hamiltonian (QOCH)

+ SCMF calculations:

- Relativistic Hartree – Bogoliubov (RHB) method:
- DD-PC1 functional + the separable pairing force of finite range
- Axially symmetric quadrupole and octupole moments:

$$\hat{Q}_{20} = 2z^2 - x^2 - y^2$$
$$\hat{Q}_{30} = 2z^3 - 3z(x^2 + y^2)$$

- Quadrupole and octupole deformation parameters:

$$\beta_2 = \frac{\sqrt{5\pi}}{3r_0^2 A^{5/3}} \langle \hat{Q}_{20} \rangle$$
$$\beta_3 = \frac{\sqrt{7\pi}}{3r_0^3 A^2} \langle \hat{Q}_{30} \rangle$$

RHB: D. Vretenar, A. V. Afanasjev, G. A. Lalazissis, and P. Ring, Phys. Rep. 409, 101 (2005)

DD-PC1: T. Nikšić, D. Vretenar, and P. Ring, Phys. Rev. C 78, 034318 (2008).

+QOCH calculations:

- Hamiltonian:

$$\hat{H}_{coll} = T_{vib} + T_{rot} + V_{coll}$$

- Vibrational kinetic energy:

$$T_{vib} = \frac{1}{2} B_{22}\dot{\beta}_2^2 + B_{23}\dot{\beta}_2\dot{\beta}_3 + \frac{1}{2} B_{33}\dot{\beta}_3^2$$

- Rotational kinetic energy:

$$T_{rot} = \frac{1}{2}\sum_{k=1}^{3} \mathfrak{I}_k \omega_k^2$$

S. Y. Xia, H. Tao, Y. Lu, Z. P. Li, T. Nikšić, and D. Vretenar, Phys. Rev. C 96, 054303 (2017).

+ QOCH calculations:

- Collective potential: includes zero-point energy (ZPE) corrections

- Collective Hamiltonian after quantization:

$$\hat{H}_{coll} = -\frac{\hbar^2}{2\sqrt{\omega I}}\left[\frac{\partial}{\partial\beta_2}\sqrt{\frac{\mathfrak{T}}{\omega}}B_{33}\frac{\partial}{\partial\beta_2} - \frac{\partial}{\partial\beta_2}\sqrt{\frac{\mathfrak{T}}{\omega}}B_{23}\frac{\partial}{\partial\beta_3} - \frac{\partial}{\partial\beta_3}\sqrt{\frac{\mathfrak{T}}{\omega}}B_{23}\frac{\partial}{\partial\beta_2} + \frac{\partial}{\partial\beta_3}\sqrt{\frac{\mathfrak{T}}{\omega}}B_{22}\frac{\partial}{\partial\beta_3}\right] + \frac{\hat{J}^2}{2\mathfrak{T}} + V_{coll}(\beta_2, \beta_3)$$

- Mass parameters are defined as the inverse of mass tensors: $B_{ij}(\boldsymbol{q}) = \mathcal{M}_{ij}^{-1}(\boldsymbol{q})$
- Cranking approximation:

$$\mathcal{M}^{C_p} = \hbar^2 M_{(1)}^{-1} M_{(3)} M_{(1)}^{-1}$$

$$\left[M_{(k)}\right]_{ij} = \sum_{\mu\nu}\frac{\langle 0|\hat{Q}_i|\mu\nu\rangle\langle\mu\nu|\hat{Q}_j|0\rangle}{\left(E_\mu + E_\nu\right)^k}$$

+QOCH calculations:

- ZPE energy:

$$E_{ZPE} = \frac{1}{4} Tr\left[M_{(2)}^{-1} M_{(1)}\right]$$

- The basis functions:

$$|n_2 n_3 IMK\rangle = (\omega\mathfrak{T})^{-\frac{1}{4}} \phi_{n_2}(\beta_2) \phi_{n_3}(\beta_3) |IMK\rangle$$

1D harmonic oscillator wave functions

- Collective wave function:

$$\Psi_{\alpha}^{IM\pi}(\beta_2, \beta_3, \Omega) = \psi_{\alpha}^{I\pi}(\beta_2, \beta_3) |IM0\rangle$$

Euler angles

+ QOCH calculations:

- The probability density distribution:

$$\rho_\alpha^{I\pi}(\beta_2,\beta_3) = \sqrt{\omega\mathfrak{T}}|\psi_\alpha^{I\pi}(\beta_2,\beta_3)|^2$$

-Transition probabilities:

$$B(E\lambda; I_i \to I_f) = \left|\langle I_i 0 \lambda 0 | I_f 0\rangle\right|^2 \left|\int d\beta_2 d\beta_3 \sqrt{\omega\mathfrak{T}}\psi_i \mathcal{M}_{E\lambda}(\beta_2,\beta_3)\psi_f^*\right|^2$$

- Operators $\widehat{\mathcal{M}}_{E\lambda}$:

$$D_1 = \sqrt{\frac{3}{4\pi}}e\left(\frac{N}{A}z_p - \frac{Z}{A}z_n\right)$$

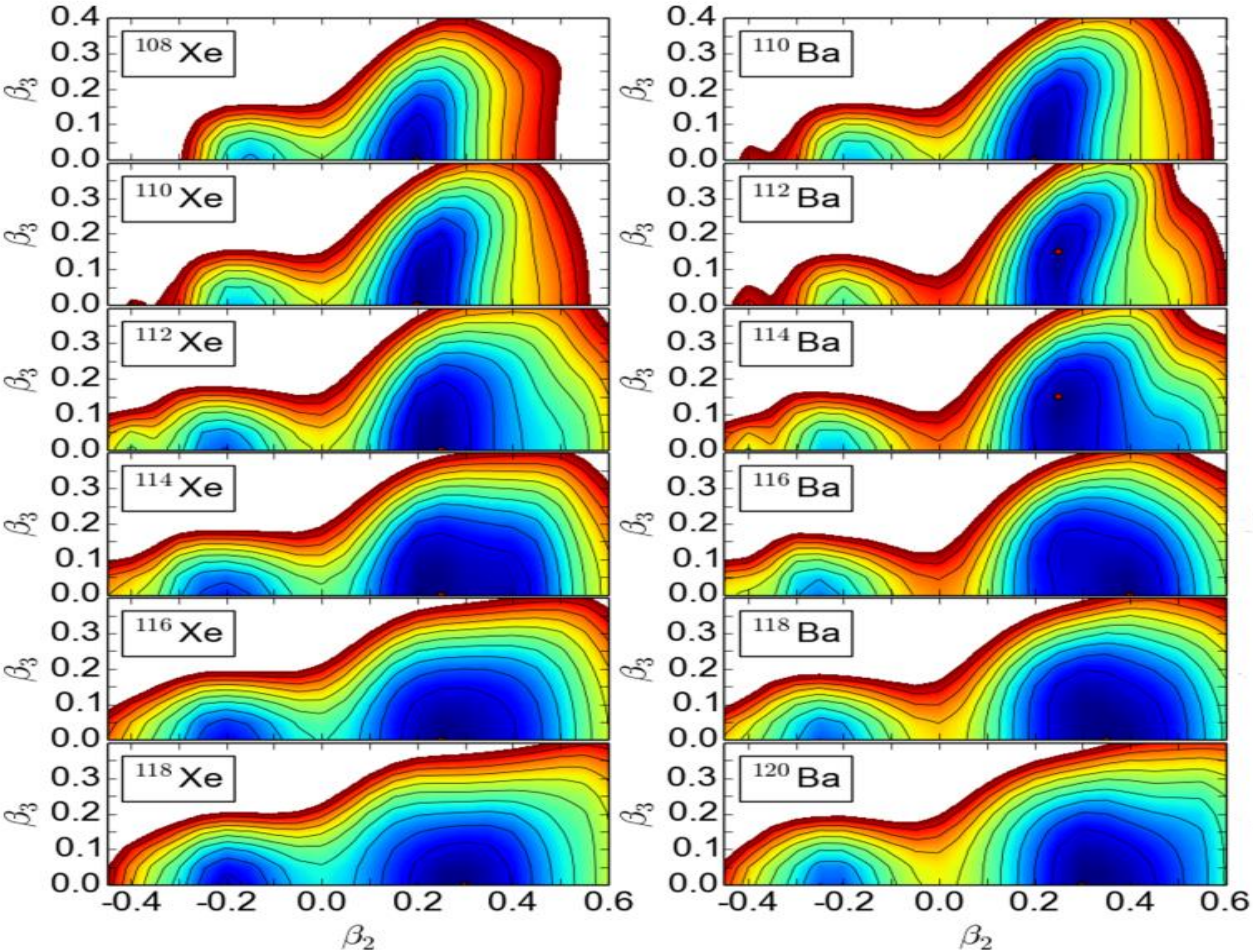
$$Q_2^p = \sqrt{\frac{5}{16\pi}}e\left(2z_p^2 - x_p^2 - y_p^2\right)$$

$$Q_3^P = \sqrt{\frac{7}{16\pi}}e\left(2z_p^3 - 3z_p\left(x_p^2 + y_p^2\right)\right)$$

- Results:

- Neutron deficient Xe and Ba isotopes – potential energy surface (PES)

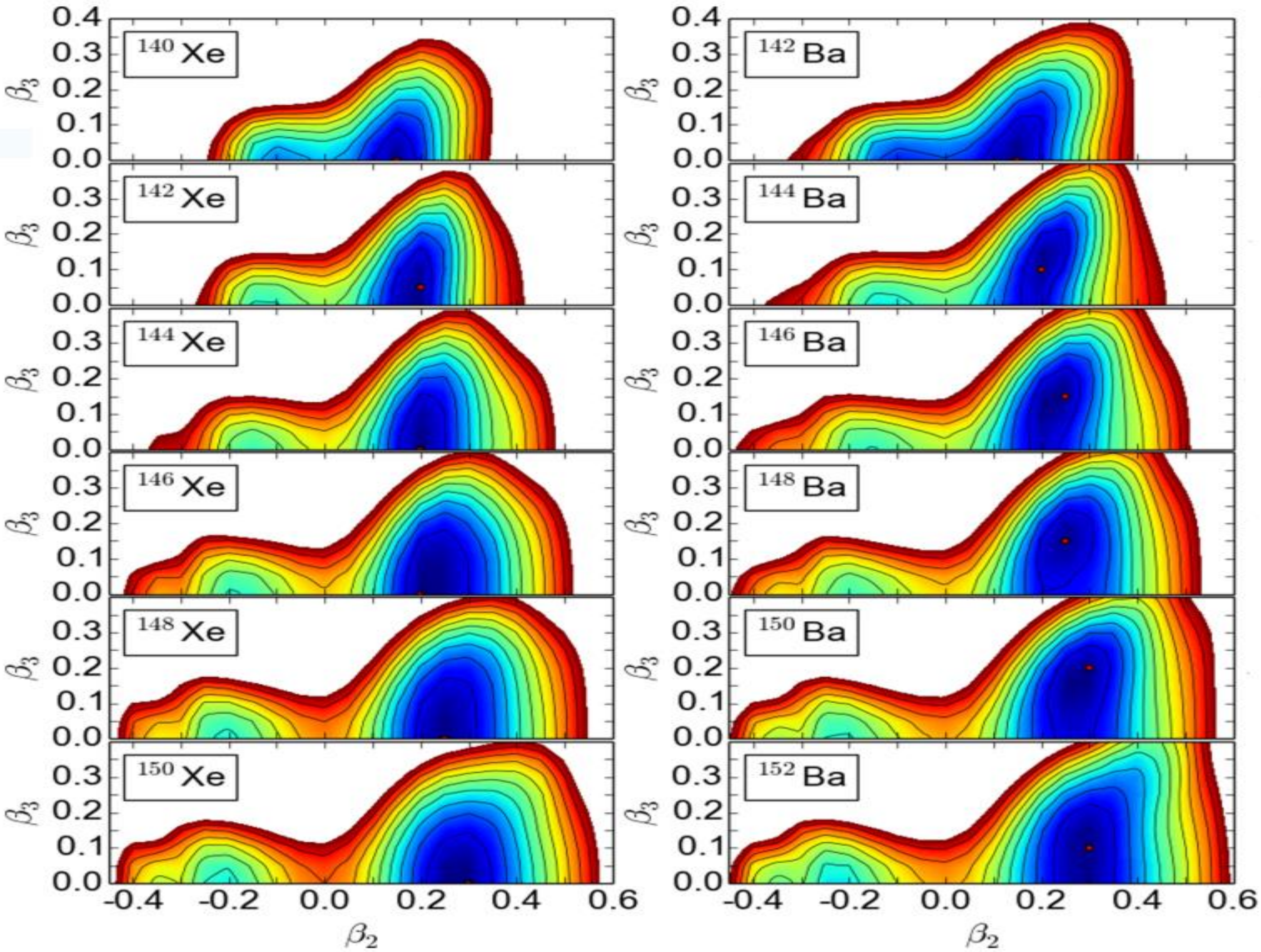
- Intrinsic octupole deformations: ^{112}Ba (N=56), ^{114}Ba (N=58)



+ Results:

- Neutron rich Xe and Ba – PES:

- Intrinsic octupole deformations: ^{142}Xe (N=88), $^{144-152}$Ba (N=88 – 96)



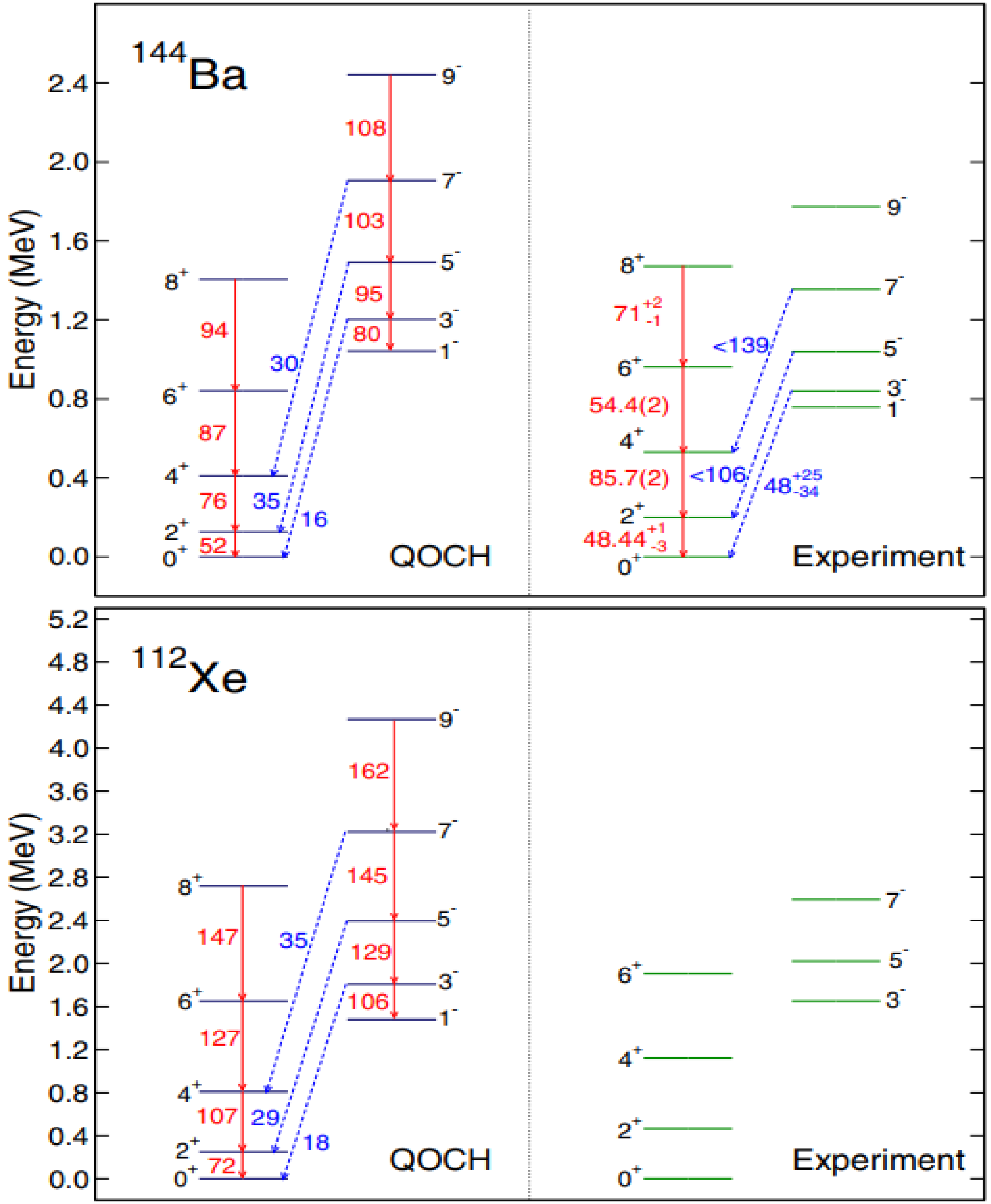
+ Results:

- Energy spectrum: examples ^{144}Ba and ^{112}Xe:

- Numbers along the arrows stand for B(E2) (red) and B(E3) (blue) transition strengths in Weisskopf units

- Positive-parity band energies and transition strengths in good agreement with experimental data

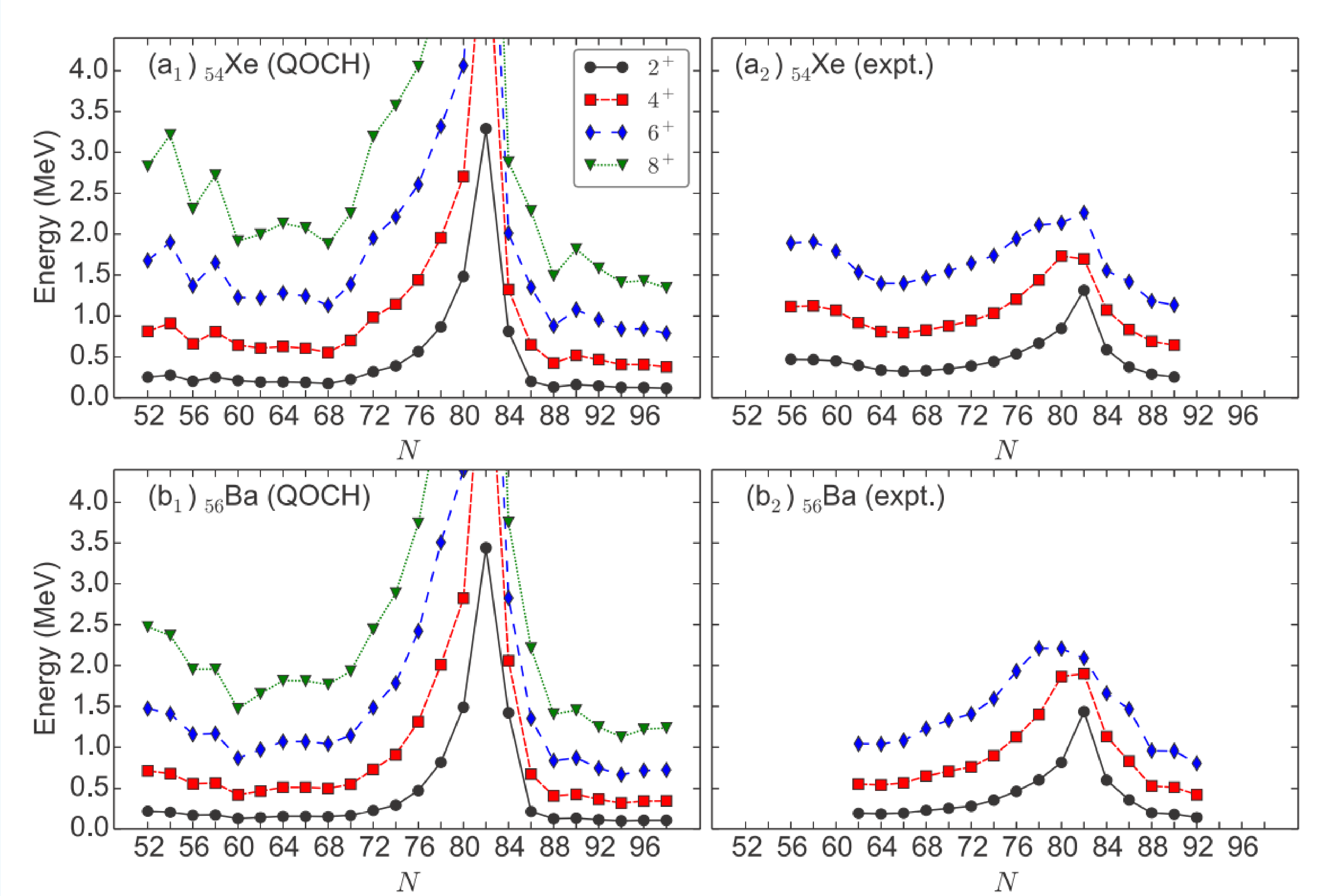
- Moments of inertia of negative parity bands are smaller than the measured ones



+ Results:

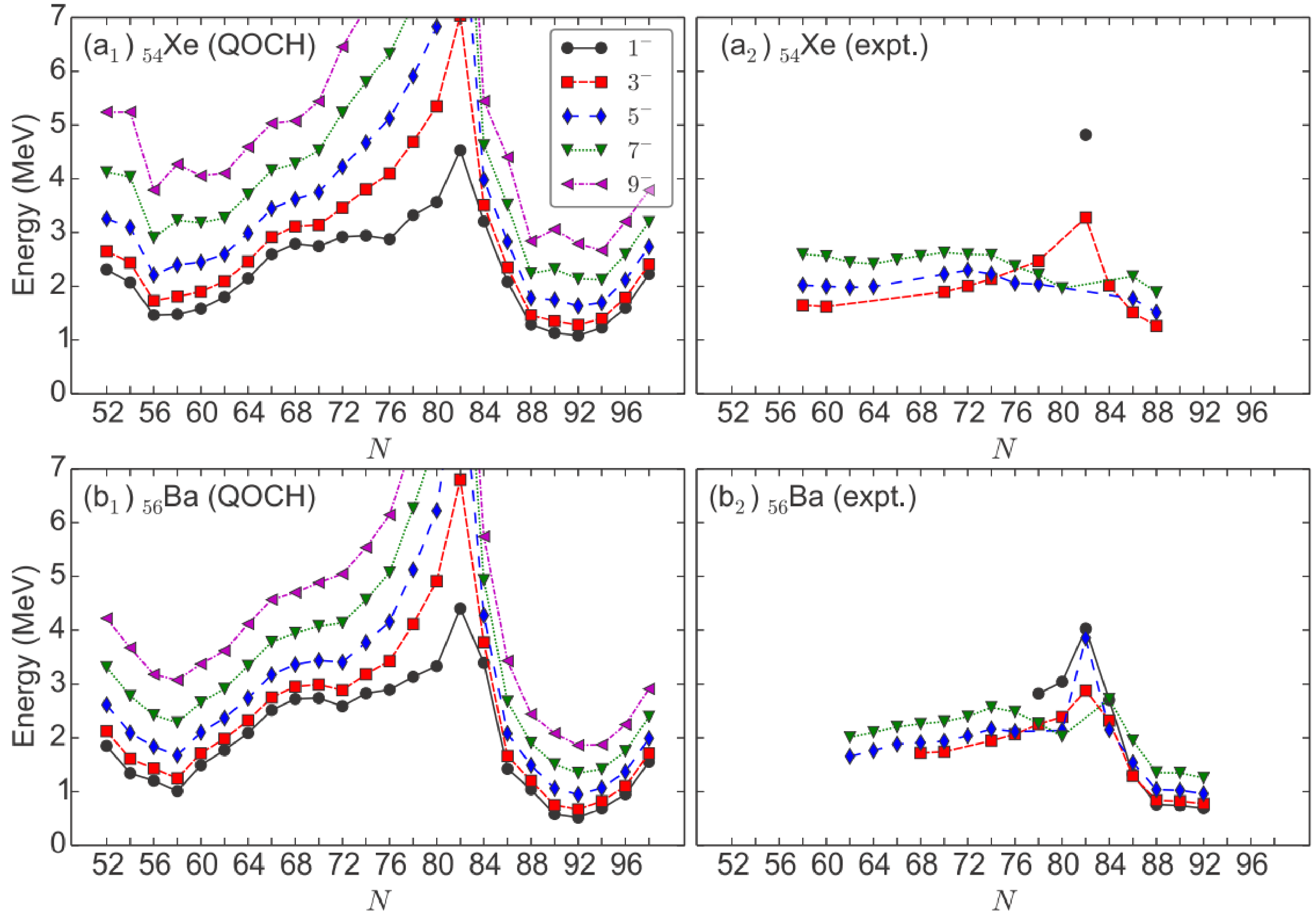
- Low energy excitation spectra - positive parity band:

- Good agreement with experimental data, except around the magic number N=82



+ Results:

- Low energy excitation spectra – negative parity bands:



- Parabolic behaviour of negative-parity band energies with respect to „octupole magic numbers" N=56, N=88; signature of octupole collectivity

+ Good agreement with experimental data around N=56 and N=88

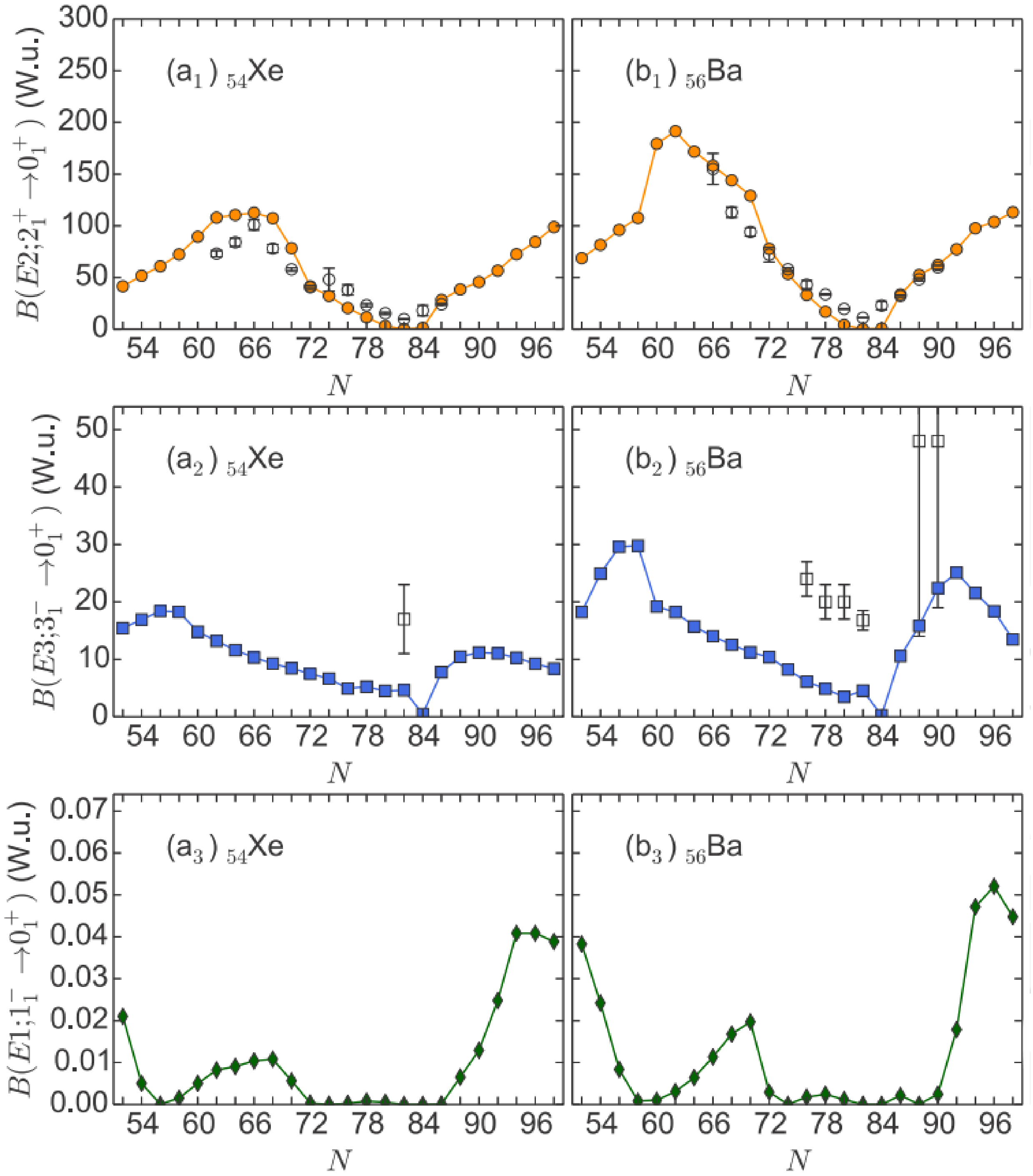
+ Results:

- Transition strengths B(E1), B(E2), B(E3):

- Good agreement with experimental data for B(E2) transition strengths

- B(E3) values significantly lower compared to measured values

- No experimental data for B(E1) transition strengths



Conclusion:

- QOCH calculations mostly in good agreement with experimental data
- Intrinsic octupole deformations calculated for one Xe and seven Ba isotopes, two Ba isotopes (^{112}Ba, ^{114}Ba) in the ($N \approx Z \approx 56$) region
- Positive parity band energies and B(E2) transition strengths well reproduced (exception around N=82)
- Negative parity band energies well reproduced in the regions $N \approx 56$ and $N \approx 88$
- A limitation of the model: restricted to axially-symmetric shapes; inclusion of triaxial shape degrees of freedom might lead to improved results

+ Data taken from:

K. Nomura, L. Lotina, T. Nikšić, and D. Vretenar: Microscopic description of octupole collective excitations near N=56 and N=88, Phys. Rev. C **103**, (2021)

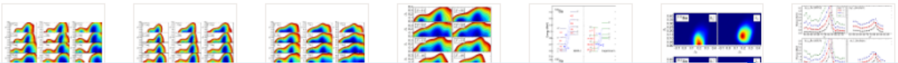
PHYSICAL REVIEW C
covering nuclear physics

Microscopic description of octupole collective excitations near $N = 56$ and $N = 88$

K. Nomura, L. Lotina, T. Nikšić, and D. Vretenar
Phys. Rev. C **103**, 054301 – Published 3 May 2021

ABSTRACT

Octupole deformations and related collective excitations are analyzed using the framework of nuclear density functional theory. Axially symmetric quadrupole-octupole constrained self-consistent mean-field (SCMF) calculations with a choice of universal energy density functional and a pairing interaction are performed for Xe, Ba, and Ce isotopes from proton-rich to neutron-rich regions, and neutron-rich Se, Kr, and Sr isotopes, in which enhanced octupole correlations are expected to occur. Low-energy positive- and negative-parity spectra and transition strengths are computed by solving the quadrupole-octupole collective Hamiltonian, with the inertia parameters and collective potential determined by the constrained SCMF calculations. Octupole-deformed equilibrium states are found in the potential energy surfaces of the Ba and Ce isotopes with $N \approx 56$ and 88. The evolution of spectroscopic properties indicates enhanced octupole correlations in the regions corresponding to $N \approx Z \approx 56$, $Z \approx 88$ and $Z \approx 56$, and $N \approx 56$ and $Z \approx 34$. The average β_{30} deformation parameter and its fluctuation exhibit signatures of octupole shape-phase transition around $N = 56$ and 88.



Issue
Vol. 103, Iss. 5 — May 2021

THE END!