山东大学
SHANDONG UNIVERSITY
空间科学与物理学院
SCHOOL OF SPACE SCIENCE AND PHYSICS

Coexistence and Interplay between nuclear chirality and octupole correlations

Speaker：Liu Chen
Shandong University

闻天逐日 探物究理

- Introduction
- Experimental studies in the A~80 mass region

1. Coexistence of the nuclear chirality and octupole correlations
2. Interplay between nuclear chirality and octupole correlations

- Conclusion

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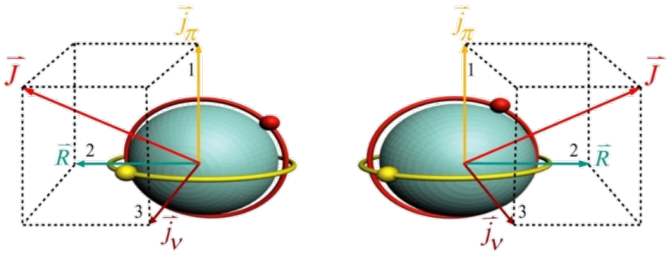
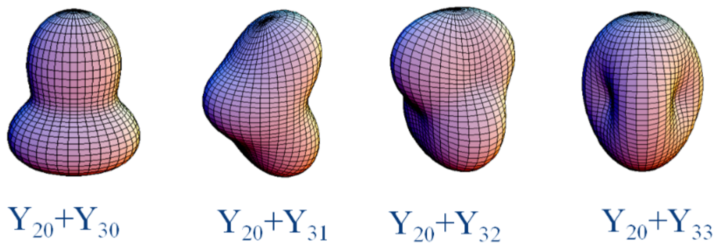
Spontaneous symmetry breaking in nuclei

- Spontaneous symmetry breaking is a fundamental concept in nature.
- The shape of a nucleus can exhibit triaxial or octupole deformation, corresponding to the chiral or reflection symmetry breaking in the intrinsic frame.





chiral symmetry breaking **reflection symmetry breaking**

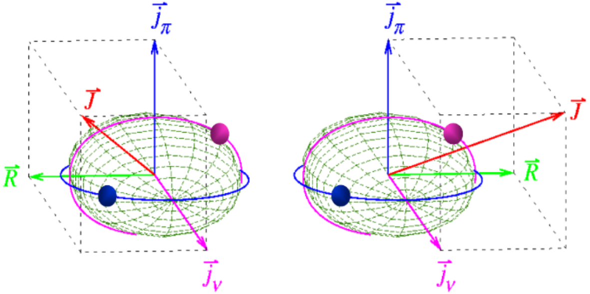
Frauendorf97, Butler96

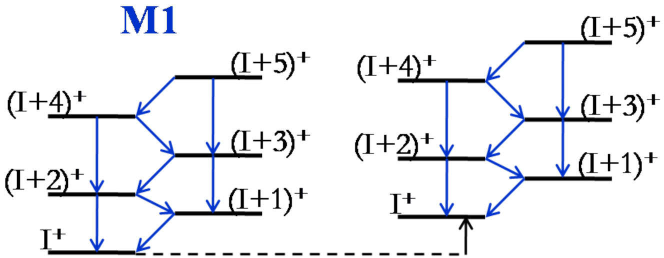
Chiral symmetry breaking in nuclei

- In 1997, Frauendorf and Meng pointed out that the rotation of triaxial nuclei may attain a chiral character -- chiral doublet bands.

Frauendorf & Meng, Nucl. Phys. A617, 131 (1997)

Intrinsic frame





Expected exp. signal： Two near degenerate ΔI =1 bands

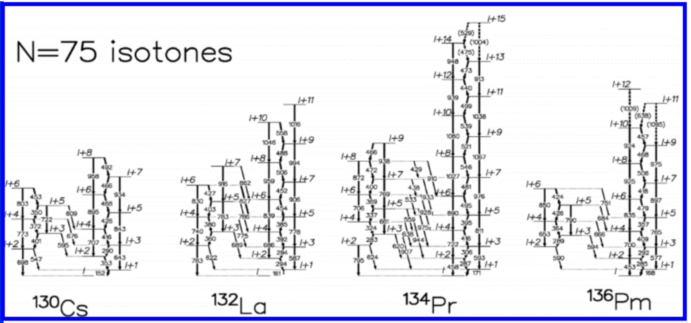
- Chiral nuclei was firstly reported in 2001.

VOLUME 86, NUMBER 6 PHYSICAL REVIEW LETTERS 5 FEBRUARY 2001

Chiral Doublet Structures in Odd-Odd $N = 75$ Isotones: Chiral Vibrations

K. Starosta,[1,*] T. Koike,[1] C. J. Chiara,[1] D. B. Fossan,[1] D. R. LaFosse,[1] A. A. Hecht,[2] C. W. Beausang,[2] M. A. Caprio,[2] J. R. Cooper,[2] R. Krücken,[2] J. R. Novak,[2] N. V. Zamfir,[2,†] K. E. Zyromski,[2] D. J. Hartley,[3] D. L. Balabanski,[3,‡] Jing-ye Zhang,[3] S. Frauendorf,[4] and V. I. Dimitrov[4,‡]

[1]*Department of Physics and Astronomy, SUNY at Stony Brook, Stony Brook, New York 11794*
[2]*Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520*
[3]*Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996*
[4]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556 and Institute for Nuclear and Hadronic Physics, Research Center Rossendorf, 01314 Dresden, Germany*



Starosta *et al*., Phys. Rev. Lett. 86, 971 (2001)

Chiral symmetry breaking in nuclei

- The study of nuclear chiral symmetry has become one of the most important frontiers in nuclear physics.

Focus

Left-Handed Nuclei

Phys. Rev. Focus 7, 4 (2001) – Published January 30, 2001

Certain asymmetrically shaped nuclei can be left-handed or right handed.

http://physics.aps.org/story/v7/st4

"The question of whether stable triaxial nuclear shapes exist has been debated for decades," says Mark Riley of Florida State University in Tallahassee. Starosta and his colleagues have "hit upon the first direct evidence," which Riley says is causing quite a stir in the nuclear physics world.

The question of whether stable triaxial nuclear shapes exist has been debated for decades.
Hit upon the first direct evidence

Understanding how these complex nuclear structures behave mayspill over to other fields as well.

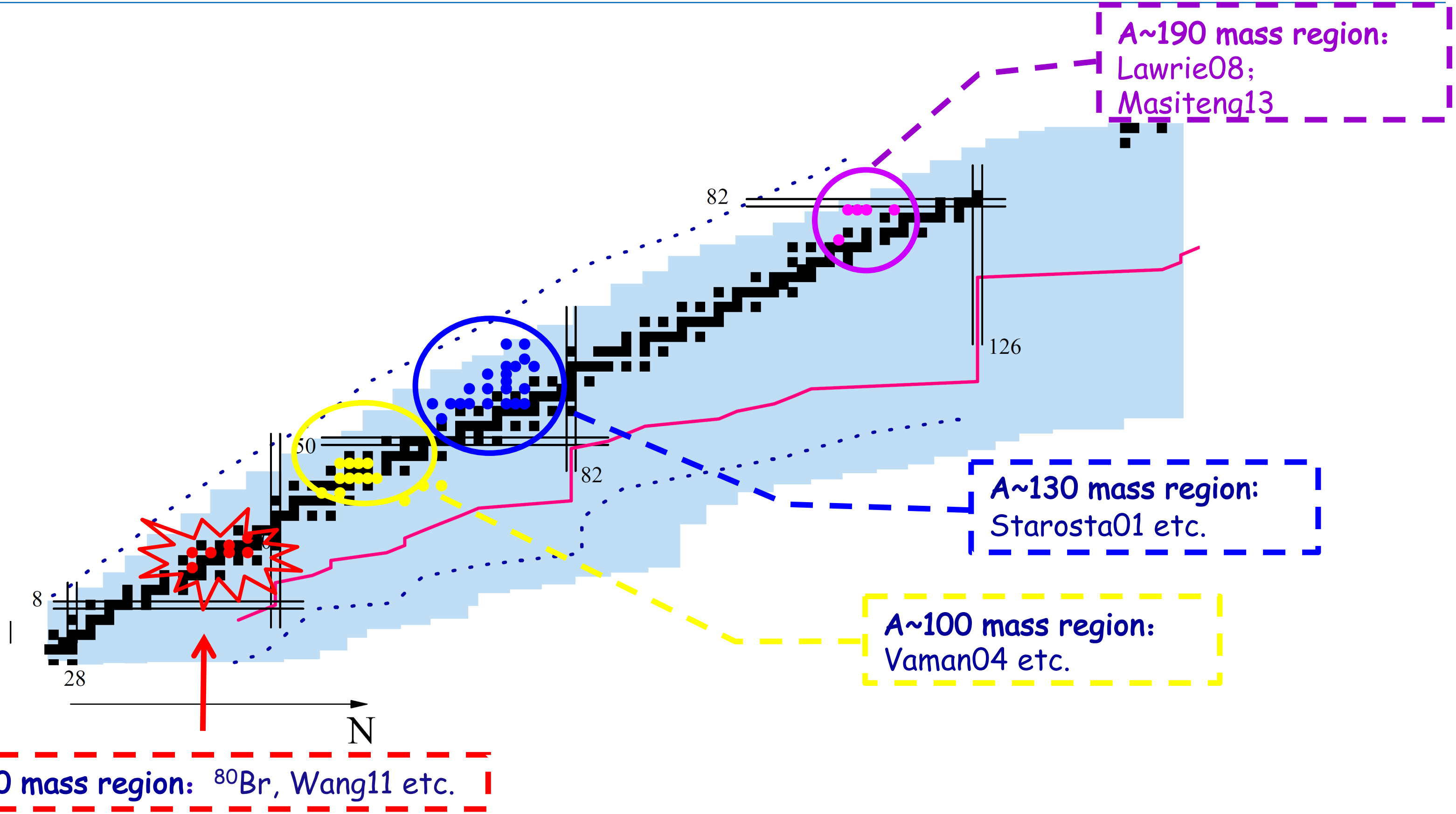
Science

Nuclei Crash Through The Looking-Glass

but we will be searching in other mass regions now." Clark says understanding how these complex nuclear structures behave may spill over to other fields as well. "The ideas and methods for understanding nuclei, molecules, metallic clusters, and atomic condensates all feed off of each other," he notes.

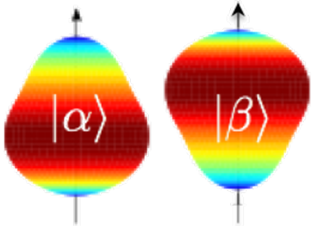
https://www.sciencemag.org/content/291/5506/962.1.full

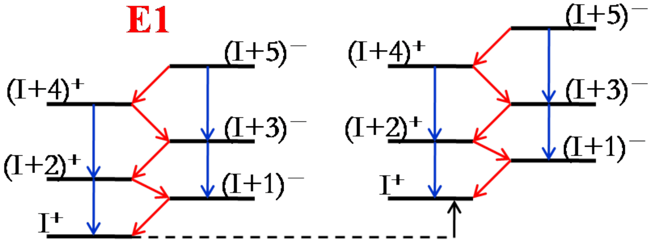
Chiral “islands”

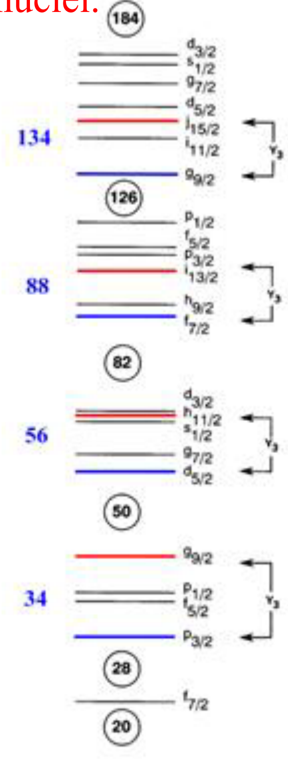


Reflection symmetry breaking in nuclei

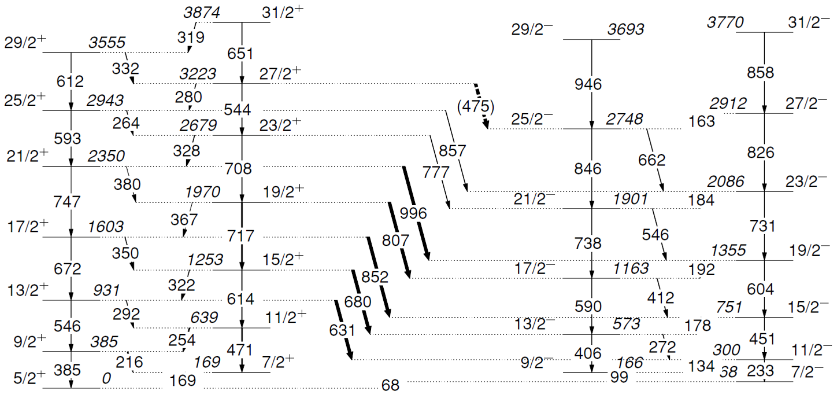
- Reflection-asymmetric shapes can play a role in the band structure of octupole deformed nuclei.







Expected exp. signal： parity doublet bands/ Octupole correlations

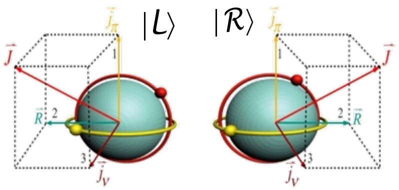


Octupole correlations in ^{125}Ba

P. A. Butler, Rev. Mod. Phys. 1996
P. Mason et al., PRC 2005

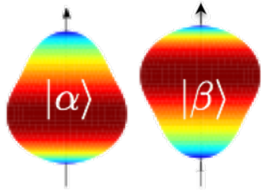
Coexistence and interplay?

Triaxial deformation

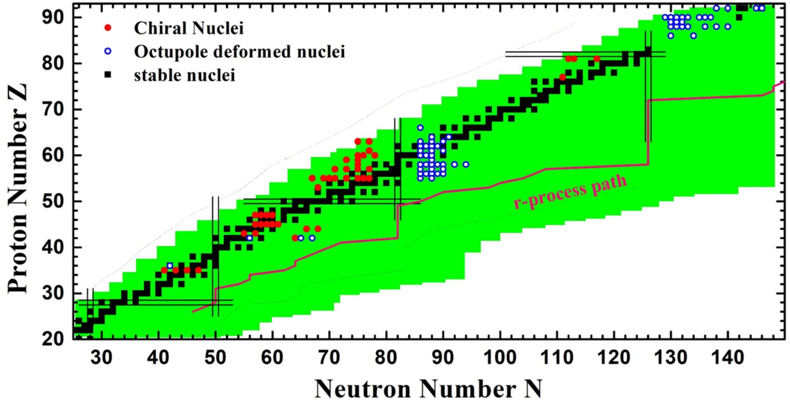


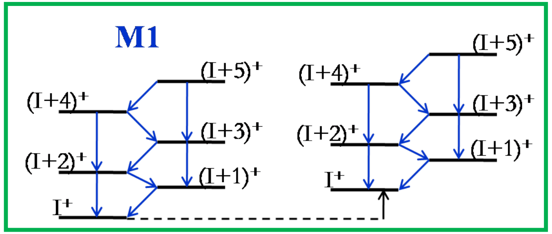
Chiral symmetry

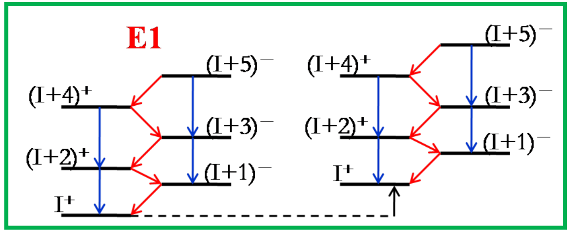
Octupole deformation



Reflection symmetry







Experimental research on chiral and reflection symmetry breaking

Starosta *et al.*, Phys. Rev. Lett. 86, 971 (2001)
Dahlinger *et al.*, Nucl. Phys. A484, 337 (1988)

- The simultaneous breaking of chiral and reflection symmetry is interesting.
- Nuclei in the 80 mass region are good candidates to study the coexistence and interplay between nuclear chirality and octupole correlations.

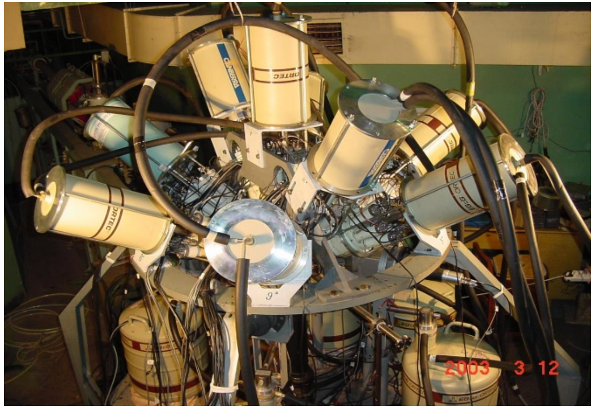
- Introduction
- Experimental studies in the A~80 mass region

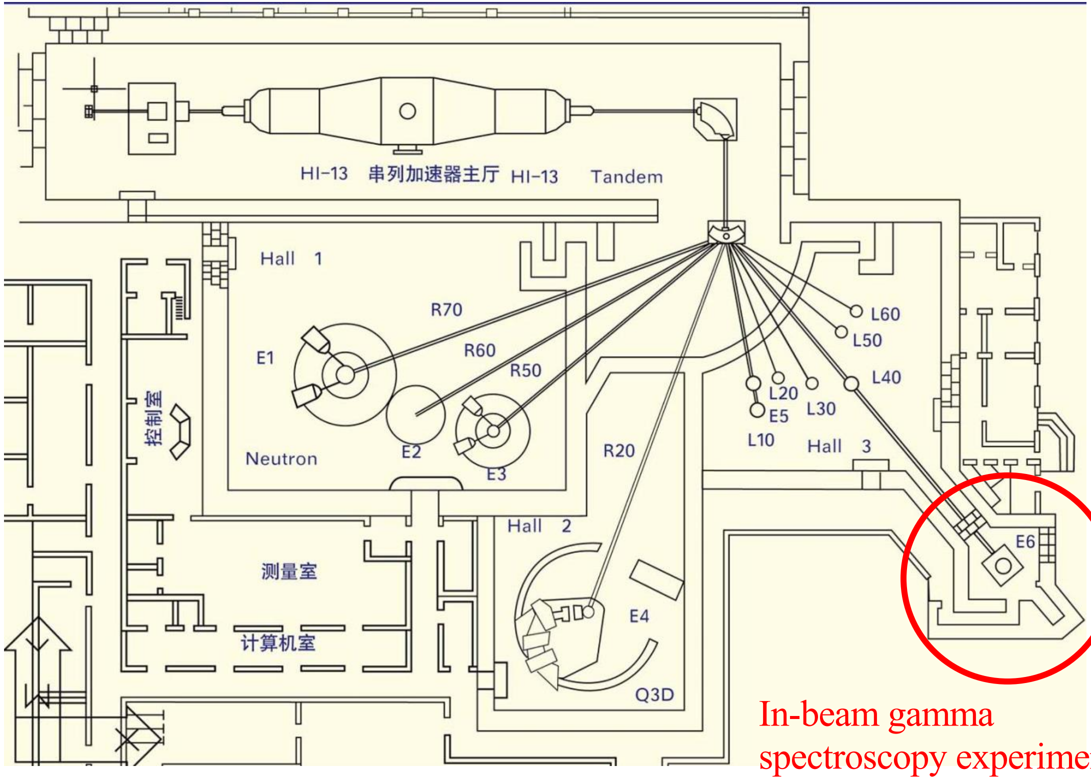
1. Coexistence of the nuclear chirality and octupole correlations
2. Interplay between nuclear chirality and octupole correlations

- Conclusion

Experimental research

- @ China Institute of Atomic Energy



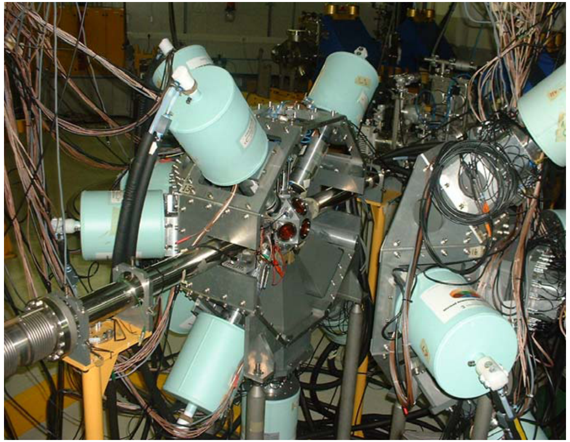


In-beam gamma spectroscopy experiment

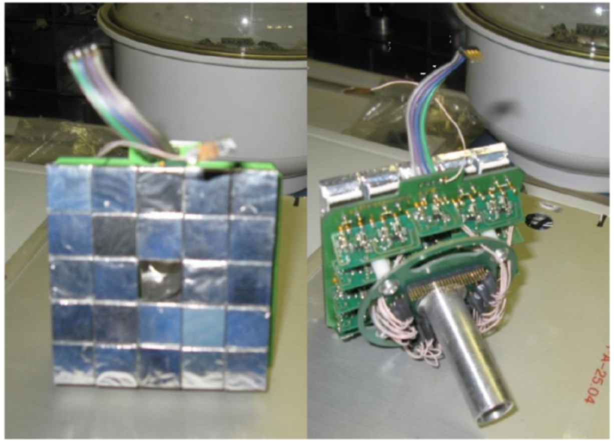
Experimental research

- @ iThemba LABS

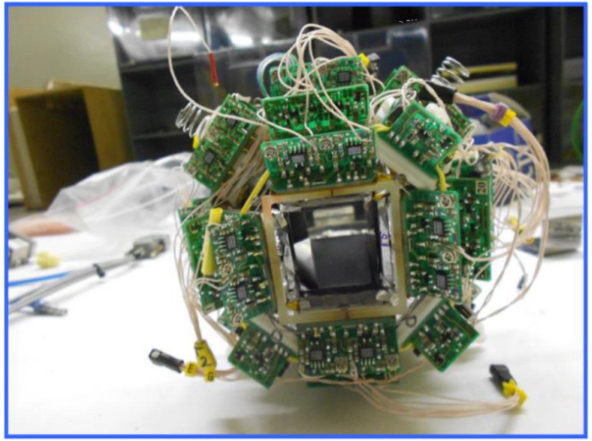
AFRODITE

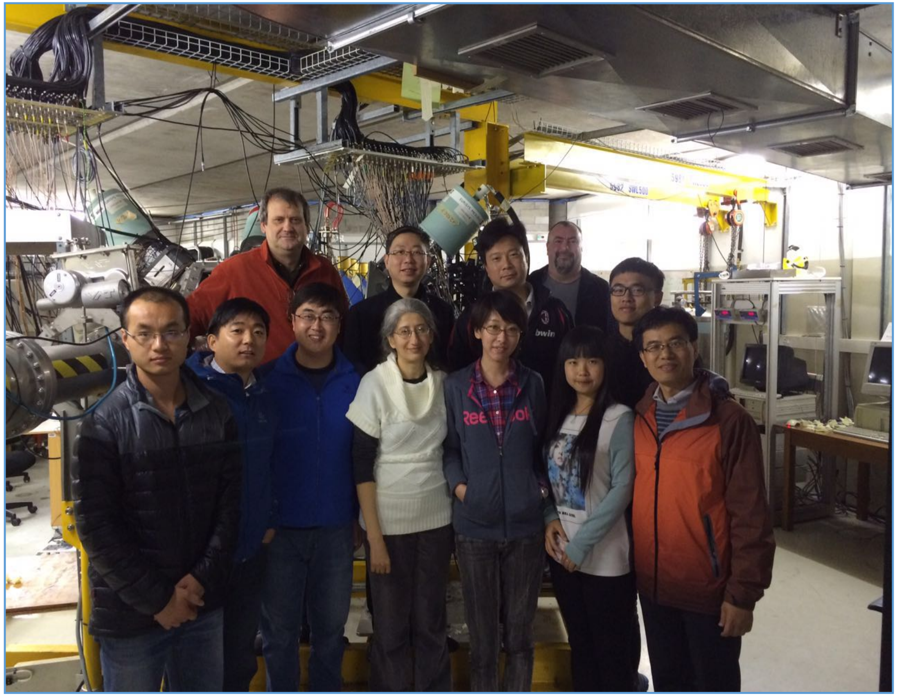


Chessboard



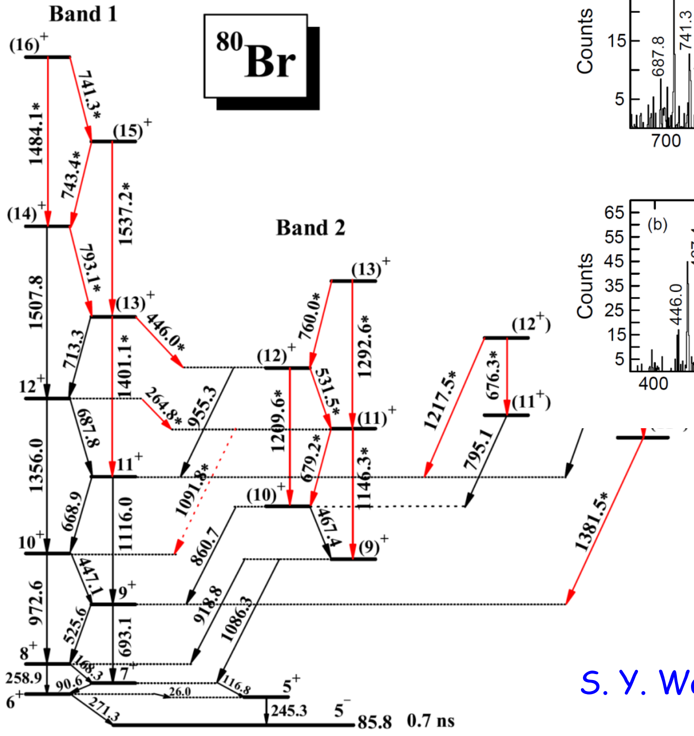
DIAMANT

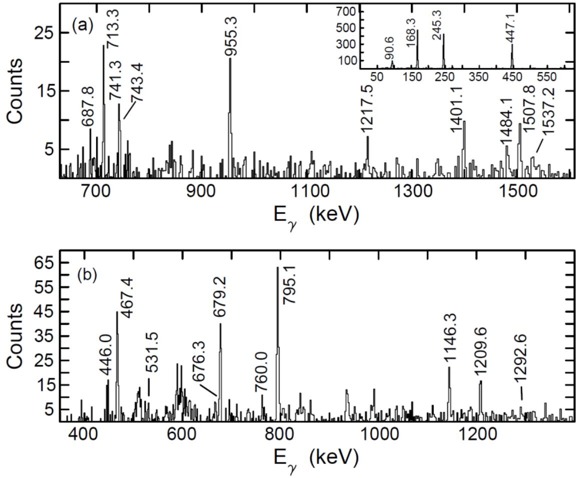


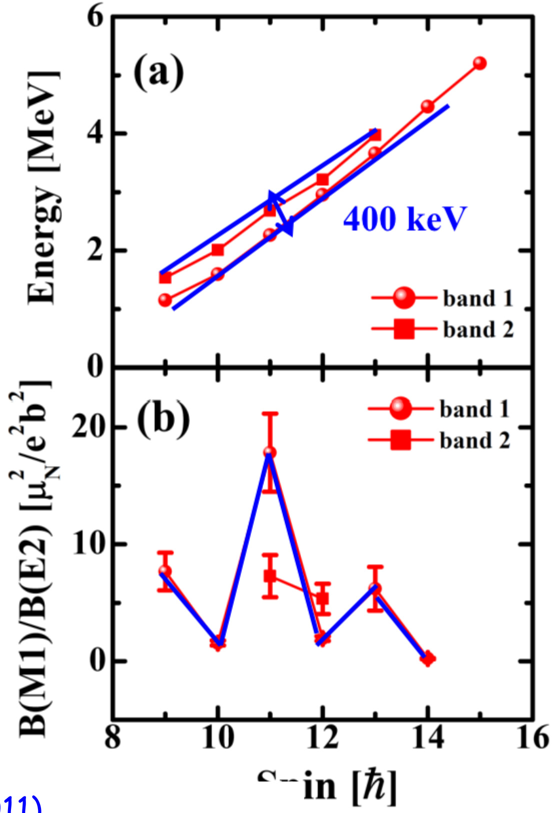


A new “Chiral island”

- A~80 mass region: a newly observed “chiral island”

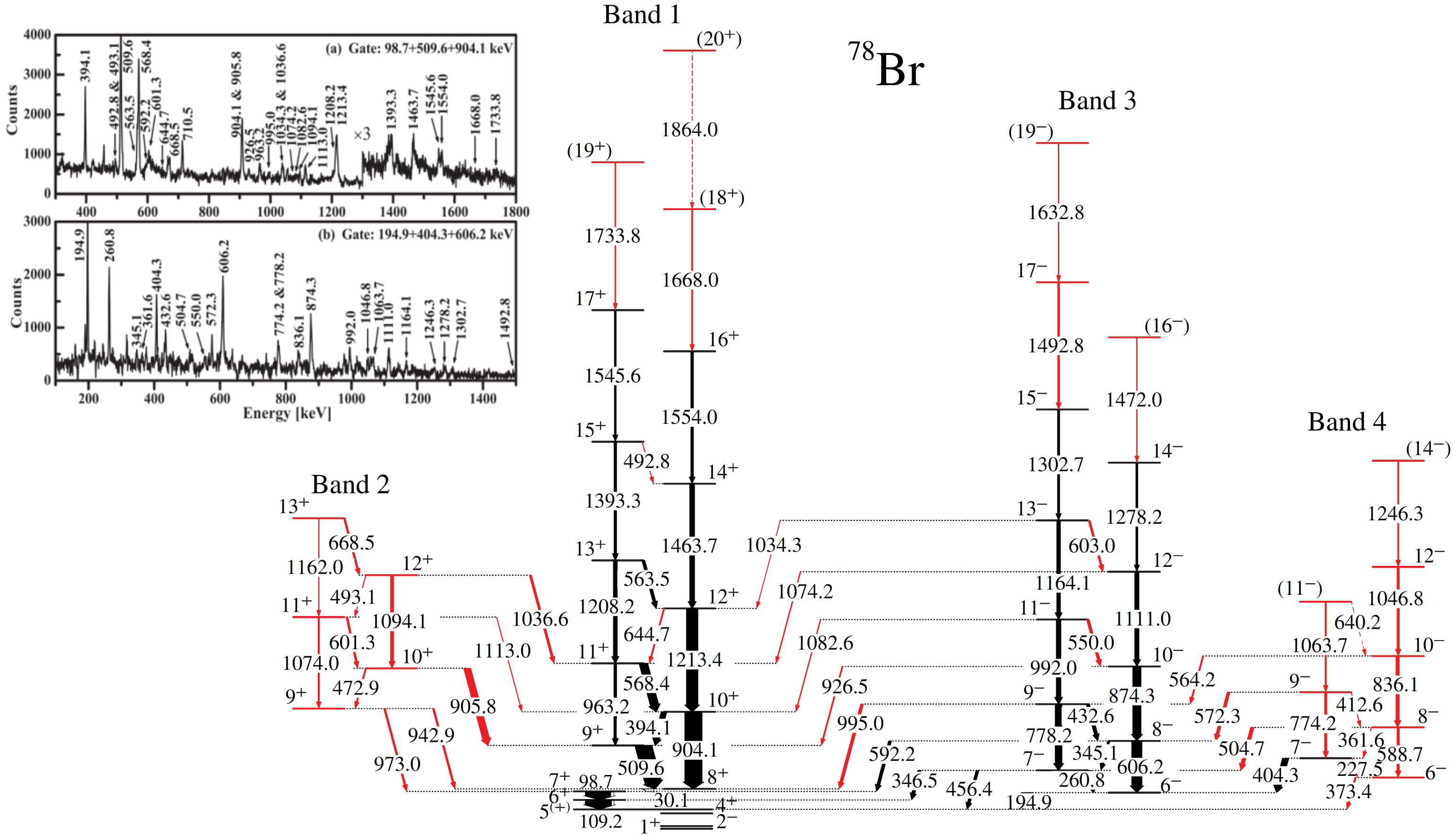






S. Y. Wang et al., Phys. Lett. B703, 40(2011)

Coexistence of nuclear chirality and octupole correlations



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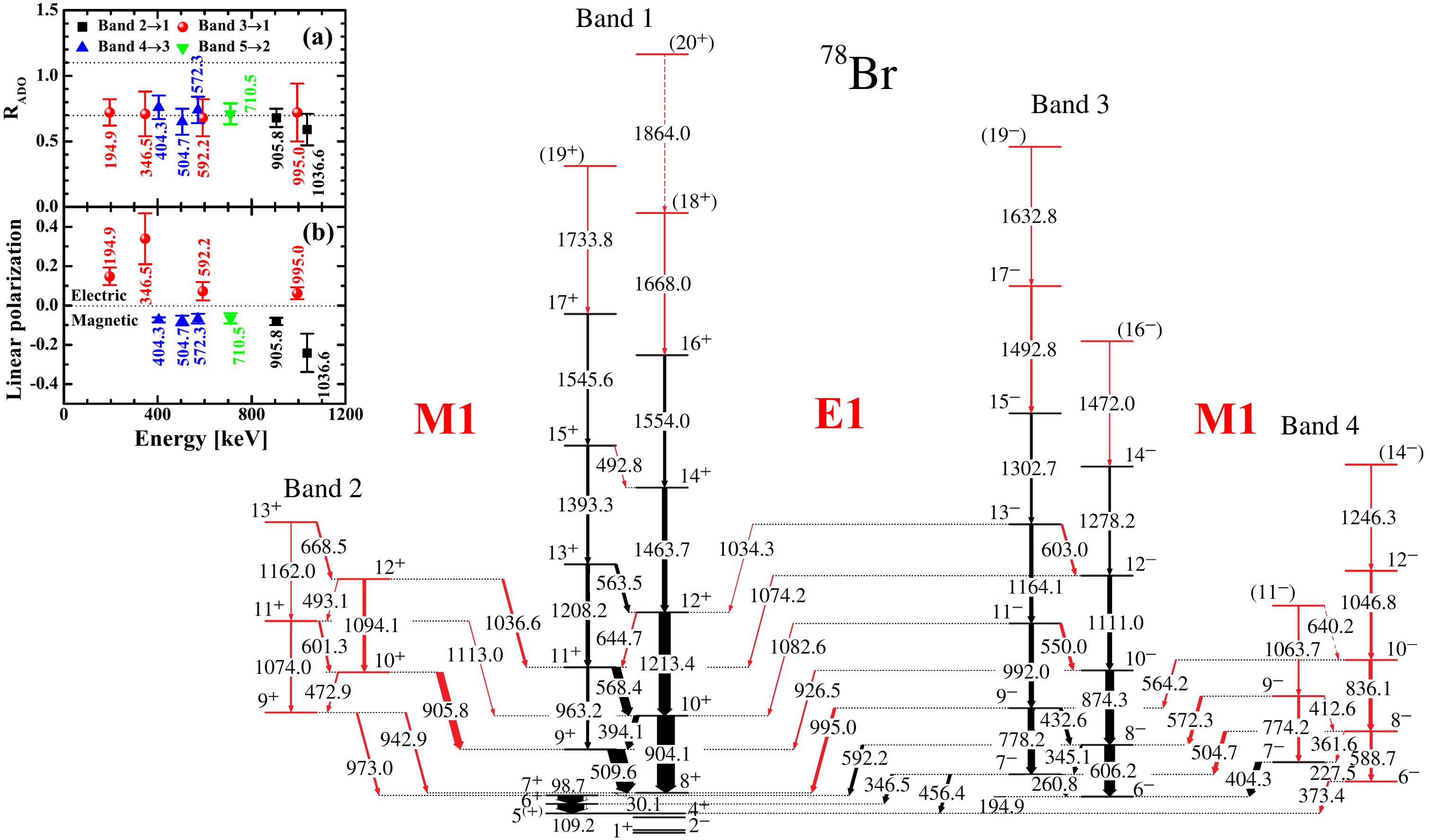
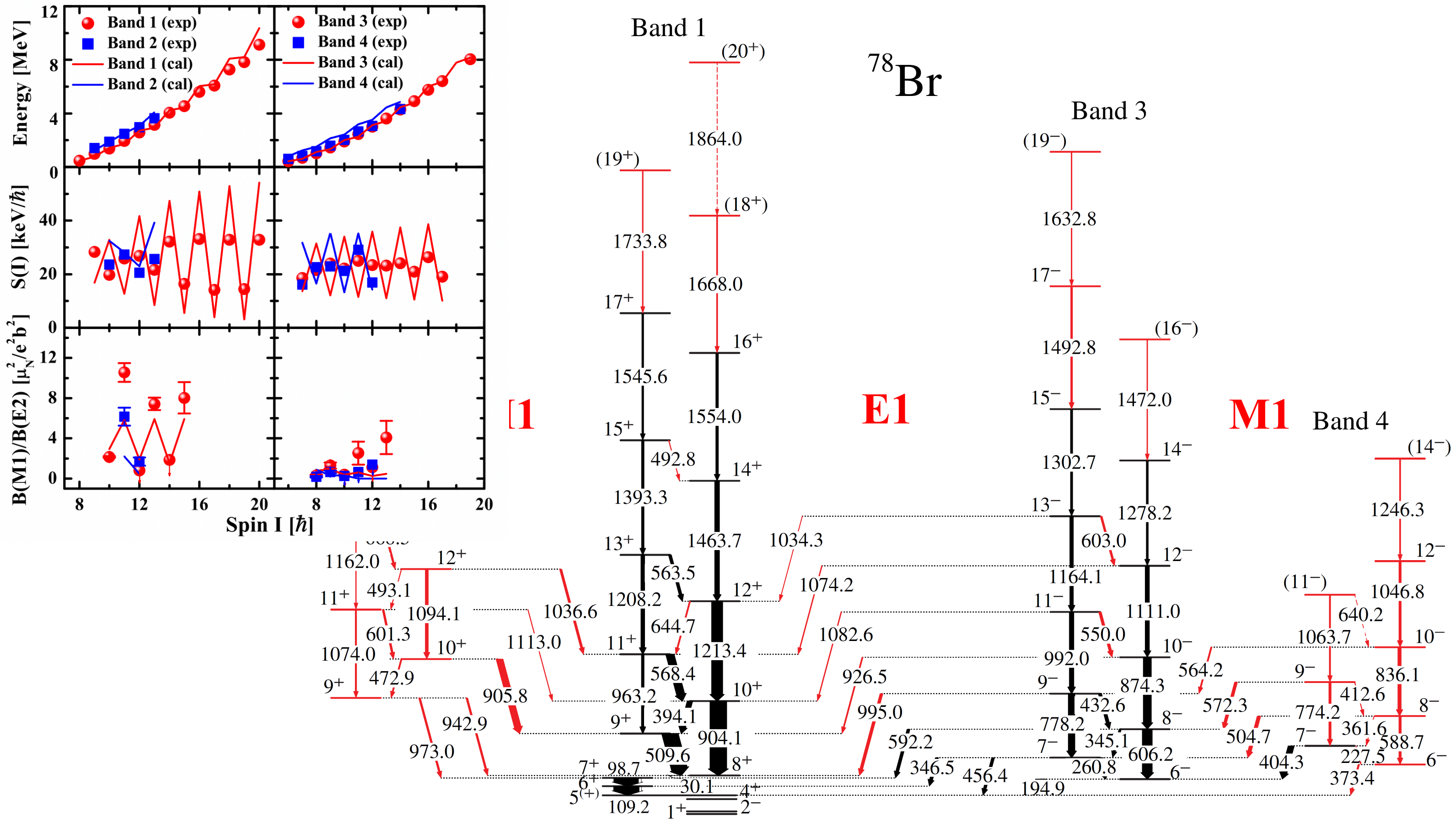
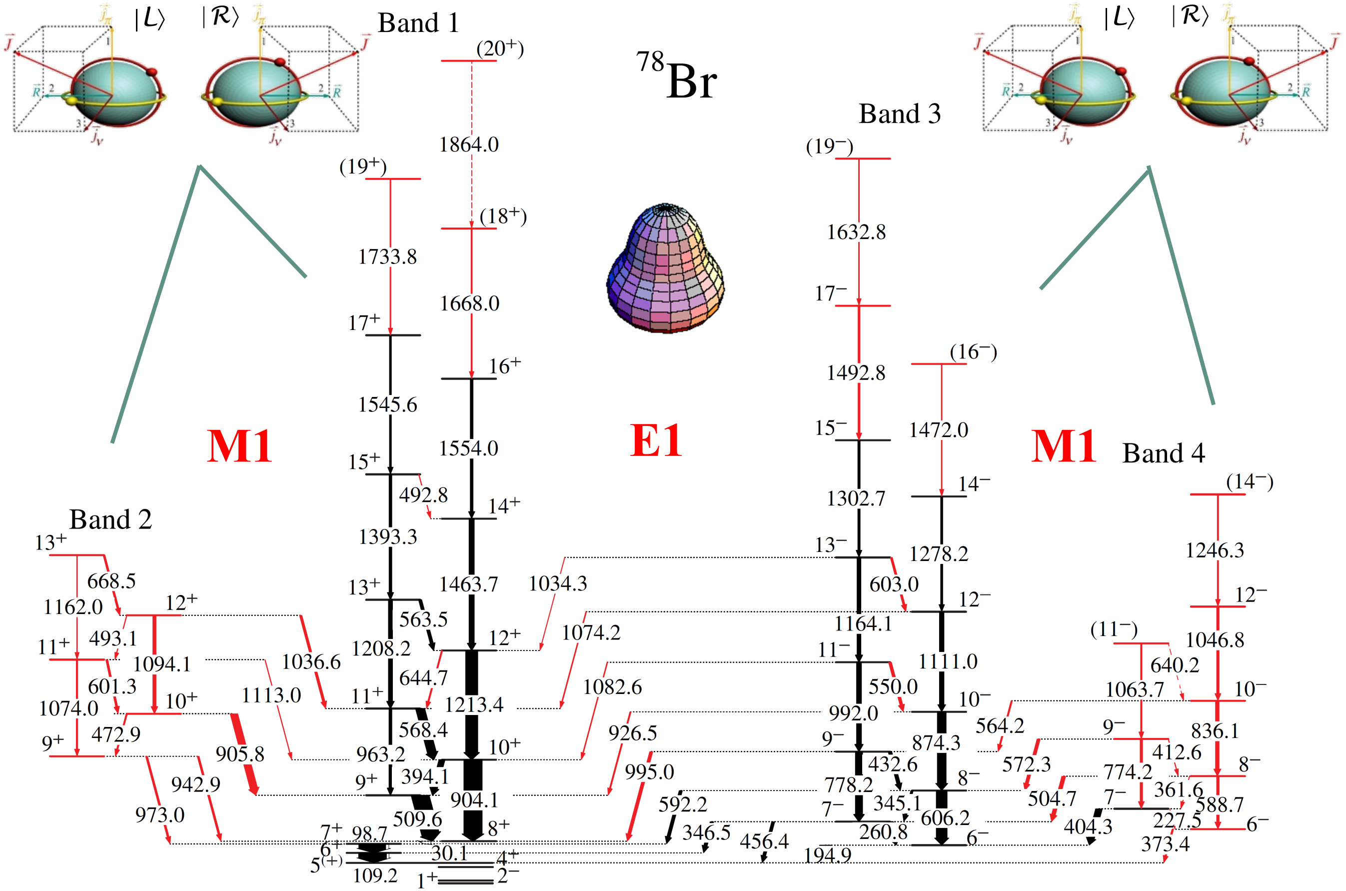
Coexistence of nuclear chirality and octupole correlations



Coexistence of nuclear chirality and octupole correlations



Coexistence of nuclear chirality and octupole correlations



Coexistence of nuclear chirality and octupole correlations

PRL 116, 112501 (2016) PHYSICAL REVIEW LETTERS week ending 18 MARCH 2016

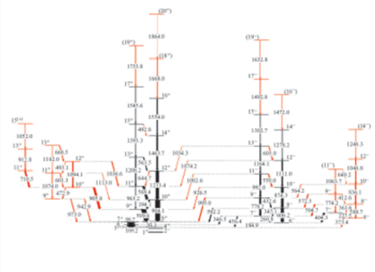
Evidence for Octupole Correlations in Multiple Chiral Doublet Bands

C. Liu (刘晨),[1] S. Y. Wang (王守宇),[1,†] R. A. Bark,[2] S. Q. Zhang (张双全),[3,‡] J. Meng (孟杰),[3,4,5,§] B. Qi (亓斌),[1] P. Jones,[2] S. M. Wyngaardt,[5] J. Zhao (赵杰),[6,7] C. Xu (徐川),[3] S.-G. Zhou (周善贵),[6] S. Wang (王硕),[1] D. P. Sun (孙大鹏),[1] L. Liu (刘雷),[1] Z. Q. Li (李志泉),[1] N. B. Zhang (张乃波),[1] H. Jia (贾慧),[1] X. Q. Li (李湘庆),[3] H. Hua (华辉),[3] Q. B. Chen (陈启博),[3] Z. G. Xiao (肖志刚),[8,9] H. J. Li (李红洁),[8] L. H. Zhu (竺礼华),[4] T. D. Bucher,[2,5] T. Dinoko,[2,10] J. Easton,[2,10] K. Juhász,[11,*] A. Kamblawe,[2,5] E. Khaleel,[2,5] N. Khumalo,[2,10,12] E. A. Lawrie,[2] J. J. Lawrie,[2] S. N. T. Majola,[2,13] S. M. Mullins,[2] S. Murray,[2] J. Ndayishimye,[2,5] D. Negi,[2] S. P. Noncolela,[2,10] S. S. Ntshangase,[12] B. M. Nyakó,[14] J. N. Orce,[10] P. Papka,[2,5] J. F. Sharpey-Schafer,[2,10] O. Shirinda,[2] P. Sithole,[2,10] M. A. Stankiewicz,[2,13] and M. Wiedeking[2]

PHYSICAL REVIEW LETTERS

Volume 116, Issue 11

18 March 2016



On the Cover

Nuclear levels of ^{78}Br measured at iThemba LABS, South Africa. New levels and transition energies (in keV) are marked in red.

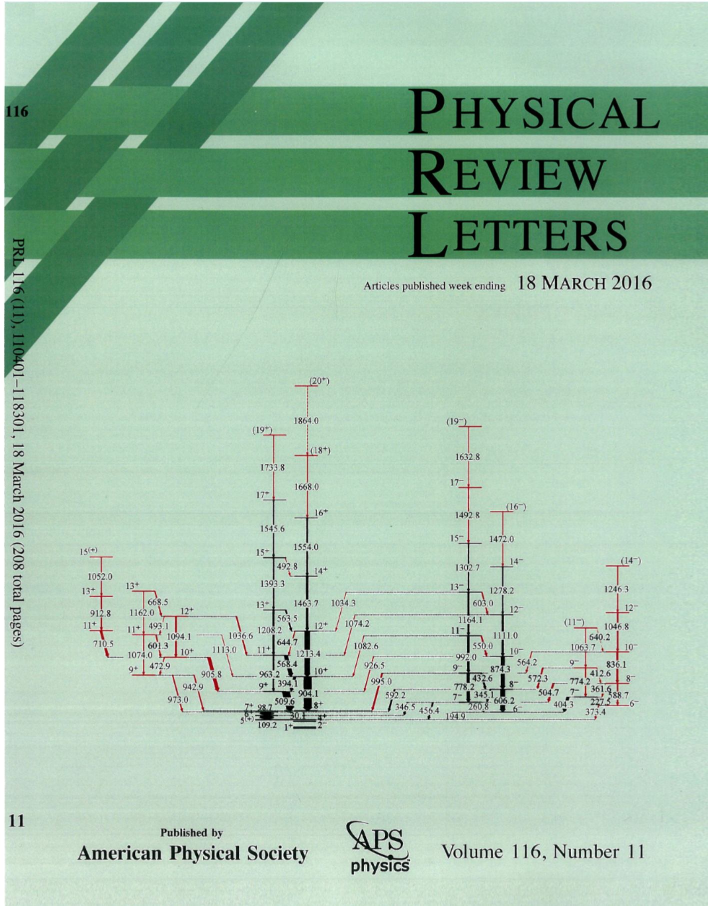
From the article

Evidence for Octupole Correlations in Multiple Chiral Doublet Bands

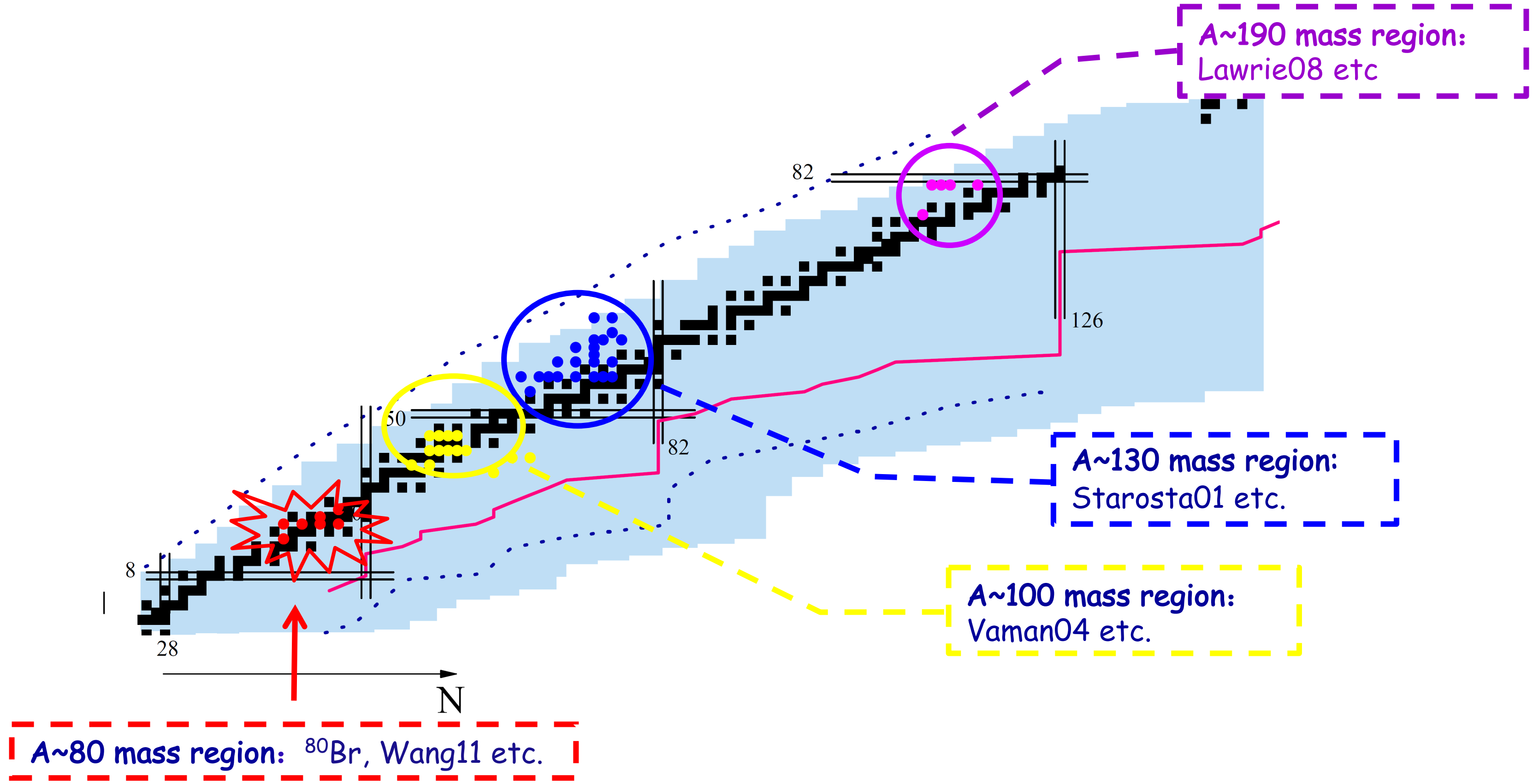
C. Liu (刘晨) *et al.*

Phys. Rev. Lett. **116**, 112501 (2016)

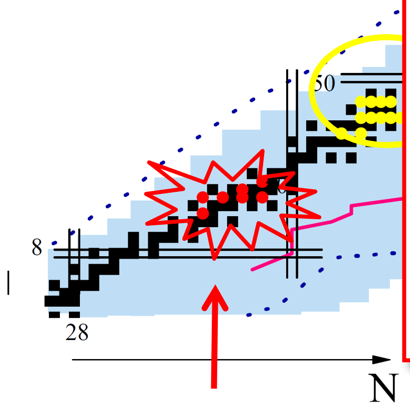
- This observation reports the first example of chiral geometry in octupole soft nuclei.
- It is proved that the simultaneous breaking of chiral and reflection symmetry can occur in atomic nuclei.



Coexistence of nuclear chirality and octupole correlations in nuclei

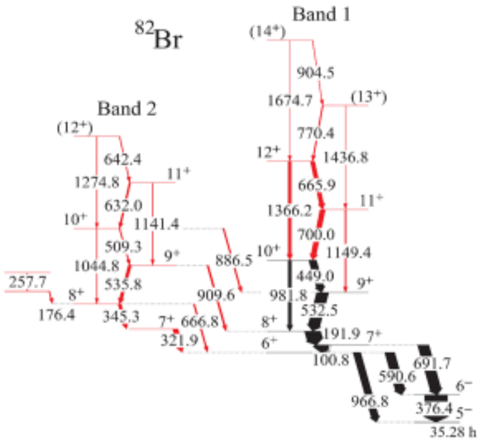


Coexistence of nuclear chirality and octupole correlations in nuclei

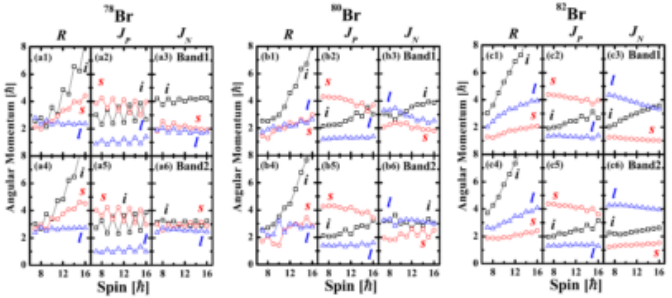


A~80 mass region: ^{80}Br, Wang11 etc.

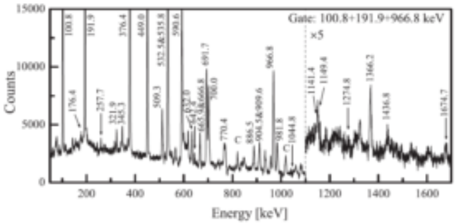
New candidate chiral nucleus in the A ≈ 80 mass region: ^{82}Br



^{82}Br中的手征双重带结构



The angular momenta for the chiral doublet bands in ^{78,80,82}Br

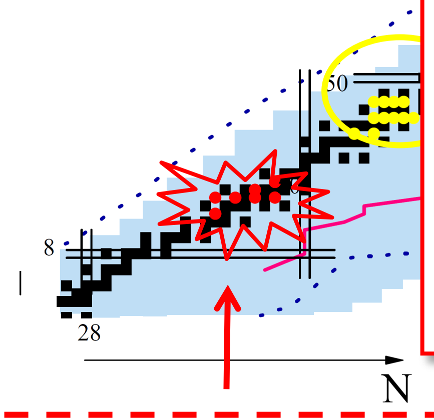


Sample coincidence spectrum

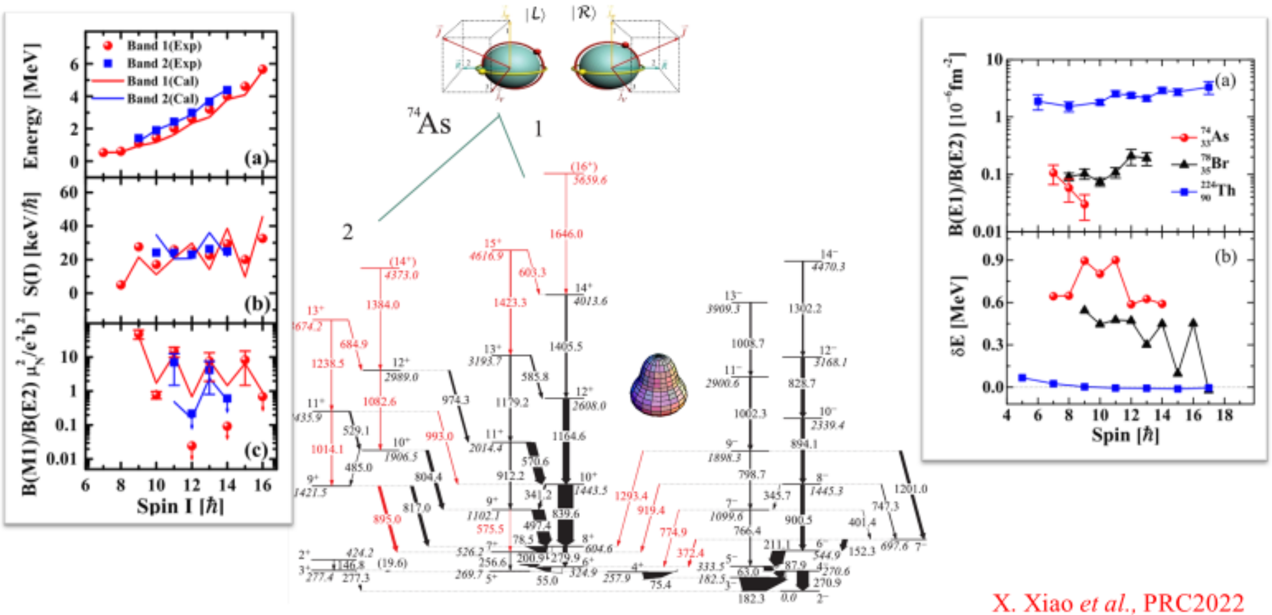
- The present work indicates that the border of the chiral nuclei in the A ≈ 80 mass region can reach N = 47 when the neutron number approaches N = 50.

C. Liu *et al.* PRC2019

Coexistence of nuclear chirality and octupole correlations in nuclei



Coexistence of nuclear chirality and octupole correlations in ^{74}As

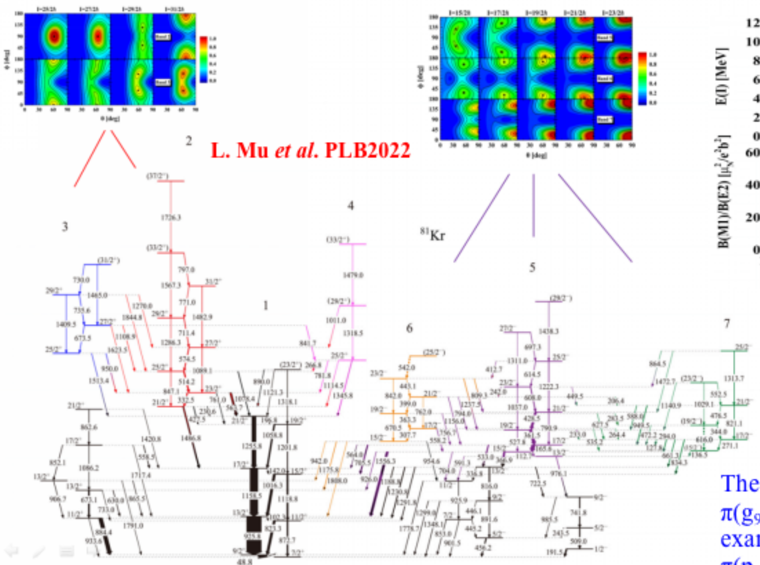


X. Xiao *et al.*, PRC2022

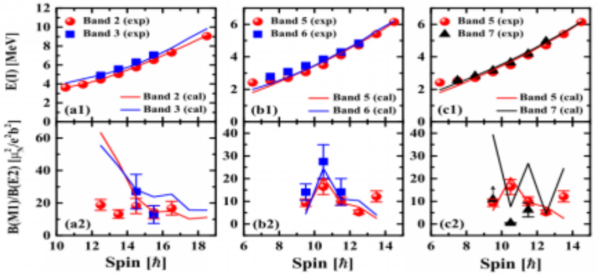
A~80 mass region: ^{80}Br, Wang11 etc.

Coexistence of nuclear chirality and octupole correlations in nuclei

First observation of the coexistence of multiple chiral doublet bands and pseudospin doublet bands in the A≈80 mass region: ^{81}Kr

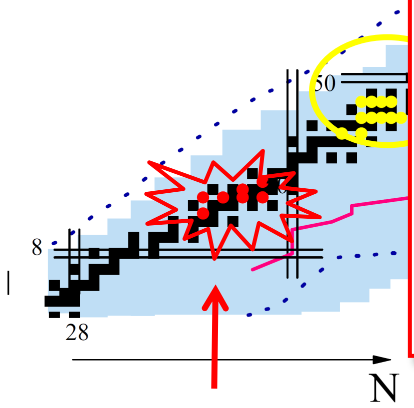


L. Mu *et al.* PLB2022



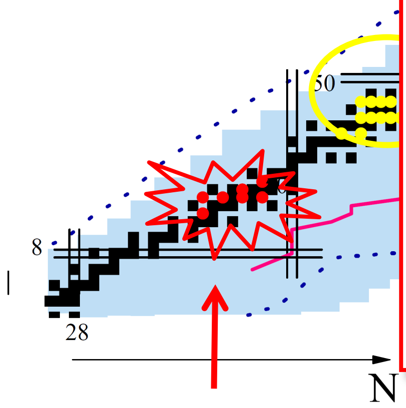
The evidence of chiral doublet bands and pseudospin-chiral triplet bands in ^{81}Kr

The present work reports two new chiral configurations $\pi(g_{9/2})^2\otimes\nu(g_{9/2})^{-1}$ and $\pi g_{9/2}(p_{3/2}, f_{5/2})\otimes\nu(g_{9/2})^{-1}$, and the first example of pseudospin-chiral triplet bands involving the $\pi(p_{3/2}, f_{5/2})$ pseudospin doublet.



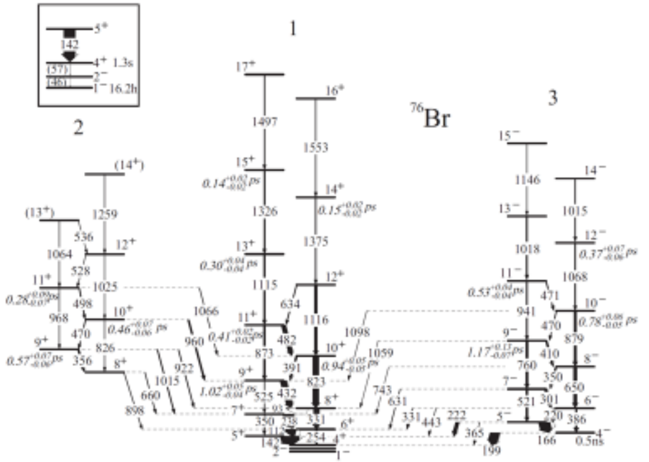
A~80 mass region: ^{80}Br, Wang11 etc.

Coexistence of nuclear chirality and octupole correlations in nuclei

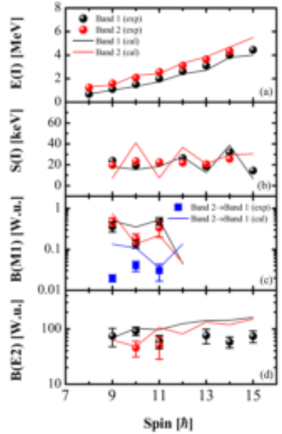


A~80 mass region: ^{80}Br, Wang11 etc.

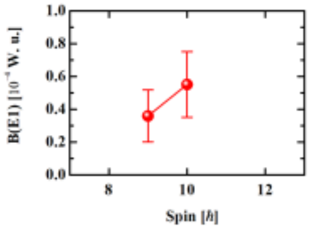
Coexistence of nuclear chirality and octupole correlations in ^{76}Br



Partial level schemes of ^{76}Br



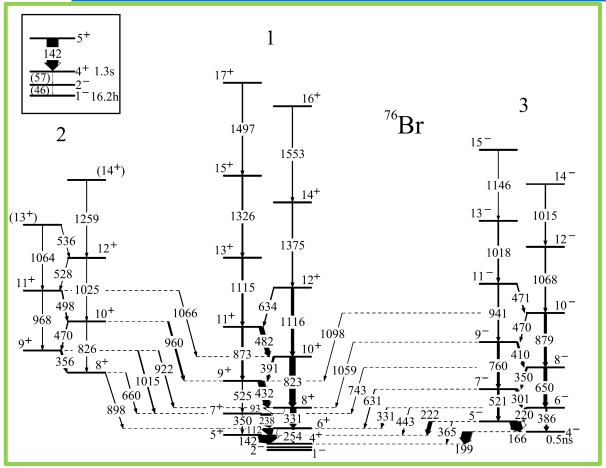
The $E(I)$, $S(I)$ and reduced transition probabilities $B(M1)$ and $B(E2)$ for bands 1 and 2 in ^{76}Br.

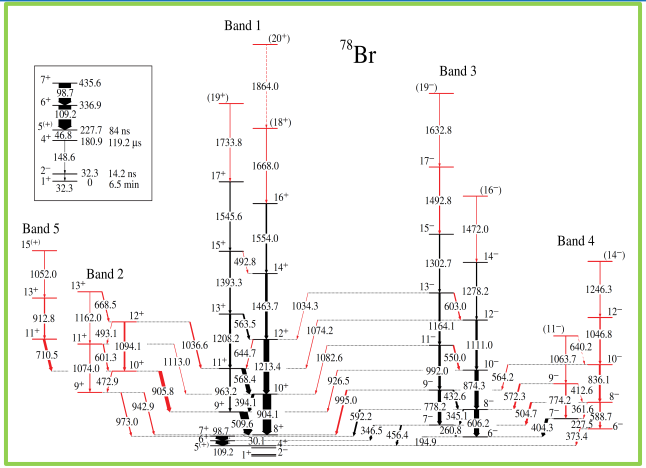


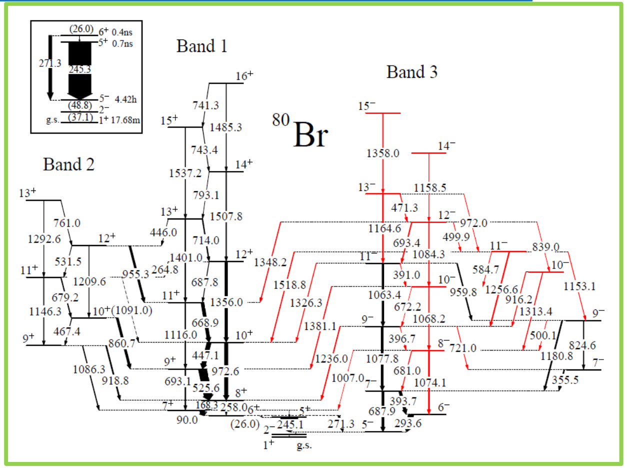
B(E1) values in ^{76}Br

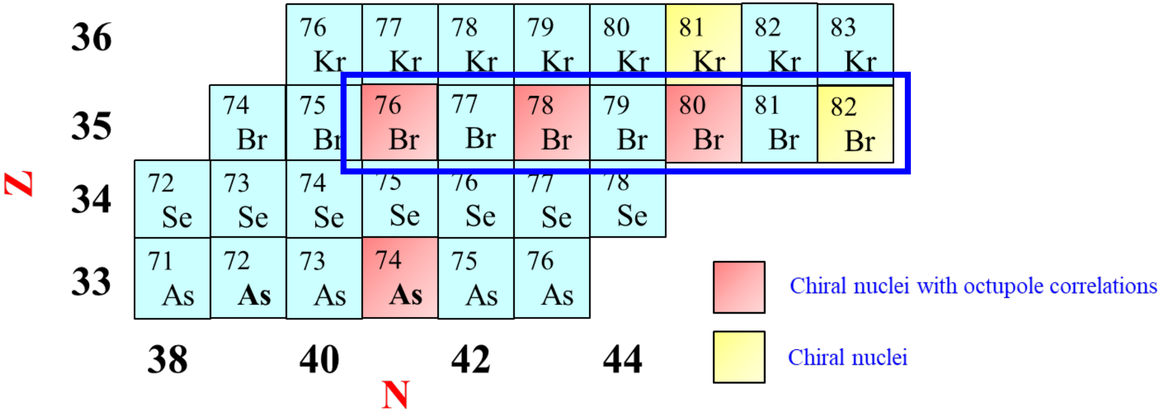
W. Z. Xu *et al.* PLB2022

Interplay between nuclear chirality and octupole correlations



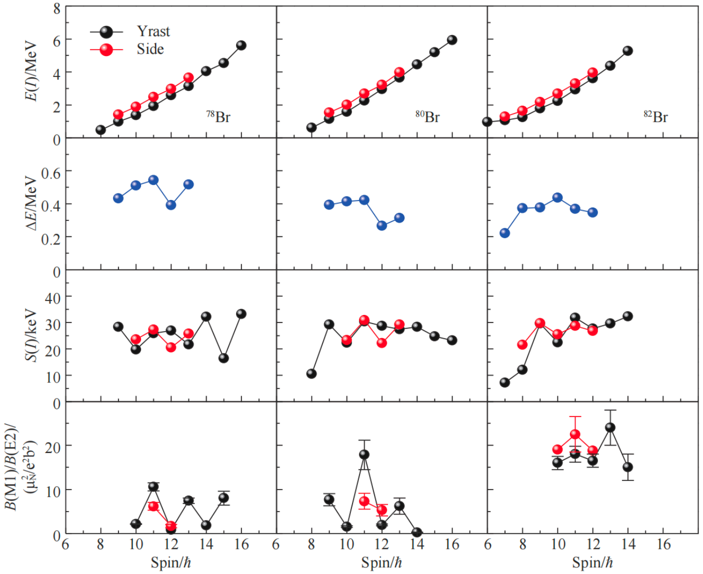


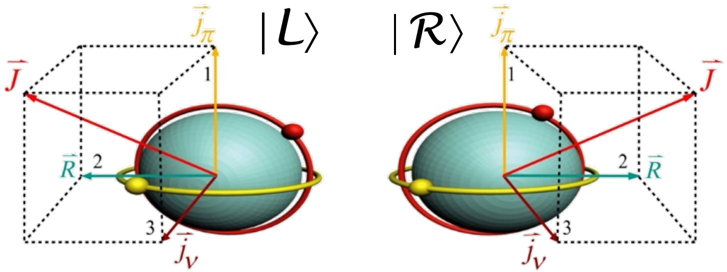


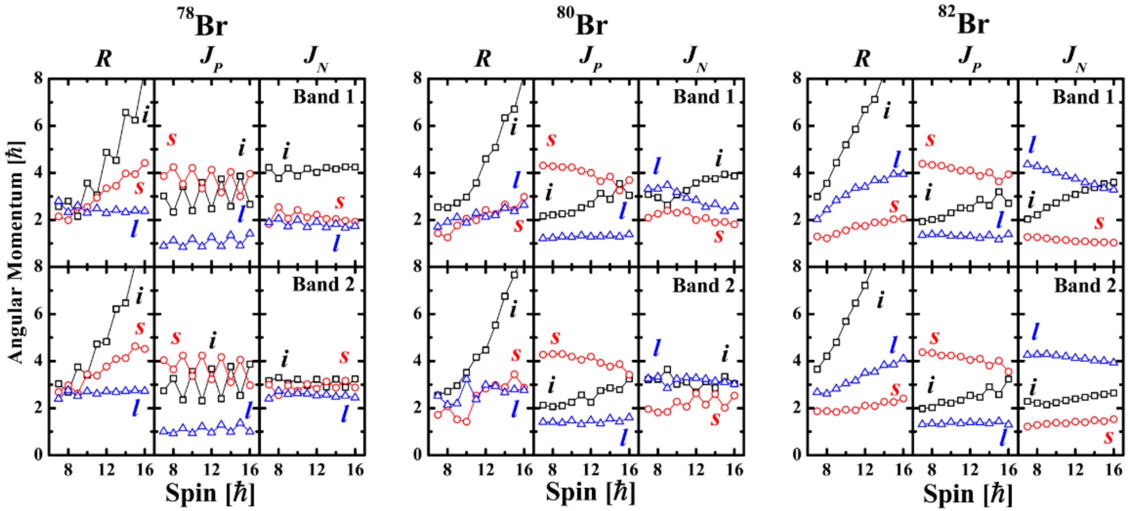


chiral geometry and its evolution in the Br isotopes

- Chiral geometry in ^{82}Br is more stable than those in ^{78}Br and ^{80}Br.

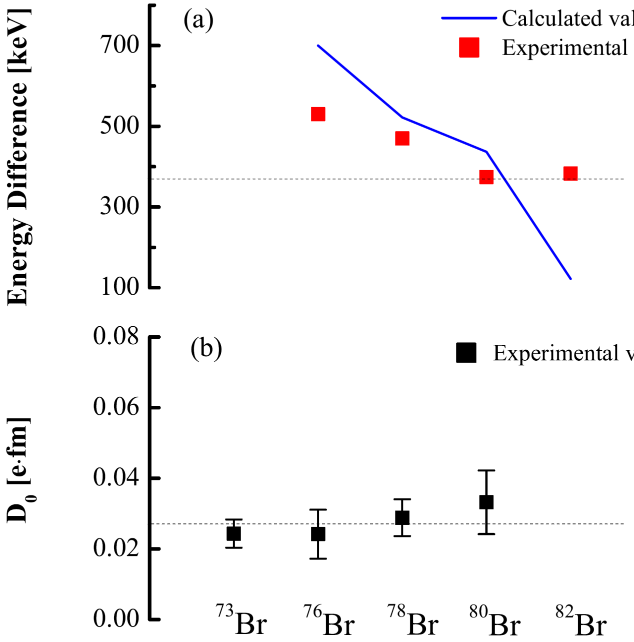






C. Liu *et al.*, Physical Review C 100, 054309 (2019)

Interplay between nuclear chirality and octupole correlations



The measured and calculated energy difference in ^{76,78,80,82}Br and average D_0 values in ^{73,76,78,80}Br

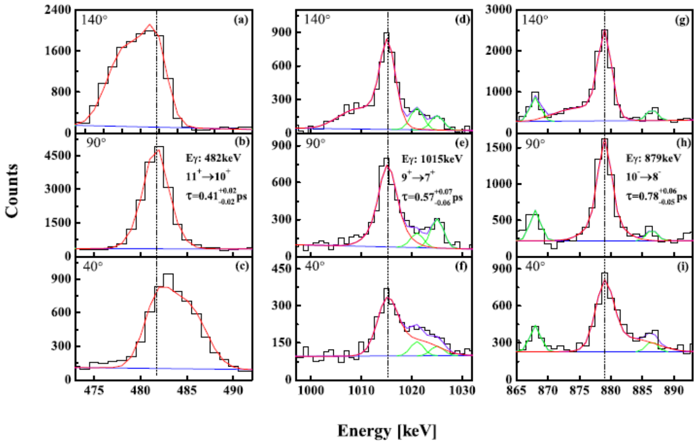


Table 1
The present lifetimes results and comparison with the known data. Uncertainties in the lifetimes were determined from the behavior of χ^2 in the vicinity of the best-fit parameter values. These uncertainties do not include the systematic errors that are associated with the stopping powers, which may be as large as ±15%.

Band	$I^\pi(\hbar)$	τ (ps)	τ (ps) [42]
Band 1	9^+	$1.02^{+0.05}_{-0.04}$	0.85(0.09)
	10^+	$0.94^{+0.05}_{-0.05}$	0.70(0.08)
	11^+	$0.41^{+0.02}_{-0.02}$	0.30(0.05)
	13^+	$0.30^{+0.04}_{-0.04}$	0.29(0.03)
	14^+	$0.15^{+0.02}_{-0.02}$	
	15^+	$0.14^{+0.02}_{-0.02}$	0.16(0.04)
Band 2	9^+	$0.57^{+0.07}_{-0.06}$	
	10^+	$0.46^{+0.07}_{-0.06}$	
	11^+	$0.28^{+0.09}_{-0.07}$	
Band 3	9^-	$1.17^{+0.13}_{-0.07}$	
	10^-	$0.78^{+0.06}_{-0.05}$	1.00(0.30)
	11^-	$0.53^{+0.04}_{-0.04}$	
	12^-	$0.37^{+0.07}_{-0.06}$	

- The present work provides the first test for chirality in the A ≈80 mass region by lifetime measurements, and firstly elucidates the formation of chiral geometry in the presence of the octupole correlations in Br isotopes, leading to the conclusion that the reflection symmetry breaking catalyzes rather than destroys chiral symmetry breaking in nuclear systems.

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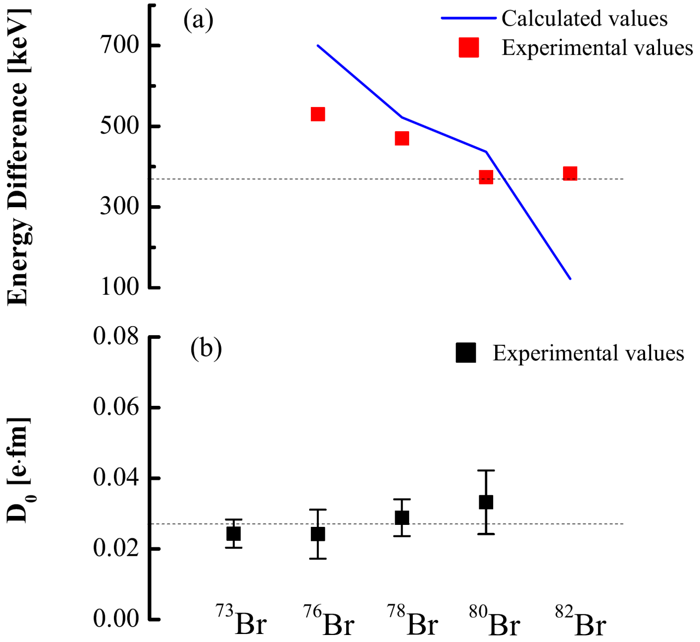

Br同位素手征双带能级差和电偶极矩D_0

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Interplay between nuclear chiral and reflection symmetry breakings revealed by the lifetime measurements in ^{76}Br

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Nearly degenerate positive-parity doublet bands and several *E*1 transitions between positive- and negative-parity bands have been identified in ^{76}Br. These experimental observations are interpreted as the coexistence of chirality and octupole correlations, based on the analysis of detailed γ-ray spectroscopy with the precise lifetime measurements and theoretical calculations, and play a key role to explore the simultaneous breaking of chiral and reflection symmetry and their interplay. The present work provides the first test for chirality in the $A \approx 80$ mass region by lifetime measurements, and firstly elucidates the formation of chiral geometry in the presence of the octupole correlations in Br isotopes, leading to the conclusion that the reflection symmetry breaking catalyzes rather than destroys chiral symmetry breaking in nuclear systems.

Conclusion

- A series of experimental studies on the spontaneous symmetry breaking in the A~80 mass region were performed:

1. Coexistence of nuclear chirality and octupole correlations in ^{74}As, ^{76,78,80}Br.
2. Chiral geometry in ^{82}Br is more stable than those in ^{78}Br and ^{80}Br.
3. Reflection symmetry breaking catalyzes rather than destroys chiral symmetry breaking in nuclear systems

Thank you for your attention！


Thank you for your attention!