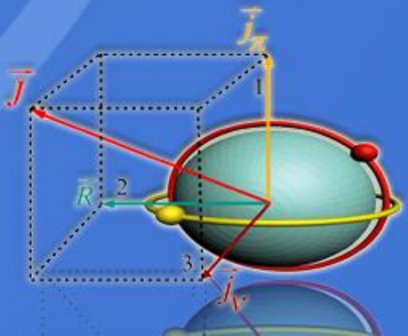
山东大学(威海)
SHANDONG UNIVERSITY, WEIHAI

Experimental studies on the nuclear chirality in the A~80 mass region

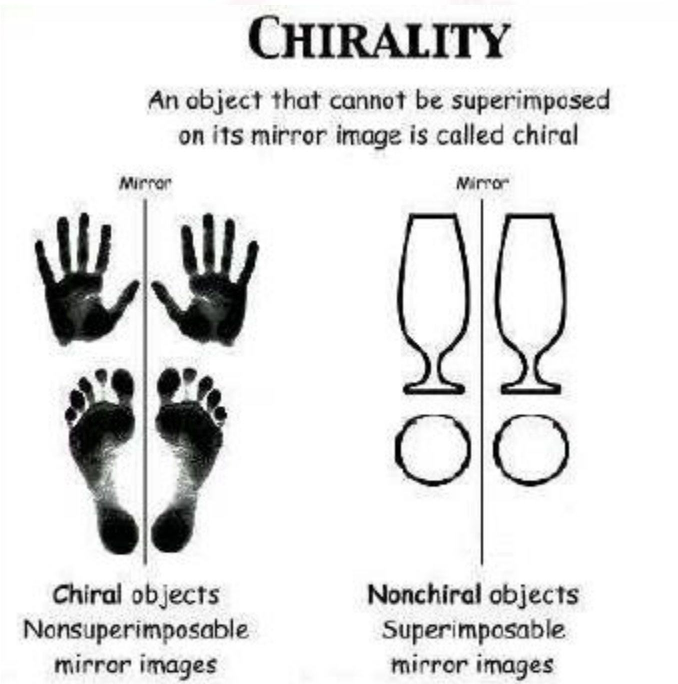
- **Speaker: Chen Liu (刘晨)**
- **Shandong University, Weihai**

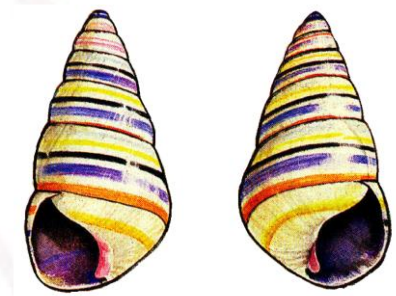


OUTLINE

- Introduction
- Experiment Details
- Result and Discussions
- Conclusion

Chiral symmetry breaking in nuclei



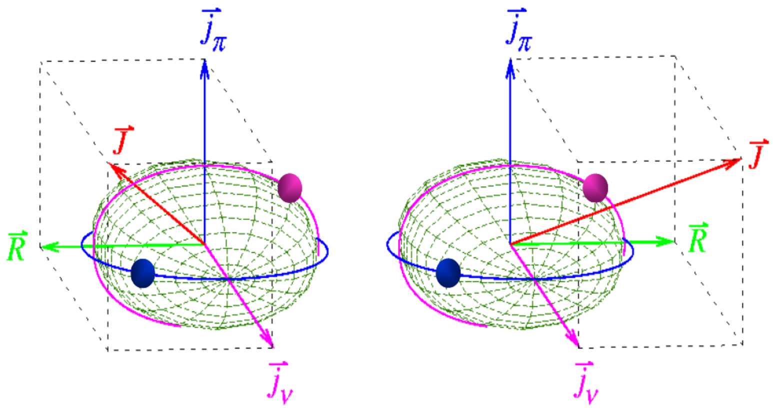


Left- Right-

Chirality exists commonly in nature.

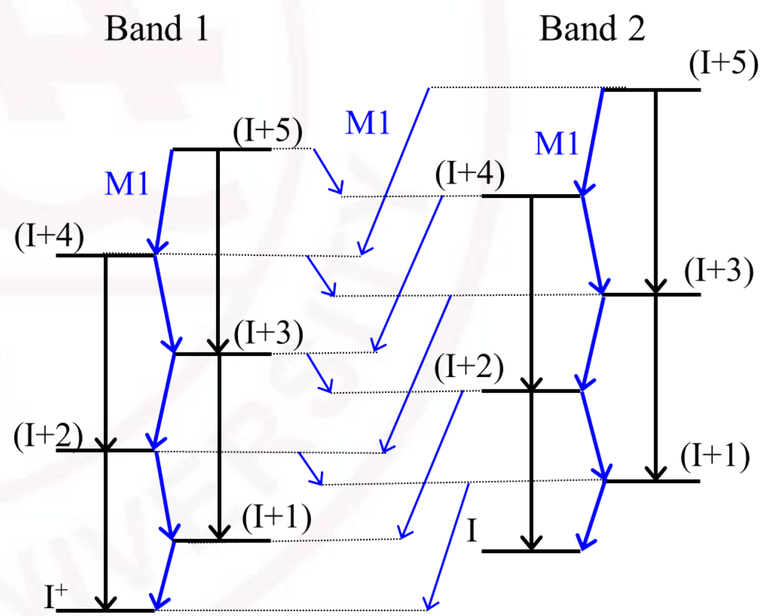
Chiral symmetry breaking in nuclei

Intrinsic frame



Frauendorf97

chiral symmetry breaking



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

Expected exp. signal:

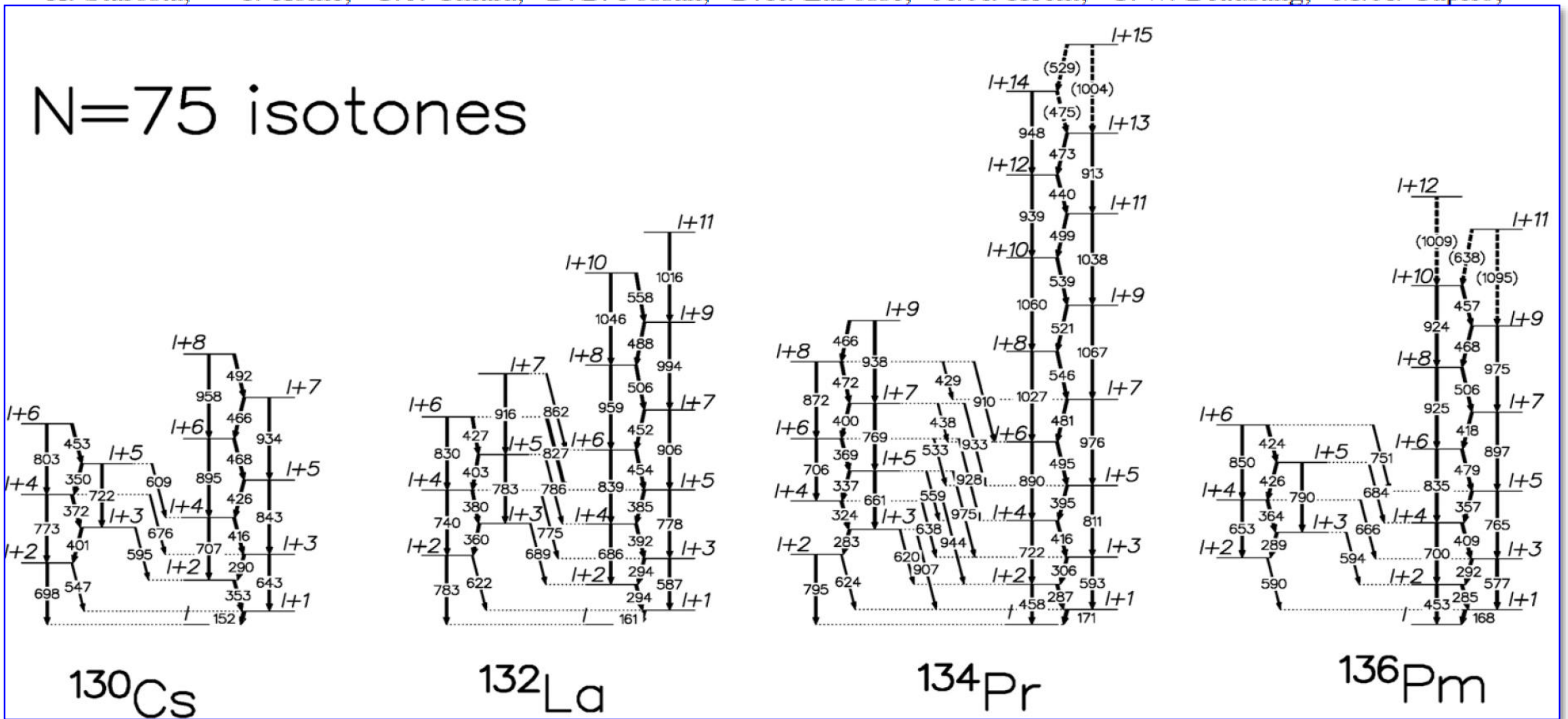
Two near degenerate ΔI =1 bands, called chiral doublet bands

Chiral symmetry breaking in nuclei

VOLUME 86, NUMBER 6 PHYSICAL REVIEW LETTERS 5 FEBRUARY 2001

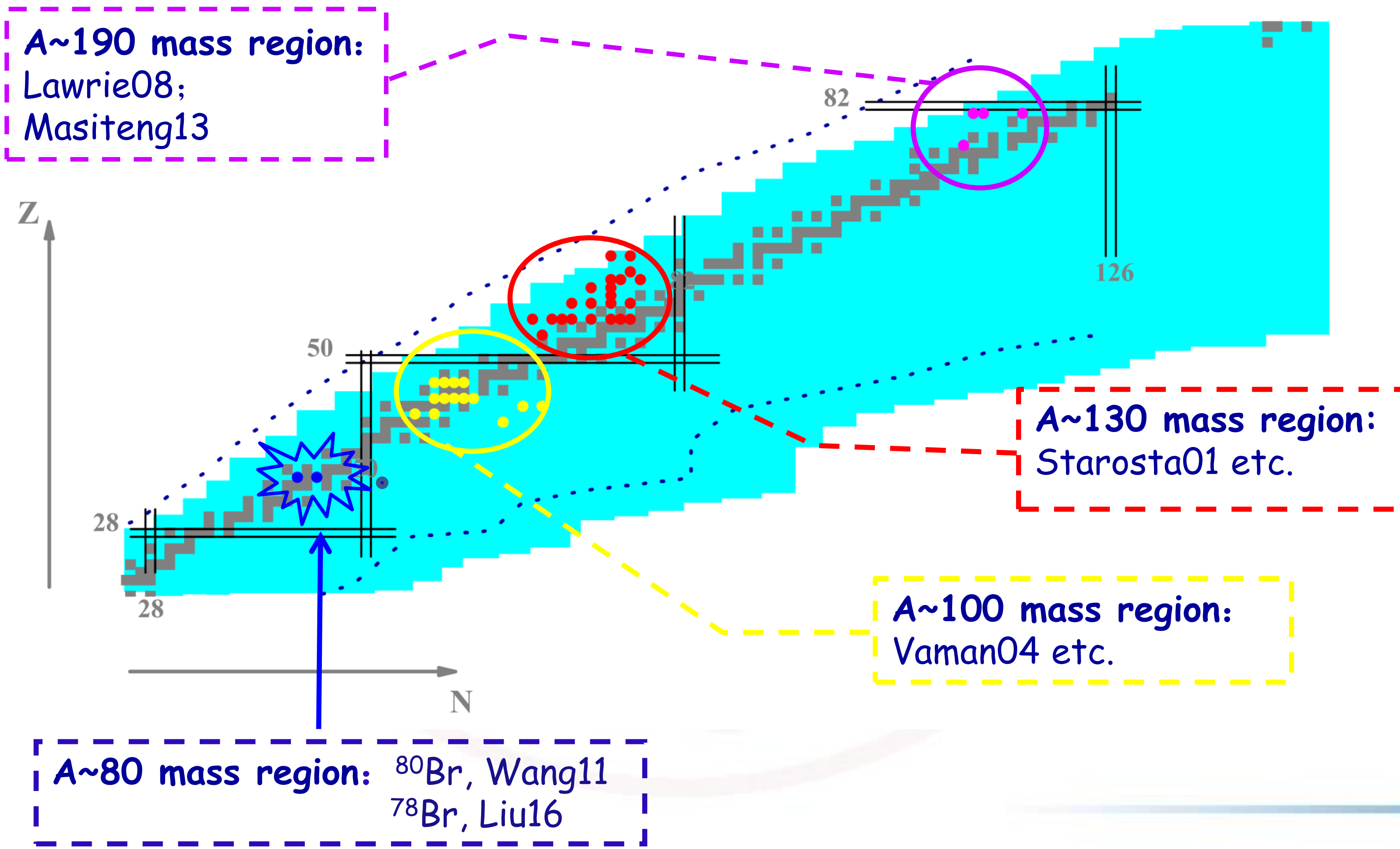
Chiral Doublet Structures in Odd-Odd $N = 75$ Isotones: Chiral Vibrations

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]



Chiral nuclei "islands"

- So far, candidates for chiral doublet bands have been observed experimentally in about 40 cases of odd-odd, odd-A and even-even nuclei.



Multiple chiral doublet bands in nuclei

山东大学（威海） SHANDONG UNIVERSITY WEIHAI

PHYSICAL REVIEW C **73**, 037303 (2006)

Possible existence of multiple chiral doublets in ^{106}Rh

J. Meng,[1,2,3,*] J. Peng,[1] S. Q. Zhang,[1] and S.-G. Zhou[2,3]
[1]*School of Physics, Peking University, Beijing 100871, China*
[2]*Institute of Theoretical Physics, Chinese Academy of Science, Beijing 100080, China*
[3]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerator, Lanzhou 730000, China*
(Received 30 March 2005; published 15 March 2006)

PRL **110**, 172504 (2013) PHYSICAL REVIEW LETTERS week ending 26 APRIL 2013

Evidence for Multiple Chiral Doublet Bands in ^{133}Ce

A. D. Ayangeakaa,[1] U. Garg,[1] M. D. Anthony,[1] S. Frauendorf,[1] J. T. Matta,[1] B. K. Nayak,[1,*] D. Patel,[1]
Q. B. Chen (陈启博),[2] S. Q. Zhang (张双全),[2] P. W. Zhao (赵鹏巍),[2] B. Qi (亓斌),[3] J. Meng (孟杰),[2,4,5]
R. V. F. Janssens,[6] M. P. Carpenter,[6] C. J. Chiara,[6,7] F. G. Kondev,[8] T. Lauritsen,[6] D. Seweryniak,[6] S. Zhu,[6]

PRL **113**, 032501 (2014) PHYSICAL REVIEW LETTERS week ending 18 JULY 2014

Multiple Chiral Doublet Bands of Identical Configuration in ^{103}Rh

I. Kuti,[1] Q. B. Chen,[2] J. Timár,[1] D. Sohler,[1] S. Q. Zhang,[2] Z. H. Zhang,[2] P. W. Zhao,[2] J. Meng,[2]
K. Starosta,[3] T. Koike,[4] E. S. Paul,[5] D. B. Fossan,[6] and C. Vaman[6]
[1]*Institute for Nuclear Research, Hungarian Academy of Sciences, Pf. 51, 4001 Debrecen, Hungary*
[2]*State Key Laboratory of Physics and Technology, School of Physics, Peking University, Beijing 100871, China*

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]

Possible multiple chiral doublet bands in ^{107}Ag

B. Qi (亓斌), H. Jia (贾慧), N. B. Zhang (张乃波), C. Liu (刘晨), and S. Y. Wang (王守宇)*
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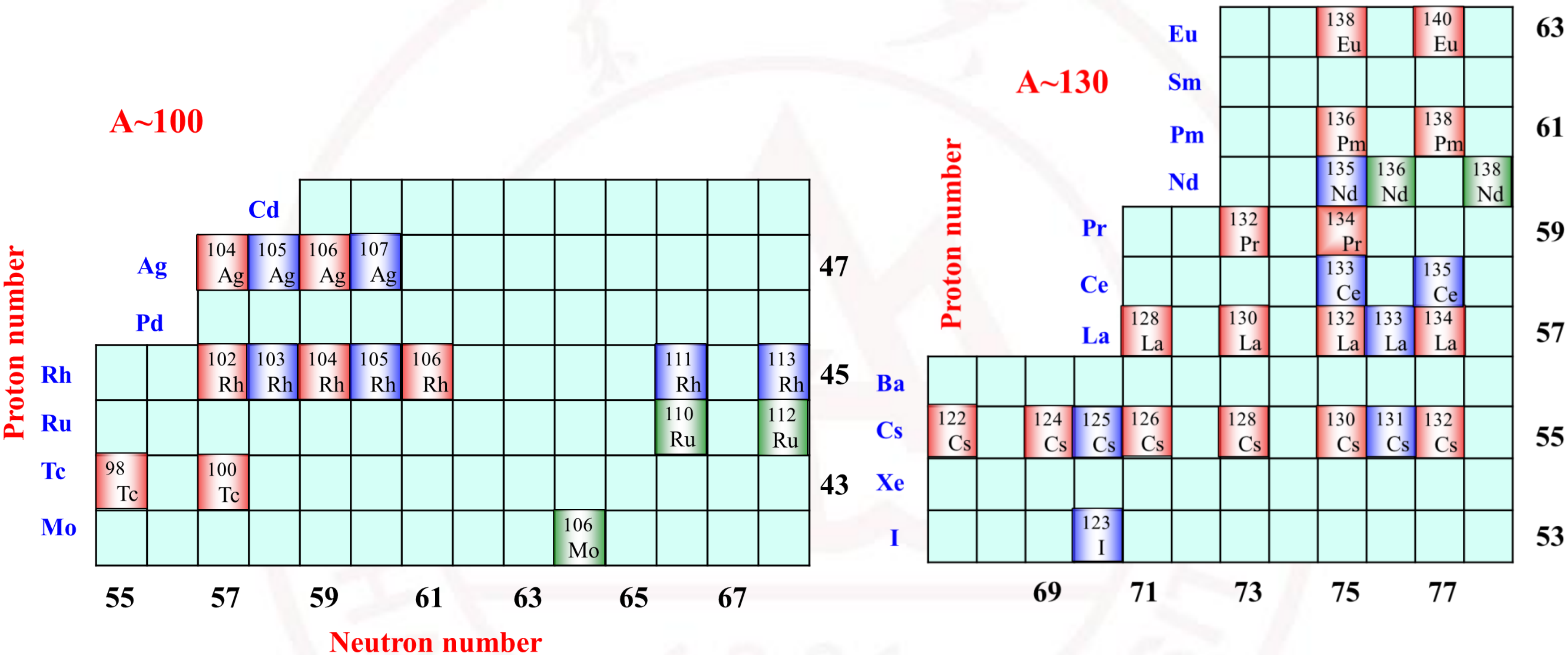
(Received 14 July 2013; published 13 August 2013)

- In 2006, a study based on the relativistic mean field (RMF) theory suggested that multiple chiral doublet bands could exist in single nucleus.
- The experimental evidences for multiple chiral bands were reported in ^{133}Ce, ^{103}Rh, ^{78}Br, and possibly in ^{107}Ag.

Chirality in A~100 & 130 mass region



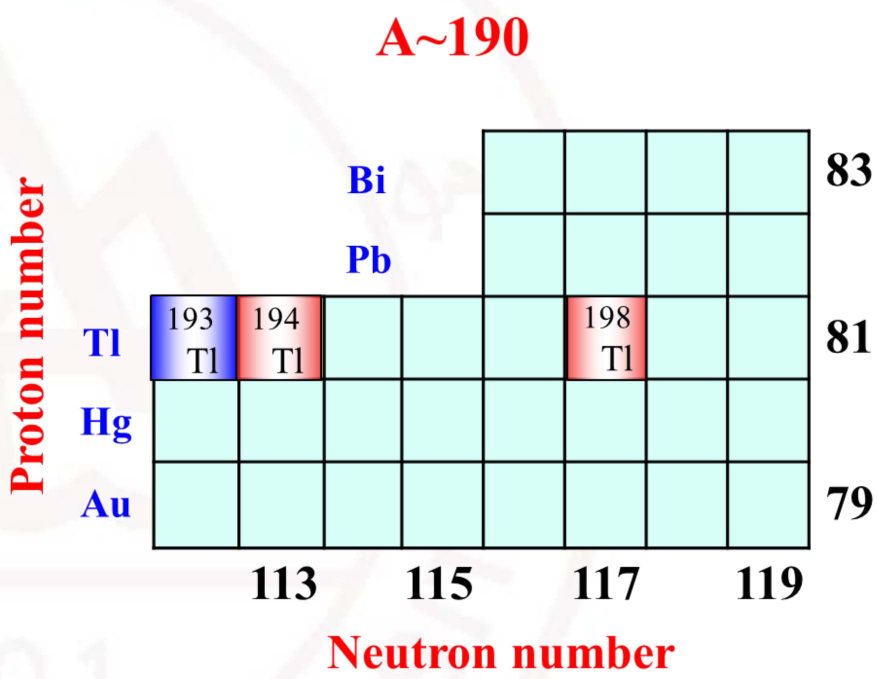
- Most studies on nuclear chirality have focused on the 100 and 130 mass regions at first.

J. Meng, and S. Q. Zhang, J. Phys. G 37 (2010) 064025.
B. W. Xiong, Y. Y. Wang, arXiv: 1804.04437.

Chirality in A~190 mass region

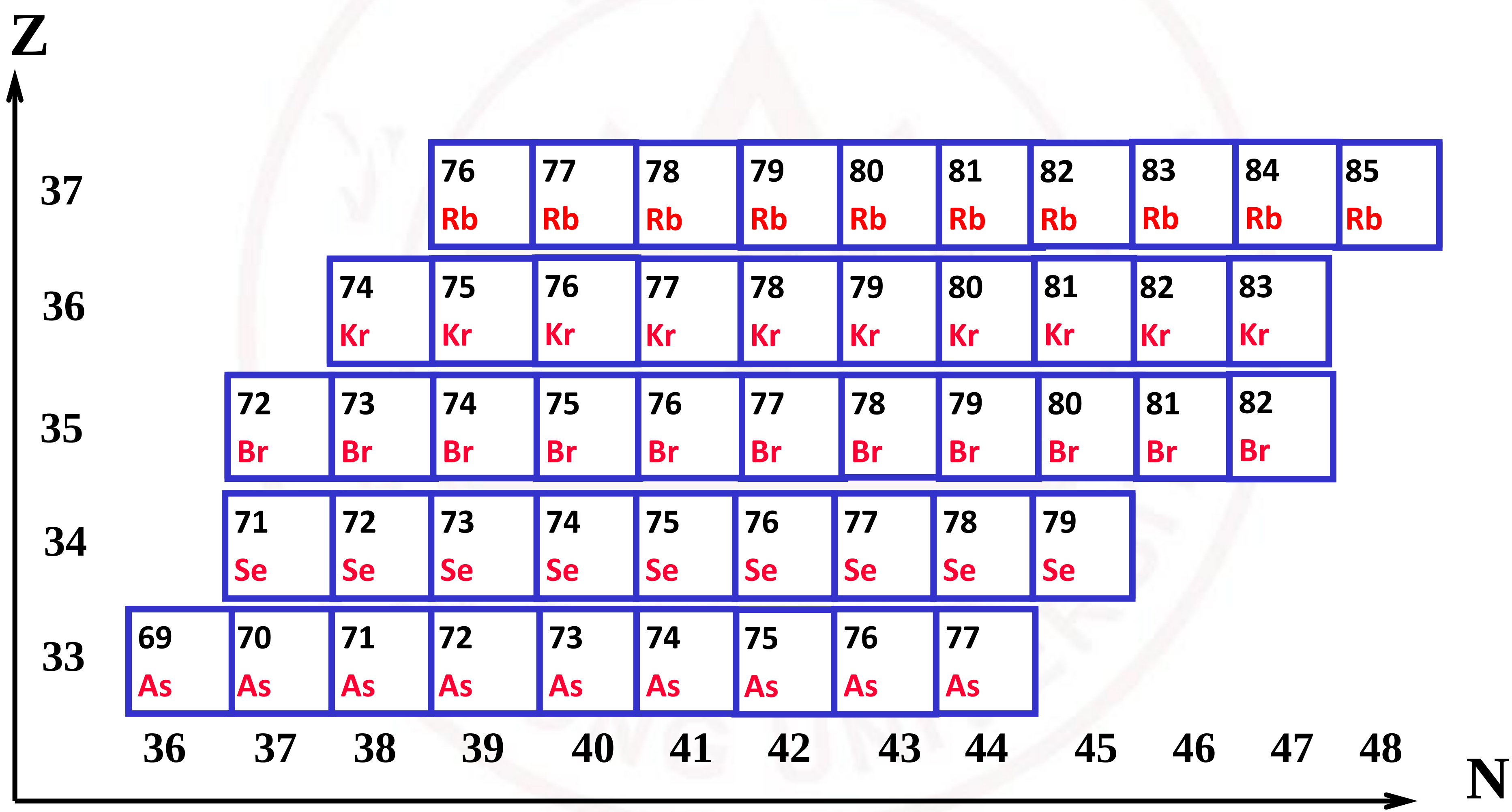
- It is necessary to search for more candidates in other mass regions to show that these chiral symmetry properties are of a general nature and not related only to a specific nuclear mass region.

- Recently, a pair of negative-parity partner bands in ^{198}Tl have been suggested as candidate chiral bands.

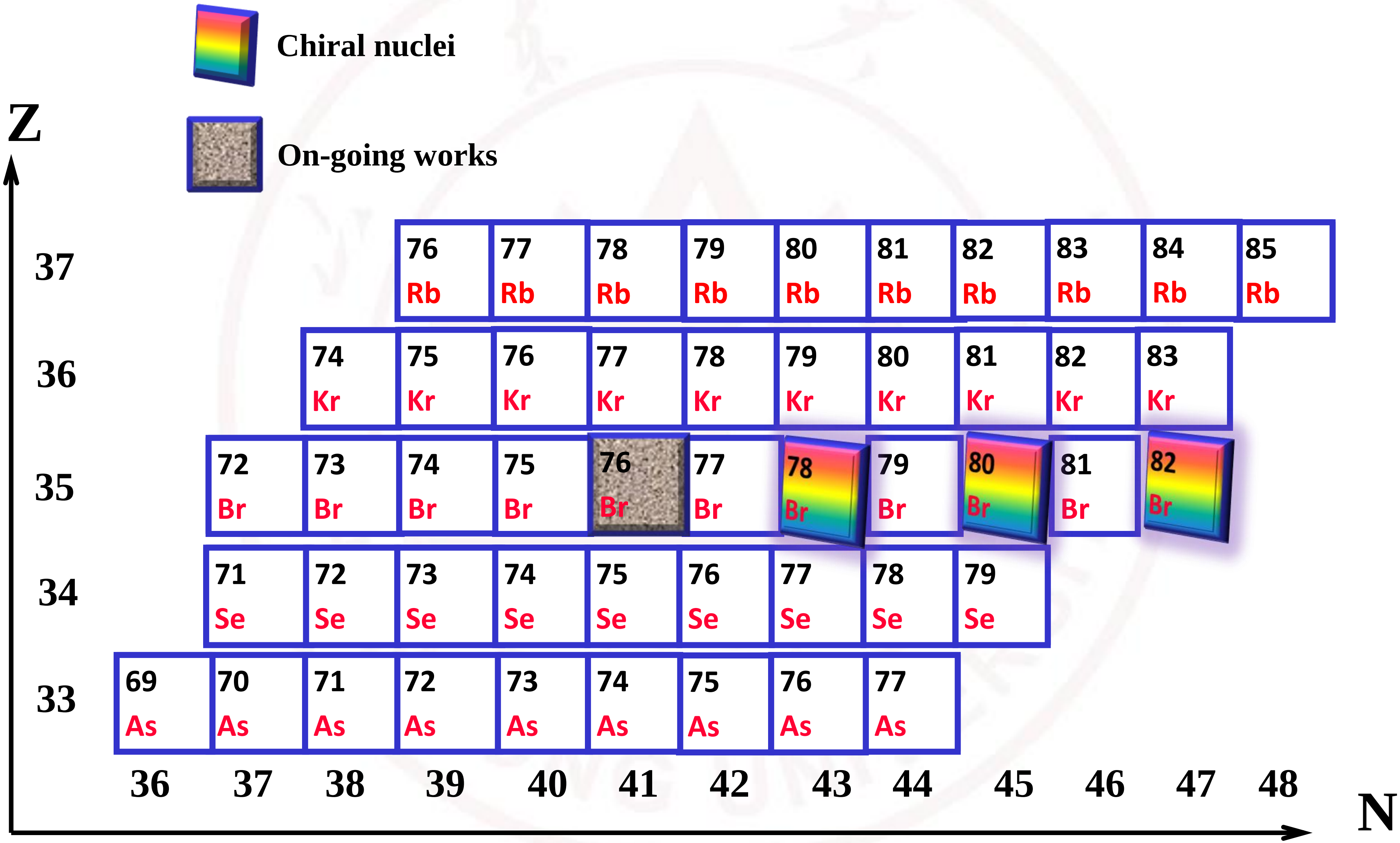


E. Lawrie et al., PRC78,021305(R) (2008).
J. Ndayishimye et al., SAIP2013 Conf. Proc., P. 302 (2013).
P. L. Masiteng et al., Eur. Phys. J. A 50, 119(2014)

New chiral island ?



New chiral island ?



OUTLINE

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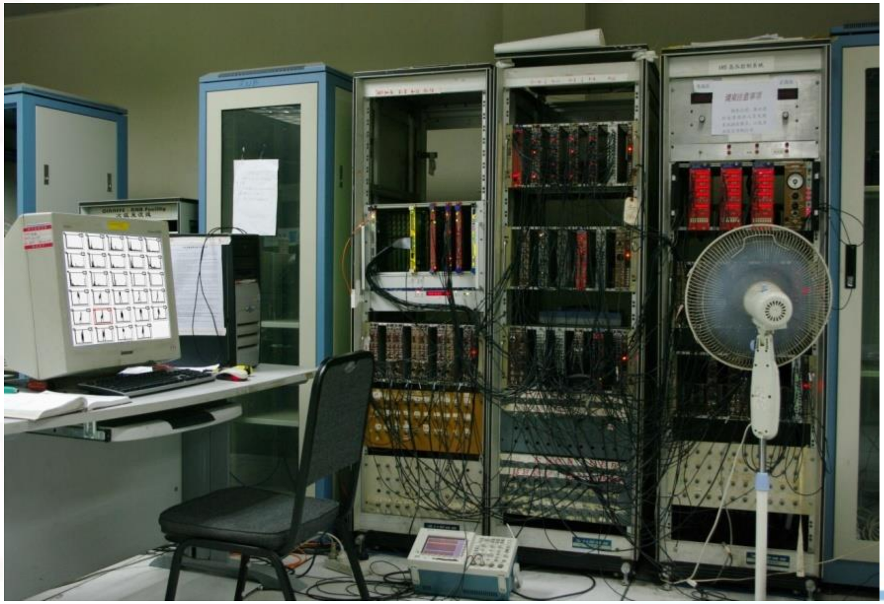
Experimental details

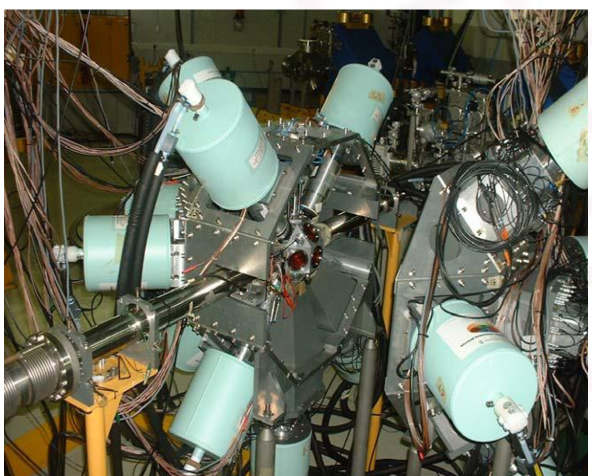
China Institute of Atomic Energy
@2015



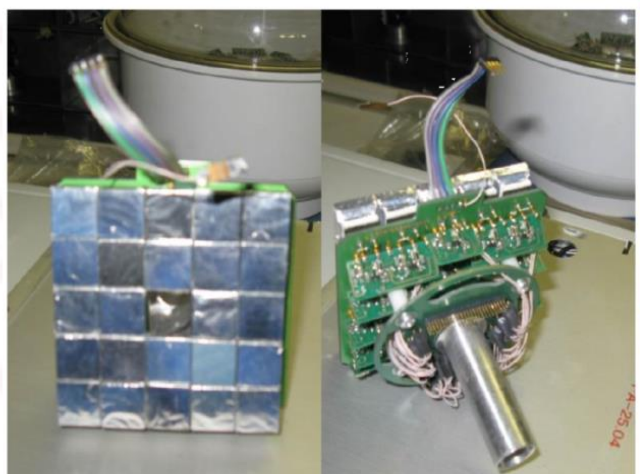
Experimental details

iThemba LABS, South Africa
@2009&2012&2015

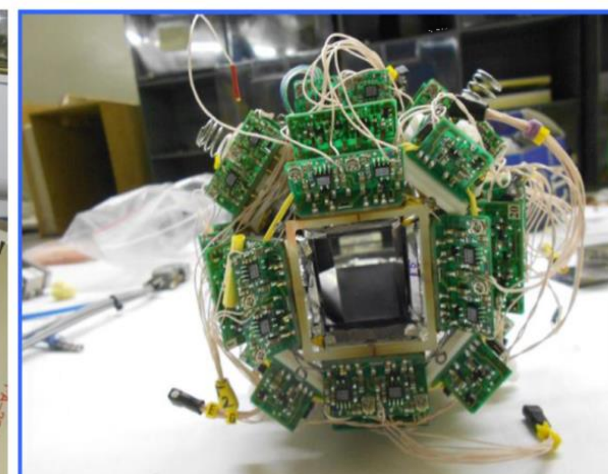
AFRODITE



Chessboard

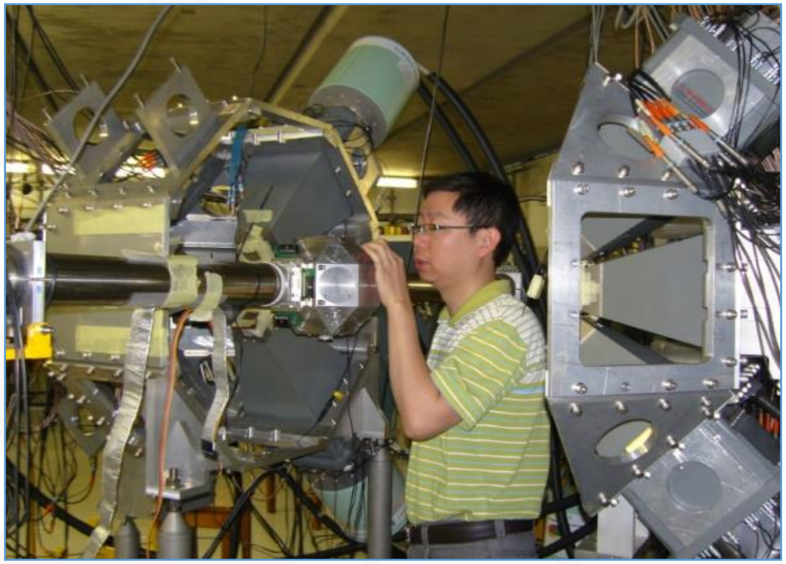


DIAMANT

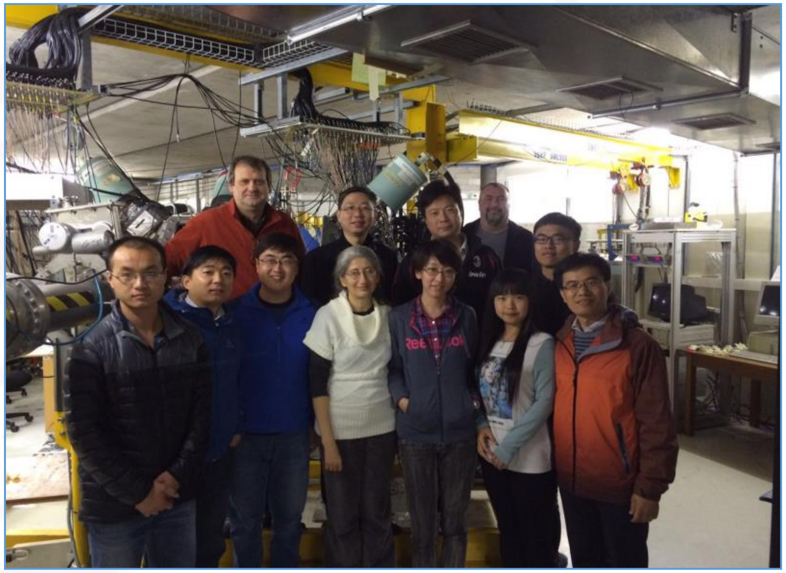


Experiments in iThemba LABS

March 2009

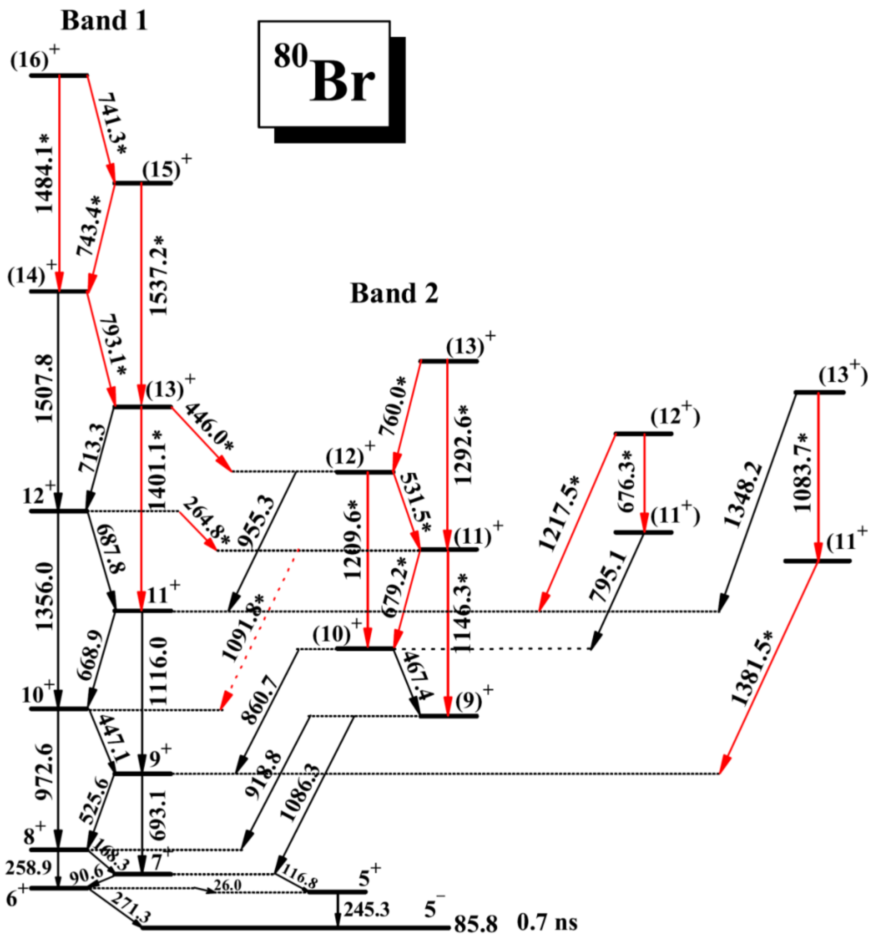


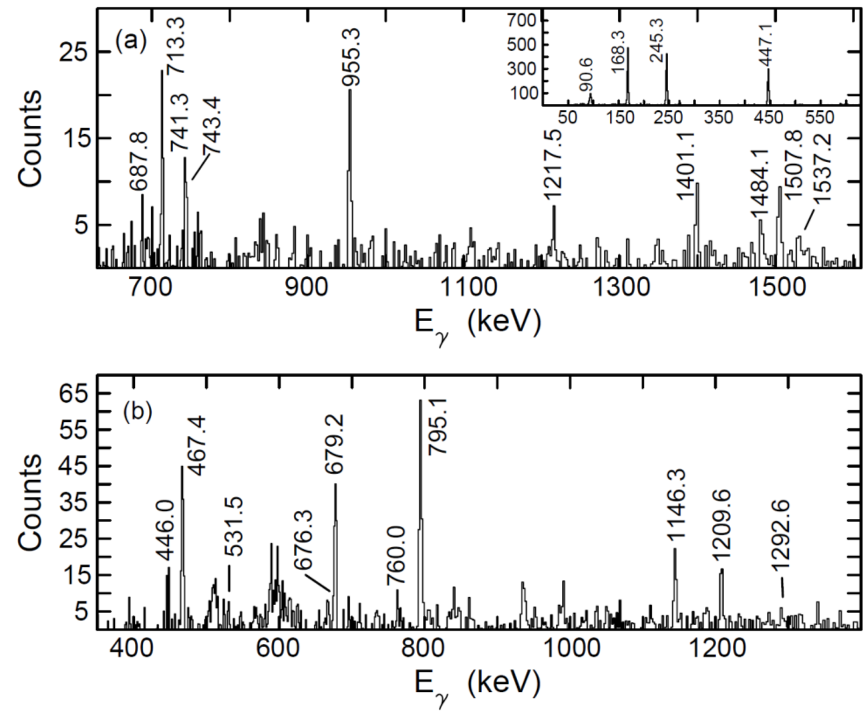
February 2012



July 2015

Level scheme for ^{80}Br

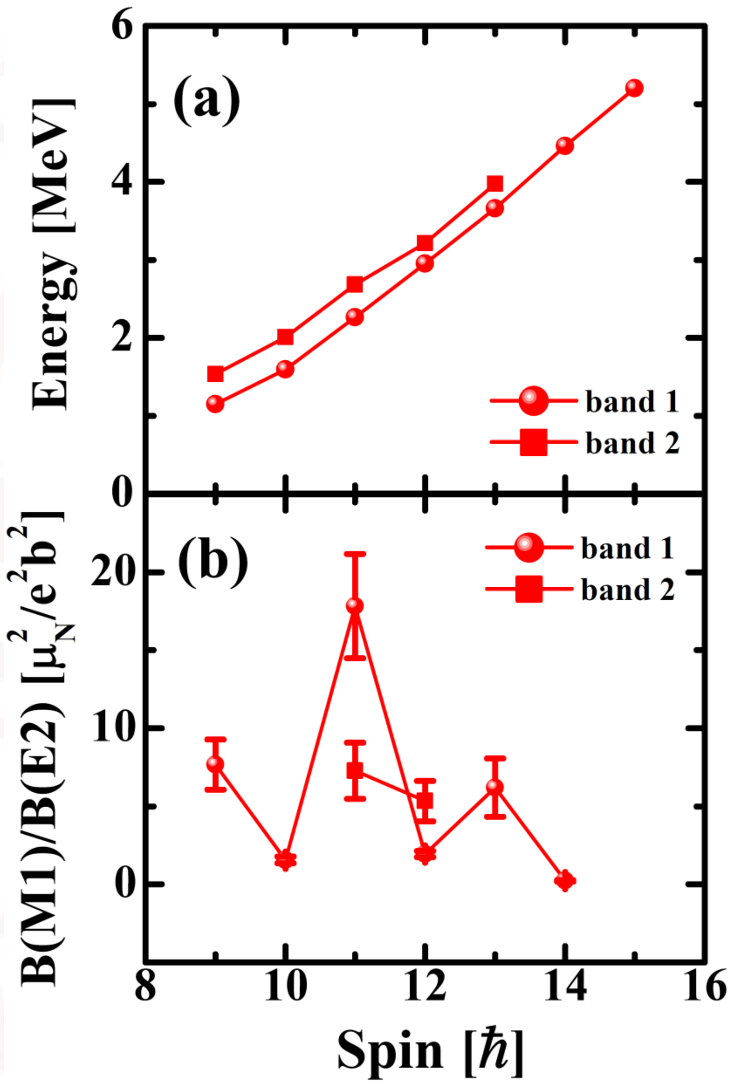




Level scheme for ^{80}Br obtained in our work.

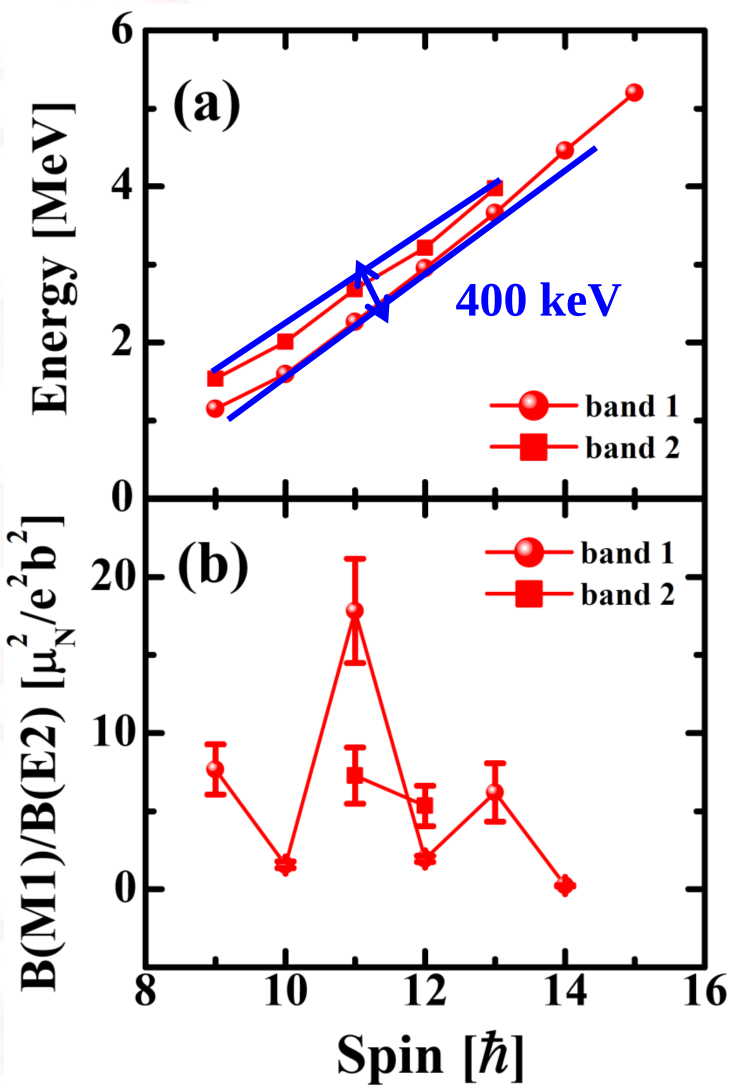
New observed transitions are shown by stars and red lines.

Results and Discussions



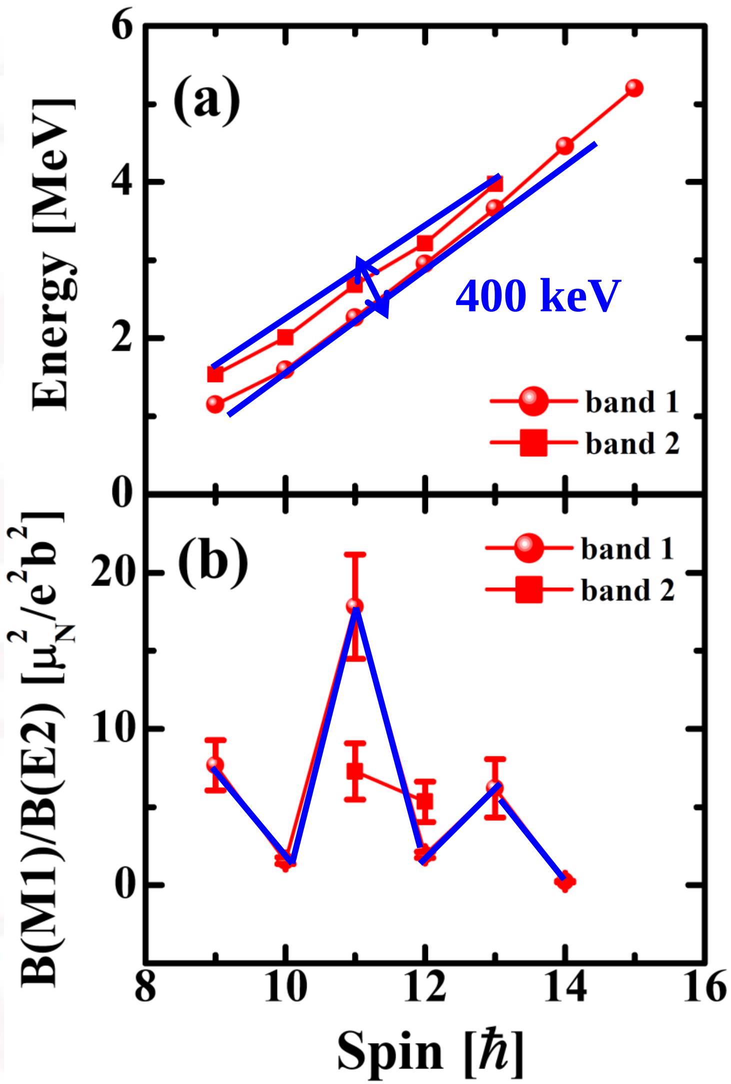
Results and Discussions

- The two bands maintain an energy difference around 400 keV.



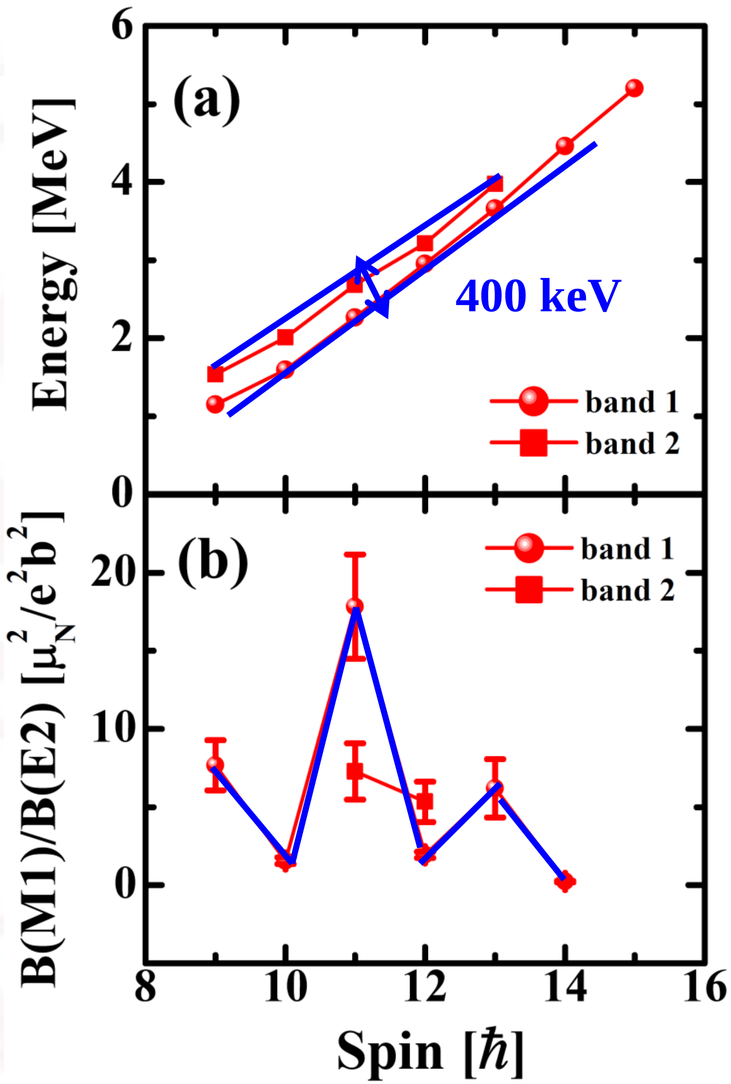
Results and Discussions

- The two bands maintain an energy difference around 400 keV.
- The B(M1)/B(E2) ratios for the two bands are similar. The ratios for band 1 show clearly the odd-even staggering as a function of spin.

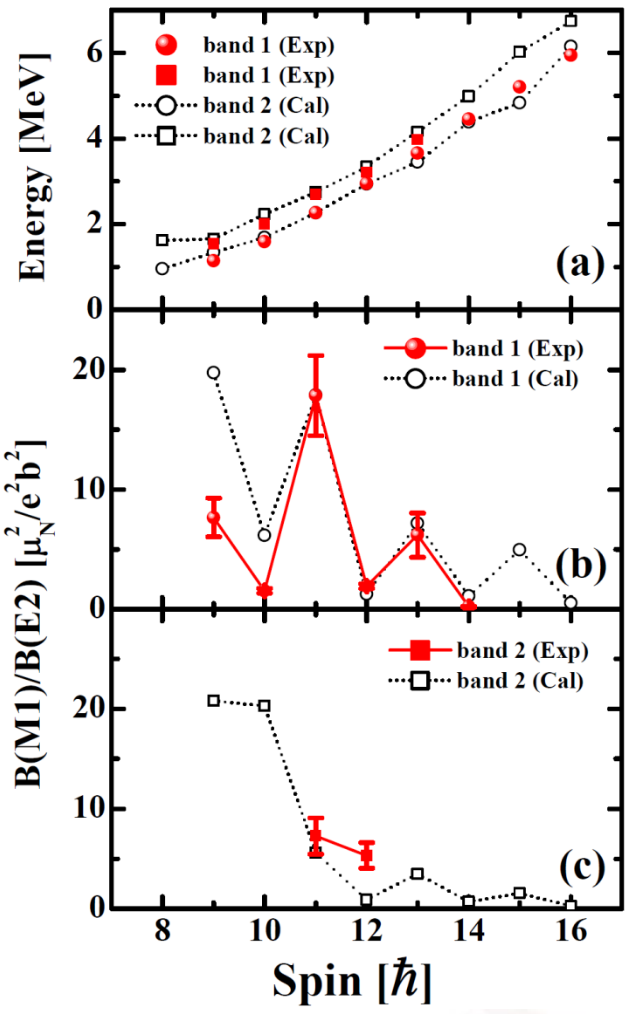


Results and Discussions

- The two bands maintain an energy difference around 400 keV.
- The B(M1)/B(E2) ratios for the two bands are similar. The ratios for band 1 show clearly the odd-even staggering as a function of spin.
- Taking the experimental results into account, bands 1 and 2 in ^{80}Br may be considered as candidate for chiral doublet bands.



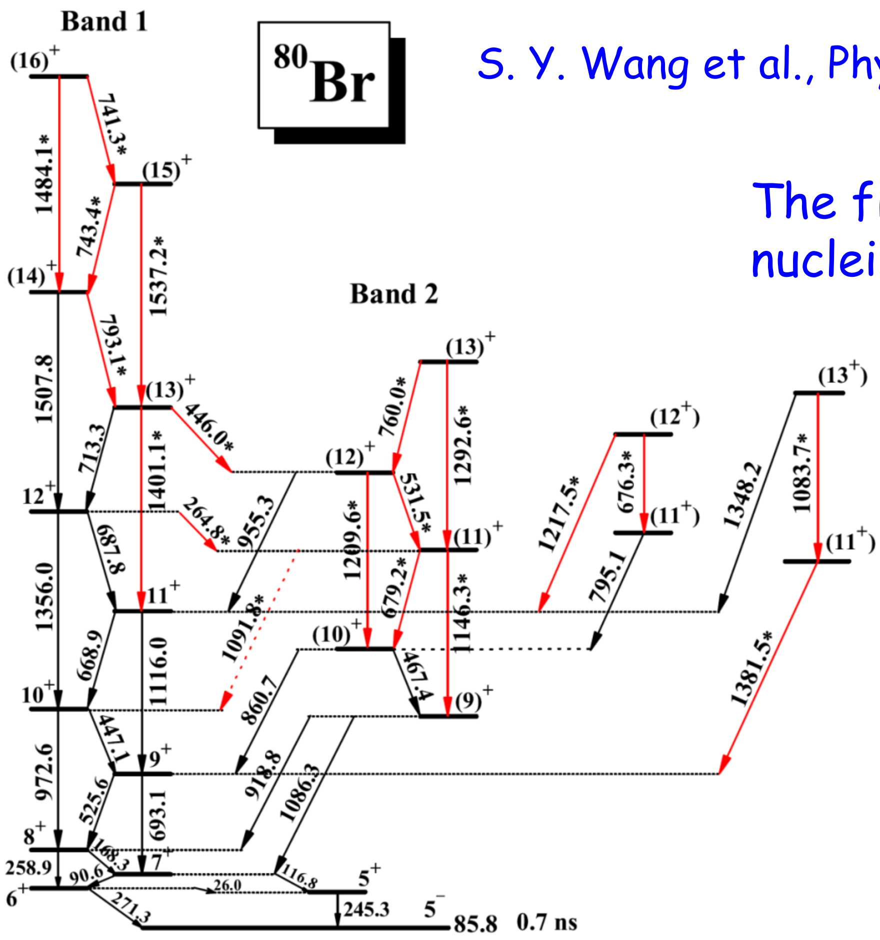
The PRM calculations for ^{80}Br



- One can see that the PRM calculations reproduce the main features of the data well.
- It can be seen that the agreement for the B(M1)/B(E2) ratios at the whole spin region is excellent.

A new "Chiral island"

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

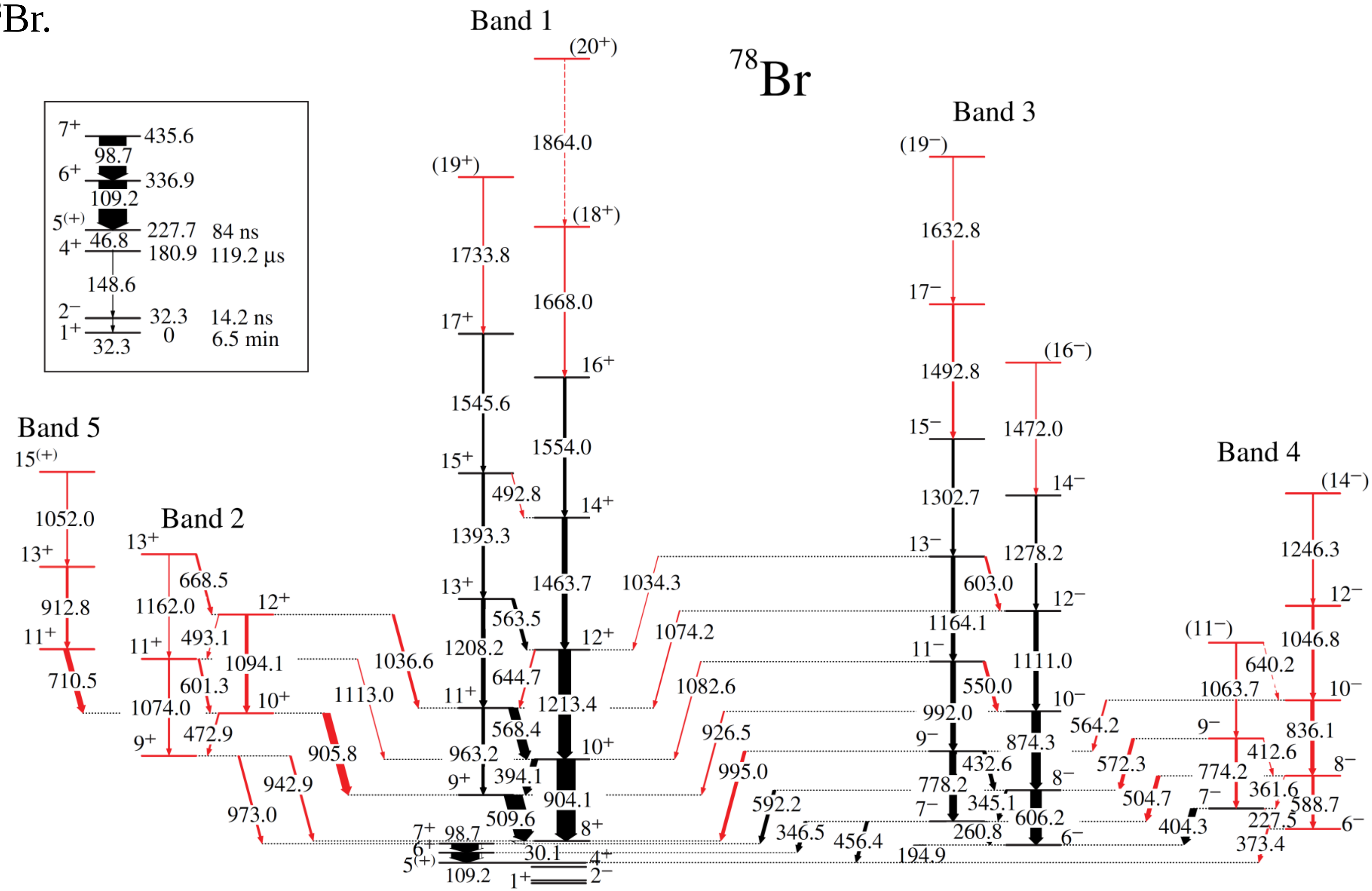


S. Y. Wang et al., Phys. Lett. B703, 40(2011)

The first candidate for chiral nuclei in the A ~ 80 mass region

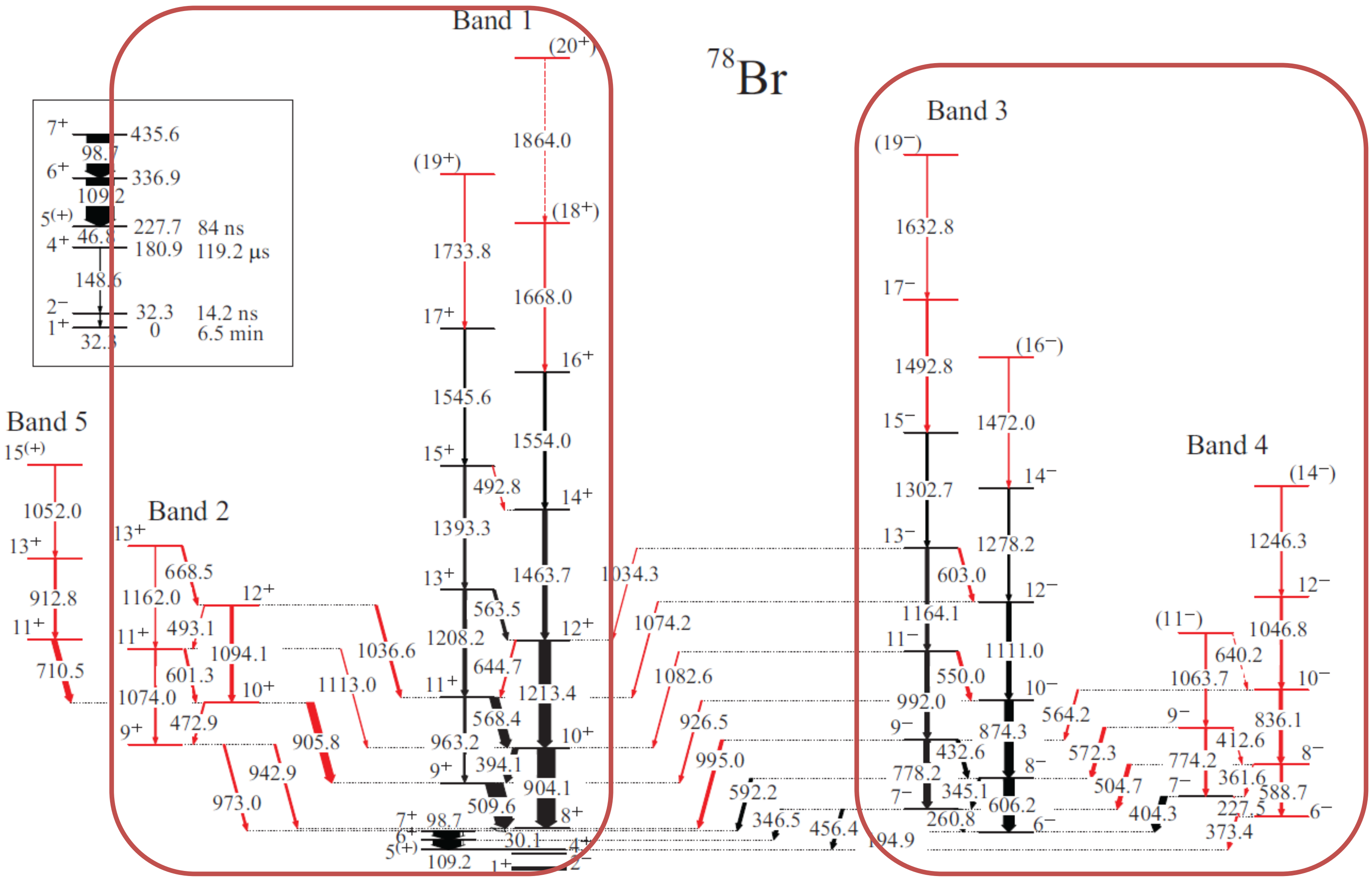
Level scheme for ^{78}Br

➢Two pairs of positive-and negative-parity doublet bands together with eight strong electric dipole transitions linking their yrast positive- and negative-parity bands have been identified in ^{78}Br.



Results and discussion

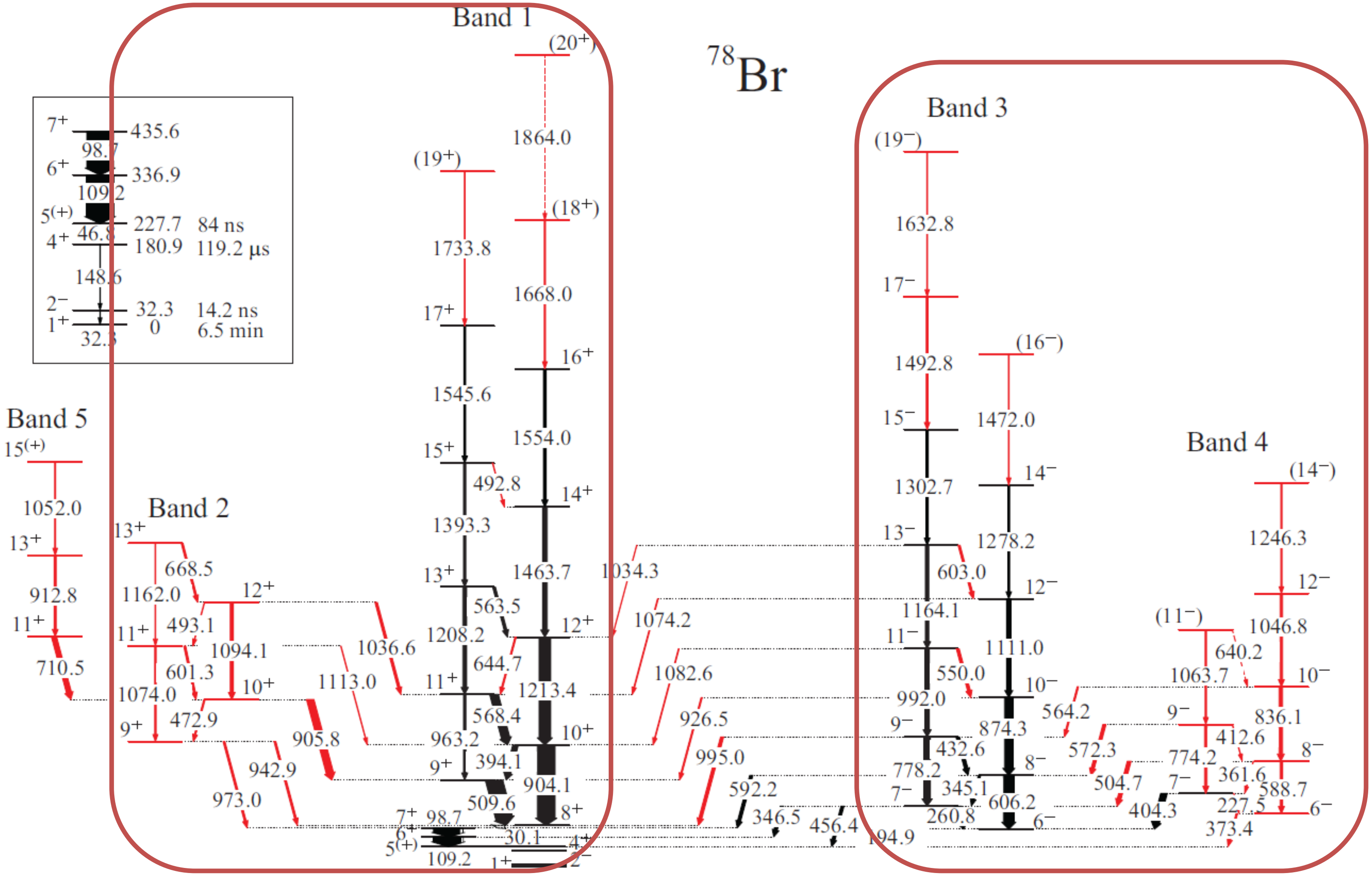
➢ One distinct feature of the level scheme is the presence of two pairs of nearly degenerate doublet bands.



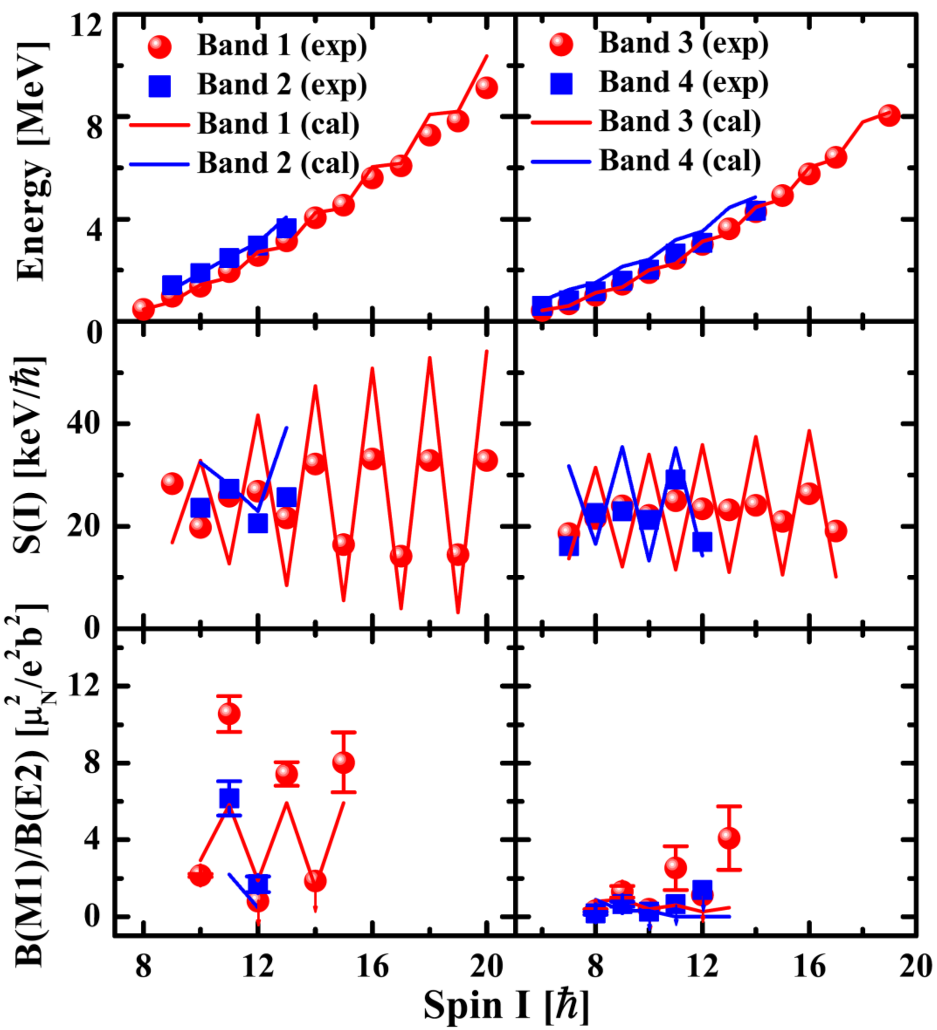
Results and discussion

$\pi g_{9/2} \otimes \nu g_{9/2}$

$\pi f_{5/2} \otimes \nu g_{9/2}$

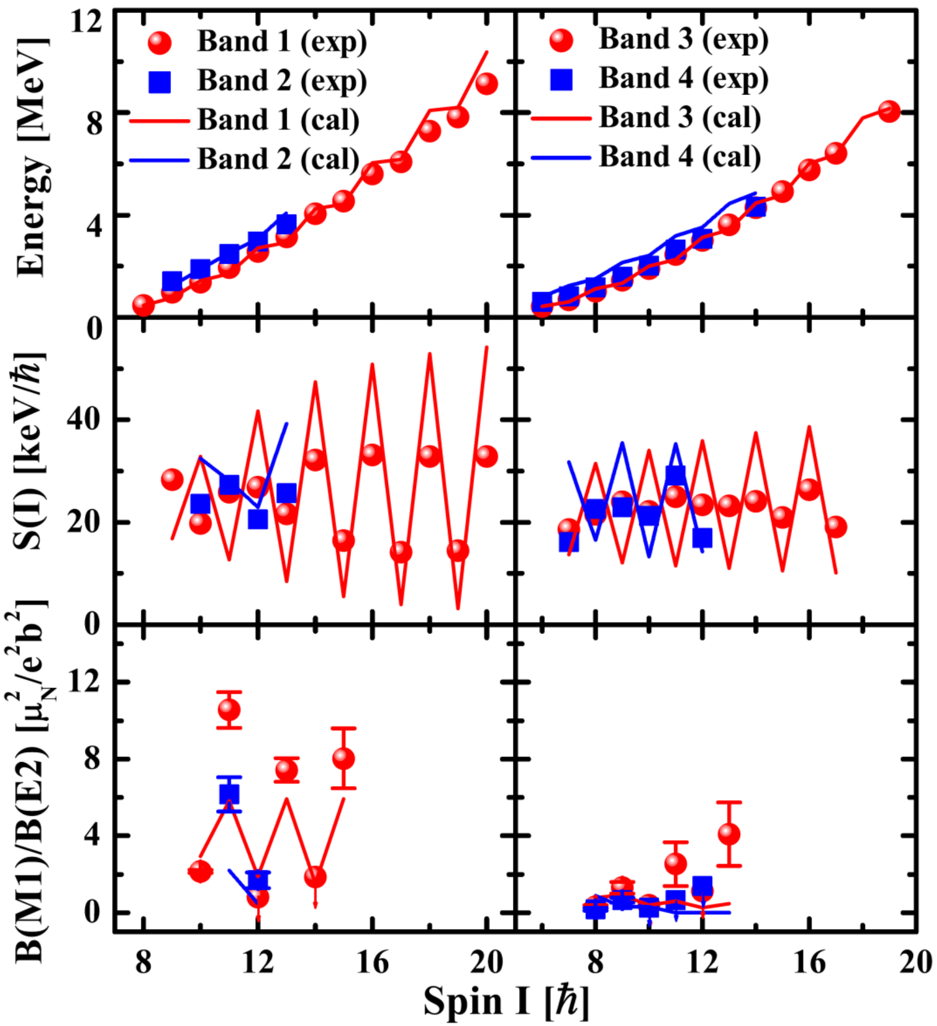


Results and discussion



- Bands 1 and 2 show similar experimental features with the chiral doublet bands observed in ^{80}Br, therefore bands 1 and 2 are suggested as chiral doublet bands.
- Bands 3 and 4 show similar experimental features, forming another pair of chiral doublet bands.

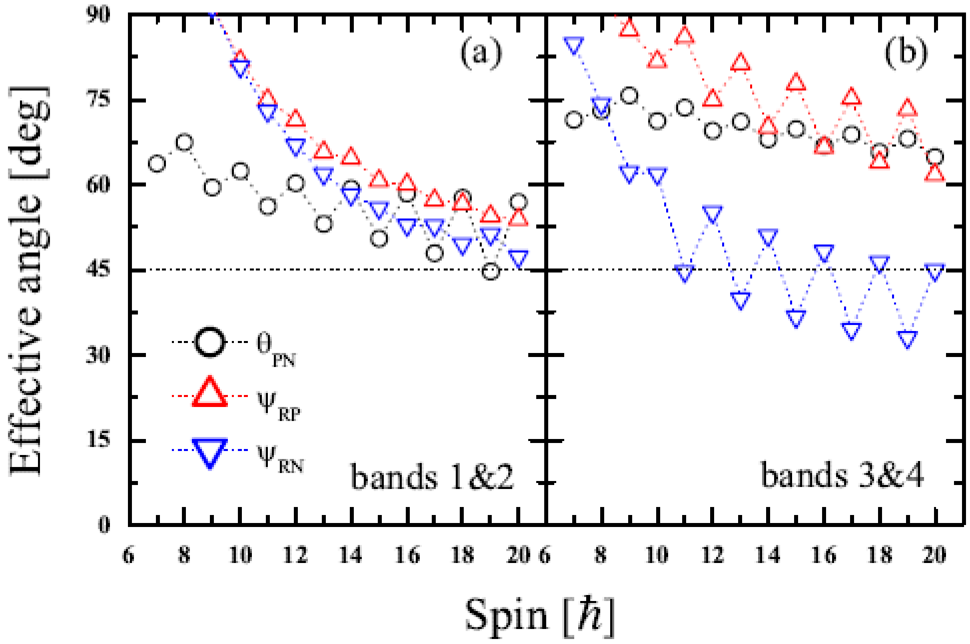
Results and discussion



- The microscopic multidimensionally-constrained covariant density functional theory (MDC-CDFT) and the triaxial particle rotor model (TPRM) calculations have been performed to investigated the two pairs of nearly degenerate bands.
- Good agreement between the calculated values and the available experimental data are found, which supports the present configuration assignments.

Lu12, Zhao12, Lu14, Wang07, Zhang07, Wang08, Wang10

Results and discussion

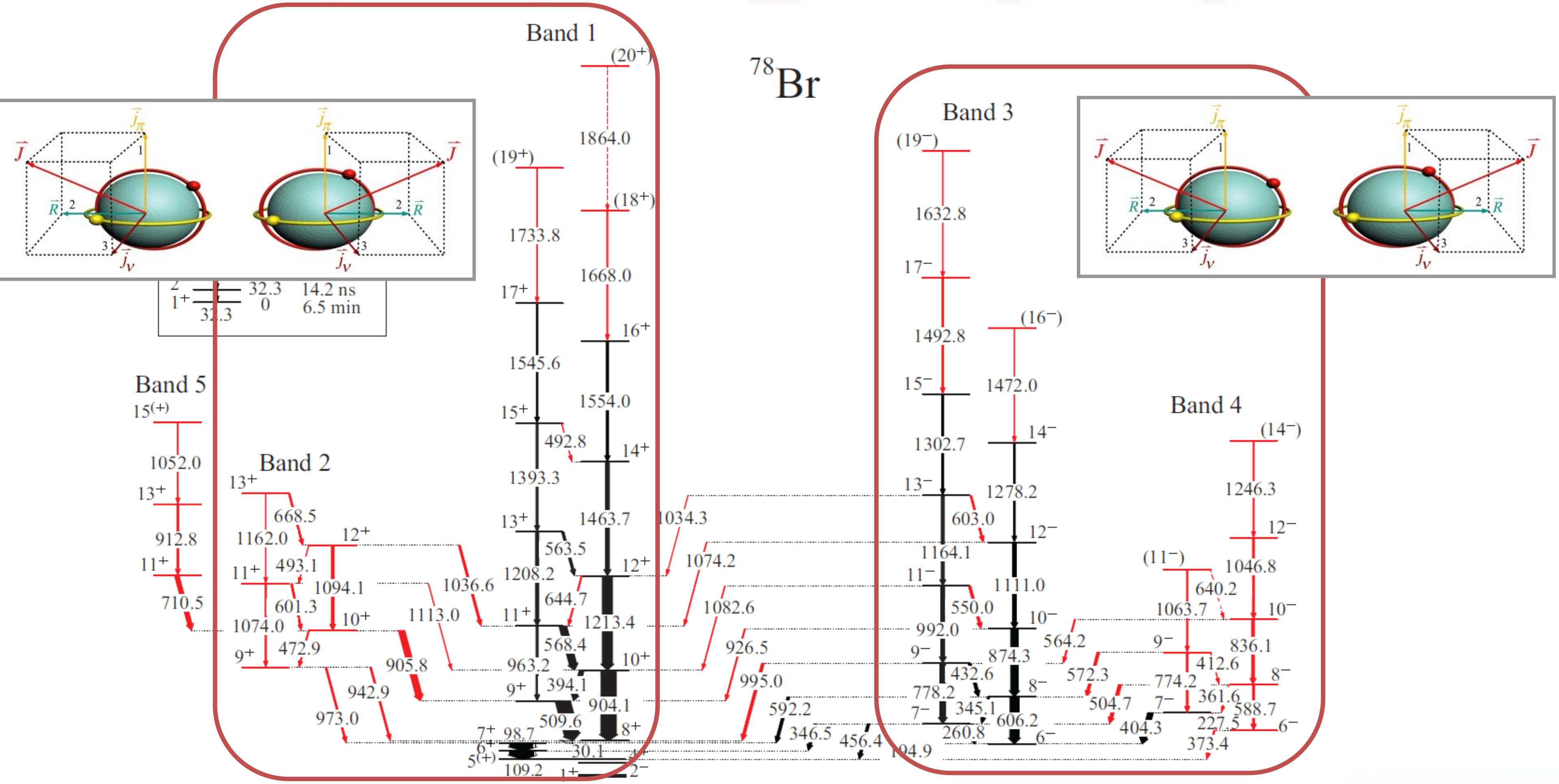


The effective angles between the angular momentum vectors of the valence proton, valence neutron, and core for the two pairs of doublet bands.

- The effective angles are equal to or greater than 45° for the two pairs of doublet bands in the observed spin region, which indicates clear nonplanar rotations for bands 1, 2 and bands 3, 4. This allows the two pairs of bands to be interpreted as pairs of chiral doublet bands, thereby forming MχD bands.

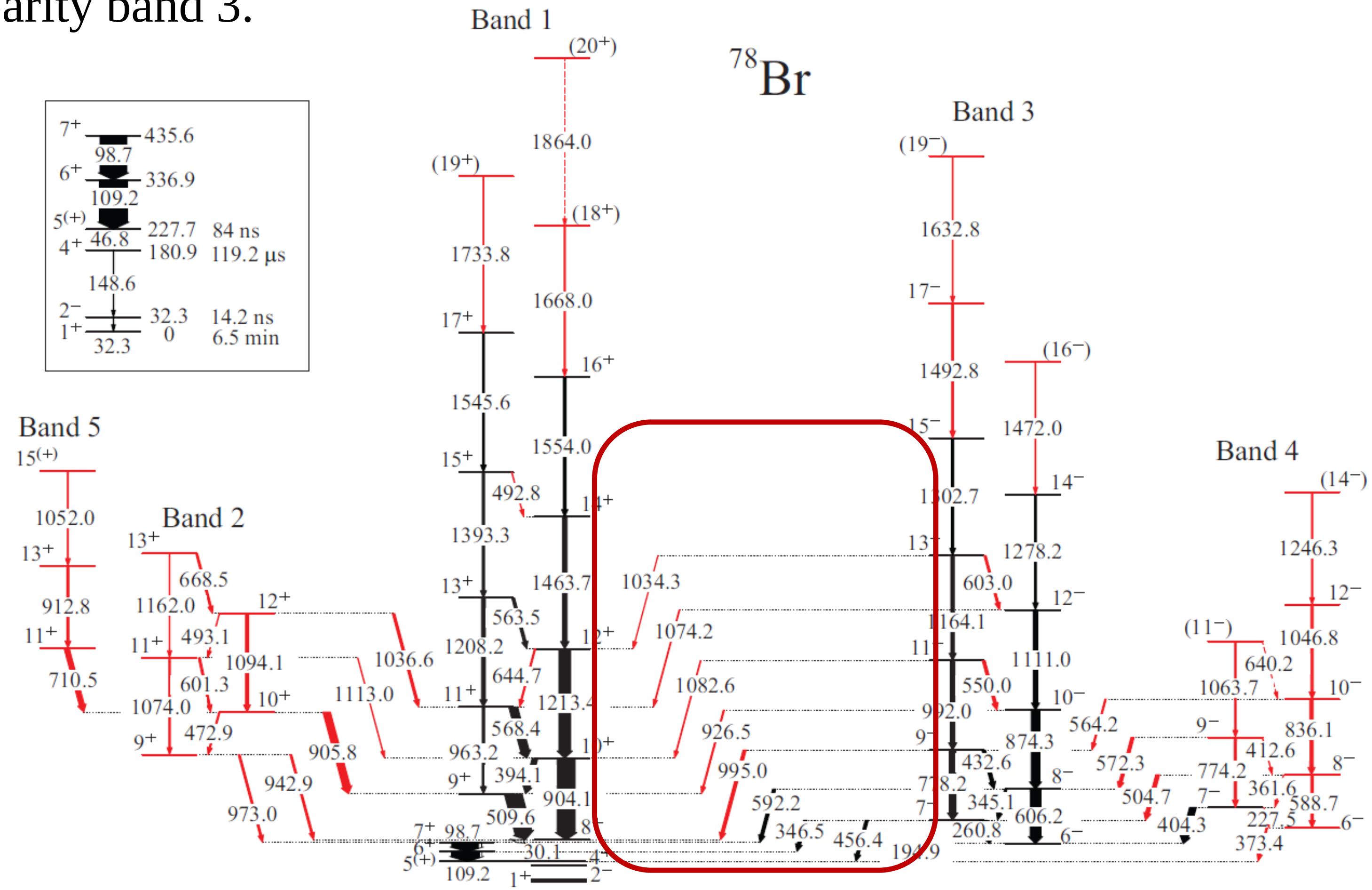
Results and discussion

Two pairs of positive-and negative-parity doublet bands in ^{78}Br were interpreted as MχD bands with $\pi g_{9/2} \otimes \nu g_{9/2}$ and $\pi f_{5/2} \otimes \nu g_{9/2}$ configurations.



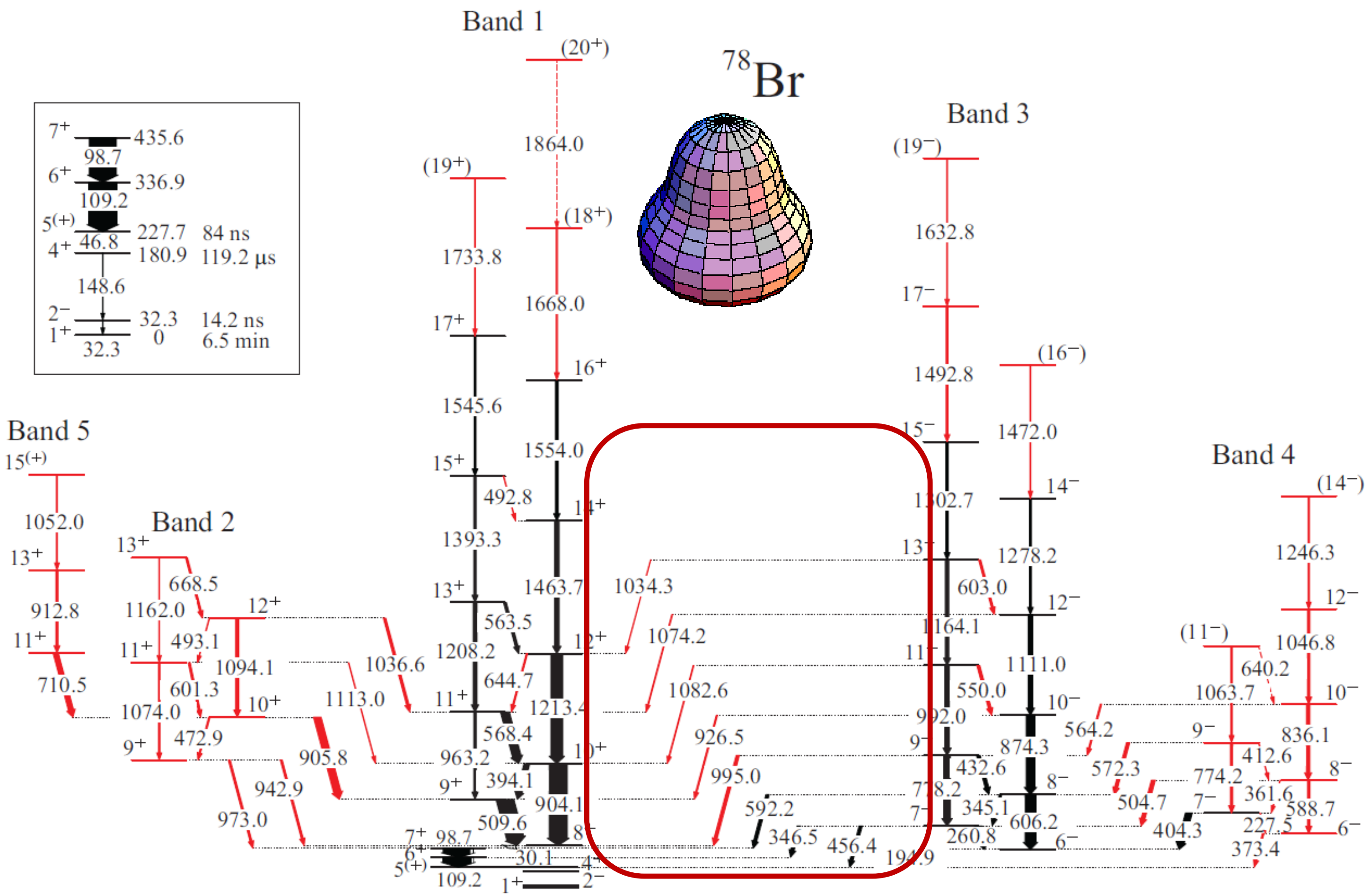
Results and discussion

➢ One more distinct feature of the level scheme is the observation of eight E1 linking transitions between the positive-parity band 1 and the negative-parity band 3.



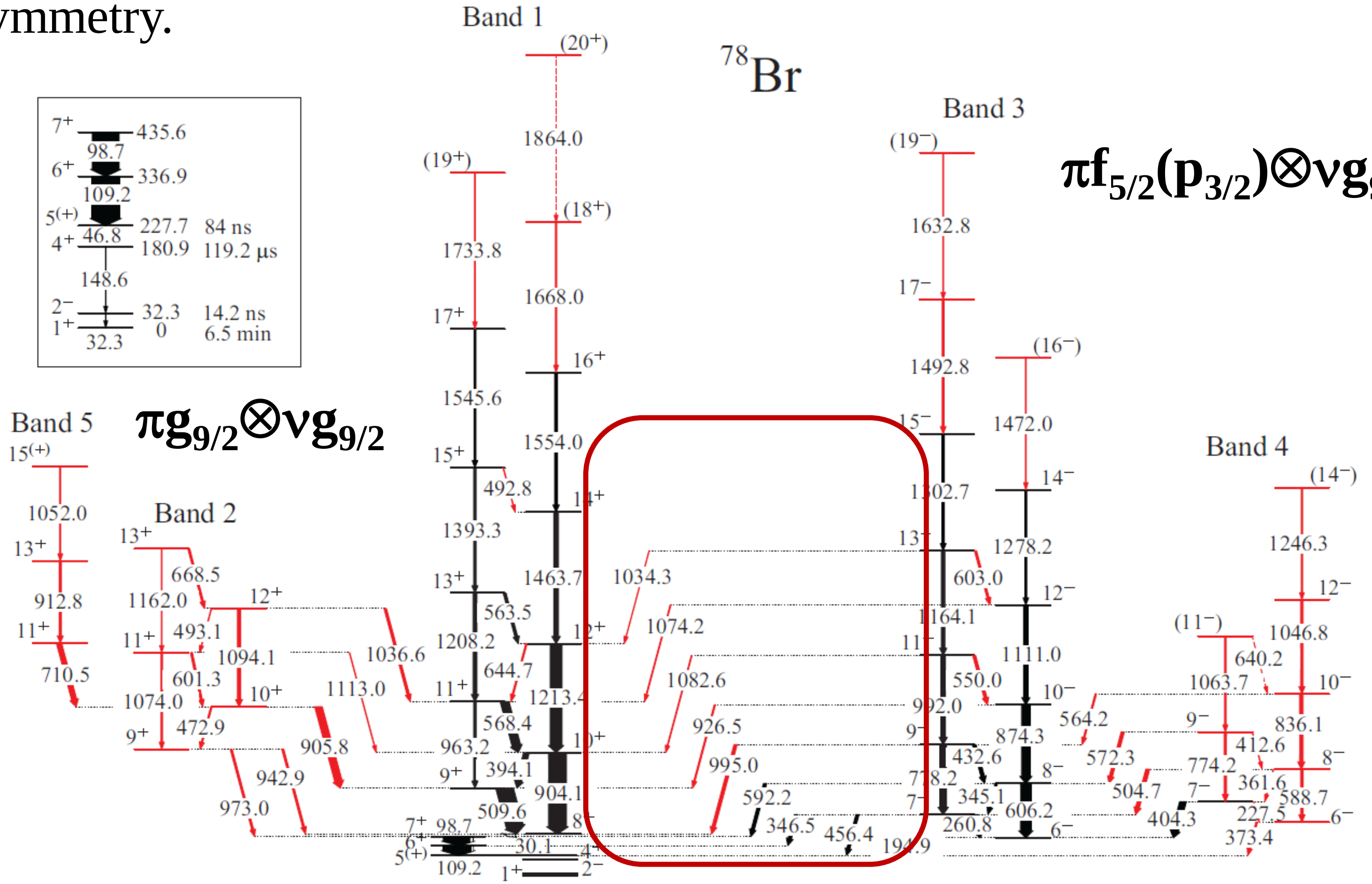
Results and discussion

➢The observation of the E1 transitions between bands 1 and 3 implies the existence of the octupole correlations in ^{78}Br.

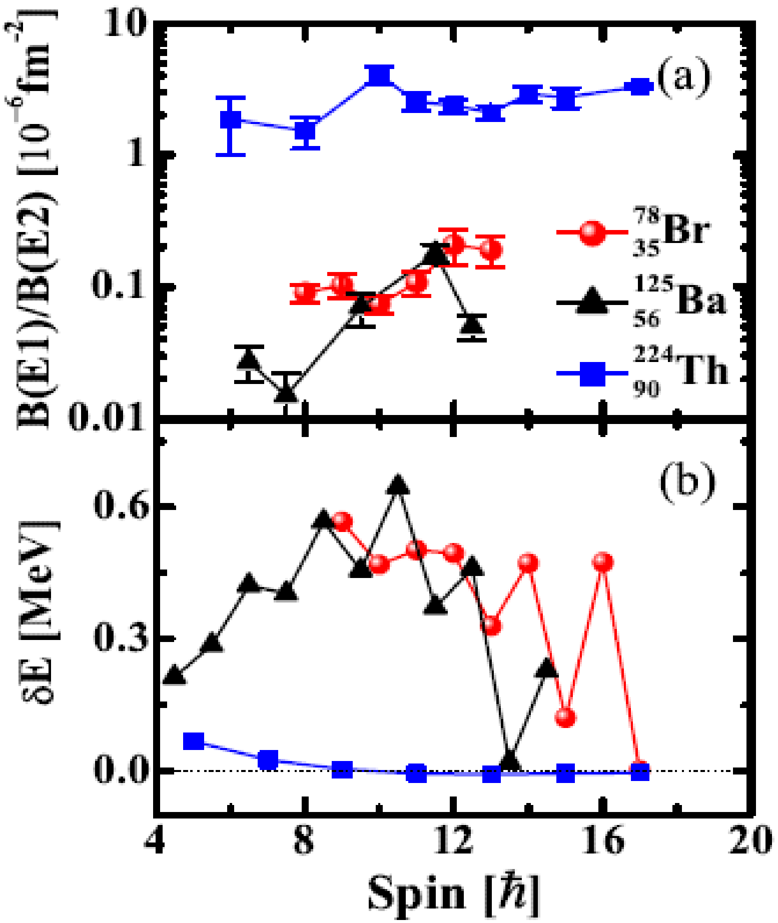


Results and discussion

➢The observation of the octupole correlations implies strong mixing between the $\pi p_{3/2}$ and $\pi f_{5/2}$ components due to triaxiality and pseudospin symmetry.



Results and discussion

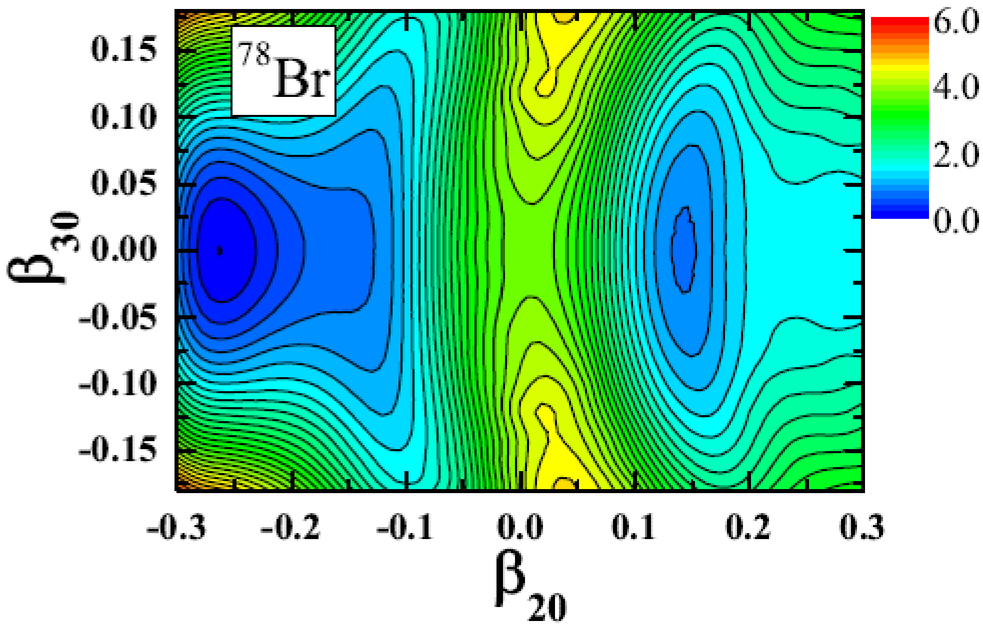


The experimental B(E1)/B(E2) ratios (a) and energy displacement δE (b) between the positive- and negative-parity bands as a function of spin in 78Br, together with those in 125Ba and 224Th

- Octupole correlations were reported in ^{125}Ba while stable octupole deformation was reported in ^{224}Th.
- The B(E1)/B(E2) and δE of ^{78}Br are comparable with those in ^{125}Ba , indicate that octupole correlations exist in ^{78}Br.
- The B(E1)/B(E2) branching ratios increase and δE decreases with spin, which indicate that the octupole correlations enhance with spin.

Mason 05, Ackermann93

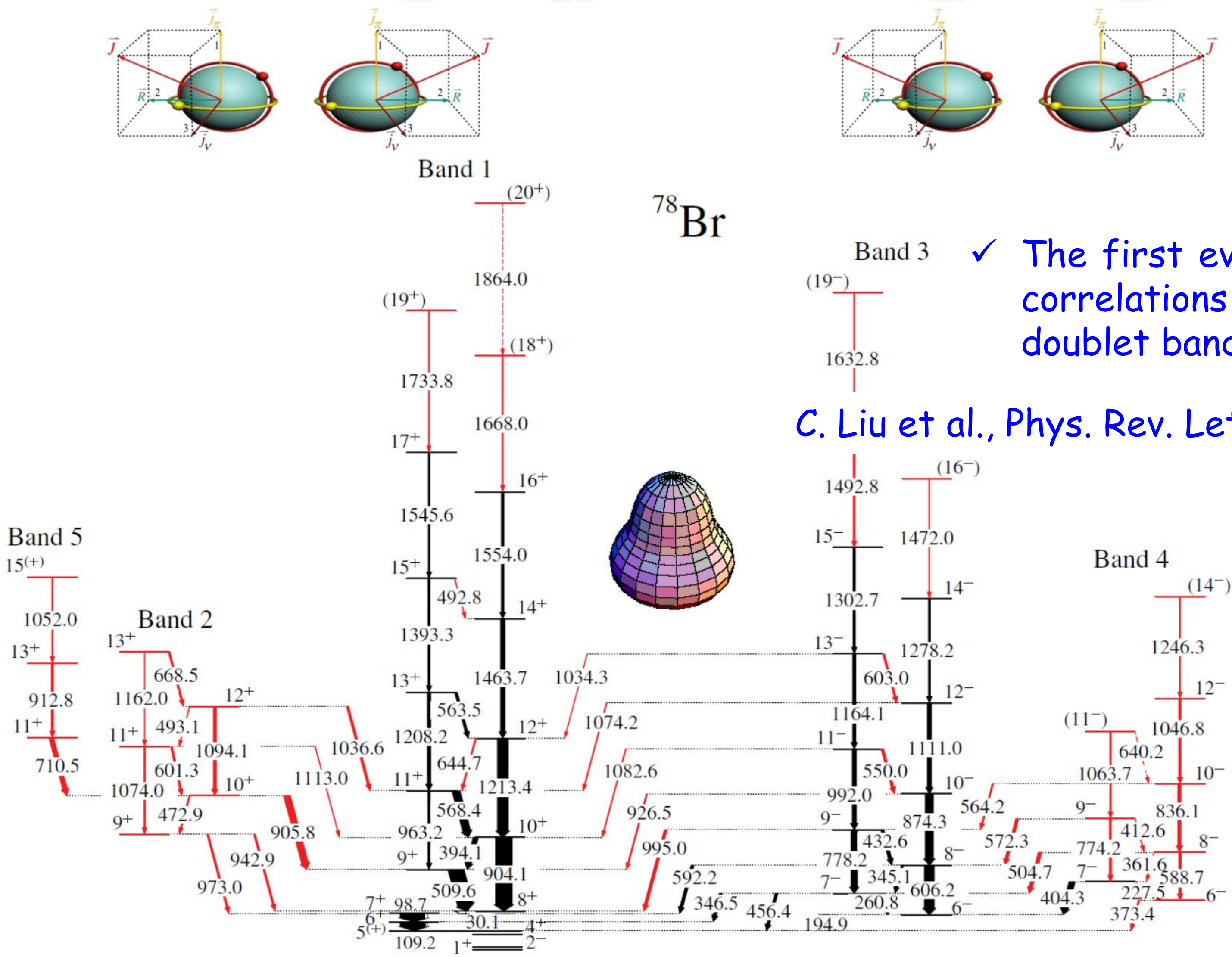
Results and discussion



The potential energy surface of ^{78}Br calculated using the MDC-CDFT approach.

- The potential energy surface is very soft with respect to the shape degree of freedom β_{30}, which supports the octupole correlations in ^{78}Br.
- Nuclear chirality can be robust against the octupole correlations.

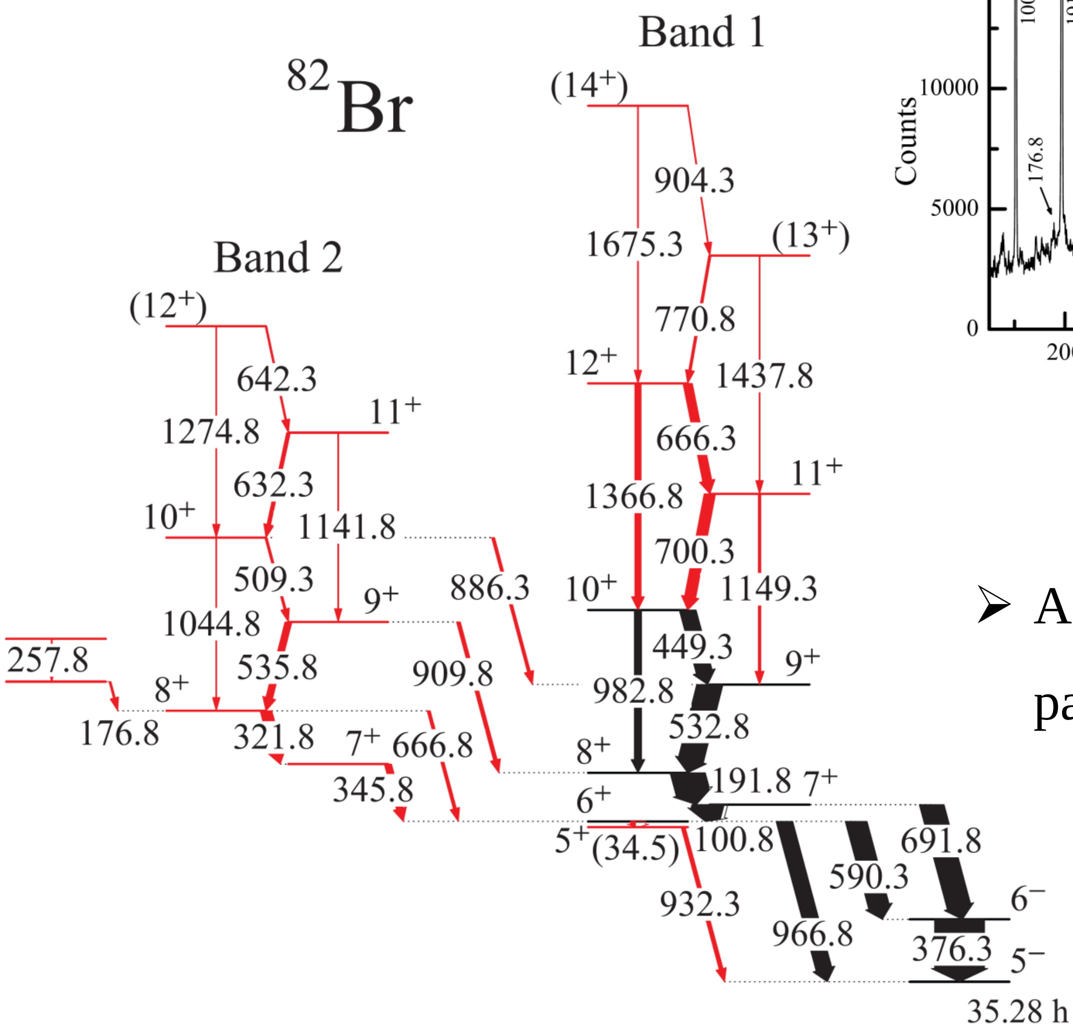
Evidence for Octupole Correlations in Multiple Chiral Doublet Bands

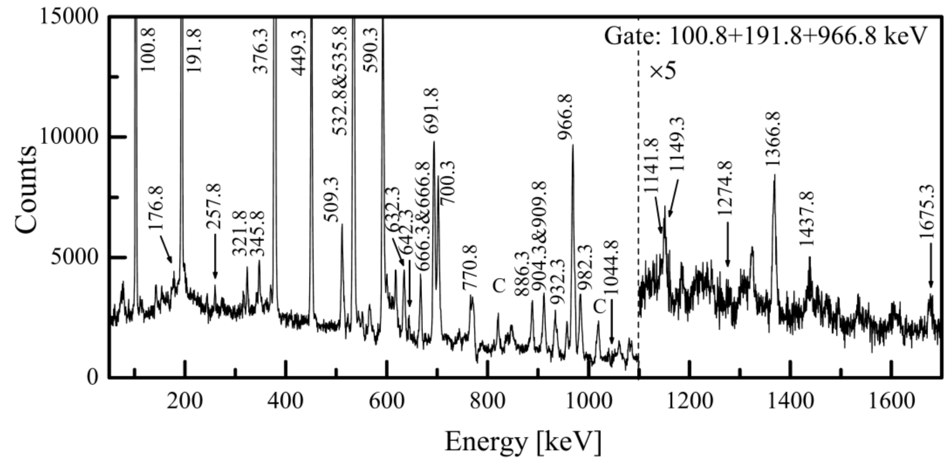


✓ The first evidence for octupole correlations in multiple chiral doublet bands !

C. Liu et al., Phys. Rev. Lett. 116, 112501(2016)

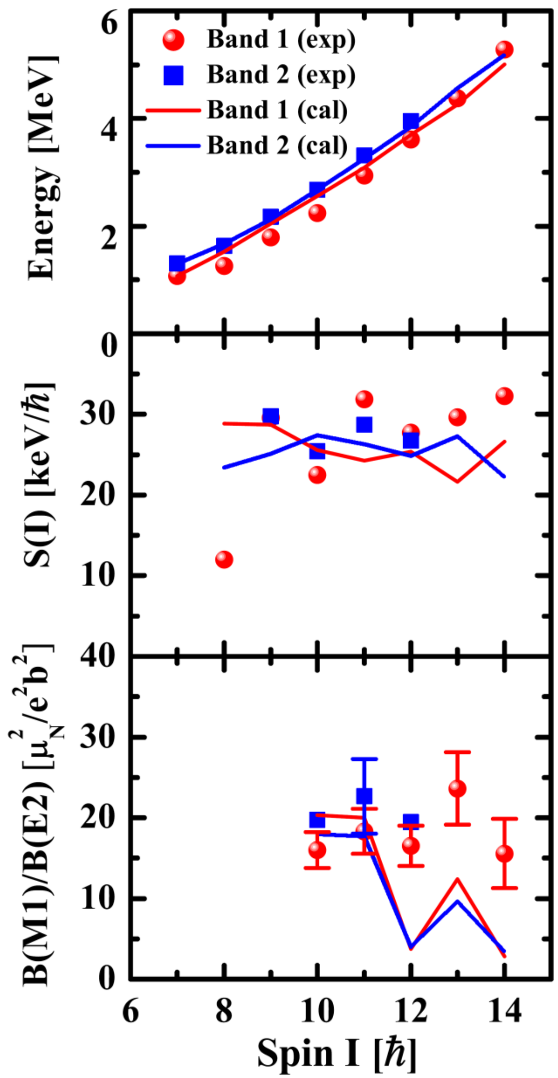
Level scheme for ^{82}Br





- A pair of nearly degenerate positive-parity bands were observed in ^{82}Br.

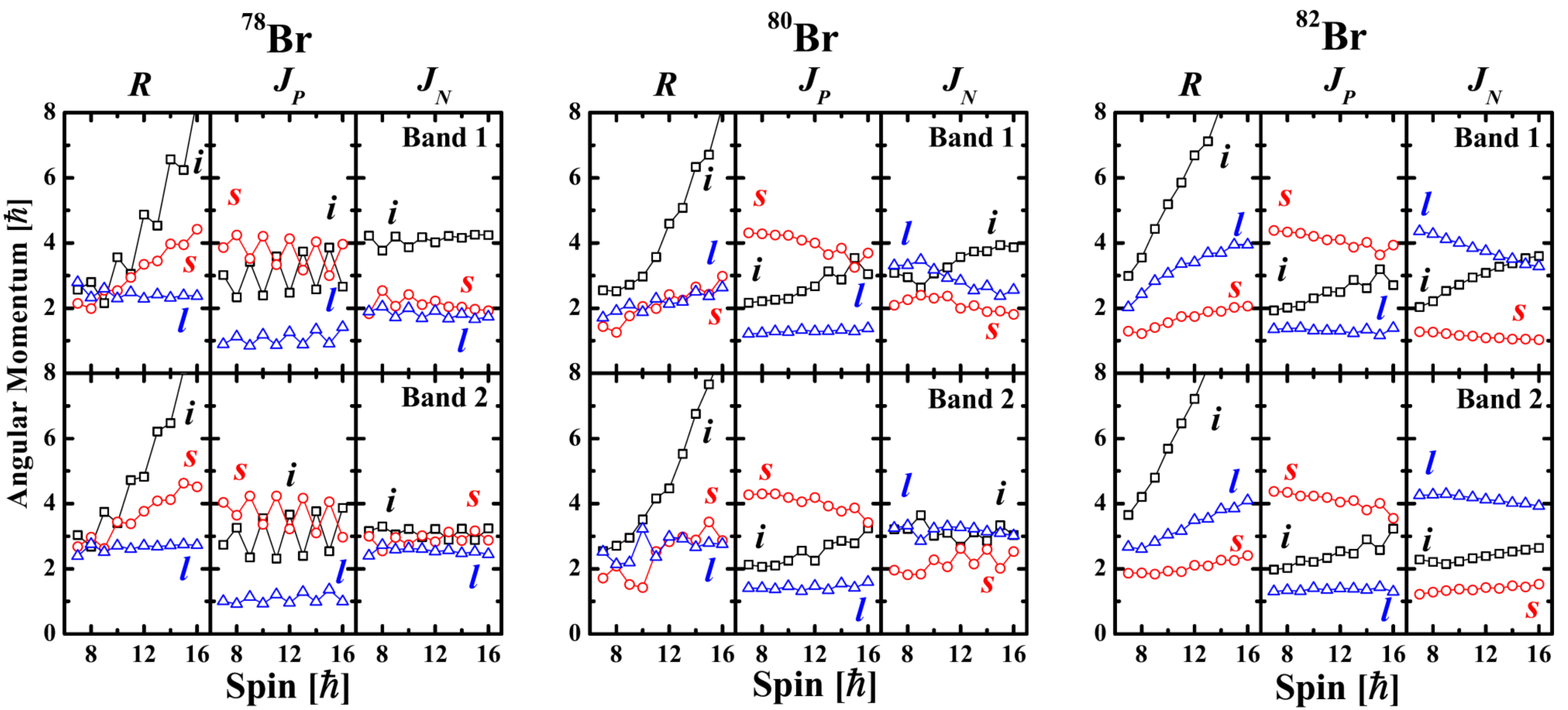
The PRM calculations for ^{82}Br



- The doublet bands in ^{82}Br have small energy differences, smooth variation $S(I)$, almost identical $B(M1)/B(E2)$ ratios within the observed spin interval.
- The PRM calculations well reproduce the experimental results, which supports the present configuration assignments.

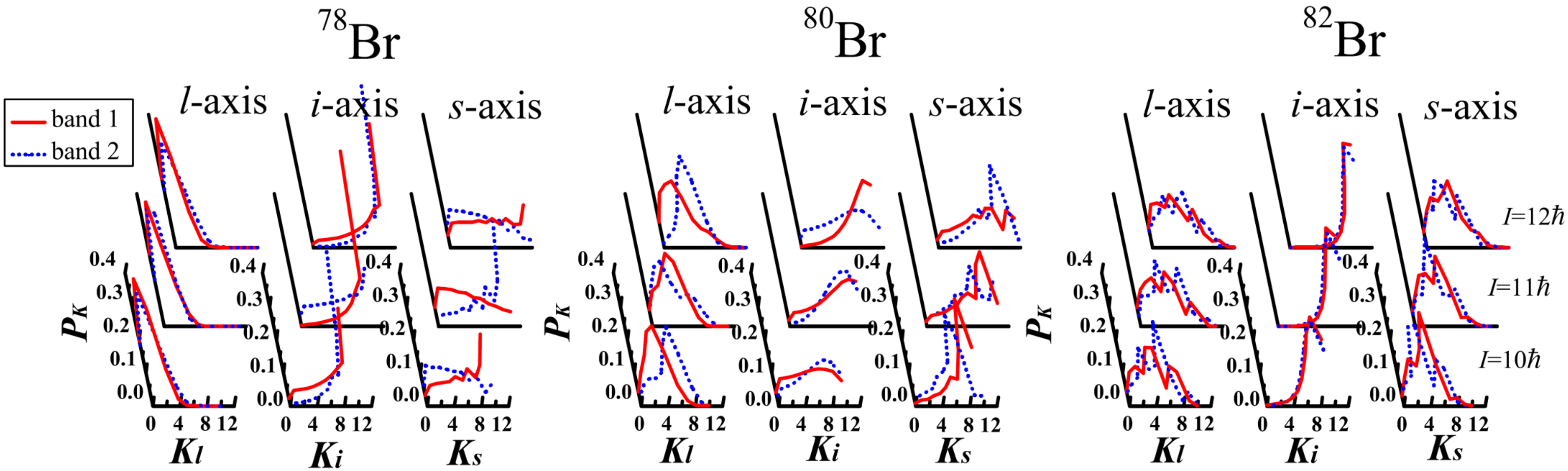
The PRM calculations for ^{82}Br

- Comparing to the ideal chiral geometry in ^{82}Br, the coupling patterns of angular momenta in ^{78}Br and ^{80}Br both somewhat deviate from the ideal chiral geometry.
- The addition of the neutrons in ^{82}Br leads to the stabilization of chirality.



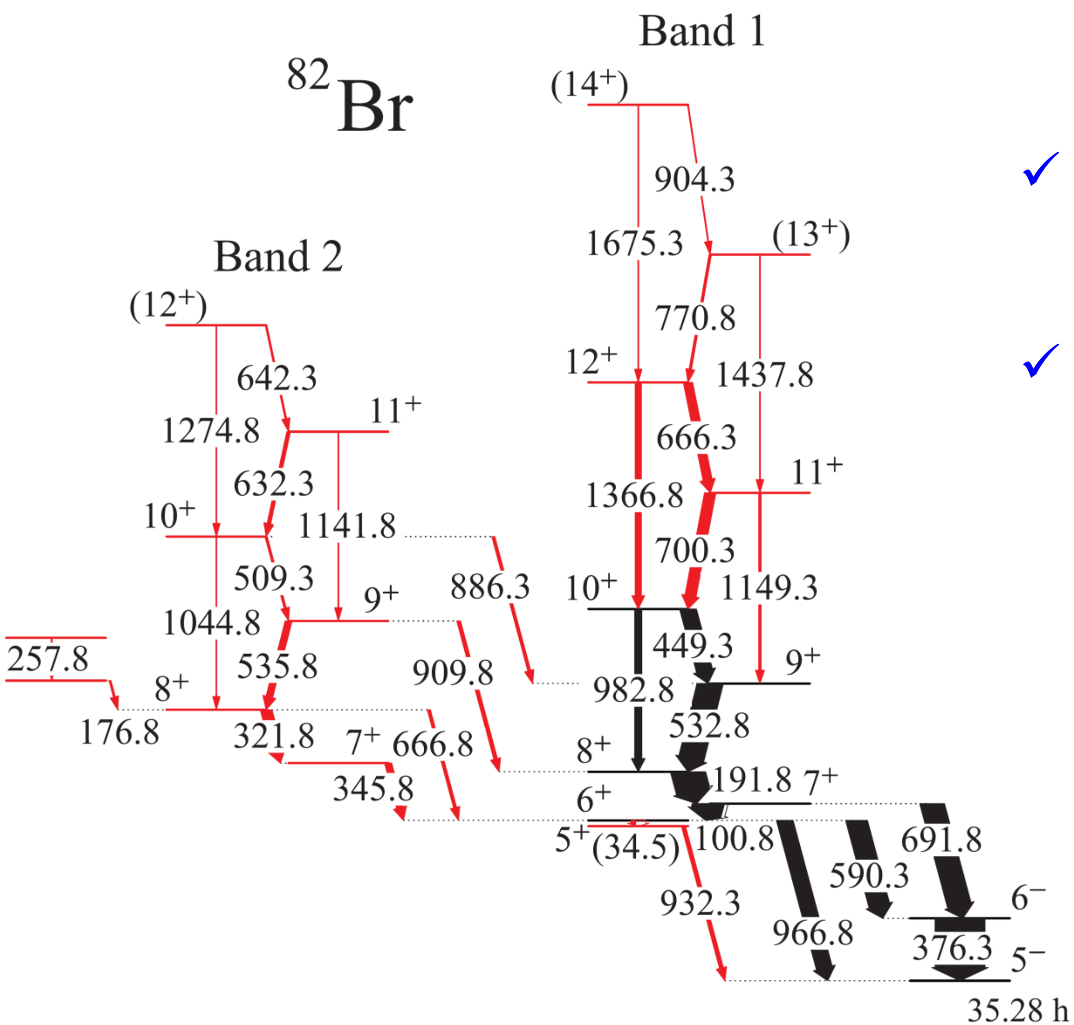
K plot of $^{78,80,82}Br$

A better chirality is exhibited in ^{82}Br than ^{78}Br and ^{80}Br.



The probability distributions for projection of total angular momentum on the long (*l*-), intermediate (*i*-) and short (*s*-) axis in TPRM for the doublet bands in ^{78}Br, ^{80}Br, and ^{82}Br.

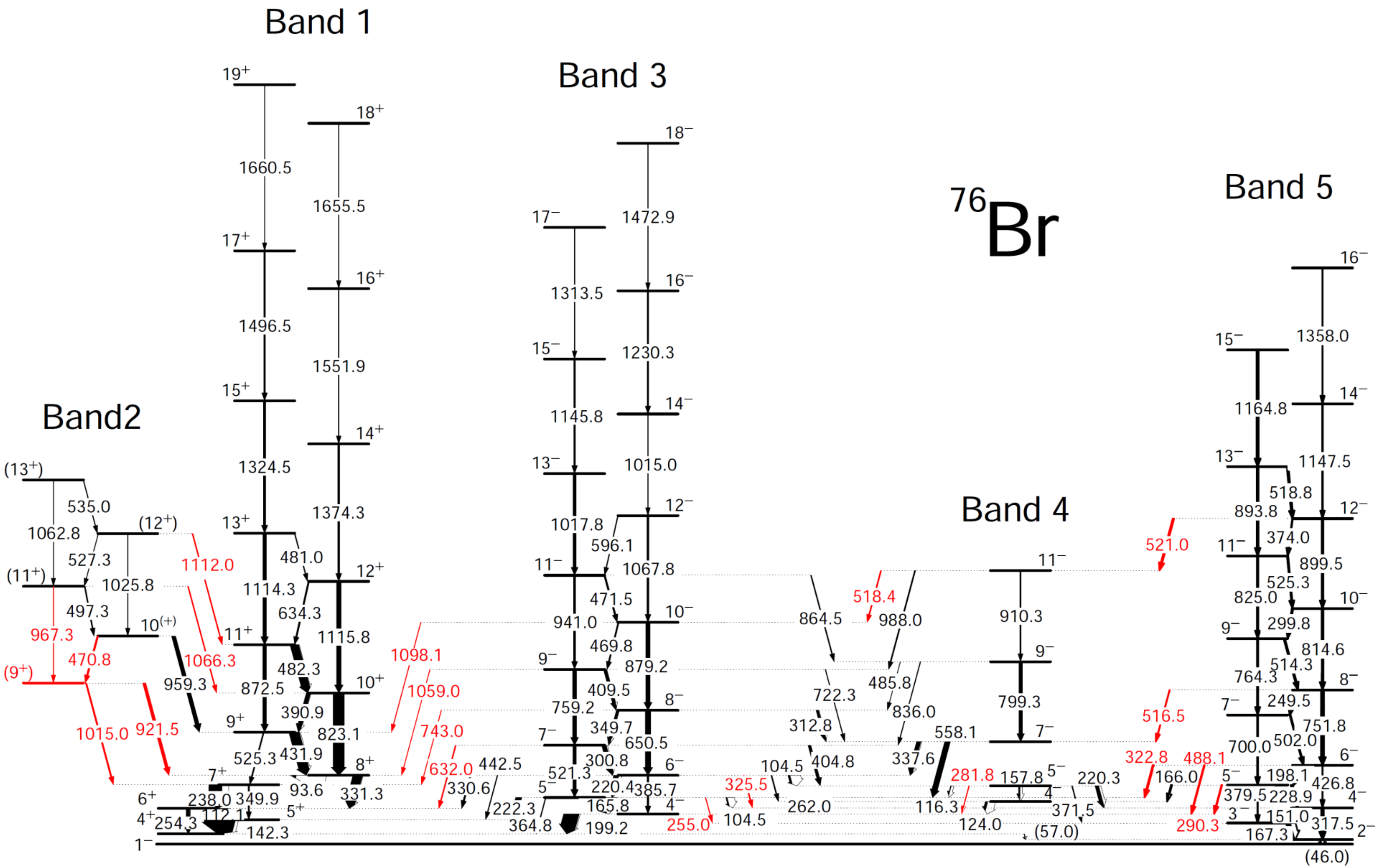
New chiral nucleus in the A~80 mass region



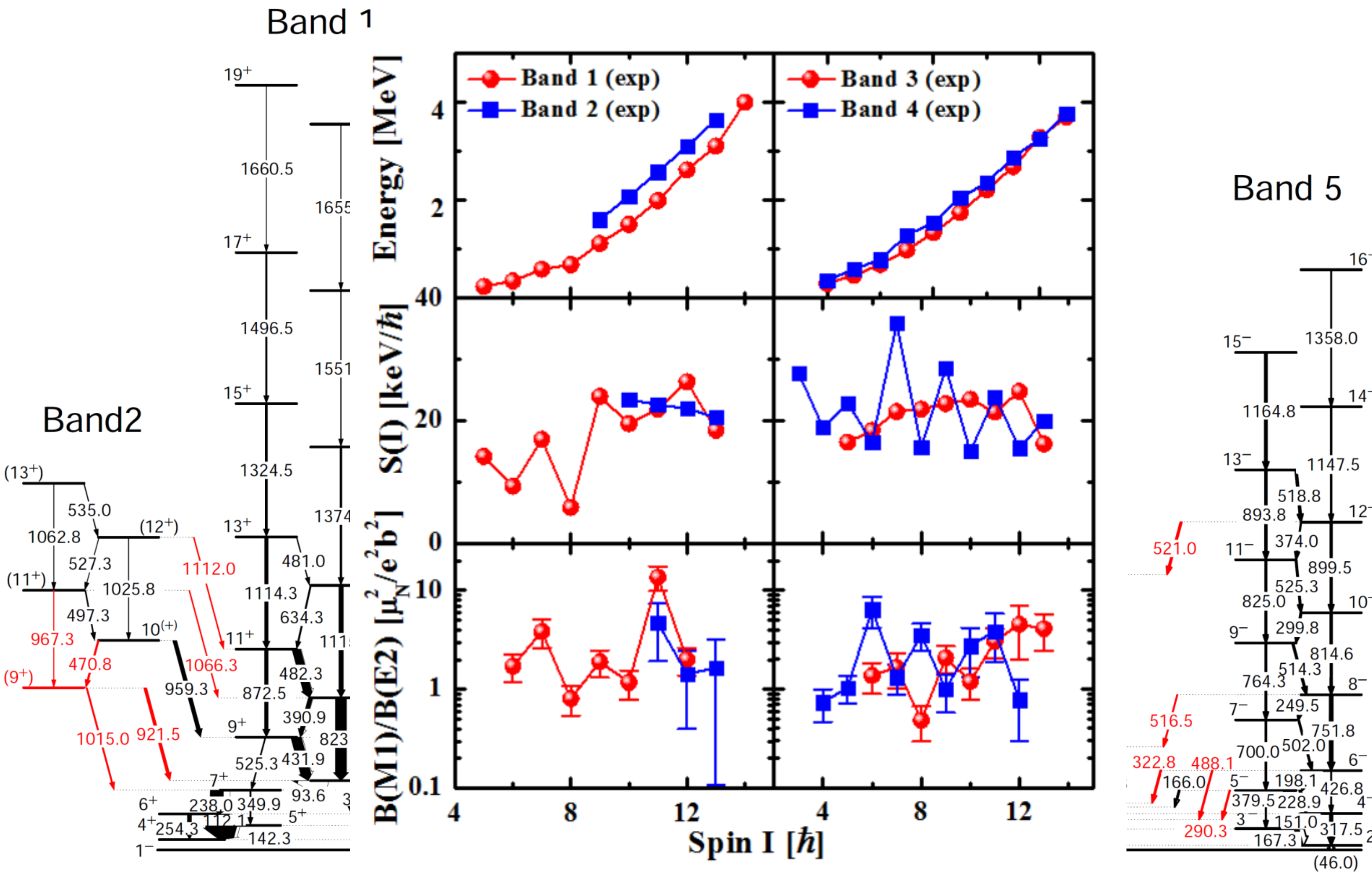
- ✓ Chiral doublet bands were observed in ^{82}Br.
- ✓ By examining the angular momentum geometry and the K plot, a better chirality is exhibited in ^{82}Br than ^{78}Br and ^{80}Br.

C. Liu, S. Y. Wang et al., Unpublished

Level scheme for ^{76}Br

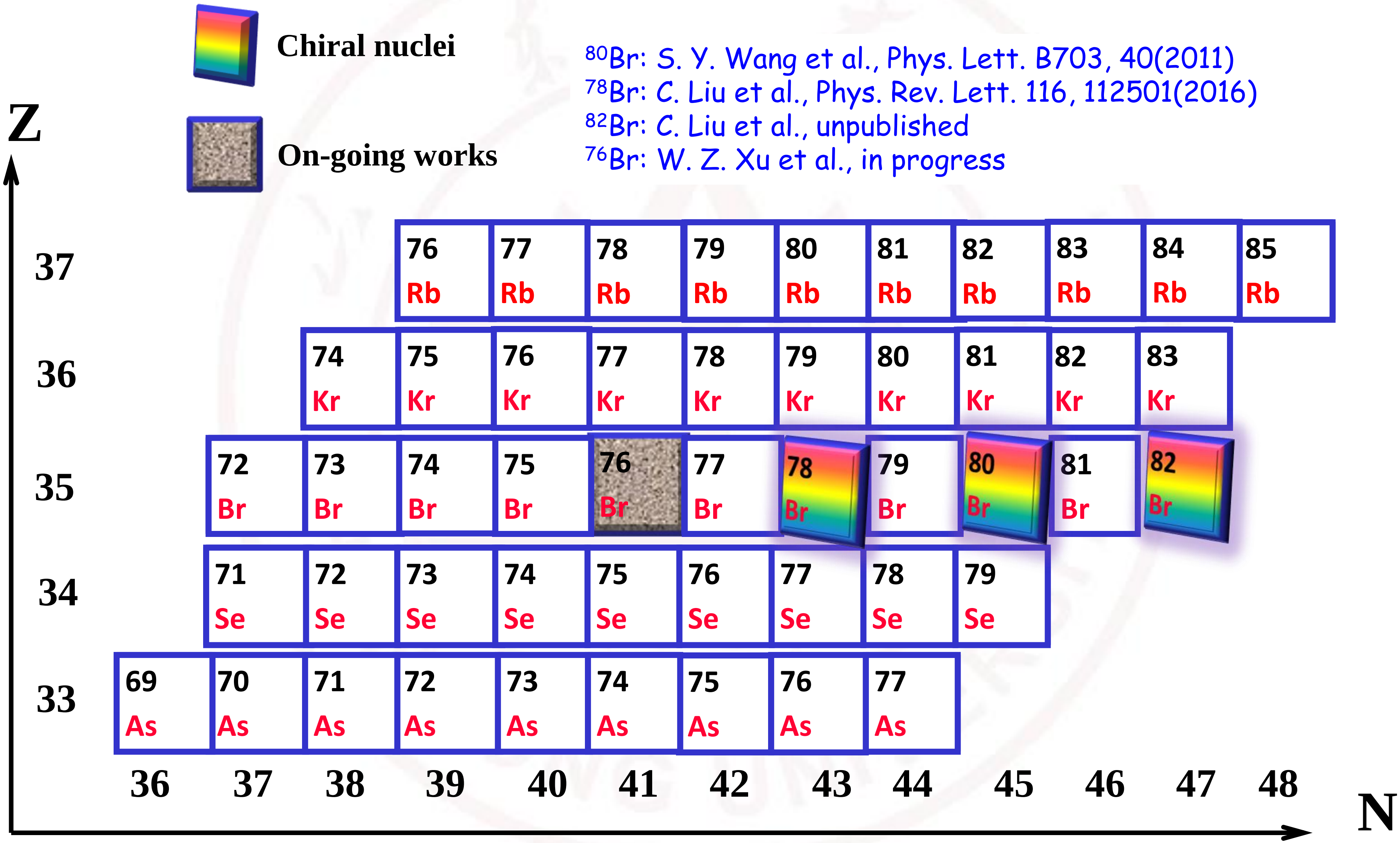


Level scheme for ^{76}Br



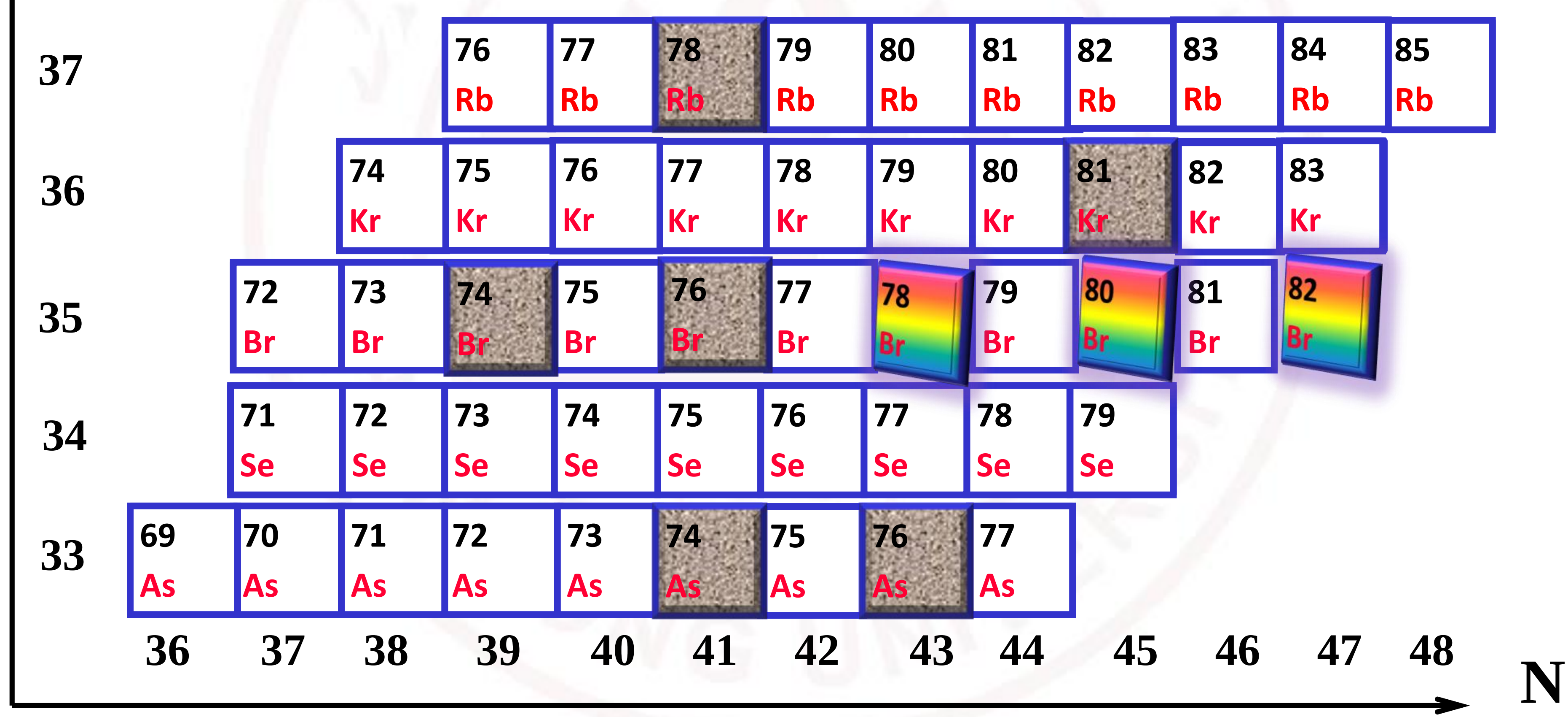
New chiral island

^{80}Br: S. Y. Wang et al., Phys. Lett. B703, 40(2011)
^{78}Br: C. Liu et al., Phys. Rev. Lett. 116, 112501(2016)
^{82}Br: C. Liu et al., unpublished
^{76}Br: W. Z. Xu et al., in progress



Where is the boundary of this chiral island ?

[78]Rb: Z. Q. Li et al., in progress. Argonne National laboratory, USA
[81]Kr: L. Mu et al ., in progress. iThemba LABS, SA
[74]Br: R. J. Guo et al., in progress. iThemba LABS, SA
[74]As: X. Xiao et al., in progress. iThemba LABS, SA
[76]As: D. P. Sun et al., in progress. iThemba LABS, SA



Conclusion

- Performed several experimental studies on the nuclear chirality in the A~80 mass region.
- Reported the first candidate for chiral nuclei in the A ~ 80 mass region: ^{80}Br.
- Reported the first example of chiral geometry in octupole soft nuclei and indicates that nuclear chirality can be robust against the octupole correlations.
- Chiral doublet bands were also observed in ^{82}Br, and a better chirality was found in ^{82}Br than ^{78}Br and ^{80}Br.
- Other experimental studies on the nuclear chirality in the A~80 mass region are still in progress.

Thank you for your attention!