## Systematics of Band Termination at High-Spin in $\mathbf{N} \sim 90$

 Nuclei: How Robust and Pure Are These Special States? Mark A. Riley - Florida State University (+ LOTS OF FRIENDS!)



# The Chart of the Nuclides 





157 Ho




## The Angular Momentum World of the Nucleus




## The Angular Momentum World of the Nucleus



T.Bengtsson and I.Ragnarsson, Physica Scripta T5 (1983) 165
I. Ragnarsson, T. Bengtsson, W. Nazarewicz, J. Dudek, and G. A. Leander; PRL 54, (1985) 982
I. Ragnarsson, T. Xing, T. Bengtsson and M.A. Riley, Phys. Scripta 34 (1986) 651.

## ${ }^{158}$ Er: Filled orbitals relative to ${ }^{146} \mathrm{Gd}$ core.

Protons, $Z=68$


Neutrons, $N=90$


30


32,33



One of my thesis expts.








ZS with AB in 1967


De Voigt M, Dudek J
Rev. Mod. Phys. 55, 949
Dudek J, Szymański and Werner T, 1981 Phys. Rev. C23 920


Zdzislaw Szymanski
another expt at Daresbury with EUROGAM


Beautiful prolate oblate shape coexistence

# Using the purity of BT states to good effect! 

PHYSICAL REVIEW C 71, 024305 (2005)

## Probing the nuclear energy functional at band termination

Honorata Zduńczuk, ${ }^{1, *}$ Wojciech Satuła, ${ }^{1,2, \dagger}$ and Ramon A. Wyss ${ }^{2, \ddagger}$ 'ute of Theoretical Physics, University of Warsaw, ul. Hoża 69, PL-00 681 Warsaw, Royal Institute of Technology), AlbaNova University Center, SE-106 91 Stockholm d 29 June 2004; revised manuscript rec ${ }^{\text {Pd }} 22$ November 2004; published 9 Febrı


A systematic study of terminating states in the $A$ mass region using the self-consistent Skyrme-HartreeFock model is presented. The objective of this study is to demonstrate that the terminating states, due to their intrinsic simplicity, offer unique and so far unexplored opportunities to study different aspects of the effective $N N$ interaction or nuclear local energy density functional. In particular, we show that the agreement of the calculations to the data depends on the spin fields and the spin-orbit term which, in turn, allows us to constrain the appropriate Landau parameters and the strength of the spin-orbit potential. The present study reveals that the structure and energy of terminating states can be used as a tool to differentiate among the many Skyrme force parametrizations.

## Review Paper on Band Termination States see, Afanasjev, Fossan, Lane and Ragnarsson, Phys. Rep. 322 (1999) 1

## BUT WHAT LIES ABOVE BAND TERMINATION?

another expt at Daresbury with EUROGAM



Previous Work on 157Ho (1992)!


## revious Work on 157Ho (1992)



## 157Ho Latest Level Scheme (Jon Baron)






(
















A historical overview of nuclear structure studies in Strasbourg Laboratories: Instrumentation, measurements and theory modelling - hand-in-hand
Focus Issue on Nuclear Structure: Celebrating the 1975 Nobel Prize F A Beck
IPHC, Strasbourg, France





Energy (keV)




States in 158Er Experiment States in 157Ho
$\begin{array}{ll}\text { States in 158Er } & \left.\begin{array}{c}\text { Exper } \\ \\ \\ \\ \\ \\ \end{array} \mathrm{keV}\right)\end{array}$
$\mathrm{v}(\mathrm{h} 9 / 2, \Omega=5 / 2) \rightarrow \mathrm{v}(\mathrm{f} 7 / 2, \Omega=-$ 7/2)
$E x(46+) \rightarrow E x(40 \quad 3284$ +)
$E x(49-) \rightarrow E x(43-) 3127$
$v(i 13 / 2, \Omega=9 / 2) \rightarrow v(f 7 / 2, \Omega=3 / \quad E x(43-) \rightarrow E x(40+1905$ )
$E x(49-) \rightarrow E x(46+1749$
) -)

This work (keV)

$$
\begin{aligned}
& \operatorname{Ex}(87 / 2-) \rightarrow \operatorname{Ex}(75 / 2- \\
& ) \\
& \operatorname{Ex}(93 / 2+) \rightarrow \operatorname{Ex}(81 / 2 \\
& +) \\
& +) \\
& \operatorname{Ex}(81 / 2+) \rightarrow \operatorname{Ex}(75 / 2 \\
& -) \\
& \begin{array}{ll}
\operatorname{Ex}(93 / 2+) \rightarrow \operatorname{Ex}(87 / 2 & 1880 \\
-) \\
-
\end{array} \\
& \hline
\end{aligned}
$$

Thin data $\left(\gamma^{3}\right)$



High-spin Study of ${ }^{161} \mathrm{Lu}$ : The Crossroads Between Lower Spin TSD Wobbling and Ultrahigh-Spin TSD Bands?
D.J. Hartley, ${ }^{1}$ M.A. Riley, ${ }^{2}$ J. Simpson, ${ }^{3}$ E. S. Paul, ${ }^{4}$ R. V. F. Janssens, ${ }^{5}$ L.L. Riedinger, ${ }^{6}$ A. D. Ayangeakaa, ${ }^{5}$ J. Baron, ${ }^{2}$ M. Benner, ${ }^{1}$ A. Boston, ${ }^{4}$, H. Boston, ${ }^{4}$ M.P. Carpenter, ${ }^{5}$ C.J. Chiara, ${ }^{5,7}$ U. Garg, ${ }^{8}$ S. Hallgren, ${ }^{1}$ J. Harker,5, 7 F.G. Kondev, ${ }^{9}$ T. Lauritsen, ${ }^{5}$ W.C. Ma, ${ }^{10}$ P. Mason, ${ }^{3}$ J. Matta, ${ }^{8}$ S. Miller, ${ }^{2}$ P. Nolan, ${ }^{4}$ J.R. Vanhoy ${ }^{1}$, K. Villafana, ${ }^{2}$ X. Wang, ${ }^{11}$ J. Wright, ${ }^{4}$ and S. Zhu ${ }^{5}$

| 73 | ${ }^{162} \mathrm{Ta}$ | ${ }^{163} \mathrm{Ta}$ | ${ }^{164} \mathrm{Ta}$ | ${ }^{165} \mathrm{Ta}$ | ${ }^{166} \mathrm{Ta}$ | ${ }^{167} \mathrm{Ta}$ | ${ }^{168} \mathrm{Ta}$ | ${ }^{169} \mathrm{Ta}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 72 | ${ }^{161} \mathrm{Hf}$ | ${ }^{162} \mathrm{Hf}$ | ${ }^{163} \mathrm{Hf}$ | ${ }^{164} \mathrm{Hf}$ | ${ }^{165} \mathrm{Hf}$ | ${ }^{166} \mathrm{Hf}$ | ${ }^{167} \mathrm{Hf}$ | ${ }^{168} \mathrm{Hf}$ |
| 71 | ${ }^{160} \mathrm{Lu}$ | ${ }^{161} \mathrm{Lu}$ | ${ }^{162} \mathrm{Lu}$ | ${ }^{163} \mathrm{Lu}$ | ${ }^{164} \mathrm{Lu}$ | ${ }^{165} \mathrm{Lu}$ | ${ }^{166} \mathrm{Lu}$ | ${ }^{167} \mathrm{Lu}$ |
| 70 | ${ }^{159} \mathrm{Yb}$ | ${ }^{160} \mathrm{Yb}$ | ${ }^{161} \mathrm{Yb}$ | ${ }^{162} \mathrm{Yb}$ | ${ }^{163} \mathrm{Yb}$ | ${ }^{164} \mathrm{Yb}$ | ${ }^{165} \mathrm{Yb}$ | ${ }^{166} \mathrm{Yb}$ |
| 69 | ${ }^{158} \mathrm{Tm}$ | ${ }^{159} \mathrm{Tm}$ | ${ }^{160} \mathrm{Tm}$ | ${ }^{161} \mathrm{Tm}$ | ${ }^{162} \mathrm{Tm}$ | ${ }^{163} \mathrm{Tm}$ | ${ }^{164} \mathrm{Tm}$ | ${ }^{165} \mathrm{Tm}$ |
| 68 | ${ }^{157} \mathrm{Er}$ | ${ }^{158} \mathrm{Er}$ | ${ }^{159} \mathrm{Er}$ | ${ }^{160} \mathrm{Er}$ | ${ }^{161} \mathrm{Er}$ | ${ }^{162} \mathrm{Er}$ | ${ }^{163} \mathrm{Er}$ | ${ }^{164} \mathrm{Er}$ |
| 67 | ${ }^{156} \mathrm{Ho}$ | ${ }^{157} \mathrm{Ho}$ | ${ }^{158} \mathrm{Ho}$ | ${ }^{159} \mathrm{Ho}$ | ${ }^{160} \mathrm{Ho}$ | ${ }^{161} \mathrm{Ho}$ | ${ }^{162} \mathrm{Ho}$ | ${ }^{163} \mathrm{Ho}$ |
| Z | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 |
| N |  | ${ }^{16}$ |  |  |  |  |  |  |

Ultra high-spin TSD
Wobbling
TSD

High-spin Study of ${ }^{161} \mathrm{Lu}$ : The Crossroads Between Lower Spin TSD Wobbling and Ultrahigh-Spin TSD Bands?
D.J. Hartley, ${ }^{1}$ M.A. Riley, ${ }^{2}$ J. Simpson, ${ }^{3}$ E. S. Paul, ${ }^{4}$ R. V. F. Janssens, ${ }^{5}$ L.L. Riedinger, ${ }^{6}$ A. D. Ayangeakaa, ${ }^{5}$ J. Baron, ${ }^{2}$ M. Benner, ${ }^{1}$ A. Boston, ${ }^{4}$, H. Boston, ${ }^{4}$ M.P. Carpenter, ${ }^{5}$ C.J. Chiara, ${ }^{5,7}$ U. Garg, ${ }^{8}$ S. Hallgren, ${ }^{1}$ J. Harker, 5,7 F.G. Kondev, ${ }^{9}$ T. Lauritsen, ${ }^{5}$ W.C. Ma, ${ }^{10}$ P. Mason, ${ }^{3}$ J. Matta, ${ }^{8}$ S. Miller, ${ }^{2}$ P. Nolan, ${ }^{4}$ J.R. Vanhoy ${ }^{1}$, K. Villafana, ${ }^{2}$ X. Wang, ${ }^{11}$ J. Wright, ${ }^{4}$ and S. Zhu ${ }^{5}$

| 73 | ${ }^{162} \mathrm{Ta}$ | ${ }^{163} \mathrm{Ta}$ | ${ }^{164} \mathrm{Ta}$ | ${ }^{165} \mathrm{Ta}$ | ${ }^{166} \mathrm{Ta}$ | ${ }^{167} \mathrm{Ta}$ | ${ }^{168} \mathrm{Ta}$ | ${ }^{169} \mathrm{Ta}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |

## To be continued at a later da

| 68 | ${ }^{157} \mathrm{Er}$ | ${ }^{158} \mathrm{Er}$ | ${ }^{159} \mathrm{Er}$ | ${ }^{160} \mathrm{Er}$ | ${ }^{161} \mathrm{Er}$ | ${ }^{162} \mathrm{Er}$ | ${ }^{163} \mathrm{Er}$ | ${ }^{164} \mathrm{Er}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 67 | ${ }^{156} \mathrm{Ho}$ | ${ }^{157} \mathrm{Ho}$ | ${ }^{158} \mathrm{Ho}$ | ${ }^{159} \mathrm{Ho}$ | ${ }^{160} \mathrm{Ho}$ | ${ }^{161} \mathrm{Ho}$ | ${ }^{162} \mathrm{Ho}$ | ${ }^{163} \mathrm{Ho}$ |
| Z | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 |
| N |  |  |  |  |  |  |  |  |




- Search for Wobbling modes in A~170 Re and W nuclei.
-Expts using Gammasphere at ANL.
-Detailed Spectroscopic Study 168,169,170,171W.
-Backbending in nuclei. A shameful advertisement. Many people in the room have participated in this great adventure!
-Good for students to know some history. ©
-Systematic Examination of Band Crossing Frequencies in the A2170 Region. Continuing on from where Jerry Garrett left off.
-The effect of seniority on pairing correlations from band crossing frequencies and comparisons to moment-of-inertia results from high-seniority high-K isomer studies.

