Summary of search for tetrahedral deformations in the mass 160 region

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Abstract. Recent theoretical work has suggested that some nuclei in the rare earth region might exhibit tetrahderal deformations. Several nuclei have been studied at iThemba LABS, resulting in evidence against the possibility of low-lying tetrahedrally deformed bands. In this paper we present results suggesting that the next set of candidates is also not tetrahedrally deformed. This region of the nuclear landscape still contains several interesting features, particularly the discrepancies in B(E2)/B(E1) ratios within the octupole bands, and deserves further study.

INTRODUCTION

In recent years, there has been interest in various regions of the periodic table regarding nuclear deformations [1, 2, 3, 4]. Work by Dudek *et al.* [2], has suggested that the region around Gd and Yb and neutron number 90 might exhibit tetrahedral deformations at a fairly low excitation energy (within 1 MeV of the yrast band). Several experiments were performed at iThemba LABS to look for these candidate tetrahedral bands and see if they agree with the theoretical predictions. The results obtained for ^{154}Gd and ^{160}Yb have been published [5]. In this article, we will summarize the experimental results finished to date, together with the status of the further analysis of nuclei in the region of interest.

Theoretical motivation

The nuclear surface in in the instrinsic frame is often exapanded as [6]

$$R(\theta,\phi) = R_0 \left[1 + \sum_{\lambda=2}^{4} \sum_{\mu=0}^{\lambda} \alpha_{\lambda\mu} Y_{\lambda\mu}(\theta,\phi) \right]. \tag{1}$$

The $\lambda = 2$ terms correspond to quadrupole deformations, which are well established, while $\lambda = 3$ terms correspond to octupole deformations. The low-lying negative parity bands are generally intepreted as octupole vibrations with pronounced α_{30}.

Calculations that included α_{32} deformations have been performed [3] that suggest that potential energy minima occur at specific regions akin to shell-gaps. Specifically, if $\alpha_{20} = 0$, an α_{32} deformation corresponds to a tetrahedral shape. Tetrahedral shell gaps have been calculated to occur at 64, 70, 90 and 94, which correspond to the nuclei from ^{154}Gd to ^{164}Yb. In addition, Dudek *et al.* [2] have shown that if a nucleus has a sizable tetrahedral deformation, it will behave almost as a tetrahedral rotor and exhibit the T_d symmetry. The nucleus must then have a zero quadrupole moment, implying a lack of E2 transitions in the tetrahedral band. The negative parity bands in the nuclei in the region of interest were usually interpreted as vibrational Y_{30} octupoles [7], but the vanishing in-band transitions at lower spin offers an alternative interpretation as 'tetrahedral candidates'.

EXPERIMENTAL RESULTS

To try and verify the predictions, several experiments have been run at iThemba LABS using the AFRODITE gamma ray detector array, which consists of eight HPGe segmented clover detectors. The reactions included ^{152}Sm(α,2n)^{154}Gd at 25 MeV, and ^{147}Sm(^{16}O,3n)^{160}Yb at 73 MeV. Approximately 0.5×10^9 $\gamma\gamma$ conincidence events were collected for the former reaction, and 2×10^9 in the latter. The complete analysis and results have already been published [8, 9, 5].

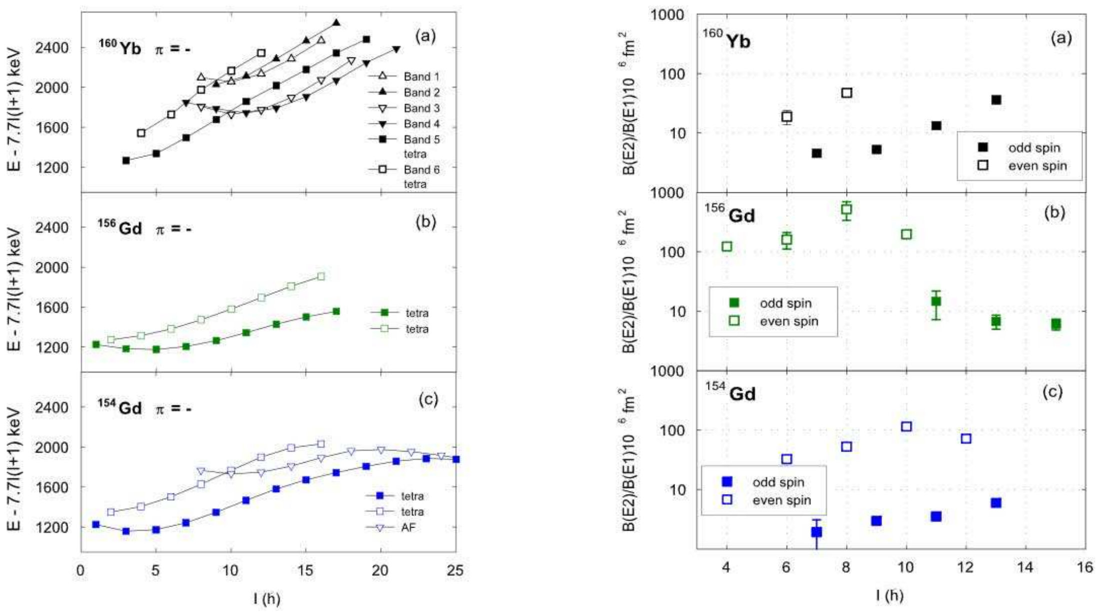

FIGURE 1. Left, energies of negative parity band levels in ^{160}Yb, ^{166}Gd and ^{164}Gd, less a rigid rotor reference against spin. Right shows the branching ratios for in-band (E2) vs out-of-band (E1) transitions in the candidate tetrahedral bands [5].

The results are shown above. The data from ^{156}Gd [10] is shown for comparison, as that was considered one of the best candidates for a tetrahedral nucleus [3]. For low spin states (below $10\hbar$), the octupole bands (labelled 'tetra' in the figure) show a fairly similar structure, both in the sign of the signature splitting between the two spin partners, and the magnitude of splitting. At higher spin, there are interactions with the negative parity two quasiparticle bands, which distort the picture.

Additionally, if one considers the branching ratio of the in-band transitions $B(E2, I \rightarrow I-2)$, against out-of-band transitions to the ground state band $B(E1, I \rightarrow I-1)$ for odd and $B(E1, I \rightarrow I)$, for even spins, one finds a staggering of the data. The observed ratios indicate that the in odd spin bands, the E2 transitions are very unfavoured, making their study difficult. The ratio could be due to the a natural suppression of the E2 transitions due to a low quadruple moment, which is the expected signature of the tetrahedral deformation, but alternately the ratio could be low simply due to very high E1 strengths.

Bark *et al.* [5] performed a careful analysis of the energies and branching ratios of the negative parity bands, and resolved the interactions and quadrupole moments with band-mixing calculations. The calculations found $Q_{t_T} \sim 4$ eb, which corresponds to a significant quadrupole deformation. This is against the expectation of the zero quadrupole moment required for the tetrahedral rotor, indicating that the low-lying negative parity bands are most likely normal octupole vibrations. The calculated quadrupole moments also disallow an explanation of the staggered B(E2)/B(E1) ratios based on the suppression of in-band transitions in the odd octupole bands. At this time there is no complete explanation of the discrepancy between odd and even spin branching ratios.

The result of the non-tetrahedral nature of ^{160}Yb does not preclude nearby nuclei from containing structures that are interesting. By performing a systematic study of the negative parity bands in the nuclei Gd, Dy, Er and Yb, with neutron numbers 88, 90 and 92 (figure 2), one can observe that the behaviour of the bands depends strongly on N, yet individual features remain to be understood. Unfortunately, a lot of the experimental data on the negative parity bands remains unknown, especially down to the very low spins. This is partly due to the low strength of the in band E2 transitions, making the transitions near the low end of the octupole bands difficult to populate and observe. The data on the B(E2)/B(E1) branching ratios are even less known.

In an attempt to learn more about this region, two more nuclei in this region were recently studied at iThemba. The reactions were ^{147}Sm(^{12}C,3n)^{156}Er and ^{152}Sm(^{12}C,4n)^{160}Er, as a slightly different neutron number has a direct effect on the nuclear shape. Approximately 1.8×10^9 $\gamma\gamma$ conincidence events were collected for each reaction.

The preliminary results are included above. The low-lying negative parity bands have been extended in both nuclei, but the branching ratios of in-band and out of band transitions are not yet available.

It is apparent that in ^{156}Er the candidate tetrahedral bands behave similarly to the other $N = 88$ nuclei at low spin (below $10\hbar$). The odd band partner is lower in excitation energy and the two band partners proceed in an almost parallel manner. Around spin 10 however, the two bands experience deviations from the expected behaviour, most likely due to the interaction of the bands with the two quasi-particle band. The expectation is that a careful band-mixing calculation can clear up these uncertainties. The negative parity bands in ^{160}Er appear to contain a similar structure to the other well-studied nuclei in the region, but there is no complete information for the other $N = 92$ nuclei, making the careful comparisons difficult.

CONCLUSION

The rare earth region of $64 \leq Z \leq 70$ and $88 \leq N \leq 92$ remains a very interesting one indeed. To date there seems to be no evince supporting the existence of tetrahedrally

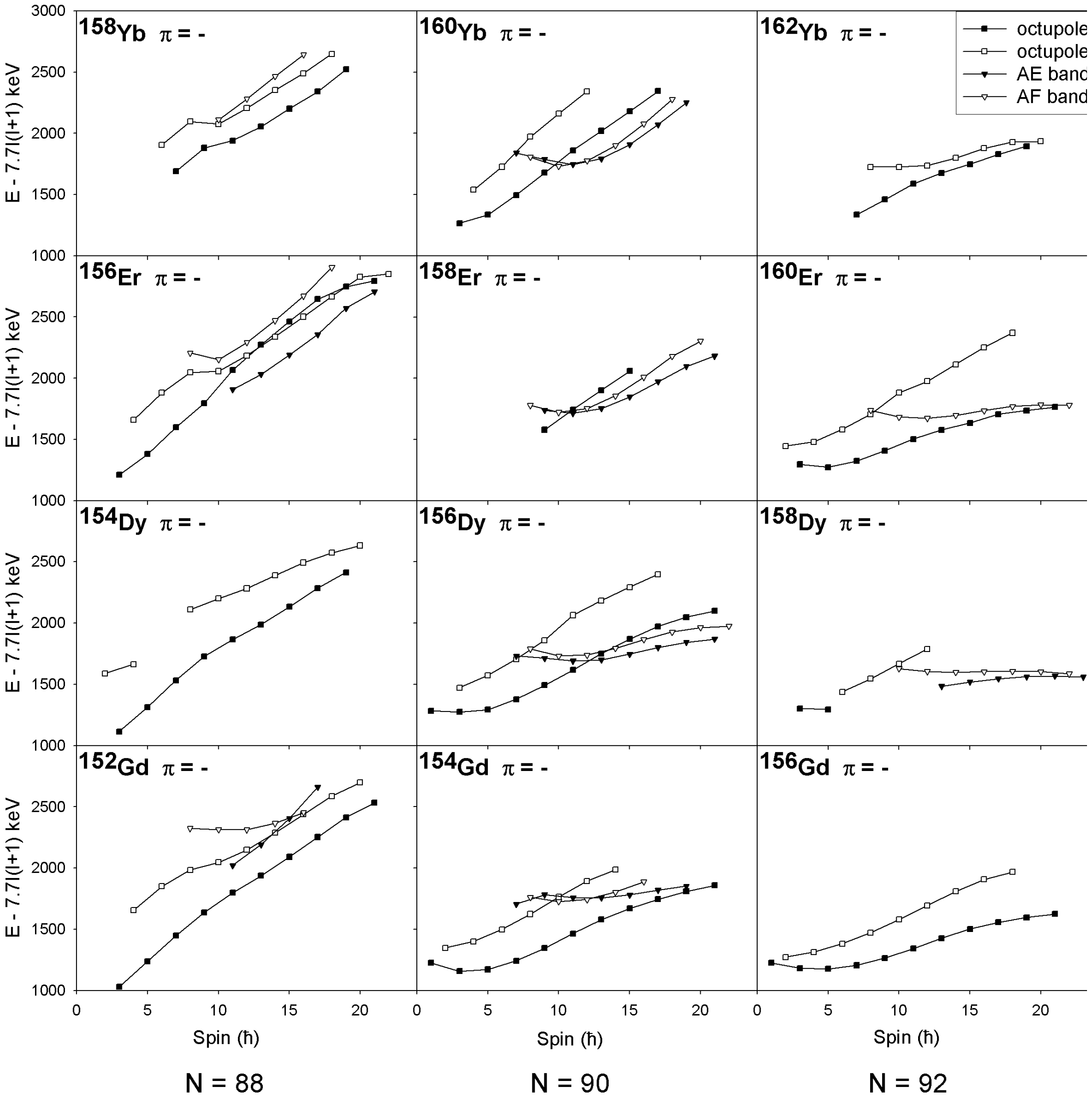

FIGURE 2. Systematics of the negative parity bands in the Gd-Yb region, for $N = 88, 90, 92$. The octupole (candidate tetrahedral) bands are marked with squares, and the two quasi-particle bands are marked with triangles. Data collected from nndc. The bands for ^{158}Dy are tentative spin and parity assignments

deformed nuclei in the region, although the search for evidence has not been exhaustive. There are several results that remain unexplained, including he nature of the variation in the branching ratios in the negative parity bands. It is hoped that the RPA calculations can shed some light on the systematic behaviour of the observed bands.

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REFERENCES

1. S. Takami *et al.*, Phys. Lett. **B 431**, 242 (1998)
2. J. Dudek *et al.*, Phys. Rev. Lett. **88**, 252502 (2002)
3. J. Dudek *et al.*, Phys. Rev. Lett. **97**, 072501(2006)
4. N. Schunck *et al.*, Phys. Rev. **C69**, 061305 (2004)
5. R.A. Bark *et al.*, Phys. Rev. Lett. **104**, 022501 (2010)
6. J.M. Eisenberg and W. Greiner, Nuclear Models (1975)
7. P.E. Garret *et al.*, J.Phys. G **31**, S1855 (2005)
8. R.A. Bark *et al.*, J.Phys G **31**, S1747 (2005)
9. J.F. Sharpey-Shafer *et al.*, Proc. XIIV Intern. Winter Meeting on Nucl. Phys., Bormio, Itali, p.295 (2006)
10. C.W. Reich, Nucl. Data Sheets **99**, 753 (2003)