# First Possible Evidence of Triaxiality in Odd-odd Nucleus $^{154}$Tb

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## Introduction

Nuclei that are deformed are known to exhibit both symmetric and asymmetric non-spherical shapes. While the commonly observed symmetric deformed shapes are prolate and oblate, some nuclei exhibit asymmetric triaxial and octupole shapes due to higher order deformations [1]. The first observed experimental manifestation of triaxial deformation was the wobbling motion in $^{163}$Lu, which many later works cited as an important experimental evidence to confirm triaxiality [2]. Wobbling motion is identified through the observation of a wobbling band, with wobbling quanta $n_w = 1$, as a side band of the main rotational band ($n_w = 0$). The connecting transitions between them are $\Delta I = 1$, from $n_w = 1$ band to $n_w = 0$ band which are predominantly E2 character as against the expected M1 character found in regular rotational bands. Wobbling bands have been observed in some even-even and odd-mass nuclei, recent one being $^{129}$Ba [3].

The odd-odd nucleus $^{154}\mathrm{Tb}^{89}_{65}$ is in the transitional rare-earth region, where the onset of rotational deformation begins [1]. An extensive previous experimental study by Bengstonn *et. al.* [4], proposed two high-spin rotational bands of configurations $\nu i13/2 \otimes \pi h11/2$ (Band 1) and $\nu i13/2 \otimes \pi d5/2$ (Band 2) with signature splitting. The present experimental study was aimed at populating the low-lying rotational levels and perform a systematic $\gamma$-coincidence spectroscopy to determine the type of deformation in $^{154}$Tb.

## Experiment and Analysis

A good yield of $^{154}$Tb was produced through the $^{153}$Eu ($\alpha$, 3n) reaction at beam energy $E_{lab}$ =39 MeV delivered from the K-130 cyclotron at the VECC. The coincidence $\gamma$-spectroscopy experiment was performed in the INGA setup of 12 Compton-suppressed clover detectors at 40°, 90° and 125° angles. The DAQ system in the setup was built on 250 MHz 12-bit PIXIE-16 digitizers (M/s XIA LLC, USA) running on a firmware conceptualized at the UGC-DAE CSR, Kolkata Center [5]. The list mode coincidence data was acquired with a condition that at least two Compton-suppressed clover detectors were fired in coincidence.

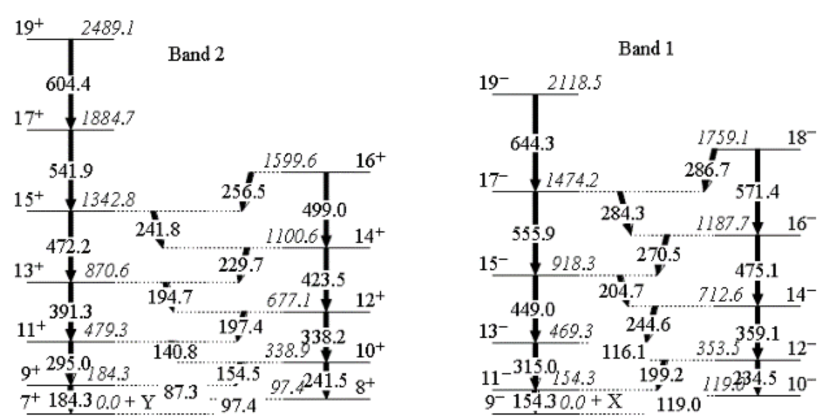


**Fig. 1**: Level scheme of $^{154}$Tb from the present study

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**Table 1:** Mixing ratios and the corresponding percentage E2 mixing in the interband transitions

| $E_\gamma$ (keV) | δ | E2 mixing % |
|---|---|---|
| | <u>Band 1</u> | |
| 119.0(2) | $1.87^{+0.33}_{-0.33}$ | $78^{+5}_{-7}$ |
| 199.2(1) | $2.22^{+1.37}_{-0.80}$ | $83^{+10}_{-16}$ |
| 116.1(7) | $1.87^{+0.51}_{-0.42}$ | $78^{+7}_{-10}$ |
| 244.6(2) | $1.59^{+0.45}_{-0.55}$ | $72^{+9}_{-20}$ |
| 204.7(2) | $3.52^{+3.37}_{-1.26}$ | $93^{+5}_{-9}$ |
| 270.5(2) | $2.31^{+0.67}_{-0.52}$ | $84^{+6}_{-8}$ |
| 284.3(6) | $2.65^{+1.81}_{-1.00}$ | $88^{+8}_{-14}$ |
| 286.7(4) | $5.34^{+12.3}_{-2.33}$ | $97^{+3}_{-7}$ |
| | <u>Band 2</u> | |
| 154.5(4) | $1.67^{+0.59}_{-0.58}$ | $74^{+10}_{-19}$ |
| 140.8(4) | $2.35^{+0.71}_{-0.54}$ | $85^{+6}_{-8}$ |
| 197.4(2) | $2.09^{+0.64}_{-0.54}$ | $81^{+7}_{-11}$ |
| 194.7(3) | $2.08^{+0.89}_{-0.75}$ | $81^{+9}_{-17}$ |
| 229.7(3) | $2.86^{+2.31}_{-1.10}$ | $89^{+7}_{-14}$ |

The low-lying levels of the νi13/2 ⊗ πh11/2 (Band 1) and νi13/2 ⊗ πd5/2 (Band 2) rotational bands were populated and their γ-decay were observed. Fig. 1 depicts the level scheme based on the observed γ-γ coincidences.

The multipolarities of the observed $^{154}$Tb γ-transitions were for the first time determined through their Ratio of Directional Correlation from Oriented states ($R_{DCO}$) and the linear polarization (P) values. These preliminary results were reported in our previous work [6]. The ΔI=2 intraband transitions in the two rotational bands were found to be of E2 nature as listed in the NDS. The ΔI=1 interband transitions between the signature partners in both the rotational band were observed to have M1+E2 admixture. To determine the percentage of E2 in the mixed transitions, their mixing ratios were calculated. The experimental $R_{DCO}$ and P values of these interband γ-transitions were compared with contour traced by theoretical $R_{DCO}$ and P values for varying mixing ratios (δ). The δ-value corresponding to the minimum deviation ($\chi^2$) of the theoretical $R_{DCO}$ and P values from the experimental values was identified as the mixing ratio of the transition. For some transitions in which the statistics of the polarization spectra was poor, only the experimental and theoretical $R_{DCO}$ values were used to obtain the δ-value.

## Results and Summary

The estimated mixing ratio values of the interband γ-transitions in both the rotational bands of $^{154}$Tb are listed in Table 1. The transitions between signature partners in both band 1 & 2 exhibit an admixture of E2+M1 with high E2 percentage which gradually increases with spin. It can be seen that at higher spins, the E2 mixing becomes close to 90%, a characteristic of wobbling band. This would suggest the onset of triaxiality in $^{154}$Tb at higher spins. However, it may be noted that bands, corresponding to signature partner and $n_w$=1 wobbling partner, have not yet been observed separately. To validate the experimental observations and further probe the nuclear shape and its evolution, Total Routhian Surface (TRS) calculations were carried out. The results confirm that at ground state both the νi13/2 ⊗ πh11/2 and νi13/2 ⊗ πd5/2 bands have prolate shape (γ = 5° & 4° respectively) and there is evolution to non-axial deformed shapes at the high spin regime (γ=-31° & -30° respectively).

This, to our knowledge, is the first recorded experimental evidence of a possible triaxial deformation in the odd-odd nucleus $^{154}$Tb. A previous study [7] of odd-odd Tb isotopes identified $^{154}$Tb as a "turning point nucleus" in shape phase transition in the N=87-90 region. Lifetime studies of excited states and their transition probabilities can further throw light on the expected shape transition that the present study has advocated.

This work was supported by CRS of UGC-DAE-CSR Kolkata center (CRS/19/NP02/0912).

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