Evidence of transverse wobbling in ^{101}Ru

A. Karmakar[1,2], P. Datta[4], J. A. Sheikh,[3,5], S. Jehangir[5], G. H. Bhat[6], S. S. Nayak[2,7], Soumik Bhattacharya[2,7], Suchorita Paul[2,7], Snigdha Pal[2,7], S. Bhattacharyya[2,7], G. Mukherjee[2,7], S. Basu[2,7], S. Chakraborty[2], S. Panwar[2,7], Pankaj K. Giri[8], R. Raut[8], S. S. Ghugre[8], R. Palit [9], S. Ali[10], W. Shaikh[11], S. Chattopadhyay[1,2]

[1]*Saha Institute of Nuclear Physics, 1/AF, Bidhan Nagar, Kolkata 700064, India*
[2]*Homi Bhabha National Institute, Training School Complex, Anushakti Nagar, Mumbai - 400094, India*
[3]*Department of Physics, University of Kashmir, Srinagar, 190 006, India*
[4]*Ananda Mohan College, Kolkata- 700009, India.*
[5]*Department of Physics, Islamic University of Science and Technology, Awantipora, 192 122, India*
[6]*Department of Higher Education (GDC Shopian), Jammu and Kashmir, 192 303, India*
[7]*Variable Energy Cyclotron Centre, Kolkata - 700064, India*
[8]*UGC-DAE Consortium for Scientific Research, Kolkata Centre, Kolkata 700106, India*
[9]*Tata Institute of Fundamental Research, Mumbai- 400005, India*
[10]*Government General Degree College at Pedong, Kalimpong 734311, India and*
[11]*Mugberia Gangadhar Mahavidyalaya, Purba Medinipur, India.*

Introduction

The generalized three-dimensional rotation is exhibited by an axially asymmetric shape commonly known as the triaxial shape, whose moments of inertia along the three principal axes are unequal [1]. The wobbling motion in a triaxial nucleus has been so far observed only in ^{105}Pd in the $A \approx 100$ mass region. It is, thus, crucial to investigate nearby isotopes to confirm nuclear wobbling as a mechanism for generating low-spin states in this mass range. In this study, ^{101}Ru was chosen based on Yamamoto *et al.*'s findings that the observed band crossing frequencies are significantly delayed, which was proposed to occur due to significant triaxial deformation. [2]. Their work established only the negative parity yrast cascade, so the main objective of the current experiment was to search for the wobbling and signature partners of this negative parity band.

Experiment

The excited states of ^{101}Ru were populated via the ^{100}Mo(^{4}He, 3n)^{101}Ru reaction using a 45 MeV beam from the K-130 cyclotron at the Variable Energy Cyclotron Centre, Kolkata. Gamma rays were detected with the Indian National Gamma Array (INGA) [3], consisting of 11 Compton-suppressed clover detectors positioned at 40°, 90°, and 125° relative to the beam direction. A 10 mg/cm^2 thick ^{100}Mo target was used. Data acquisition employed a 250 MHz, 12-bit PIXIE-16 digitizer (XIA LLC), recording 4×10^9 γ-γ coincidence events, of which 35% were attributed to ^{101}Ru.

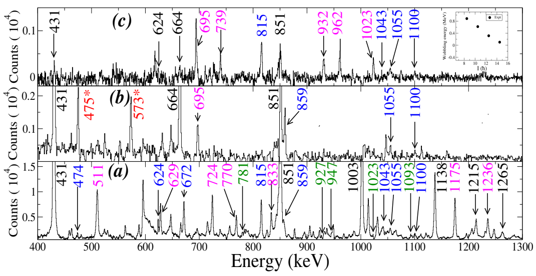

FIG. 1: γ - γ coincidence spectra with (a) 663.6, (b) 815.4 and (c) 858.7 keV gates in ^{101}Ru. The transitions marked in black, green and blue belong to Bands 1, 2 and 3 respectively, while those marked in magenta are from the other bands of ^{101}Ru, which are not shown in the current level scheme.

Analysis and Results

Both symmetric and angle-dependent asymmetric matrices required for further analysis were generated using BINDAS [4]. The present level scheme was built from the coincidence spectra of γ-rays belonging to the previously known negative parity cascade of ^{101}Ru [2].

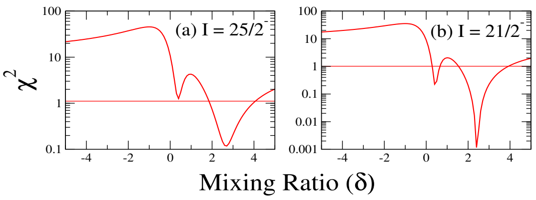

FIG. 2: The χ^2 analysis to establish the true minima of the mixing ratio values for the transitions from wobbling band to main band. The horizontal lines correspond to the +1 of the minima value for determining the uncertainties.

Two negative parity band structures connected to the previously observed yrast cascade have been established from the present work. The transitions belonging to main band (Band 1), possible signature and wobbling partners (Bands 2 and 3 respectively) are marked in black, green and blue respectively. The intensities of the γ-rays were estimated from the γ-gated spectra at 90° following the prescription described in Ref. [5]. The spins and parities of the levels of Bands 2 and 3 were assigned through the simultaneous measurement of directional correlation from oriented states (DCO) and linear polarisation (P) of the interconnecting transitions from Bands 2 and 3 to Band 1. However, to establish the true minima, χ^2 analysis was done as shown in Fig. 2. The values of the mixing ratios (δ) for ΔI = 1 trantions, decaying from I = $21/2^-$, $25/2^-$ and $29/2^-$ levels of wobbling partner, were found to be $2.4^{+1.4}_{-0.8}$, $2.5^{+1.5}_{-0.5}$, $0.5^{0.3}_{-0.2}$ respectively. Thus, the E2 mixing for the two bottom transitions are as large as 85% while the mixing is about 19% for the highest ΔI = 1 transition.

Even for the lower mixing ratio of the transition decaying from I = $29/2^-$, B(E2)$_{out}$ and B(E2)$_{in}$ values are nearly equal while the B(M1)$_{out}$/B(E2)$_{in}$ values are small (≈ 0.1 $\frac{\mu_N^2}{e^2b^2}$) for all three low spin levels of ^{101}Ru 3. These are the common features for all the observed wobbled bands. These observed ratios of the transition rates in ^{101}Ru and ^{105}Pd have been plotted in Fig. 3. The wobbling energy is observed to decrease with spin as shown in the inset of Fig. 1, thus indicating the transverse nature of the wobbling motion.

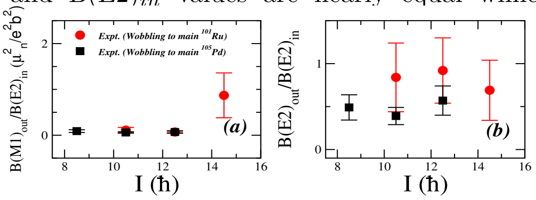

FIG. 3: Experimental transitional rate ratios of ΔI = 1 transition decaying from wobbling band to main band for ^{105}Pd (plotted in black) and ^{101}Ru (plotted in red).

Conclusion

The transverse wobbling motion has been established for ^{101}Ru, which is the second nucleus of A $\approx$ 100 region to exhibit this exotic collective excitation.

Acknowledgements

We are thankful to INGA collaboration for constant support and the operators of VECC, Kolkata for quality beam. A.K. acknowledges the financial support from CSIR.

References

[1] S. Frauendorf and F. Dönau Phys. Rev. C **89**, 014322 (2014).

[2] A. D. Yamamoto *et. al.* Phys. Rev. C **66**, 024302 (2002).

[3] S. Muralithar *et al.*, Nucl. Instrum. Methods A **622**, 281 (2010).

[4] S. S. Nayak and G. Mukherjee, IEEE Transactions on Nuclear Science, **70**, 12, 2561-2571 (2023).

[5] A. Karmakar *et al.* Phys. Rev. C **109**, 054312 (2024).