# Lifetime measurements in the rotational bands of $^{130}$La by the Doppler-shift attenuation method

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## I. SCIENTIFIC MOTIVATION

The odd-odd $^{130}$La nucleus belongs to a region of transitional nuclei that exhibit interesting structural characteristics. These nuclei are $\gamma$-soft and their shapes are strongly influenced by the configurations of the valence quasiparticles. The bands built on the low-$\Omega$ $h_{11/2}$ proton and the high-$\Omega$ $h_{11/2}$ neutron orbitals having different shape-driving effects are of particular interest. The signature splitting and inversion are important phenomena observed in these nuclei. One of the most striking features was the observation of the nearly degenerate doublet bands interpreted as the manifestation of chiral symmetry breaking [1]. This phenomenon has been rather intensively investigated over the last decade both experimentally and theoretically. It was pointed out that a triaxial nucleus becomes chiral if it rotates about an axis that lies outside the three planes spanned by the principal axis of its triaxial ellipsoidal shape. The short, intermediate, and long principal axes form a screw with respect to the angular momentum vector, resulting in the formation of two chiral systems, with left- and right-handed orientations. The results of theoretical calculations of tilted axis cranking [2], core-particle-hole-coupling [3] and tilted Skyrme Hartree-Fock [4] approaches revealed the possibility of spontaneous breaking of chiral symmetry in the intrinsic reference frame of the nucleus. The restoration of the broken chiral symmetry in the laboratory frame manifests itself by the appearance of two rotational bands (chiral partner bands) with the same spins and parities and almost equal excitation energy. Chiral-candidate doublet band structures have been observed in the $A \approx 130$ mass region [5–9], as well as in the $A \approx 80$ [10], 100 [11], and 190 [12, 13] mass regions.

In addition to close level energies, the two chiral partners should de-excite in a very similar way via electromagnetic transitions. Thus, measurements of transition probabilities are essential probes of nuclear chirality. Up to now, several Doppler-shift attenuation method (DSAM) lifetime measurements in chiral partners have been reported in the $A \approx$130 mass region [14–18], with rather different results. For $^{126,128}$Cs [14, 15] and $^{135}$Nd [16] it was established that the electromagnetic transition probabilities in the partner bands are similar, indicating these nuclei as good examples revealing the chiral symmetry breaking phenomenon. On the other hand, in $^{132}$La [14], $^{134}$Pr [17], and $^{136}$Nd [18], the $B(E2)$ values in the chiral-candidate doublet bands differ considerably from each other. It was suggested that the dissimilar transitions rates may originate due to chiral vibrations and chiral fluctuations [17, 18].

The objective of the present proposal is to perform DSAM lifetime measurements in the rotational bands of $^{130}$La. The main interest is to determine transition probabilities in the yrast band described by the $\pi h_{11/2} \otimes \nu h_{11/2}$ configuration [19] and in the side band interpreted as resulting from chiral symmetry breaking [6]. In the previously reported level scheme of this nucleus [19, 20], the excitation energies of the rotational bandheads were not known, and the spins and parities were only tentatively assigned. In a recent experiment performed at the Bucharest FN tandem accelerator we investigated in detail the low- and medium-spin states in $^{130}$La. As a result of our study, the decay out of the previously known rotational bands to the ground state has been elucidated, and spins and parities have been firmly established. This experiment is briefly described in Section 2, while the experimental details of the present proposal are given in Section 3.

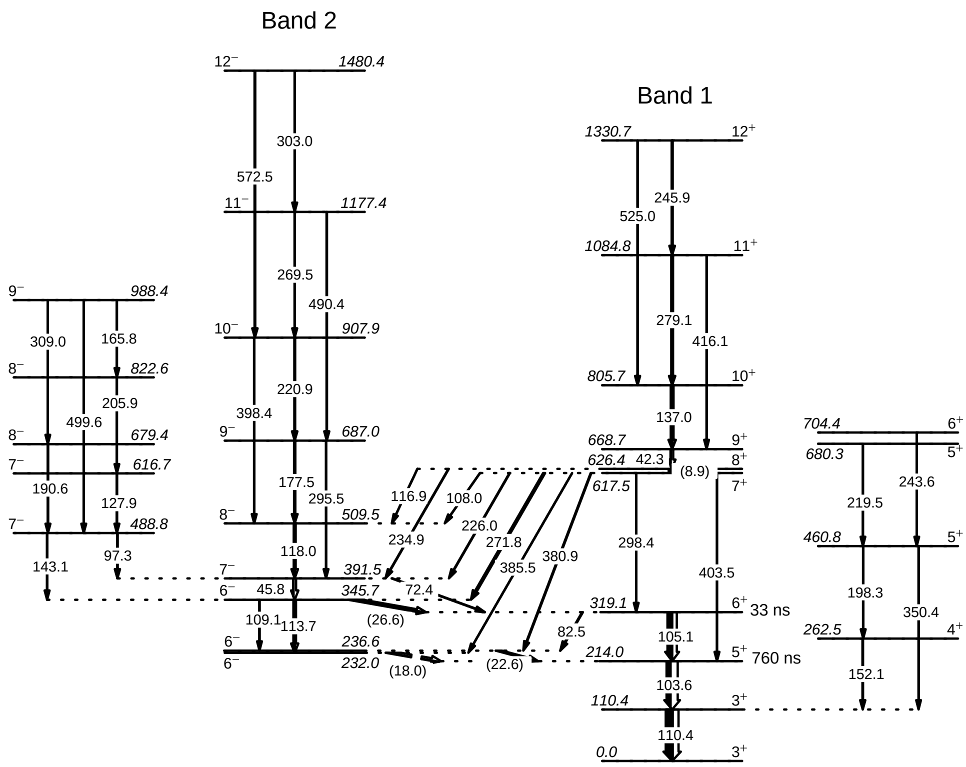


FIG. 1: Partial level scheme of $^{130}$La established on the basis of the experiment performed at the Bucharest FN tandem accelerator [21]. Arrow widths are proportional to transition intensities, while unfilled regions show the extent of internal conversion. The arrows with energy labels in parentheses indicate unobserved tentative transitions.

## II. REPORT ON THE EXPERIMENT PERFORMED AT THE FN TANDEM IN 2012

The experiment was performed in April 2012. The excited states in $^{130}$La were populated in the reaction $^{121}$Sb($^{12}$C,3n) at a bombarding energy of 50 MeV. The target was a 93 mg/cm$^2$ thick metallic Sb foil of natural enrichment placed on a Pb frame. An array consisting of four HPGe planar detectors and five coaxial HPGe detectors of 50% relative efficiency was used for $\gamma$-rays detection. The detectors were placed in three rings at the angles of 143°, 90°, and 45° with respect to the beam axis. The construction of the level scheme was based on the analysis of prompt and prompt-delayed $\gamma$-$\gamma$-coincidences. Information about the transition multipolarities was obtained on the basis of the angular distribution ratios. In the derived $^{130}$La level scheme, shown in Fig. 1, the previously known rotational bands are linked to the ground state through a rather complex scheme containing several low-energy transitions. Two isomeric states were identified and placed in the level scheme, with the characteristics $J^{\pi}$=5$^+$, $E_x$=214.0 keV, $T_{1/2}$=0.76(9) $\mu$s and $J^{\pi}$=6$^+$, $E_x$=319.1 keV, $T_{1/2}$=33(1) ns. In addition, new medium-spin states, not connected with the

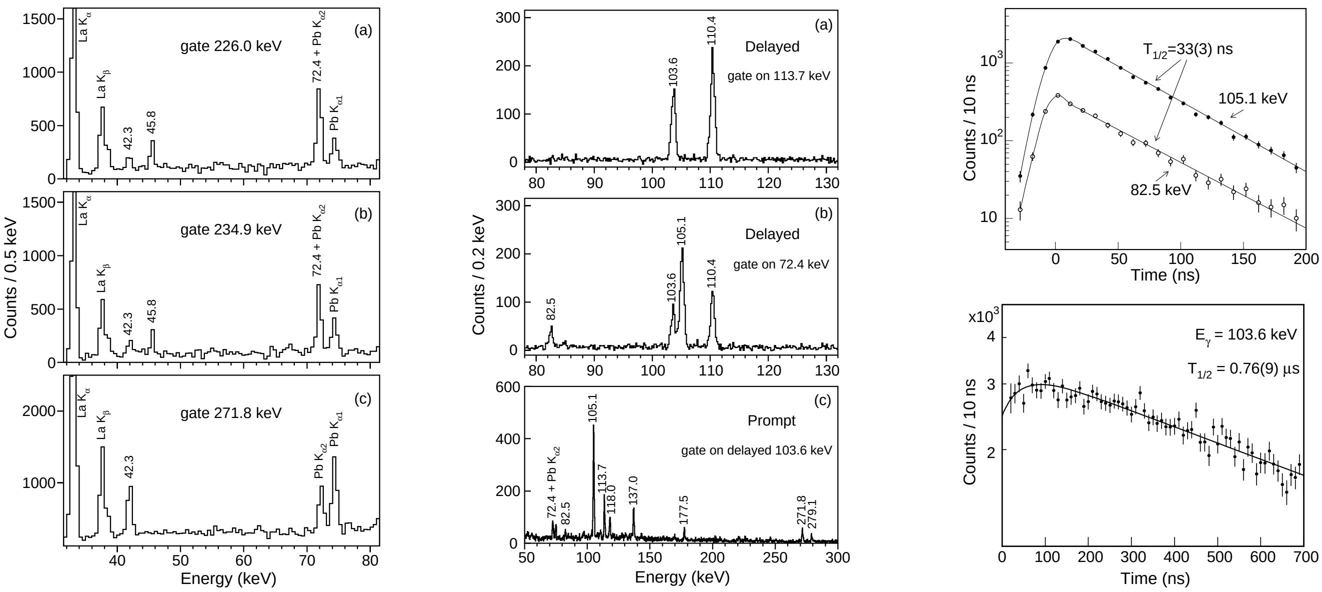


FIG. 2: Spectra registered by the planar detectors showing the coincidence relations between selected transitions in the decay-out of band 1 and the low-energy transitions of 42.3, 45.8 and 72.4 keV (left), prompt-delayed $\gamma$-$\gamma$ coincidences (center) and time spectra of the 82.5-, 105.1-, and 103.6-keV $\gamma$ rays (right).

rotational bands, have been observed. Illustrative spectra are shown in Fig. 2. The experimental level scheme was compared to calculations in the two-quasiparticles plus rotor model. The results are presented in a paper accepted for publication at Phys. Rev. C [21]

## III. DETAILS OF THE PROPOSED EXPERIMENT

In the proposed experiment, lifetime measurements in the rotational bands of $^{130}$La will be performed by applying the Doppler-shift attenuation method. The partial level scheme shown in Fig. 3 illustrates the bands 1 and 2, based on the $\pi h_{11/2} \otimes \nu h_{11/2}$ and $\pi h_{11/2} \otimes \nu g_{7/2}$ configurations, respectively, as well as the band 3 interpreted as resulting from chiral symmetry breaking [6]. In addition, the lifetimes of the medium-spin low-lying states in $^{130}$La (see Fig. 1) will also be investigated by using the electronic fast-timing technique.

The $^{130}$La nuclei will be populated by the $^{121}$Sb($^{12}$C,3n) reaction at $E(^{12}\mathrm{C})$=52 MeV. The target will be a 1 mg/cm$^2$ metallic Sb, enriched in $^{121}$Sb to 96%, on thick Pb backing in order to slow down and stop the $^{130}$La recoiling nuclei. The $\gamma$-rays will be detected by the ROSPHERE setup consisting of 17 HPGe detectors of 50% relative efficiency and 8 LaBr$_3$(Ce) detectors. The line-shapes of the $\gamma$ transitions in the bands will be analyzed in spectra gated by lower-lying stopped transitions, registered by the HPGe detectors placed at forward and backward rings.

In our recently performed experiment, the transitions deexciting the states with $J$ $\leq$13 in bands 1 and 2 exhibited only a stopped component, pointing to lifetimes longer than several ps. Doppler-broadened lineshapes could be observed for the quadrupole transitions deexciting the states with $J$=14 and $J$=15, indicating lifetimes in the sub-picosecond range. The transitions deexciting the higher-spin states in these bands, as well as the transitions of band 3 had very low statistics. This was due to the small number of used coaxial HPGe detectors, corresponding to an absolute detection efficiency of $\approx$0.2% at $E_\gamma$ around 1 MeV. In the presently proposed

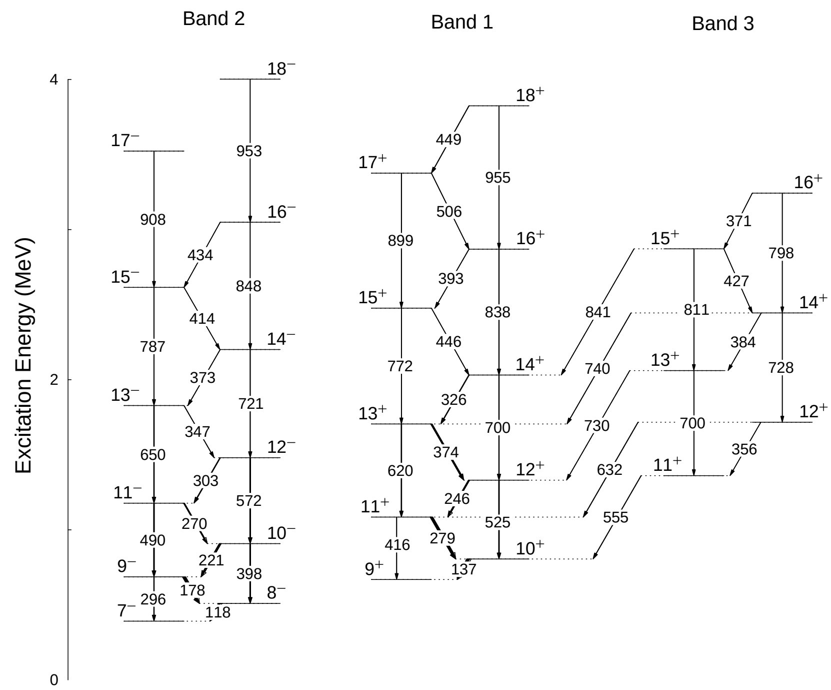


FIG. 3: Partial level scheme showing the rotational bands of interest in $^{130}$La.

experiment by using the ROSPHERE setup the $\gamma$-rays detection efficiency for HPGe will be a factor of ten higher. Moreover much cleaner spectra will be obtained by using an isotopically enriched target. By taking into account the results of the previous measurement and the above mentioned improvements in the experimental conditions, in order to achieve the goals of the experiment we ask for 8 days of beam time.

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