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Short note

Decay from superdeformed yrast states to normal deformed states in ^{193}Tl

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Abstract. Three high energy γ rays have been observed to connect the two yrast signature-partners superdeformed bands in ^{193}Tl to the normal deformed states. Thereby, both excitation energy and spin of these bands are proposed for the first time in an odd-proton nucleus.

PACS. 21.10.Re Collective levels – 23.20.Lv Gamma transitions and level energies – 27.80.+w $190 \leq A \leq 219$

In the mass $A \sim 190$ region the excitation energies of superdeformed (SD) states are calculated to lie between 4 and 6 MeV above the ground state of the nucleus at normal deformation (ND) [1–4]. The first information on the decay out process of SD states in this mass region has been brought by the observation of statistical quasicontinuous γ-decay spectrum of the yrast SD states in ^{192}Hg [5]. Nevertheless, the probability of the decay-out to the ND yrast states by direct one-step transitions, estimated to represent a few percents of the total deexcitation of SD states [6], should be observed using new generation γ-array. Such one-step decay from SD to ND states have been found to occur for the yrast SD bands in ^{194}Hg [7] and ^{194}Pb [8–10] as well as for the excited SD band 3 in ^{194}Hg [11] allowing the determination of their excitation energies and spins. Some high energy discrete γ-rays have been also found in coincidence with the yrast SD band in the odd-neutron ^{193}Pb nucleus and have been put forward as possible candidates for a one-step decay to the ND states [12]. Finally, an excitation energy has been tentatively assigned to states of the yrast SD band in ^{192}Pb [13]. We report here on the observation of high energy discrete γ-rays linking SD states of bands 1 and 2 to the ND states in ^{193}Tl. Thus, excitation energy and spin values of SD states can be proposed for the first time in an odd-proton nucleus.

The nucleus ^{193}Tl was populated at high spin by the ^{181}Ta (^{16}O, 6n) reaction at a beam energy of 110 MeV. The beam was provided by the Vivitron tandem accelerator at CRN Strasbourg. The target consisted of stacked 2×250 $\mu g cm^{-2}$ self-supporting foils of ^{181}Ta. γ rays were detected with the multidetector EUROGAM II [14] which comprised 54 Compton-suppressed Ge detectors consisting in 30 large volume Ge detectors at backward and forward angles and 24 "clovers" located around 90^o with respect to the beam axis. Approximately 0.8×10^9 γ-ray coincidence events were recorded to tape for which at least 5 unsuppressed Ge detectors had fired. In this experiment, in addition to the two known SD bands 1 and 2, which have been extended at higher rotational frequency

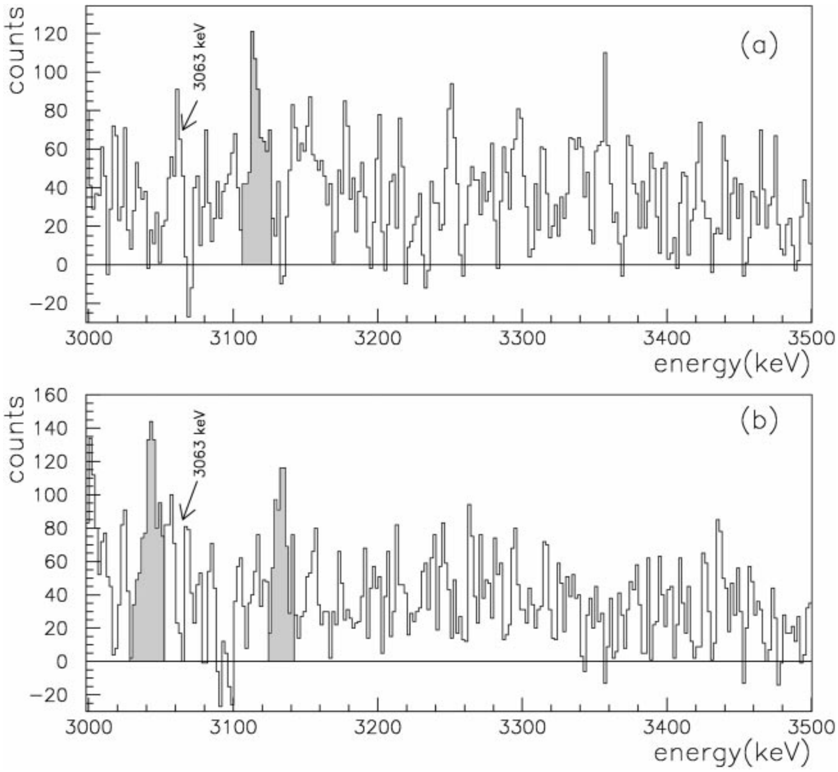

Fig. 1. **a** Sum of triple gated spectra on the γ-ray transitions of SD band 1 and **b** on the γ-ray transitions of SD band 2. Dark lines are one-step γ decay from SD to ND states and the uncertainty of the 3113 keV transition **a**, 3046 keV and 3134 keV transitions **b** is 5 keV, 6 keV and 4 keV respectively

[15], three new SD bands have been observed in ^{193}Tl [16]. The search of high energy γ-rays involved in the decay out of SD bands has been performed from spectra corresponding to the two energy ranges, 4 MeV and 20 MeV, provided by the EUROGAM II data acquisition system.

Triple gated spectra on the γ-ray transitions of SD bands 1 and 2 have been performed. The energy range between 2.9 MeV and 3.6 MeV of such spectra are displayed in Fig. 1. In these spectra, one peak at 3113 keV and two peaks at 3046 keV and 3134 keV are observed in coincidence with SD bands 1 and 2 respectively. These three high-energy γ lines fulfill two relevant criteria. The first criterion concerns the width of the peaks. Indeed, the velocity of the recoil nucleus ^{193}Tl is $\beta \sim 0.8$ %. This implies that the width of the peaks at an energy of about 3 MeV is expected to be about 10 keV, which is the case for these three peaks. The second criterion concerns the coincidence relationships between the high energy γ-rays and SD bands γ transitions. For that purpose, we have proceeded as following. A spectrum obtained by requiring a coincidence between the 3113 keV transition and two other transitions of band 1 is shown in Fig. 2a. In this spectrum, transitions of band 1 are observed as well as the ones of band 2 at low rotational frequency, establishing that the 3113 keV transition is in coincidence with band 1. The observation of γ transition from band 2, in the spectrum of Fig. 2a, is natural since bands 1 and 2 in ^{193}Tl have been previously shown to be connected by M1 transitions [15]. A similar spectrum obtained by requiring coincidence between γ transitions of band 2 and the 3046 keV transition (see Fig. 2b) establishes the coincidence relationship between band 2 and the 3046 keV γ

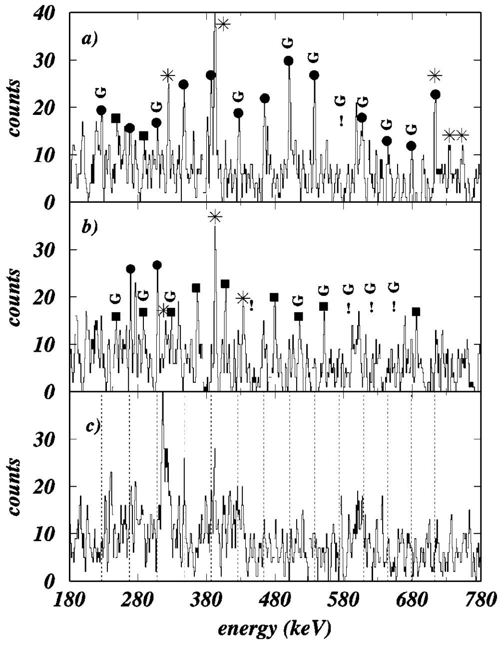

Fig. 2. **a** Sum of triple gated spectrum on the 3046 keV γ-ray and two γ-ray transitions of band 2, **b** sum of triple gated spectrum on the 3113 keV γ-ray and two γ-ray transitions of band 1. In both spectra, transitions of bands 1 and 2 are indicated respectively by (filled circles) and (filled squares) and the ones used as gate are indicated by "G". The symbol "!" indicates the missing transitions in the bands. The γ transitions connecting low-lying normal deformed states are labeled by stars, **c** sum of triple gated spectrum on the 3063 keV (see Fig. 1) background γ-ray and two transitions of band 1. The dashed lines indicate the location of the SD band 1 lines

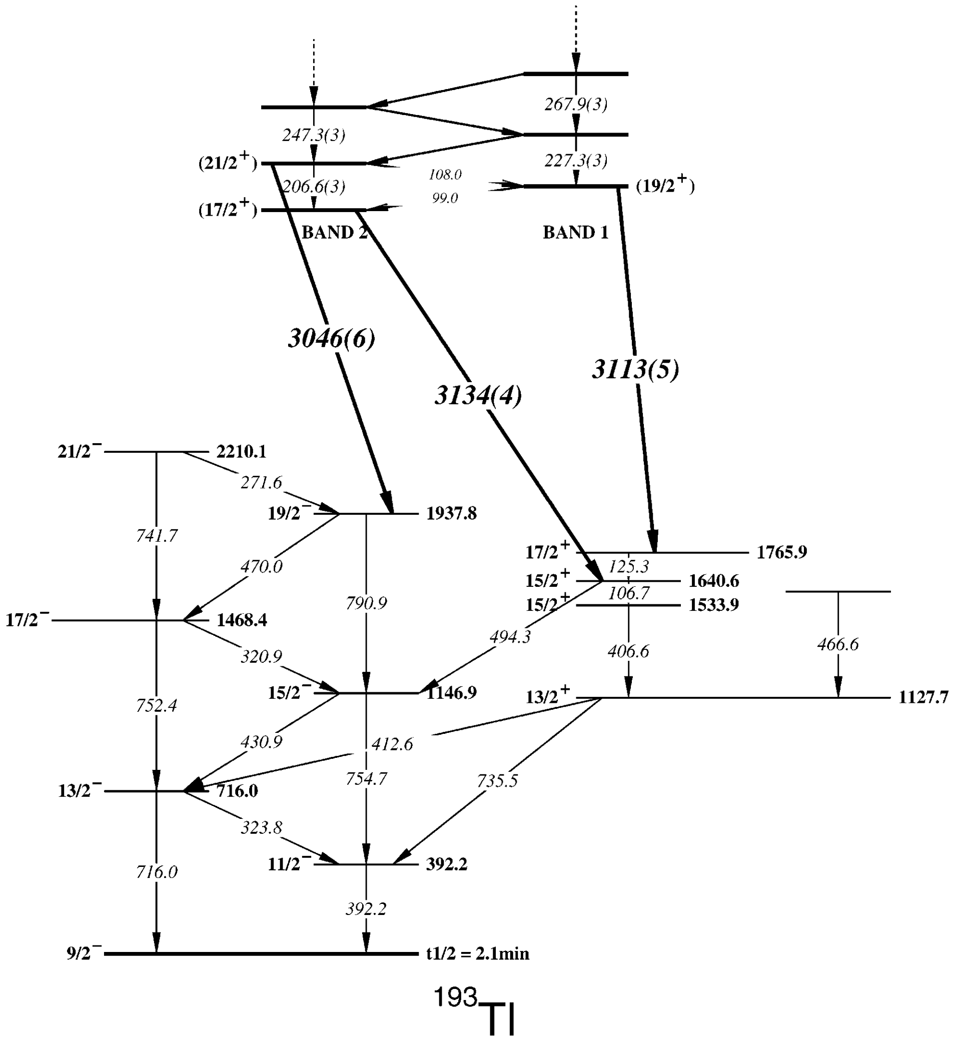

Fig. 3. The decay level scheme of SD bands 1 and 2. The numbers in parentheses are the uncertainties of the γ transitions. The partial level scheme of low-lying ND states are from [22] and their energy are in keV

transition. The absence of any γ line from SD band in the spectrum displayed in Fig. 2c, which is obtained by requiring coincidence between a background γ-ray with energy of 3063 keV (see Fig. 1) and two γ transitions of band 1 is an illustration of the validity of the used procedure.

Due to the limit of our experimental sensitivity, spectra in Figs. 2a and 2b do not allow us to identify which ND states is linked to which SD states. Furthemore, no information could be obtained on the SD states of bands 1 and 2 from which the one-step linking transitions are emitted. Nevertheless, taking into account the energy of the γ transitions in bands 1 and 2 and knowing that the relative energy of these two bands is fixed by the M1 transitions connecting their states [15], there is a unique way to place these three linking transitions. This is sketched in the decay scheme shown in Fig. 3. The fraction of the decay out of SD states through each of the three high energy γ transition has been evaluated to be less than 5 % which is consistent with the theoretical estimation for the one-step decay out [6].

Having in mind that band 2 corresponds to the positive signature of the $i_{13/2}$, $\Omega = 5/2$ intruder orbital [15], and assuming M1, E1 or E2 character for the linking transitions, two spin values, $13/2^+$ or $17/2^+$, are possible for the final state of the 206.6 keV transition in band 2. It is worth pointing out that the value $17/2^+$ is in agreement with the one obtained by the spin fit method [17]. From the three decay paths, the extracted excitation energy, with respect to the $9/2^-$ isomeric ND state, of the final state involved in the 206.6 keV transition of band 2, was found to be (4777 ± 6) keV. Using an [I(I+1)] extrapolation of the $\Im^{(2)}$ moment of inertia down to the $K = 5/2$ SD band-head, we could estimate the excitation energy of the SD band, with respect to the $9/2^-$ ND isomeric state, to be (4409 ± 6) keV.

The cranked Hartree-Fock-Bogoliubov calculations [18] using the Sly4 effective force [19] (named Sly230b in this Ref.) give an excitation energy value of 4700 keV [20] whereas the excitation energy from extended total routhian surface calculations based on a Wood-Saxon potential [21] is 3950 keV (with respect to the $9/2^-$ ND isomeric state).

To summarize, three γ-rays of high energy, 3046 keV, 3134 keV and 3113 keV, involved in the decay out of the two signature partners SD bands have been observed in ^{193}Tl. These three γ transitions are proposed to be the one-step γ-rays linking SD states of bands 1 and 2 to the ND states. The excitation energy deduced for the $K = 5/2$ SD bandhead, on which the two signature partners SD bands are built, is found to be 4409 ± 6 keV with respect to the ND isomeric state $9/2^-$ which is in agreement with both the HFB and WS type of calculation.

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