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Coexisting shape- and high-K isomers in the shape transitional nucleus ^{188}Pt

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ABSTRACT

A high-spin study of the shape transitional nucleus ^{188}Pt reveals the unusual coexistence of both shape- and K-isomeric states. Reduced $B(E2)$ transition probabilities for decays from these states inferred from the data clearly establish their hindered character. In addition to other excited structures, a rotational band built upon the K isomer is identified, and its configuration has been assigned through an analysis of alignments and branching ratios. The shape evolution with spin in this nucleus has been inferred from both experimental observables and cranking calculations. The yrast positive parity structure appears to evolve from a near-prolate deformed shape through triaxial at intermediate excitation, and eventually to oblate at the highest spins.

Shape coexistence is an important theme in nuclear structure research, and has been reported in many nuclei in the chart of nuclides [1]. The most extensive manifestation of this nuclear phenomenon known anywhere on the nuclear mass surface is found in the neutron-deficient isotopes at and near $Z = 82$ [1]. The shape coexistence and/or shape evolution in the Pt nuclei with $Z = 78$ has generated a lot of research interest in recent years. It has been observed that with increasing proton and neutron numbers, beyond $Z = 72$ and $N = 106$, the nuclear shape becomes more prone to non-axial fluctuation, induced by multi-quasiparticle excitation. Indeed, in the self-consistent Relativistic Hartree–Bogoliubov (RHB) calculations, the gradual transition from the prolate deformed ^{186}Pt, through the region of triaxially deformed $^{188-198}$Pt, to the slightly oblate ^{200}Pt, and finally the spherical $^{202-204}$Pt isotopes has been revealed [2]. Again, in the self-consistent Hartree–Fock–Bogoliubov (HFB) calculations using non-relativistic Skyrme and Gogny interactions, a sudden prolate to oblate shape change was observed in the Pt chain of isotopes around $A = 188$ [2]. A good agreement was found when the latter calculation was compared with a recent study on the evolution of the total energy surface and the nuclear shape in the isotopic chain $^{172-194}$Pt in the framework of the interacting boson model, including configuration mixing (IBM-CM) [3]. All these different theoretical approaches point towards the common fact that the lightest Pt isotopes are slightly deformed and prolate. With increasing neutron number, those attain more strongly deformed shape, while at the same time the γ deformation increases, leading to a triaxial nuclear shape. Eventually, the triaxial shape becomes oblate with the addition of more neutrons.

The presence of isomeric states is also well established in the $A \approx 180$ mass region both in experiment and theory. The occurrence of these metastable states can be interpreted in terms of both protons and neutrons in high-Ω orbitals. In axially symmetric nuclei, transitions involving large changes in the projection of angular momentum on the symmetry axis, K, are highly hindered. This leads to long half-lives and the resulting isomeric state is called the K isomer [4–8]. The presence of K isomers is an indication of nuclear axiality and the degree of transitional hindrance tells if the K quantum number is conserved. Shape isomerism, on the other hand, happens due to the transition from one shape to another [4,9–11]. This arises from a sudden, striking change in the intrinsic structure of the nucleus. In the case of a shape isomer,

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the degree of hindrance reflects the extent of structural change. In many instances, shape isomerism is observed when there is a prolate–oblate shape coexistence and the nucleus makes a transitional jump from oblate to prolate or vice-versa. Given the nature of the $A \sim 180$–190 mass region where prolate deformed axiality as well as prolate–oblate shape coexistence are favored, it is imperative to carry out detailed spectroscopic investigations. Recently, the coexistence of oblate rotation-aligned states with prolate deformation-aligned states has been observed in ^{192}Os [12].

The ^{188}Pt nucleus with its prolate deformed ground state has recently been described within the context of prolate–oblate shape coexistence [13]. In addition, the possibility of a new type of shape phase transition occurring along its yrast cascade has also been predicted in this nucleus. Similar type of shape phase transition, occurring along the yrast line between states of prolate and oblate shapes, was predicted in ^{190}W [14], which is yet to be studied in detail in experiments owing to its neutron-richness. In view of the theoretical prediction and present experimental limitation vis-à-vis ^{190}W, a detailed spectroscopic investigation on the high-spin level structure of ^{188}Pt is important, which will, in turn, also be useful to extrapolate the explanations on shape phase transition to ^{190}W in greater detail.

The experimental data on the excited states of ^{188}Pt are rather sparse. The latest work on this nucleus was reported by Yuan et al. where the ^{176}Yb(^{18}O, 6n) reaction was used with a moderate array of thirteen HPGe detectors [13]. In that work, it was suggested that the rotation alignment of $i_{13/2}$ neutrons drives the yrast sequence to change suddenly from prolate to oblate shape at angular momentum $10\hbar$. The continuation of the yrast sequence was reported up to $I = (20^+)\hbar$ [13].

Here in this Letter, we report certain interesting findings following a detailed spectroscopic investigation of the high-spin level structure of ^{188}Pt. The shape-transitional feature of this nucleus has been presented in greater detail following cranking calculations. One previously known yrast isomeric state has been argued to be a shape isomer. In the presence of this shape isomer, one high-K band structure (based on a high-K isomer) is newly proposed in this Letter. The coexistence of these two isomers in a single nucleus makes the case quite unusual and interesting.

High-spin states in the ^{188}Pt nucleus were populated employing the ^{174}Yb(^{18}O, 4n) reaction at a beam energy of 85 MeV. The ^{18}O beam was delivered by the Pelletron-Linac facility, TIFR, Mumbai. The enriched ^{174}Yb target was prepared by electro-deposition on an Al foil of thickness $\sim$750 μg/cm^2. The thickness of the target was 1.14 mg/cm^2. Emitted γ rays from the ^{188}Pt residual nucleus were detected by the Indian National Gamma Array (INGA) spectrometer. During this measurement, INGA was comprised of eighteen Compton-suppressed clover Ge detectors, out of which, four were at 90°, two at 65°, and three each at 40°, 115°, 140° and 157° with respect to the beam direction. The integration of the digital data acquisition system into the INGA spectrometer [15] helped in acquiring more than one billion two- and higher-fold time-stamped coincidence events for further offline analysis. The acquired data were sorted into conventional symmetric γ–γ matrix and 3-dimensional γ^3 cube, and subsequently analyzed using the RADWARE software package [16] to establish γ-ray coincidence relationships. The spin and parity of the levels were assigned based on DCO ratio and polarization measurements, respectively. The asymmetric γ–γ matrix for the DCO ratio analysis was constructed with the detectors at 90° along the x axis and the detectors at 157° along the y axis. The intensity ratios obtained from the angle dependent asymmetric γ–γ matrix were duly corrected for the relative efficiencies of the detectors at corresponding angles. The DCO ratio analysis using the matrix thus constructed was calibrated with transitions of known multipolarity. The extracted DCO ratios from stretched quadrupole gated spectra fall into two distinct groups with values of $\sim$1 and $\sim$0.5 for stretched quadrupole and dipole transitions, respectively. The parity assignments of levels were also calibrated with the known strong transitions in the level scheme. The details of these analysis procedures can be found elsewhere [17,18], and the elaborate results from the DCO and polarization analysis will be presented in a forthcoming publication [19].

The partial level scheme, as deduced from the present data, is shown in Fig. 1. It should be noted that in this Letter the discussion on the level scheme will be confined to only Seqs. I, II, III and VI (Fig. 1). The remaining details of the level scheme will be presented and discussed in a forthcoming publication [19]. The main features of the earlier reported ^{188}Pt level scheme were: a prolate ground band, a coexisting oblate γ-vibration like band with proposed oblate character, and the rotation alignment of $i_{13/2}$ neutrons driving the yrast sequence from prolate to oblate shape at $10\hbar$ of angular momentum [13]. In the present data, the ground band (g-band) was observed up to spin $I = 16^+$. The 16^+ state has been found to be fed by two newly observed transitions of energies 810 and 786 keV. Up to spin 10^+, the yrast states are members of the ground band. Beyond this, the yrast line follows the states of Seq. III. Interestingly, toward the observed highest spin of this g-band, $\Delta I = 0$ (380.6 keV, 441.5 keV) and $\Delta I = 2$ (770.4 keV) interband (Seq. I → Seq. III) transitions have been newly observed. Further investigation might be needed to explain the significance of this observation.

Seq. II was earlier reported as a γ-vibrational band by Richter et al. [20]. In the published work by Yuan et al., Seq. II and Seq. III were presented as a single continuous sequence which was assigned an oblate character [13]. The γ-vibration like band with bandhead $K^\pi = 2^+$ (Seq. II) has been confirmed in the present work but unlike Ref. [20], we suggest the 10^+_2 level at excitation energy, $E_x = 2663.3$ keV as part of this band. All the interband (from Seq. II to Seq. I) $\Delta I = 0$ and $\Delta I = 2$ transitions (including the previously unobserved 1062.1 keV ($8^+_2 \to 6^+_1$) and 226.5 keV ($10^+_2 \to 10^+_1$) transitions), which are crucial for the interpretation of this γ band, have been observed in the present work and their relative intensities have been measured.

Seq. III is built on 12^+_1 ($E_x = 2809.8$ keV) isomeric level with $T_{1/2} = 0.66(4)$ ns. The half-life of this level was measured earlier with the recoil shadow method based on the detection of conversion electrons [20]. All the three decay branches of this 12^+_1 state, observed by Richter et al. [20], have been confirmed in the present measurement. The 108.1 keV transition that was earlier seen in e^-–e^- and e^-–γ coincidence, is clearly visible in γ–γ coincidence data as well, thus confirming the decay branch: $12^+_1 \to 10^+_3$. The regular rotational $\Delta I = 2$ band (Seq. III) with bandhead $I^\pi = 12^+$ was observed up to spin $I = (22^+)$, with a tentative 805-keV γ transition feeding the (22^+) state.

The most significant finding of the present work is the high-K band structure on $I = 9^-_3$ isomer at $E_x = 2457.7$ keV (Fig. 1, Fig. 2). The spin and parity of this isomeric 9^-_3 level has been unambiguously determined in the present work following DCO ratio and polarization measurements, respectively. The half-life ($T_{1/2} = 0.66$ ns) of this level was measured earlier using recoil shadow method [20]. From observed γ–γ and triple-γ coincidences in the present data, it is clear that no transitions from either the isomeric 12^+_1 level or any of the first three 10^+ levels feed the 9^-_3 level at 2457.7 keV. It is to be noted that the E2 transition energies, which have been firmly assigned to this newly proposed high-K structure, were known earlier from a private communication to NNDC [21]. However, neither those were presented as two signature partner sequences of a coupled structure, nor any interpretation on their evolution was available. In the present work,

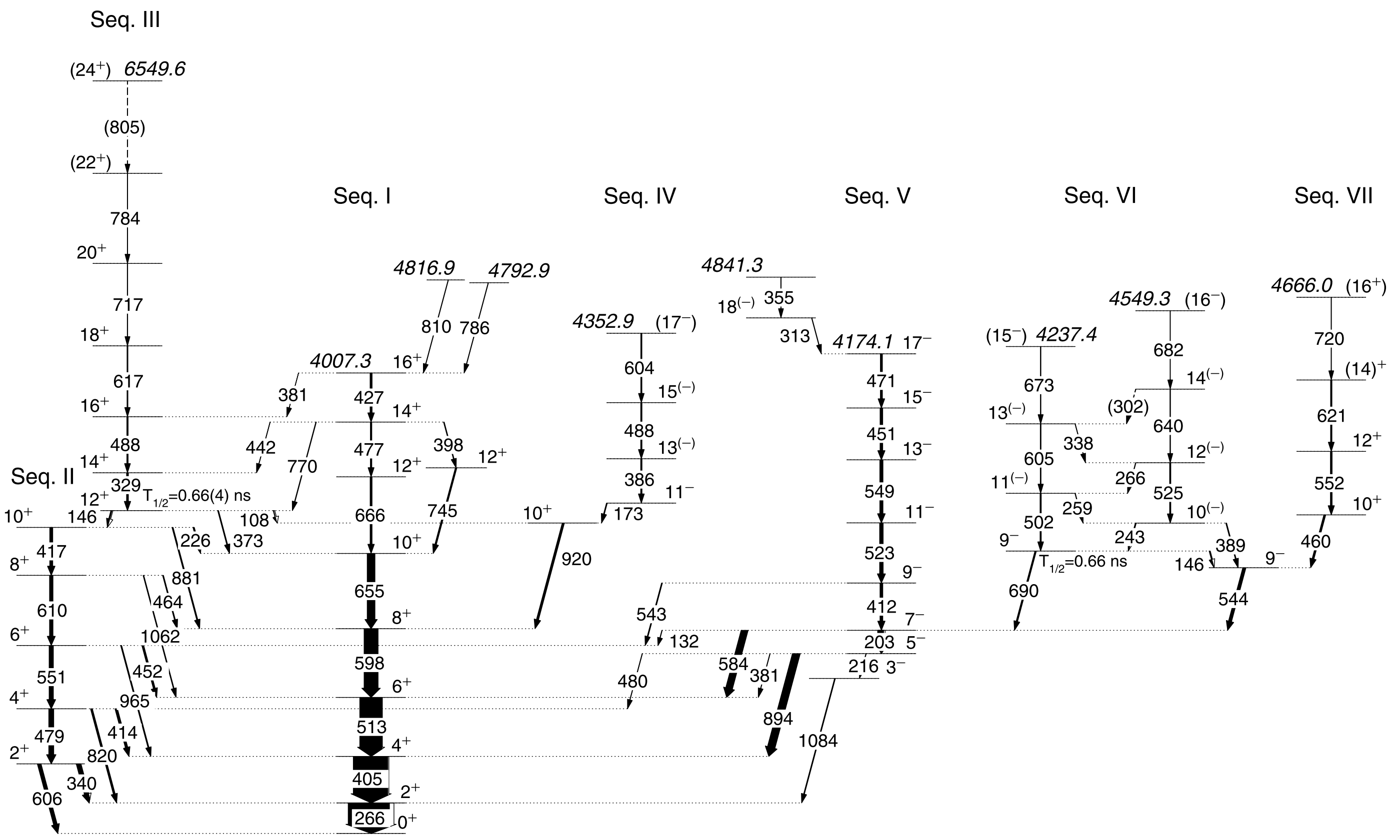

Fig. 1. Partial level scheme of ^{188}Pt obtained from the present work.

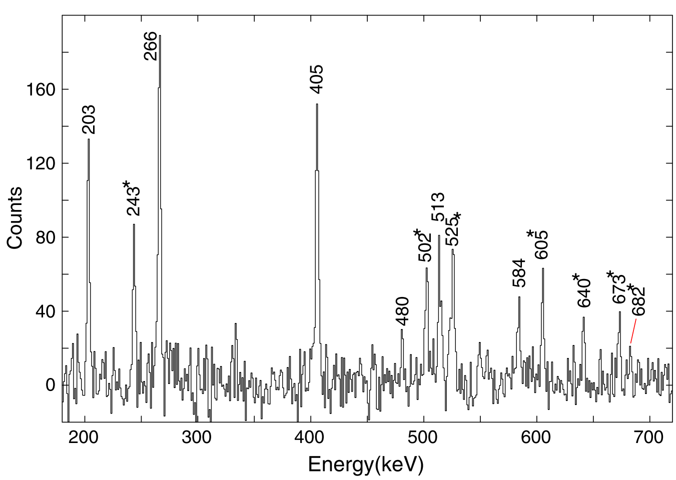

Fig. 2. Spectrum generated from sum of double-coincidence gates, showing the transitions (marked with "∗") in the newly proposed high-K band structure. Double coincidence gates were put on 689.9 keV and one of the transitions from the list, L: 202.6, 583.7, 894.5, 405.1, 265.6 keV.

the band structure has been observed up to spin $I = (16^-)\hbar$. In addition, the M1 transitions connecting the levels with two different signatures of this band structure have been newly observed. In this high-K structure, the decay of the $10^{(-)}$ state is rather fragmented. Apart from the 243.3 keV in-band M1 transition that feeds in to the isomeric bandhead, the $10^{(-)}$ state finds an alternative decay path via out-of-band 388.9 keV transition. This transition feeds in to the 9^-_2 state. The relative intensities and branching ratios (for both the E2 and M1 transitions), measured in the present work, were used to calculate the g-factors, which, in turn, have helped in configuration assignment (discussed below) for this high-K band.

In order to substantiate the previous quasi-γ band interpretation for Seq. II [20], the experimental branching ratios of the transitions from Seq. II to the g-band when compared with the ratios obtained from Alaga intensity rules [22], were found to differ substantially, by almost an order of magnitude. Similar observations were reported earlier in some of the even–even neighboring nuclei, such as ^{186}Pt, ^{186}Os, ^{188}Os, ^{190}Os [23–25]. Efforts were put earlier to describe the γ or quasi-γ bands in these nuclei assuming band-mixing and asymmetric rotor model, or even sometimes combining these two (*viz.* Davydov model [26] in presence of certain amount of band-mixing) [23–25]. These previous descriptions were reasonably successful with an yield of asymmetry parameter $\gamma \sim 12°$ for ^{186}Os and $\gamma \sim 18.8°$ for ^{188}Os [25]. With this background, an endeavor has been made in the present work to understand the quasi-γ band in ^{188}Pt employing Davydov model, and compare the magnitude of γ deformation (associated with this band) to that of neighboring nuclei. This exercise has revealed that, indeed, triaxiality is associated with Seq. II with γ degrees of freedom ranging from 20° to 28°. Therefore, Seq. II cannot be described as γ vibration of a prolate deformed rotor since the value of γ is considerably different from zero, especially with increasing spin in the g-band. A systematic study has been performed for some of the proposed γ bands in the neighboring nuclei (Table 1), and the results are in conformity with the earlier reported values (mentioned above in the text).

In Seq. I (g-band), as previously mentioned, the yrast states follow up to spin $I = 10\hbar$. Beyond this, the yrast line jumps to the 12^+ bandhead of Seq. III and thereafter, follows the higher-lying states in that sequence. Cranking calculations using standard Nilsson parameters in the ULTIMATE CRANKER (UC) code [27,28]

Table 1
Results from the systematic study of γ bands in ^{188}Pt and some neighboring nuclei following analysis in the framework of the Davydov model [26].

Isotope	Asymmetry parameter, γ
^{184}Pt	$\gamma = 0°$
^{186}Pt	$20° < \gamma < 25°$
^{188}Pt	$20° < \gamma < 28°$
^{184}Os	$10° < \gamma < 15°$
^{186}Os	$10° < \gamma < 15°$
^{188}Os	$15° < \gamma < 20°$

Table 2
A comparison of B(E2) values for estimation of the degree of hindrance for selected E2 transitions. Level lifetimes from Ref. [20] were used in the present calculations.

I ($\hbar$)	E_γ (keV)	$I_i \to I_f$	B(E2) (W.u.)	
			Present work	NNDC [21]
12_1^+	373.0	$12_1^+ \to 10_1^+$	0.64(11)	0.22(4)
12_1^+	146.5	$12_1^+ \to 10_2^+$	50(11)	67(7)
12_1^+	108.1	$12_1^+ \to 10_3^+$	49(13)	27(7)
2_1^+	265.6	$2_1^+ \to 0^+$	84(15)	82(15)
9_3^-	689.9	$9_3^- \to 7^-$	0.06(1)[a]	–

[a] Error does not include the uncertainty in level lifetime/half-life.

and also the universal Woods–Saxon potential [29] have been performed. The results from both the calculations are in qualitative agreement. The UC results are described in detail below. The ground state of ^{188}Pt is predicted to be near prolate with $\epsilon_2 = 0.18$ and $\gamma = -6°$. At higher excitation, triaxiality sets in, with $\epsilon_2 = 0.22$ and $\gamma = -13°$ for $I = 10\hbar$, and $\epsilon_2 = 0.16$ and $\gamma = -40°$ for $I = 12\hbar$. The shape evolution with spin is illustrated in Fig. 3. From the calculation, the yrast positive-parity structure is predicted to remain triaxial over a relatively large range of spins until a transition to an oblate shape occurs around $I = 22\hbar$. These predictions are consistent with Projected Shell Model (PSM) calculations [13] which indicate the coexistence of both prolate and oblate shapes in ^{188}Pt.

The yrast 12^+ state is built on a complete alignment of two $i_{13/2}$ neutrons. The nucleus makes a transition from this triaxially deformed state to the near-prolate 10^+ yrast state through the 373 keV transition. Due to the limited overlap between the wave-functions associated with these two states, this γ ray is hindered and the yrast 12^+ state becomes isomeric. We argue in favor of this 12_1^+ state to be a shape isomer as this appears right at the point where shape phase transition occurs along the yrast line of ^{188}Pt. Since this shape-transition in ^{188}Pt involves a relatively smaller change in γ value as compared to that from a purely prolate ($\gamma = 0°$) to oblate ($\gamma = 60°$) configuration, it is less hindered, and that may account for the shorter (sub-nanosecond) half-life for this shape isomer. To estimate the degree of this hindrance, B(E2) values have been calculated for all the three E2 transitions depopulating this state, and compared with the values for the yrast 2^+ level and the 9_3^- high-K isomeric state (depopulating by K-forbidden, hindered, 689.9 keV transition). The deduced values are given in Table 2. It is evident that the B(E2) value for the 12_1^+ state, de-exciting to the yrast 10^+ state by emitting 373-keV γ ray, is ∼130 times less than the B(E2) value for the yrast 2^+ state which depopulates in to the ground state by emitting 265.6-keV γ ray. It is also worth noting that when B(E2) values are compared, the 373 keV transition from the 12_1^+ state is almost 10 times less hindered than the 689.9 keV transition depopulating the high-K isomeric level.

Calculations suggest that the rotational band above an oblate shape isomer should be decoupled and will have high rotational

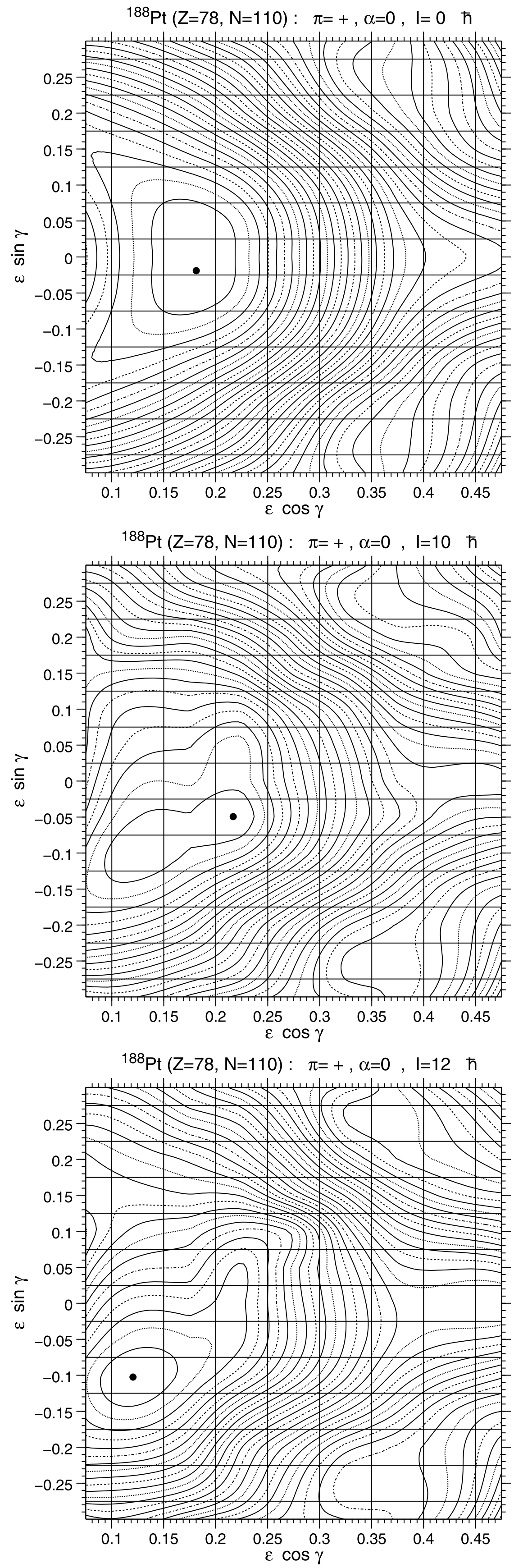

Fig. 3. Shape change with spin in ^{188}Pt from Ultimate Cranker calculations. The lowest energy minimum is indicated by a dot. The horizontal axis in the plots corresponds to $\gamma = 0°$, while the spacing between adjacent energy contours is 200 keV.

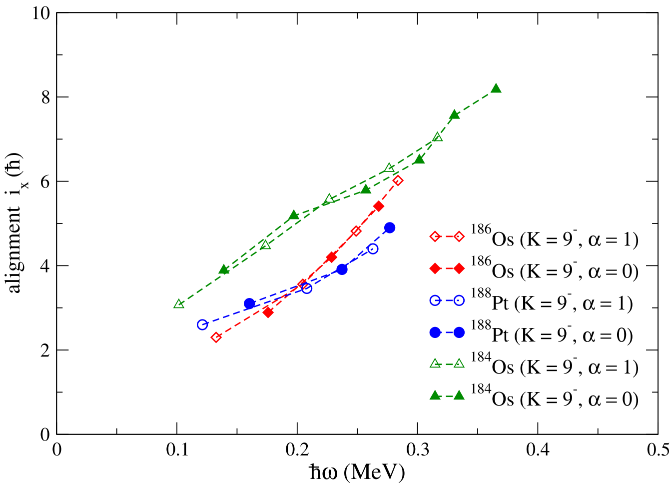

Fig. 4. Evolution of aligned angular momenta with rotational frequency for the $K^\pi = 9^-$ bands in ^{188}Pt and neighboring nuclei.

alignments than strongly coupled bands, associated with the alternative prolate, high-K interpretation [9]. Although the proposed shape isomer in ^{188}Pt is not purely oblate, the presence of the decoupled rotational band above this and higher alignments compared to the prolate high-K band carry significant fingerprint toward its unique identity.

Now, for the newly proposed high-K structure (Seq. VI), it is evident that the $K^\pi = 9_3^-$ bandhead de-excites via both a K-allowed 146.6 keV transition to the $K^\pi = 9_2^-$ state and a relatively more intense K-forbidden E2 transition of energy 689.9 keV to the 7^- state of a sequence of levels with $K^\pi = 5^-$. The $K^\pi = 5^-$ assignment for the Seq. V is based on a systematic comparison with similar semi-decoupled structures in neighbouring even-A Pt isotopes. The assignment is further supported by contrasting relative intensities of the in-band transitions above the $K^\pi = 5^-$ bandhead as compared to the transition de-exciting the bandhead. However, a $K^\pi = 3^-$ possibility for the Seq. V cannot be excluded based on available limited experimental data. Reduced hindrance or the hindrance per degree of K-forbiddenness (f_ν) which gives an estimate for the 'goodness' of the K-quantum number, has been calculated for this particular case. This is given by $f_\nu = [F_W]^{1/\nu}$, where $\nu = \Delta K - \lambda$, λ is the multipolarity of the transition and F_W is the ratio of the partial γ-ray half-life to the Weisskopf single-particle estimate. The 689.9 keV transition from the 0.66 ns isomer at 2457.7 keV excitation energy has $f_\nu = 4$, assuming $K^\pi = 5^-$ for the Seq. V; with $K^\pi = 3^-$, the value of f_ν becomes 2. With such small value of reduced hindrance, the K quantum number remains only partially conserved.

The configuration assignment for the $K^\pi = 9_3^-$ high-K band was attempted at first by comparing the alignments with similar bands in neighboring nuclei. The Harris parameters that have been used in the plot are: $\Im_0^{(1)} = 22.1\hbar^2$ MeV^{-1} and $\Im_1^{(2)} = 67.0\hbar^2$ MeV^{-3} [6]. Earlier $K^\pi = 9^-$ bands were reported in this mass region in ^{186}Os (isotone), ^{184}Os [6,30]. The assumed Nilsson configuration for the $K^\pi = 9^-$ band in ^{186}Os is: $\nu[615]\frac{11}{2}^+ \otimes \nu[503]\frac{7}{2}^-$. The $K^\pi = 9^-$ band in ^{184}Os has a higher alignment than the band in ^{188}Pt (Fig. 4). When the alignments of ^{188}Pt and its isotone ^{186}Os were compared over a range of rotational frequency, those do not seem to be identical. Also, towards the lower rotational frequency, their slopes appear significantly different (Fig. 4). This comparative analysis suggests the possibility that the $i_{13/2}$ neutron configuration for the 9^- band in ^{188}Pt contains different Nilsson orbitals than those in ^{184}Os and ^{186}Os. In order to have a clearer view on the configuration of the 9^- band in ^{188}Pt, the branching ratios and g-factors were analyzed.

Table 3
Comparison of the experimental g-factor (for the $K^\pi = 9_3^-$ band) with calculated values for different probable configurations.

Configuration	$(\frac{g_K-g_R}{Q_0})_{calc.}$	$\lvert\frac{g_K-g_R}{Q_0}\rvert_{exp.}$
$\nu[615]\frac{11}{2}^+ \otimes \nu[503]\frac{7}{2}^-$	−0.09	0.02(1)
$\nu[624]\frac{9}{2}^+ \otimes \nu[505]\frac{9}{2}^-$	−0.04	

The relation between g_K and g_R, the intrinsic and rotational g-factors, respectively, and δ is given by

$$\frac{(g_K - g_R)}{Q_0} = 0.933\frac{E_\gamma(I \to I-1)}{\delta\sqrt{(I^2-1)}} \tag{1}$$

where, Q_0 (in eb) is the intrinsic quadrupole moment, E_γ is the γ-ray energy (in MeV) for the $\Delta I = 1$ transition and δ is the E2/M1 mixing ratio. The mixing ratio can be calculated from the following expression:

$$\frac{1}{\delta} = \pm\sqrt{\frac{1}{\lambda}\left(\frac{E_\gamma(I\to I-2)}{E_\gamma(I\to I-1)}\right)^5\frac{(I+1)(I-1+K)(I-1-K)}{2K^2(2I-1)} - 1} \tag{2}$$

Here, $\lambda = T_\gamma(I \to I-2)/T_\gamma(I \to I-1)$, T is the γ ray intensity, K is the bandhead spin and I is the spin of the level of interest. The sign of $\frac{1}{\delta}$ can be obtained from the DCO ratio of the $\Delta I = 1$ transition.

In the calculation, two probable Nilsson configurations that can lead to a $K^\pi = 9^-$ state were considered. Taking $Q_0 = 5.4$ eb and the rotational g-factor, $g_R = 0.21$ [6,23], the calculated values were compared with the experimental number (Table 3). From the comparison, it is evident that the $\nu[624]\frac{9}{2}^+ \otimes \nu[505]\frac{9}{2}^-$ configuration is more favorable for this $K^\pi = 9_3^-$ high-K sequence. This configuration assignment finds support in the work of Bearden et al. where it was suggested that the $I^\pi = 9^-$ is one of the calculated optimal neutron states for $N = 110$, and the associated configuration is $(i_{13/2})^9_{9/2} \otimes (h_{9/2})^{-1}_{9/2}$ [31]. In view of the fact that the 9_2^- state ($E_x = 2312.1$ keV) lies very close in excitation energy to that of the 9_3^- state ($E_x = 2457.7$ keV), it is possible that the former state is also built on two $i_{13/2}$ quasi-neutron coupling with the probable configuration $\nu[615]\frac{11}{2}^+ \otimes \nu[503]\frac{7}{2}^-$.

The presence of the shape isomer along with the high-K isomer in a single nucleus is unusual. The high-K isomer is a consequence of nuclear axiality and the occurrence of this in ^{188}Pt nucleus attests to the fact that nuclear axiality is preserved to some extent along with the onset of triaxiality. In other words, this nucleus may have just the right amount of γ softness (and rigidity), along with the high-Ω orbitals near the Fermi level, to allow for both the structures to be present. Beyond ^{188}Pt, the axiality is lost, and the isotopes with $N > 110$ become fully triaxial. Therefore, the nucleus ^{188}Pt can be described as the one that sets the limit of axiality in the Pt chain of isotopes.

To summarize, the high-spin level structure of the ^{188}Pt nucleus has been thoroughly investigated using a multi-clover Ge detector array. Several new γ rays and de-exciting sequences have enriched the previously reported level scheme of this nucleus. The real character of the γ-vibrational band has been substantiated by comparing the experimental observables with Alaga rules and Davydov model. The shape coexistence feature that was attributed to this nucleus previously, has been corroborated in detail by UC calculations. The isomeric yrast 12^+ level has been strongly argued to be a shape isomer. One high-K band structure with $\nu[624]\frac{9}{2}^+ \otimes \nu[505]\frac{9}{2}^-$ configuration has been newly proposed in the present investigation. Although here K seems to be only partially conserved, this new observation attests to the fact that the nucleus ^{188}Pt preserves some amount of axiality, whereas, triaxiality becomes substantial beyond $N = 110$ in the Pt chain of isotopes. Finally, the coexistence of shape- and high-K isomers in ^{188}Pt presents a rare opportunity to further study the interplay between axiality and triaxiality with more detailed investigations.

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