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New excited superdeformed bands in heavy Pb nuclei: Clue for an octupole softness near the N = 118 gap at large deformation

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Abstract. We report the identification of six new superdeformed (SD) bands in ^{197,198}Pb observed with the EUROBALL IV spectrometer. The results are interpreted in the framework of cranked Hartree-Fock calculations with approximate projection on the particle number by means of the Lipkin-Nogami method. A mixing between quasi-particle excitations and an octupole vibration is suggested in the two SD isotopes. We have estimated the ordering of the neutron valence orbitals and confirm indirectly a $N = 118$ SD gap.

PACS. 21.10.Re Collective levels – 21.60.Ev Collective models – 23.20.Lv Gamma transitions and level energies – 27.80.+w $190 \leq A \leq 219$

1 Introduction

The advent of the new generation of γ-ray spectrometers (EUROBALL [1], GAMMASPHERE [2]) has allowed the study of nuclear structure at high excitation energy and high spin. Following the observation of a rotational superdeformed (SD) band in ^{152}Dy [3], a large number of such bands has been discovered in several mass regions, each one having its own characteristics. Because SD bands can be observed down to low spin, $A \sim 190$ nuclei are interesting to study for the competition between the Coriolis force and pairing correlations at large deformation. The general trend of the dynamic moment of inertia ($\Im^{(2)}$) is qualitatively well-described by various theoretical approaches [4]. It results from the gradual alignment of pairs of nucleons occupying high-N intruder orbitals (originating from the $j_{15/2}$ neutron and $i_{13/2}$ proton shells) combined with a decrease of the pairing strength. It was recently proposed that such a cancellation mechanism could also be an explanation for the striking phenomenon of identical bands [5]. A quantitative description of the dynamic properties of SD nuclei is still needed and requires further investigations. In the $A \sim 190$ mass region, the ^{198}Pb case, which is the heaviest known SD lead nucleus, is very interesting since the $\Im^{(2)}$ of the yrast SD band is much flatter than theoretically expected. Even the relative properties with respect to the ^{196}Pb yrast SD band are not understood. A detailed study of the ^{198}Pb nucleus and its neighbouring isotopes is needed to determine the origin of this effect. We report here the results of an experiment in which SD states have been populated in ^{197,198}Pb nuclei. Cross-talk transitions between two signature partner SD bands in ^{197}Pb, based upon the $\nu[752]5/2$ neutron intruder orbital, have been recently found with an established M1 character, giving access to the magnetic properties of this orbital [6]. Six new SD bands, which probably represent three pairs of signature partners, have been found in this work. Two pairs have been assigned to the ^{197}Pb nucleus, the third one to the ^{198}Pb nucleus. The results are discussed in the framework of cranked Hartree-Fock Bogoliubov (HFB) calculations with approximate projection on the particle number by means of the Lipkin-Nogami (LN) method [7,8].

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Table 1. Transition energies (in keV) of the previously known (^{197}Pb band 1 and band 2, ^{198}Pb band 1) and the new SD bands (^{197}Pb band 3a, band 3b, band 4a, band 4b, ^{198}Pb band 2a and band 2b) observed in this work. The estimated spin of the first SD state is also given for each band.

^{197}Pb band 1 11/2	band 2 9/2	band 3a 17/2	band 3b 19/2	band 4a 19/2	band 4b 17/2	^{198}Pb band 1 12	band 2a 10	band 2b 8
142.6 (5)	123.0 (5)	200.1 (8)	221.8 (5)	237.5 (7)	215.8 (5)	304.4 (5)	281.4 (6)	215.8 (6)
183.7 (4)	163.7 (5)	240.8 (8)	261.8 (5)	279.7 (6)	259.6 (5)	347.7 (5)	324.1 (5)	259.6 (5)
223.8 (5)	204.6 (4)	281.3 (6)	301.7 (5)	322.5 (6)	302.6 (5)	390.3 (4)	365.6 (5)	302.6 (5)
264.0 (5)	245.2 (5)	321.2 (6)	340.6 (5)	364.5 (6)	344.6 (5)	432.4 (5)	406.7 (5)	344.6 (5)
304.3 (5)	286.4 (5)	361.4 (6)	380.7 (5)	405.7 (6)	386.3 (5)	473.8 (5)	447.9 (5)	386.3 (5)
344.2 (5)	327.3 (5)	401.1 (6)	419.4 (5)	445.8 (6)	425.7 (5)	514.6 (5)	488.2 (5)	428.5 (5)
383.9 (5)	368.6 (5)	440.5 (7)	458.6 (5)	485.7 (6)	466.9 (6)	554.8 (5)	527.9 (5)	468.8 (5)
423.3 (5)	409.7 (5)	479.3 (6)	497.8 (5)	525.1 (6)	506.2 (6)	633.4 (5)	567.2 (5)	508.2 (5)
462.6 (5)	451.0 (5)	518.1 (7)	535.6 (5)	563.2 (6)	546.1 (5)	671.8 (5)	605.4 (5)	547.8 (5)
501.2 (5)	491.9 (5)	557.0 (8)	573.4 (5)	600.7 (6)	583.2 (5)	709.4 (5)	641.8 (5)	586.4 (5)
540.4 (5)	532.5 (5)	594.3 (7)	610.4 (5)	636.7 (6)	619.6 (5)	746.7 (5)	676.3 (5)	623.8 (5)
578.6 (5)	572.7 (5)	631.3 (7)	648.1 (5)	670.1 (6)	655.0 (5)	782.7 (5)	705.7 (5)	660.0 (5)
616.9 (5)	613.3 (6)	668.3 (8)	684.1 (6)	701.5 (7)	687.5 (7)	818.5 (6)	731.7 (5)	695.8 (6)
654.5 (6)	652.8 (6)	704.7 (13)	720.5 (10)	732.8 (9)	717.7 (9)	851.2 (7)	759.1 (6)	
692.2 (6)	692.1 (6)					890.0 (8)		
729.8 (7)	731.2 (7)							
766.8 (8)	769.5 (8)							
803.1 (10)	807.2 (8)							

2 Experiment and results

Excited high-spin states in ^{197,198}Pb were populated by the ^{186}W(^{18}O,xn)^{197,198}Pb reactions at a beam energy of 117 MeV. For six days, the $\sim$ 3 pnA ^{18}O beam was supplied by the VIVITRON accelerator at the Institut de Recherches Subatomiques, Strasbourg. The target consisted of two self-supported ^{186}W foils of about 200 μg/cm^2 thickness each. The γ-rays were detected with the EUROBALL IV spectrometer comprising an inner-ball [9] of 210 BGO crystals, and 71 Compton-suppressed Ge detectors which represent 239 Ge individual crystals: 30 tapered Ge detectors placed on three rings at forward angles, 26 clover detectors each composed of 4 Ge crystals in the same cryostat at angles close to 90° and 15 clusters, each formed by 7 Ge capsules, at backward angles. A condition of unsuppressed Ge fold ≥ 4 and an inner-ball multiplicity of at least 8 were required to store events on DLT tapes. After time filtering, Compton rejection and add-back of clover and cluster detectors, a total of 10^9 events with fold ≥ 4 were available for subsequent analysis.

The present data set allowed us to study in detail the two ^{197}Pb SD bands (namely band 1 and band 2) found by Hibbert *et al.* [10]. The relative intensities of all transitions are shown in the inserts of fig. 1. Despite the low intensity ($\sim$ 0.2% and $\sim$ 0.1% for band 1 and 2, respectively, compared to the ^{197}Pb reaction channel), M1 cross-talk transitions between the two signature partners have been observed [6]. As well, DCO measurements on the transitions of the ^{198}Pb yrast SD band confirmed their $\Delta I = 2$ nature. As already mentioned [10], this band is characterized by the extremely rapid depopulation illustrated in fig. 1. Despite evidence for several high-energy γ-rays (above 1 MeV) in coincidence with the SD transitions, their extremely weak intensities do not allow any construction of a level scheme linking the SD band to the normally deformed (ND) states.

A systematic search for rotational cascades having a dynamic moment of inertia typical of the Hg, Tl and Pb bands revealed six new SD structures labeled bands 2a, 2b, 3a, 3b, 4a and 4b. The spectra, which represent most likely three pairs of signature partners, are shown in fig. 2. The transition energies extracted are listed in table 1 and the procedure proposed by Wu *et al.* [11] was applied to determine the spin of the band heads. Those spins have been obtained using the K values determined in the next section. The proposed spins for the band heads of bands 2a, 2b, 3a, 3b, 4a and 4b are 10, 8, 17/2, 19/2, 19/2 and 17/2, respectively.

It was extremely difficult to assign the excited SD bands, for several reasons. First, their intensities are very low. Indeed, the yrast SD band in ^{197}Pb (^{198}Pb) represents only 0.2% (0.5%) of the corresponding reaction channel, which is weaker than in lighter SD lead nuclei. To observe SD states with the present reaction, the compound nucleus was produced at high angular momentum in a region where the fission process is important, producing a large γ-ray background. In both ^{197}Pb and ^{198}Pb nuclei, five intense long cascades of M1 transitions have been found [12] representing an important source of contamination, especially in the low-energy SD range. Finally, long-lived isomeric states (470 ns ($21/2^- \rightarrow 19/2^+$) in ^{197}Pb and 240 ns ($12^+ \rightarrow 10^+$) in ^{198}Pb) reduce the intensity of the ND transitions in coincidence with the new SD bands. However, those bands can be unambiguously assigned to the

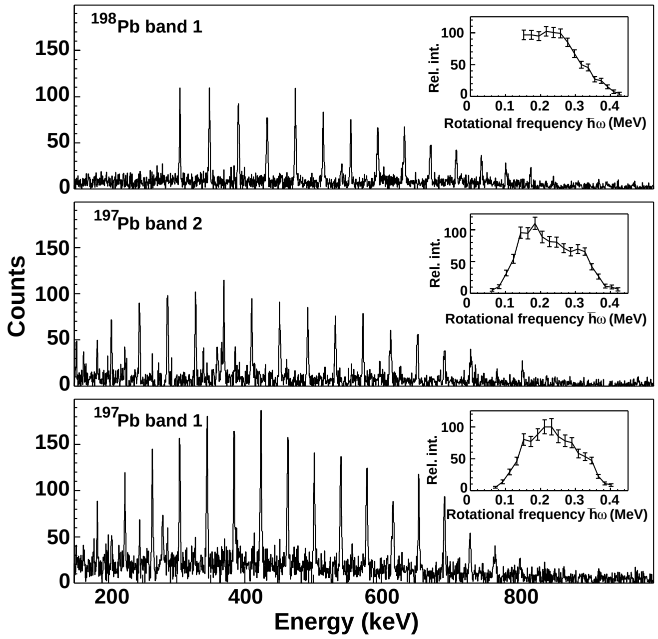

Fig. 1. Four-gated spectra of the previously known SD bands in ^{198}Pb (band 1) and ^{197}Pb (band 1 and band 2). The intensity patterns are plotted in the inserts.

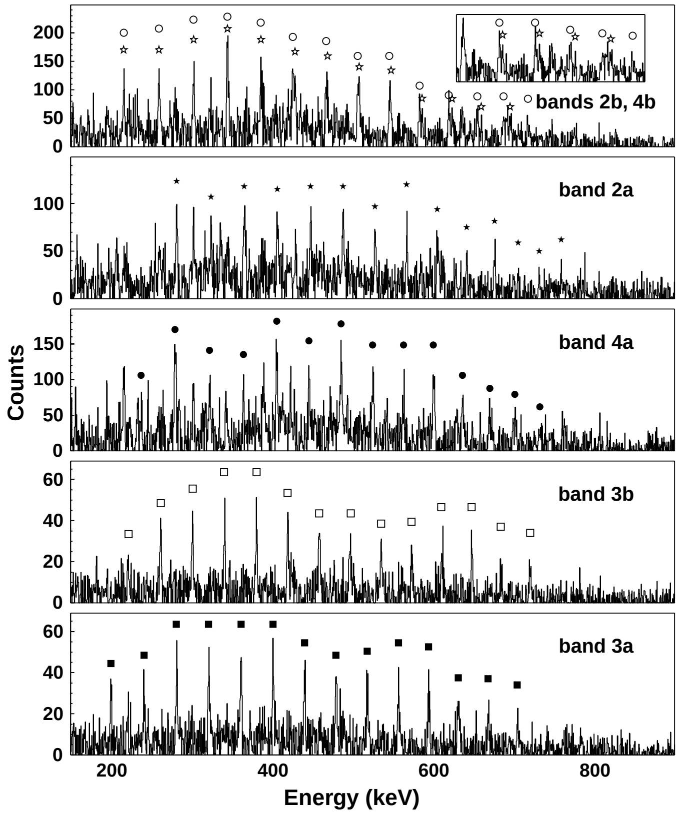

Fig. 2. Four-fold gated spectra of the new SD bands 3a and 3b, and three-fold spectra of the new SD bands 2a, 2b, 4a and 4b. Band 3a, 3b, 4a, 4b are assigned to ^{197}Pb and bands 2a, 2b to ^{198}Pb. The insert of the upper figure enlarging the high-energy range shows the separation between bands 2b and 4b.

lead isotope because of the X-rays observed in all gated spectra. The ^{196}Pb nucleus is excluded since, due to a lower production cross-section (compared to ^{197}Pb and ^{198}Pb), the previously reported SD bands [13,14] were not seen in this data set. In the present experiment, the ^{197}Pb nucleus has a larger production cross-section than the ^{198}Pb nucleus.

Let us analyze now the new bands. The two strongest cascades, labeled band 3a and band 3b, belong most likely to the ^{197}Pb nucleus. Their intensities, normalized to 1.0 for the yrast SD band, are 0.27(2); such intensities are not compatible with excited bands of an even-even nucleus since the intensity of these two bands normalized to the ^{198}Pb yrast SD band, would be 0.49(2). Because of the pairing gap, SD bands based on 2 quasi-particle (qp) excitations have always been found with an experimental intensity less than 0.1 in even-even nuclei. This is the case for the ^{190}Hg band 3 (~ 0.04) [15], the ^{192}Hg band 2 (~ 0.07) [16] and the ^{194}Pb bands 2a and 2b (~ 0.05 and 0.06) [17]. The most intense excited bands in even-even nuclei are assigned to collectively vibrating SD states with an experimental intensity close to 0.2. The known cases are the ^{190}Hg band 2 (~ 0.2) [15], ^{194}Hg band 2 (~ 0.25) [5,4] and ^{196}Pb band 2 (~ 0.2) [18,19]. The transition energies of band 3a lie at the mid-point of the transition energies of band 3b along the complete observed range, which is expected for strongly coupled signature partners. There is no evidence for cross-talk between those two bands. It was not possible to obtain their intensity pattern since too many conditions were needed to observe the bands.

It should be noticed that band 2a and band 2b have very close γ-ray energies to band 4a and band 4b, respectively, it is then very difficult to get a clean spectrum of each band. Only three-fold gated spectra have been used since the statistics were not sufficient to work with four-fold gated spectra. Under such conditions, a unique spectrum was obtained for bands 2b and 4b (see fig. 2). The width of the transitions at low energy are greater than expected (from 400 to 600 keV), pointing out the existence of double peaks, the splitting between the two bands increasing with the γ-ray energy. The situation is fortunately less complicated for band 2a and band 4a because of a larger energy difference, especially at high energy, which has allowed us to obtain a spectrum for each band. The transition energies of band 4a (band 2a) lie at the mid-point of the transition energies of band 4b (band 2b) suggesting that they are two pairs of signature partners. Those four remaining new bands have been tentatively assigned to ^{197}Pb (band 4a and band 4b) and ^{198}Pb nucleus (band 2a, band 2b). As pointed out in the following section, these assignments are based on the properties of the new bands with respect to theoretical calculations and comparison with known configurations of the neighbouring nuclei. The intensities of band 4a and band 4b, normalized to 1.0 for the ^{197}Pb yrast SD band, are about 0.09(2). In the same way, the intensities of band 2a and band 2b normalized to 1.0 for the ^{198}Pb yrast SD band are about 0.17(2). None of the feeding patterns of these

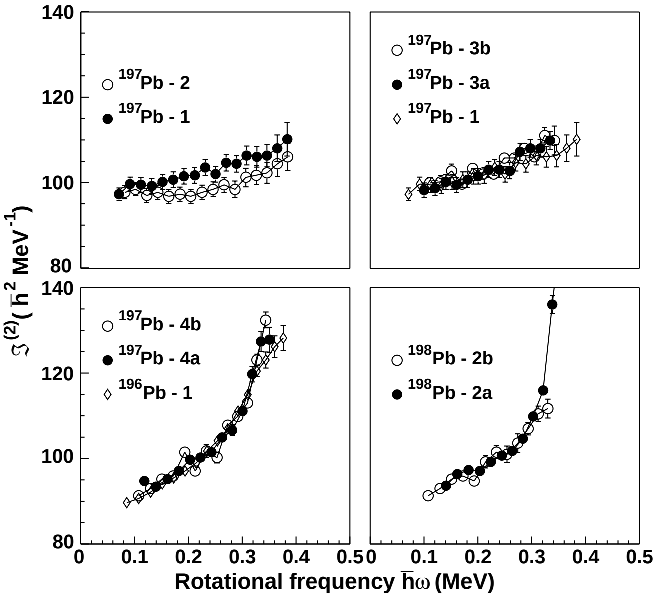

Fig. 3. Dynamic moments of inertia $\Im^{(2)}$ of the SD bands in ^{197,198}Pb observed in this work. For comparison, the $\Im^{(2)}$ of the SD band 1 in ^{196}Pb is also plotted.

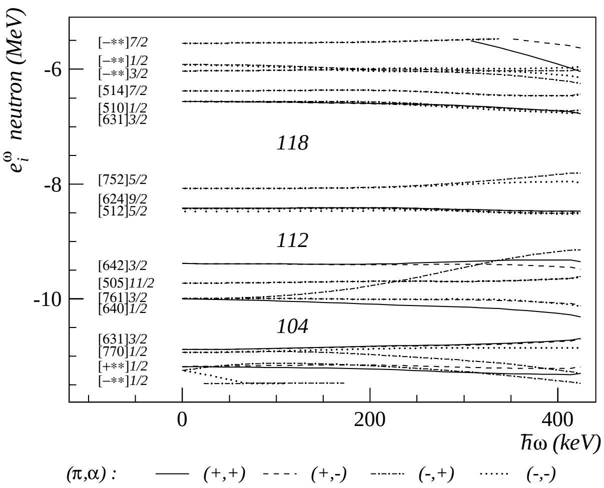

Fig. 4. Neutron single-particle Routhians obtained in cranked Hartree-Fock-Bogoliubov + Lipkin-Nogami calculations (using the SkM* effective force and constant pairing G_τ=12.6) for ^{196}Pb [8].

new bands could be determined because of their very weak intensities.

The experimental moments of inertia of the known ^{197}Pb SD bands (band 1 and band 2) and the new observed SD bands in ^{197,198}Pb (band 3a, band 3b, band 4a, band 4b in ^{197}Pb, and band 2a, band 2b in ^{198}Pb) are shown in fig. 3. In the case of band 1 and band 2 in ^{197}Pb, we note a rather flat behaviour of $\Im^{(2)}$ (between 95 and 110 $\hbar^2$MeV^{-1} for frequencies between 0.1 MeV and 0.4 MeV). The same pattern occurs in ^{197}Pb for band 3a and band 3b and, moreover, a striking similarity exists between these two bands and the ^{197}Pb band 1. Concerning band 4a and band 4b in ^{197}Pb and band 2a and band 2b in ^{198}Pb, a slow rise of the dynamic moment of inertia *versus* the rotational frequency is observed from 90 $\hbar^2$MeV^{-1} identical to that of ^{196}Pb band 1. It is important to note the clear difference existing between the $\Im^{(2)}$ values for band 2a and band 2b at $\hbar\omega = 0.35\,$MeV, the former being much larger ($\sim 140\,\hbar^2$MeV^{-1}).

3 Discussion

Six new SD bands have been identified in ^{197,198}Pb nuclei as described above in addition to the known SD bands in ^{197}Pb (bands 1 and 2) and ^{198}Pb (band 1). The results obtained will be discussed with self-consistent cranked HFB calculations and we also make comparisons with other SD bands of the $A \sim 190$ mass region. As mentioned before, two of the new SD bands (band 3a and band 3b) can be assigned to the ^{197}Pb nucleus as excited bands. For the four remaining new SD bands (2a, 2b, 4a, 4b), we will propose a tentative assignment with two bands belonging to ^{197}Pb and two to ^{198}Pb.

B. Gall [8] has performed cranked HFB calculations using different parameterizations of the Skyrme effective force SkM* (and SLy4) with the approximate particle number Lipkin-Nogami projection for ^{196,198}Pb as presented in [7] for ^{192,194}Pb. The single-particle Routhians obtained for ^{196}Pb in these calculations are presented in fig. 4. The only neutron valence SD orbitals are the [512]5/2, [624]9/2 and [752]5/2 orbitals. The latter is the $N = 7$ intruder orbital coming from the $j_{15/2}$ shell labeled also 7_3. Two gaps at $N = 112$ and $N = 118$ limit the available configurations. The same results have been obtained with the SLy4 interaction [20] and a density-dependent pairing treatment [21]. As shown by the neutron quasi-particle Routhians given in fig. 5, the intruder 7_3 [752]5/2 becomes the lowest configuration around a rotational frequency of 0.15 MeV. The splitting of the favoured $\alpha = -1/2$ and unfavoured $\alpha = +1/2$ signatures is predicted to occur at a frequency around 0.2 MeV, so cross-talk transitions between the two structures are expected to exist up to this frequency, which correspond to SD transitions up to 340 keV. They have been recently identified and the extraction of experimental $B(M1)/B(E2)$ ratios has confirmed the assignment of these two bands as being built on the [752]5/2 orbital [6]. The Pauli blocking of a single high $N = 7$ orbital leading to an essentially constant $\Im^{(2)}$ has already been observed in ^{193}Pb [22,23], ^{195}Pb [24] as shown in fig. 3 for bands 1 and 2 in ^{197}Pb.

To generate excited SD bands in an odd nucleus, the simplest way is to promote the external particle or quasiparticle to a higher-energy orbital, which means in the case of ^{197}Pb promoting one neutron of the ν[752]5/2 orbital to the ν[512]5/2 or ν[624]9/2 orbital. Such configurations would give rise to a $\Im^{(2)}$ quite similar to that of the yrast SD band of the ^{196}Pb core. However, one may expect a difference between the two orbitals. In a

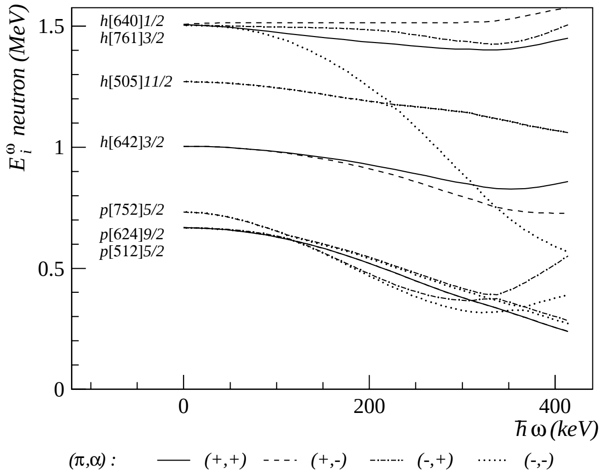

Fig. 5. Neutron quasi-particle Routhians obtained in cranked Hartree-Fock-Bogoliubov + Lipkin-Nogami calculations (using the SkM* effective force and constant pairing G_τ=12.6) for ^{196}Pb [8]. The *p* label stands for particle and *h* for hole.

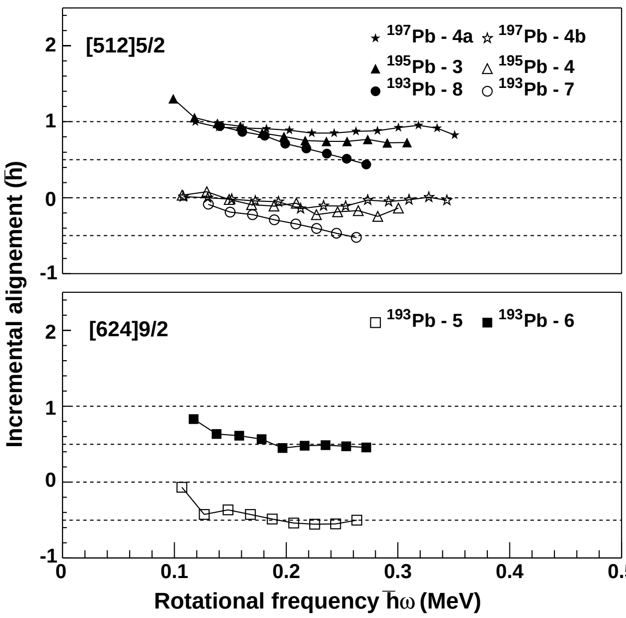

Fig. 6. Incremental alignment (in units of ħ) of odd-Pb ^{193,195,197}Pb SD bands. For each SD band the reference is the yrast SD band of the corresponding even-even core. For the ν[624]9/2 orbital the values are extracted from ref. [22] and for ν[512]5/2 one from refs. [23,26] for ^{193,195}Pb, respectively.

strong coupling scheme, a rotational SD band involving the ν[624]9/2 orbital should have its γ-ray energies at the 1/4 or 3/4 point energies of the even core. Excited SD bands based on the ν[624]9/2 orbital have been observed in ^{193}Pb [22]. The corresponding ^{193}Pb bands labeled band 5 and band 6 have the correct incremental alignments [25] (-0.5 and 0.5) as shown in fig. 6 and their configuration ν[624]9/2 was unambiguously established by measuring the M1 cross-talk transitions between the two bands. A recent experiment has confirmed these results in ^{193}Pb [23]. Concerning the case of the ν[512]5/2 orbital, the application of the strong coupling scheme is not so clearly valid and also a possible mixing with the intruder ν[752]5/2 orbital can occur. Therefore, the 1/4-3/4 point energy rule is not fulfilled by all observed ν[512]5/2 cases. In ^{193}Pb (ref. [23]), two additional excited bands (band 7 and band 8) not governed by this 1/4-3/4 energy rule have been found at higher excitation energy and have been assigned to the ν[512]5/2 orbital in this nucleus. The corresponding incremental alignment is presented in fig. 6, pointing out a gradual change over the frequency range. Then, these results suggest that the ν[624]9/2 orbital lies at lower energy than the ν[512]5/2 orbital in the second well. Indeed in the ^{195}Pb nucleus, there is no evidence for the ν[624]9/2 orbital, the two observed excited bands (band 3 and band 4) [26] not having the alignment expected in the case of a strong coupling scheme. Those ones, displayed in fig. 6, show that the two bands are most probably based on the ν[512]5/2 orbital, however with a weaker change of the alignment *versus* the rotational frequency than in the ^{193}Pb case. As expected from the ^{193}Pb study, it appears that the ν[624]9/2 orbital lies below the Fermi surface in the ^{195}Pb nucleus. Our experimental results on ^{197}Pb suggest the relative position of these two orbitals in the second well: we do not observe SD bands with γ-rays energies at the 1/4-3/4 point energies of the ^{196}Pb yrast band which is expected for the ν[624]9/2 orbital. In our experiment, nevertheless, two bands (band 4a and band 4b) have the properties (behaviour of the moment of inertia $\Im^{(2)}$ and incremental alignment) required for a configuration based on the ν[512]5/2 orbital. Their dynamic moment of inertia is similar to the even-even core ^{196}Pb (see fig. 3) over the whole frequency range, however with a smaller variation of the alignment (see fig. 6) compared to what is found for the same orbital in ^{193}Pb and ^{195}Pb. It should be noticed that the incremental alignment increases gradually from ^{193}Pb to ^{197}Pb.

As already mentioned, two new SD bands (band 3a and band 3b) have been observed with stronger intensities than those of band 4a and band 4b. Such intensities are unlikely for excited bands of an even-even SD nucleus, here the ^{198}Pb nucleus, and they belong most probably to the ^{197}Pb nucleus. Cranked HFB calculations predict a large gap at $N = 118$ so that no more single quasi-particle excitation is available for these bands. However, an excitation with a hole in the ν[624]9/2 orbital and a particle in the ν[512]5/2 orbital would give rise to a $\Im^{(2)}$ similar to that of the yrast SD band 1 of the ^{197}Pb nucleus which is the case for bands 3a and 3b (see fig. 3). The large experimental intensity for such a 3qp configuration suggests the presence of a degree of freedom not having been included in the calculations. These two orbitals ν[512]5/2 and ν[624]9/2 could be coupled by a residual Y_{32} interaction since they obey the approximate rules for asymptotic states for SD nuclei [27]: $\Delta N = \Delta n_z = 1$; $\Delta\Omega = \Delta\Lambda = \pm 2$. An octupole softness of the SD Hg-Pb nuclei has been suggested experimentally first in ^{190}Hg [28], then in ^{194}Hg [5,26] and ^{196}Pb [18]. From the theoretical point of view, RPA calculations based on the cranked Nilsson model and with a

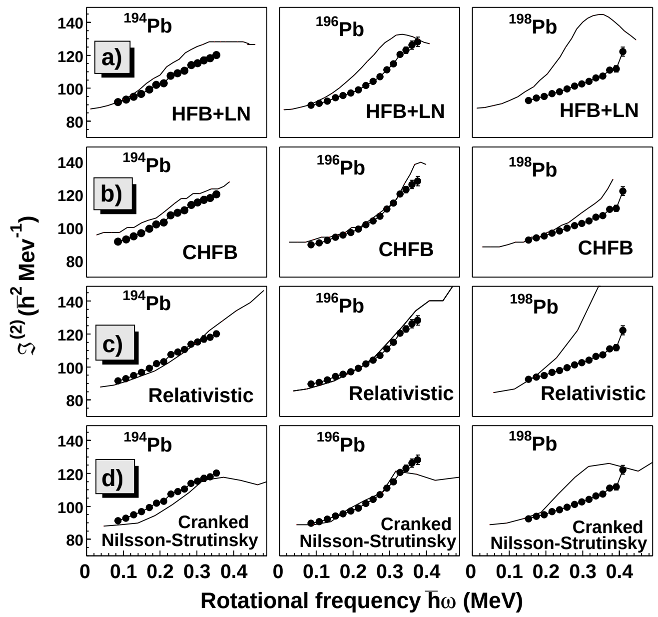

Fig. 7. Predicted and experimental $\Im^{(2)}$ for the yrast SD bands of ^{194}Pb, ^{196}Pb and ^{198}Pb isotopes. a) Hartree-Fock-Bogoliubov+Lipkin-Nogami calculations, from refs. [7,8]; b): cranked Hartree-Fock-Bogoliubov with Gogny force calculations, from ref. [33]; c) relativistic cranked HFB calculations, from ref. [34]; d) cranked Nilsson-Strutinsky+Lipkin-Nogami calculations using the Woods-Saxon potential, from ref. [35].

phenomenological residual interaction [29] have predicted that the $K^\pi = 2^-$ octupole vibrations are the lowest excitation modes at zero rotational frequency. The Generator Coordinate Method using a set of microscopic HF+BCS states has been applied to Pb SD nuclei to investigate beyond the mean-field octupole vibrations (Y_{30} and Y_{32} associated with $K^\pi = 0^-$ and 2^-, respectively, by Skalski *et al.* [30], Meyer *et al.* [31], and Dancer *et al.* [32]). It turns out that for ^{194}Hg, ^{196}Pb and ^{198}Pb the Y_{30} and Y_{32} octupole band heads are predicted quite degenerate in energy with 2qp excitations (within 400 keV). Concerning band 3a and band 3b, there is no strong evidence for a pure octupole vibrating nature. Even if the statistics is very low in the spectra, these two bands do not seem in coincidence with the yrast ^{197}Pb SD band which is the case for ^{190}Hg(2) [15] and ^{194}Hg(2) [17] interpreted as a $K = 2^-$ octupole band. However, we suggest that an octupole softness lowers the 3qp excitation in ^{197}Pb which would explain the experimental intensities of band 3a and band 3b.

We discuss now the ^{198}Pb case. Going from ^{194}Pb to ^{198}Pb, a puzzling phenomenon appears for the yrast SD band: if we compare the experimental and theoretical dynamic moments of inertia $\Im^{(2)}$, a considerable disagreement is seen at high frequencies in ^{198}Pb. The experimental $\Im^{(2)}$ remains flatter than all calculated curves at high frequencies as shown in fig. 7. The calculations give a progressive diminution of proton and neutron pairing correlations leading to a rise of the $\Im^{(2)}$ in contradiction with the experimental observation. As shown in fig. 7, this phenomenon exists with all recent microscopic cranked theories. The results of cranked HFB calculations using parameterizations of the Skyrme effective force SkM* with the approximate particle number LN projection for ^{194,196,198}Pb [7,8] are also shown in fig. 7a. In cranked HFB calculations (fig. 7b) using the finite-range Gogny force, the pairing correlations are not well taken into account at frequencies higher than 0.2 MeV (see [33]). However, the neutron pairing which is very small at $\hbar\omega = 0.3$ MeV in ^{194}Pb remains important in ^{198}Pb (around 5-7 MeV) at the same frequency but not sufficient to reproduce the data. Relativistic cranked HFB calculations [34] present the same disagreement, as we expected, because the word "relativistic" applies only to the Hartree particle-hole channel and the pairing part used is exactly that of the Gogny force (fig. 7c). Cranked Nilsson-Strutinsky-LN calculations using the Woods-Saxon potential have the same difficulty to reproduce the behaviour of $\Im^{(2)}$ at large frequencies in the Pb isotopes, and most particularly in ^{198}Pb (fig. 7d [10,35]). According to the experiment, the pairing energies seem stronger in ^{198}Pb than in ^{196}Pb and ^{194}Pb, which corroborates the fact that the pairing correlations are governed by a power of the $(N-Z)/A$ factor and increase with the neutron number N in an isotopic chain. The value of this factor varies from 0.155 in ^{194}Pb to 0.171 in ^{198}Pb. Another hypothesis proposed by Satula and Wyss [35] is that the simultaneous presence of high-j proton and high-j neutron alignments may generate a residual proton-neutron interaction which could play a role in the particle-hole channel.

Concerning the possible excited bands in ^{198}Pb, one may expect from what we have proposed in ^{197}Pb that the lowest 2qp neutron state is $\nu[512]5/2 \otimes \nu[624]9/2$. In the same way, the rather strong intensities (17%) of these bands could be enhanced by a possible coupling between the 2qp and the octupole excitation. Semmes *et al.* [36] have already suggested that an octupole softness, together with a spin-spin interaction, could lower the 2qp excitation $\nu[512]5/2 \otimes \nu[624]9/2$ in ^{194}Hg. We tentatively assign the last pair of the new bands (band 2a and band 2b) to that mixed configuration: octupole vibration coupled to the 2qp excitation $\nu[512]5/2 \otimes \nu[624]9/2$.

4 Conclusion

In summary, six new excited SD bands have been identified in ^{197,198}Pb nuclei, in an experiment with the EUROBALL IV array. The SD bands consist of three signature partners. Two pairs are assigned to the ^{197}Pb nucleus and one pair to the ^{198}Pb nucleus. In the framework of microscopic cranked Hartree-Fock-Bogoliubov calculations and by comparison with the neighbouring odd Pb isotopes, two of the new excited SD bands are intepreted as being built on the $\nu[512]5/2$ orbital in ^{197}Pb. However, the qp-excitation scheme can explain neither the two other excited SD bands in ^{197}Pb nor the two bands in ^{198}Pb which have a too large intensity relative to the yrast SD band. We suggest that the $\nu[512]5/2 \otimes \nu[624]9/2$ excitation might be lowered by a coupling with a residual octupole Y_{32} interaction. The experimental data underline also the importance of pairing in the Pb isotopes. All microscopic calculations have difficulties to reproduce the $\Im^{(2)}$ when dealing with the heaviest nuclei, ^{198}Pb being therefore a stringent test for further theoretical investigations.

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