### Collectivity in the light Xenon isotopes: A shell model study

E. Caurier, F. Nowacki, A. Poves, and K. Sieja 1

<sup>1</sup>IPHC, IN2P3-CNRS et Université Louis Pasteur, F-67037 Strasbourg, France <sup>2</sup>Departamento de Física Teórica e IFT-UAM/CSIC, Universidad Autónoma de Madrid, E-28049 Madrid, Spain (Dated: November 19, 2018)

The lightest Xenon isotopes are studied in the framework of the Interacting Shell Model (ISM). The valence space comprises all the orbits lying between the magic closures N=Z=50 and N=Z=82. The calculations produce collective deformed structures of triaxial nature that encompass nicely the known experimental data. Predictions are made for the (still unknown) N=Z nucleus  $^{108}$ Xe. The results are interpreted in terms of the competition between the quadrupole correlations enhanced by the pseudo-SU(3) structure of the positive parity orbits and the pairing correlations brought in by the  $0h_{11/2}$  orbit. We have studied as well the effect of the excitations from the  $^{100}$ Sn core on our predictions. We show that the backbending in this region is due to the alignment of two particles in the  $0h_{11/2}$  orbit. In the N=Z case, one neutron and one proton align to J=11 and T=0. In  $^{110,112}$ Xe the alignment begins in the J=10 T=1 channel and it is dominantly of neutron neutron type. Approaching the band termination the alignment of a neutron and a proton to J=11 and T=0 takes over. In a more academic mood, we have explored the role of the isovector and isoscalar pairing correlations on the structure on the yrast bands of  $^{108,110}$ Xe and examined the role of the isovector and isoscalar pairing condensates in these  $N\sim Z$  nuclei.

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#### I. INTRODUCTION

The lightest Xenon isotopes have been recently explored down to <sup>110</sup>Xe, only two neutrons away of the would-be N=Z nucleus <sup>108</sup>Xe. In a very demanding experiment carried out at the University of Jyväskylä, using the recoil-decay tagging technique [1], the excitation energies of the lowest members of the yrast band were measured. The experimental spectrum shows remarkable rotational-like features. The authors of this work argue that such a behavior is unexpected and invoke a large depletion of the doubly magic closure in <sup>100</sup>Sn to explain it. However, it is well known that nuclei with six neutrons and four protons on top of a N=Z doubly magic core develop collective features that can be explained microscopically without resorting to extensive core excitations. The same is true, and even more accentuated, for the nuclei with four neutrons and four protons outside the corresponding N=Z cores. Well documented cases are  $^{26}$ Mg and  $^{24}$ Mg in the sd-shell (core of  $^{16}$ O) and  $^{50}$ Cr and  $^{48}$ Cr in the pf-shell (core of  $^{40}$ Ca). In both cases the closures correspond to major shells of the harmonic oscillator. The next magic numbers are originated by the spin-orbit interaction, giving rise first to the <sup>56</sup>Ni core and to the nuclei <sup>66</sup>Ge and <sup>64</sup>Ge, that show also collective features, even if less prominent than in the other cases. Indeed, the next N=Z spin-orbit closure is <sup>100</sup>Sn, and the replicas of the lower mass isotopes are  $^{110}\mathrm{Xe}$  and  $^{108}{\rm Xe}.$ 

For  $^{26}$ Mg and  $^{24}$ Mg, Elliott's SU(3) [2] gives the explanation of the onset of collectivity. Both nuclei are well deformed and triaxial, due to the predominance of the quadrupole-quadrupole part of the effective nuclear interaction, either in the limit of degenerate sd-shell orbits

(SU(3) proper) or in the limit of very large spin-orbit splitting (quasi-SU3) [3]). <sup>48</sup>Cr and <sup>50</sup>Cr have became the paradigm of deformed nuclei amenable to a fully microscopic description in the laboratory frame via the interacting shell model (ISM) [4–6]. The underlying coupling scheme in this region is quasi-SU3.

As we shift to the spin-orbit driven shell closures, the situation varies again. For instance, the quasi-degenerate orbits above  $^{56}\mathrm{Ni}$ ,  $1\mathrm{p}_{3/2}$ ,  $0\mathrm{f}_{5/2}$ , and  $1\mathrm{p}_{1/2}$ , form a pseudo-SU3 sequence [7], with principal quantum number p=2. The physical valence space in this region includes also the  $0\mathrm{g}_{9/2}$  orbit, the down-going intruder of opposite parity, which couples to the pseudo-SU(3) block through the off-diagonal pairing matrix elements. Mutatis mutandis the same physics occurs in the region of very proton rich nuclei beyond  $^{100}\mathrm{Sn}$ .

The plan of the paper is as follows: In section II we describe the framework of the calculations; valence space, effective interaction, etc. We also deal with the group theoretical issues of the pseudo-SU(3) scheme, and advance some of its predictions. In section III we discuss the results for <sup>110,112</sup>Xe, comparing with the experimental results, and we make predictions for <sup>108</sup>Xe. Then we study the influence of the core excitations on the different observables and finally we analyze the mechanisms that produce the backbending of the yrast bands of both <sup>108</sup>Xe and <sup>110</sup>Xe. In section IV we examine in detail some, much debated, aspects of the physics of the N=Z nuclei. Among others, the role of the isovector and isoscalar L=0 pairing components of the interaction. In section V we gather our conclusions.

#### II. VALENCE SPACE. EFFECTIVE INTERACTION

The valence space is the one comprised between the magic closures N=Z=50 and N=Z=82. This means that we have an inert core of  $^{100}\mathrm{Sn}$ . The space contains two doubly magic nuclei  $^{132}\mathrm{Sn}$  and  $^{164}\mathrm{Pb}$ .

We use the effective interaction GCN50:82 which is obtained from a realistic G-matrix [8] based upon the Bonn-C potential [9]. Taking the G-matrix as the starting point, different combinations of two body matrix elements are fitted to a large set of experimental excitation energies in the region (about 400 data points from 80 nuclei). As can be seen in Table I the modifications of the monopole hamiltonian are, as usual, the ones that improve most the agreement with the data. Subsequent modifications of the pairing and multipole hamiltonians bring the root mean square deviation to a very satisfactory value of 110 keV [10].

TABLE I. Evolution of the rms deviation with the corrections brought to the realistic interaction

Corrections	m rms(MeV)
G (none)	1.350
+monopole	0.250
+pairing	0.180
+multipole	0.110

In this valence space the dimensions grow rapidly reaching  $O(10^{10})$  in some of the calculations presented here. In spite of this, one can have an idea of the kind of results that can be achieved in this model space in the limit of pure pseudo-SU3 symmetry. The Nilssonlike orbits of pseudo-SU3 corresponding to the principal quantum number p have intrinsic quadrupole moments given by [11],  $q(p,\chi,k)=(-2p-3\chi)b^2$ , where  $\chi$  can take integer values between 0 and  $p, k=\pm(\frac{1}{2}\dots\frac{1}{2}+\chi)$ and b is the harmonic oscillator length parameter. The total quadrupole moment is the sum of the contributions of all the valence protons and neutrons with the corresponding effective charges. The orbits are filled orderly, starting from  $\chi=0$  or  $\chi=p$  depending on which choice gives the largest total intrinsic quadrupole moment in absolute value. This is so because in this scheme the correlation energy is proportional to  $Q_0^2$ .

The four valence protons of the Xenons can adopt several degenerate configurations;

$$\begin{split} &(\chi=0,k=\pm\tfrac{1}{2})^2(\chi=1,k=\pm\tfrac{1}{2})^2;\\ &(\chi=0,k=\pm\tfrac{1}{2})^2(\chi=1,k=\pm\tfrac{3}{2})^2 \text{ and }\\ &(\chi=0,k=\pm\tfrac{1}{2})^2(\chi=1,k=\pm\tfrac{1}{2})\\ &(\chi=1,k=\pm\tfrac{3}{2}), \end{split}$$

leading to K=0 and K=2. Even a small K-mixing produces triaxiality and we should expect it to show up in the experiments and in the realistic calculations.

TABLE II. B(E2)(0<sup>+</sup> $\rightarrow$  2<sup>+</sup>) for the Xenon isotopes (in e<sup>2</sup>b<sup>2</sup>)

	. ,				
A=	114	116	118	120	122
SU3	1.05	1.27	1.52	1.60	1.62
EXP	0.93(6)	1.21(6)	1.40(7)	1.73(11)	1.40(6)

Moving to the neutron side, the model predicts that triaxiality should be larger in <sup>108</sup>Xe than in <sup>110</sup>Xe because of the neutron contribution. In addition, it turns out that for p=3 the contribution to the intrinsic quadrupole moments of the valence neutrons in excess of six is zero. The predicted values for the light Xenon isotopes are:  $Q_0(^{108}\text{Xe}) = 210 \text{ e fm}^2 \text{ and } Q_0(^{110-116}\text{Xe}) = 225 \text{ e fm}^2.$  This corresponds to  $B(E2)(2^+{\to}0^+)$  of 870  $e^2$  fm<sup>4</sup> and 1000 e<sup>2</sup> fm<sup>4</sup> respectively. Therefore, the increase of collectivity that is seen experimentally toward mid-shell, reaching a maximum in 120Xe with 16 valence neutrons cannot be explained in this scheme. To get more quadrupole collectivity we need to enlarge the valence space, and the more conservative choice is to include the 1f<sub>7/2</sub> neutron orbit, which is the quasi-SU3 partner of the  $0h_{11/2}$ . Assuming that the valence neutrons in excess of six occupy the lowest quasi-SU3 intrinsic orbits corresponding to p=5, the quadrupole moments will keep increasing up to <sup>120</sup>Xe as demanded by the experimental data.

We compare in Table II the predictions of this simple model with the experimental results. The agreement is astonishingly good. We have made exploratory calculations for  $^{112}\mathrm{Xe}$  finding an increase of the B(E2) from 1130  $\mathrm{e^2~fm^4}$  in the pseudo-SU3 valence space to 1460  $\mathrm{e^2~fm^4}$  in the space corresponding to the proposed pseudo+quasi-SU3 scenario.

# III. SPECTROSCOPY OF THE LIGHT XENON ISOTOPES

Let's start with the results for <sup>110</sup>Xe. The calculated energy levels are shown in Fig. 1 in comparison with the experimental results from [1]. The agreement is quite satisfactory even if the theoretical calculation predict a moment of inertia slightly larger than the experimental one. We have checked that it is possible to obtain perfect agreement for the excitation energies, without changing the quadrupole properties of the band, just increasing  $\sim 20\%$  the isovector pairing channel of the effective interaction. Nevertheless this residual discrepancy does not justify to make modifications in the effective interaction GCN50:82 which was designed to give good spectroscopy in the full r4h valence space. Notice that the rotational features of the shell model calculation persist till the backbending that occurs at J=14. In addition, the calculation produces a  $\gamma$  band which will be analyzed below.

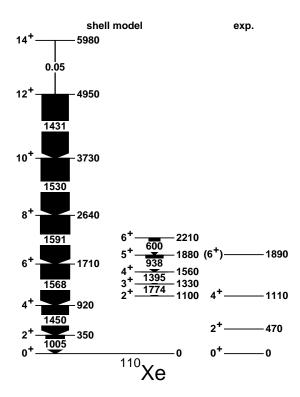


FIG. 1. (color online) The energy levels of <sup>110</sup>Xe.

TABLE III. Properties of the yrast band of  $^{110}\rm{Xe}$  (energies in MeV, Q's in  $\rm{efm^2}$  and BE2's in  $\rm{e^2fm^4})$ 

J	E*	$\mathrm{E}_{\gamma}$	BE2	$Q_{sp}$	$Q_0$ (BE2)	$Q_0 \\ (Q_{sp})$	β
$2^+$	0.35	0.35	1005	-62	225	217	0.17
$4^{+}$	0.92	0.57	1450	-78	226	215	0.17
$6^{+}$	1.71	0.79	1568	-83	224	208	0.17
8+	2.64	0.94	1591	-87	220	207	0.17
$10^{+}$	3.73	1.09	1530	-86	213	198	0.17
$12^{+}$	4.95	1.22	1431	-85	204	191	0.16
$14^{+}$	5.98	0.99	0.05	-126			
$16^{+}$	6.63	0.69	111	-125			
$18^{+}$	7.51	0.88	1184	-130			
20+	8.51	1.00	1043	-134			

In Table III we collect the quadrupole properties of the yrast band. They are compatible with a deformed intrinsic state with constant intrinsic quadrupole moment  $Q_0=200~\rm efm^2$ , corresponding to  $\beta=0.16$ , not far from the expectations of the pseudo-SU3 model. Beyond J=12 the alignment regime takes over, as we shall analyze in detail in the next sections, and the rotation is no longer collective.

We can now turn back to the  $\gamma$  band. Besides the characteristic sequence of energy levels shown in Fig. 1

TABLE IV. Properties of the  $\gamma$  band of  $^{110}$ Xe (energies in MeV, Q's in efm² and BE2's in e²fm²)

J	E*	$\mathrm{E}_{\gamma}$	BE2	$Q_{sp}$	$Q_0(BE2)$	$Q_0(Q_{sp})$	β
$2_{2}^{+}$	1.10			+61		214	0.17
$3^+$	1.33	0.23	1774	-1.3			
$4_{2}^{+}$	1.56	0.23	1395	-38	219	261	0.18
$5^+$	1.88	0.32	938	-54	217	234	0.17
$6_{2}^{+}$	2.21	0.33	600	-74	209	259	0.18

the quadrupole properties of the band, gathered in Table IV, strongly suggest that the  $\gamma$  band of  $^{110}\mathrm{Xe}$  has K=2. In the first place, the intrinsic quadrupole moment, extracted from the spectroscopic quadrupole moments or from the B(E2)'s, assuming K=2, is fairly constant and very close to that of the yrast band. The more so if we realize that Q(2 $_{\gamma}^{+}$ )=-Q(2 $_{y}^{+}$ ) and Q(3 $_{\gamma}^{+}$ ) $\approx$ 0 as it should be the case if the  $\gamma$  band could be labeled by K=2.

The question now is whether  $^{110}$ Xe it is a triaxial nucleus or not. For that, a certain amount of K-mixing is required. In fact, in the limit of pure pseudo-SU3 symmetry the mixing is zero and this would not be the case. In some models [12], the amount of triaxiality,  $\gamma$  is derived from the ratio:

$$\frac{BE2(2_{\gamma}^{+} \to 2_{y}^{+})}{BE2(2_{\gamma}^{+} \to 0_{y}^{+})} \tag{1}$$

In our case this corresponds to a value  $\gamma=20^o$ . As we have already mentioned, the valence space r4h contains a pseudo-SU3 triplet plus the intruder orbit  $0h_{11/2}$ . When we remove the intruder orbit from the space, the moment of inertia of the nucleus gets reduced by 30%, the backbending is suppressed, the triaxiality is reduced to  $\gamma=12^o$ ; and the magnetic moments become fully consistent with the rotational model up to J=20. The changes in the E2 transition probabilities and quadrupole moments below the backbending region are negligible.

$$\mathbf{B}$$
.  $^{112}\mathbf{X}\mathbf{e}$ 

The shell model description of this isotope is a real challenge because the dimension of the basis in the full space calculation (number of M=0 Slater determinants) is  $\sim 10^{10}$  (exactly 9324751339). The results are gathered in Table V and compared with the available experimental data [13]. For the lowest part of the yrast band they resemble very much to those of and the agreement with the experimental excitation energies is even better. Nevertheless, when entering in the backbending region, which is predicted by the calculation at the right spin, J=10, the accord deteriorates somehow. As we have discussed

in the previous sections this can be a manifestation of the limitations of our valence for the description of the heavier Xenon isotopes. The backbending corresponds to the alignment of two neutrons in the  $0h_{11/2}$  orbit as in the lighter isotope  $^{110}$ Xe. This change of structure is clearly seen in the drastic reduction of the B(E2) of the  $10^+ \rightarrow 8^+$  transition, which is simultaneous with an increase of the spectroscopic quadrupole moment of the  $10^+$  state.

TABLE V. Properties of the yrast band of  $^{112}$ Xe (energies in MeV, Q's in efm<sup>2</sup> and BE2's in  $^{2}$ fm<sup>4</sup>)

J	E*	$\mathbf{E}_{exp}$	BE2	$Q_{sp}$	$Q_0$ (BE2)	$Q_0 \\ (Q_{sp})$	β
2 <sup>+</sup> 4 <sup>+</sup> 6 <sup>+</sup> 8 <sup>+</sup> 10 <sup>+</sup> 12 <sup>+</sup>	0.38 1.00 1.82 2.79 3.72 4.20	0.46 1.12 1.91 2.78 3.55 4.47	1063 1560 1727 1783 600 1471	-62 -75 -76 -74 -97	217 206 190 176	231 236 236 232	0.17 0.17 0.17 0.17

$$\mathbf{C}$$
.  $^{108}\mathbf{X}\mathbf{e}$ 

The N=Z isotope of Xenon has not been experimentally studied yet. The ISM predictions for the yeast band are collected in Table VI. The results at low spin resemble very much to the ones obtained for the heavier isotopes, even if the the quadrupole collectivity is slightly smaller. The backbending occurs at J=16 and it is preceded by an upbending at J=14 while in <sup>110</sup>Xe the backbending occurs sharply at J=14. We shall dwell with this issue in the next section. As predicted by the pseudo-SU3 model,  $^{108}$ Xe exhibits also a  $\gamma$  band whose properties are listed in Table VII. Notice that, in spite of some small irregularities, both the yrast and the  $\gamma$  band share a common intrinsic state whose quadrupole moment is very close to the pseudo-SU3 number. Using equation (1) we can deduce a value  $\gamma=24^{\circ}$ , indicating the triaxial nature of this nucleus. This value of  $\gamma$  is larger than the one obtained for <sup>110</sup>Xe, again in good accord with the model predictions.

#### D. The effect of the excitations of the <sup>100</sup>Sn core

At the very origin of this paper was the question about the stiffness of the <sup>100</sup>Sn core and the eventual need of a soft core in order to understand the collective aspects found in the very proton rich Xenon isotopes. We have argued "in extenso" that collectivity can be obtained without any opening of the doubly magic <sup>100</sup>Sn core. However, it doesn't exist in nature such a thing as a perfectly closed core. The dimensions of the basis make

TABLE VI. Properties of the yrast band of  $^{108}$ Xe (energies in MeV, Q's in efm<sup>2</sup> and BE2's in e<sup>2</sup>fm<sup>4</sup>)

J	E*	$\mathrm{E}_{\gamma}$	BE2	$Q_{sp}$	$Q_0$ (BE2)	$Q_0 \\ (Q_{sp})$	β
$2^+$	0.41	0.41	888	-57	200	211	0.16
$4^+$	1.03	0.62	1285	-71	195	210	0.16
$6^+$	1.89	0.86	1345	-65	163	208	0.16
8+	2.90	1.01	1404	-64	154	206	0.16
$10^{+}$	4.03	1.13	1334	-67	160	198	0.15
$12^{+}$	5.37	1.34	1129	-71	175	182	0.15
$14^{+}$	6.69	1.32	990	-79	176	168	0.14
$16^{+}$	7.75	1.07	0.1	-137			
$18^{+}$	8.34	0.58	830	-140			
$20^{+}$	9.24	0.90	753	-143			

TABLE VII. Properties of the  $\gamma$  band of  $^{108}$ Xe (energies in MeV, Q's in efm<sup>2</sup> and BE2's in e<sup>2</sup>fm<sup>2</sup>)

J	E*	$\mathrm{E}_{\gamma}$	BE2	$Q_{sp}$	$Q_0(Q_{sp})$	β
2+	1.03			+59	196	0.16
$2_{2}^{+}$ $3^{+}$	1.28	0.25	1624	-1.3		
$4_{2}^{+}$ $5^{+}$	1.51	0.24	1090	-38	265	0.18
$5^+$	1.84	0.32	882	-51	220	0.17
$6_{2}^{+}$	2.25	0.42	372	-83	290	0.19

it impossible to perform calculations adding the  $0g_{9/2}$  orbit to the r4h valence space. Thus we have proceeded as follows: In the first place we have repeated the calculations in the r4 space -i.e. removing the  $0h_{11/2}$  orbit– The quadrupole properties of the low lying states—the ones we are after- remain unchanged in all cases. For the lower part of the yeast band, the effect of this removal is just an increase of the moments of inertia by a factor two. Correspondingly, the spectra are much more compressed. In the next set of calculations we allow 1p-1h and 2p-2h excitations from the  $0g_{9/2}$  orbit into the r4 space. Even in this case the dimensions are huge (5 x  $10^9$  for the 2p-2h calculation in <sup>110</sup>Xe), and in fact the 2p-2h calculation for <sup>112</sup>Xe is out of reach. In these calculations <sup>100</sup>Sn is still a very good doubly closed shell. At the 1p-1h level only 0.25 particles (out of 20) are promoted to the r4 orbits. At the 2p-2h level 0.5 particles are promoted. In spite of the small size of the vacancy, its effect in the E2 properties is not negligible at all. The 1p-1h excitations are the ones that are more efficient in the building up of the quadrupole collectivity, leading to increases of the intrinsic quadrupole moments of 15%, 17% and 20% for <sup>108</sup>Xe, <sup>110</sup>Xe and <sup>112</sup>Xe, respectively. Adding the 2p-2h excitations does not change these numbers a lot, they rise

to 19% and 21% for  $^{108}$ Xe and  $^{110}$ Xe. Notice that these percentages have to be doubled to get the effect on the transition probabilities.

#### E. Backbending and alignment

We have represented the energies of the E2  $\gamma$  cascade along the yrast bands of  $^{108}$ Xe and  $^{110}$ Xe in the form of a backbending plot in Fig. 2. We can observe a very similar (collective) behavior up to the backbending that occurs at J=14 in both cases. The differences are related to the alignment mechanisms that produce it, whose nature we will explore now. In order to do so we have constructed operators that count the number of  $0h_{11/2}$  pairs coupled to J=11 T=0 and to J=10 T=1. In the first case, the particles that align must be one neutron and one proton, while in the second mode they can be two neutrons or two protons as well. Let's start with  $^{108}$ Xe. The number of J=11 T=0 neutron proton pairs

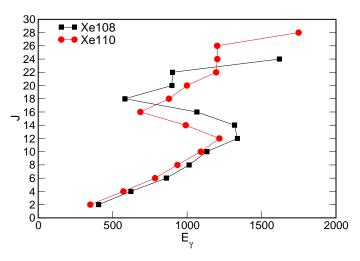


FIG. 2. (color online) Backbending plot of the theoretical yrast bands of  $^{108}{\rm Xe}$  and  $^{110}{\rm Xe}$ 

along the yrast band is shown in Fig. 3. We observe a sudden transition from zero aligned pairs up to J=14, to nearly one fully aligned pair at J=16. From there, up to the band termination, the number of aligned pairs approaches slowly one. This reflects in the backbending in a subtle way. As we can see the real backbending in this case is preceded by an upbending which does not involve alignment but is probably due to the mixing associated to the band crossing. In the same figure we have plotted the yrast band of the configuration that has two particles blocked in the  $0h_{11/2}$  orbit. Here the alignment is much smoother. Notice that only when this configuration is fully aligned it becomes the physical yrast band. This is better seen in Fig. 4 which is alike to a cartoon of the band crossing. At low spin the yrast band is dominated by the  $(r4)^8$  configurations, with the  $(r4)^6(h_{11/2})^2$  ones lying at about 4 MeV. The crossing happens at J=16 pro-

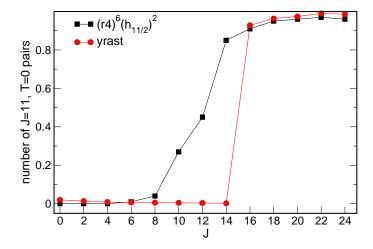


FIG. 3. (color online) The number of J=11 T=0 pairs in the yrast band of  $^{108}$ Xe. The same for the yrast states of the configuration  $(r4)^6(h_{11/2})^2$ 

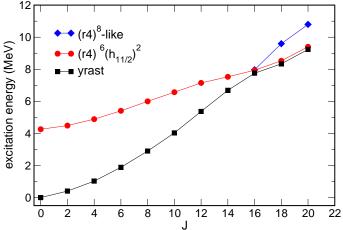


FIG. 4. (color online) The yrast band of  $^{108}$ Xe. Also plotted the yrast states of the configuration  $(r4)^6(h_{11/2})^2$  (circles) and the lowest  $(r4)^8$ -like states beyond J=16 (lozenges) to illustrate the origin of the backbending

ducing local distortions in the backbending plot. We have been able to locate the states belonging to the (r4)<sup>8</sup> yrast band beyond the crossing point. Once the crossing has taken place, the backbending disappears. The situation is quite different in the case of the N $\neq$ Z nucleus <sup>110</sup>Xe as can be gathered from Fig. 5. Here the backbending occurs abruptly at J=14 and corresponds to the alignment of (mostly) two neutrons to J=10 T=1. Beyond J=16 the yrast line becomes parallel to the low energy one, as if the angular momentum put in the system were again of collective nature. At J=22 the isovector alignment is depressed and the isoscalar one takes over till the band termination producing new irregularities in the backbending plot.

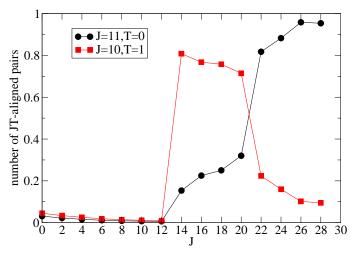


FIG. 5. (color online) The number of J=10 T=1 and J=11 T=0 pairs in the yrast band of  $^{110}$ Xe

## IV. THE ROLE OF THE ISOSCALAR AND ISOVECTOR PAIRING

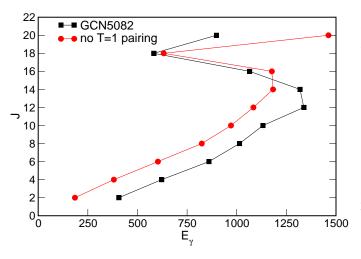


FIG. 6. (color online) Backbending plot of the yrast band of  $^{108}$ Xe. Results with the GCN5082 interaction before (squares) and after (circles) removing the isovector J=0 pairing

Quite some time ago, the question of the pairing modes near N=Z knew an uprise of interest as more and more experimental data accumulated on this class of nuclei. Among the topics of interest were the Wigner energy and the possibility of finding manifestations of an isoscalar pairing condensate (deuteron like) in the yrast bands of these proton rich nuclei in the form of delayed alignments etc. [14, 15]. It was realized relatively soon that these effect were bound to be elusive, because, in normal circumstances, the spin orbit splitting hinders strongly the deuteron-like condensation [16]. Recent studies of the beta-decay of <sup>62</sup>Ge, where super-allowed beta-transitions

due to the existence of the T=0 collective 1<sup>+</sup> state were predicted [17], have ruled out such a possibility as well.

On the contrary, the effect of the isovector pairing channel in the rotational properties of the N~Z is well understood. It is directly linked to the moment of inertia of the band, and does not affect appreciably its electromagnetic decay properties. We have verified that for the light Xenon isotopes. In Fig. 6 we compare the energies of the  $\gamma$  cascades along the yrast band for  $^{108}\rm{Xe}$  using the effective interaction GCN5082 on one side and, on the other, this same interaction after removal of an schematic isovector pairing hamiltonian whose coupling strength is obtained as in ref. [18]. Below the backbending the effect is just an increase of the moment of inertia by a factor two. As expected, the E2 properties do not change. The backbending is delayed two units of angular momentum.

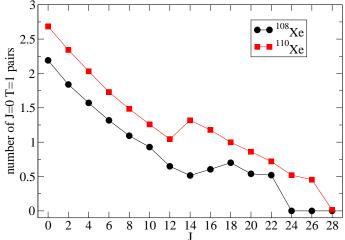


FIG. 7. (color online) The number of J=0 T=1 pairs in the yrast bands of  $^{108}\rm{Xe}$  and  $^{110}\rm{Xe}.$ 

To verify the possibility of existence of pair condensates in the ground states of Xenon isotopes we have also constructed pair counting operators, and have computed their expectation values along their yrast bands. The results for the isovector pairs are plotted in Fig. 7. A fully condensed state should have nearly four pairs for <sup>108</sup>Xe and five pairs in <sup>110</sup>Xe. What we find for the ground states, which is consistent in both cases, amounts to one half of the value expected for the condensate, indeed a quite important pairing contribution. As the angular momentum increases, the pair content decreases linearly reaching negligible values at the backbending. The pattern in this region is simpler in  $^{108}\mathrm{Xe}$  than  $^{108}\mathrm{Xe}$ , due to the different alignment mechanisms in both isotopes which we have discussed already. The results for the isocalar pairs are plotted in Fig. 8. In the limit of an isovector condensate we should expect typically four pairs, and we can see that we are far from that. In addition, the

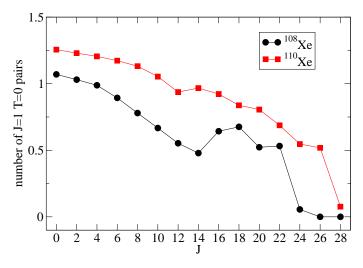


FIG. 8. (color online) The number of J=1 T=0 pairs in the yrast bands of  $^{108}\rm{Xe}$  and  $^{110}\rm{Xe}.$ 

"a priori" more favorable case, N=Z, is depressed with respect to the  $N\neq Z$ . All in all there seems to be no indications of any structural effect due to the isoscalar pairing channel.

#### V. CONCLUSIONS

We have carried out large scale shell model calculations for the lighter Xenon isotopes in the valence space r4h that encompasses all the orbits between the magic numbers 50 and 82. We obtain collective behaviors of triaxial nature and can explain the experimental results withouts resorting to large openings of the  $^{100}\mathrm{Sn}$  core. We propose a mechanism that can explain the very large values of the intrinsic quadrupole moments of the Xenon isotopes at mid neutron shell based in variants of the SU3 symmetry. We have shown that the backbending in <sup>108</sup>Xe is produced by the alignment of a neutron proton pair in the  $0h_{11/2}$  orbit to the maximum allowed spin J=11. In <sup>110</sup>Xe it is a two step process, first a pair of neutrons align to J=10 and afterwords the neutron proton alignment takes over. Finally we have studied the pair content of the yrast states. Isovector J=0 pairs have a large presence in the lowest states of the yeast bands of  $^{108}$ Xe and  $^{110}$ Xe. On the contrary, the deuteron like J=1 isoscalar pairs have a negligible presence in these nuclei.

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