THE OBSERVATION OF SUPERDEFORMED STRUCTURE IN MASS 80 NUCLEI*

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The reaction of ^{30}Si on ^{58}Ni at 134 MeV was used to populate ^{82}Sr and ^{82}Y. The experiment was performed at the C.R.N Laboratory in Strasbourg where the EUROGAM Phase 2 array was used to detect coincident γ rays. Three high spin rotational cascades have been observed, two signature partner bands in ^{82}Sr and one band in ^{82}Y. All three bands exhibit characteristic superdeformed behaviour. The bands have been interpreted as superdeformed bands built upon the [431]1/2 orbital with a $\pi 5^1 \nu 5^2$ intrinsic intruder configuration.

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It is almost a decade now since the first observation of a high spin discrete line SD band in ^{152}Dy [1]. As detector technology has developed and

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large multi detector γ ray arrays have become more sensitive, the observations of superdeformed (SD) states in nuclei in the mass 150 region and the mass 190 region has become more common. Numerous examples of SD bands have now been reported [2] confirming theoretical predictions of islands of superdeformation in these mass regions [3]. The mass 80 region is also predicted as a region of SD [4, 5, 6, 7]. Many groups have studied mass 80 nuclei, however, it was not untill recently with the latest generation of high efficiency arrays, such as Eurogam and Gammasphere, that SD states in mass 80 nuclei could be observed. The first such sighting was reported by Baktash *et al.* [8]; since then a number of SD bands have been observed in mass 80 nuclei including isotopes of strontium [8, 9, 10], yttrium [11] and zirconium [12], establishing mass 80 as the newest region of superdeformation. The low single particle level density in mass 80 nuclei means that small changes in particle number, excitation energy and configuration can have dramatic effect on the deformation. Indeed the mass 80 region is well known as a region of shape coexistence [13, 14]. The $N = 44$ shell gap at a 2:1 axis ratio ($\beta_2 \approx 0.6$) and the $Z = 38$ shell gap at $\beta_2 \approx 0.4$ indicate that ^{82}Sr is an ideal candidate in which to observe superdeformation. In this work we present experimental evidence for two SD signature partner bands in ^{82}Sr and one SD band in ^{82}Y.

The experiment was performed over 14 shifts of 8 hours at the C.R.N Laboratory in Strasbourg where the $^{30}Si^{9+}$ beam was provided by the Vivitron. Two stacked self supporting foils of ^{58}Ni, each 500μg/cm^2 were bombarded with a 134 Mev ^{30}Si beam. The beam current was 1pnA. A number of different channels were populated, ranging from the ^{84}Zr(α) channel down to the ^{76}Kr(3 α) channel. The most strongly populated channel was the ^{82}Sr (α 2p) channel. The EUROGAM phase 2 array was used to detect coincident γ rays depopulating the high spin states produced by the reactions mentioned above. Consisting of 126 individual Ge detector elements this is at present the largest array of its kind. The array has 30 large coaxial Ge detectors and 24 clover detectors each comprising 4 Ge elements. All 54 individual detectors have BGO shields for the purpose of escape suppression. Events in which 6 or more detectors fired were accepted, and subsequent suppression by the BGO shields reduced the average fold to 3.5. A total of 9×10^8 suppressed events with at least two gamma rays detected were recorded.

The event by event data were written to magnetic tape and subsequently sorted into a compressed format containing only the (gain matched) energy information from each event. The compressed data tapes were then sorted into a number of 2 and 3 dimensional matrices.

Three discrete line high spin rotational cascades have been observed. The first two of these bands figures 1(a) and 1(b) are assigned to ^{82}Sr.

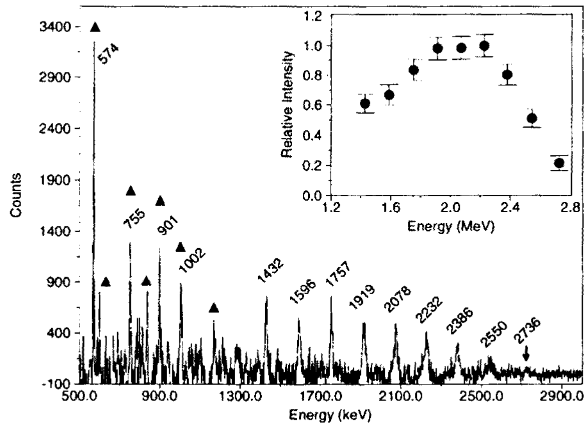

Fig. 1(a). Spectrum produced by double gating on the members of SD band 1. Transitions that are known to belong to ^{82}Sr are indicated by filled triangles. The inset shows the relative intensities of the members of the band. (b1) Spectrum produced by double gating, the first gate is on low-lying members of the ground-state band in ^{82}Sr, the second gate is on the members of SD band 2. Transitions that are known to belong to ^{82}Sr are indicated by filled triangles. The inset shows the relative intensities of the members of the band. (b2) Spectrum produced by double gating on the members of SD band 2. (c) Double gated spectrum with the first gate on low-lying members of the ground-state band in ^{82}Y and the second gate on members of SD band 3 showing the band in coincidence with low lying transitions in ^{82}Y(*). Peaks labled with (C) are contaminants, probably due to coincidences with background under the SD gated transitions. The inset shows the relative gamma-ray intensity of the band members, corrected for contaminants from ^{82}Y yrast lines at the same energies (•) and uncorrected (◇).

With the third band figure 1(c) belonging to ^{82}Y. The band assignments to their respective nuclei are based on coincidence relationships with low lying yrast transitions. The intensity of these bands relative to the respective channel intensity is of the order of 1-1.5%, which is typical for SD bands. The insets in figures 1(a), 1(b) and 1(c) show the relative intensity profile of these bands which is again typical for SD bands observed in the heavier mass regions. The bands feed in over 3 or 4 transitions, then a plateau region exists over which no feeding in or out occurs and finally the bands depopulate rapidly over a couple of transitions. Bands 1 and 2 are observed to feed several of the strong normally deformed bands in ^{82}Sr [14], including the collective oblate and the prolate sequences up to spin around $16\hbar$.

The dynamic moment of inertia of these bands is almost constant at $\sim 25\hbar^2 MeV^{-1}$ over the whole frequency range. This is comparable with the rigid body value with a deformation of approximatly 0.55.

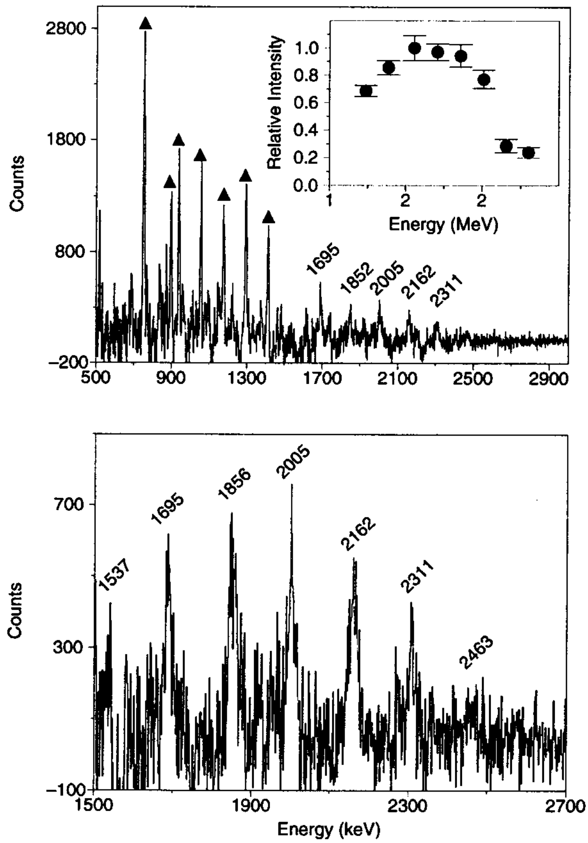

Fig. 1(b).

In depth theoretical calculations have been performed for the SD band structures in ^{82}Sr, using the cranking approximation and the Strutinsky method that incorporates the Woods–Saxon potential for the microscopic part and the Yukawa-plus-exponential mass formula for the macroscopic part of the total energy. For a given configuration, the equilibrium deformation at a fixed value of angular momentum was determined by minimizing the total energy at each (β_2, γ) grid point with respect to the hexadecapole deformation β_4. Pairing correlations were neglected, since they are expected to play a minor role in high-spin SD bands in the mass-80 region [4, 7].

The calculated high-spin properties of ^{82}Sr are displayed in Fig. 2. The superdeformed states become yrast at approximately $38\hbar$. All the SD bands displayed in Fig. 2 correspond to a single optimal neutron configuration governed by the presence of the SD shell gap at particle number=44. This configuration contains two aligned N=5 (N being the principal quantum

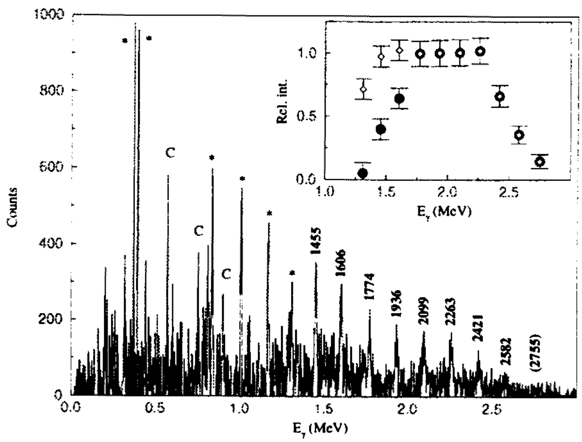

Fig. 1(c).

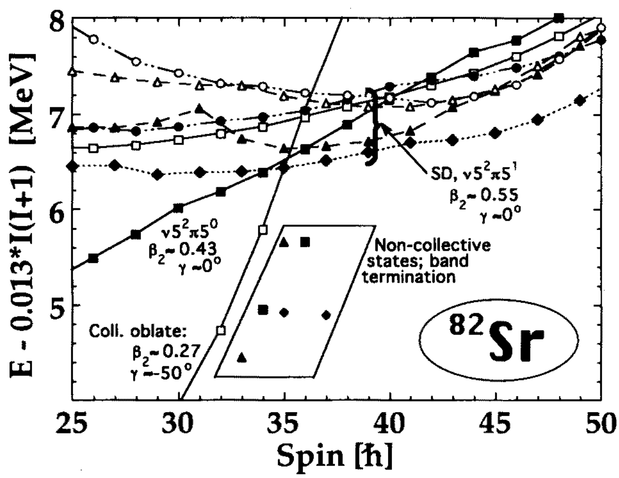

Fig. 2. The calculated behaviour of the lowest energy SD structures in ^{82}Sr for spin $25 \leq I \leq 50$. The energies E_I are displayed relative to an average reference of 0.013 I(I+1) MeV. The yrast structures appearing at normal deformations a re also indicated (there are many excited bands predicted in the calculations which are not displayed). The collective bands are indicated by lines while the predicted non-collective states ($\gamma = 60°$) are indicated by dots.

number) intruder ne utrons. The proton configuration of the lowest SD band contains one $N = 5$ and one [431]1/2 proton. The excited bands are built on various particle-hole proton excitations with respect to this yrast configuration.

Cranked shell model calculations using a Woods–Saxon potential with a quadrupole deformation $\beta_2 \approx 0.55$ (β_4 and $\gamma = 0$) indicate that in the frequency range $\hbar\omega \approx$ 1.1-1.3 MeV where the bands are fed, a SD shell gap occurs at $Z = 39$ with a neutron SD shell gap existing at $N = 44$, (see Fig. 3).

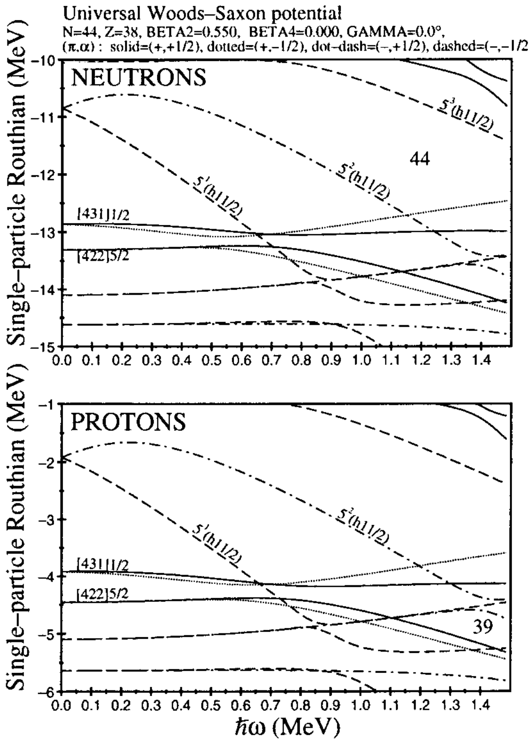

Fig. 3. Calculated proton and neutron Woods–Saxon single particle routhians for deformation parameter β_2= 0.55, β_4= 0.00, γ= 0.0°. The parity and signature (π, α) of the orbitals is given by solid line (+,+1/2), dotted line (+,-1/2), dot-dash line (-,+1/2), dashed line (-,-1/2).

The high-N intruder configuration for the SD band observed in ^{83}Sr [8] has been assigned as $\pi(N = 5)^1\nu(N = 5)^3$. With the 45th neutron in $[541]3/2_{\alpha=-1/2}$ orbital, which is the lowest single particle state above the $N = 44$ shell gap.

The sensitivity of the $\mathcal{J}^{(2)}$ dynamic moment of inertia to the number of high-N intruder orbitals occupied in SD nuclei is well established in the mass 150 region [12]. The general features of the ^{82}Y SD $\mathcal{J}^{(2)}$ are similar to those of the yrast SD $\mathcal{J}^{(2)}$ in ^{82}Sr, see Fig. 4. Therefore, it is suggested that the same high-N intruder orbitals are occupied in both cases. The $\mathcal{J}^{(2)}$ for the ^{83}Sr SD band is approximately 4% higher than the $\mathcal{J}^{(2)}$ for the ^{82}Sr SD band, this is due to the 45th neutron which occupies the third N=5 intruder orbital the $[541]3/2_{\alpha=-1/2}$.

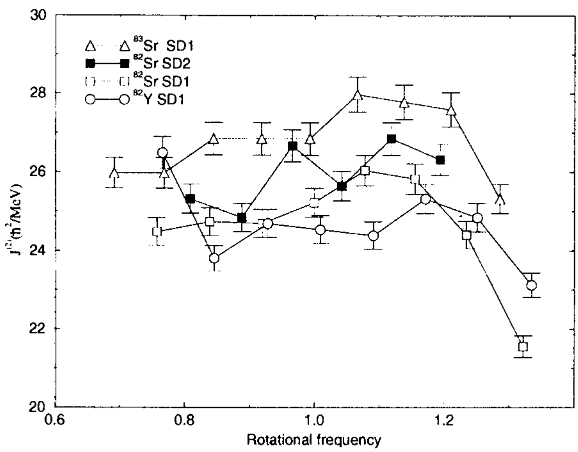

Fig. 4. Dynamic moments of inertia $\mathcal{J}^2$ plotted as a function of rotational frequency for SD bands in ^{82}Sr, ^{83}Sr and ^{82}Y.

The available proton orbitals near the Fermi level are the [431]1/2 signature partners. The yrast proton configuration for the strontium isotopes has the last proton occupying the negative signature component of the [431]1/2 orbital. Clearly the first excited proton configuration is built on the positive signature component of the [431]1/2 orbital.

The proposed configuration for the ^{82}Y band is based on this ^{82}Sr SD core configuration. Relative to ^{82}Sr there is a hole in the [422]5/2 (signature -1/2) neutron orbital, and, one extra proton occupies the vacant [431]1/2 orbital. The single particle routhians presented in figure 3 indicate that at the frequency over which the band is fed, this is the yrast configuration. Also at a frequency of approximately 0.8 MeV the [431]1/2 neutron orbital interacts with and crosses the [422]5/2 orbital. This band crossing could explain the observed increase in the ^{82}Y SD $\mathcal{J}^{(2)}$ at this frequency. In the case of the st rontium SD bands the [422]5/2 and the [431]1/2 neutron orbitals are occupied and this crossing is blocked.

An interesting observation which deserves comment is that the $\mathcal{J}^{(2)}$ moment of inertia of all the observed strontium and yttrium bands decreases at frequencies above 1.2 MeV. This behaviour is not reminiscent of a band crossing, which would usually result in an increase in $\mathcal{J}^{(2)}$ before any subsequent decrease. Besides there is no obvious band crossing common to these bands that could be responsible for this behaviou r.

The observed mass 80 SD $\mathcal{J}^{(2)}$ behaviour is not reproduced by cranked Woods-Saxon shell model calculations. The curvature of the occupied orbitals at frequencies above 1.2 MeV, if anything suggest an increase in $\mathcal{J}^{(2)}$. Furthermore total routhian surface (TRS) calculations seem to suggest a decrease in γ and an increase in β_2 with increasing frequency for SD nuclei in the mass 80 region. Such a trend would again contradict the obseved $\mathcal{J}^{(2)}$ beh aviour.

To summarise three highly deformed rotational bands have been observed, two signature partner bands in ^{82}Sr and one band in ^{82}Y. The bands are all low intensity; they have the characteristic SD intensity profile, and large, almost constant $\mathcal{J}^{(2)}$ moments of inertia, roughly double that of the normal deformed bands at high frequency. In addition the bands are all observed to high spins. A possible SD band crossing has been observed in ^{82}Y. The bands observed in ^{82}Sr and ^{82}Y have been interpreted as SD bands built on the $\pi(N=5)^1\nu(N=5)^2$ high-N intruder configurations.

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