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Short Note

Results from GAMMASPHERE in the $A \approx 80$ Mass Region

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Abstract. We present recent results obtained with GAMMASPHERE for nuclei in the $A \approx 80$ mass region. These studies have concentrated on a systematic study of superdeformed bands and their transitional quadrupole moments. Normally-deformed rotational bands in a series of even-even $T_z = 1$ nuclei were also investigated to probe the possible influence of the *np* pairing on the structure of their yrast bands.

The mass region $A \approx 80$ is known to provide a rich variety of nuclear structures. The low density of single-particle energy levels may lead to rapid changes in nuclear shape, depending on the occupation of particular orbitals near the Fermi surface. Among others, an island of high-spin superdeformed (SD) shapes with deformations of $\beta_2 \approx 0.55$ has long been predicted to exist in this mass region. However, mainly due to experimental difficulties, these predicted SD shapes had not been observed until recently. Using the EUROGAM I array, one of the new generation of γ-ray detector systems, Baktash *et al.* [1] reported the first observation of a discrete SD band, which was tentatively assigned to ^{83}Sr. Later, this assignment was confirmed [2] in an experiment using the GAMMASPHERE in conjunction with the charged-particle detector MICROBALL. Jin *et al.* [3] have identified a SD band in ^{84}Zr and determined its quadrupole moment ($Q_t = 5.2(8)$ eb; $\beta_2 \approx 0.53$), thus providing direct evidence for the presence of a SD shell gap in the mass region. Subsequently, multiple SD bands have been reported for ^{81}Sr [4], ^{82}Sr [5], and ^{82}Y [6].

The latest experiment was performed at the 88-Inch Cyclotron at the Lawrence Berkeley National Laboratory. High-spin states in some 30 residual nuclei were populated via the ^{28}Si+^{58}Ni reaction at 130 MeV beam energy. The target was a self-supporting ^{58}Ni foil of approximately 350 μg/cm^2 thickness and an enrichment of 99.7 %. Gamma rays were detected with 57 Compton-suppressed Ge detectors of the GAMMASPHERE array [7]. The proton and alpha evaporation particles were detected using the MICROBALL, a nearly 4π charged-particle detector array which consists of 95 CsI(Tl) scintillators with photodiode read-out [8]. A total of $1.3 \cdot 10^9$ three- and higher-fold events were sorted off-line into various E_γ-E_γ matrices and E_γ-E_γ-E_γ cubes subject to the appropriate charged-particle coincidence and analysis conditions.

New SD bands were established in ^{83}Zr [9], ^{83}Y [10], and ^{80}Sr [11]. The moments of inertia of these and the previously reported bands are generally in good agreement with the predictions of cranked shell model calculations which suggest that two to four aligned $h_{11/2}$ orbitals are involved in their configurations. Special among the known SD bands is the one in ^{84}Zr which has the largest quadrupole moment and is populated with 4.2(2) % intensity (versus the 1.5–2% which is the typical value in this region). The new results indicate that this large population is due to a larger-than-expected shell gap at $Z = 40$ at high rotational frequencies of $\hbar\omega \approx 1.3$ MeV.

The yrast SD band in ^{83}Zr has also an exceptional large yield of 5.3(3) %. Interestingly, both SD bands in ^{83}Zr were found to decay almost exclusively into the positive-parity yrast band. Considering all possible branches into the negative-parity bands, the 742 keV $13/2^+ \rightarrow 9/2^+$ transition collects 84(6) % of the yrast SD band, though it carries only 53(2) % of the whole γ-ray flux of ^{83}Zr towards the ground state. A forking at the bottom of the same SD band is interpreted as a possible band interaction with the normally-deformed bands. However, statistic were too low to observe discrete linking transitions. Details can be found in Ref. [9].

Other results from this experiment include the identification of two pairs of twinned identical superdeformed bands [10], and quadrupole moments, Q_t, in some 10 SD bands. The Q_t of the ^{83}Zr yrast band is consistent with a value of ≈ 5 eb (similar to ^{84}Zr) while the bands in the Y- and Sr-isotopes reveal $Q_t \approx 4$ eb [12].

Nuclei having $N \approx Z$ are expected to be influenced by the isospin $T = 0$ *np*-pairing interaction. For rotational bands, a delay of the $g_{9/2}$ band crossings and a smooth alignment pattern is predicted. Therefore, we

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Abbildung 1. Level scheme for ^{78}Sr and ^{82}Zr established in this work. The widths of the arrows are proportional to the relative intensities of the γ rays. Tentative transitions and levels are dashed.

examined the ^{80}Zr+$\alpha 2n$ channel in our data set. However, the low production cross section ($\sigma_{\rm rel} \approx 0.001$ %), and the less-than-100 % α-detection efficiency allowed us to only establish a coincidence relationship between the two reported γ rays in this nucleus and a tentative third transition at 792 keV.

Near the $N = Z$ line, we have investigated the $N = Z + 2$ nuclei ^{86}Mo, ^{82}Zr, and ^{78}Sr. Figure 1 shows the greatly extended level schemes of the latter two nuclei. A seemingly shell-model structure, likely due to the strong *np* two-body matrix-elements, was observed in the 4 qp regime of the yrast band of ^{86}Mo which shows basically collective band structures [13].

The previously reported level scheme for ^{82}Zr [14] was generally confirmed and greatly extended. The $\pi =-$ bands were identified and the $\pi = +$ yrast band was observed beyond the second band crossing. The first band crossing in ^{82}Zr is delayed with respect to that in ^{84}Zr, while the second crossing takes place at about the same frequency. The overall behaviour of ^{82}Zr is more similar to its isotope ^{84}Zr rather than to its isotone ^{80}Sr. Calculations suggest a prolate shape for the ground state of ^{82}Zr. However, this prolate minimum is less pronounced than those in the Sr-isotopes and shows some softness in the γ-degree of freedom. At higher frequencies, a well defined triaxial minimum occurs which corresponds to the steep decrease in the experimental Routhians. However, this crossing is predicted too early, possibly due to reduced pairing.

The previous level scheme of ^{78}Sr [15] was also confirmed and greatly extended. The $\pi =-$ bands were established and a forking in the $\pi = +$ yrast band above spin $I = 18\hbar$ was identified. The alignment of the ^{78}Sr yrast band until $\hbar\omega \approx 1$ MeV is extremely small, although both proton and neutron $g_{9/2}$ crossings should have occured. This may be due to reduced pairing correlations which yield flat Routhians leading to a small alignment. Interestingly, ^{78}Sr provides the largest $\mathcal{J}^{(1)}$ moment of inertia at low spins compared to its neighbouring even-even nuclei. The comparatively large and sharp gain of alignment in the yrast band after the forking does not fit very well into the picture of reduced pairing. However, a possible explanation is the so called "unpaired band crossing", where a *pair* of neutrons moves from the $[422]5/2^+$ into the $[301]3/2^-$ orbit, driving the nucleus towards smaller deformation and a possibly triaxial shape [16].

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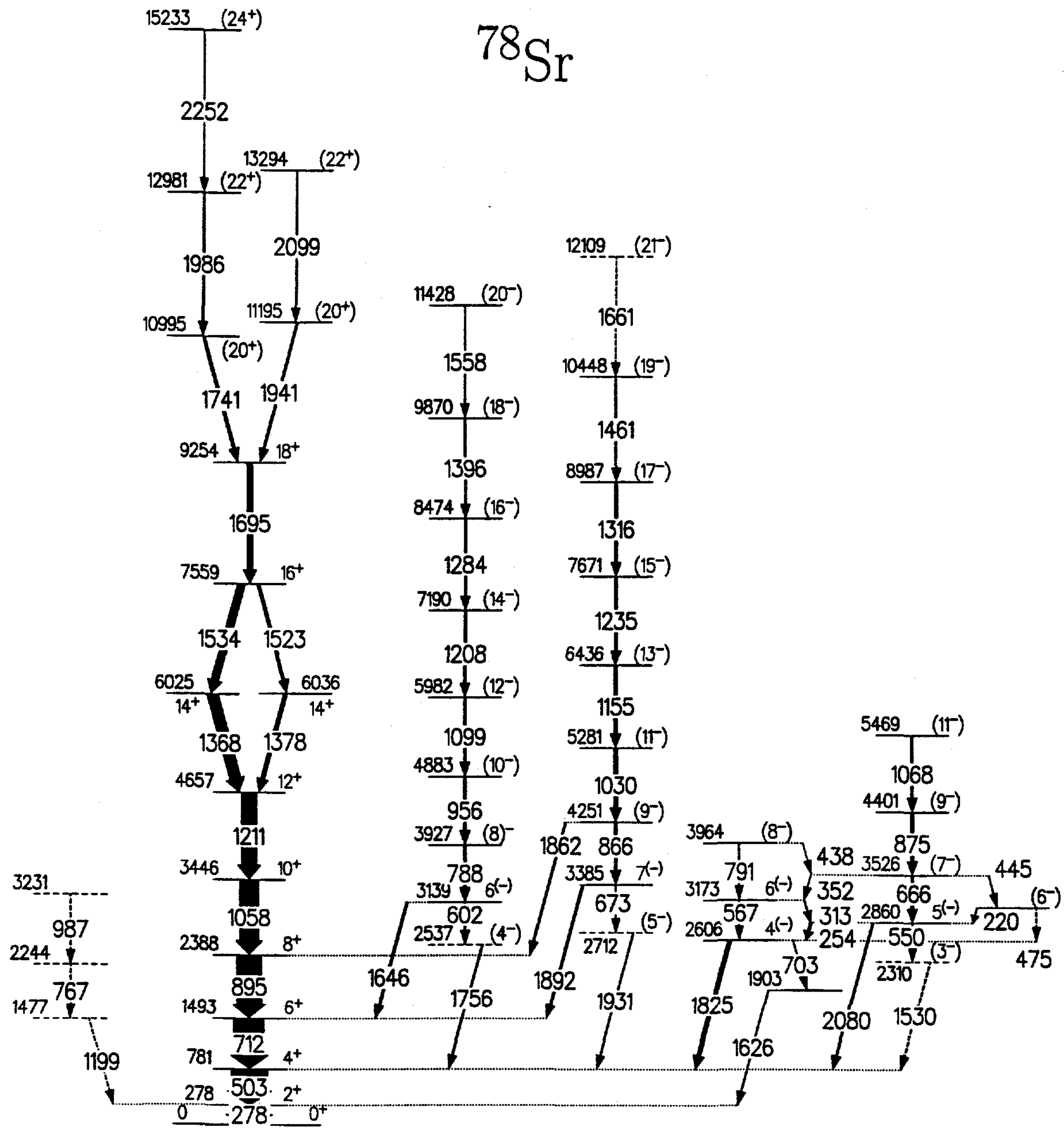
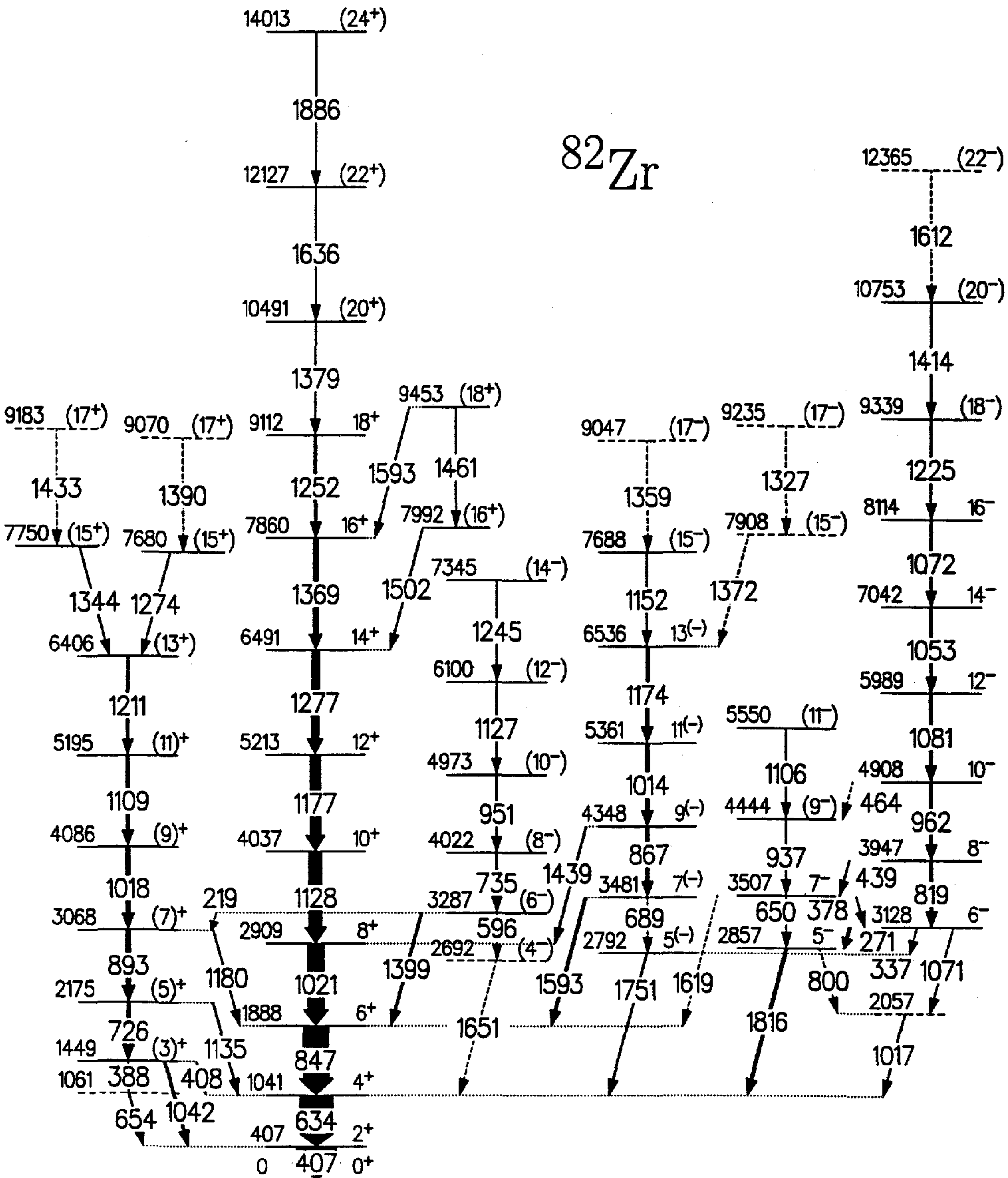


^{78}Sr
15233 (24+)
2252
12981 (22+)
13294 (22+)
1986
2099
10995 (20+)
11195 (20+)
1741
1941
9254 18+
1695
7559 16+
1534
1523
6025 14+
6036 14+
1368
1378
4657 12+
1211
3446 10+
1058
2388 8+
895
1493 6+
712
781 4+
503
278 2+
278
0 0+
3231
987
2244
767
1477
1199
11428 (20−)
1558
9870 (18−)
1396
8474 (16−)
1284
7190 (14−)
1208
5982 (12−)
1099
4883 (10−)
956
3927 (8)−
788
3139 6(−)
602
2537 (4−)
1646
1756
12109 (21−)
1661
10448 (19−)
1461
8987 (17−)
1316
7671 (15−)
1235
6436 (13−)
1155
5281 (11−)
1030
4251 (9−)
1862
866
3385 7(−)
673
2712 (5−)
1892
1931
3964 (8−)
791
3173 6(−)
567
2606 4(−)
438
352
313
254
703
1903
1825
1626
5469 (11−)
1068
4401 (9−)
875
3526 (7−)
445
666
2860 5(−)
(6−)
220
550
2310 (3−)
475
2080
1530



^{82}Zr
14013 (24+)
1886
12127 (22+)
1636
10491 (20+)
1379
9112 18+
1252
7860 16+
1369
6491 14+
1277
5213 12+
1177
4037 10+
1128
2909 8+
1021
1888 6+
847
1041 4+
634
407 2+
407
0 0+
9183 (17+)
1433
7750 (15+)
9070 (17+)
1390
7680 (15+)
1344
1274
6406 (13+)
1211
5195 (11)+
1109
4086 (9)+
1018
3068 (7)+
893
2175 (5)+
726
1449 (3)+
388
1061
654
1042
408
1135
1180
219
9453 (18+)
1593
1461
7992 (16+)
1502
7345 (14−)
1245
6100 (12−)
1127
4973 (10−)
951
4022 (8−)
735
3287 (6−)
596
2692 (4−)
1399
1651
1439
1593
9047 (17−)
1359
7688 (15−)
1152
6536 13(−)
1174
5361 11(−)
1014
4348 9(−)
867
3481 7(−)
689
2792 5(−)
1751
1619
9235 (17−)
1327
7908 (15−)
1372
5550 (11−)
1106
4444 (9−)
937
3507 7−
650
378
2857 5−
1816
800
12365 (22−)
1612
10753 (20−)
1414
9339 (18−)
1225
8114 16−
1072
7042 14−
1053
5989 12−
1081
4908 10−
464
962
3947 8−
439
819
3128 6−
271
337
1071
2057
1017