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SUPERDEFORMATION IN ^{104,105}Pd

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In the present communication we report the discovery of a rotational band in ^{104}Pd and one in ^{105}Pd that can be interpreted as arising from superdeformed shapes. The moments of inertia, $J^{(1)}$ and $J^{(2)}$, of these bands are similar to those measured in the Ce-Nd region, once the $A^{5/3}$ mass dependence is removed. This implies a deformation $\epsilon \sim 0.35$-0.4. This is the third mass region where superdeformed bands have been found at high spins.

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The understanding of the nuclear shape requires a knowledge of macroscopic properties, determined by the interplay of Coulomb, surface and rotational energies, and of microscopic properties associated with the detailed motion of the nucleons near the Fermi surface. Of special interest are those shapes known as "superdeformed" (SD) where the nucleus acquires a very elongated shape that can be approximately represented by an ellipsoid where the ratio of the long to short axis is considerably larger than that of normal deformation $\sim$ 1.3:1. Within the framework of the anisotropic harmonic oscillator model[1] one can expect the existence of favorable shell gaps that appear regularly as a function of deformation and nucleon number. They are predicted to occur for particular "superdeformed magic numbers" and at deformations corresponding to integer ratios of the lengths of the axes (e.g., $\epsilon = 0.6$ corresponds to a ratio of 2:1). More realistic calculations provide a better prediction of regions of superdeformation[2] and these simple regularities are largely lost. Nevertheless, superdeformed shapes are predicted to occur, and their observation and systematic study will result in a better understanding of the interplay between the macroscopic and microscopic aspects of the nuclear motion.

The first observation of SD nuclei goes back to the discovery of fission isomers[3] and the identification of the rotational bands built on them[4]. This interesting topic of nuclear structure had to wait 15 years until other discrete superdeformed bands were discovered at high spins in the 150 and 130 mass regions[5]. This was possible only when large arrays of Compton-suppressed Ge detectors became operational and were able to extract these bands from the complex background that occurs in the spin region where they are found. Not much is yet known about the actual properties of these bands, such as their single-particle configuration, pairing correlations and their population and decay mechanisms. It is important, at this stage, to determine experimentally the regions where superdeformation occurs. In the present communication we report the discovery of rotational bands in ^{104}Pd and ^{105}Pd that can be interpreted as originating from a second minimum in the potential energy surface of these nuclei at high spin and large deformation. This is a new mass region where discrete superdeformed bands have been found at high spins, the other known regions being around ^{152}Dy and in the light Ce-Nd nuclei.

The experiment was carried out at the Lawrence Berkeley Laboratory 88-inch Cyclotron. Two stacked ^{64}Ni, self-supporting targets 0.5 mg/cm^2 thick, were bombarded with a 200 MeV ^{48}Ca beam. The emitted γ-rays were detected in 20 Compton-suppressed Ge detectors from the HERA array at an event rate for triple and higher fold coincidences of approximately 2000 s^{-1}. A total of 70 million events were recorded event-by-event on magnetic tapes for subsequent off-line analysis.

A "doubles" sort, in which the events were broken into independent pairs showed the existence of a very strong ridge structure in the γ-γ correlation matrix [6]. The observed energy spacing is consistent with that from a strongly deformed shape. A more detailed inspection revealed the presence of two discrete bands that were associated with ^{104}Pd and ^{105}Pd , the α4n and the α3n products, respectively. Figure 1a shows a background-substracted spectrum obtained by summing spectra having gates within the band assigned to ^{105}Pd . These transitions are also clearly seen in the spectrum in Fig. 1b, which corresponds to a gate on the known 306 keV ground-state transition in ^{105}Pd [7]. A summed spectrum derived from gates in the band assigned to ^{104}Pd is shown in Fig. 1c. A partial decay scheme is shown in Fig. 2 for the two nuclei.

-^{105}Pd : In an attempt to find links between the SD band and the yrast states, a "triples" sort was performed, requiring two γ-ray gates in the SD band or one gate in the band and the other in the ground state ($g_{7/2}$) band before incrementing a spectrum with the third γ. As in previous cases, no obvious links could be found. However, the γ-ray intensities deduced from the triples sort of the data, summarized in Table 1, show that the band deexcites both to the $g_{7/2}$ and the $h_{11/2}$ bands with roughly equal intensity. The feeding of the $g_{7/2}$ band seems to take place at a spin of 39/2 and therefore the deexcitation pattern suggests a spin of 43/2 for the first observed level of the new rotational band, with an uncertainty of ± 2 units. Angular correlations with gates on the band members or on the 306 keV (ΔI=1) transition established that the transitions are consistent with stretched quadrupole character[8], thus extending the spin sequence up to 83/2 for the top transition. With the branching derived from the triples sort, the relative intensities from a gate in the 306 keV transition and its known intensity, the population of this band was determined to be ~ 30% of the total events leading to ^{105}Pd .

-^{104}Pd : In contrast with ^{105}Pd , the data from the triples sort were insufficient to provide additional useful information, but consistent with the doubles sort analysis (perhaps due to the relatively lower intensity of this product and of its band). From the single-gated spectra it was possible to conclude that the band feeds the yrast states at around spin 22, and therefore a spin 24 ± 2 could be assigned for the lowest state of the band. The population of this band represents ~ 15% of the events in ^{104}Pd , as obtained from gates in low-spin members of the yrast band [9]. Relative intensities are also given in Table 1.

It can be argued that these bands should be populated when they are in the yrast region, i.e., close to the highest spins observed. Therefore, due to their large moment of inertia they would deexcite at ~ 2-3MeV above the yrast line.

The moments of inertia $J^{(1)}$ and $J^{(2)}$, shown in Fig. 3, are similar to those measured in the mass 130 region, once the $A^{5/3}$ dependence is removed, suggesting a deformation of $\epsilon \sim$ 0.35-0.4 for these bands. The gradual decrease in $J^{(2)}$ can be qualitatively understood by the gradual alignment of the valence nucleons' angular momentum with the rotation axis, as the rotational frequency increases. Therefore, the generation of angular momentum becomes energetically more expensive and the nucleus approaches the "band termination" that will occur when all the angular momentum available for that configuration is aligned. In comparison with ^{152}Dy, it is expected[10] that in the spin range observed a bigger proportion of this maximun angular momentum is exhausted for these lighter systems, and therefore the reduction of $J^{(2)}$ is faster.

Both ^{104}Pd and ^{105}Pd can be interpreted as soft, slightly deformed, prolate rotors in the normal (low frequency) regime[7,9]. The observation of SD bands indicates the existence of a second minimum in the potential-energy surface of these nuclei. As mentioned before, these minima are likely at $\epsilon \sim 0.35$-0.4 and become yrast (lowest in energy) at a spin of about 40. The increase in $J^{(2)}$ in ^{105}Pd at $\hbar\omega \sim 1$ MeV is quite interesting and may be caused by a band crossing. It is the first time such a crossing has been seen in a SD band.

The structure of these bands can be discussed in terms of the cranked shell model[11]. We have calculated the single-particle routhians at a deformation of ϵ=0.4 and, at the frequencies where the SD bands are observed, a plausible configuration involves levels from the N=4 and 5 shells for both neutrons and protons, i.e. $\pi(N=4)^4(N=5)^2$ $\nu(N=4)^{14}(N=5)^4$. The deformation-driving effect of the π and ν N=5($h_{11/2}$) high-j orbitals will favor the stabilization of the second minima in the potential-energy surface of these nuclei. Furthermore, the calculations suggests that the increase of $J^{(2)}$ in ^{105}Pd at the highest frequencies can be attributed to the alignment of a pair of neutrons in the N=6 $i_{13/2}$ level. The crossing is predicted to occur at $\hbar\omega \sim 1.1$MeV, very close to the observed frequency.

A more general calculation, regarding the existence of SD gaps in a realistic Wood-Saxon potential has been presented by Dudek et al.[2]. An inspection of single-particle levels as a function of deformation reveals the presence of gaps at large quadrupole deformation for Z=46 and N=58 . These predictions are consistent with our observations, altough a quantitative comparison is beyond the scope of this work. It is interesting to note that the neutron number of N=58,59 for the present cases can be related to the proton number Z=58,60 in th Ce-Nd region.

In conclusion, we have observed bands in ^{104}Pd and ^{105}Pd consisting of stretched E2 transitions. Their regularity and measured moments of inertia suggest that these bands are based on a superdeformed configuration having $\epsilon \sim 0.35$-0.4, similar to those observed in the Ce-Nd region. The sudden increase in $J^{(2)}$ in the SD band of ^{105}Pd at the highest spins may be due to the alignment of a pair of $i_{13/2}$ neutrons.

References

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Table 1

Gamma-ray energies, relative intensities and initial spin of transitions seen in the decay of the SD band. Intensities were derived from "doubles" and "triples" sorts of the data (see text).

^{104}Pd

E_γ (keV)	Intensity I_γ [a] %	I^π
556	100	2^+
768	96	4^+
926	142[b]	6^+, 16^+
971	87	8^+
802	175[b]	10^+, 14^+
612	89	12^+
1064	100	18^+
1194	100	20^+
1263	127[c]	22^+ ,(26)
1381	78	(28)
1511	93	(30)
1638	79	(32)
1763	92	(34)
1919	78	(36)
2079	64	(38)

^{105}Pd

E_γ (keV)	Intensity I_γ [a] %	I^π
306	50	$7/2^+$
706	50	$11/2^+$
891	51	$15/2^+$
854	45	$19/2^+$
539	41	$23/2^+$
578	41	$27/2^+$
795	35	$31/2^+$
1014	35	$35/2^+$
1178	24	$39/2^+$
481	50	$15/2^-$
772	52	$19/2^-$
958	53	$23/2^-$
1208	51	(47/2)
1282	47	(51/2)
1379	96	(55/2)
1488	105	(59/2)
1597	110	(63/2)
1720	100	(67/2)
1846	60	(71/2)
2007	55	(75/2)
2141	30	(79/2)
2240	12	(83/2)

a : Intensities have an uncertainty of ± 10% .

b : Sum of transitions in the yrast sequence.

c : Includes the 1257keV transition in the yrast band.

Figure Captions

Fig.1. a) Spectrum in coincidence with gates within the members of the SD band assigned to ^{105}Pd ; γ -ray transitions are labeled by their energy in keV.

b) Spectrum in coincidence with the 306keV transition in ^{105}Pd . The lines show the position of SD transitions. Transitions in the yrast band are labeled by their initial spin (See Fig. 2).

c) Same as a) for the band assigned to ^{104}Pd . Yrast transitions are labeled by their initial spin.

Fig. 2. Partial decay schemes of the SD bands in ^{104}Pd and ^{105}Pd .

Fig 3. Moments of inertia for the observed rotational bands. The dotted area represents $J^{(1)}$ with an uncertainty of ± 2 in the spin assignment. Open circles are for ^{104}Pd and full circles for ^{105}Pd . For comparison, the dynamic moment of inertia (scaled by $A^{5/3}$) in the SD band in ^{132}Ce is shown as a dotted line. The right-hand scale is in units of the rigid sphere.

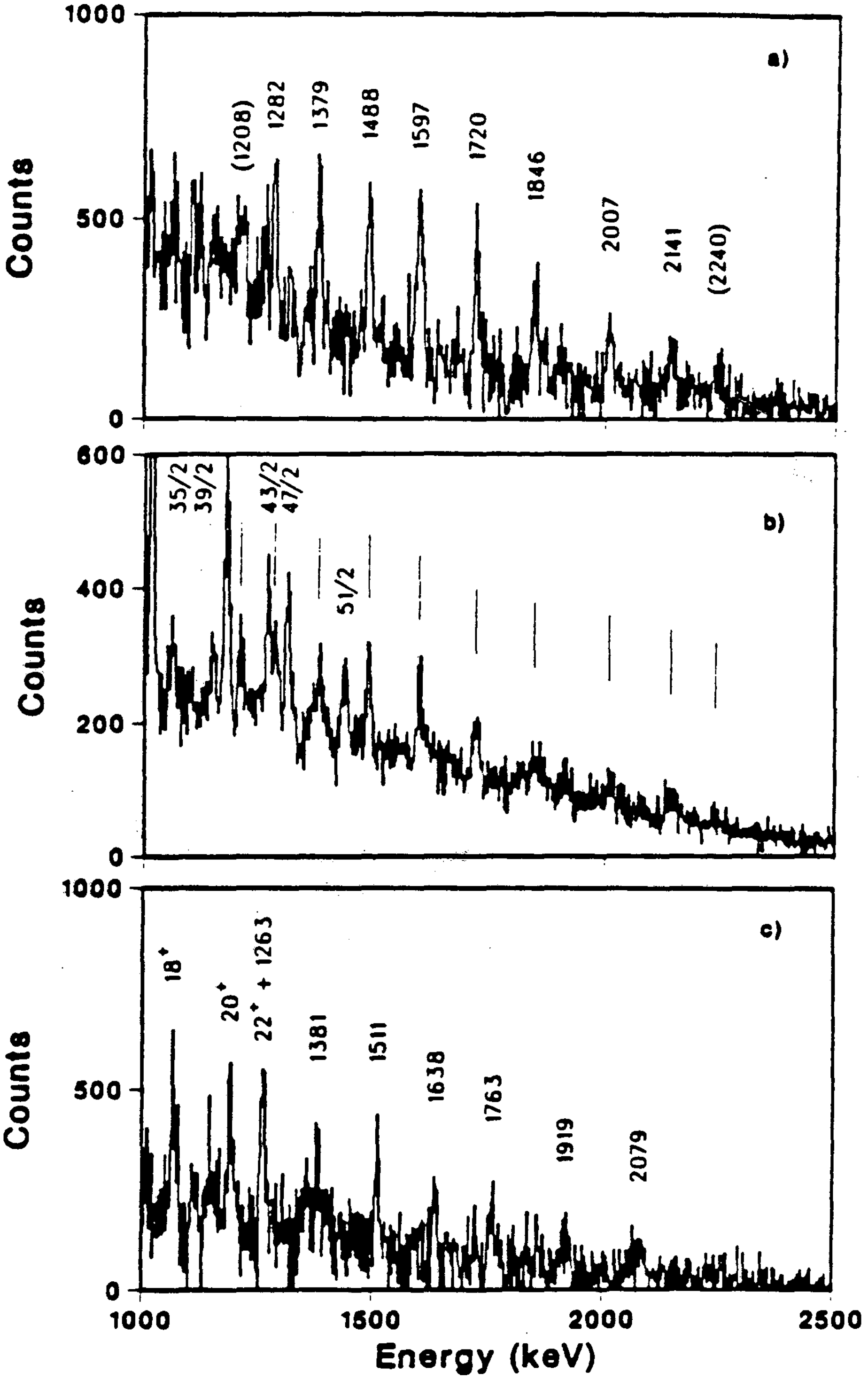

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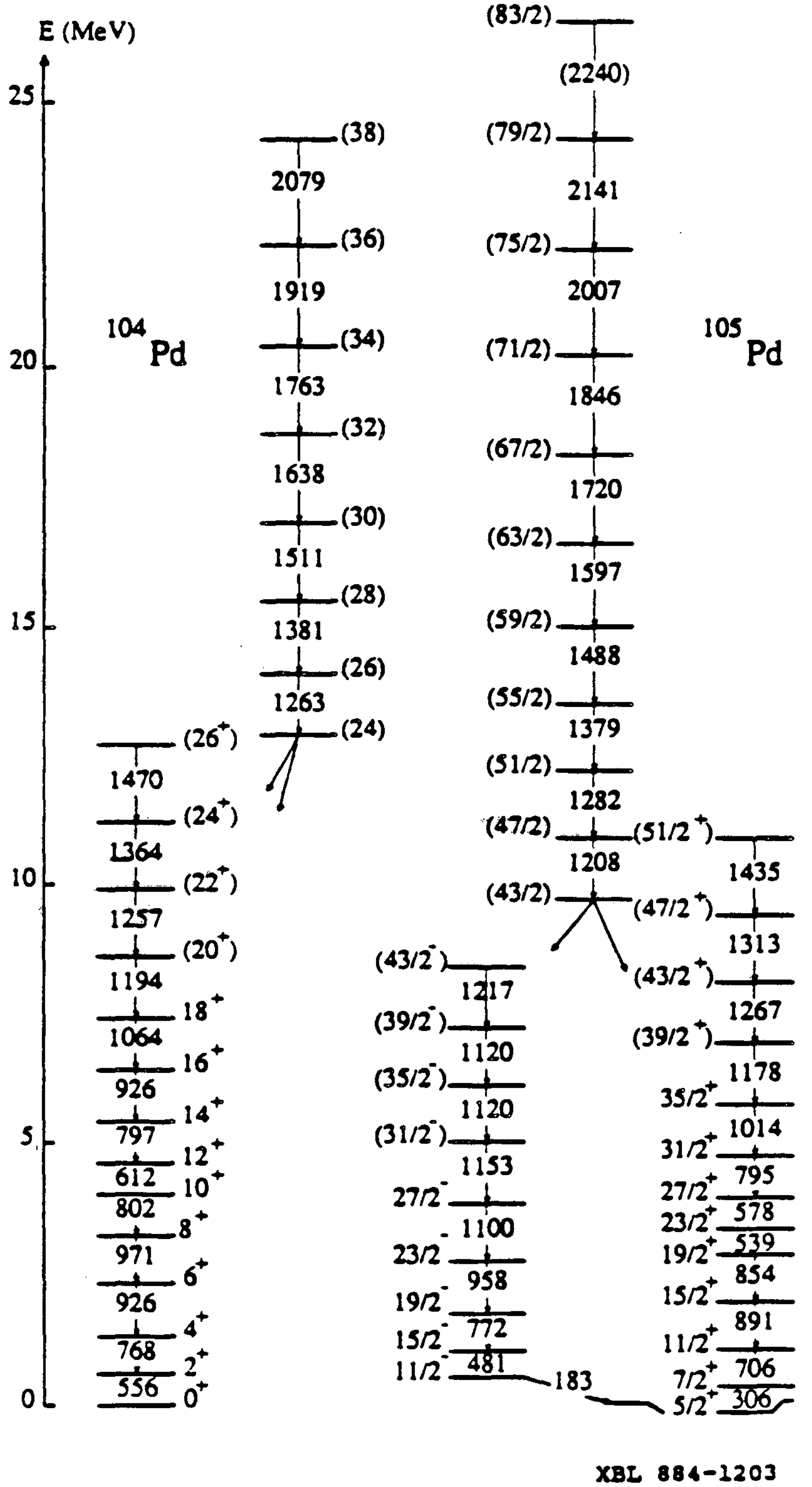
Figure 1

E (MeV)
25
20
15
10
5
0
104Pd
105Pd
556
768
926
971
802
612
797
926
1064
1194
1257
1364
1470
0+
2+
4+
6+
8+
10+
12+
14+
16+
18+
(20+)
(22+)
(24+)
(26+)
(24)
1263
(26)
1381
(28)
1511
(30)
1638
(32)
1763
(34)
1919
(36)
2079
(38)
11/2-
481
15/2-
772
19/2-
958
23/2-
1100
27/2-
1153
(31/2-)
1120
(35/2-)
1120
(39/2-)
1217
(43/2-)
183
(43/2)
1208
(47/2)
1282
(51/2)
1379
(55/2)
1488
(59/2)
1597
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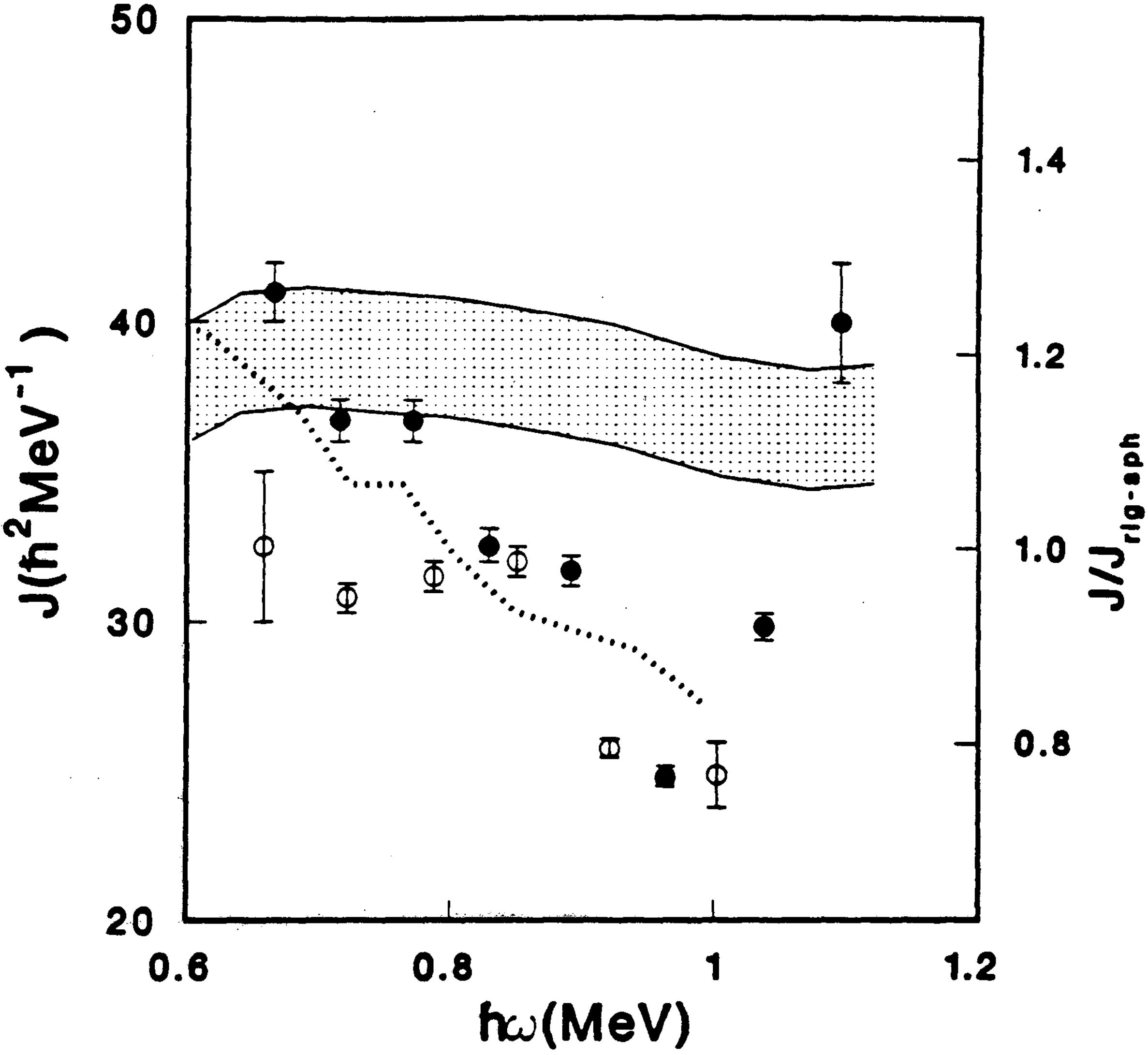
5/2+
306
7/2+
706
11/2+
891
15/2+
854
19/2+
539
23/2+
578
27/2+
795
31/2+
1014
35/2+
1178
(39/2+)
1267
(43/2+)
1313
(47/2+)
1435
(51/2+)
XBL 884-1203

Figure 2



XBL 884-1205

Figure 3

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