Michigan State University

National Superconducting Cyclotron Laboratory

DECOUPLING AND DEFORMATION

WM. C. McHARRIS, RAHMAT ARYEINEJAD,
WEN-TSAE CHOU, YVES X. DARDENNE,
CHRISTINE V. HAMPTON, BIN LIAN, WADE OLIVIER,
ARACELYS RIOS, and R.M. RONNINGEN

MSUCL-873

FEBRUARY 1993

Invited paper presented at symposium on Nuclear Physics of Our Times, Sanibel Island, Florida, 17-21 November 1993

MSUCL-873
February 1993

DECOUPLING AND DEFORMATION

Wm. C. McHarris, Rabmat Aryaeinejad,* Wen-Tsae Chou,† Yves X. Dardenne,‡
Christine V. Hampton, Bin Lian, Wade Olivier, Aracelys Rlos, and R M. Ronningen

National Superconducting Cyclotron Laboratory
and
Departments of Chemistry and Physics/Astronomy
Michigan State University
East Lansing, Michigan 48824, USA

ABSTRACT

Decoupled and doubly-decoupled bands are the most intensely populated systems in Ta-Re-Ir nuclei produced by heavy-ion induced reactions, and their population intensity patterns are remarkably independent of entrance-channel effects. We investigate several of these in light Re nuclei in some detail. In odd-odd nuclei, the doubly-decoupled bands may furnish some information about the residual p-n interaction. In ^{175}Re there is some evidence for a decoupled hand "forking" into two deformations, and one is led to speculate on the possibility of decoupling being a stop on the way toward higher (perhaps even super-) deformation.

In γ-ray spectra produced by heavy-ion induced reactions in the Ta-Re-Ir region, certain bands stand out as receiving the bulk of the population. An example of this is shown in Fig. 1, a "singles" (but requiring a multiplicity of four or greater) spectrum produced by the ^{165}Ho(^{16}O,$6n\gamma$)^{175}Re reaction. The labeled peaks originate from the $\pi h_{9/2}\,1/2^-[541]$ decoupled band in ^{175}Re. The summed-gated spectra shown in Fig. 2 illustrate that this band's population intensity is remarkably independent of entrance-channel effects, remaining constant in reactions induced by ^{16}O, ^{20}Ne, and ^{40}Ar; this pattern has been confirmed by other investigators.[1,2] In Fig. 3 we show the level scheme of ^{175}Re, including this decoupled band (Band I), a highly-compressed band based on the $\pi h_{11/2}\,9/2^-[514]$ state (Band II), a possible forked branch of the decoupled band (Band III), and a less-distorted band based on the $\pi d_{5/2}\ 5/2^+[402]$ state.

Decoupled bands are ΔI = 2 bands, low-Ω bands derived from high-j states. As a result, they have very large decoupling parameters. (For an $\Omega = 1/2$ band, the decoupling parameter is ($\left|\left\langle(\hbar^2/2\Im)I_\pm j_\mp\right\rangle\right| = \hbar^2/2\Im\,\sqrt{I(I+1)-K(K\pm 1)}\sqrt{j(j+1)-\Omega(\Omega\pm 1)}$, the diagonal coriolis matrix element.)

*Present address: Department of Nuclear Science, Nationsl Tsing Hua University, 30043 Hsinchu, Taiwan, ROC
†Present address: EG&G Idaho National Engineering Laboratory, Idaho Falls, ID 83415, USA
‡Present address: Nuclear Science Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA

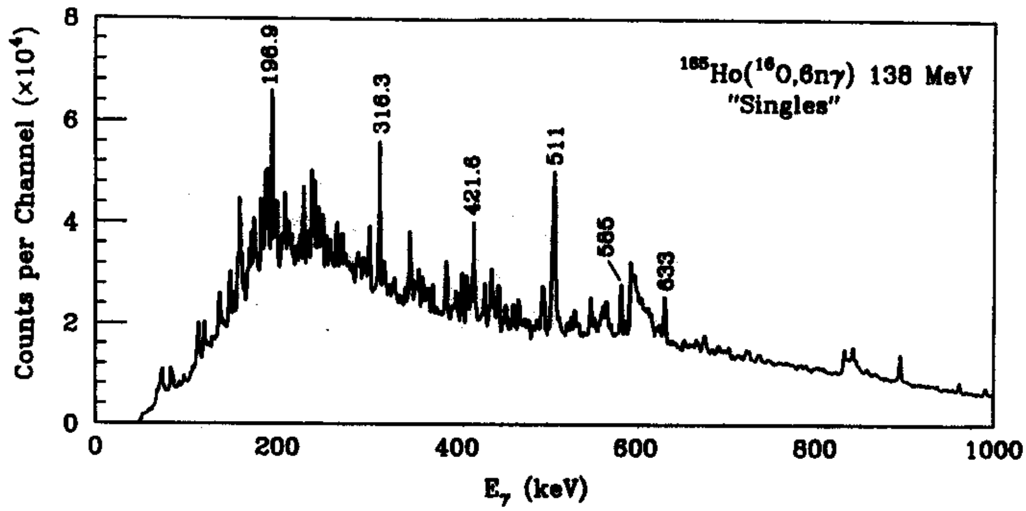

Figure 1. Spectrum from the ^{165}Ho(^{16}O,6$n\gamma$) reaction, showing the decoupled band in ^{175}Re. (Experiment performed at SUNY Stony Brook.)

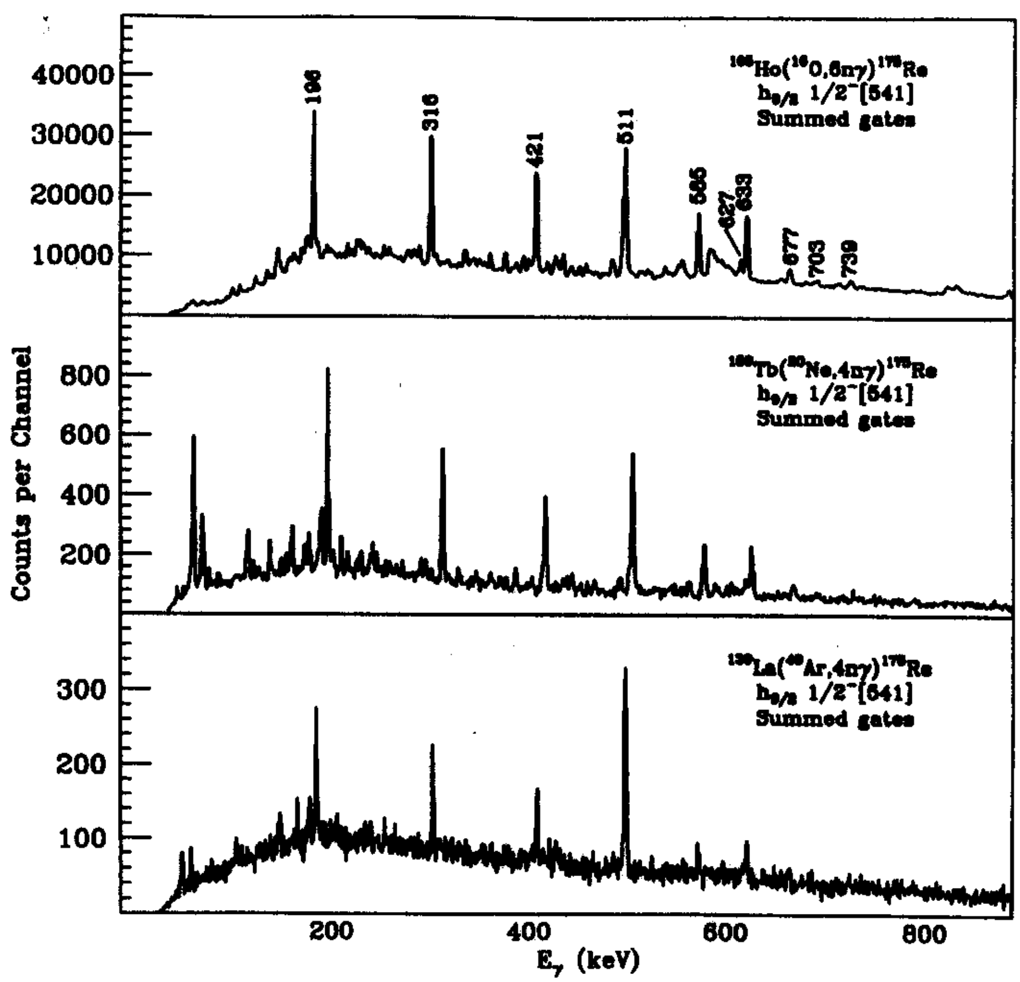

Figure 2. Enhanced summed-gated spectrum showing the remarkable similarity in intensity pattern for the decoupled band in reactions induced by projectiles having significantly different masses.

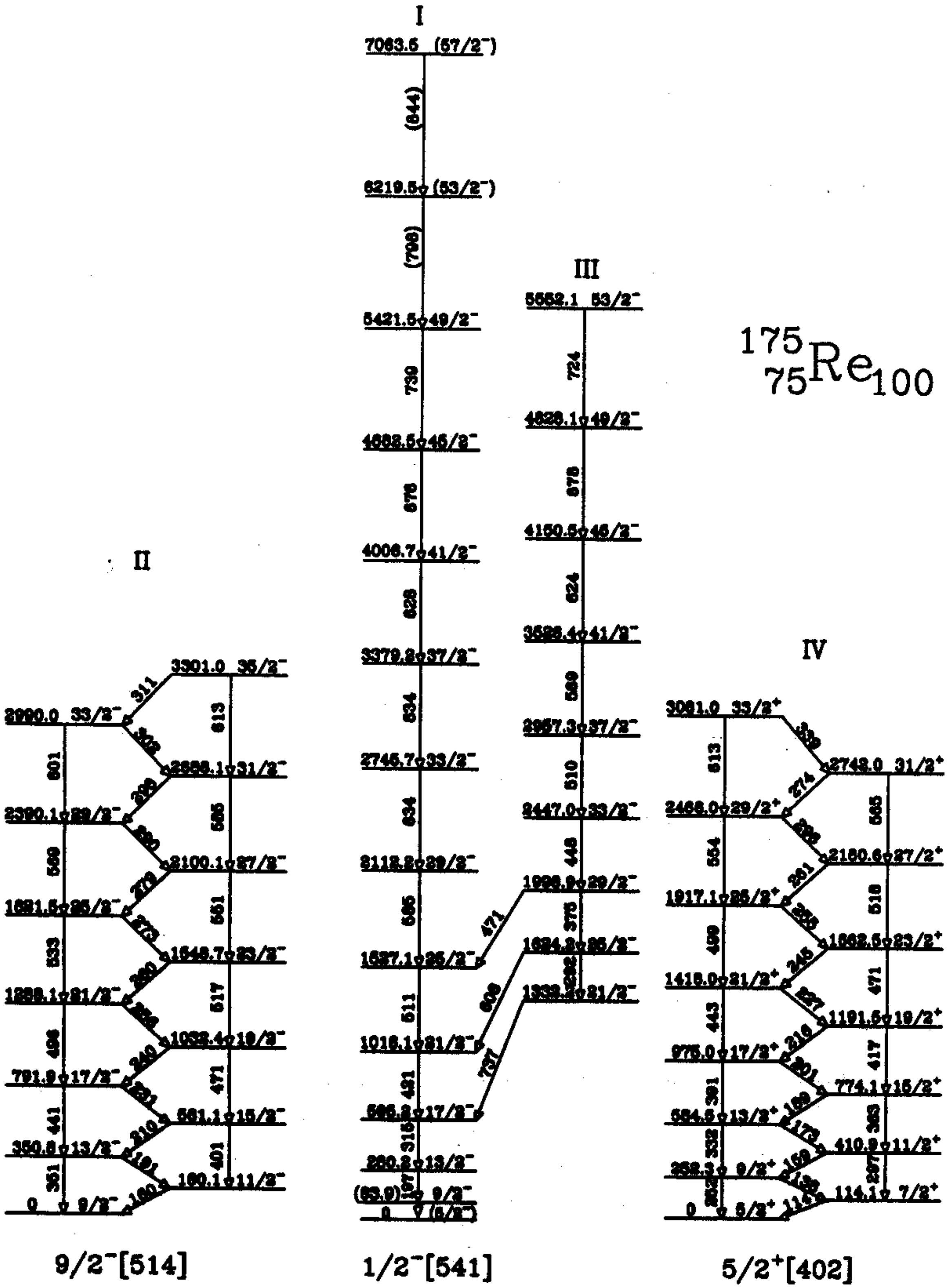

Figure 3. Level scheme of ^{175}Re showing the four most intense rotational bands.

Examples of these bands (and doubly-decoupled bands in adjacent odd-odd nuclei, where the $\pi h_{9/2}1/2^{-}[541]$ state is coupled with an $\Omega = 1/2$ neutron, most likely the $p_{3/2}1/2^{-}[521]$ state) are shown in Fig. 4.[3] Only the favored signature states are observed experimentally; the other signature is pushed up too high to receive significant population, and the (often unobserved) base states of the odd-mass and odd-odd bands are generally related—3^{+} in odd-odd systems near $5/2^{-}$ odd-mass systems, and 5^{+} near $9/2^{-}$.

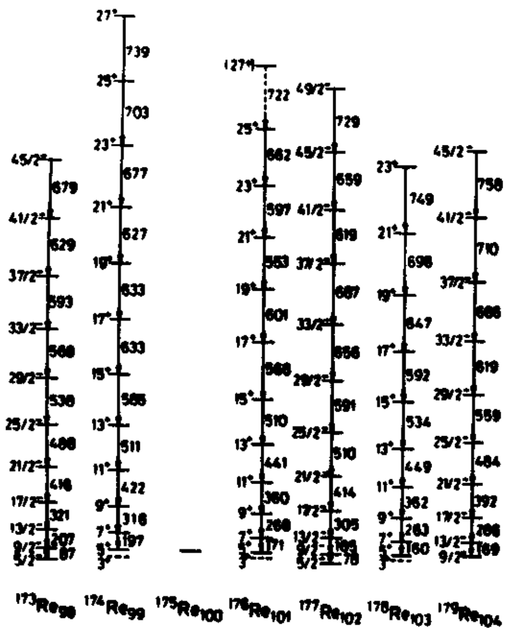

Figure 4. Systematics of decoupled and doubly-decoupled bands in Re nuclei prior to the present work.

A qualitative explanation for the intense population of decoupled bands is straightforward: The most efficient means of handling the large amounts of angular momentum brought in by heavy ions in fusion-evaporation reactions is for the outer nucleons to decouple and line up with the rotation. Thus, the initial states populated should consist primarily of (multiply-) decoupled bands. The γ-ray depopulation then preferentially feeds down through related coriolis-admixed states, ultimately reaching the yrast decoupled bands (or yrast bands having large coriolis matrix elements). This also explains the insensitivity to entrance-channel effects — although ^{40}Ar undoubtedly populates states of higher angular momentum than, say, does ^{16}O, it is the γ-ray deexcitation "funnel," rather than the initial manifold of states, that determines the observed bands. (In a sense, this explanation is nothing more than multiple-backbending in reverse.)

In other ways, such as band-crossings and alignments, decoupled bands behave predictably. For example, the alignment plots of the Re decoupled bands are compared with those of the corresponding even-even cores in Fig. 5. The downsloping $\pi h_{9/2}1/2^{-}[541]$ state is deformation driving, and, as expected, delays the onset of band crossing in the odd-mass systems. Interestingly enough, a compromise behavior is found in the odd-odd systems.[4] In ^{174}Re and ^{176}Re, the crossing frequencies are essentially the same for the doubly-decoupled bands as for the corresponding cores. Here, the proton states tend toward increasing the crossing frequencies, but the neutron states do the opposite, thus more or less canceling out the effects.

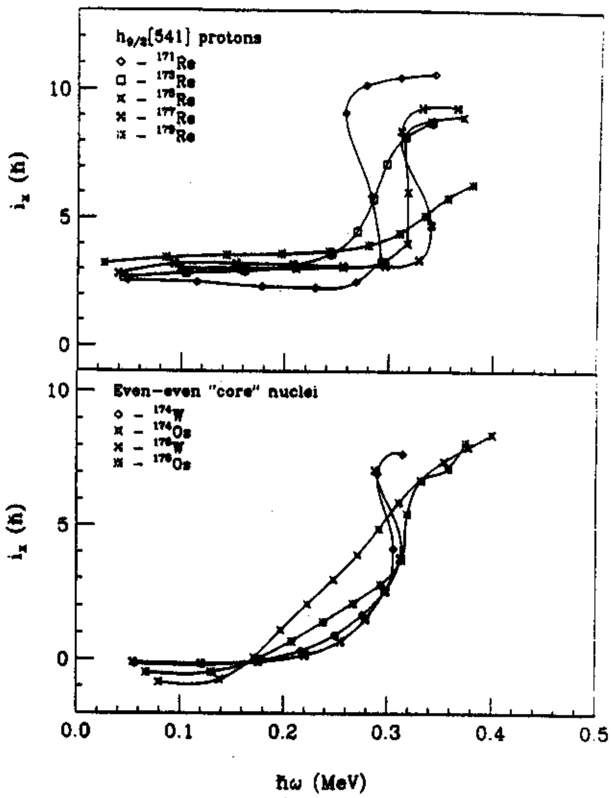

Figure 5. Alignment plots for the decoupled bands in light Re nuclei compared with those of the even-even core nuclei.

These bands are also well reproduced by interacting boson approximation calculations.[5] Figure 6 shows the results of our calculations for the doubly-decoupled band in ^{176}Re compared with the experimental results. The agreement is striking, especially since the extreme coriolis distortions are reproduced, using no additional free parameters. Again, only the favored signature members of a nominally triplet $K = 1$ band are observed, with the unfavored members of this band and those of a singlet $K = 0$ band pushed to higher energies. (Although K is not strictly a good quantum number for decoupled bands, it makes a useful point of reference.)

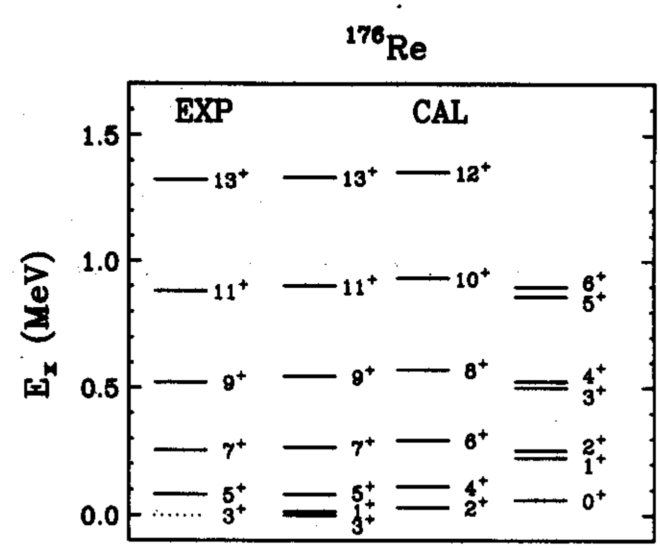

Figure 6. Comparison of the experimentally observed lower-lying members of the doubly decoupled band in ^{176}Re with interacting boson approximation calculations.

We end this short survey with a bit of speculation. Band III in ^{175}Re (Fig. 2) *could* be a fork of Band I, the decoupled band. (It should be emphasized that this is controversial, and other investigators[1,2] have assigned this band as the $\pi i_{13/2} 1/2^+[660]$ state.) There is not room to go into detail, but feeding-intensity arguments and the fact that it feeds across into the decoupled band by enhanced transitions ($E1$'s from a $1/2^+$ band would be highly retarded) well before it reaches its own band-head make it seem related to the decoupled band. And since it has a considerably higher moment of inertia and shows no backbending, it could be a higher-deformation branch of the decoupled band. (Total Routhian surface calculations for nuclei in this region indicate a second prolate minimum.) If so, the simple-minded ideas in Fig. 7 could explain its population behavior.

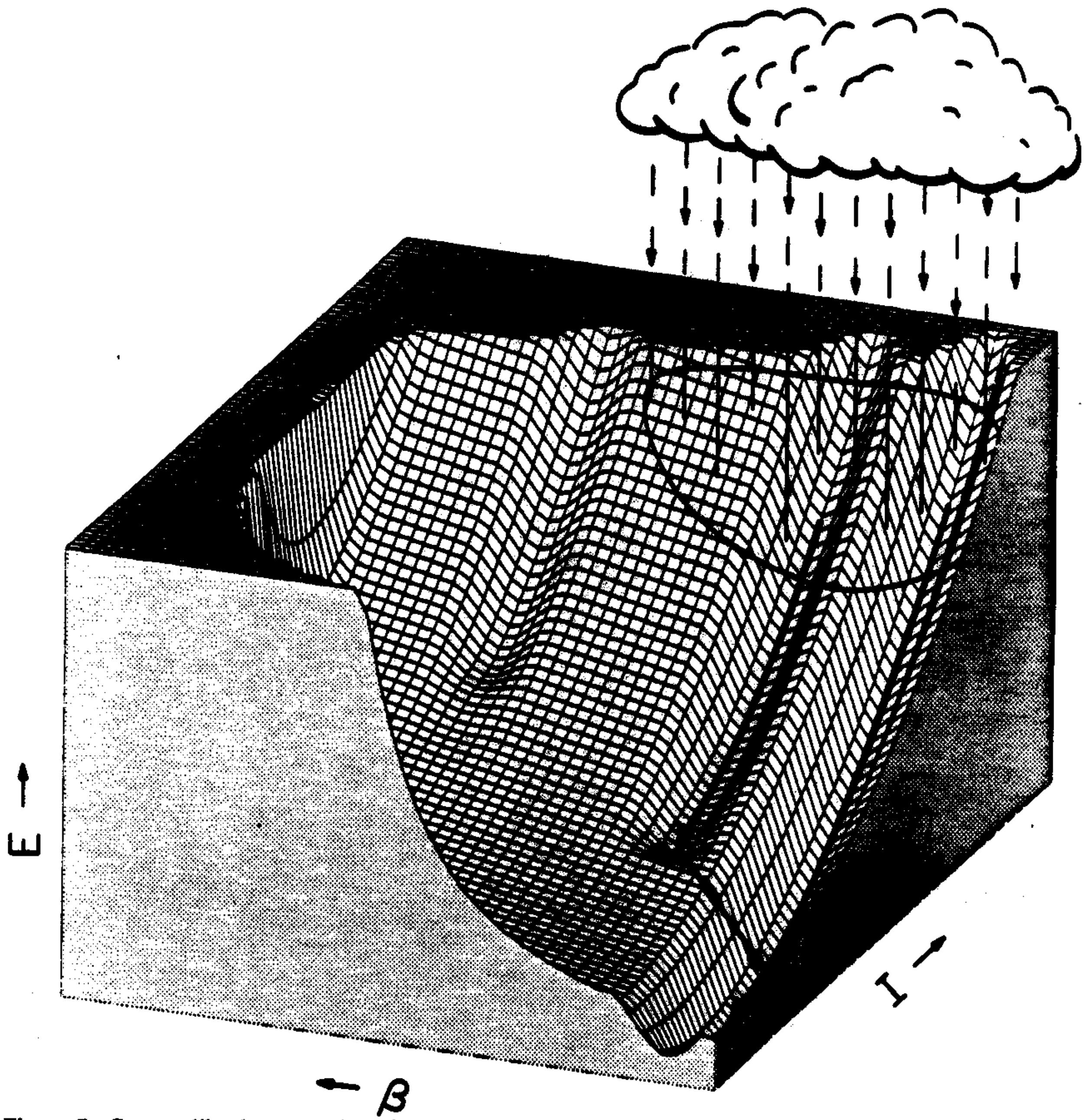

Figure 7. Cartoon-like demonstration of a possible mechanism for a "forked" rotational band. Excitation energy is plotted against both spin and deformation. The cloud represents the manifold of states populated in a fusion-evapoation reaction. These then rain down onto the yrast surface of states, and the higher deformation branch eventually falls into the lower deformation valley.

Finally, in Fig. 8, we show a schematic of the progress of multiple decoupling. Perhaps decoupling is a step on the way toward superdeformation?!

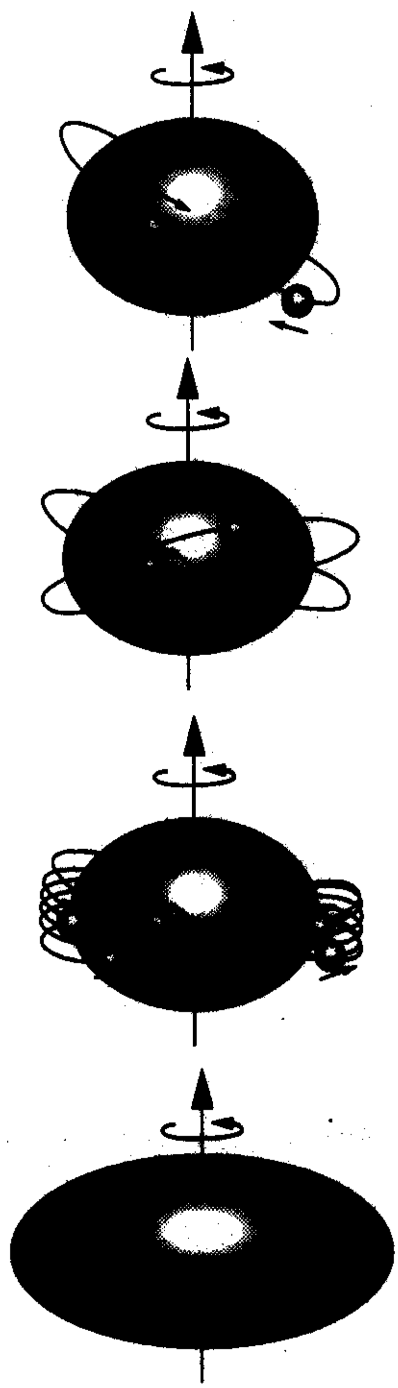

Figure 8. Schematic views of a) a normal strongly-coupled band, b) a doubly-decoupled band, c) a multiply-decoupled band, and d) a superdeformed nucleus. One can speculate that multiple decoupling is a stop on the way to superdeformation.

References

1. H.-Q. Jin, L. L. Riedinger, C.-H. Yu, W. Nazarewicz, R. Wyss, J.-Y. Zhang, C. Baktash, J. D. Garrett, N. R. Johnson, I. Y. Lee, and F. K. McGowan, *Phys. Lett.* **B277**, 387 (1992).
2. T. Kibédi, G. D. Dracoulis, F. Fabricius, A. P. Byrne, and A. F. Stuchbery, *Nucl. Phys.* **A539**, 137 (1992).
3. Andrés J. Kreiner, Chapter 26 in *Exotic Nuclear Spectroscopy*, Ed. by Wm. C. McHarris, Plenum Press, 1991.
4. Wade A. Olivier, Wen-Tsae Chou, Aracelys Ríos, Wm. C. McHarris, and Rahmat Aryaeinejad, Chapter 25 in *Exotic Nuclear Spectroscopy*, Ed. by Wm. C. McHarris, Plenum Press, 1991.
5. W.-T. Chou, W. A. Olivier, Wm. C. McHarris, and Olaf Scholten, *Phys. Rev. C* **42**, 221 (1990).