Super-radiance and two-neutron transfer reactions *

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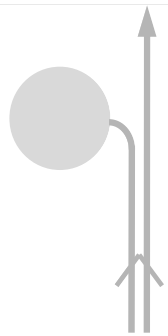
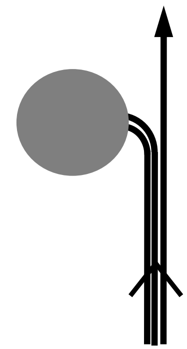
Direct Reactions



$$< A+1 \mid a^{+} \mid A >$$

Spectroscopic *(u, v)* Factors



$$< A+2 \mid a^{+}a^{+} \mid A >$$

Constructive interference

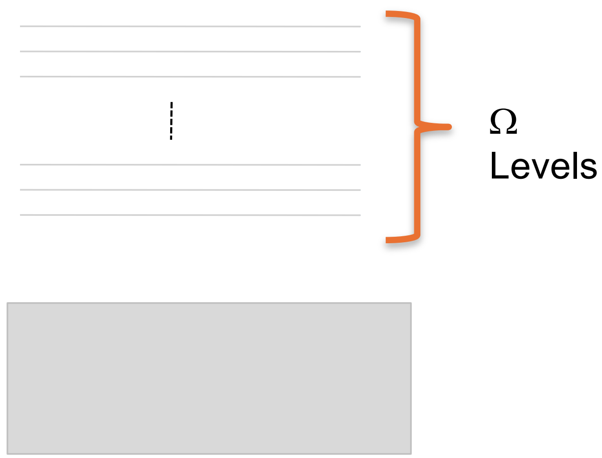
Two particle transfer reactions like (t,p) or (p,t), where 2 nucleons are deposited or picked up at the same point in space provide a specific tool to probe the amplitude of this collective motion.

The transition operators $<f|a^{+}a^{+}|i>$, $<f|aa|i>$ are the analogous to the transition probabilities *B(E2)*'s on the quadrupole case.

R.A. Broglia, O. Hansen and C. Riedel, Adv. Nucl. Phys. Vol 6 (1973) 287

D. M. Brink and R.A. Broglia, Nuclear Superfluidity, Cambridge Monographs.

Pairing vibrations and the (t,p) reaction



Closed shell nucleus, A_0

$$\sigma \propto < A_o + 2 | T | A_o >^2$$

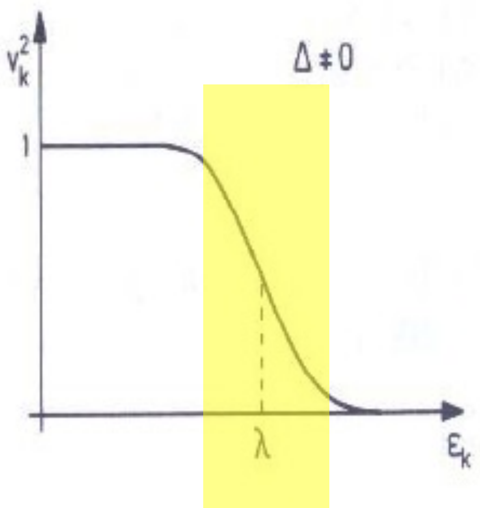
$$| A_o + 2 > = \sum_i \frac{1}{\sqrt{\Omega}} | i >$$

$$\sigma \propto \left(\sum_i \frac{1}{\sqrt{\Omega}} < i | T | o > \right)^2$$

$$\sigma \approx \Omega \sigma_{sp}$$

Collective enhancement over *sp* cross-section due to coherent contributions of correlated *nn* pairs

Pairing rotations and the (t,p) reaction



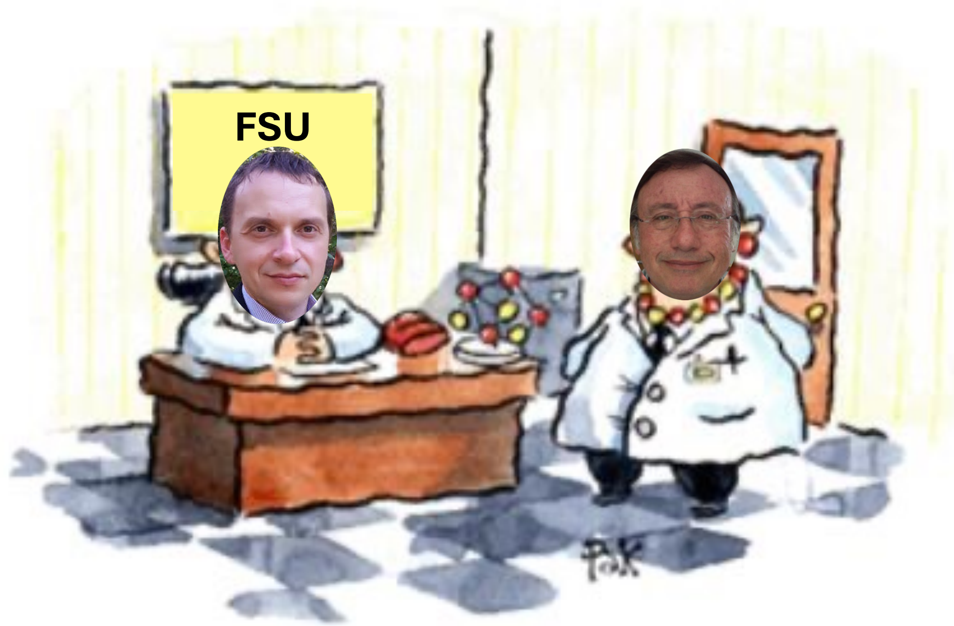
$$\sigma \propto < A_o + 2 | T | A_o >^2$$

$$\sigma \propto \left(\sum_i u_i^o v_i^1 < 1 | T | o > \right)^2$$

$$\sigma \approx \left(\sum_i u_i^o v_i^o \right)^2 \sigma_{sp} = \left(\frac{\Delta}{G} \right)^2 \sigma_{sp}$$

Yoshida, Nuclear Physics 33 (1962) 685--692

On Supperadiance



Augusto,

" WE FEEL THAT YOU JUST DON'T APPRECIATE THE IMPORTANCE OF WHAT WE DO HERE"

Superradiance

Superradiance was first studied by Dicke within the context of coherence effects in spontaneous radiation processes. Since then, the phenomenon has been referenced in many areas of modern science, among them: quantum optics, condensed matter, biophysics, and nuclear physics.

In atomic nuclei, seen as a complex open quantum many-body system, the effect arises from the coupling to continuum states that can be treated in terms of a non-hermitian hamiltonian (non- hermitian super-radiance). Increasing coupling to the continuum leads to the separation of long- lived and short-lived (superradiant) resonance states.

R. J. Dicke, Phys. Rev. 93, 99 (1954)

P. von Brentano, Physics Report 264**,** 57 (1996) 57
A. Volya, V. Zelevinsky, AIP Conf.Proc. 777, 229 (2004)
N. Auerbach, V. Zelevinsky, Rep. Prog. Phys. 74, 106301 (2011)
I. Rotter, J.P. Bird, Rep. Prog. Phys. 78, 114001 (2015)

communications physics

ARTICLE

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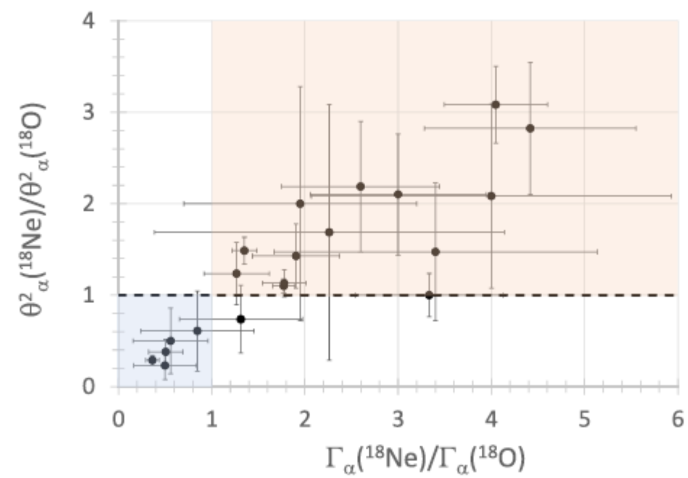
https://doi.org/10.1038/s42005-022-01105-9 OPEN

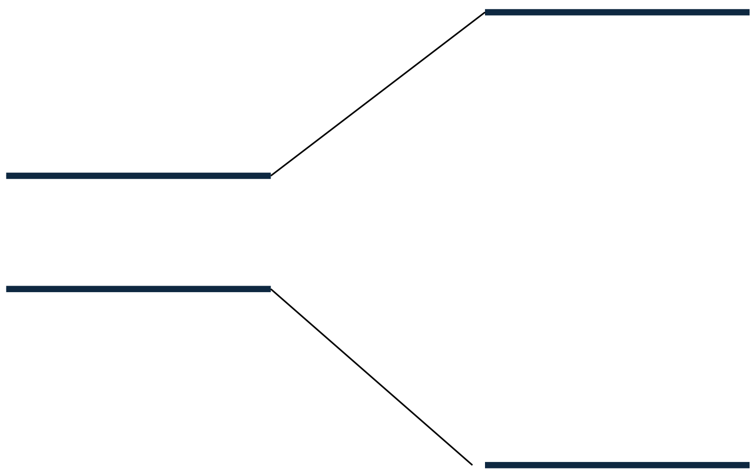
Superradiance in alpha clustered mirror nuclei

Alexander Volya [1,2✉], Marina Barbui [2], Vladilen Z. Goldberg[2] & Grigory V. Rogachev[2,3,4]

includes other decay channels are necessary. It would also be interesting to use different reactions, such as alpha-transfer, to populate the cluster states and provide an independent measure of the total width and branching ratios in mirror nuclei to verify and benchmark current findings. Yet, our findings here may be the clearest manifestation of the superradiance phenomenon in nuclear physics to date.

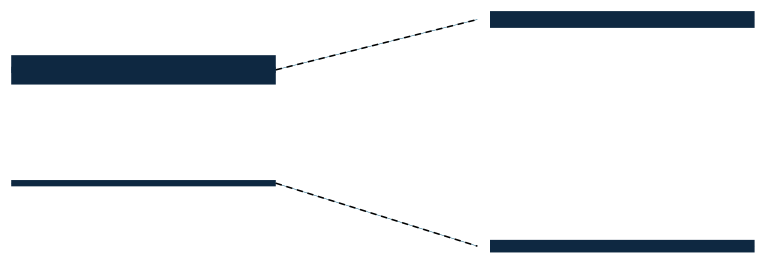


What is superradiance anyway?



Normal mixing of bound levels

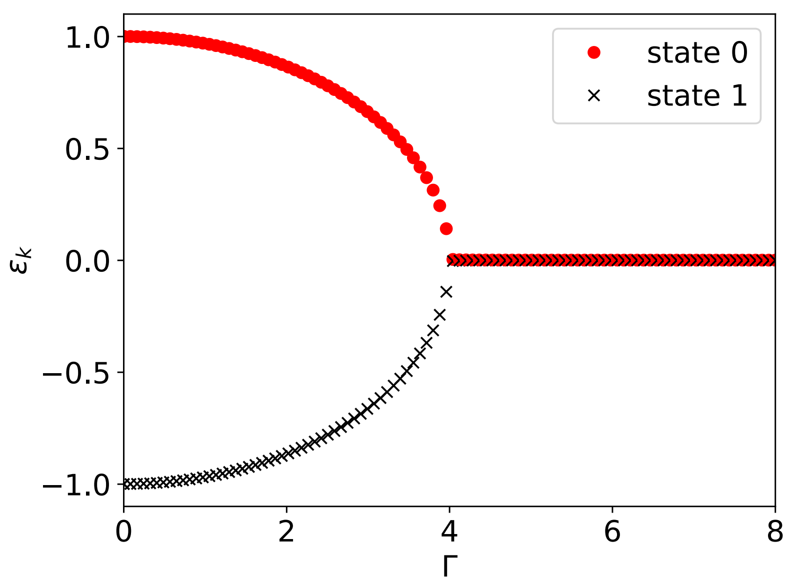
What is superradiance anyway?

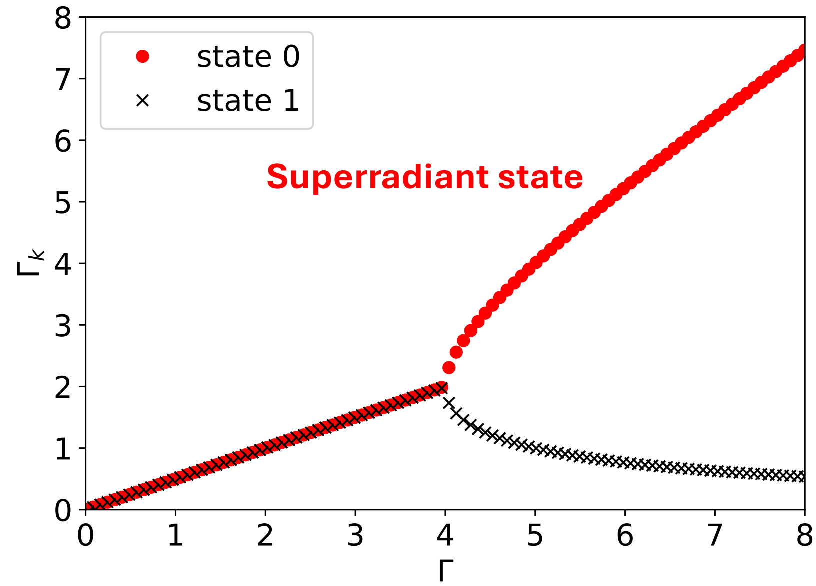


Mixing of unbound levels

$$H = \begin{pmatrix} \epsilon - \frac{i}{2}\Gamma & v \\ v & 0 \end{pmatrix}$$

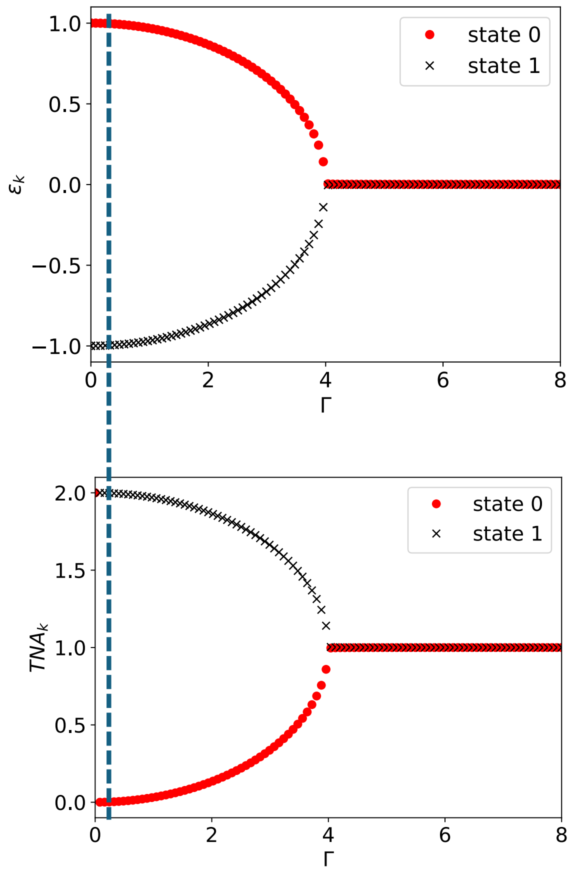
$$\mathcal{E}_{1,2} = \frac{1}{2}\left(\epsilon - \frac{i}{2}\Gamma \pm \sqrt{\left(\epsilon - \frac{i}{2}\Gamma\right)^2 + 4v^2}\right)$$

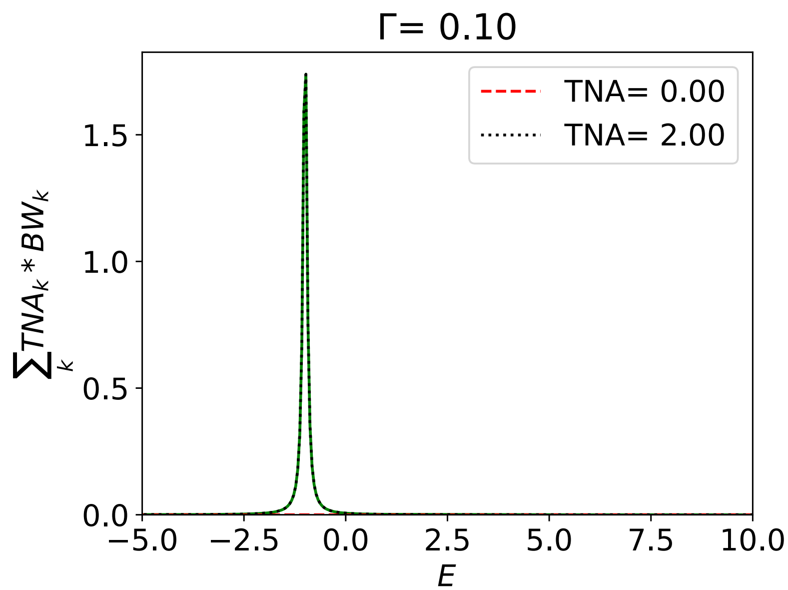




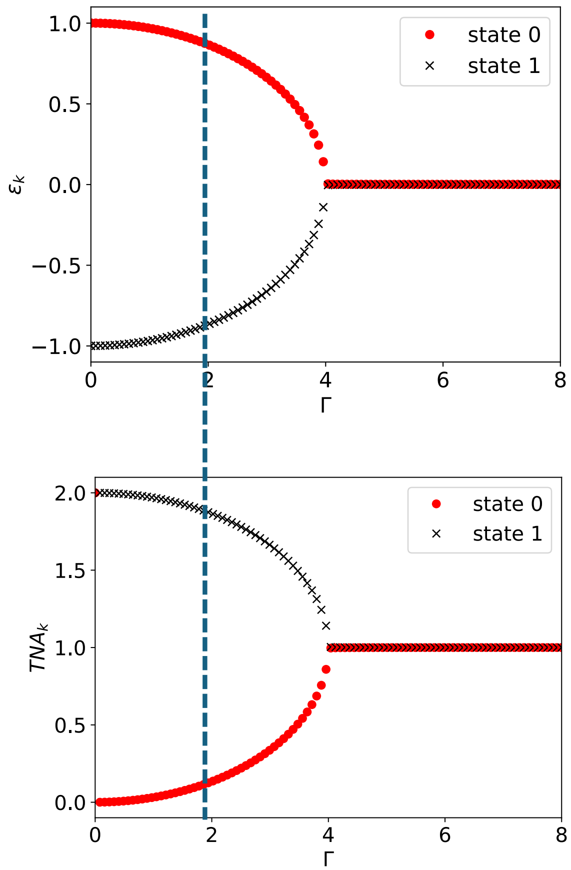
Simplest case degenerate levels, $\varepsilon = 0$

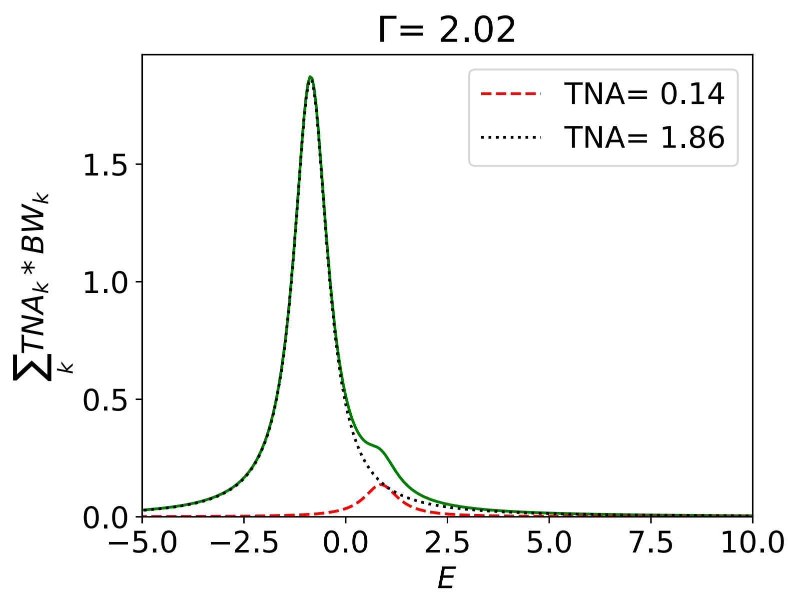
Superradiance and two-neutron transfer reactions



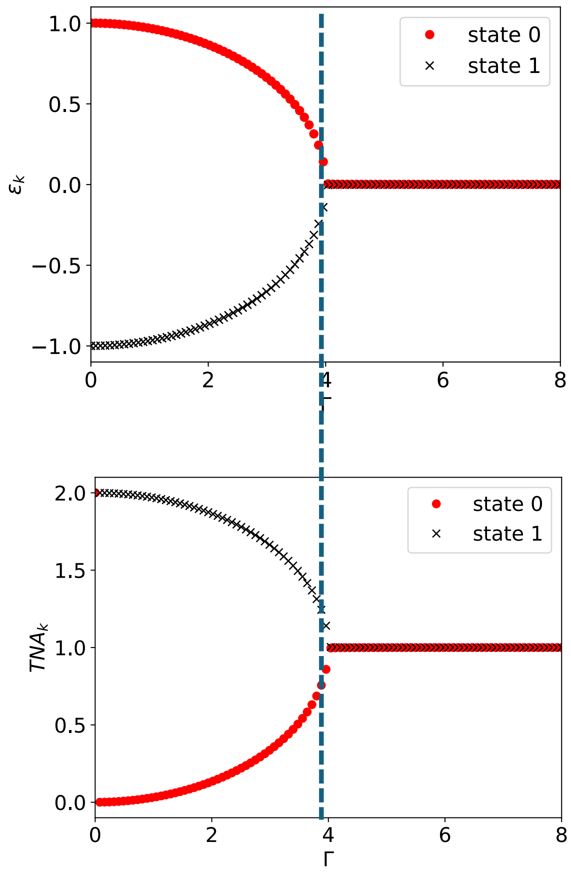


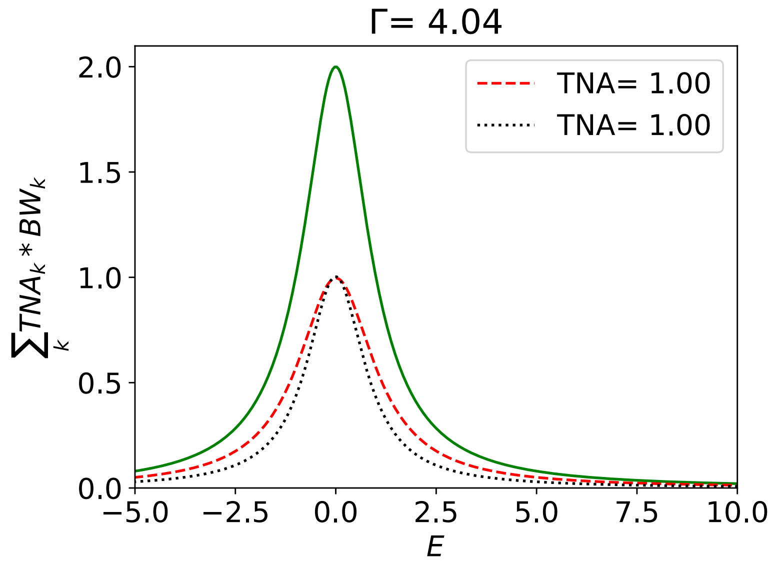
Superradiance and two-neutron transfer reactions



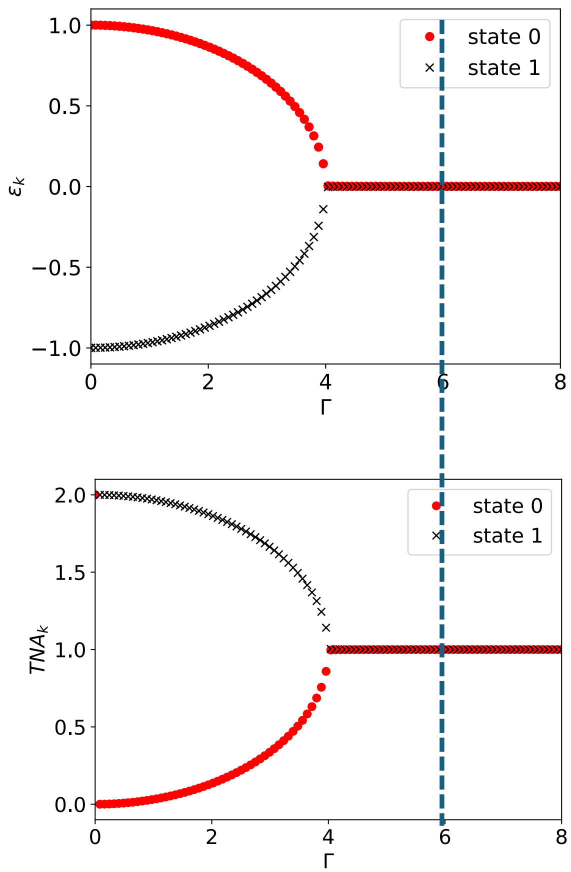


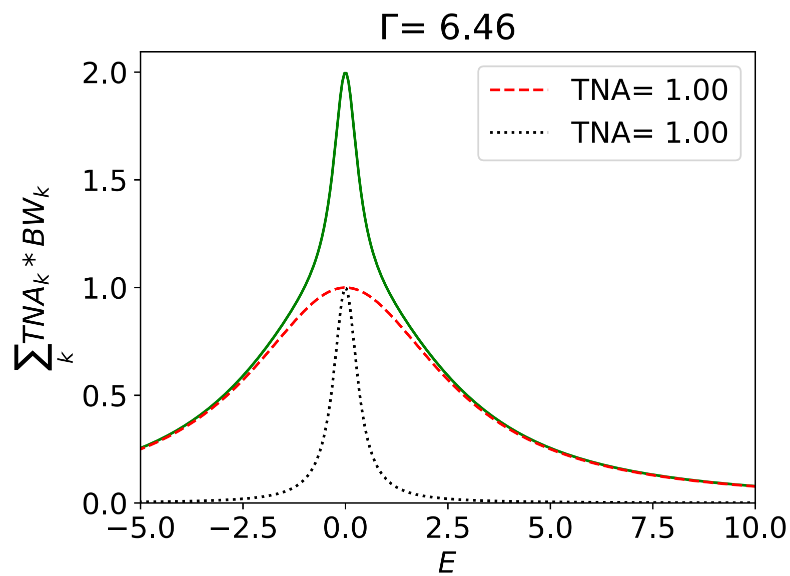
Superradiance and two-neutron transfer reactions





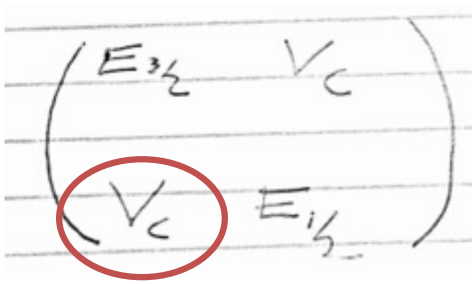
Superradiance and two-neutron transfer reactions



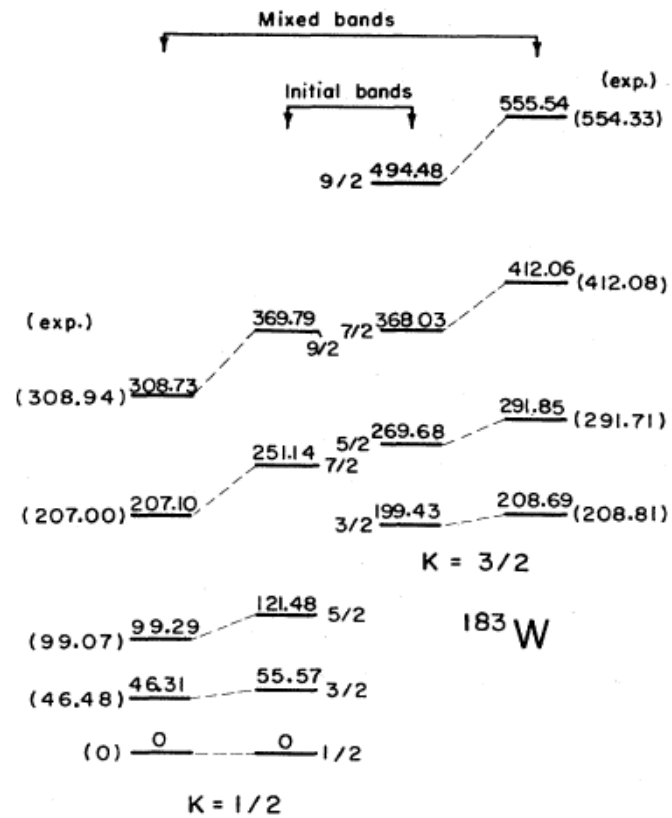


Superradiance and Coriolis coupling

2x2 matrix



$$-(\hbar^2/2\mathfrak{J})[I_+j_- + I_-j_+].$$



Kerman, A. K., 1956, Dan. Mat. Fys. Medd. 30, No. 15.

Arthur Kerman to Rick Casten, ca. 1980

"Experimentalists should not dabble in thought …"

Strong Coupling limit

$$\Delta E_\Omega >> 2AIj$$

CORIOLIS

ROTATIONAL BAND

$$\begin{pmatrix} AI^2 & -2AIj \\ -2AIj & AI^2 + \Delta E_\Omega - i\gamma \end{pmatrix}$$

WIDTH

NILSSON Energies

$$\frac{E_\pm}{A} = (1 \pm \frac{4j^2 \Delta E_\Omega}{\Delta E_\Omega^2 + \gamma^2}) I^2 + iW_\pm$$

RENORMALIZED

Decoupled limit
Degenerate Nilsson levels

CORIOLIS

ROTATIONAL BAND

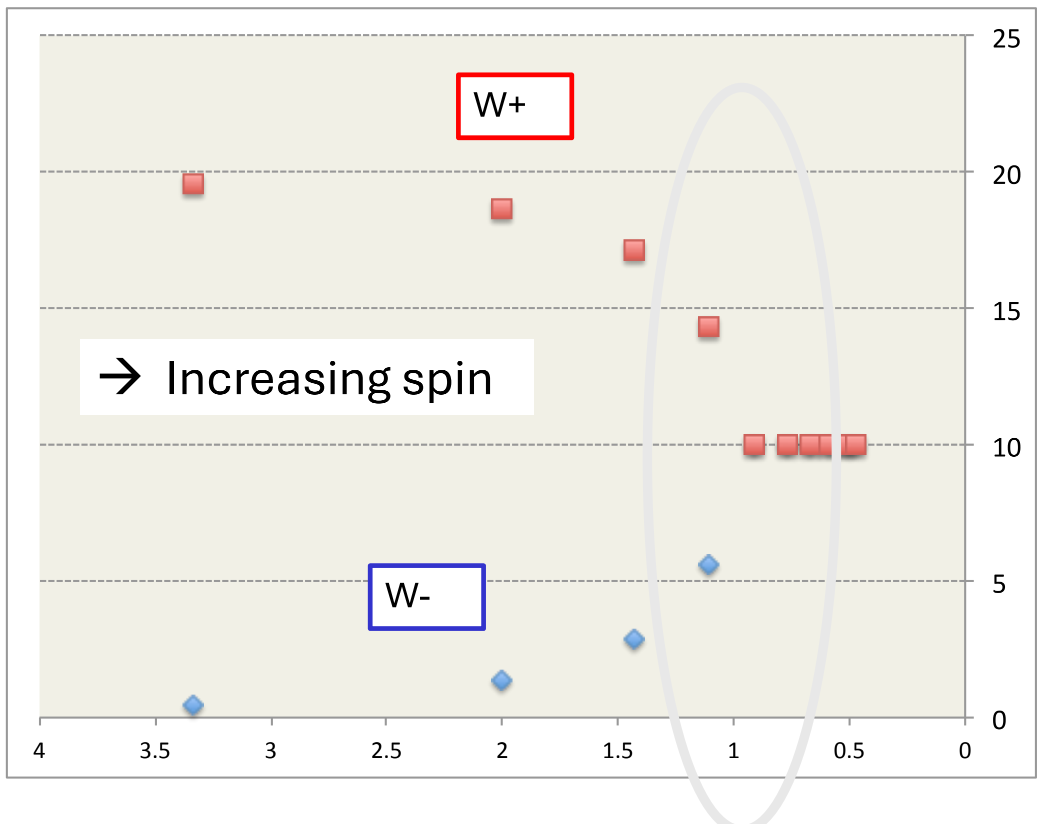
$$\begin{pmatrix} AI^2 & -2AIj \\ -2AIj & AI^2 - i\gamma \end{pmatrix}$$

WIDTH

$$\frac{E_\pm}{A} = I^2 \pm \sqrt{(2Ij)^2 - (\frac{\gamma}{2A})^2} - i\frac{\gamma}{2A}$$

Dimensionless quantity

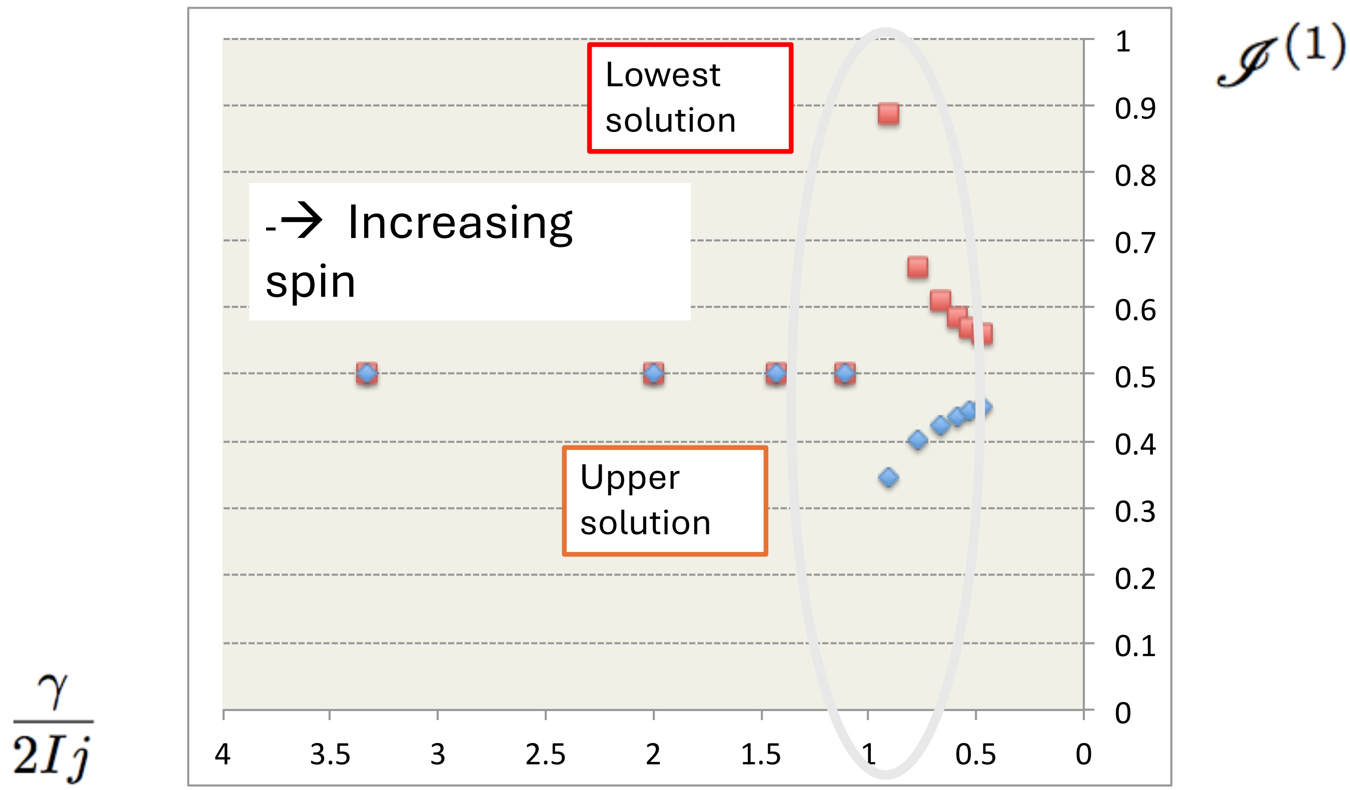
$$\frac{\gamma}{2Ij}$$



WIDTHS

$$\frac{\gamma}{2Ij}$$

$$\omega = \frac{\partial E}{\partial I} \qquad \mathscr{I}^{(1)} = \frac{I}{\omega}$$



Summary I

The evolution of Shell Structure, Pairing Correlations, and Collective motion in exotic nuclei near the drip lines is a topic of much interest in nuclear structure

A 2-level model calculation, including mixing with an unbound state, was used to explore possible consequences on pairing and two-nucleon transfer reactions, and rotational properties of an odd-A system

Despite its simplicity the model captures the main physical (coupling) ingredients and qualitative effects associated with the phenomenon of superradiance seem to appear

Possible cases where these effects could show-up include:

> Study of (t,p) reactions crossing the n-drip line: ^{8He}(t,p), ^{14}Be(t,p), ^{22}O(t,p) ....
> Band-structure of ^{39}Mg

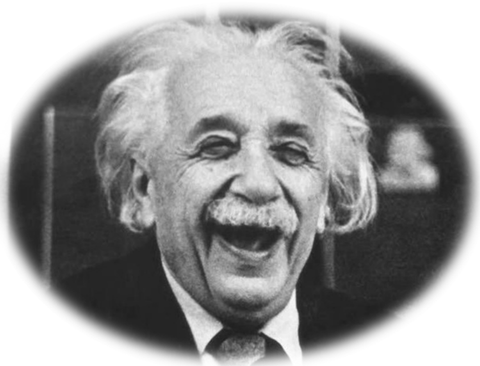
Next steps include an extension the N-levels and the transition to the pairing-rotations regime

Of course, we trust this work will stimulate more realistic calculations to further guide experimental studies

Summary II

We think it looks interesting,   however   ……

….. wonder if it passes the audience



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Acknowledgement

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Danke schön!