Low energy excitations : pairing, cluster and soft modes

Florian Mercier
IJCLab, Orsay, Paris-Saclay University
A. Bjelčić, T. Nikšić, J.-P. Ebran, E. Khan, D. Vretenar

Covariant EDF and Finite Amplitude Method (FAM)

1 First solve RHB equations to obtain static solution

$$\begin{pmatrix} h(\boldsymbol{q}) - \lambda & \Delta(\boldsymbol{q}) \\ -\Delta^*(\boldsymbol{q}) & -h^*(\boldsymbol{q}) + \lambda \end{pmatrix} \begin{pmatrix} U_\mu(\boldsymbol{q}) \\ V_\mu(\boldsymbol{q}) \end{pmatrix} = E_\mu(\boldsymbol{q}) \begin{pmatrix} U_\mu(\boldsymbol{q}) \\ V_\mu(\boldsymbol{q}) \end{pmatrix}$$

2 Start from the usual QRPA equations

$$\left[\begin{pmatrix} A & B \\ B^\star & A^\star \end{pmatrix} - \omega \begin{pmatrix} \mathbb{I} & 0 \\ 0 & -\mathbb{I} \end{pmatrix}\right] \begin{pmatrix} X(\omega) \\ Y(\omega) \end{pmatrix} = \begin{pmatrix} F^{20}(\omega) \\ F^{02}(\omega) \end{pmatrix}$$

Complicated function involving second derivative of density functional ➡ Prohibitive cost of two-qp configurations which prevents systematic applications

3 Linearize the induced hamiltonian and solve the QFAM equations [1,2]

$$\delta h = \lim_{\eta \to 0} \frac{1}{\eta}\left[h(\rho_0 + \delta\rho) - h(\rho_0)\right] \Rightarrow \begin{cases} X_{\mu\nu} = \frac{\delta H^{20}_{\mu\nu} + F^{20}_{\mu\nu}}{\omega - E_\mu - E_\nu} \\ Y_{\mu\nu} = -\frac{\delta H^{02}_{\mu\nu} + F^{02}_{\mu\nu}}{\omega + E_\mu + E_\nu} \end{cases}$$

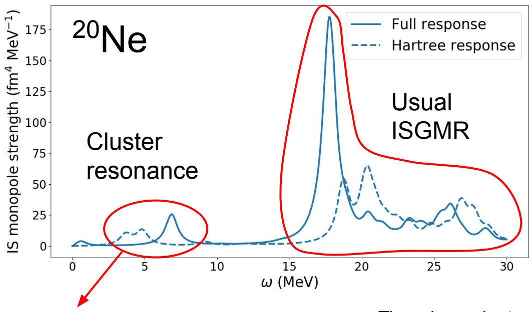
… or explicit linearization

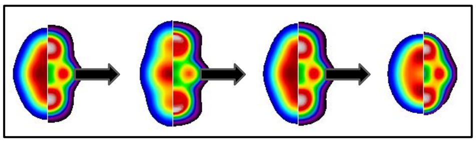
4 Compute strength, density transition, ...

$$S(f,\omega) = -\frac{1}{\pi}\mathrm{Im}\mathrm{Tr}\left[f^\dagger \delta\rho(\omega)\right] \qquad \delta\rho(\omega) = V^\star Y^T U^\dagger + U X V^T$$

Cluster excitation in isoscalar monopole channel

Many experimental results show significant transition strengths in light nuclei at low energy below giant resonance transition. In some cases, these low energy excitations can be associated with α cluster states [3].

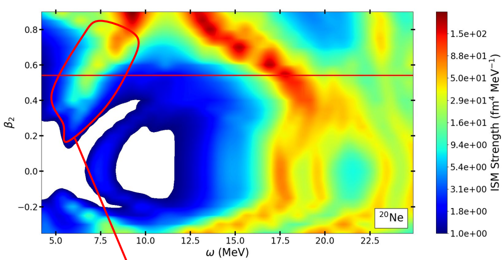




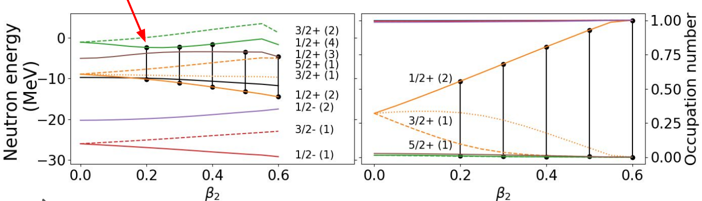
Time dependent evolution of the density and localization function of ^{20}Ne.

$$\rho(\mathbf{r},t) = \rho_{gs}(r_\perp, z) + 2\eta \mathrm{Re}\left[e^{-i\omega t}\delta\rho(\omega, r_\perp, z)\right]$$

Link with deformation



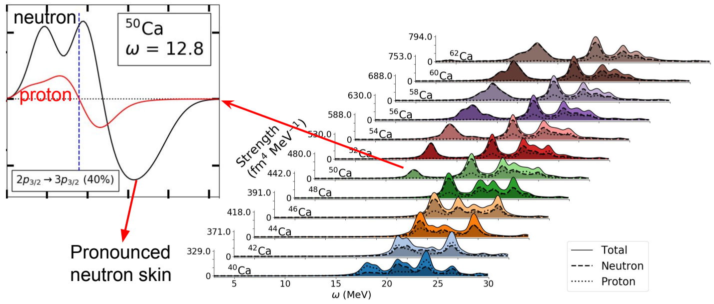
To understand the previous excitation it is useful to compute the ISM response for different (constraint) deformations and see how the system behaves.

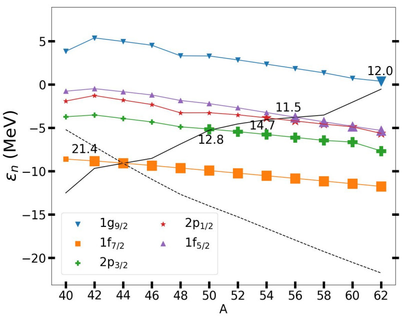


➡ The deformation allows the splitting of some shells, leading to the excitation.

Soft modes

Low energy strengths is not only found in deformed nuclei but also in neutron rich ones. The phenomenon was already known for few years but no systematic explanation was given. The calculation of ISM responses have then been performed for different isotopic chain. Results are presented here for Calcium [4].





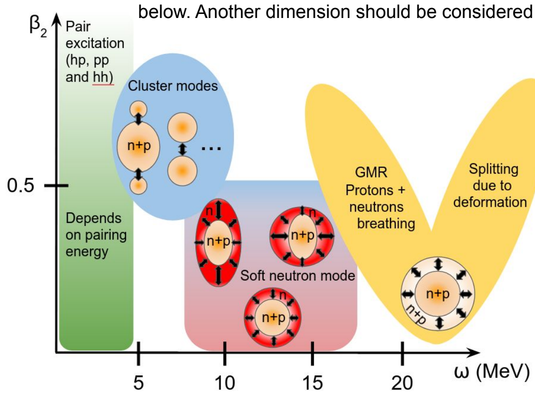
These low energy excitations can be interpreted as single particle excitation linked with opening of neutron shells as neutron are added to the system. Each opening leads to a new excitation at lower energy since the Fermi level becomes closer and closer to the last occupied level.

Other isotopic chains have been studied leading to the conclusion that this pattern is very general and universal for neutron rich system.

Conclusion

It is then possible to compute and find these features for different nuclei, which leads to quite universal behaviours, at least for low mass nuclei.

A typical landscape including the effect of deformation is given in the figure below. Another dimension should be considered for the effect of pairing.



Very different modes co-exist at low energy giving rise, sometimes, to very complex strengths responses.

References

[1] T. Nakatsukasa, T. Inakura and K.Yabana PRC 76, 024318 (2011).
[2] T. Nikšić, N. Kralj, T. Tutiš, D. Vretenar and P. Ring, PRC 88, 044327 (2013).
[3] F. Mercier, A. Bjelčić, T. Nikšić, et al., PRC 103, 024303 (2021).
[4] F. Mercier, J.-P. Ebran and E. Khan, (e-print) arxiv 2109.02498 (2021).