Excited states of zero seniority based on a pair condensate

Theodor Popa

IFIN-HH, Magurele, Romania

Work done in collaboration with N. Sandulescu and M. Sambataro

Phys. Rev. C 107, 034318 (2023)

Outline

- Introduction: open issues
- Zero seniority states: definitions and calculation scheme
- Zero seniority states for ^{108}Sn
    - one-broken pair states
    - excited pair condensates (EPC)
    - EPC and giant pairing vibration
- Conclusions

Open issues

- Excited states of zero seniority are not well-defined in the BCS approximation
- In the particle-number projected BCS (PBCS) the excited states of zero seniority can be defined in the framework of the “one-broken-pair” approximation (OBP). However, there are presently no studies of how the OBP approximation works for the seniority zero excited states past the first such excited state.
- In the present study we investigate a new type of excited states of zero seniority, which has the structure of an Excited Pair Condensate (EPC). We shall show that some of these states have properties in common with the Giant Pairing Vibration.

Seniority zero states within PBCS

$$H = \sum_{i}^{\Omega} \epsilon_i (a_i^\dagger a_i + a_{\bar{i}}^\dagger a_{\bar{i}}) - \frac{1}{4} \sum_{ij}^{\Omega} v_{ij} a_i^\dagger a_{\bar{i}}^\dagger a_{\bar{j}} a_j$$

I. Ground state $\quad |PBCS\rangle = (\Gamma^\dagger)^N |-\rangle \qquad \Gamma^\dagger = \sum_i x_i a_i^\dagger a_{\bar{i}}^\dagger$

II. One broken pair excited state

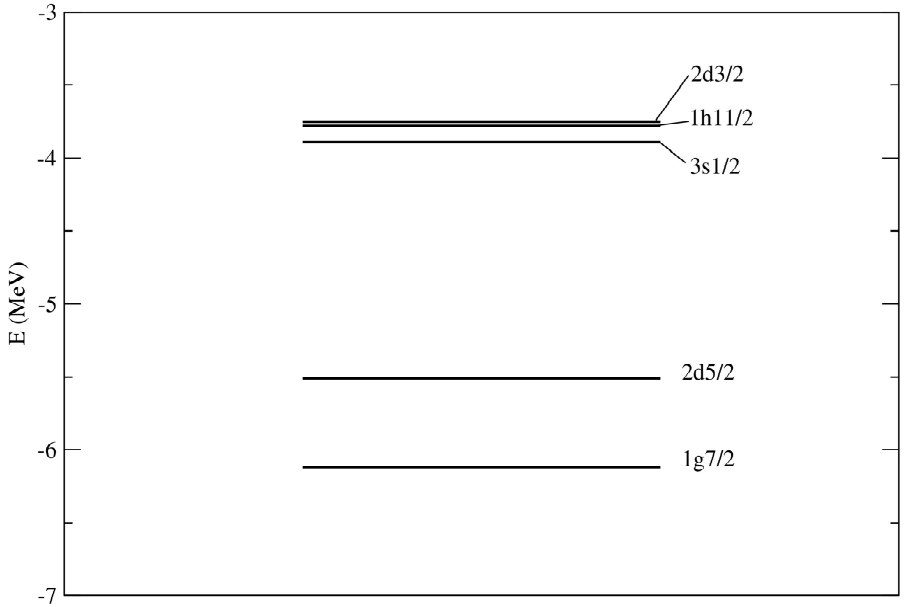
$$|0_k\rangle = \tilde{\Gamma}_k^\dagger (\bar{\Gamma}^\dagger)^{N-1} |-\rangle \qquad \bar{\Gamma}_k^\dagger = \sum_i y_i^{(k)} a_i^\dagger a_{\bar{i}}^\dagger \qquad \tilde{\Gamma}_k^\dagger = \sum_i z_i^{(k)} a_i^\dagger a_{\bar{i}}^\dagger$$

III. Excited pair condensate (EPC)

$$|EPC(k)\rangle = (\hat{\Gamma}_k^\dagger)^N |-\rangle \qquad \hat{\Gamma}_k^\dagger = \textstyle\sum_i w_i^{(k)} a_i^\dagger a_{\bar{i}}^\dagger \qquad \langle PBCS | EPC(k) \rangle = 0$$

the sets of mixing amplitudes are determined variationally

Seniority zero states in ^{108}Sn: state dependent pairing interaction

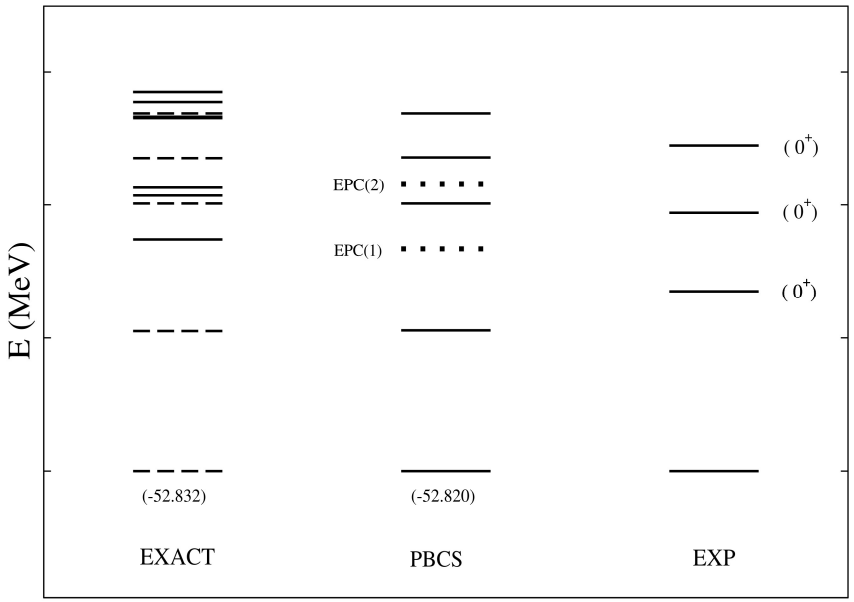


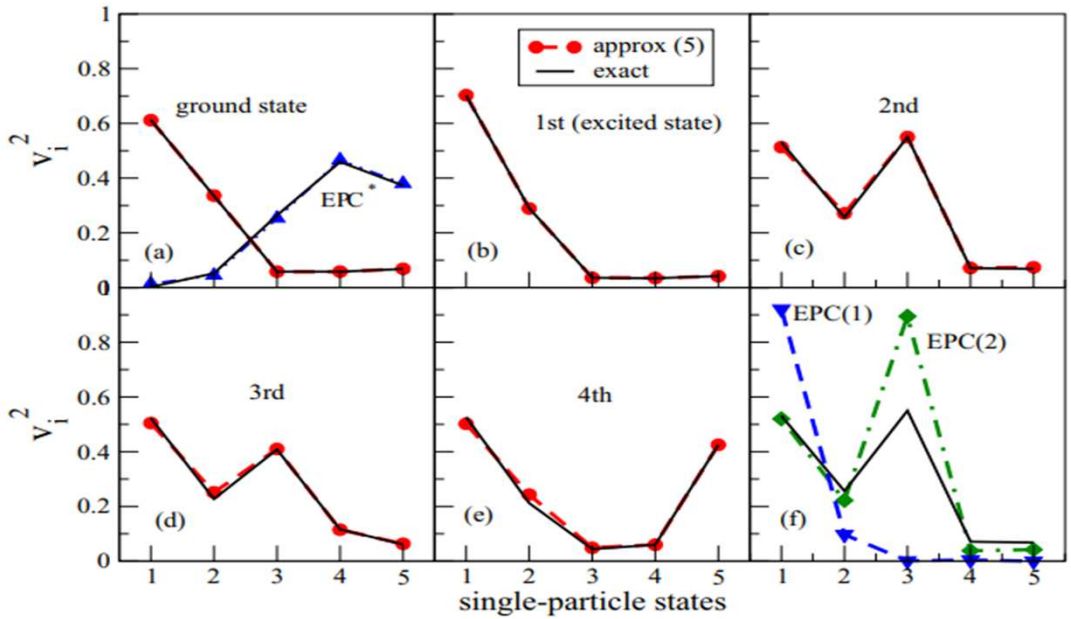
50-82 shell s.p. level distribution

	$g_{7/2}$	$d_{5/2}$	$d_{3/2}$	$s_{1/2}$	$h_{11/2}$
ϵ_j	−6.121	−5.508	−3.749	−3.891	−3.778
$g_{7/2}$	−0.9850	−0.5711	−0.5184	−0.2920	−1.1454
$d_{5/2}$		−0.7063	−0.9056	−0.3456	−0.9546
$d_{3/2}$			−0.4063	−0.3515	−0.6102
$s_{1/2}$				−0.7244	−0.4265
$h_{11/2}$					−1.0599

Single-particle energies ε_j and matrix elements $V_0(j,j')$ employed in the calculations for Sn isotopes - from V. Zelevinsky and A. Volya, Phys. At. Nucl. 66, 1781 (2003)

Seniority zero states in ^{108}Sn: state dependent pairing interaction

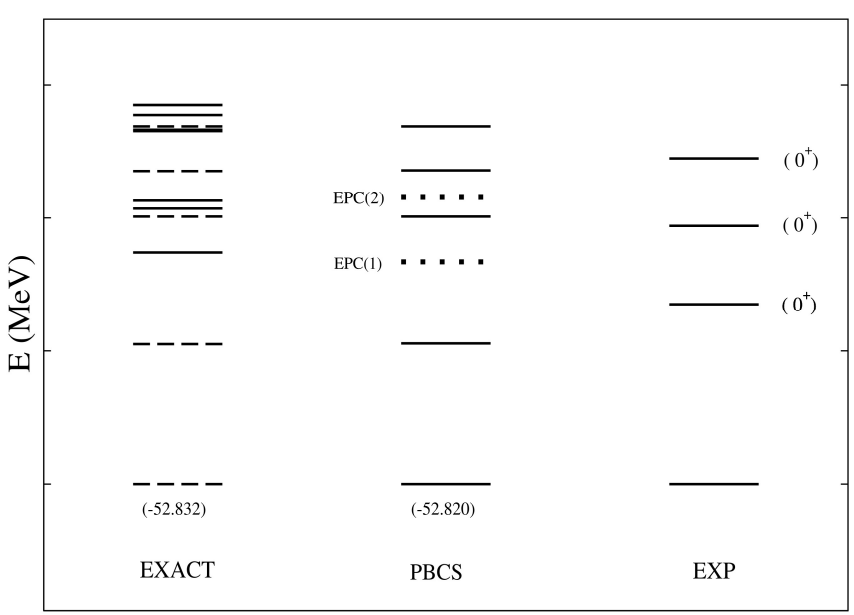


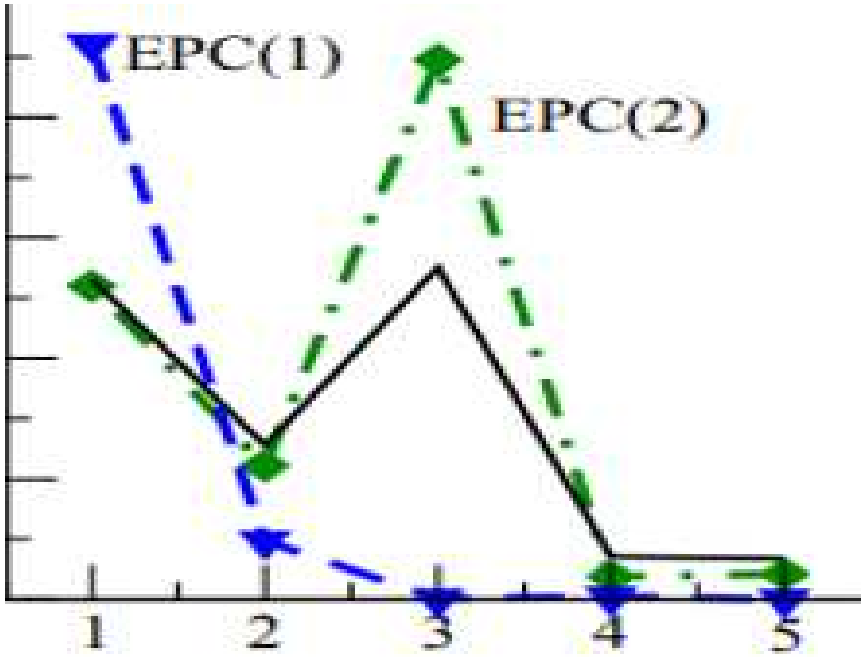


- the one-broken pair (OBP) approximation is able to describe the known J=0 excited states very well !

  - the OBP states have a very similar structure with the exact solutions

Seniority zero states in ^{108}Sn: state dependent pairing interaction





- there are two excited pair condensate states (EPC) found at surprisingly low energies !

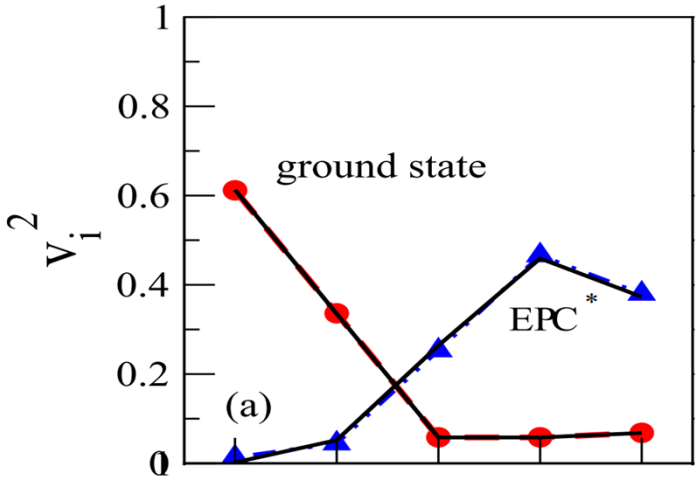
- these EPC states do not have a similar structure to the exact states

The excited pair condensate at high energy

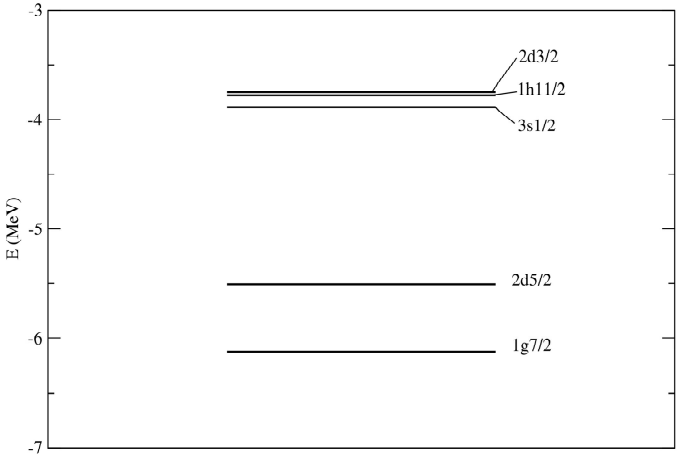
At high excitation energy, around 21 MeV, there is an exact state which has the structure of a pair condensate

This state is analogous to the ground state, but built on the second half of the valence shell 50-82

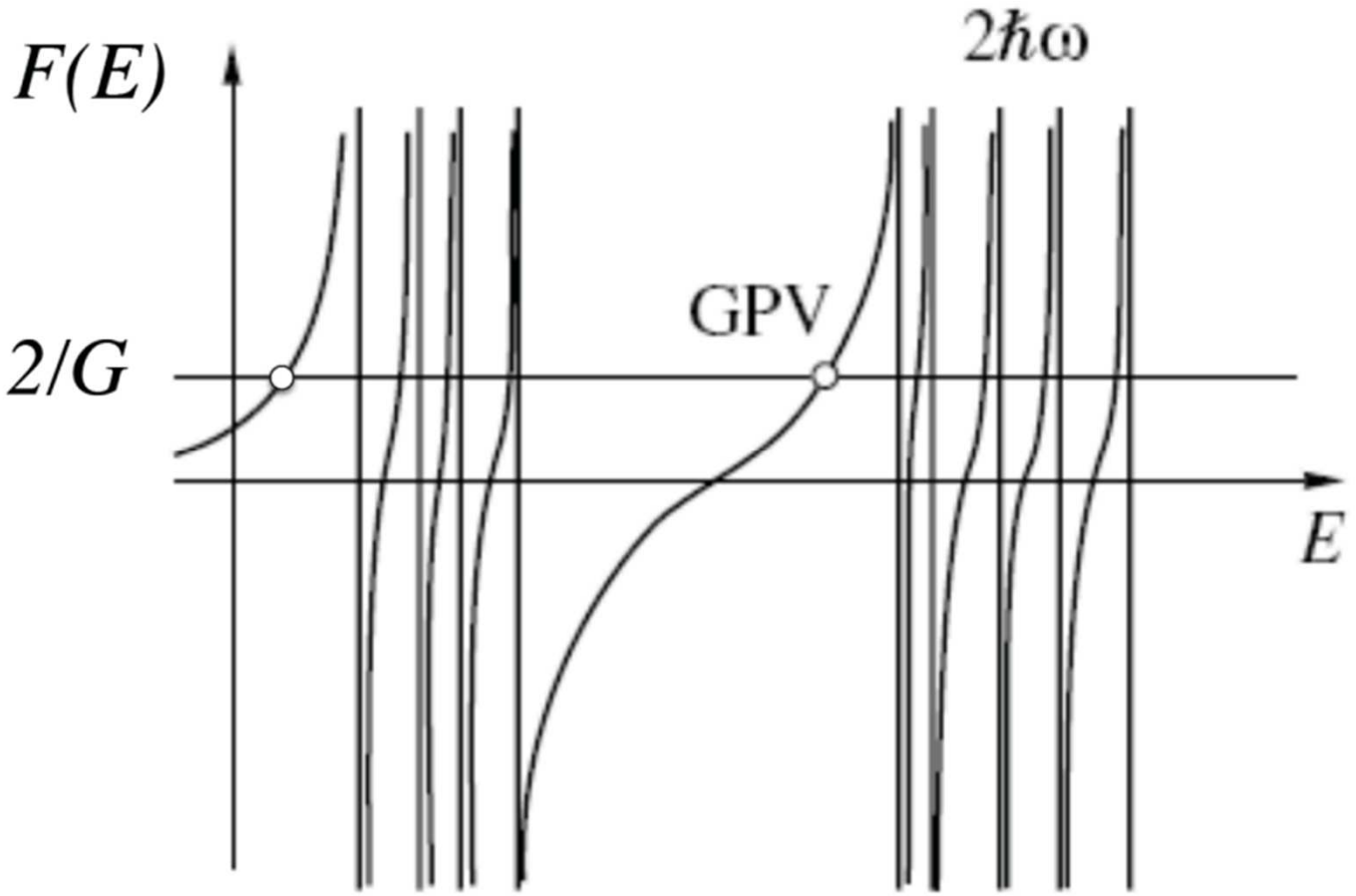
Occupation probabilities



single-particle energies

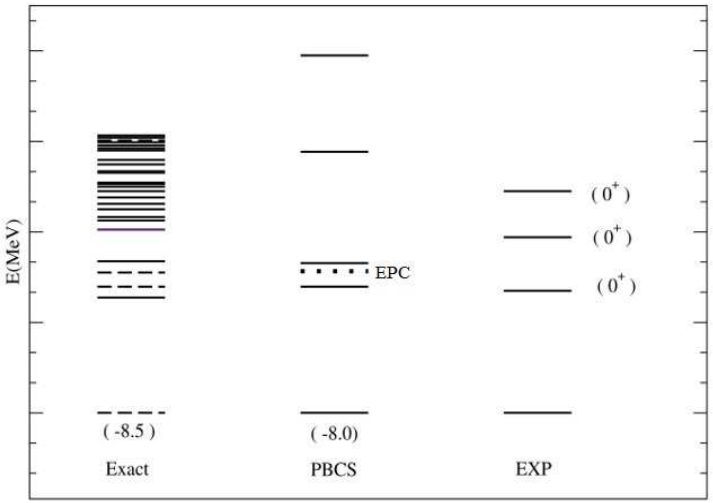


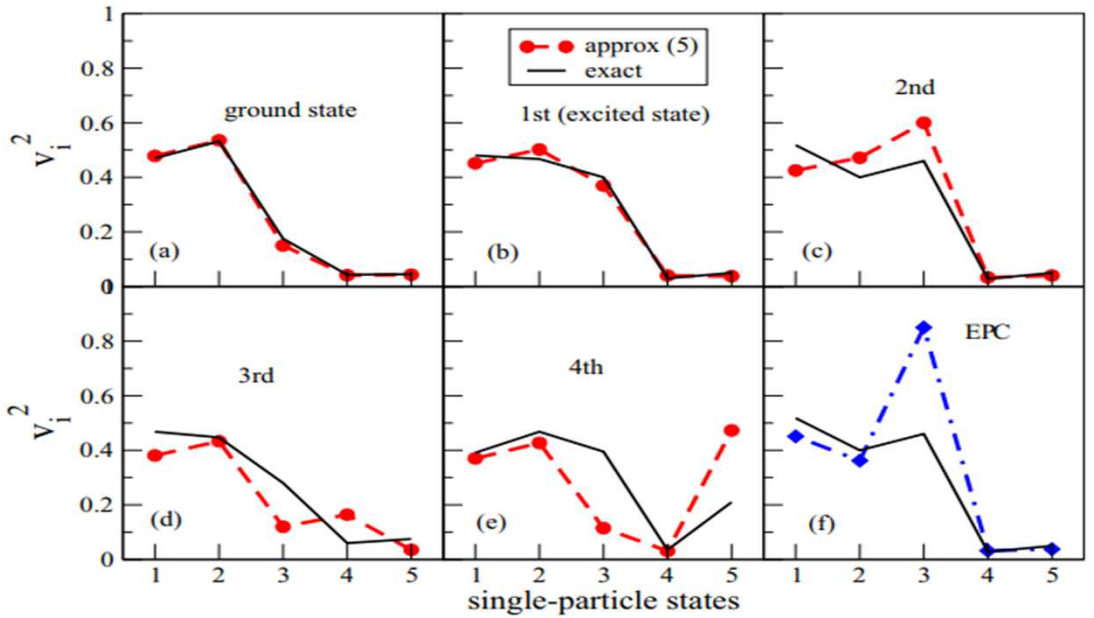
- The distribution of single-particle energies shows that the major shell is split into two parts, which, for 108Sn, play the role of the valence shell and, respectively, the next major shell.
- This fact suggests that the EPC has properties similar to the giant pairing vibration (GPV) !



Schematic of the appearance of the collective state of GPV - from *M. Assié, C. H. Dasso, R. J. Liotta, A. Macchiavelli, and A. Vitturi. The Giant Pairing Vibration in heavy nuclei. Eur. Phys. J. A* ***55****, 245 (2019)*

Excited seniority states for ^{108}Sn: general two-body interaction





- The agreement between the OBP states and the experimental J=0 state is better for the first excited state, but worse for the other two states. The first 3 OBP can be still associated unambigously to an exact state
- The first excited pair condensate appears at low energy and has a different structure from exact states.
- Due to the too many exact J=0 states at high energies, one cannot identify an exact state which would have the structure of an excited pair condensate.

Summary and Conclusions

- We have analyzed the properties of excited states of zero seniority both within the ”one-broken-pair” approximation and for a special class of states that have the structure of an Excited Pair Condensate.
- It was shown that the known J=0 states in 108Sn have a structure of one-broken pair type.
- The excited pair condensate states appear at surprisingly low energies and are different in structure from the exact eigenstates.
- For the state-dependent pairing interaction there is a high energy exact state which has the structure of a pair condensate. This state is mainly built on the second half the single-particle spectrum and has properties in common with the giant pairing vibration states.

Do such excited pair condensate states exist in nuclei ?
How could they be excited in such a way ?

Thank you for your attention!