Recent developments and challenges for (Q)RPA-based methods

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I. SCIENTIFIC ISSUE

The theory of nuclear response plays a paramount role for our understanding of nuclear structure itself, but also for applications to particle physics and astrophysics. Multipole responses probe the basic properties of the nuclear Hamiltonian, while isovector excitations provide unique constraints on the nuclear equation of state and the symmetry energy. Moreover, understanding spin–isospin responses is essential to advance our studies of, e.g., double-β decay and the propagation of neutrinos in the dense matter that characterises compact objects.

The Random Phase Approximation (RPA) is a microscopic approach extensively used for the study of nuclear response. Within the energy density functionals (EDF) framework, it provides a self-consistent description of small-amplitude collective excitations around the ground state. When pairing correlations are included through a superfluid description of the ground state, RPA is naturally extended to the quasiparticle RPA (QRPA).

Building on this framework, over the past decades, numerous advances have been proposed and implemented by different research groups to go beyond the standard RPA framework [1–13]. Some of these developments address the breaking and restoration of symmetries, such as particle number or spherical symmetry in order to describe the open shell and deformed systems more accurately [8, 9], or aim at including finite-temperature effects [10, 14, 15] which are needed for reactions in stellar environments [6, 16].

To overcome the limited configuration complexity of standard (Q)RPA, significant efforts have been devoted to incorporating dynamical many-body correlations beyond the one-particle–one-hole (two-quasiparticle) *ph* (2*qp*) ones constituting (Q)RPA. The implementations of the (superfluid) particle-vibration coupling schemes [17–23], pure 2p-2h configurations [3–5, 24–26], and the multi-phonon structures [13, 27–34] ultimately head to a spectroscopically accurate description in wide energy intervals for medium-mass and heavy nuclei by handling higher configuration complexity [29, 30, 35–38].

Various interactions or EDFs are employed within these theoretical frameworks, including covariant EDFs [39] and effective interactions of the Skyrme or Gogny type [40], each following a specific adjustment protocol. As a result, different (Q)RPA-based approaches may lead to comparable or significantly divergent predictions, depending on the observable and nuclear system under consideration.

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These developments are most often implemented independently, each within a specific numerical code tailored to a given interaction, resolution scheme, or type of beyond-RPA extension. This fragmentation increasingly hampers cross-validation and makes it difficult—particularly for non-expert users—to assess the respective domains of applicability, limitations, and complementarities of the various approaches.

Moreover, recent experimental advances now probe fine structure, strength fragmentation, characteristic energy scales, total widths and their components (Landau, escape, and spreading), as well as transitions between excited states—features that lie beyond standard RPA capabilities. This growing experimental sensitivity places additional pressure on theory to provide quantitatively reliable and systematically improvable descriptions of nuclear response.

In this context, we believe that a dedicated discussion among theorists actively involved in the development of advanced RPA-type methods has become timely and necessary. Such an exchange would aim to (i) identify possible synergies between existing methods, (ii) clarify and communicate their respective complementarities and limitations, and (iii) help each other, i.e. benefit from the knowledge and expertise of colleagues to accelerate the range of applicability of the associated tools. An open exchange between EDF practitioners also about the relationship between the approaches we have discussed, and those carried out by so-called *ab initio* practitioners, should be also envisioned.

II. GOALS OF THE PROJECT

In summary, the goals of the project are:

1. Bring together developers and users of RPA and extended-RPA frameworks to compare their theoretical assumptions, numerical implementations, and domains of applicability.
2. Build bridges and foster collaborations between research groups working with different nuclear interactions and/or models. Discuss which tools need to be developed to study spherical and deformed systems, or closed-shell and open-shell systems, treating deformation and pairing correlations on equal footing.
3. Compare standard diagonalization solutions versus FAM and iterative techniques.
4. Identify the main advantages and limitations introduced in beyond-RPA methods, such as the Second RPA, particle-vibration coupling, multi-phonon approaches.
5. Extend current approaches to the description of electromagnetic or weak transitions between excited states.
6. Identifying the key theoretical extensions and methodological advances needed to address upcoming experimental data and emerging physics questions.

III. LIST OF SPEAKERS

The following list identifies experts in the field, actively involved in the development and improvement of theoretical and computational tools and who have agreed to participate in the workshop. Given the format of the meeting we propose, we do not include a specific presentation topic for each person on this list.

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— Mikael Frosini, CEA Cadarache, France, mikael.frosini@cea.fr
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IV. PRELIMINARY PROGRAM

To ensure the smooth running of the workshop, we propose technical and pedagogical presentations during the morning sessions in order to provide all participants with key technical details that are often omitted in standard conference presentations. The meetings are then organized in the form of round tables focused on the theoretical approaches presented in the morning.

For each round table, a chair will be responsible for a short presentation summarizing the state of the art, the objectives of the session, and the main discussion axes proposed by the participants. The chair of each session will be chosen according to their expertise in the field in order to ensure a constructive and well-oriented discussion. For each of these discussions, we will explicitly invite participants with relevant expertise to prepare discussion material and to inform the session chair of its content. We aim to encourage active participation from all attendees across all topics and to promote open and constructive discussions.

	Tuesday 07/07	Wednesday 08/07	Thursday 09/07
09h15	Opening by organizers Sophie Péru		
09h30	N. Paar	E. Litvinova	S. Péru
10h00	E. Yüksel	G. Colò	E. Khan
10h30	**Break**	**Break**	**Break**
11h00	S. Péru	D. Gambacurta	Focused Session I Colò, Litvinova, Yüksel
11h30	M. Frosini	F. Knapp	Focused Session II Colò, Litvinova, Yüksel
12h00 13h45	**Lunch**	**Lunch**	**Lunch**
13h45 15h00 15h30 16h45	Round table T1 **Break** Round table T1 **End**	Round table T2 **Break** Round table T2 **End**	Round table T3 **Break** Final round table **End**

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