# Symmetry-breaking *versus* symmetry-preserving many-body schemes: how to most efficiently grasp collective correlations in mesoscopic many-body systems?


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## I. SCIENTIFIC ISSUE

Paraphrasing Anderson, the whole is not only greater than but also very different from the sum of the parts [And72]. Put differently, many-body systems exhibit novel features, essentially emergent order or cooperative behaviors, arising out of the properties and/or dynamics of their constituents, without being reducible, explainable nor predictable from them. In the macroscopic world, these novel organizing principles have proven to be efficiently discussed via the concept of (continuous) spontaneous symmetry breaking (SSB) [Gol61] which functions as a structural constraint on the many-body system. Within such a framework, macroscopic systems are described in terms of effective many-body ground states whose symmetry is lower than the symmetry of the underlying many-body Hamiltonian.

The situation is far more involved in finite mesoscopic systems such as atomic nuclei. Indeed, a description of a many-body system based on SSB is appropriate when its number of constituents is large enough to suppress quantum fluctuations, whose effect leads to the superposition of the manifold of degenerate classical symmetry-breaking ground states. In such a case, the features of the system are captured by a set of non-linear mean-field equations for the order parameters associated to the broken symmetries. In mesoscopic systems however, finite-size effects are non-negligible and strong quantum fluctuations eventually prevent the breaking of any symmetry. On the other hand, mesoscopic systems do host a variety of cooperative features very much akin to the collective properties emerging in macroscopic systems and suitably discussed in terms of SSB. Therefore, the way to account in an effective way for such correlations in mesoscopic systems is an open question.

The nuclear many-body problem has seen the deployment of two major strategies thus far, namely *i)* symmetry-preserving approaches that conserve the symmetries of the system at every stage of its implementation, and *ii)* symmetry-unrestricted approaches that rely on the breaking of as many symmetries as necessary to account for collective features in a first step, followed by a post-treatment where all the broken symmetries are eventually restored via, e.g., projection techniques. Each of these two strategies have their pluses and minuses, for instance the


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ability to account both for individual and collective nucleon's excitations but a detrimental scaling with the size of the system for the former, a favorable scaling with the size of the system but the inadequacy to tackle non-adiabatic features as is for the latter. Alongside the traditional approaches representing these two main streams of nuclear many-body approach, new schemes mixing techniques specific to each of them start to develop and provide interesting preliminary results.

### References

[And72] P. W. Anderson, "More is different", Science 177, 393 (1973).
[Gol61] J. Goldstone, "Field Theories with Superconductor Solutions", Nuovo Cim. 19, 154-164 (1961).

## II. GOALS

The main goals of the workshop are:

1. To review the various state of the art approaches developed to tackle the many-body problem
2. To put in vis-a-vis the symmetry-preserving and symmetry-unrestricted approaches
3. To transfer the know-how of techniques specific to one or the other of the two strategies in order to build new hybrid approaches

## III. PROGRAM

### Structure

The meeting takes place over the week. The first day is devoted to introductory/pedagogical presentations that have the aim of informing/educating the local research community on the state of the art approaches developed to tackle the many-body problem. The following days will be more focused on the specificities of symmetry-preserving and symmetry-unrestricted approaches, as well as novel hybrid techniques mixing the know-how of each of these two frames.

### Introductory Lectures

1. P. Palacios *Emergent symmetry breaking in finite systems: philosophical aspects*
2. L. M. Robledo *Basic elements of group theory in quantum mechanics*
3. L. M. Robledo *Fundamentals of symmetry breaking and restoration*
4. T. Duguet *Breaking and restoring symmetries beyond the mean-field*

### Scientific talks

1. Energy density functional (EDF) and Shell-Model (SM) methods
   - M. Bender *State-of-the-art multi-reference EDF calculations. I. Odd systems*
   - T. Rodriguez Frutos *State-of-the-art multi-reference EDF calculations. II. Shape and pairing fluctuations*
   - M. Bender *Spuriosities in the multi-reference EDF formalism*
   - N. Pillet *Symmetry-conserving multi-particle/multi-hole calculations*
   - J.-P. Ebran *Symmetry considerations in the relativistic EDF method*

- C. W. Johnson *From the shell model to generator coordinates and back*
- A. Gorling *Symmetry in density functional theory*

2. *Ab initio* many-body methods

- H. Hergert *Multi-reference in-medium similarity renormalization group theory*
- C. Yannouleas *Symmetry breaking and restoration for ring-trapped ions and neutral atoms*
- M. Frosini *High-order Bogoliubov many-body perturbation theory*
- U. Meißner *Nucleons on a Lattice: Symmetry Breaking & Restoration*
- V. Somà *Particle-number breaking self-consistent Gorkov Green's function calculations*
- M. Veis *Hartree-Fock and many-body perturbation theory for periodic helical systems*
- A. Tichai *Particle-number-projected Bogoliubov many-body perturbation theory*
- J. Ripoche *Normal-ordering approximation in particle-number breaking theories*
- C. Robin *Single-particle relaxation effects from the multi-particle-multi-hole configuration mixing approach*

### A. Schedule

| | Monday | | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|---|
| 09h30 | Welcome | | | | | |
| 09h45 | **Palacio** | 9h30 | **Bender I** | **Pillet** | **Robin** | **Bender II** |
| 11h00 | Break | 10h30 | Break | Break | Break | Break |
| 11h30 | **Robledo I** | 11h00 | **Ebran** | **Johnson** | **Hergert** | **Meißner**$^*$ |
| 12h45 | Lunch | 12h00 | Lunch | Lunch | Lunch | Lunch |
| 14h15 | **Robledo II** | 14h00 | **Ripoche** | **Rodriguez** | **Somà** | **Veis** |
| 15h30 | Break | 15h00 | Break | Break | Break | Break |
| 16h00 | **Duguet** | 15h30 | **Tichai** | **Gorling** | **Yannouleas** | **Frosini** |
| 17h30 | End | 16h30 | Discussions | Discussions | Discussions | End |
| | | 18h00 | End | End | End | |
| | | 20h00 | | Social dinner | | |

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