Many-body correlations, phase transitions, and clustering:
how to identify and quantify them?

Organizers
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I. SCIENTIFIC ISSUE

The structure of atomic nuclei reflects a delicate interplay between single-particle motion and collective correlations. Phenomena such as pairing, shape coexistence and clustering exemplify how complex emergent behavior arises from fundamental nucleon–nucleon interactions.

In recent years, major progress has been achieved in *ab initio*, shell-model, and energy-density functional approaches, as well as through advanced experimental probes. However, the field still lacks unified diagnostics capable of quantifying the degree of collectivity, correlation, and condensation in a model-independent manner.

Information-theoretic and correlation measures, such as invariant correlation entropy, Shannon entanglement entropy, group-theoretic decompositions, and Yang's criterion for off-diagonal long-range order, based on the eigenvalues of the density matrix, offer powerful tools to quantify correlations beyond conventional observables. Their systematic application to nuclear systems opens new opportunities to identify clustering and condensation in both ground and excited states, to trace signatures of pairing-to-clustering transitions, and to explore analogs of condensed-matter phenomena such as the Josephson effect in nuclei. Furthermore, these ideas can and do drive novel theoretical models, such as weak-entanglement between proton and neutron components suggesting a novel importance truncation method.

The topics we intend to discuss are:

(a) Clustering and α-like Correlations: Identification of cluster structures and α-condensate components in ground and excited states; connections between cluster models, the shell model, and *ab initio* calculations; manifestations of clusterisation in light and medium-mass nuclei.

(b) Pairing and Condensation Phenomena: Theoretical fingerprints of pair and α-condensation; observables in spectroscopy and reactions; analogies to superfluidity and Bose–Einstein condensation in finite systems.

(c) *Josephson Effect in Nuclear Systems*: Recent theoretical and experimental studies of pair-transfer between superfluid nuclei; possible extension toward α-transfer in N = Z systems; links to tunneling phenomena and coherence effects in nuclear reactions.

(d) Information-Theoretic and Correlation Measures: Application of invariant correlation entropy, Shannon entanglement entropy, mutual information, and Yang's criterion to characterize correlations and long-range order in nuclear models; benchmarking across theoretical frameworks.

(e) *Emergent Symmetries and Quantum Phase Transitions*: Role of dynamical symmetries and symmetry-breaking transitions ((SU(3)–U(5), pairing–quadrupole competition, shape coexistence) as organizing principles of nuclear collectivity.

(f) *Entropy, Complexity, and Chaos in Finite Quantum Systems:* Using entanglement and information measures to quantify chaos, complexity, and mixing in nuclear spectra; connections with quantum thermalization and statistical behavior in finite nuclei.

(g) *Interdisciplinary Perspectives*: Cross-fertilization with quantum information science, condensed-matter superfluidity, ultracold atomic gases, and quantum chemistry; identifying universal indicators of long-range order and condensation.

(h) *Computational and Data-Driven Approaches:* Techniques for identifying correlated structures, dimensionality reduction of many-body wavefunctions.

II. GOALS OF THE WORKSHOP

(i) To discuss how correlations and clusterisations are treated in various models and how they manifest in experimental data.

(ii) To discuss how to identify and to quantify, theoretically and experimentally, the emergence of quantum phase transitions associated to pairing and α-like condensation.

(iii) To explore the methods employed to describe correlations, phase transitions and condensation in condensed matter superfluidity, ultracold gases and quantum information, and to discuss how they can be applied to nuclear systems.

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III. PRELIMINARY PROGRAM

Tentative List of Speakers (subject to change)

M. Assié (IJCLab Orsay)
F. Barranco (University of Sevilla)
D. Beaumel (IJCLab Orsay)
O. Bessidskaia-Bylund (IJCLab, Orsay)
B. Cederwall (Stockholm)
L. Corradi (INFN-LNL, Legnaro)
J.-P. Ebran (CEA DAM)
D. Gambacurta (INFN Catania)
V. Goldberg (Texas A&M)
N. Itagaki (Osaka Metropolitan University)
C. W. Johnson (SDSU, San Diego)
E. Khan (IJCLab Orsay)
K. Kravvaris (Lawrence Livermore National Laboratory)
D. Lee (Michigan State University)
H.-Z. Liang (U. Tokyo/RIKEN)
E. Litvinova (Western Michigan University)
P. Magierski (Warsaw University of Technology)
A. Nurmukhanbetova (Nazarbayev University)
T. Otsuka (University of Tokyo)
G. Rogachev (Texas A&M)
N. Sandulescu (IFIN-HH, Bucharest)
P. Van Isacker (GANIL)
A. Volya (Florida State University)

7 September	8 September	9 September	10 September	11 September
10:00-10:45 **Lecture**	10:00-10:45 **Lecture**	10:00-10:45 **Lecture**	10:00-10:45 **Lecture**	10:00-10:45 Talk
		10:45-11:00 Break		
11:00-11:45 **Talk** 11:45-12:30 Talk	11:00-11:45 **Talk** 11:45-12:30 Talk	11:00-11:45 **Talk** 11:45-12:30 Talk	11:00-12:00 **Seminar** 12:00-12:30 Short com.	11:00-11:45 Talk 11:45-12:30 Talk
		12:30-14:00 Lunch		
14:00-14:45 **Talk**	14:00-14:45 **Talk**	14:00-14:45 **Talk**	14:00-14:45 **Talk**	14:00-14:45 **Talk**
14:45-15:15		Short communications		14:45-15:15 Closeout
		15:15-15:30 Break		
15:30-16:30		Discussions		-----