

Master 2: International Centre for Fundamental Physics

INTERNSHIP PROPOSAL

Laboratory name : Matériaux et Phénomènes Quantiques – MPQ UMR7162

Location : Université Paris Cité – 10 Rue A. Domon et L. Duquet – Bât. Condorcet – 75013 PARIS

Internship director : Prof. Cristiano Ciuti (THEORIE group)

Email: cristiano.ciuti@u-pariscite.fr

<https://scholar.google.it/citations?user=rzc1ND0AAAAJ&hl=en>

Variational Phase-Space Methods for Quantum and Complex Dynamics

Simulating the dynamics of complex systems is one of the major challenges of modern physics. The number of relevant degrees of freedom can grow extremely rapidly, making exact approaches prohibitively expensive and motivating the search for radically different strategies.

A promising route is to replace the exact description of a system by a flexible representation in phase space, whose parameters evolve according to a variational principle. For quantum systems, the Wigner distribution provides such a representation in terms of generalized positions and momenta. Unlike a classical probability distribution, it can take negative values, reflecting quantum features such as interference. Its dependence on several modes also encodes their correlations. In our recent work [1], we introduced a variational multi-Gaussian phase-space framework in which complex quantum states are represented through a superposition of Gaussian structures. A key breakthrough is the combination of analytical Gaussian integrals with automatic differentiation to evaluate the variational equations of motion efficiently. This makes it possible to handle rich and highly structured variational representations without having to derive and implement increasingly cumbersome expressions by hand.

The aim of this internship is to push this idea further and investigate a new generation of variational phase-space methods. The central question will be how to design compact and adaptive representations that capture the essential correlations and collective structures of a complex dynamical system while avoiding the extremely large spaces encountered by brute-force approaches.

The range of possible applications is particularly broad. Starting from quantum physics, these methods can be explored for open and driven quantum systems, quantum many-body dynamics, nonlinear light-matter systems and strongly correlated problems. More generally, the same combination of phase-space representations and variational principles can potentially be extended to nonlinear and stochastic systems, semiclassical dynamics, high-dimensional classical dynamics, collective phenomena and other problems in complex physics.

An important aspect of the project will therefore be to explore how far the underlying methodology can be generalized beyond the setting in which it was originally developed. The internship may involve the development of new variational representations and their application to selected physical problems.

The project is primarily a theoretical physics project. Depending on the student's interests, it can range from analytical developments to numerical simulations and concrete applications. The necessary computational tools will be introduced progressively during the internship.

Reference

[1] J. Tosca, F. Carnazza, L. Giacomelli, and C. Ciuti, "Variational Multi-Gaussian Phase-Space Bosonic Dynamics via Automatic Differentiation," *Physical Review X* 16, 031077 (2026).

<https://doi.org/10.1103/q3m5-q44b>

Condensed Matter Physics : YES

Quantum Physics : YES

Macroscopic Physics and complexity : YES

Theoretical Physics : YES