

INTERNSHIP PROPOSAL

Laboratoire Kastler Brossel & LPENS

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Internship location: Collège de France

Thesis possibility after internship: YES

Funding for the PhD: YES (ANR)

Microscopic nature of the polaron-dimeron transition

Strongly correlated fermions are ubiquitous in various contexts: electrons in solids or molecules, nucleons in nuclei or neutron stars, quarks in QCD. Our understanding of such systems is limited by the difficulty to compute their properties in a reliable and unbiased way. For conventional quantum Monte Carlo methods, the computational time generically grows exponentially with the number of fermions, due to the “fermion sign problem”.

The situation is different with connected Feynman diagrams, which can be computed directly in the thermodynamic limit. In contrast to usual diagrammatic calculations which are limited to low orders, the idea of the *diagrammatic Monte Carlo* approach is to evaluate high enough orders to control the series-truncation error. This allowed us to obtain results for strongly correlated Fermi gases which served as benchmarks for cold atom experiments [1].

This PhD project is focused on the “Fermi polaron” problem, in which a single spin- $\downarrow$ impurity interacts with a Fermi sea of spin- $\uparrow$ particles. Interactions give rise to the “polaron” quasiparticle, where the $\downarrow$ impurity is dressed by particle-hole excitations of the $\uparrow$ Fermi sea. In 2D and 3D, when the interaction becomes increasingly attractive, a first-order transition is believed to occur: the polaron turns into a “dimeron” where the $\downarrow$ particle binds with one of the $\uparrow$ particles. Using an efficient numerical algorithm developed in our group [2], we will compute key microscopic properties of the Fermi polaron with high precision and investigate fundamental open questions concerning the nature of the polaron-dimeron transition.

The project is closely connected to an ongoing experimental effort in the group of Tarik Yefsah at Laboratoire Kastler Brossel. Building on a recently developed technique for imaging ultracold fermions with single-atom resolution in the continuum [3], these experiments will offer new opportunities to probe the microscopic properties and correlations of the Fermi polaron and strongly interacting Fermi gases. Our theoretical results for the 2D Fermi polaron will serve as benchmarks and guides for the experiments that will be done in parallel.

The internship will consist in preliminary studies for the PhD project.

[1] Van Houcke *et al.*, [Nature Phys. 8, 366 \(2012\)](#); Rossi *et al.*, [PRL 121, 130406 \(2018\)](#)

[2] Van Houcke *et al.*, [PRB 101, 045134 \(2020\)](#)

[3] Daix *et al.*, [PRL 136, 153402 \(2026\)](#)

Condensed Matter Physics, Quantum Physics, Theoretical Physics: YES

Soft Matter and Biological Physics, Physics of Energy and Climate Dynamics: NO