Master 2: ***International Centre for Fundamental Physics***

INTERNSHIP PROPOSAL

Laboratoire Kastler Brossel & LPENS
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Internship location: Collège de France Thesis possibility after internship: YES
Funding: NO (need to apply for EDPIF scholarship)

Diagrammatic Monte Carlo study of the unitary Fermi gas

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 fundamentally different with connected Feynman diagrams, which can be computed directly for infinite volume. In contrast to usual diagrammatic calculations, we control the series-truncation error by going to high orders. To this end we develop Monte Carlo algorithms allowing to sample diagrammatic series. Furthermore, diagrammatic series are often divergent. One then has to give a mathematical meaning to the series, and then to construct a resummation method capable of transforming the divergent series into a result that converges towards the exact physical value (in the limit of infinite truncation-order). The appropriate resummation method can be found by studying the large-order asymptotic behavior.

We have realized this program for the first time for strongly correlated fermions in continuous space, obtaining the large-order asymptotics analytically using functional-integral and saddle-point techniques. Specifically, we studied spin-1/2 non-relativistic fermions in 3D with contact interactions of infinite scattering length, the so-called unitary Fermi gas [1-3]. Apart from being qualitatively relevant for neutron stars, the unitary gas model accurately describes experiments on ultracold atomic gases conducted in several labs (LKB, MIT, Hamburg, Technion, Yale…) which gives opportunities for direct theory-experiment comparison.

Our projects include extending our computations to new regimes –in particular the polarized regime, where conventional QMC suffers from the sign problem– and new observables –motivated by recent and ongoing experiments. On the algorithmic side, we plan to make use of the approach of [4], which has several advantages over the algorithm described in [5] that we have used so far. Possible internship projects include extensions of our works on large-order asymptotics [1] or on the "Fermi polaron" [6].

References:

[1] R. Rossi, T. Ohgoe, K. Van Houcke, F. Werner, PRL 121, 130405 (2018)
[2] R. Rossi, T. Ohgoe, E. Kozik, N. Prokof'ev, B. Svistunov, K. Van Houcke, F. Werner, PRL 121, 130406 (2018)
[3] K. Van Houcke, F. Werner, E. Kozik, N. Prokofev, B. Svistunov, M. Ku, A. Sommer, L. Cheuk, A. Schirotzek, M. Zwierlein, Nature Phys. 8, 366 (2012)
[4] R. Rossi, PRL **119**, 045701 (2017)
[5] K. Van Houcke, F. Werner, T. Ohgoe, N. Prokof'ev, B. Svistunov, PRB 99, 035140 (2019)
[6] K. Van Houcke, F. Werner, R. Rossi, PRB 101, 045134 (2020)

specialities adapted to the subject:

Theoretical Physics: YES Quantum Physics: YES
Condensed Matter Physics: YES Soft Matter and Biological Physics: NO