PhD proposal in Theoretical Condensed Matter Physics

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Measuring entanglement of quantum systems with novel Quantum Monte Carlo algorithms

Entanglement is probably the most prominent feature that allows to distinguish quantum from classical systems. At the application level, it is a vital ingredient for newly developed quantum communication devices as entanglement is a resource for quantum information processing. The field of quantum metrology, which aims at improving the precision of measurements of physical quantities, also heavily relies of entanglement properties of condensed-matter systems.

At the fundamental level, the study of entanglement properties of quantum many-body states has recently shed new light on our understanding of condensed matter systems at zero temperature. Let us mention the characterization of new states of matter (such as topological liquids[1]) or the detection of quantum phase transitions.

Quantifying how much entanglement is present in a system is however a difficult task, specially for many-body systems with an exponential number of degrees of freedom. Very recent breakthroughs[2] in the numerical determination of entanglement with Quantum Monte Carlo techniques are changing the situation.

This PhD proposal aims at developing and improving on these recent developments, in the goal of providing a powerful tool for the characterization of entanglement of quantum many-body systems. Applications will be in the field of quantum magnets, superfluid systems, as well as quantum systems with intrinsic disorder (such as quantum "superglasses", new states of matter with unusual physical properties).

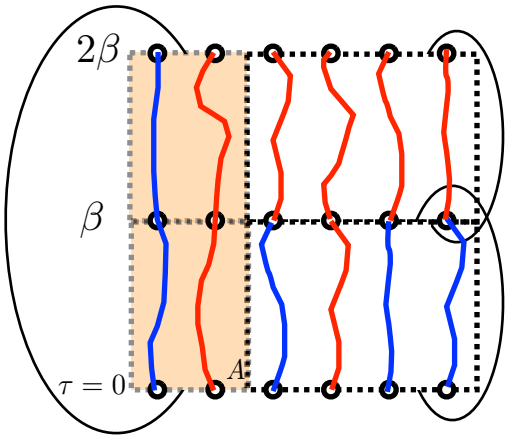

Illustration of the path integral formulation used to measure entanglement entropy in Quantum Monte Carlo.

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[1] S.V. Isakov, M.B. Hastings, R.G. Melko, Nature Physics **7**, 772 (2011)

[2] M.B. Hastings, I. Gonzalez, A.B. Kallin, R. G. Melko, Physical Review Letters **104**, 157201 (2010); S. Humeniuk and T. Roscilde, preprint arXiv:1203.5752 (March 2012)

The PhD student will benefit from the supervisor's expertise on implementing large-scale, state-of-the-art Quantum Monte Carlo algorithms for quantum information properties of condensed-matter systems[3], as well as from a strong condensed-matter community in Toulouse. The PhD applicant should have a strong background in quantum mechanics and statistical physics. Experience with programming languages will be appreciated, but is not mandatory.

Expected collaboration in Brazil :

The PhD supervisor just started an ongoing collaboration on the topic of quantum disordered systems with Brazilian condensed-matter theory groups, in particular with :
- J.A. Hoyos, Instituto de Fisica de Sao Carlos, Universidade de Sao Paulo
- E. Miranda, Instituto de Fisica Gleb Wataghin, Universidade Estadual de Campinas
- A.P. Vieira, Instituto de Fisica, Universidade de Sao Paulo.

The entanglement approach developed in this PhD proposal will hopefully provide new insights of these poorly understood states of matter. The numerical simulations proposed here will nicely complement the analytical techniques developed on the Brazilian side.

Procedure for application :

The application has to be made individually by the applicant through the programme Ciência sem fronteiras of the Brazilian government where this PhD proposal can be found (PhD proposal in France, Université de Toulouse). More details at http://www.cienciasemfronteiras.gov.br.

The applicant should feel free to also contact the PhD advisor (Fabien Alet, alet@irsamc.ups-tlse.fr) for any further scientific details.

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[3] F. Alet, S. Capponi, N. Laflorencie and M. Mambrini, Physical Review Letters **99**, 117204 (2007); D. Schwandt, F. Alet and S. Capponi, Physical Review Letters **103**, 170501 (2009); A.F. Albuquerque, F. Alet, C. Sire and S. Capponi, Physical Review B **81**, 064418 (2010)