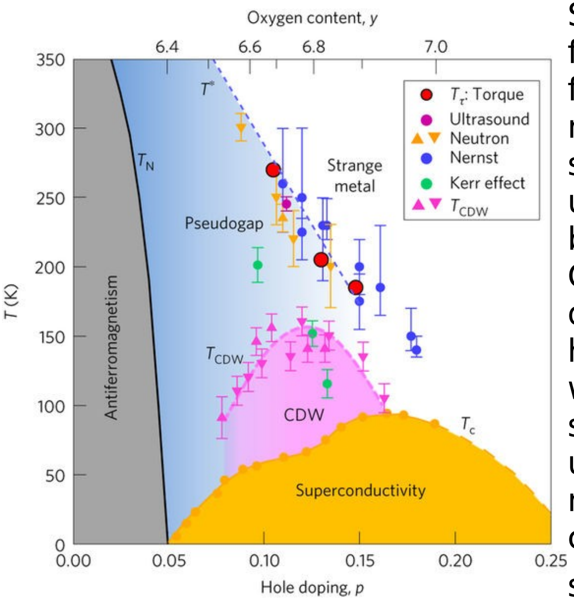
Theoretical probing the high-Tc superconducting mechanism

Name of laboratory : Laboratoire de Physique des Solides (LPS)
Address : Centre Scientifique d'Orsay, Bâtiment 510, 91405 Orsay CEDEX
Name of thesis advisor : Marcello Civelli
(co-director I. Paul, Paris-Diderot)
E-mail : marcello.civelli@u-psud.fr **Phone number** : +33 (0)169156937
Web Page : https://www.lps.u-psud.fr/index.php?page=pageperso&nom=CIVELLI&prenom=Marcello
Source of funding : application to fellowship by the candidate
Doctoral School : EDPIF



Superconductivity, the dissipation-less flow of charge, is one of the most fascinating macroscopic manifestations of an exotic quantum state of matter. Our current understanding of this phenomenon is based on the theory by Bardeen Cooper and Schrieffer (BCS theory) developed in the 50s. There are however a large class of materials which display an unconventional superconductivity, which is not well understood. Among them we can mention the so called "heavy fermion compounds" (e.g. $CeCoIn_5$), organic salts, fullerides, graphene heterostructures, Fe-based and Cu-based (cuprates) compounds. This latter are the most famous ones, because "unconventional" is equivalent to "high critical temperature" (Tc): cuprates display Tc up to 150 K, which is 10 times larger than the limit set by the BCS theory. The dream is to discover room temperature superconductivity, which would mark a turning point in our technology.

The project of this thesis is centered on theoretical studies of the elusive superconducting mechanism in cuprates within a theory-experiment collaboration between Paris-Sud and Paris-Diderot. Besides the hight Tc superconductivity, cuprates phase displays a variety of exotic phases (see figure above) : anti-ferromagnetism (and other not-well-identified magnetic orders), the mysterious pseudo-gap phase (an unconventional metallic state), charge density waves, nematic instabilities. Nowadays challenge is to identify which of these phases is the one that could originate the high Tc mechanism. Our group has developed a theoretical tool, the cluster dynamical mean field theory (CDMFT)[1], capable to well treat the strong electronic correlation, which represent a bottleneck in most theoretical methods that attack this difficult problem. Our task is to "probe" the model by applying breaking fields in key channels, like the charge or spin ones, which can drive one of the exotic phases mentioned above and study its effect on superconductivity. Our theoretical approach includes a low-energy modelling, known as hidden-fermions[2], which we have shown to well reproduce the CDMFT results and can bring new physical insights using analytical approaches.

Our theory can extract the Raman spectroscopic response that can be compared with experiments performed by our collaborators at Paris-Diderot[3-4]. A main task of the project is to reveal how our theoretical findings can impact Raman experiments on cuprate materials.

Skills required : background in condensed matter physics, many-body, positive attitude to implement numerical methods

References :

[1] *Doping-driven evolution of the superconducting state from a doped Mott insulator: Cluster dynamical mean-field theory*, M. Civelli, Phys. Rev. B 79, 195113.
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[3] *Unconventional High-Energy-State Contribution to the Cooper Pairing in the Underdoped Copper-Oxide Superconductor $HgBa_2Ca_2Cu_3O_{8+\delta}$*, B. Loret, S. Sakai, Y. Gallais, M. Cazayous, M.-A. Méasson, A. Forget, D. Colson,M. Civelli, and A. Sacuto Phys. Rev. Lett. 116, 197001.
[4] *Vertical temperature-boundary of the pseudogap under the superconducting dome of the $Bi_2Sr_2CaCu_2O_{8+\delta}$ phase-diagram*, B. Loret, S. Sakai, S. Benhabib, Y. Gallais, M. Cazayous, M. A. Measson, R. D. Zhong, J. Schneeloch, G. D. Gu, A. Forget, D. Colson, I. Paul, M. Civelli, A. Sacuto, Phys. Rev. B 96, 094525 (2017).