Thierry Klein

1. ABSTRACT OF THE 5 MOST SIGNIFICANT PUBLICATIONS

TITLE	**1. EVIDENCE OF THE BRAGG GLASS PHASE BY NEUTRON SCATTERING**
REFERENCE	T.Klein, I.Joumard, S.Blanchard, J.Marcus, R.Cubitt, T.Giamarchi, P.Le Doussal Nature 413, 404 (2001).
SUMMARY	It was known for a long time that the (elastic) interactions between particles in solids lead to the formation of well-ordered structures, the periodic lattices. On the other hand, the distribution of those particles is expected to be fully disordered (glassy) if they strongly interact with an underlying random distribution of defects. But what would be the structure of the solid when disorder and elasticity are of the same order of magnitude remained an open question for a very long time. This intriguing issue obtained a theoretical answer in 1994 when T. Giamarchi and P. Le Doussal suggested that there should exist a new state of matter neither ordered nor disordered which they baptised Bragg Glass. However, a direct evidence for the existence of this new phase was still lacking. Superconductors are mainly known for their exceptional electronic and magnetic properties but they also offer a unique opportunity to study the influence of disorder on the structure of elastic systems. Indeed, in type II superconductors, vortices interact with each other forming, in the absence of defects, a hexagonal lattice. The great advantage of this elastic medium is that disorder can then be tuned easily and continuously just by ramping the external magnetic field (which plays as an effective disorder). In this work, we have performed a detailed analysis of the field dependence of both the amplitude and width of the neutron diffraction peaks (in $(K,Ba)BiO_3$) and showed that they do not obey the laws expected for either well-ordered lattices or fully disordered glasses but are in perfect agreement with the Bragg glass expectations. This work (see also [13]) hence brought the first evidence for the existence of this new state of matter (more than 100 citations)
TITLE	**2. EVIDENCE FOR TWO SUPERCONDUCTING GAPS IN MgB_2 BY POINT CONTACT SPECTROSCOPY**
REFERENCE	P.Szabo, P.Samuely, J.Kacmarcik, T.Klein, J.Marcus, D.Fruchart, et al. Physical Review Letters 87, 137005 (2001).
RESUME/SUMMARY	MgB_2 is a system with a surprisingly simple chemical and crystallographic structure and yet the discovery of its superconducting properties in 2004 was fully unexpected and led to a tremendous number of theoretical and experimental works. First because its critical temperature is surprisingly high (~40K) for a conventional superconductor, being about twice that of the previous record in Nb_3Ge, but mainly because it was the first system in which superconductivity develops simultaneously in two almost completely decoupled electronic bands. MgB_2 crystallizes in a honeycomb-like structure made of hexagonal Boron layers

	intercalated by Magnesium atoms. As in graphite, the Boron atoms then form three-dimensional π-bounds as well as in plane (2D) covalent σ-bounds. The particularity of MgB_2 is that both of these bounds contribute to the electronic properties of the system (in graphite the σ-bounds lie well below the Fermi surface and only contribute to the cohesion of the layers). Both of them can then lead to superconductivity but with very different critical temperatures. Everything happens as if two superconductors coexist in the same system, one with a T_c of about 10K (π-band) and the other with a very high (for a conventional system, see also abstract 4 below) T_c value, rising up to ~ 40K (σ-band). In collaboration with P. Szabo, a Slovak colleague visiting our group, we brought the first experimental evidence for this coexistence. We performed point contact spectroscopic measurements in order to obtain the electronic structure of this system and showed the existence of two well-separated superconducting gaps associated to the two electronic bands. Even though the two superconductors are mostly decoupled a small but finite coupling between them leads to one unique critical temperature (~ 40K) and superconductivity remains induced in the π-band well above its intrinsic T_c (~ 10K). This article has been cited more than 370 times and is in the top 15 of the most cited articles on MgB_2 (out of about 7500).
TITRE/TITLE	**3.** DIRECT TRANSITION FROM BOSE GLASS TO NORMAL STATE IN (K,BA)BIO$_3$
REFERENCE	T.Klein, C.Marcenat, S.Blanchard, J.Marcus et al. Physical Review Letters, 92, 037005 (2004).
RESUME/ SUMMARY	This publication has been the epilogue of a puzzling story that started two years earlier with the observation of a very anomalous temperature dependence of the so-called upper critical field (H_{c2}) separation the superconducting and normal states in $KBaBiO_3$ [see 19] and, that this transition line is even sensitive to the orientation of the magnetic field in heavy ion irradiated samples [see 21]. Indeed, the H_{c2} line was expected to be fully determined by the balance between the condensation energy of the superconducting state and the magnetic energy associated with the applied field but was absolutely not expected to depend on the presence of defects (here columnar defects artificially introduced by heavy ion irradiation) and even less on the orientation between the field and those defects. In this final publication, we have shown that the thermal fluctuations and pinning energy of the vortex cores on the defects introduced by the irradiation can – under some conditions - play a significant role in the above mentioned energy balance and proposed a model taking into account those subtle contributions. This model does then perfectly reproduce both the anomalous temperature dependence and anisotropic enhancement of the H_{c2} line in presence of columnar defects. Note that this theoretical description relied on our previous experimental studies [19 and 21] in which we presented the first thermodynamic determination of the upper critical field in this system. Indeed, those demanding experiments required very

	sensitive thermodynamic probes (the specific heat is in this case dominated by the phonon contribution and the superconducting part corresponds to less than 0.5% of the signal) and this study was at the origin of my longstanding collaboration with Christophe Marcenat devoted to the developments of specific heat measurements. In total, those 3 publications in Physical Review Letters have been cited almost 50 times
TITRE/TITLE	4. SUPERCONDUCTING GROUP-IV SEMICONDUCTORS
REFERENCE	X.Blase, E.Bustarret, C.Chapelier, T.Klein and C.Marcenat Nature Materials 8, 375 (2009).
RESUME/ SUMMARY	Electrical resistance is one of the few physical quantities that is spanning all the way from zero (in superconductors) to infinity (in insulators). Those two extremes are indeed out of reach of any experimental techniques but still, more than 60 orders of magnitude separate those two electronic states. Doping insulators to open an alternative new route to high temperature superconductivity may hence seem to be a surprising approach. However, in (conventional) superconductors, superconductivity is the result of the coupling between electrons and lattice vibrations (phonons), and this coupling is particularly strong in so-called covalent insulators (such as diamond or silicon). This new route has been first highlighted by the discovery of MgB_2 (see above), in which the boron covalent bounds are “self-doped” by the magnesium atoms leading to a critical temperature ~ 40K or in so-called “cage structures” such as C_{60} Bucky balls for which T_c reaches ~30K (when doped by alkali atoms in K_3C_{60}). A few years latter, the discovery of superconductivity in diamond confirmed that covalent insulator might be a fruitful starting point towards new superconductors. Although still modest, the critical temperature of this compound (up to 25K) is about 20 larger than that of aluminum despite a much smaller electronic density (100 times smaller). The main problem is actually to increase this electronic density (i.e. the doping level) to further increase T_c. In this "progress article" (> 50 citations) we present a revue of the properties of existing compounds (see for instance our extensive study of C:B in [63]) but also highlight new potential systems. Indeed, *ab-initio* calculations predicted new structures that could be superconducting at temperatures well above 100K (as Li_xBC) although none of these systems has been realized yet. Note that doped insulators are also an powerful platform to investigate the physics of the insulator to superconductor transition, which is still a very debated issue (see [62] and [76]).
TITRE/TITLE	**5.** THERMODYNAMIC PHASE DIAGRAM IN $Fe(Se_{0.5},Te_{0.5})$ SINGLE CRYSTALS UP TO 28T
REFERENCE	T. Klein, D.Braithwaite, A.Demuer, C.Marcenat, P.Rodière, et al. Physical Review B, 82, 184506 (2010).

RESUME/ SUMMARY	The discovery in 2008 of a new family of superconductors based on iron caught once again the community unprepared. Indeed, while superconductivity and magnetism used to be considered as two antagonistic properties, magnetism might here play an essential role in the (unconventional) coupling mechanism leading to critical temperatures as high as 55K, only bettered by the high temperature cuprates. Tens of new systems were discovered within a few years and this work is a detailed and exhaustive study of the H-T phase diagram of one of these compounds: Fe(Se,Te) (T_c~15K). This study is mainly based on specific heat measurements under extreme conditions of magnetic fields (up to 28 T). It put an end to the controversy over the H_{c2}(T) line that emerged from contradictory transport measurements showing that this field is limited by so-called paramagnetic effects on a surprisingly large temperature range (up to 0.99 times T_c for fields along the superconducting planes). This work also highlighted the important role of electron correlations leading to very small values of the electron velocity. Finally, magnetic measurements revealed that pair-breaking effects are important stressing out the anomalous coupling mechanism (see also [73] for a comment in Physical Review on this subject, and [72] for a systematic investigation of those pair-breaking effect in Ni doped samples). This publication (about 40 citations) is a collaborative work combining complementary experimental techniques: specific heat, local and non-local magnetization measurements and transport measurements in pulsed fields.

2. CURRICULUM VITAE

Education and training	
Dates	2000
Title of qualification awarded	"Habilitation" to supervise researches (DHDR), University J.Fourier, Grenoble
Dissertation Topic	Superconducting properties of the (K,Ba)BiO_3 perovskite
Dates	1989 -1992
Title of qualification awarded	PhD in Physics University J.Fourier, Grenoble – grade: "très honorable avec felicitations du jury" Laboratoire d'Etude des Propriétés Electroniques des Solides, CNRS Directed by F.Cyrot-Lackmann
Dissertation Topic	Electronic properties of the AlCuFe quasicrystal
Dates	1985-1988
Title of qualification awarded	• Graduation from the "Institut National Polytechnique de Grenoble", "Grande Ecole" in Condensed Matter Physics (ENSIEG) - grade "Very Good" • Master in Condensed Matter Physics, University J.Fourier, Grenoble (DEA Matière et Rayonnement) - grade "Very Good" • Internship at CEA-Grenoble, Department of Fundamental Research Group of Dr. F. Volino (March-June 1988)
Dissertation Topic	Study of the molecular mass dependence of the twist viscosity coefficient in a nematic polymer by NMR measurements

Research Positions

- LEPES – CNRS, Grenoble: 1989-1992 and 1994-2006
  Department of Physics, University of Utah, Salt Lake City: 1992-1994
  Institut Néel – CNRS, Grenoble 2007, onwards
- Coauthor of 157 publications and communications, including 1 in Nature, 1 in Nature Materials, 1 in Nature Physics (submitted), 16 in Physical Review Letters and 26 invited lectures (see below).
- Partner of several international research consortiums (see below)
- Supervision of several PhD thesis (11), Master projects (6) and post-doctoral internships (2).
- Referee of several international journals (Physical Review Letters,…).

Teaching positions

Department of Physics, University of Utah, Salt Lake City

- Teaching Assistant: 1992-1994

University J.Fourier, Grenoble

- Teaching Assistant (Vacataire): 1989-1992
- Temporary Teaching and Research Assistant (ATER): 1994-1995
- Assistant Professor (Maître de Conférences): 1995-2002
- Junior member of the "Institut Universitaire de France": 2001
- Full Professor (2nd class): 2002-2007
- Full Professor (1st class): 2007-2013
- Full Professor (Exceptional Class): 2013-onwards

Responsibilities

- Many times member of the Laboratory Board, Academic (UFR) and scientific (GDR) Boards
- Many times member of expert committees for the recruitment of assistant and full professors
- Member of the National University Council (CNU, 2000-2002)
- Member of the international magnetic structures subcommittee for the attribution of neutron diffraction beam time at the Institut Laue - Langevin Grenoble (2004-2006)
- Head of "Magistere", University J.Fourier-Grenoble (2003-2007)
- Organization of a summer school on "disordered elastic systems" (GDR-2284 Autrans 2004)
- Participation in the organization of the General Congress of the French Physical Society (SFP) in Grenoble (2007) and member of the National Advisory Board of the International Conference on Strongly Correlated Electronic Systems (Grenoble, 2014)
- Heat of Master I (2006-2012) and Master in Physics (2012-onwards)

For further details: see http://thierry-klein.fr

Research Activities

My current research activity is mainly centered on the study of the magnetic and thermodynamic properties of **superconductors**. As an experimentalist, I made two major instrumental developments. First, I developed **local magnetometry measurements** based on Hall probe sensors and assisted the group of Pr. Peter Samuely (Institute of Experimental Physics, Kosice, Slovakia) in the development of this technique (several visits). Currently, I am working on the development of original **state-of-the-art calorimetric measurements** in close collaboration with Christophe Marcenat (CEA-Grenoble). High sensitivity specific heat measurements have been implemented to work under extreme conditions of temperature (down to 0.3H) and magnetic fields (up to 35T) and I collaborated in the development of pulsed fields specific heat measurements (April 2011, visiting scientist in the group of Pr. Marcello Jaime, Los Alamos High Magnetic Field Laboratory, see also publication [66]).

I supervised the “Cible” research project from the “Région Rhône-Alpes” on the superconducting properties of doped silicon and I was responsible for the Néel Institute of an ANR project on the development of Hall probe magnetometry (2007-2011). I have also been a partner in three other ANR collaborative projects (superconducting diamond (2005-2008), superconducting silicon (2009-2012) and iron-based superconductors (2009-2013)). Finally I have been in charge of a “Stefanik” bilateral project (CNRS, Institut Néel and Slovak Academy of Sciences, Institute of Experimental Physics, Kosice, 2009-2011) and I have been a partner of several national and international consortiums (see below). Finally I actively participated to the development of the “superconductivity group” (7 permanent members) in the Department of Condensed Matter and Low Temperature Physics of the Neel Institut - CNRS, Grenoble. I am now one the main lead scientist and animator of this group.

The main steps of my research activities are summarized below.

• **1989-1995**. Although already known by mathematicians, *aperiodic structures* such as Penrose tiling had not found any implementation in nature before the discovery by D. Shechtman and co-workers of a perfect 5-fold symmetry order in aluminium based alloys. Unravelling the physical properties of those neither periodic nor disordered structures, baptized *quasicrystals*, rapidly became a fundamental issue and my **PhD thesis** has been devoted to the study of the **electronic properties of AlCuFe quasicrystals** (1989-1992). I continued this work during my two-year **post-doctoral internship** in the group of Pr. Orest G. Symko[1] and I joined the LEPES-CNRS in 1994 to pursue this study. During this six-year period, I have demonstrated that the ground state of defect free quasicrystals is an “exotic” insulating state [see publication 2 and 4 for further details] and performed the *first spectroscopic measurements showing the existence of a narrow pseudogap* in ”real” samples [see publication 8]. During my post-doctoral internship, I have also been involved in a second project devoted to the realisation of thermo-acoustic refrigerators and two patents were filed during this period (US 6712915 & US 6574968). I received the *“Jack Keuffel (University of Utah) award for outstanding research in Physics”* in 1994, awarding my contributions on these two topics.

• **1995-2001.** In 1995 I switched to the study of **phase transitions in the mixed state of so-called type II superconductors[2]**. This fascinating state of matter is mostly known for its capability of carrying an electrical current without any losses but it also presents striking magnetic properties. A detailed analysis of the distribution of flux lines by neutron diffraction allowed us to bring the *first experimental evidence for the existence of a new state of condensed matter* (so-called Bragg Glass, [see publication 16 and abstract 1]). 2001 has been a major turning point in my carrier. Thanks to my nomination as a *junior member of the Institut Universitaire* de France, I had the opportunity to develop a new collaboration with Christophe Marcenat[3] (see abstract 3 above) and start two new subjects, centred first on MgB_2[4] (2001) and Diamond[5] (2004).

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[1] Department of Physics, University of Utah (Salt Lake City, USA)
[2] In collaboration with teams from Paris and Palaiseau
[3] On the development of calorimetric measurements.
[4] In collaboration with teams from Seoul and Kosice
[5] In collaboration with teams from Grenoble, Lyon and Paris

• **2001-2005**. Combining thermodynamic and magnetic measurements, we have shown that disorder - combined to strong thermal fluctuations - can affect the transition from the normal to superconducting states [see abstract 3 and publications 19, 21, 23 and 69] and, more recently that the Bragg glass "melts" into a fully disordered (glassy) state through a first order phase transition above some characteristic magnetic field [see 34]. On the other hand, the discovery of superconductivity in MgB_2 in 2001 has been a major turning point in the superconductivity field. Indeed, besides its rather high critical temperature (~40K) MgB_2 is the first compound in which superconductivity develops on two sheets of the Fermi surface (so-called **"multigap superconductivity"**). All happens as if two superconductors coexist in the same material. We have been the *first group to unambiguously demonstrate this coexistence* [see publication 18 and abstract 2].

• **2005-2012**. The year 2004 has then been marked by the discovery of **superconductivity in diamond**. Known to be the hardest material diamond is also the prototype of insulators and still it can be turned into a superconductor when doped with boron. It can then be used as a very interesting platform to study the still very debated issue of **the insulator to superconductor transition**. Our group played a major role in *the study of the superconducting properties of both boron doped diamond and silicon* [see publications 24,33,62 and abstract 3]. During this period, I have also been involved in the study of the **iron-based superconductors**[6]. This discovery (2008) was totally unexpected because these systems combine magnetic and superconducting properties, a priori antagonistic. Yet their critical temperatures are very high (up to 55K), only bettered by high temperature cuprates. We performed very detailed studies of the critical fields in several families *showing that electronic correlations and pair breaking effects are very strong in those systems* [see 67,72 and abstract 4].

• **2012-onwards.** In most of the unconventional superconductors (such as iron based compounds or high T_c cuprates) the superconducting state develops in the vicinity of a competing magnetic or electronic instability and understanding the role of this **competing instability** is now a key issue in the study of superconductivity (see project). We recently redirected our activity on this issue[7], performing the first detailed study of the superconducting to normal transition in underdoped cuprates. Finally, We recently started a new collaboration with Dr. Shimpei Ono[8] on the development of new doping routes based on ionic liquid gating (see project). As the recipient of a "Chaire d'excellence" from the LANEF-Grenoble "laboratory of Excellence" (2013),

Teaching Activities and Responsibilities :

My main teaching activities are summarized in the table below:

Lab Trainings	Tutorials	Lectures
• Optics (L3)	• Magnetism (M1)	• Magnetism (M1)
• Electricity (L1)	• Solid-state physics (M1)	• Superconductivity (M2)
• Magnetism (M1)	• Quantum mechanics (L3 & M1)	• Solid-state physics I & II (M1)
• Solid State Physics (M1)	• Electromagnetism (L2)	• Quantum mechanics (L3)

[6] In collaboration with teams from Beijing, Kosice, Ames, Los Alamos and Argonne
[7] In collaboration with teams from Vancouver, Tallahassee and Sherbrooke
[8] Central Research Institute of Electrical Power Industry, Tokyo, Japan

I also had the opportunity (1995-2000) to supervise lectures and tutorials for disabled students of the university (SAUH) providing lessons in a wide range of subjects: electrodynamics, analytical mechanics, fluid mechanics and statistical mechanics. In October 2012, I have been invited by the Institute of Experimental Physics in Kosice (Slovakia, group of Pr. P. Samuely) to give a graduate school lecture on the magnetic properties of superconductors and magnetic measurement techniques. I also took a very active part in the referee process of the book "Superconductivity" recently published by P. Mangin and R. Kahn editions Grenoble - Sciences. As part of the celebration of the "100 years of superconductivity " (2011), I animated an exhibition at the “Centre for Scientific Culture, Technology and Industry” (CCSTI-Grenoble) and made several visits in high schools in order to present superconductivity.

Between 2006 and 2012 I have been in charge of the Master 1 in “Fundamental Physics and Nanosciences”. The combination of a large number of students (~90 including 30 ERASMUS students) and a large variety of domains covered by this formation (astrophysics, high energy physics, condensed matter physics) is an interesting but demanding organisation issue. In 2012 I took in charge the whole master in Physics (coordination of the different specialities through the 2 years of the formation). I am now leading the discussions related to the implementation of the pedagogical structure for the forthcoming master (starting September 2016).

3. RESEARCH PROJECT 2014-2019

All physicists learned once that *perpetual motion* is impossible because of friction and other sources of energy loss, *yet it exists*, in **superconductors**. Indeed, Heike Kammerlingh-Onnes and his collaborators discovered in 1911 that the electrical resistance of some materials abruptly drops to zero below some critical temperature (T_c) and that a DC electrical current then flows without any losses, for eternity… Walter Meissner and Robert Ochsenfeld latter showed that those materials also have the unique ability to fully expel an external magnetic field (under some conditions) and after 40 years of intensive research superconductivity seemed to have unveiled all its mysteries when Bardeen, Cooper and Schrieffer proposed a microscopic model for the coupling mechanism that binds electrons in one single quantum condensate of so-called Cooper pairs (1955). Bernd Matthias, who discovered hundreds of elements and alloys with superconducting properties, finally proposed a famous recipe to find new superconductors in 1973:

1. High symmetry is good, cubic symmetry is best
2. High Density of electronic states is good
3. Stay away from oxygen
4. Stay away from magnetic materials
5. Stay away from insulators
6. Stay away from theorists

and Nb_3Ge, with a T_c on the order of 22K, held the record of the highest critical temperature for years, with no real hope to substantially break this record. End of a fascinating story…

… until the discovery (in 1986) of **a new class of superconductors** with T_c’s exceeding 100K, in highly anisotropic (violating rule 1) ceramics (violating rule 3) being very poor (violating rule 2) antiferromagnetic (violating rule 4) metals. This fully unexpected discovery proved that all of those rules - except maybe rule 6 - were unexpectedly wrong[9] and marked the beginning of a new story.

Whereas most of the standard metals (lead, mercury, tin,…) are superconductors, the "best" of them, copper, is not. So it was even more surprising that high temperature superconductivity has been discovered in *copper oxides* (cuprates). All members of this family are composed of a stacking of CuO_2 superconducting layers separated by non-superconducting buffers[10]. As an example, Figure 1 beside sketches the structure of the archetype of this family: $Y_1Ba_2Cu_3O_y$ (T_c = 92K). This family still holds the record[11] of critical temperature reaching 163K in a mercury-based alloy (under pressure) but, other "exotic" families of superconductors have been discovered in the last decades: organic materials, dichalcogenides, heavy fermions or more recently even *iron* based superconductors (pnictides, see abstract 5). Most of them have an highly anisotropic structure, again composed of a stacking of superconducting and non superconducting blocks, but they also share another striking similarity: in all of them superconductivity appears in the vicinity of a competing magnetic, electronic and/or lattice instability (see Figure 2 below). The transition temperature of this competing instability progressively decreases under the action of some external parameter (chemical electron or hole doping, pressure,…) and a superconducting dome finally develops in the vicinity of the critical value of this parameter for which the transition temperature of the instability vanishes[12].

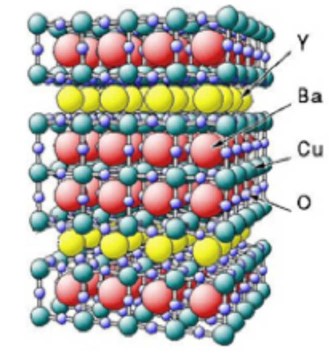

Fig.1: Crystallographic structure of $Y_1Ba_2Cu_3O_7$

However, the most striking characteristic of those "exotic" superconductors is neither there complex layered structure nor their complex phase diagram but the fact that most of them (hereafter referred as *unconventional* systems) can **not** be described by the Bardeen-Cooper-Schrieffer coupling model. Despite three decades of intensive studies, the nature of the "glue" binding together the electrons of the Cooper pairs is still unknown in most of them (including cuprates) and understanding the mechanism leading to this new type of - high temperature - superconductivity remains one of the most challenging issues of modern solid-state physics. The richness of the physical properties of unconventional superconductors seems to be ineluctably related to the complexity of their phase diagram and, the key probably lies in this complexity. Indeed, fluctuations in the competing phase[13] has been rapidly considered as a possible alternative to the standard coupling by the lattice vibrations (phonons) introduced by Bardeen,Cooper, and Schrieffer in their model. For almost three decades, the leading paradigm in hole-doped samples was then that magnetic fluctuations could play a fundamental role in the so-called - and still poorly understood- *pseudogap* phase (see Figure 2). However, the recent discovery of a major reconstruction of the Fermi surface leading to the formation of a fully

[9] as discussed in abstract 5, some insulators can be very promising starting materials to obtain new superconductors (violating rule 5), and T_c up to 25K have been very recently reported in doped diamond (see arXiv 1411.7752 (2014)).
[10] so-called charge reservoirs.
[11] **Conventional superconductivity up to 190K** has been reported a few days ago in H_2S under extremely high pressure (200 GPa, see ArXiv 1412.0460 (2014))!
[12] So-called quantum critical point.
[13] Getting strong in the vicinity of the associated phase transition.

unexpected *charge order phase*[14] definitely shed some doubt on this initial paradigm, reviving the interest of the community for those systems.

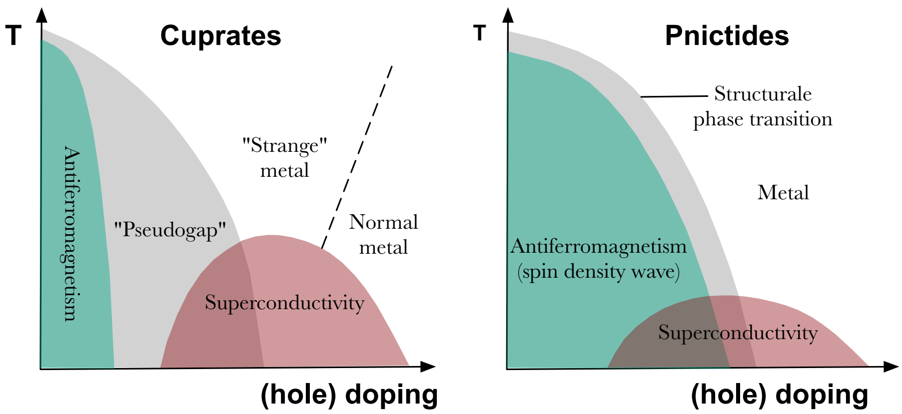

Fig.2: Schematical phase diagram of cuprates and pnictides (iron based superconductors)

Determining the phase diagram in cuprates – and related compounds – is now a major issue. The development of the experimental probes in the last decades[15] as well as major improvements in the sample quality is now giving the opportunity to "revisit" this phase diagram. Those better tools in better samples were at the origin of the discovery of the above mentioned charge order phase but a lot of questions remain open: are they other phases, are those phases essential, or on the contrary detrimental to superconductivity, what is the influence of an external magnetic field on this phase diagram,… The first aim of this experimental project will hence be to contribute **to the determination of the phase diagrams of cuprates and related systems**. It is not aimed to provide a microscopic model for high temperature superconductivity (or more generally speaking for unconventional superconductivity) but it is definitely expected to *contribute to unveil this mechanism*. On the long term, the project may even provide new guidelines for the discovery of new (high temperature) superconductors.

As pointed out above, superconductivity is induced in those systems by doping a parent non-superconducting phase (hosting the competing phase). In most of the cases this doping is realized by chemical substitution of one of the elements[16]. However this chemical doping technique also ineluctably induces some disorder and the role of this disorder is badly understood. The second part of the project will hence be devoted to **the development of a new doping route**: *ionic liquid gating.* This technique is still at a very early stage but has already yielded some outstanding results such as a 2D metal to insulator transition in Mott insulators or even insulator to superconductor transitions in various materials, such as $SrTiO_3$. This original doping technique will be essential to perform a fine tuning of the doping content which may lead to major breakthroughs in our knowledge of the influence of electronic correlation in those systems but it will also enable us to **explore parts of the phase diagrams that could not be explored by standard chemical doping techniques**.

[14] See T. Wu et al. Nature, 477, 191 (2011). This Fermi surface reconstruction surprisingly leads to the formation of small *electron* pockets in those *hole*-doped samples. A detailed theoretical model for the reconstruction mechanism is still lacking.
[15] Some of those will be finalized within this project.
[16] Or by introducing oxygen vacancies in the charge reservoirs in cuprates. Pressure can also be used as an alternative doping route and led to the record of critical temperature in mercury-based cuprates.