ELECTRONIC TRANSPORT PROPERTIES AND FERMI SURFACE TOPOLOGY IN CUPRATE SUPERCONDUCTORS.

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INTRODUCTION

The phenomenon of high-transition-temperature (high-T_c) superconductivity is one of the most exciting, thoroughly investigated, yet still unresolved problems in solid-state physics.[1] A major difficulty in understanding high-T_c systems is the complexity of the materials, the presence of strong electron-electron interactions, resulting in rich phase diagrams. The delicate balance among several coexisting phases makes it hard to identify the principal interactions. The copper-oxide superconductors, so called cuprates, in their undoped state are anti-ferromagnetic (AF) Mott insulators,[2] where the charge motion is frozen due to the strong on-site Coulomb interactions. When doped with holes, the anti-ferromagnetic order is quickly suppressed, multiple magnetic and electronic instabilities occur, and high temperature superconductivity (SC) appears.[1,3,4] Beside the origin of the superconductivity, the nature of the pseudogap (PG) regime, associated with opening of partial gaps at the Fermi level, has been an open question for the past three decades. Despite intense studies, the topology of the Fermi surface (FS) within the pseudogap is still strongly debated.[1]

PHASE DIAGRAM OF THE CUPRATES – UNIVERSAL SCATTERING RATE

The superconductivity in the hole-doped cuprates appears above $p \approx 0.05$ (Fig. 1). With increasing the carrier concentration, T_c increases to its maximal value $T_{c,max}$ at $p \approx 0.18$, and then decreases in the overdoped side of the doping-temperature phase diagram.[1] The cuprates in the heavily overdoped regime are quite well understood and can be well described by the conventional Fermi liquid (FL) theory. The resistivity displays quadratic temperature dependence, characteristic of FL.[5] Furthermore, a large, hole-like Fermi surface detected by photoemission and quantum oscillation measurements is consistent with the band structure calculations[6,7] (Fig. 2a). In recent work, it was demonstrated that at moderate doping, in the pseudogap regime, the nature of charge carriers is, in fact, also best described as a Fermi liquid.[8,9] This motivated the attempts to connect the FL properties found in the overdoped regime with those found in the pseudogap (green areas in the phase diagram in Fig. 1). I will present the results of systematic, temperature and doping dependent, electronic transport (resistivity and Hall effect) measurements in single crystals of the model cuprate $HgBa_2CuO_{4+\delta}$ (Hg1201). Results imply that the transport scattering rate $1/\tau$ remains quadratic in temperature upon crossing the pseudogap temperature and entering the strange-metal

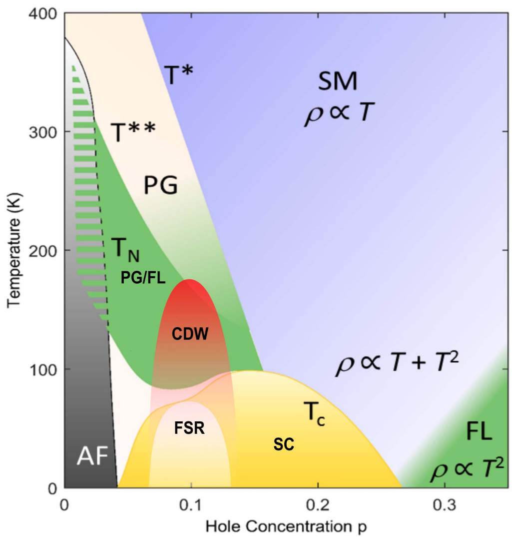

Figure 1: Phase diagram of Hg1201, presenting various phases, discussed in the main text. [10] The red area indicates the charge density wave (CDW) order, which reconstructs the Fermi surface (FSR) at lower temperatures.

phase (SM). Importantly, the comparison of the results with the data available for other cuprate families demonstrates that this key quantity is doping and compound independent, and hence universal.[10–13]

PSEUDOGAP & PERCOLATIVE LOCALISATION OF ONE CARRIER – ARCS

It has long been known that on the overdoped side of the phase diagram, where the FS is large (Fig. 2a), the carrier density corresponds to $n = 1 + p$ (p denotes the doped hole concentration).[6,14] It was also established that the underdoped cuprates have a carrier density that corresponds to $n = p$. Consequently, upon decreasing the hole concentration from the overdoped regime at high doping ($n = 1 + p$) to low carrier concentrations ($n = p$), one hole per CuO_2 unit becomes localized.[13] I will discuss the evolution of the carrier localization occurring upon decreasing doping and temperature. Accordingly, the large hole-like FS, characteristic of the overdoped cuprates, gradually transforms into disconnected Fermi arcs containing p carriers.[13] However, in the underdoped regime, the carrier density increases with temperature, from $n = p$ to $n = 1 + p$, and the Fermi arcs presumably fully close at high temperatures. This gradual (de)localisation gives rise to the exotic strange-metal T-linear behaviour, while the scattering rate remains quadratic in temperature.[10]

SUMMARY & OUTLOOK

Much of the mystery surrounding the strange-metal and pseudogap regimes was demystified by our findings. First, by systematic electronic transport measurements, we demonstrated ubiquitous Fermi-liquid scattering rate throughout the cuprate phase diagram. Furthermore, our work is a major step in the determination of the FS topology of the underdoped cuprates. It suggests that the Fermi surface within the pseudogap consists of Fermi arcs (Fig. 2b), instead of theoretically predicted small hole-pockets (Fig. 2c).[15] This description, of the puzzling features found in the normal state of the cuprates, will presumably allow for a deeper understanding of superconductivity emerging from the normal state.

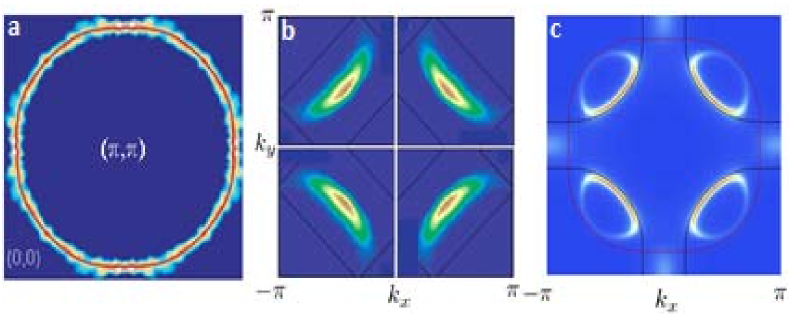

Figure 2. Fermi surface topology of the cuprates. **a** Large FS centred at (π,π) characteristic of the FL regime on the overdoped side. **b** Fermi arcs observed by photoemission spectroscopy within the PG. **c** Fermi pockets theoretically predicted for the PG. **b** and **c** are centred around (0,0).[3, 15]

REFERENCES

[1] B. Keimer, S. A. Kivelson, M. R. Norman, S. Uchida, and J. Zaanen, *Nature*, **518**, 179–186, 2015.
[2] M. A. Kastner, R. J. Birgeneau, G. Shirane, and Y. Endoh, *Rev. Mod. Phys.*, **70**, 897–928, 1998.
[3] M. Platé *et al.*, *Phys. Rev. Lett.*, **95**, 7, 2005.
[4] J. C. Phillips, A. Saxena, and A. R. Bishop, *Rep. Prog. Phys.*, **66**, 2111, 2003.
[5] S. Nakamae *et al.*, *Phys. Rev. B*, **68**, R100502, 2003.
[6] B. Vignolle *et al.*, *Nature*, **455**, 952–955, 2008.
[7] C. O. Rodriguez, *Phys. Rev. B*, **49**, 1200–1204, 1994.
[8] N. Barišić, *et al.*, *Proc. Natl. Acad. Sci. U. S. Am. PNAS*, **110**, 12235–12240, 2013.
[9] M. K. Chan *et al.*, *Phys. Rev. Lett.*, **113**, 7005, 2014.
[10] N. Barišić *et al.*, *ArXiv E-Prints*, 1507.07885, 2015.
[11] D. Pelc *et al.*, *ArXiv E-Prints*, 1710.10219, 2017.
[12] P. Popčević *et al.*, *ArXiv E-Prints*, 1710.10220, 2017.
[13] D. Pelc, P. Popčević, G. Yu, M. Požek, M. Greven, and N. Barišić, *ArXiv E-Prints*, 1710.10221, 2017.
[14] A. P. Mackenzie, S. R. Julian, D. C. Sinclair, and C. T. Lin, *Phys. Rev. B*, **53**, 5848–5855, 1996.
[15] S. Sachdev, *Phil Trans R Soc A*, **374**, 2075, 2016.