# Disorder and the overdoped cuprates: application to $La_{2-x}Sr_xCuO_4$

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The cuprate phase diagram has been the subject of considerable controversy over the 30 years since the discovery of high-Tc superconductivity.[1] The overdoped side of the cuprate phase diagram is thought to be the simplest to understand, with the d-wave superconducting phase existing in many systems without competing or coexisting orders of other types. However, recent superfluid density and conductivity experiments have cast doubt on this simple picture.

Božović et al. measured the superfluid density in high quality MBE films of $La_{2-x}Sr_xCuO_4$ (LSCO) and found a linear temperature dependence of the superfluid density.[2] This was claimed as evidence that the materials are in the clean limit. The superfluid density and Tc were also found to decrease with increasing doping. This is inconsistent with clean d-wave BCS superconductivity, as the superfluid density should be almost independent of Tc for a given plasma frequency.

Subsequently, Mahmood et al. measured the THz conductivity of LSCO in order to locate the spectral weight missing from the superfluid.[3] They discovered that there is indeed a large amount of uncondensed spectral weight at low temperature, and that the conductivity in the superconducting state is approximately Drude-like. They showed consistency with the earlier superfluid density measurements, but argued that the broad uncondensed spectrum implies a quasiparticle scattering rate too large to be consistent with the linear-T-penetration depth observed. Mahmood et al. therefore concluded that their results definitively rules out a disorder-based explanation of the overdoped data.

We show that a weak-coupling, d-wave BCS model, playing out on a semi-realistic parameterization of the doping-dependent Fermi surface, provides a remarkably good description of experiments on overdoped LSCO, including recent measurements of superfluid density and terahertz conductivity on high-quality MBE-grown thin films. A key element of this approach is the consideration of weak-limit disorder from out-of-plane defects, which allows some of the hallmarks of the clean d-wave state (linear-in-T superfluid density and Volovik effect) to remain intact, while severely suppressing superfluid density and Tc.

[1] B. Keimer, S. A. Kivelson, M. R. Norman, S. Uchida, and J. Zaanen, Nature (London) 518, 179 (2015)
[2] I. Božović, X. He, J. Wu, and A. T. Bollinger, Nature 536, 309 (2016)
[3] F. Mahmood, X. He, I. Božović, and N. Armitage, ArXiv e-prints (2017), arXiv:1802.02101 [cond-mat.supr-con]