# Evolution of the Energy Spectrum of Underdoped Cuprates in the Pseudogap Phase with Temperature and Dopants Concentration

Gor'kov, L.P. (FSU, NHMFL); Teitel'baum, G.B. (Zavoiskii Institut, Kazan', Russia)

## Introduction

Transition into the superconducting state in metals occurs at a critical temperature $T_c$ from a normal phase with a well defined spectrum of excitations at the Fermi surface (FS). High-transition-temperature ($HT_c$) cuprates dramatically deviate from ordinary metals in that the pseudogap (PG) phase precedes onset of superconductivity. Instead of the Fermi liquid (FL) energy spectrum, in the PG phase the angle-resolved photoemission spectroscopy (ARPES) reveals coherent excitations *only* within the so-called "Fermi arcs" (FAs). Another spectrum branch - small electronic pocket - manifests itself indirectly in the quantum oscillations (QOs). But ARPES is unavailable as yet for every material, while QOs are observable only at low temperatures. Therefore the nature of the pocket and its very existence at other temperatures has been debated for a long time. With tendency to a charge ordering (CO) revealed in the recent X-rays experiments the view currently prevailing in the literature is that the pocket appears as the result of Fermi surface reconstruction at the CO transition.

We report on analysis of the experimental data on the resistivity and the Hall coefficient in the PG phase for three families of underdoped (UD) cuprates: YBCO, LSCO and Hg1201, both above and below the CO transition; the theoretical interpretation of the ($T$,$x$ )-phase diagram ($x$-the dopants concentration) agrees well with the low-temperature Hall data and the recent finding in the X-ray and NMR experiments.

## Results and Discussion

The main results are as follows [1-3]. 1) At low doping analysis of resistivity and the Hall coefficient shows that the coherent excitations on the Fermi arcs are the only charge carriers (holes) in the system. At higher dopants' concentrations $x$>0.08-0.10 the experimental Hall coefficient identifies the pocket as a *permanent* feature, in contrast to the idea of FS reconstruction at the CO phase transition. 2) Deviation of the Hall numbers in LSCO and YBCO from proportionality to dopants' concentration finds its natural explanation as due to the contribution from a small pocket of electrons *dragged* by holes on the Fermi arcs. 3) On lowering the temperature the Fermi arc carriers scatter strongly off fluctuations of incommensurable charge density waves, their mobility rapidly decreases and the contribution of holes to the transport properties gives way to that of electrons on the pocket.4) Small hole pockets in the energy spectrum of $YBa_2Cu_3O_y$ [4] are formed below the CO transition in the potential relief of "pseudogaps" and new gaps in the CO phase with a unidirectional wave vector.

## Conclusions

At higher temperatures the energy spectrum of UD cuprates consists of holes on Fermi arcs and the electron pocket at the BZ center. At low temperature, if superconductivity is suppressed by a strong magnetic field, charge density fluctuations destroy the Fermi arcs leaving electrons as the only mobile carriers.

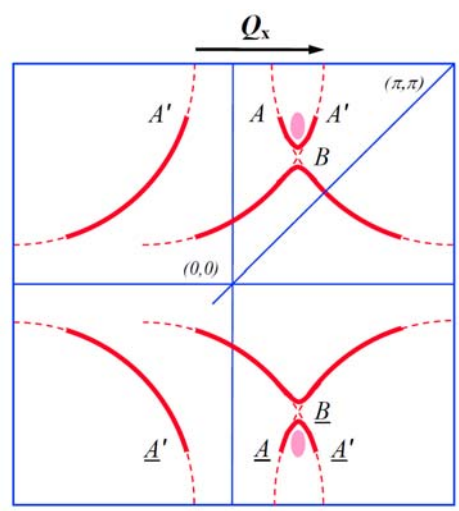


Fig.1 New spectrum in the CO phase with the uniaxial vector $\boldsymbol{Q}_x$ . Holes pockets form in two triangular areas near the antinodal directions.

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## References

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[4] N. Doiron-Leyraud et al., arXiv:1409.2788v1 (2014).