Multiple quantum critical points in the doping phase diagram of cuprates

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What is the real high-Tc phase diagram?

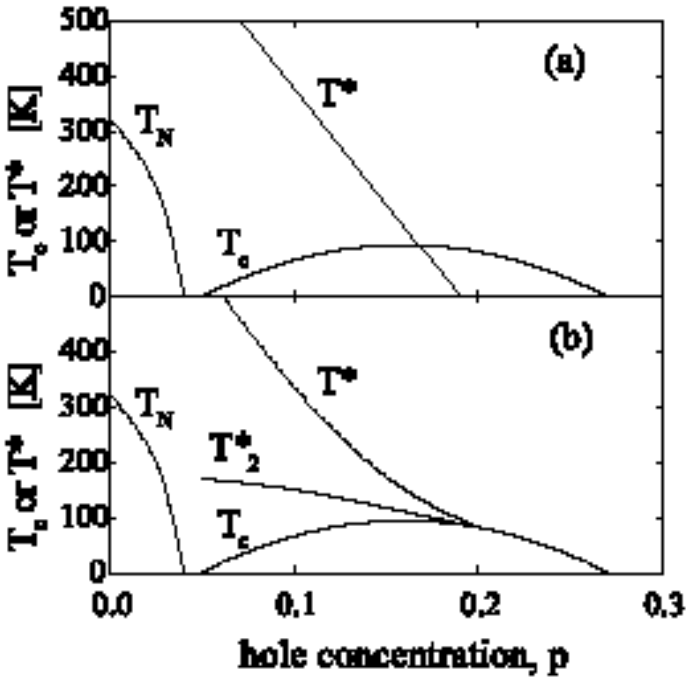


Fig. 1. Two scenarios for the "phase diagram" for HTS cuprates. (a) T^* represents an energy scale, which falls abruptly to zero at a critical doping, $p_{crit} = 0.19$. (b) T^* merges with T_c on the overdoped side and often a lower T_2^* associated with a small pseudogap or a spin gap is invoked. T_N is the Neel temperature for the 3D AF state.

Tallon JL, Loram JW, Physica C 349 (2001) 53

What is the Pseudogap?

Superconducting:

- Precursor superconductivity, BKT- transition
- Preformed pairs, Bose condensation

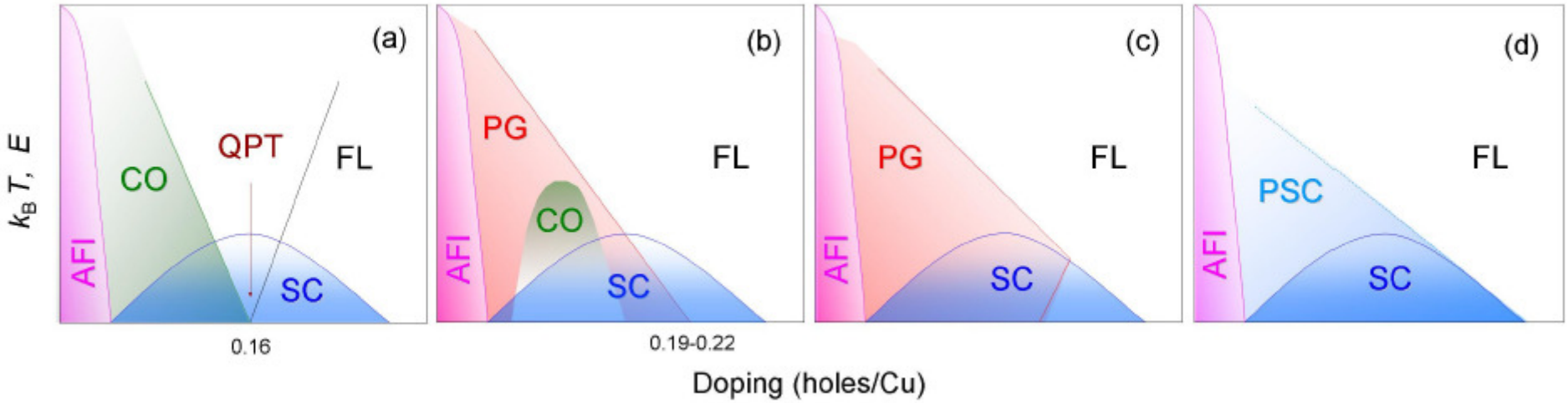
Non-superconducting:

- Hidden order parameter: CDW, SDW, d-DW
- Coulomb blocking (dynamic)

Quantum critical point

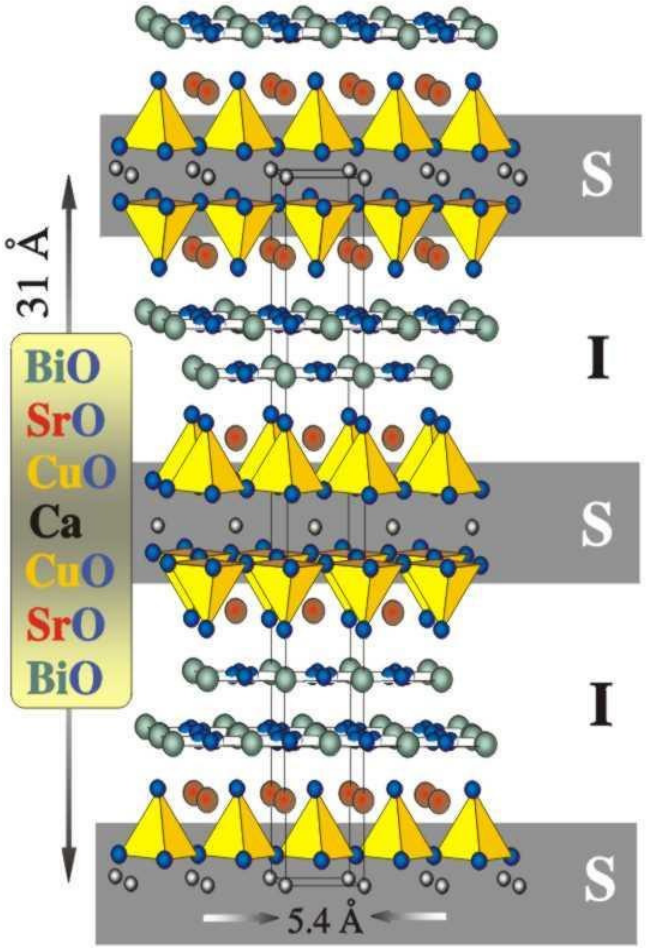
Stripes (good or bad?)

Examples of reported doping diagrams



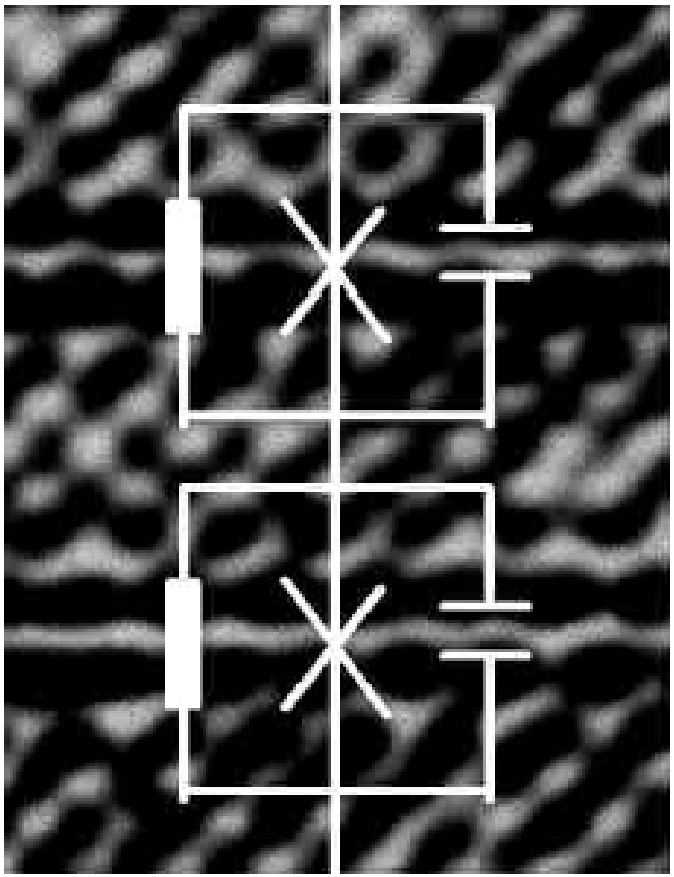
Intrinsic Josephson junctions in strongly anisotropic HTSC

$Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212)



by A. Yurgens

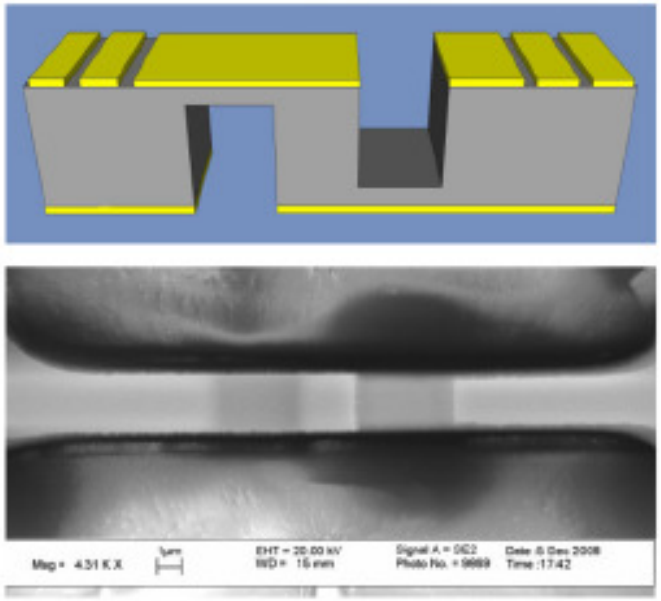
c-axis



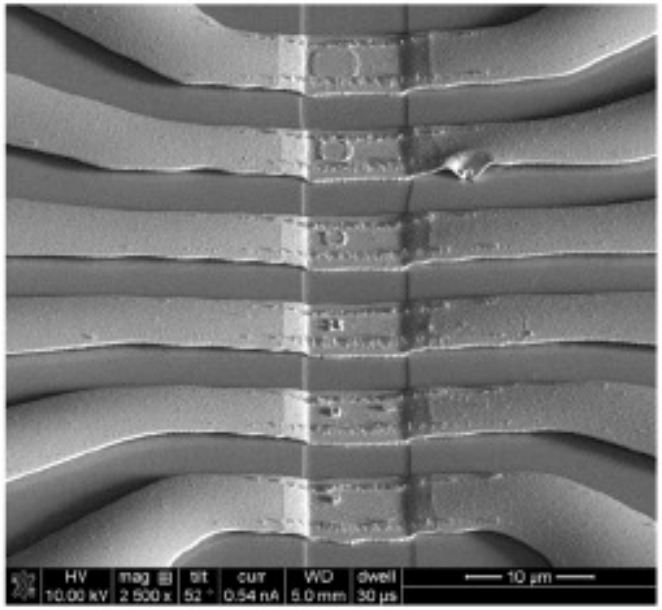
by P. Müller

Samples

(a)

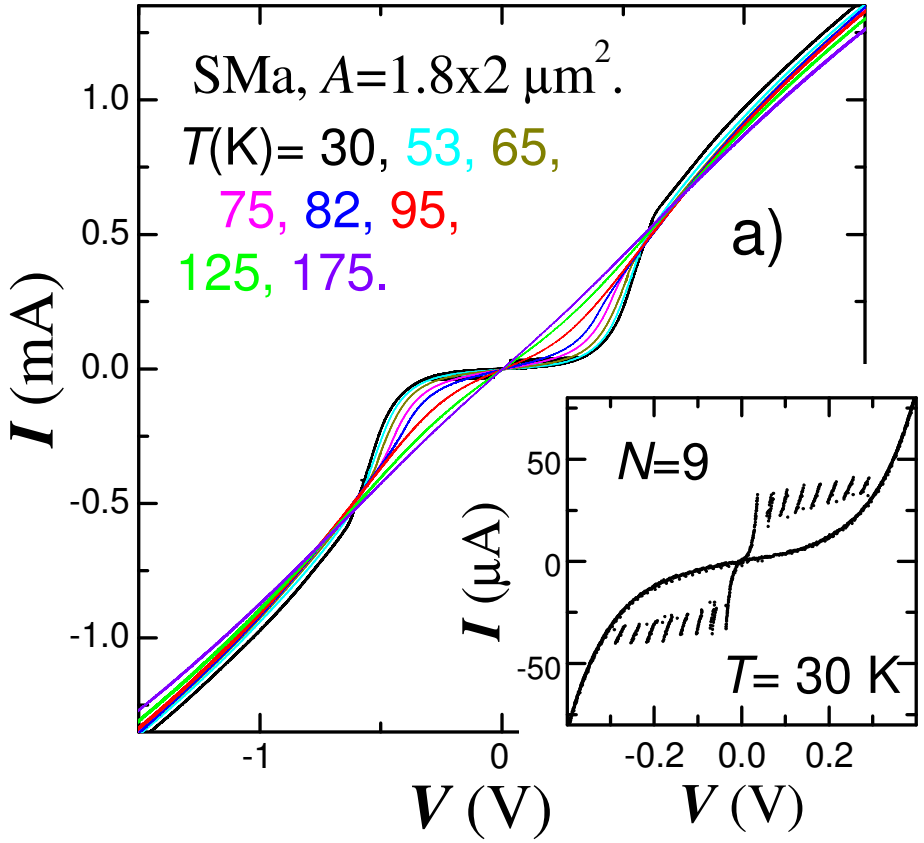


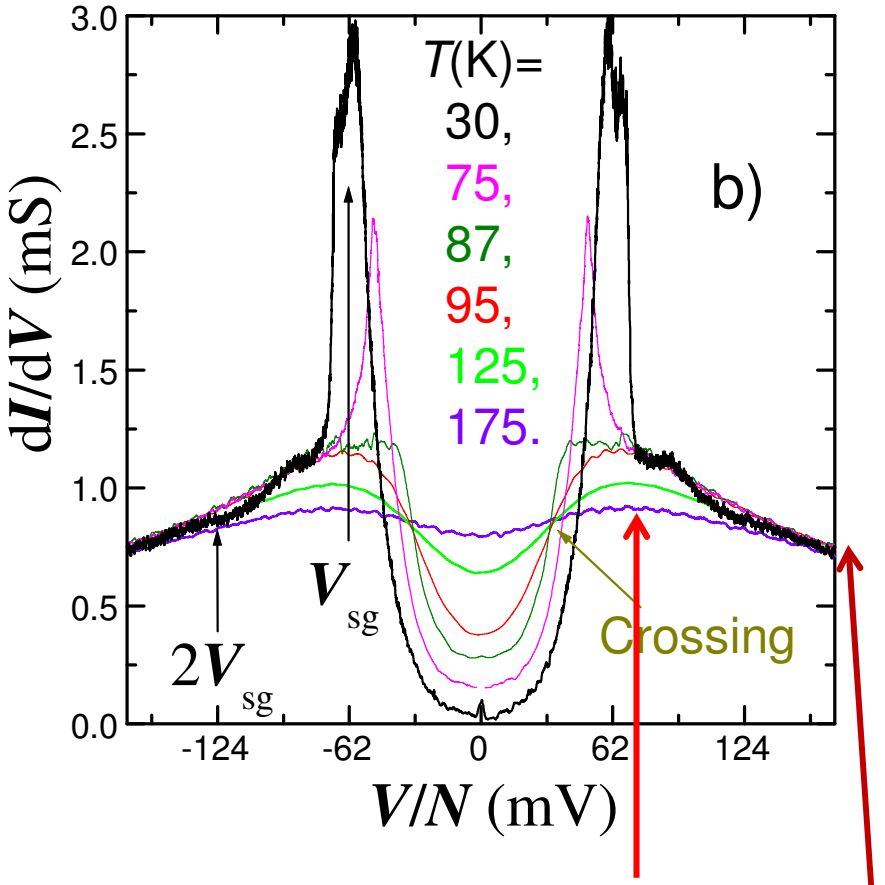
(b)



ITS: Intrinsic Tunneling Spectroscopy of small Bi-2212 mesas

Optimal doping $T_c \approx 92$K





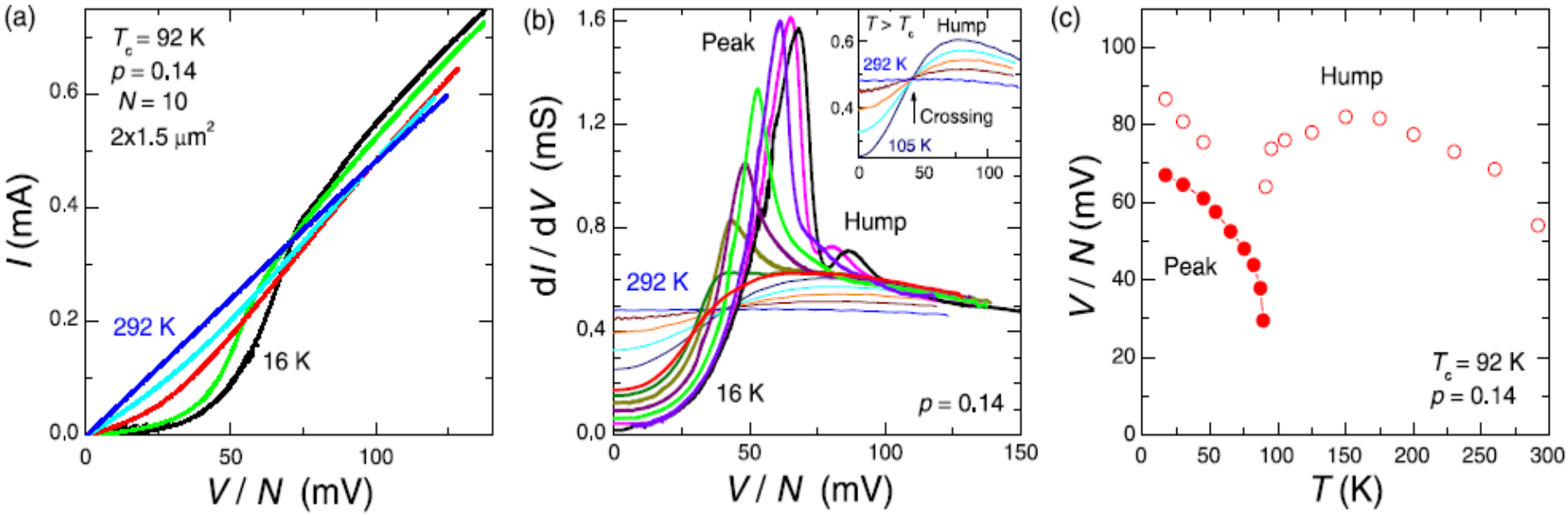
Sum-gap Peak: $V_{sg}=2\Delta/e$

S.O.Katterwe et al, PRL 101, 087003 (2008)

1. The superconducting gap at $T=0$ ~ the PG at $T>T_c$

2. T – independence of tunnel R implies state conservation

Temperature dependence in the UD state

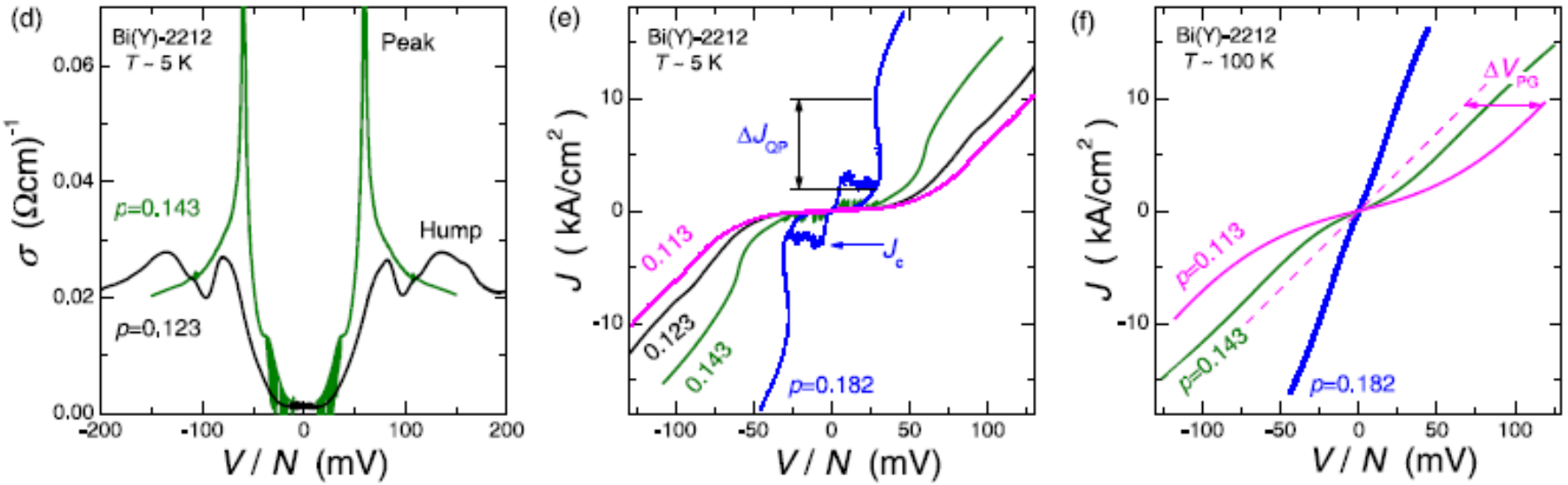


PHYSICAL REVIEW B **91**, 224508 (2015)

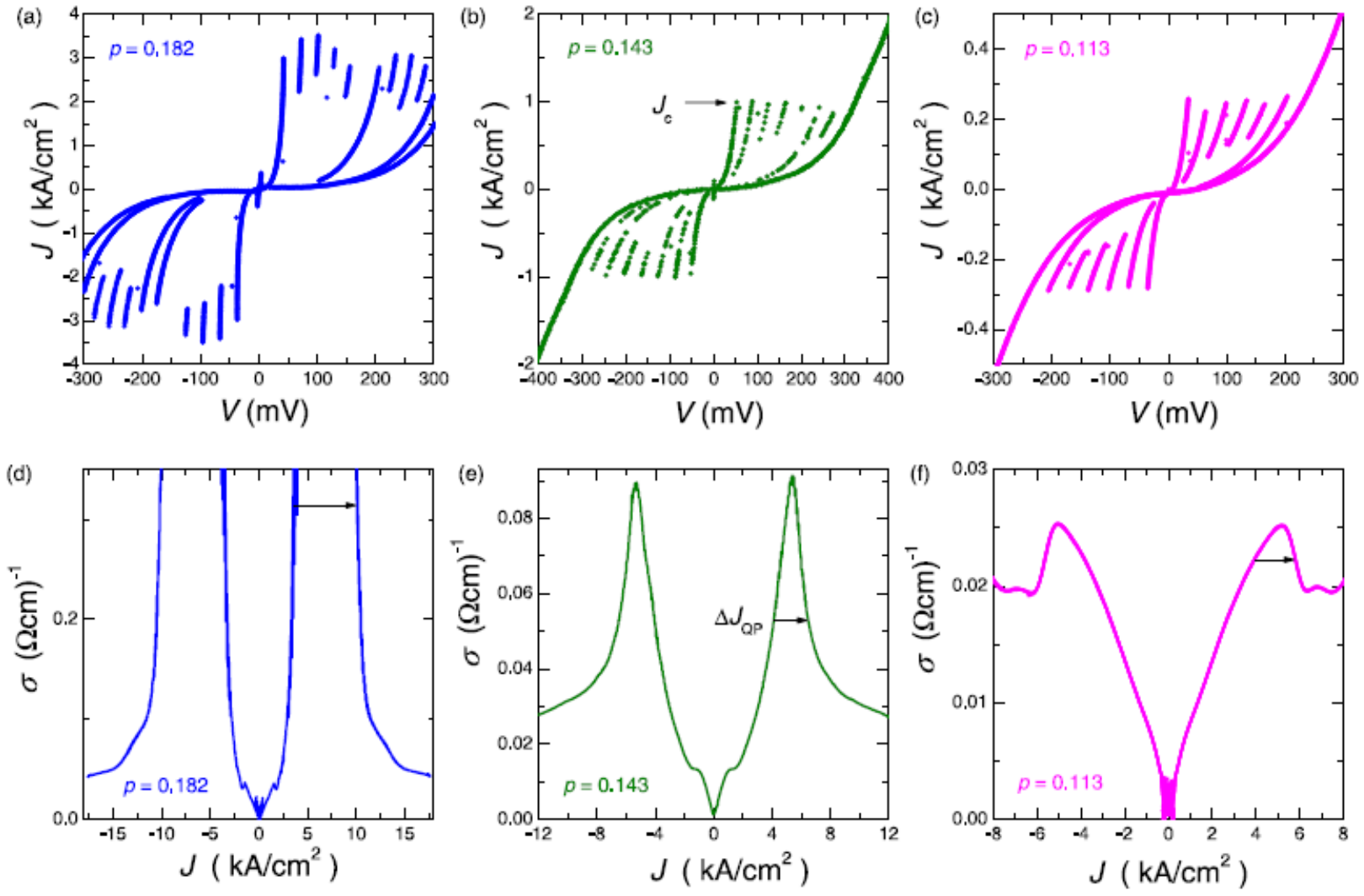
Superconducting condensate residing on small Fermi pockets in underdoped cuprates

V. M. Krasnov*

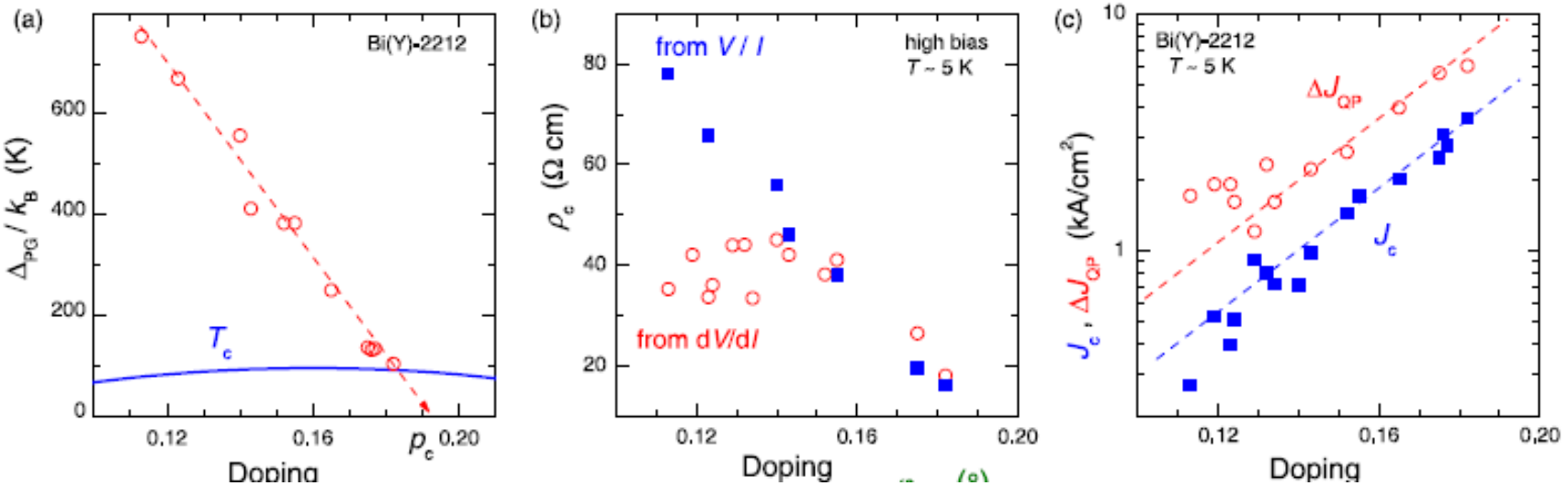
Oxygen-doping dependence of ITS characteristics



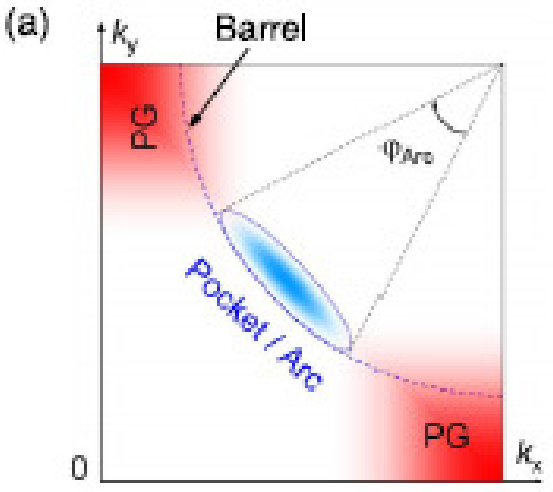
Oxygen-doping dependence of ITS

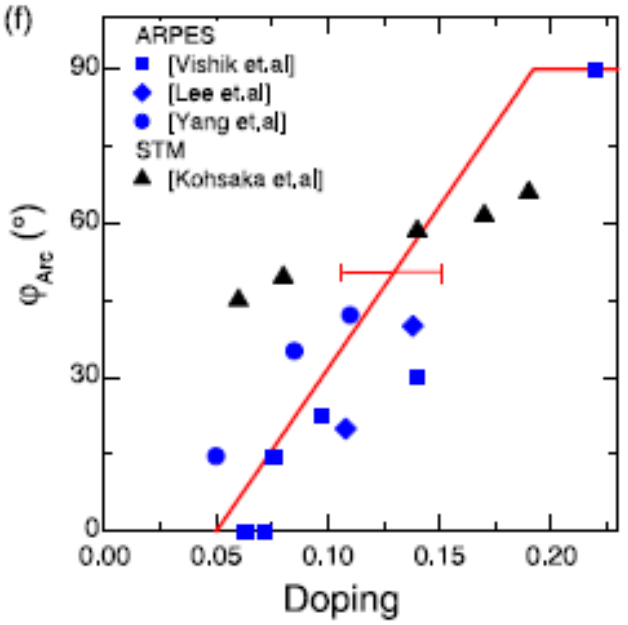


Summary: Oxygen-doping of ITS



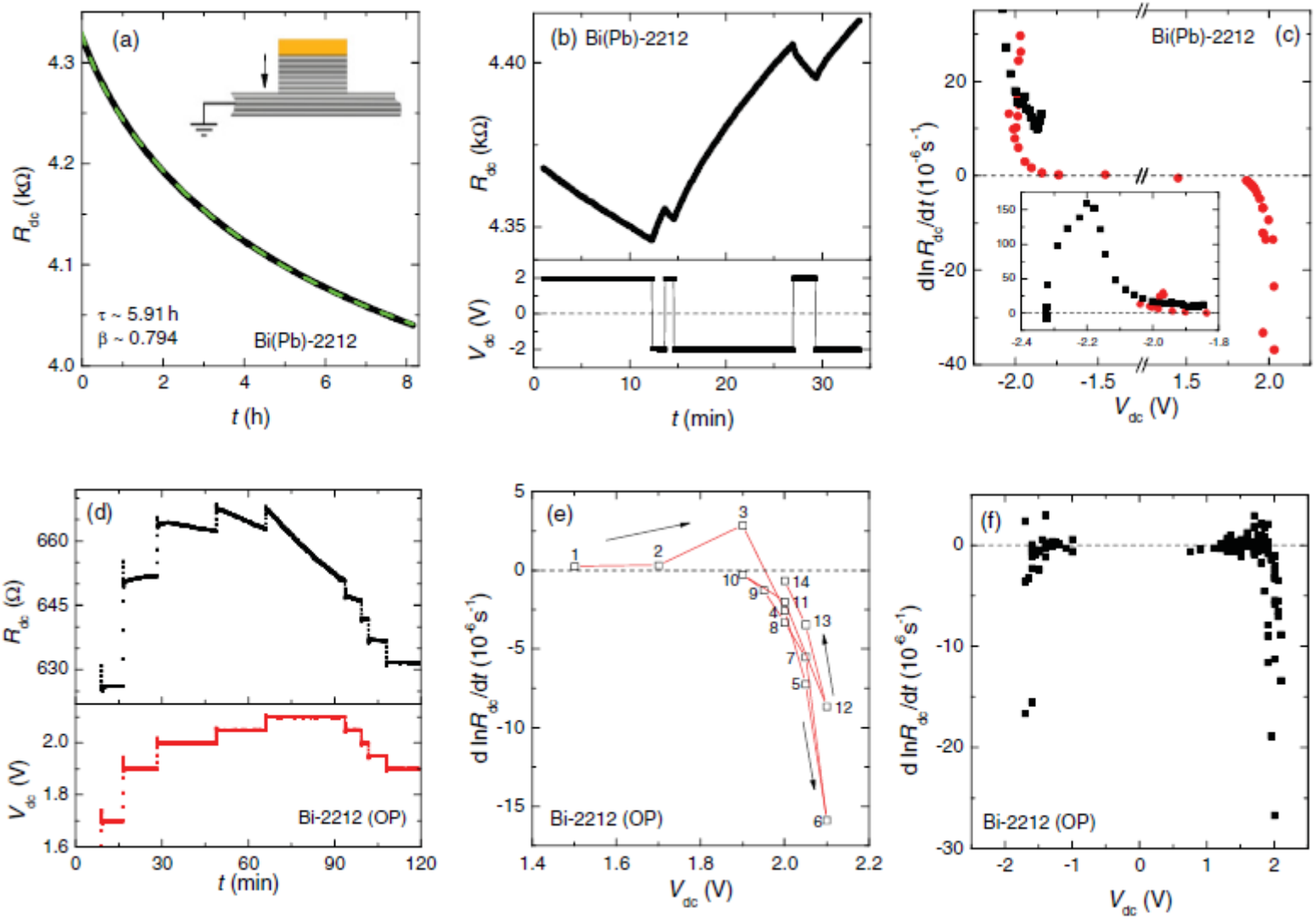
Too rapid decrease of Jc(p) due to shrinking of Fermi pockets at which SC condensate is residing





PHYSICAL REVIEW B 85, 144519 (2012)

Persistent electrical doping of $Bi_2Sr_2CaCu_2O_{8+x}$ mesa structures



ITS characteristics of the same sample upon electric doping

PRL 116, 067001 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Sequence of Quantum Phase Transitions in $Bi_2Sr_2CaCu_2O_{8+\delta}$ Cuprates Revealed by *In Situ* Electrical Doping of One and the Same Sample

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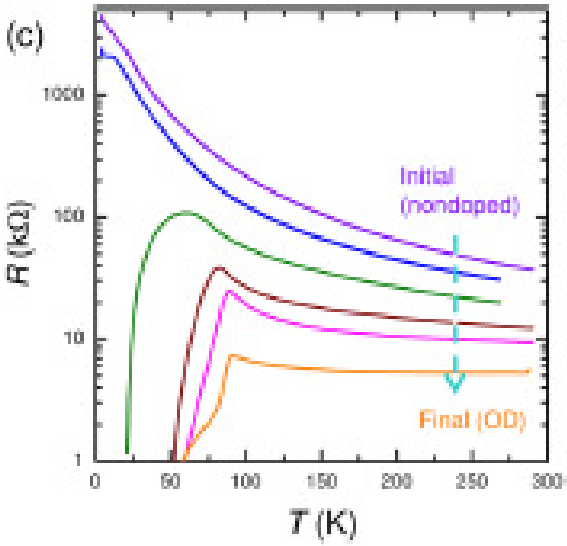
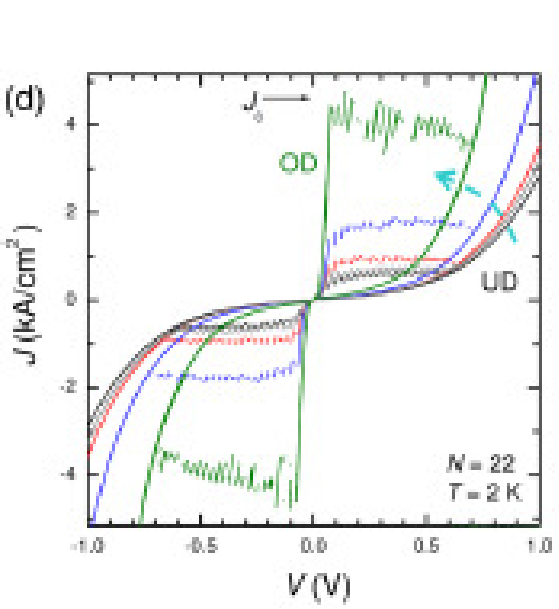
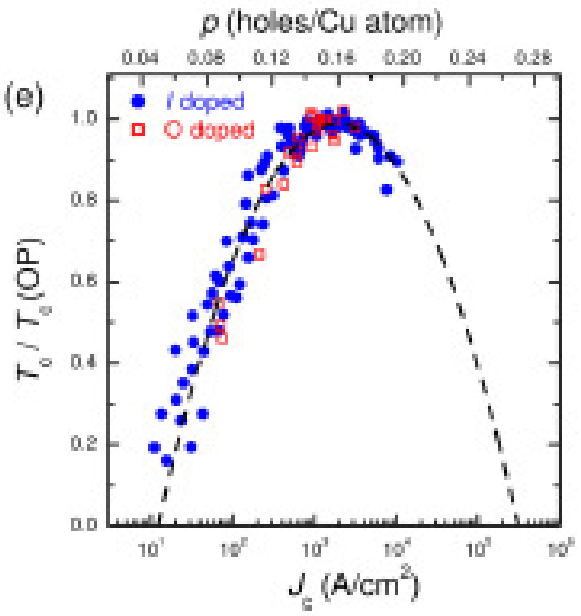
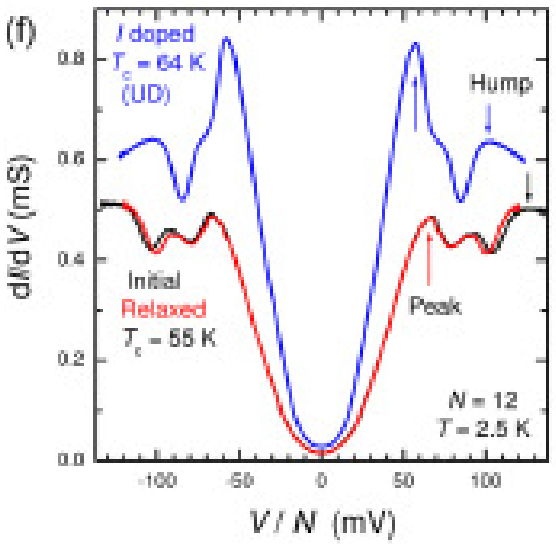
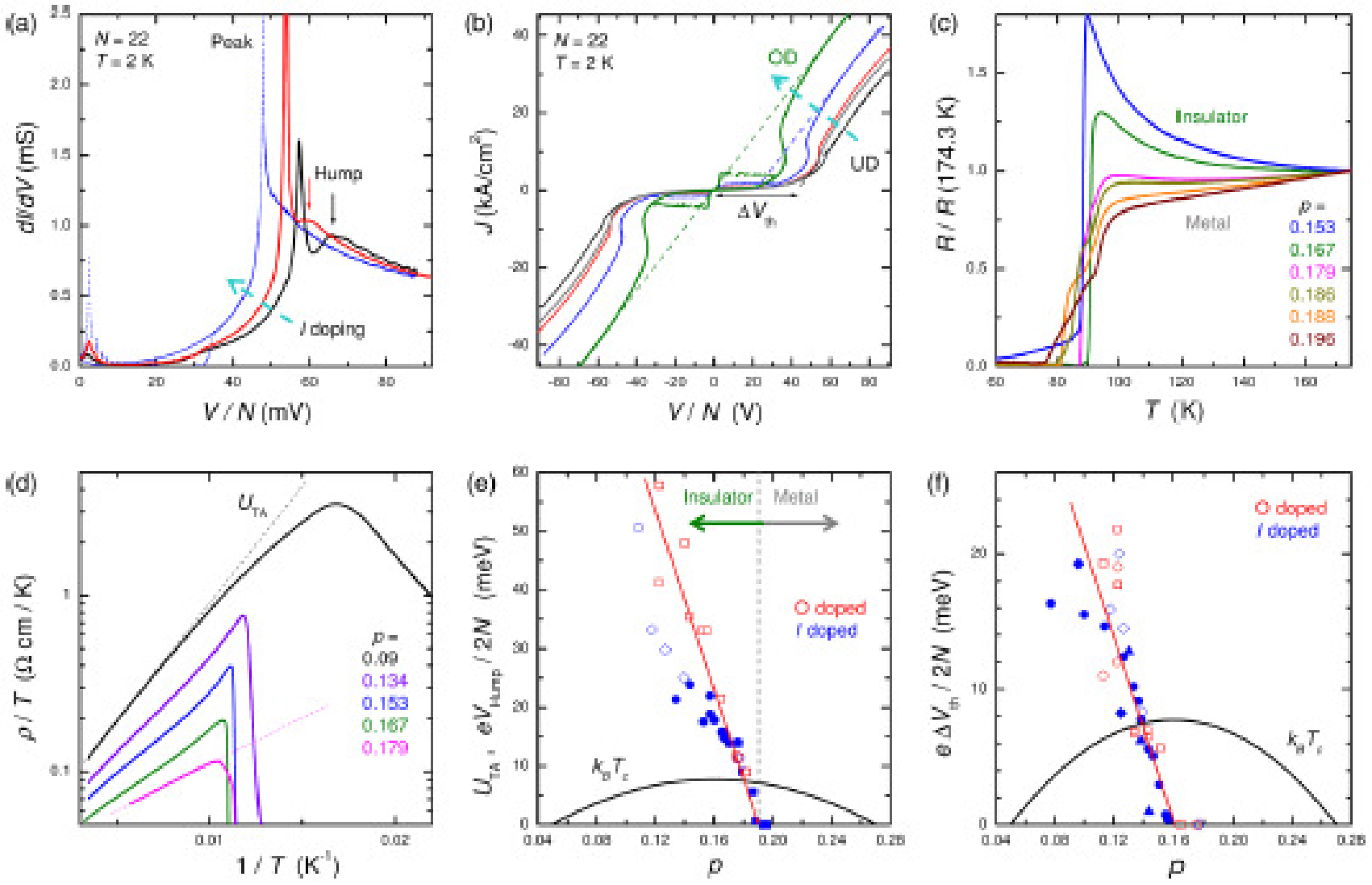








ITS characteristics of the same sample upon electric doping



Conclusions

Our recently discovered electrical doping technique allows a broad-range variation of carrier concentration without changing the chemical composition. We show that it is possible to induce superconductivity in a nondoped insulating sample and to tune it reversibly all the way to an overdoped metallic state. This way, we can investigate the whole doping diagram of one and the same sample, avoiding sample-to sample variation.

Our study reveals two distinct critical points.

i) The one at the overdoped side p=0.19 is associated with the onset of the pseudogap and with the metal-to-insulator transition in the c-axis transport.

ii) The other at optimal doping is associated with the appearance of a “dressed” electron energy.

Our study confirms the existence of multiple
phase transitions under the superconducting dome in cuprates.