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**Superconductor-Insulator Transition in High-Tc and Conventional  
Superconducting Films**

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# Superconductor-Insulator Transition in High- $T_c$ and Conventional Superconducting Films

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# Outline

## 1. High-T<sub>c</sub> cuprates

- SIT in cuprates: similarities and differences to low-T<sub>c</sub> systems
- Our experiment:  
positive orbital magnetoresistance in barely insulating LaSrCuO - evidence of superconducting fluctuations

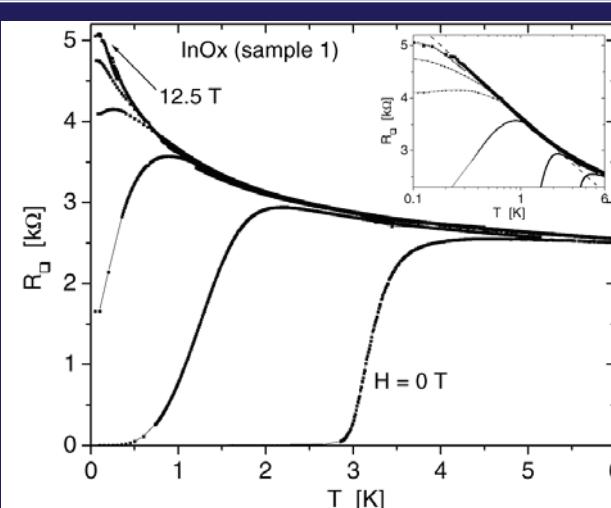
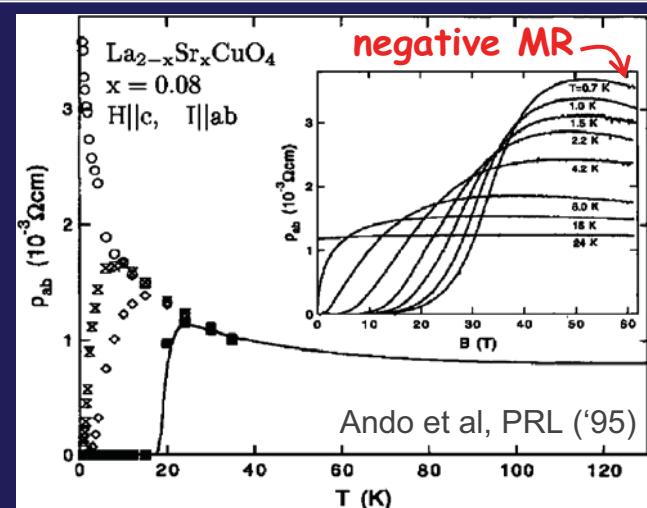
## 2. Low-T<sub>c</sub> material: Si/Nb/Si trilayers

- Motivation and material properties
- SIT in trilayers: MR peak and oscillations

## 3. Summary & conclusions



## High- $T_c$ cuprates

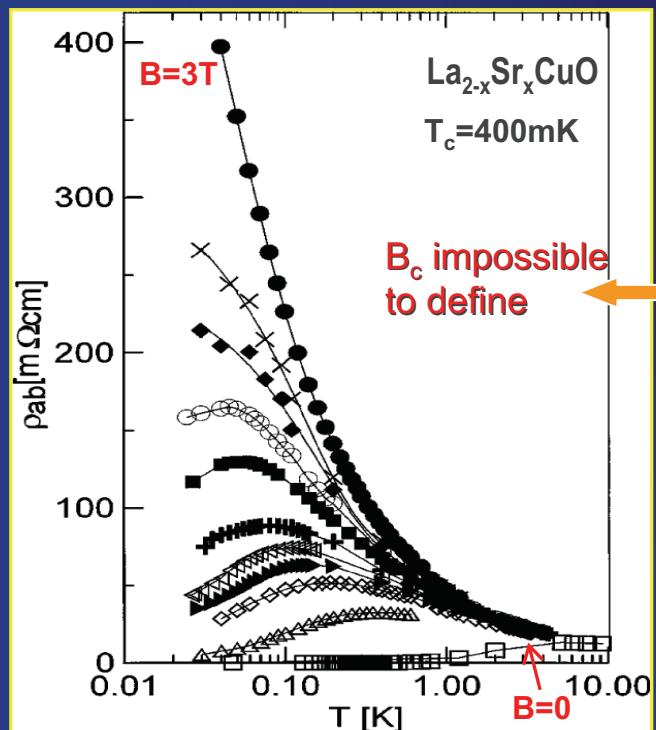


Steiner et al, PRL ('05)

Similarities between  
 $\text{LaSrCuO}$  and  $\text{InO}_x$

Resistive envelope:  
amplitude fluctuations ?

But: no crossing at  $B_c$



- Mandrus et al., PRB ('91) BiSrCaCuO
- Wang et al., PRB ('91) DyBaCuO
- Seidler et al., PRB ('92) YBCO
- Tanda et al., PRL ('92) NdCuO
- Rullier-Albenque et al., Physica C('95) YBCO & BiSrCaCuO
- Karpinska et al., PRL ('96) LaSrCuO
- Singh et al., PRB ('97) LaBaCaCuO
- Gantmakher et al., JETP Lett. ('03) NdCeCuO
- Dagan et al., PRL ('05) NdCeCuO
- Oh et al., PRL ('06) BiSrLaCaCuO
- Orgiani et al., PRL ('07) BaNdCuO/CaCuO
- Jin et al., PRB ('08) LaCeCuO

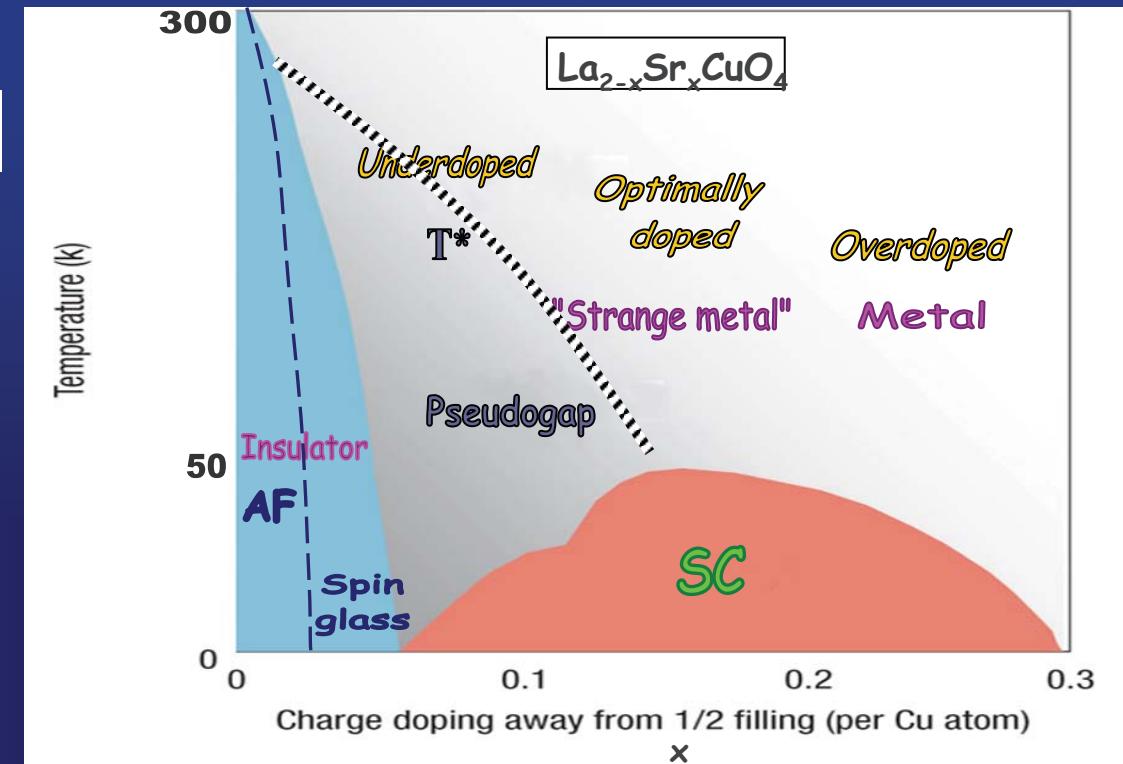
## High-T<sub>c</sub> cuprates

- Superconductivity  $d_{x^2-y^2}$
- Spin and charge fluctuations
- ◆ Pseudogap

ARPES:

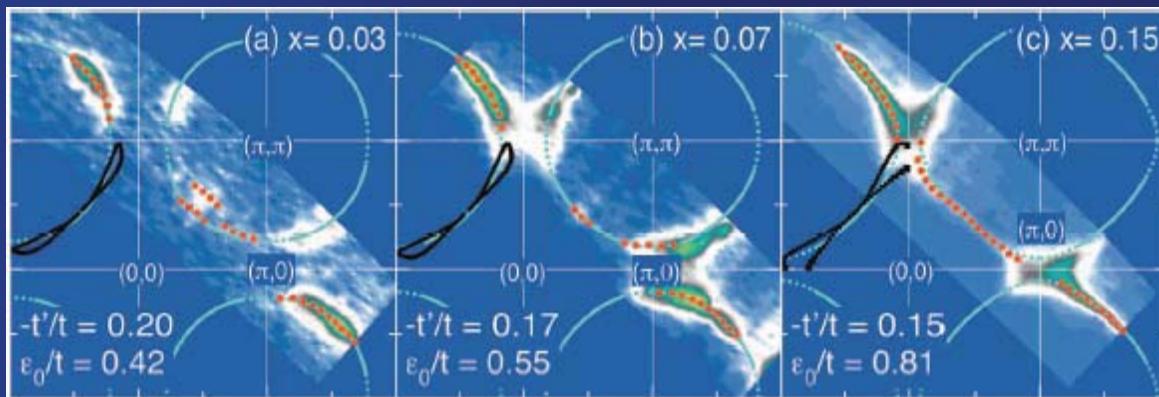
Final spectral weight on nodal directions: "nodal quasiparticles"

→ only a fraction of carriers contributes to transport

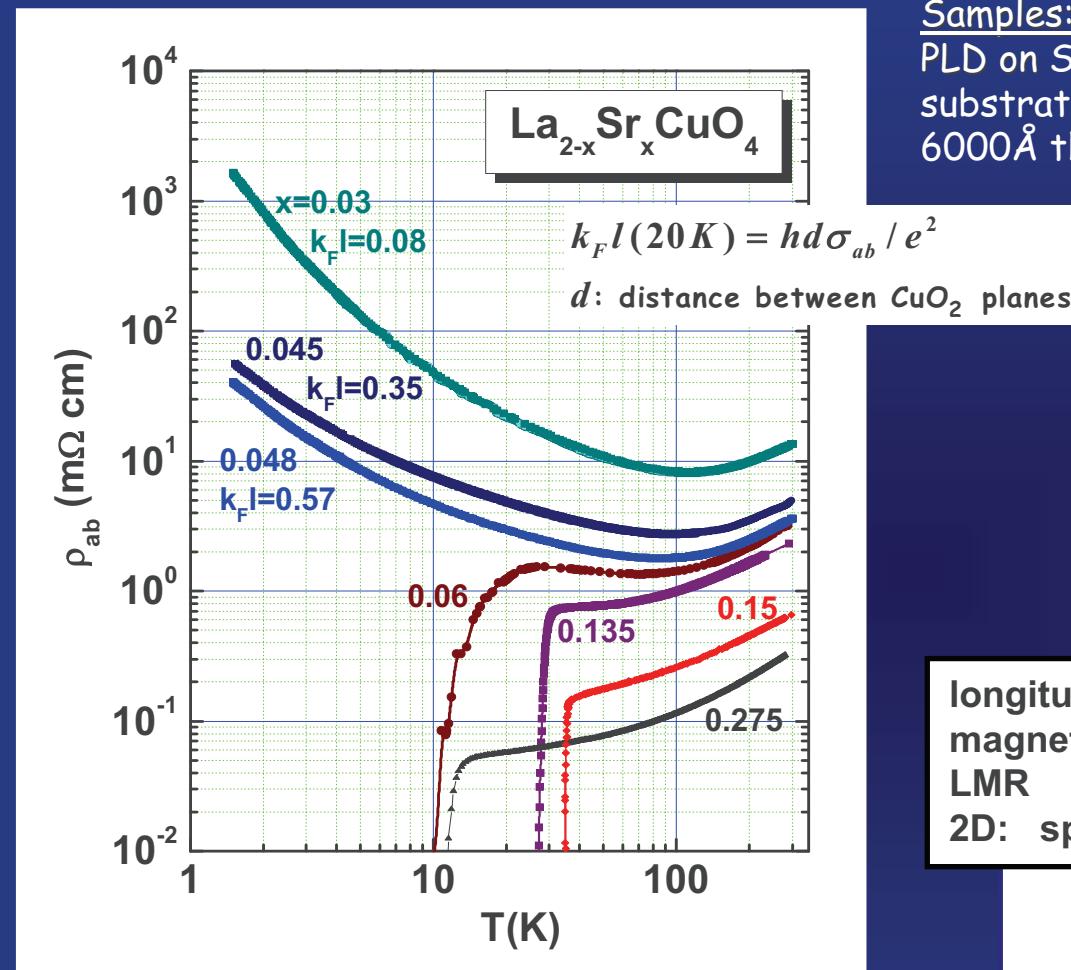


ARPES: Yosida et al., Phys.  
Rev. B 74, 224510 (2006)

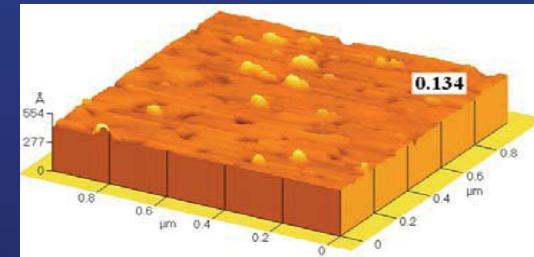
T=20K  $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$



## Barely insulating LSCO: magnetoresistance

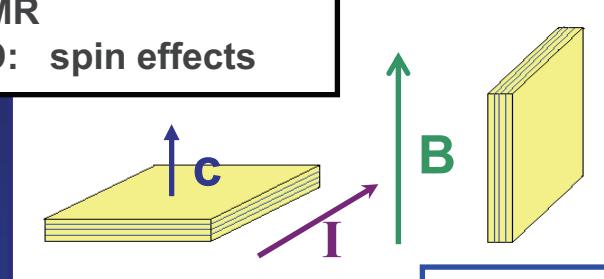


Samples: films grown by PLD on  $\text{SrLaAlO}_4$  substrates, about  $6000\text{\AA}$  thick



Measurements: 4-probe  
Temperatures: 1.6-70 K  
Magnetic fields: 0-14 T

longitudinal magnetoresistance LMR  
2D: spin effects



transverse magnetoresistance TMR  
spin + orbital effects

Marta Z. Cieplak et al., PRL ('04);  
A. Malinowski et al., JPCM ('08)

## Barely insulating LSCO: magnetoresistance

VRH:

$$\sigma_{ab} = \sigma_0 T^{-2w} \exp\left[-\left(\frac{T_0}{T}\right)^w\right]; \quad w = \frac{p+1}{p+4}$$

Pollak ('72) & Hamilton ('72):  $N(\varepsilon) = N_0 \varepsilon^p$

$p=0$ :  $w=\frac{1}{4}$  Mott's VRH;

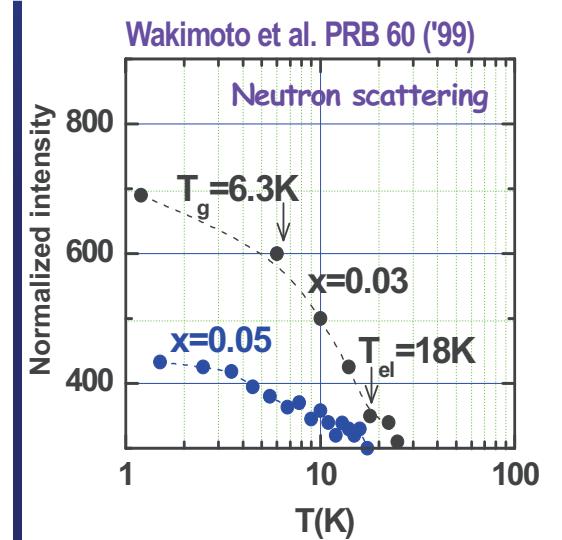
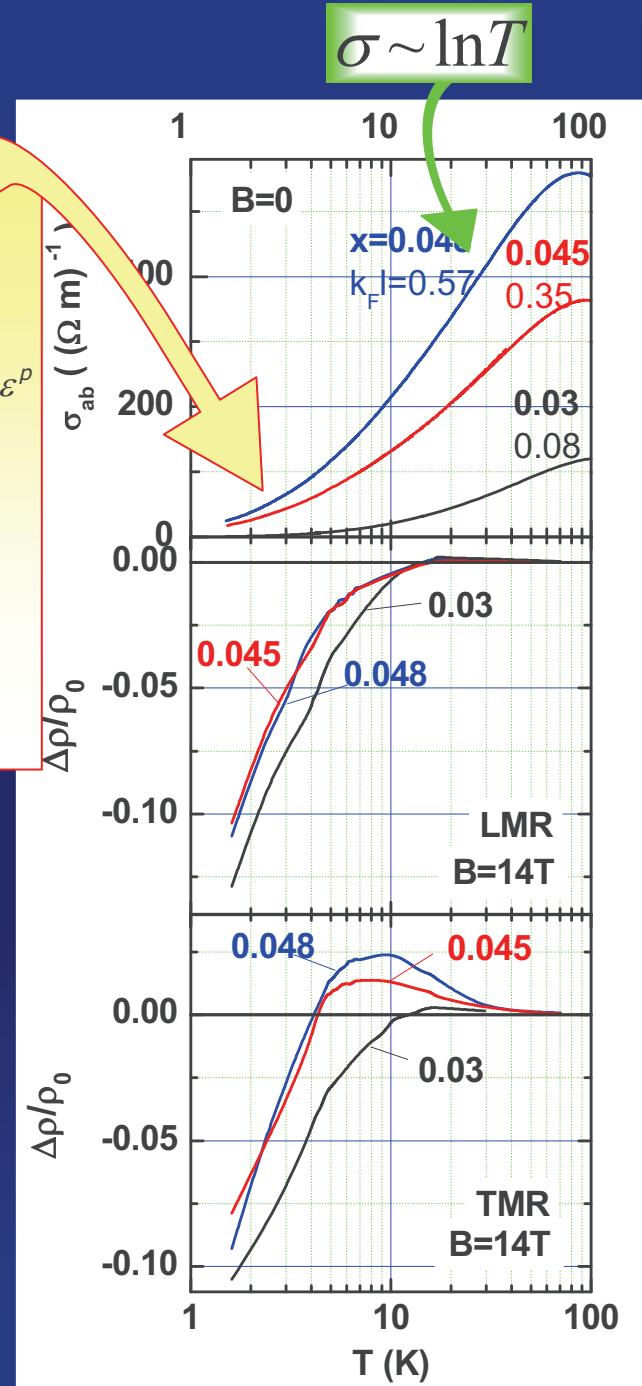
$p=2$ :  $w=\frac{1}{2}$  Coulomb gap

$x=0.03$ :  $p \sim 0.25 \rightarrow w \sim 0.3$

$x=0.045, 0.048$ :  $p \sim 0.06$

High T: TMR > LMR

- Positive orbital MR  
→ absence of weak localization



Low T: negative MR with large LMR contribution

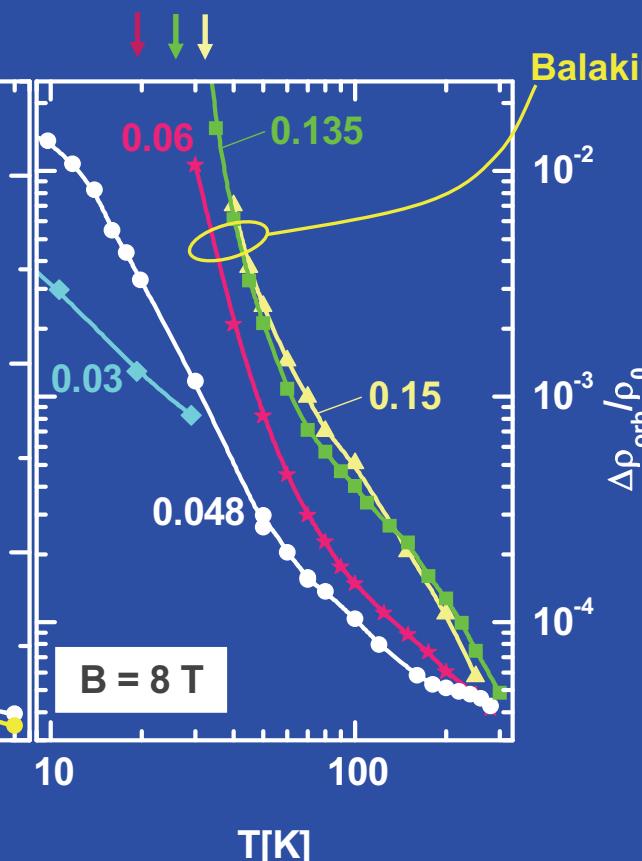
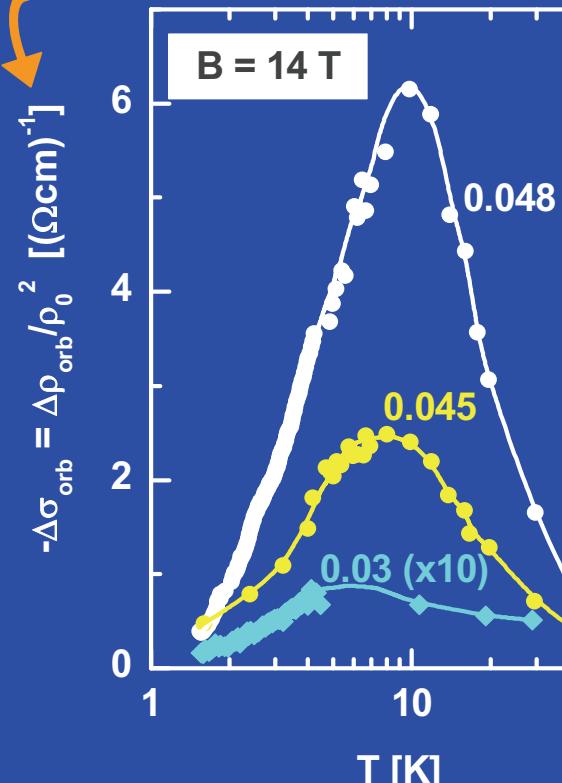
- Negative LMR: correlated with the magnetic signal → spin-related scattering  
(below  $T_{el} \sim 10K$  at  $x=0.05$ )

## Orbital magnetocconductivity:

$$\frac{\Delta \rho_{orb}}{\rho_0} = \frac{\Delta \rho_{TMR}}{\rho_0} - \frac{\Delta \rho_{LMR}}{\rho_0}$$

$$\Delta \sigma_{orb} = -\frac{\Delta \rho_{orb}}{\rho_0^2}$$

magnetic field induced  
change of conductivity



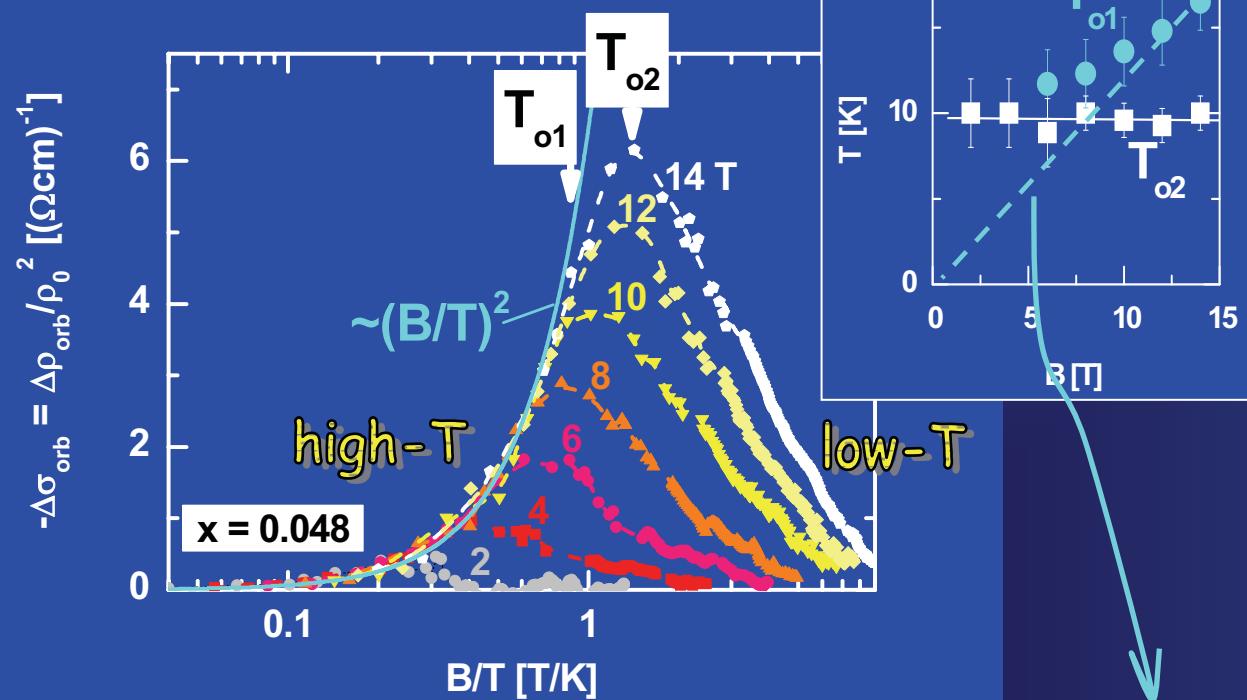
Balakirev et al., ('98):

Smooth evolution  
across SI transition:  
 • maximum in  
insulating samples  
 • divergence in  
superconducting  
 → origin similar:  
superconducting  
(MT) fluctuations ?

H.Kontani, PRL 89 ('02):  
Fermi-liquid theory with strong AF  
and sc fluctuations of Maki-Thompson  
type below the pseudogap opening  
R. Ikeda, PRB 66 ('02):  
quantum sc fluctuations

good description of the  
anomalous normal-state  
properties, including  
divergent OMR

## The origin of the OMR



$$-\Delta\sigma \sim \left(\frac{B}{B_{in}}\right)^2 \quad B \ll B_{in}$$

$$-\Delta\sigma \sim \ln\left(\frac{B}{B_{in}}\right) \quad B \gg B_{in}$$

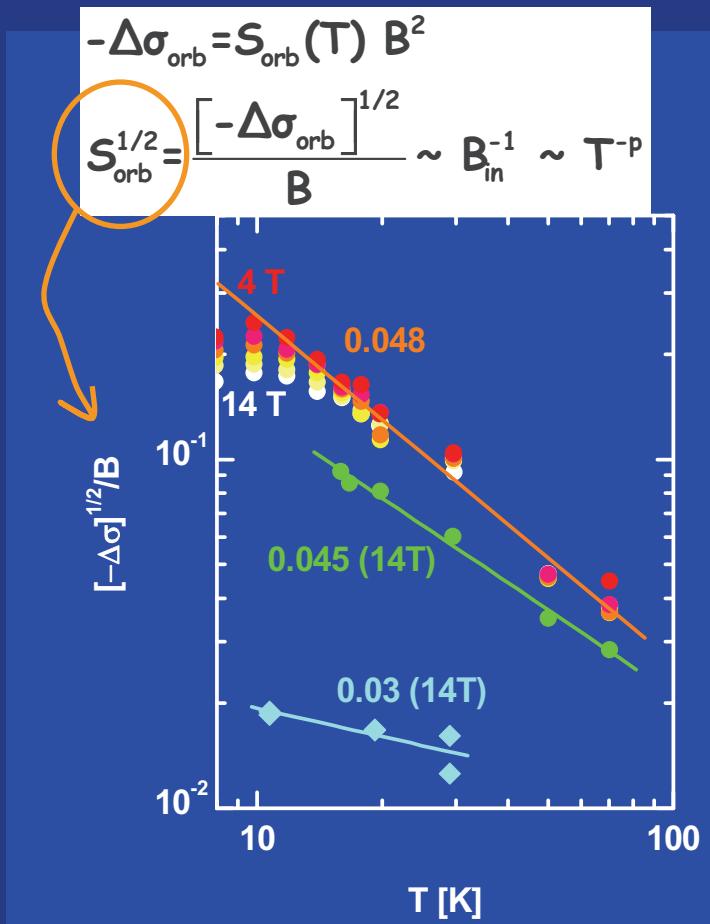
$$B_{in} = \frac{\hbar}{4eD\tau_{in}} \quad \tau_{in} \sim T^{-p}$$

$p=1$  el-el interactions

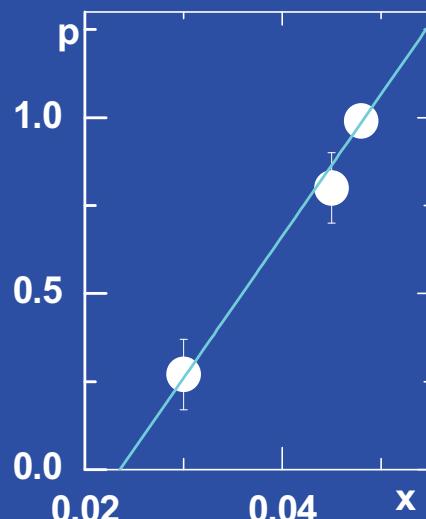
Crossover at  $B \approx B_{in}$ :  $T_{o1}(B)$ -line  
 $\Rightarrow B_{in}(T) = B_{in}/T = 0.83 \text{ Tesla/K}$   
 $D\tau_{in} \equiv L_{in}^2 = 198 T^{-1} \text{ nm}^2$   
 $L_{in} = 3 \text{ nm at } T = 20\text{K}$

$D \approx 0.39 \text{ cm}^2/\text{s} (T=20 \text{ K}) \Rightarrow \tau_{in} \approx 2.6 \times 10^{-13} \text{ s}$   
 Disordered conventional metals:  $\tau_{in} \approx 10^{-11} \text{ s}$

Strong interactions!!



### The origin of the OMR



0.048:  $p=0.99\pm0.03$

0.03:  $p=0.27\pm0.1$   
stronger interactions

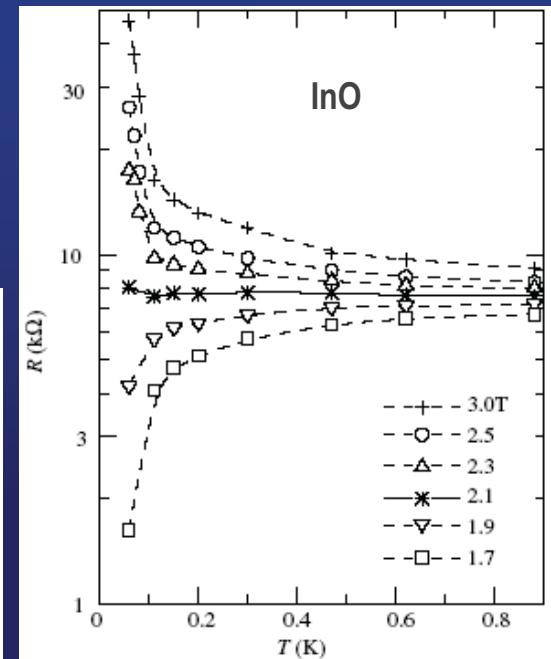
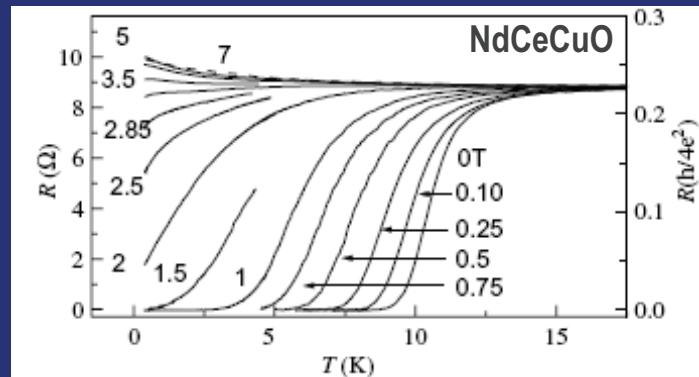
$p \downarrow 0$  at  $x_c=0.023$  - close to the boundary between the AF & the spin glass phase

$\Rightarrow$  OMR is detectable deep inside the insulating phase - as soon as the concentration of carriers is large enough to frustrate the long-range AF order

## Si/Nb/Si trilayers: motivation

Two groups of materials (Gantmakher, 2004):

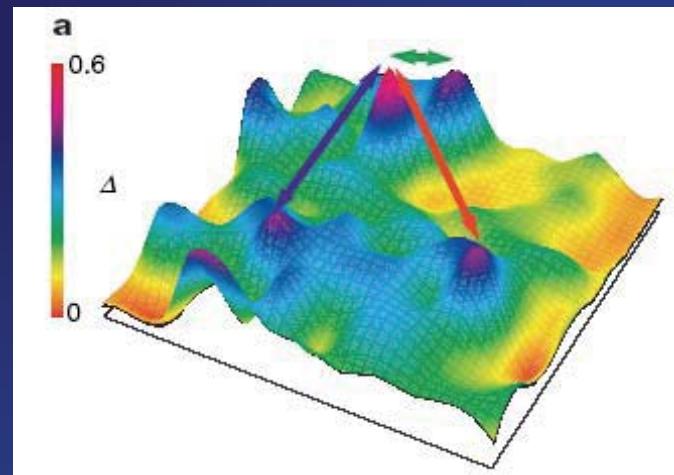
- (1) weak disorder & high carrier concentration
- (2) Large disorder & low carrier concentration



Dubi, Meir & Avishai (2007): numerical simulations

group (1) - uniform suppression of the amplitude of the OP by the magnetic field

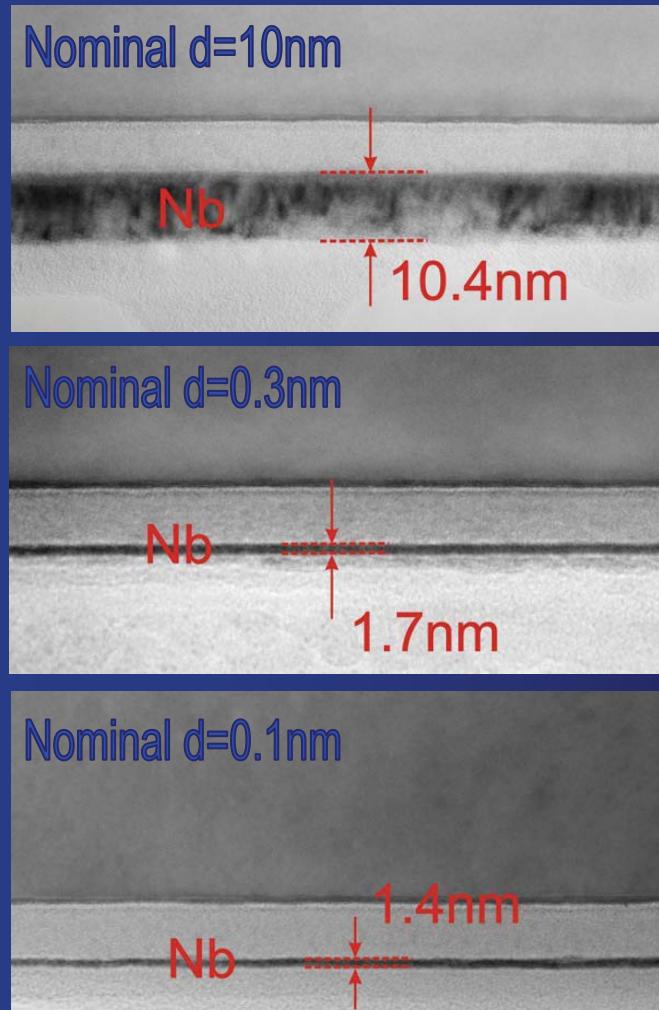
group (2) - sc islands on the insulating side (phase fluctuations)



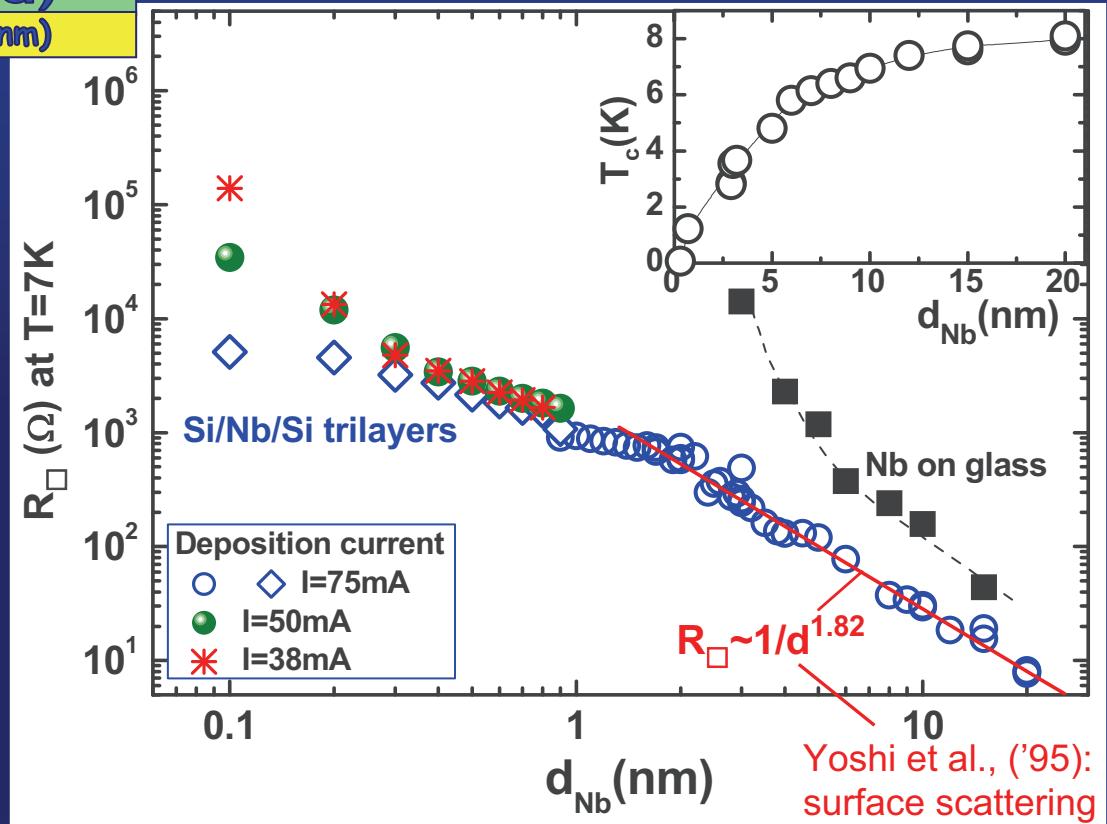
Goal:

create a system, in which a transformation  
can be made from (1) to (2)

## Si/Nb/Si trilayers



grown by sputtering on glass substrates



$Nb_{1-x}Si_x$ : Hertel et al. ('83)

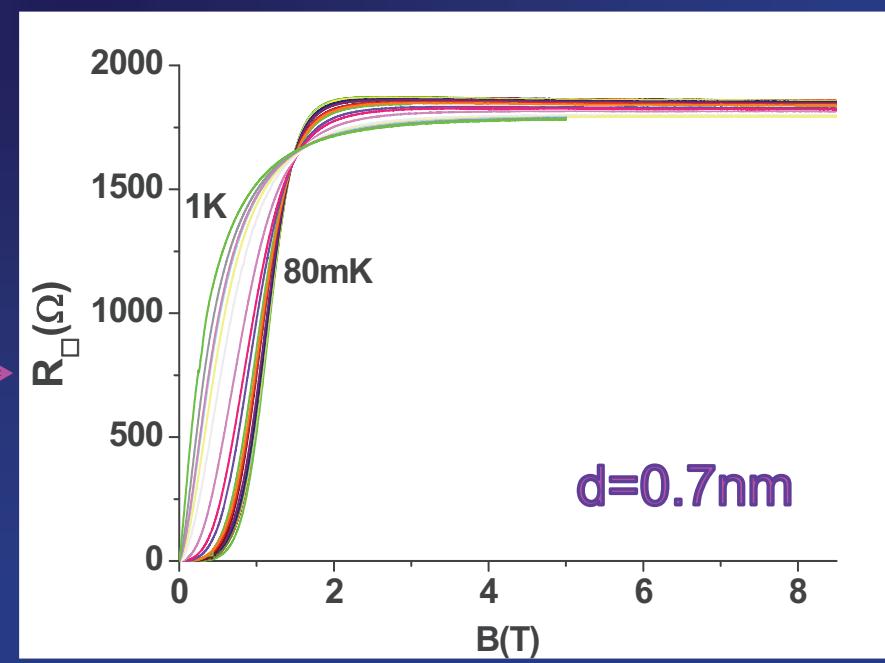
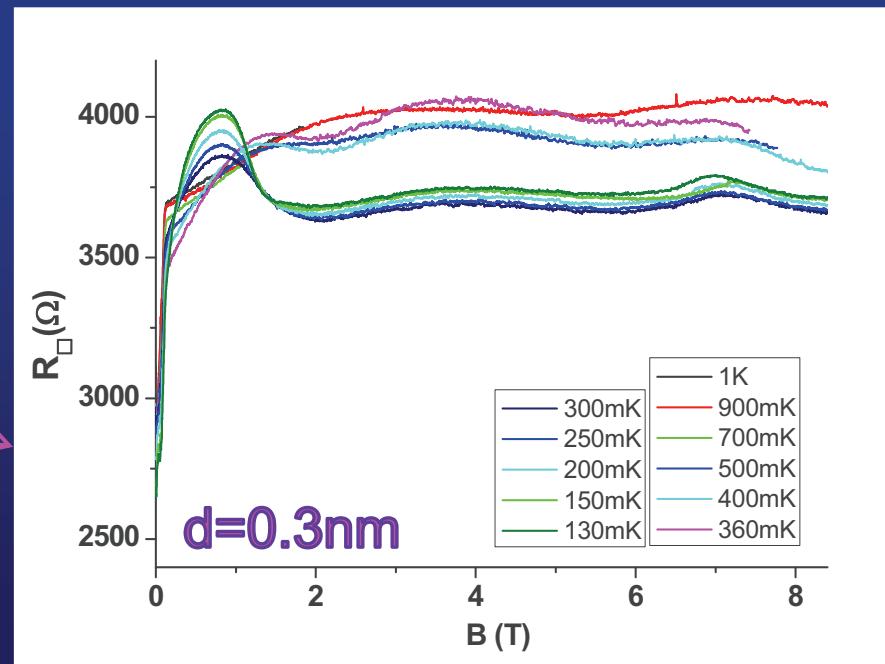
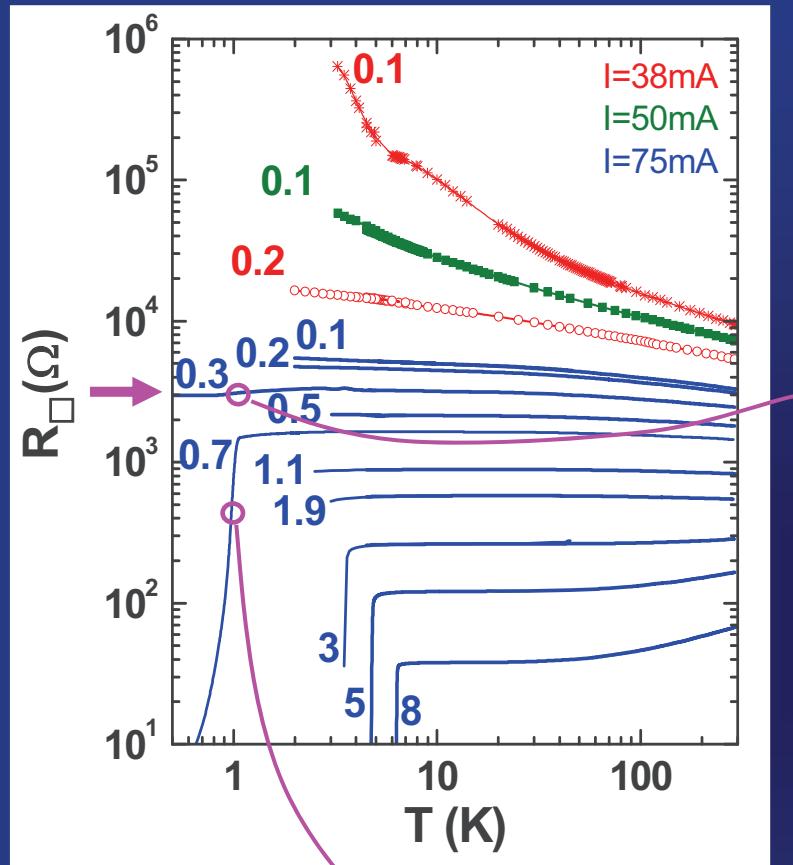
$\Rightarrow$  SIT at  $x \sim 0.13$  (decrease of the carrier concentration)

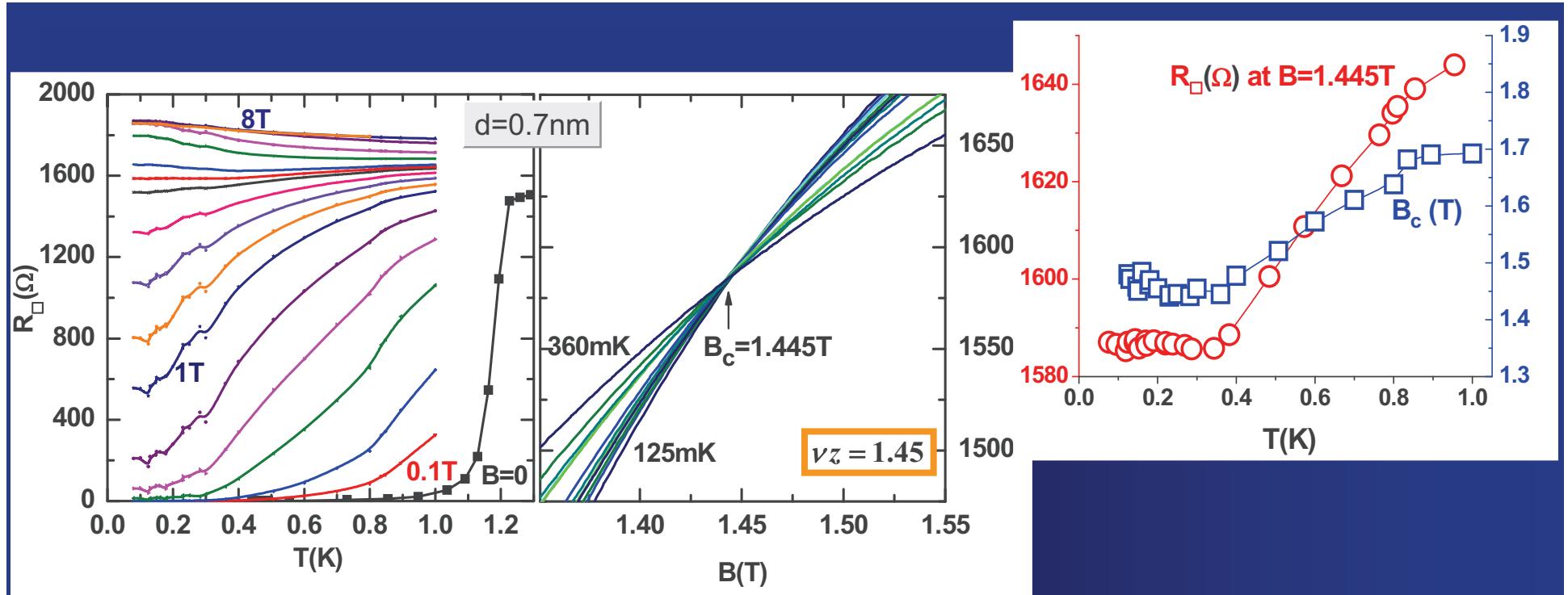
$d=0.7nm$ :  $R_H \sim 1 \times 10^{-10} m^3/C$

Bulk Nb:  $R_H \sim 5 \times 10^{-11} m^3/C$ ;  $InO_x$ :  $R_H \sim 6 \times 10^{-9} m^3/C$

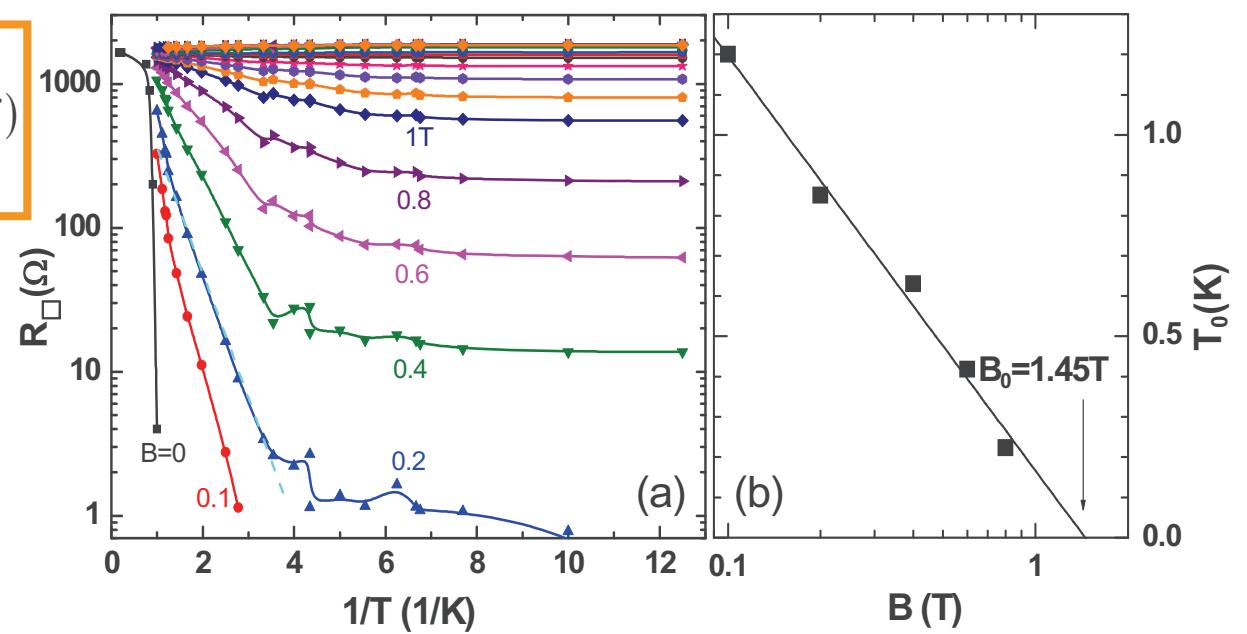
Song et al., ('89,'91);  
Fullerton et al. ('93);  
Zhang & Wang ('98);  
Bochnicek (2000).

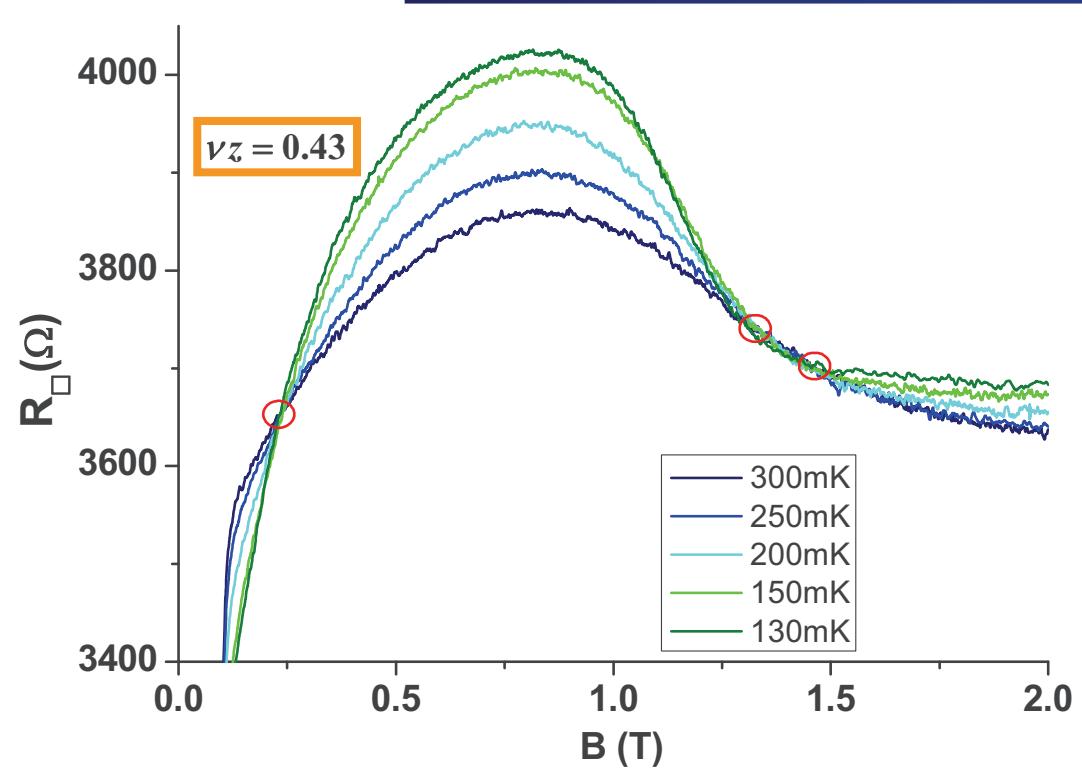
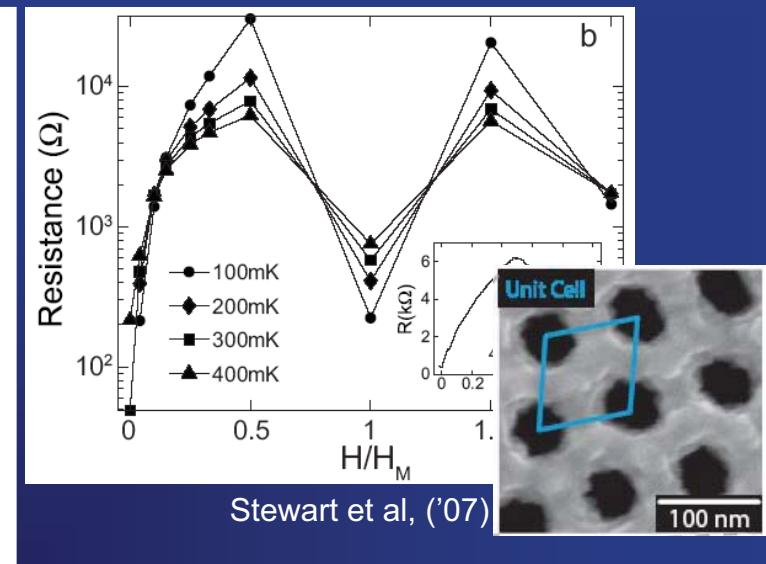
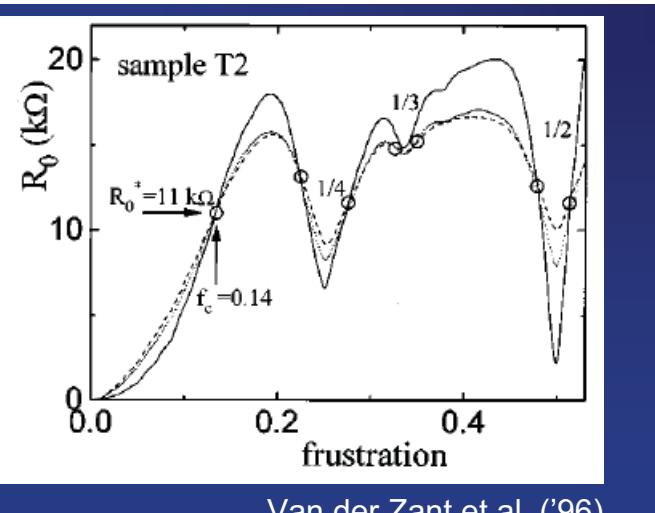
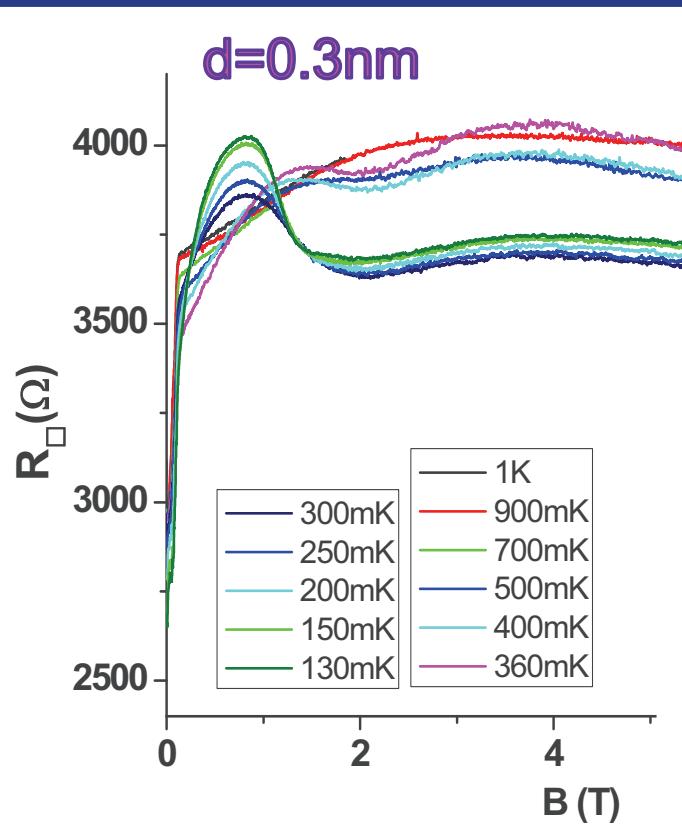
## Si/Nb(d)/Si trilayers





**TAFF**  
 $R = R_0 \exp(-T_0/T)$   
 $T_0 \sim \ln(B_0/B)$





## Summary & conclusions

### High-T<sub>c</sub> cuprates

magnetoresistance in strongly underdoped  $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$

- spin-related scattering at low T
- weak localization is absent; interactions are important
- sc fluctuations exist in the insulating phase: onset of the OMR at the AF-SG phase boundary

### Si/Nb/Si trilayers

- System with carrier concentration intermediate between two limiting behaviors (InO,TiN and NbSi, MoGe, Bi...etc)
- Evolution of MR peak:  
from “conventional” peak with one crossing point to oscillating behavior with many crossing points

