

Mott insulator bilayers

At the interface between electron and hole doped Mott insulators

Marcel Hoek¹, Louk Rademaker², Francesco Coneri¹, Denise Leusink¹, Jan Zaanen², Hans Hilgenkamp^{1,2}

m.hoek@utwente.nl & rademaker@lorentz.leidenuniv.nl

¹MESA+ institute for Nanotechnology, University of Twente

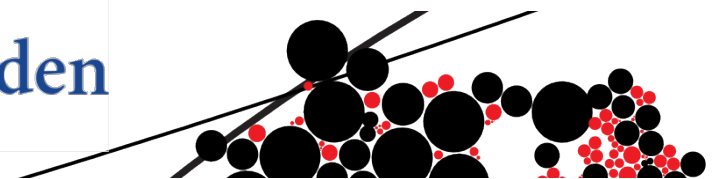
²Institute-Lorentz, University of Leiden

Bristol – ICE2UK – 2012

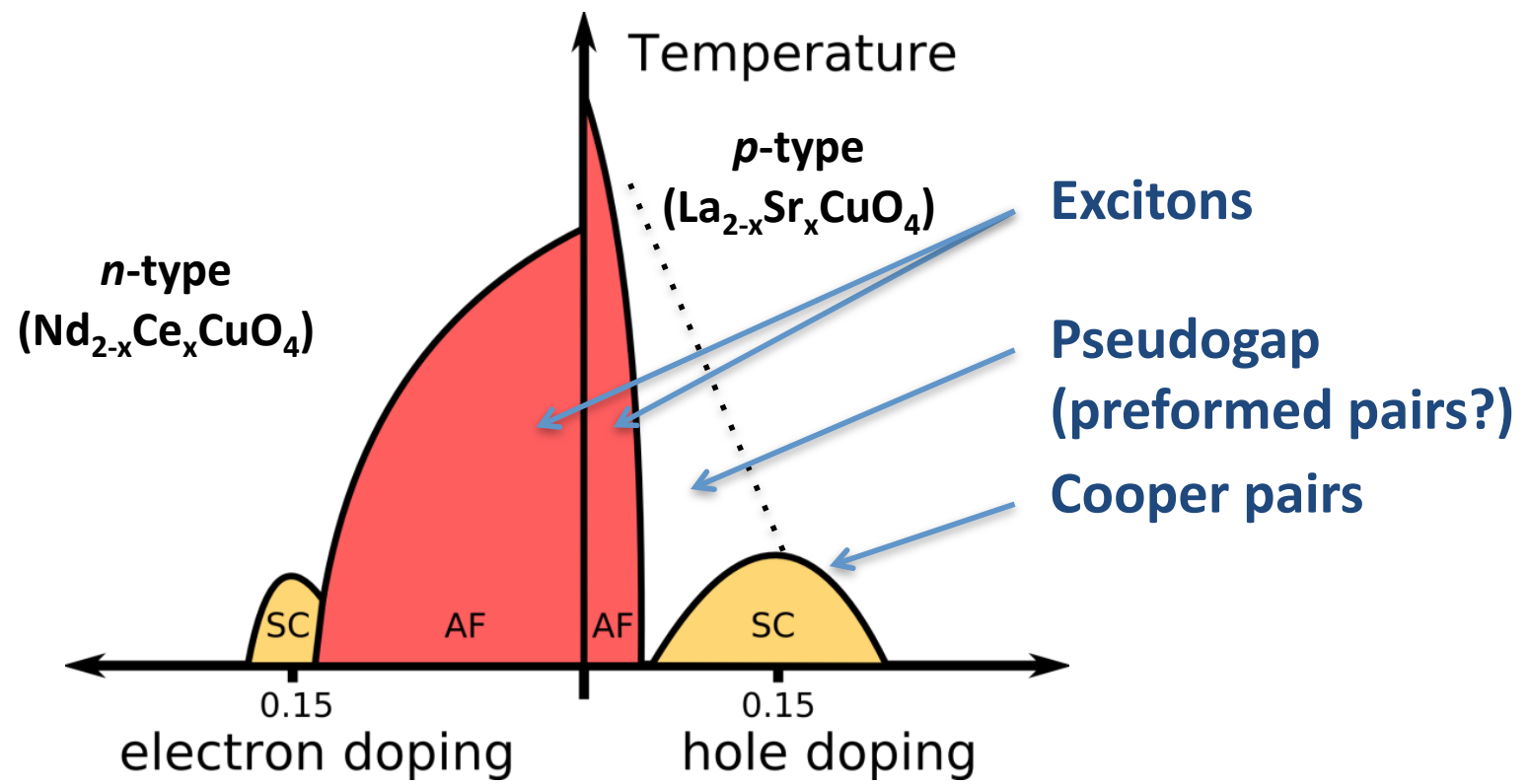
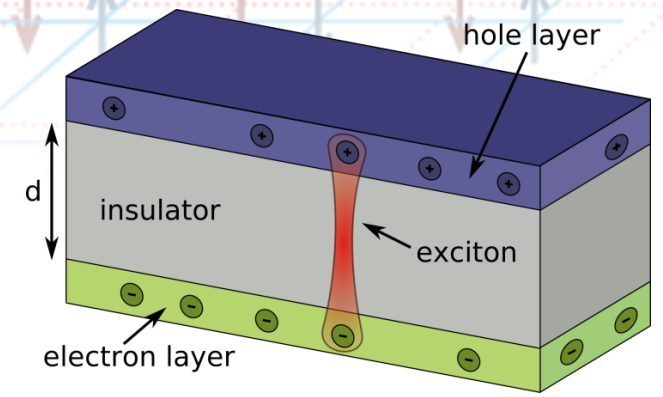
UNIVERSITY OF TWENTE.



Universiteit Leiden

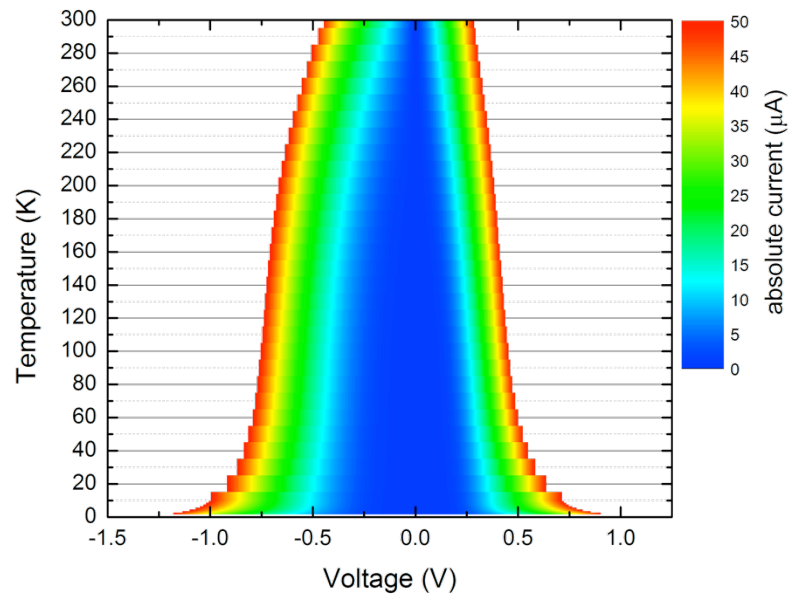
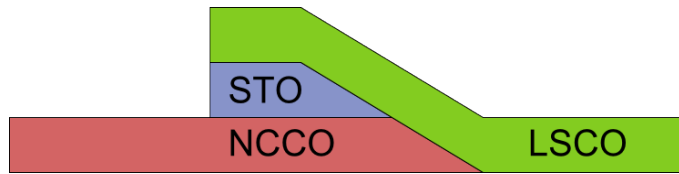
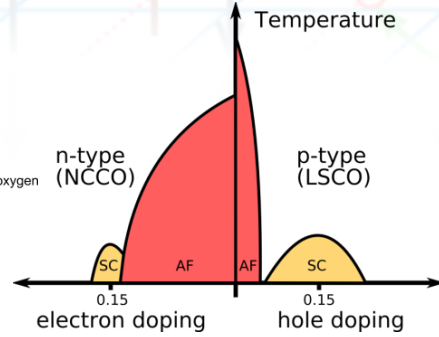
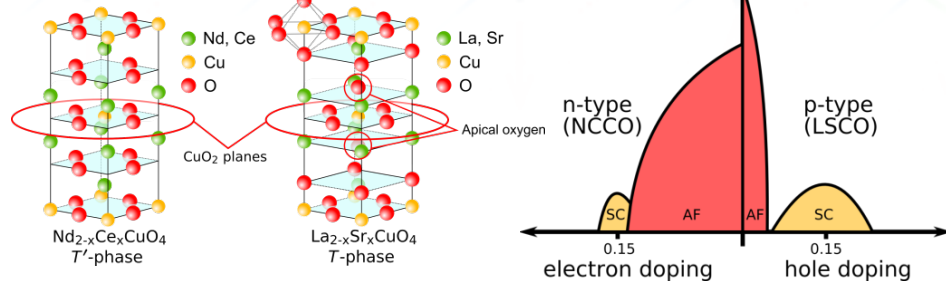


Bosons in cuprates

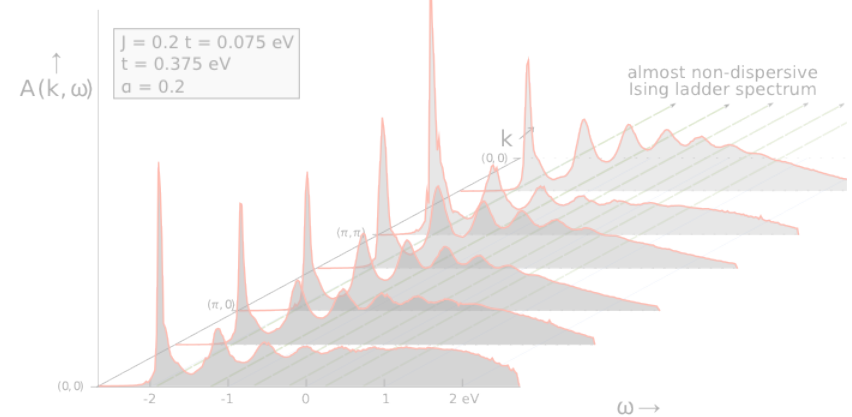
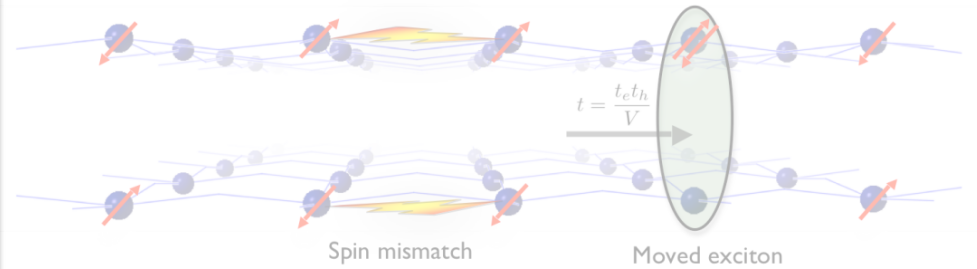
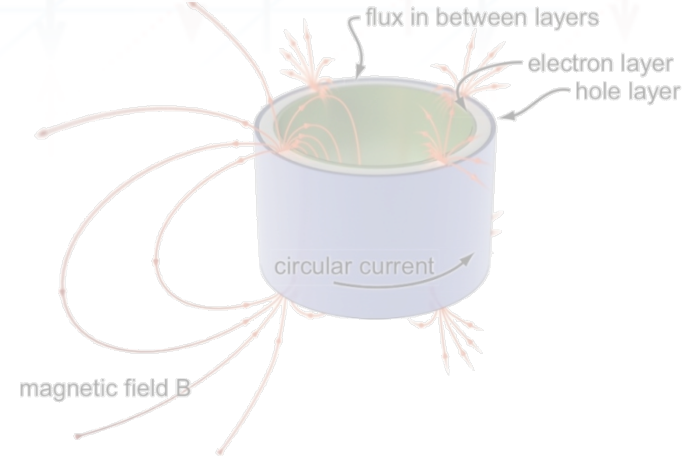


e.g., Armitage et al., Rev. Mod. Phys. 82, 2421–2487 (2010)

Experiment



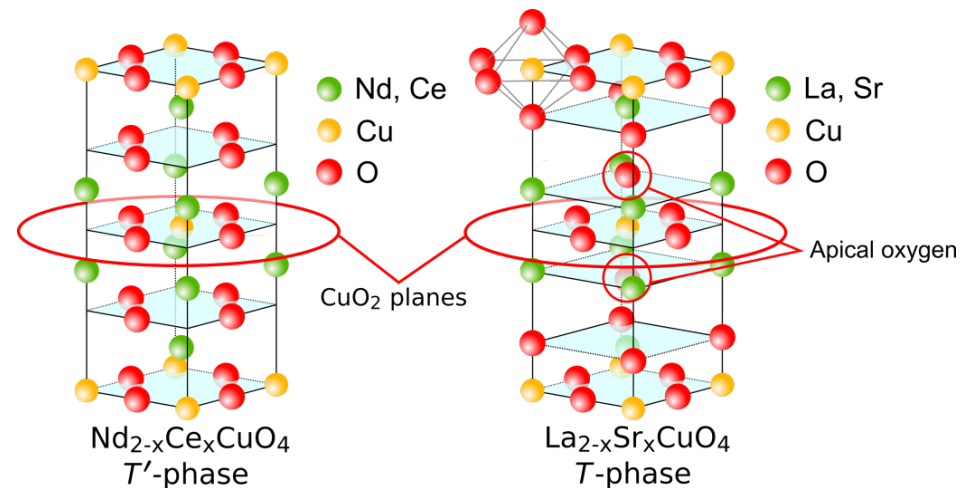
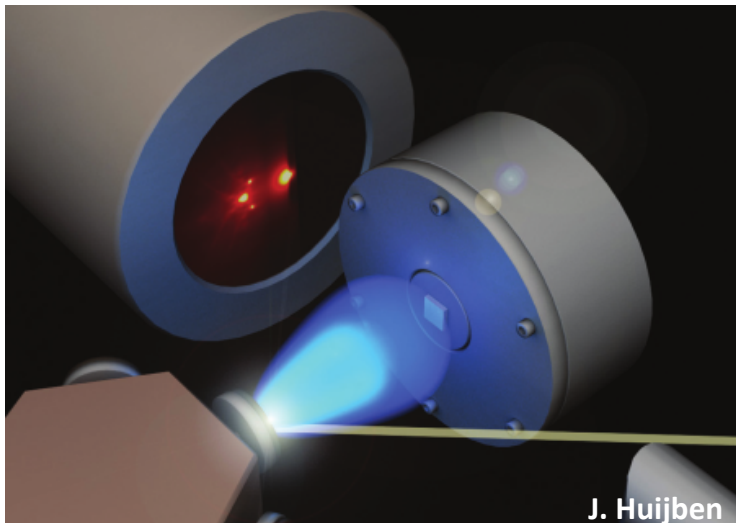
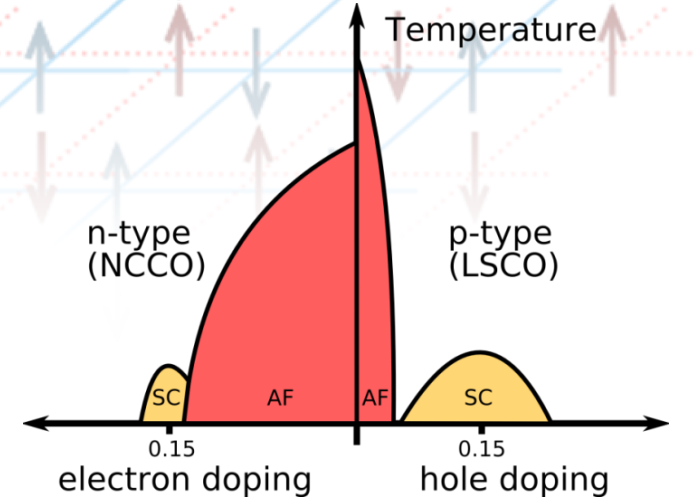
Theory



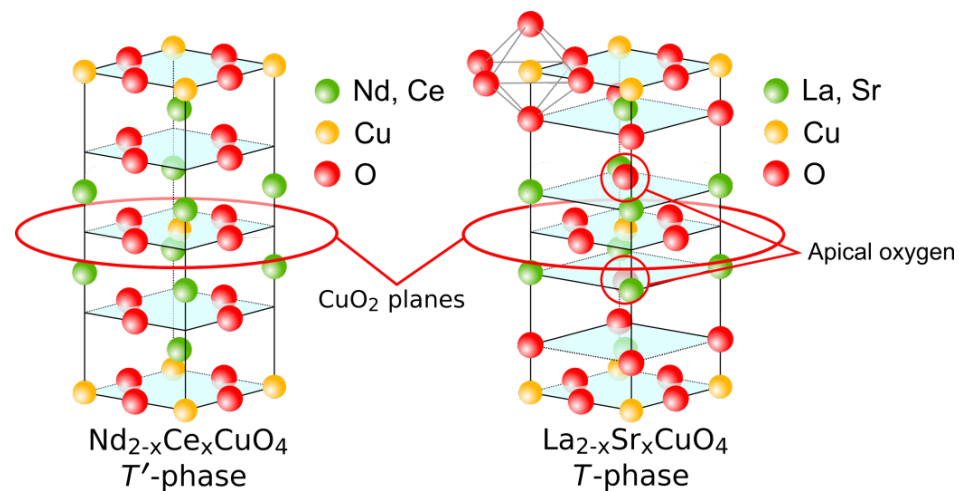
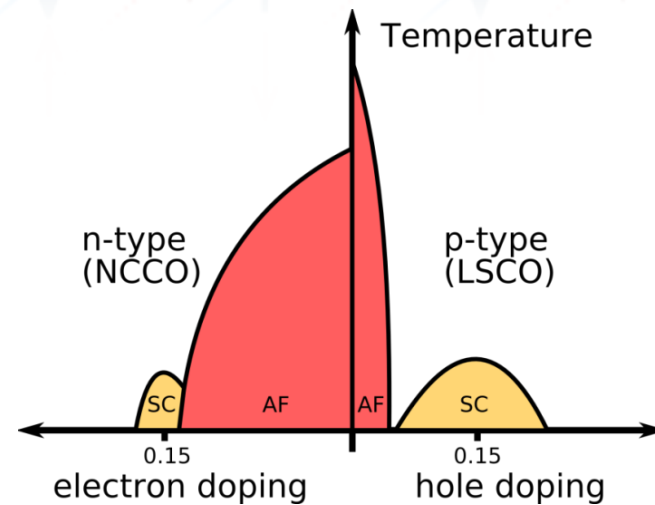
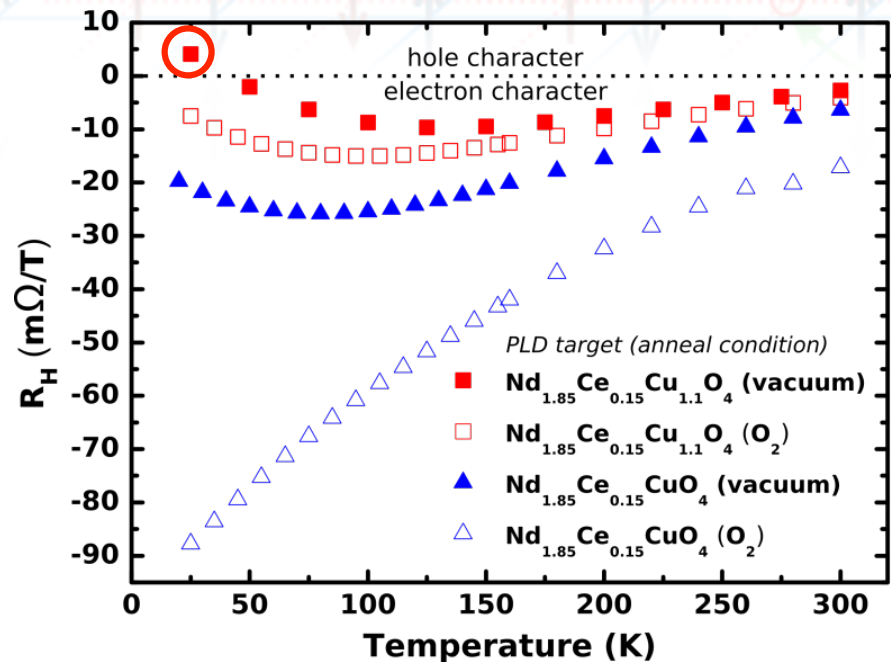
Sample preparation

Pulsed Laser Deposition (PLD)

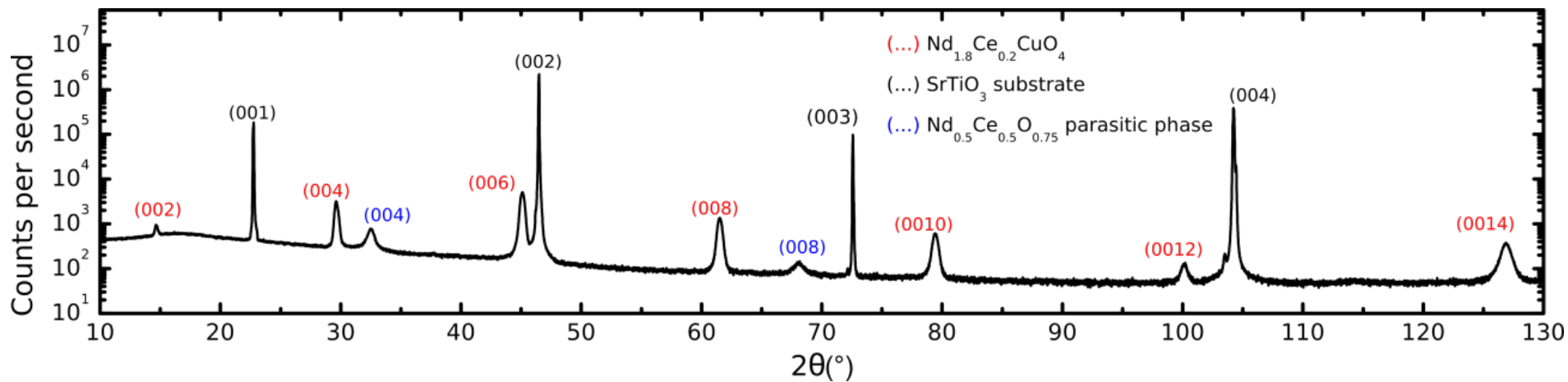
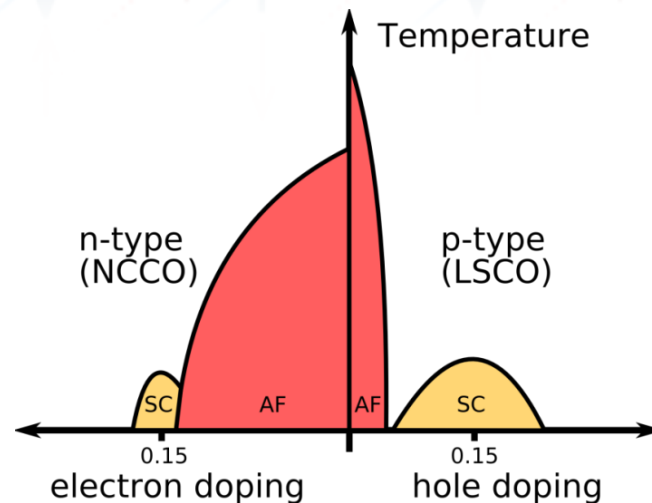
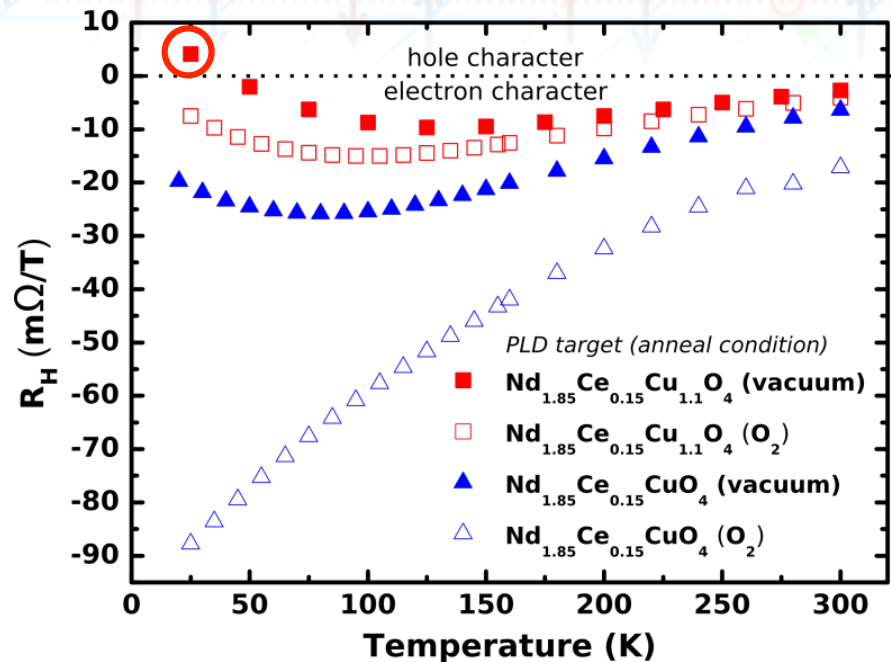
- $\text{Nd}_{2-x}\text{Ce}_x\text{CuO}_4$ and $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$
- LSAT $[(\text{LaAlO}_3)_{0.3}-(\text{Sr}_2\text{AlTaO}_6)_{0.7}]$ substrates
- Oxygen or vacuum anneal



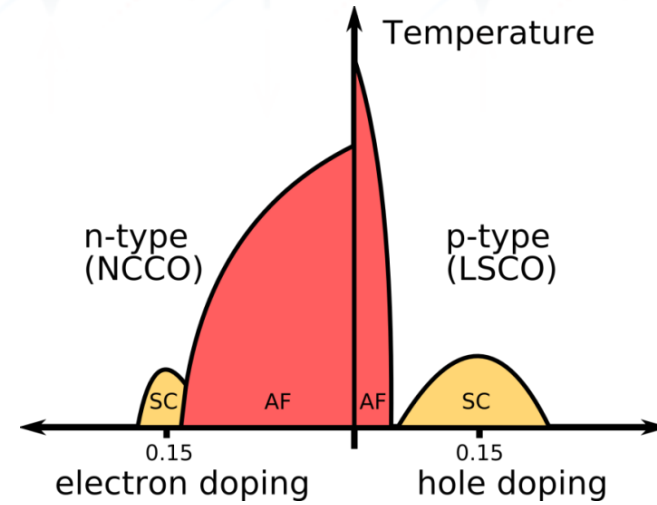
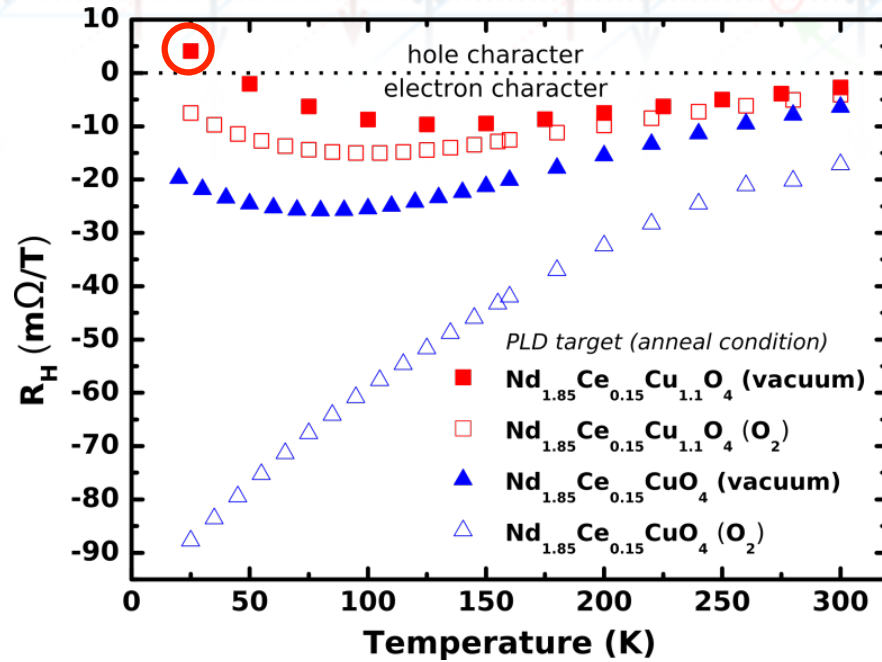
Nd_{2-x}Ce_xCuO₄ oxygen treatment



Nd_{2-x}Ce_xCuO₄ oxygen treatment

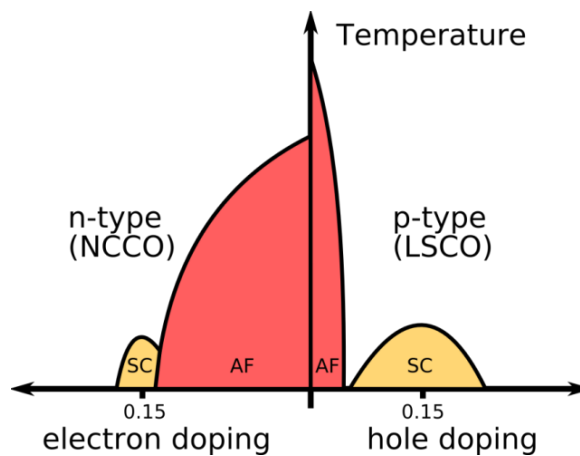
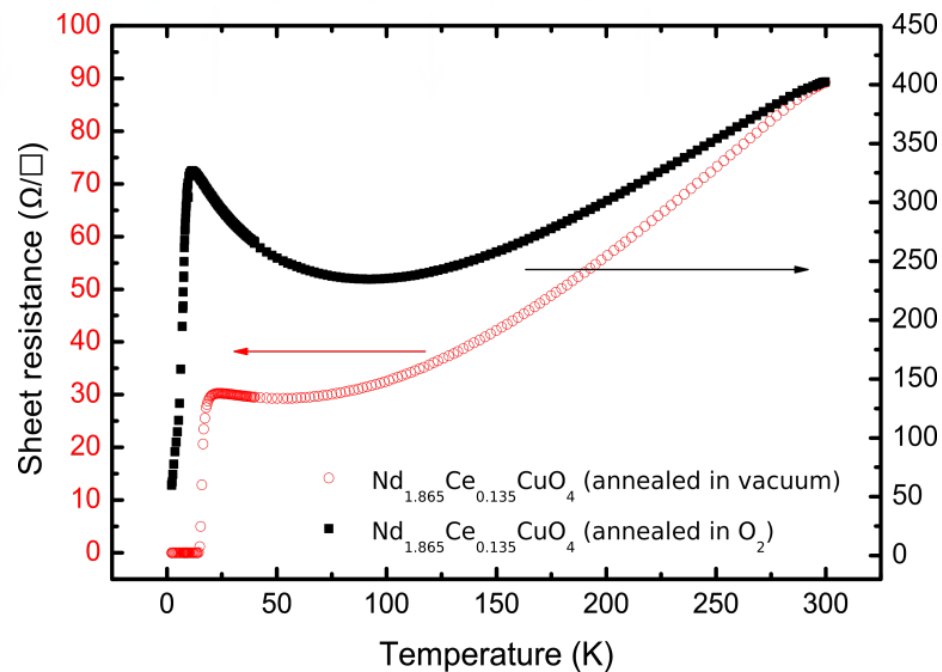
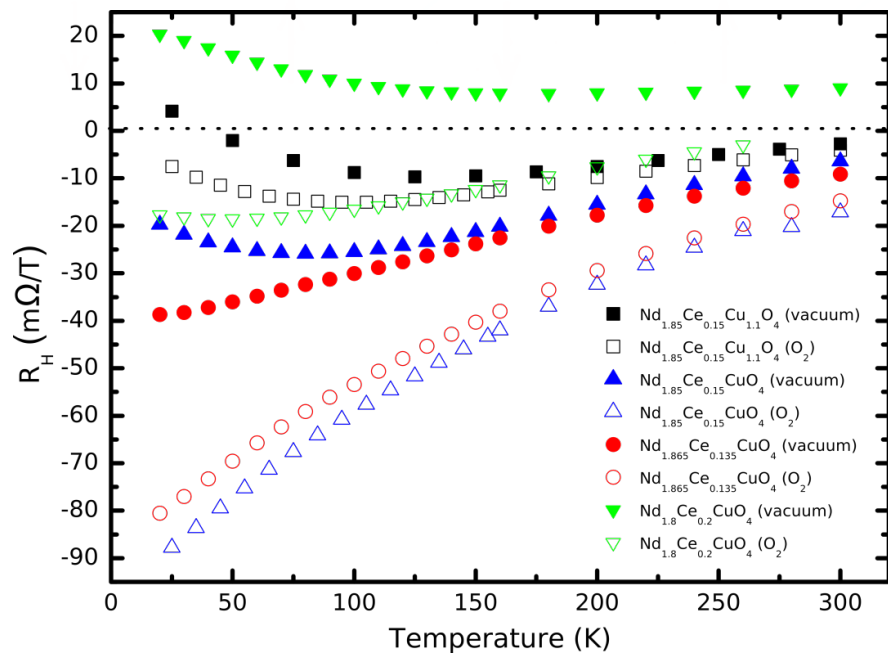


$\text{Nd}_{2-x}\text{Ce}_x\text{CuO}_4$ oxygen treatment



n-type character is retained

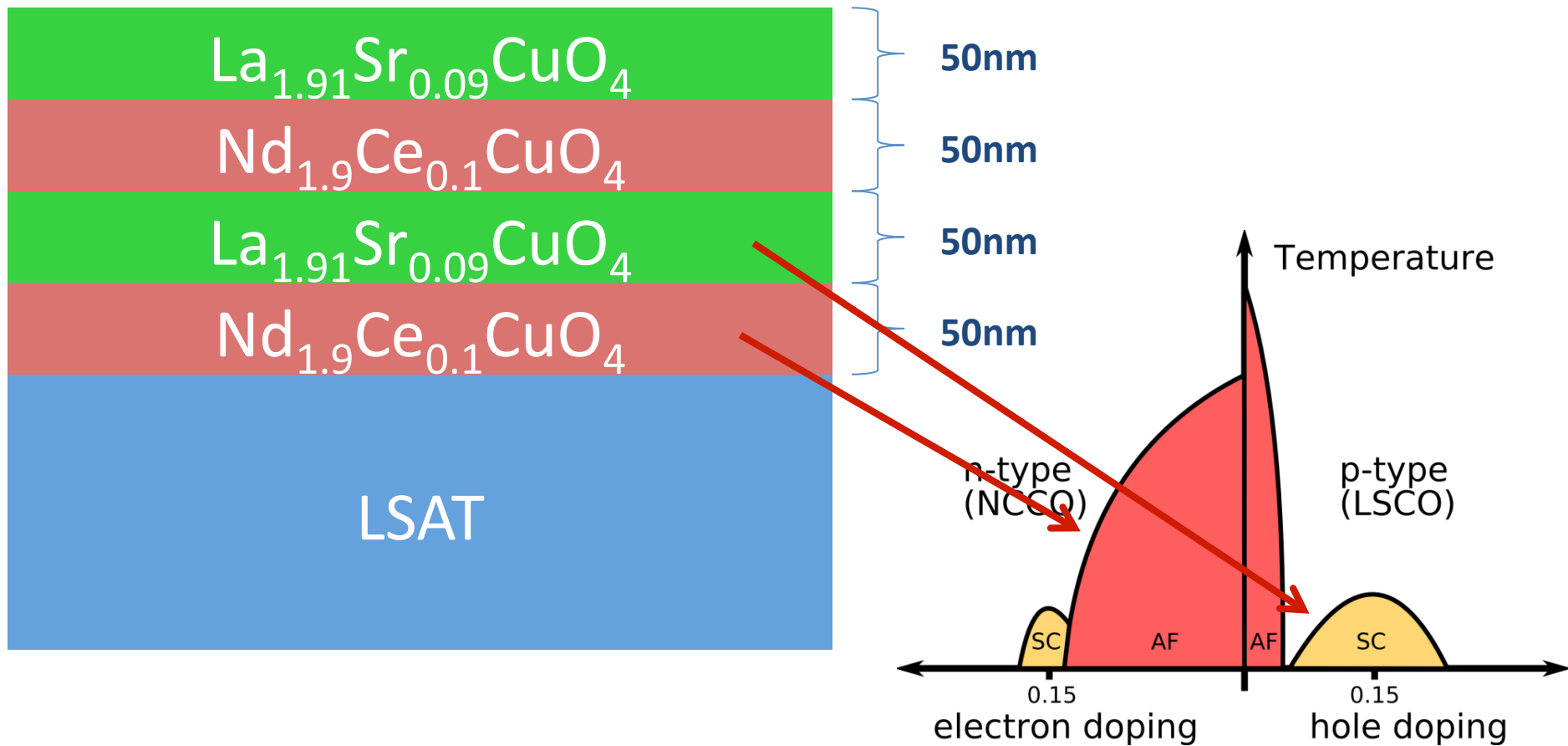
Nd_{2-x}Ce_xCuO₄ oxygen treatment



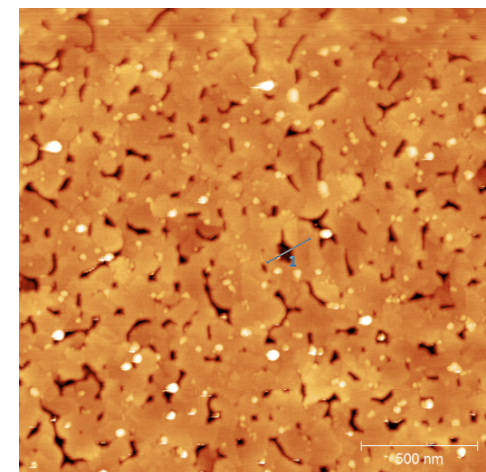
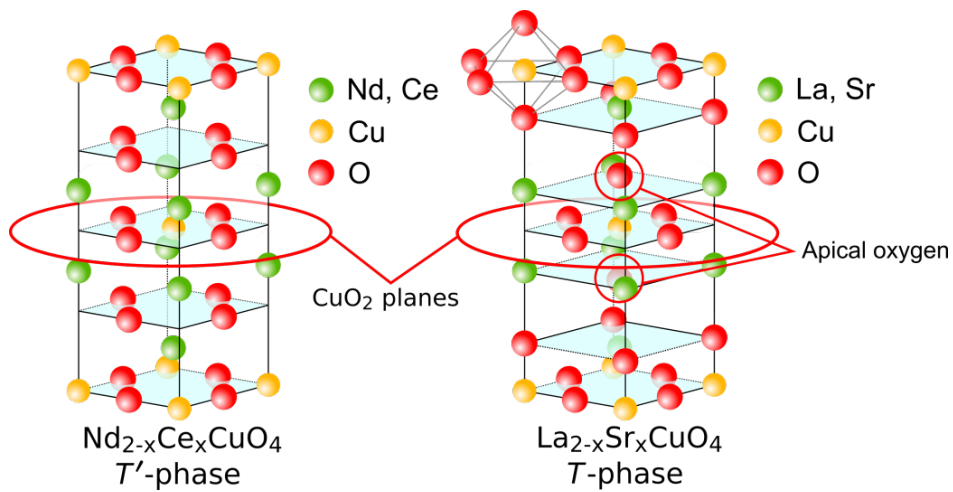
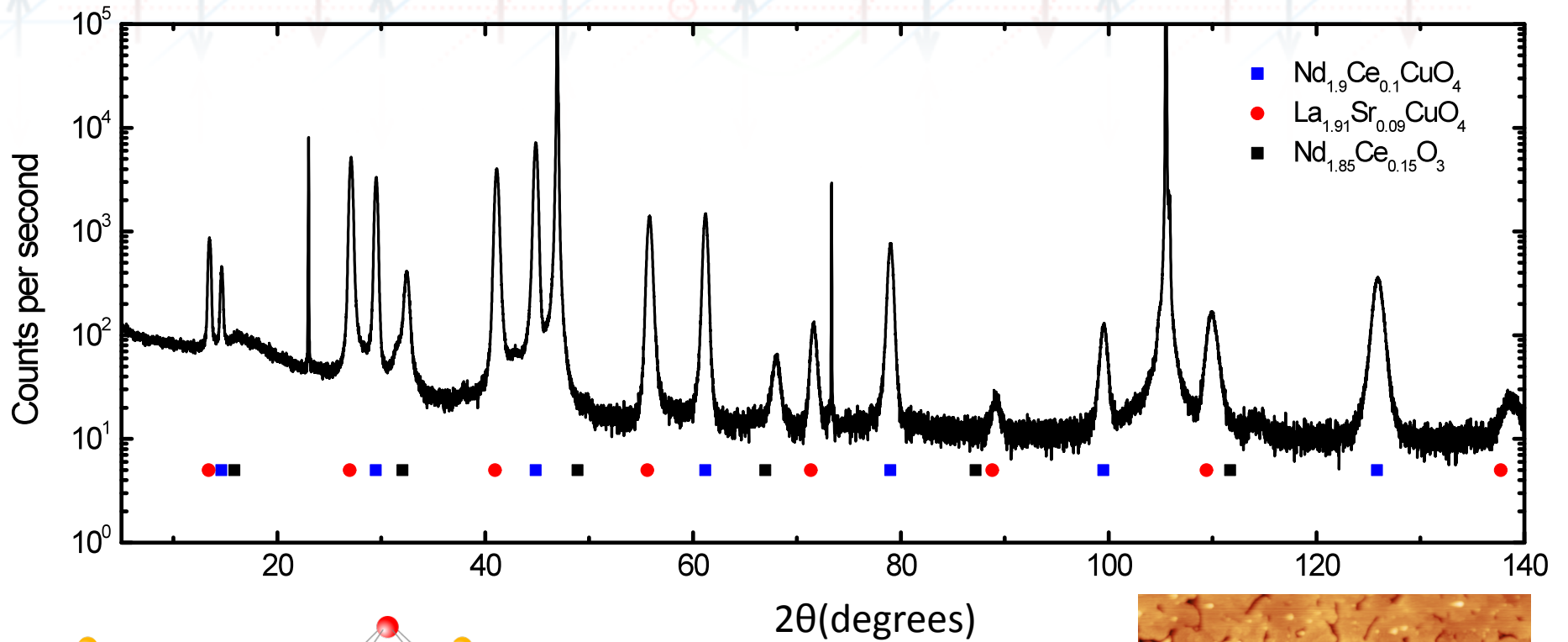
NCCO/LSCO multilayer



- $(\text{La}_{1.91}\text{Sr}_{0.09}\text{CuO}_4 (50\text{nm})/\text{Nd}_{1.9}\text{Ce}_{0.1}\text{CuO}_4 (50\text{nm}))\times 2$ on LSAT

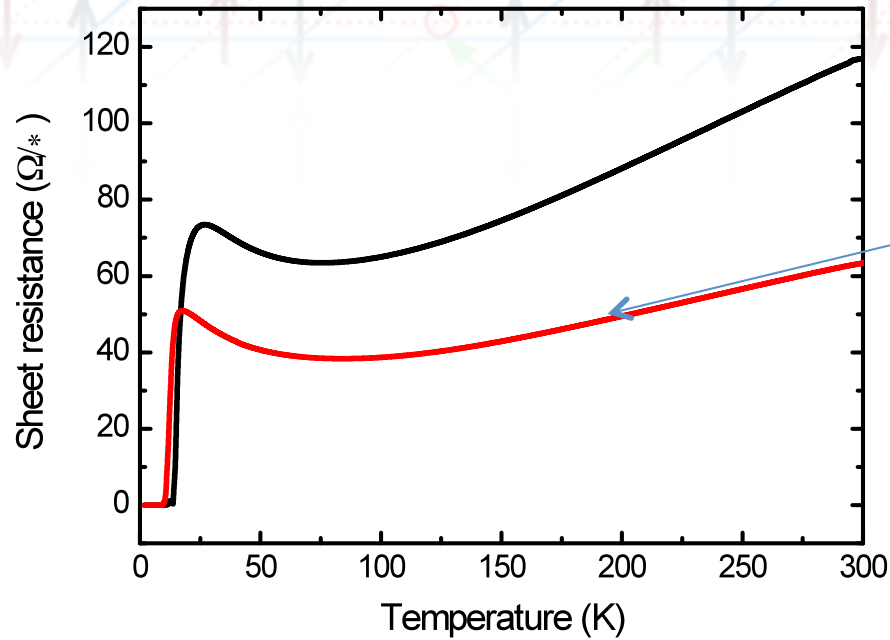


NCCO/LSCO multilayer

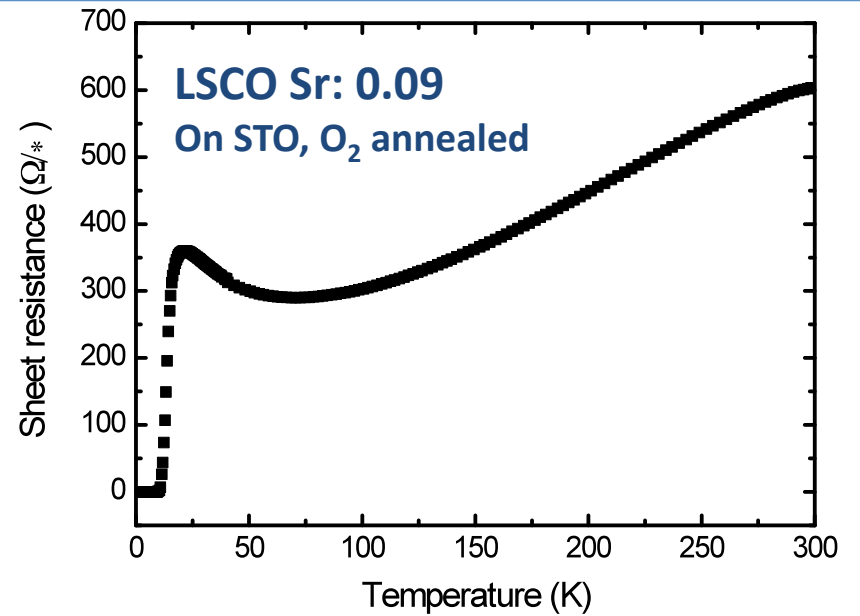
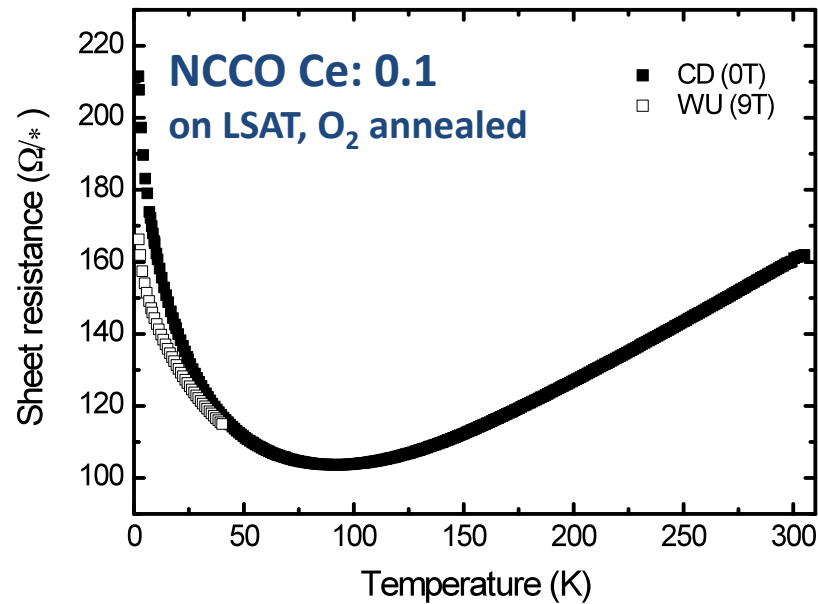


AFM 2x2μm
 roughness 1.3 nm, 6nm holes

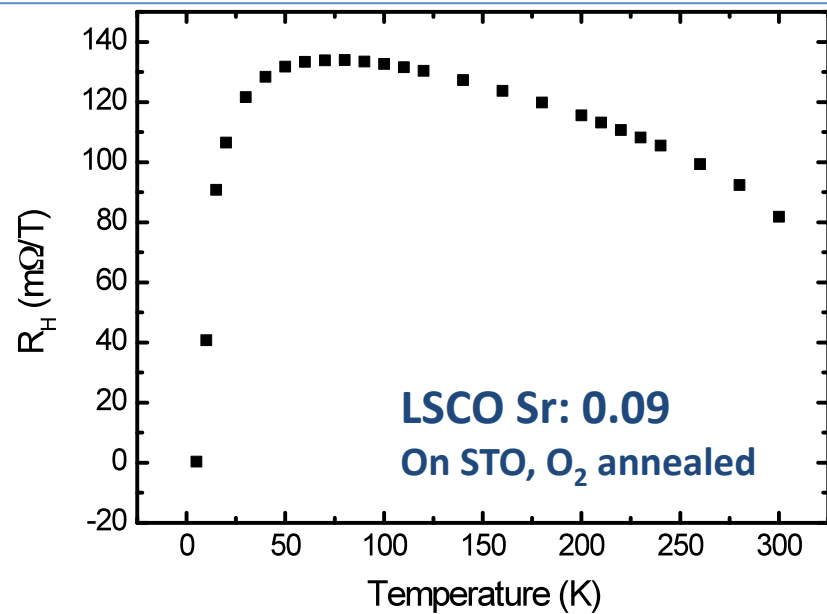
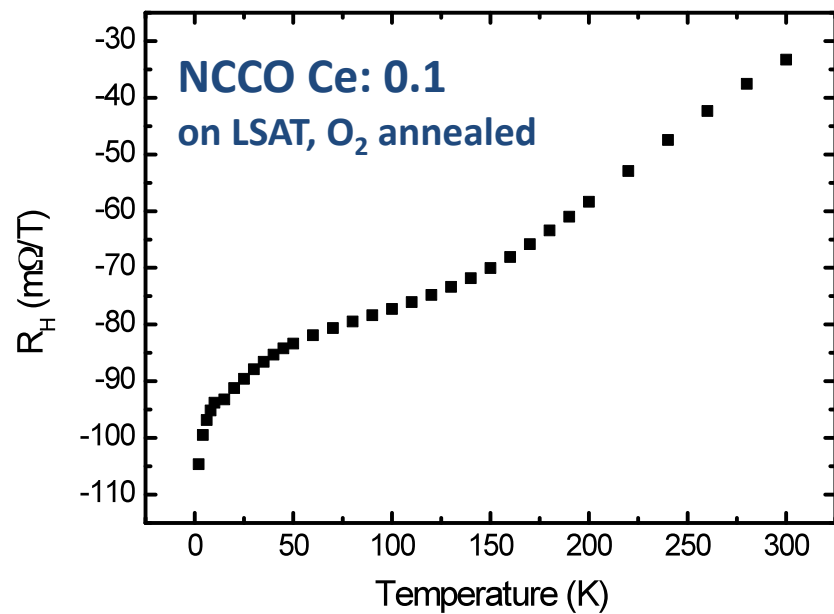
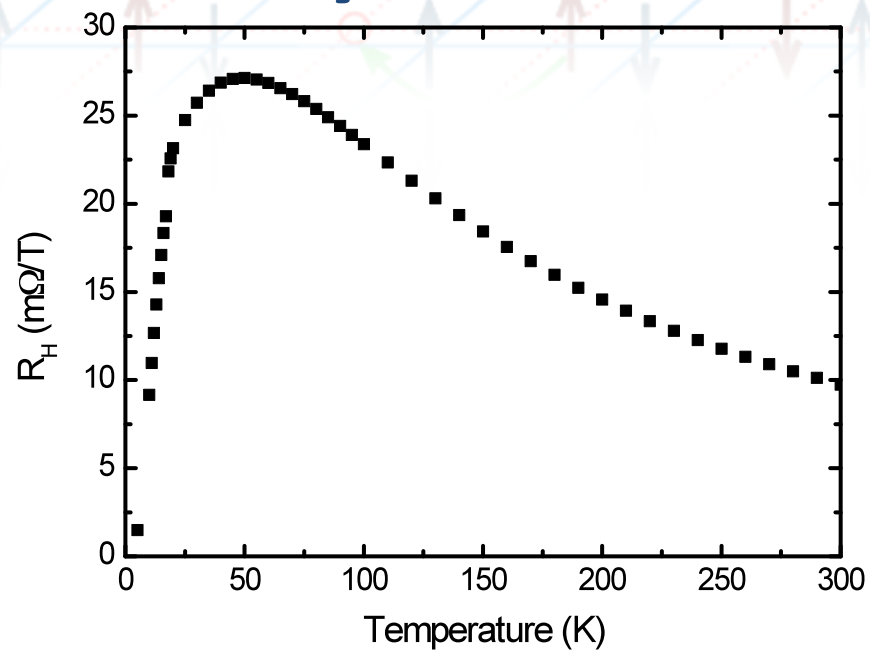
NCCO/LSCO multilayer



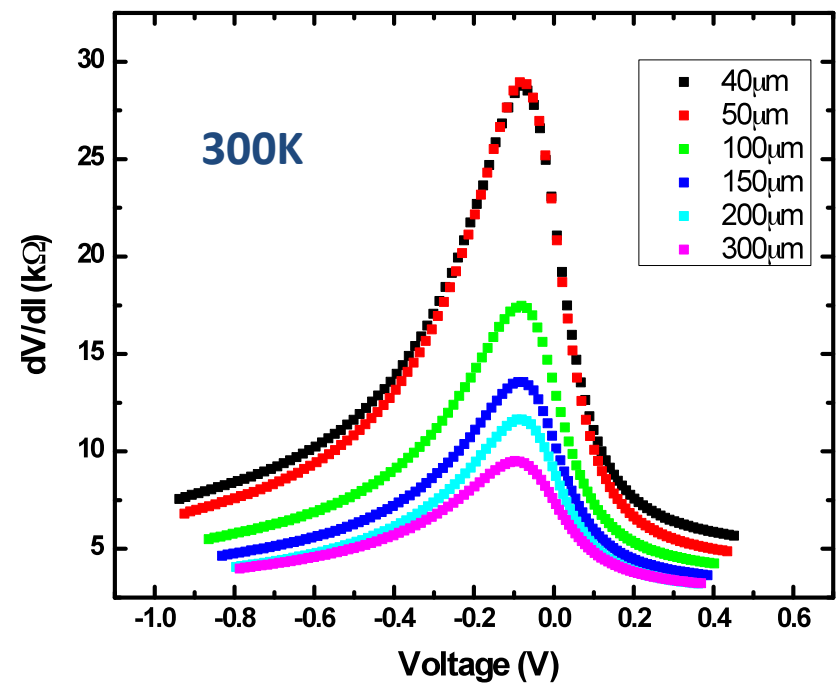
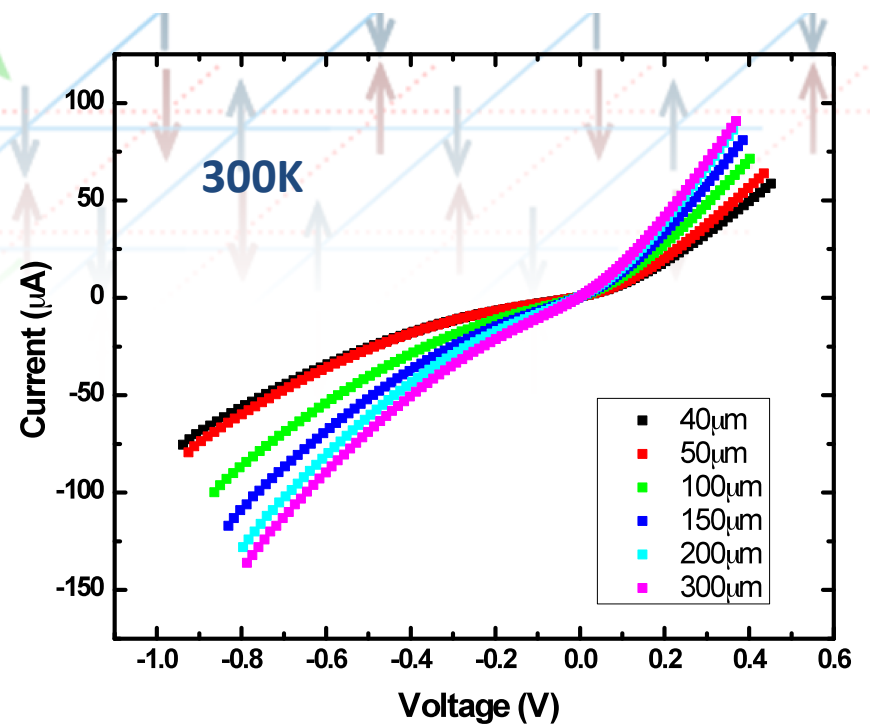
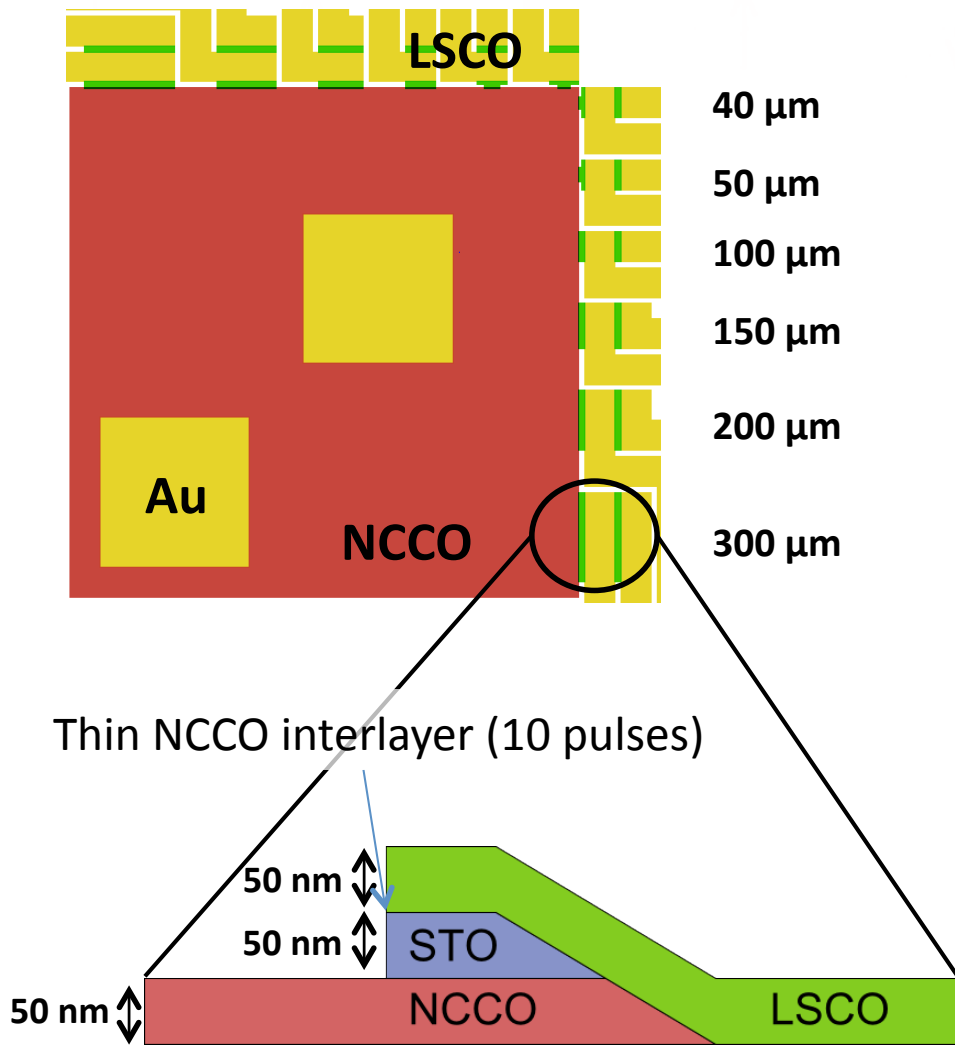
Expected sheet resistance from individual layers



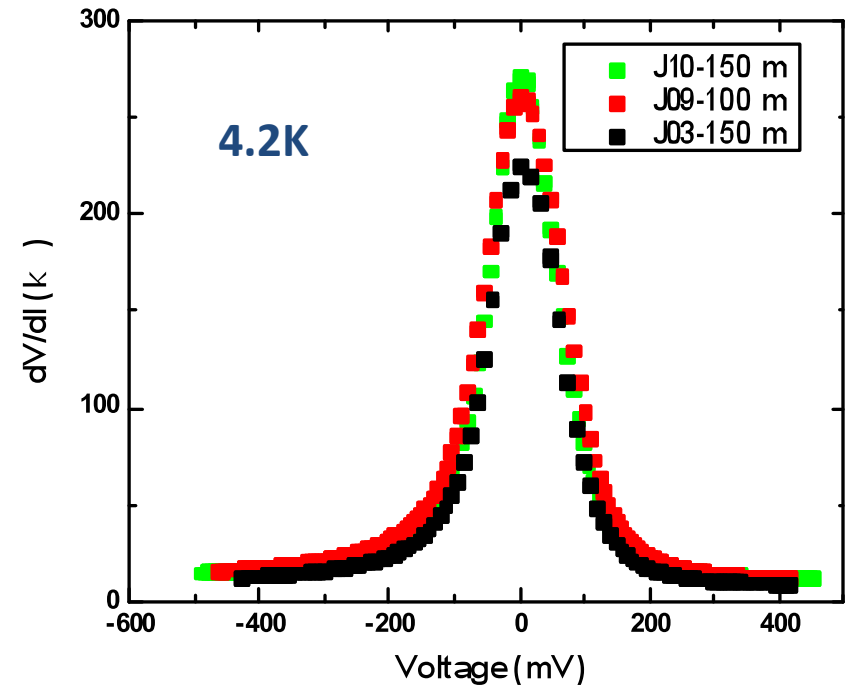
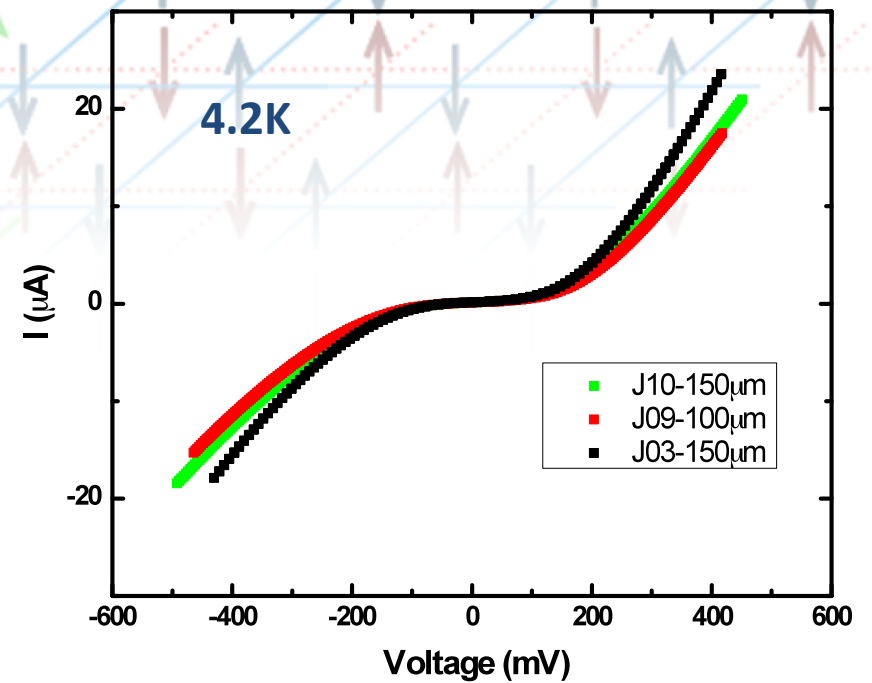
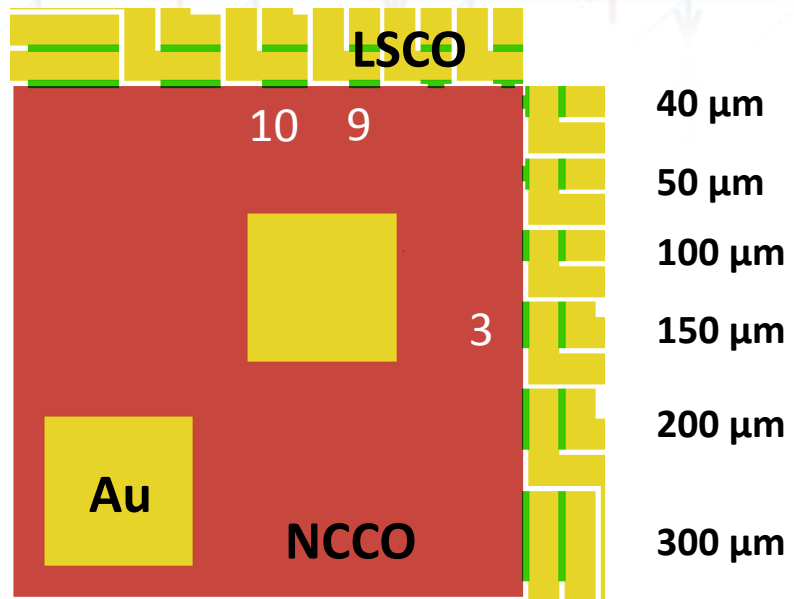
NCCO/LSCO multilayer



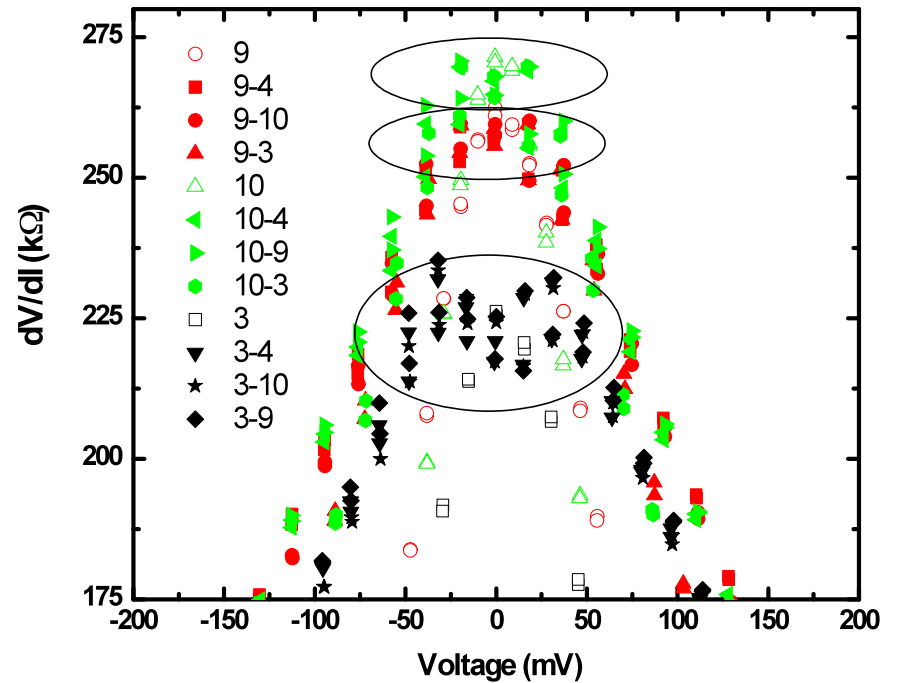
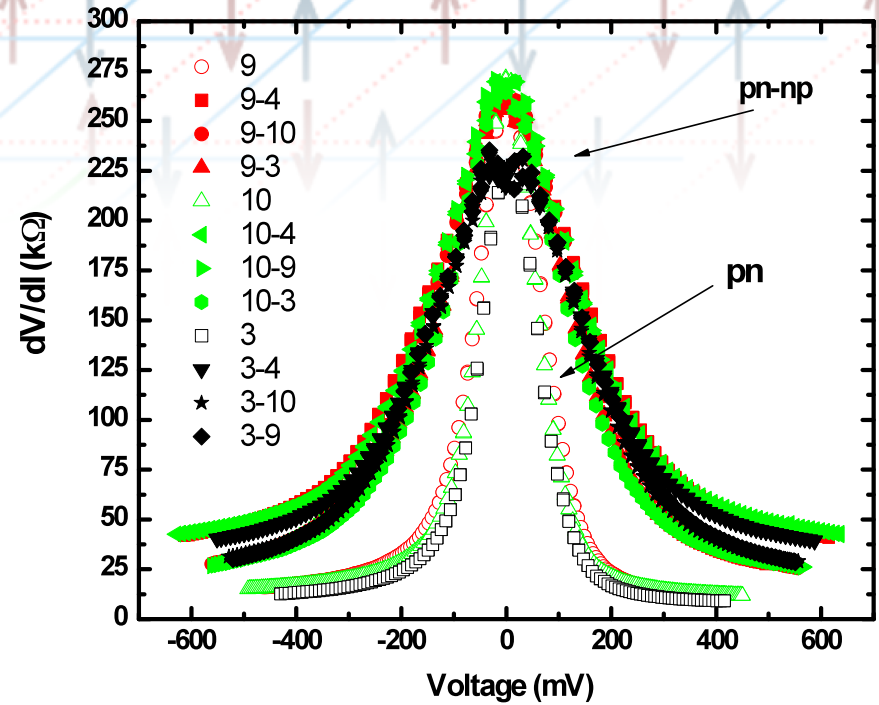
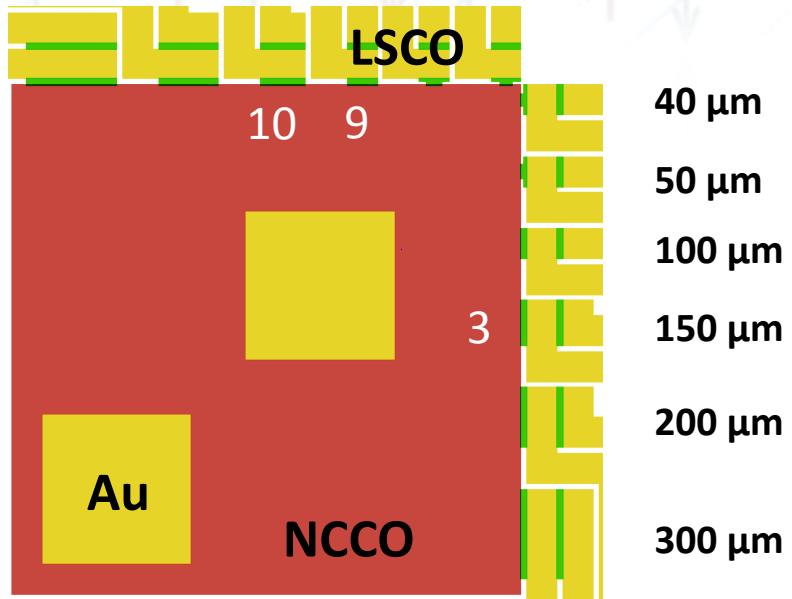
p/n contacts 300 K



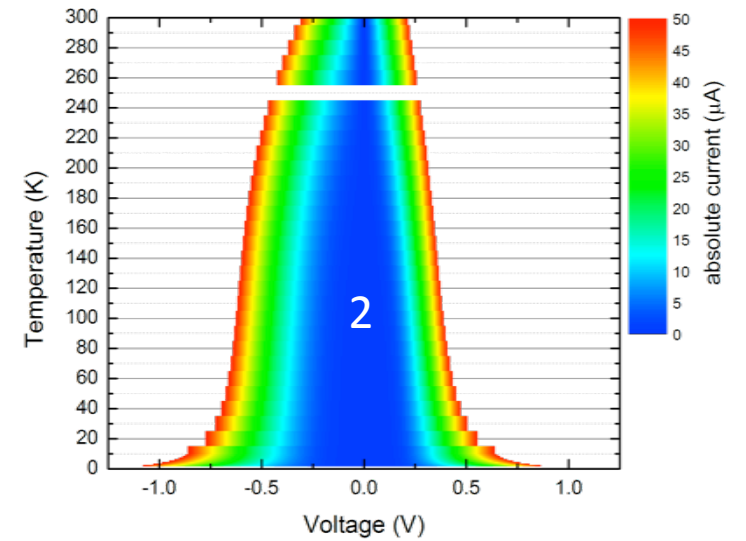
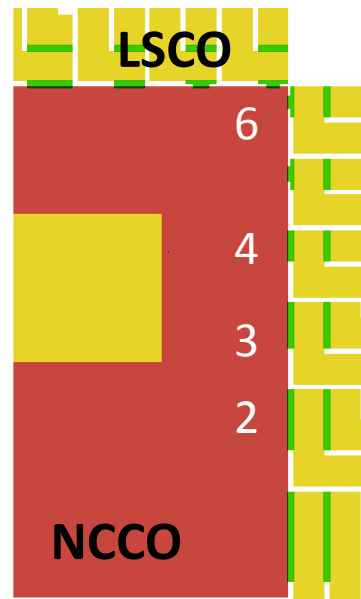
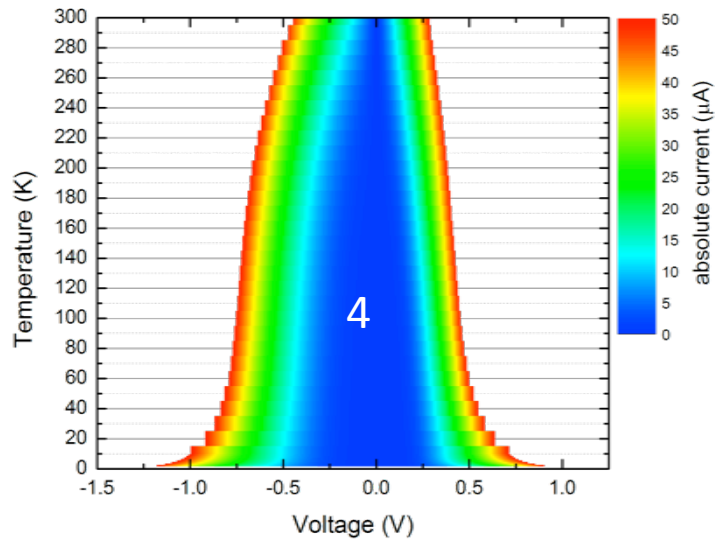
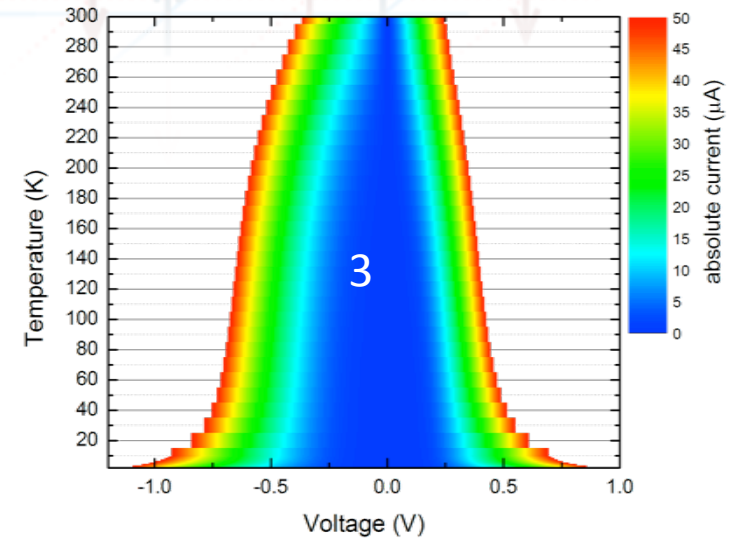
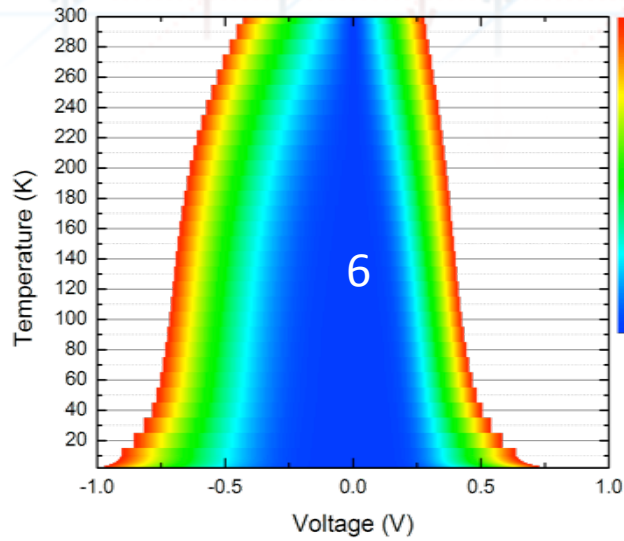
p/n contacts 4.2 K



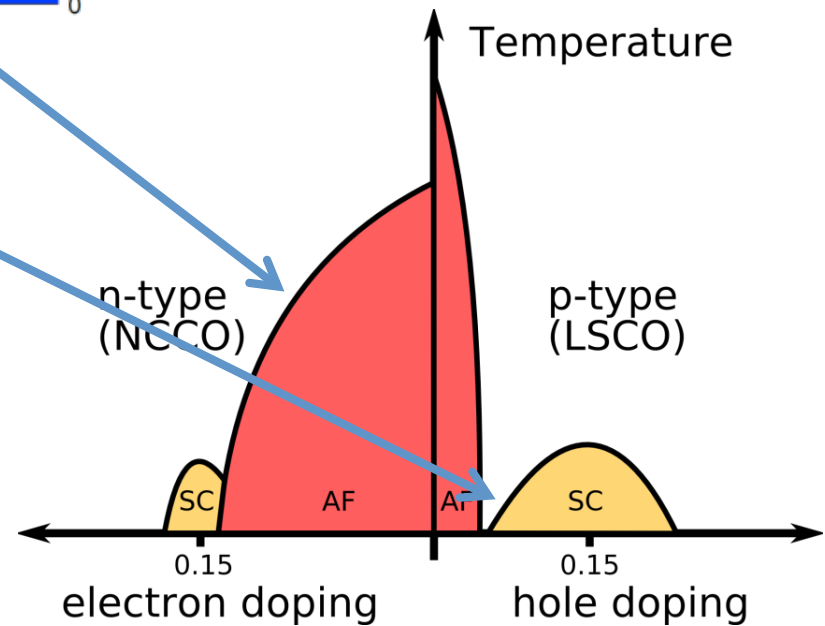
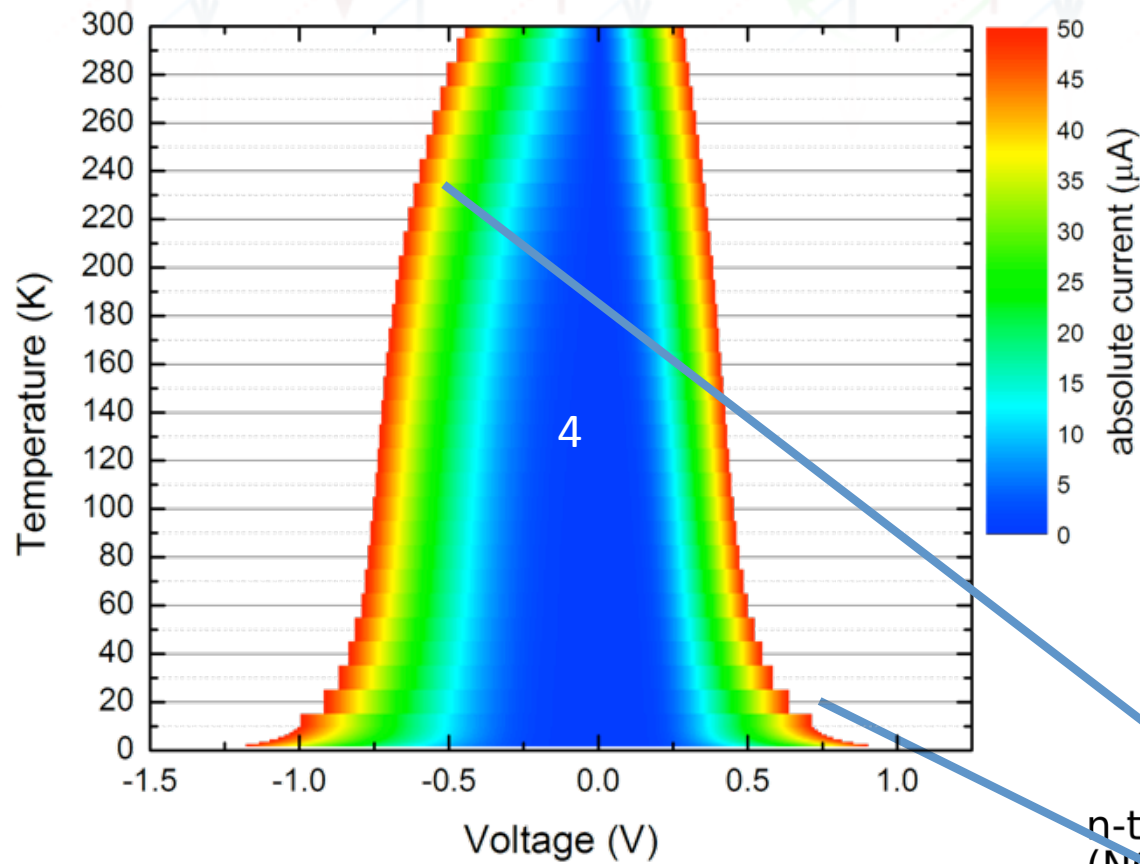
p/n contacts 4.2K



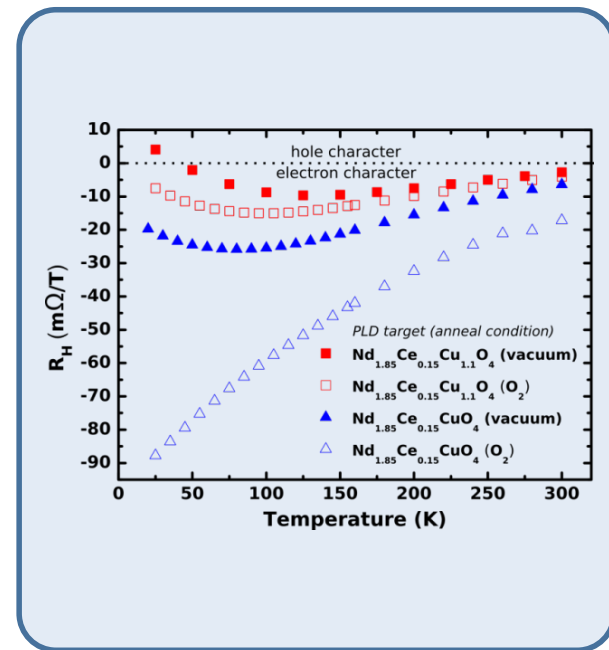
p/n contact temperature dependence



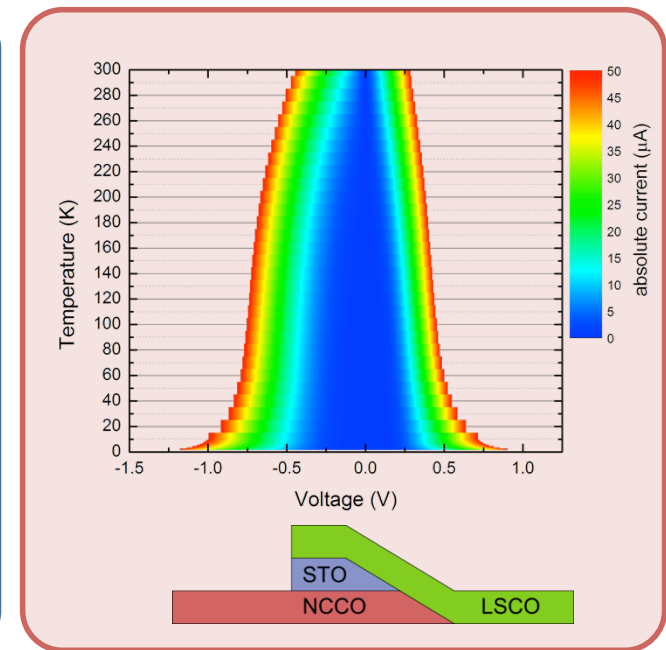
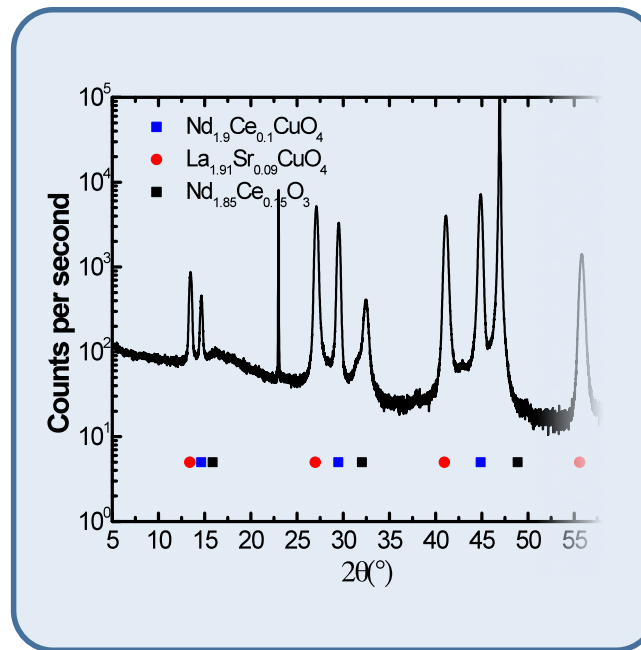
p/n contact temperature dependence



Conclusions

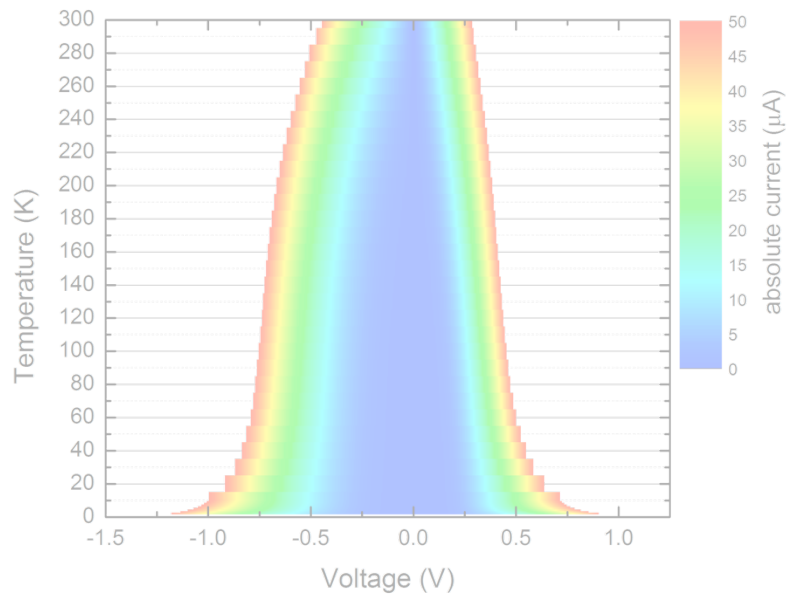
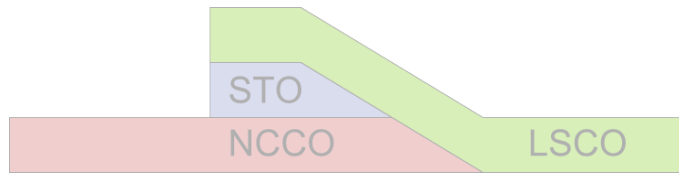
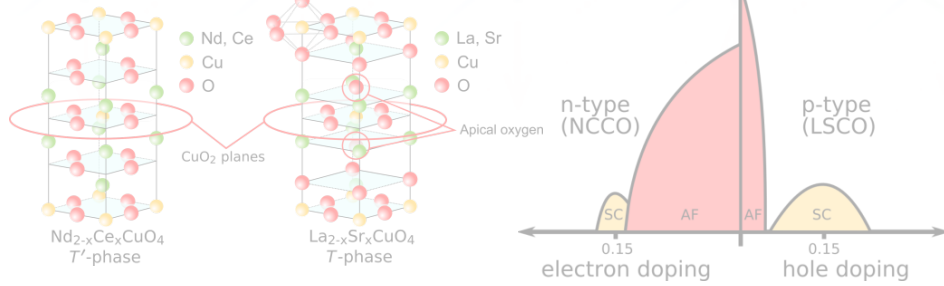


Combining electron and hole doped cuprates

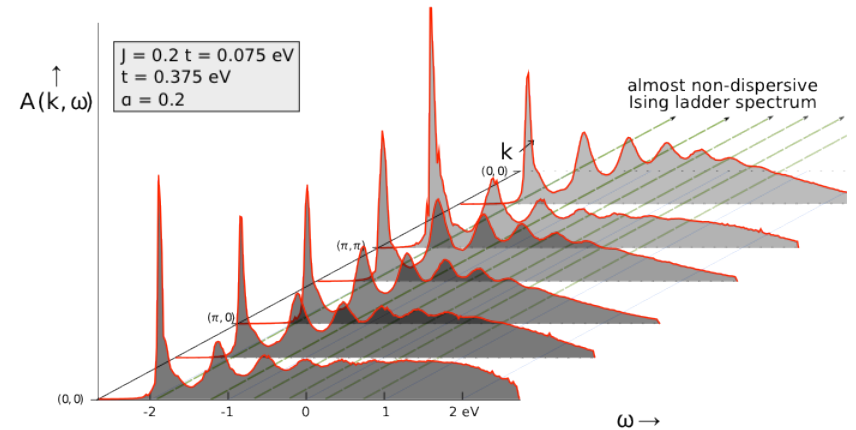
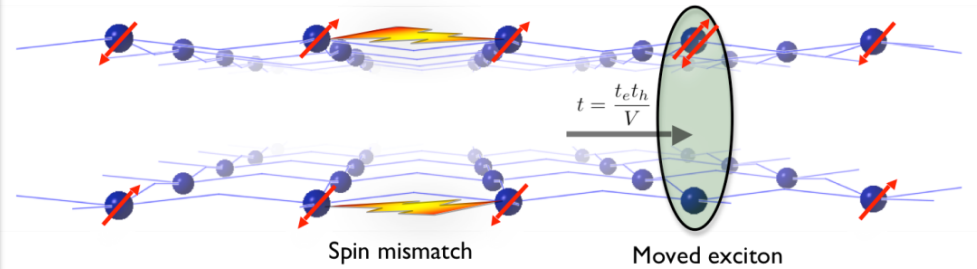
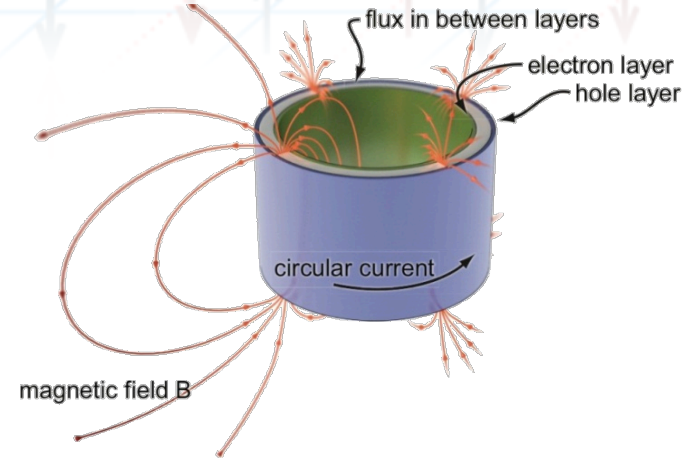


Interplay of electrons and holes

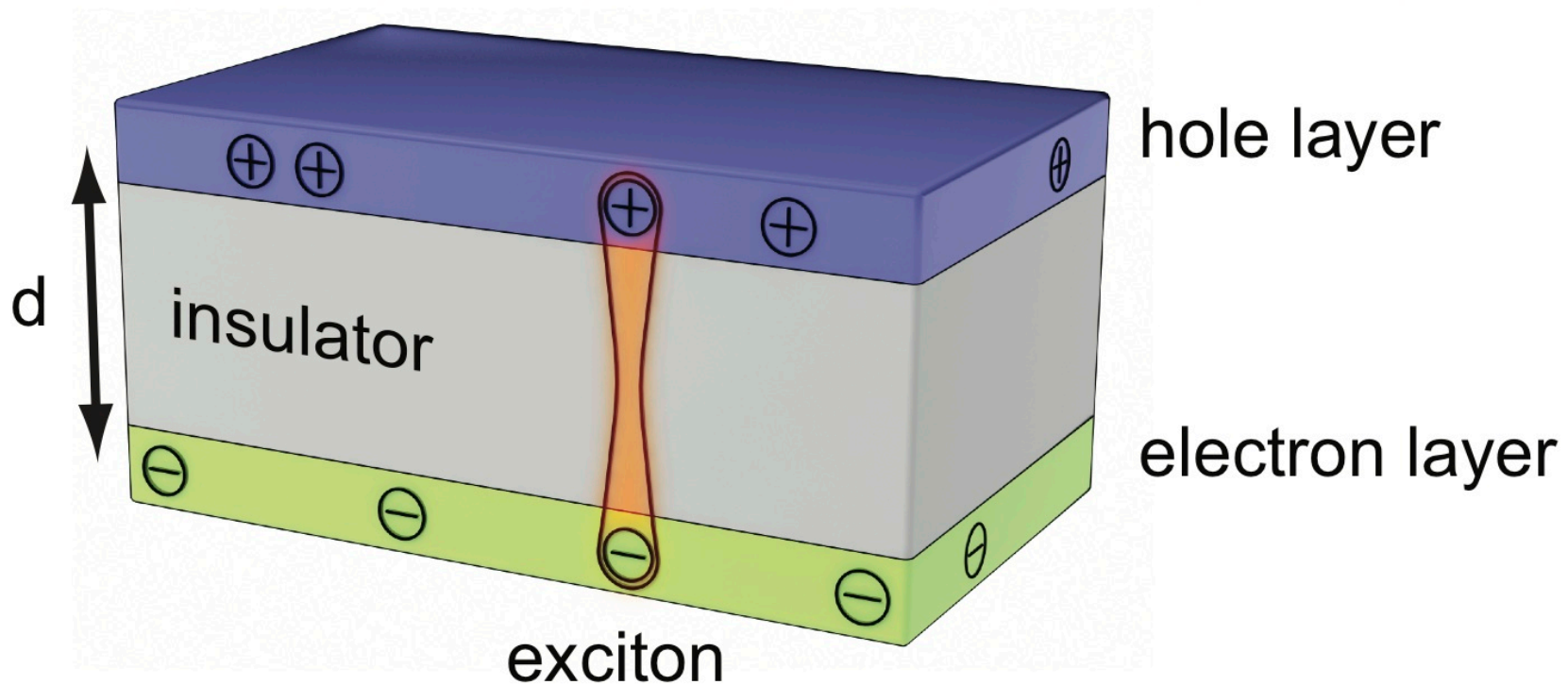
Experiment



Theory



Dream: Exciton condensation



- Counterflow superfluidity

Exciton superfluids



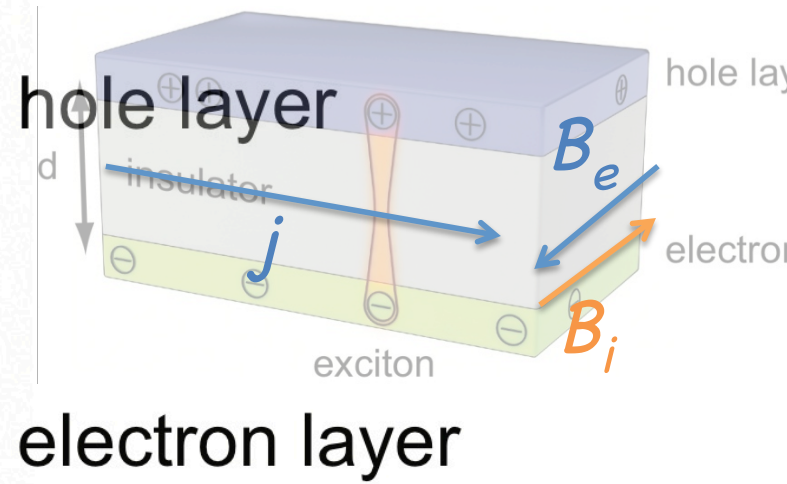
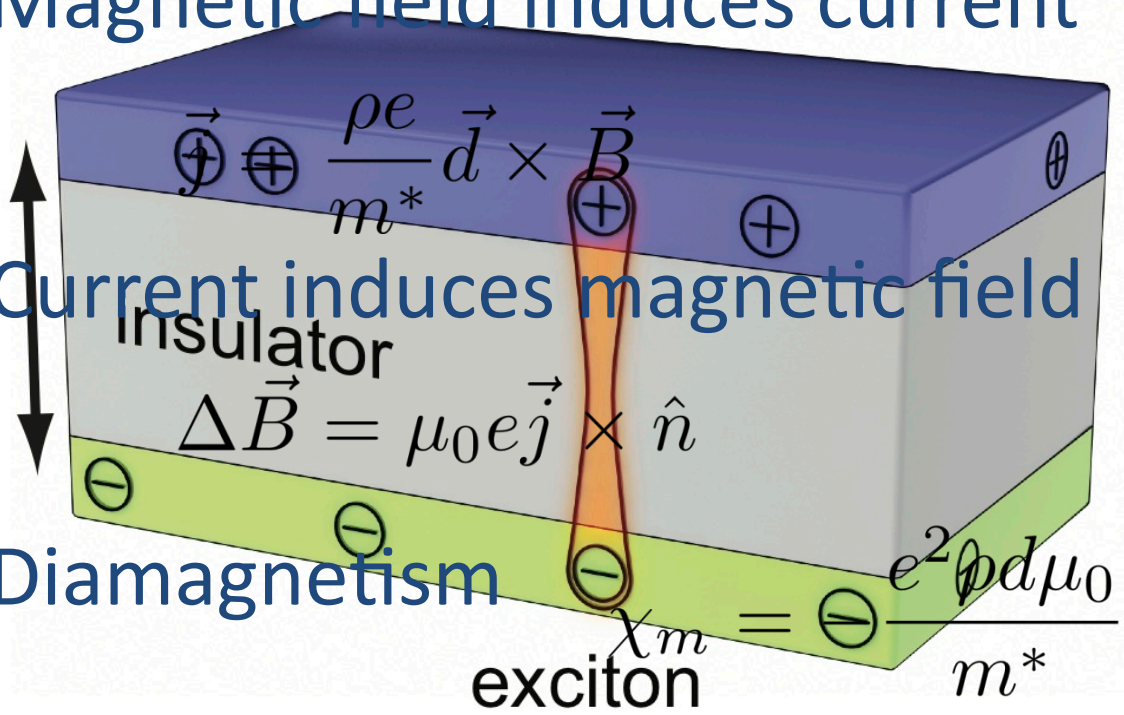
- Simple description with GL theory

$$F[\Psi] = \int d^2x \left[\alpha |\Psi|^2 + \frac{1}{2} \beta |\Psi|^4 + \frac{\hbar^2}{2m^*} (\nabla |\Psi|)^2 + \frac{1}{2m^*} \left[\hbar \vec{\nabla} \phi - e \vec{d} \times \vec{B} \right]^2 |\Psi|^2 + d \frac{B^2}{2\mu_0} \right]$$

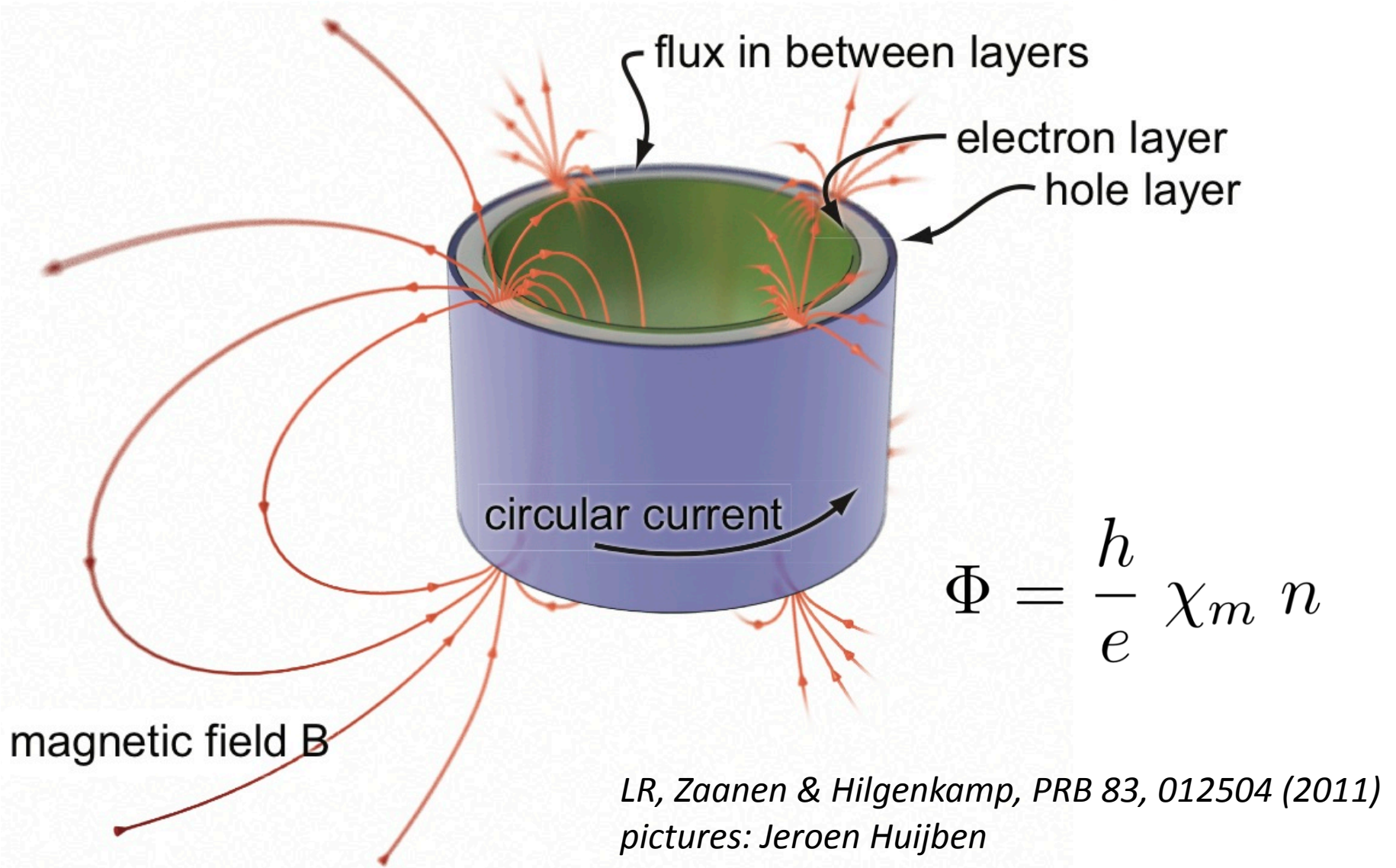
- Magnetic field induces current

- Current induces magnetic field

- Diamagnetism

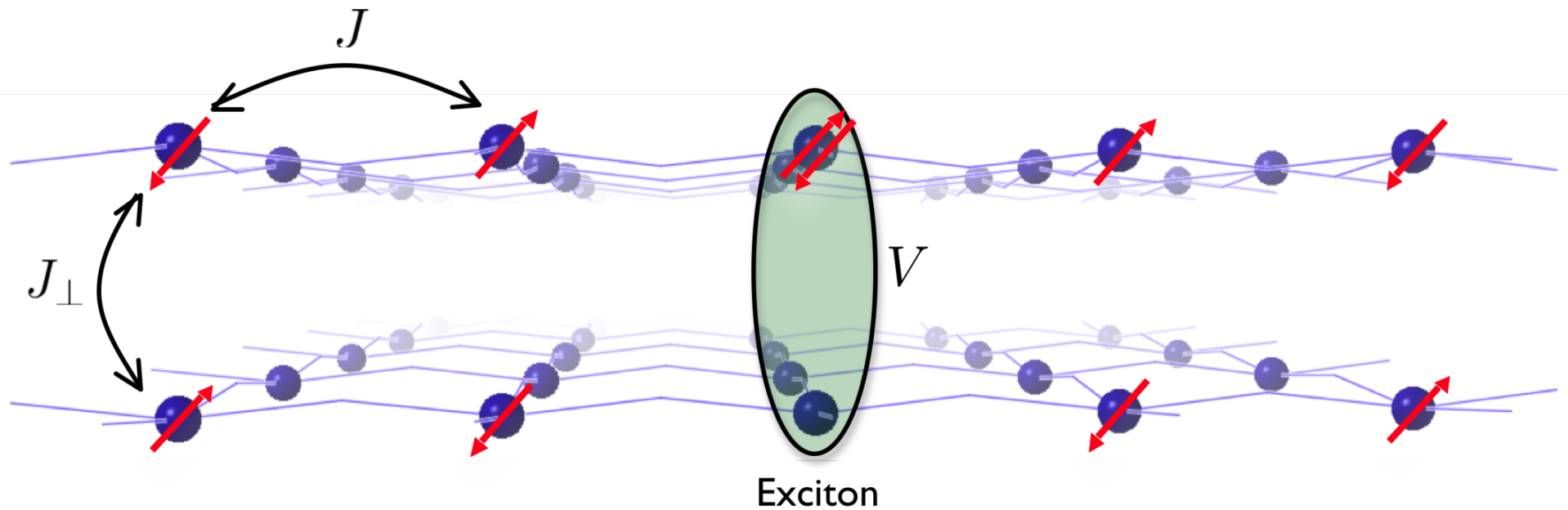


Unconventional flux quantization

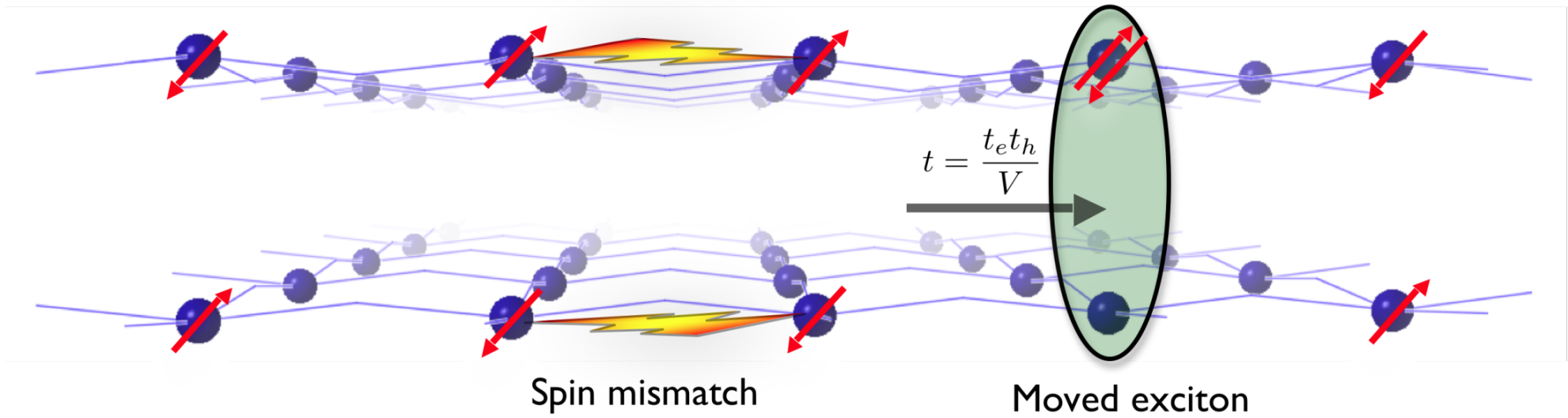


Excitons in doped Mott insulators?

- Half-filled antiferromagnetic background



Frustrated excitons



Frustrated excitons: Theory

- Spin background: bilayer Heisenberg

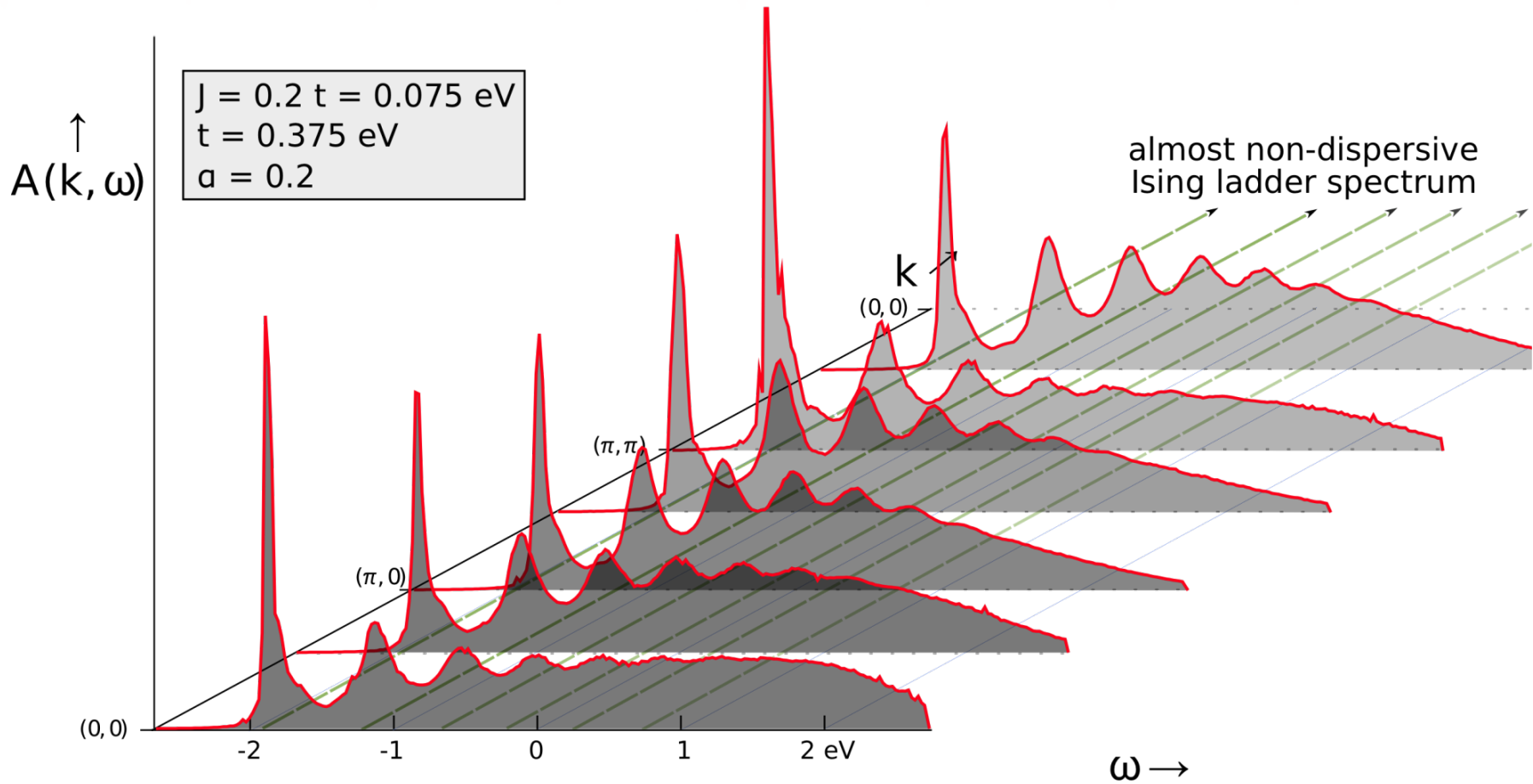
$$H_J = J \sum_{\langle ij \rangle} \left(\vec{S}_{1,i} \cdot \vec{S}_{1,j} + \vec{S}_{2,i} \cdot \vec{S}_{2,j} \right) + J_{\perp} \sum_i \vec{S}_{1,i} \cdot \vec{S}_{2,i}$$

- Exciton hopping:

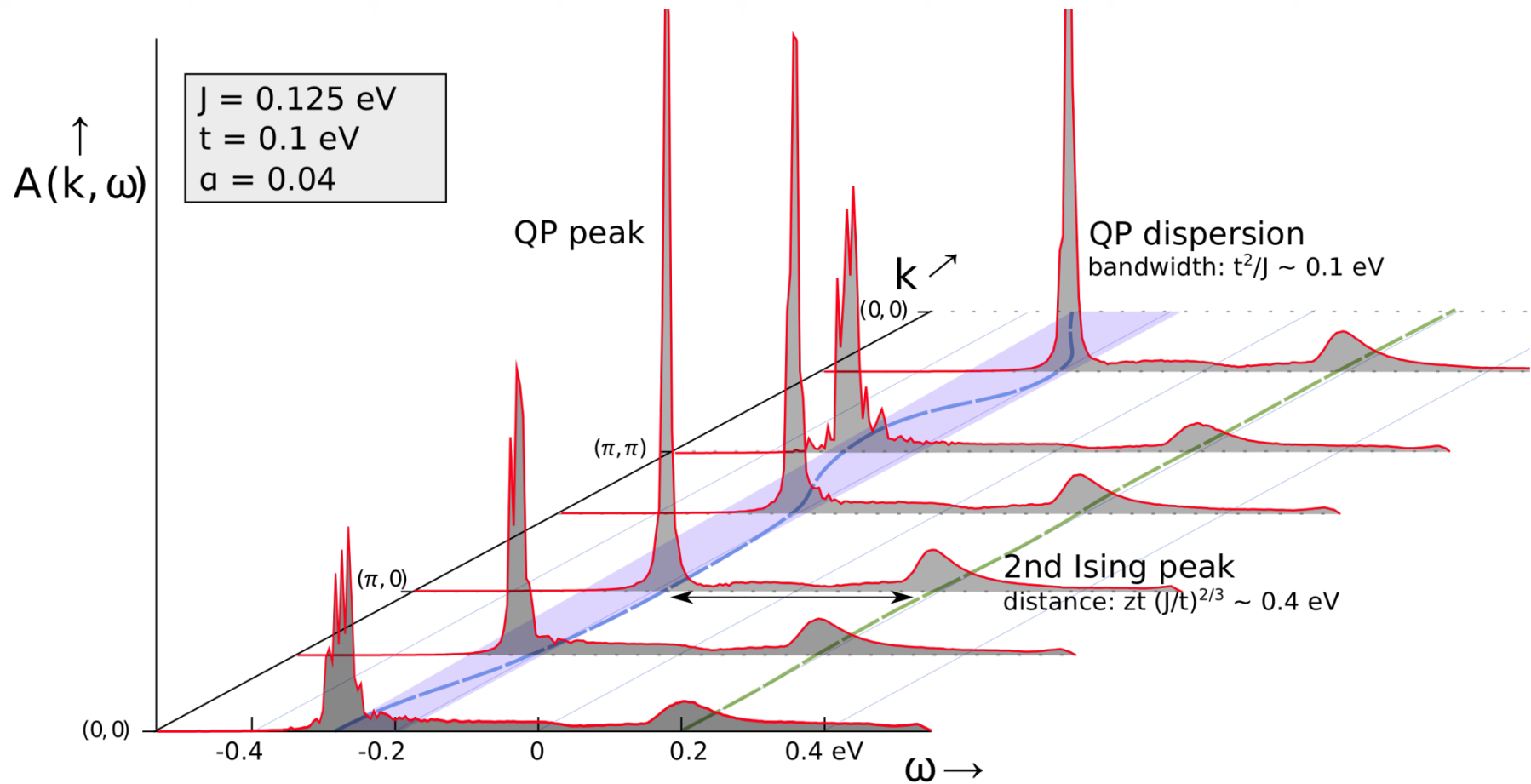
$$H_t = -t \sum_{\langle ij \rangle} |E_j\rangle \left(|0\ 0\rangle_i \langle 0\ 0|_j + \sum_m |1\ m\rangle_i \langle 1\ m|_j \right) \langle E_i|$$

- Compute exciton spectrum with LSW-SCBA

Frustrated single exciton: Ising confinement

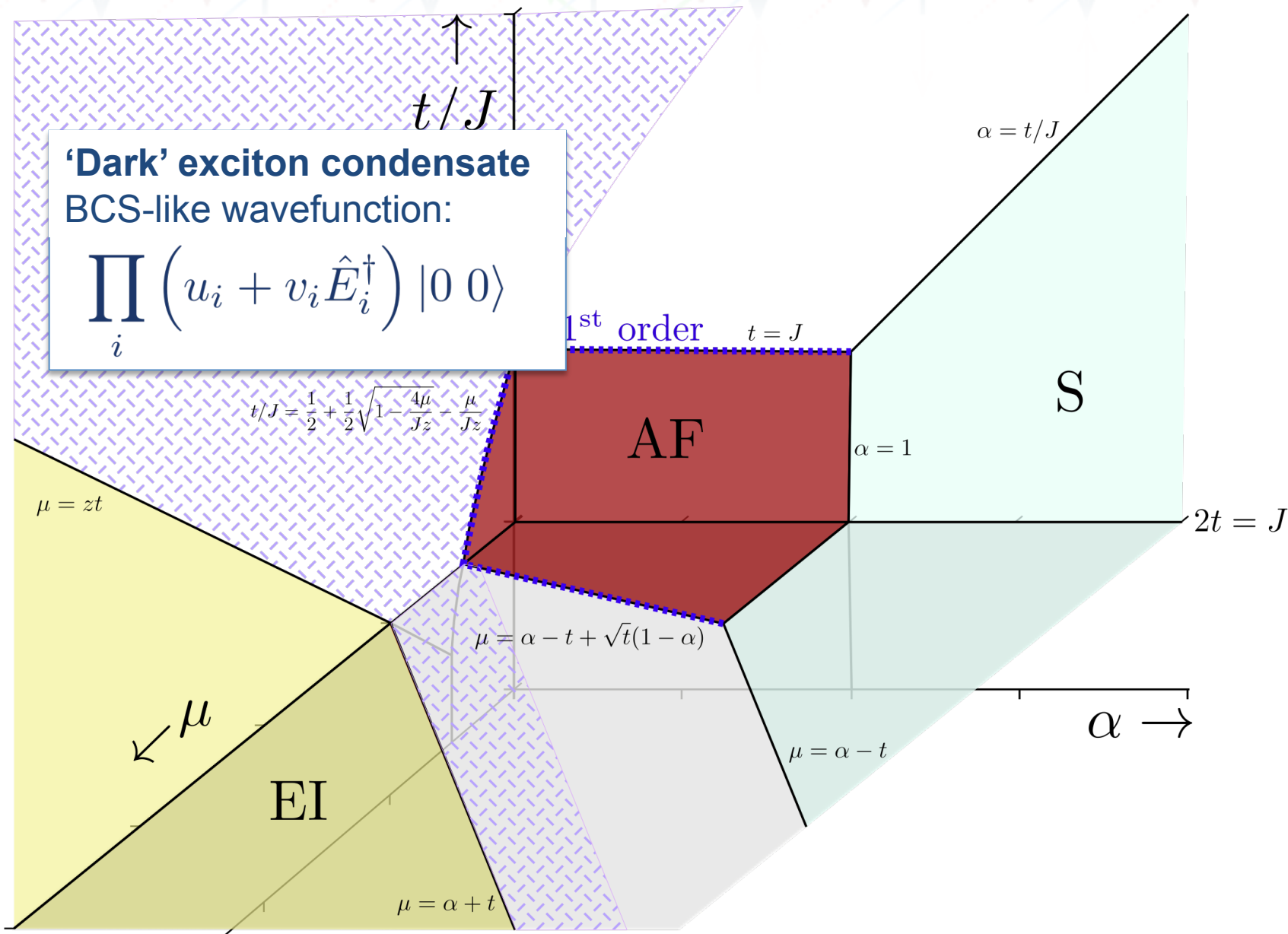


Frustrated single exciton: YBCO results



LR, Wu, Hilgenkamp & Zaanen, *EPL* 97, 27004 (2012);
 and arXiv:1202.3616.

Finite exciton density

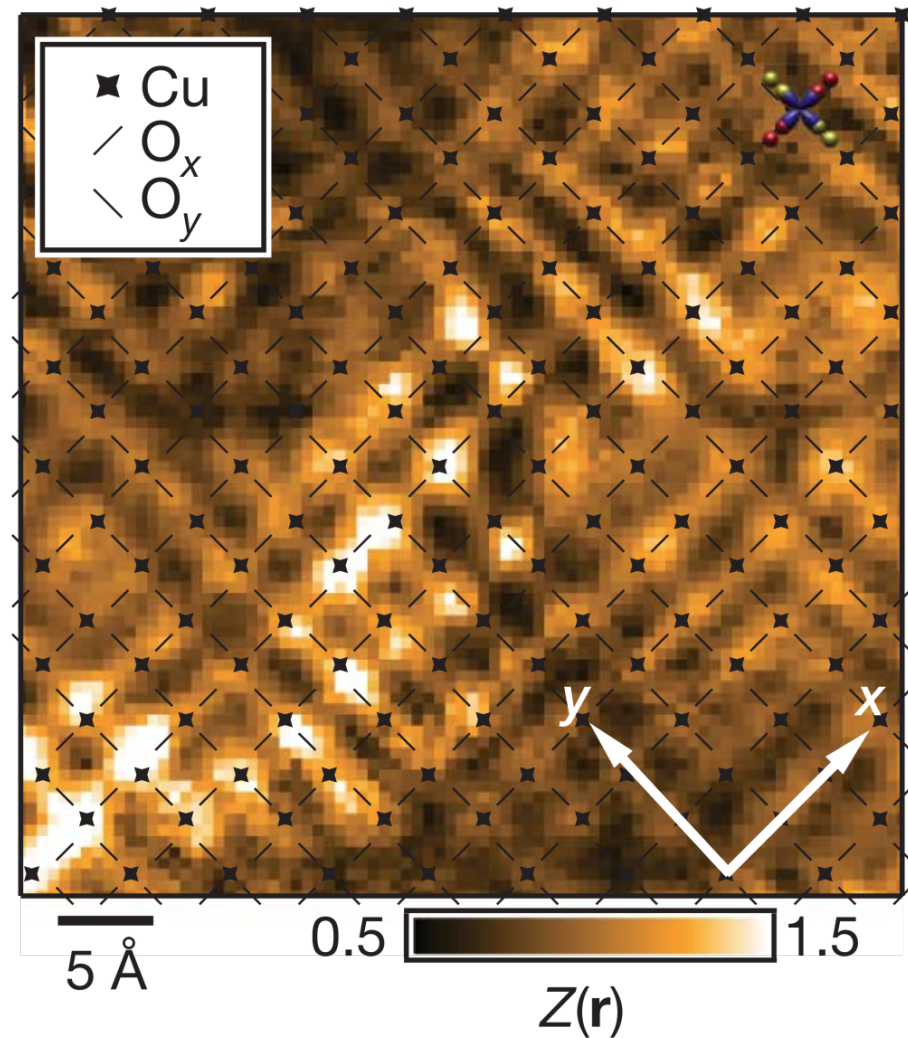


Current work: Antiferromagnetism + Excitons

Bonus: no fermion signs!

Subtle issues:

- Inhomogeneous phases
- Exciton-exciton dipole repulsion
- Frustration of excitons with spins
- Canonical ensemble



Mesaros, et al. *Science* **333**, 426 (2011)