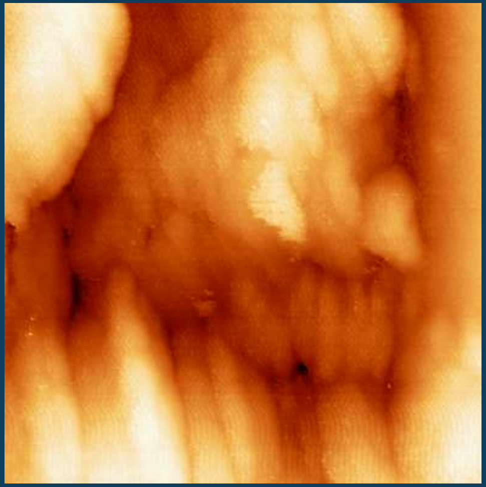
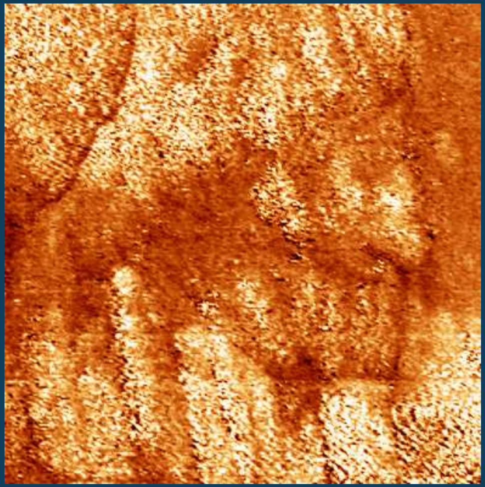
Investigating the Insulator to Metal Transition in CMR $La_{0.67}Ca_{0.33}MnO_3$ via Scanning Tunneling Spectroscopy.





F. Galli, S.J. Kelly, I. Komissarov and J. Aarts.

Nano Ned User Meeting 06-07/03/2007

Progress Report

Coupled Metal-Insulator/Ferromagnetic-Paramagnetic Transition in CMR Manganites

=> mixed valence via doping (Mn^{3+} & Mn^{4+})

Zero field transport:

Above Tc

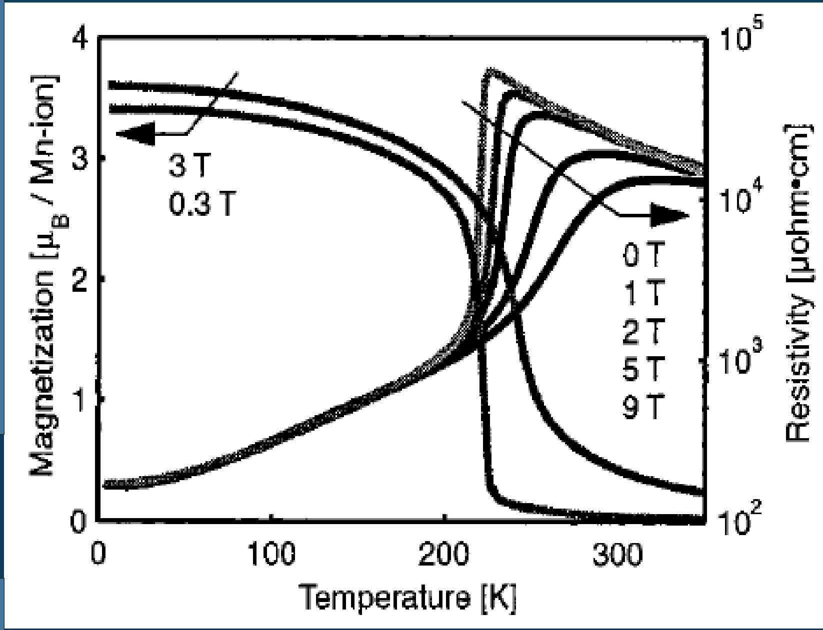
=> electron scattering dominated by polarons (e-ph. coupling mediated by J-T distortion at Mn^{3+})

=> paramagnetism

Below Tc

=> metallicity

=> ferromagnetism ↔ double exchange



Colossal Magneto Resistance (CMR)

Applied magnetic field aligns spins, decreases PM (insulating) & increases FM (metallic). The effect changes resistance of several decades.

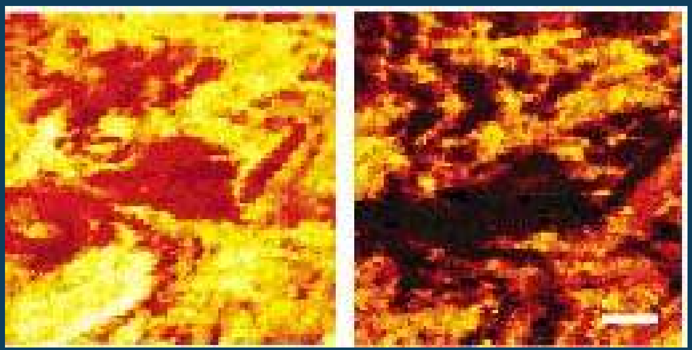
Engineering the Electronic Properties Locally

Spatial Electronic Phase Separation (PS)

=>Coexisting but spatially distinct insulating & metallic domains

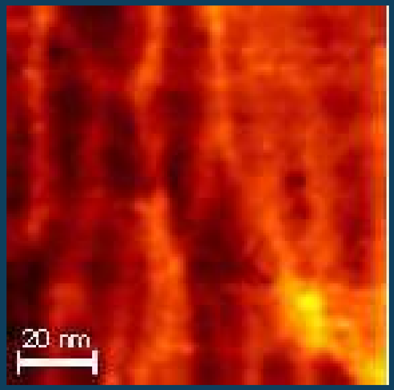
=>Associated with *strained manganite films* grown on lattice mismatched substrates such as $LaAlO_3$ (~2.3%), $SrTiO_3$ (~-0.6%), and MgO (~8%).

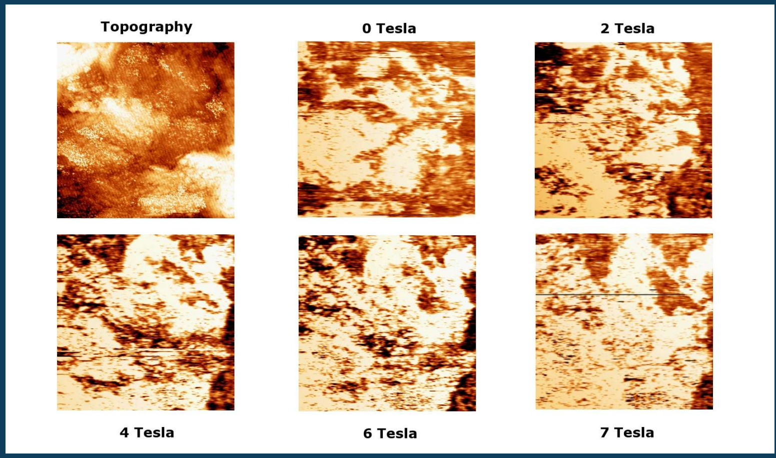
=>*Strain free* films ($NdGaO_3$ has a ~0.23% lattice mismatch with $La_{0.7}Ca_{0.3}MnO_3$) are considered homogeneous (no PS).



600 nm

M. Fäth et al. Science **285**, 1540 (1999)





600 nm

F.Galli et al. To be published.

=> Influencing/inducing phase separations with artificial structures

Motivation

=> What happens to the local DOS while going through such a dramatic phase transition (homogeneous systems)? STM/STS probes **locally** the DOS.

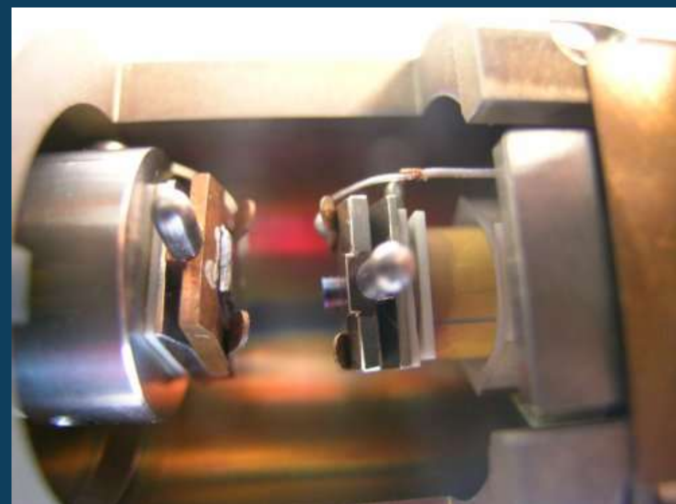
=> Finger print of the metallic phase in order to carefully study the homogeneities (or inhomogeneities) of the low temperature (metallic) phase.

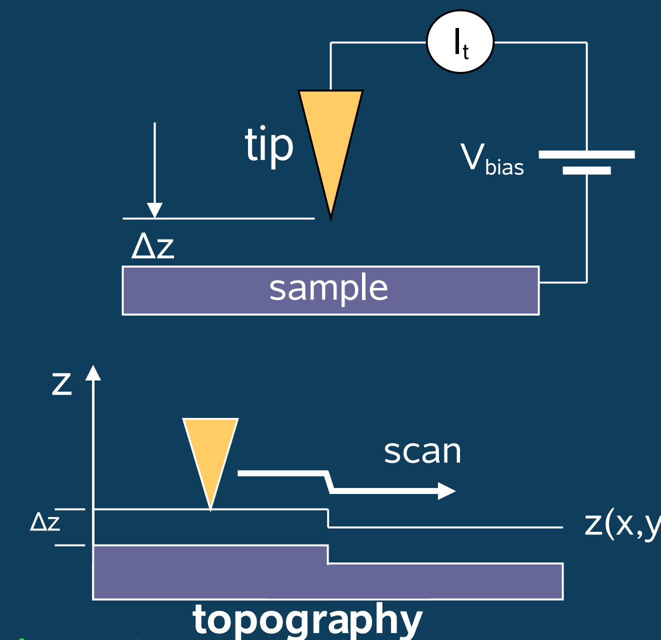
=> DOS mapping at low bias V (0-500mV or less) where maximum change is seen in the MIT, versus high (1-2V) biases (less sensitive to changes in the MIT).

Scanning Tunneling Microscopy and Spectroscopy

Variable Temperature He-gas flow STM

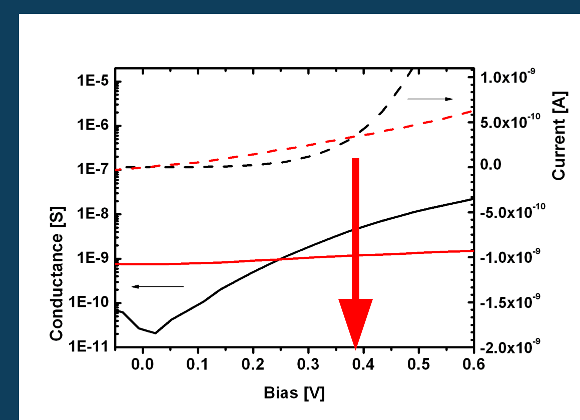
=> 4K to 300K
=> 0 to +/- 8 T
=> home made STM
=> range:
RT: 3.6µm or 1.5mm
4K: 0.7µm or 0.3mm



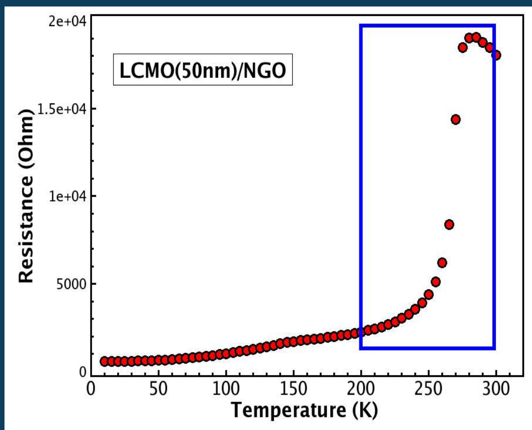


Scanning Tunneling Spectroscopy (STS) → measure sample DOS

- scan topography
- at each pixel take I-V
  - stop scanning→x,y fixed
  - feedback off →Δz fixed
  - sweep bias ±V
  - measure I_t
  - differentiate I-V curve for dI/dV
  - Alternatively, measure directly dI/dV with lock-in technique.
  - No scanning, point spectroscopy.

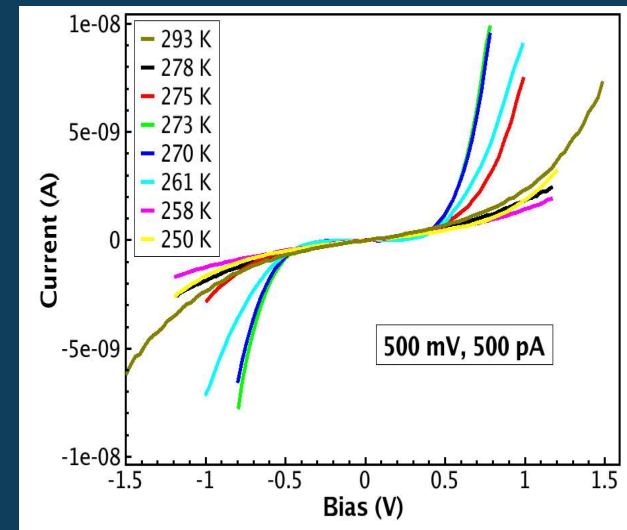


$La_{0.7}Ca_{0.3}MnO_3$ (50nm Film) on $NdGaO_3$ Substrate Matching => Strain Free



R-T Transport Measurement

=> Sharp transition at Tp=280 K indicative of unstrained and electronically homogeneous film as expected for LCMO on lattice matched NGO substrate



Temperature Dependent Point Spectroscopy

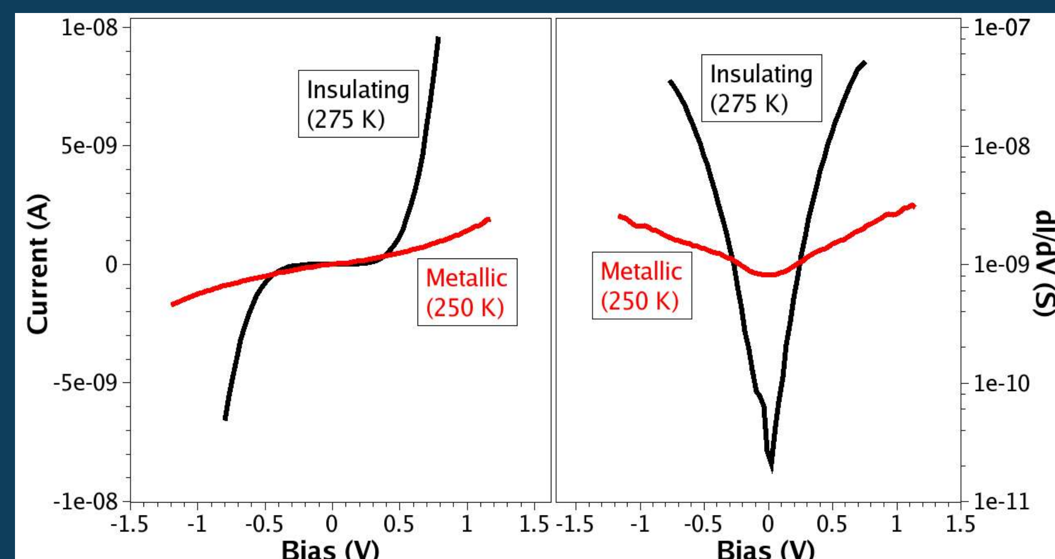
=>Low Bias to study changes of DOS around E_F

=>I-V curves average of 5-20 I-V sweeps

=>I-V data shows metallic behavior well below T_P changing to insulating character around T_P

=>Metallic-like I-V curve zero-bias slope indicates significant conductance

=>Insulating-like I-V curves are flat around zero bias, indicative of gap-like character



Tunneling Barrier Contribution (LCMO(50nm)/NGO)

=>Tip-Sample tunneling current across a tunneling barrier: barrier, t, sample DOS, N_s. and tip DOS, N_t

$$I(s,V,W,T) = c\int_{-\infty}^{\infty} N_s(E+\frac{eV}{2})N_t(E-\frac{eV}{2})t(s,E,W)\times[f(E-\frac{eV}{2})-f(E+\frac{eV}{2})]dE$$

=>Let's assume Nt and Ns as being both “flat” and try to deconvolute tunneling barrier part. Any deviation from a flat DOS will represent an energy dependence of the DOS itself. At low temperatures, we can approximate the Fermi-Dirac distribution as a step function, and simplify the above relation as:

$$I(s,V,W) \propto N_s N_t \int_{-\frac{eV}{2}}^{\frac{eV}{2}} t(s,E,W)dE$$

=>Model the tunneling barrier as one-dimensional and trapezoidal,

$$t(s,E,W) = e^{[-2ks\sqrt{2(W-E)}]}$$

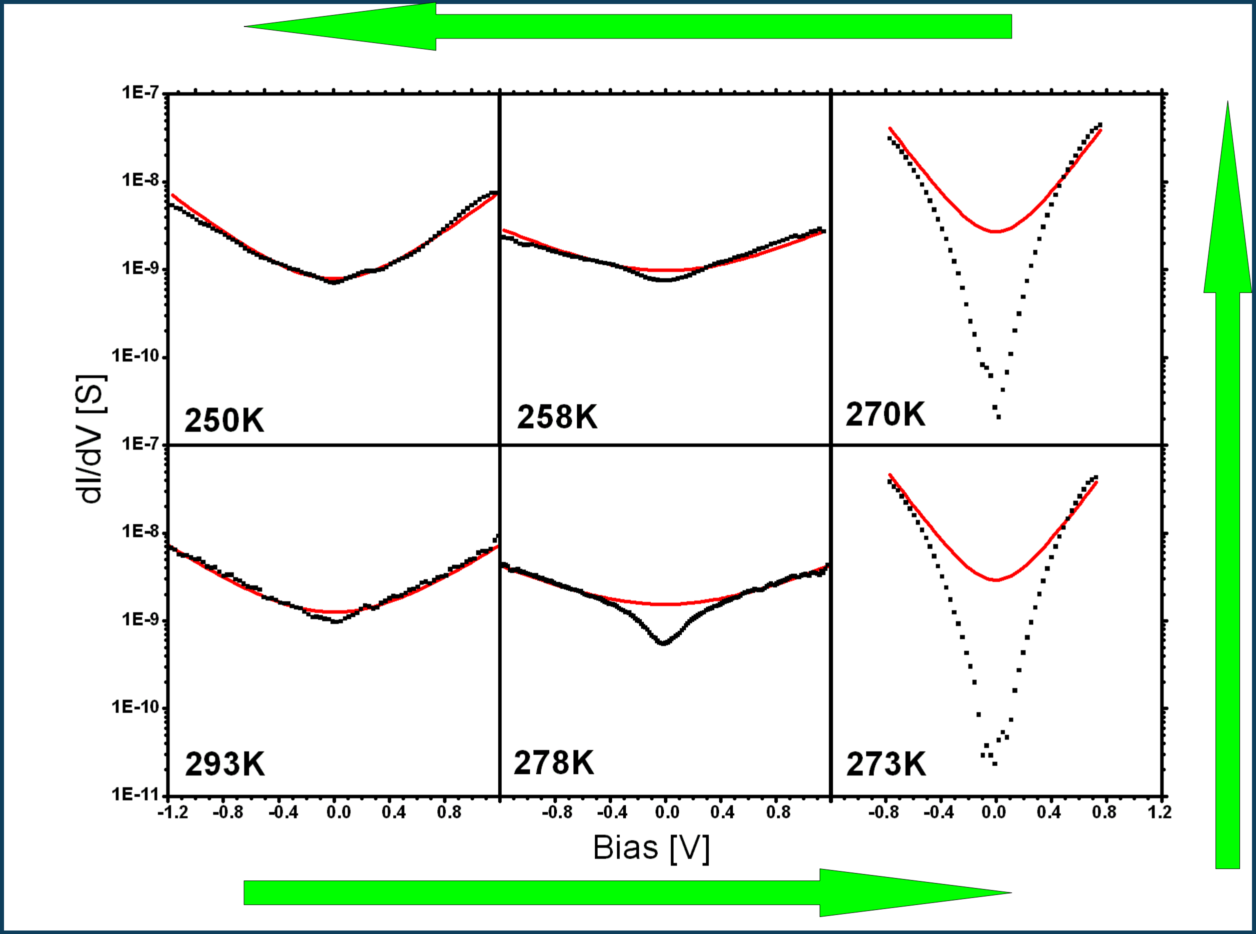
=>Now we can relate conductance, dI/dV, to the tunneling barrier,

$$\frac{dI}{dV} \propto N_t N_s[t(s,\frac{eV}{2},W)+t(s,-\frac{eV}{2},W)]$$

=>If we fit this function to our conductance data, we can estimate the tip-sample distance, s (~10Å), and the work function, W (~1-4eV), and use these parameters to calculate the tunneling barrier as a function of temperature.

dI/dV with Tunneling Barrier Fit (LCMO(50nm)/NGO)

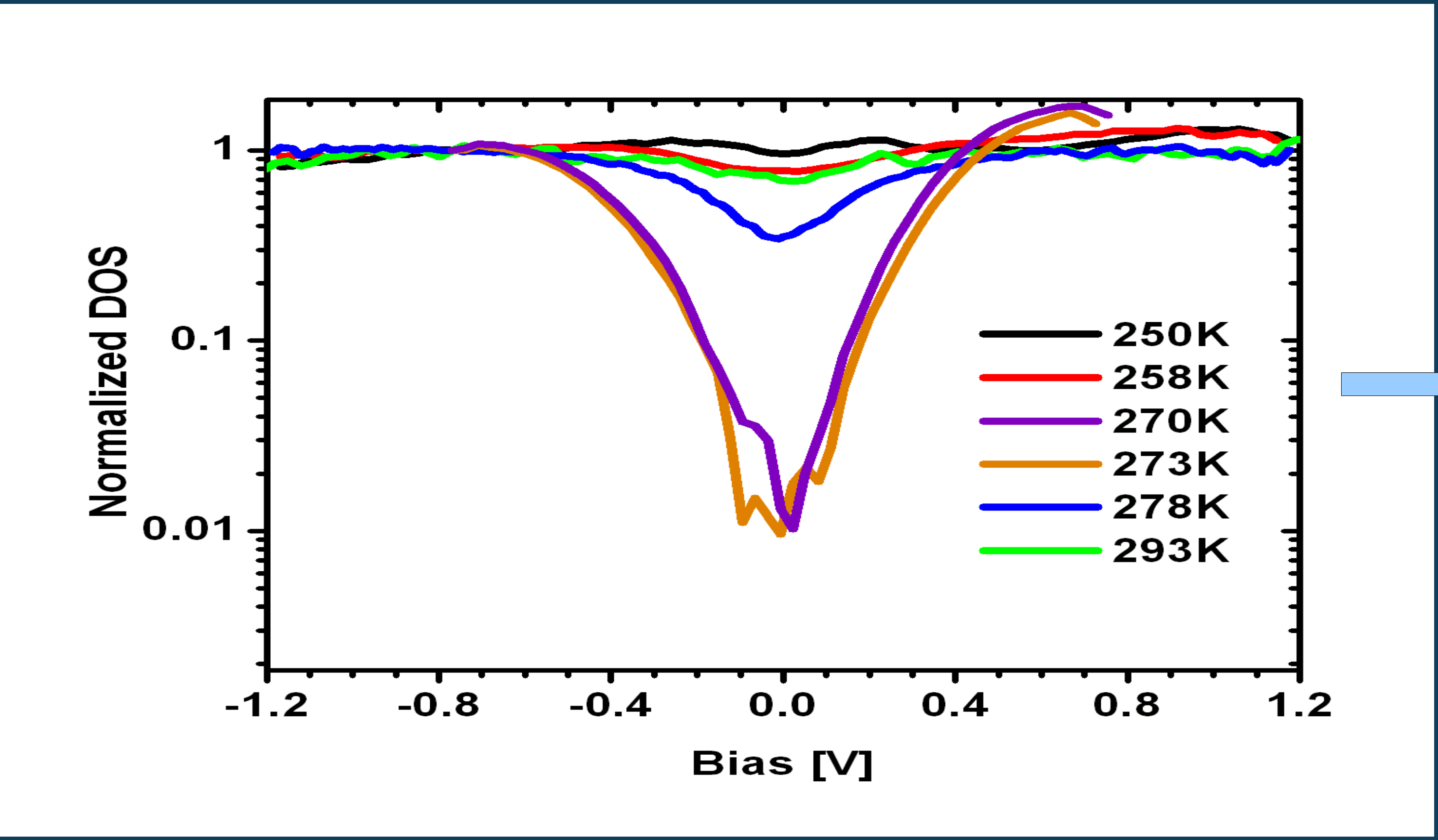
=> dI/dV computed from I-V data (numerically differentiate).
=> Tunneling barrier fit (red) using higher bias data.
=> Difference clearly shows depletion of DOS in transition region is not associated with tunneling barrier effect

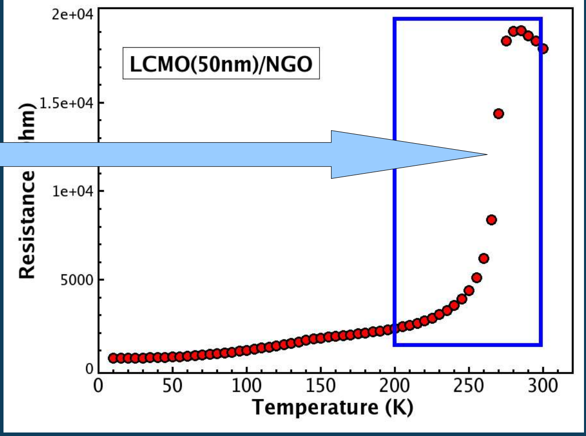


See also Mitra et al., PRB 71, 094426 (2005)- PRB 68, 134428 (2003)

Normalized dI/dV: Temperature Dependent DOS (LCMO(50nm)/NGO)

$$N_s \propto \frac{\frac{dI}{dV}}{N_t[t(s, \frac{eV}{2}, W) + t(s, -\frac{eV}{2}, W)]}$$





=> DOS indicates depletion, maximum below T_P, filling up again in the tail of the transition.
=> Temperature dependent *Coulomb gap? Pseudo gap* -precursor of metallic phase- ?
=> Only reported before by Mitra et al., PRB 71, 094426 (2005)

Conclusions

=>Observed strong temperature dependence of DOS via Tunneling Spectroscopy at low bias voltage.

=> Observe depletion of electronic states around Tp. Before the onset of the metallic phase the depletion gap fills up.

=> Depletion provides mechanism for significant conductance drop. Filling up of the gap is precursor of the metallic phase.