



Wir schaffen Wissen – heute für morgen

# Tuning of **ELECTRONIC** states of **TITANATES**: From 3D trough 2D to 1D

*Milan  
Radovic*

# Collaborators

- The SIS team
- The Group
- PSI

## SIS beamline @ SLS:



MingShi



Nick.Plumb



Hugo Dil ( EPFL )



Z. Wang



S. Muff



Felix Baumberger

U. Geneva, CH

## ADRESS beamline @ SLS

RIXS



Thorsten Schmitt

SXARPES



Vladimir Strocov

PNR @ SINQ



Jochen Stahn

LEM @ LMU



Zaher Salman

SLS



Urs Staub,

SwissFEL



Luc Patthey

PSI Directorship



Joel Mesot

## National and International

CNR-SPIN,  
Napoli, IT



Marco Salluzzo

U. Paris-Sud, FRA



Andrés Santander

Universität München



Jan Minar

Indian Institute  
of Science



Tanmoy Das

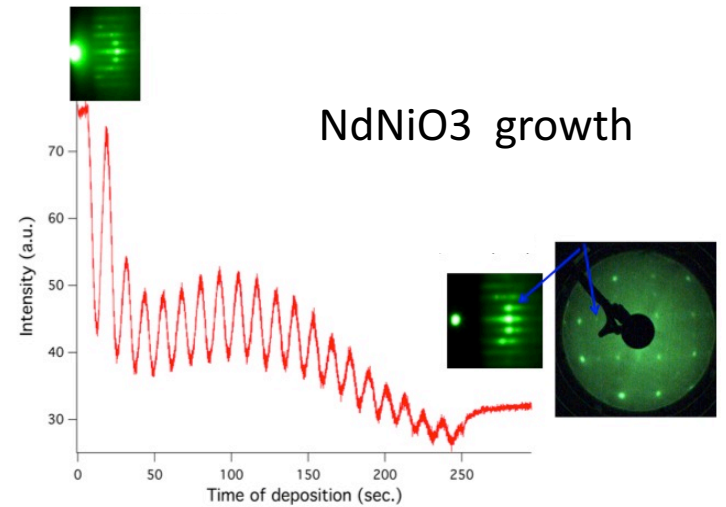
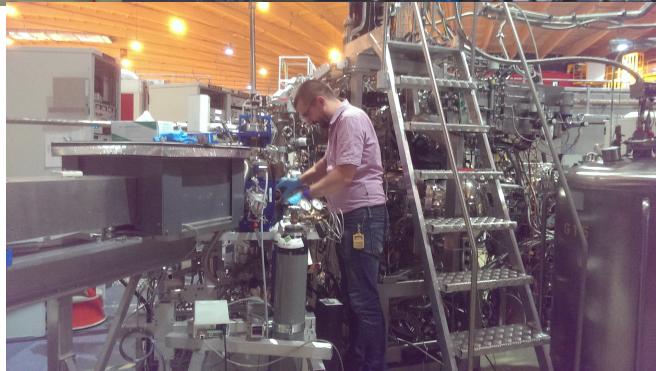
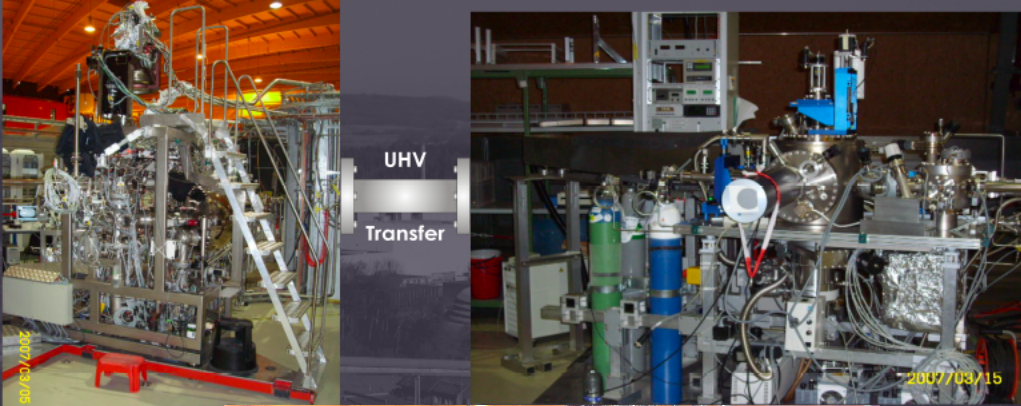
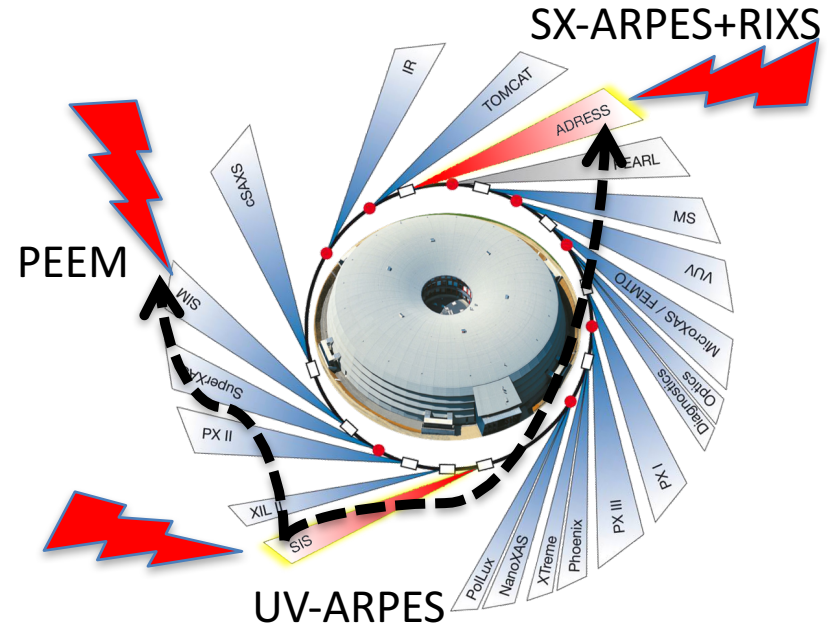
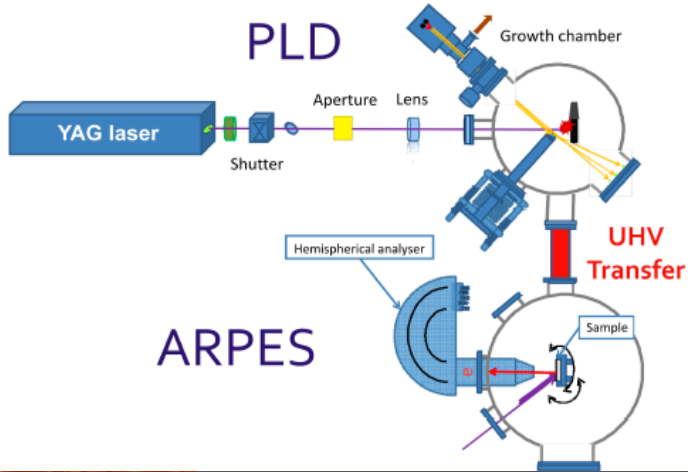
Indian Institute  
of Technology



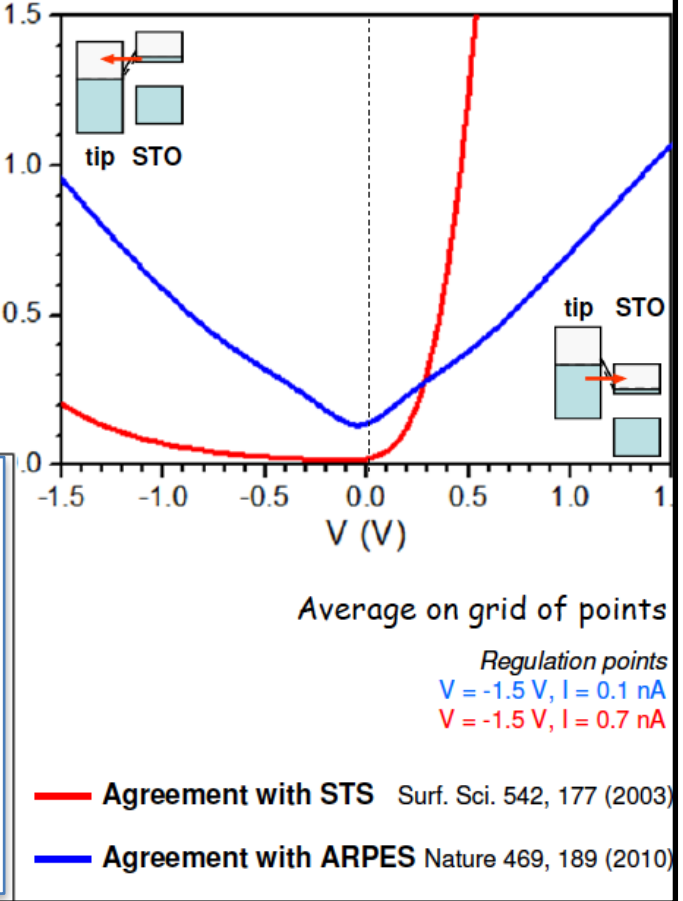
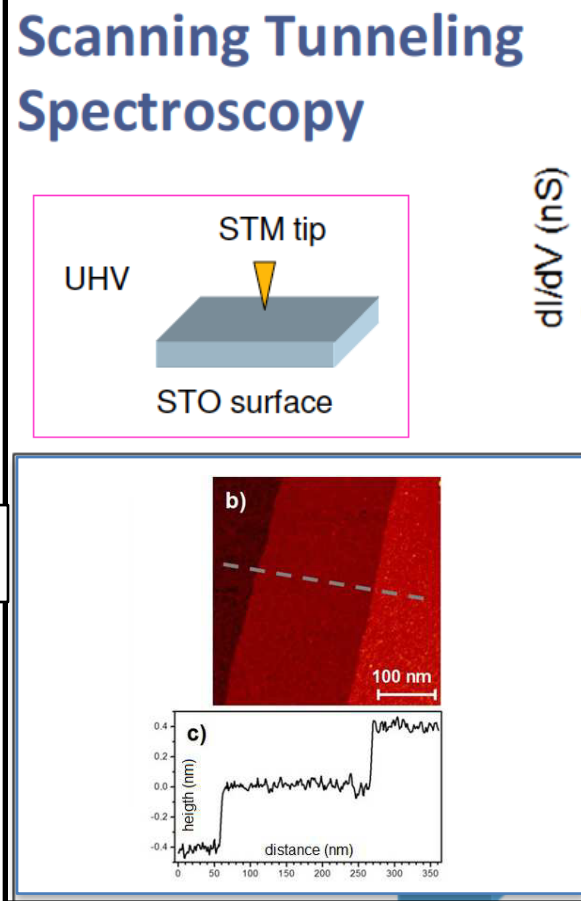
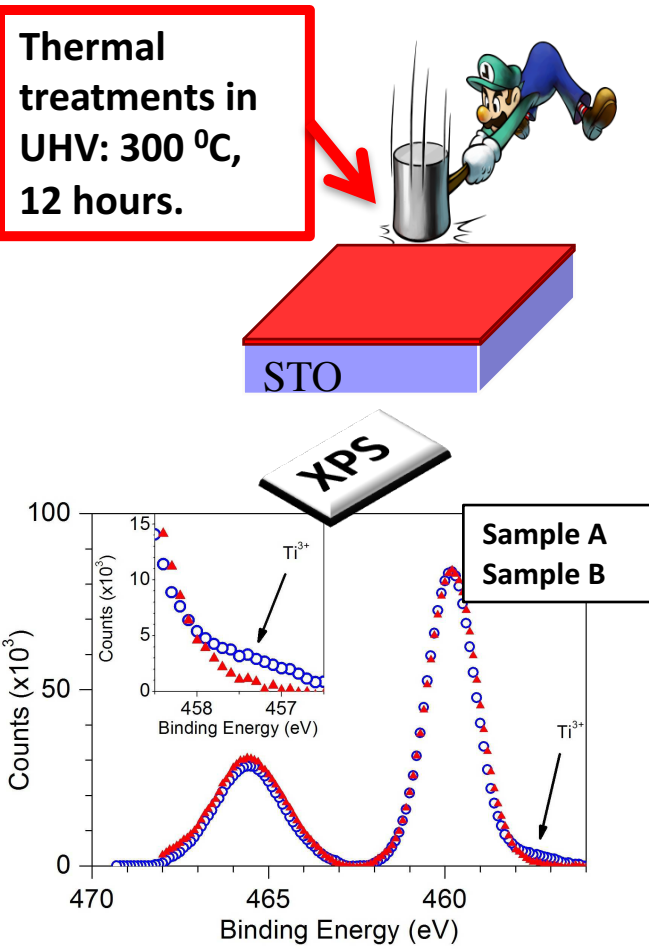
R. S. Dhaka



# PLD+ARPES facilities at SIS beamline (SLS-PSI)



# Conductivity on STO surface (work done in 2007)



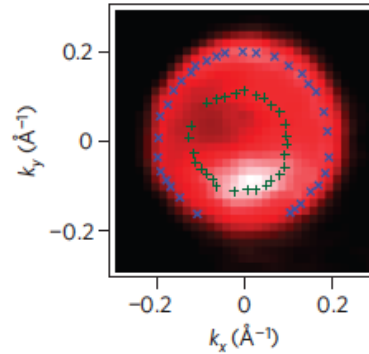
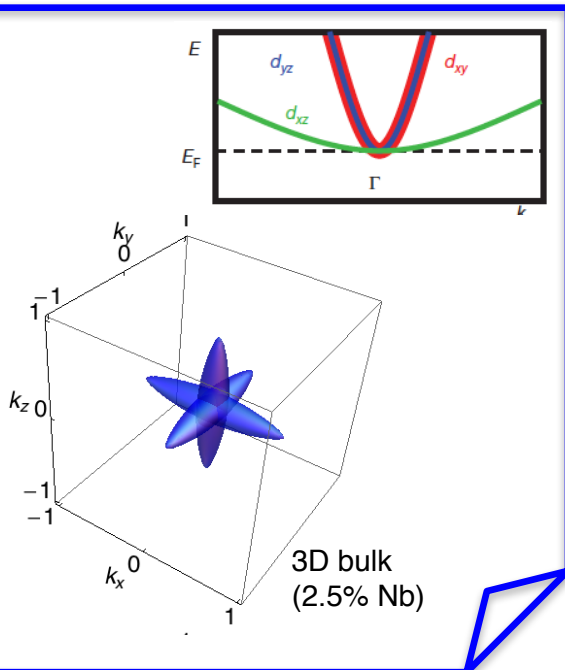
R. Di Capua, M. Radovic, et al., Phys. Rev. B 86, 155425 (2012).

The  $dI/dV$  curves of the different samples:

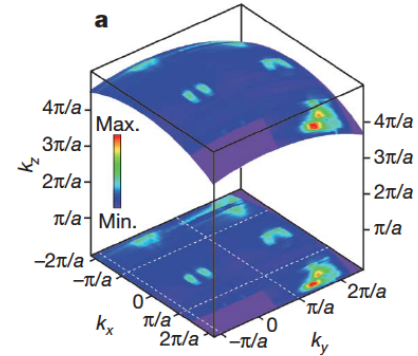
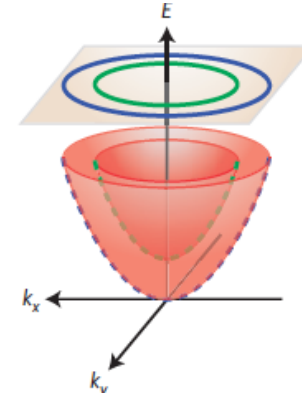
- ✦ **The red curve:** Sample B determines conducting bulk and insulating surfaces
- ✦ **Blue curve:** Sample A consists a finite density of states at the Fermi level –  
 The surface itself is **conducting**.



# Metallic surface in/on STO: facts and doubts?



Meevasana et al., Nature Mater. **10**, (2011).



Santander-Syro et al., Nature **469**, (2011).

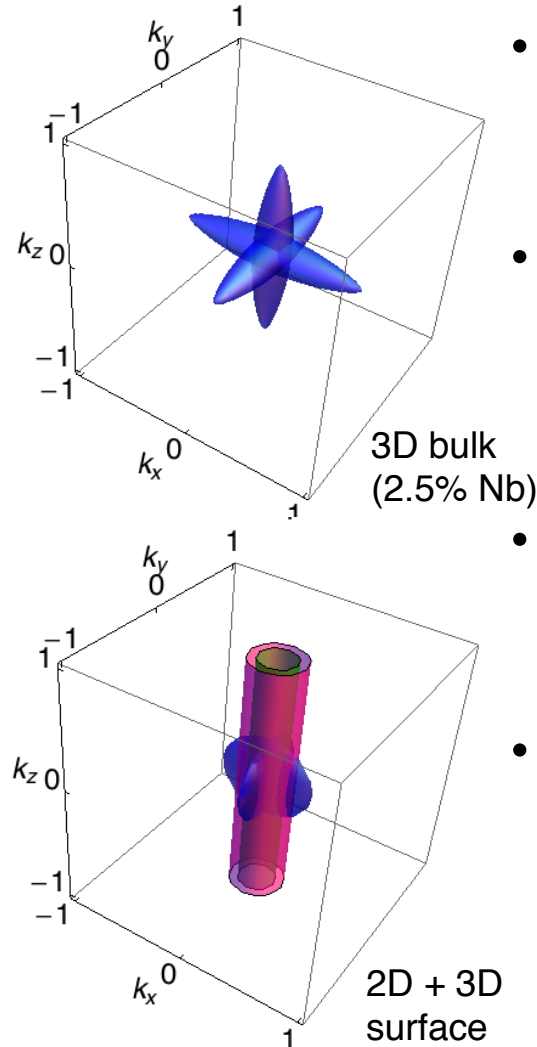
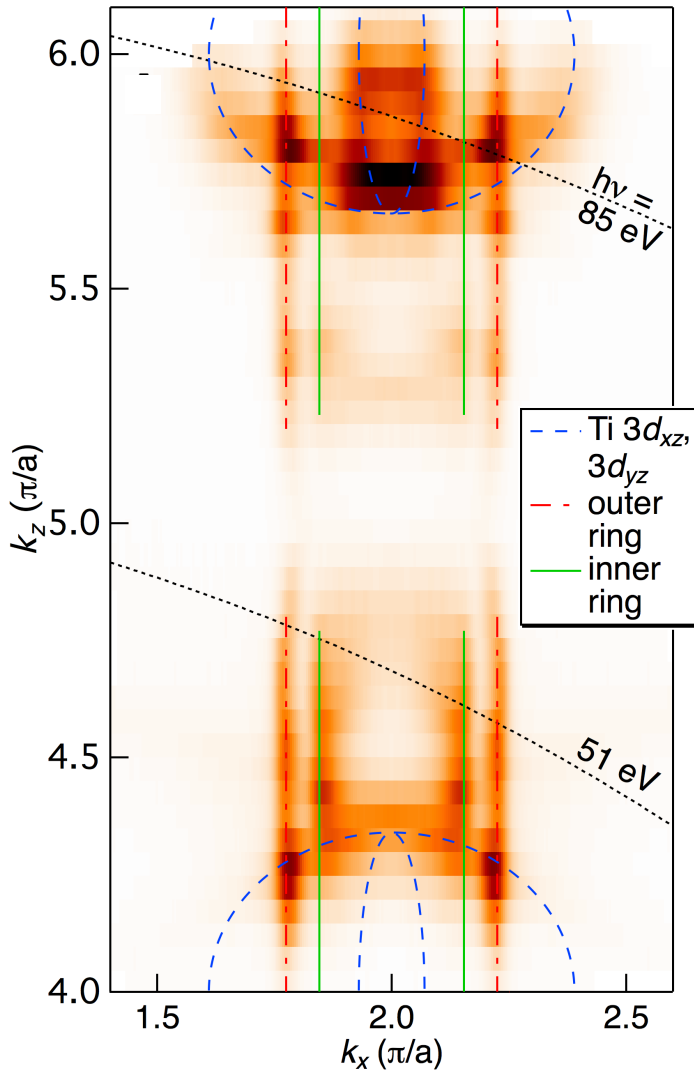
Proposed scenarios:

- the 2DEG is generated by exposure to light, which creates oxygen vacancies (Meevasana et al.)
- Cleaving procedure creates Oxygen vacancies (Santander-Syro et al)

Questions/  
motivations:

- **FS composed by? What about dimensionality? Details?**
- **Control of LDE gas?**

# Study of Metallic surface on STO: Surface-driven state with 3D dispersion

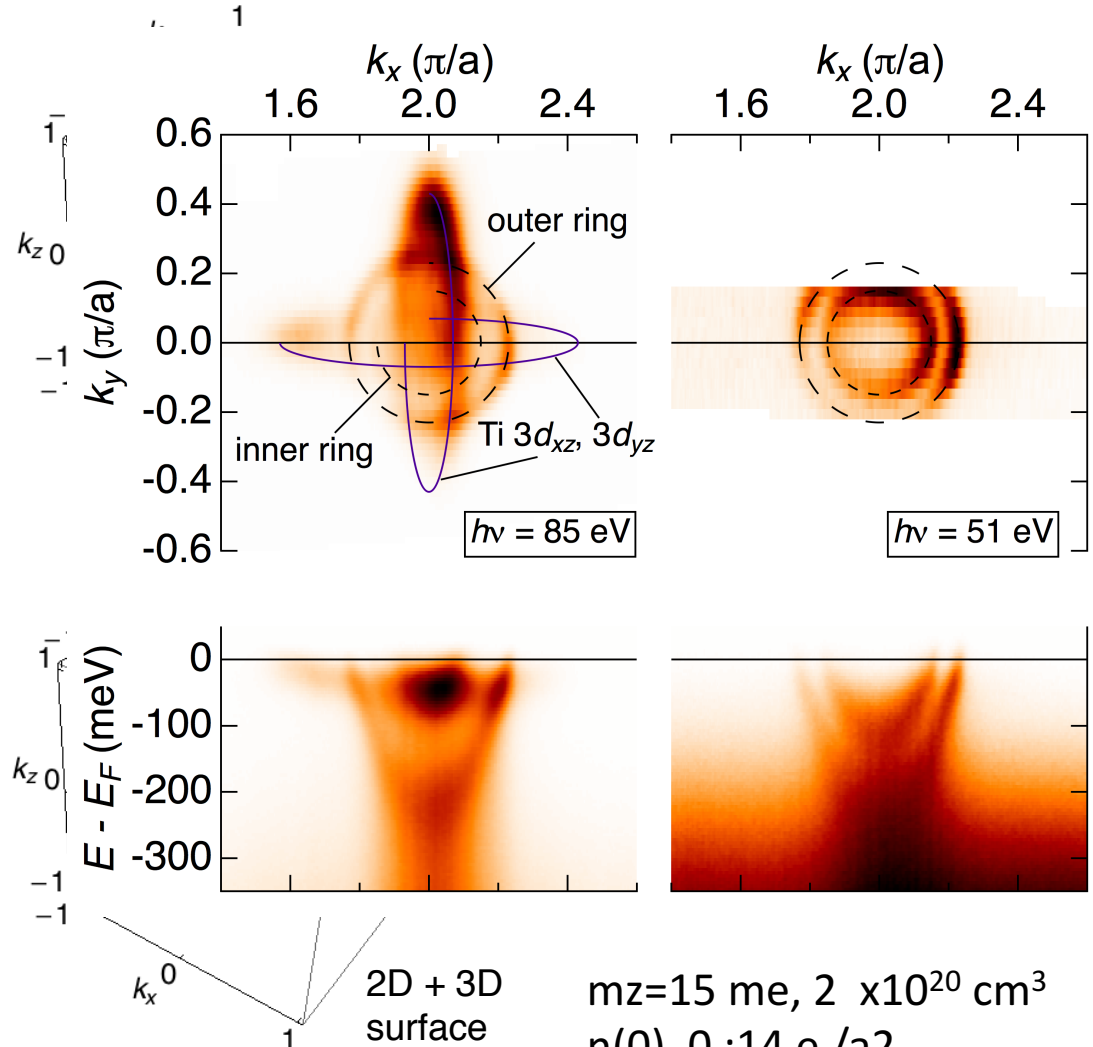
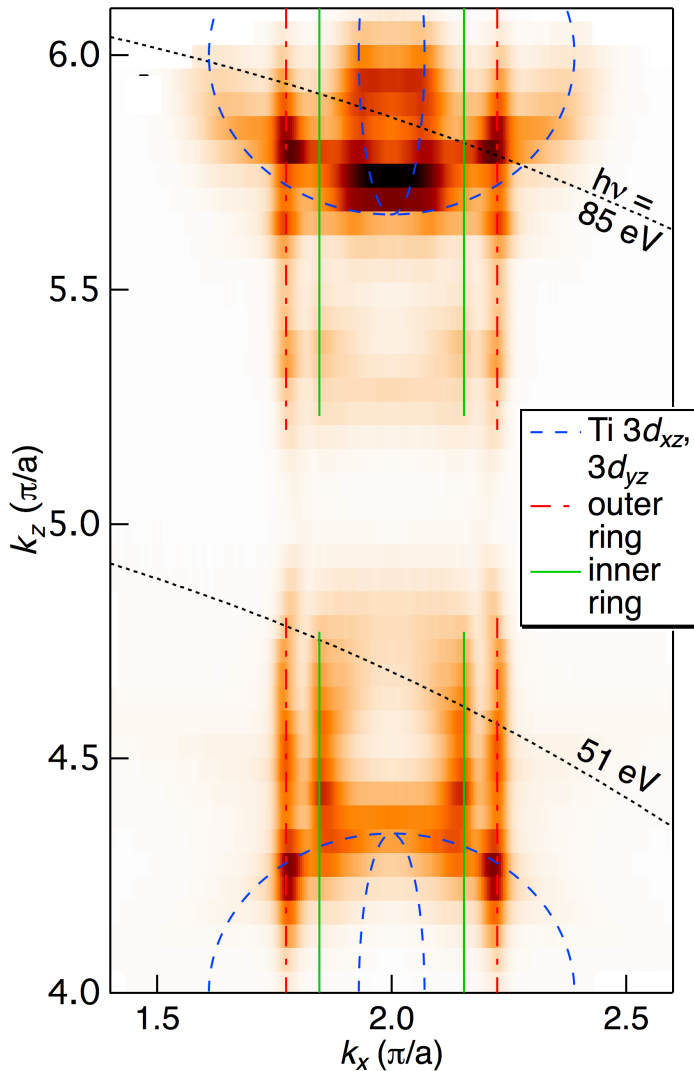


- All FS components differ drastically from expectations for bulk
- From 3 prolate spheroids to:
  - $d_{xy} \rightarrow$  2D cylinder(s)
  - $d_{xz}, d_{yz} \rightarrow$  3D oblate ellipsoids
- “Stretching” of  $d_{xz}, d_{yz}$  sheets along  $k_z$  signals crossover to confinement
- $\rightarrow$  electronic reconstruction extends multiple unit cells from surface

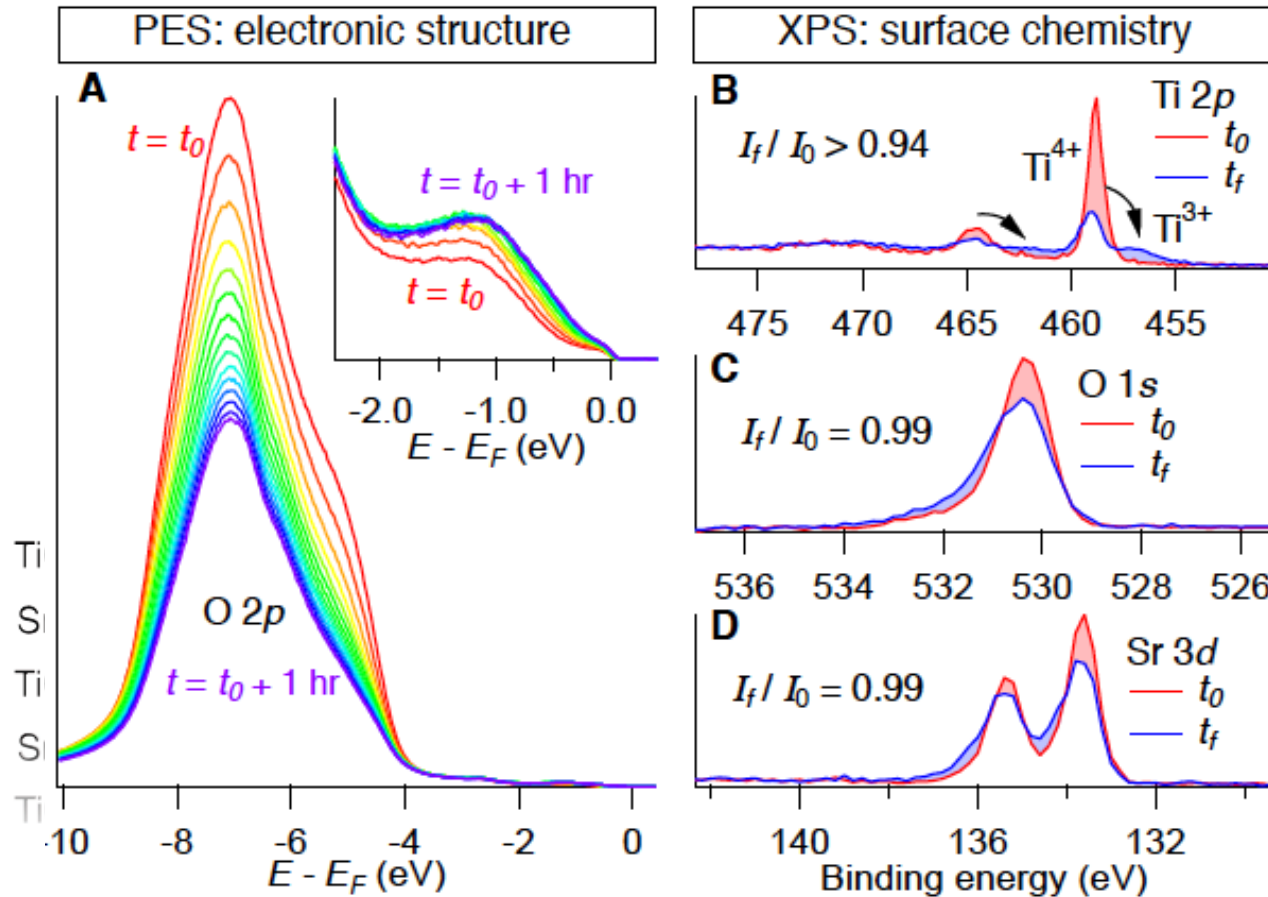
$$m^* = 15 m_e, \quad n(0) = 2 \times 10^{20} \text{ cm}^{-3}$$

$$n(0) = 0.14 e/a^2$$

# Study of Metallic surface on STO: Surface-driven state with 3D dispersion





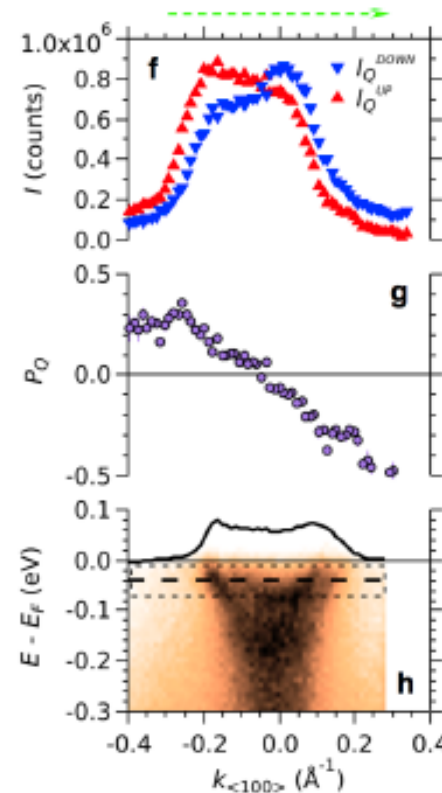
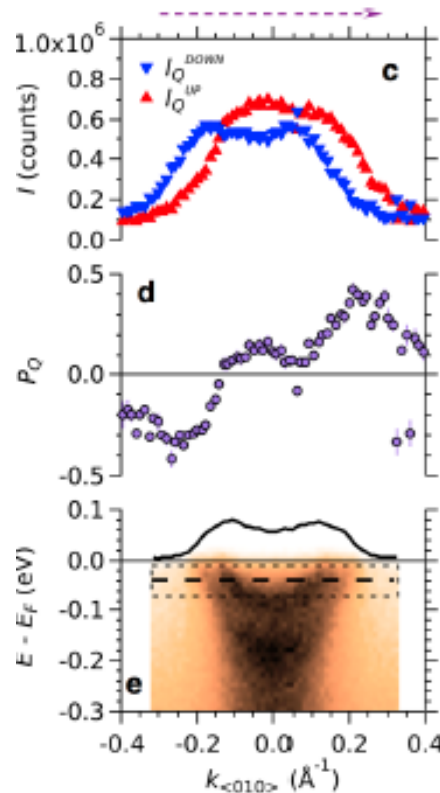
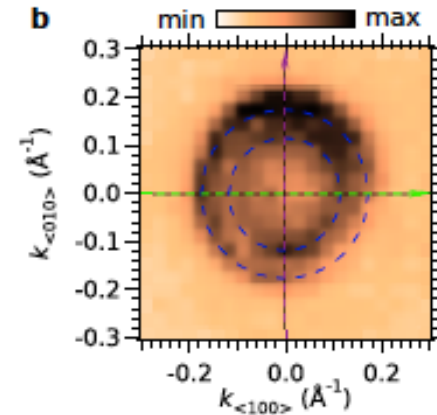
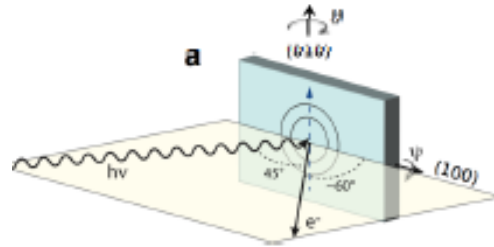


Surface of STO(001) is known to exhibit Ti-O buckling. Likely that photons trigger/enhance/align this behavior and cause the crystal transition.

- Can explain  $\text{Ti}^{4+} \rightarrow \text{Ti}^{3+}$  shift in core level spectra
- Can account for formation of in-gap states

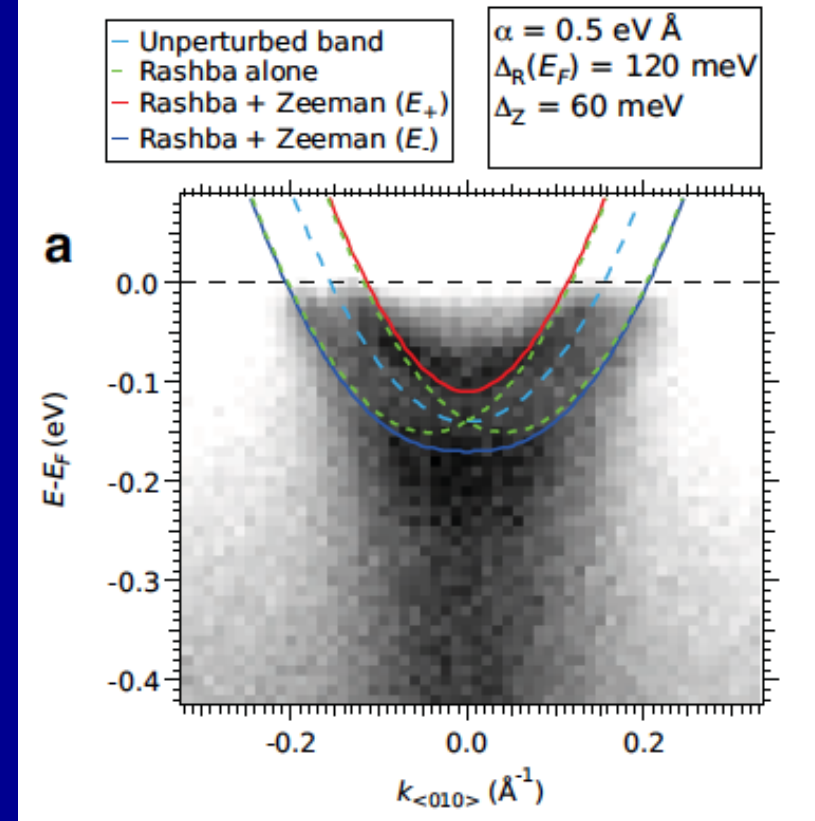
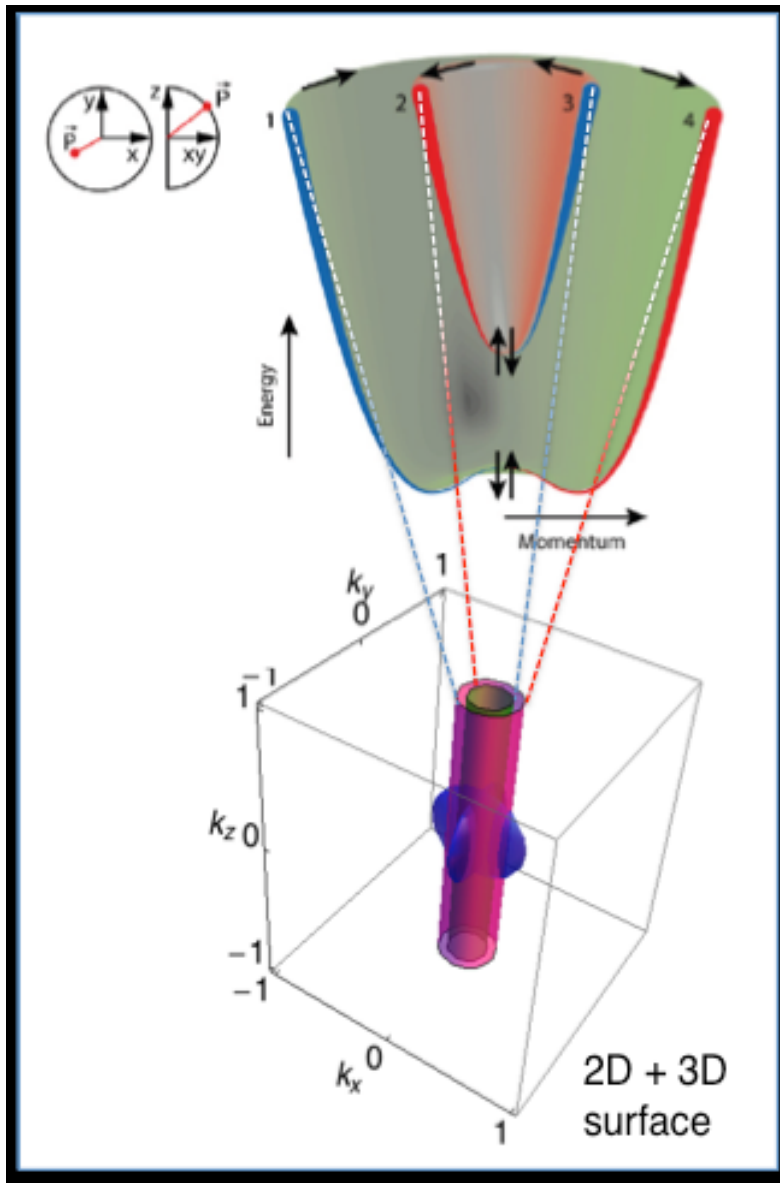
# More: Spin Polarized 2DEG!

LV light, 47 eV, 20K



A. F. Santander-Syro, MR,  
et al. Nature Mat, 2014

# More: Spin Polarized 2DEG!



Energy-momentum intensity map along (010) and fits using a parabolic-band model subject Rashba and Zeeman splittings. Zeeman field is along (001).



# Tuning of electronic states via an interface!

(September 2002)

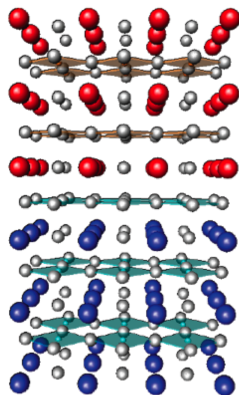
**letters to nature**

## Artificial charge-modulation in atomic-scale perovskite titanate superlattices

A. Ohtomo, D. A. Muller, J. L. Grazul & H. Y. Hwang

Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey 07974, USA

Oxide A( LaTiO<sub>3</sub>, LaAlO<sub>3</sub>)



Oxide B (SrTiO<sub>3</sub>)

(January 2004)

## A high-mobility electron gas at the LaAlO<sub>3</sub>/SrTiO<sub>3</sub> heterointerface

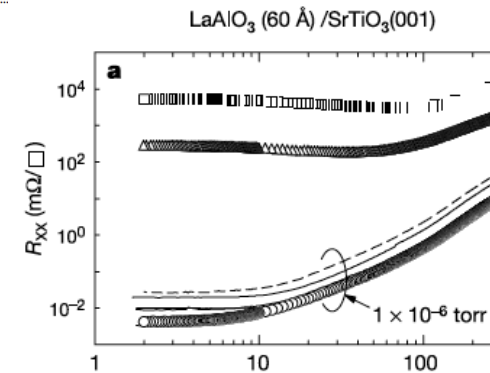
A. Ohtomo<sup>1,2,3</sup> & H. Y. Hwang<sup>1,3,4</sup>

<sup>1</sup>Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey 07974, USA

<sup>2</sup>Institute for Materials Research, Tohoku University, Sendai, 980-8577, Japan

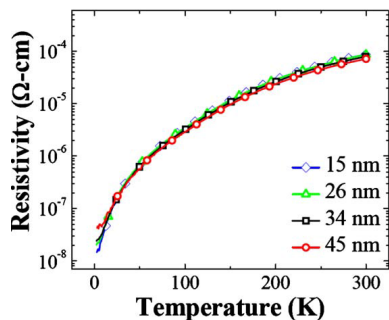
<sup>3</sup>Japan Science and Technology Agency, Kawaguchi, 332-0012, Japan

<sup>4</sup>Department of Advanced Materials Science, University of Tokyo, Kashiwa, Chiba, 277-8651, Japan



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**Superconducting Interfaces Between Insulating Oxides**  
N. Reyren et al.  
*Science* **317**, 1196 (2007);  
DOI: 10.1126/science.1146006



PHYSICAL REVIEW B **81**, 161101(R) (2010)

## Metallicity in LaTiO<sub>3</sub> thin films induced by lattice deformation

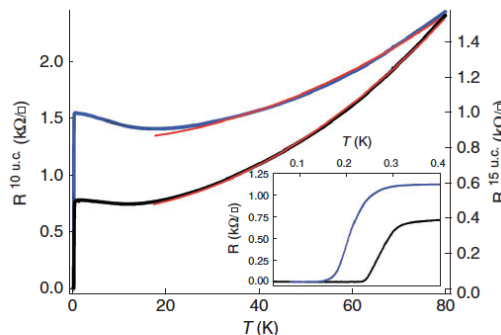
Franklin J. Wong,<sup>1,2</sup> Seung-Hyub Baek,<sup>3</sup> Rajesh V. Chopdekar,<sup>1</sup> Virat V. Mehta,<sup>1,2</sup> Ho-Won Jang,<sup>3</sup> Chang-Beom Eom,<sup>3</sup> and Yuri Suzuki<sup>1,2</sup>

<sup>1</sup>Department of Materials Science and Engineering, University of California, Berkeley, California 94720, USA

<sup>2</sup>Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

<sup>3</sup>Department of Materials Science and Engineering, University of Wisconsin, Madison, Wisconsin 53706, USA

(Received 2 October 2009; revised manuscript received 8 December 2009; published 15 April 2010)



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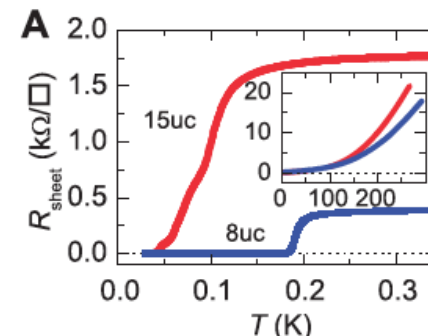
Received 29 Jul 2010 | Accepted 6 Sep 2010 | Published 5 Oct 2010

DOI:10.1038/ncomms1084

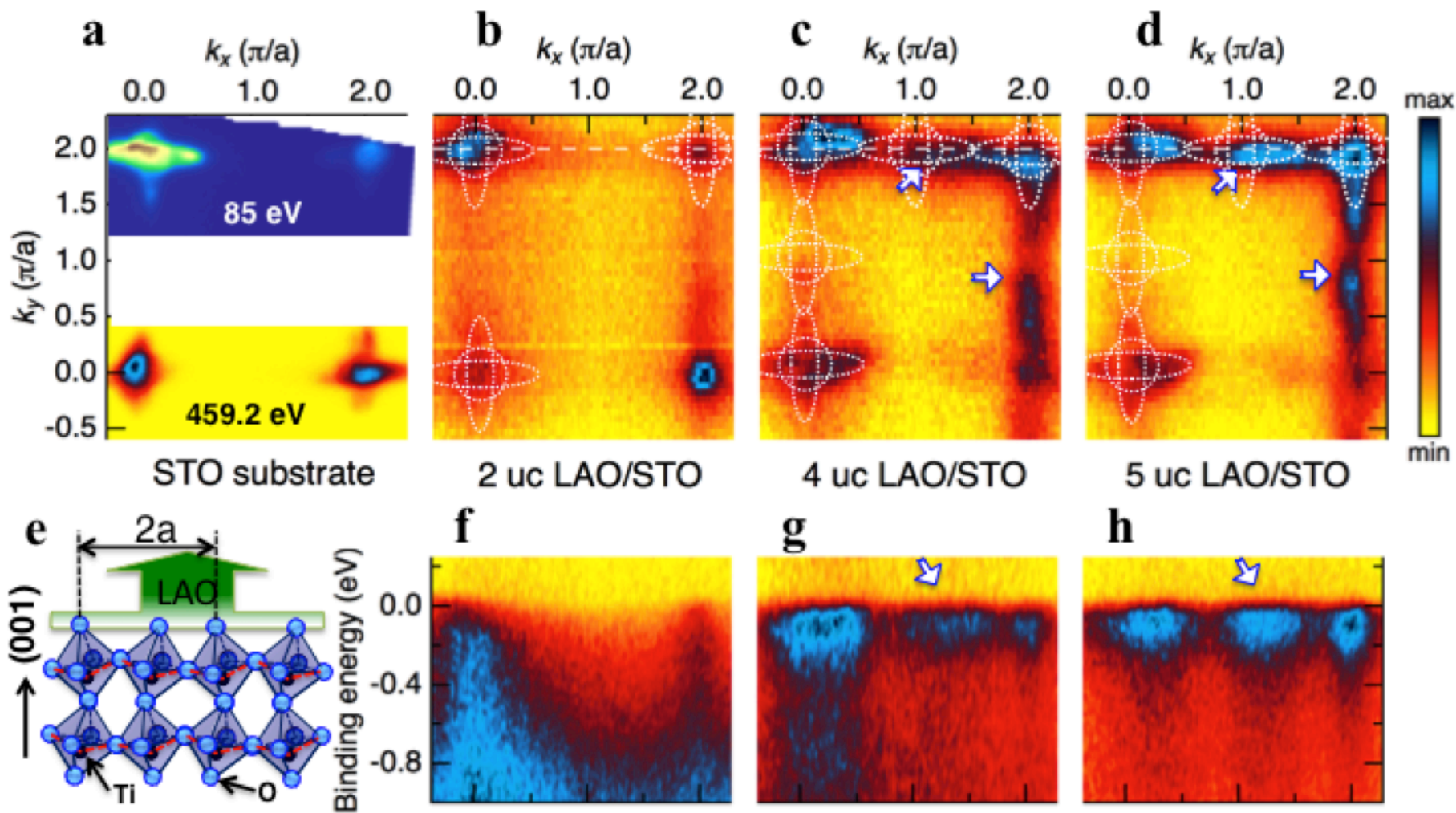
## Two-dimensional superconductivity at a Mott insulator/band insulator interface LaTiO<sub>3</sub>/SrTiO<sub>3</sub>

J. Biscaras<sup>1</sup>, N. Bergeal<sup>1</sup>, A. Kushwaha<sup>2</sup>, T. Wolf<sup>1</sup>, A. Rastogi<sup>2</sup>, R.C. Budhani<sup>2,3</sup> & J. Lesueur<sup>1</sup>

**Figure 1 | Sheet resistance of the heterostructures.** Sheet resistance a of the 10 u.c. (black dots, left axis) and 15 u.c. (blue dots, right axis)

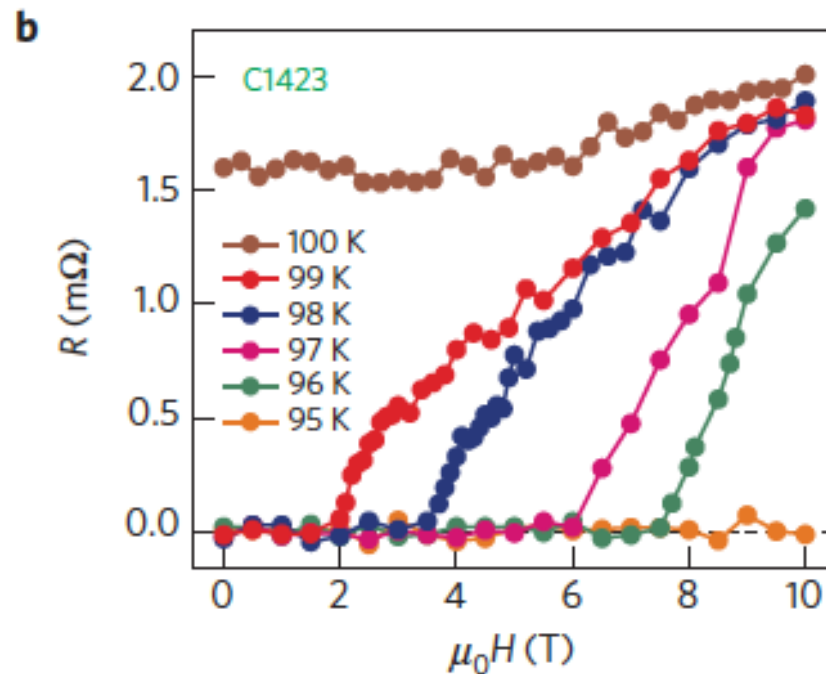
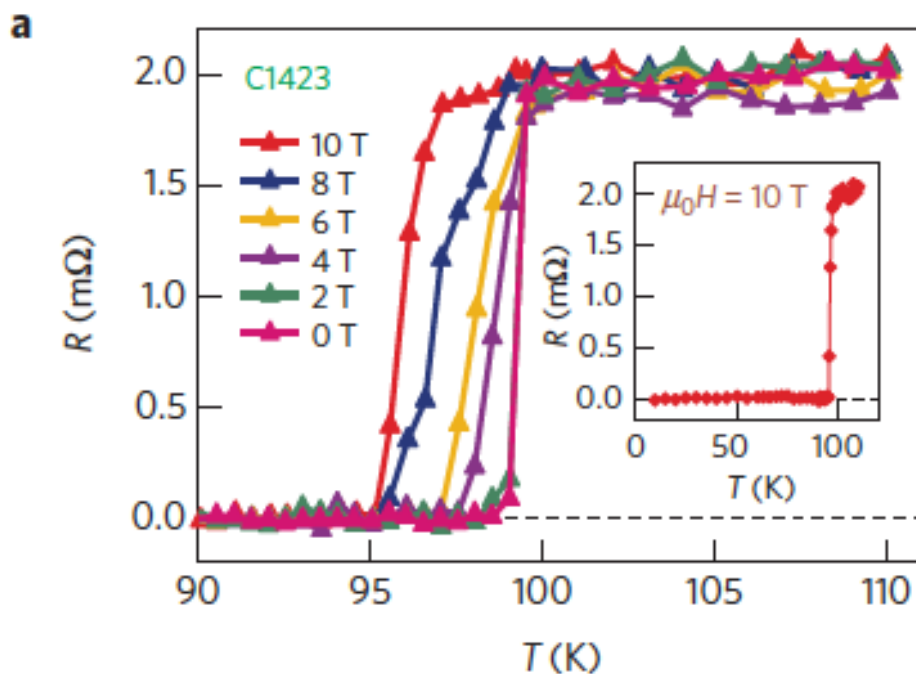


# Tuning of **electronic** states via an **interface!**



## Superconductivity above 100 K in single-layer FeSe films on doped SrTiO<sub>3</sub>

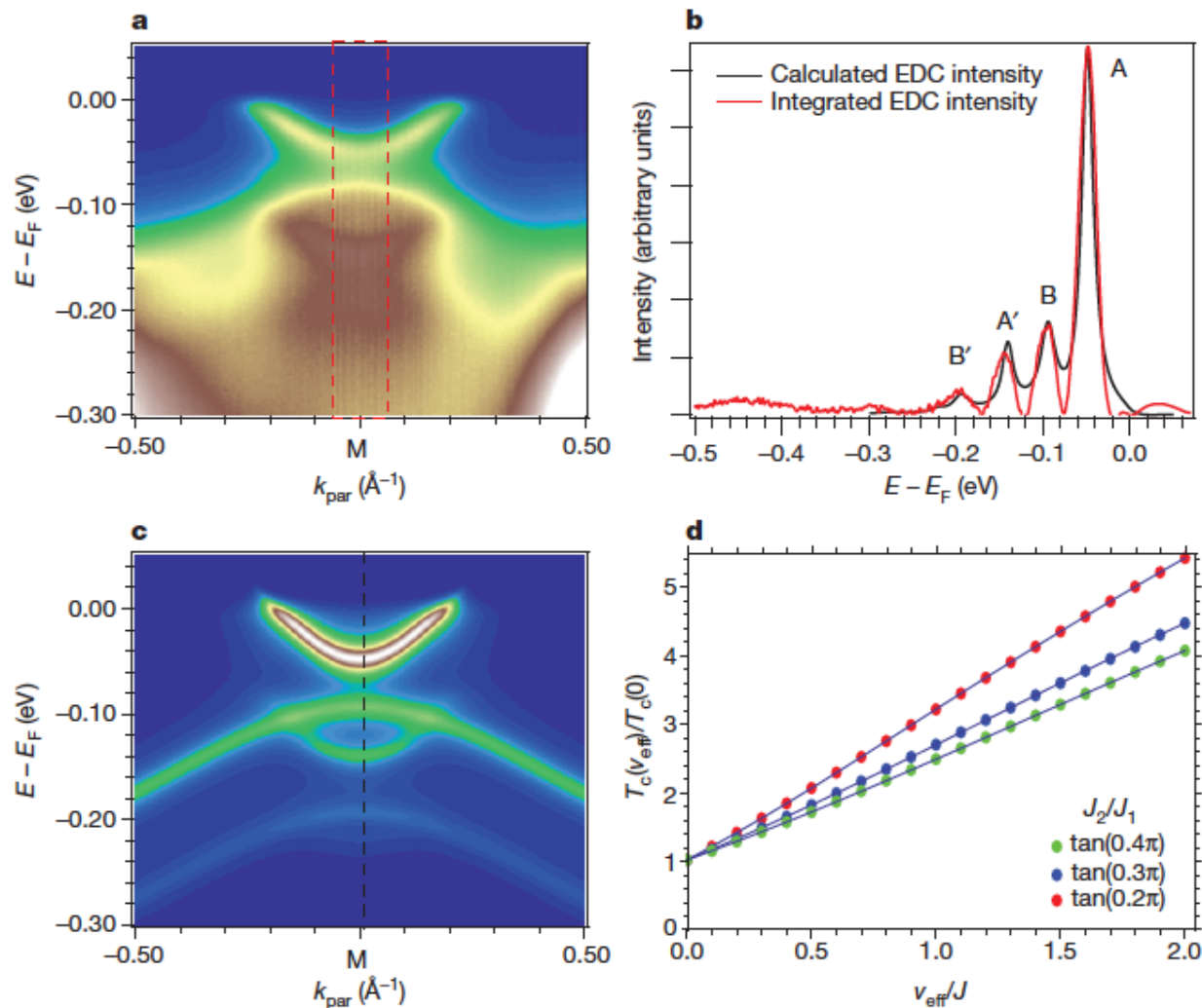
Jian-Feng Ge<sup>1</sup>, Zhi-Long Liu<sup>1</sup>, Canhua Liu<sup>1,2\*</sup>, Chun-Lei Gao<sup>1,2</sup>, Dong Qian<sup>1,2</sup>, Qi-Kun Xue<sup>3\*</sup>, Ying Liu<sup>1,2,4</sup> and Jin-Feng Jia<sup>1,2\*</sup>



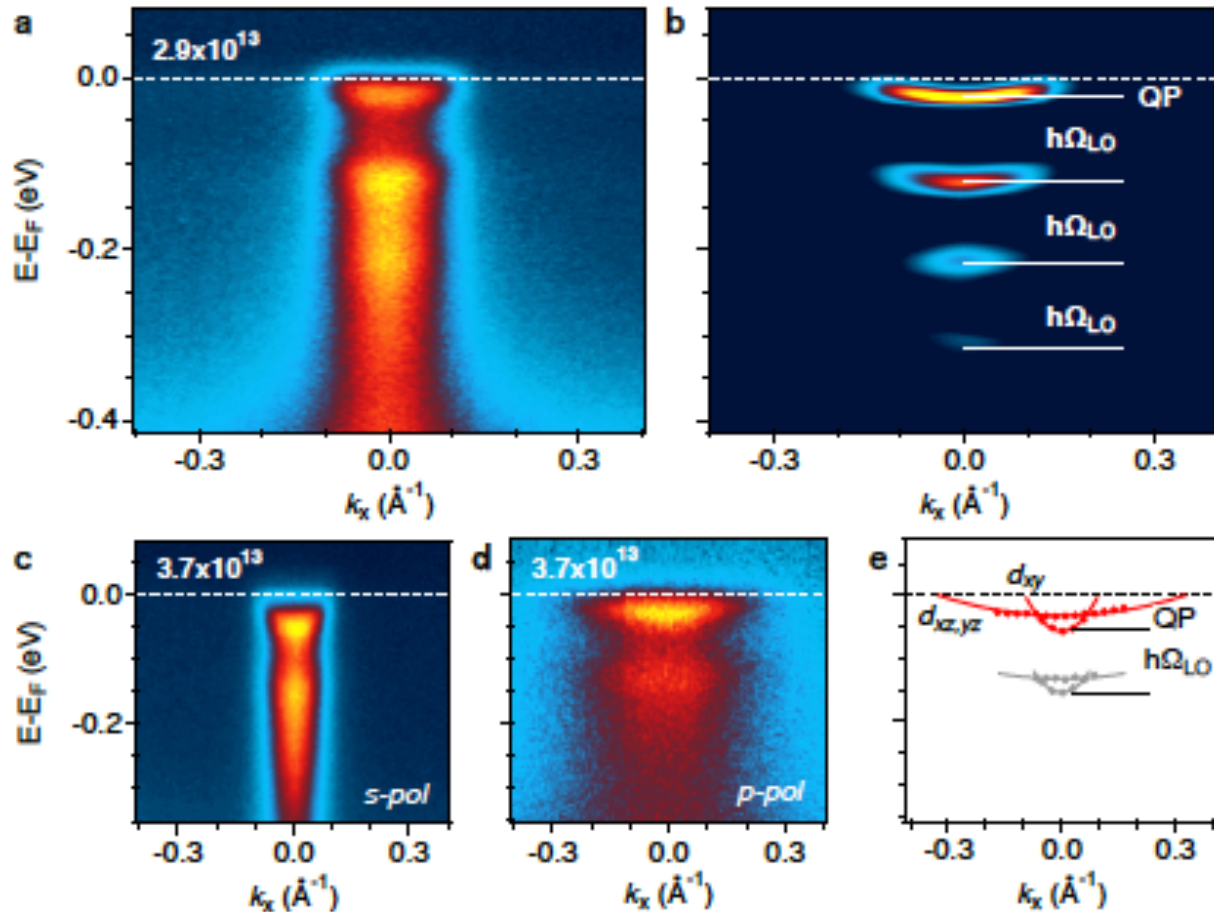


# Interfacial mode coupling as the origin of the enhancement of $T_c$ in FeSe films on SrTiO<sub>3</sub>

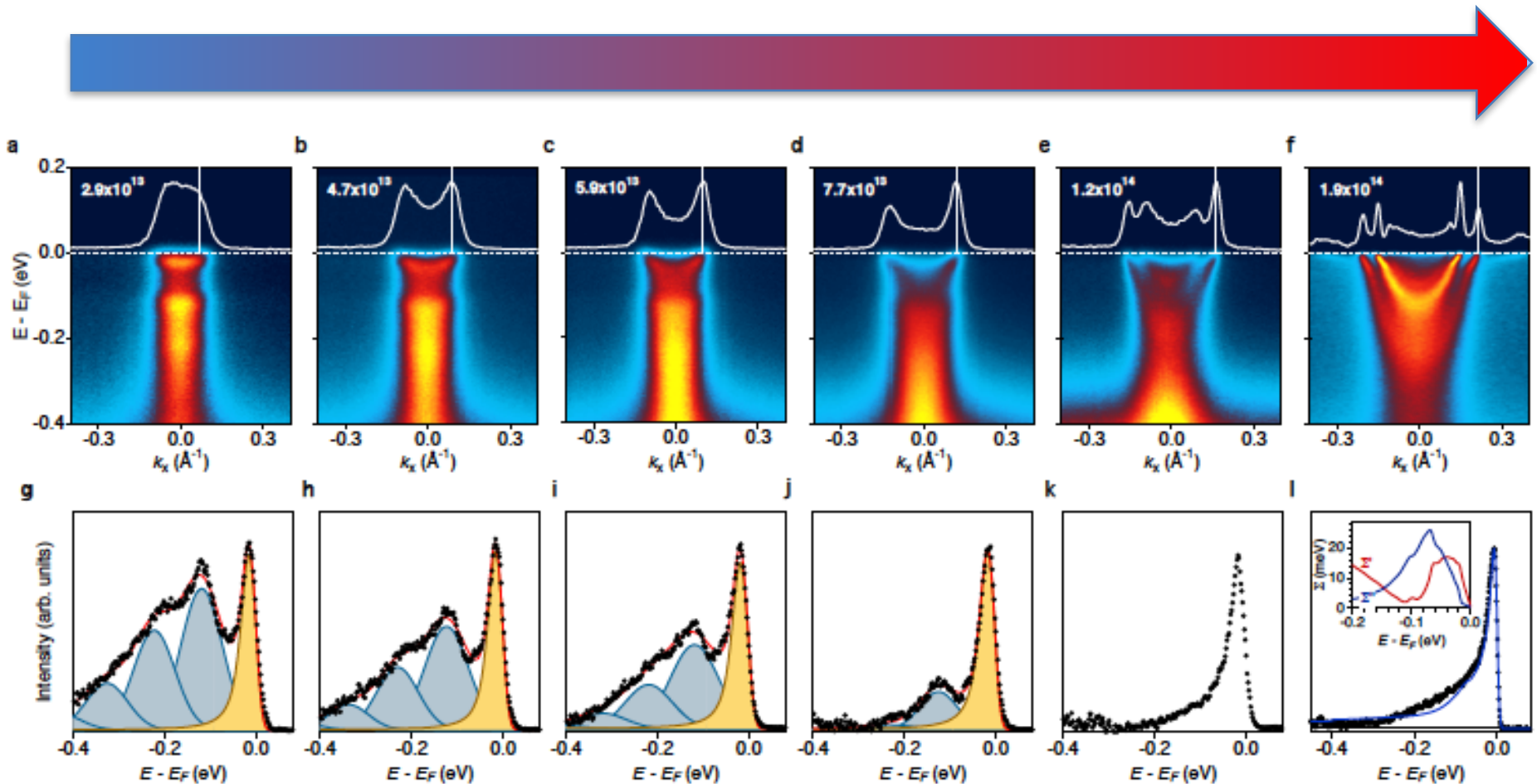
J. J. Lee<sup>1,2\*</sup>, F. T. Schmitt<sup>1\*</sup>, R. G. Moore<sup>1\*</sup>, S. Johnston<sup>3,4,5</sup>, Y.-T. Cui<sup>1</sup>, W. Li<sup>1</sup>, M. Yi<sup>1,2</sup>, Z. K. Liu<sup>1,2</sup>, M. Hashimoto<sup>6</sup>, Y. Zhang<sup>1,7</sup>, D. H. Lu<sup>6</sup>, T. P. Devereaux<sup>1</sup>, D.-H. Lee<sup>8,9</sup> & Z.-X. Shen<sup>1,2</sup>



Electronic structure of STO surface with a “low doping”.

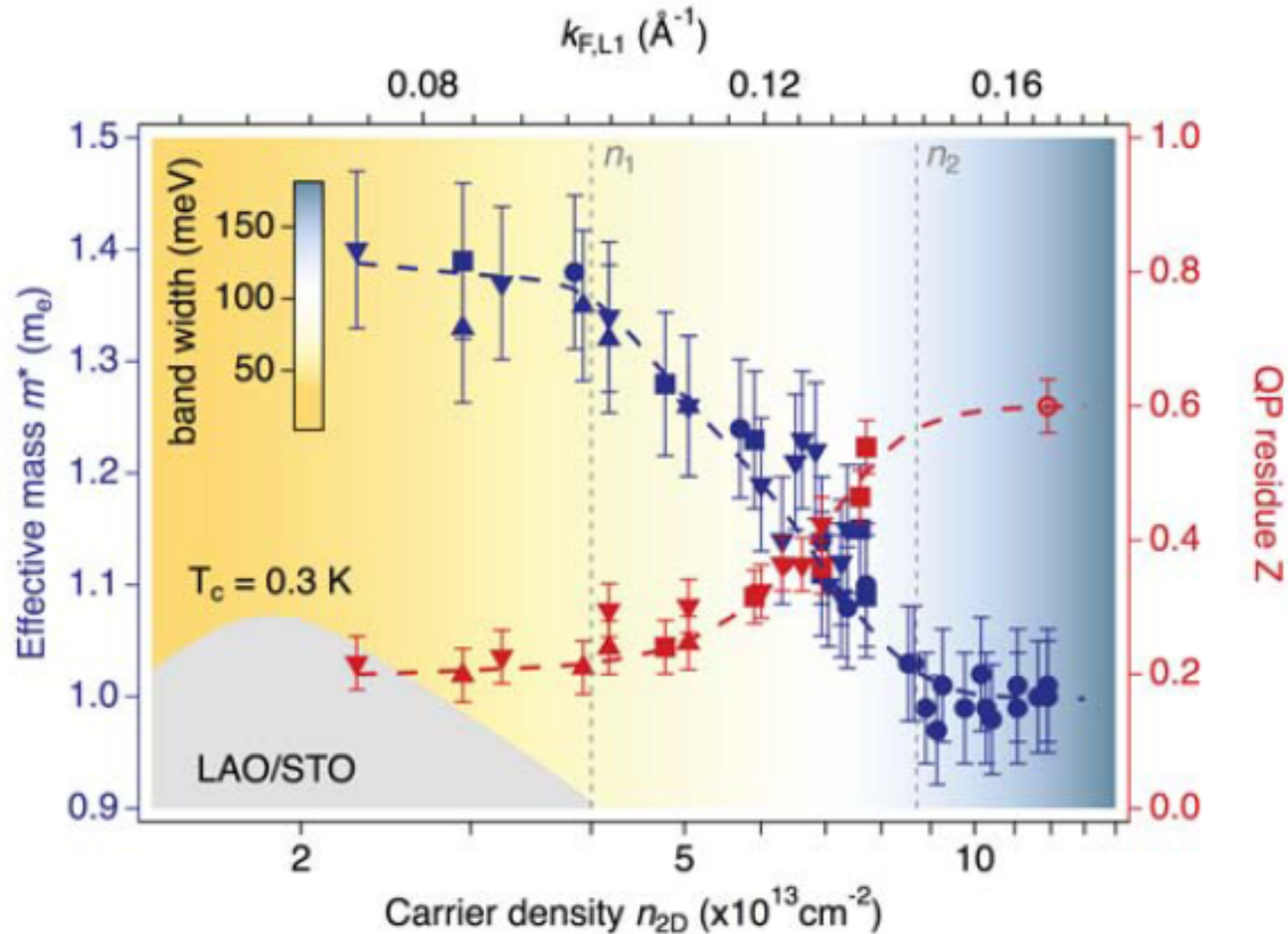


# Polaron at STO surface





# Polaron at STO surface



$m^*$ =effective mass  
 $Z$ - quasiparticle residue

$Z=1-\alpha/2$  (Frohlich model)

$\alpha=2.8$  coupling strength  
 for lower carrier density