IASTU Physics Seminar

Mapping the electronic structure of each ingredient oxide layer of high-T_c cuprate superconductors

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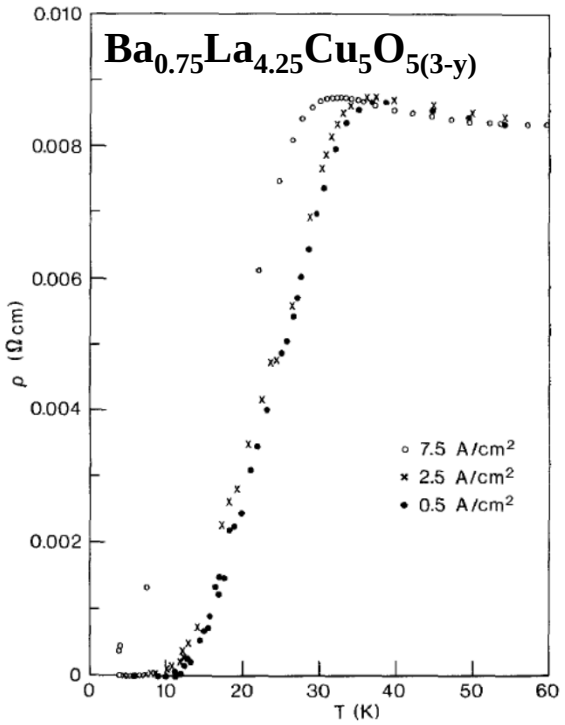
Bi-2212 samples: Ruidan Zhong, John Schneeloch, Gen-Da Gu

Bi-2201 samples: Lin Zhao, Xing-Jiang Zhou…

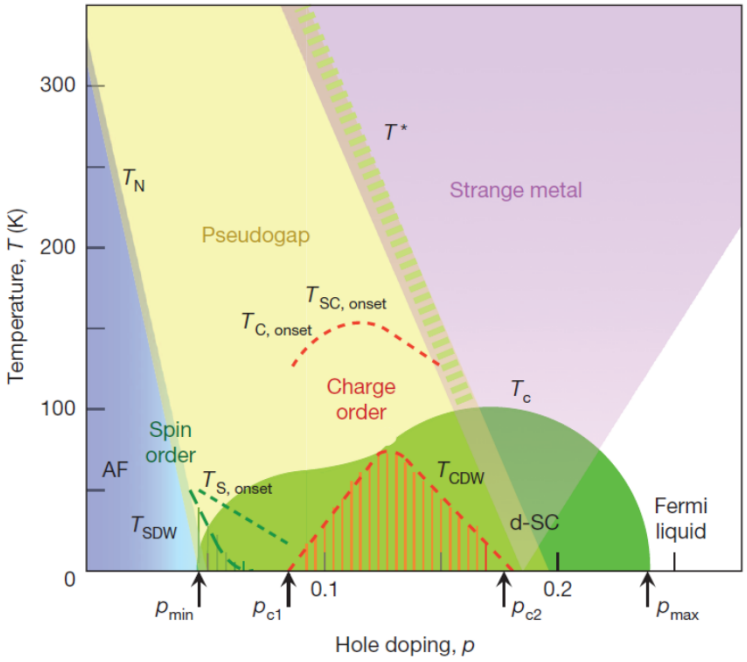
$$$: NSFC & MOST of China

High-T_c Cuprate Superconductors

Bednorz and Müller, Z. Phys. B 64, 189 (1986)



Keimer, Natrue 518, 179 (2015)



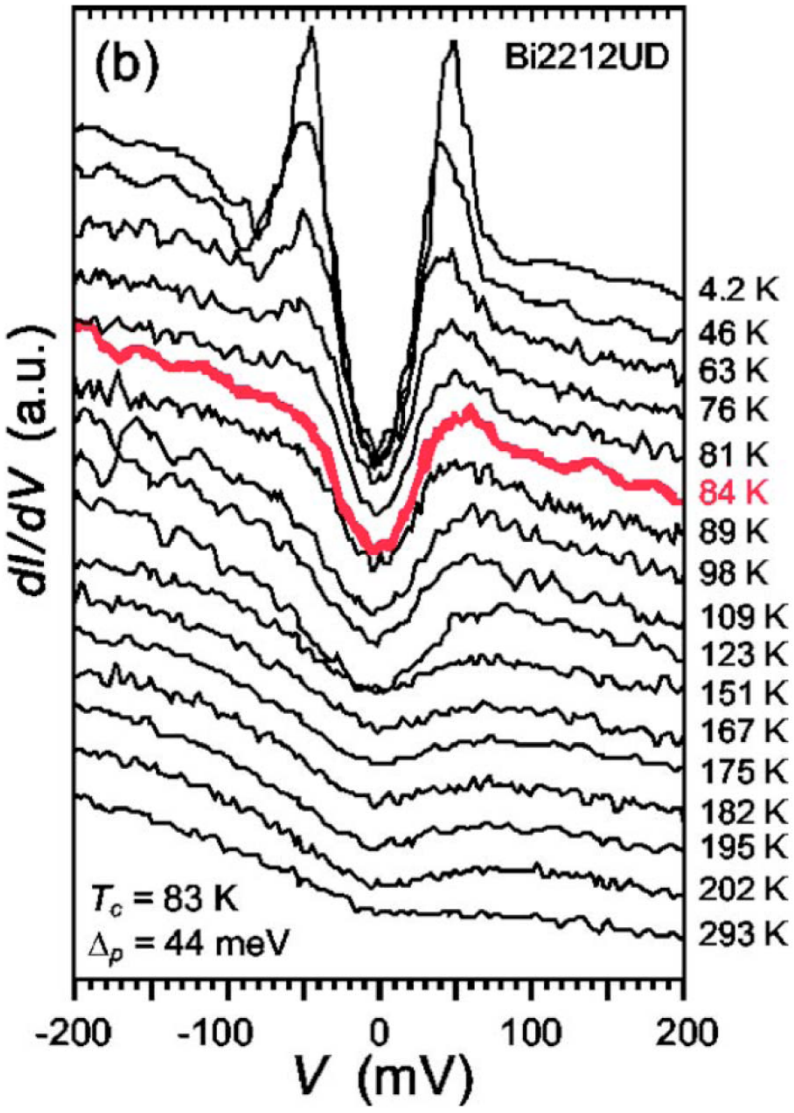
Sophisticated phase diagram

Unsolved issues of high-T_c superconductors:

1) **Electron pairing mechanism: spin fluctuation?**
2) **Various sorts of charge orders and their interplay with superconductivity?**
3) **The nature of non-Fermi liquid behavior (strange metal)?**
4) **Pseudogap and its connection with superconductivity as well as broken-symmetry states?**

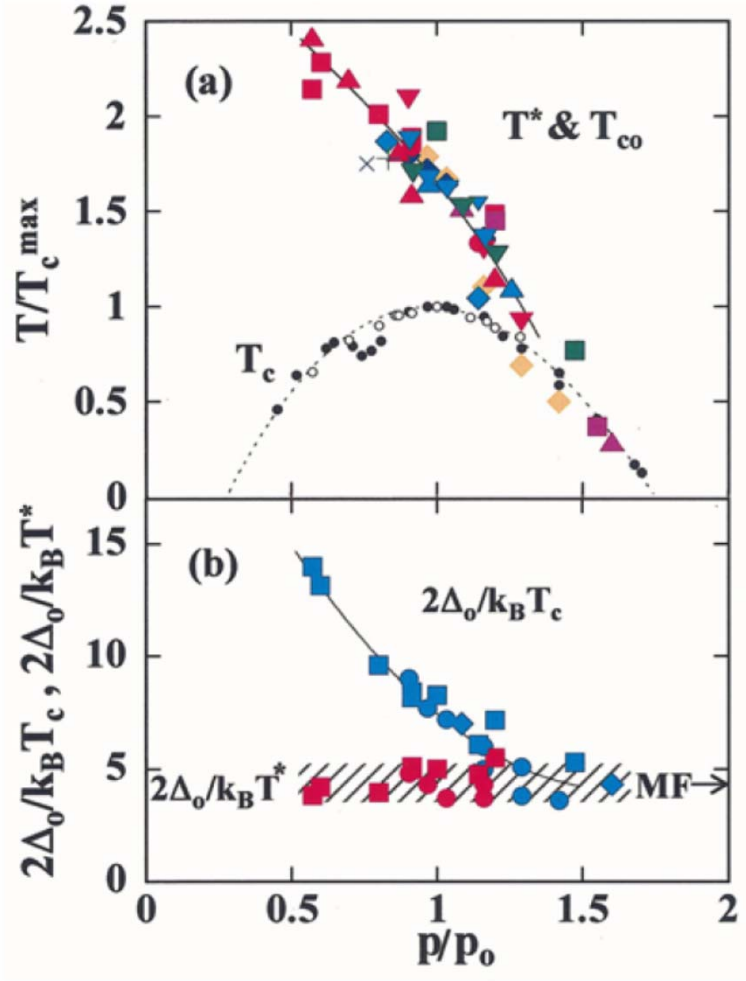
Pseudogap of Cuprates by STM

Renner, PRL 80, 149 (1998)



Spectral depletion at E_F above T_c

Nakano, JPSJ 67, 2622 (1998)



T^* versus p: linear behavior

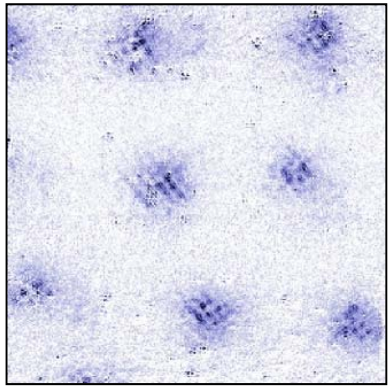
T_c versus p: dome-shaped behavior

Possible Origin for Pseudogap

1) Precursor pairing

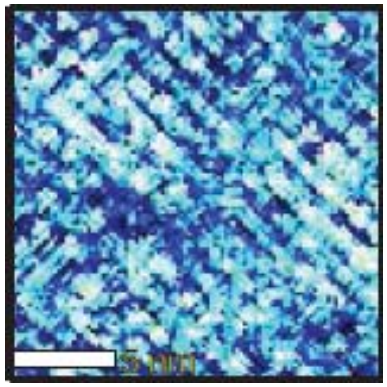
2) A non superconducting related pseudogap, e.g. various broken-symmetry states

Checkerboard



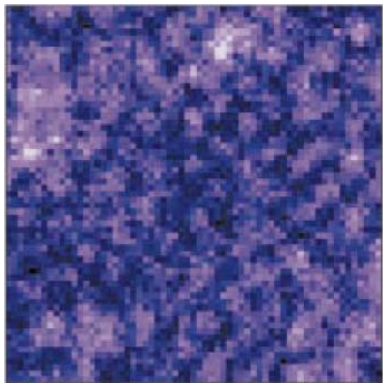
Hoffman, Science 295, 466 (2002)

Fluctuating Stripes



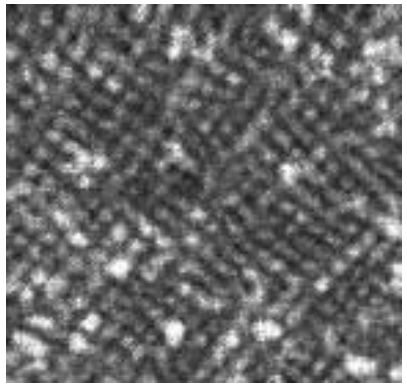
Parker, Nature 468, 677 (2010)

Static Striped DOS



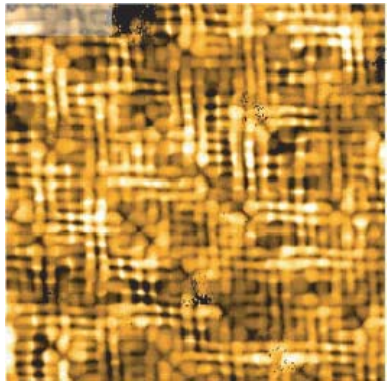
Howald, PRB 67, 014533 (2003)

CDW



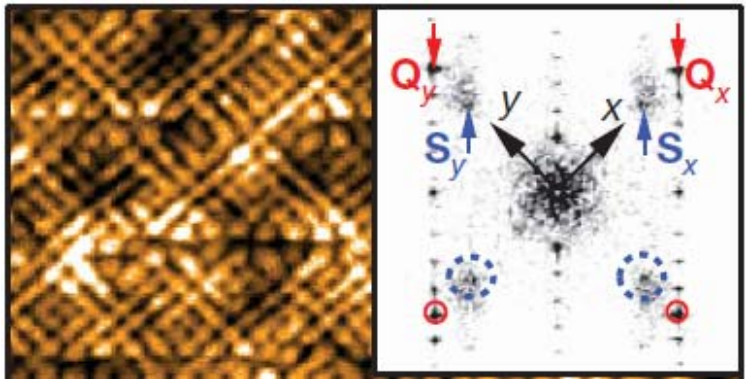
Wise, Nat Phys. 4, 696(2008)

Electronic cluster glass



Kohsaka, Science (2007)

"Nematic" and "Smectic"



Lawler, Nature 466, 7304 (2010)

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Challenges and Opportunity

- **Strongly correlated electron systems**
- **Structural complexity**

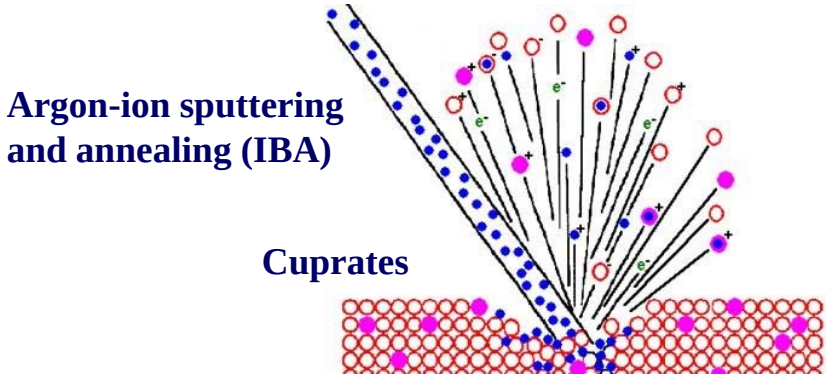
  Superconducting CuO_2 layer, charge reservoir building layer (for example, BiO/SrO in Bi-2212)

- **Unattainable CuO_2 layers**

  Surface-sensitive measurements on the vacuum cleaved BiO planes: the properties of superconducting CuO_2 planes?

Possible path to address the challenges

Atomic-layer-resolved spectral study of cuprates



Up-Down

MBE + LT STM/STS + magnetic field + IBA

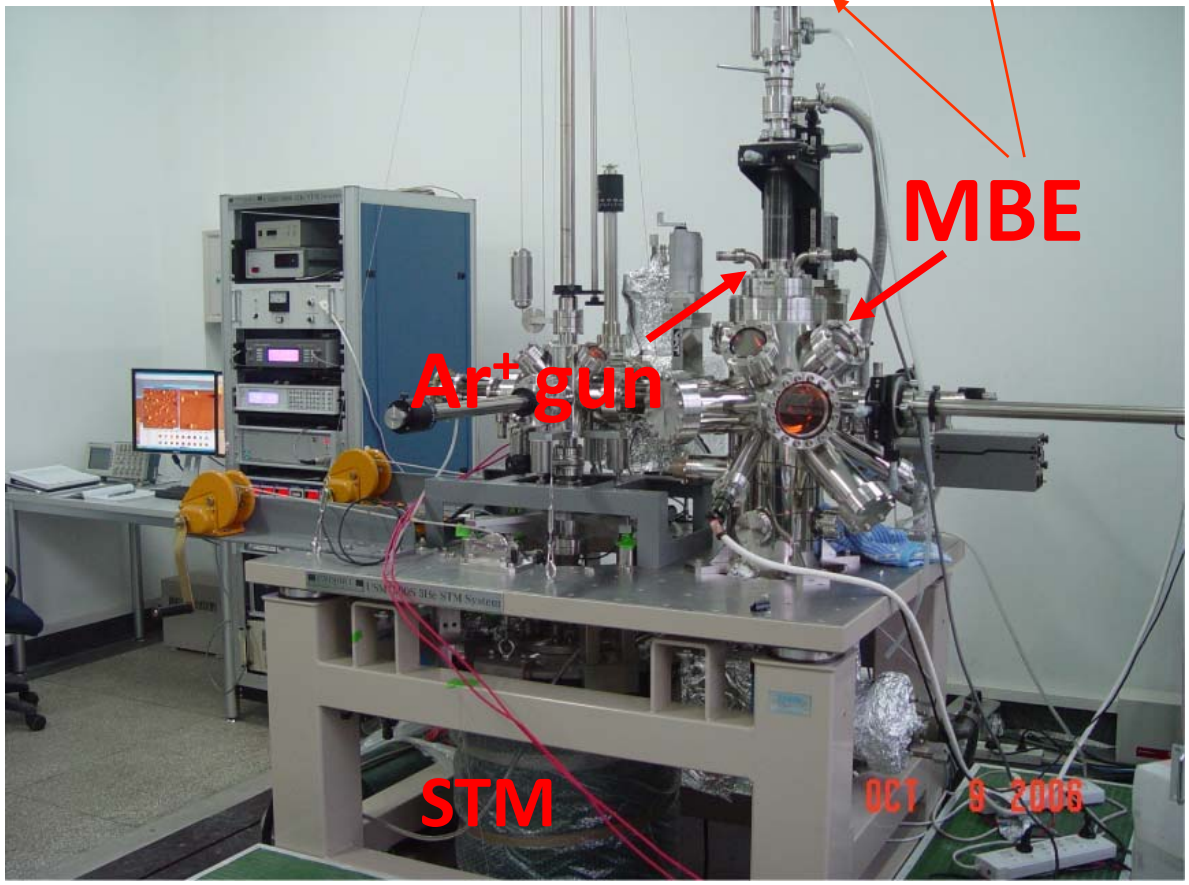
A precise control of growth flux

Metal sources (99.999%) :
evaporated from standard Knudsen cells

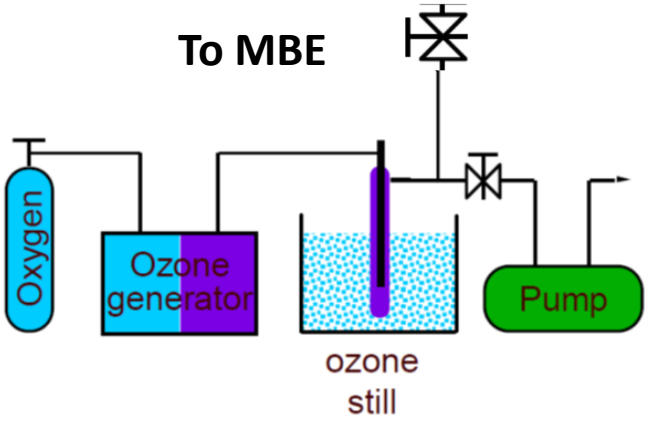
STM/STS: 0.4 K, 4.3 K, 78K

Magnetic field: 11 T

Vacuum: 5×10^{-11} Torr



Ozone-assisted MBE

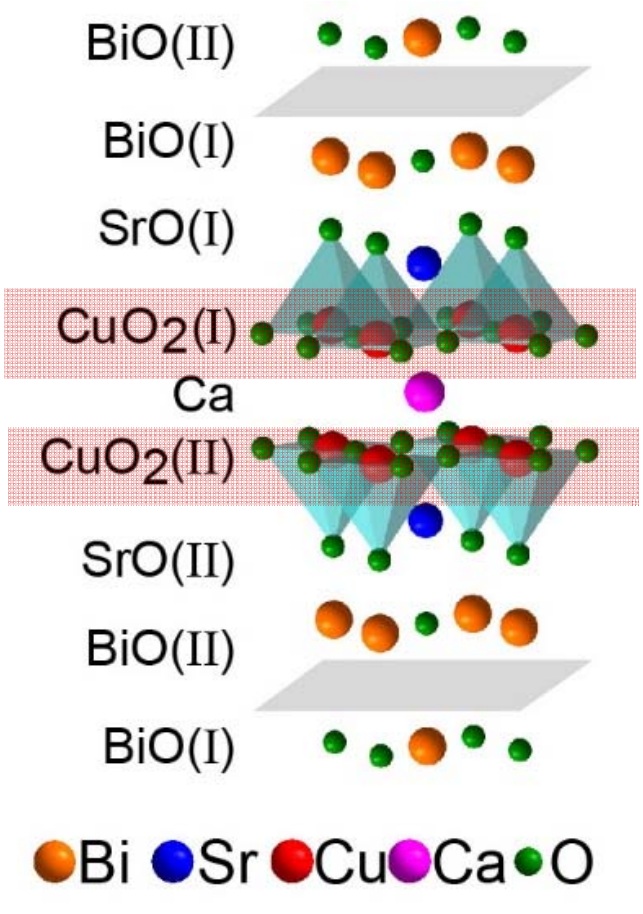


Ozone system

(Fermi Instruments)

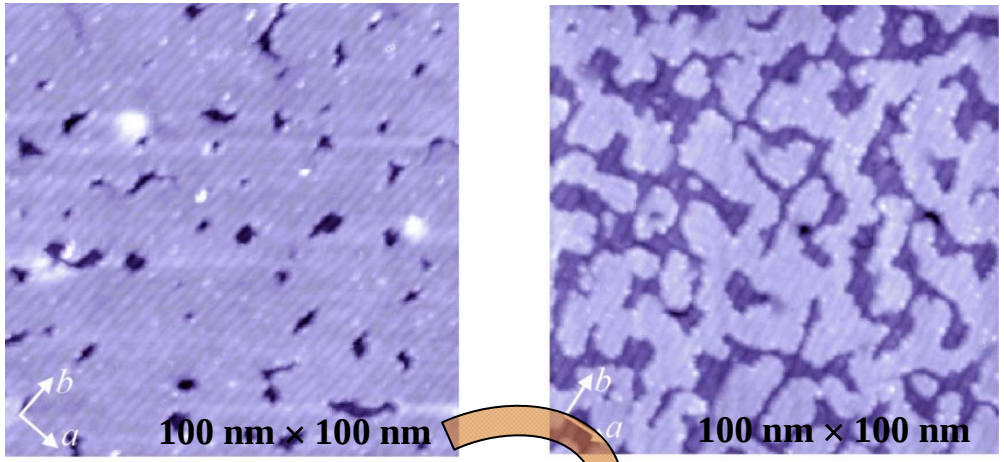
IBA on Bi-2212

Multilayerd structure

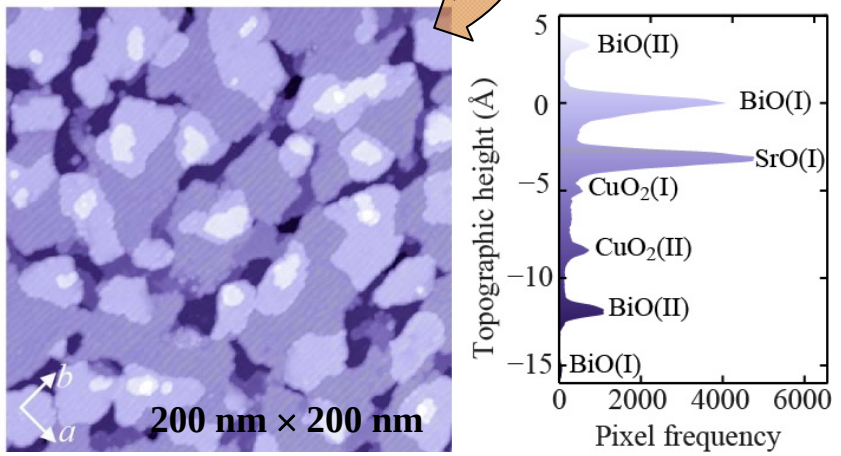


$Bi_2Sr_2CaCu_2O_{8+\delta}$ **(Bi2212)**

IBA

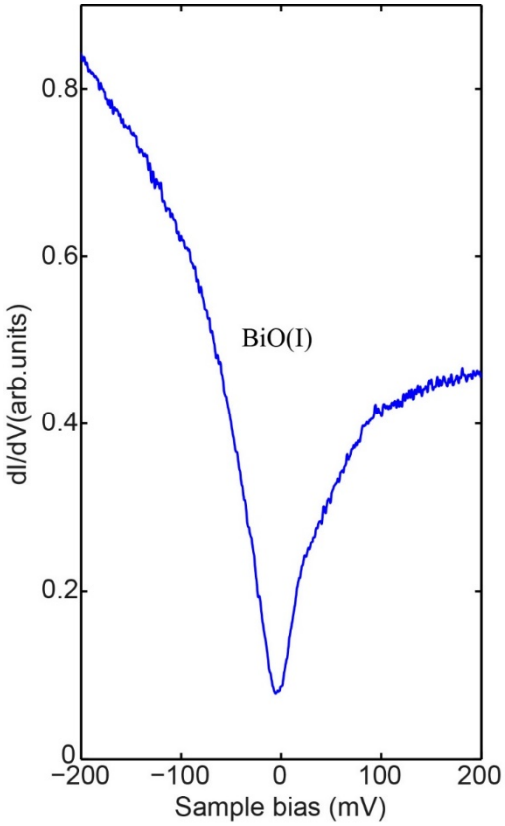


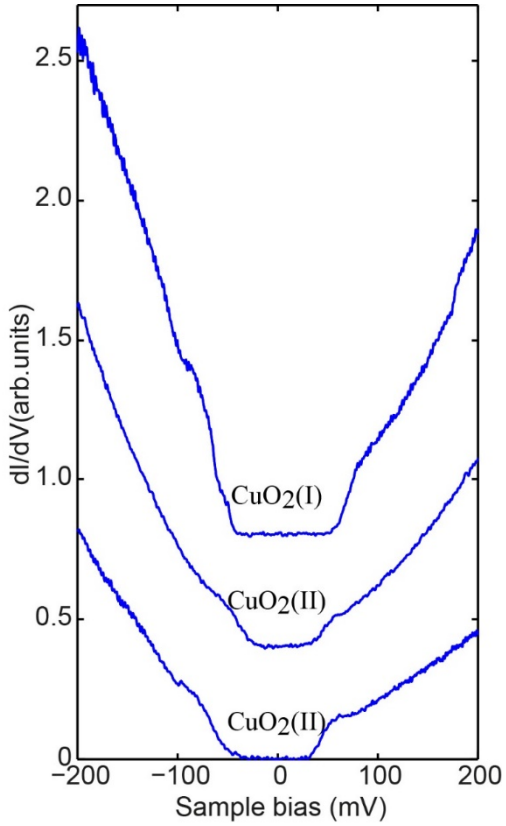
Increasing IBA cycles



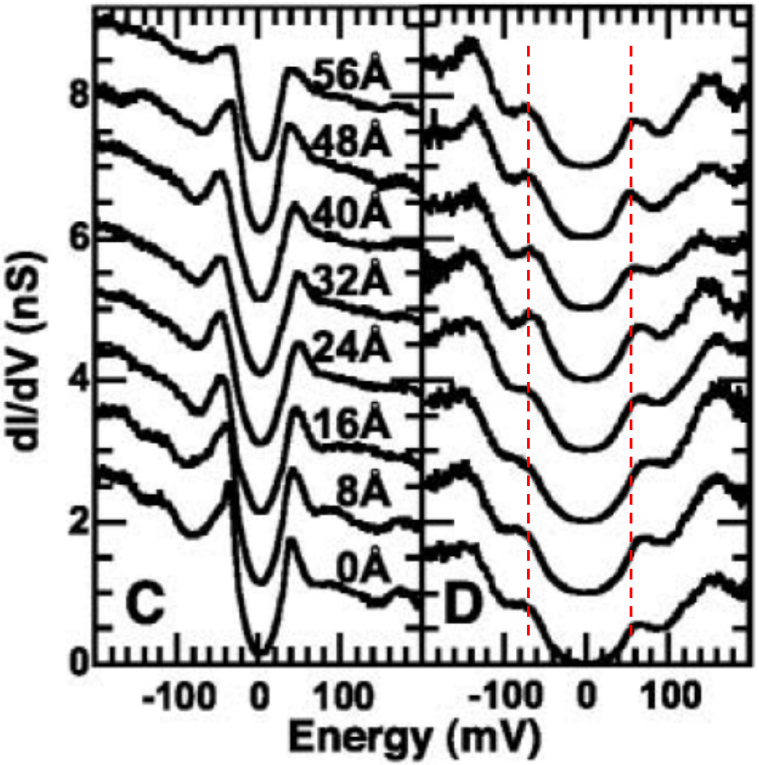
Deeper and deeper atomic layers of Bi-2212 are exposed with increasing IBA.

STS spectra on as-sputtered Bi-2212



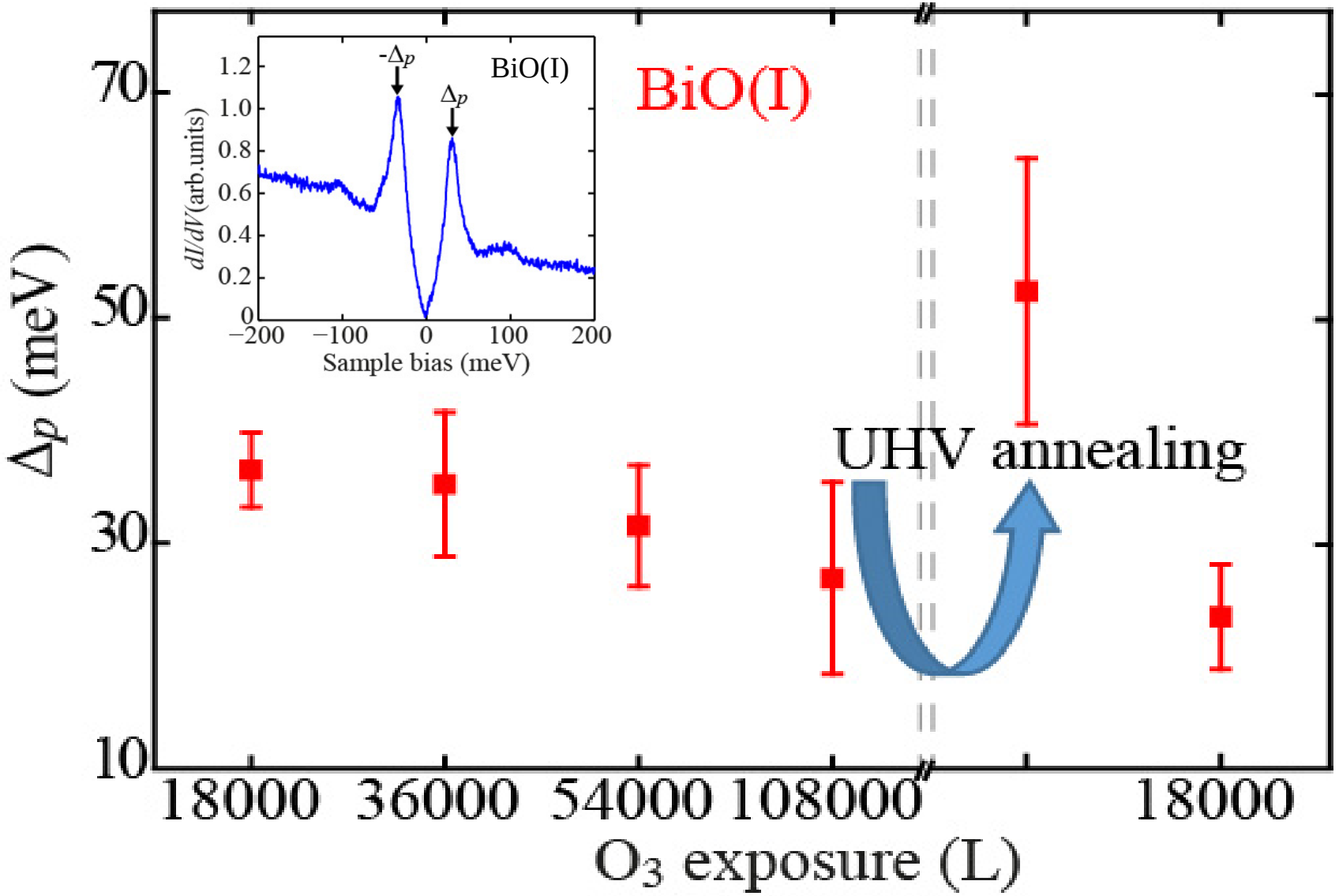


Misra, PRL. 89, 087002 (2002)



- **Contrasting spectral feature between BiO and CuO_2**
- **A substantial loss of near-surface oxygen dopants during IBA**
- **Asymmetric gap of CuO_2 planes, neither superconducting gap nor pseudogap**

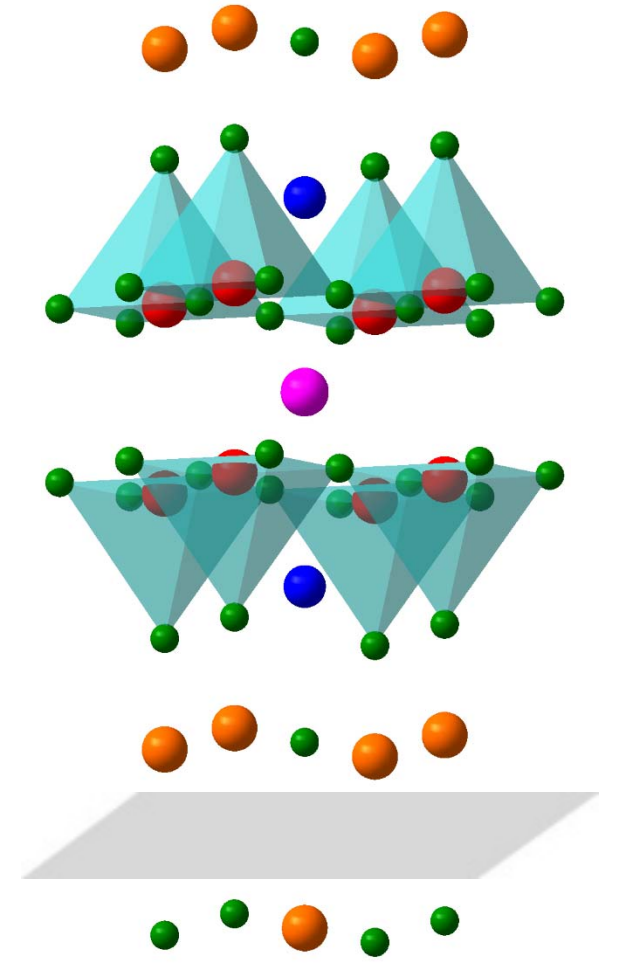
Post-anneal under Ozone Flux

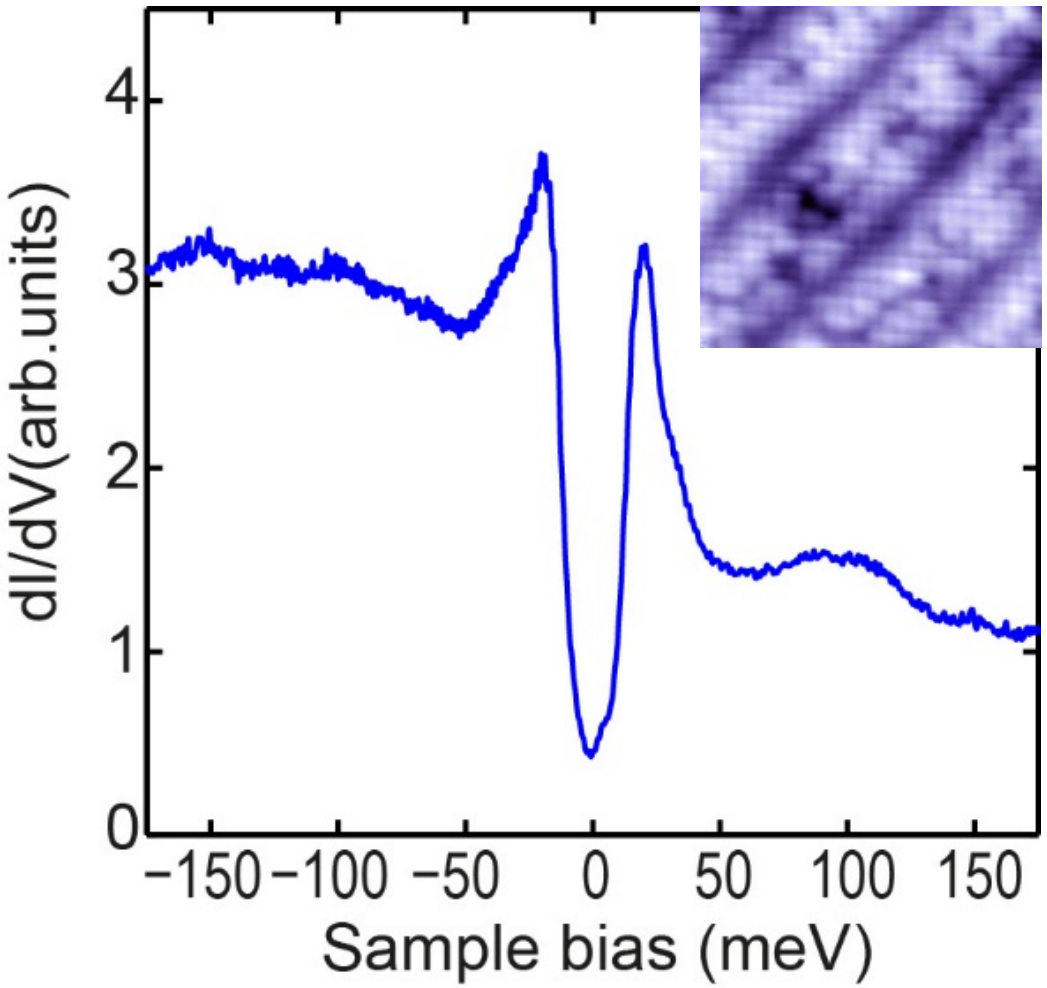


A precise control of oxygen stoichiometry!

Atomic-Layer-Resolved Spectra of Bi-2212

BiO(I)

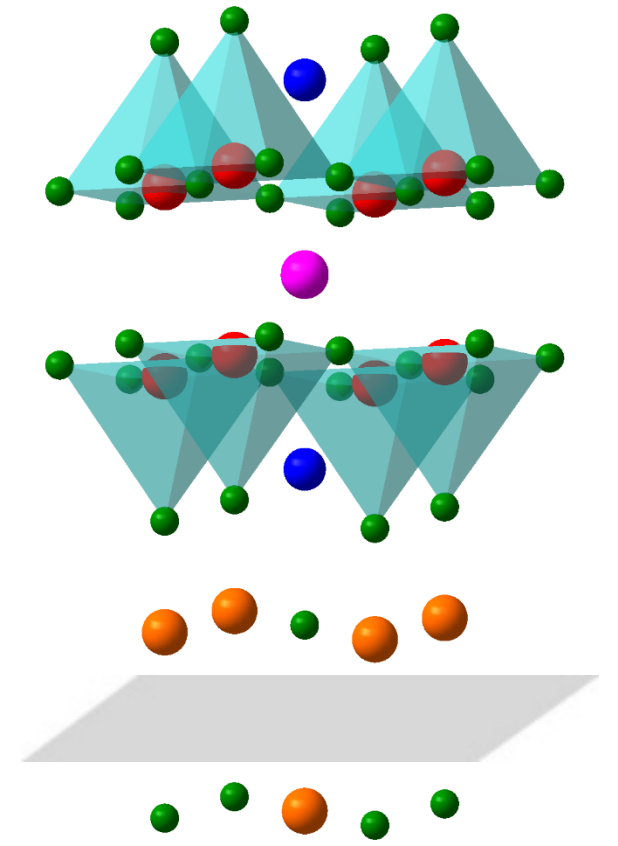


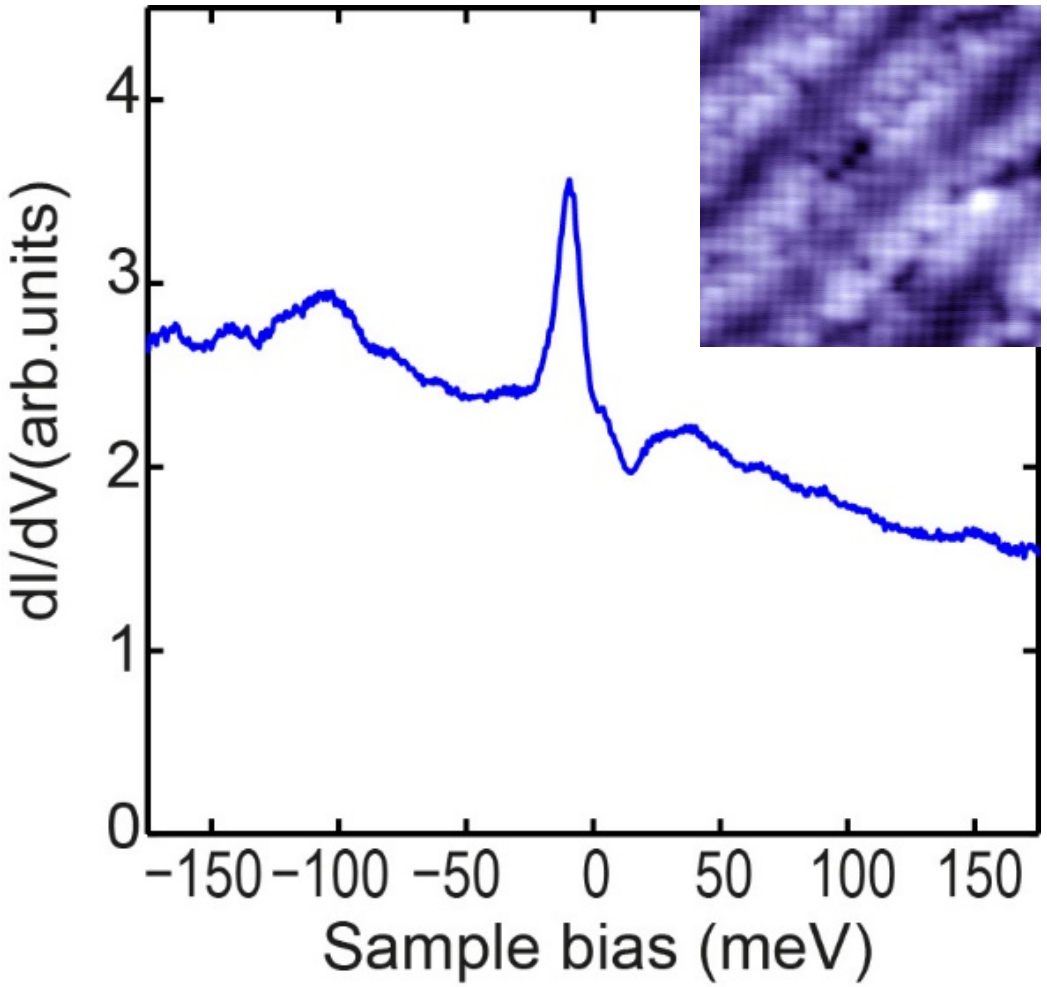


Single dominant pseudogap

Atomic-Layer-Resolved Spectra of Bi-2212

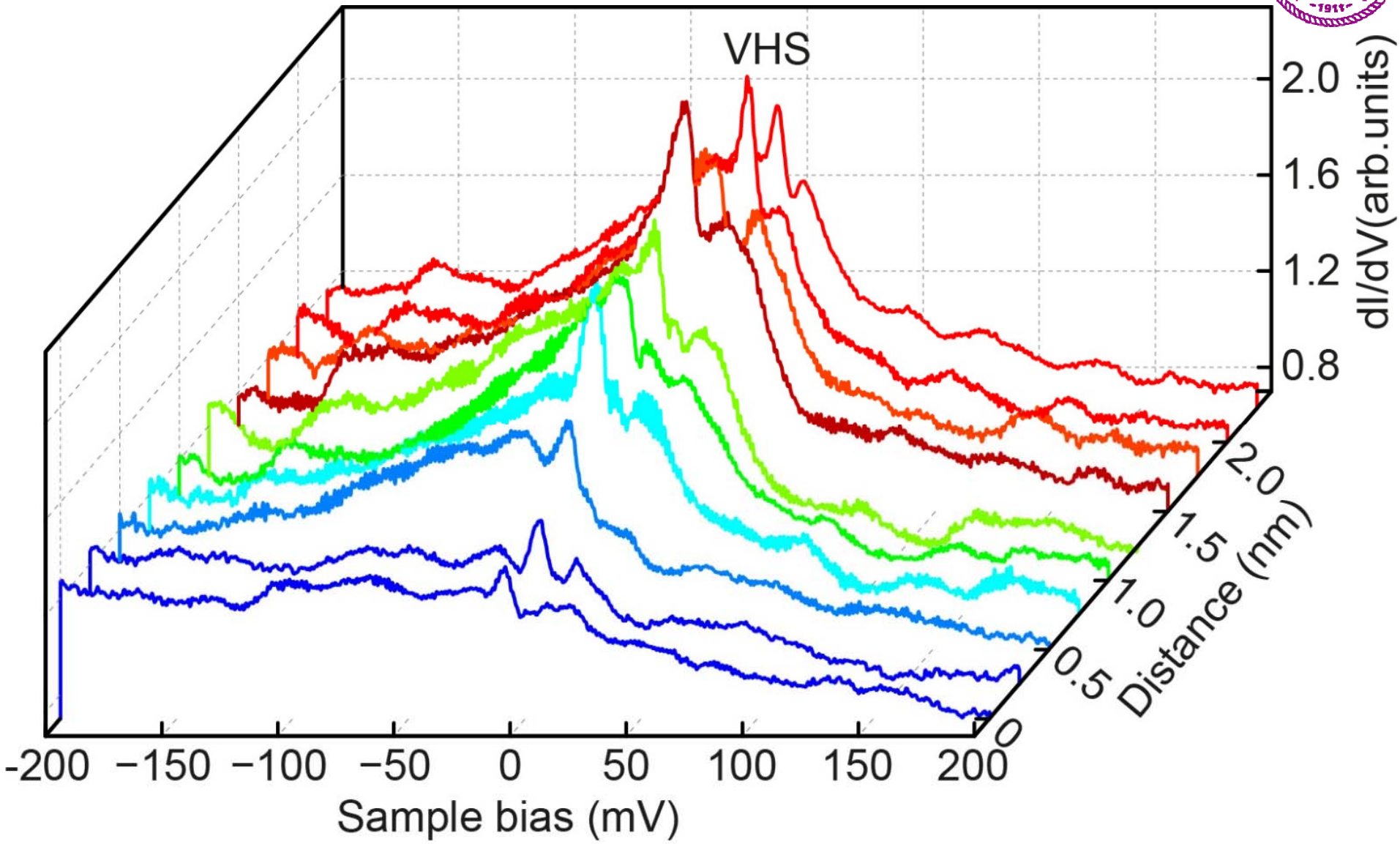
SrO(I)





Van Hove singularity

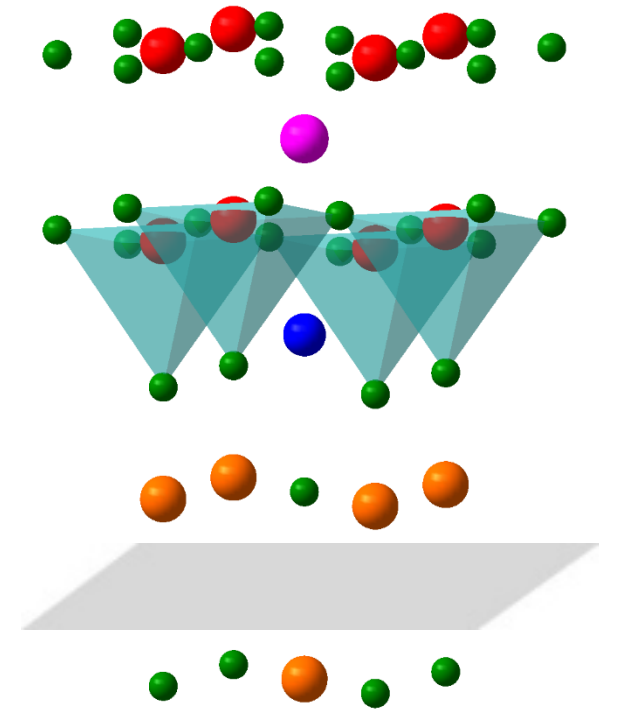
Atomic-Layer-Resolved Spectra of Bi-2212

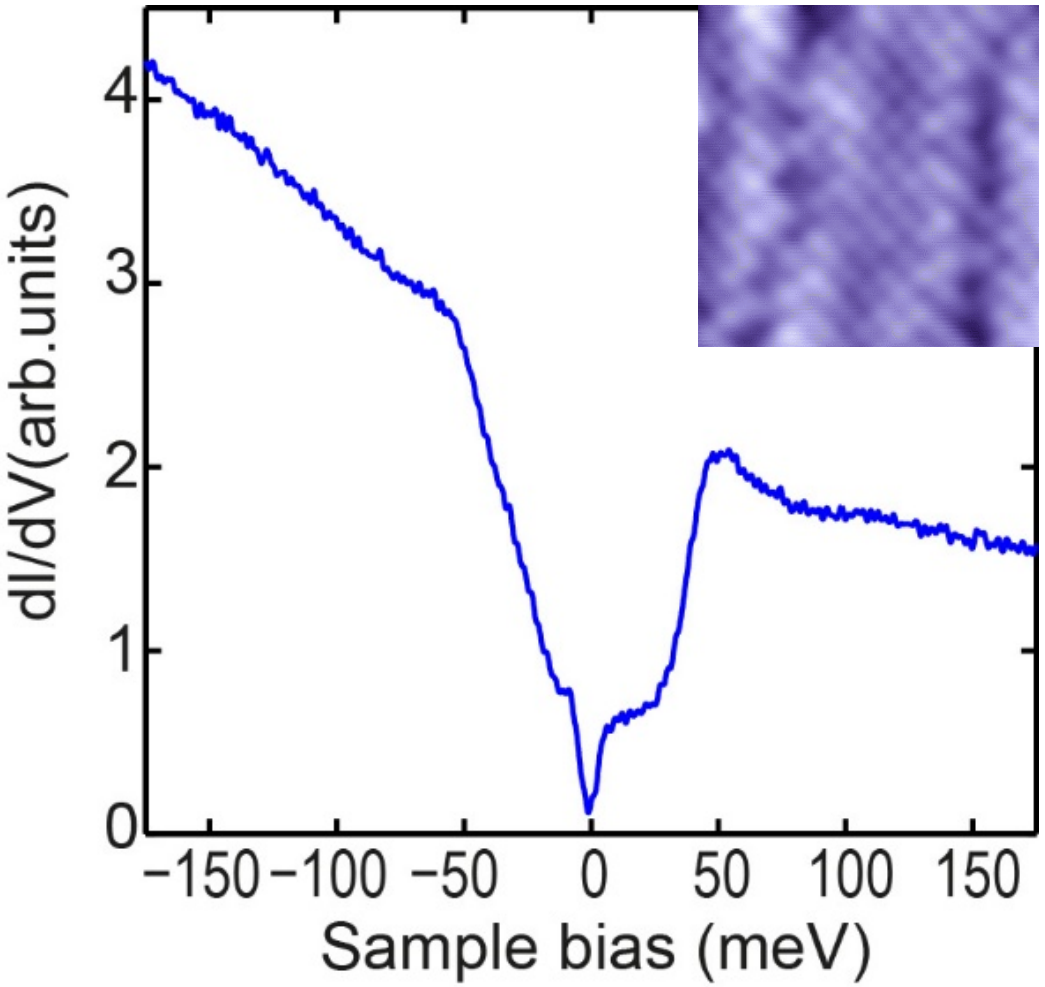


Robust VHS on SrO planes!

Atomic-Layer-Resolved Spectra of Bi-2212

CuO_2(I)

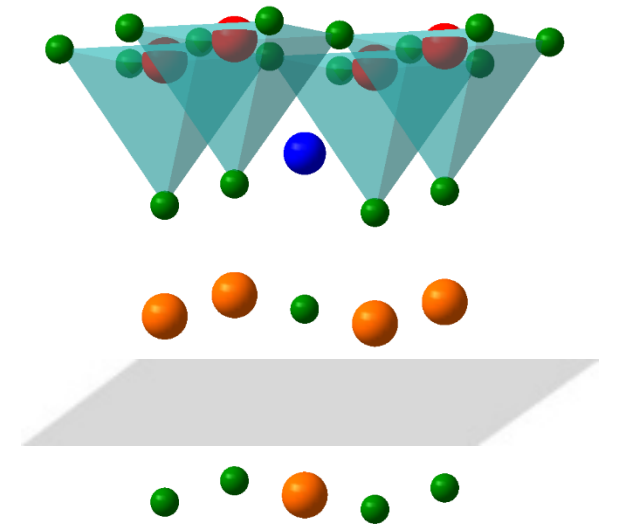


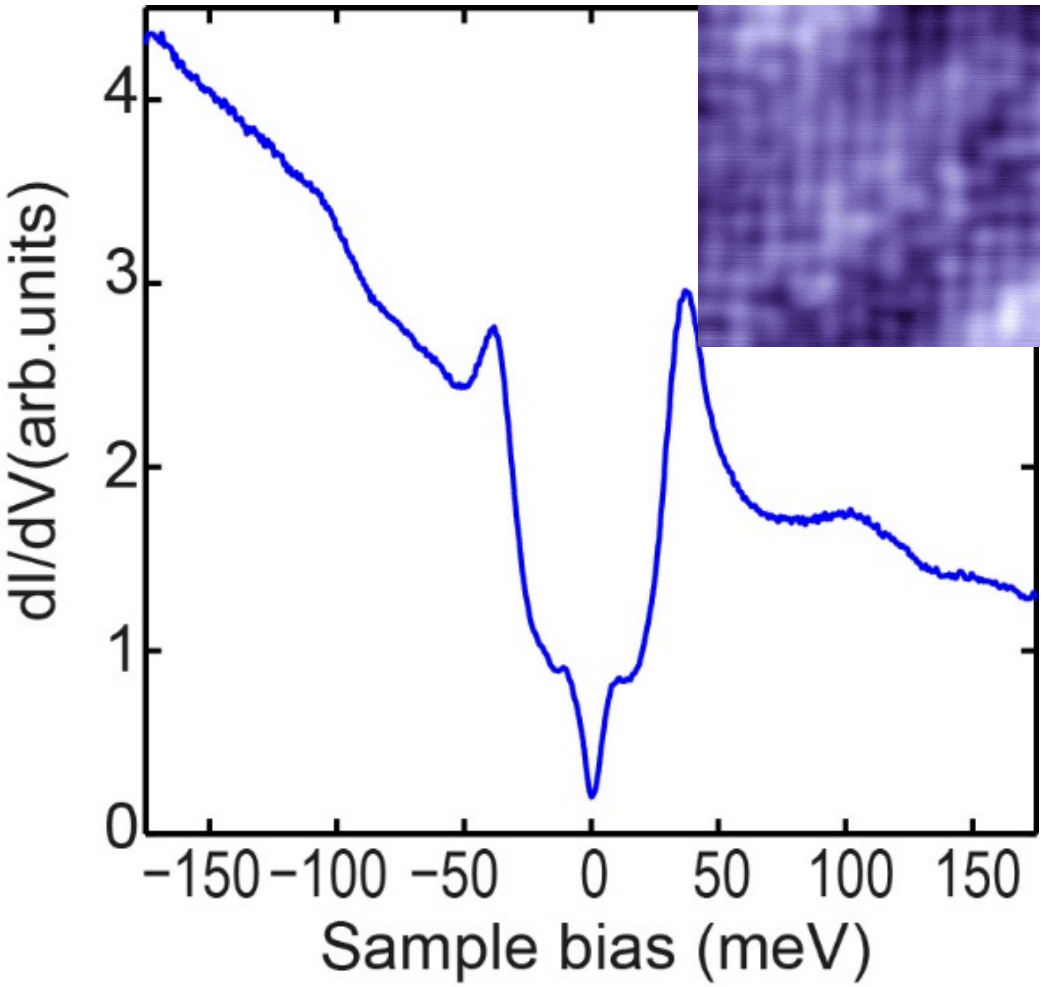


Two-gap spectral feature

Atomic-Layer-Resolved Spectra of Bi-2212

CuO_2(II)

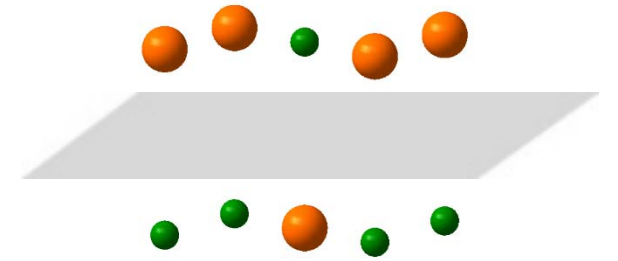


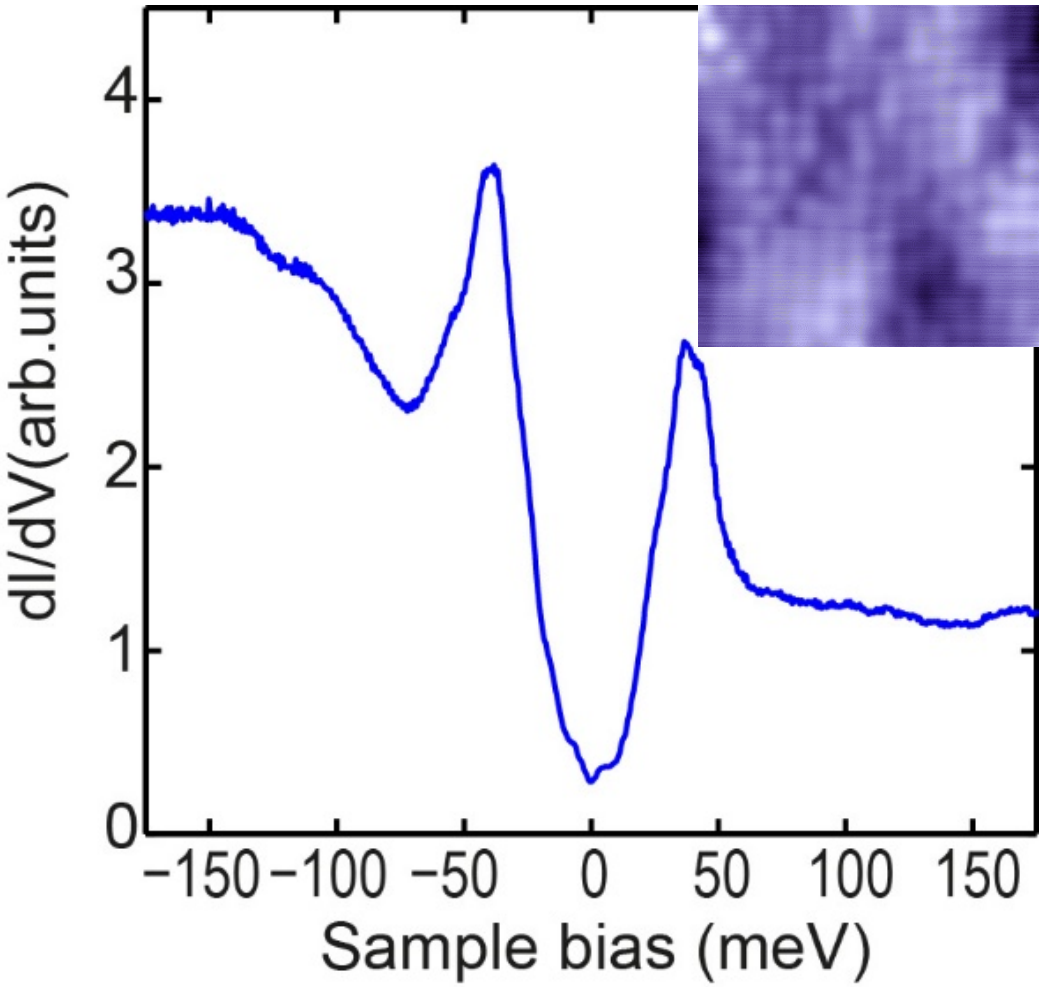


Two-gap spectral feature

Atomic-Layer-Resolved Spectra of Bi-2212

BiO(II)

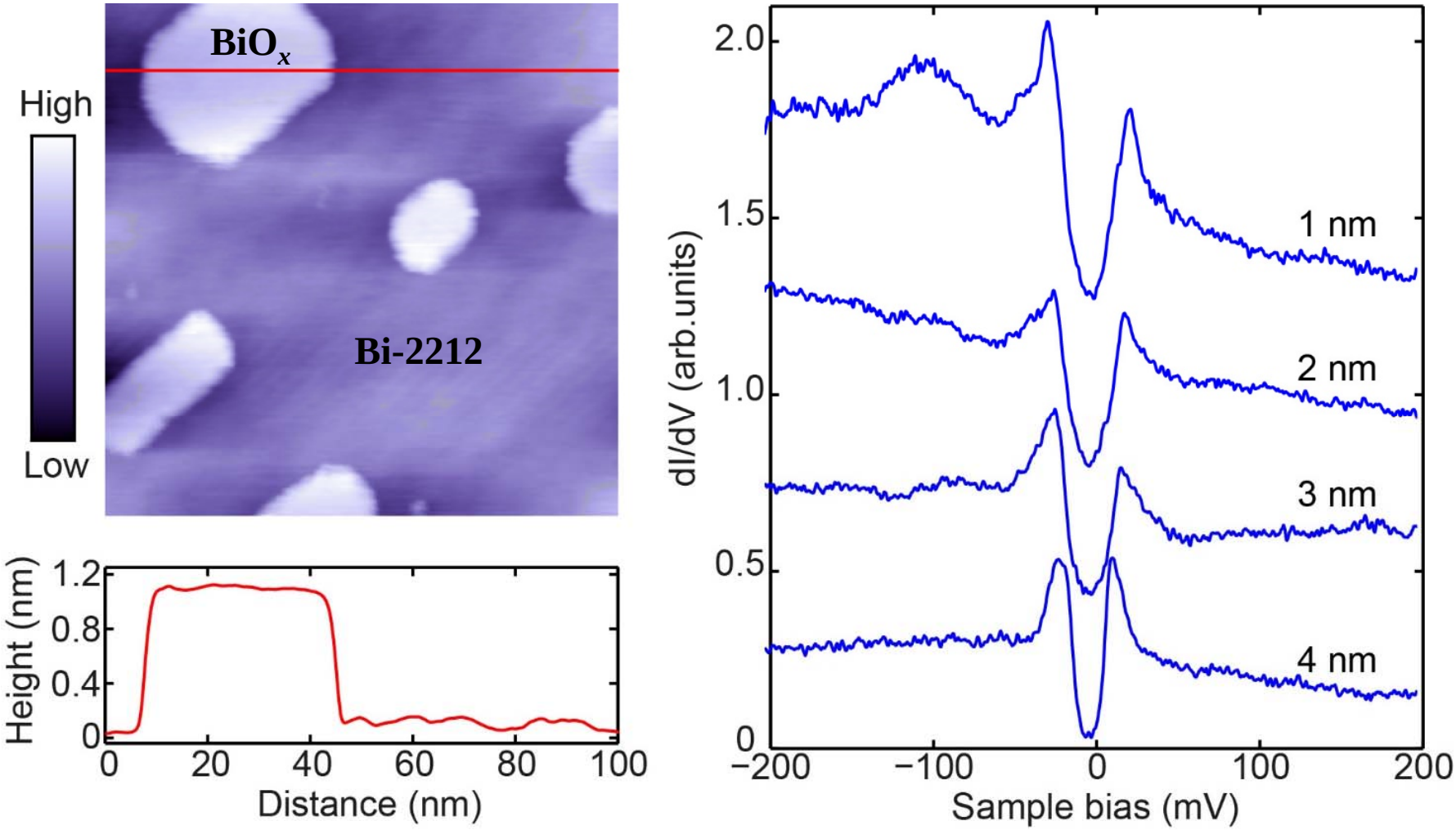




Bi Sr Cu Ca O

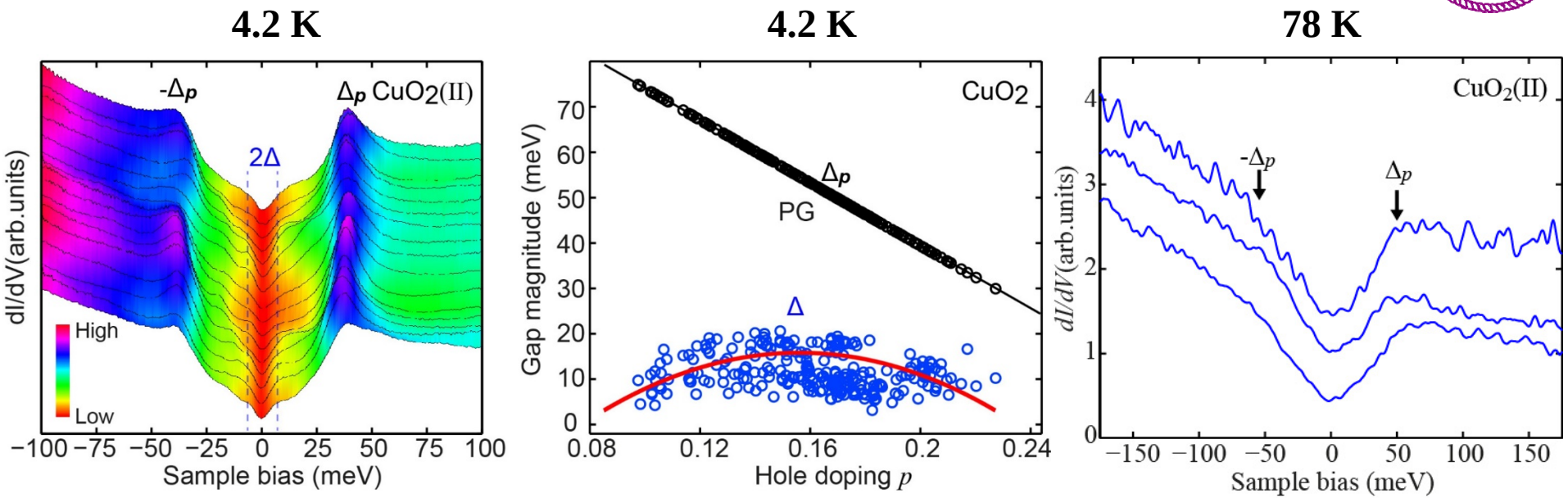
Single dominant pseudogap again

Pseudogap: a property of BiO



Pseudogap on MBE-grown BiO$_x$ islands

Spectra of superconducting CuO_2 layers



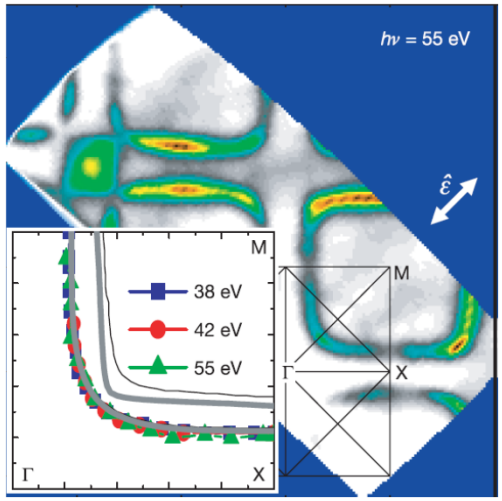
- **Robust two-gap feature on CuO_2**
- **The smaller gap becomes invisible near T_c**
- **Δ follows a dome-shaped behavior, like T_c**
- **$2\Delta/k_BT_c=3.8\pm1.0$**

Preparation and direct measurements of CuO_2 Superconducting layers are so essential!!!

arXiv: 1508.07460

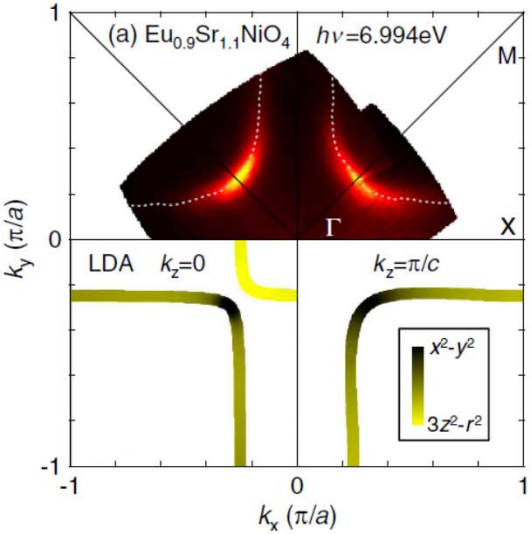
d-wave Pseudogap in Noncuprate Compounds

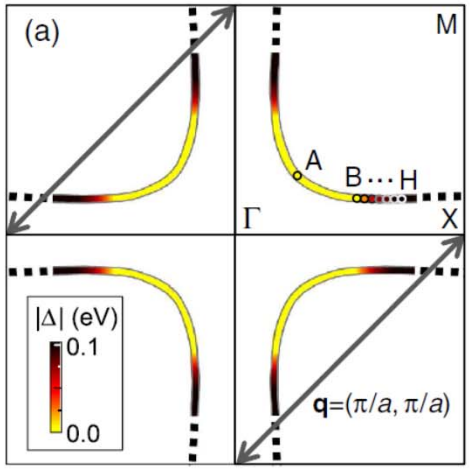
$La_{1.2}Sr_{1.8}Mn_2O_7$ manganites

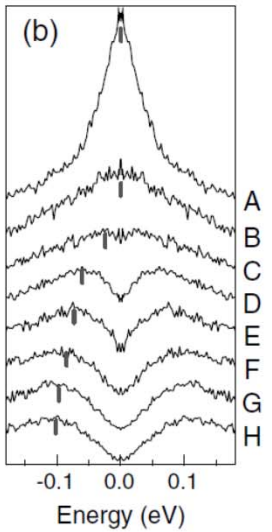


Shen, Nature 438, 474 (2005)

Meatllic nickelate $R_{2-x}SrNiO_4$ (R=Nd, Eu)

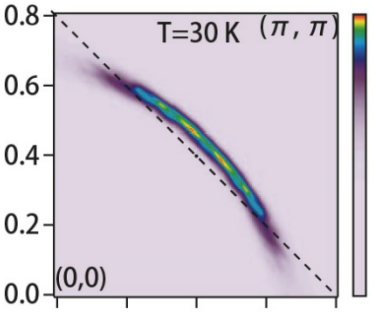


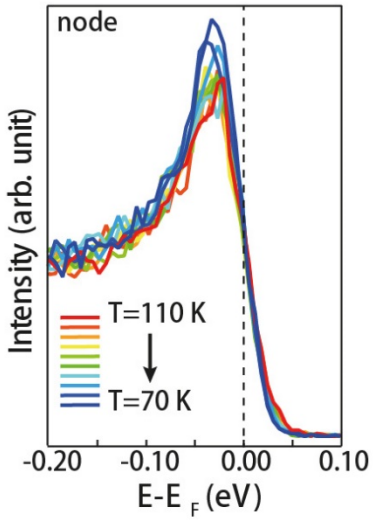


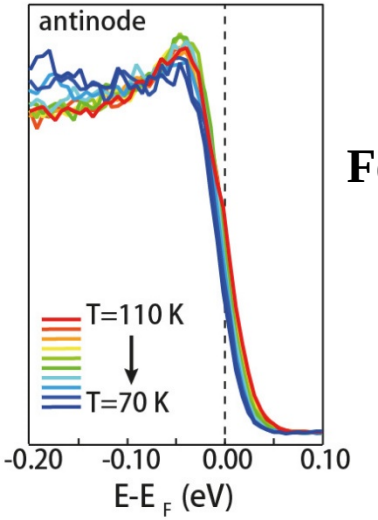


Uchida, PRL 106, 027001 (2011)

Alkali-metal doped Sr_2IrO_4





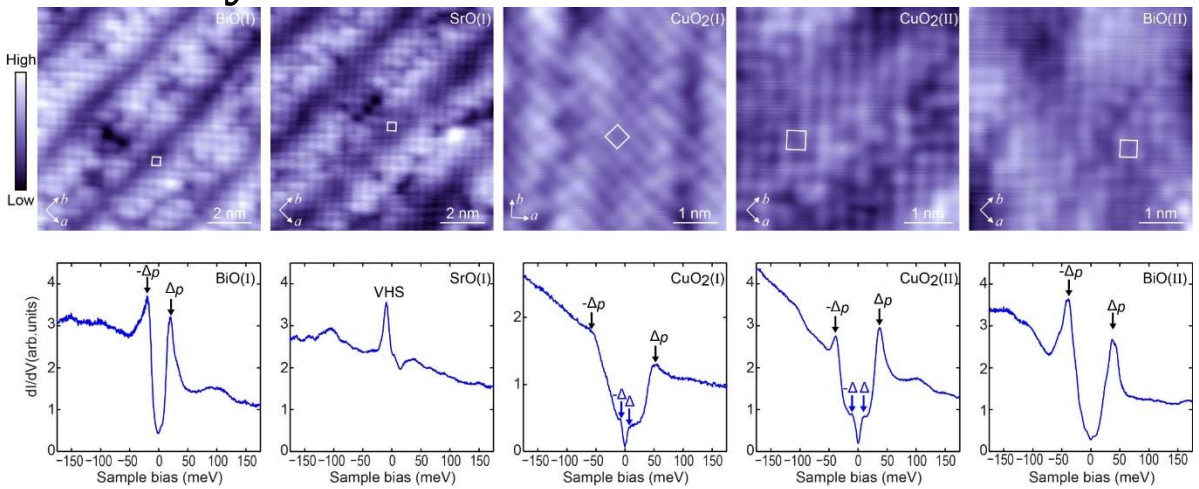


Kim, Science 345, 187 (2014) & Nature Physics (2015)

Fermi arc and *d*-wave gap are not unique to cuprates

Summary and Perspective

- **Atomic-layer-resolved electronic structures of cuprates**



Pseudogap and VHS: possibly a property of oxygen-doped oxides
Real superconducting gap in CuO_2 layer
SrO/BiO: VHS and acts carrier reservoir for CuO_2

- **Bottom-Up (MBE) & Top-Down (IBA) strategies**

Thank You Very Much!