Methods of electronic structure mapping in real space

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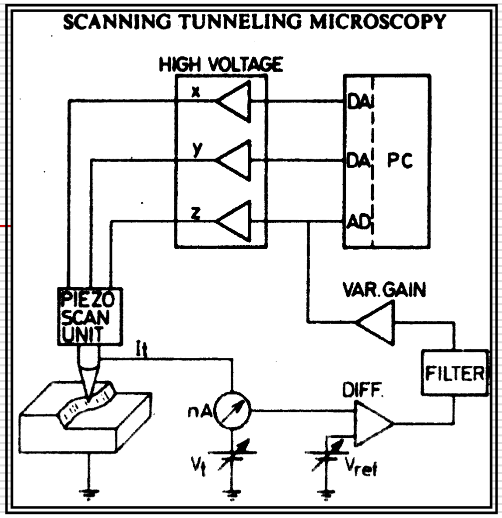
Background: STM



History

1971 Topografiner: Russel D. Young

1981 STM: G. Binnig & H. Rohrer => Nobel Prize 1986

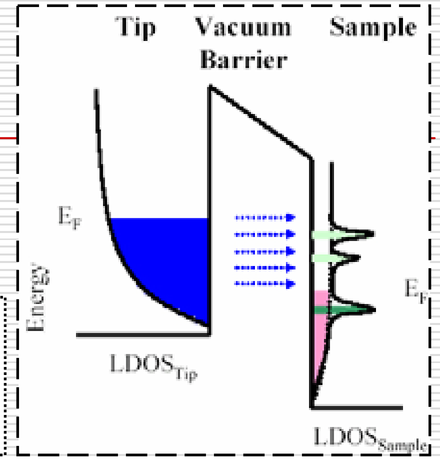
Properties of STM

- Small tunnel junction area, provides atomic resolution ..nanotechnology
- Primary measured quantity is total flux of electrons
- The tip height is regulated or *not* (topography or *current*)

Applications in surface science

- Crystal surfaces: semiconductor, metal, etc.
- Adsorption of anorganic and organic materials
- Study of diffusion
- Nanomanipulation
- Local spectroscopies (LDOS, spin-resolved, workfunction, molecule vibrations, electroluminiscence)

Electron spectroscopy

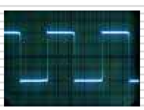


Basic expression:

$$dI/dV \propto \rho_{sample}(\vec{r}, E_F - eV)\, D(E_F - eV)$$

=> I-V or dI/dV measurement is crucial for LDOS mapping

Two elementary techniques:


digital dI/dV: an I-V curve taken in every "pixel" of scanning, derivative calculated


phase-sensitive **lock-in**: dI/dV retrieved directly without interrupting the scanning process

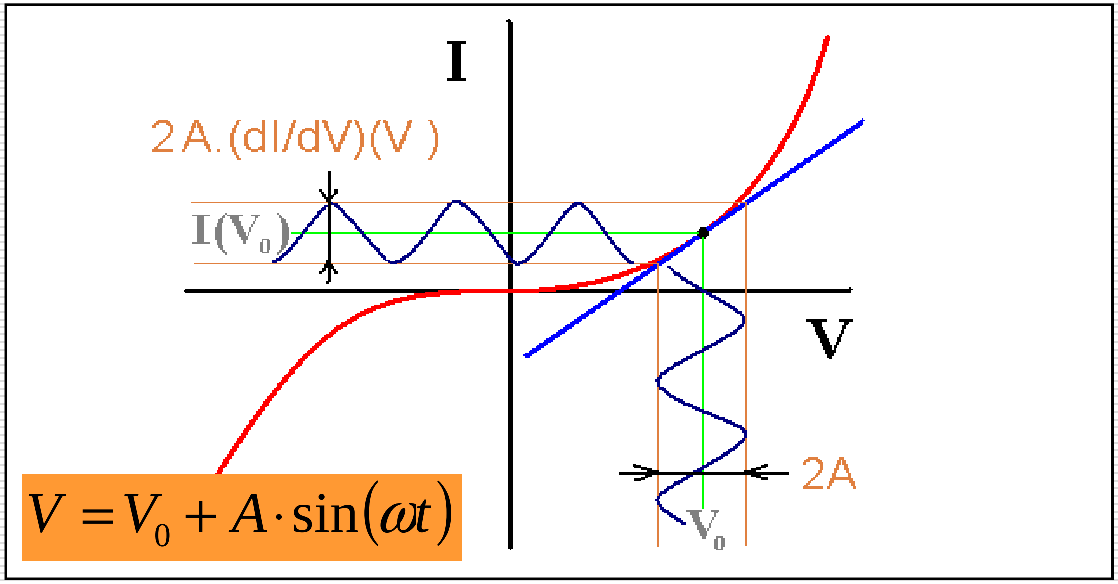
Note: In an ideal case, STS is comparable with photoemission valence band & inverse photoemission spectra

Lock-in technique

Response of the tunneling junction

response:

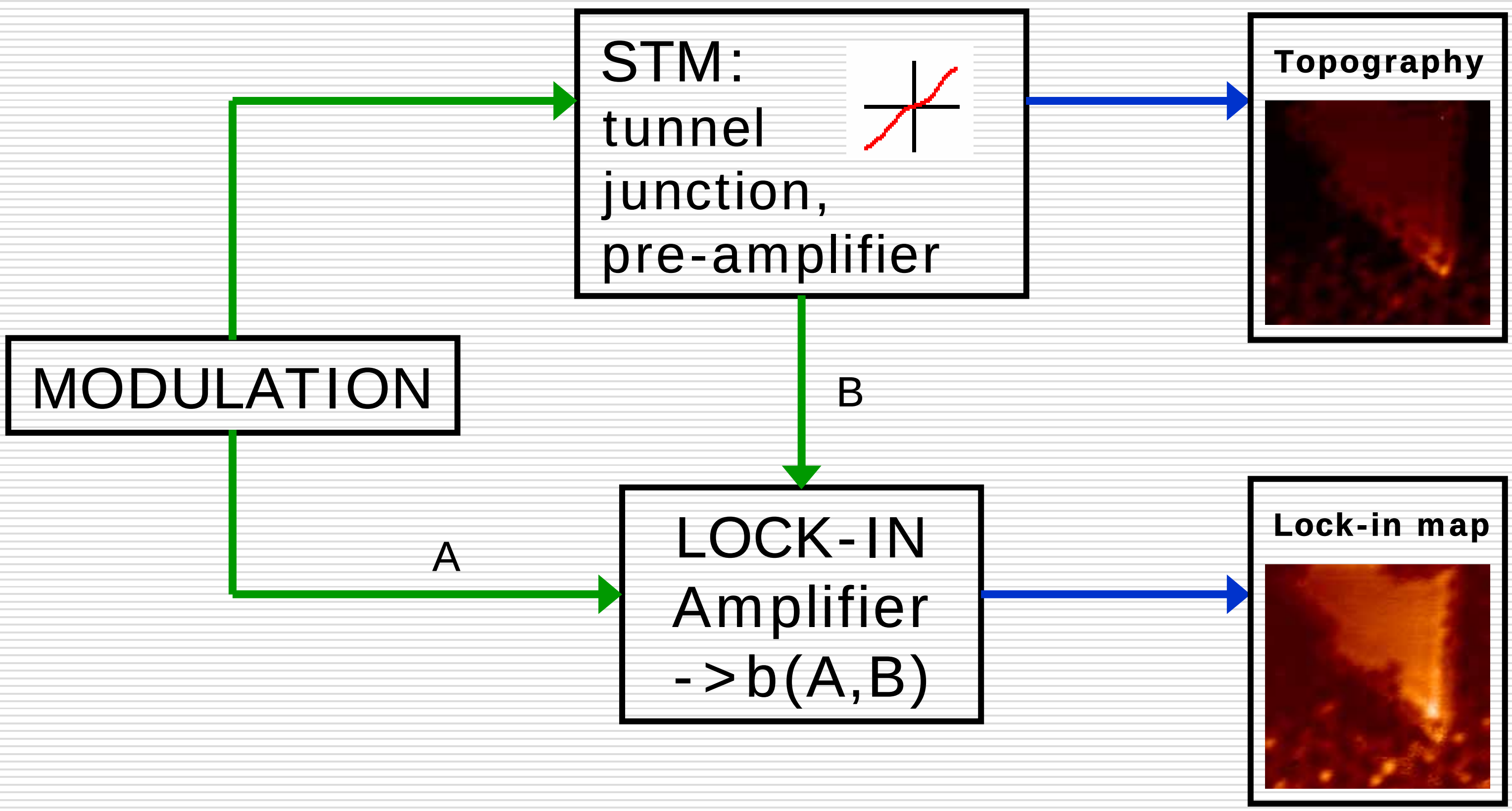
modulation:



Taylor series of the response:

$$I(V) = I(V_0) + \left.\frac{dI}{dV}\right|_{V_0} \cdot A \cdot \sin(\omega t) + \left.\frac{d^2 I}{dV^2}\right|_{V_0} \cdot A^2 \cdot \frac{\cos(2\omega t)}{4} + \ldots$$

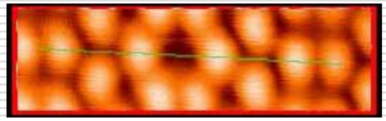
Block diagram



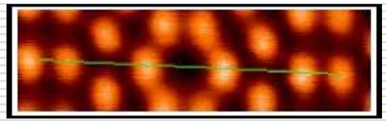
Examples: Si(111)-7x7

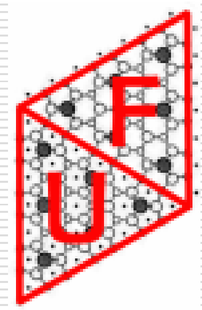
Integral images

Topography



Current map

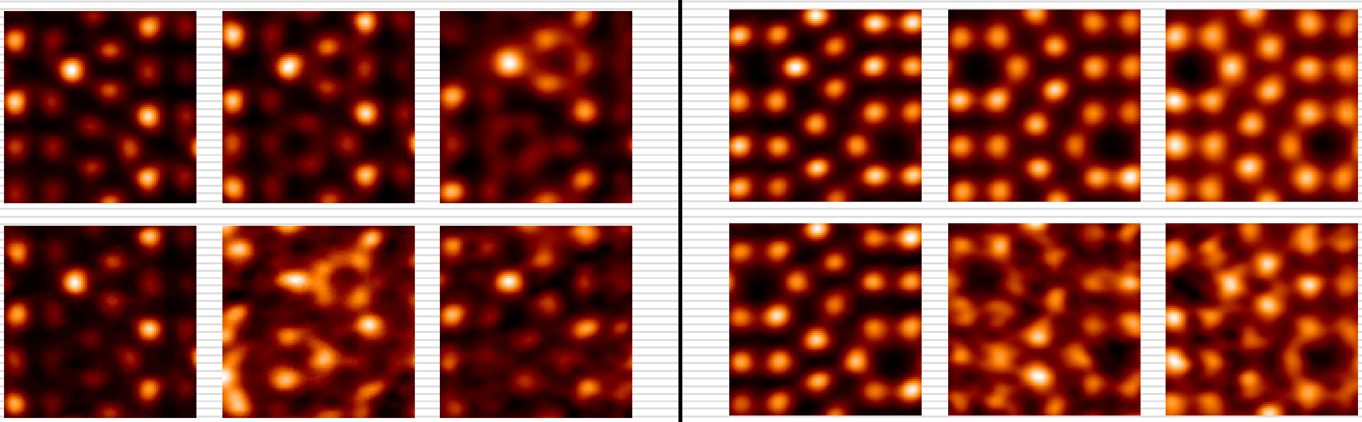




Filled states | **Empty states**

Current

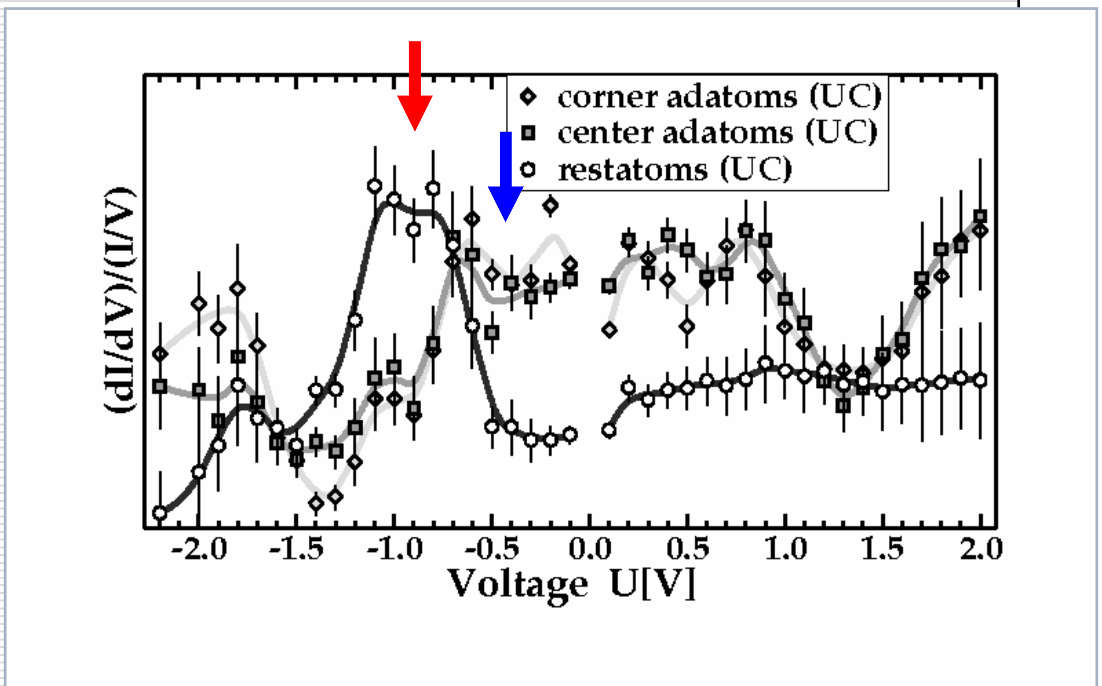
Lock-in

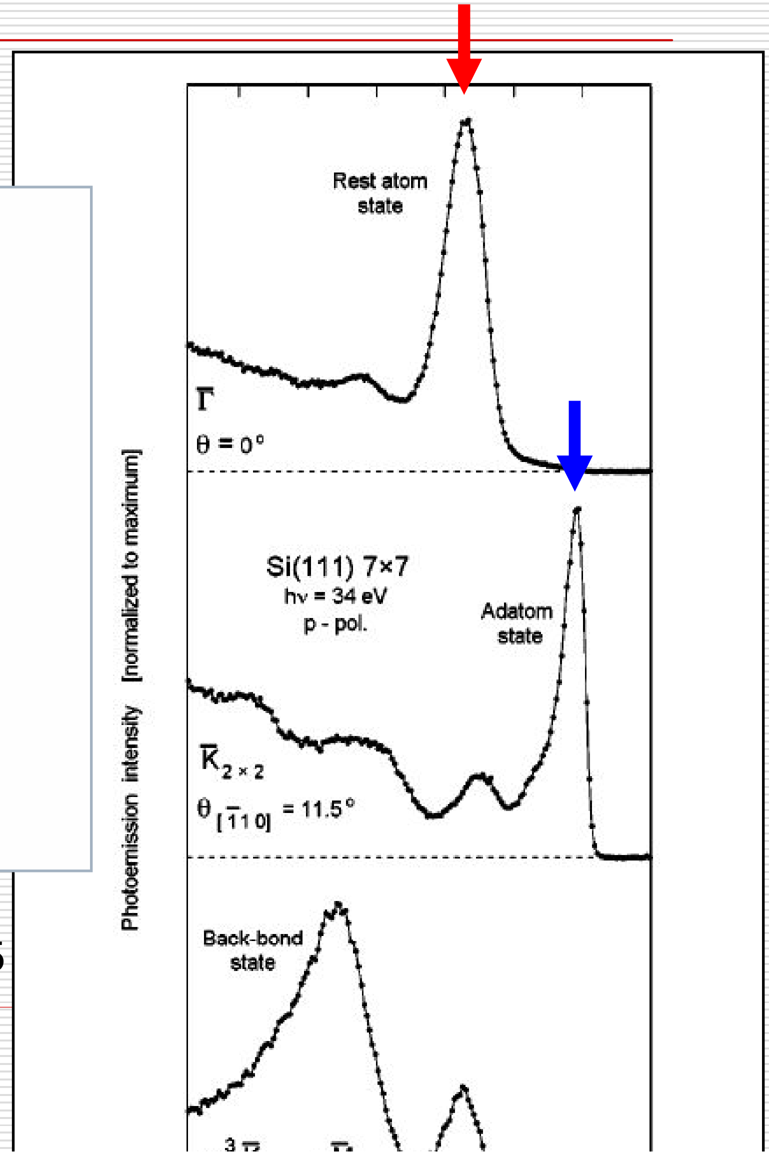


-0.3 V   -0.9 V   -1.9 V   0.3 V   1.0 V   1.8 V

Examples: Si(111)-7x7

STS constructed of the lock-in maps





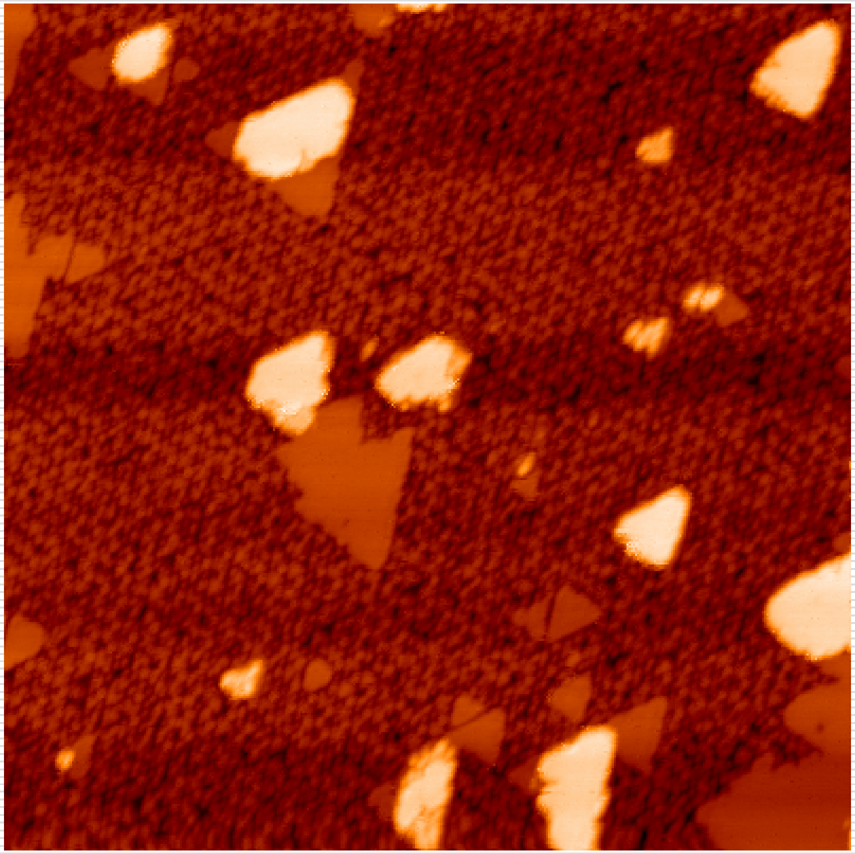
ARUPS: Losio et. al. Phys. Rev. **B 61**, 10845

Pb/Si(111) <1ML

Pb evaporation on Si(111)-7x7 + heating up to 600K

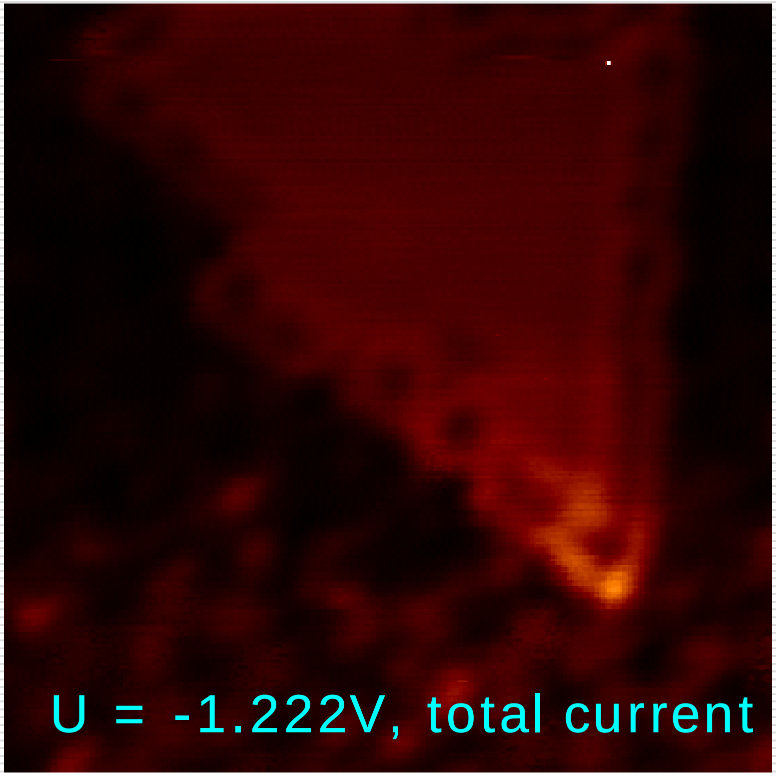
= incomplete layer + 1x1 islands

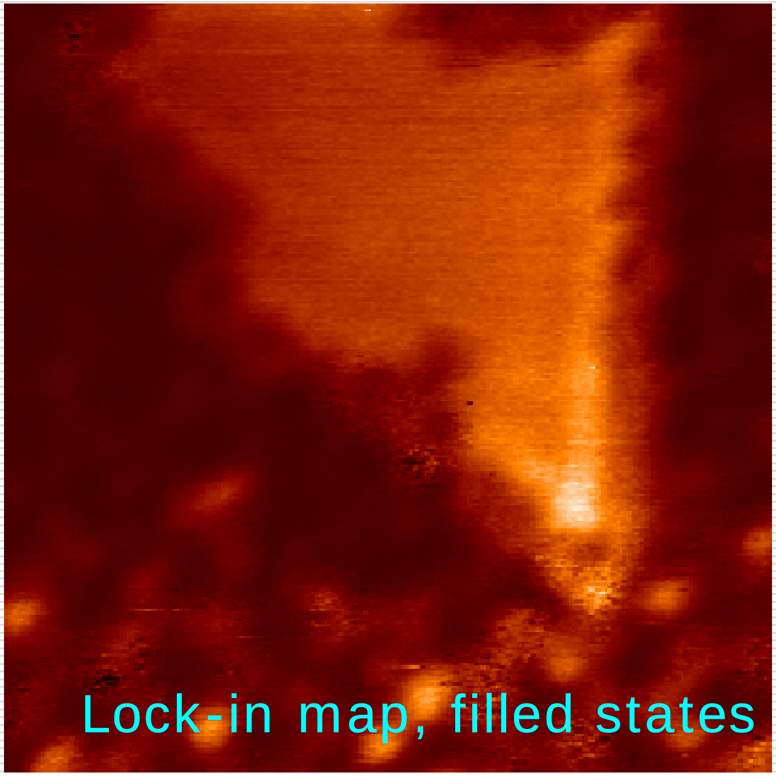
U=-1.1V, I=0.5nA, standard topography, size of 100x100 nm^2



Pb/Si(111) <1ML

1x1 islands: vanishing island boundary



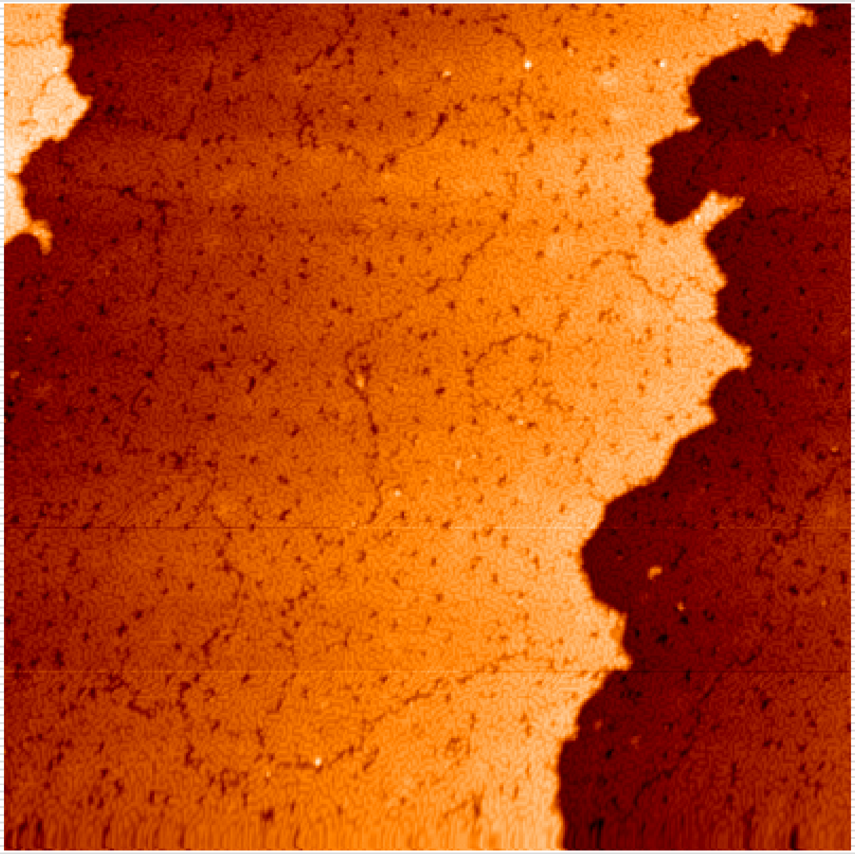


Pb/Si(111) 1/6ML: mosaic

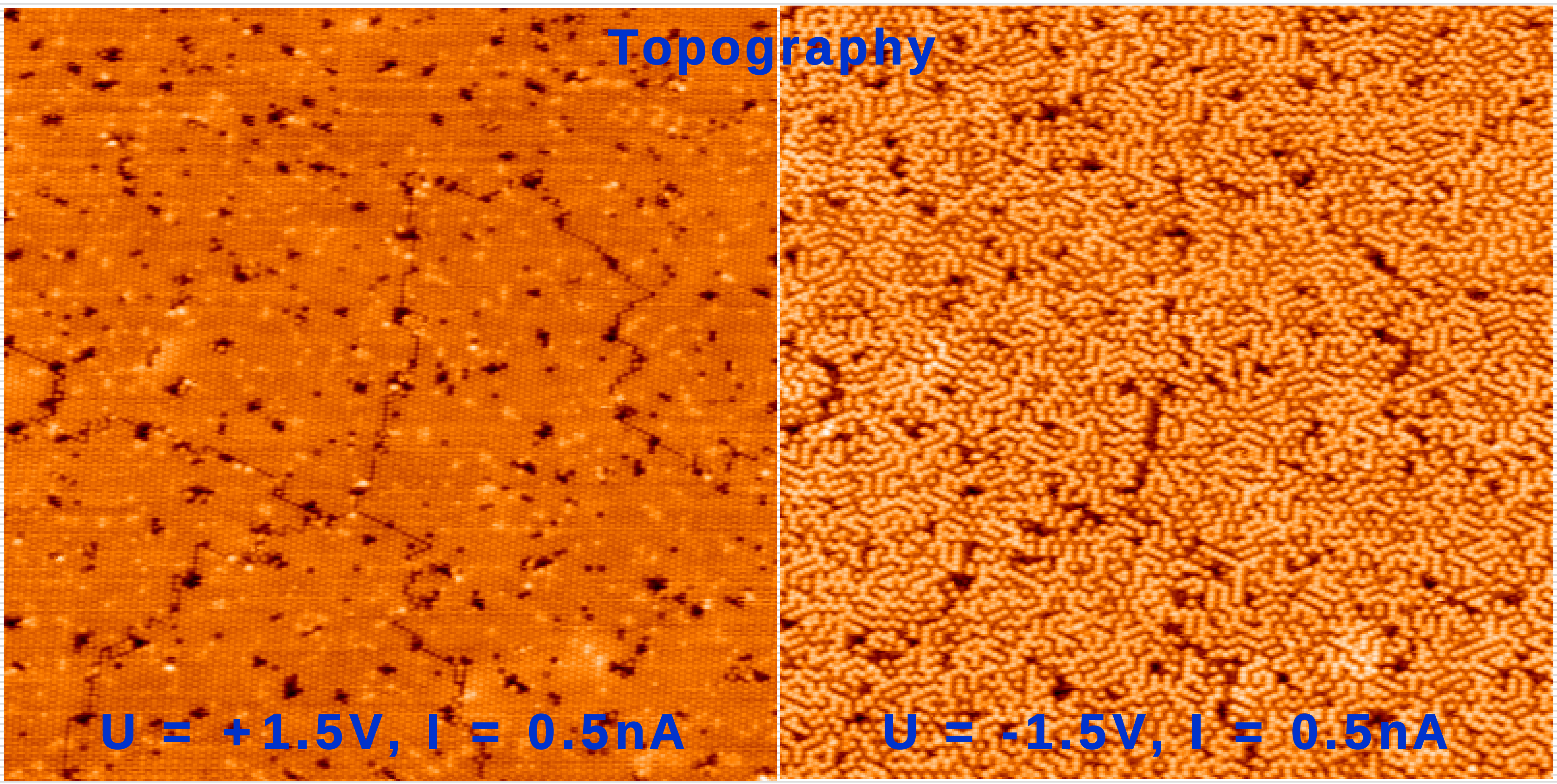
Pb evaporation on Si(111)-7x7 + heating up to 700K

= mosaic structure

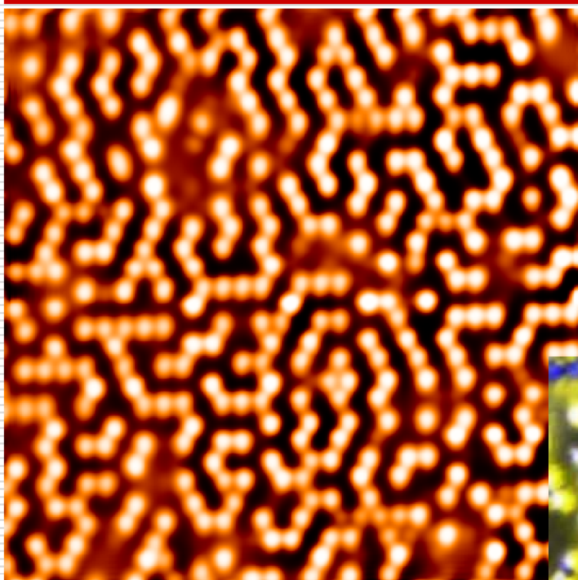
U=-1.5V, I=0.5nA, standard topography, size of 200x200 nm^2



Mosaic: 100x100nm^2

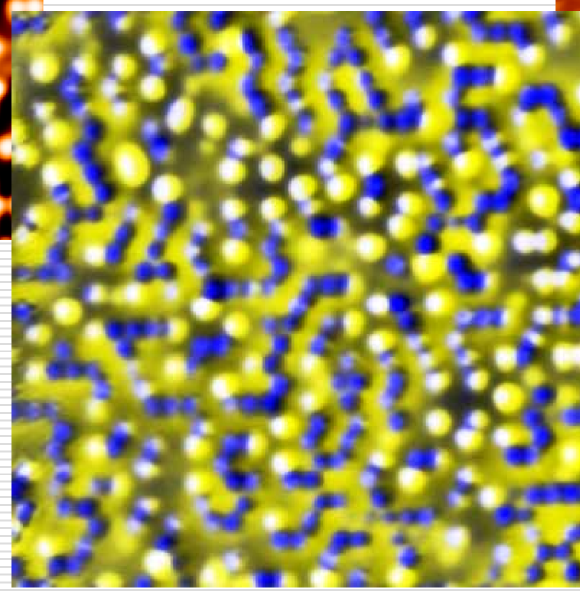


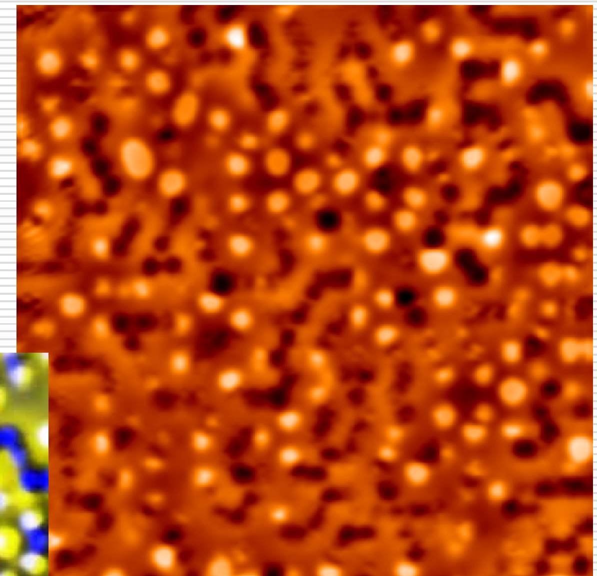
Mosaic: LDOS study



Current image,
U = -1.0V,
blue channel

Combined image





Lock-in image at
U = -1.0V,
red and green
(=yellow) channel

Summary & Conclusion

Real-space LDOS probing

- sensitive to chemical states, even of identical atoms
- distinguishes different species
- provides a complete view of system’s electronic behaviour
  ...nanoelectronics
- a complementary method to angle-resolved photoemission
- at most localized among other methods

Outlook:

- co-adsorbed systems LDOS (improved atom identification)