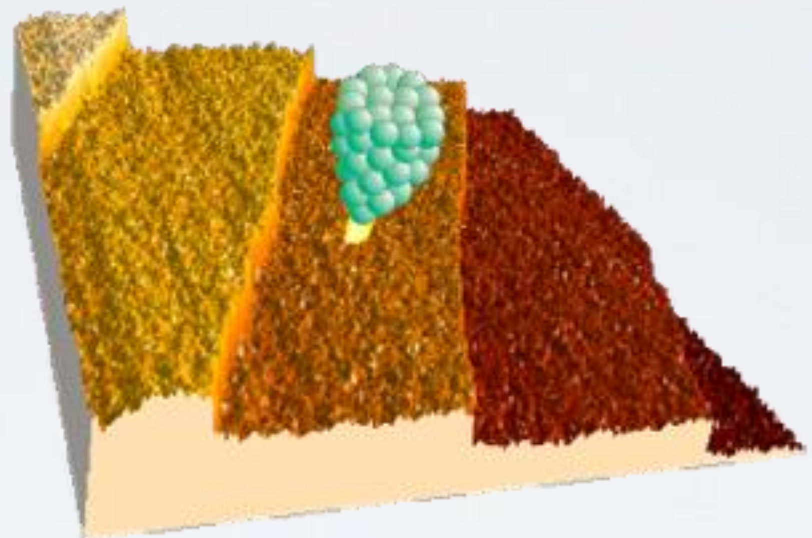
OSSERVARE IL NANOMONDO

Marco Salluzzo



STM-STS Spectroscopy

Quantox

CNR-SPIN

Microscopia: osservazione della superfice dei campioni

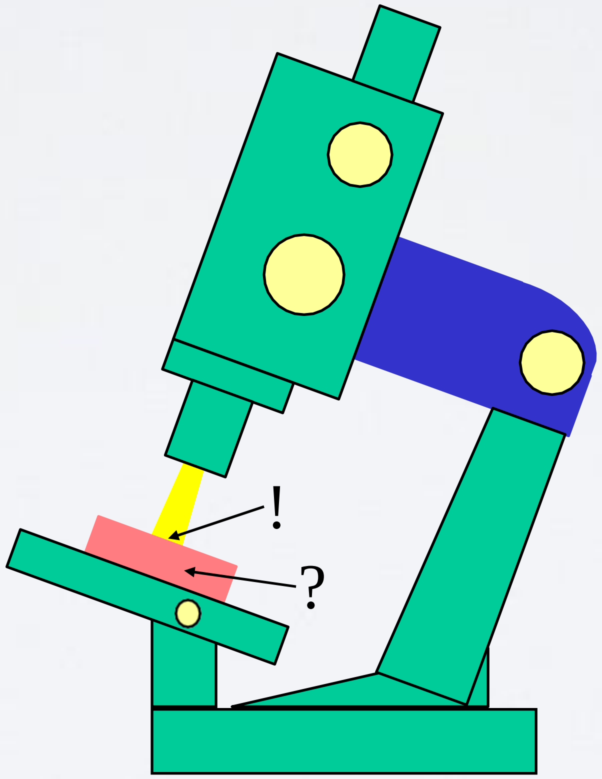
Microscopy = surface analysis

"By observing in a microscope, we look at the surface of things.

It makes them larger and clearer, nut at the same time, enlarging them it does not show us the reality.

Do not think you are looking at the intrinsic essence that things you are observing have!"

From *The Microscope*, **Feng-Shen Yin-Te**



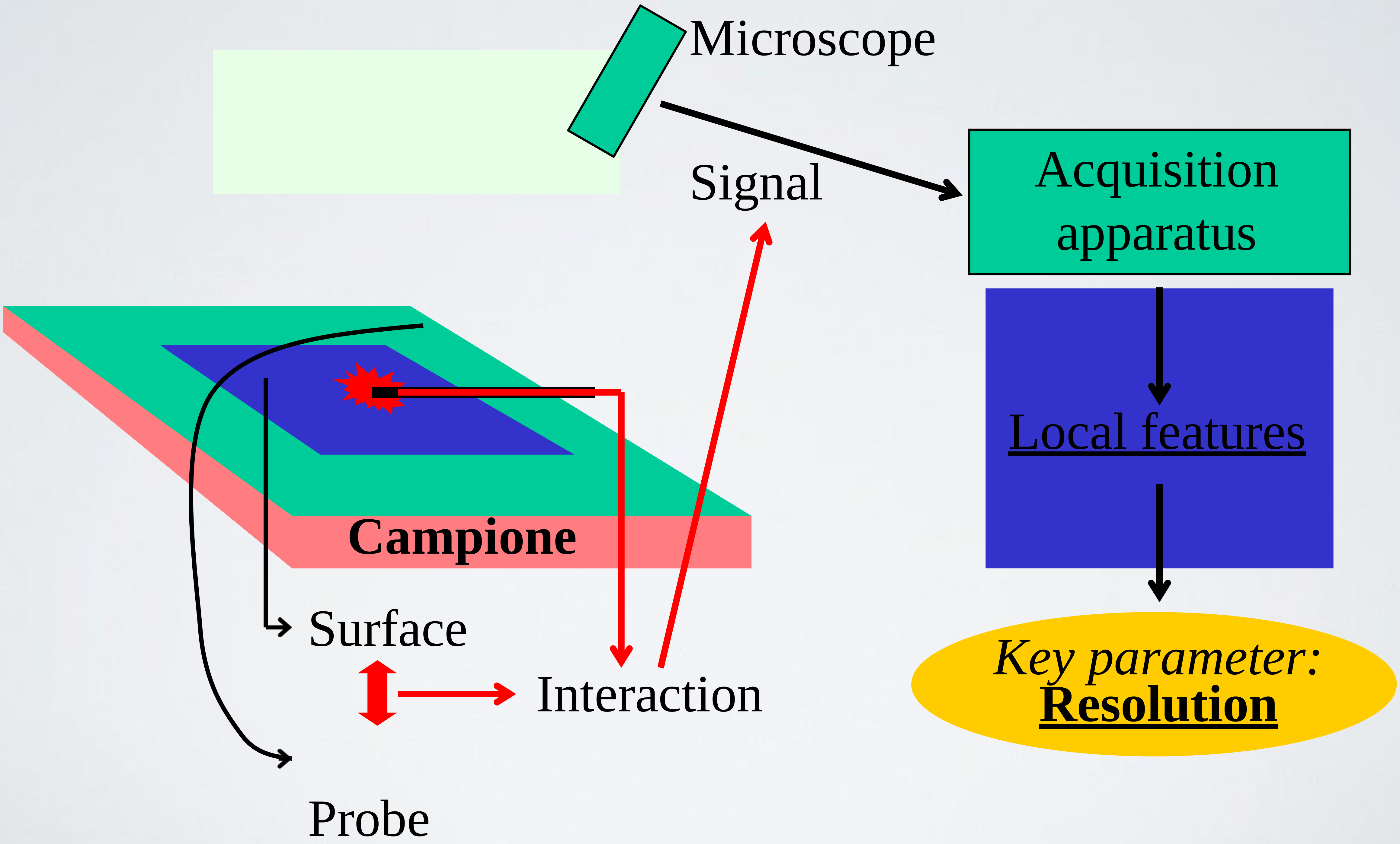
Quando si guarda in un microscopio, guardiamo alla superfice degli oggetti

Lo strumento rende gli oggetti piu' grandi e piu' chiari,
Li rende più grandi e più chiari, allo stesso tempo, allargandoli non ci mostra la realtà

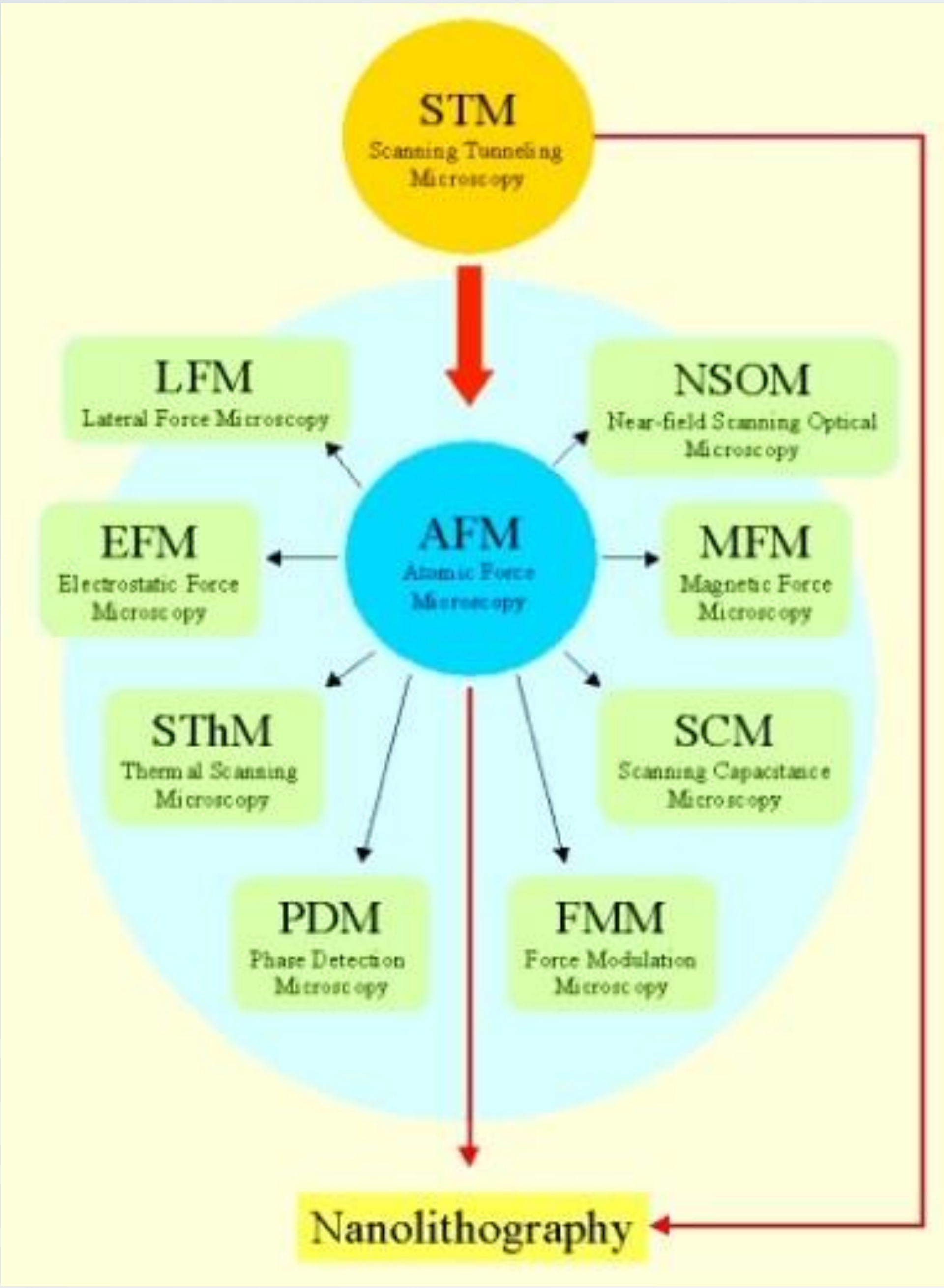
Non pensare di guardare l'essenza intrinseca delle cose che stai osservando!"

From *The Microscope*, **Feng-Shen Yin-Te**

SPM: principle of working
(SPM: Scanning Probe Microscopy)



STM: Scanning Tunnelling Microscope



Realized by:

<u>Gerd Binnig, Heinrich Rohrer</u>

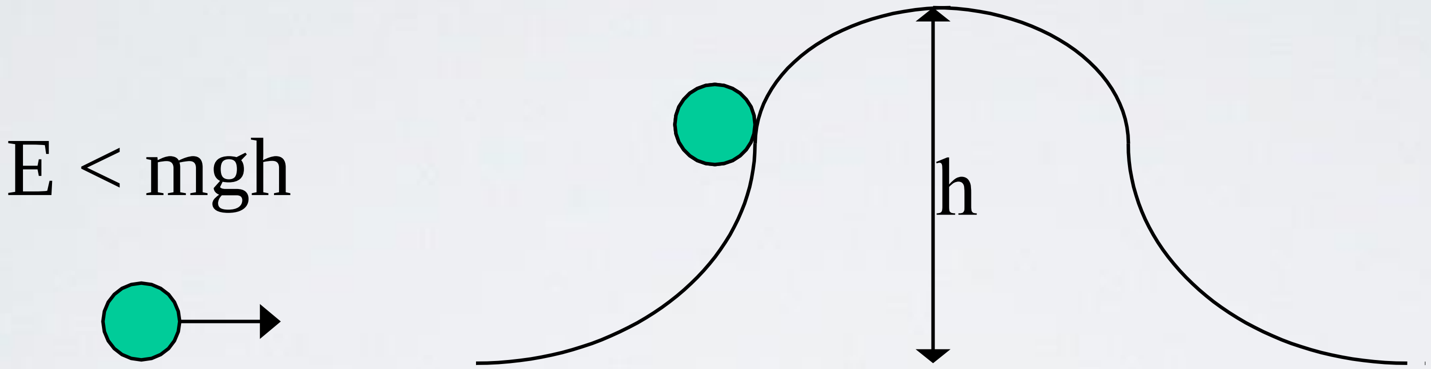
IBM Research Division,

Zurich (Switzerland)

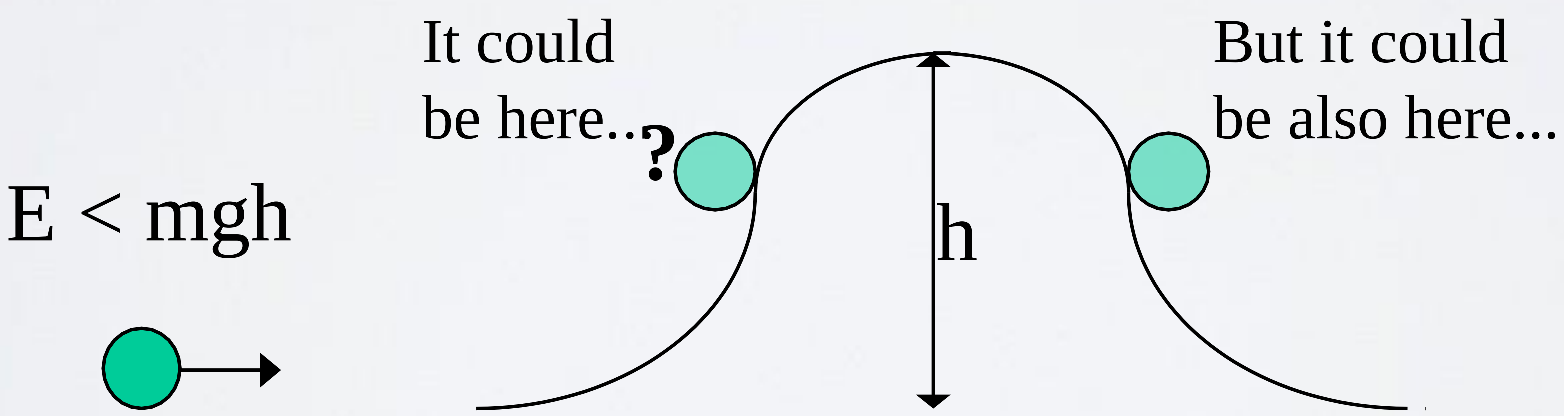
Nobel Prize in 1985

The Tunnel Effect

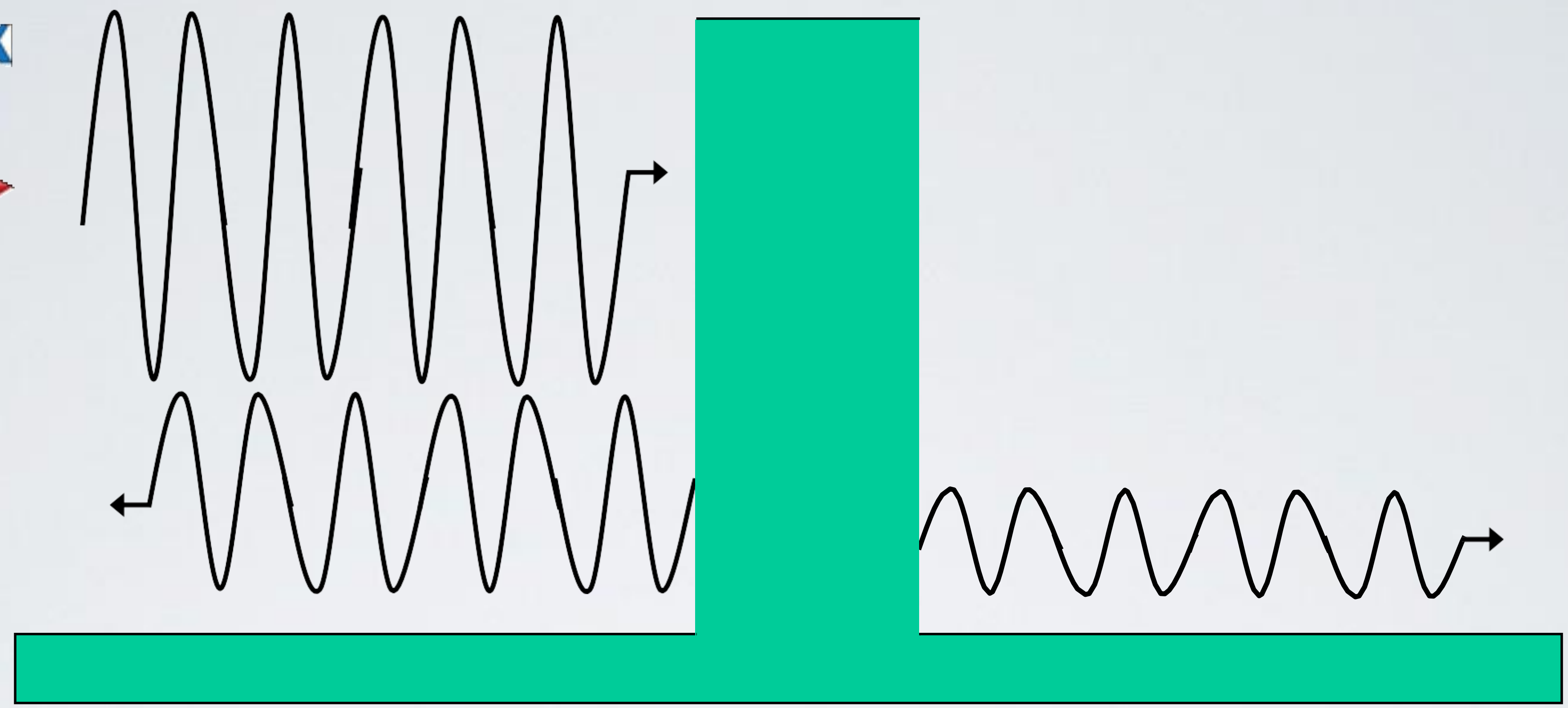
Classical mechanics

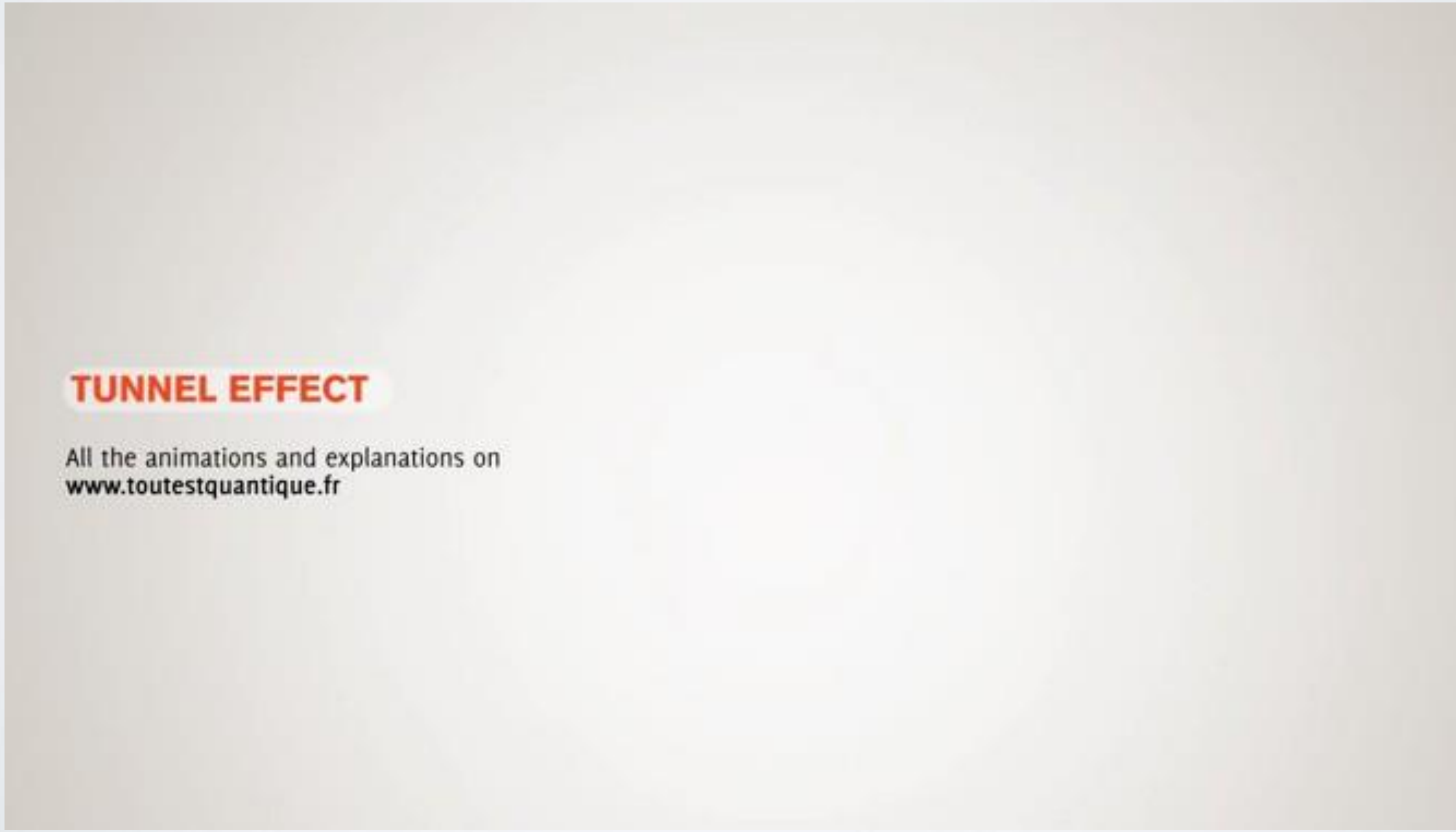


Quantum mechanics

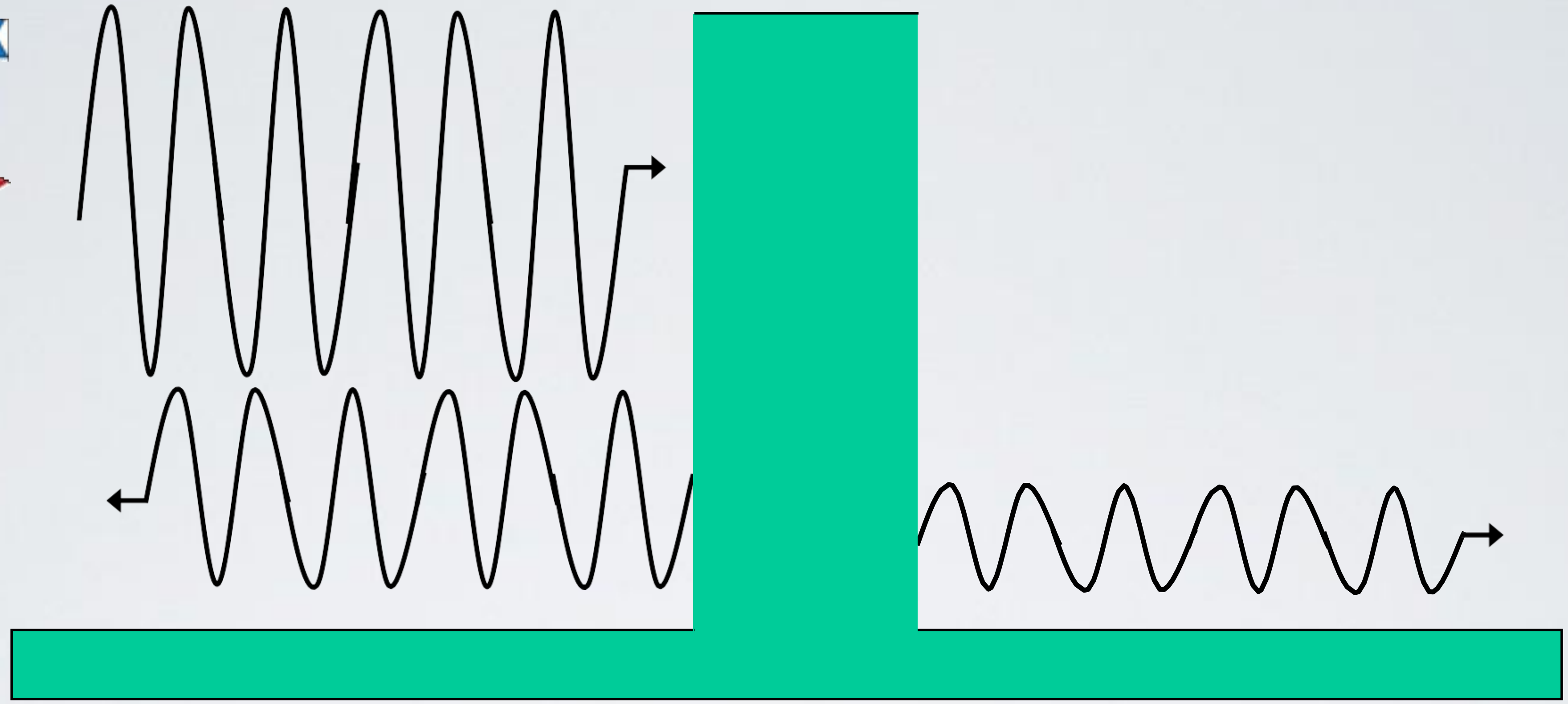


The Tunnel Effect



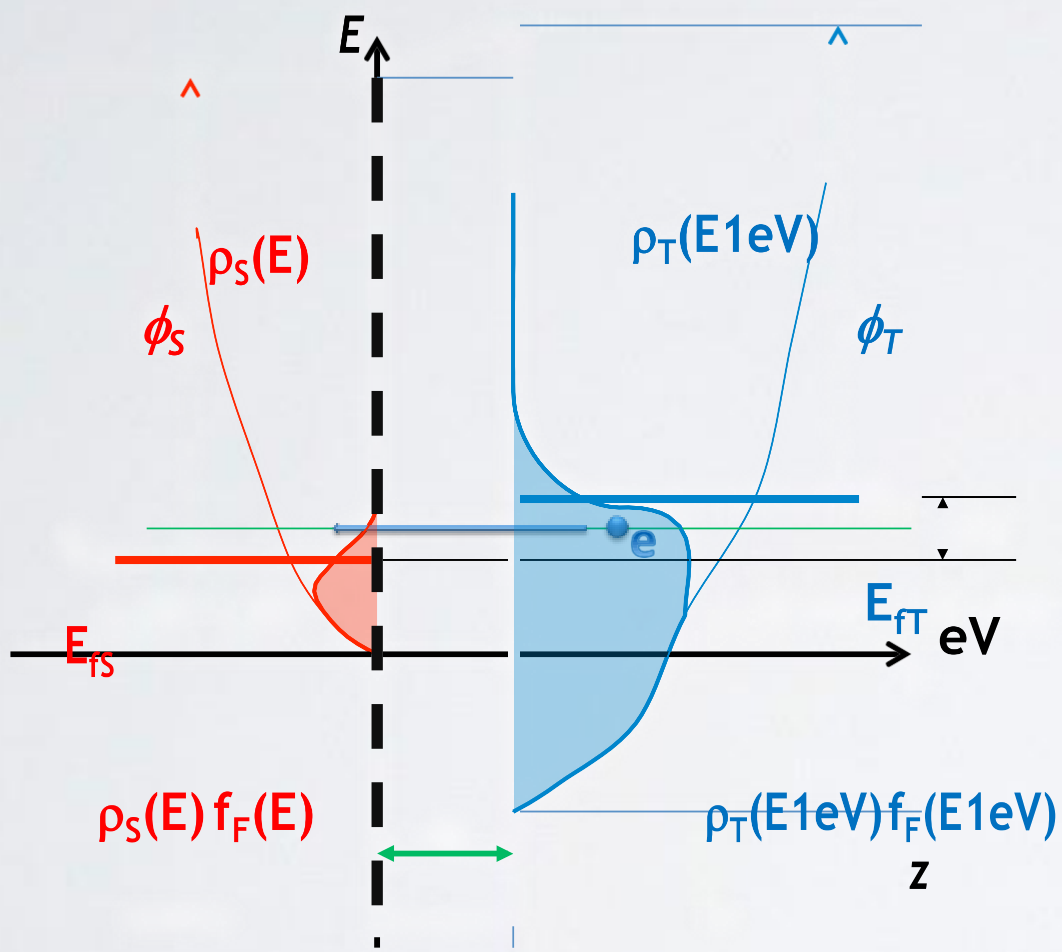


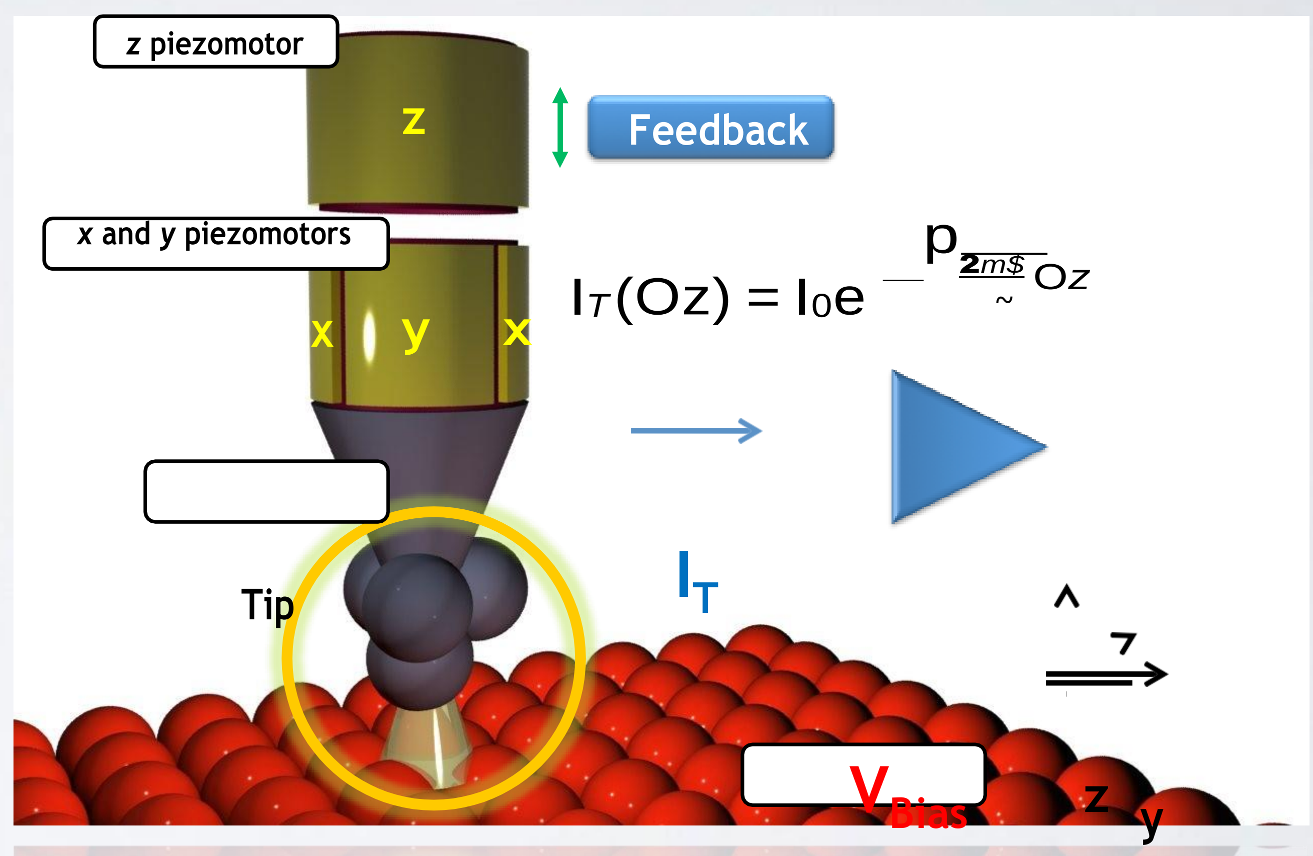
The Tunnel Effect



Approfondimenti: STM/STS principles

Quantum mechanical electron Tunneling





w

A SAMPLE

vacuum

I (V, w) ≒ —

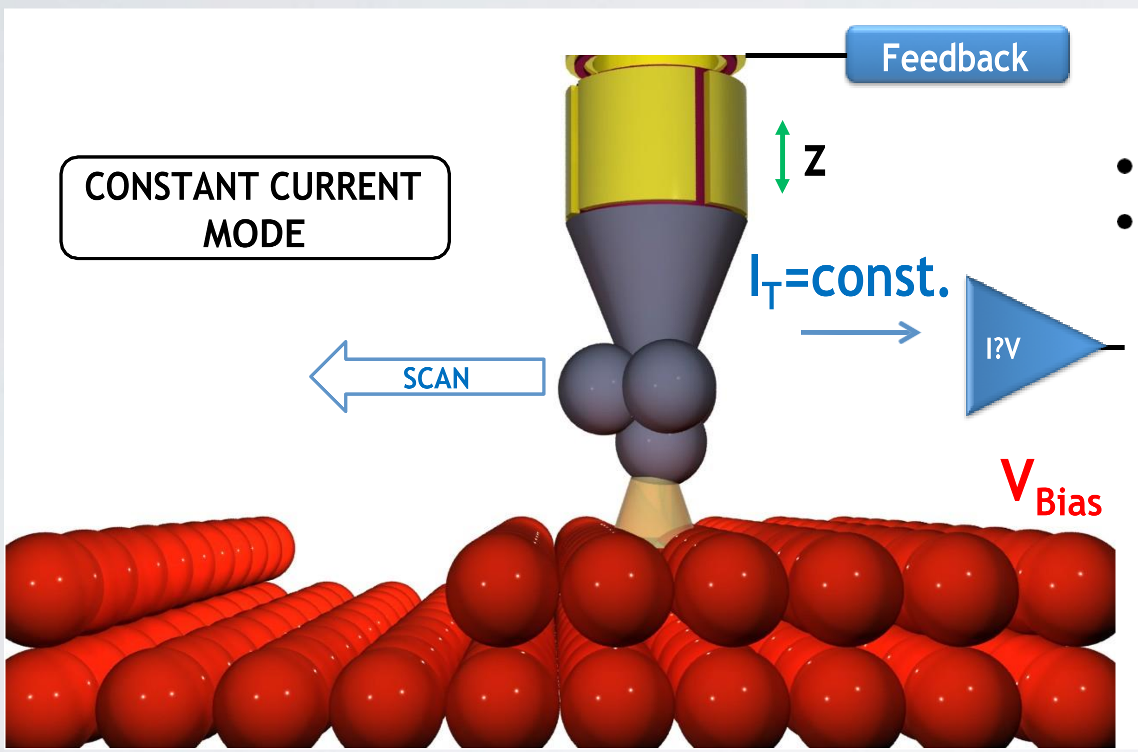
2 ~

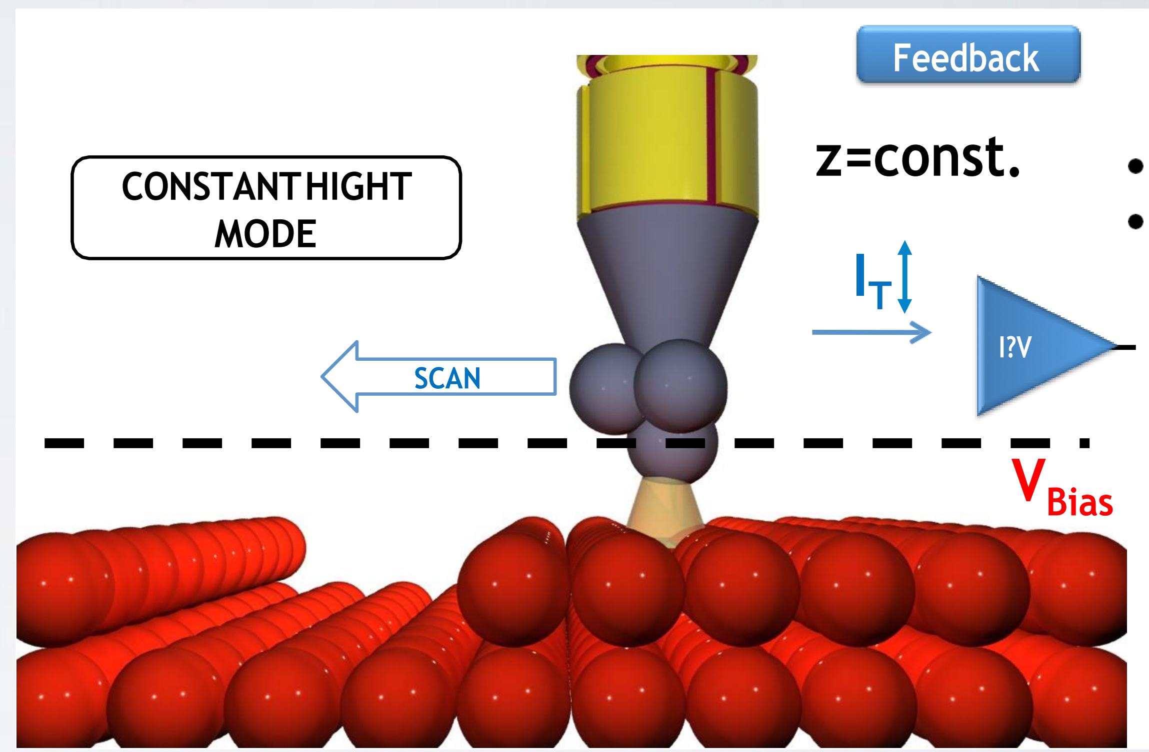
v 2

e

$$\int_{\text{TIP}}^{\text{Sample}} \frac{2}{\hbar}\left(\frac{1}{2m}\right) T(E, V, w)\,\rho_S(E)\,\rho_T(E - eV)\,\big(f(E - eV) - f(E)\big)\,dE$$

STM
TOPOGRAPHIC MODES





$$I_T(z_{TIP}, z_{SURF}) = I_0 e^{-\sqrt{\frac{2m\Phi}{\hbar}}(z_{TIP}(x,y) - z_{SURF}(x,y))}$$

$$I_T = \text{const.}$$

$$z_{TIP}(x,y) = z_{SURF}(x,y) + \text{const.}$$

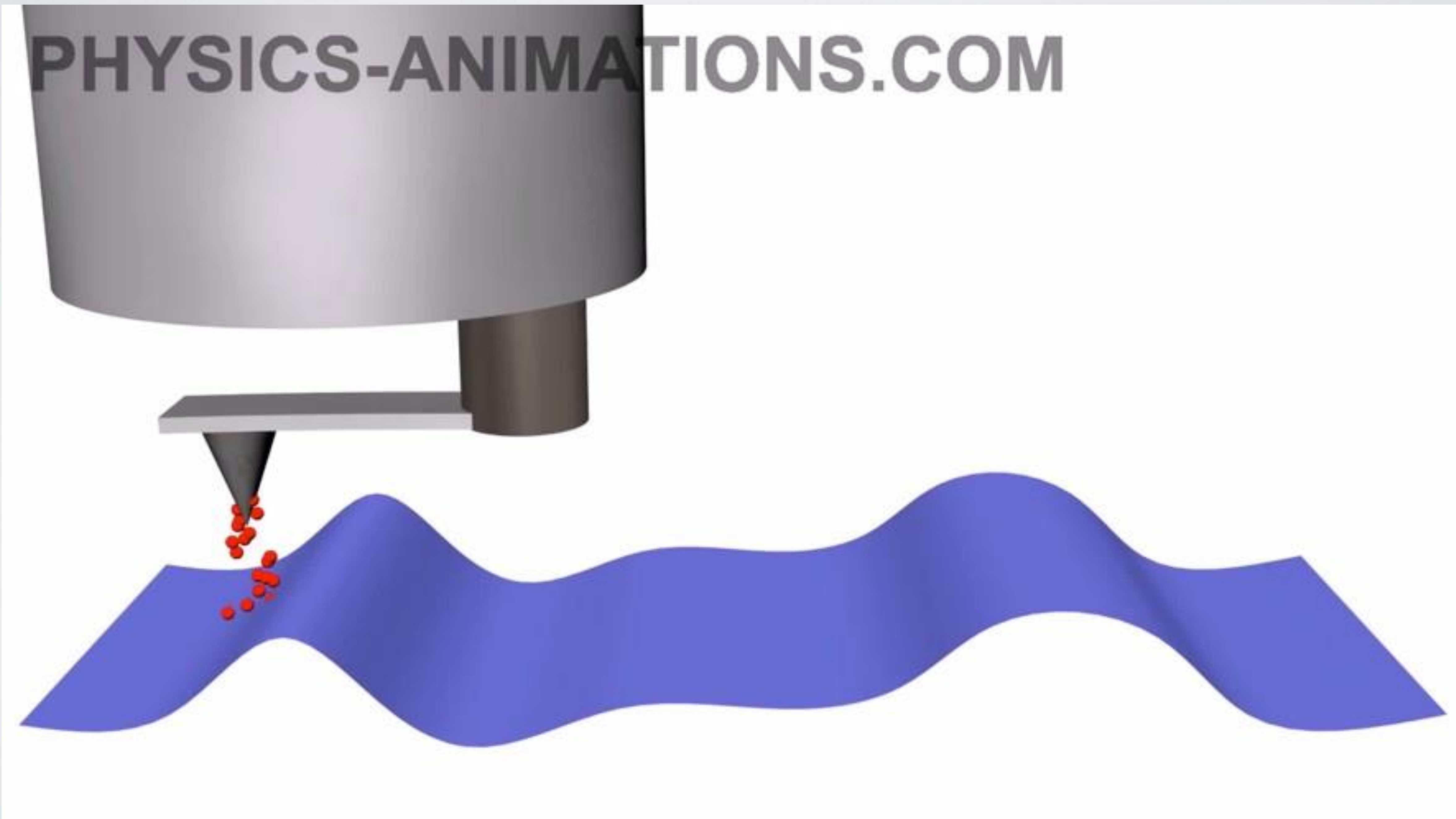
$$V_{PIEZO}(x,y) = k_z z_{SURF}(x,y) + \text{const.}$$

$$z_{TIP}(x,y) = \text{const.}$$

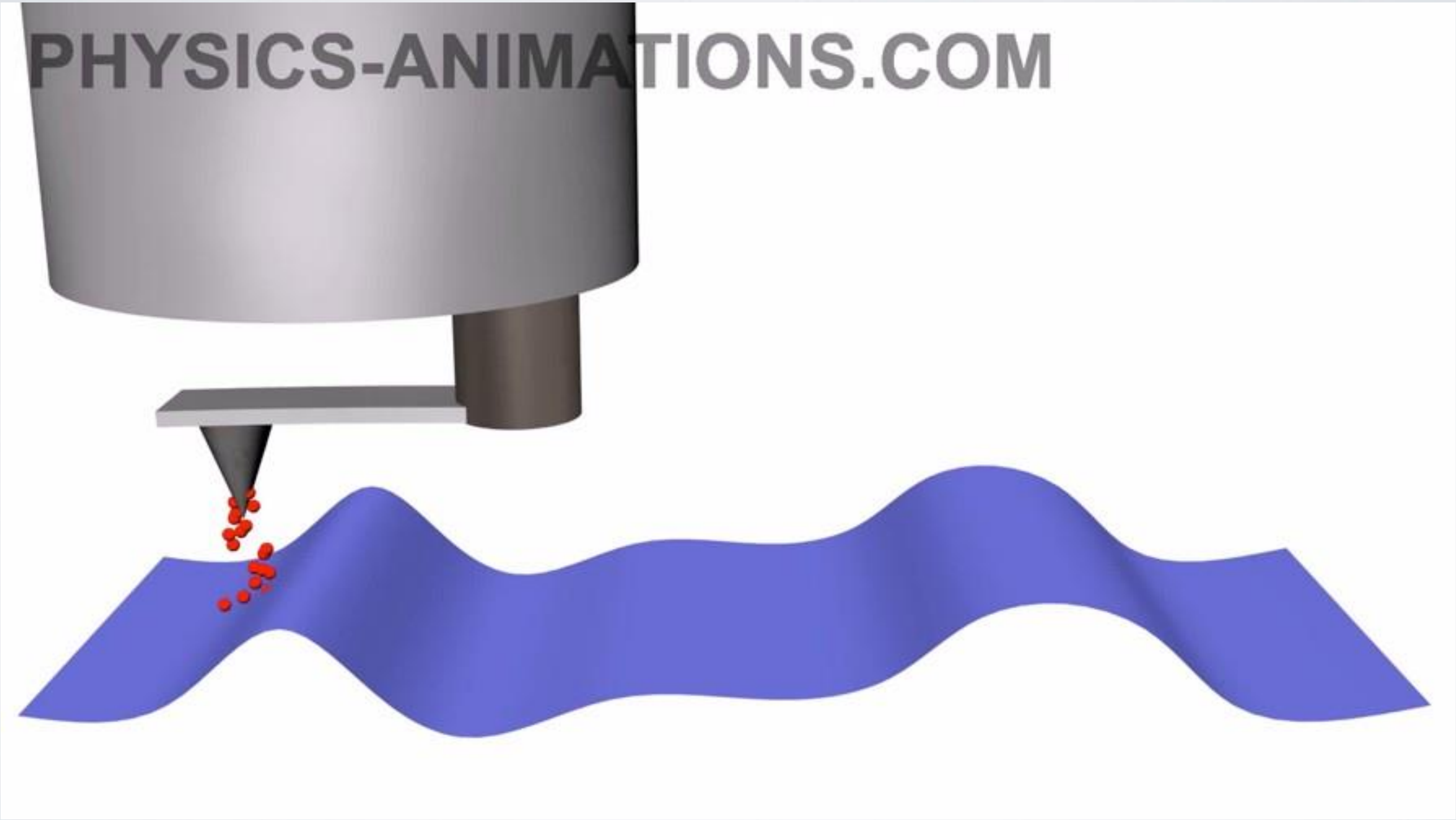
$$I_T = I_T(x,y)$$

$$V_{PIEZO}(x,y) = \text{const.}$$

TOPOGRAPHIC MODE

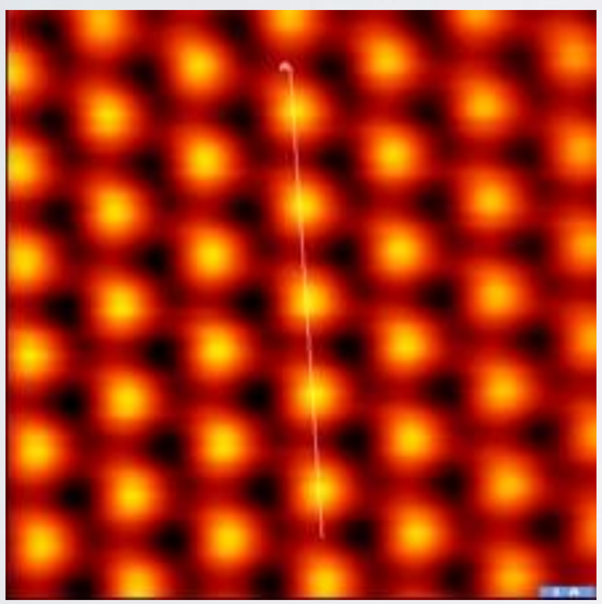


TOPOGRAPHIC MODE

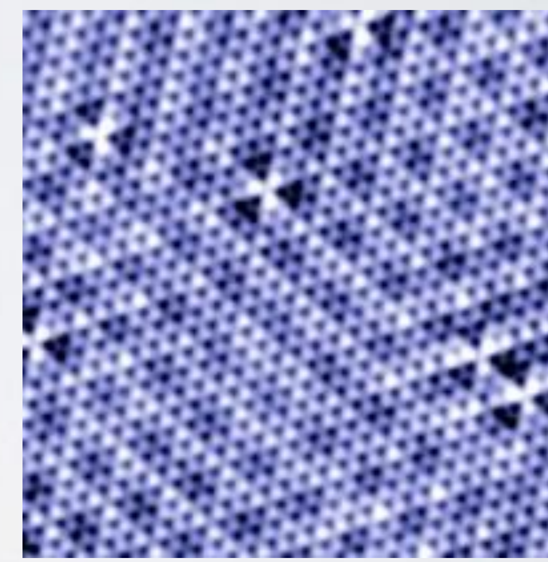


ATOMIC RESOLUTION

Even when in a realistic case a tip have a finite curvature radius the last relation is approximatively valid. On the contrary atomic resolution can be obtained only with very sharp tip (apex dimension of order of few Angstroms)



$$I \propto \sum_{\mu,\nu} |\psi_\nu(\mathbf{r}_0)|^2 \delta(E_\nu - E_f)$$



$NbSe_2$

ATOMIC RESOLUTION

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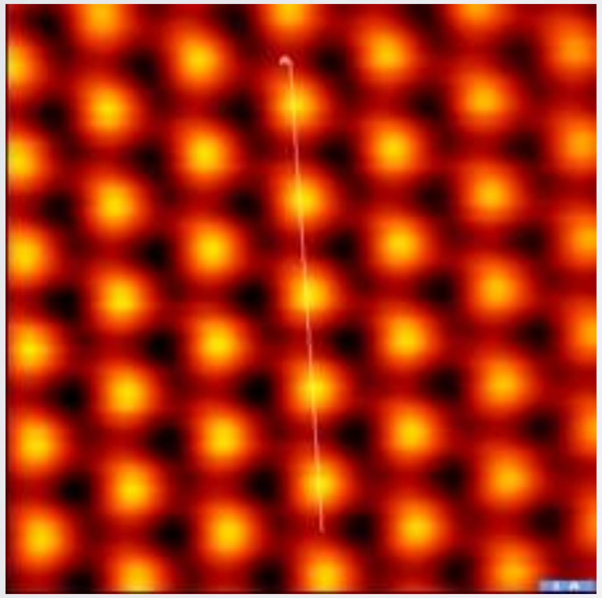
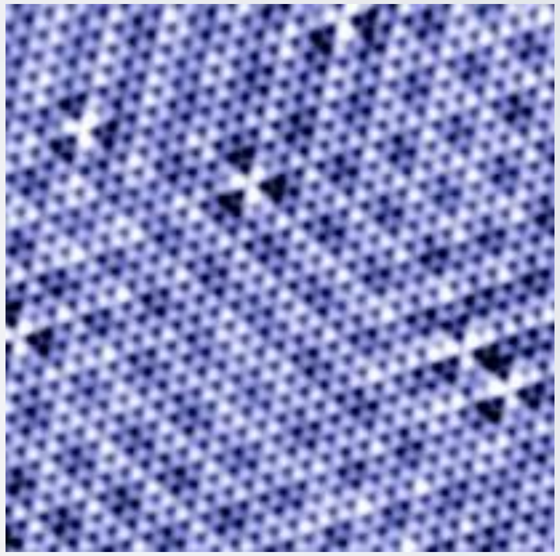


$$I \propto \sum_{\mu,\nu} |\psi_\nu(\mathbf{r}_0)|^2 \delta(E_\nu - E_f)$$

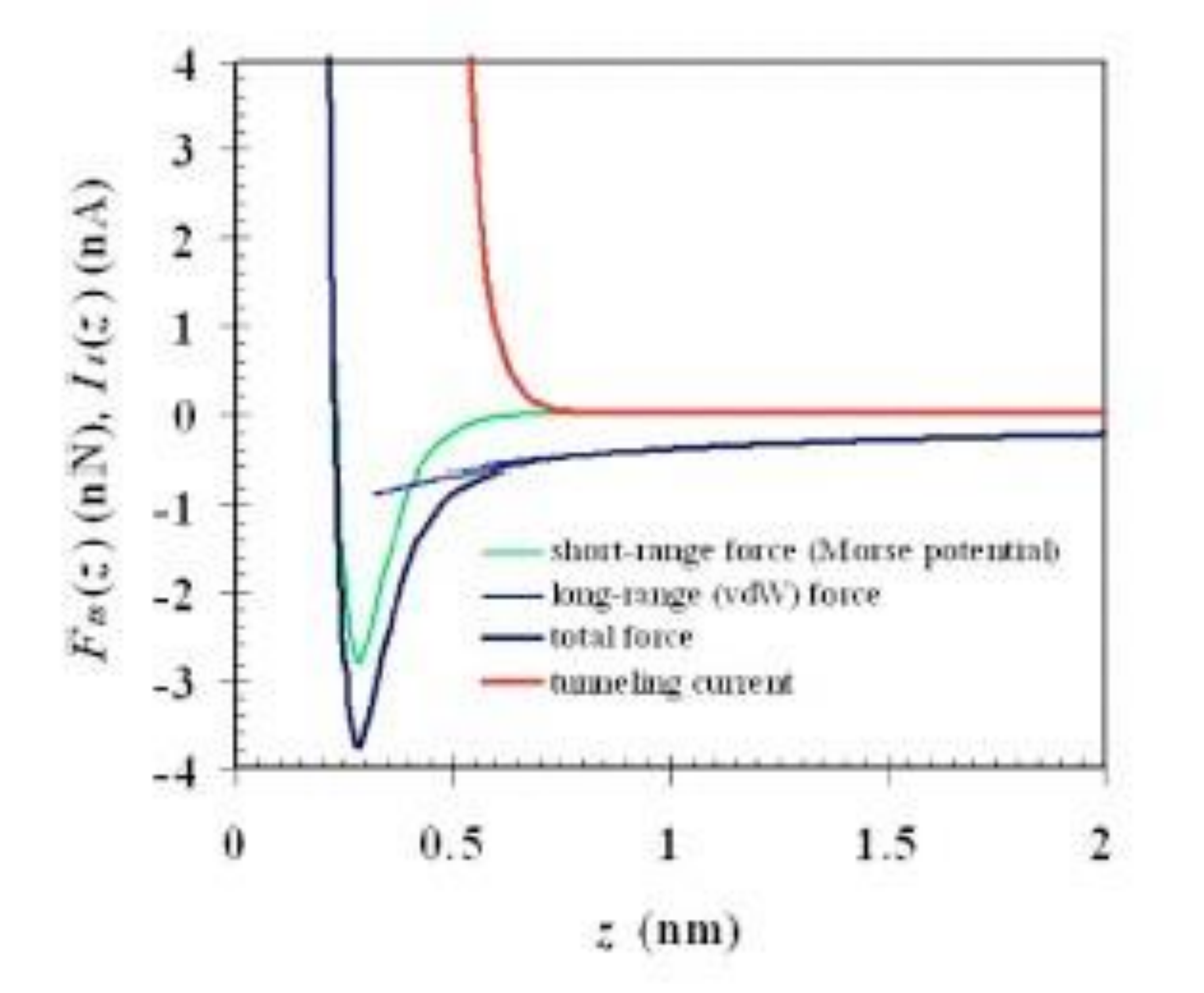


$NbSe_2$

HOPGraphite: 1.5 x 1.5 nm^2

AFM principles

Short range and long range Forces



Van der Wals: long range
Morse Potential: short range
Lennard Jones: short+long range

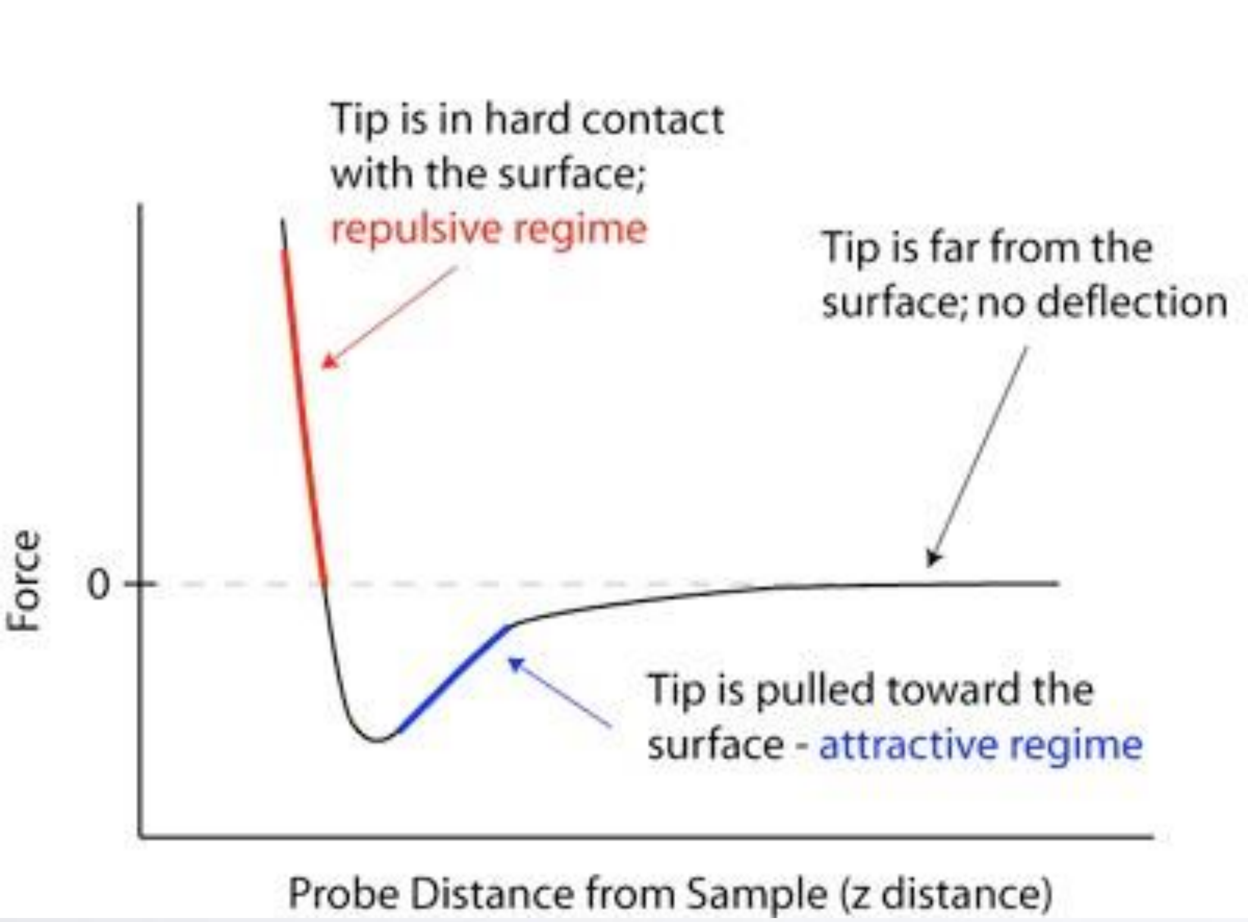
$$V_{Lennard\text{-}Jones} = -E_{bond}\left(2\frac{z^6}{\sigma^6} - \frac{z^{12}}{\sigma^{12}}\right),$$

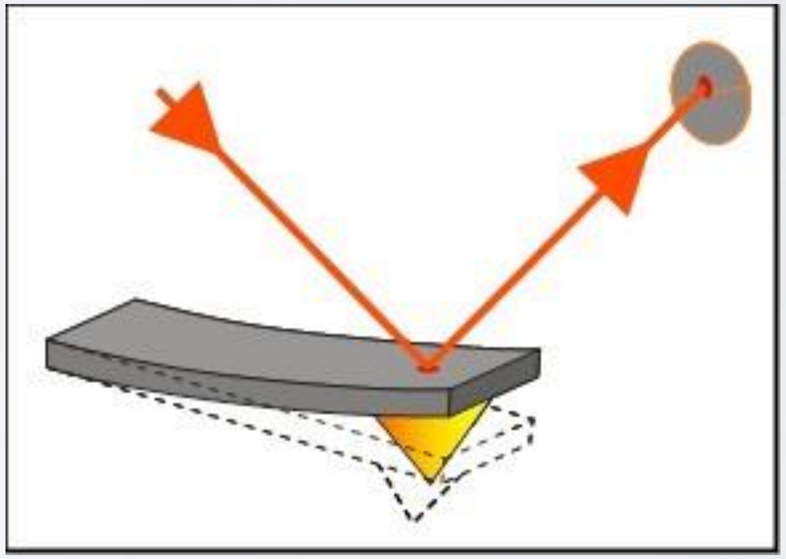
chemical bonding

$$V_{Morse} = -E_{bond}\left(2e^{-\kappa(z-\sigma)} - e^{-2\kappa(z-\sigma)}\right)$$

HOW TO DETECT FORCES

MAKE A SPRING (tuning fork, cantilever)
AND MEASURE A DEFLECTION



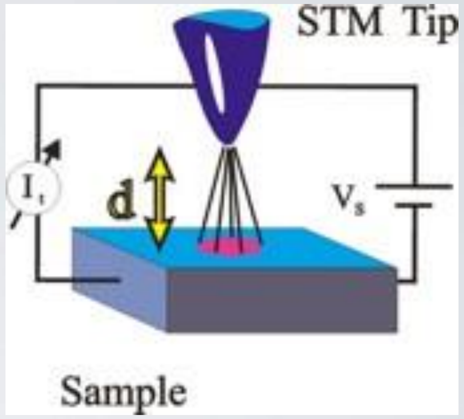


Different regimes: contact, non contact, intermittent contact

Electron Spectroscopy by STM

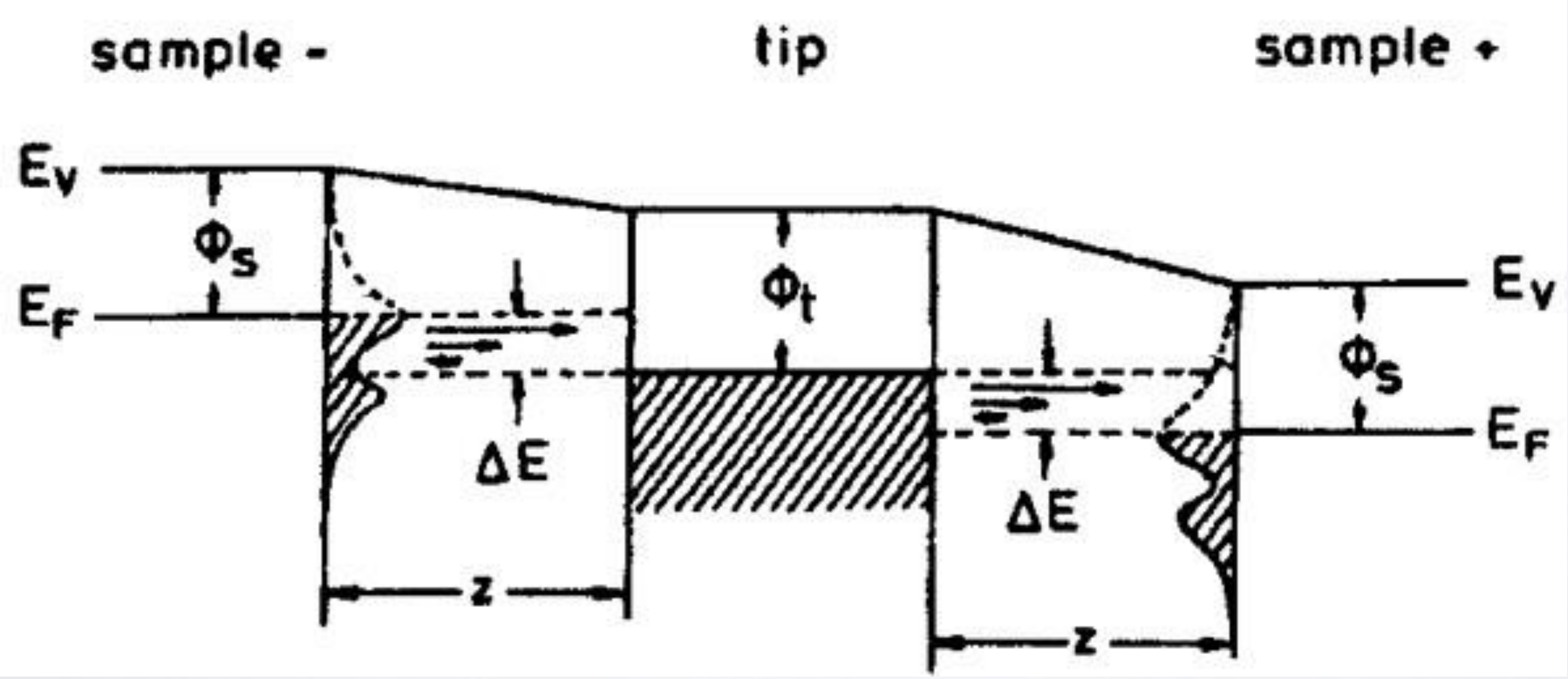
$$J(V) = \frac{2e}{(2\pi)^2 h} \int_0^{\infty} dE_{\perp} \left[f(E) - f(E + eV) \right] \iint d^2 k_{//} D(E_{\perp}, eV)$$

Within the WKB approximation



$$D(E_{\perp}, eV) \propto exp\left\{ -2s \sqrt{\frac{2m}{\hbar^2} \left[\frac{\phi_S + \phi_T}{2} + \frac{eV}{2} - (E_{\perp} - E_f) \right]} \right\}$$

When samples having closed Fermi Surfaces are probed, states with maximum $E_{\perp}$ give the maximum contribution to the current, i.e the filled states at $E_{\perp} = E_f$ for negative sample bias and the empy states at $E_{\perp} = E_f + eV$ for positive sample bias.



SPECTROSCOPY

STM/STS

DIFFERENTIAL CONDUCTANCE

I (V, w) ≐

2ve ~2 2 Z 1

A ~ (2m) T(E, V, w) S(E) T(E — eV)(f(E — eV) — f(E))dE

Z +1 Z E_F

k_BT ☒eV ❯ —1 (...) ! E_F—eV (. . .)

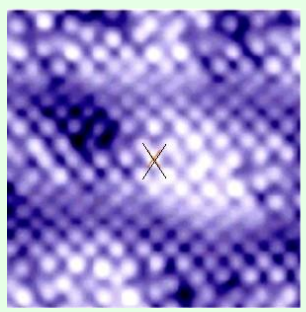
dI(V, w) 2 e ~2 2

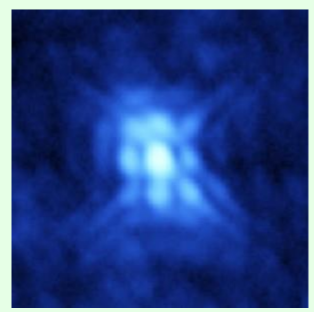
eV ☒$ ❯ T(E, V) T(E, 0)

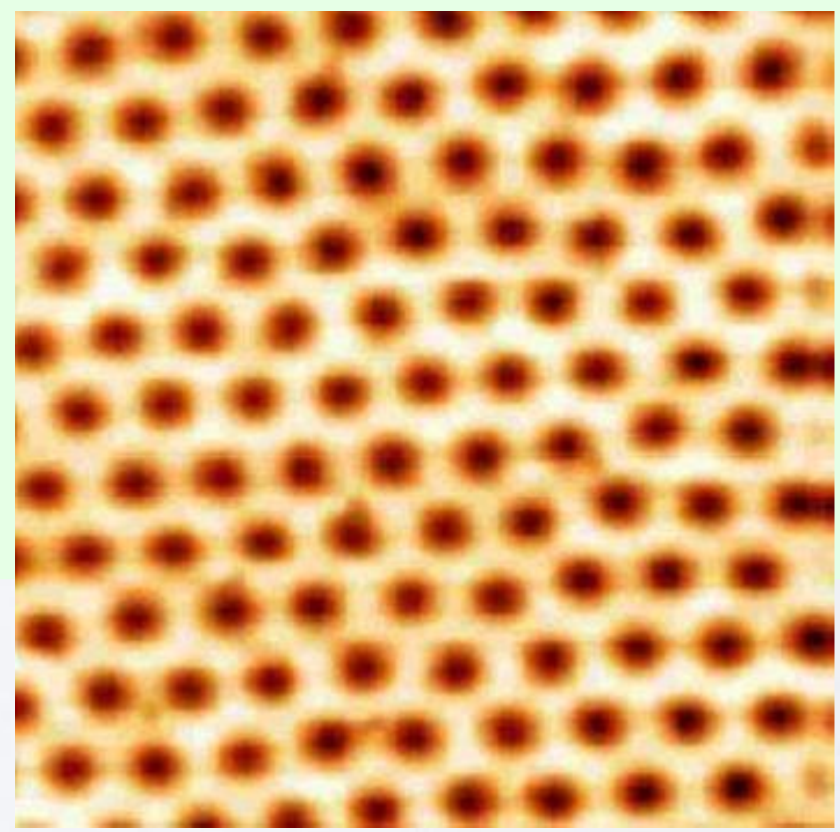
$eV \boxtimes E_F) D_{TIP}(E) \uparrow D_{TIP}(E_F)$

$$dV = A \sim \left(2m\right) T(eV, w) \rho_T(E_{fT}) \rho_S(eV)$$

dI/dV maps: “topo-spectroscopy”







Abrikosov vortices on $NbSe_2$

Atoms in: Quantum corral