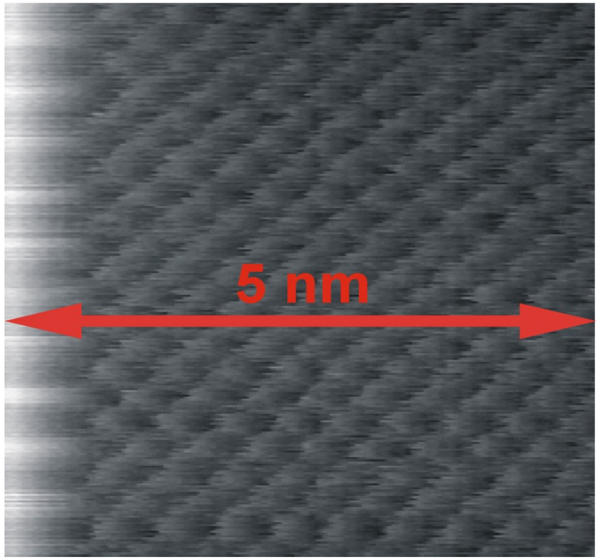
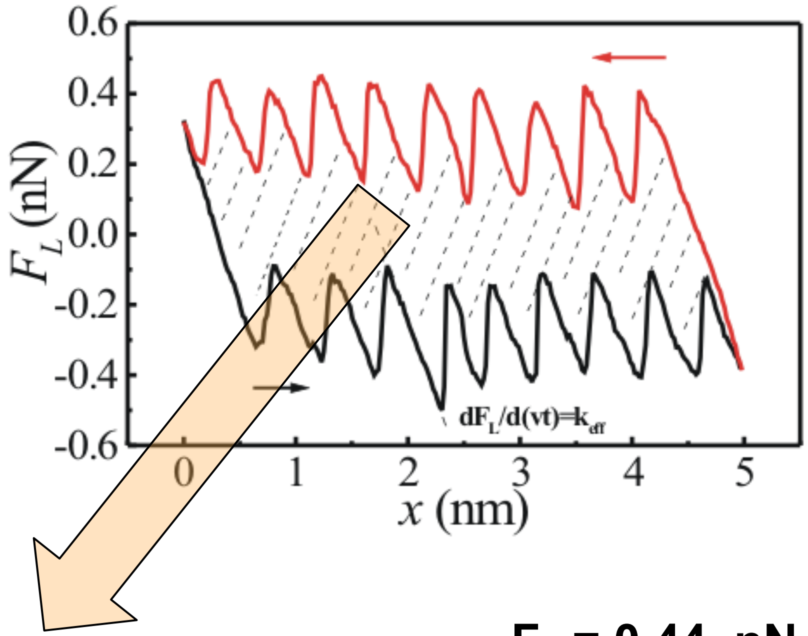
Friction on the Nanometer-scale: Atomic-Stick Slip

Atomic stick-slip



KBr(001)-crystal

Friction loop



What are the dissipation channels?

F_N = 0.44 nN

E_{diss} = 1.4 eV (per slip)

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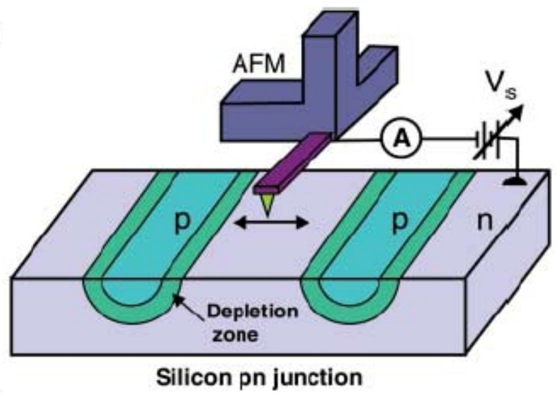
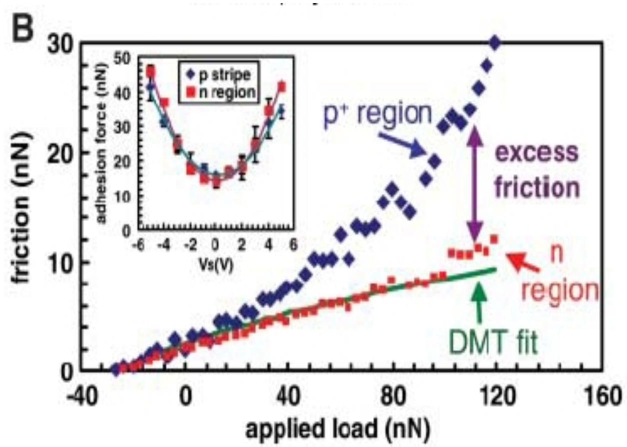
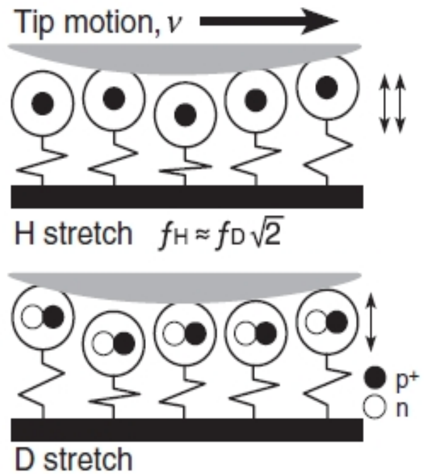
Electronic vs. Phononic Friction Experiments

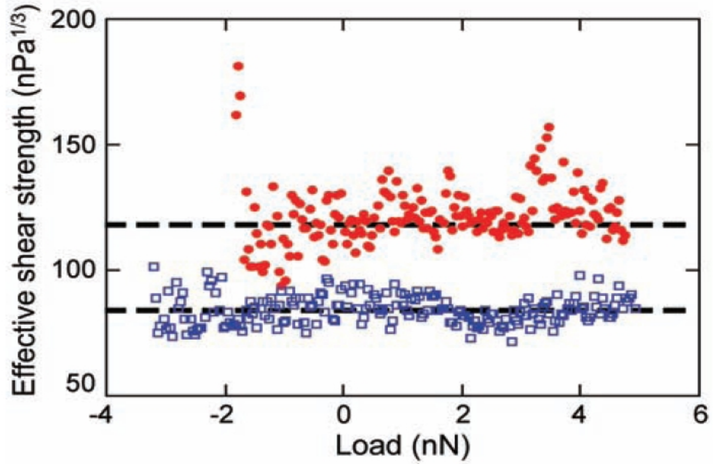
J.Y. Park, D.F. Ogletree, P.A. Thiel, and M. Salmeron, ***Electronic Control of Friction in Silicon pn Junctions,*** Science313, 186 (2006)





R.J. Cannara, M.J. Brukman, K. Cimatu, A.V. Sumant, S. Baldelli, and R.W. Carpick, ***Nanoscale Friction Varied by Isotopic Shifting of Surface Vibrational Frequencies,*** Science318, 780-783 (2007)





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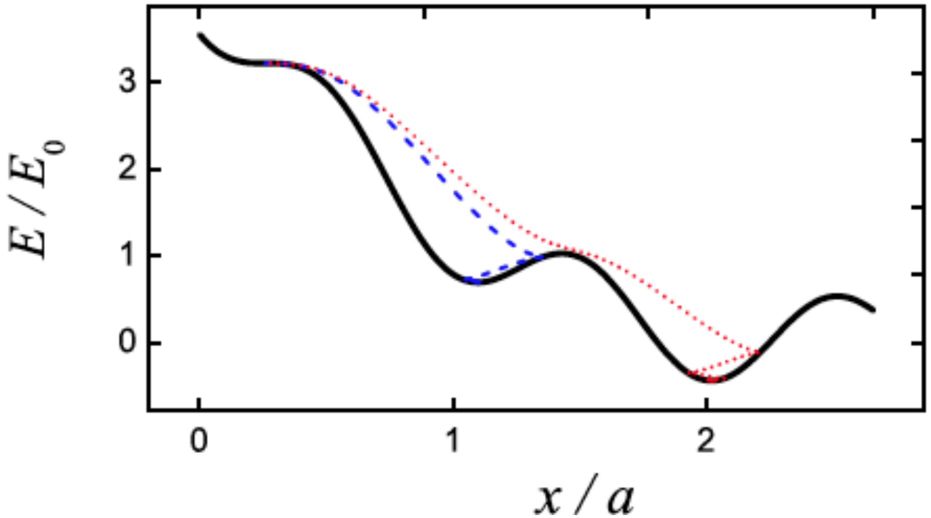
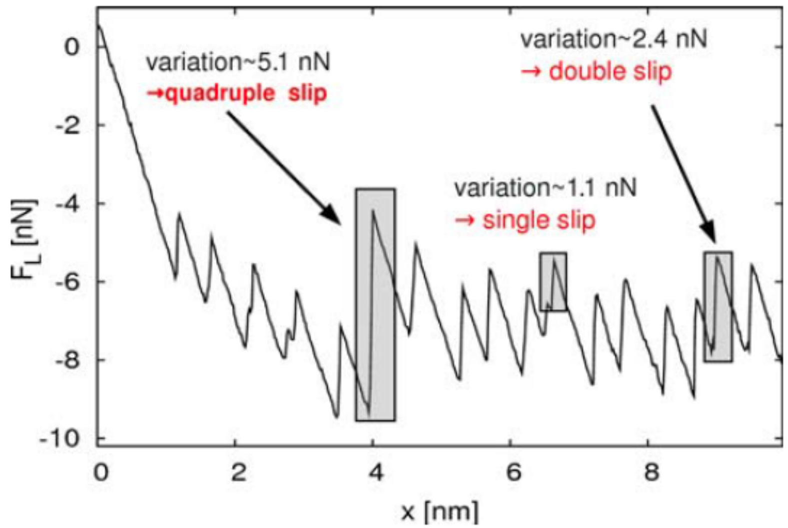
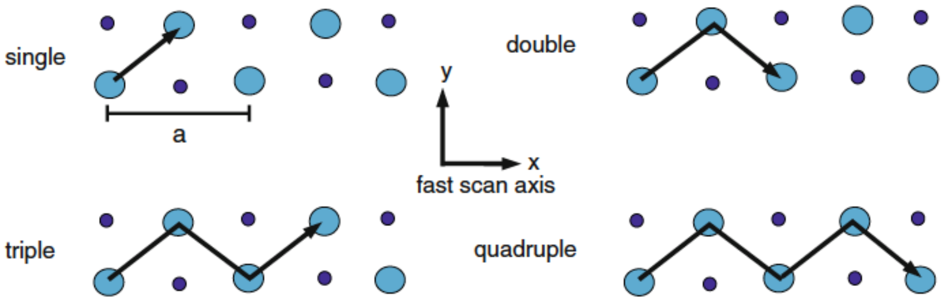
Depending on the damping coefficient single or multiple jumps are observed







$$m\frac{d^2x}{dt^2} + \gamma\frac{dx}{dt} + \frac{\partial U_{\mathrm{int}}(x,y)}{\partial x} = \xi(t)$$

$$\gamma_c = 2\sqrt{k_{\mathrm{eff}} m_{\mathrm{tip}}} = 10^{-12} - 10^{-6}\,\mathrm{kg/s}$$

R. Roth et al., Trib. Lett., **39**, 321 (2010).

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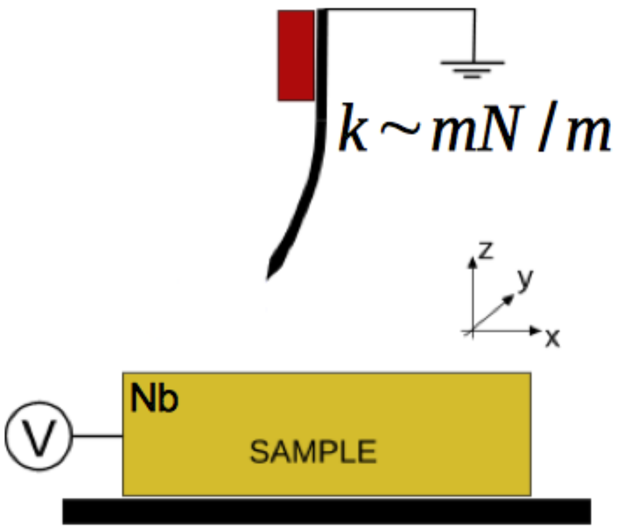
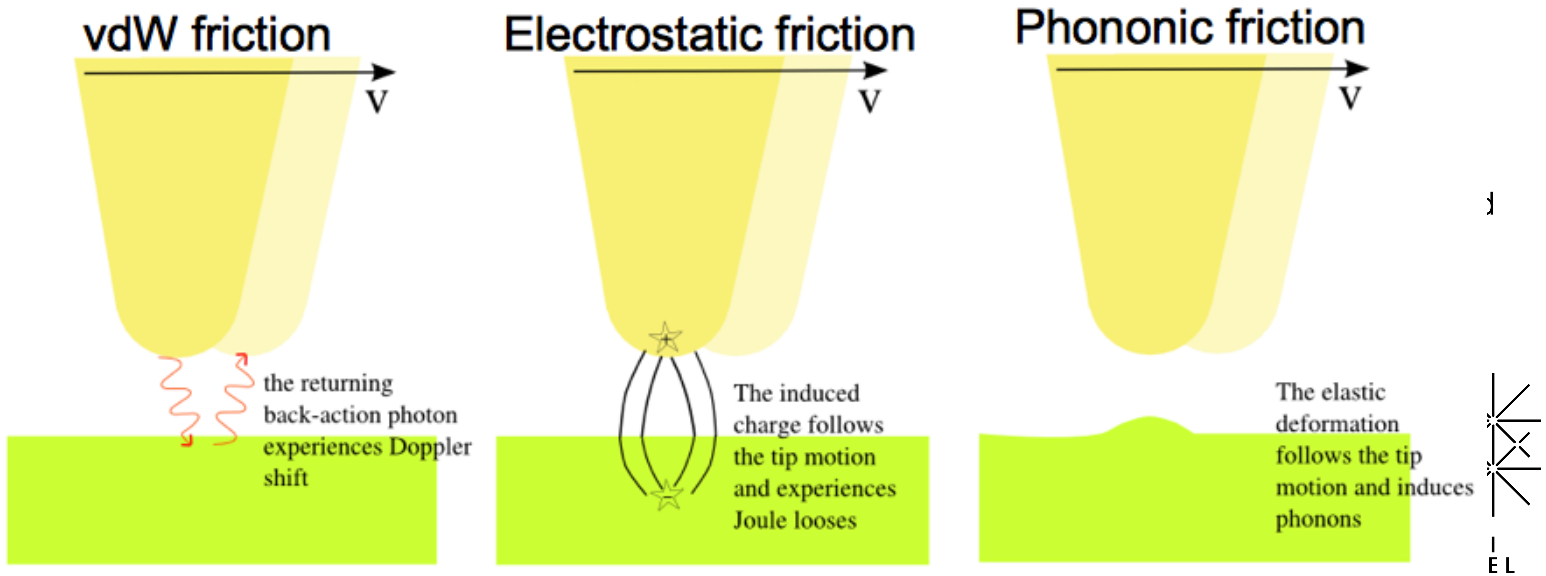
Method – AFM in pendulum geometry

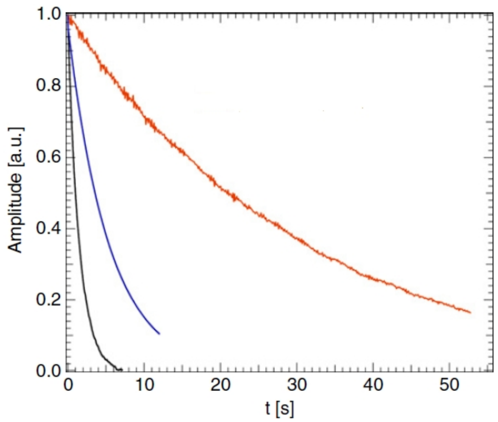


Friction without contact !

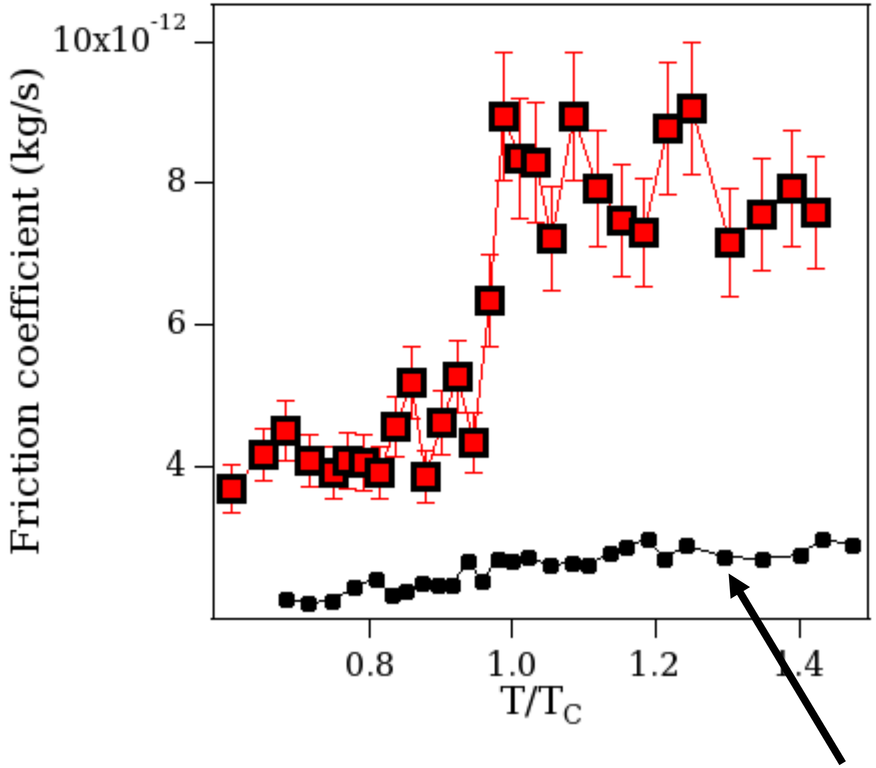
• A.I. Volokitin, et.al., ***Giant enhancement of noncontact friction between closely spaced bodies by dielectric films and two-dimensional systems***, Journ. Exp. Theor. Phys.104, (2007)



Damping coefficients vs. temperature



$$\Gamma = \frac{k}{2(\pi \cdot f)^2 \tau}$$



$A_{pk-pk} = 5\text{nm}$
$T = 6 - 13\text{K}$
$T_C = 9.2\text{K}$

Constant
Tip – sample
Distance
d=0.5nm

Free cantilever

The damping coefficient is reduceed by a factor of ~3 when the sample enters the superconducting state

M. Marcin et al., *Nature Materials* 10, 119 (2011)

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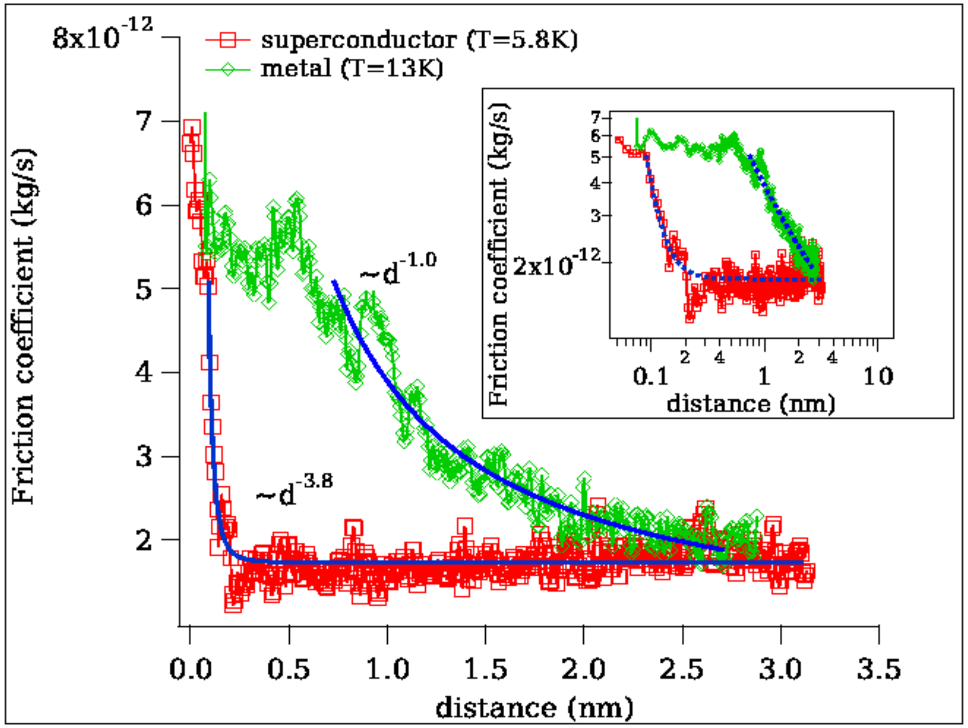
Distance dependence of damping



- A.I. Volokitin, B.N.J. Persson, and H. Ueba, ***Giant enhancement of noncontact friction between closely spaced bodies by dielectric films and two-dimensional systems***, Journ. Exp. Theor. Phys.104, 96-110 (2007)
- B.C. Stipe, H.J. Mamin, T.D. Stowe, T.W. Kenny, and D. Rugar, ***Noncontact Friction and Force Fluctuations between Closely Spaced Bodies***, Phys. Rev. Lett.87, 096801 (2001),

Metal (electronic friction):
For a spherical tip exponent n predicted by the theory (Volokitin et.al.)is n=-1.6, experimentally measured value n=-1.3 for Au (Stipe et. al.)

Superconductor (phononic friction – lateral oscillations):
For spherical tip $\Gamma \propto F(d)^2$
According to Lifshitz theory the elastic stress caused by van der Waals interaction leads to a force $F(d) \propto d^{-2}$, so the exponent n=-4.0 (Volokitin et. al.)

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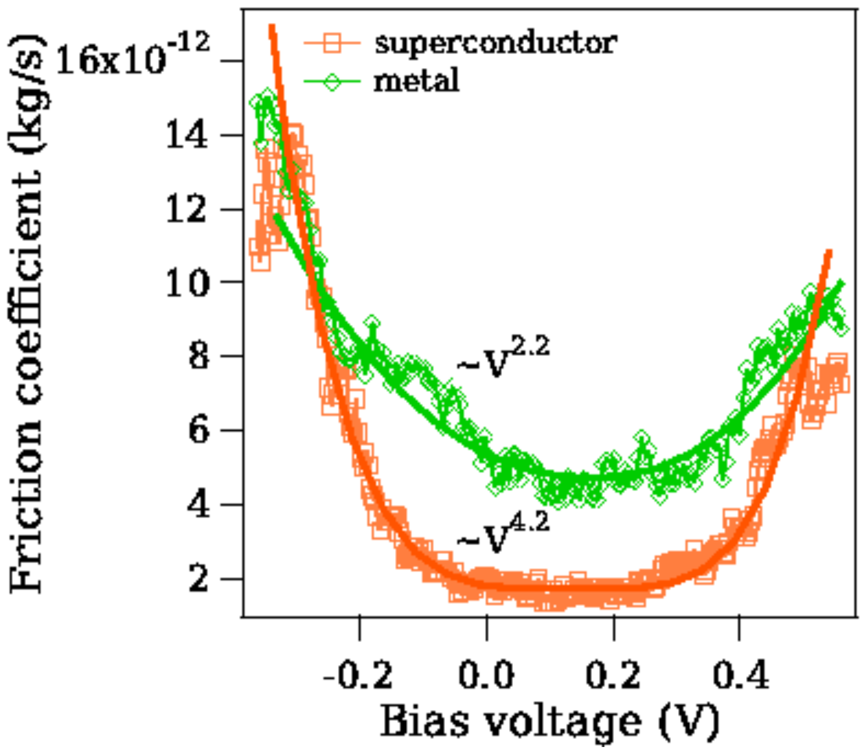
Voltage dependence of damping



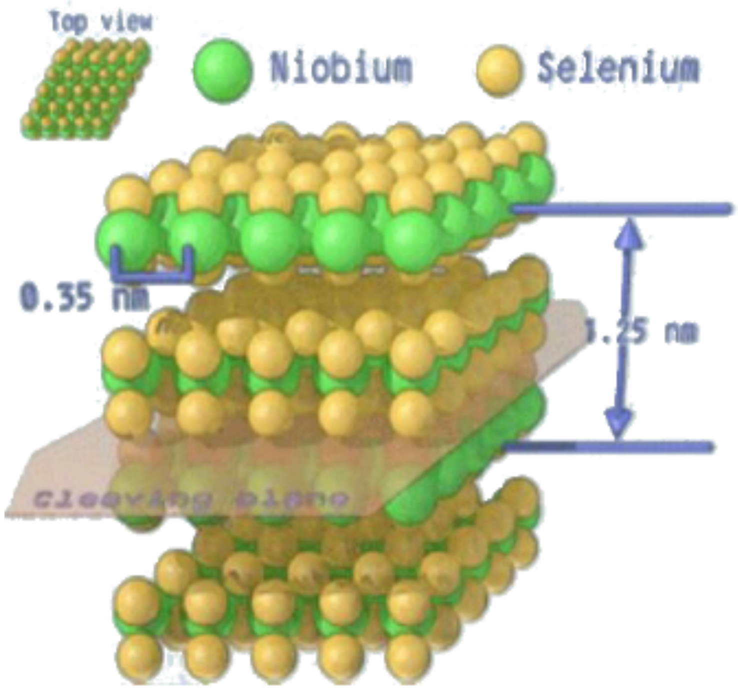
- A.I. Volokitin, B.N.J. Persson, and H. Ueba, ***Giant enhancement of noncontact friction between closely spaced bodies by dielectric films and two-dimensional systems***, Journ. Exp. Theor. Phys.104, 96-110 (2007)

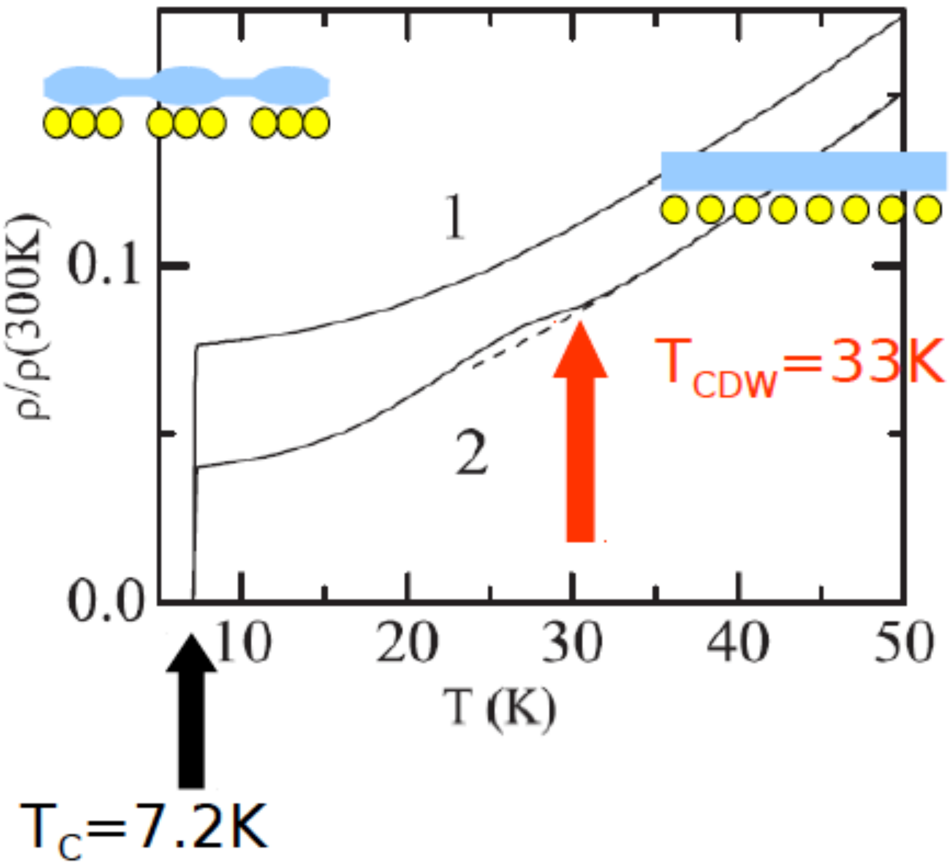
$$\Gamma \propto \left(V - V_0\right)^{\alpha}$$

Metal: friction coefficient vary as ~V^2
Superconductor: ~V^4

How about other phase transitions?

Superconductivity and charge density wave of $NbSe_2$





T_c=7.2 K and T_{CDW}=33K

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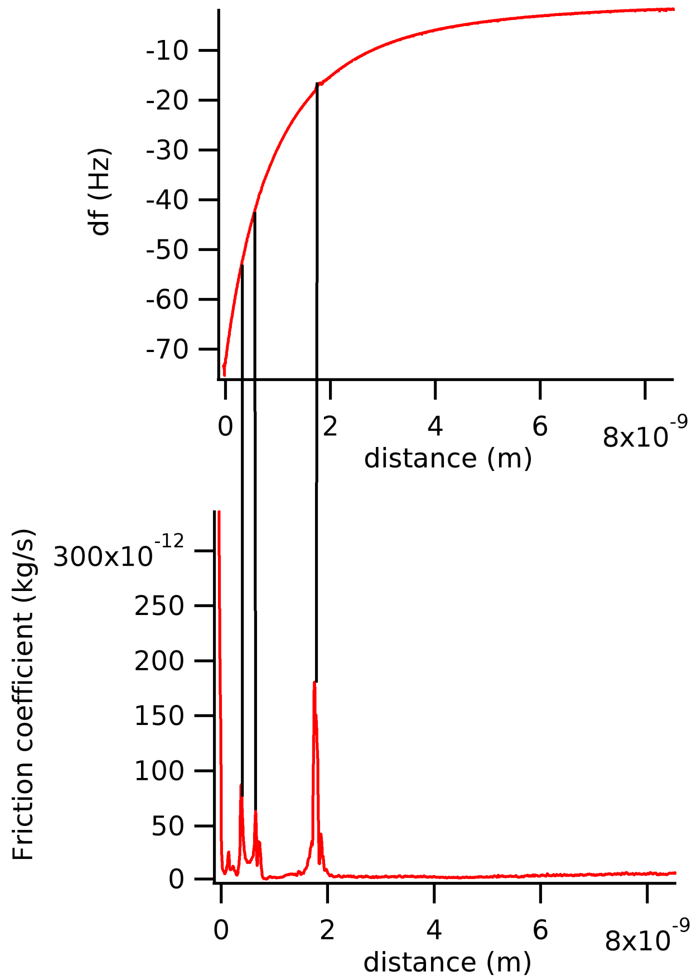
Results – force distance curves on $NbSe_2$

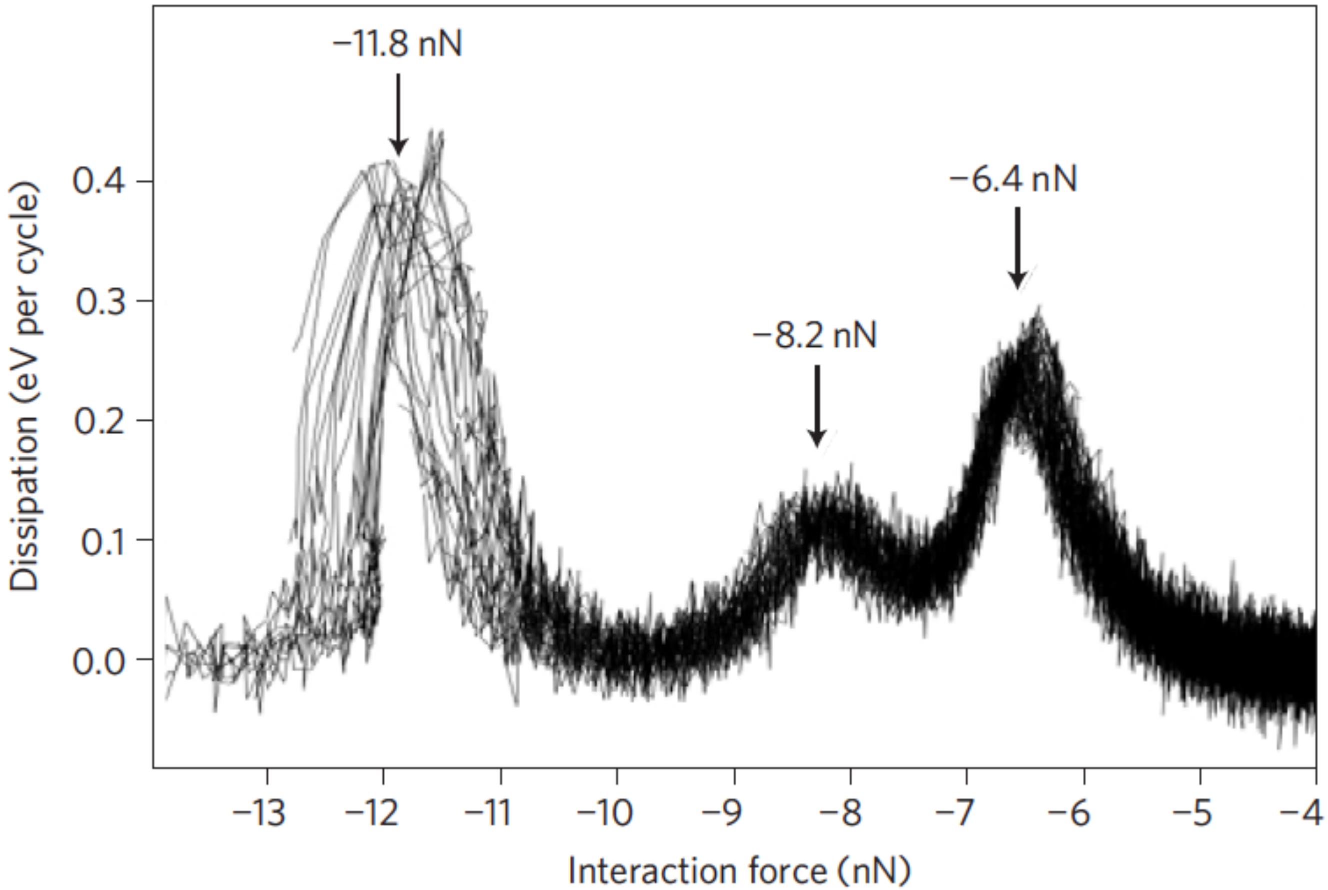
Results obtained with pendulum geom. AFM. The giant peaks of non-contact friction were observed.
(as reported before: K. Saitoh, et.al., *Gigantic maximum of nanoscale noncontact friction,* PRL105 (2010), 236103.)



Contact potential compensated

T=6.2K

Dissipation maxima at the same forces



Dissipation vs. distance data with different voltages coincide by plotting dissipation vs. force curves

M. Langer et al., Nat. Mat. 15th Dec 2013, DOI: 10.1038/NMAT3836

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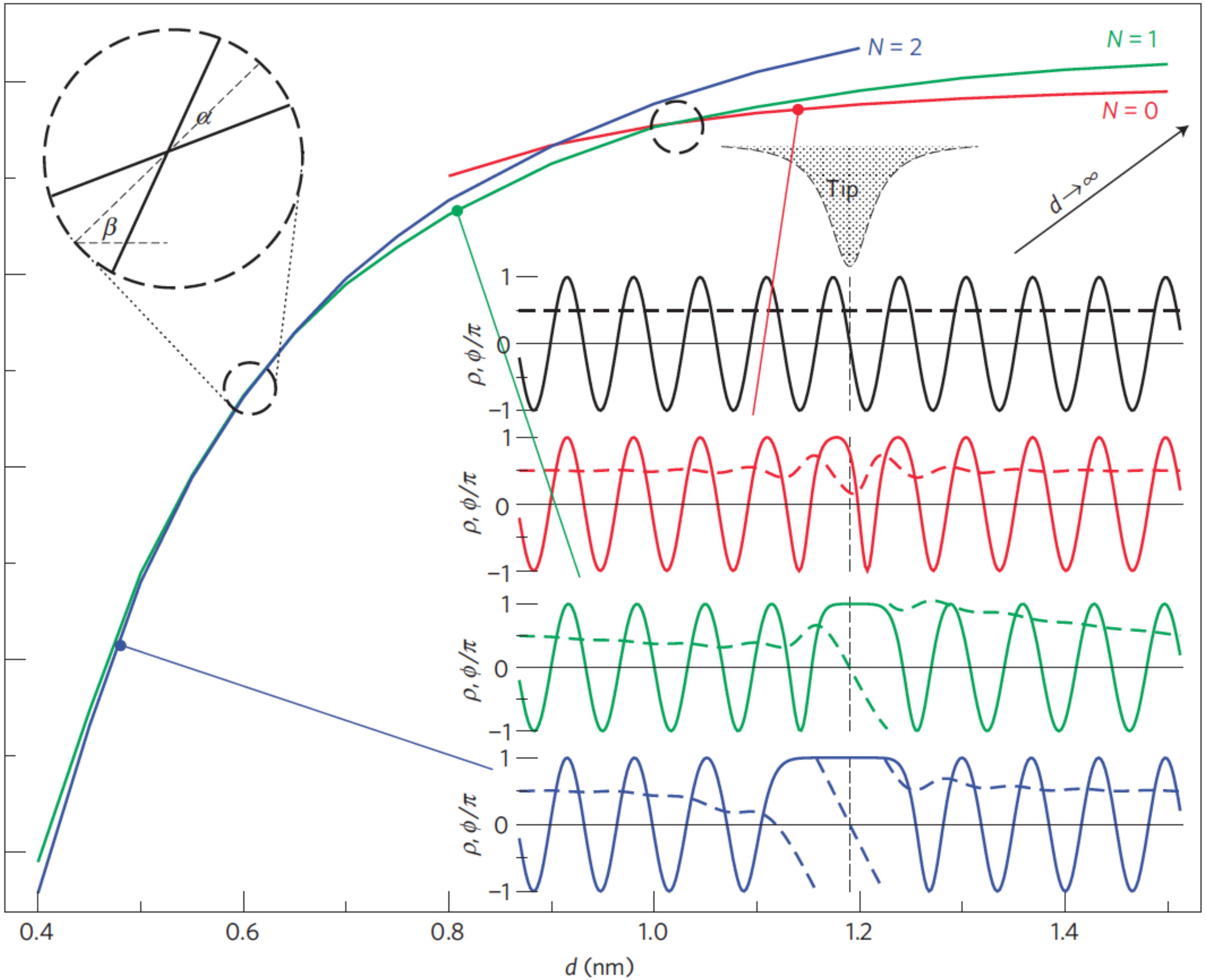
Perturbation of probing tip leads to phase slips of the local charge density wave



F. Pellegrini, G.E. Santoro, E. Tossatti

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Summary

•Contact resonance force microscopy gives information about the normal contact stiffness, which can be related to the contact size
•Lateral contact stiffness show very small values and more scatter

•Submolecular resolution with CO-terminated tips

•Pulling of single molecules to probe the energy landscape
(detachment energy, energy corrugation for lateral motion/diffusion energy)

•Pendulum AFM on a superconductor
-Influence of electronic friction observed

•Damping on $NbSe_2$: Tip induced phase slips are related to giant non-contact friction

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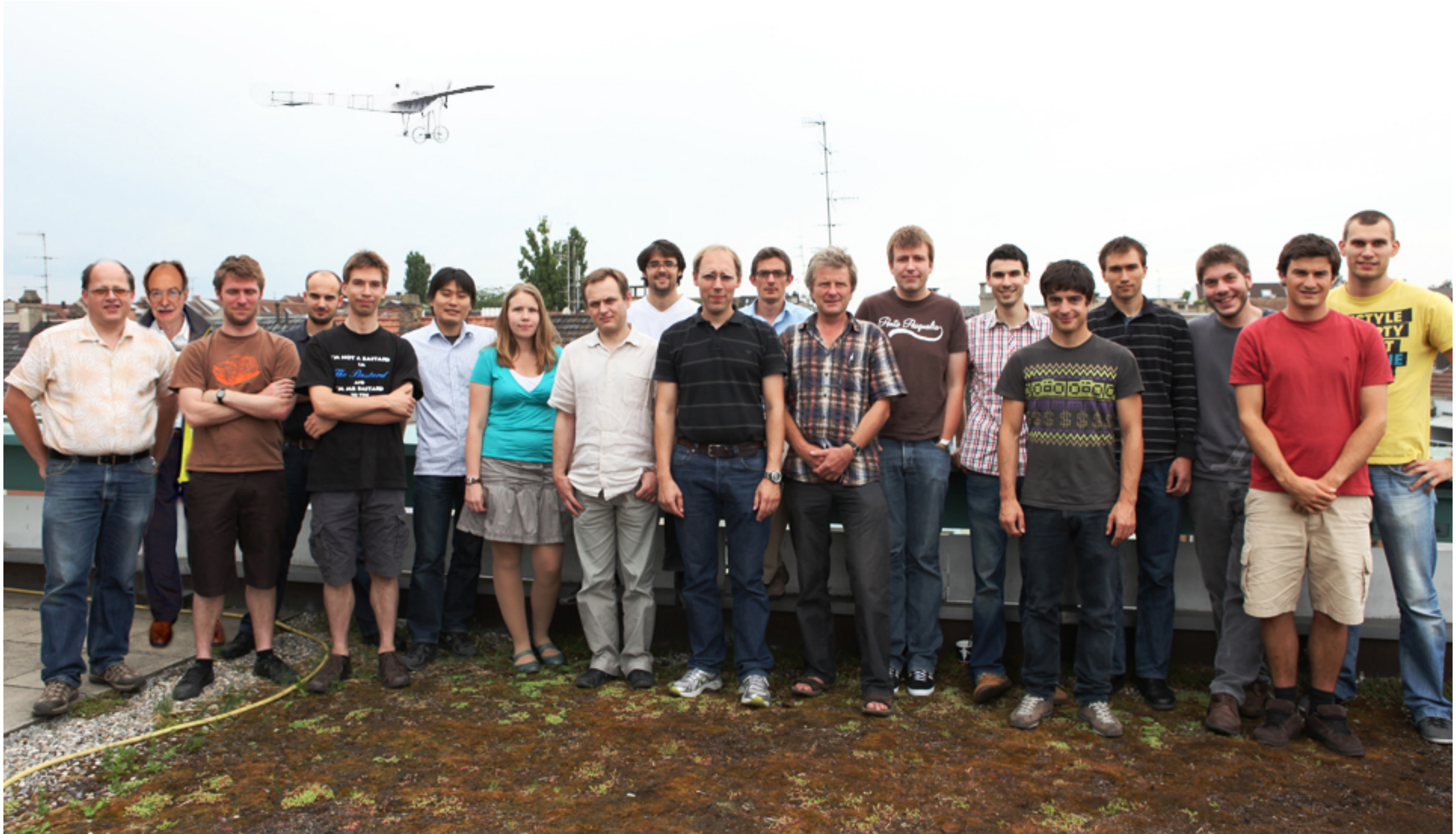
Acknowledgement



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