



qbio
quantitative
biology

1) Introduction to Scanning Probe Microscopy

2) The Force

3) Methods

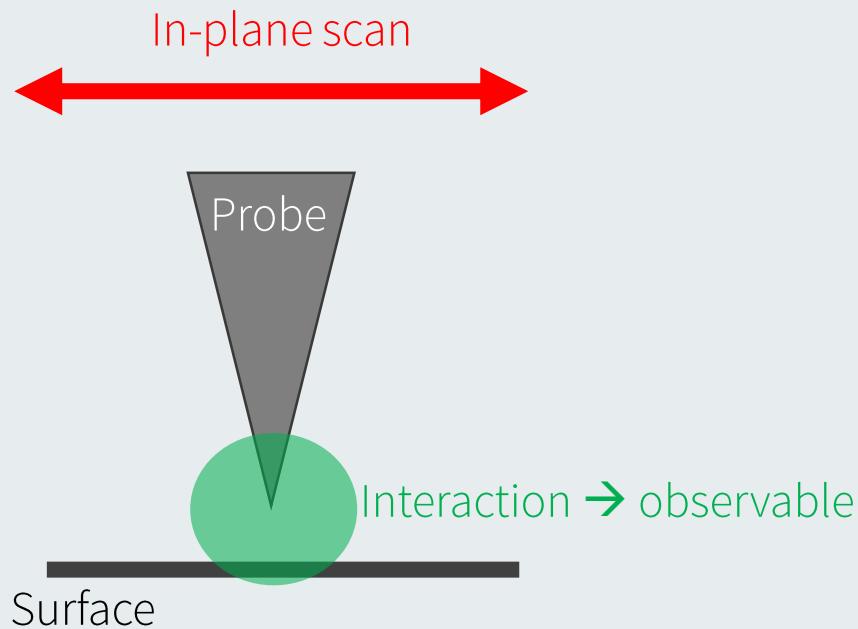
Cantilevers

Static and Dynamic AFM

4) Instruments

5) Advanced and novel AFM methods

Atomic Force Microscopy and Scanning Probe Microscopy



The Nobel Prize in Physics 1986
Ernst Ruska, Gerd Binnig, Heinrich Rohrer

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The Nobel Prize in Physics 1986



Ernst Ruska
Prize share: 1/2

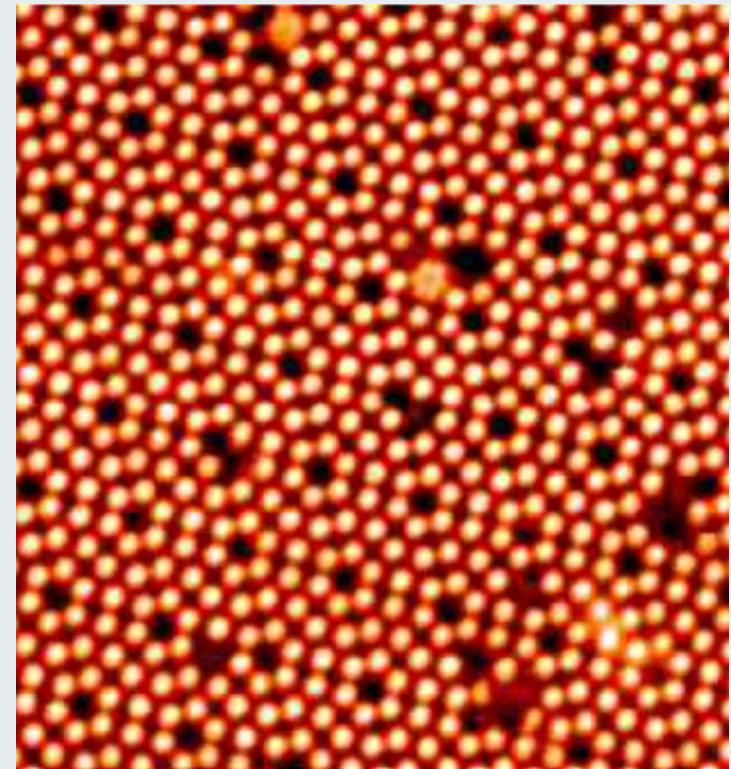
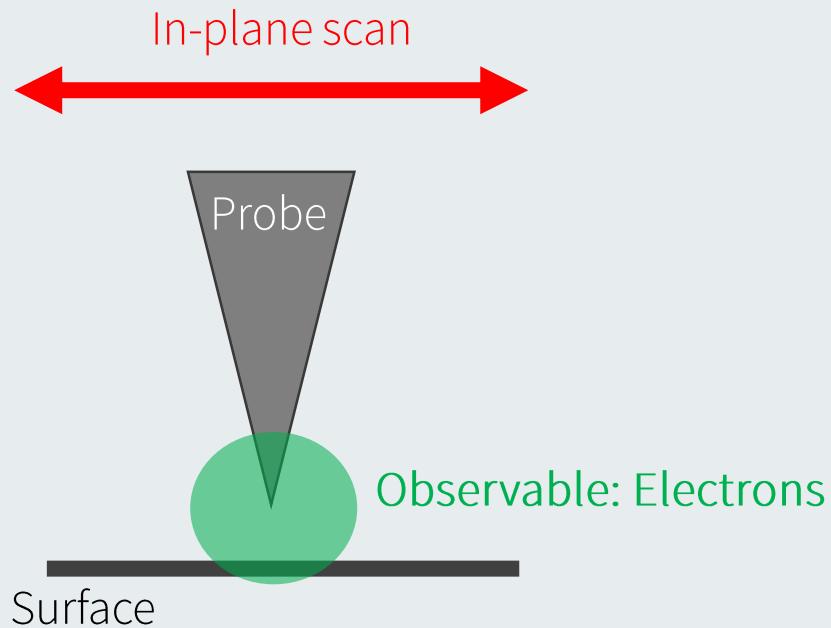
Gerd Binnig
Prize share: 1/4

Heinrich Rohrer
Prize share: 1/4

Atomic Force Microscopy and Scanning Probe Microscopy

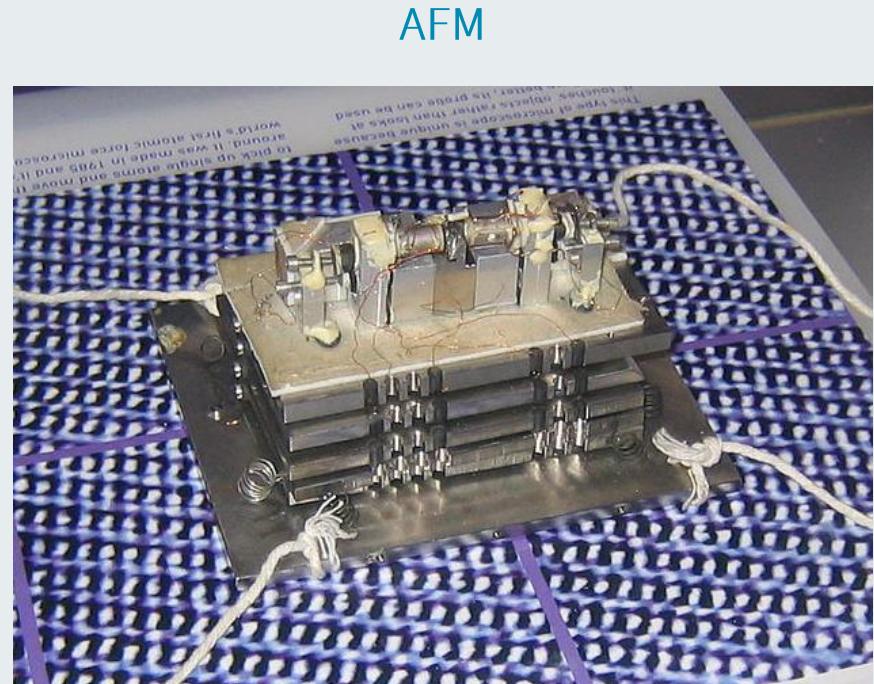
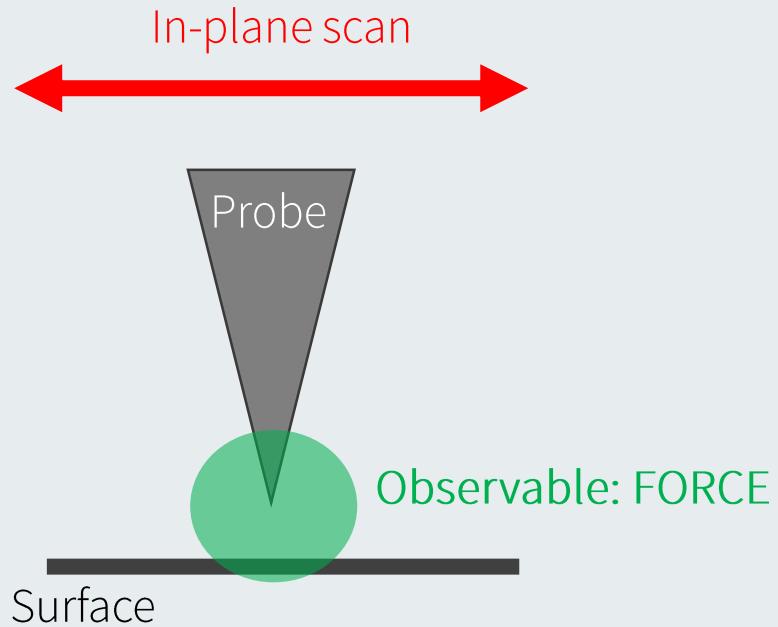


1981 - Invention of the STM



Si (111) 7x7
Omicron website:
<http://www.omicron.de/results>

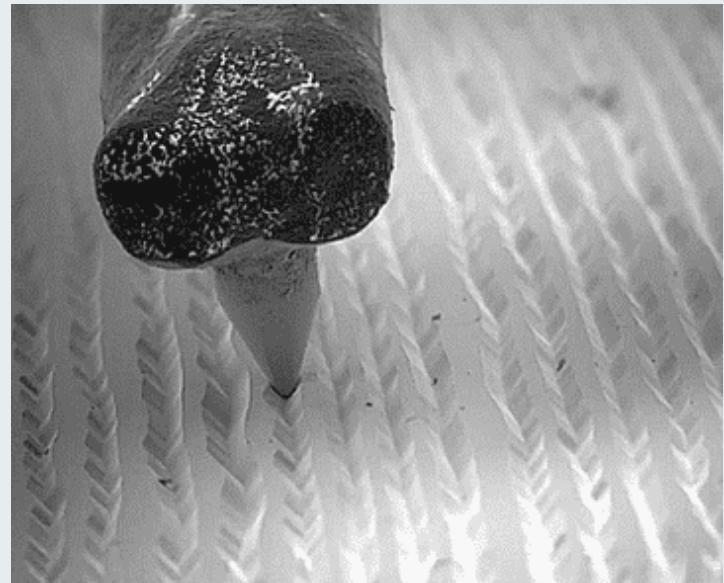
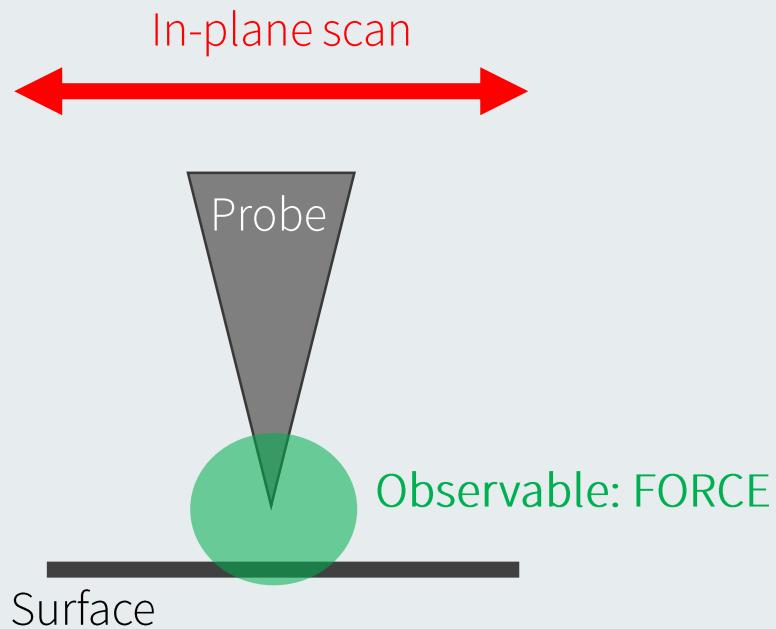
Atomic Force Microscopy and Scanning Probe Microscopy



Science Museum, London, UK.

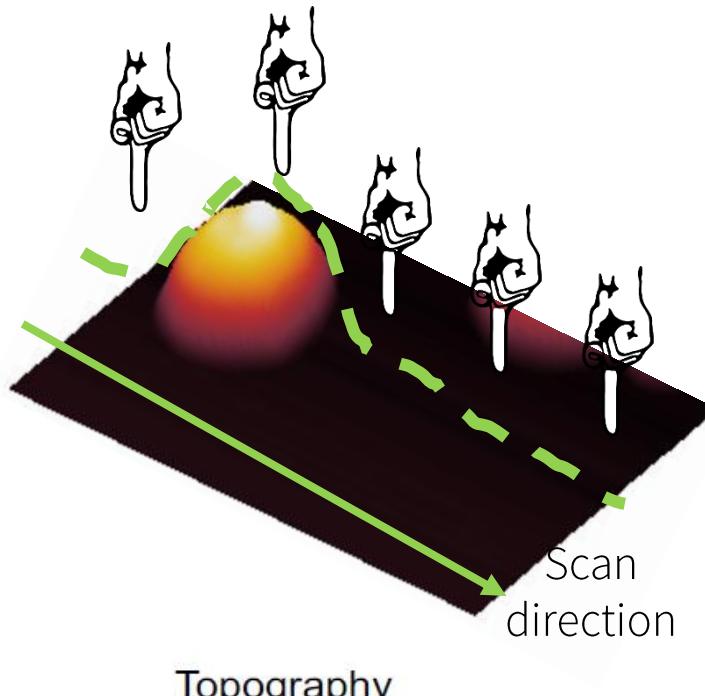
Binnig G, Quate CF, Gerber C. Atomic force microscope. *Phys. Rev. Lett.* 1986 Mar 3;56(9):930-933

Atomic Force Microscopy and Scanning Probe Microscopy

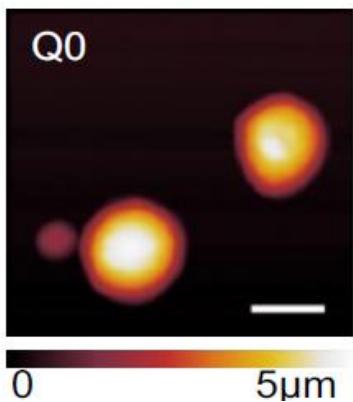


Source: wikipedia

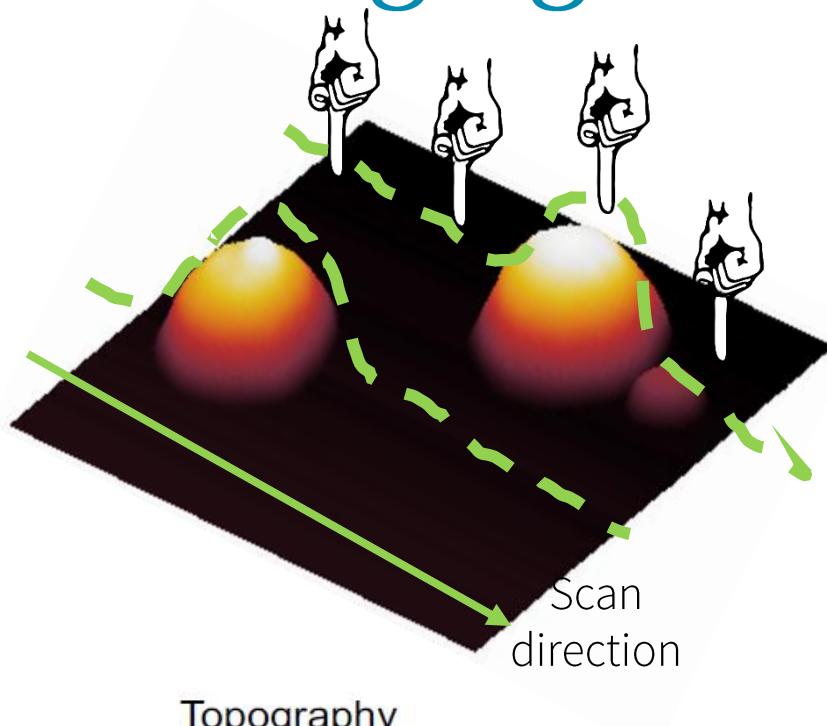
Imaging



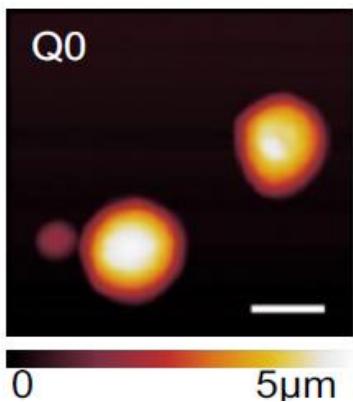
Topography



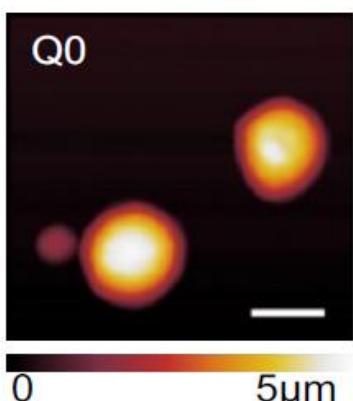
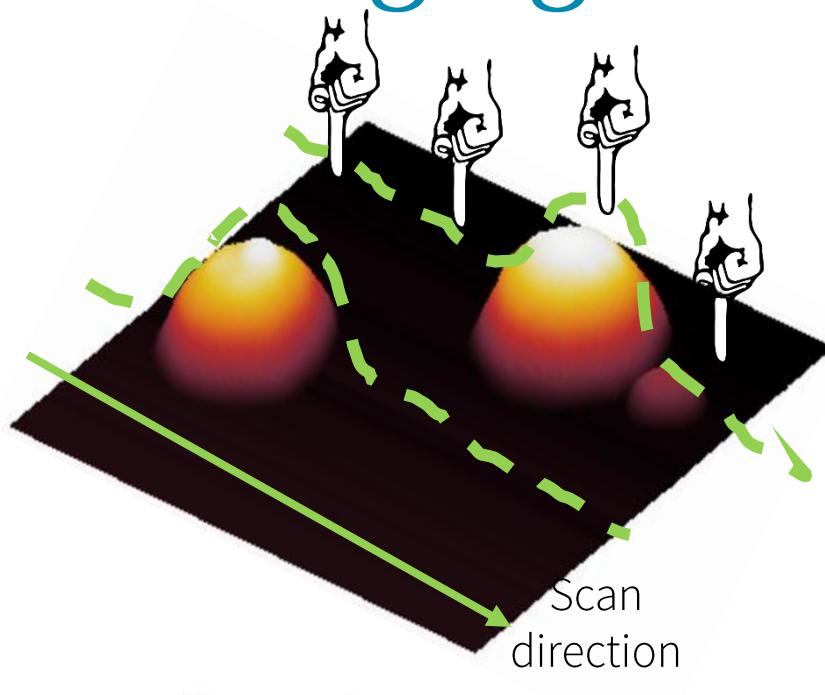
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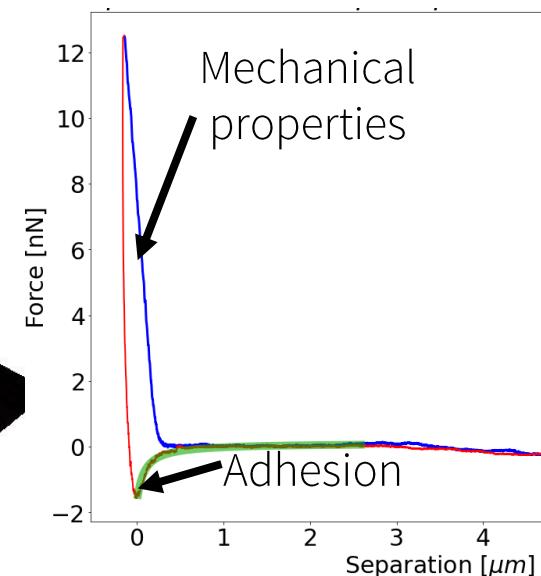
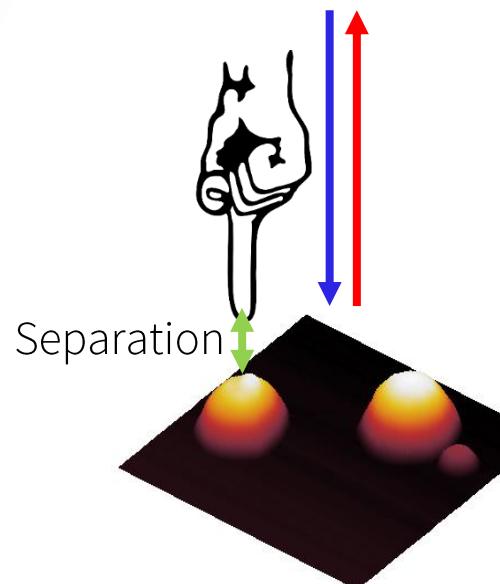
Topography



Imaging



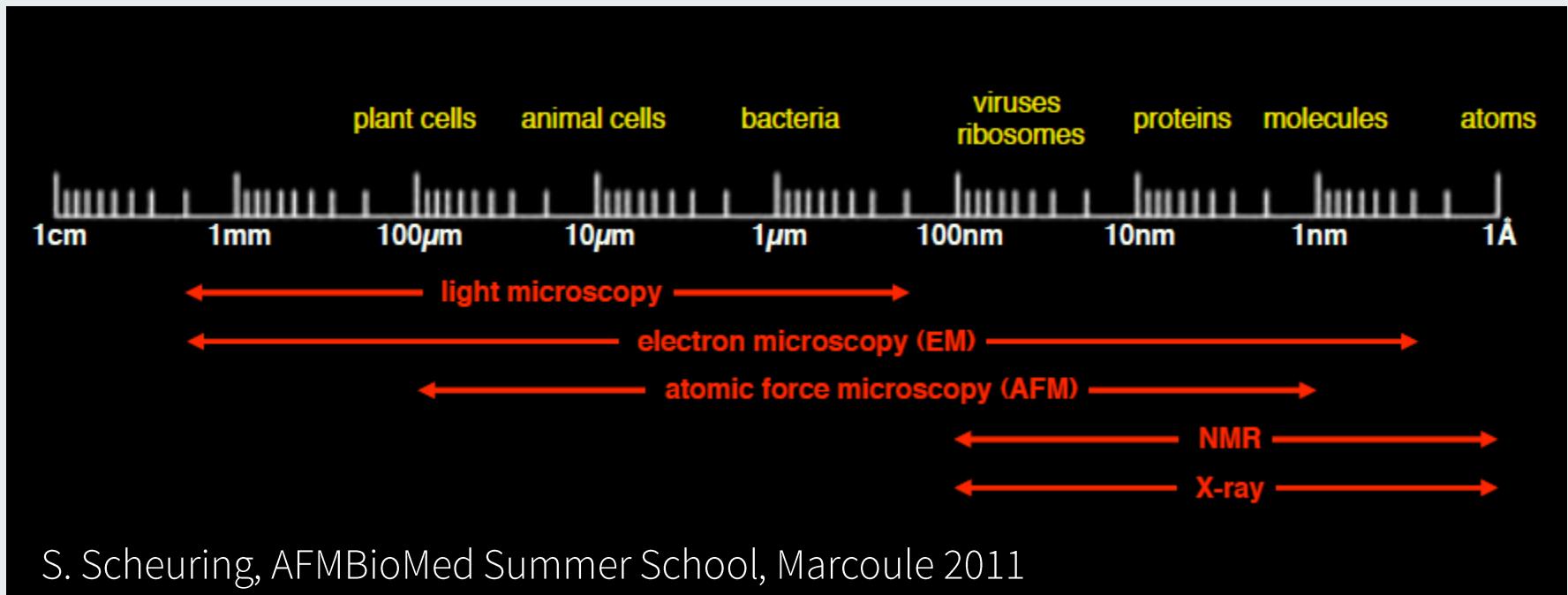
Force Spectroscopy



Techniques in Structural Biology



Dimensions in life science – what technique is appropriate

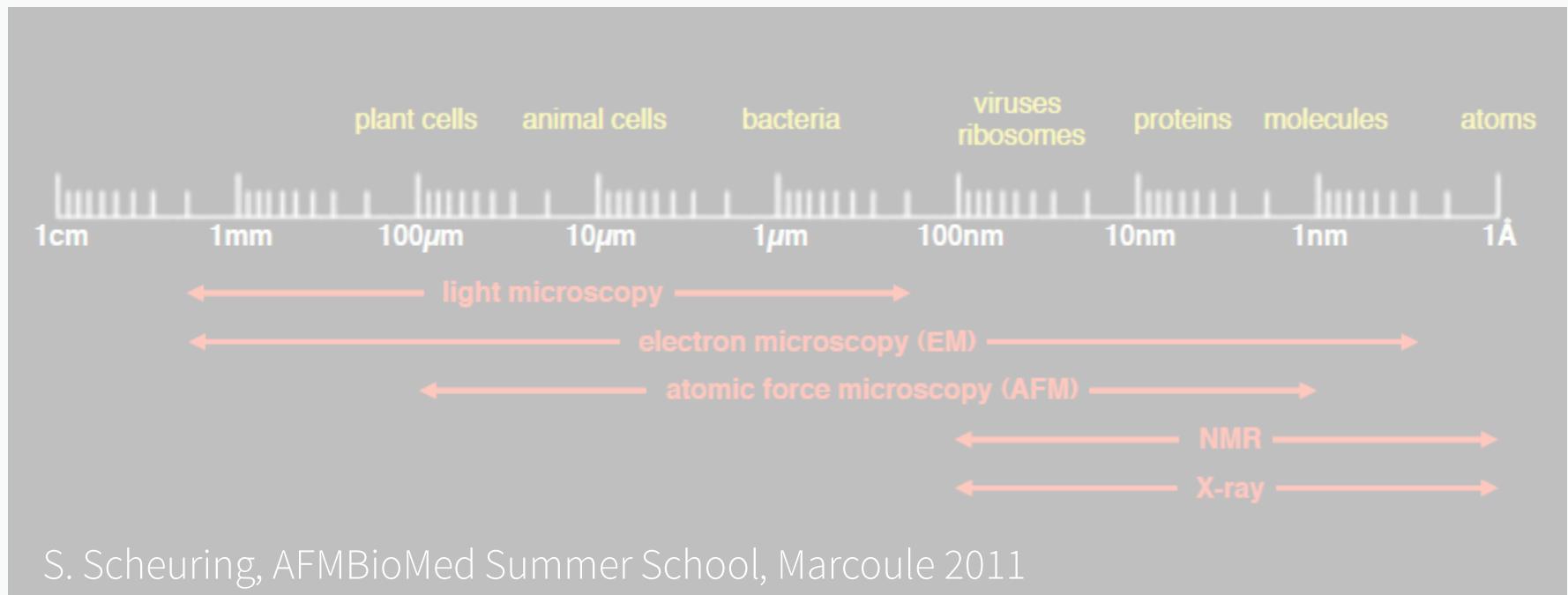


LENGTHSCALE

Techniques in Structural Biology



Dimensions in life science – what technique is appropriate

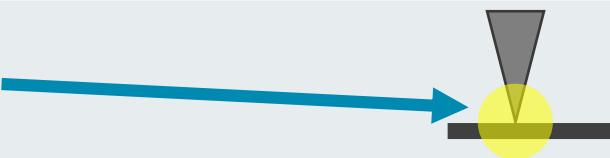


S. Scheuring, AFMBioMed Summer School, Marcoule 2011

LENGTHSCALE
TIMESCALE → Dynamics

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3) Methods

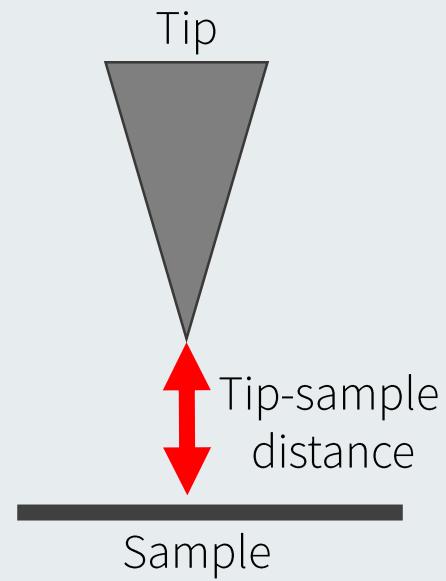
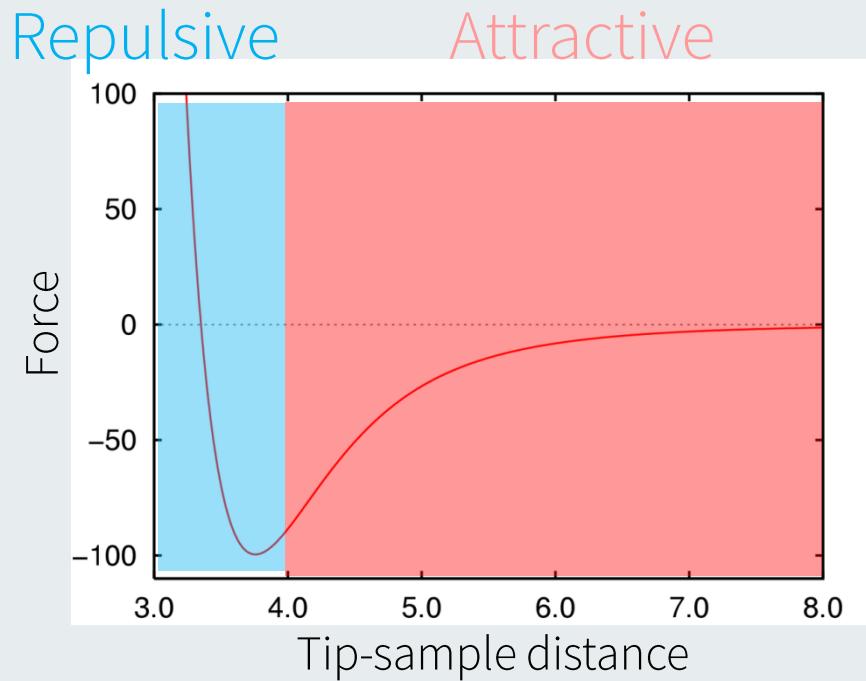
Cantilevers

Static and Dynamic AFM

4) Instruments

5) Advanced and novel AFM methods

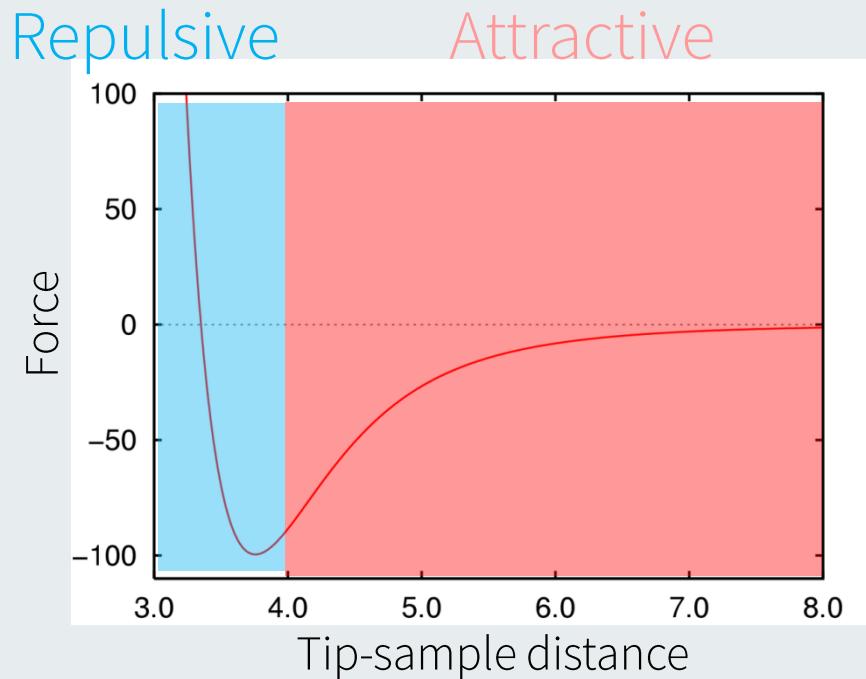
Interaction Forces at nanoscale



Repulsion due to overlap of tip-sample electronic shells

Attractive due to Van der Waals, capillarity, charges, etc

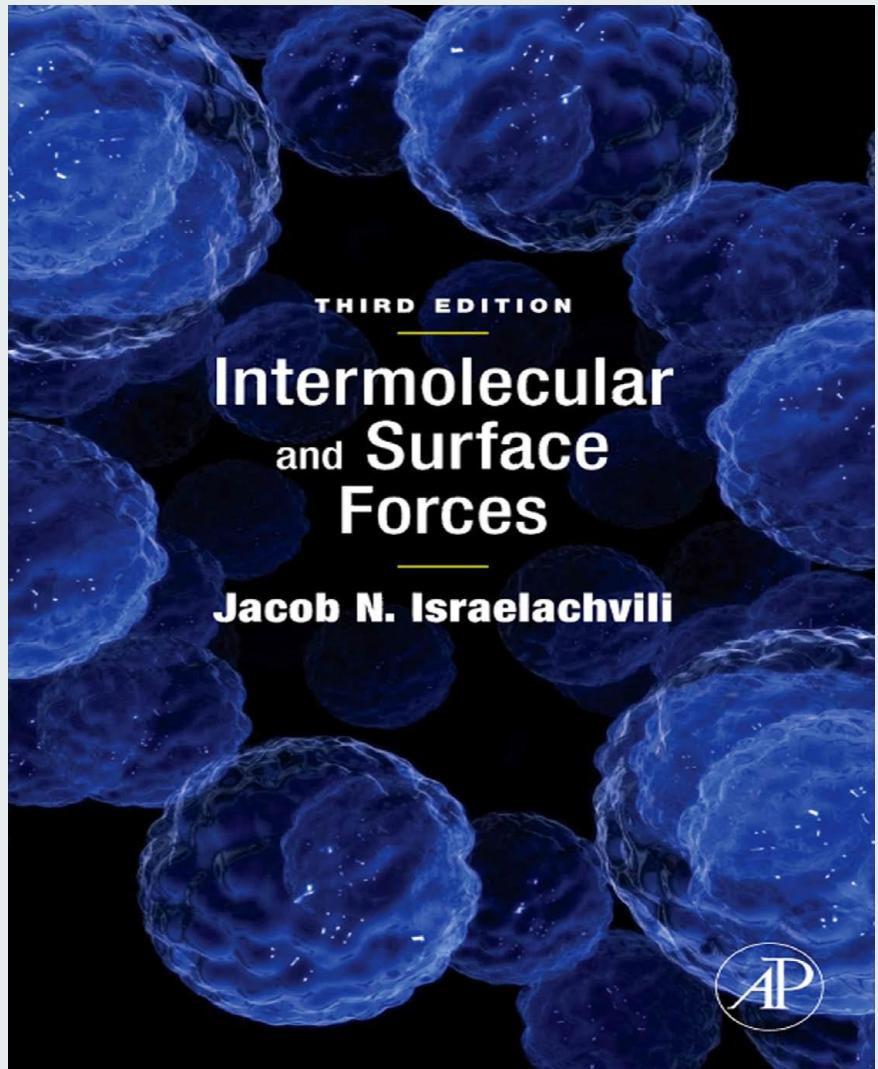
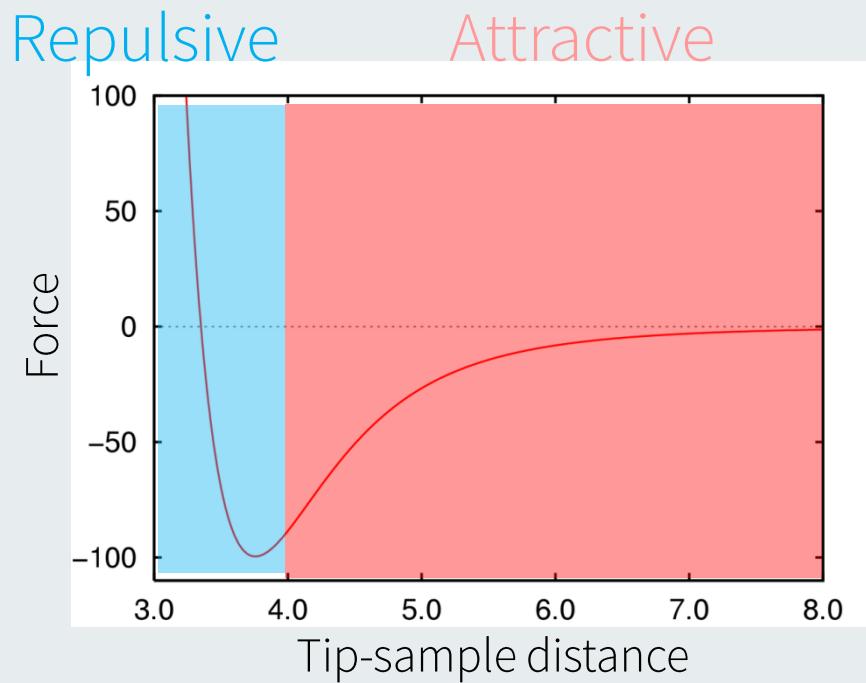
Interaction Forces at nanoscale

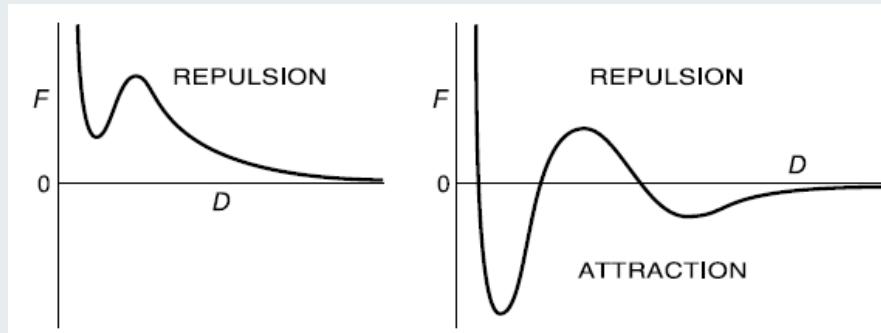


Richard P.
Feynman
(1918 – 1988)

“... If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another...”

Interaction Forces at nanoscale





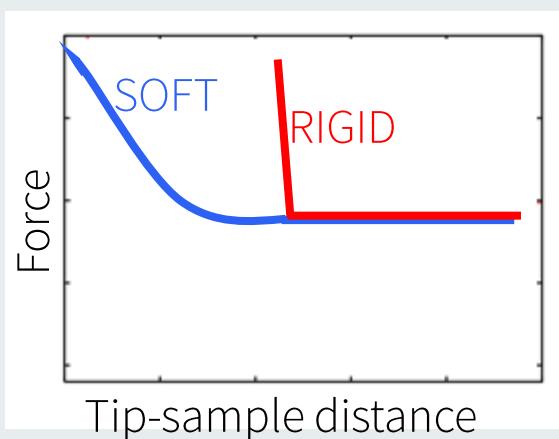
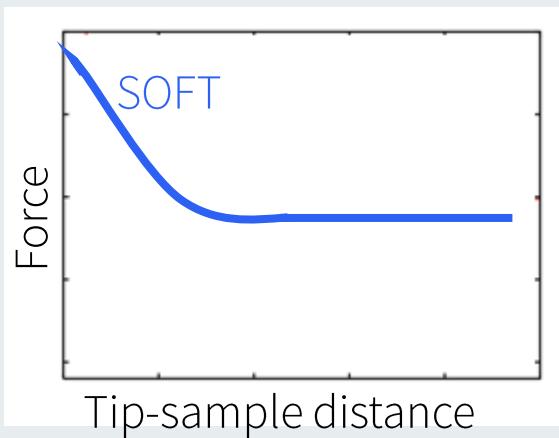
Tip sample Interaction Force depends on

- 1) Tip and sample geometry
- 2) Tip and sample nature (chemical affinity, charges)
- 3) Tip and/or Sample stiffness
- 4) Environment (liquid, air, gas, vacuum)

Interaction Forces at nanoscale



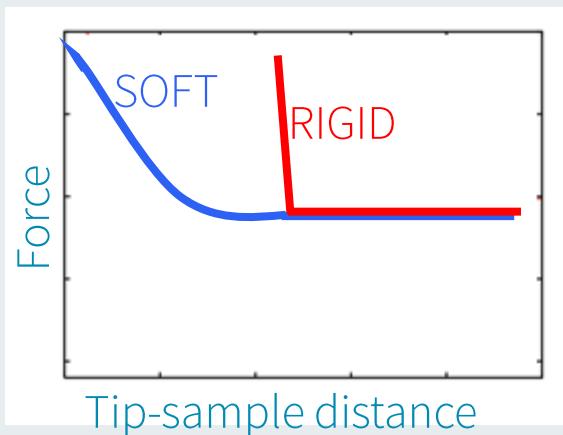
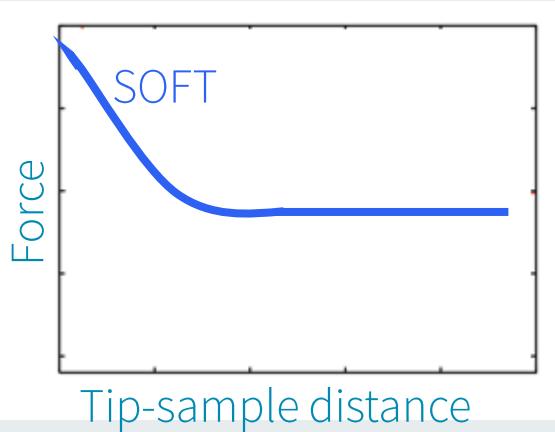
Tip and/or Sample stiffness



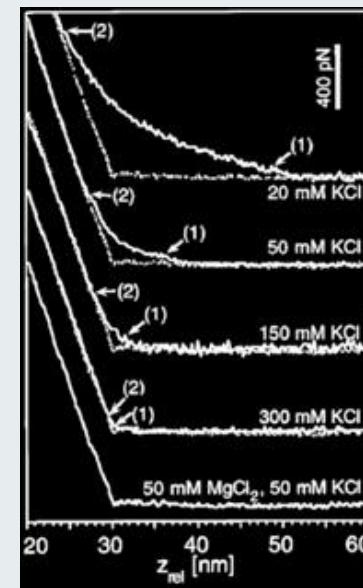
Interaction Forces at nanoscale



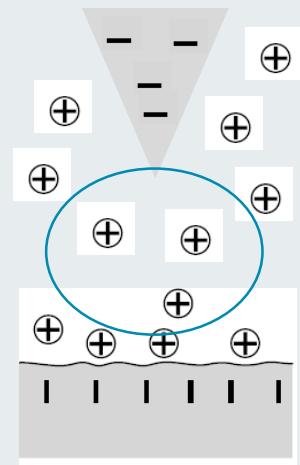
Tip and/or Sample stiffness



Environment: liquid + salt



IONS ARE
IMPORTANT!!!



Daniel J Müller, Dimitrios Fotiadis, Simon Scheuring, Shirley A Müller & Andreas Engel *Electrostatically balanced subnanometer imaging of biological specimens by atomic force microscopy* *Biophys J*, 1999, 76 (2): 1101-1111

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Cantilevers

Static and Dynamic AFM

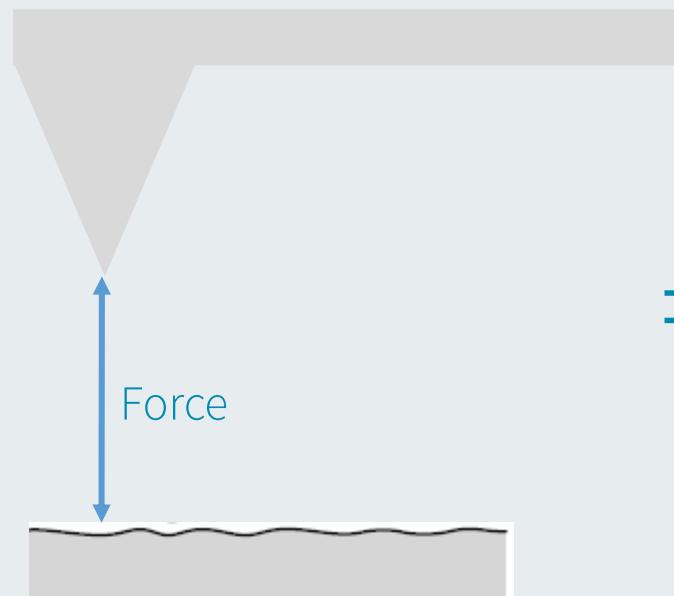
4) Instruments

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Cantilevers

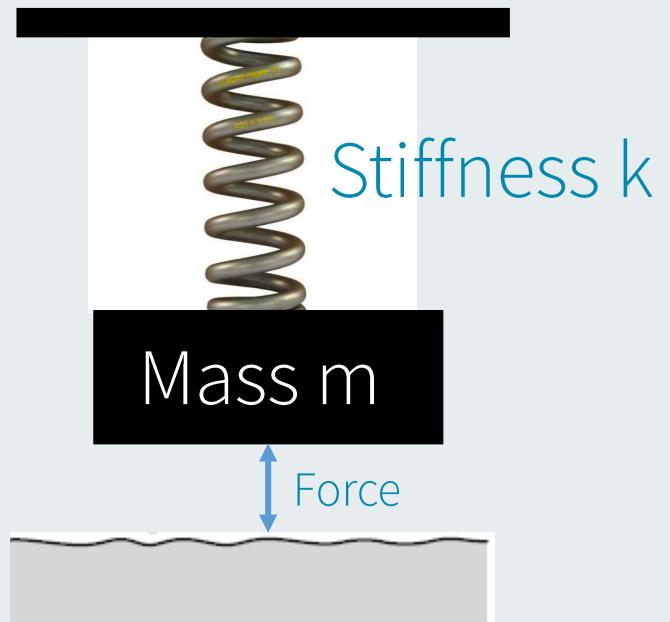


Cantilever



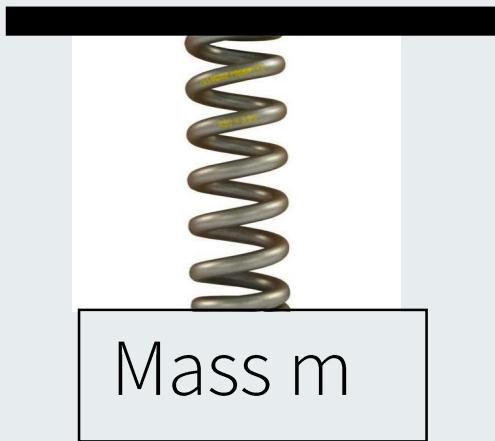
Sample

=

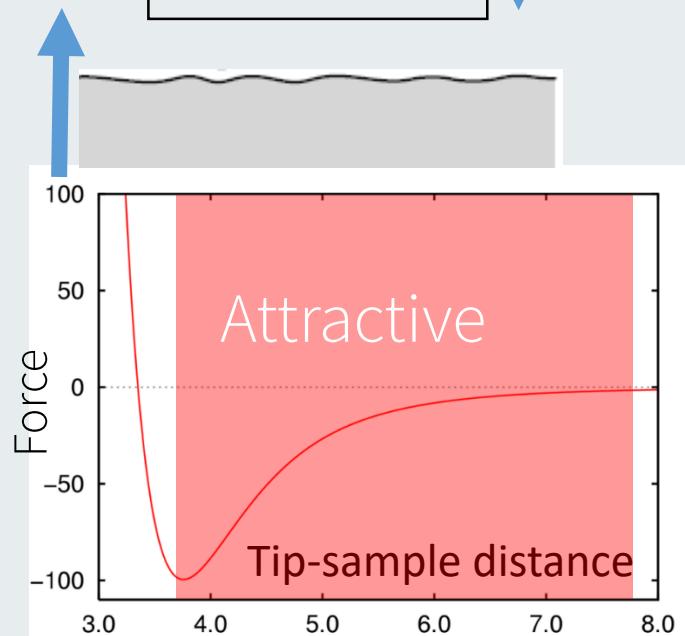
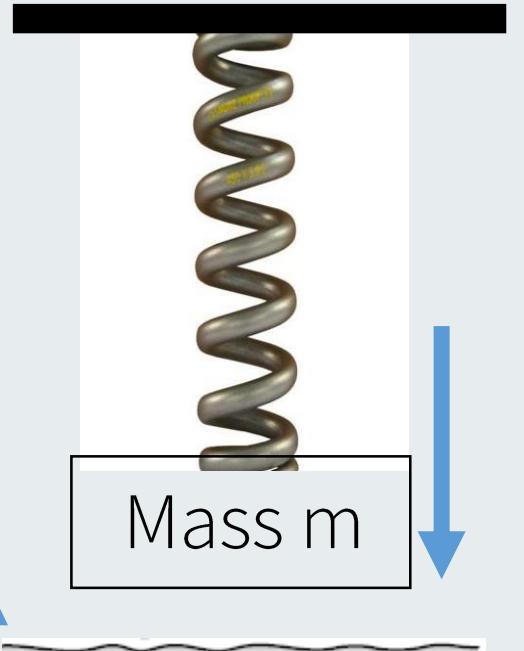


Sample

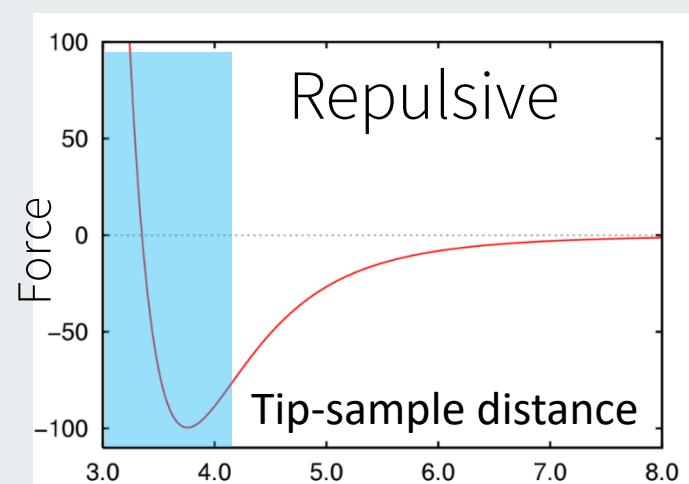
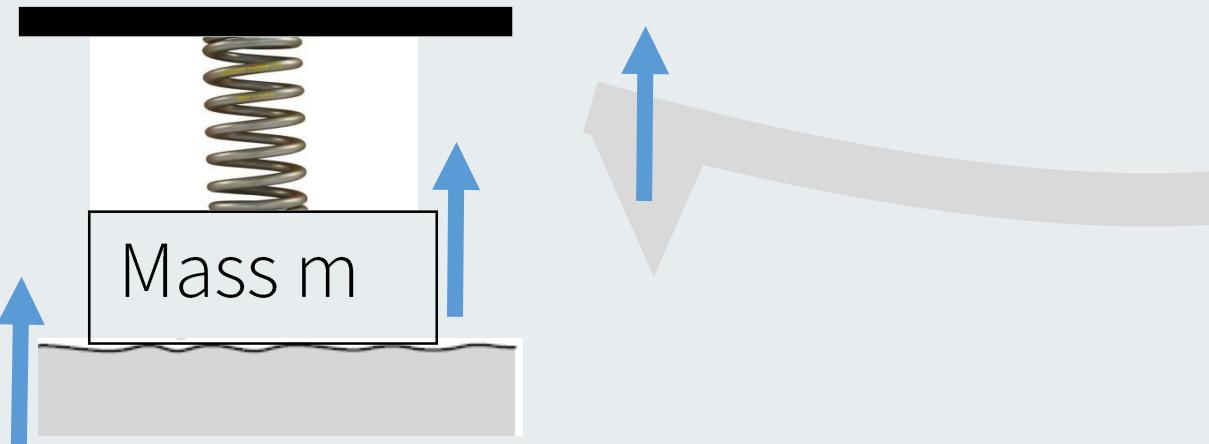
Cantilevers



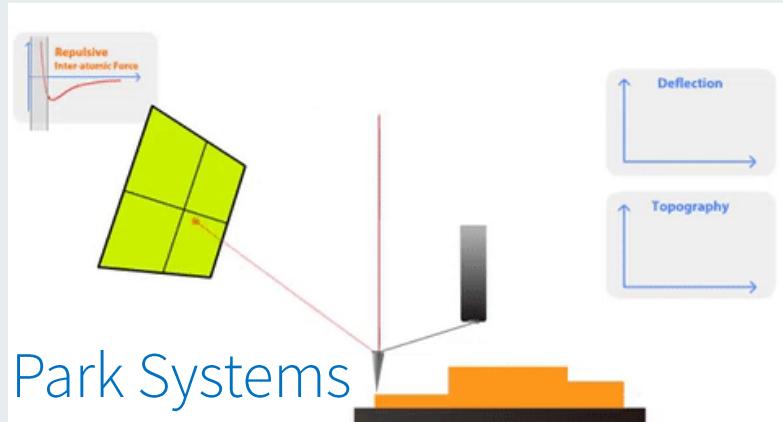
Cantilevers



Cantilevers



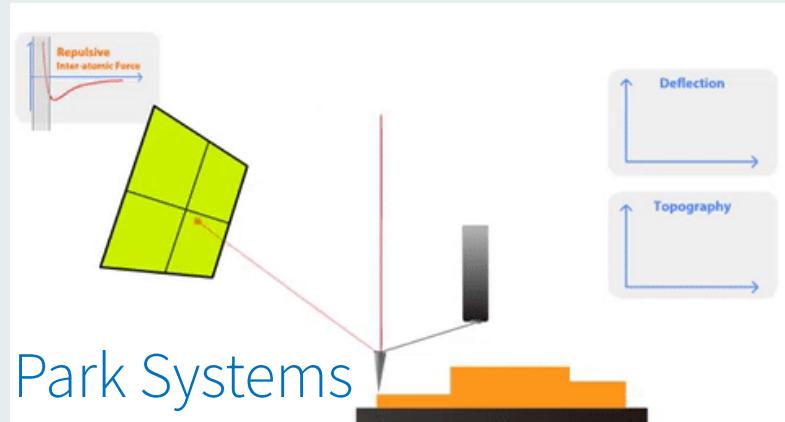
Contact Mode



Park Systems

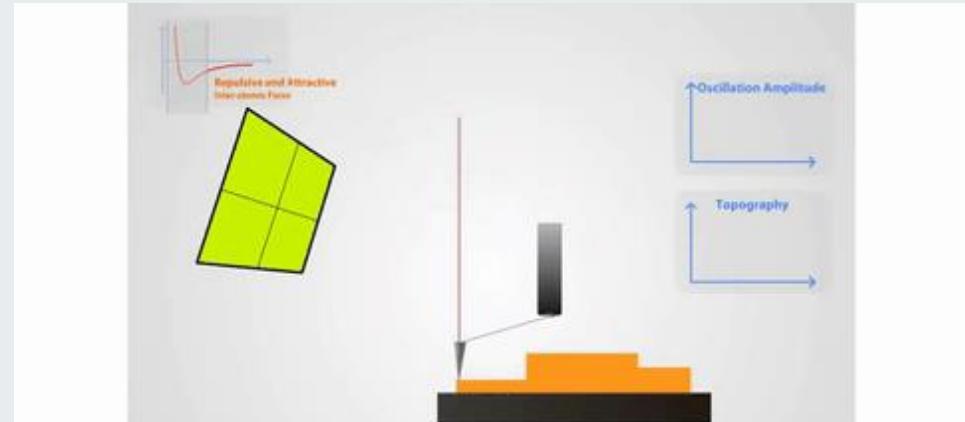
- Tip and sample in mechanical contact
- Images acquired at constant deflection

Contact Mode



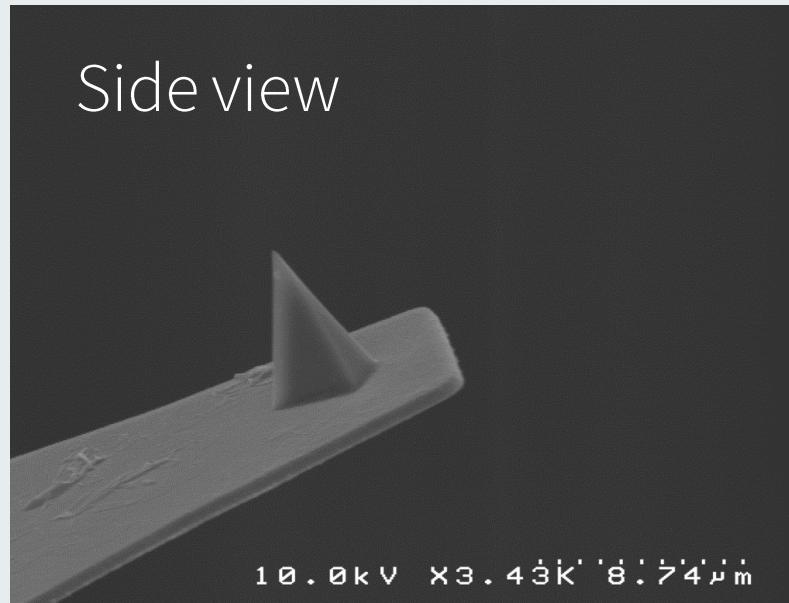
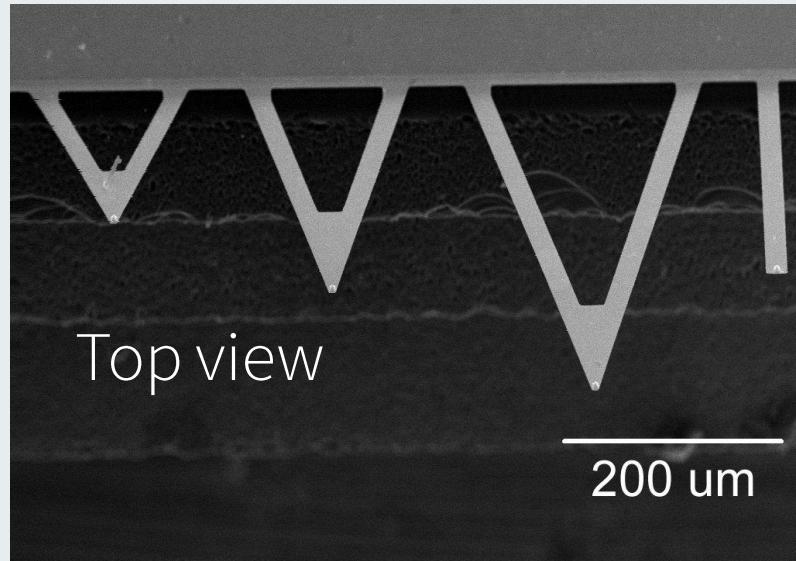
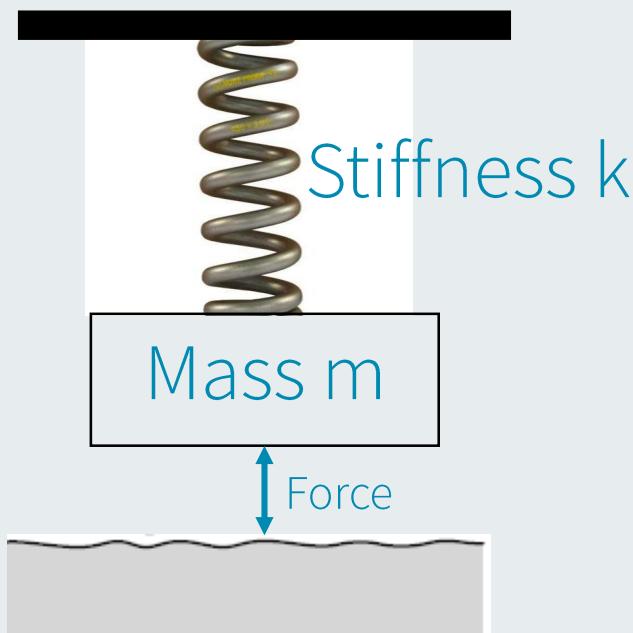
- Tip and sample in mechanical contact
- Images acquired at constant deflection

Dynamic (intermittent) Mode



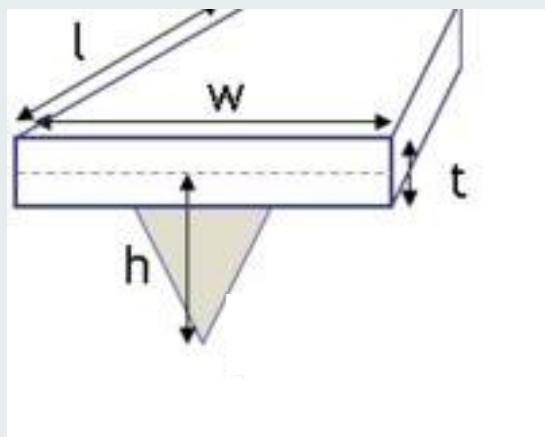
- Tip and sample in intermittent mechanical contact
- Images acquired at constant oscillation amplitude
- Less friction

Cantilevers





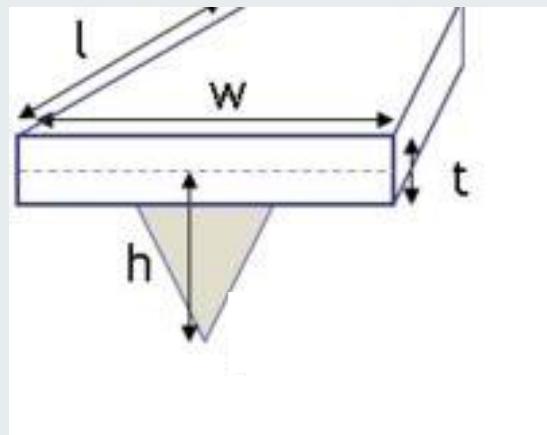
Stiffness k : from 0.006 N/m to 100 N/m
Extrinsic property



$$k = \frac{Ewt^3}{4L^3} \quad k \text{ must be calibrated !!}$$



Stiffness k : from 0.006 N/m to 100 N/m
Extrinsic property

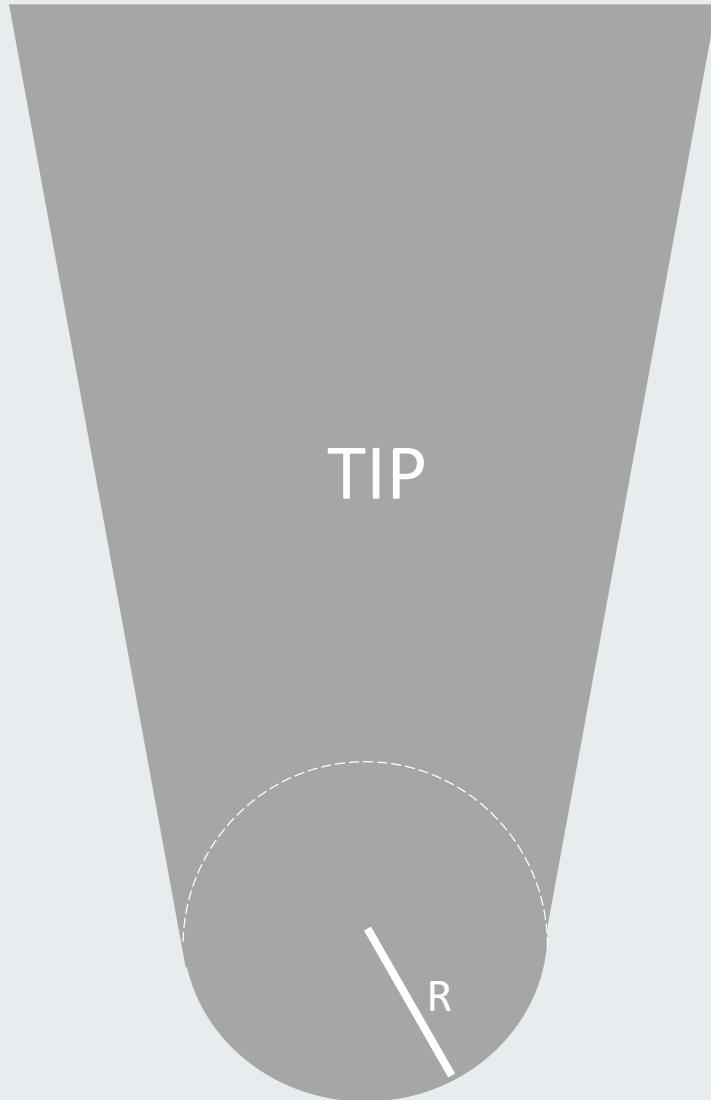


$$k = \frac{Ewt^3}{4L^3} \quad k \text{ must be calibrated !!}$$

E = Young's modulus [Pa] Intrinsic property

Length L : from 10 μm to 500 μm

Materials: Silicon and Silicon Nitride



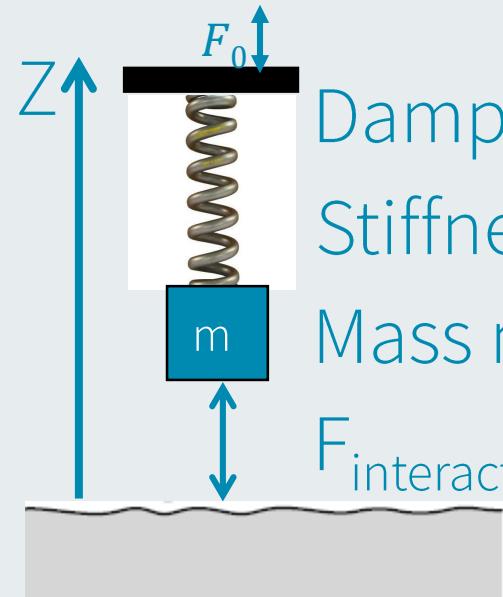
R= radius of curvature

R in the range between
2 nm
and 10 microns

Cantilevers and harmonic oscillators



$$m\ddot{z} + \delta\dot{z} + kz = F_{interaction}(z) + F_0(\omega t)$$



Damping δ [N s /m]: environment, viscosity

Stiffness k [N/m]

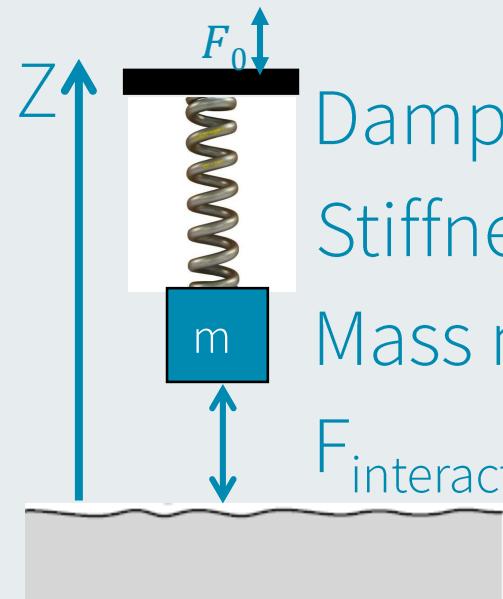
Mass m [Kg]

$F_{interaction}$ [N]

Cantilevers and harmonic oscillators



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Damping δ [N s /m]: environment, viscosity

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Static AFM mode (contact mode)



STATIC AFM: tip in permanent contact with the sample



Static AFM mode (contact mode)



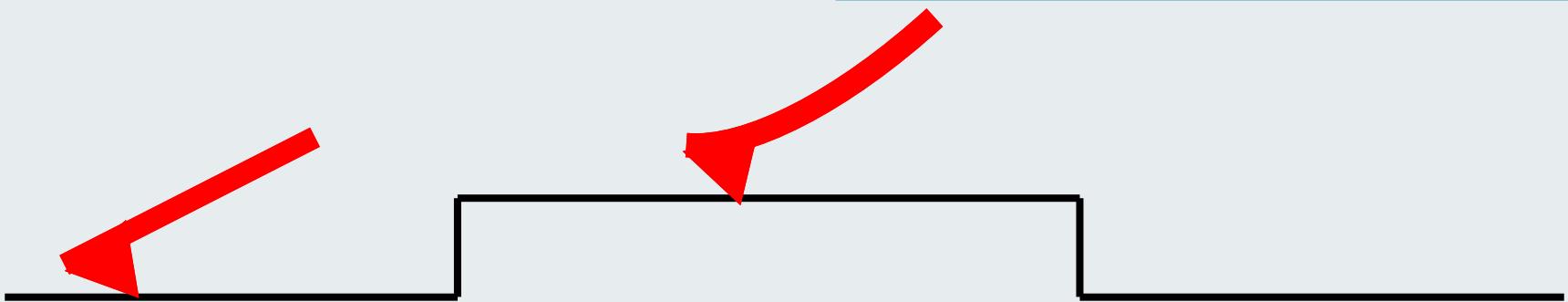
STATIC AFM: tip in permanent contact with the sample



Static AFM mode (contact mode)



STATIC AFM: tip in permanent contact with the sample



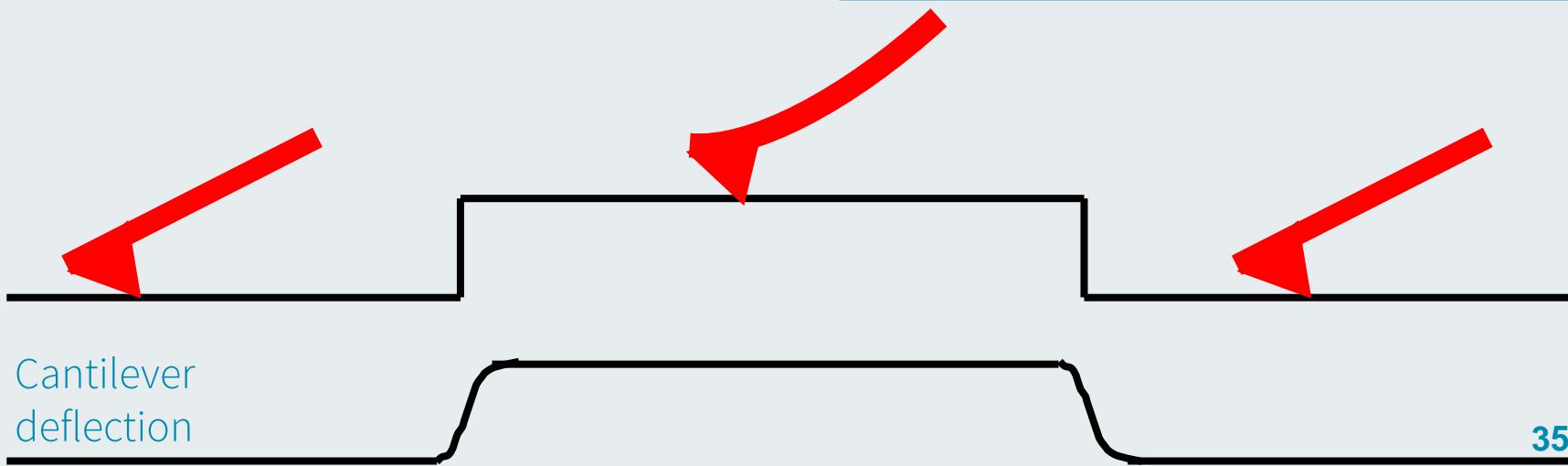
Static AFM mode (contact mode)



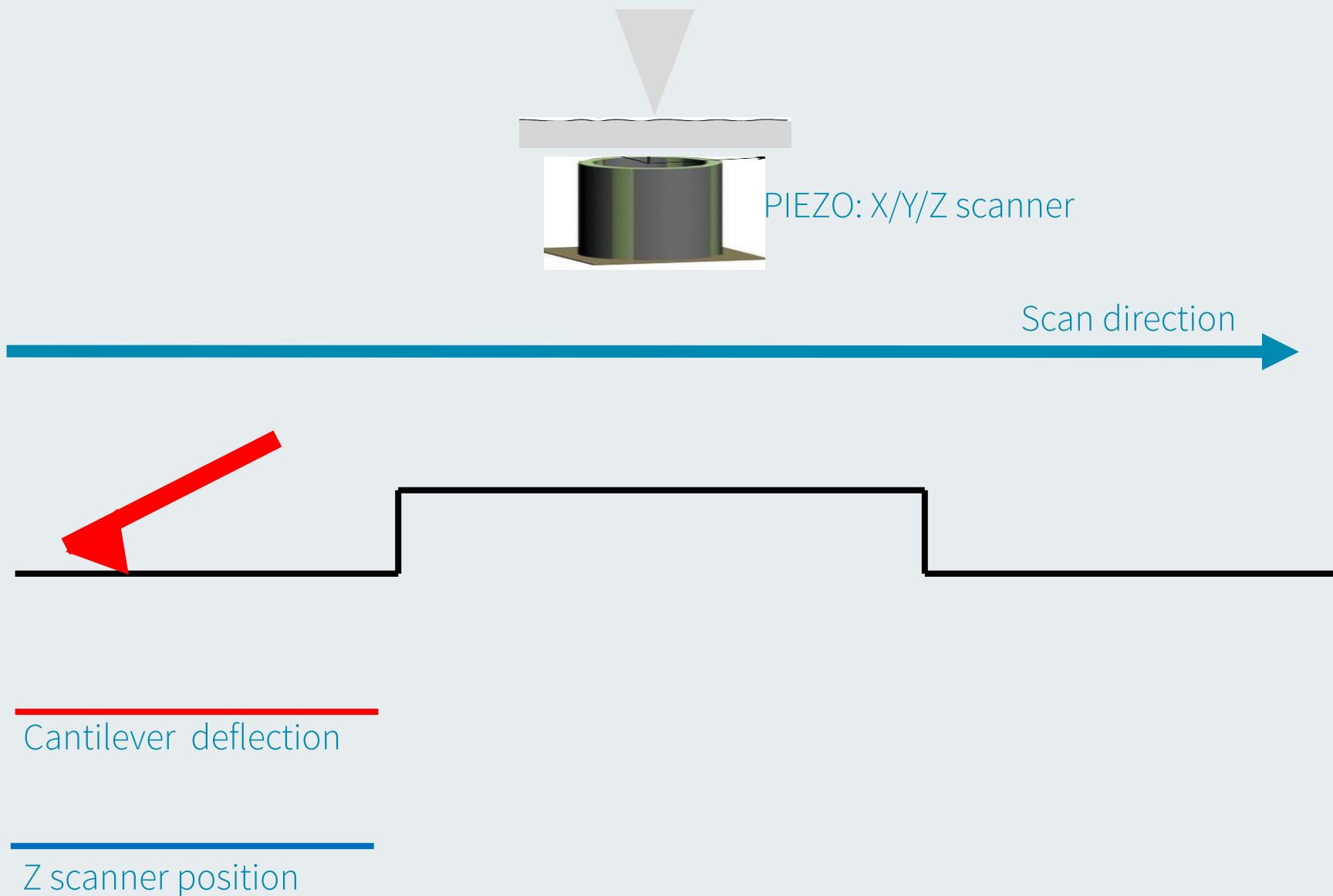
STATIC AFM: tip in permanent contact with the sample



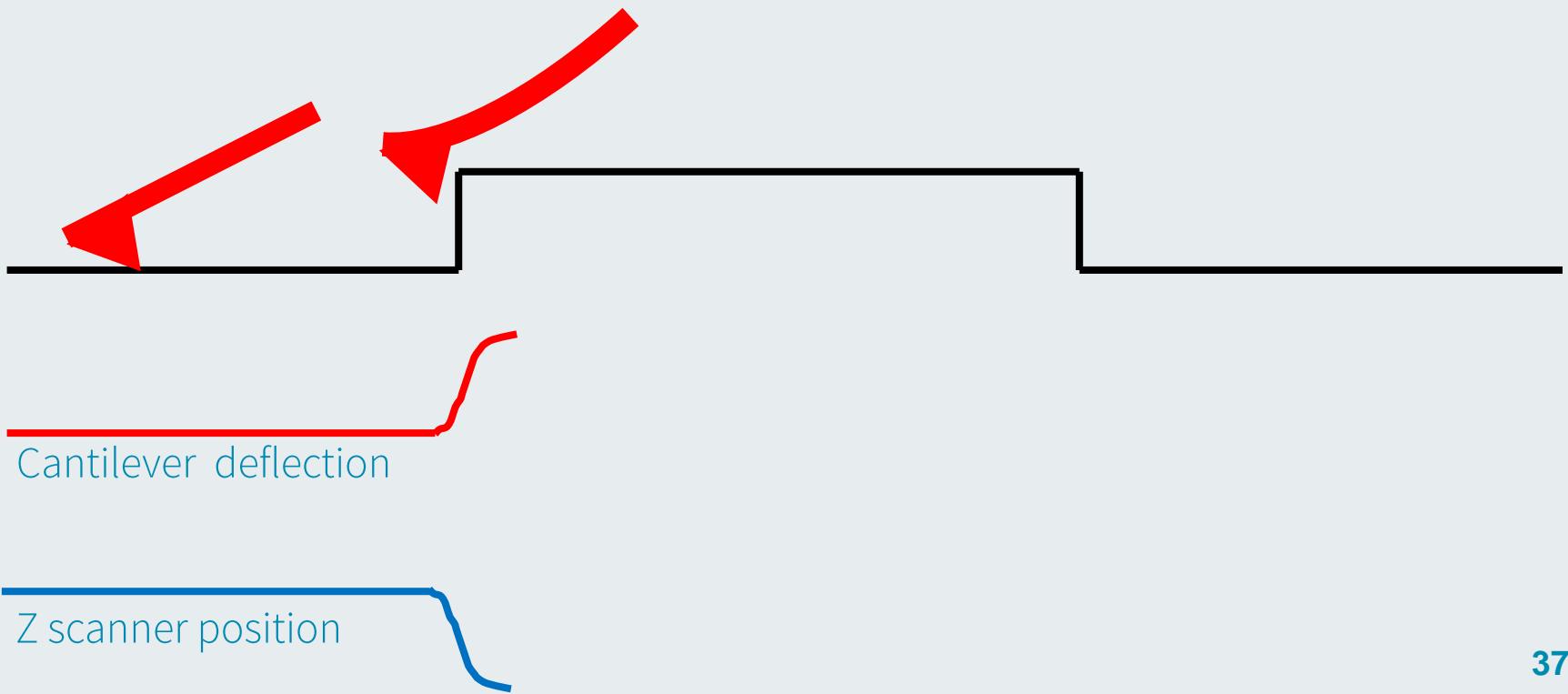
Phonograph



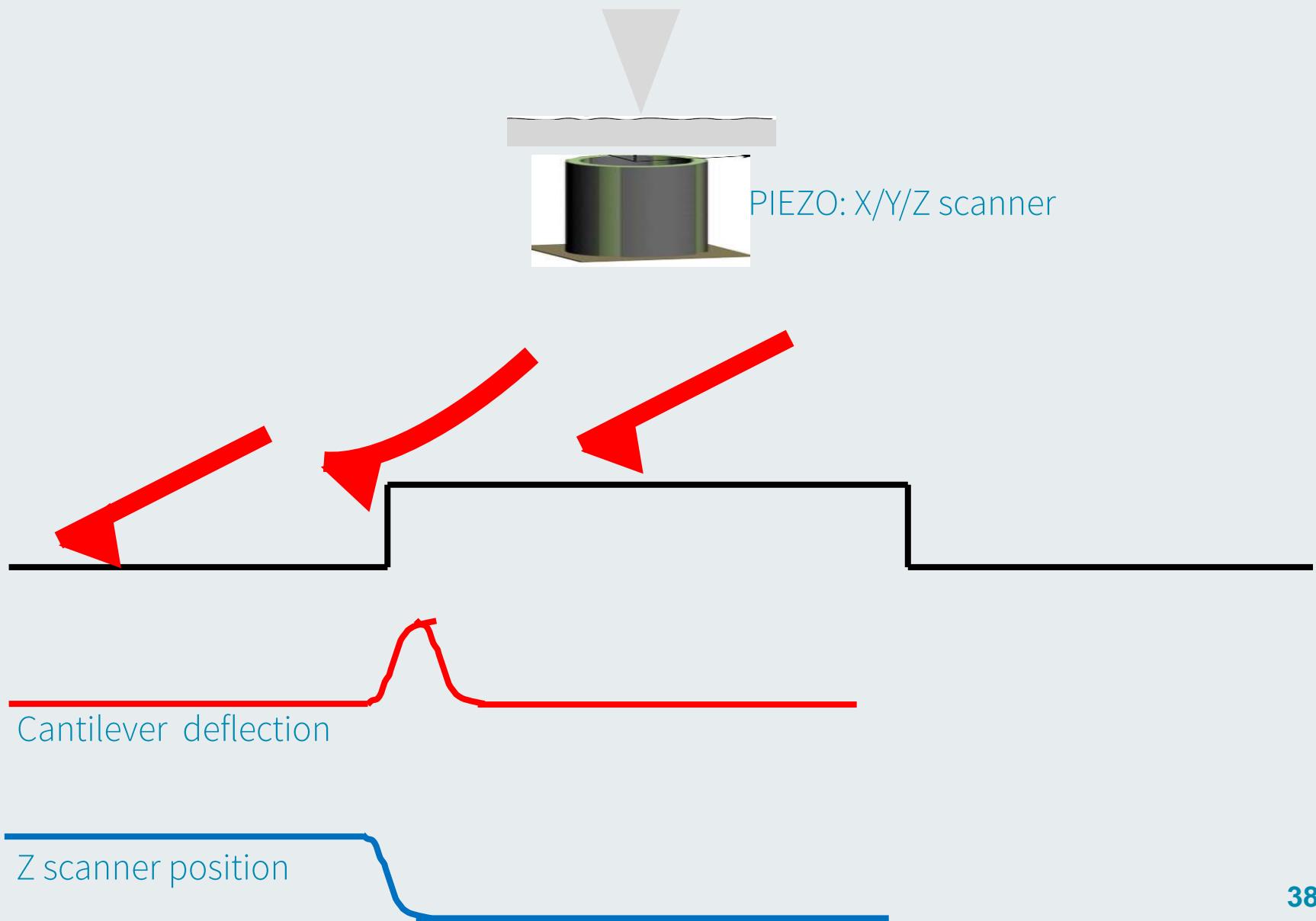
Static AFM mode (contact mode) – The closed loop



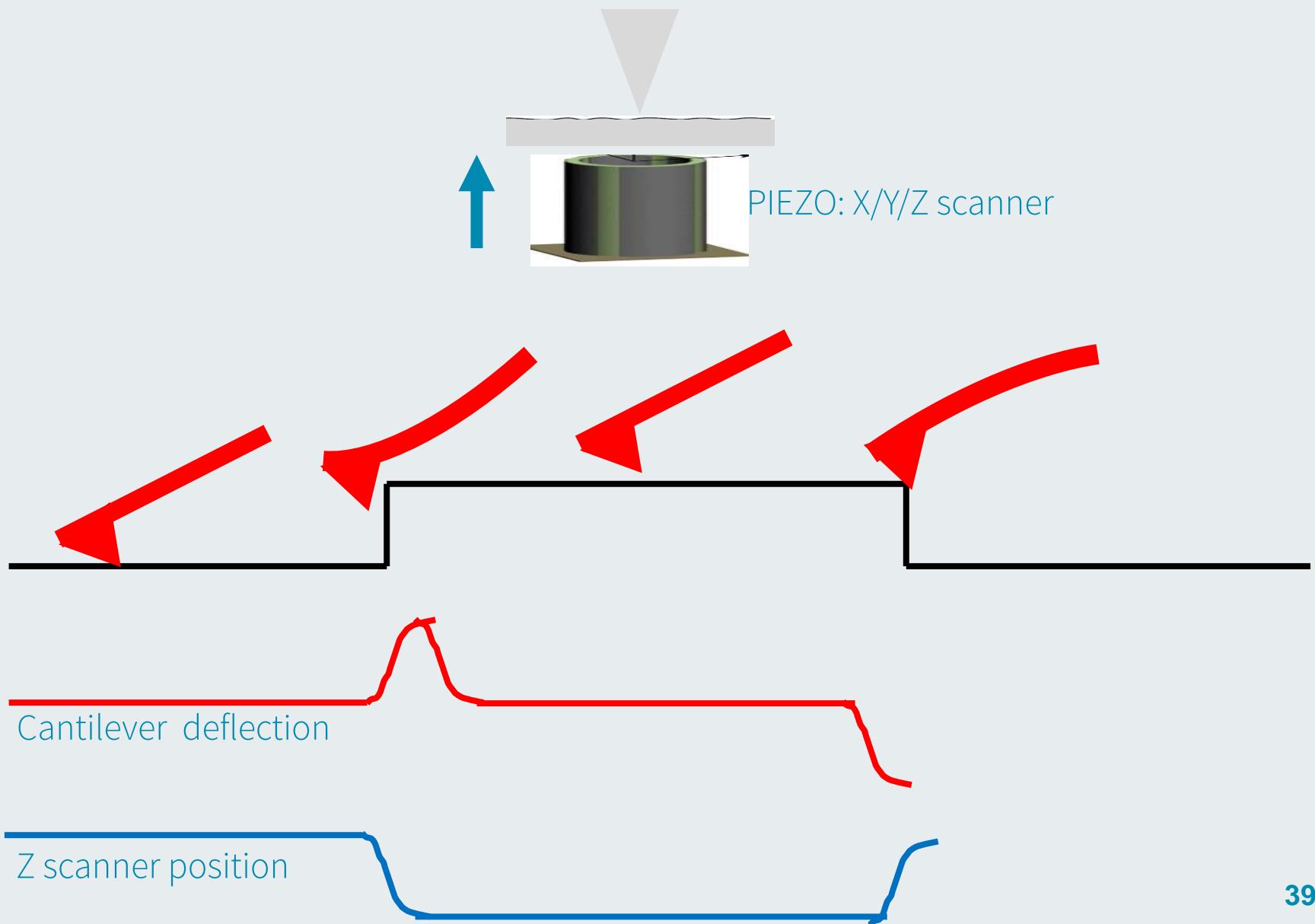
Static AFM mode (contact mode) – The closed loop



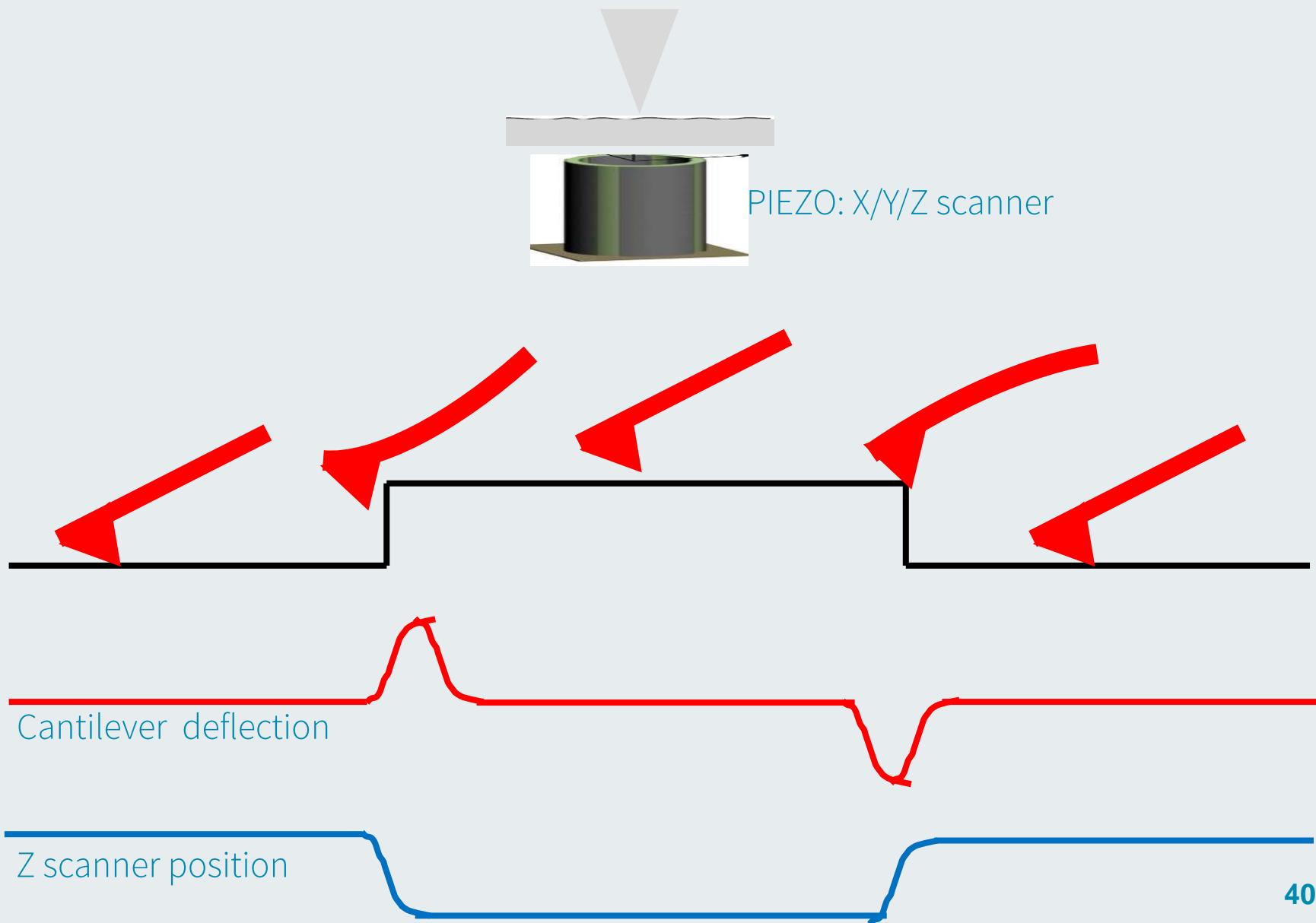
Static AFM mode (contact mode) – The closed loop



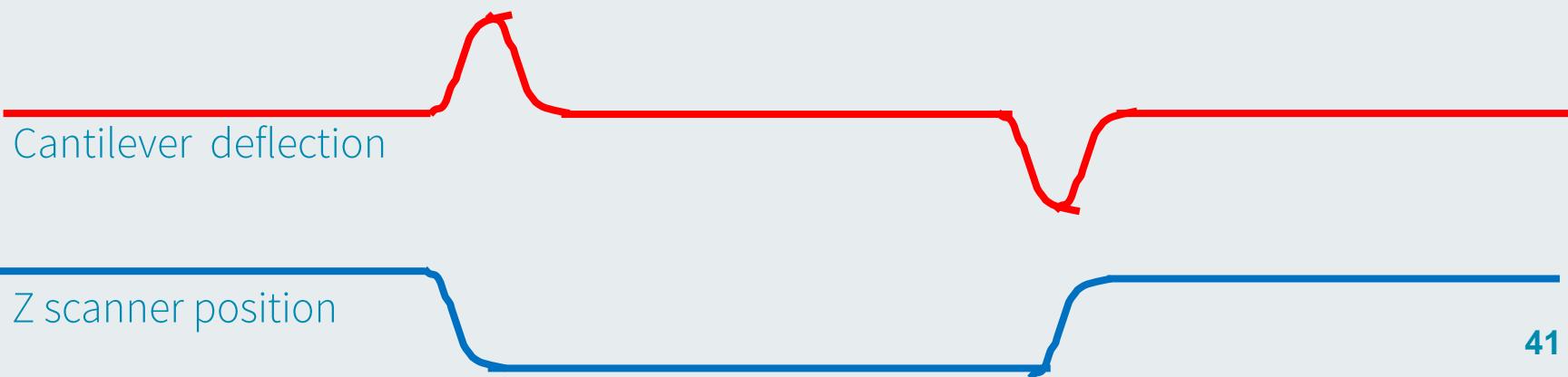
Static AFM mode (contact mode) – The closed loop



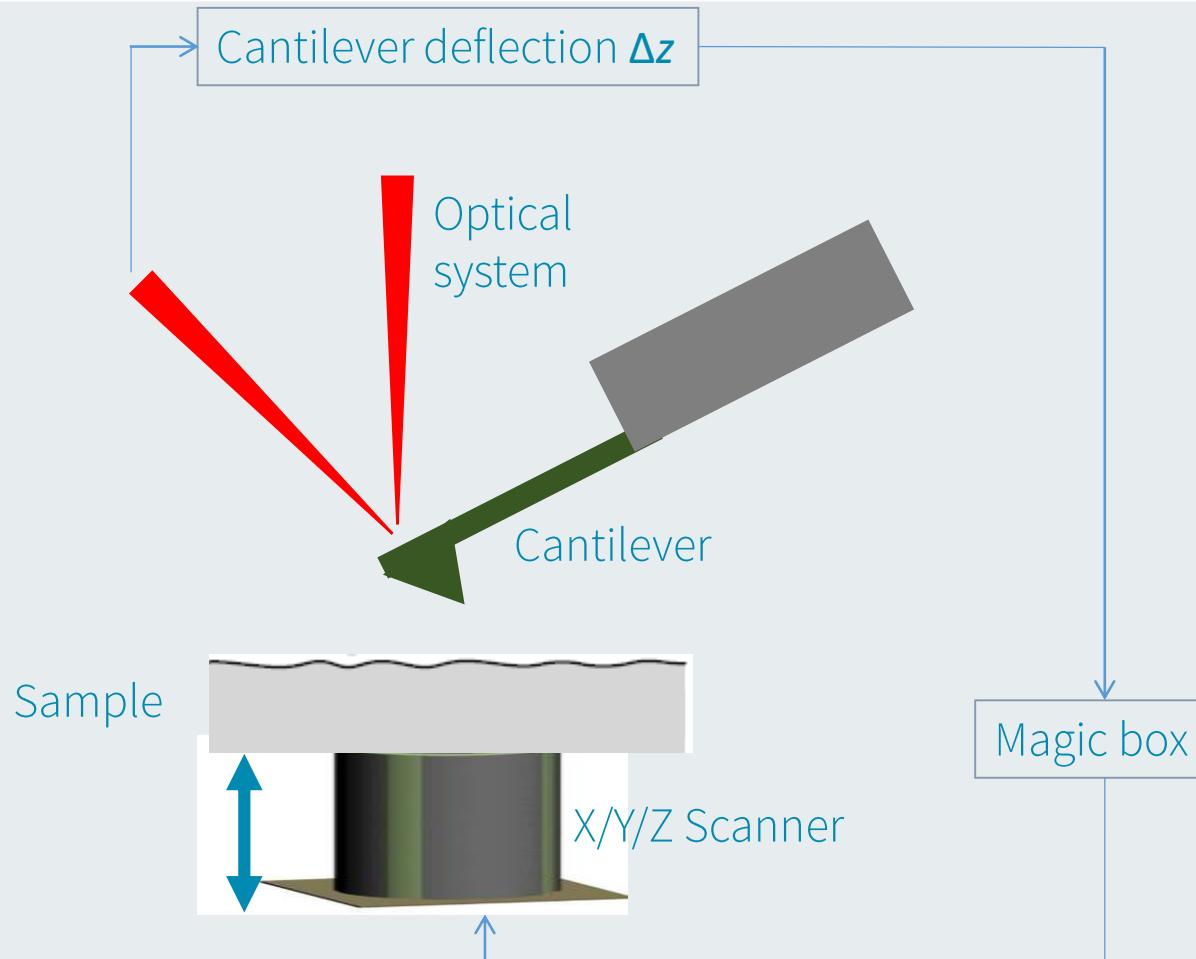
Static AFM mode (contact mode) – The closed loop



Constant deflection



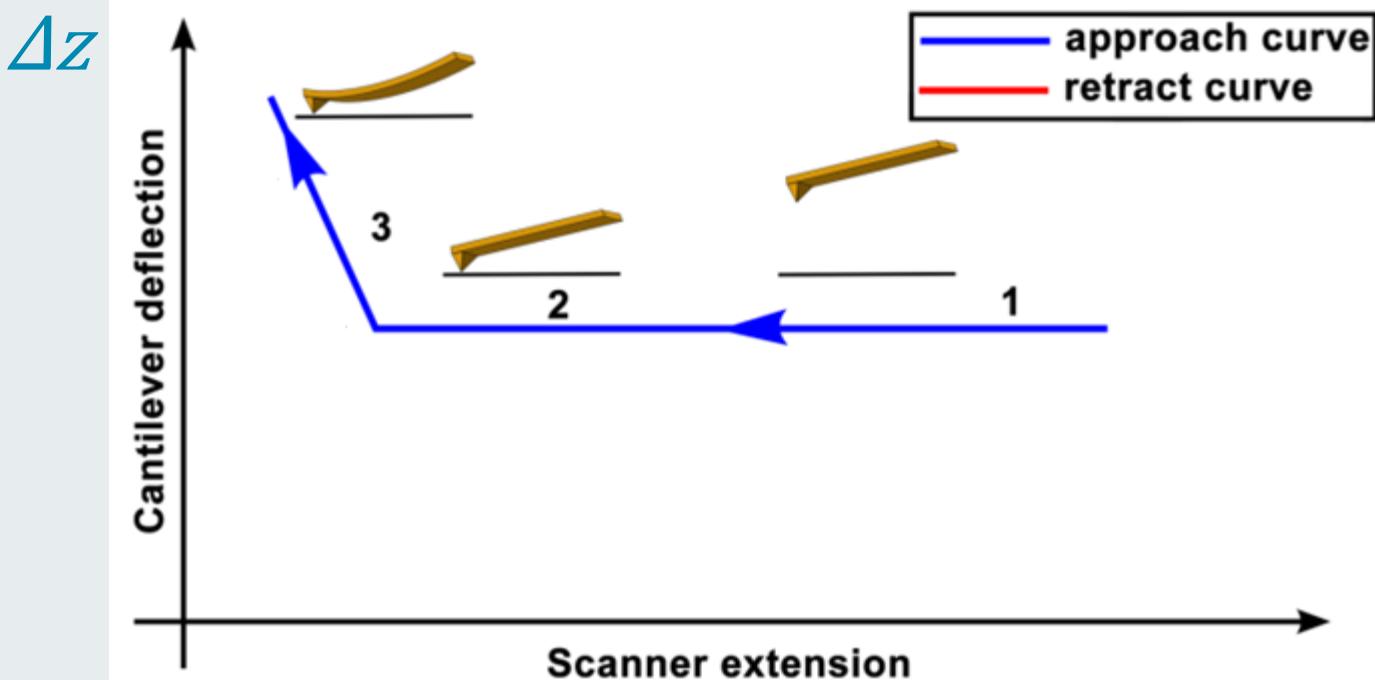
Static AFM mode (contact mode) – Operational scheme



$$m\ddot{z} + \delta\dot{z} + kz = F_{interaction}(z) + F_0(\omega t)$$

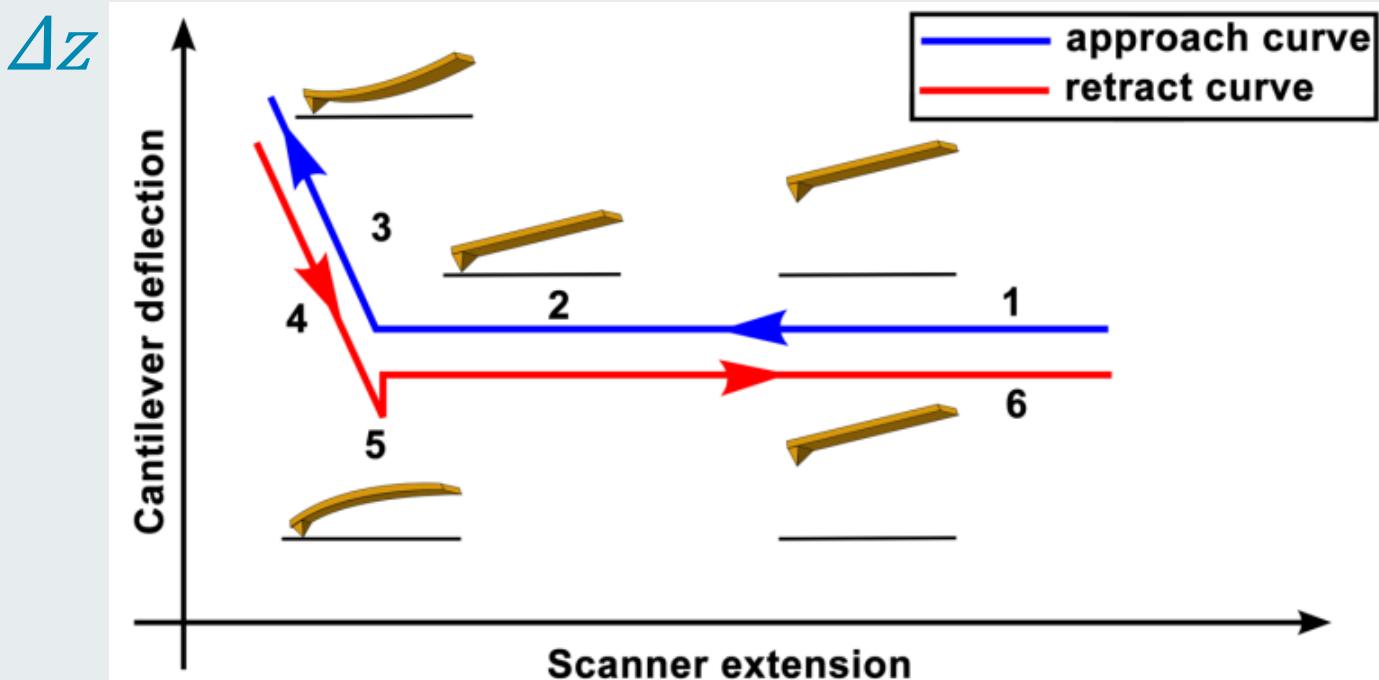
$$\ddot{z} = 0, \dot{z} = 0, F_0(\omega t) = 0 \rightarrow F_{interaction}(z) = k\Delta z \quad \text{Hook Law}$$

Static AFM mode (contact mode) – Force curves



Adapted from Polymer Science, Chapter 4, U. Maver et al., Intech, 2013

Static AFM mode (contact mode) – Force curves



Adapted from Polymer Science, Chapter 4, U. Maver et al., Intech, 2013



Available online at www.sciencedirect.com

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Surface Science Reports 59 (2005) 1–152



Force measurements with the atomic force microscope:
Technique, interpretation and applications

Hans-Jürgen Butt^a, Brunero Cappella^{b,*}, Michael Kappl^a

^aMax-Planck-Institute for Polymer Research, D-55128 Mainz, Germany

^bFederal Institute for Material Research and Testing, D-12205 Berlin, Germany

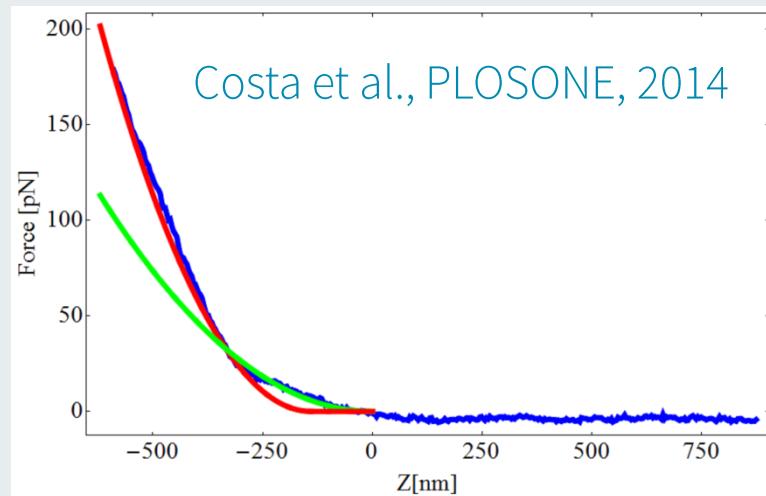
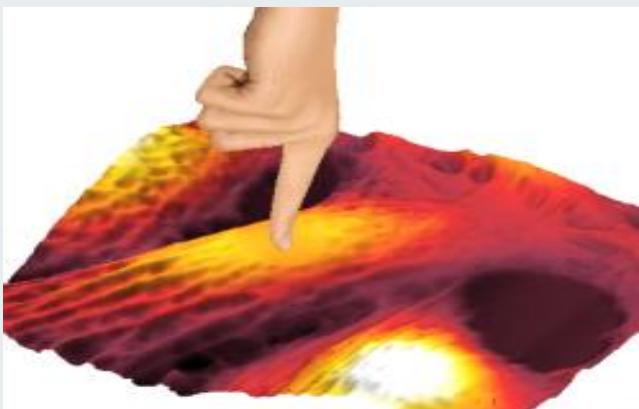
Accepted 1 August 2005

H.-J. Butt, B. Cappella and M. Kappl,
Surface Science Reports, 59, 1-152, 2005

Static AFM mode (contact mode) – Force curves



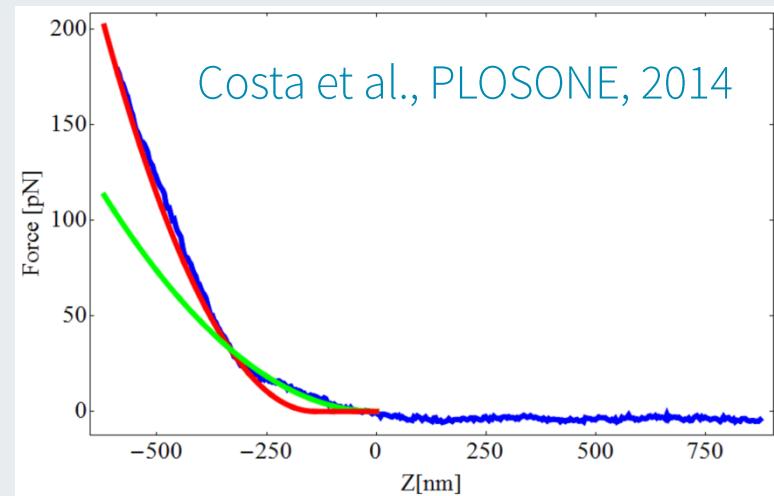
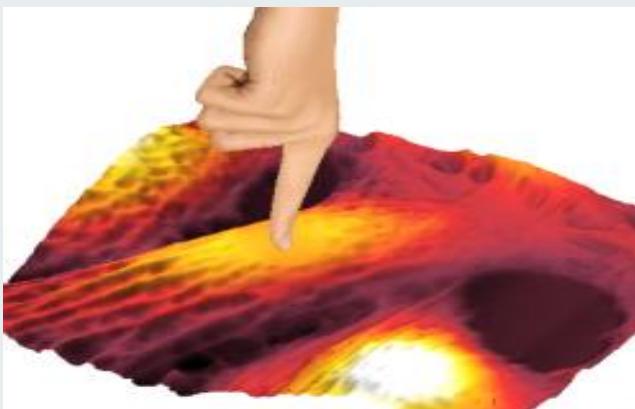
Mechanics



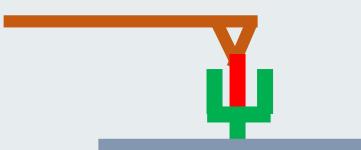
Static AFM mode (contact mode) – Force curves



Mechanics



Molecular recognition



Ligand



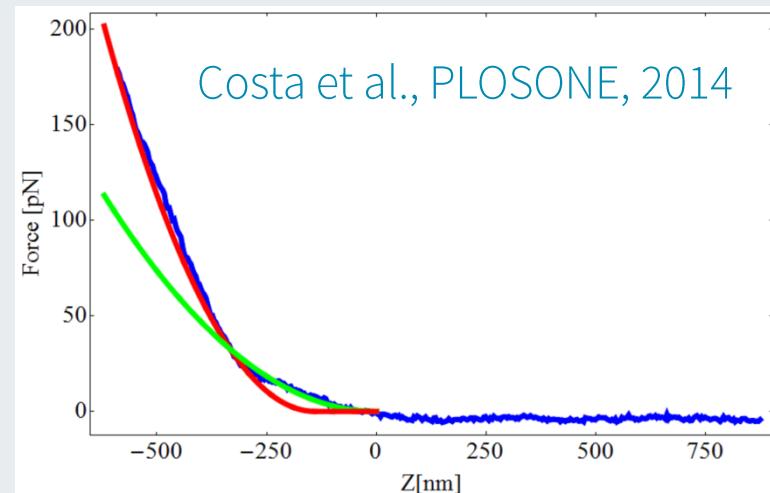
Receptor



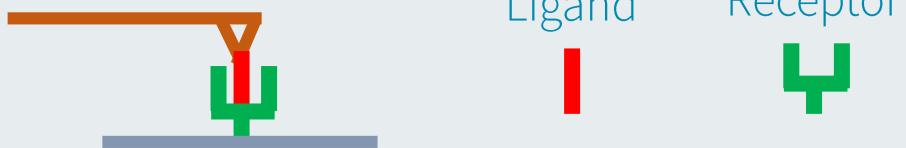
Static AFM mode (contact mode) – Force curves



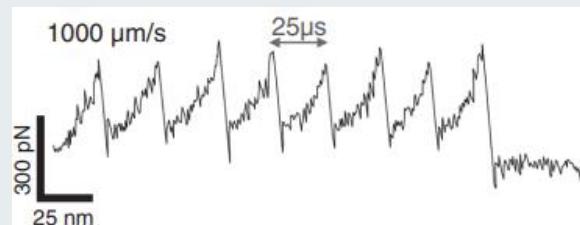
Mechanics



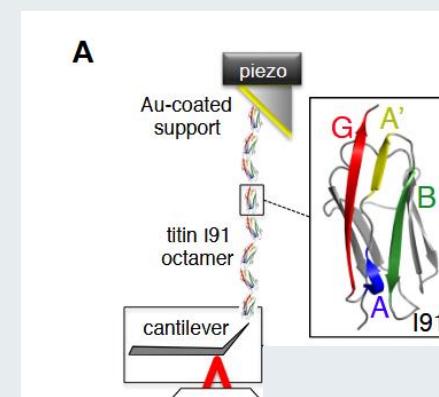
Molecular recognition



Protein unfolding



F. Rico et al.
Science,
342(6159),
741-743, 2013



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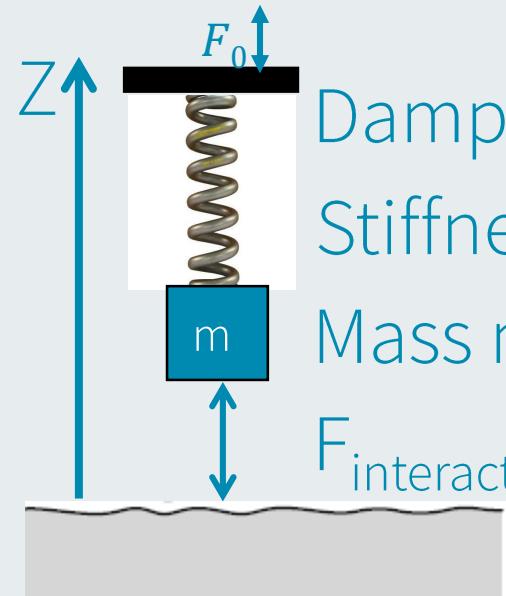
Cantilevers

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$$m\ddot{z} + \delta\dot{z} + kz = F_{interaction}(z) + F_0(\omega t)$$



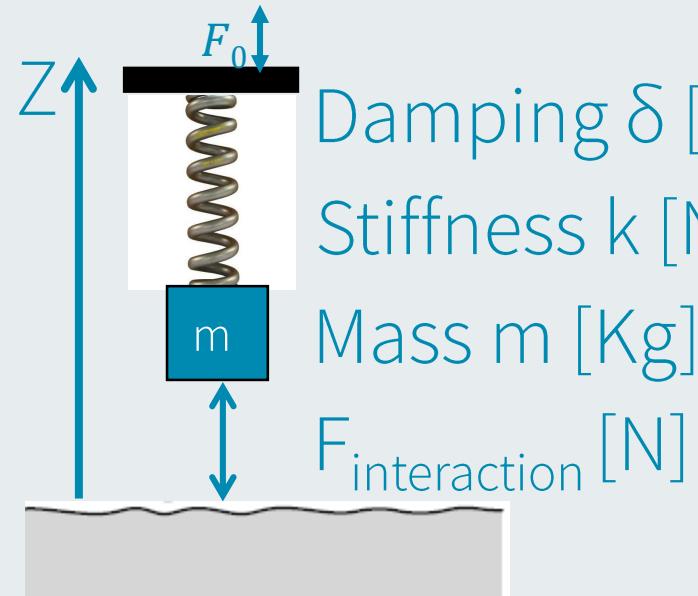
Damping δ [N s /m]: environment, viscosity

Stiffness k [N/m]

Mass m [Kg]

$F_{interaction}$ [N]

$$m\ddot{z} + \delta\dot{z} + kz = F_{interaction}(z) + F_0(\omega t)$$



Damping δ [N s /m]: environment, viscosity

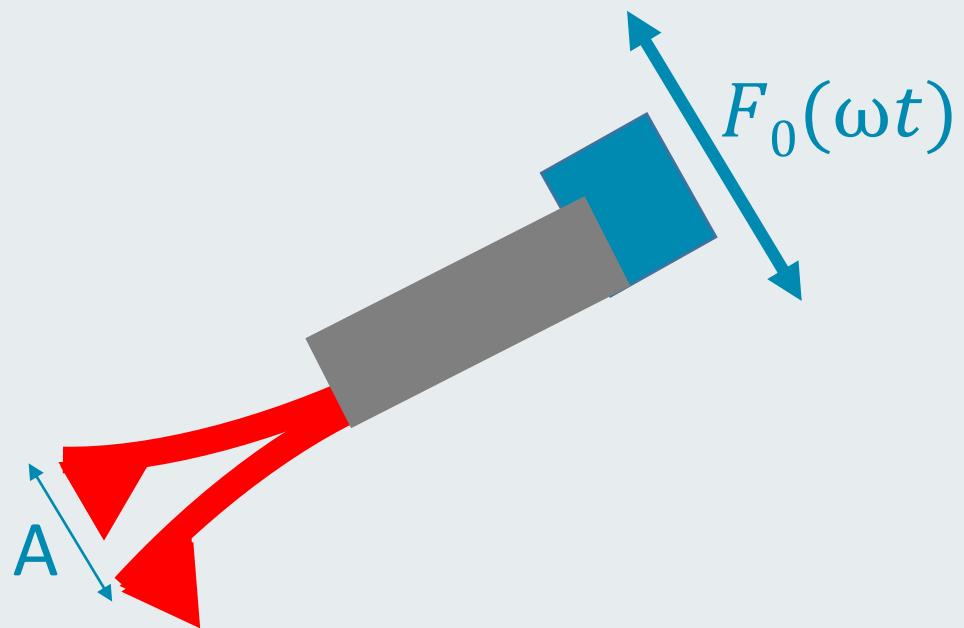
Stiffness k [N/m]

Mass m [Kg]

$F_{interaction}$ [N]

Resonance frequency

$$\omega_R = \sqrt{\frac{k}{m}}$$



$$m\ddot{z} + \delta\dot{z} + kz = F_{interaction}(z) + F_0(\omega t)$$

if $F_{interaction}(z) = 0$ meaning no sample

solution: $z = z_0 e^{i\omega t} = z_0 (\cos(\omega t) + i \sin(\omega t))$

$$z_0 = F_0 / (-m\omega^2 + i\delta\omega + k)$$

$$z_0 = F_0 / (-m\omega^2 + i\delta\omega + k)$$

$$z = a + ib$$

$$\text{Modulus: } |z| = \sqrt{a^2 + b^2}$$

$$\text{Phase: } \varphi = 2\arctan\left(\frac{b}{a+\sqrt{a^2+b^2}}\right)$$

Dynamic AFM mode – Harmonic Oscillator



$$z_0 = F_0 / (-m\omega^2 + i\delta\omega + k)$$

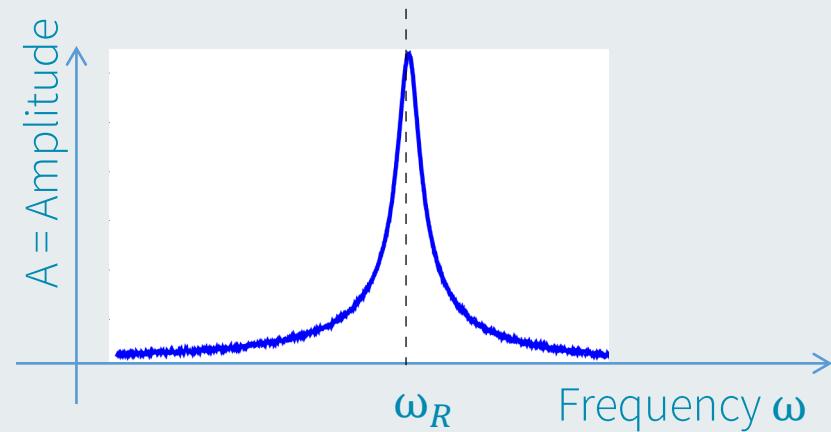
$$z = a + ib$$

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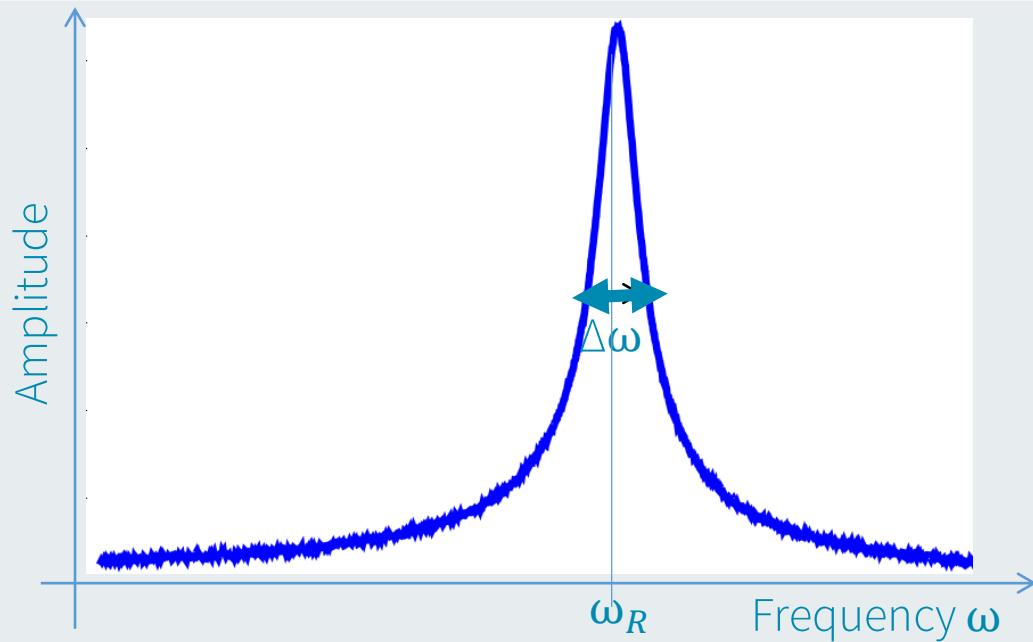
$$\text{Phase: } \varphi = 2\arctan\left(\frac{b}{a+\sqrt{a^2+b^2}}\right)$$

$$A = |z| = \frac{\frac{F_0}{m}}{\sqrt{(\omega_R^2 - \omega^2)^2 + \omega^2 \delta^2}}$$

$$\text{Phase} = \arctan(\varphi) = \frac{\delta\omega}{\omega_R^2 - \omega^2}$$



Dynamic AFM mode – Harmonic Oscillator (Q factor)



Q factor

$$Q = \frac{\omega_R}{\Delta\omega}$$

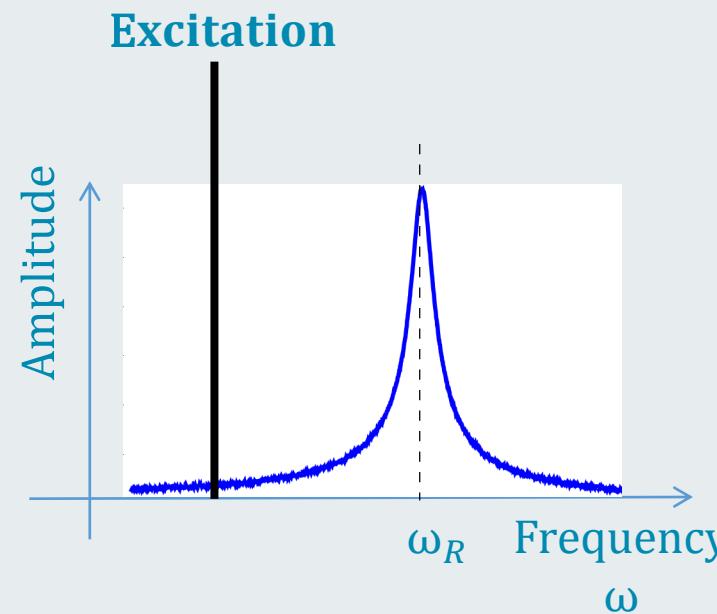
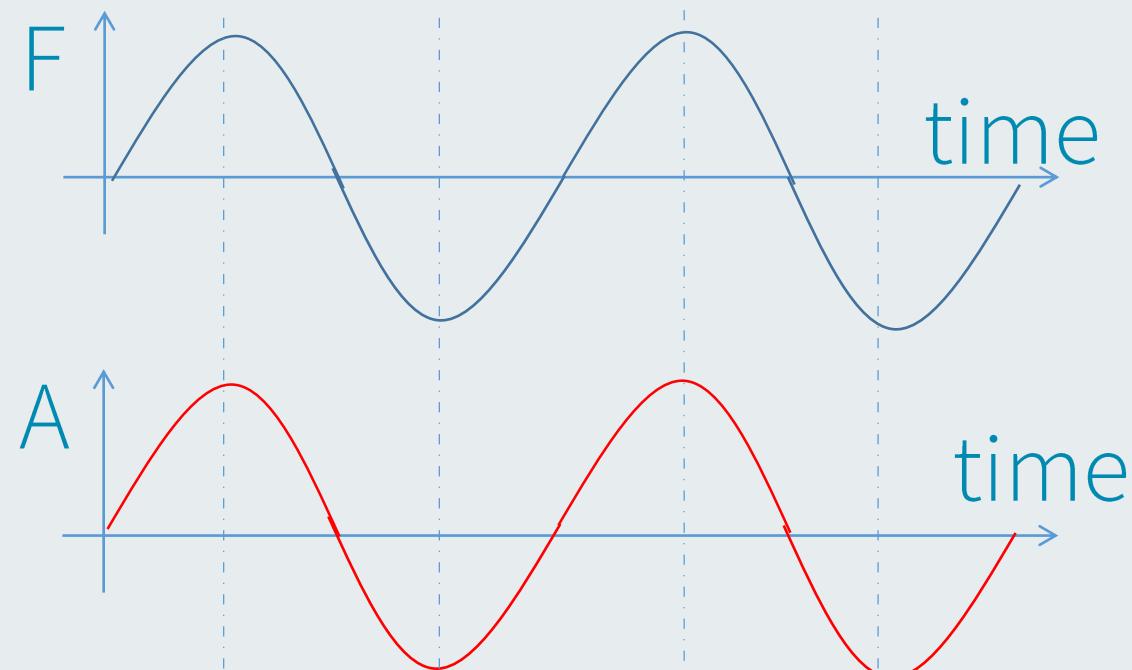
High Q



Dynamic AFM mode – Harmonic Oscillator (phase)



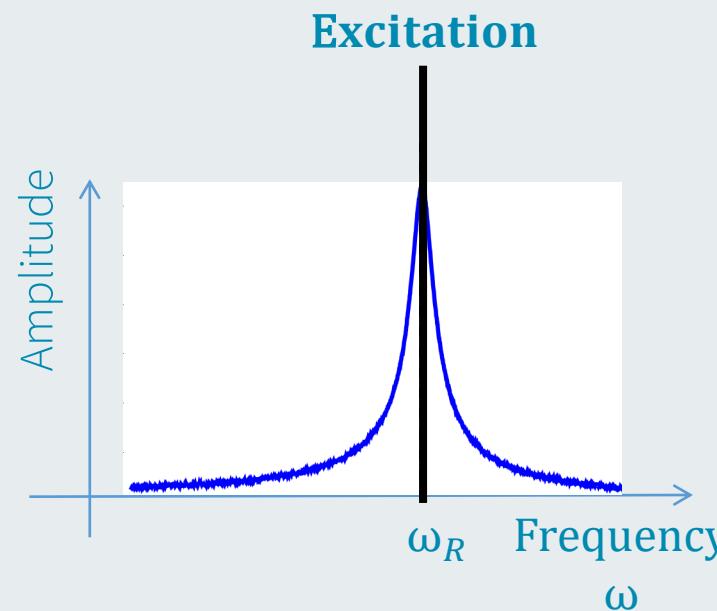
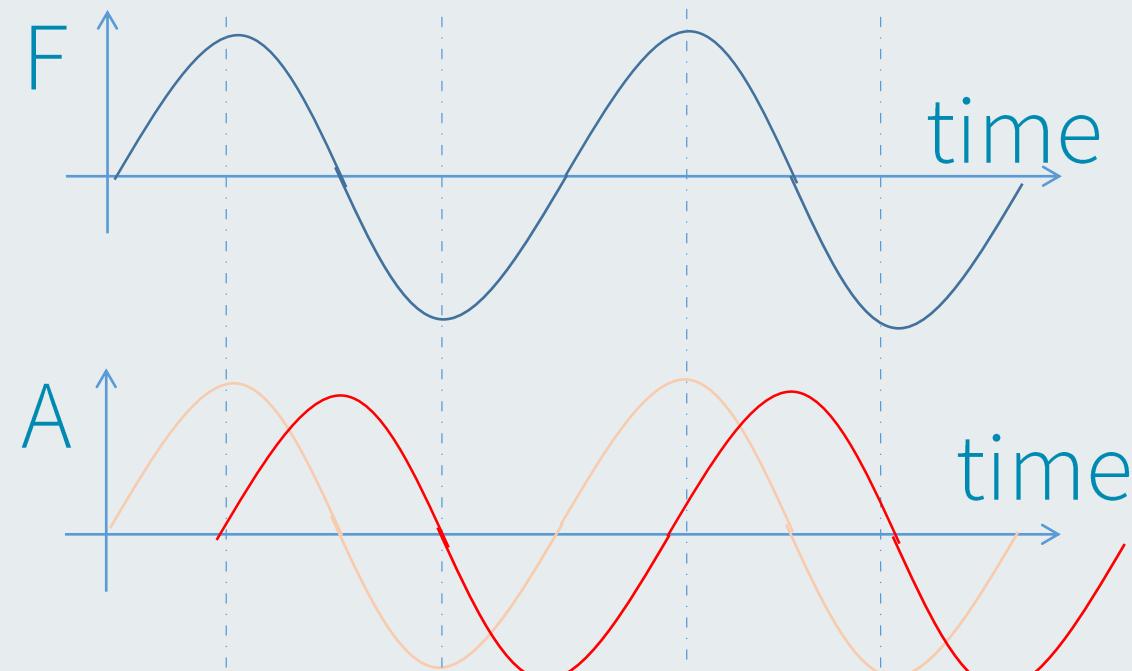
At low frequency



Dynamic AFM mode – Harmonic Oscillator (phase)



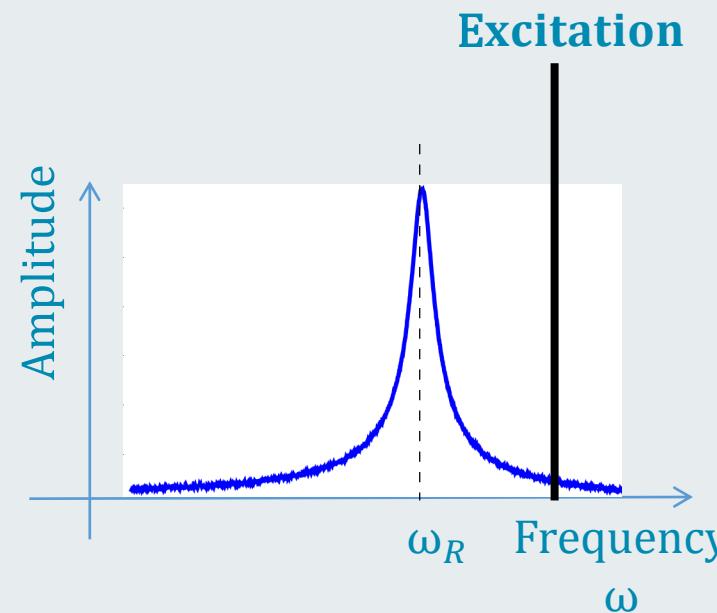
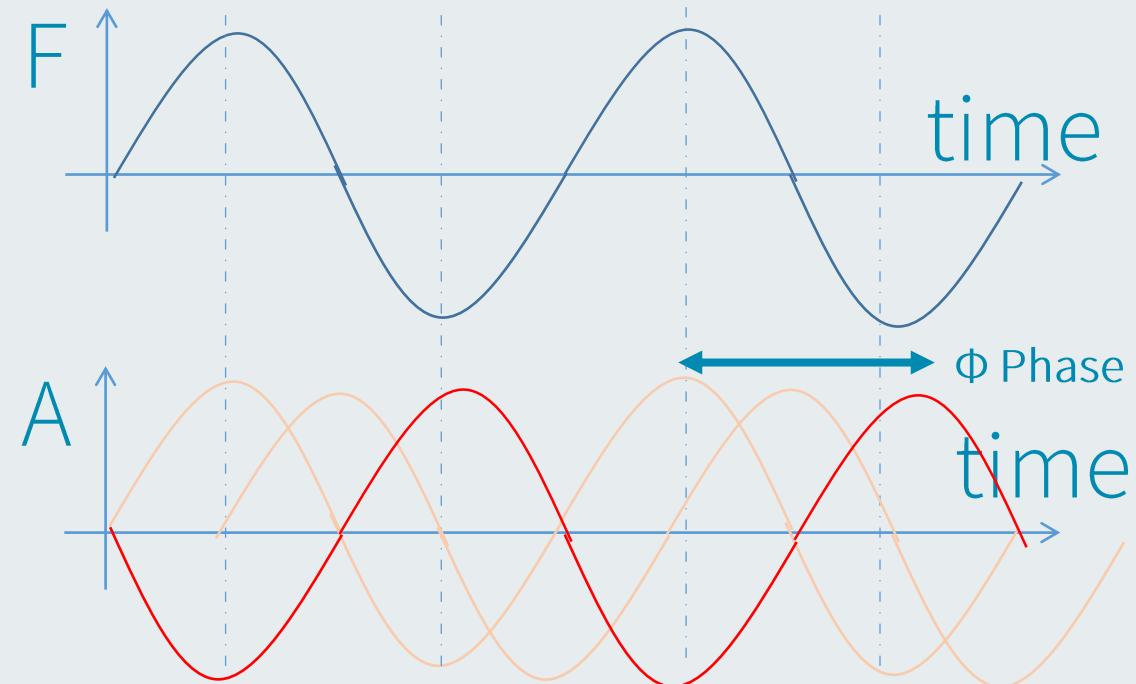
At resonance ω_R



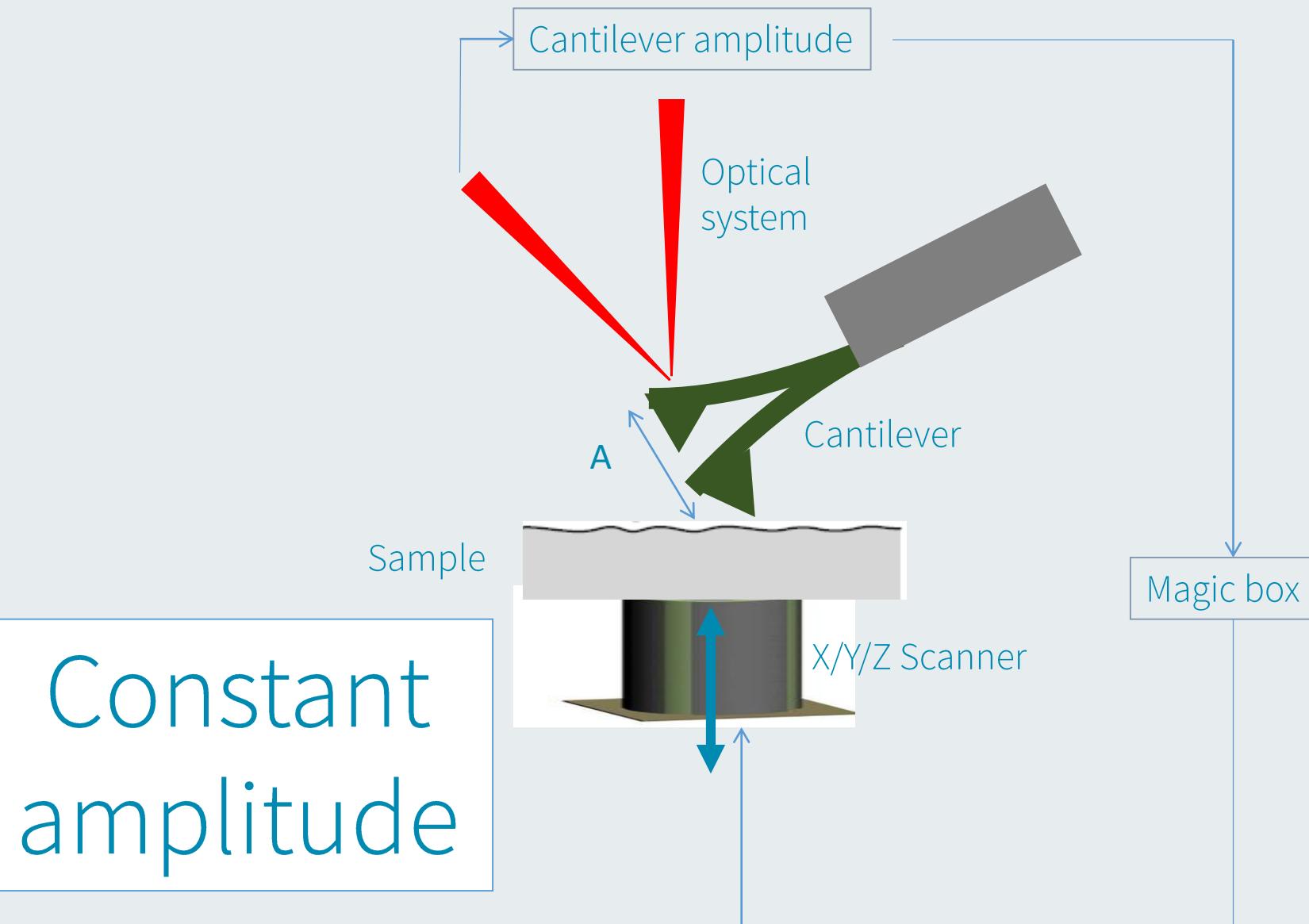
Dynamic AFM mode – Harmonic Oscillator (phase)



After resonance



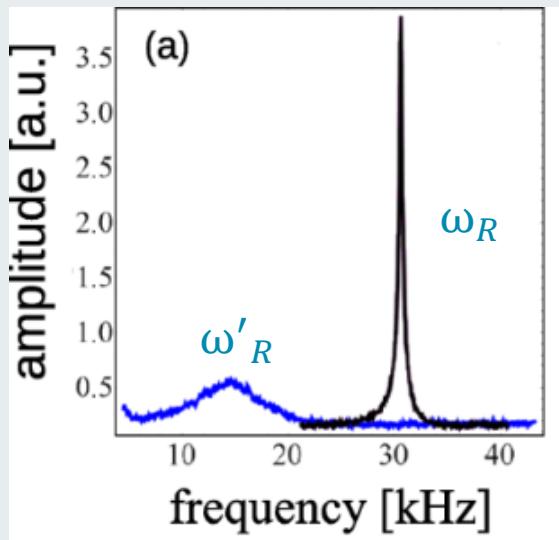
Dynamic AFM mode (AM-AFM) – Operational scheme



Dynamic AFM mode (AM-AFM) – in liquid, for biology



1) Part of the liquid participates (coupled) to cantilever motion

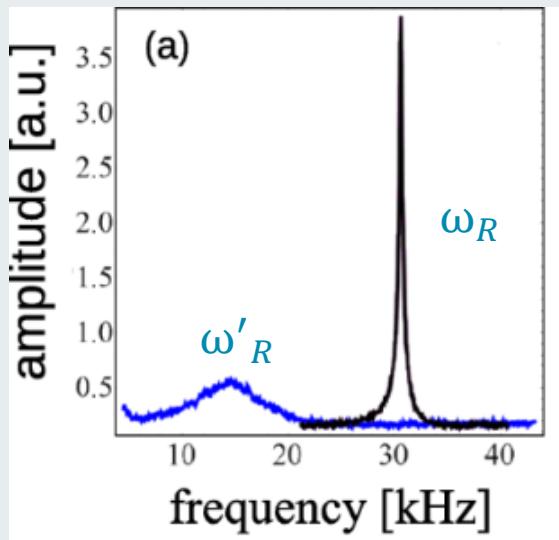


$$\omega_R = \sqrt{\frac{k}{m}} \longrightarrow \omega'_R = \sqrt{\frac{k}{m + m_L}}$$

Dynamic AFM mode (AM-AFM) – in liquid, for biology



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$$\omega_R = \sqrt{\frac{k}{m}} \rightarrow \omega'_R = \sqrt{\frac{k}{m + m_L}}$$

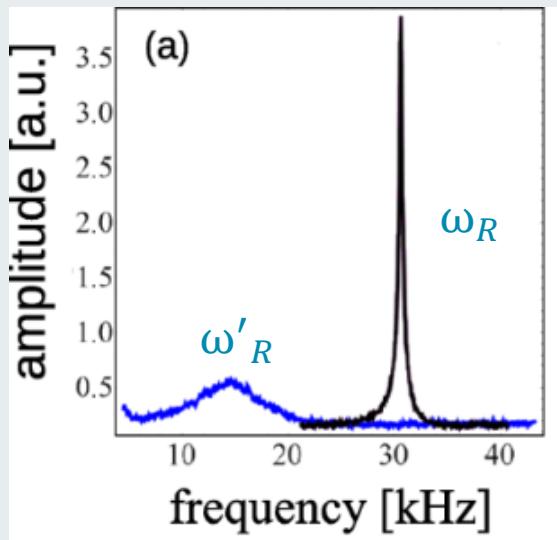
2) The resonance gets broader → decrease of Q factor. That's because water has higher viscosity than air $\delta_{\text{liquid}} > \delta_{\text{air}}$

$$m\ddot{z} + \delta\dot{z} + kz = F_{\text{interaction}}(z) + F_0(\omega t)$$

Dynamic AFM mode (AM-AFM) – in liquid, for biology



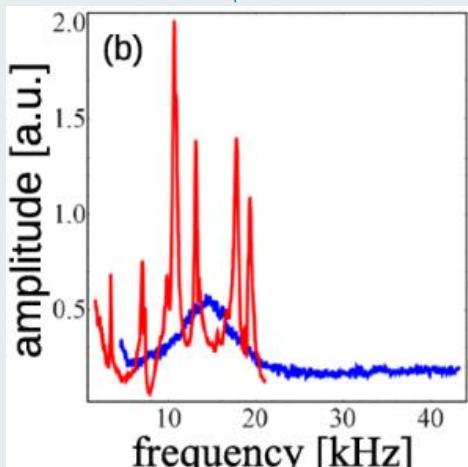
1) Part of the liquid participates (coupled) to cantilever motion



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$$m\ddot{z} + \delta\dot{z} + kz = F_{\text{interaction}}(z) + F_0(\omega t)$$



3) When excited mechanically, the response of the tip is plenty of spurious peaks

1) Introduction to Scanning Probe Microscopy

2) The Force

3) Methods

Cantilevers

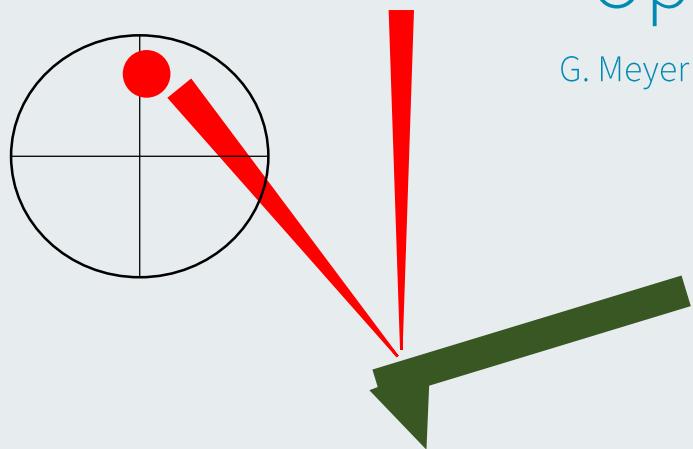
Static and Dynamic AFM

4) Instruments

5) Advanced and novel AFM methods

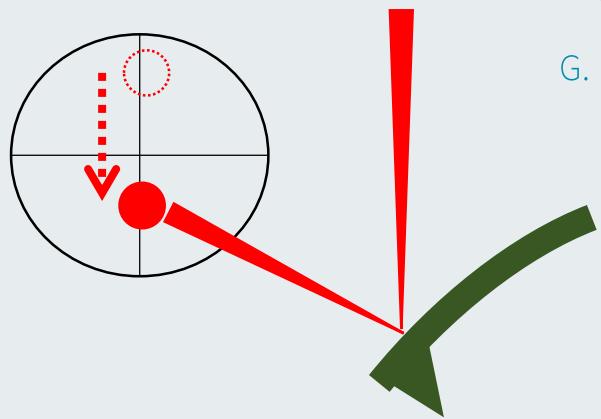
Optical beam deflection

G. Meyer and N. M. Amer, Appl. Phys. Lett. 53, 1045 (1988).



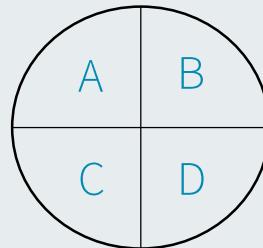
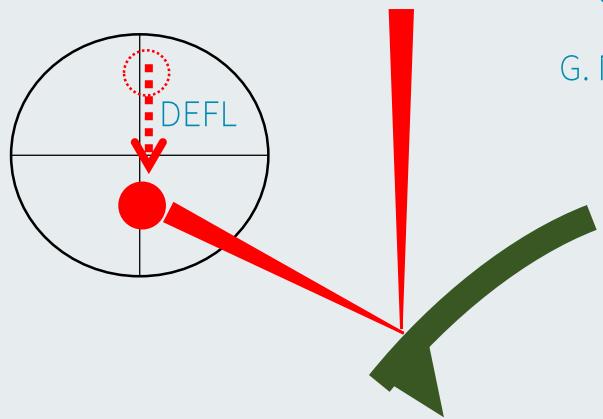
Optical beam deflection

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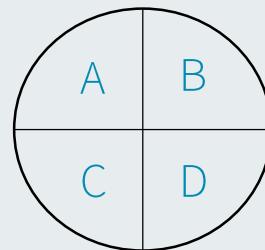
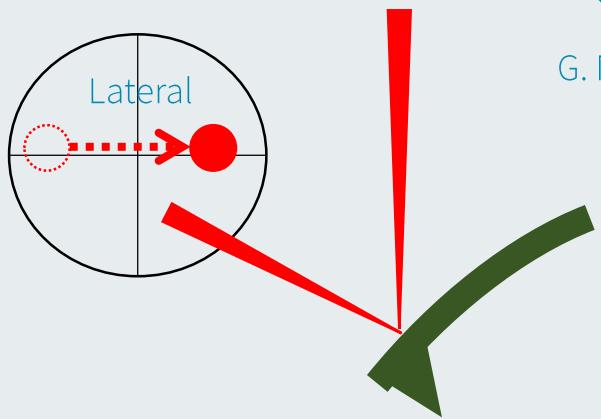


$$\text{DEFL} = \frac{(A+B)-(C+D)}{A+B+C+D}$$

$$\text{SUM} = A + B + C + D$$

Optical beam deflection

G. Meyer and N. M. Amer, Appl. Phys. Lett. 53, 1045 (1988).



$$\text{DEFL} = \frac{(A+B)-(C+D)}{A+B+C+D}$$

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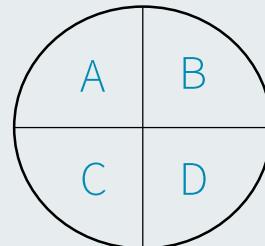
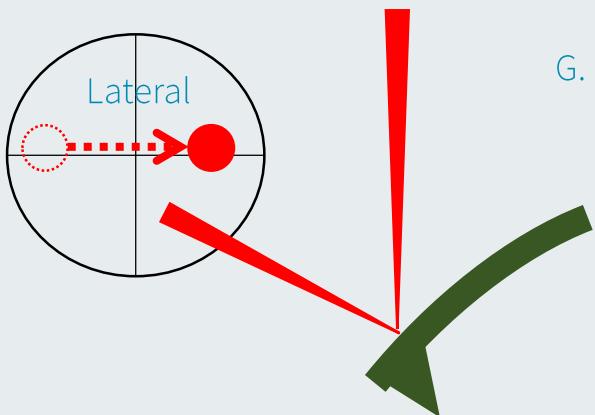
$$\text{Lateral} = \frac{(A+C)-(B+D)}{A+B+C+D}$$

Tip position measurement



Optical beam deflection

G. Meyer and N. M. Amer, Appl. Phys. Lett. 53, 1045 (1988).



$$\text{DEFL} = \frac{(A+B)-(C+D)}{A+B+C+D}$$

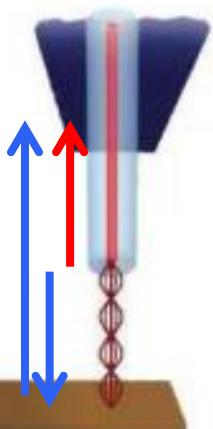
$$\text{SUM} = A + B + C + D$$

$$\text{Lateral} = \frac{(A+C)-(B+D)}{A+B+C+D}$$

Interferometry

D. Rugar, H. J. Mamin, R. Erlandsson, J. E. Stern, and B. D. Terris, Rev. Sci. Instrum. 59, 2337 (1988).

Drawback:
DRIFT!!!



Interference of red and blue beams

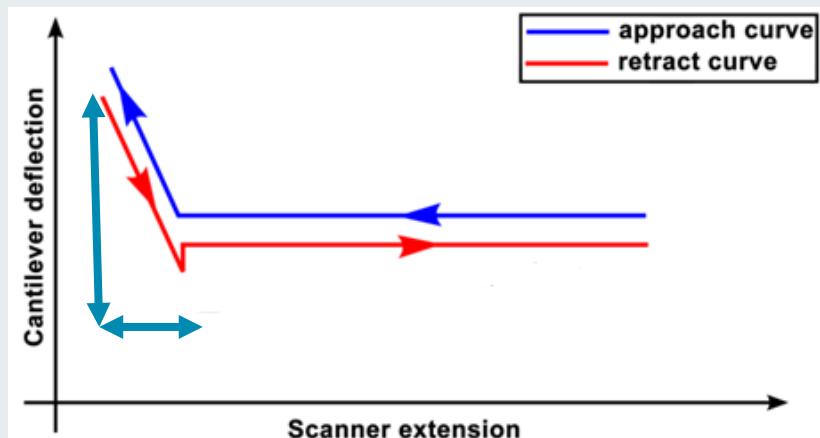
$$\xrightarrow{\hspace{1cm}} I(d)$$

$$I(d) = I_0 + \Delta I_0 \sin \left(\frac{4\pi}{\lambda} d + \phi \right)$$

B. Hogenboom Imp. College London

-1- Detector sensitivity

Acquire a force curve on a very rigid surface (i.e. mica or silicon)



Condition:

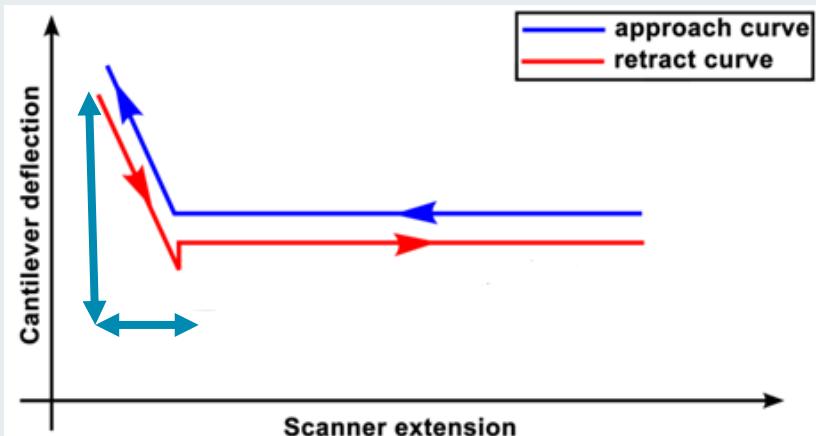
scanner extension (nm) = cantilever deflection (nm)

scanner extension (nm) = $\Phi \times$ cantilever deflection (V)

$$\Phi = \frac{\text{scanner extension}}{\text{cantilever deflection}} \quad [\text{nm/V}]$$

-1- Detector sensitivity

Acquire a force curve on a very rigid surface (i.e. mica or silicon)



Condition:

scanner extension (nm) = cantilever deflection (nm)
 scanner extension (nm) = $\Phi \times$ cantilever deflection (V)

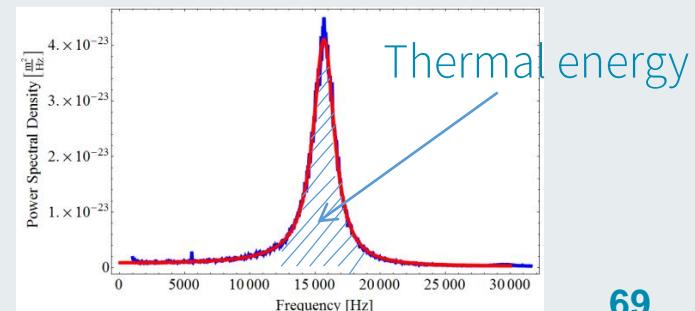
$$\Phi = \frac{\text{scanner extension}}{\text{cantilever deflection}} \quad [\text{nm/V}]$$

-2- Cantilever stiffness

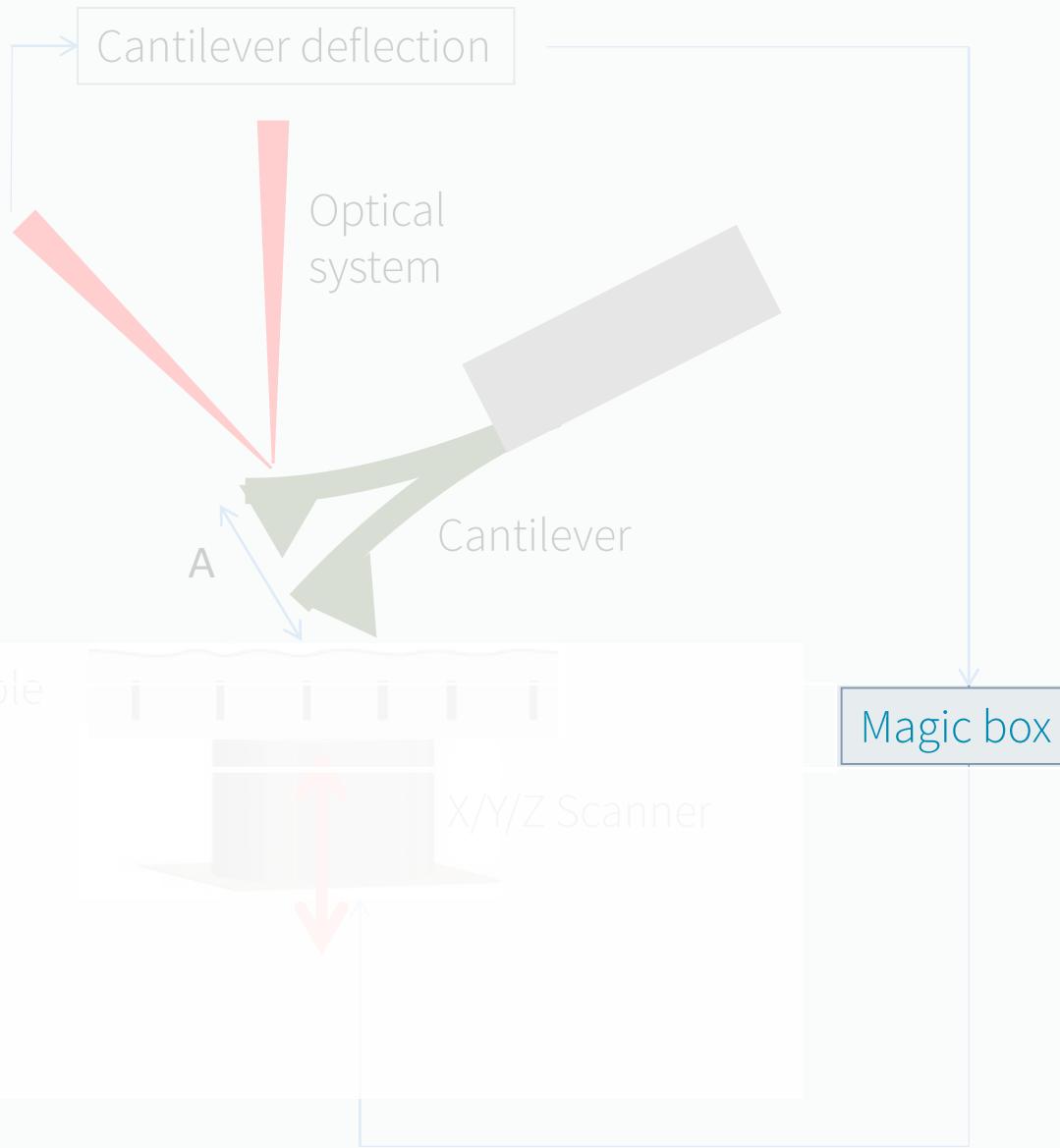
Thermal method

Thermal energy = $\frac{1}{2} K_B T$ = Cantilever energy = $\frac{1}{2} k \text{ deflection}^2$

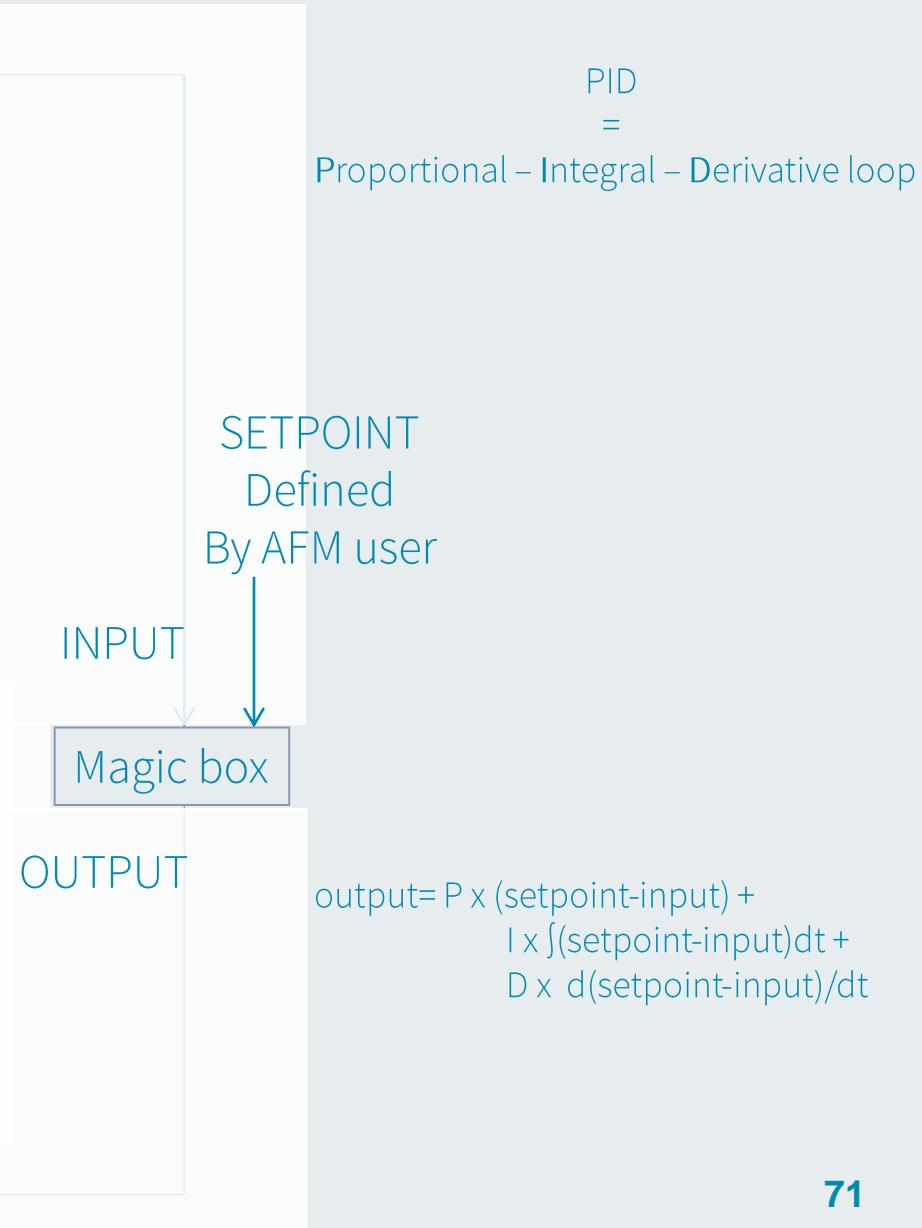
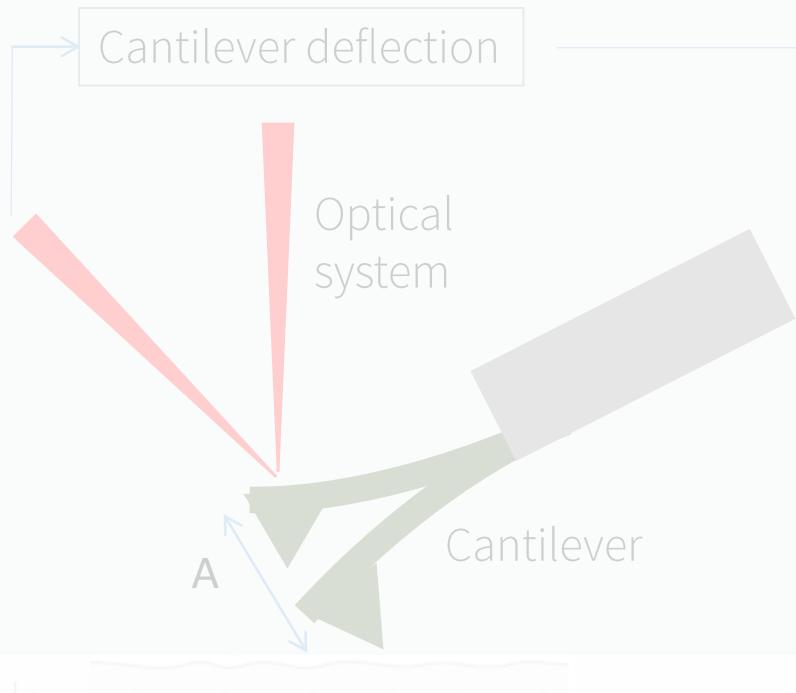
$$k = \frac{K_B T}{\text{deflection}^2(\omega)} \quad [\text{N/m}]$$



The « magic box »



The « magic box »



Tip excitation

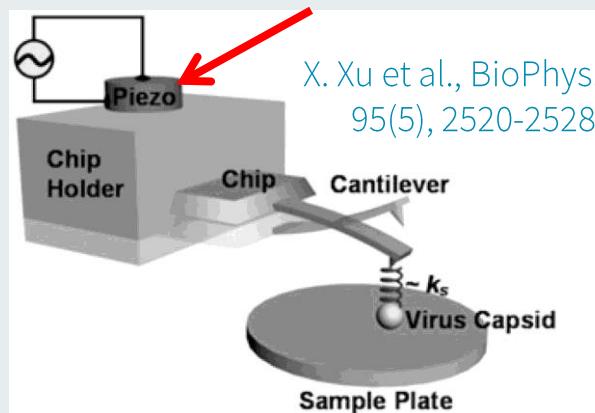


-1- Piezo-dither mode

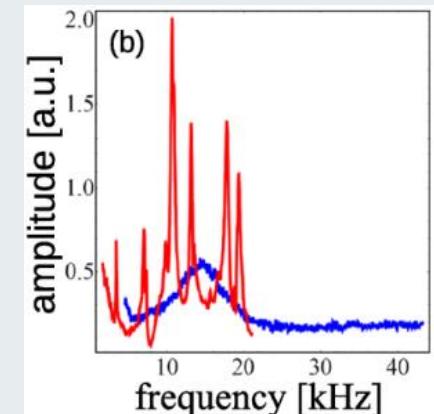
Present in all AFMs

Drawback:

Excitation in liquid



X. Xu et al., BioPhys. Journal,
95(5), 2520-2528, 2008



Tip excitation

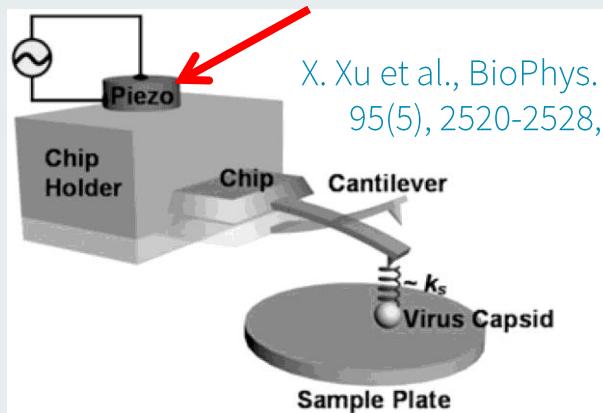


-1- Piezo-dither mode

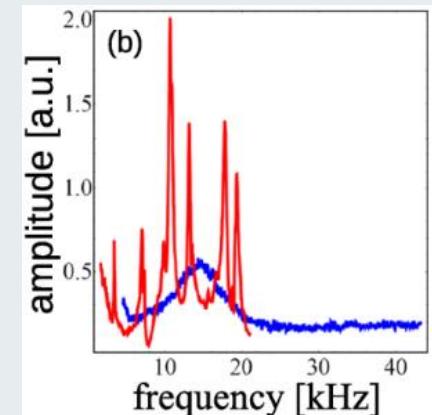
Present in all AFMs

Drawback:

Excitation in liquid



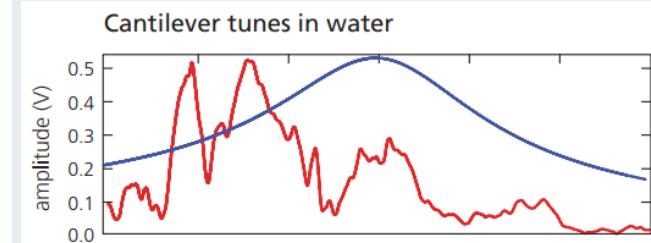
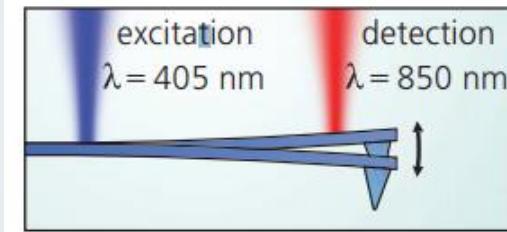
X. Xu et al., BioPhys. Journal, 95(5), 2520-2528, 2008



-2- Photothermal excitation

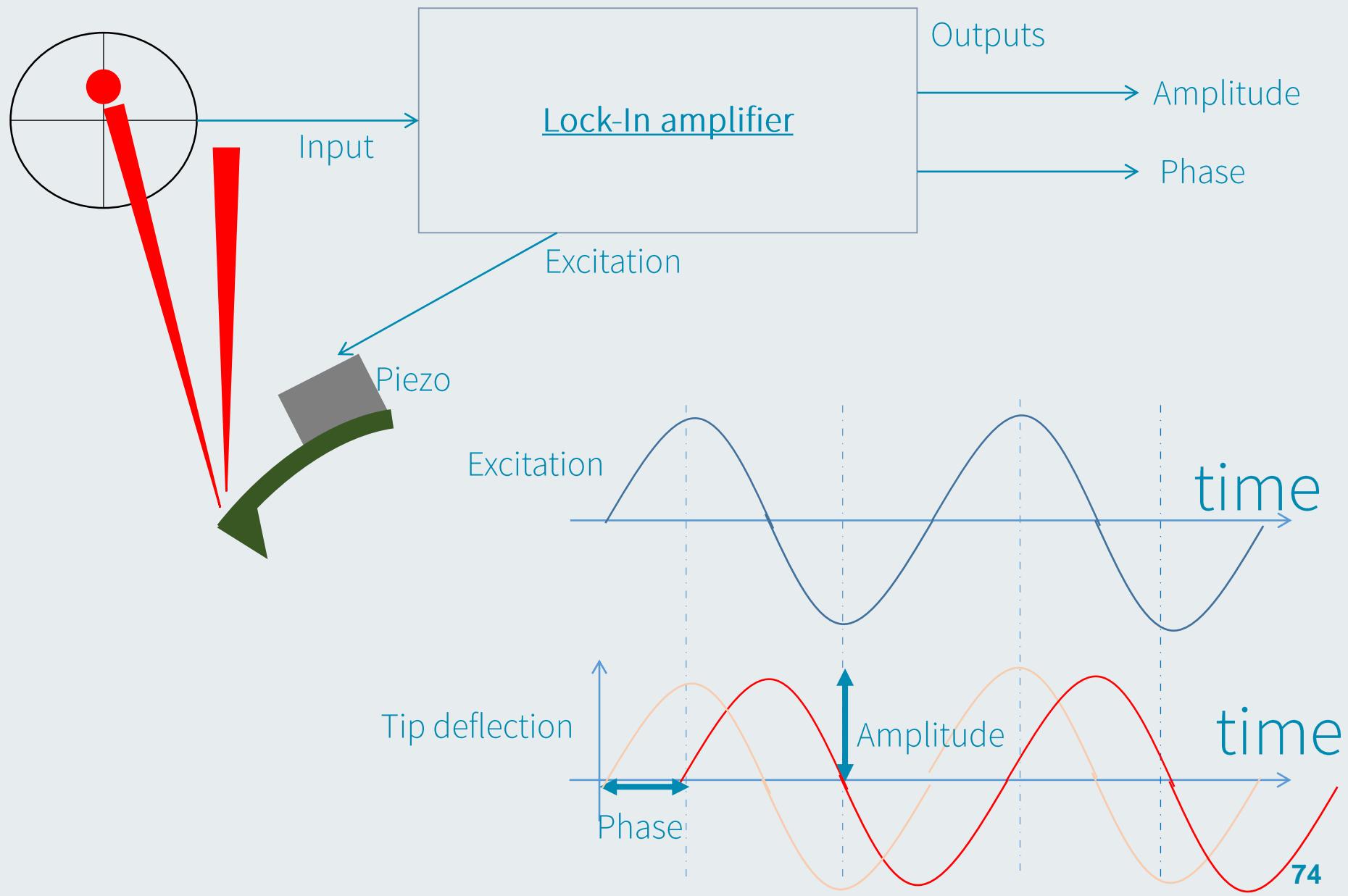
Provided by Asylum Research

Makes use of a 2nd laser (blue) to excite the cantilever base

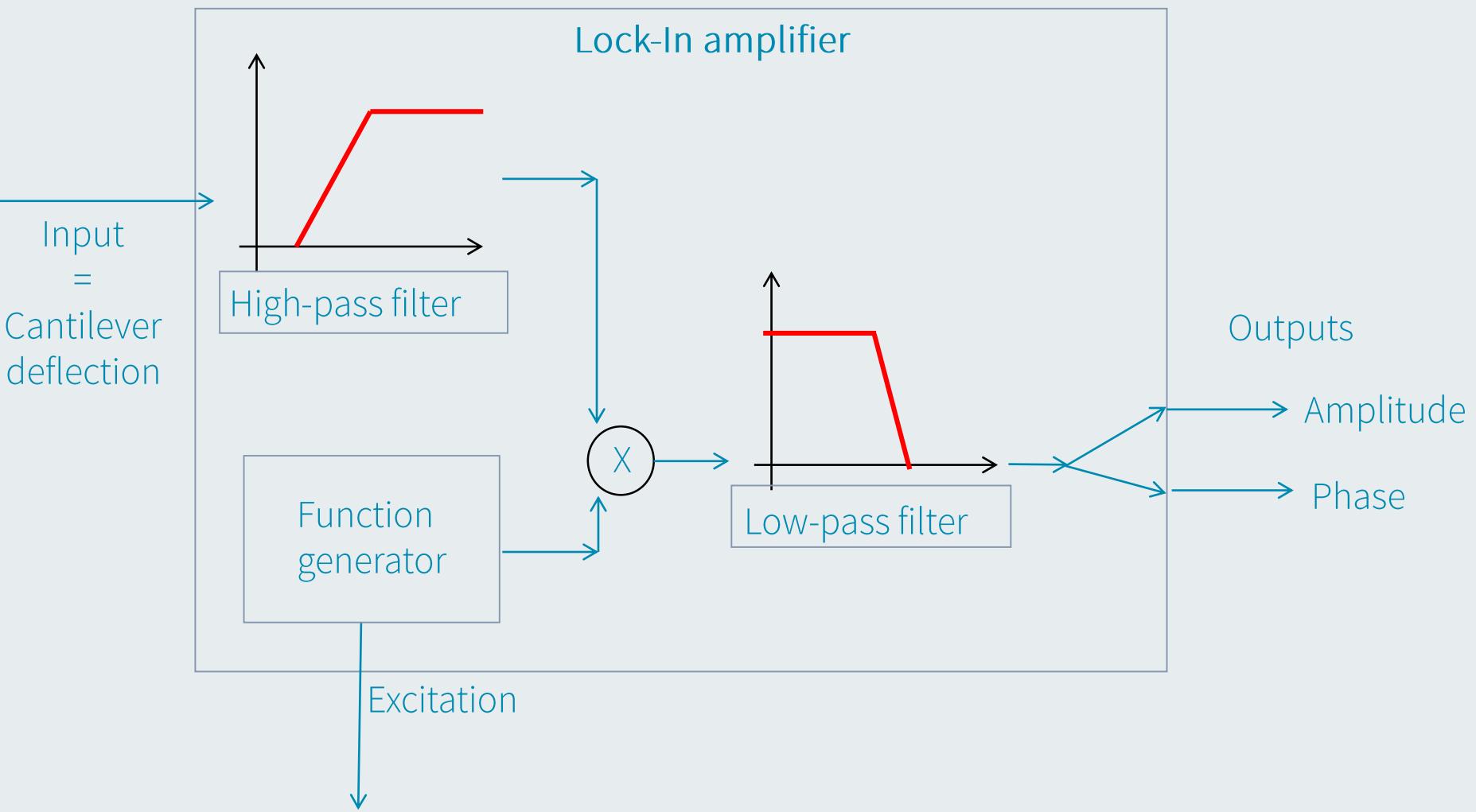


From Asylum Research website

Lock-in Amplifier



Lock-in Amplifier



1) Introduction to Scanning Probe Microscopy

2) The Force

3) Methods

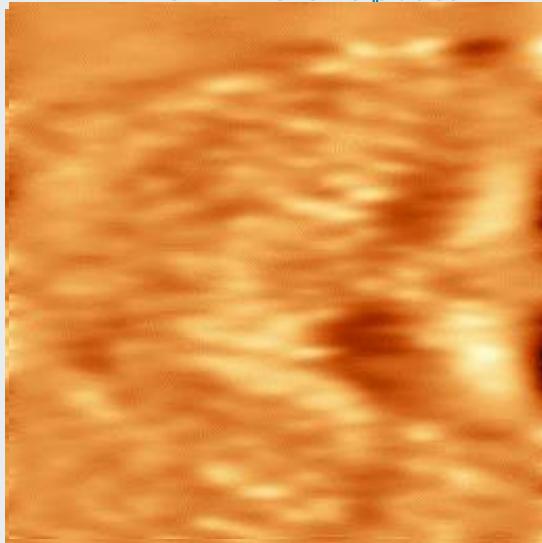
Cantilevers

Static and Dynamic AFM

4) Instruments

5) Advanced and novel AFM methods

ELF3 LLPS droplets



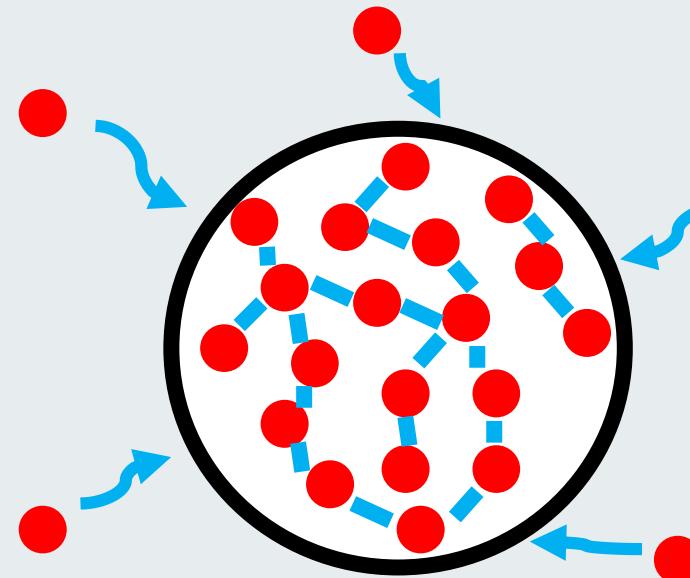
Walking myosin



Toshio Ando



Ando T. et al, PNAS
98(22), 12468-12472,
2001

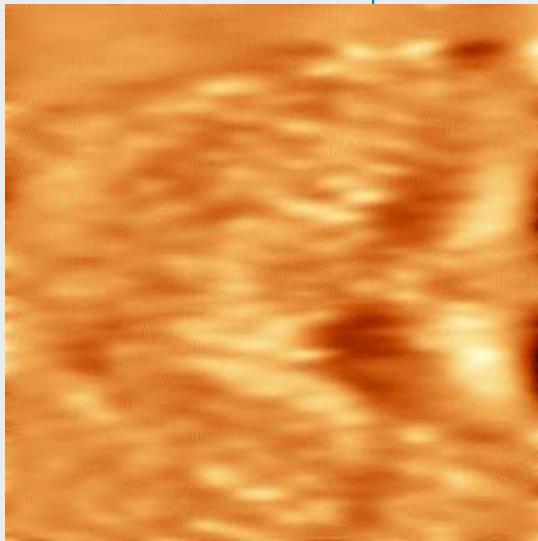


SURFACE TENSION
VISCOSITY
DENSITY

High-Speed AFM



ELF3 LLPS droplets



Walking myosin

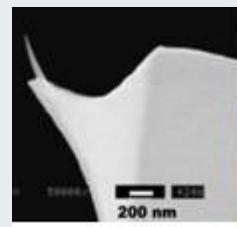
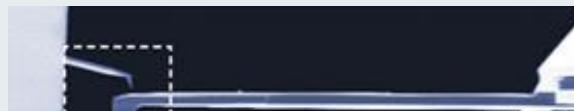
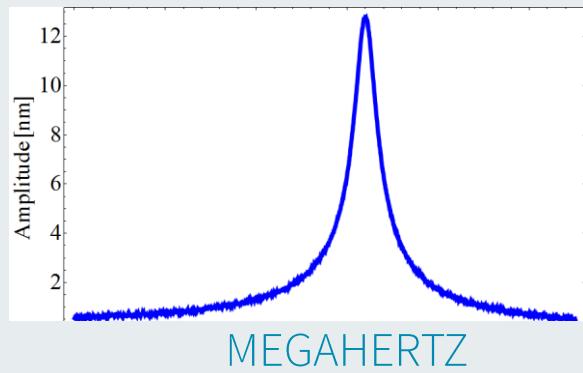


Toshio Ando



Ando T. et al, PNAS
98(22), 12468-12472,
2001

FAST (SMALL)
CANTILEVERS



FAST
XYZ
SCANNER



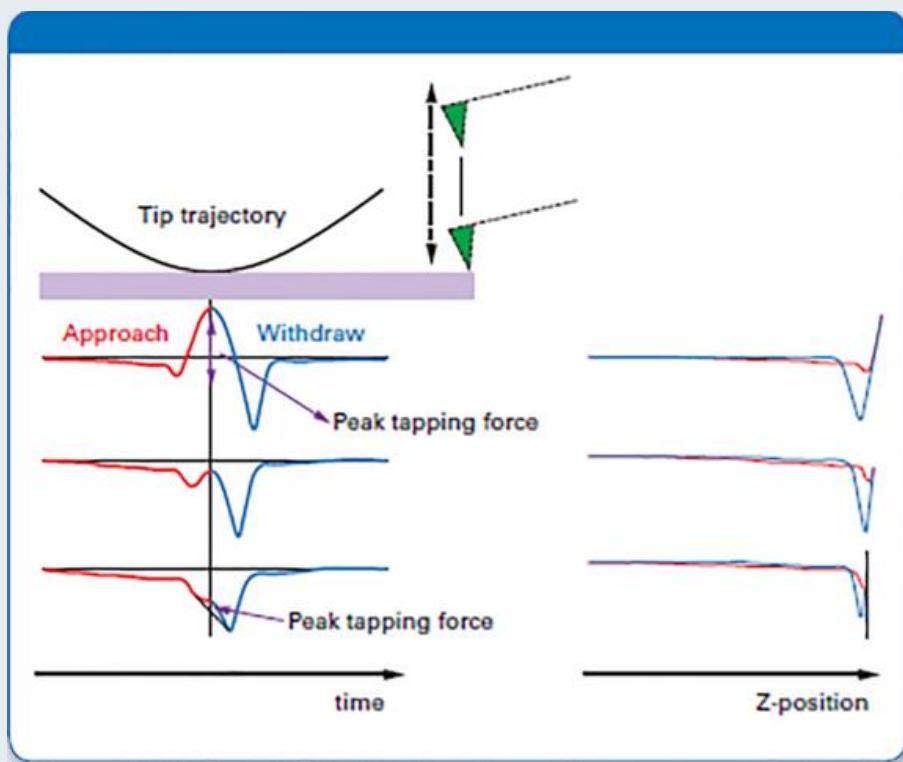
Fast Force-Curves Imaging



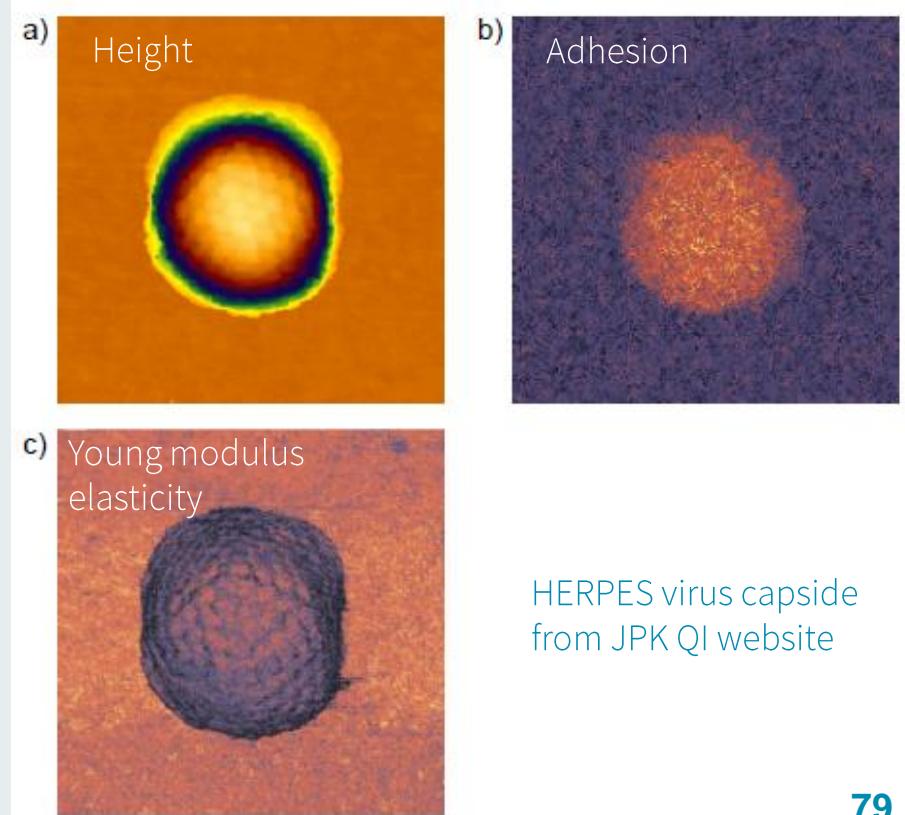
Bruker: PeakForce Tapping

JPK: QI quantitative imaging

Asylum Research: Fast Force Mapping



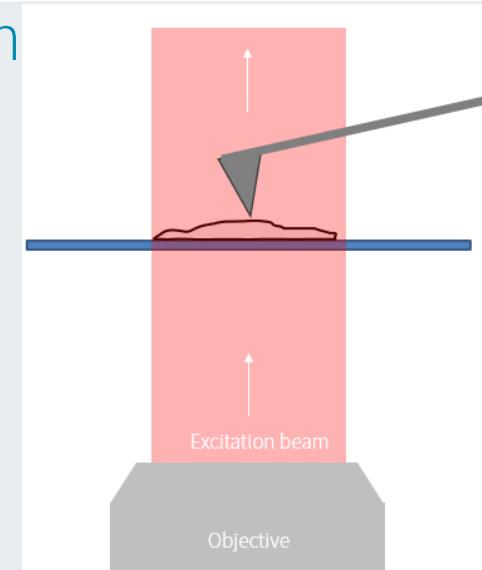
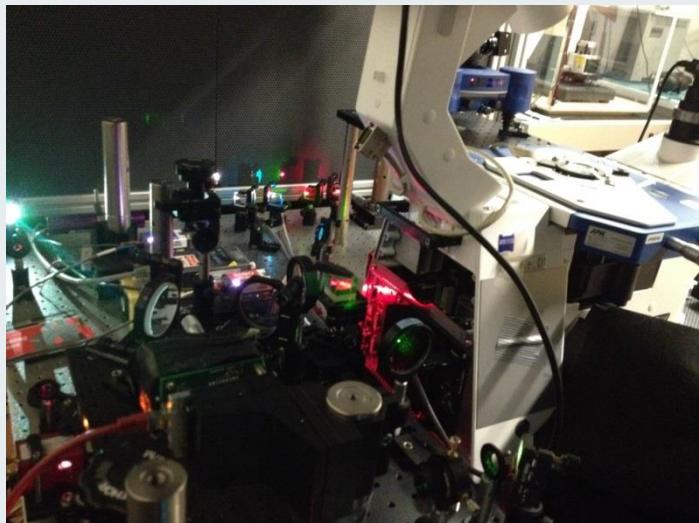
From Bruker website



Correlative AFM - Fluorescence

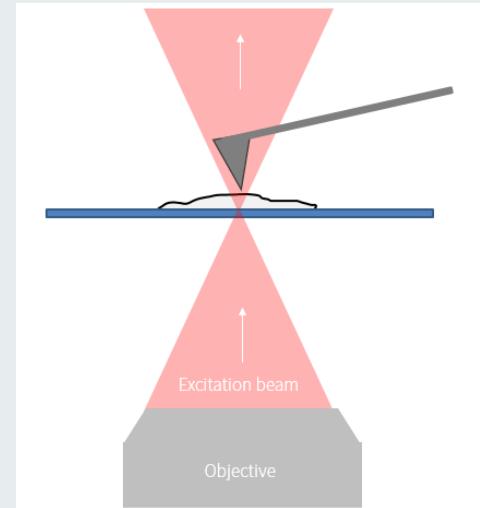
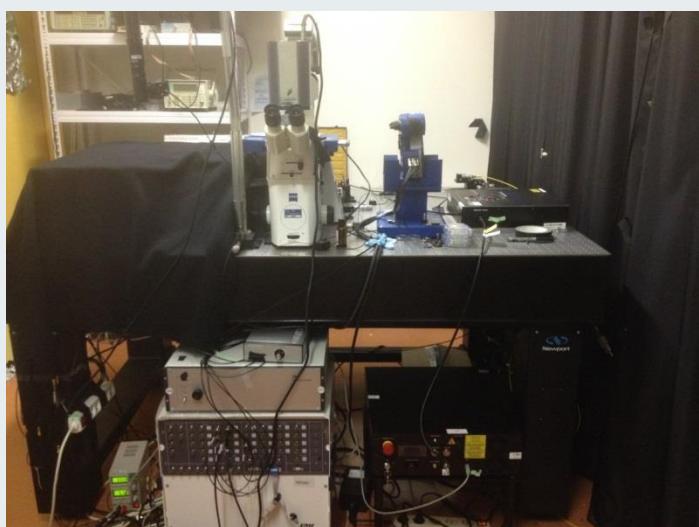


AFM + Fluorescence → Wide field illumination



Wide Field / TIRF - AFM

AFM + Fluorescence → Confocal illumination

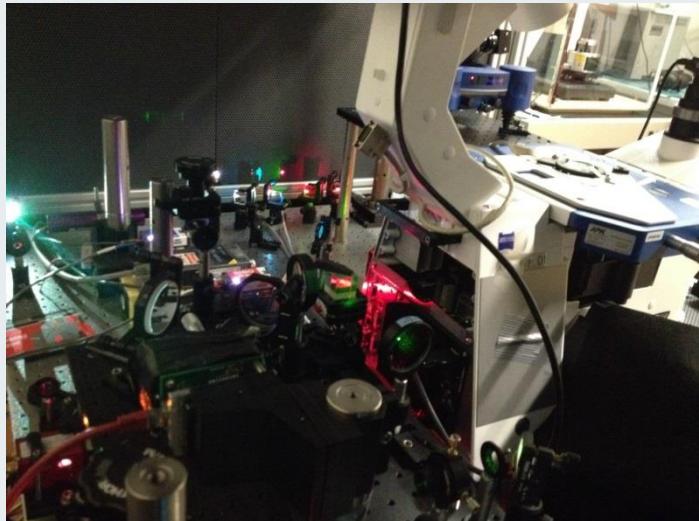


Confocal- AFM

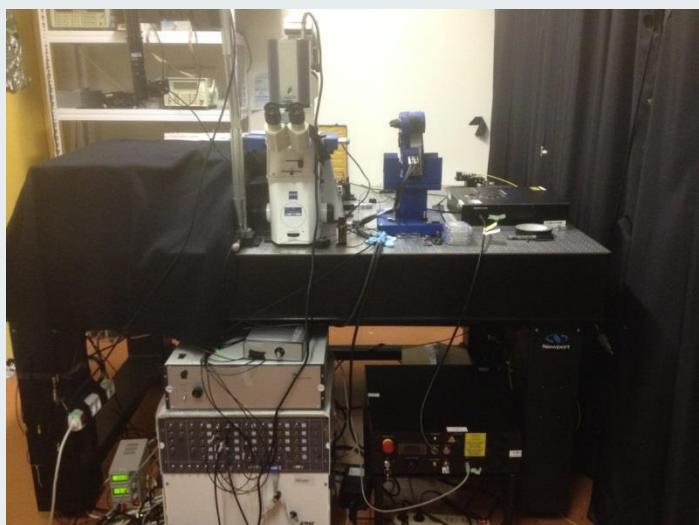
Correlative AFM - Fluorescence



AFM + Fluorescence → Wide field illumination



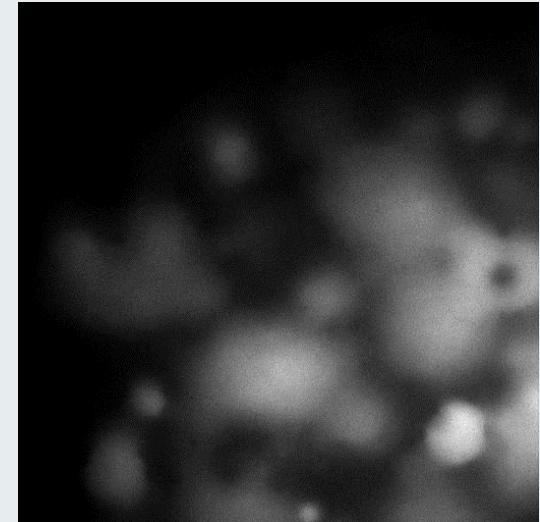
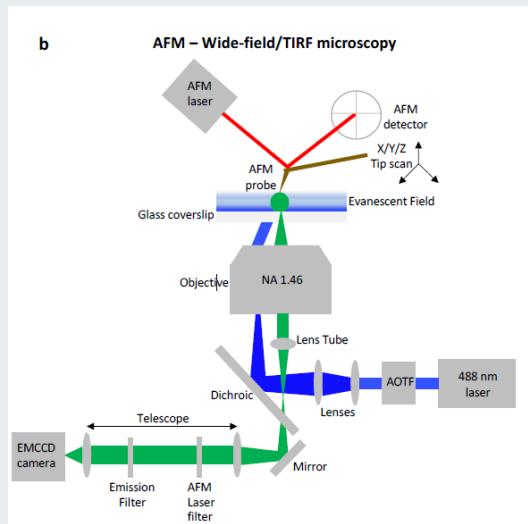
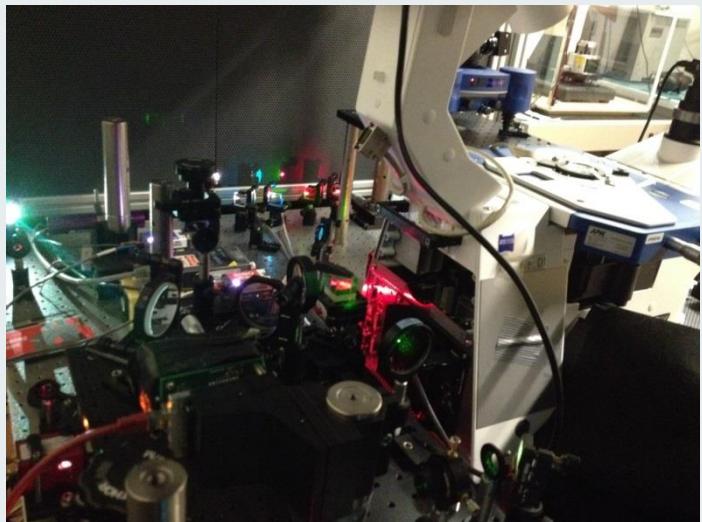
AFM + Fluorescence → Confocal illumination



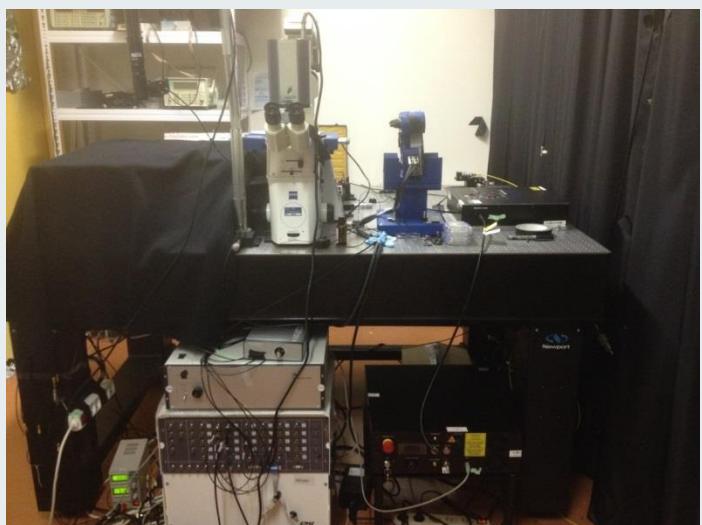
Correlative AFM - Fluorescence



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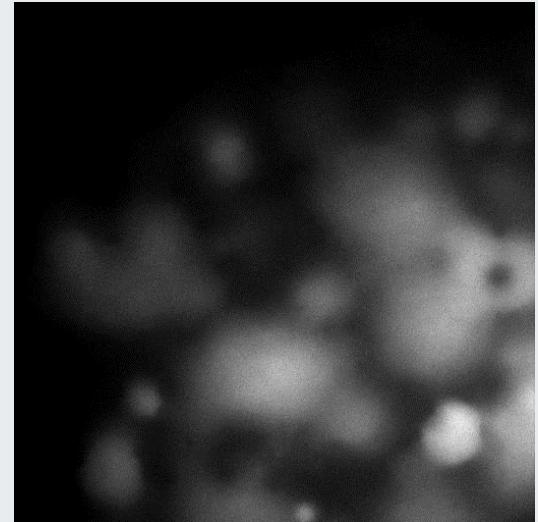
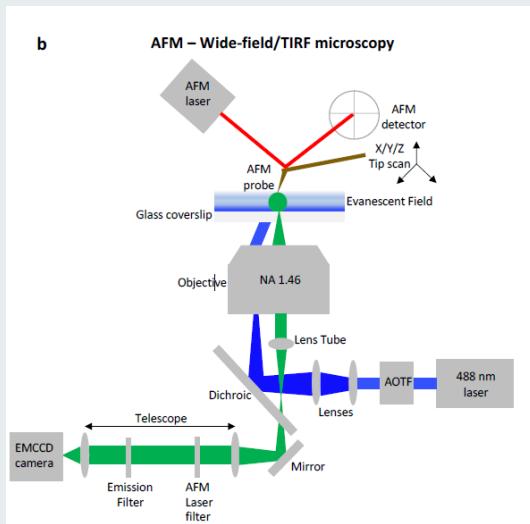
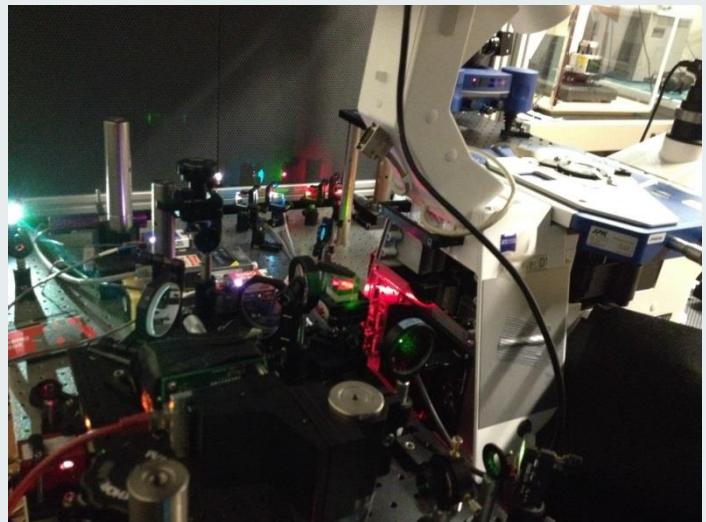
AFM + Fluorescence → Confocal illumination



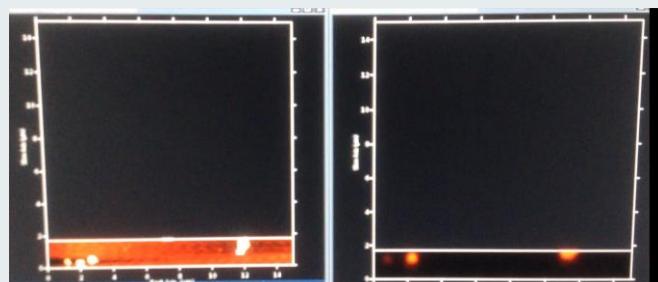
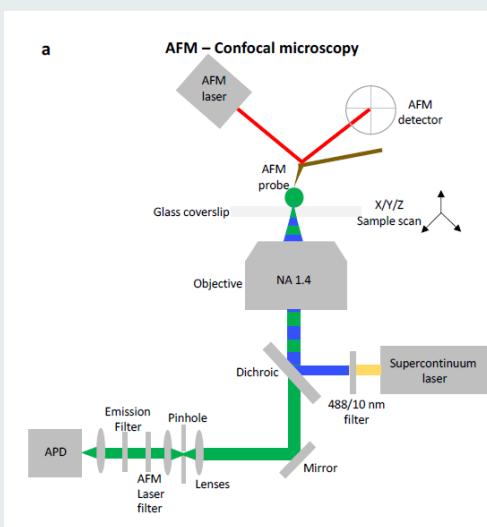
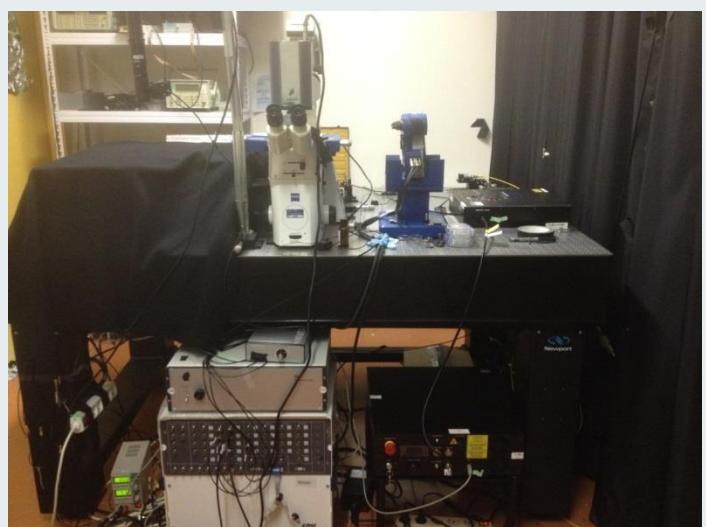
Correlative AFM - Fluorescence



AFM + Fluorescence → Wide field illumination



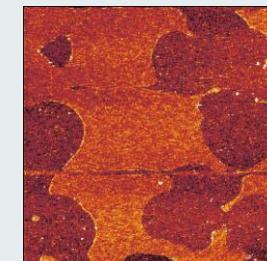
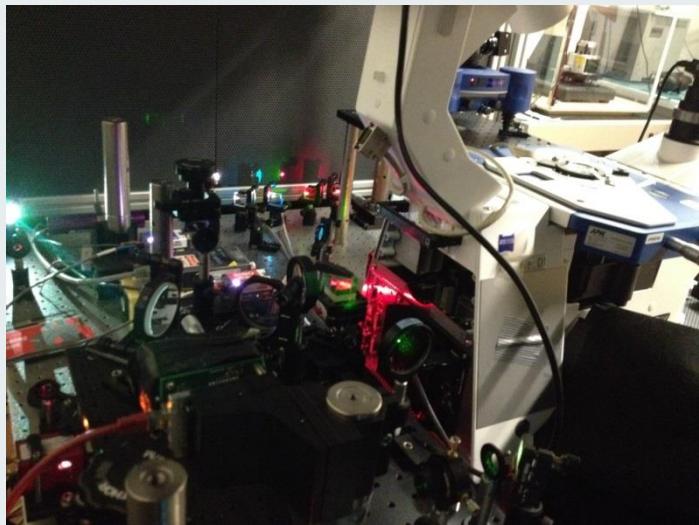
AFM + Fluorescence → Confocal illumination



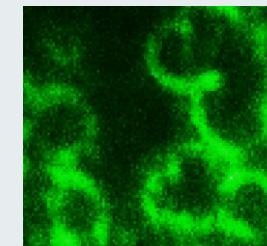
Correlative AFM - Fluorescence



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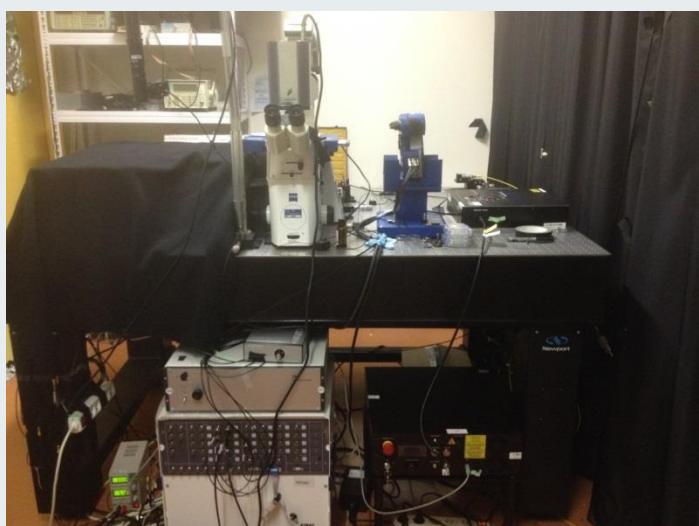


AFM



TIRF
Fluorescence

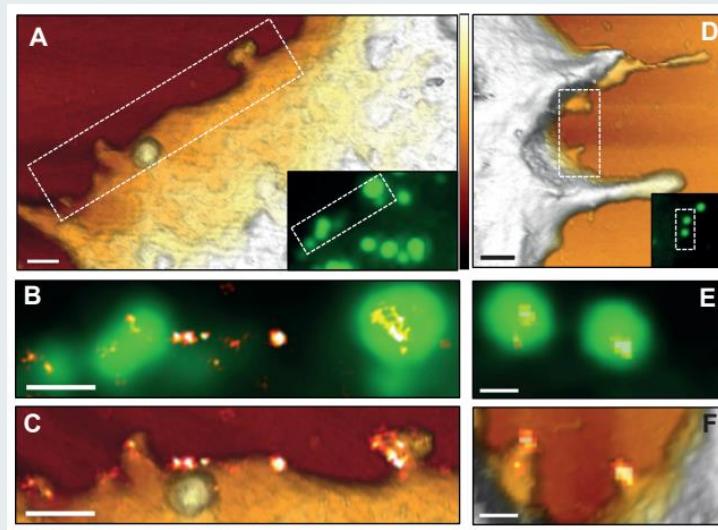
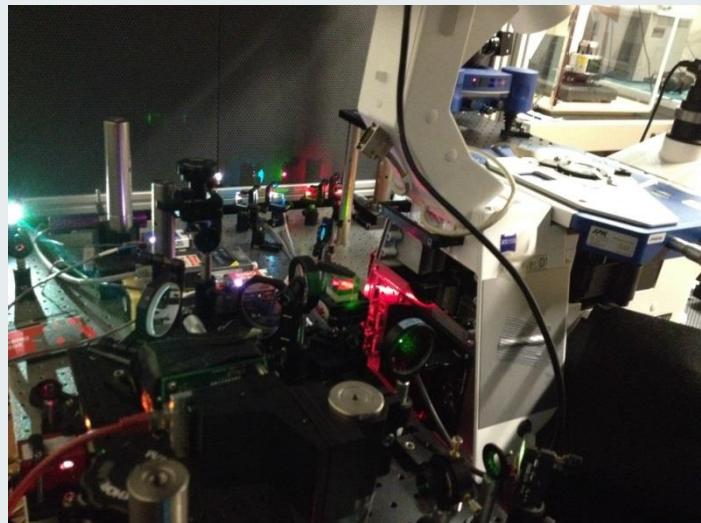
AFM + Fluorescence → Confocal illumination



Correlative AFM - Fluorescence



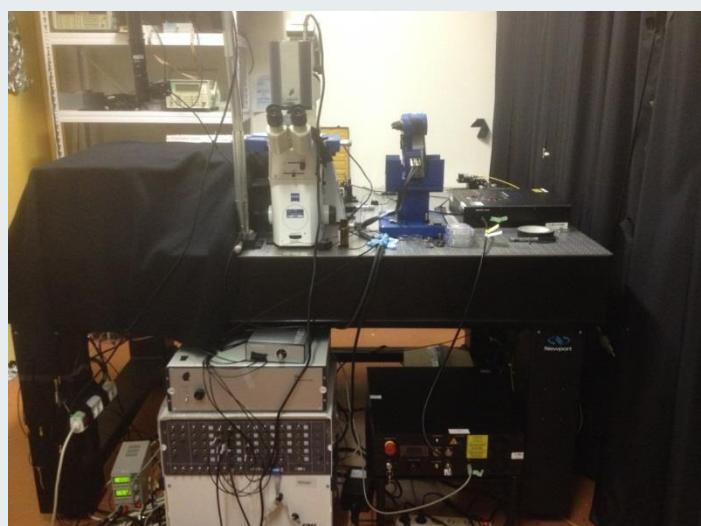
AFM + Fluorescence → Wide field illumination



AFM
and
STORM

Dahmane,
S. et al.,
Nanoscale,
2019

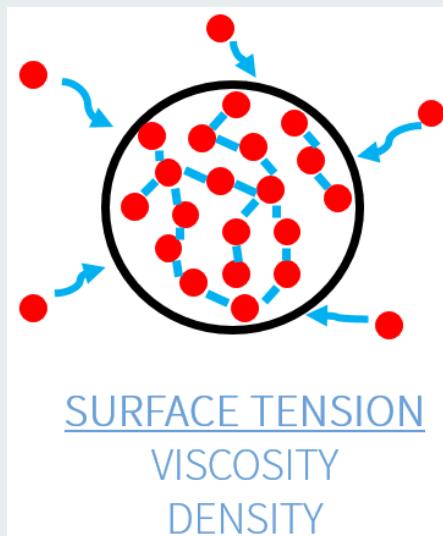
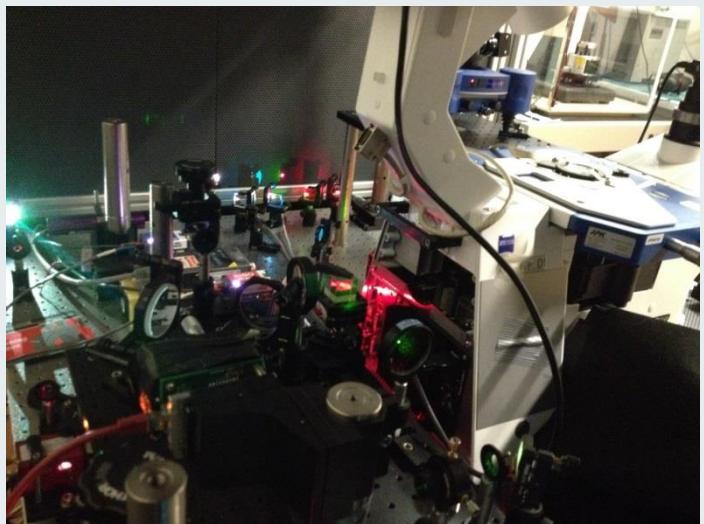
AFM + Fluorescence → Confocal illumination



Correlative AFM - Fluorescence



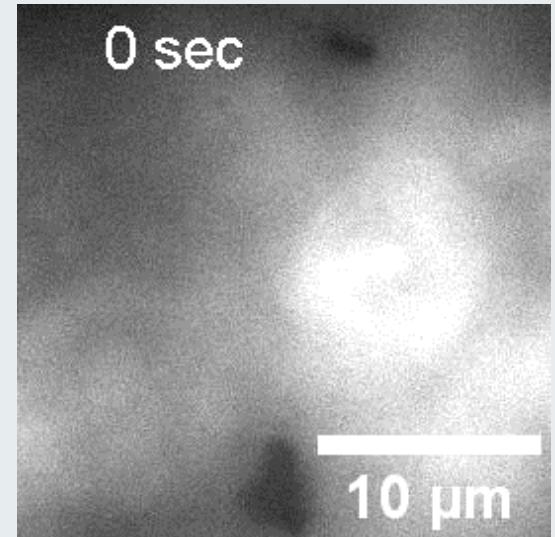
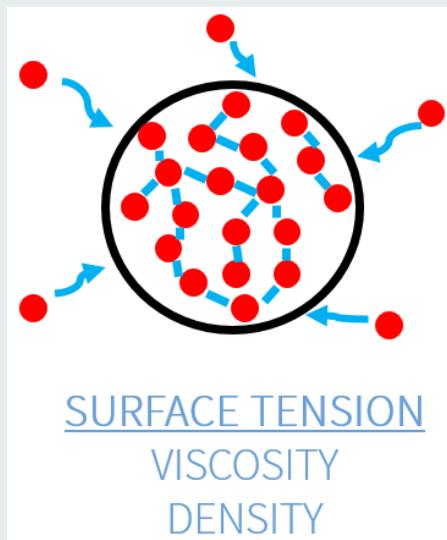
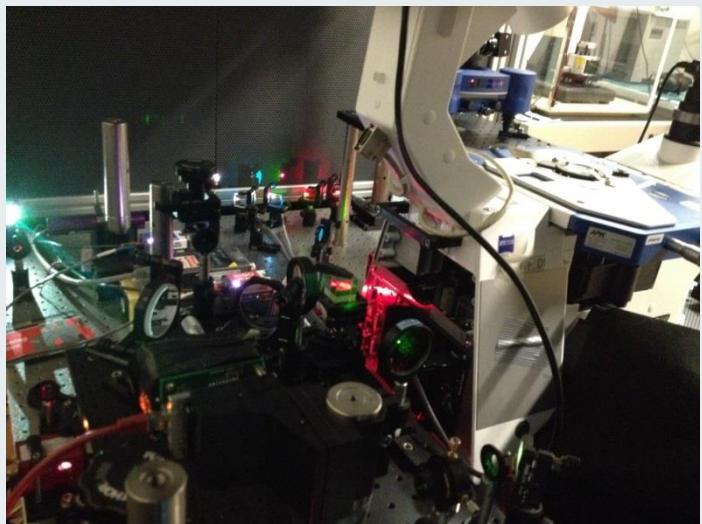
AFM + Fluorescence → Wide field illumination



Correlative AFM - Fluorescence



AFM + Fluorescence → Wide field illumination

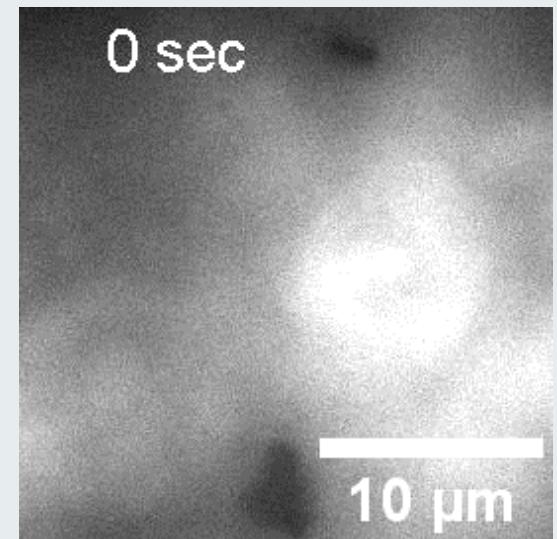
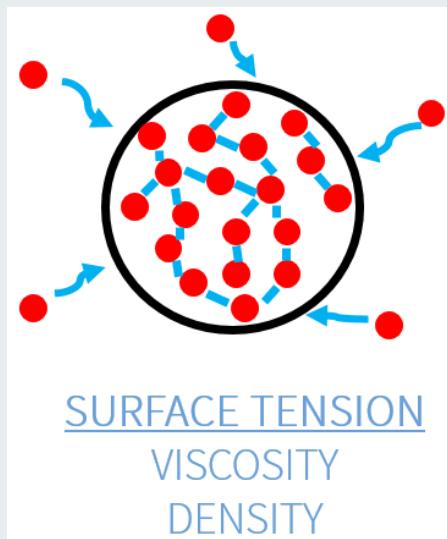
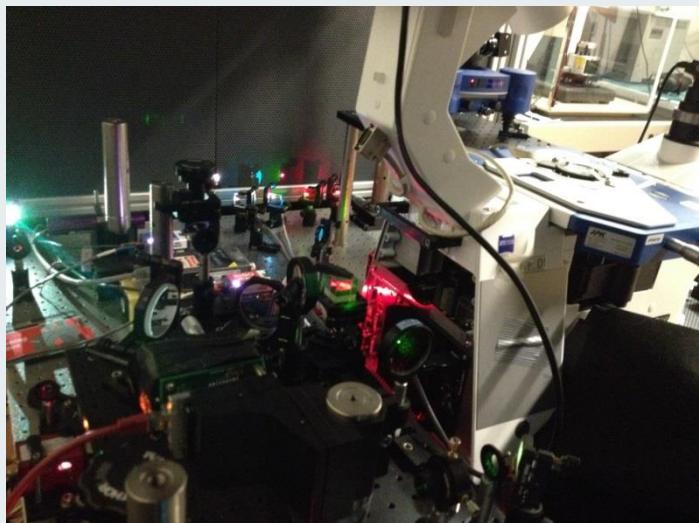


Santamaria A. et al., Biophysical Journal, 2024

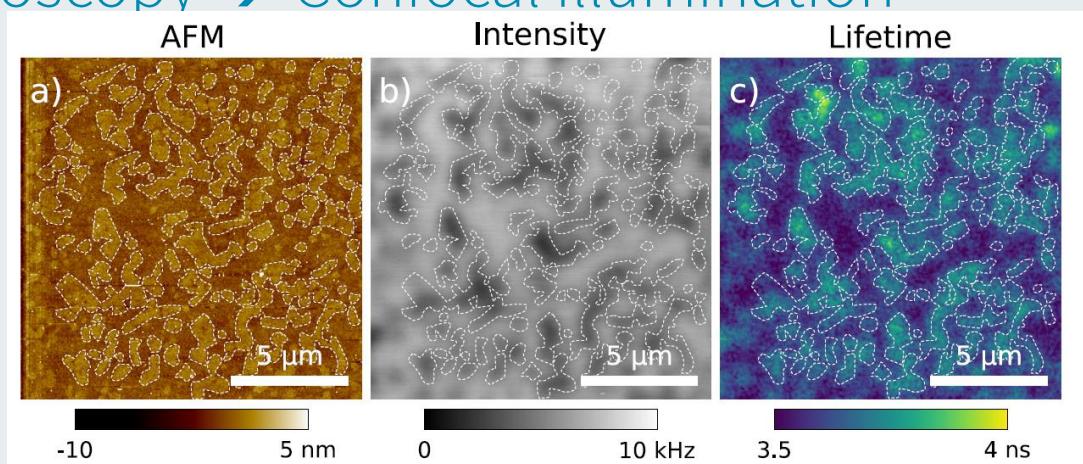
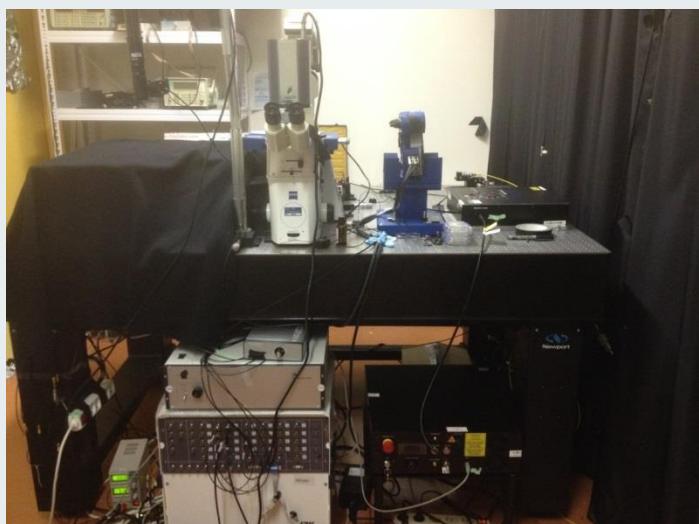
Correlative AFM - Fluorescence



AFM + Fluorescence → Wide field illumination



AFM + Fluorescence Spectroscopy → Confocal illumination



1) Introduction to Scanning Probe Microscopy

2) The Force

3) Methods

Cantilevers

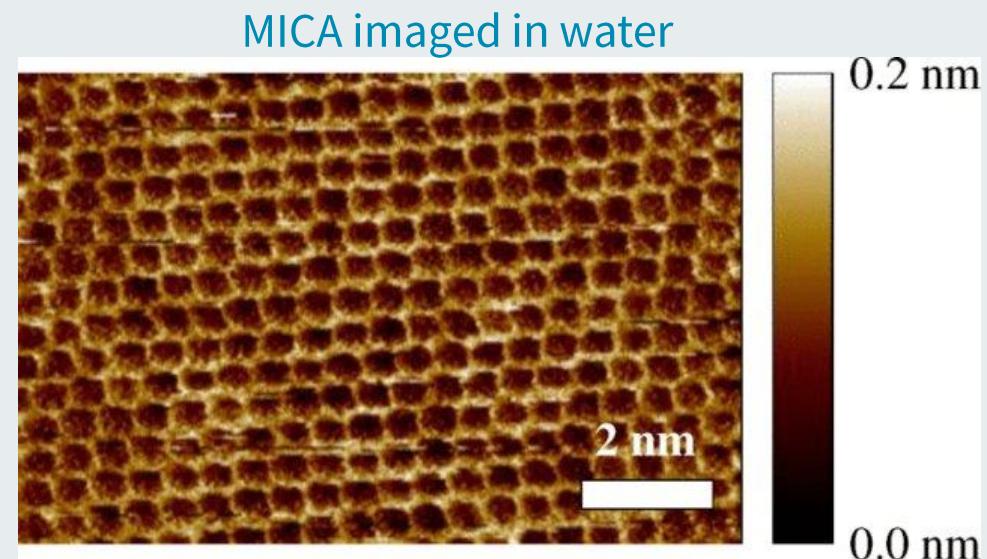
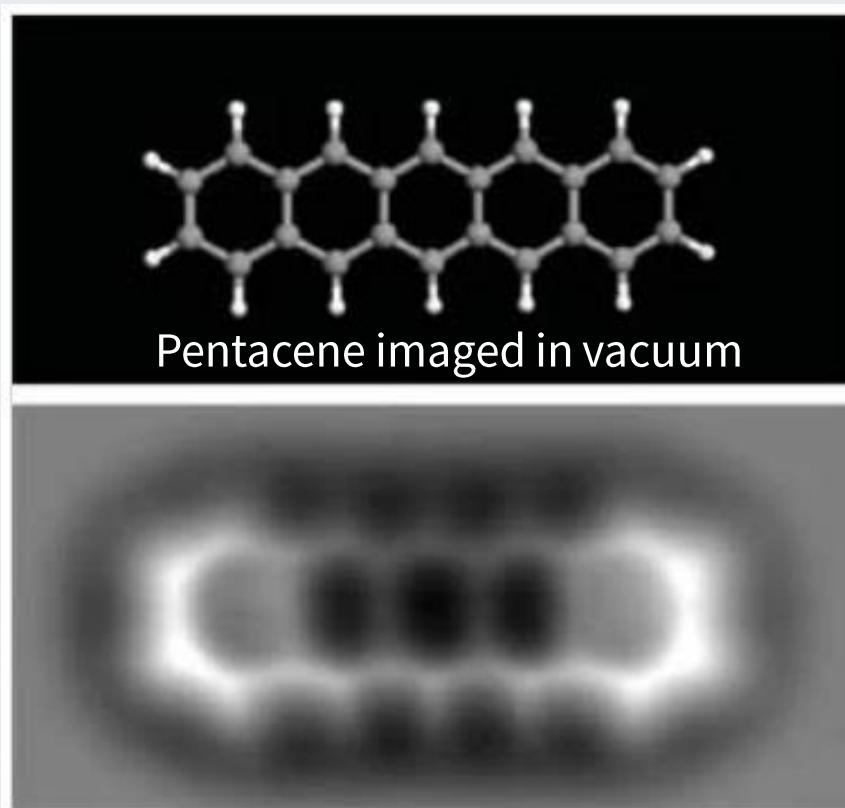
Static and Dynamic AFM

4) Instruments

5) Advanced and novel AFM methods

6) Applications, BYS and literature

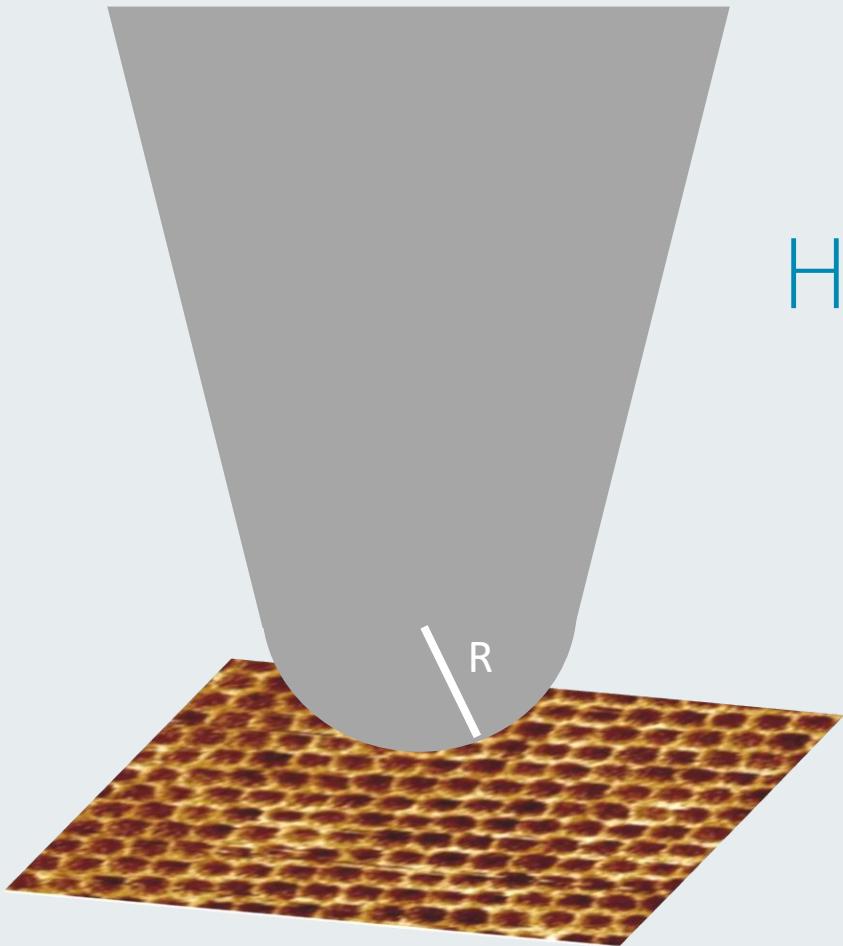
High Resolution on flat atomic surfaces



Khan, Z., et al. *Review of Scientific Instruments* 81.7 (2010)

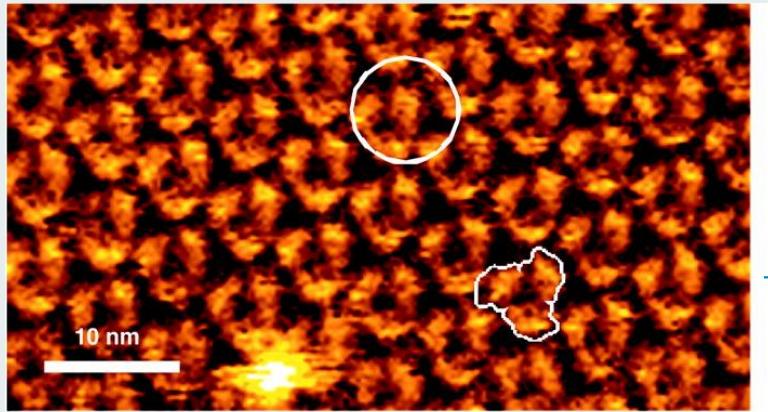
Gross, L. et al. *Science* 325, 1110–1114 (2009)

Tip radius and resolution



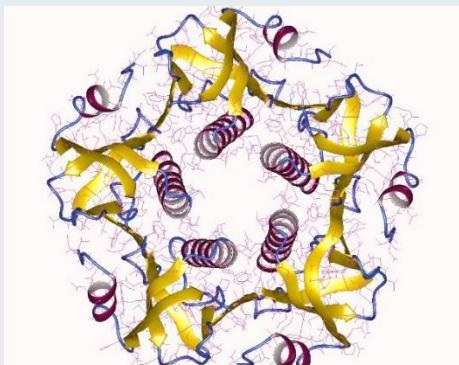
How can a 2 nm-sized tip
image atoms spaced
angstroms apart?

High Resolution within membranes

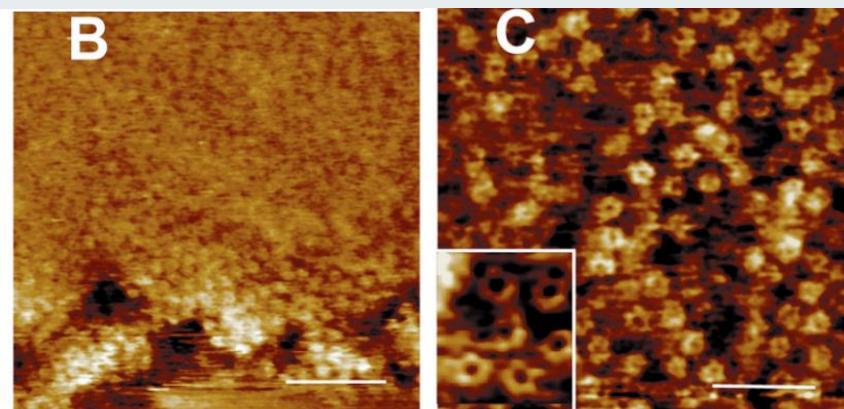


Oesterhelt, F.,
Oesterhelt, D.,
Pfeiffer, M., Engel,
A., Gaub, H. E., &
Muller, D. J. (2000).
Science, 288(5463),
143-146.

Individual BR from native purple membrane.

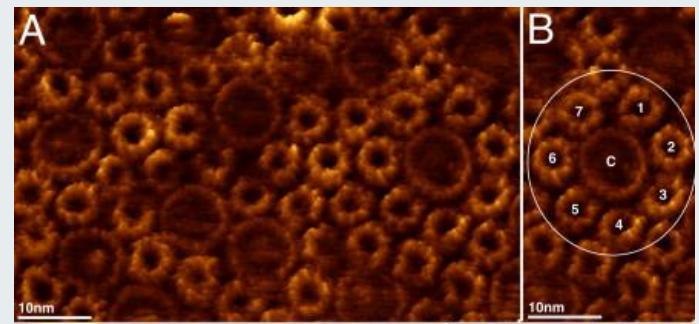


Cholera toxin Pentamer, wikipedia



Scale Bar = 25 nm

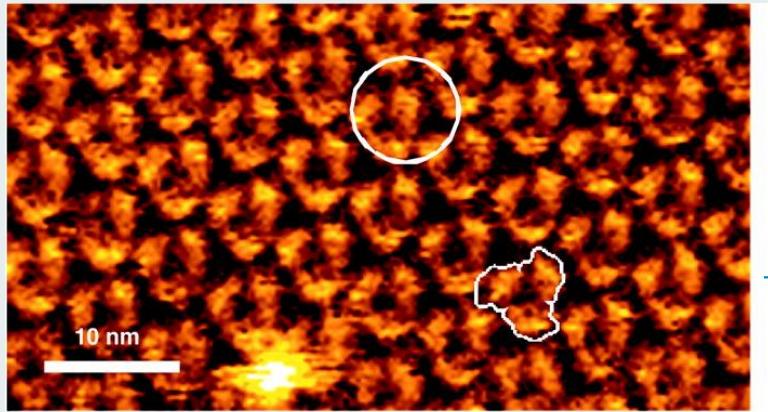
Photosynthetic complexes in native
membranes of *Rsp. photometricum*



Scheuring, Simon, Thomas Boudier, and
James N. Sturgis, *Journal of Structural Biology*
159.2 (2007): 268-276.

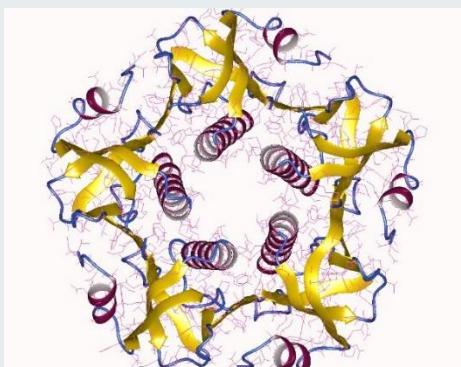
Milhiet, Pierre
Emmanuel, et al. "AFM
characterization of
model rafts in
supported bilayers."
Single Molecules 2.2
(2001): 109-112.

High Resolution within membranes

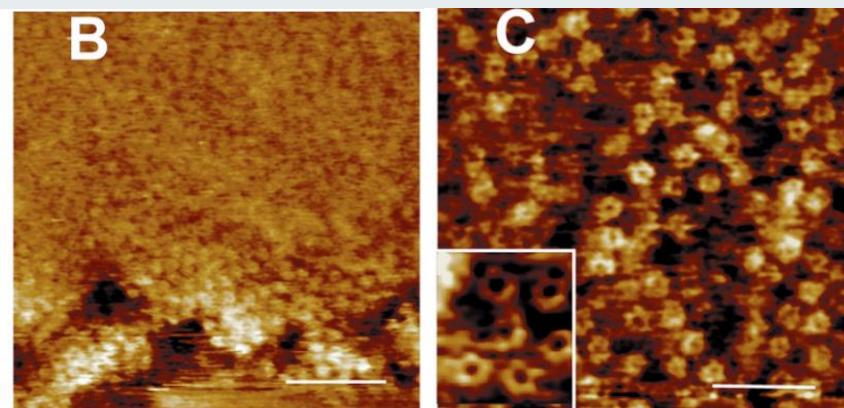


Oesterhelt, F.,
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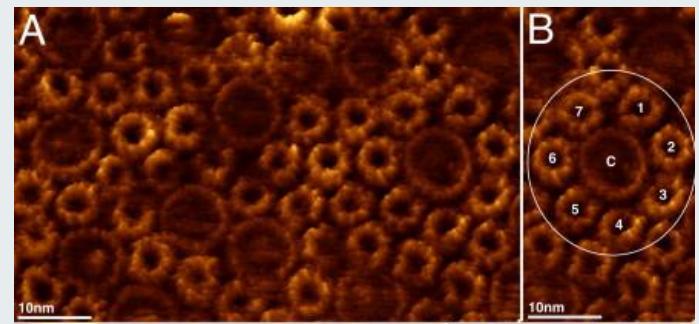


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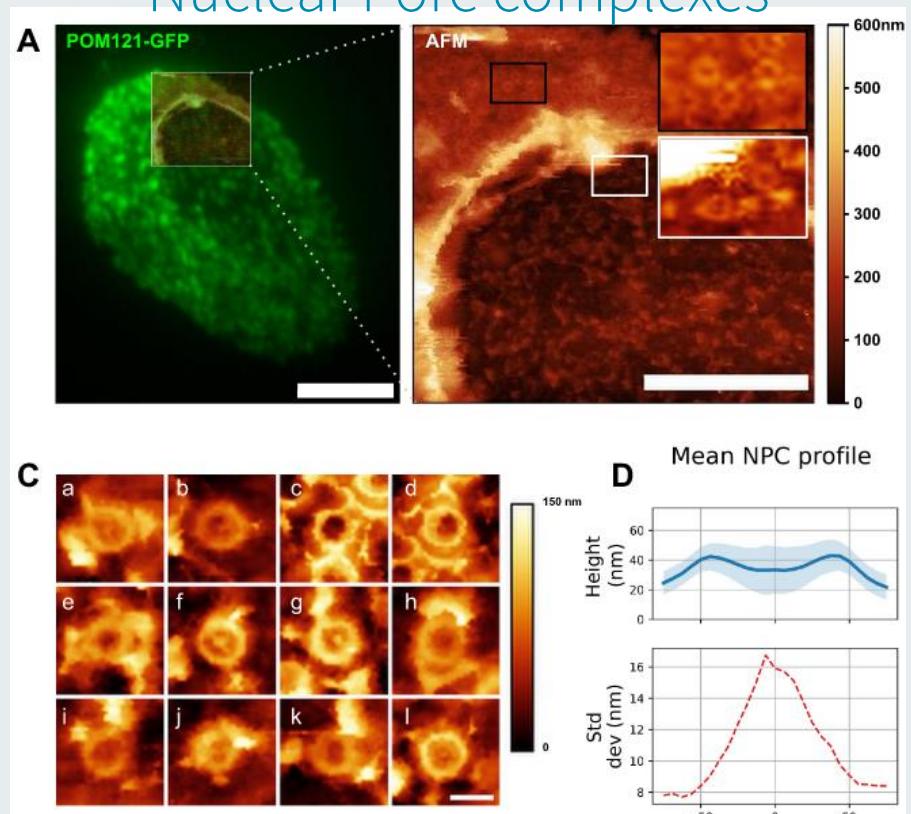


Scheuring, Simon, Thomas Boudier, and
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Milhiet, Pierre
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Single Molecules 2.2
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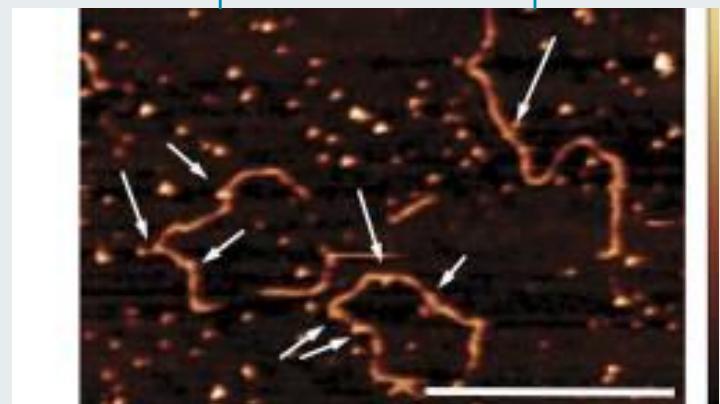
High Resolution within larger complexes

Nuclear Pore complexes



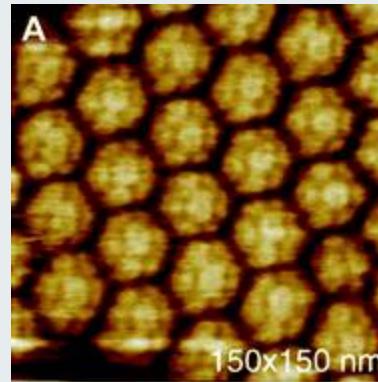
Vial, Anthony, et al. "Structure and mechanics of the human nuclear pore complex basket using correlative AFM-fluorescence superresolution microscopy." *Nanoscale* 15.12 (2023): 5756-5770.

DNA-protein complexes



Puranik, Sriharsha, et al. *The Plant Cell* 26.9 (2014): 3603-3615.

Viral capsid



brome mosaic virus (BMV)

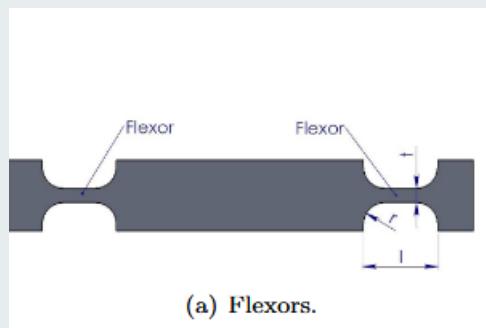
Baclayon, M., G. J. L. Wuite, and W. H. Roos. *Soft Matter* 6.21 (2010): 5273-5285.

BUILD YOUR SETUP BYS - AFM

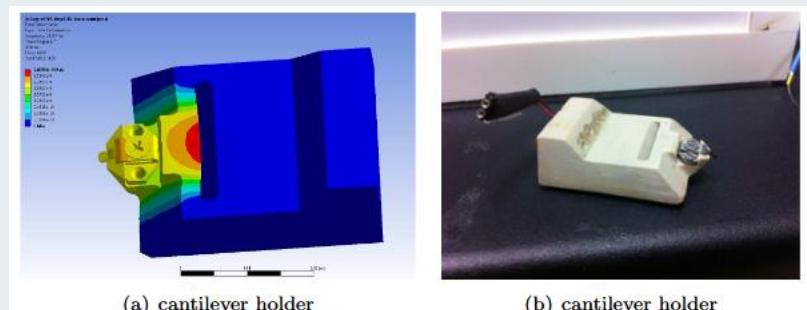


1) Make a list of the necessary equipment to build up an atomic force microscope.

- AAA



- BBB



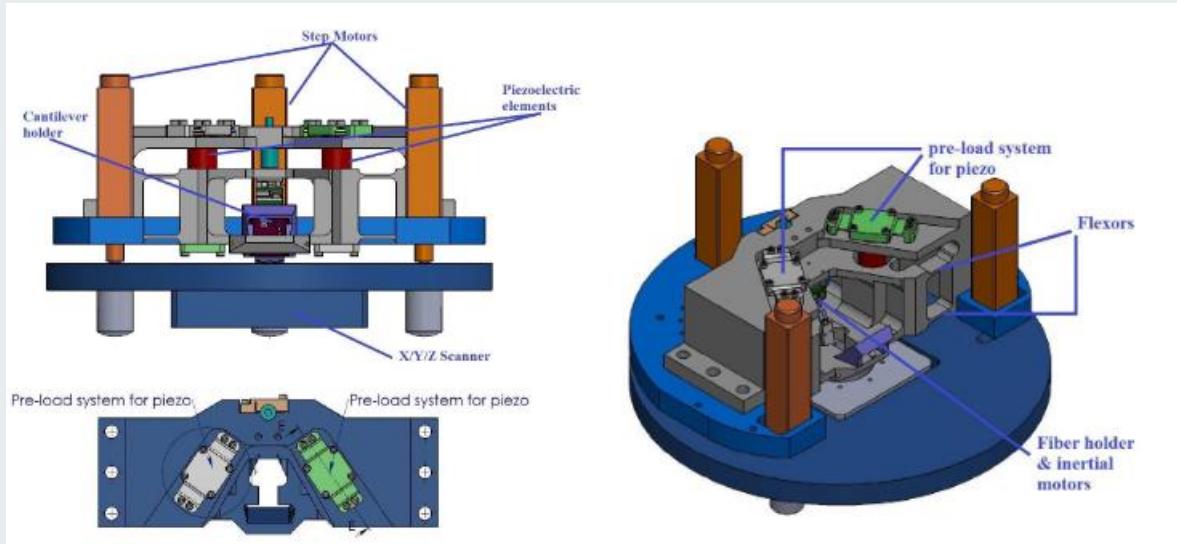
- CCC



BUILD YOUR SETUP BYS - AFM

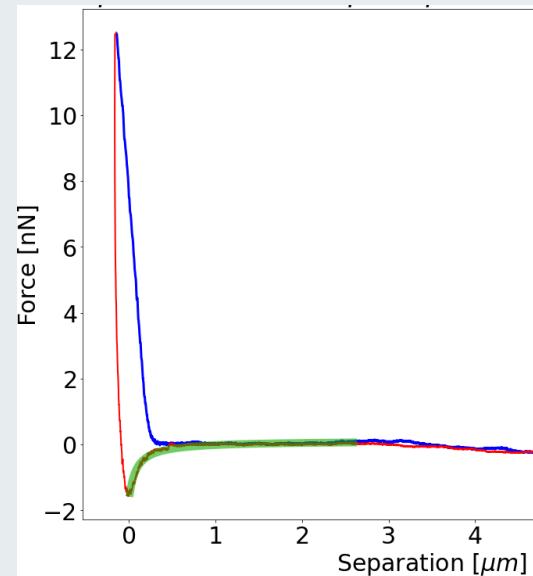
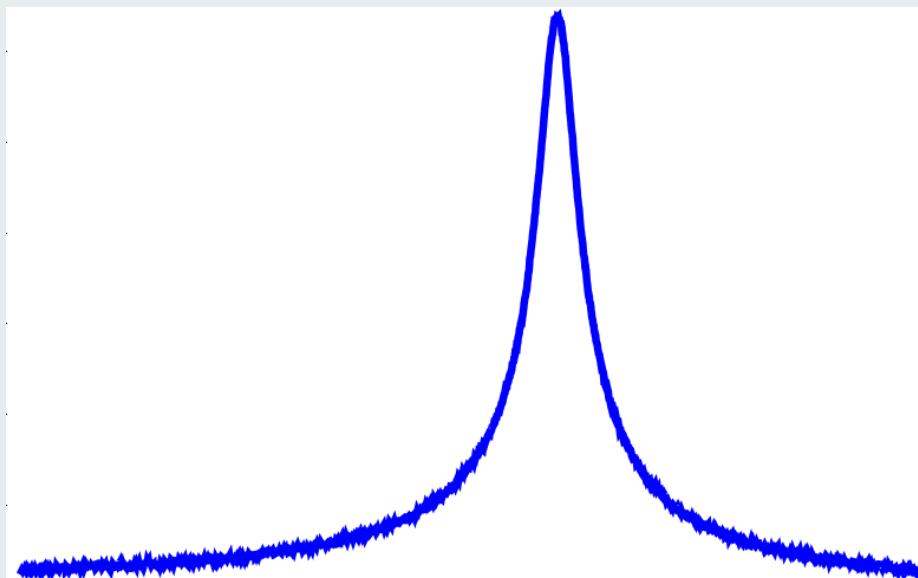


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- 2) AFM design: geometry, mounting.



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- 3) Troubleshooting: make sure all equipment works.

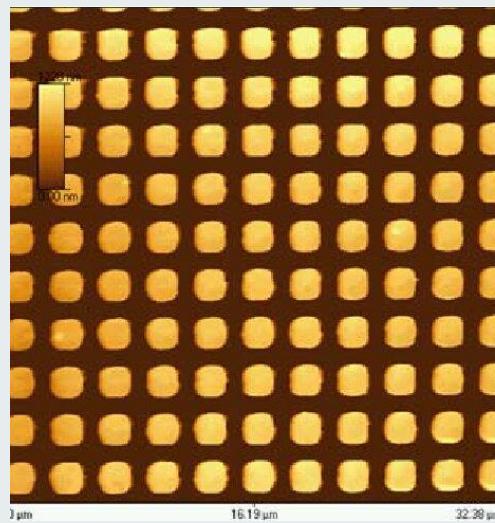
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BUILD YOUR SETUP BYS - AFM



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- 5) AFM images in contact mode in air on top of a silicon calibration grating.



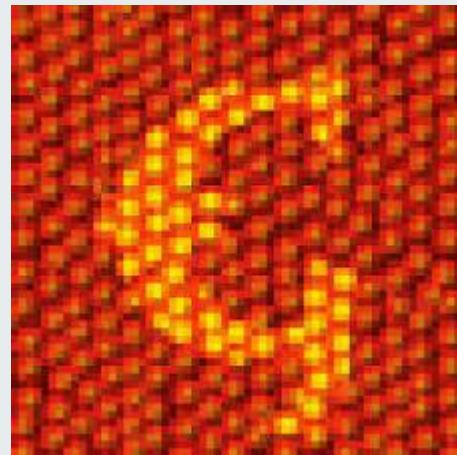
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- 5) AFM images in contact mode in air on top of a silicon calibration grating.
- 6) AFM images in amplitude modulation mode.

Tips for High-Resolution AFM imaging



- 1) The instrumental noise should be smaller than the aimed resolution.
- 2) The lateral resolution cannot be smaller than the size of the tip apex.
- 3) The decay length of the tip surface interaction should be smaller than the tip apex.
- 4) Imaging isolated three dimensional objects imposes limits on the lateral resolution.
- 5) The adhesion energy should be minimized. This is usually achieved by using sharp tips.
- 6) The applied force should be as small as possible.
- 7) Under identical conditions (tip radius and applied force), the stiffer the sample the better the lateral resolution.

Ricardo Garcia, Amplitude Modulation Atomic Force Microscopy, Wiley, 2010



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Some documents



Available online at www.sciencedirect.com



Surface Science Reports 59 (2005) 1–152



www.elsevier.com/locate/surfrept

Force measurements with the atomic force microscope: Technique, interpretation and applications

Hans-Jürgen Butt^a, Brunero Cappella^{b,*}, Michael Kappl^a

^a Max-Planck-Institute for Polymer Research, D-55128 Mainz, Germany

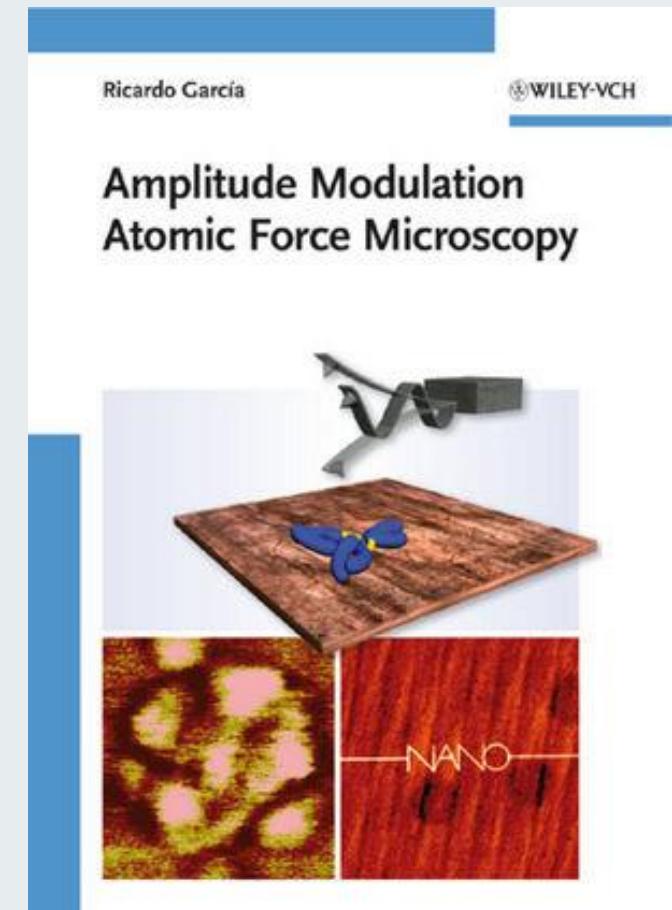
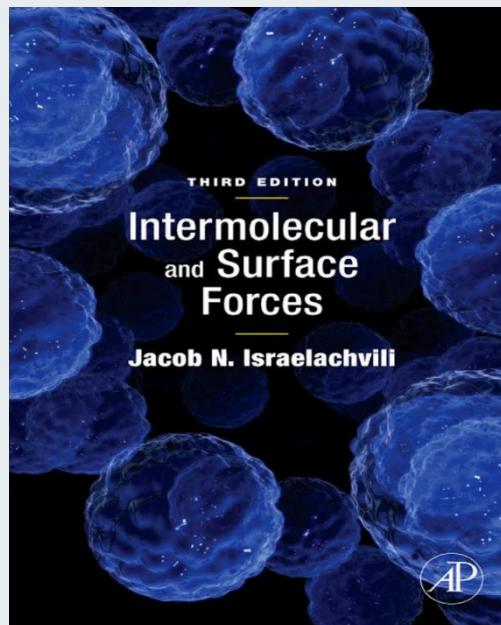
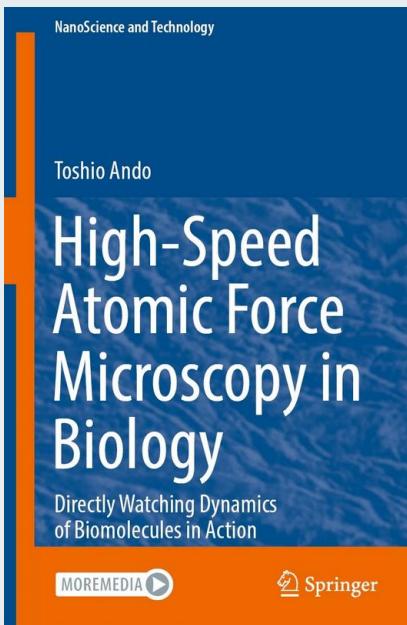
^b Federal Institute for Material Research and Testing, D-12205 Berlin, Germany

Accepted 1 August 2005

Ricardo García



Amplitude Modulation Atomic Force Microscopy



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Team Integrative Biophysics of Membranes (IBM)

<https://integrativebiophysicsofmembranes.wordpress.com/>

