Overview of Scanning Probe Microscopy (SPM)

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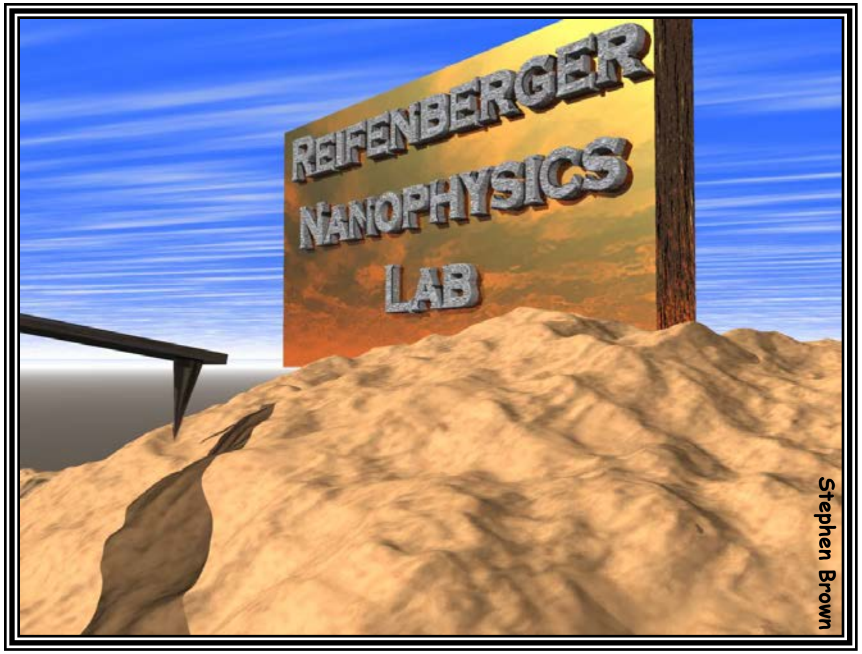
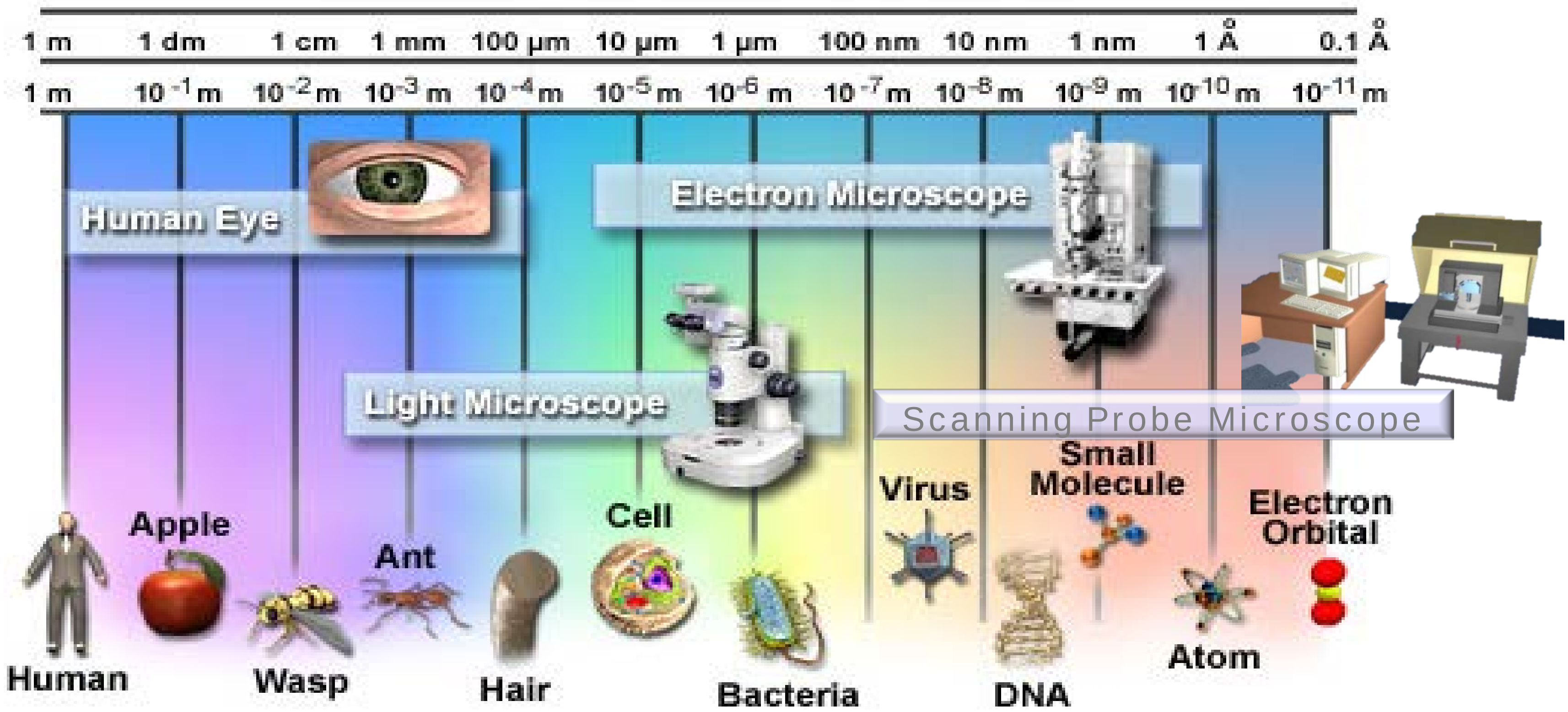


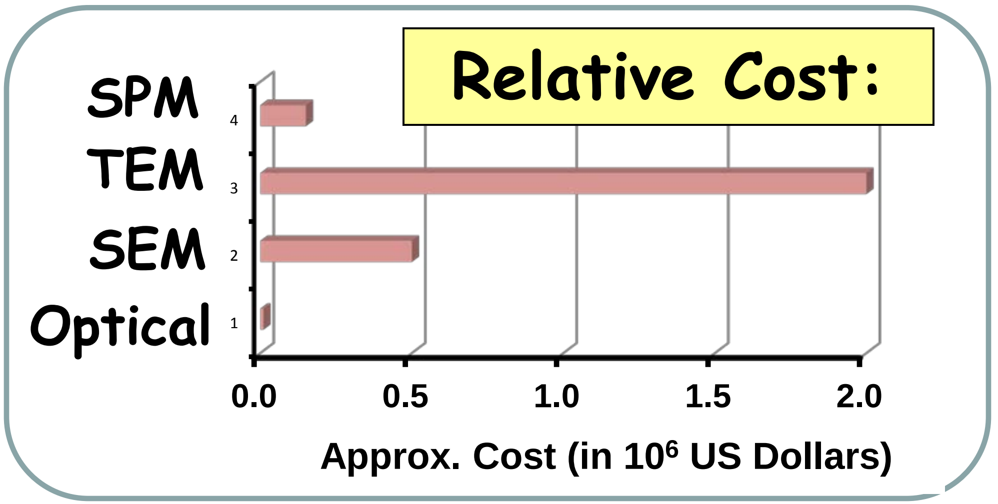
Microscopy Summary



"Seeing" with Sharp Probes (1981)

"Seeing" with Electrons (1931)

Enhanced seeing with Light (~1600)



Source: http://micro.magnet.fsu.edu/cells/index.html

What's so special about SPMs?

Optical and electron microscopy:

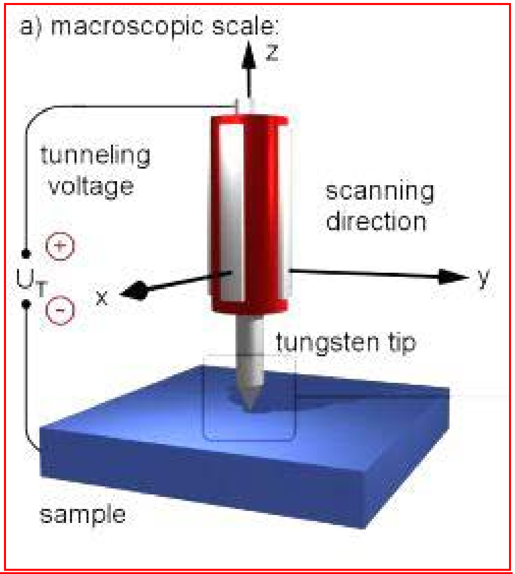
- provide 2D lateral information.
- images appear "flat".
- difficult to obtain information in the 3rd dimension.

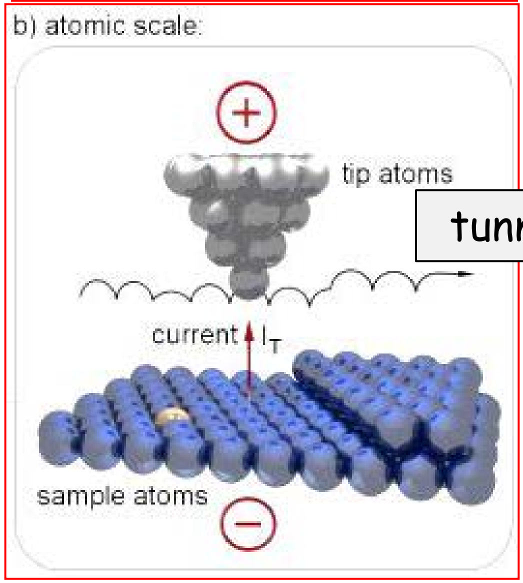
Scanning Probe Microscopy:

- image features extend in the **vertical** direction, out of the horizontal plane
- allow for manipulation at the nanoscale
- provide material properties at the nanoscale

Operational Principles

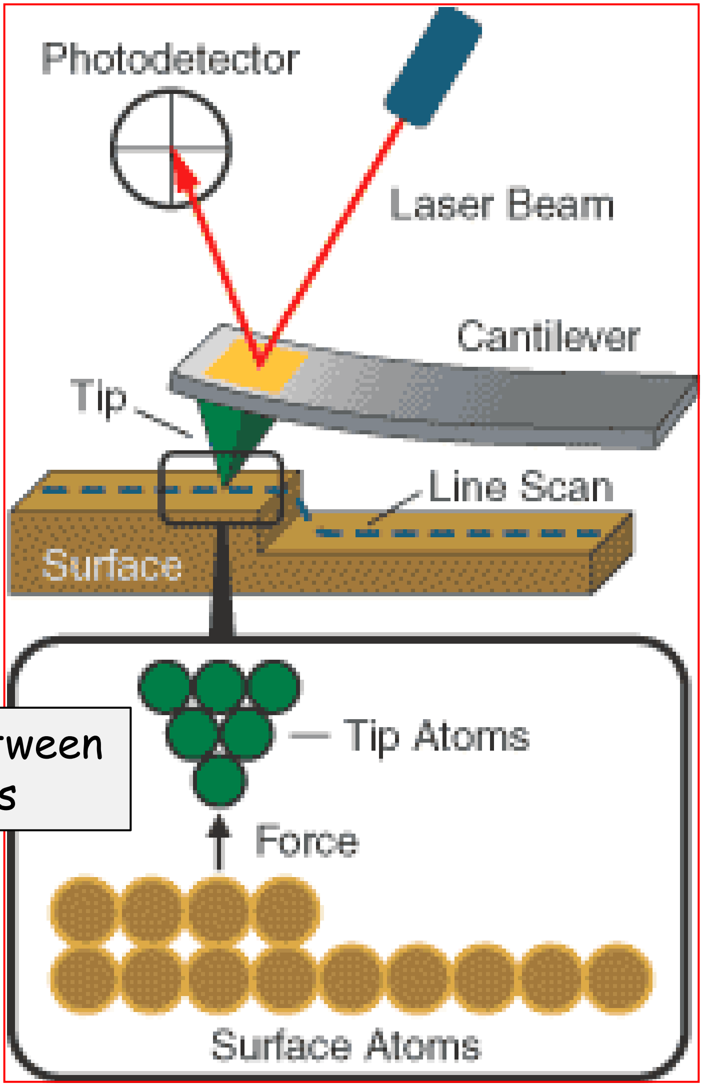
Scanning Tunneling Microscope (STM)





tunnel current

Atomic Force Microscope (AFM)



force between atoms

A good tip ends in one atom!

The Atomic Force Microscope

VOLUME 56, NUMBER 9 PHYSICAL REVIEW LETTERS 3 MARCH 1986

Atomic Force Microscope

G. Binnig[(a)] and C. F. Quate[(b)]
Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

and

Ch. Gerber[(c)]
IBM San Jose Research Laboratory, San Jose, California 95193
(Received 5 December 1985)

Control the tip-substrate force!

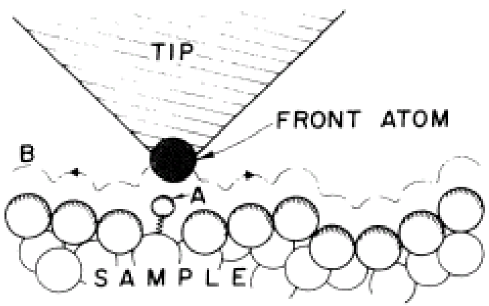
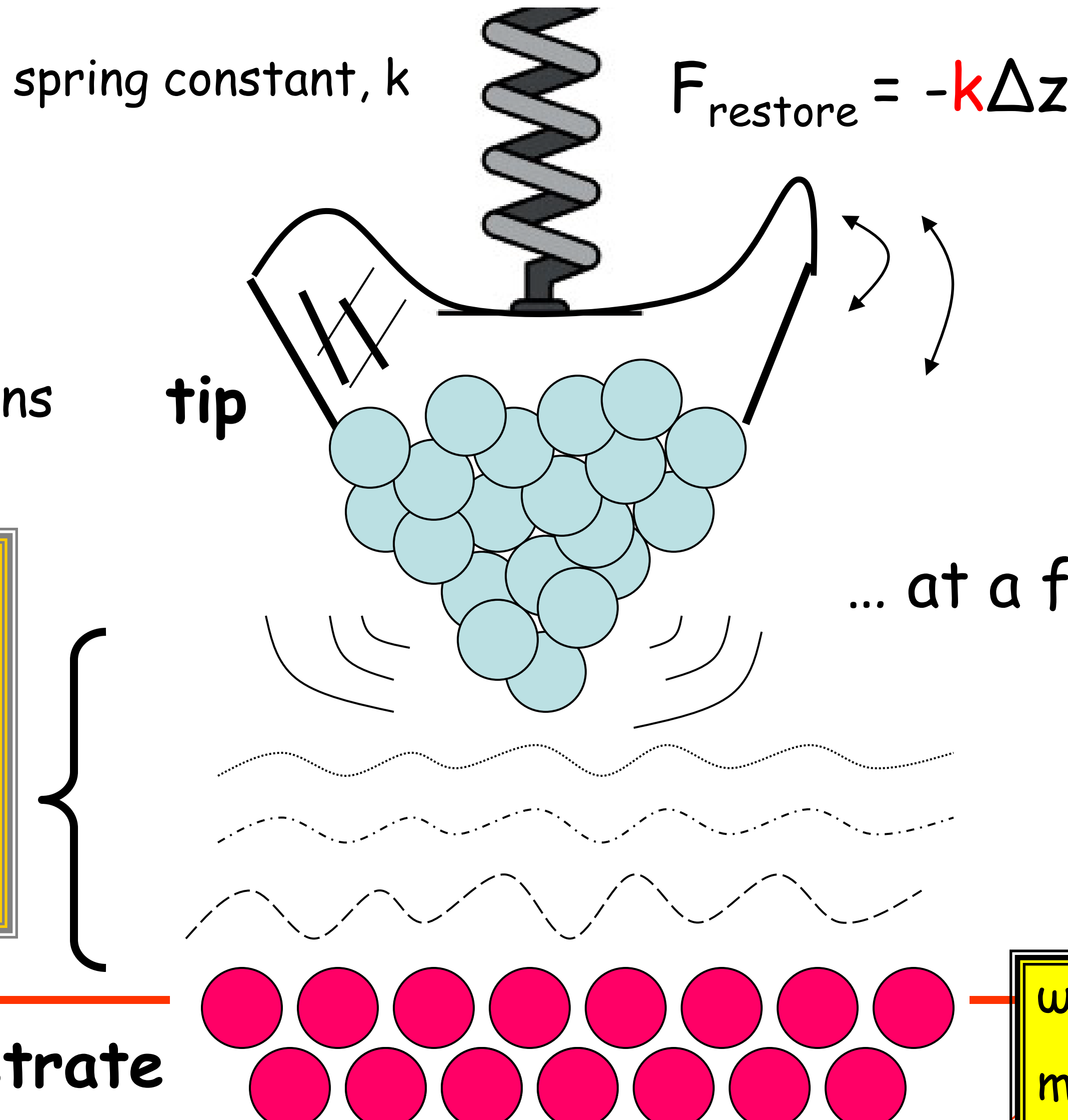


FIG. 1. Description of the principle operation of an STM as well as that of an AFM. The tip follows contour *B*, in one case to keep the tunneling current constant (STM) and in the other to maintain constant force between tip and sample (AFM, sample, and tip either insulating or conducting). The STM itself may probe forces when a periodic force on the adatom *A* varies its position in the gap and modulates the tunneling current in the STM. The force can come from an ac voltage on the tip, or from an externally applied magnetic field for adatoms with a magnetic moment.

Impact:

5,200 citations by 2008

Why the AFM Works



Two contributions to the force

1. collective tip-substrate interaction

+

2. atom-atom interactions

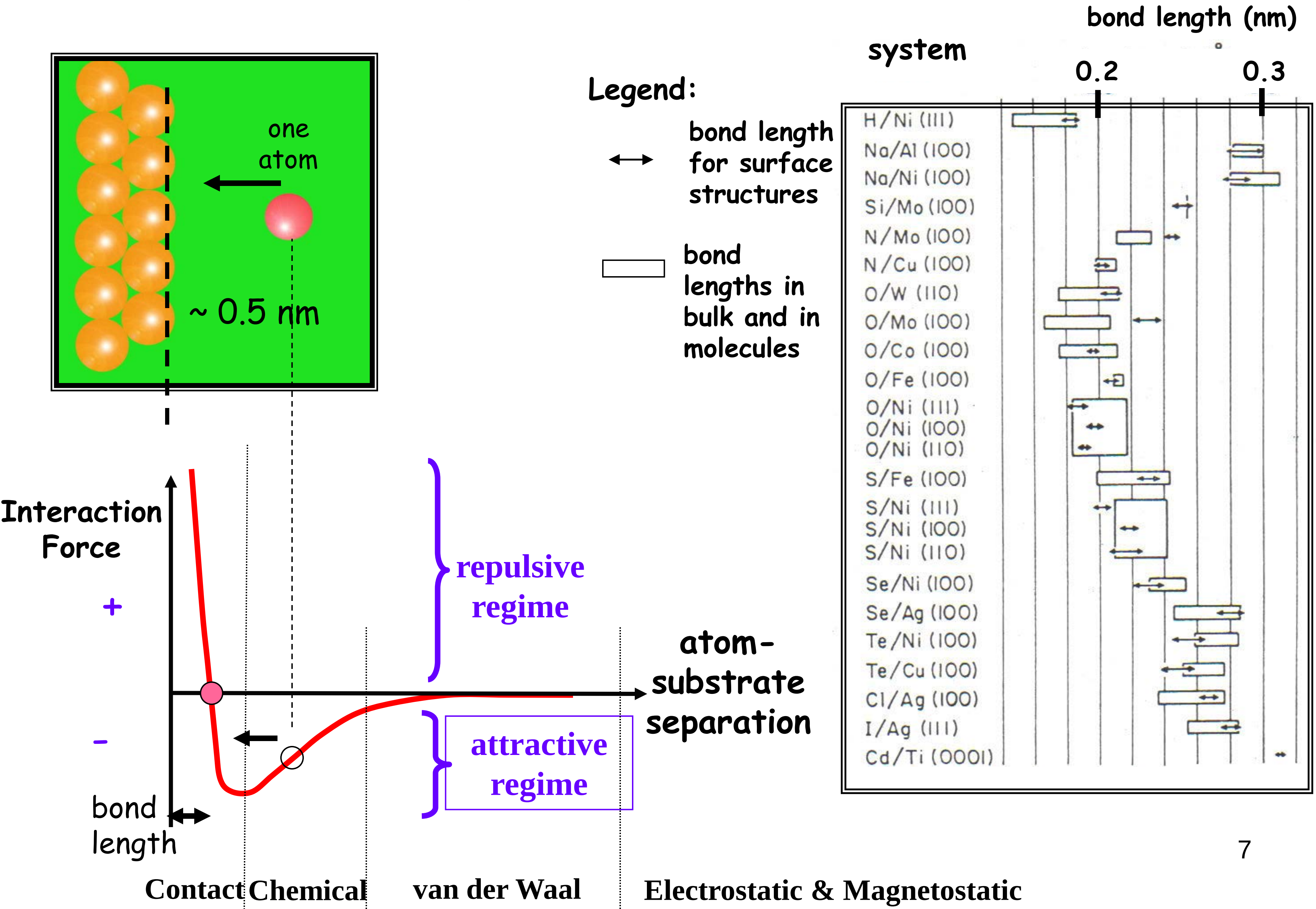
... at a fixed point

$\omega \sim 10^{15}$ Hz

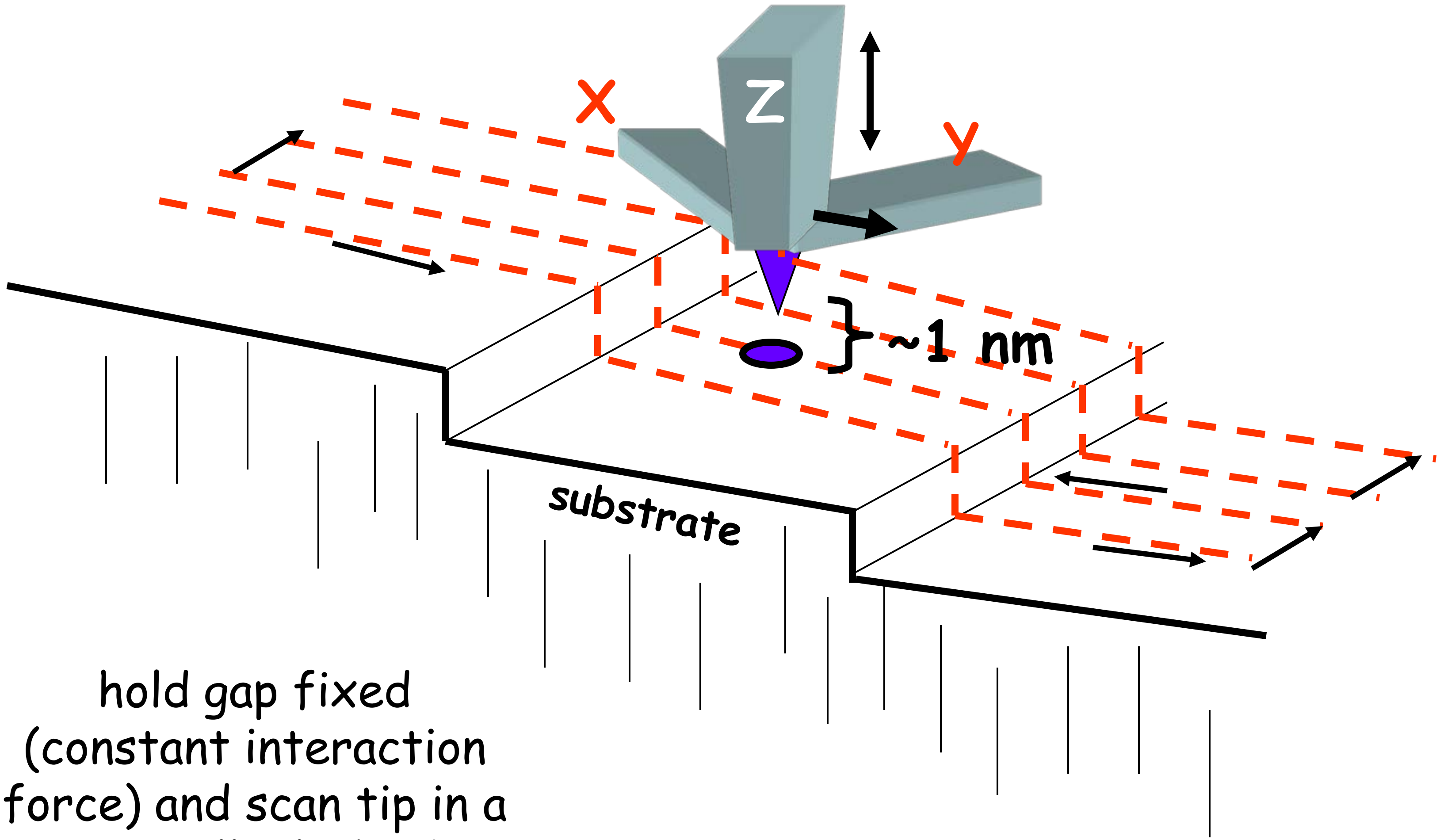
$m \sim 10^{-30}$ kg

$k \sim \omega^2 m \sim 1$ N/m

Short-range Adatom-Substrate Forces

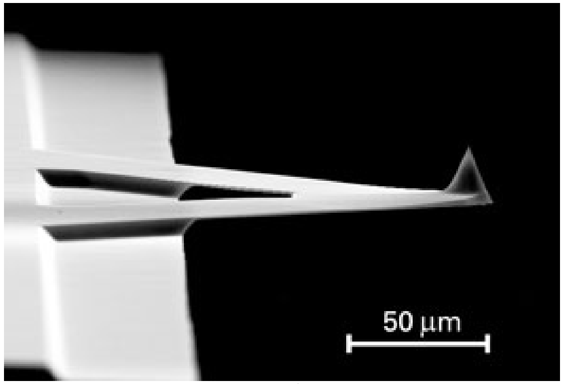


How is it a scanning microscope?

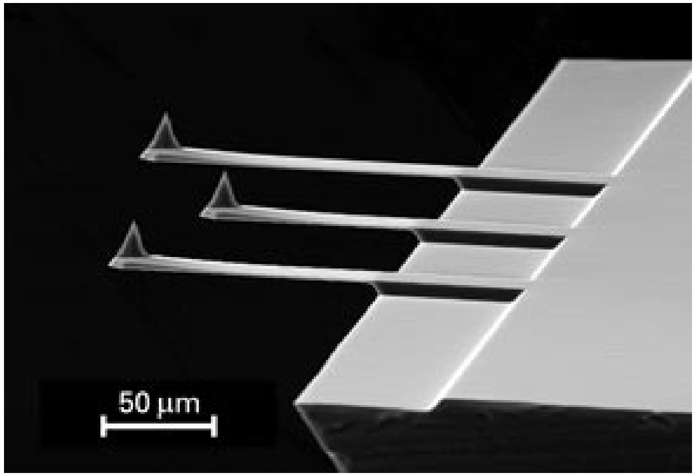


hold gap fixed (constant interaction force) and scan tip in a controllable (and vibrationless!) way - a microscope!

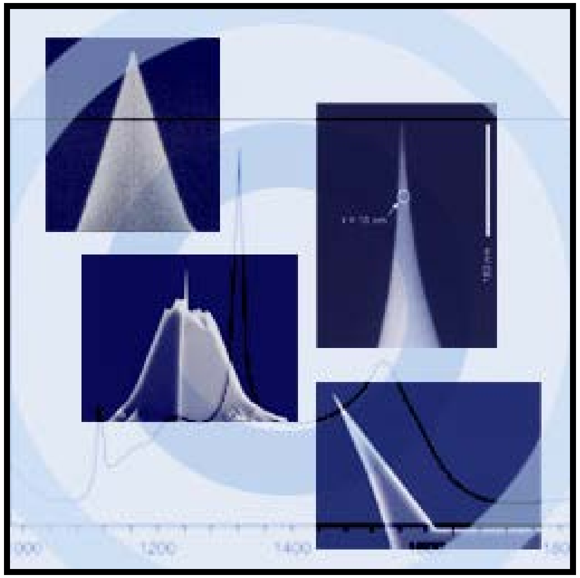
Commercially available microcantilever force sensors



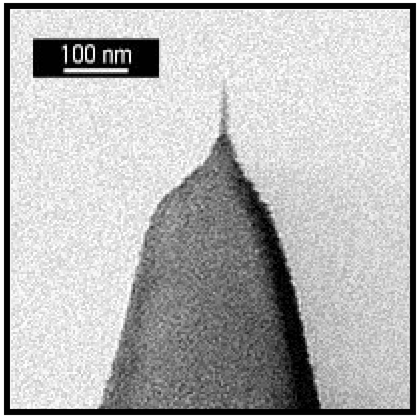
www.spmtips.com



www.spmtips.com



www.nanosensors.com



µmasch

Cantilever Physics

Static model

$$\delta = \frac{\ell^3}{3EI}F \qquad \theta = \frac{\ell^2}{2EI}F$$

$$k = \frac{3EI}{\ell^3} = \frac{Ewt^3}{4\ell^3}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m_{eff}}} = \frac{1}{2\pi}\sqrt{\frac{Ew}{4m_{eff}}\frac{t^3}{\ell^3}}$$

Dynamic model

(Euler-Bernoulli Equation)

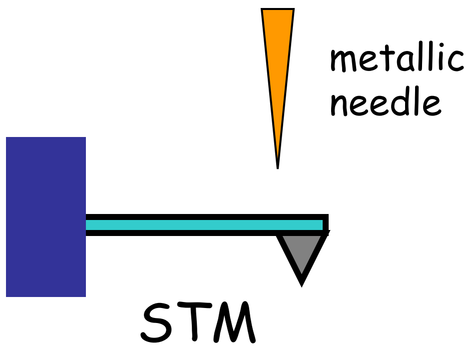
$$EI\frac{\partial^4 z}{\partial y^4} + \rho wt\frac{\partial^2 z}{\partial t^2} = 0$$

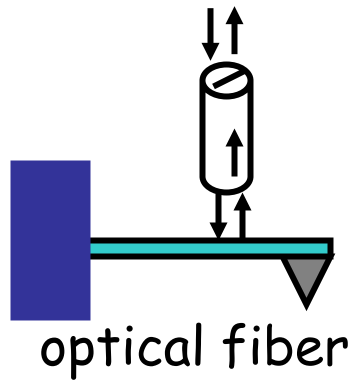
$$f_i = \frac{1}{2\pi}\beta_i^2\sqrt{\frac{EI}{\rho A}} = \frac{1}{2\pi}\beta_i^2\sqrt{\frac{Et^2}{12\rho}}$$

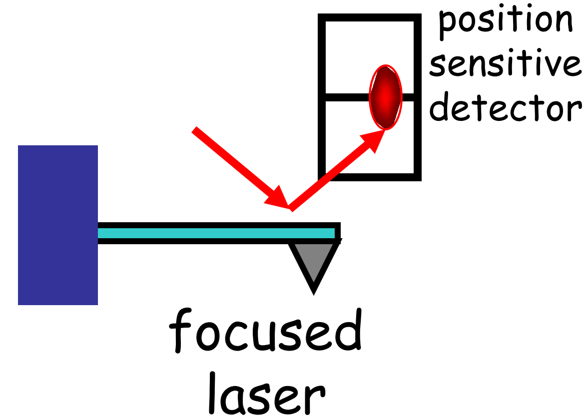
First mode (i=1)

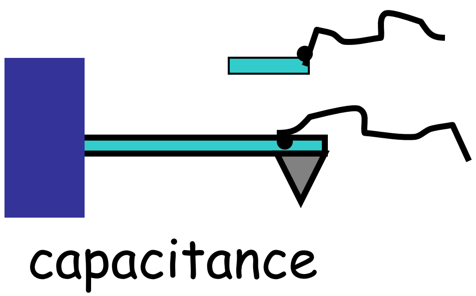
$$f_1 = \frac{1}{2\pi}\frac{(1.876)^2}{\sqrt{3}}\sqrt{\frac{Ew}{4m_c}\frac{t^3}{\ell^3}}$$

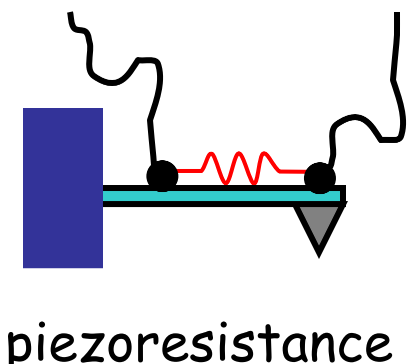
Detecting Picometer (~10-100 $\times 10^{-12}$ m) Deflections

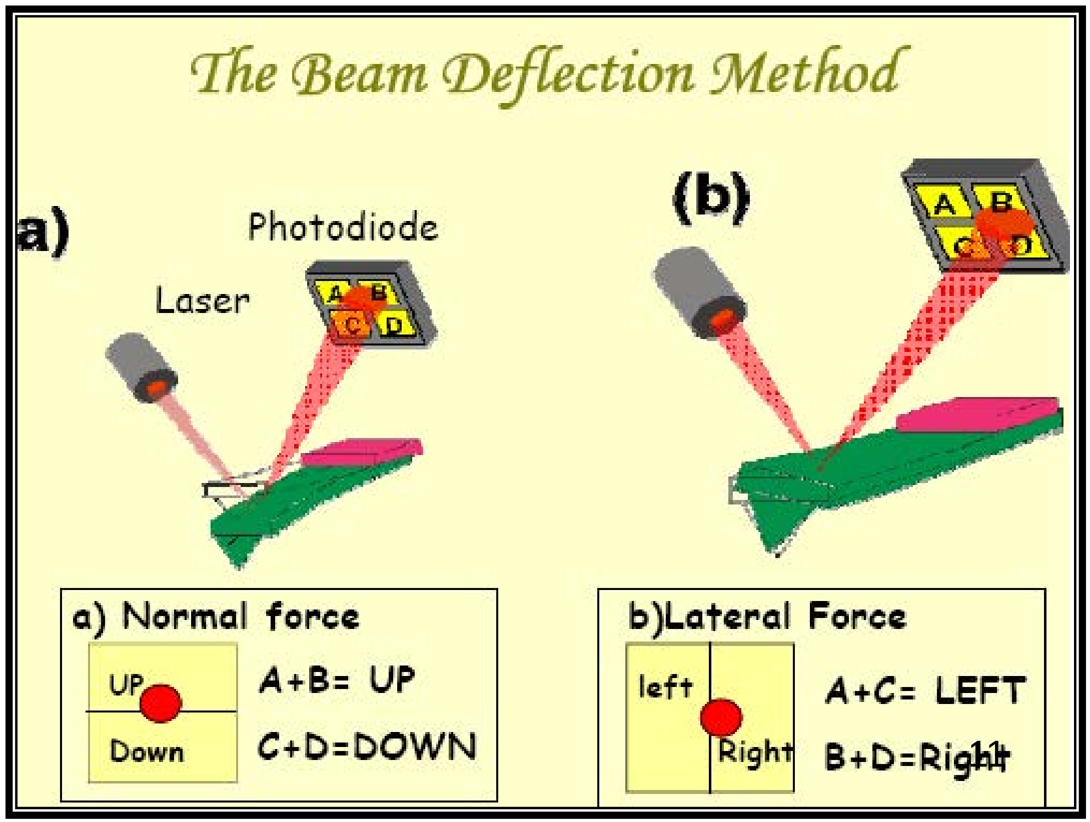




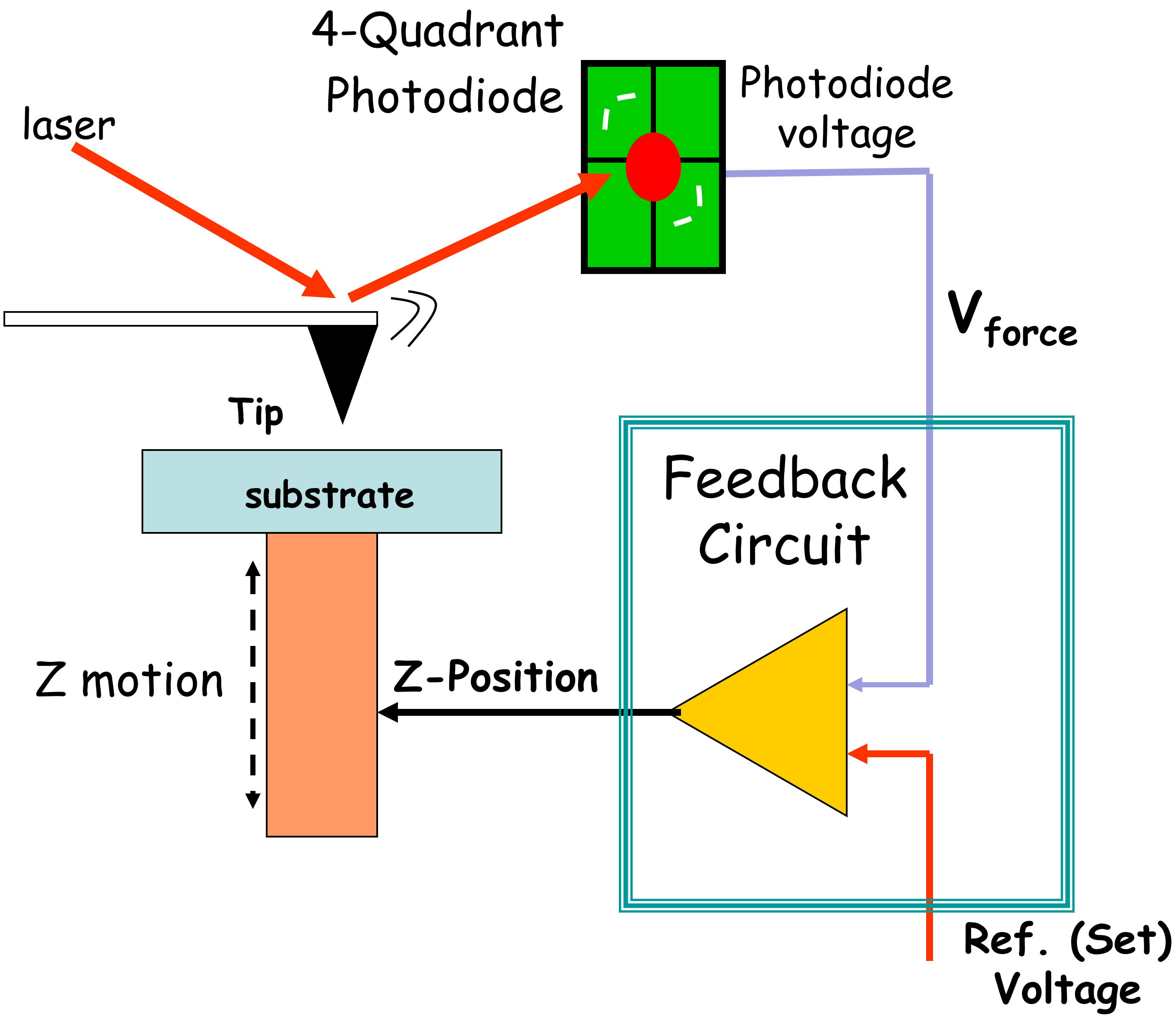






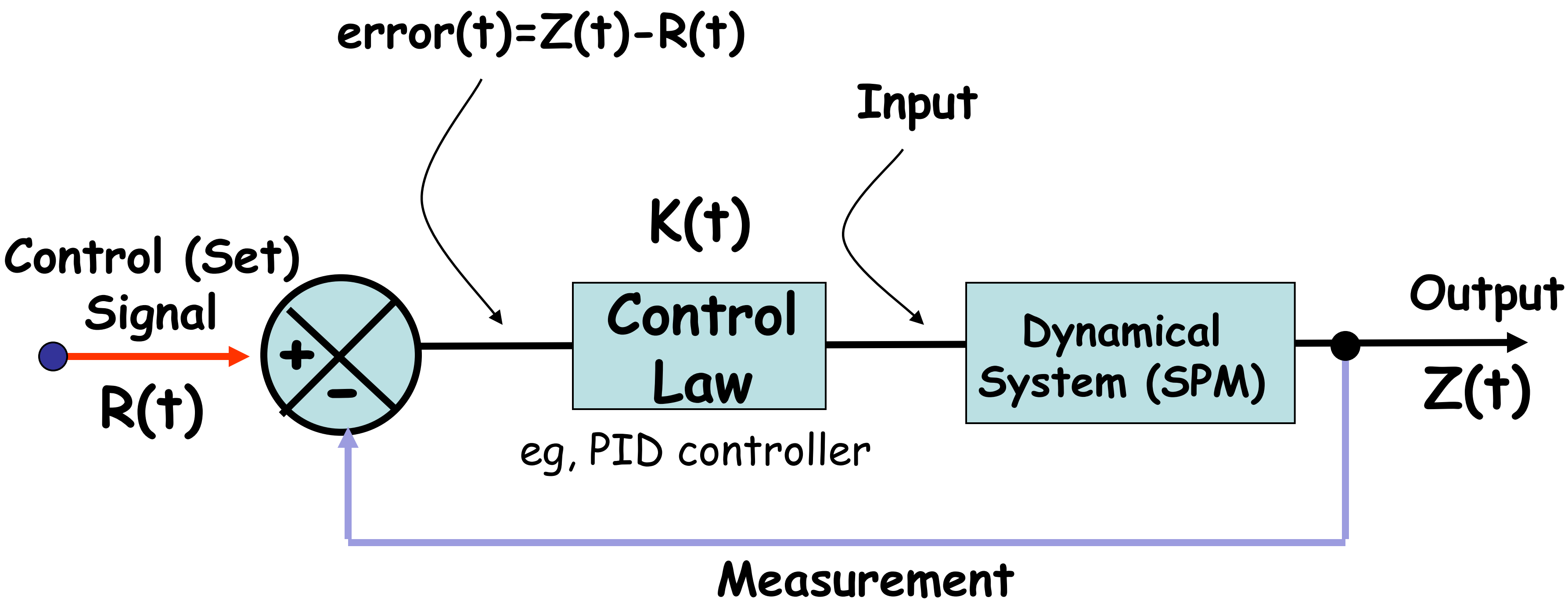


Maintaining a constant force



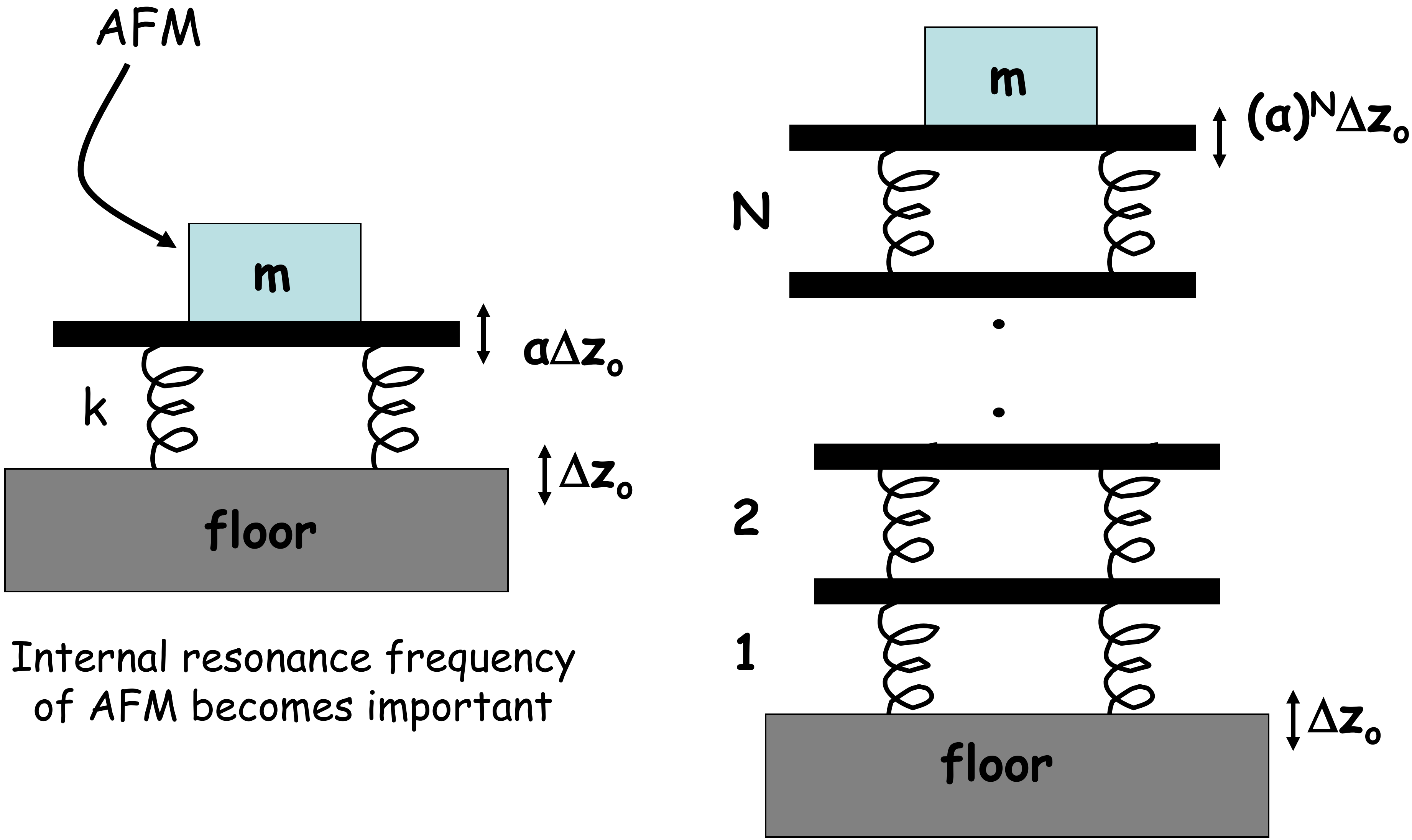
Principle of Feedback Control

Goal: Make Z(t) follow R(t) as closely as possible



- K(t) tries to minimize error(t)
- Negative feedback!

Reducing Floor Vibrations *circa* 1986



Internal resonance frequency of AFM becomes important

Reducing Floor Vibrations circa 2005
Kevin G. Hall Nanometrology Lab

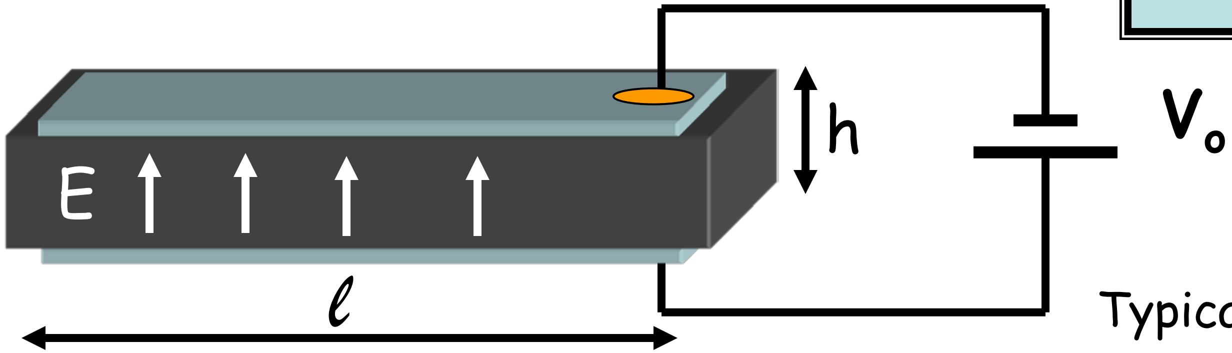
Interior Dimensions:
22'8" x 18'7" x 10'8"
(6.9 m x 5.7 m x 3.3 m)

October 2005

Achieving Vibrationless Motion at the Nanoscale

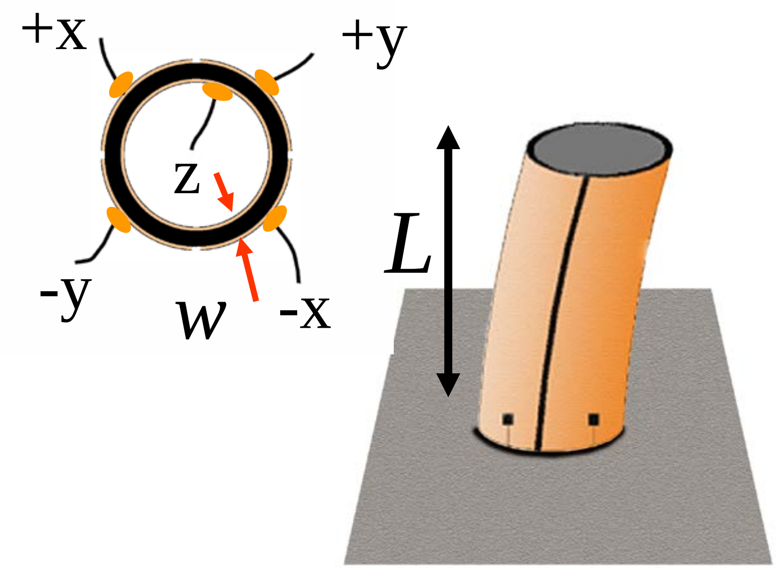
$$\Delta\ell = d_{31}\frac{\ell}{h}V_o$$

Piezoelectric Bar



Typically, Δ ℓ ~ 0.5 nm/V

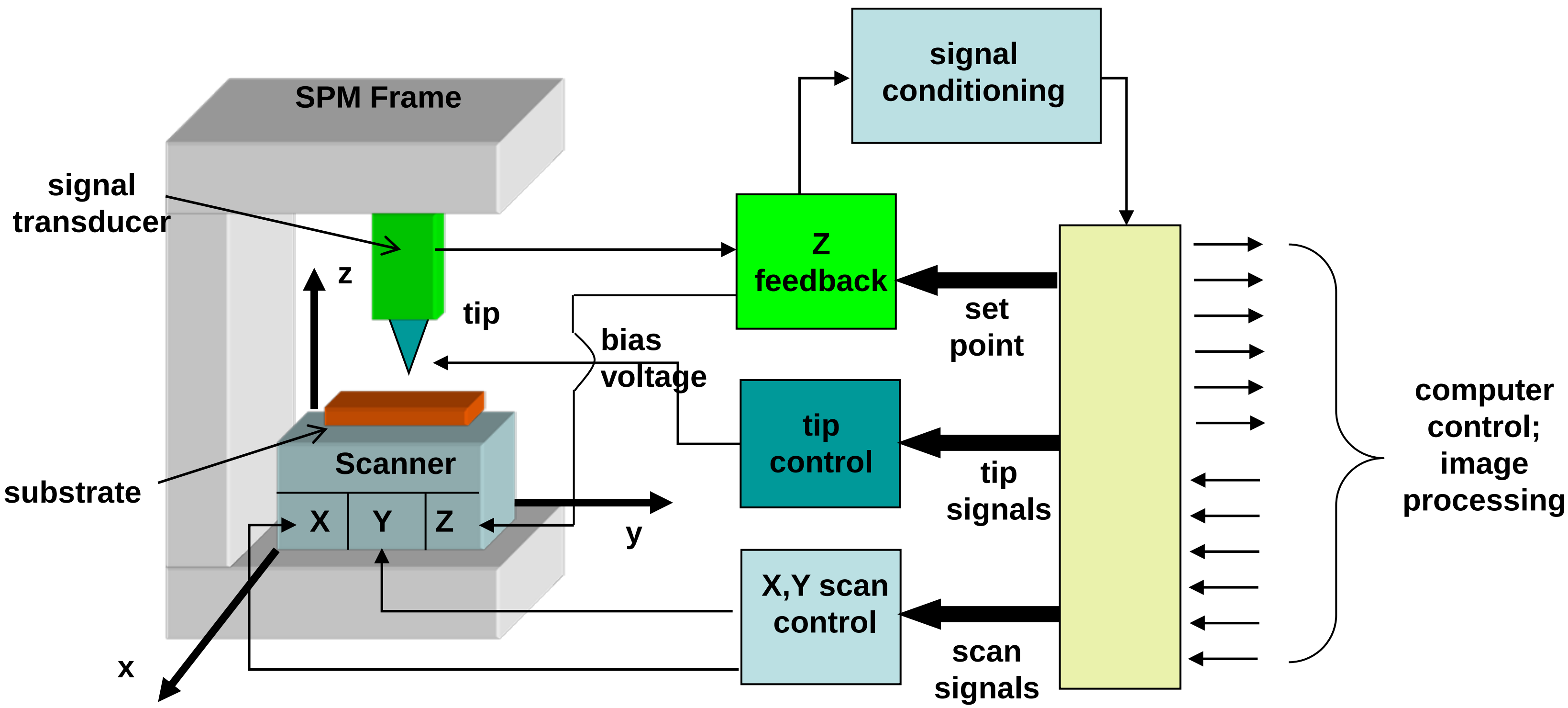
Quadranted Piezoelectric Tube



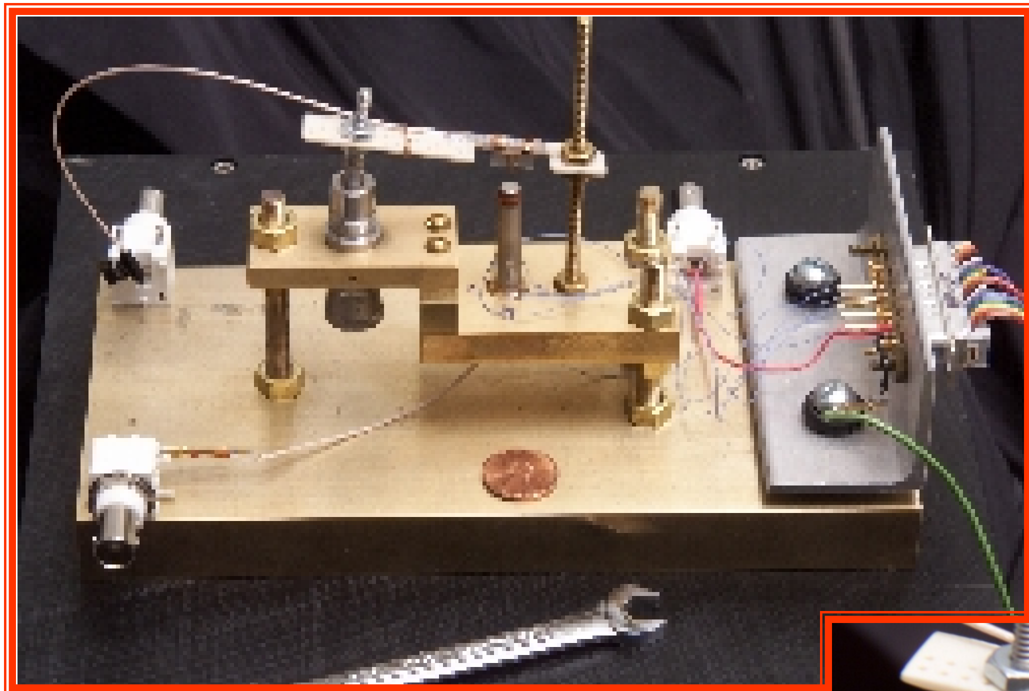
$$\Delta z = L\frac{V_o}{w}d_{31}$$

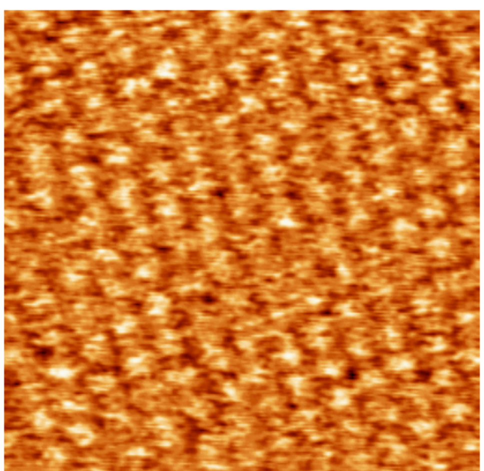
$$\Delta x \simeq \Delta y = \frac{2\sqrt{2}}{\pi D}\frac{V_o}{w}L^2 d_{31}$$

Generic Scanning Probe System Overview

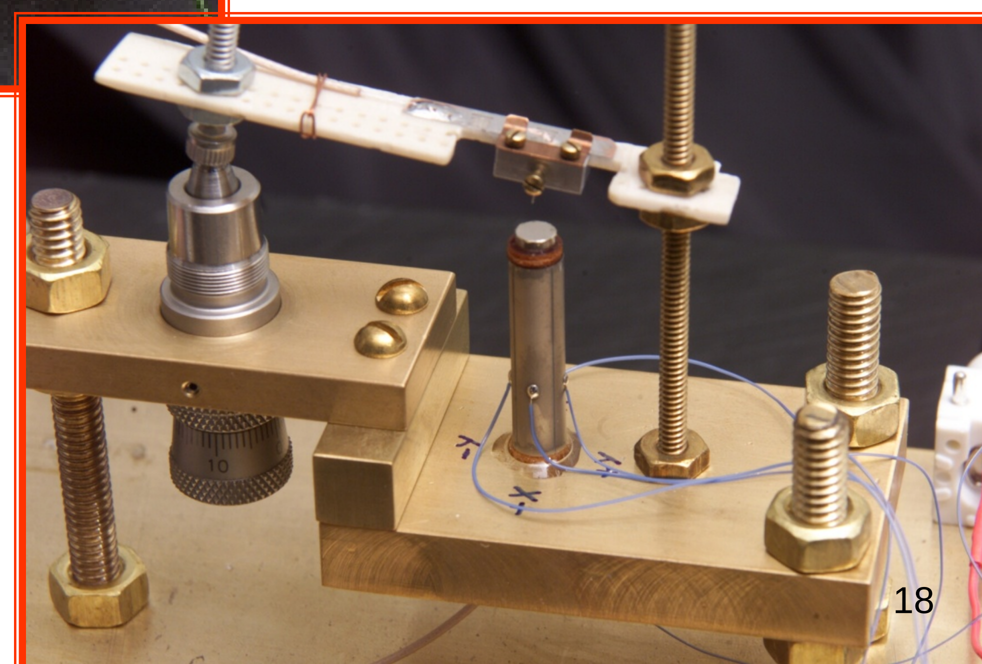


Seeing atoms in a day

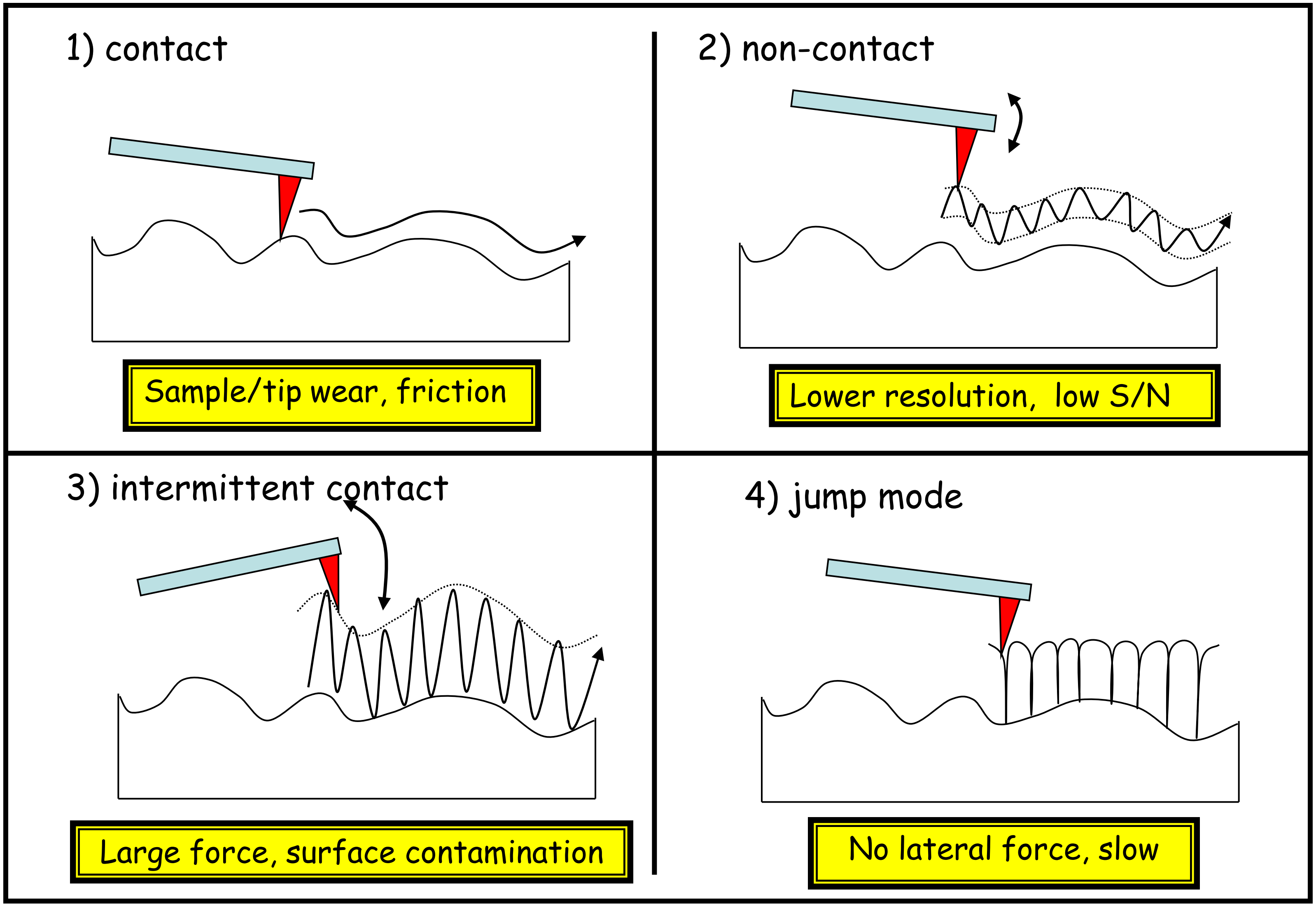




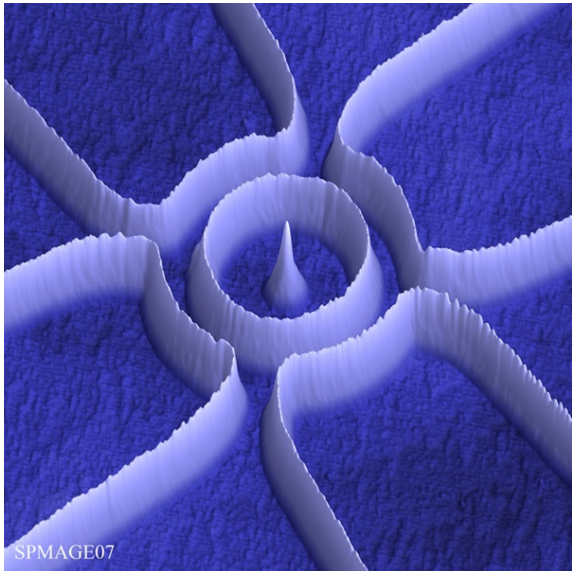
4.8 nm x 4.8 nm



Imaging Modes

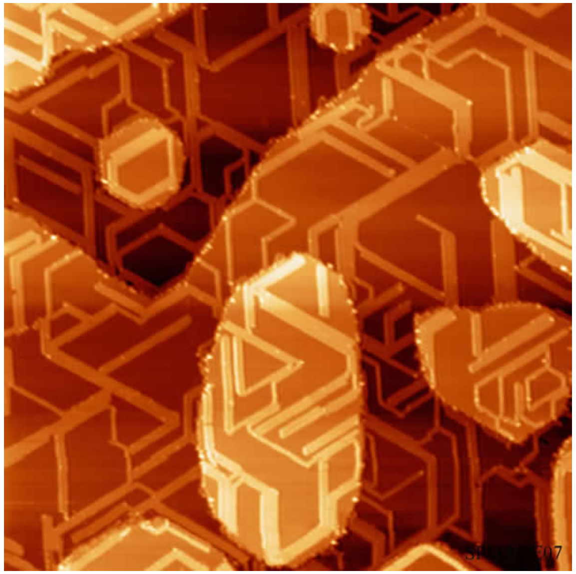


SPM Images Make an Impact



Andreas Fuhrer (Switzerland)

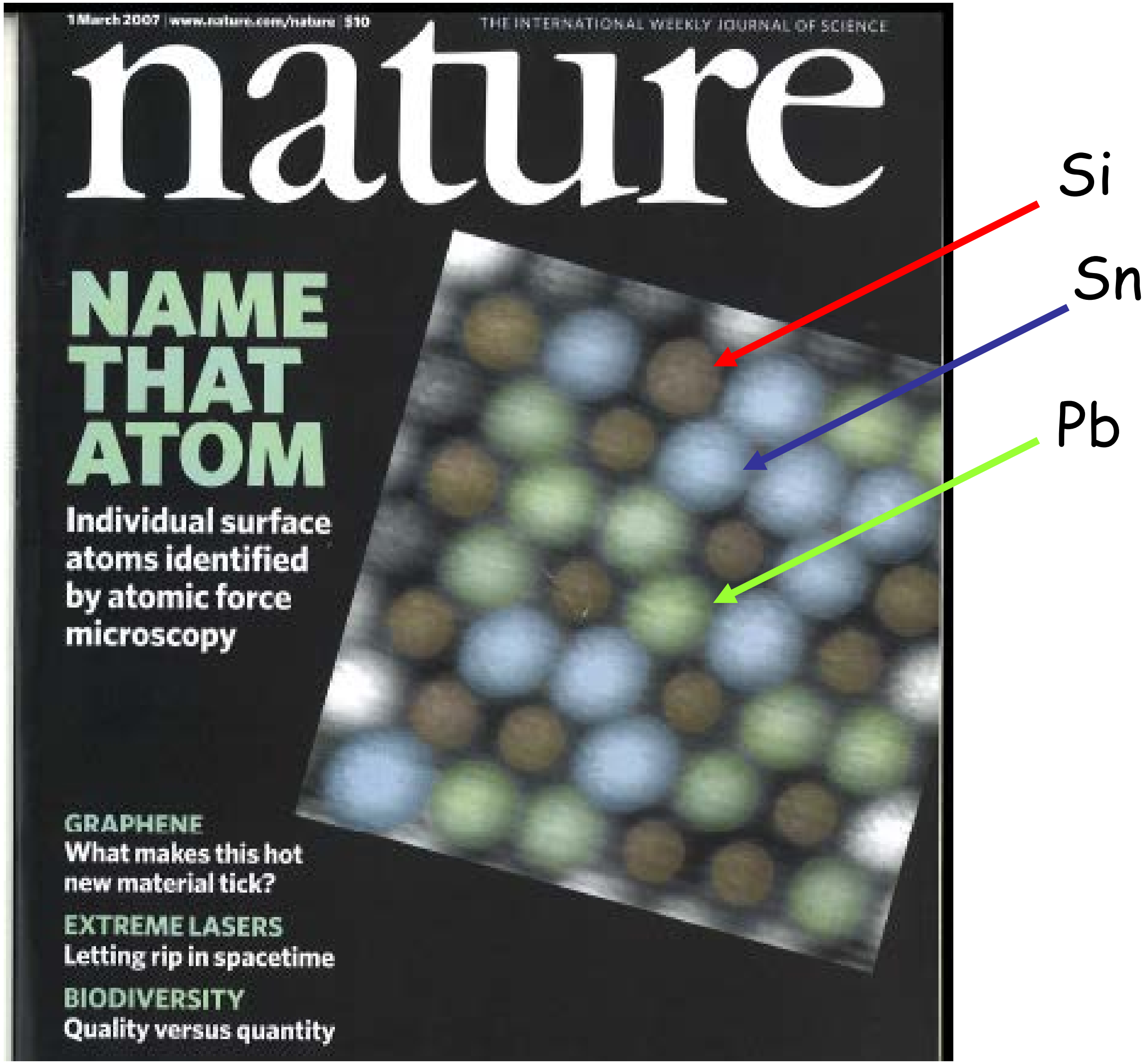
Luciano Paulino Silva (Brazil)



Carmen Munuera (Spain)

Julio Gomez-Herrero (Spain)

Identifying Atoms



After 28 Years of Looking at Nanotechnology through Rose-Colored Glasses

RESOURCES:
Complete AFM course on the NanoHub:

https://nanohub.org/courses/AFM1/

Coming soon: *Fundamentals of Atomic Force Microscopy, Part I: Foundations* (World Scientific, 2014).