Advances in Structural & Chemical Imaging (ASCI) 2016 Workshop
May 20, 2016
Stueckle Sky Center, Boise State University

A Force-Feedback Atomic Force Microscope for Biological Studies

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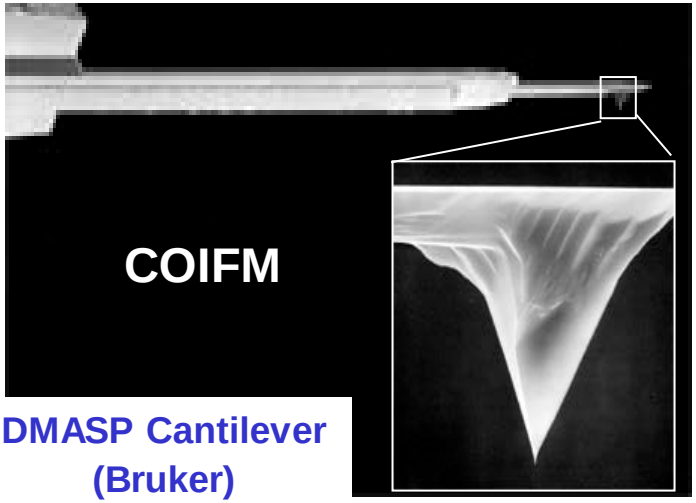


DMASP Cantilever (Bruker)

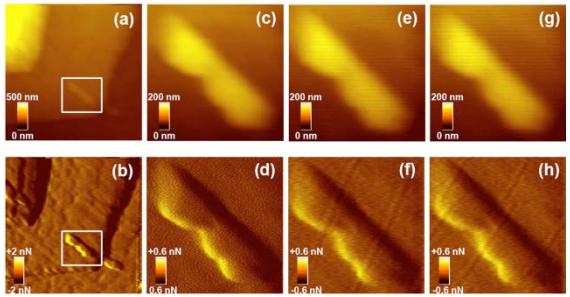
Bonander and Km, Appl. Phys. Lett. 92, 103124 (2008).

Kim, Bonander, and Rasmussen Rev. Sci. Instrum. 82, 053711 (2011).

Chain-like water

Kim et. al. J. Chem. Phys. 139, 054701 (2013).

One frame per second



B. I. Kim and R.D. Boehm, *Micron* 43, 1372-1379 (2012).

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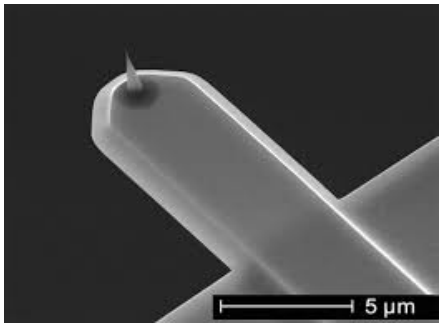
Highspeed AFM for Biological Studies

$$\omega_0 \sim \sqrt{\frac{k}{m}}$$

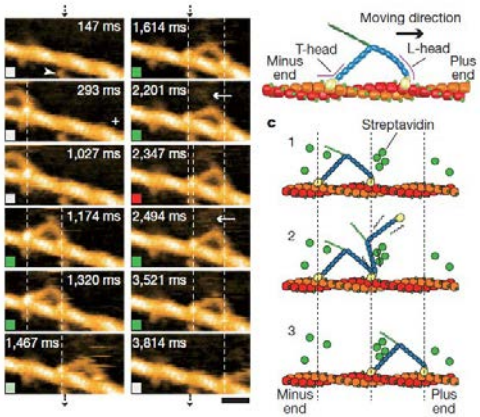
"small cantilever"



Olympus

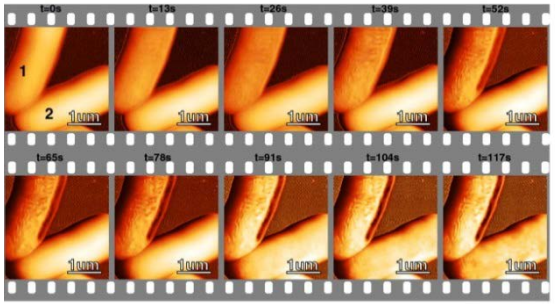
Tens frames/s

Ando et al.
Nature **468**, 72–76 (2010)

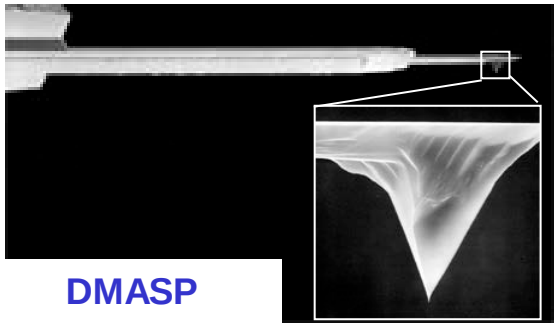


One tenth frames/s

Fantner et al. Nat. Nanotechnol. 5, 280–285



"force feedback AFM"



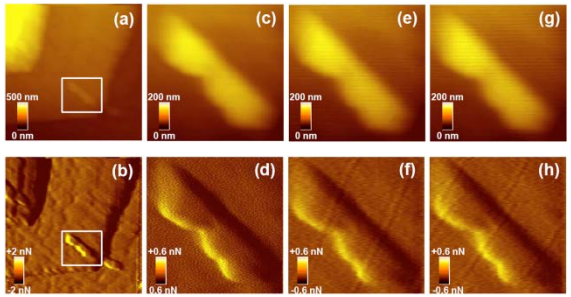
DMASP
(Bruker)

$$k = \Delta F / \Delta z$$

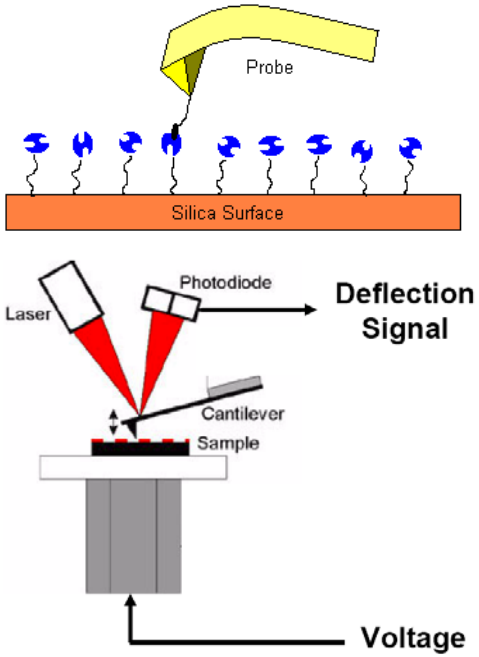
As $\Delta z \to 0, \quad k \to \infty$

One frame/ s

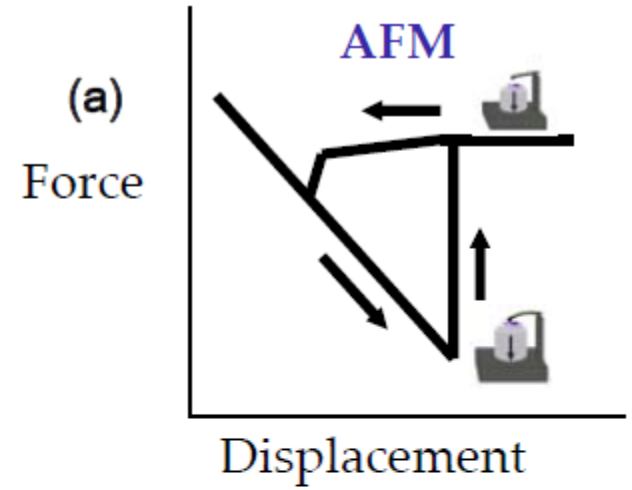
Kim and Boehm, *Micron* **43**, 1372 (2012).



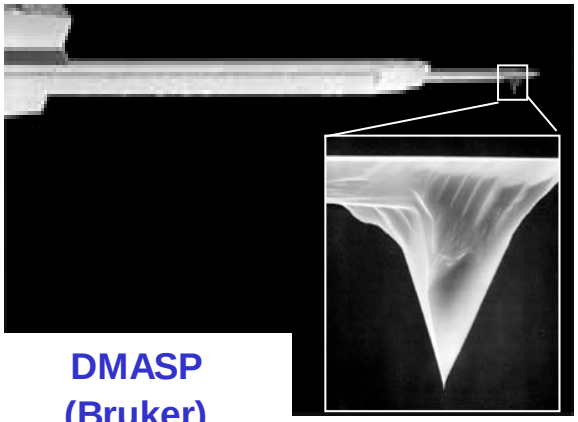
Can AFM measure biological interactions?



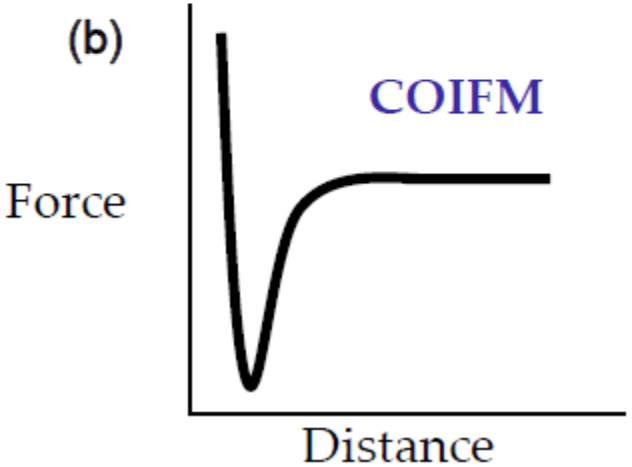
"Snap to Contact Problem"



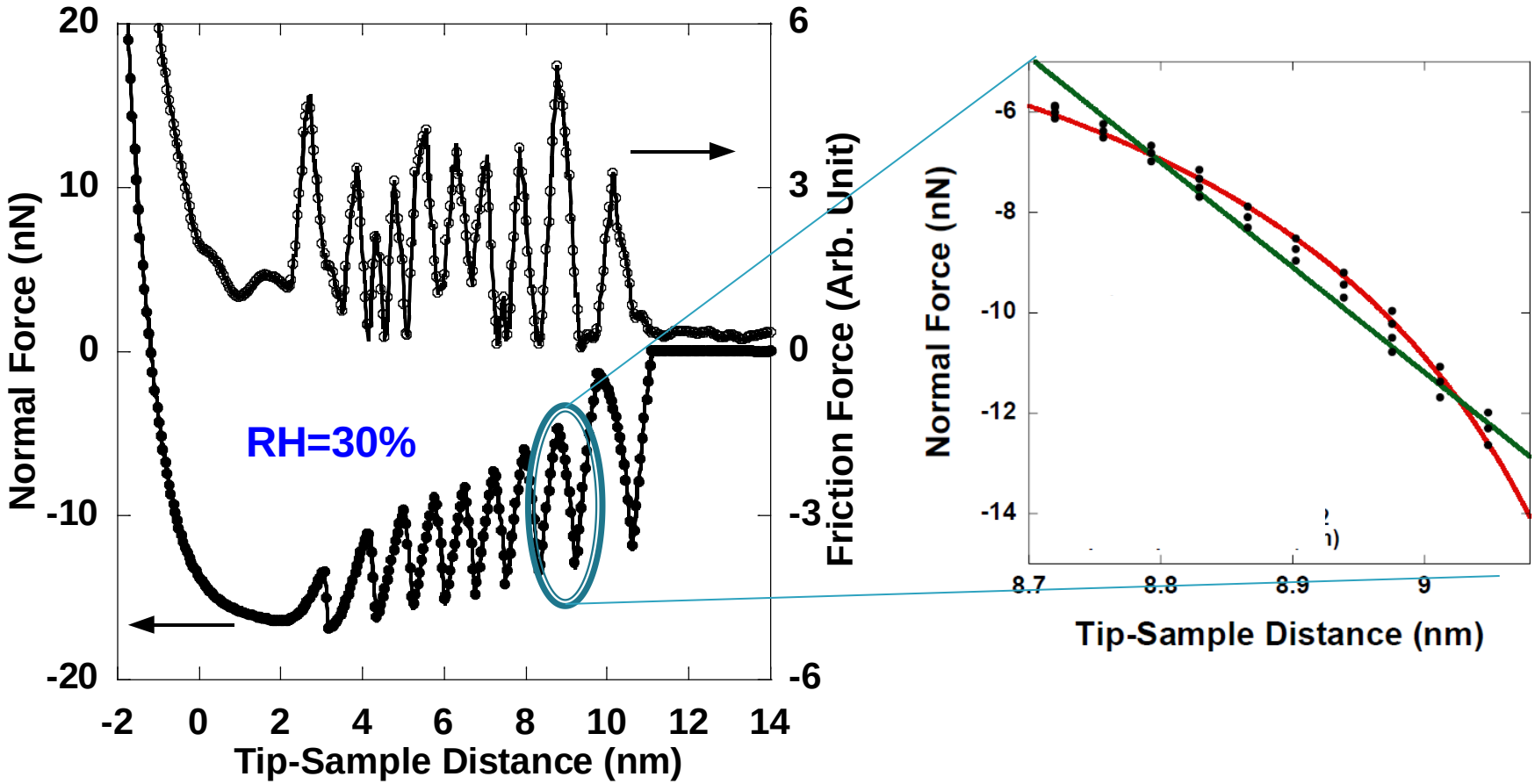
"force feedback AFM"



DMASP (Bruker)



Nonlinear f-d response



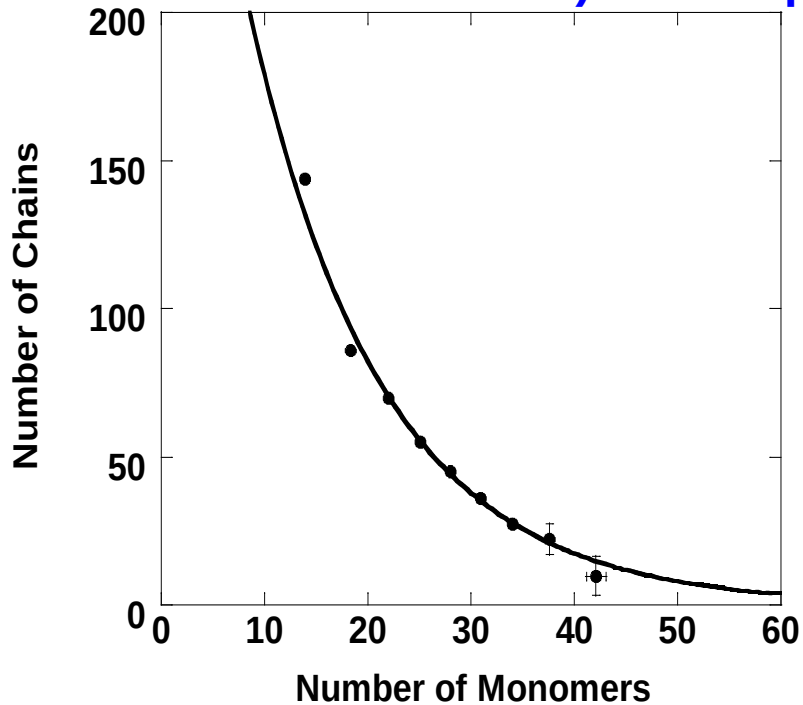
linear fitting (green) vs. FJC fitting (red))

→ ~~Ice-like Water Structure vs.~~
Chain-like Water Structure

Size Distribution

Number of chains (n) as a function of chain length (l)

The water junction experiences multiple layering transitions (without single layer transition) from *l = 36* layers to *l = 12* layers (36→31→28→26→24→21 →19→16→12) as the tip approaches the surface



$$n = n_0 \cdot e^{-l/\lambda}$$

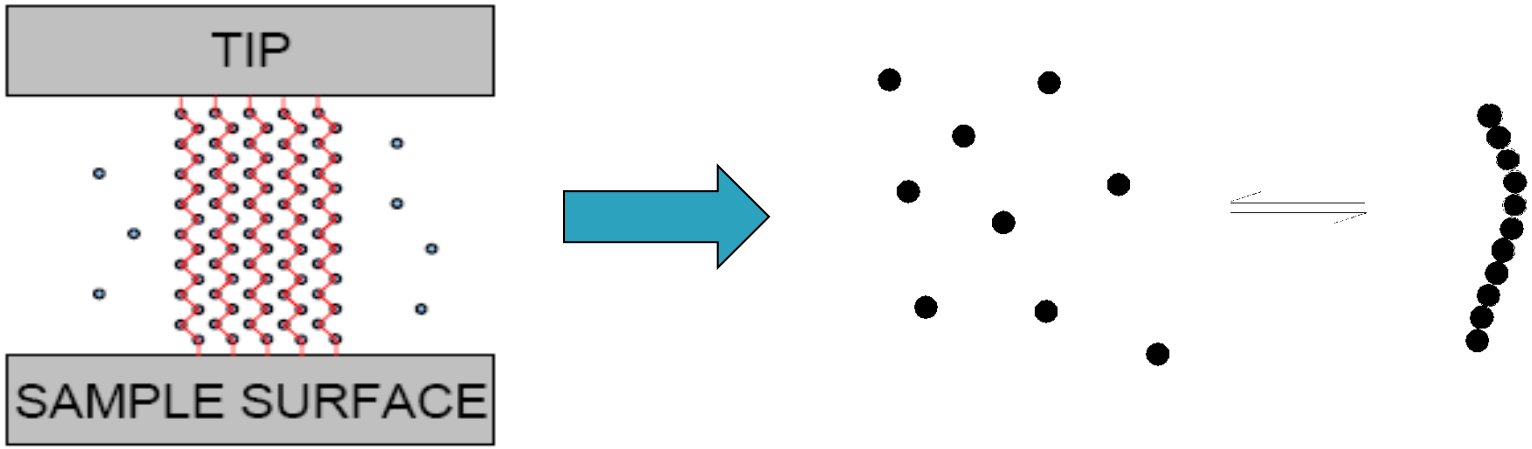
$$\lambda = \sqrt{Ce^{\gamma}} = 12.86$$ for $C=7.75\times10^{-3}$

→ γ=9.97

→The hydrogen bond strength ~10 k_BT agrees with the known literature value 9 k_BT of hydrogen bond strength in bulk water.

[Nelson P. Biological Physics. Freeman Publishing Co: New York (2004).]

The observed water structure is a **self-assembled chain-like water structure.**



Impurity or Contamination?

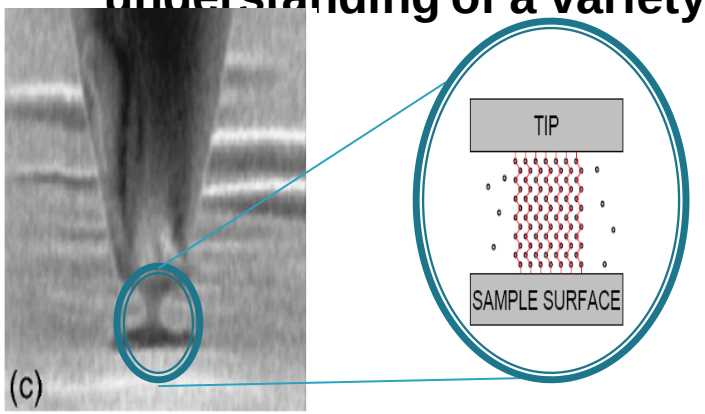
$$\lambda = \sqrt{Ce^{\gamma}} = 12.86$$

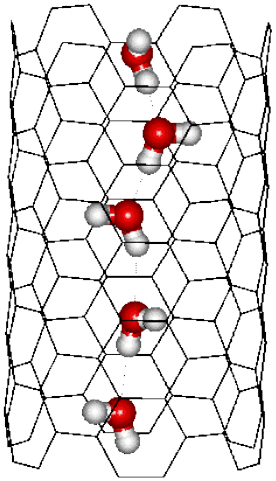
The highest possible organic contaminant is reported to be methane whose bonding energy is ~$3k_BT$ and ambient concentration is 10^{-4} times smaller than water concentration.* Therefore, we excluded the possibility that any molecules other than water molecules created the observed oscillatory forces.

*M. Pidwirny, "Atmospheric composition" edited by D. Budikova and K. Vranes, in *Encyclopedia of Earth* edited by Cutler J. Cleveland (Environmental Information Coalition, National Council for Science and the Environment, Washington, DC, 2010).

In Summary

- We investigated interfacial water structures between two silica surfaces using the cantilever based interfacial force microscope (COIFM).
- The COIFM force-distance curves showed remarkable oscillatory behavior in normal and friction forces, not previously observed using conventional AFM measurements.
- We described the structured water molecules between tip and substrate in an ambient hydrophobic environment using a freely jointed chain (FJC) model .
- A self-assembly process is the formation mechanism of the water chain.
- The proposed chain-like water structure explains many previously mysterious properties of confined water at the nanometer scale (e.g. positive Kelvin radii, and etc.), thus dramatically improving the understanding of a variety of water systems in nature.





Acknowledgements

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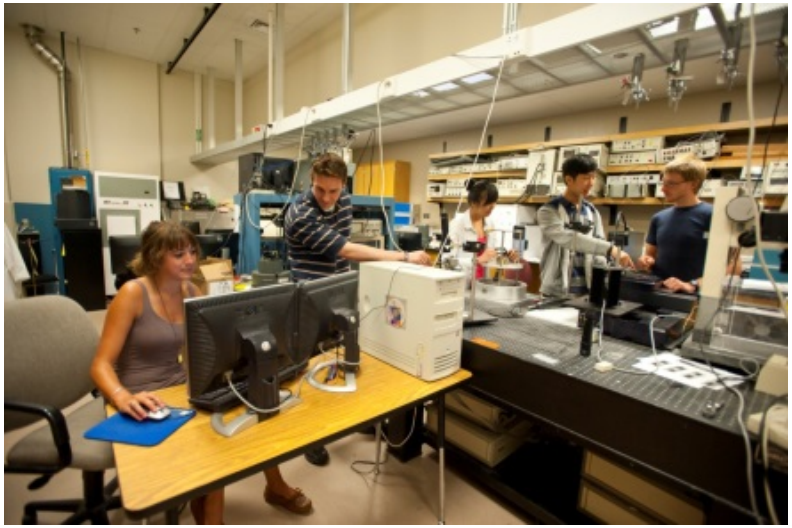

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