TRENDS IN NANOTRIBOLOGY
ICTP Trieste – 12-16 Sept 2011

Transient and steady-state features of anisotropic friction forces

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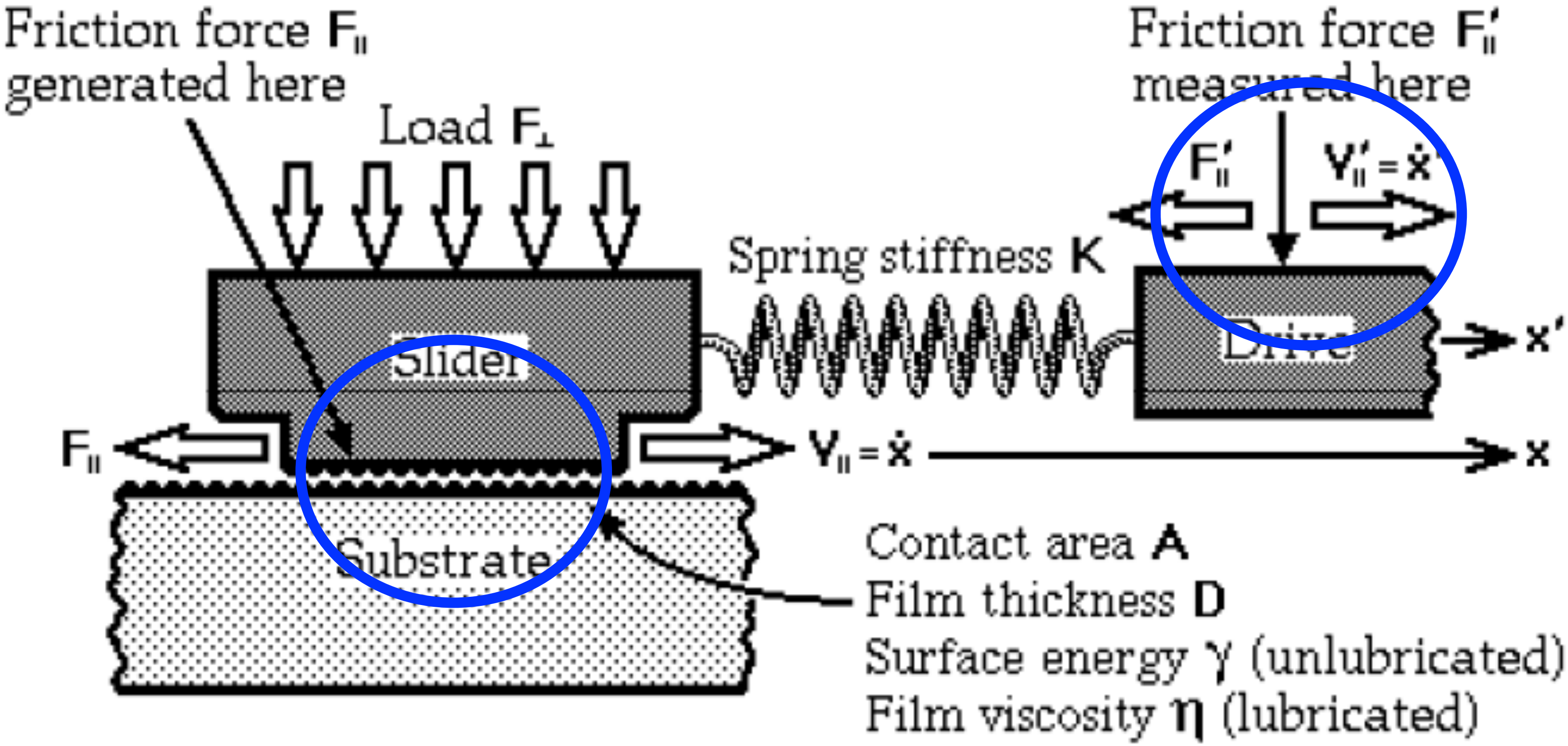
John Temelier & Kim Turner (UCSB)

Hongbo Zeng (Alberta)

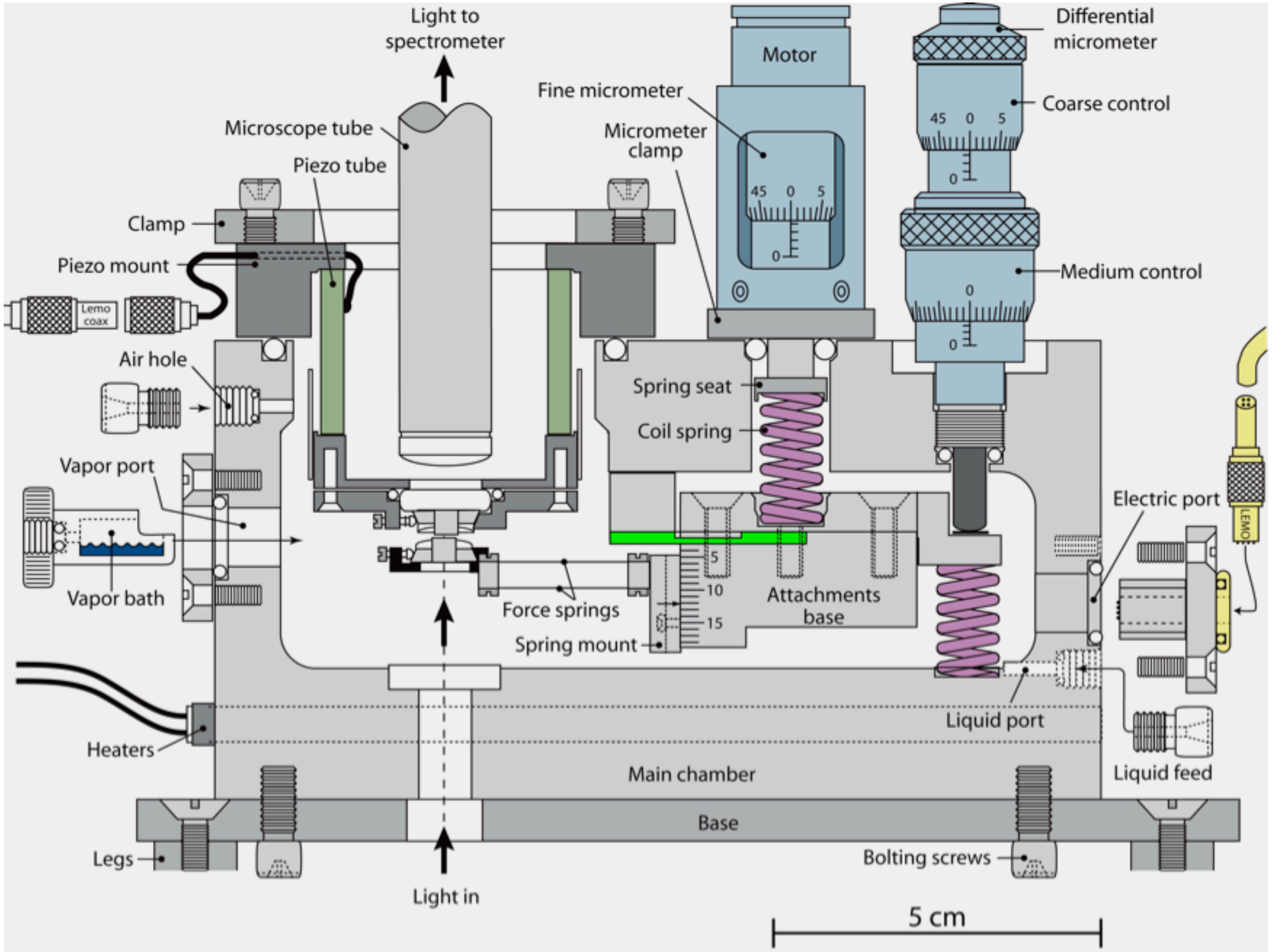
Eric Charrault & Suzanne Giasson (Montreal)

What needs to be measured in a complete friction experiment



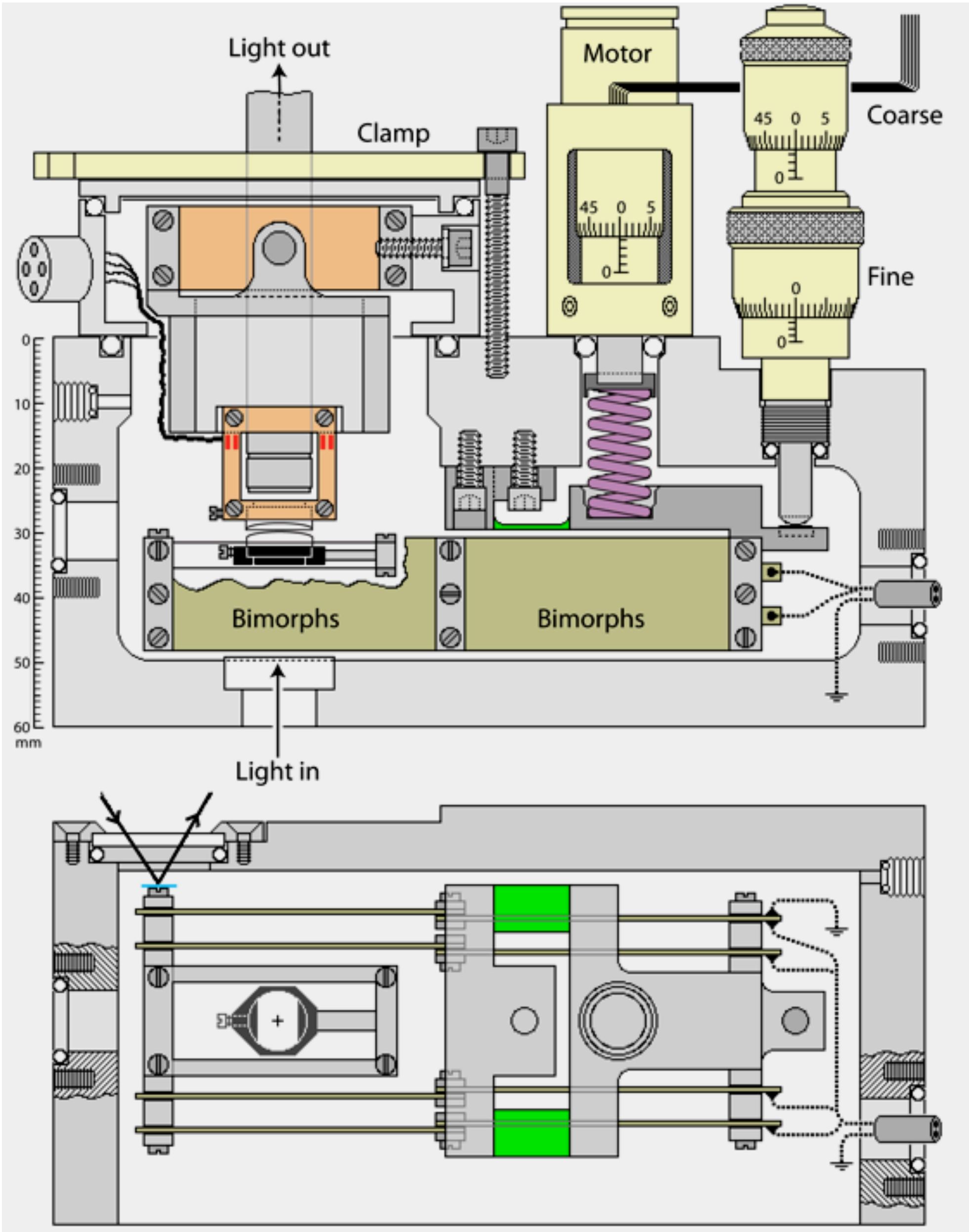
Also: Surface structure (roughness, topology), transient, time-dependent *vs* steady-state effects, e.g., stick-slip, …

Surface Forces Apparatus (SFA 2000)

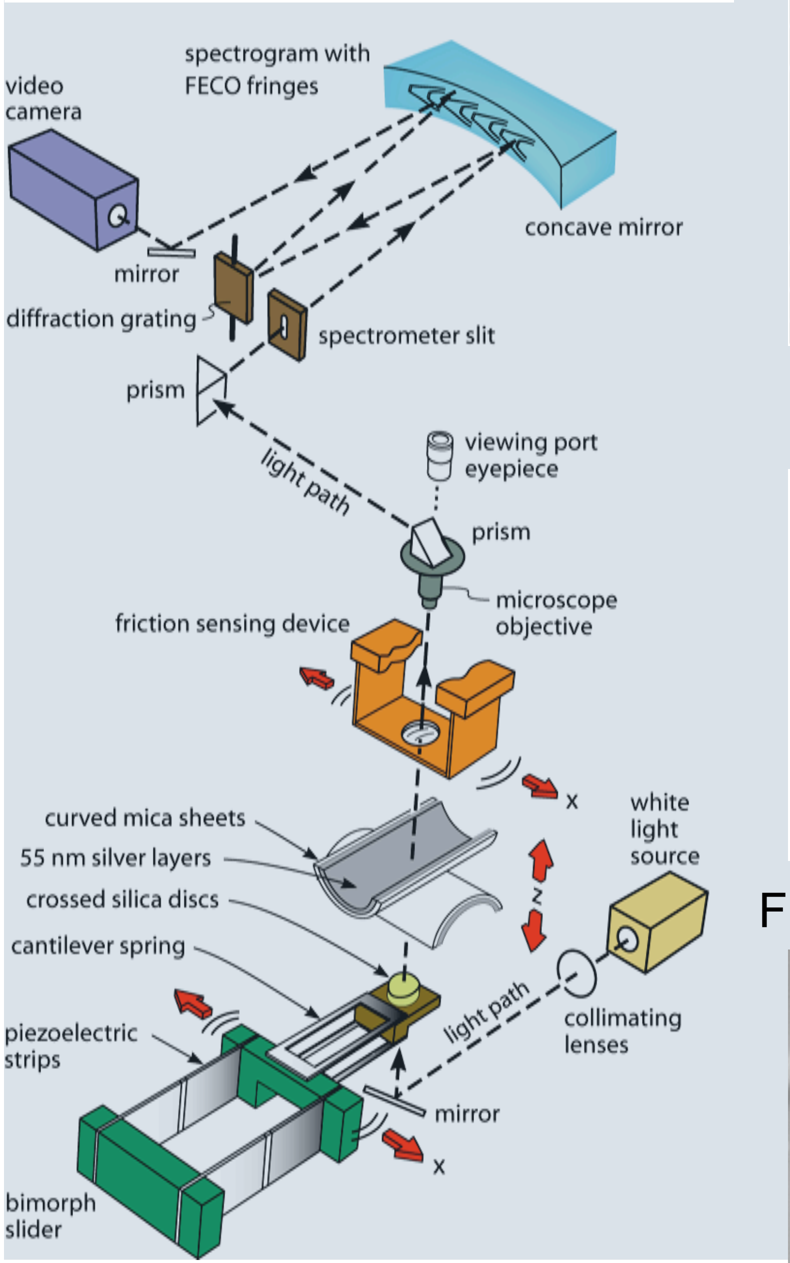


Recent advances in the surface forces apparatus (SFA) technique. J Israelachvili, Y Min, M Akbulut, A Alig, G Carver, W Greene, K Kristiansen, E Meyer, N Pesika, K Rosenberg and H Zeng, *Reports on Progress in Physics* 73 (2010) 1-16.

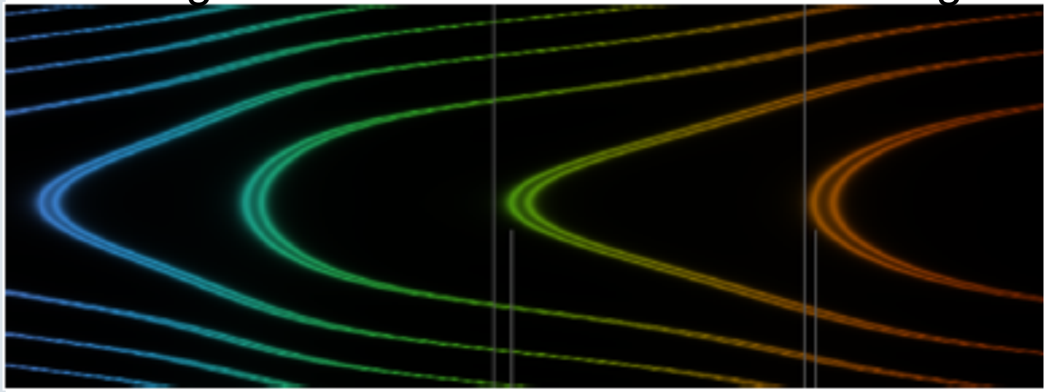
Shearing attachments to the SFA



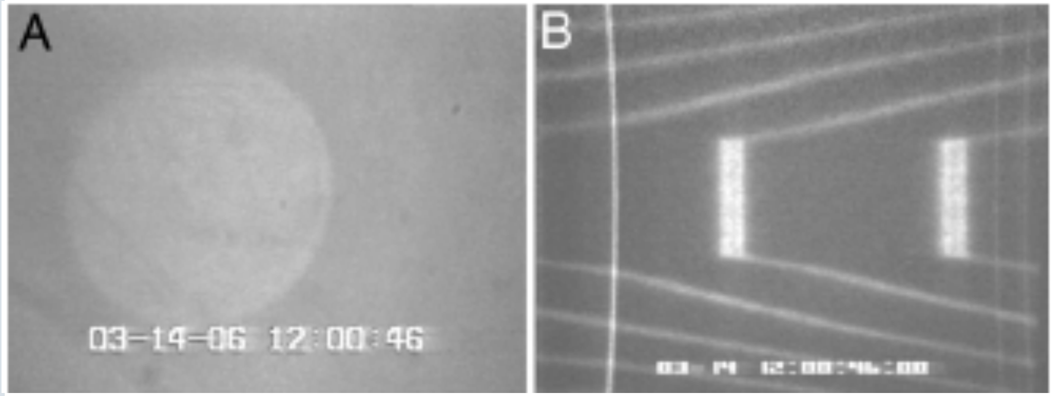
SFA EXPERIEMENTAL SETUP



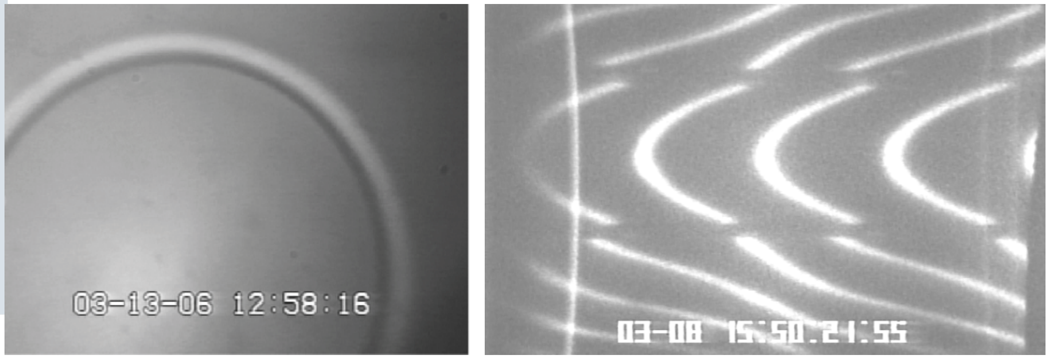
FECO fringes of two curved surfaces close together



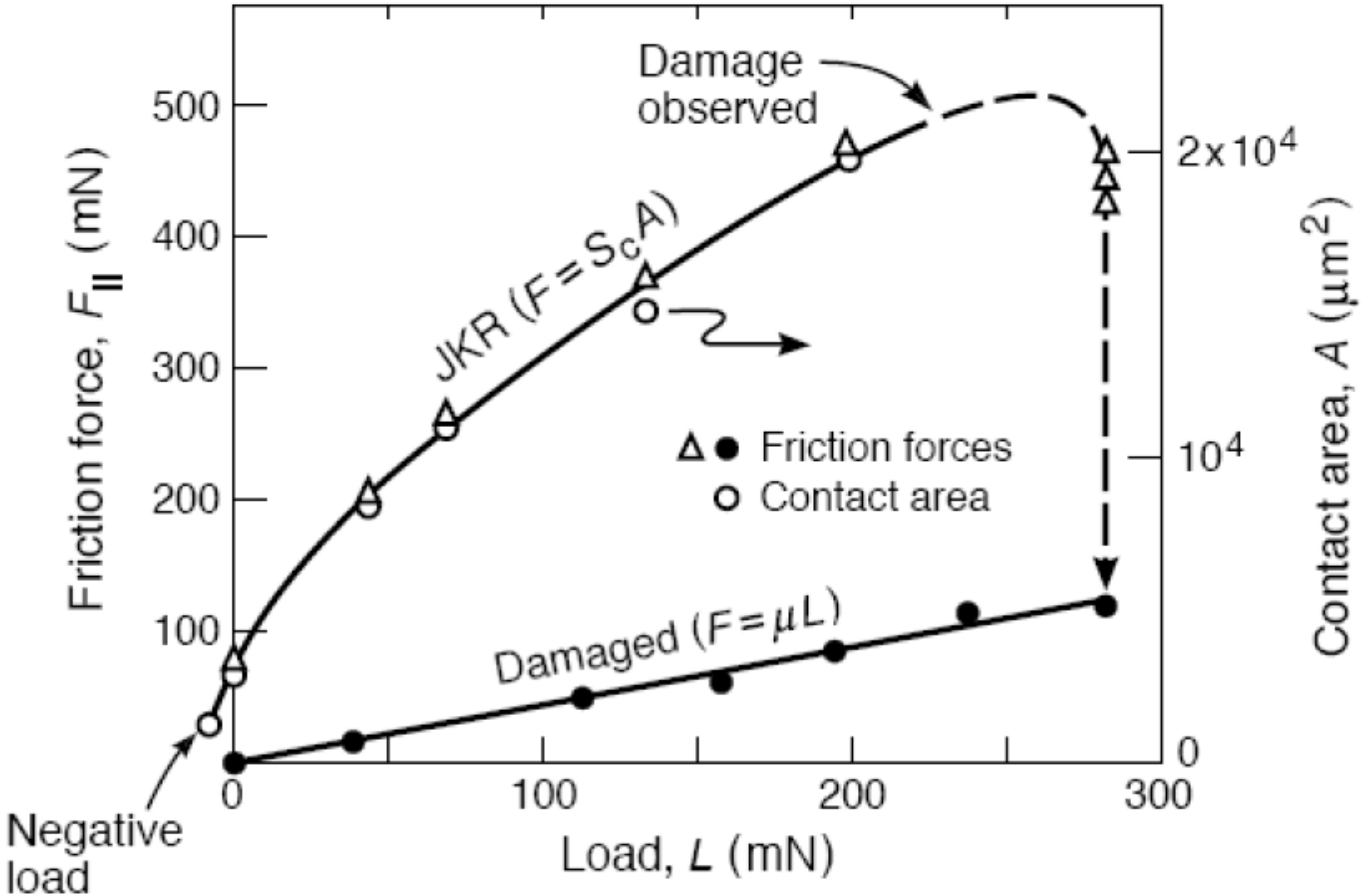
FECO (right) and normal microscope view (left) of the two surfaces in flattened adhesive contact



FECO and microscope views of a liquid bridge/neck

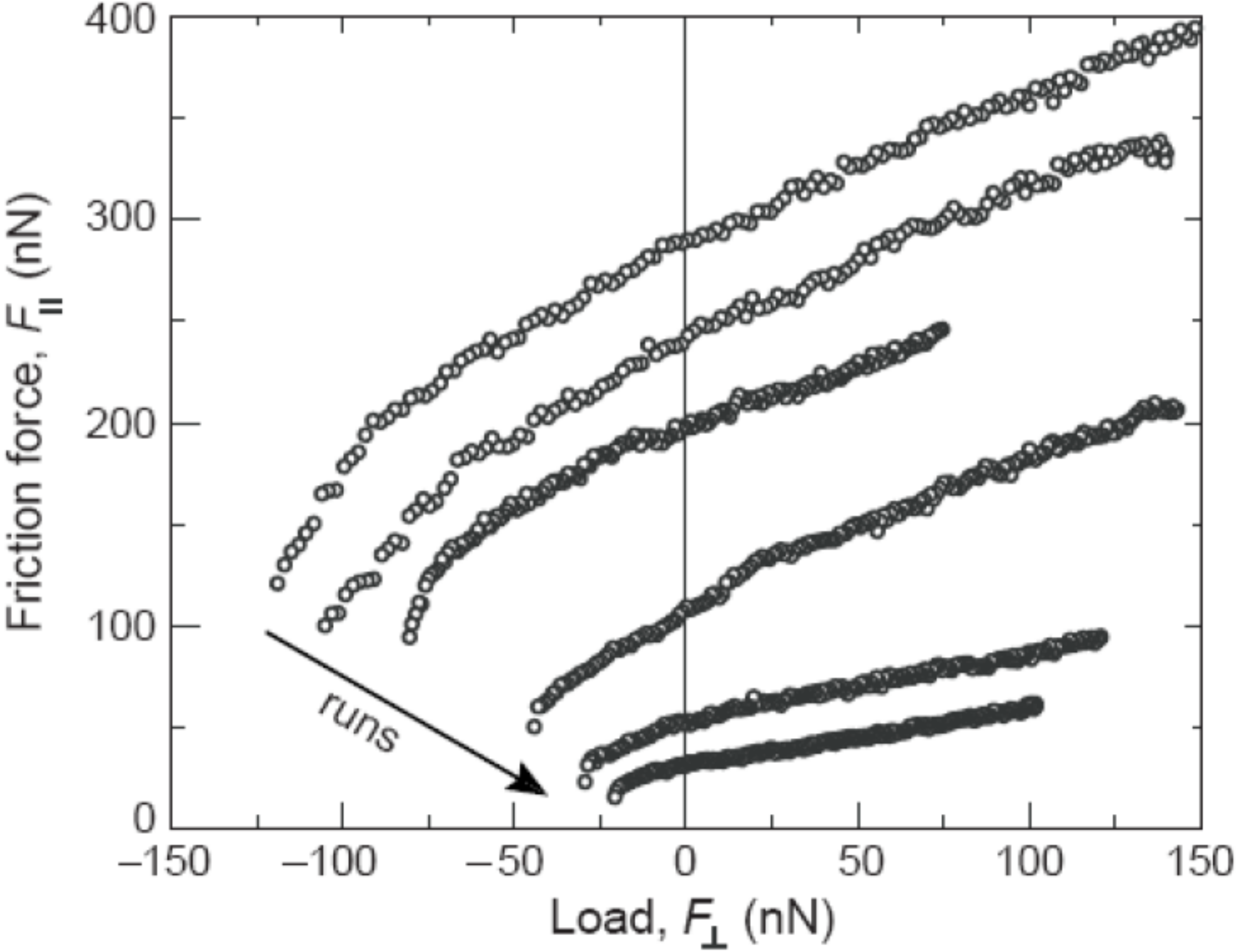


Adhesion-controlled and load-controlled friction forces by SFA

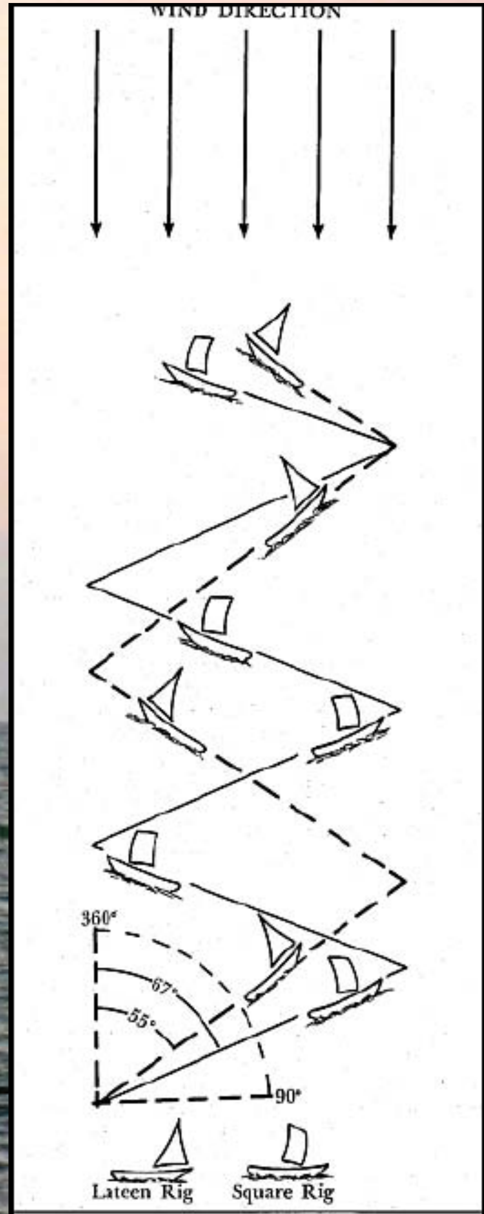


Intermolecular and Surface Forces, 3rd Edition, Elsevier and Academic Press (2010).

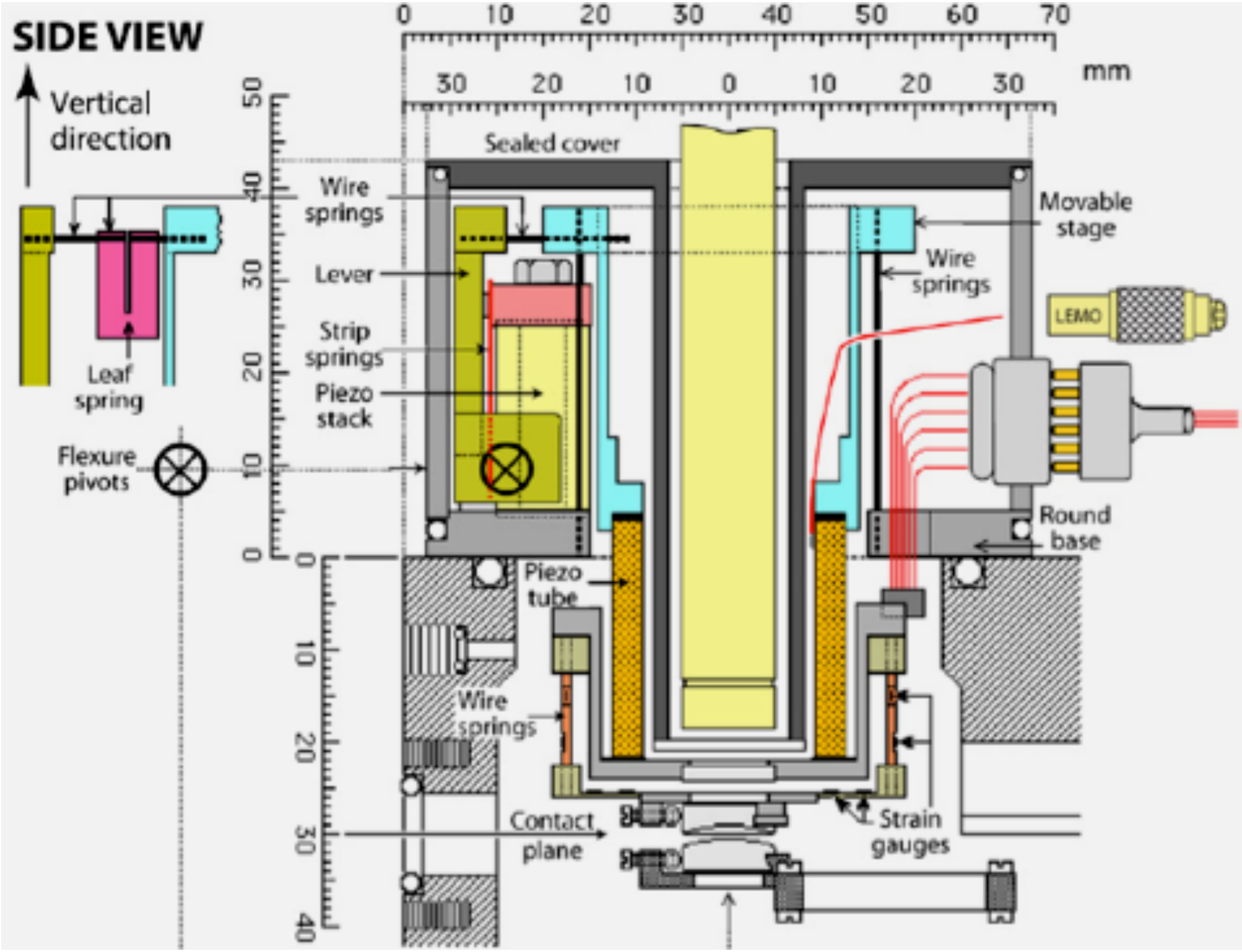
Adhesion- and load-controlled friction forces by AFM



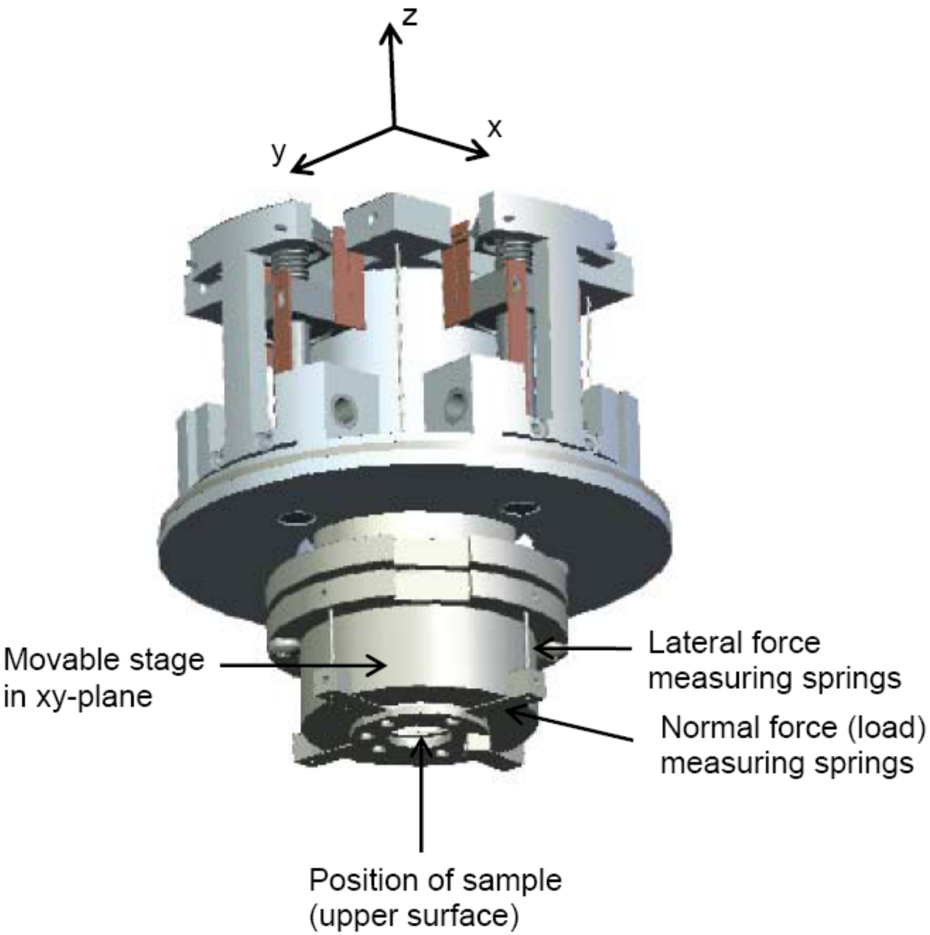
Viscous-controlled friction forces …. also, a good way to introduce anisotropic friction

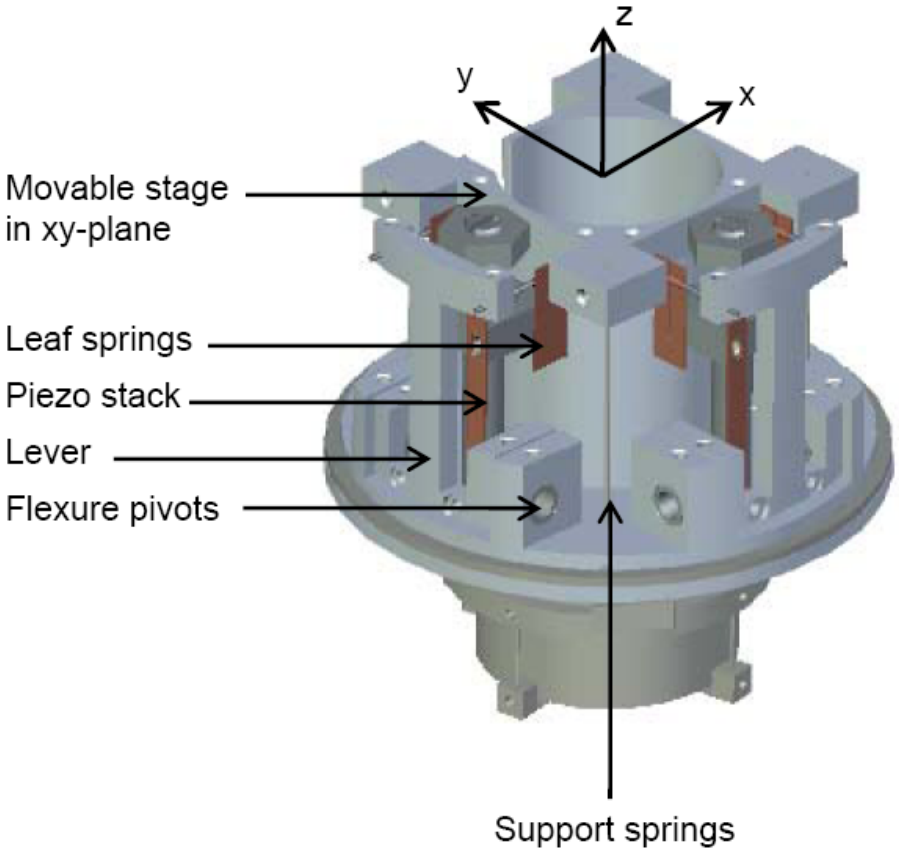


XYZ actuator-sensor for the SFA 2000 (3D SFA)



3D SFA attachment





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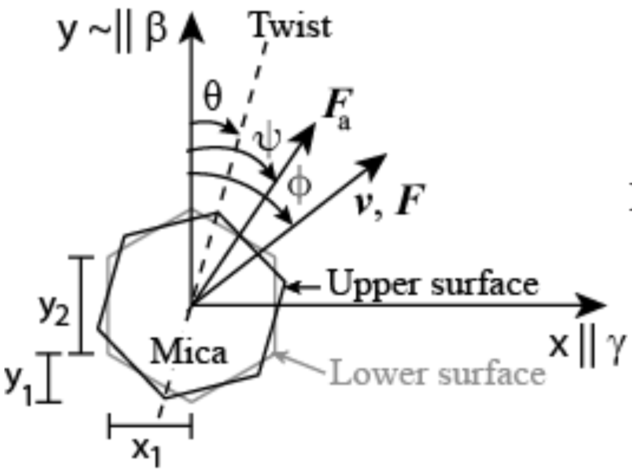
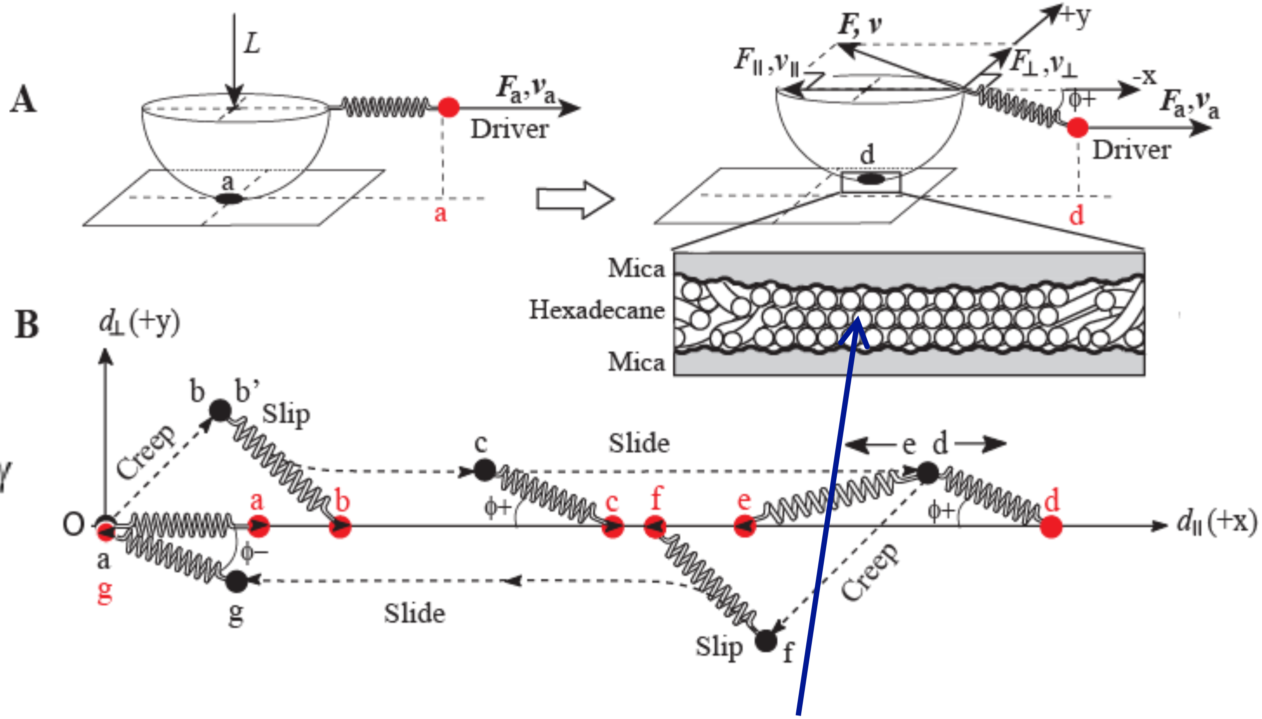
Anisotropic lubricant fluid: *n*-hexadecane between mica

Sliding path of linear n-alkane molecules

Mica configuration

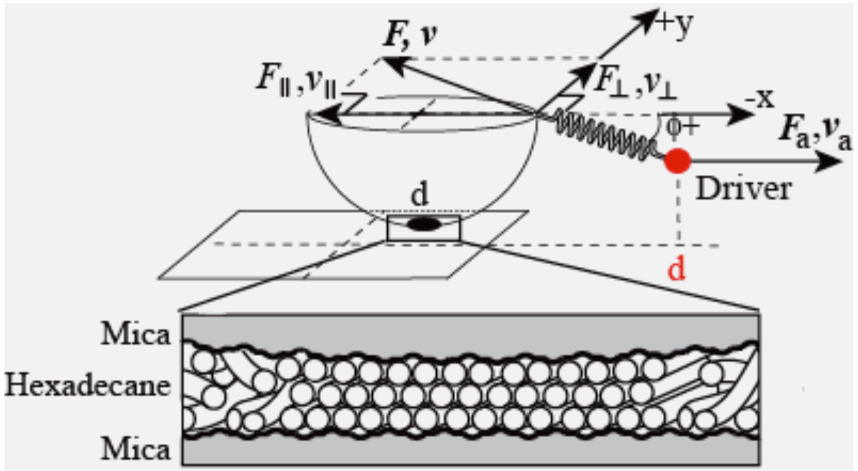


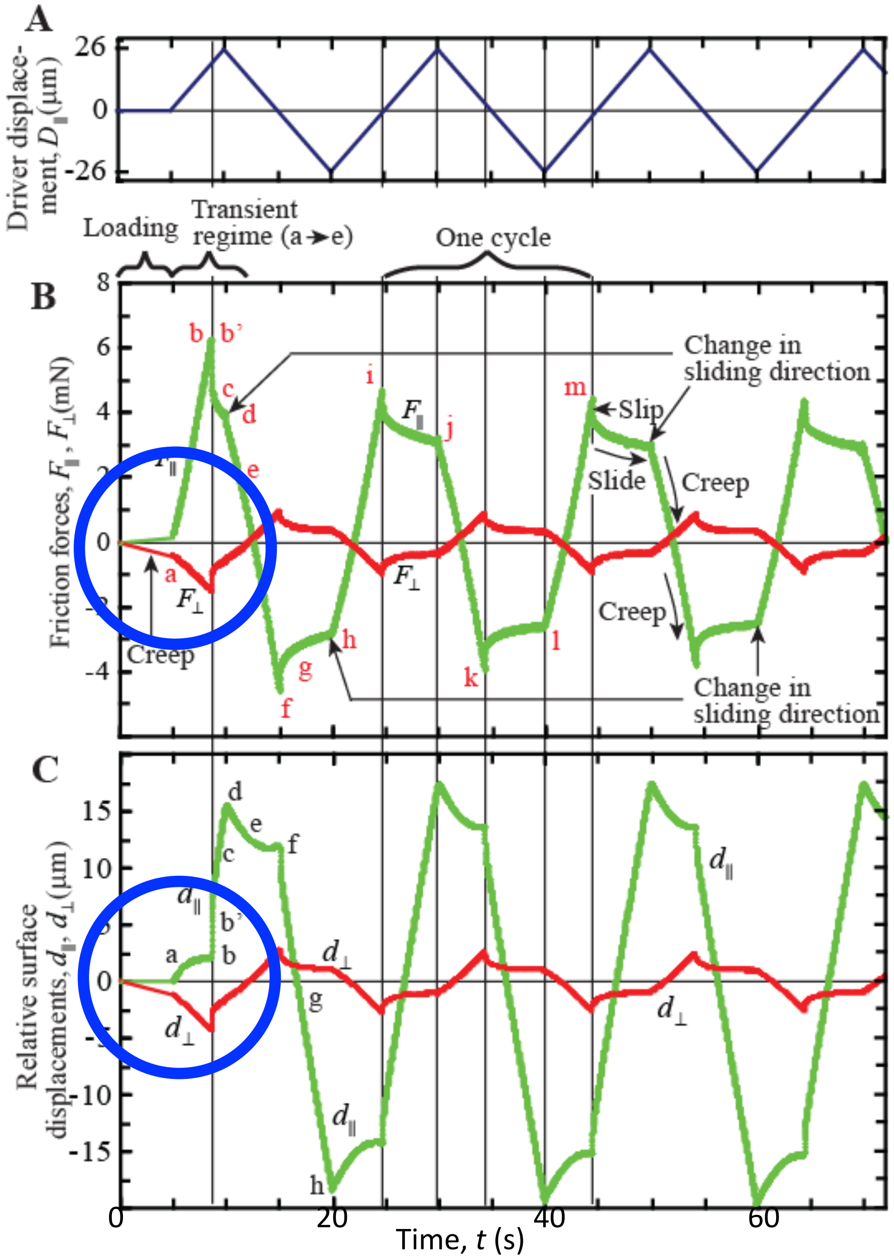


Shear-induced ordering of n-eicosane previously shown by Drummond *et al.*, PRE **66** (2002) 011705, and others.

Friction of hexadecane films: details of the on- and off-axis friction forces and displacements during back and forth sliding

- Twist angle θ = 0°.
- Applied force angle ψ = 0°.
- Load 6 mN (No. of layers: 5?).
- Sliding velocity v_a = 5.1 μm/s.

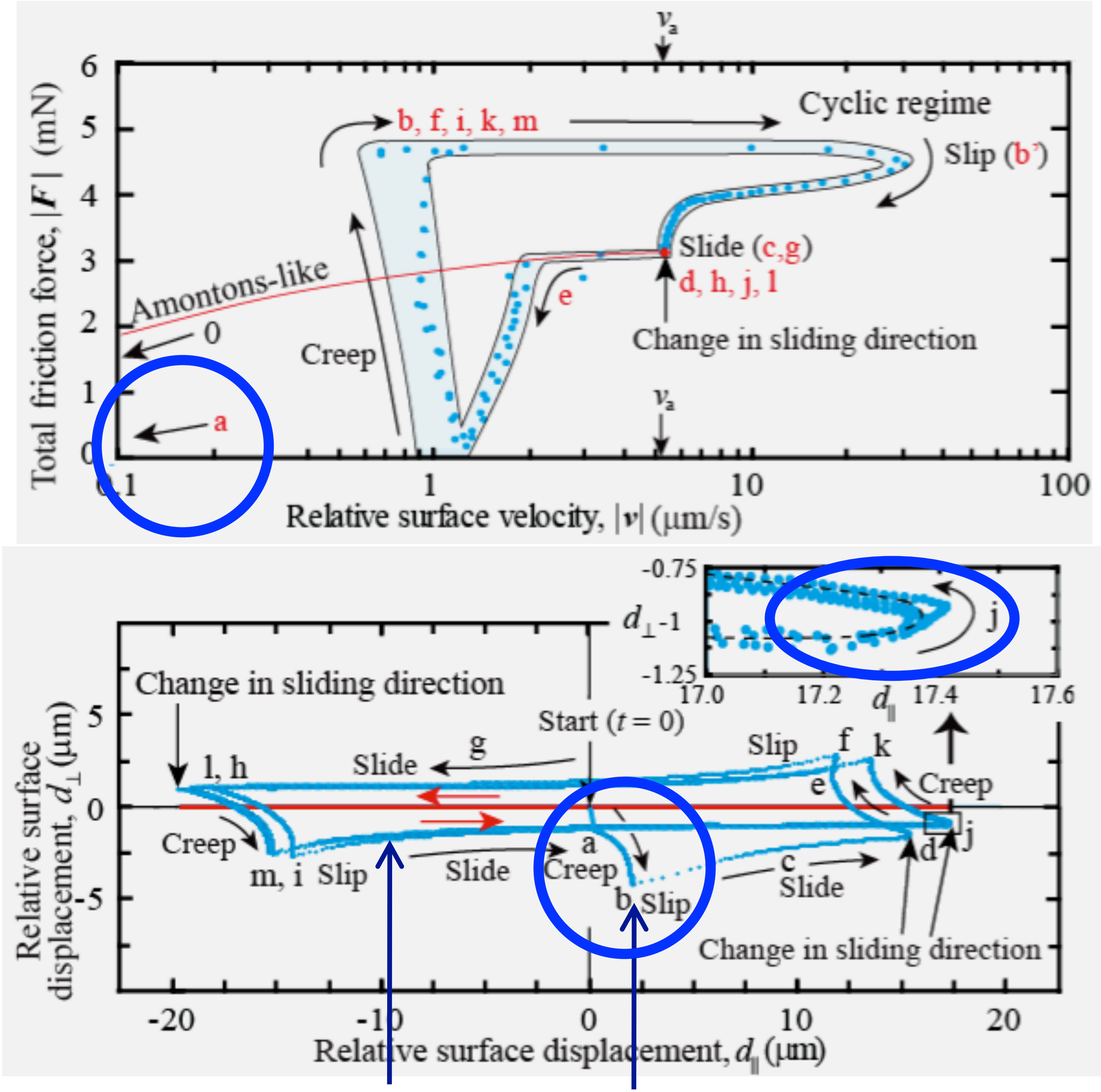




→Shear-induced ordering of hexadecane gives anisotropic friction forces and off-axis relative surface displacements.
→Note long transient (*distance*).

Friction 'limit cycles' of hexadecane films

- Limit cycles of: (a) the total friction force, and (b) absolute relative surface velocity.
- **Red path** shows smooth, linear, isotropic Amontons-like sliding cycle (no off-axis displacement), shown for comparison.
- **Note: displacement and velocity change smoothly at the (discontinuous) changes in the sliding direction.**
- Mica configurations with other twist angles and applied force angles also give off-axis motions.

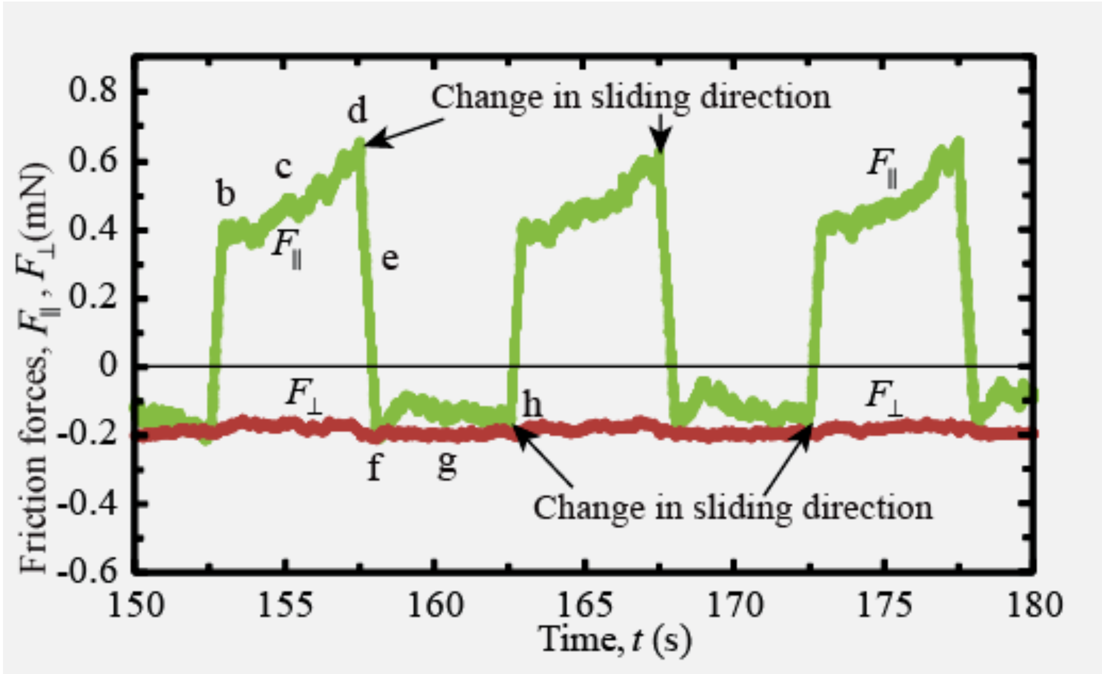


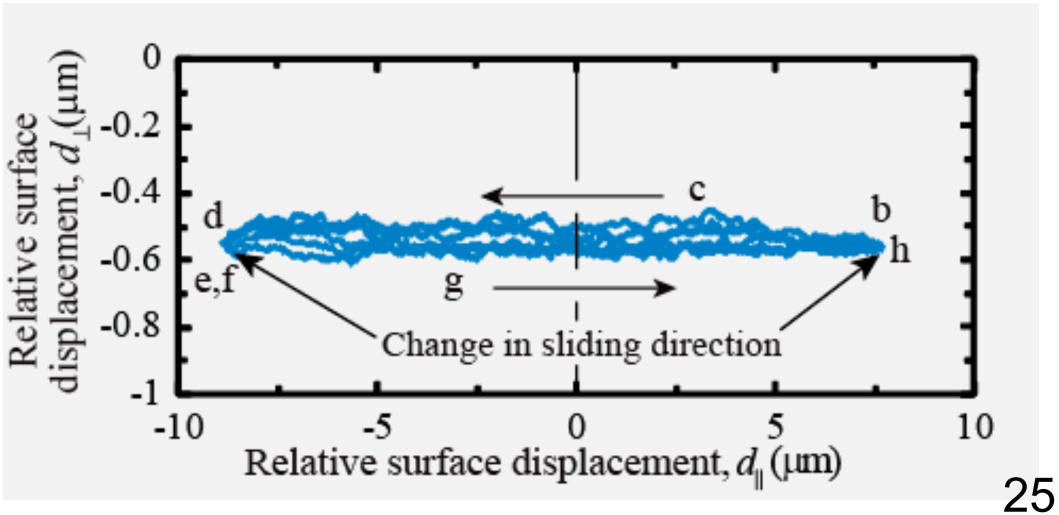
Steady-state Transient ***distance***

Friction of squalane – a highly branched alkane

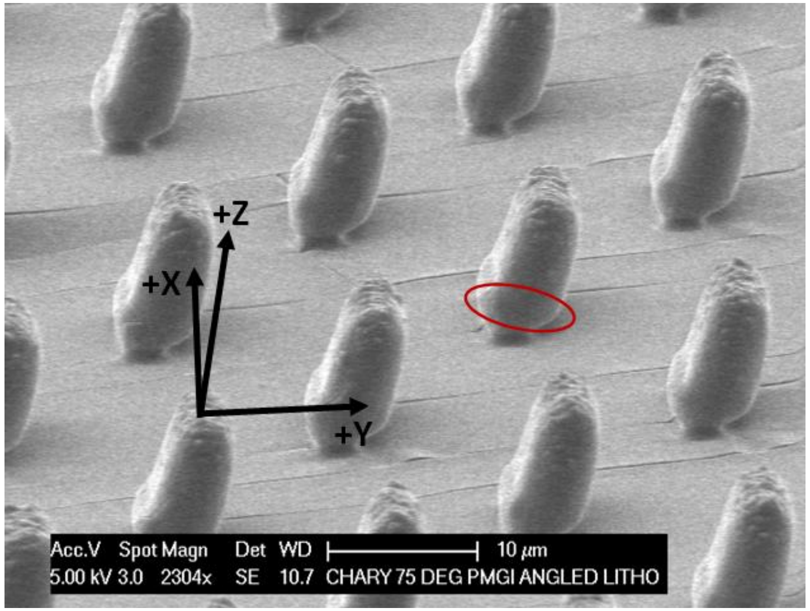
- Load 3 mN,
- Velocity v_a = 2 μm/s,
- Twist angle $\theta = 0°$,
- Applied force at $\psi = 0°$,

→ *F*[illegible] ≈ 0: No off-axis friction forces or motions measured.

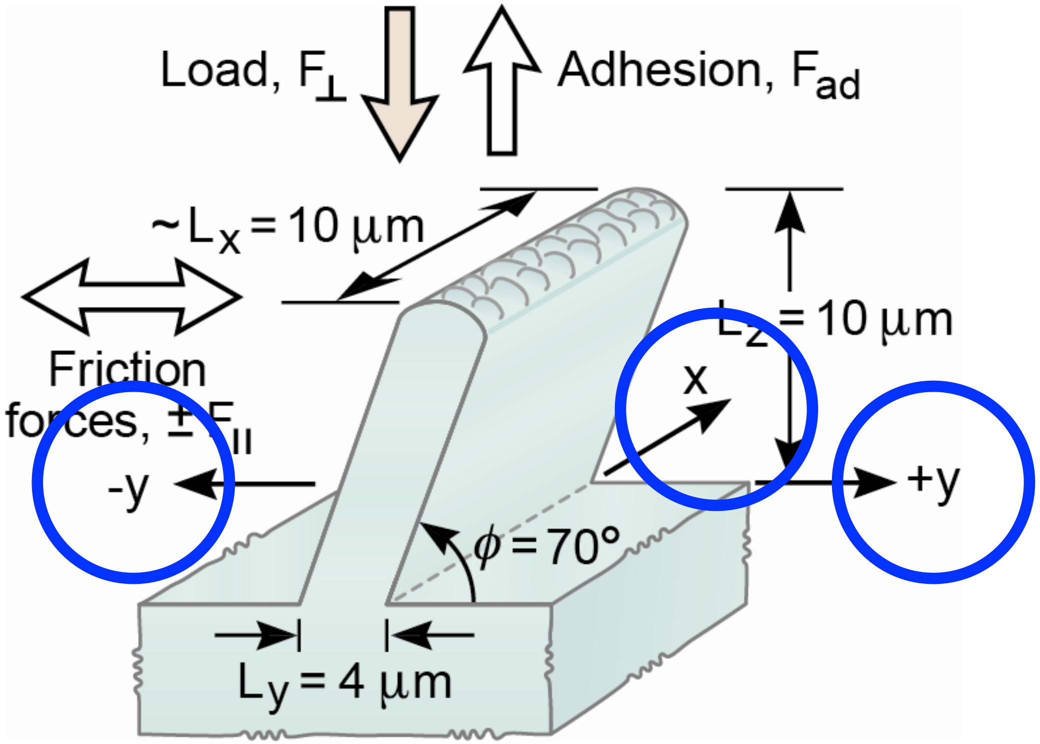




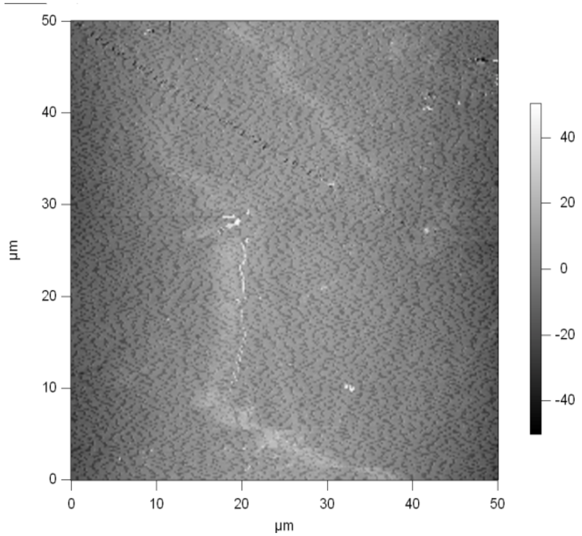
Anisotropically structured (polymer) surfaces: fabricated PDMS tilted micro-flaps ….

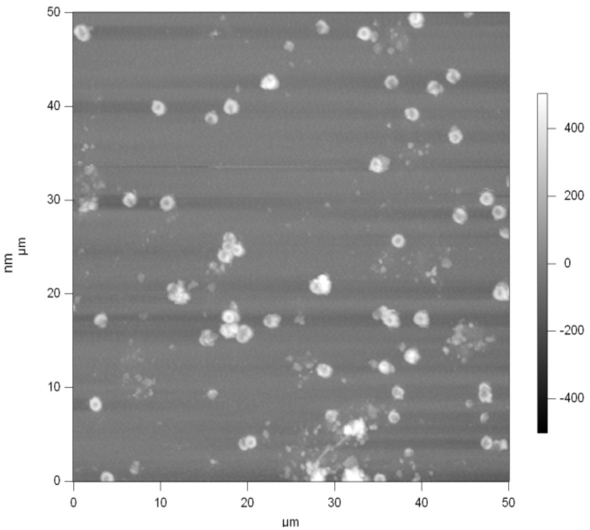


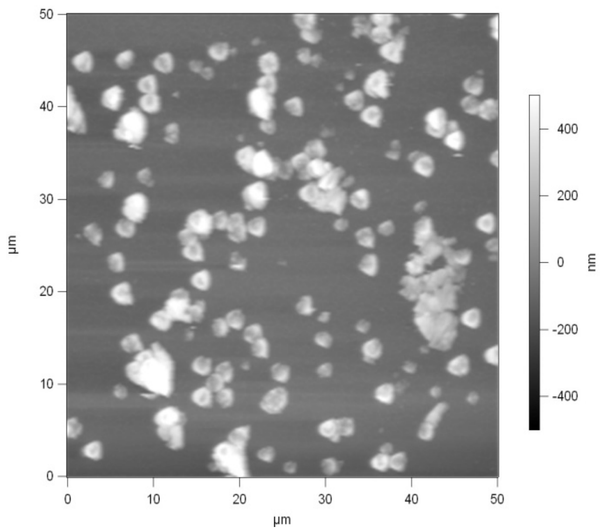
Tilted PDMS micro-flaps

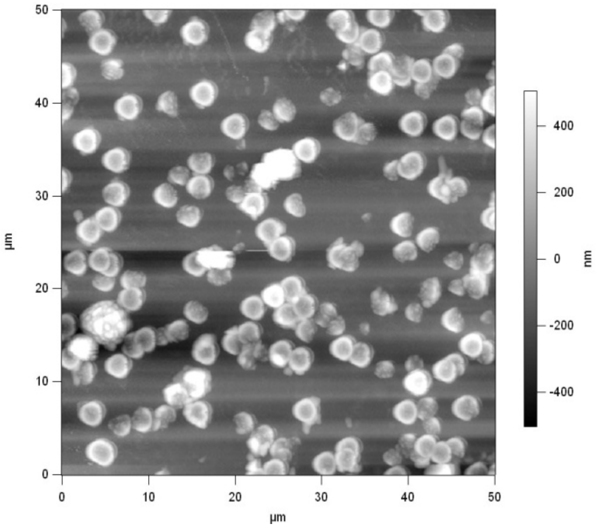


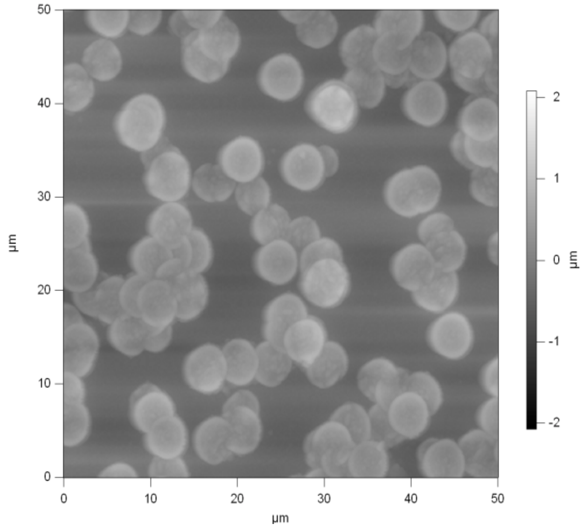
…. sliding against: smooth and rough glass surfaces


RMS = 11±8 nm


RMS = 72±35 nm

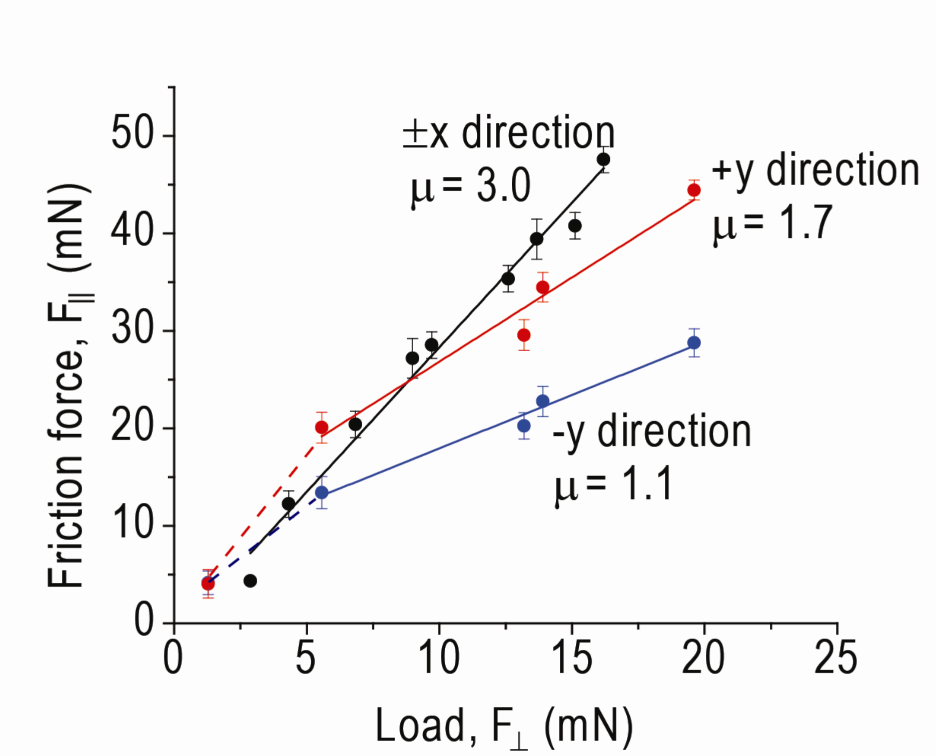

RMS = 140±100 nm


RMS = 180±150 nm


RMS = 350±300 nm

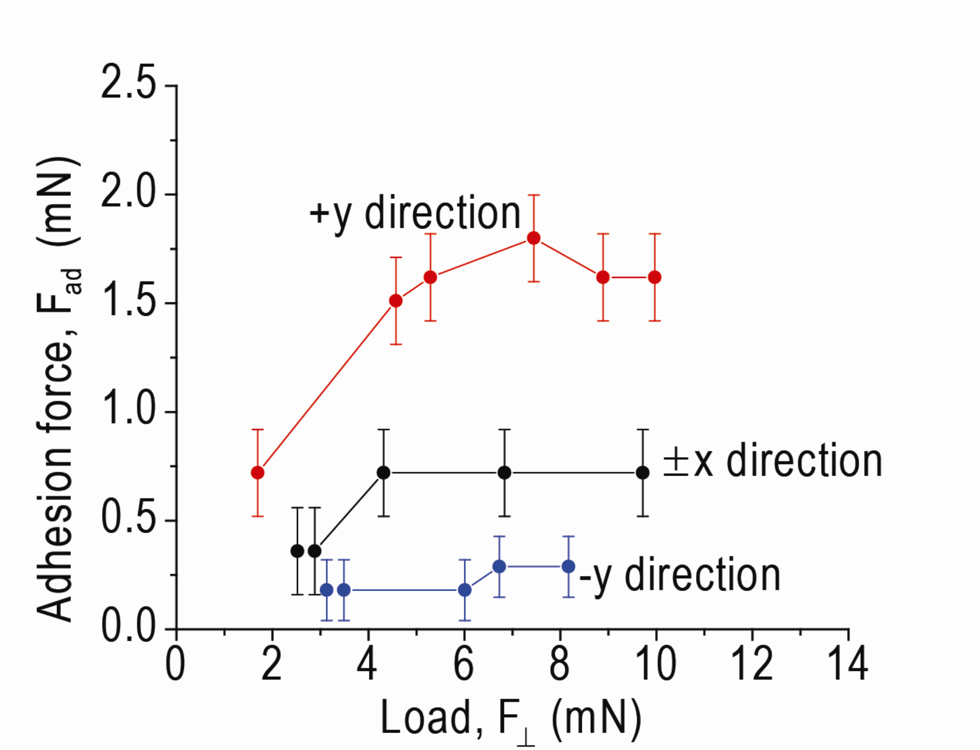
Adhesion and friction against smooth (11 nm) glass

Friction



Adhesion

Adhesion measured after shearing



Adhesion and friction against rough glass