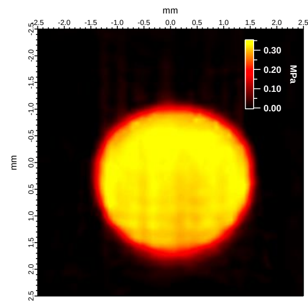
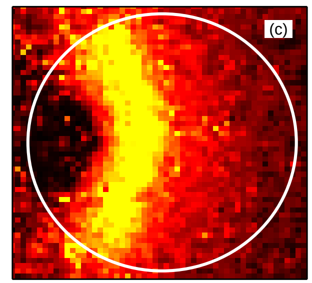
Local friction of rough contact interfaces with rubbers using contact imaging approaches





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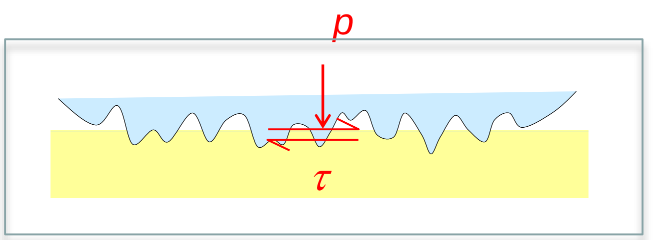
Soft Matter Science and Engineering Laboratory - SIMM
Ecole Supérieure de Physique et Chimie Industrielles (ESPCI), Paris, France

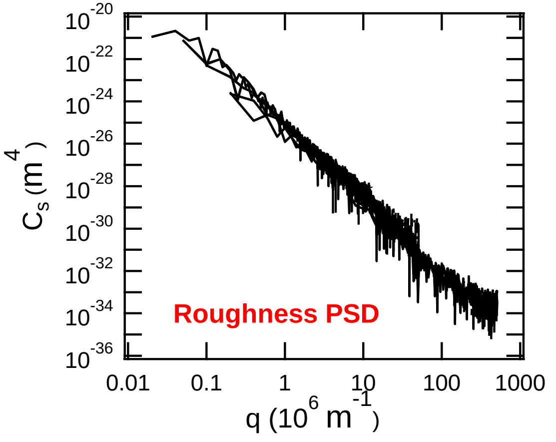
E. Barthel & J .Teisseire
Surface du Verre et Interfaces , CNRS – Saint Gobain, Aubervilliers

A.Prevost & E. Wandersman
Jean Perrin Laboratory (LJP), Université P. et M. Curie, Paris

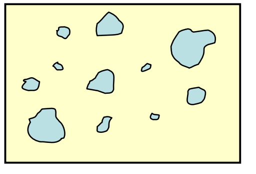
Steady state friction of dry multi-contact interfaces



- **Surface geometry, contact mechanics**



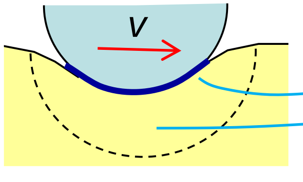
Micro-contacts distribution



Real contact area ??

Non linear material response
Adhesion
Viscoelasticity
....

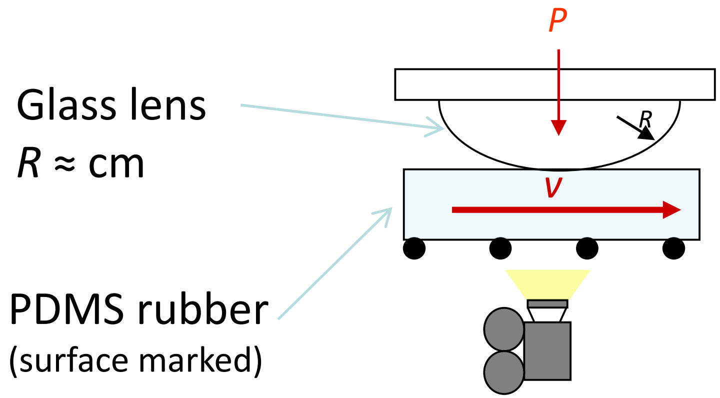
- **Frictional energy dissipation at micro-asperity scale**



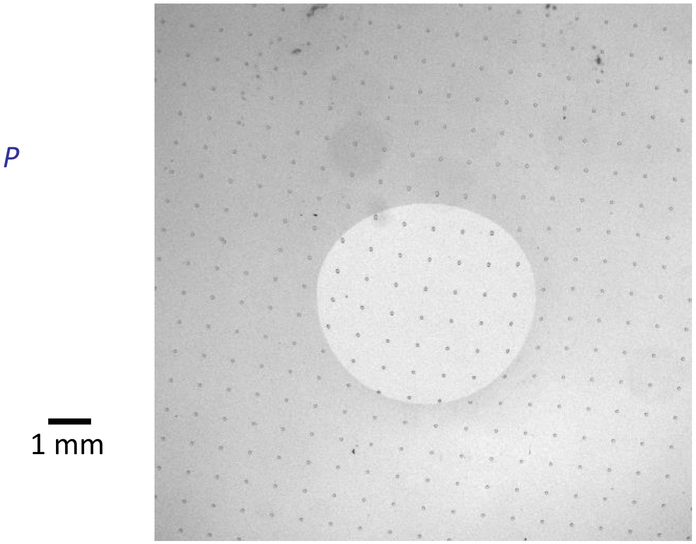
- Interfacial dissipation
- Bulk plastic or viscoelastic dissipation

Local friction law $\tau(p)$??

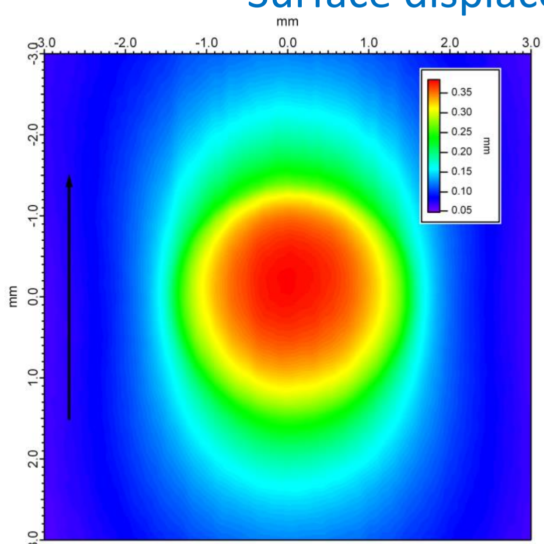
Displacement field measurements within contacts with rubber



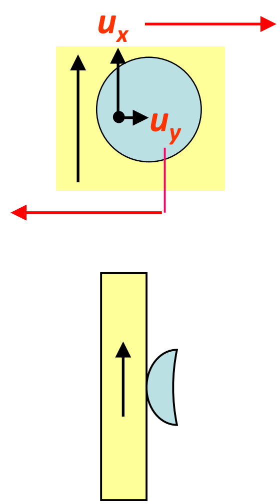
Imposed - normal load, *P*
- velocity, *v*

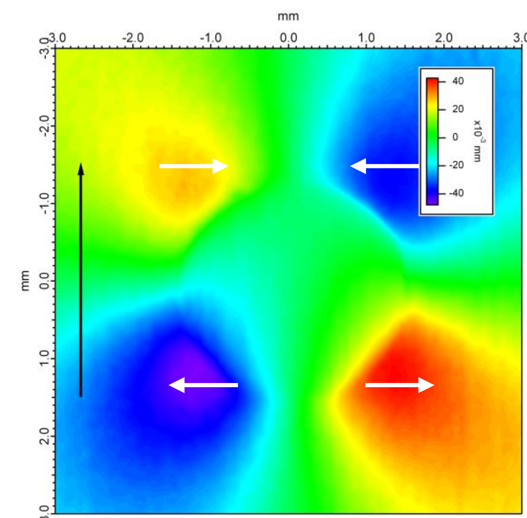


Surface displacements during steady state friction



Along sliding direction





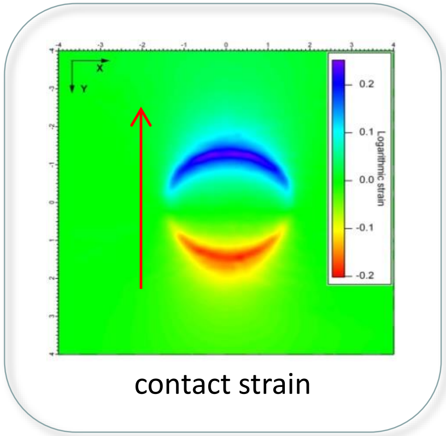
Perpendicular to sliding direction

Space resolution ~ 10 x 10 μm²

Contact stresses : inversion of the displacement field

Inversion???

Surface displacement ➡ Surface stresses



contact strain

- Linear elasticity → Green's tensor

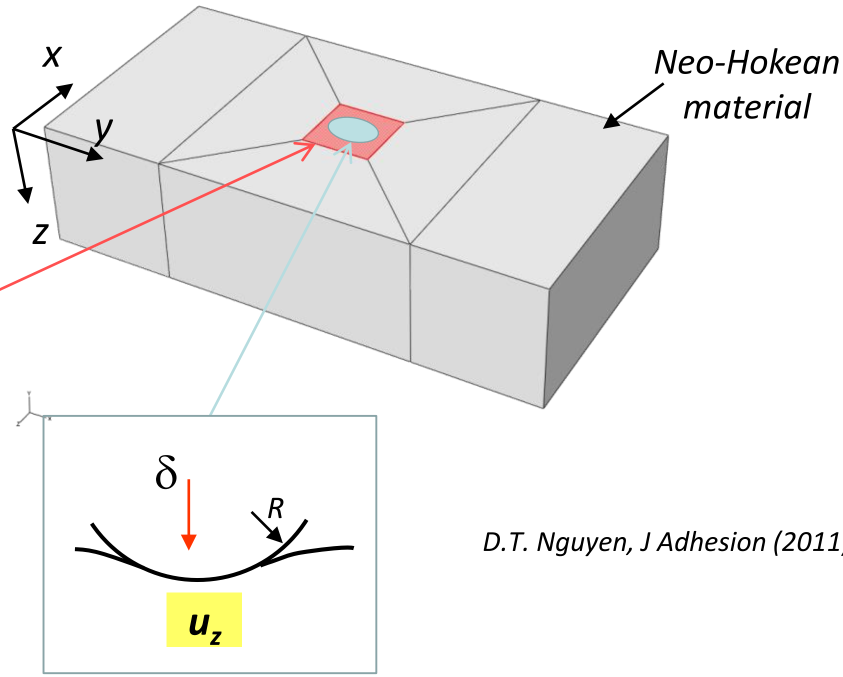
Incompressible materials, ν=0.5

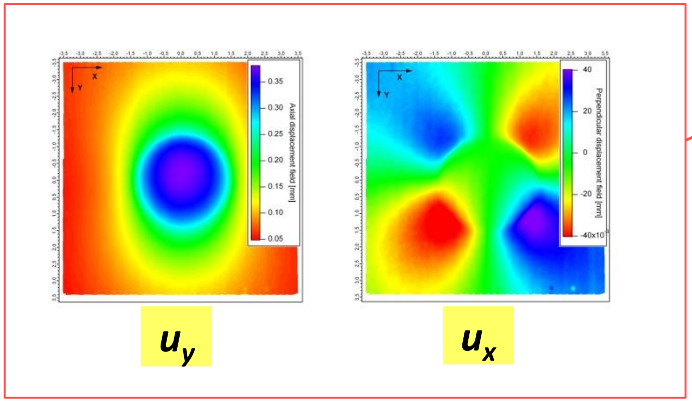
Lateral displacements $u_i = G_{ij} * \sigma_{jz}$

Vertical displacement $u_{zz} = G_{zz} * \sigma_{zz}$

$i, j = x, y$

- Experimentally : large strains ! → Numerical inversion using FEM

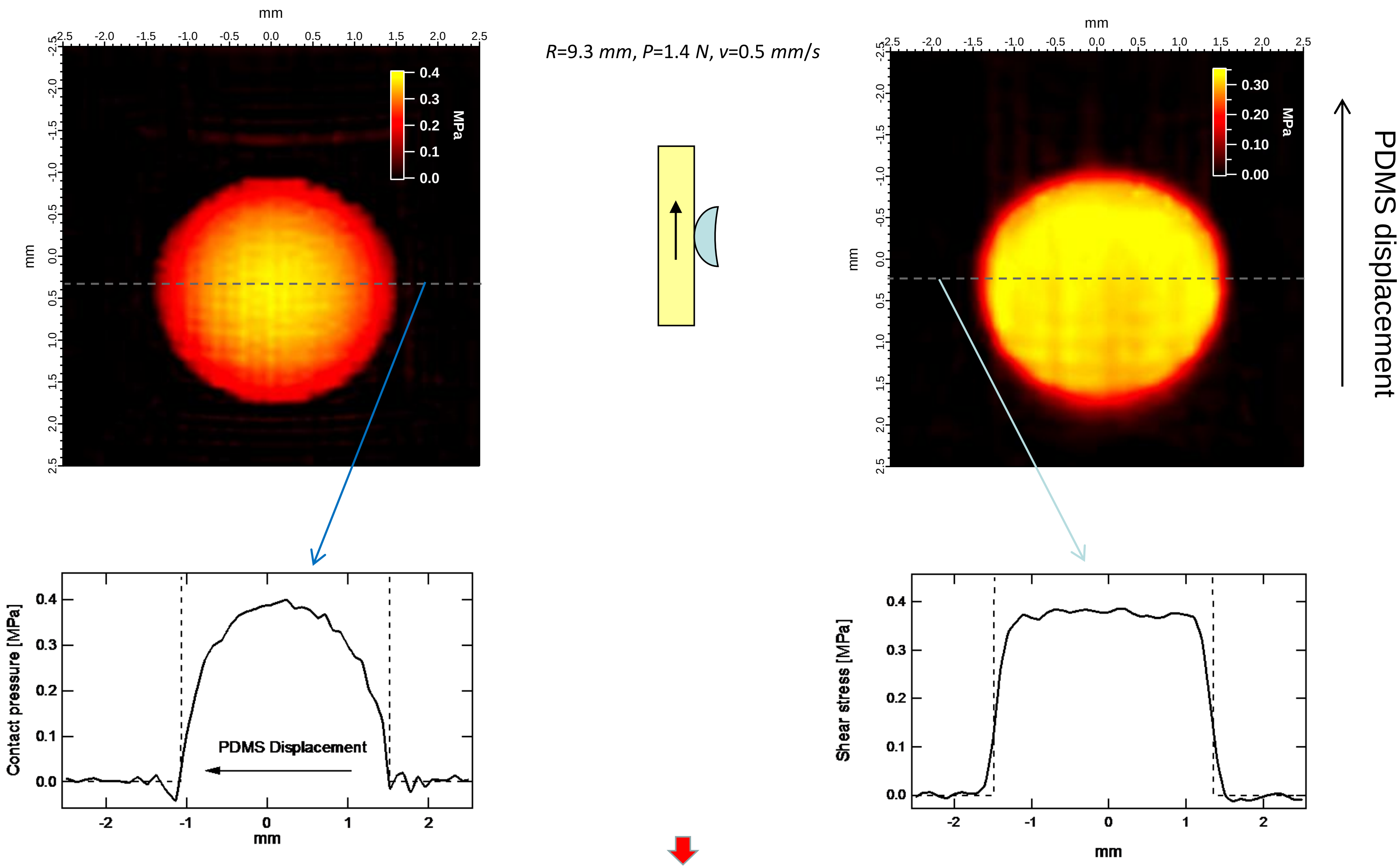




D.T. Nguyen, J Adhesion (2011)

Contact stresses: single asperity contact

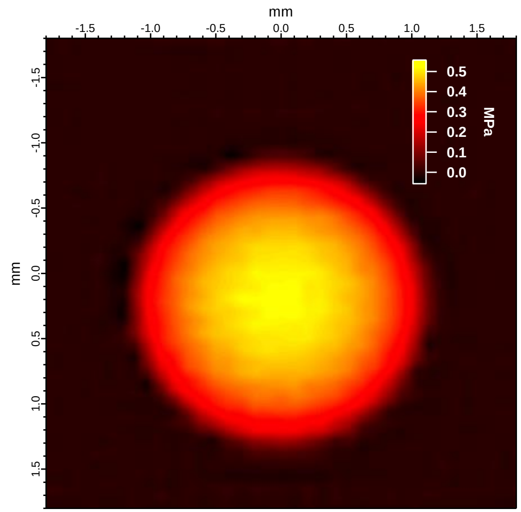
Smooth Glass/**PDMS** contact



Pressure independent shear stress

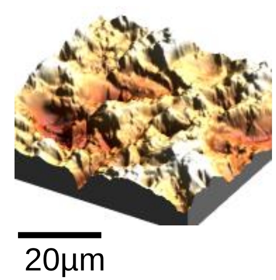
Contact stresses: rough multi-contact interface

Contact pressure



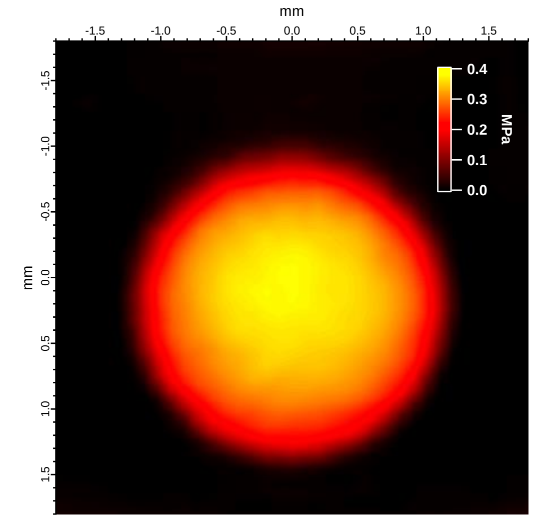
Gaussian roughness

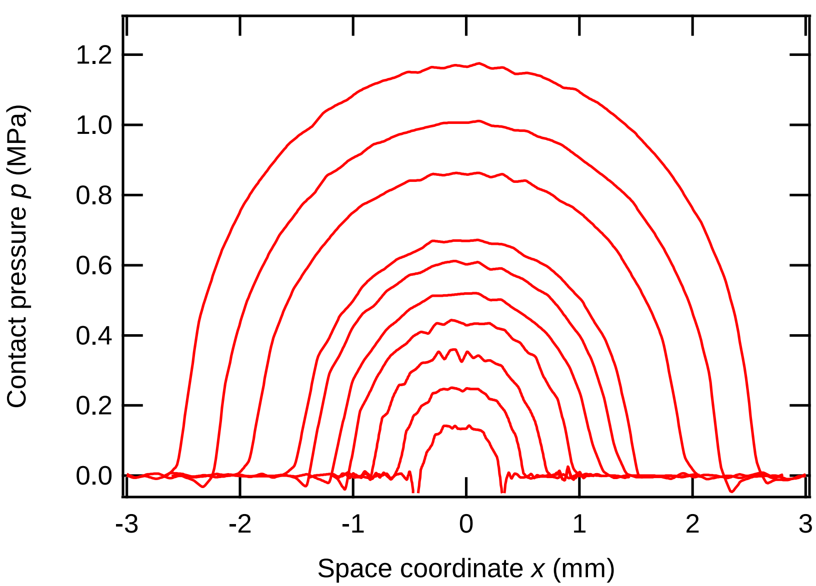
r.m.s roughness ~ 1 µm

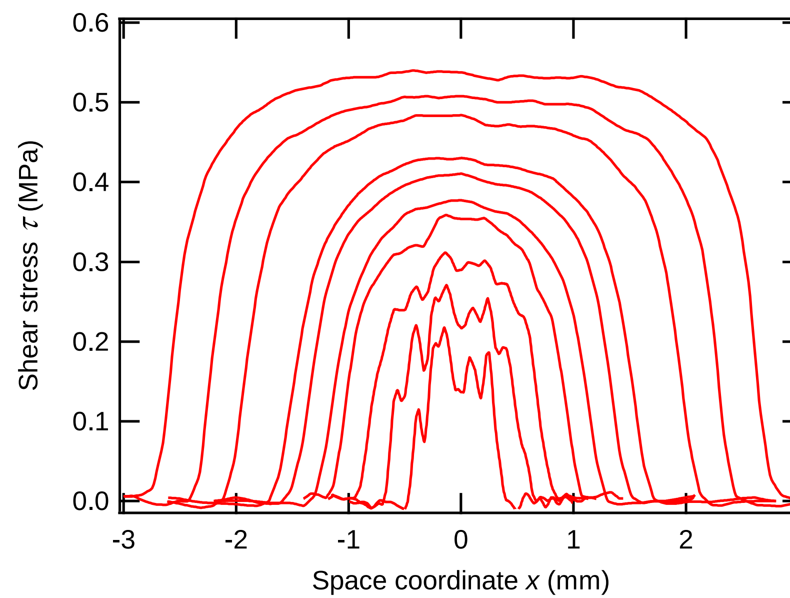


Sand blasted glass lens

Shear stress



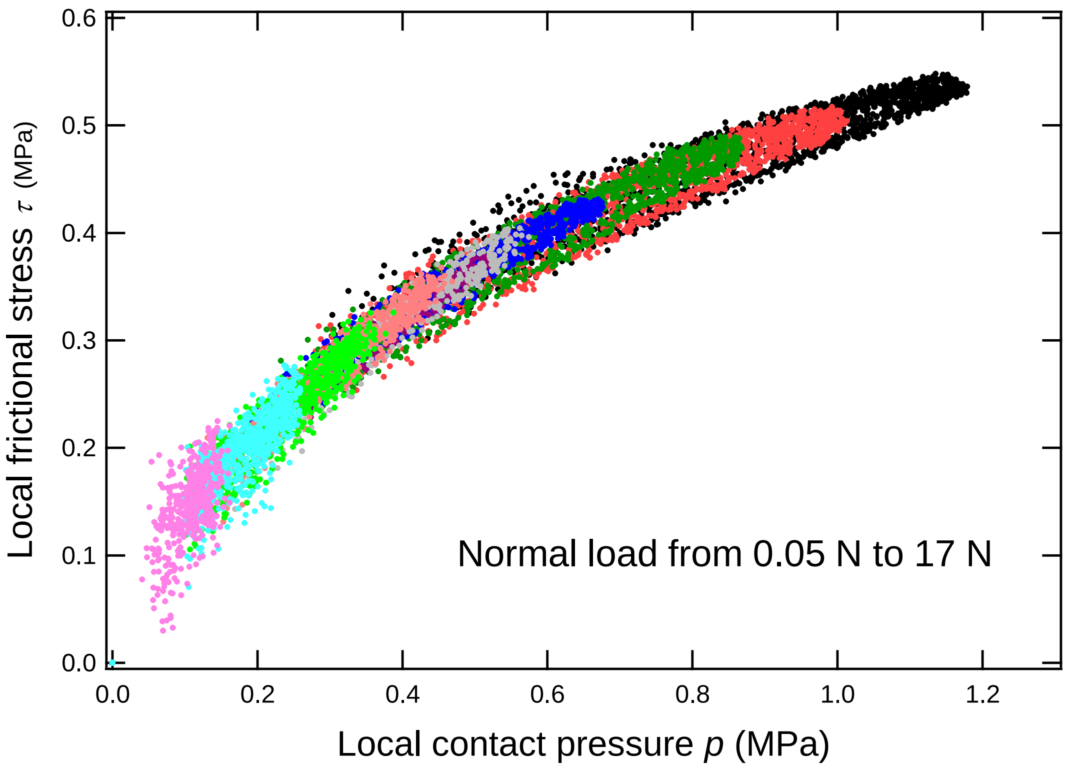


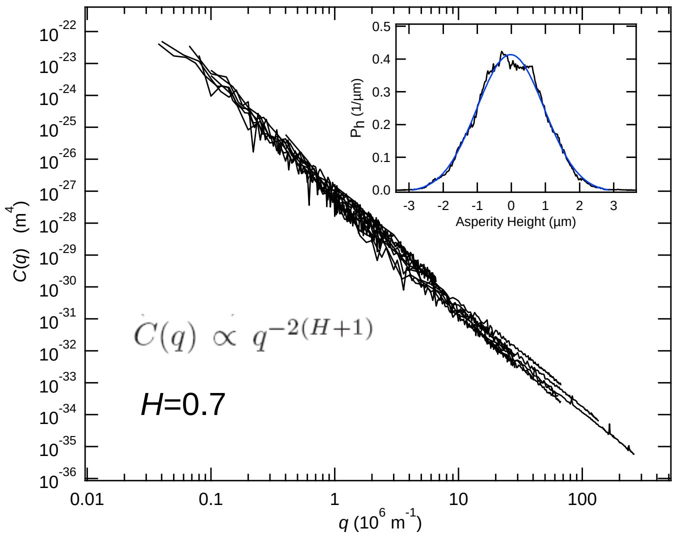


Stress profiles at increasing applied normal load

Local friction law

- PDMS / self affine rough glass surface



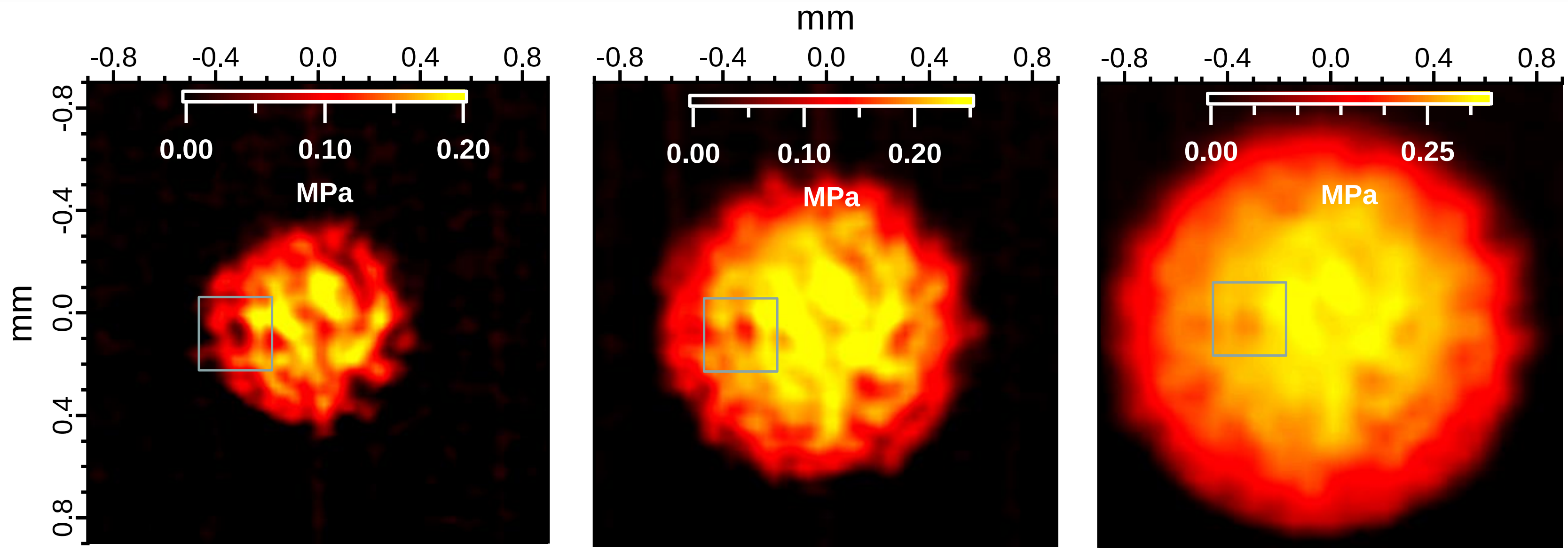


Roughness PSD

Non Amontons-Coulomb local friction law

D.T Nguyen *et al* EPL (2014)

Spatial fluctuations in the shear stress at low contact pressures



P = 0.05 N

P = 0.2 N

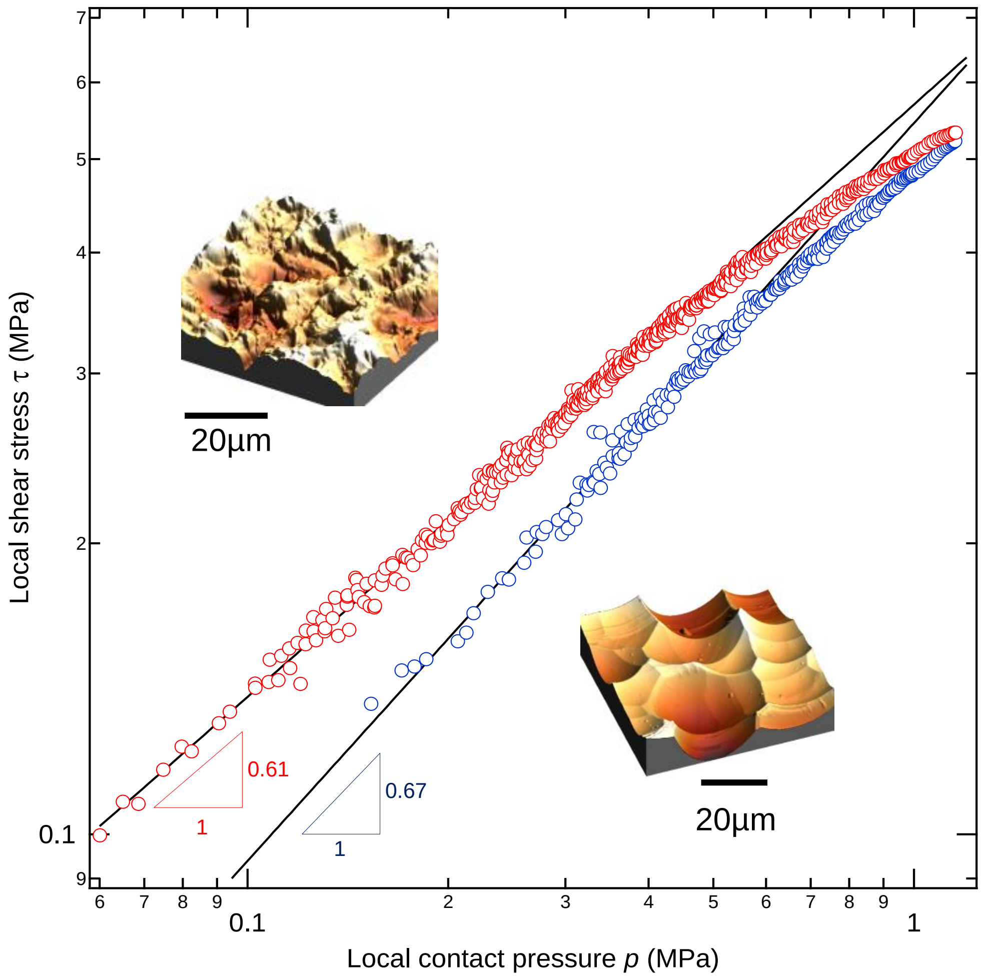
P = 0.5 N

Stress fluctuations over length scales of the order of a few tens of micrometers

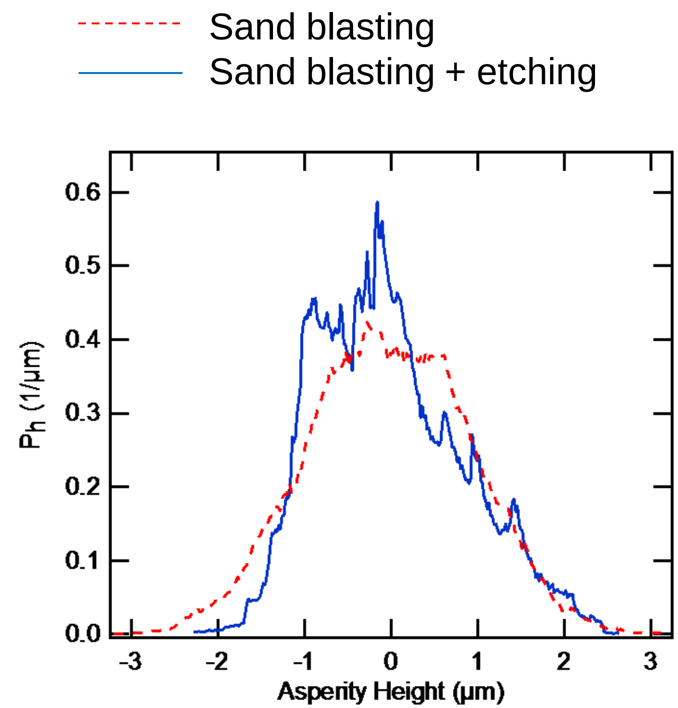
Local changes in the contact stress distribution induced by details of the topography of the rough lens

Gaussian *vs* non Gaussian surface roughness

- PDMS rubber



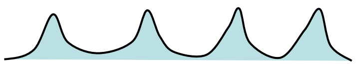
Local friction law



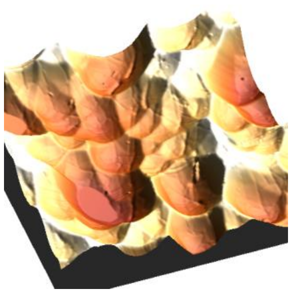
Height distribution

Additional roughnesses…

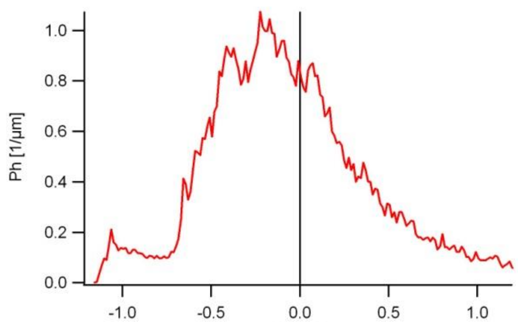
‘Cups’ | *Sol-gel Replica* ⟷ | ‘Bumps’

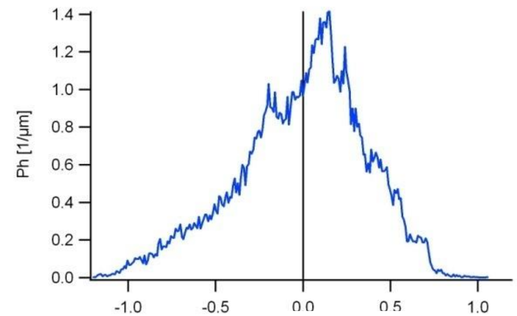


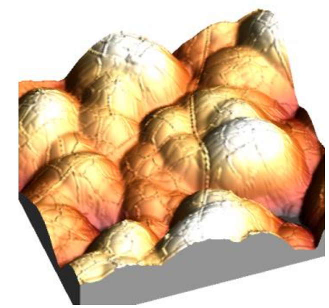
Different height distributions



30µm

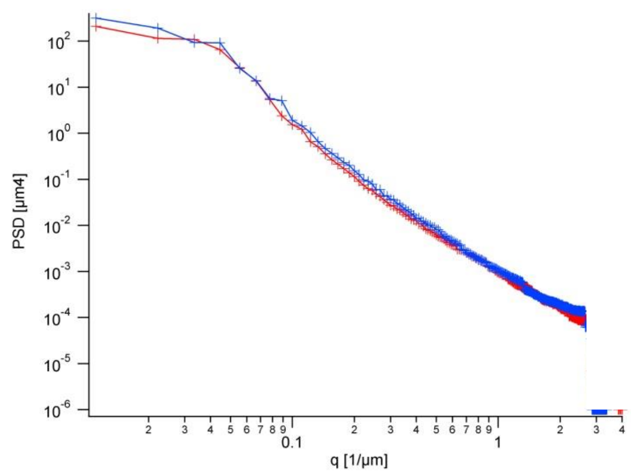




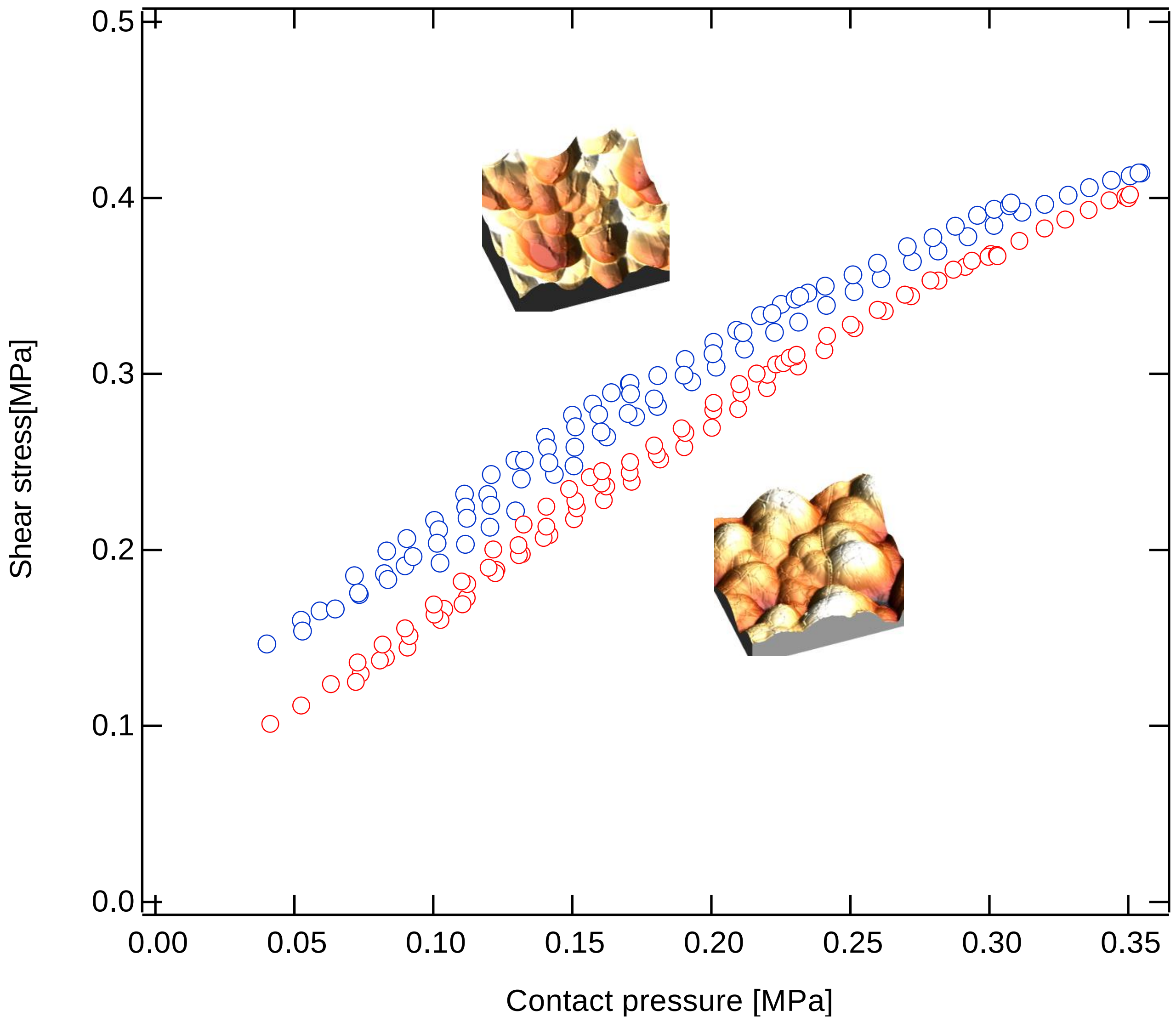


30µm

Same roughness power spectrum density

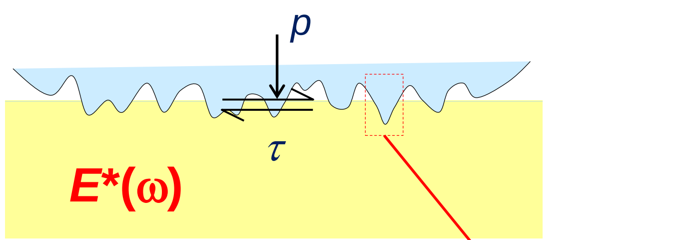


Cusps vs bumbs: local friction law

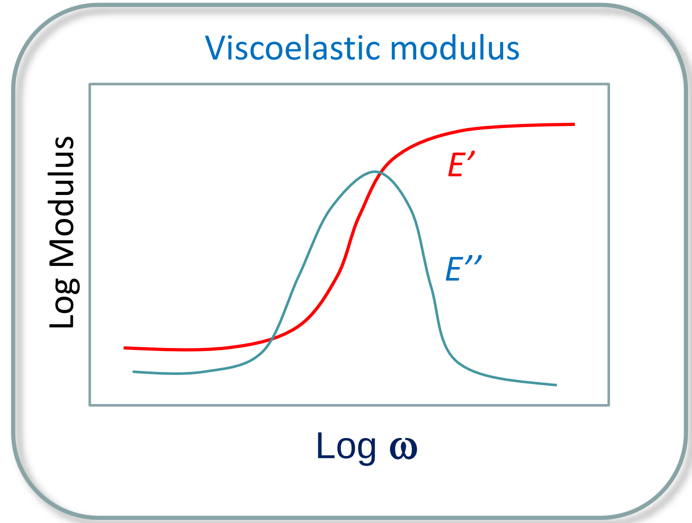


All the topographical information relevant to friction is not embedded in the PSD

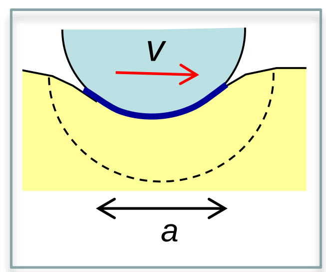
Friction of rubbers with rough surfaces: the role of viscoelastic losses



Multicontact interface



Characteristic frequency $\omega \sim v / a$

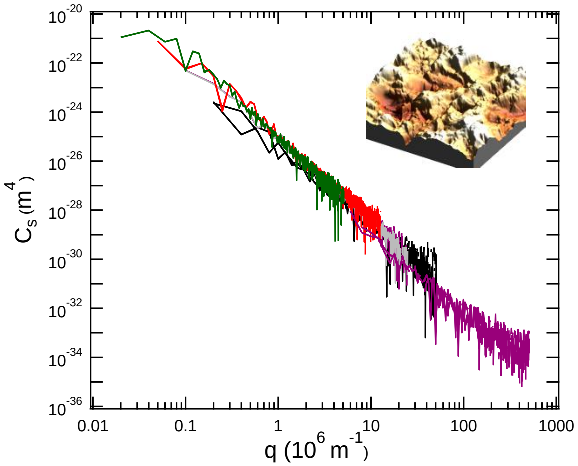


Single asperity contact

- **Velocity and pressure dependence of the real contact area ?**
- **Viscoelastic losses at micro-asperity scale ?**

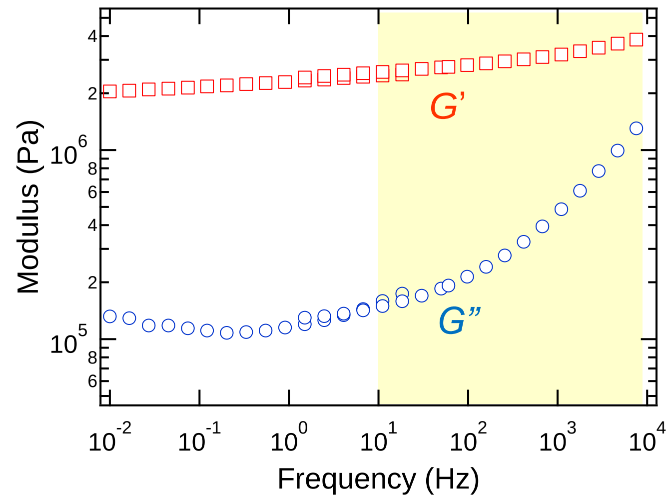
Local friction of viscoelastic rubbers with randomly rough surfaces

Sand blasted glass surface

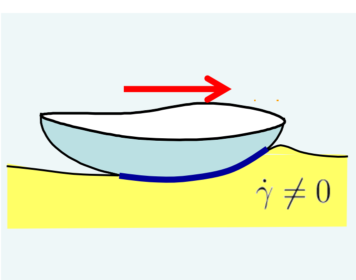


rms roughness µm

Epoxy rubber Tg = - 42°C

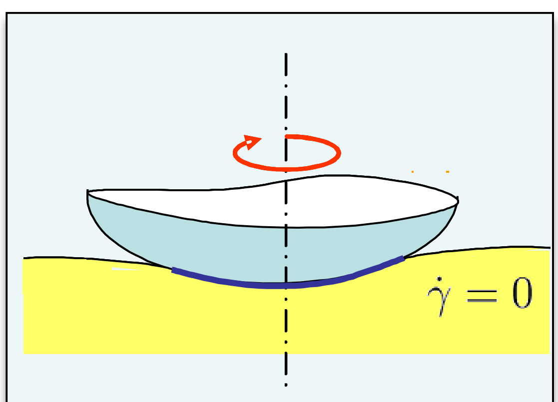


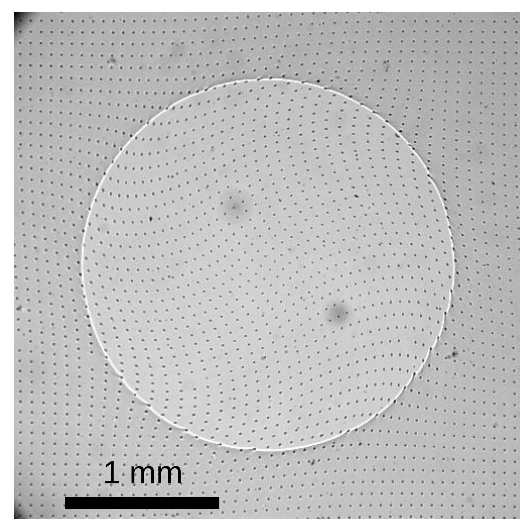
Torsional contacts



Linear sliding

Bulk viscoelastic dissipation
at contact scale !

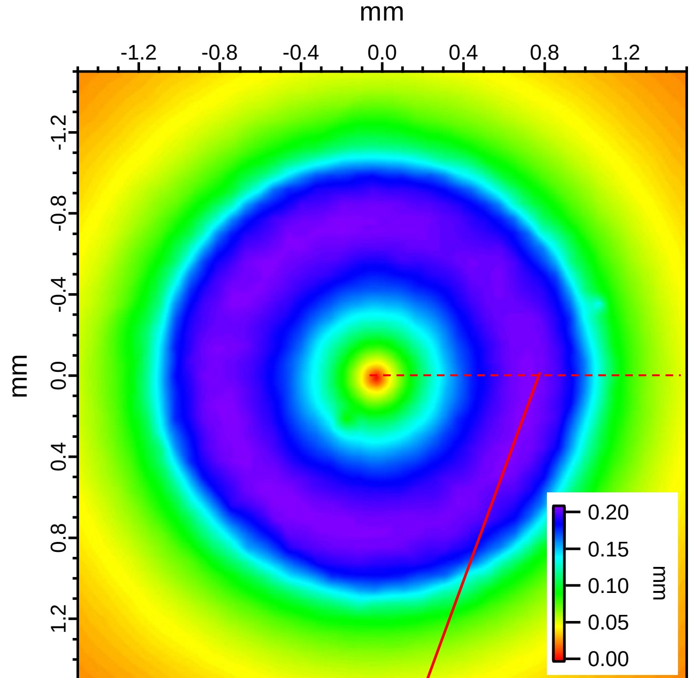


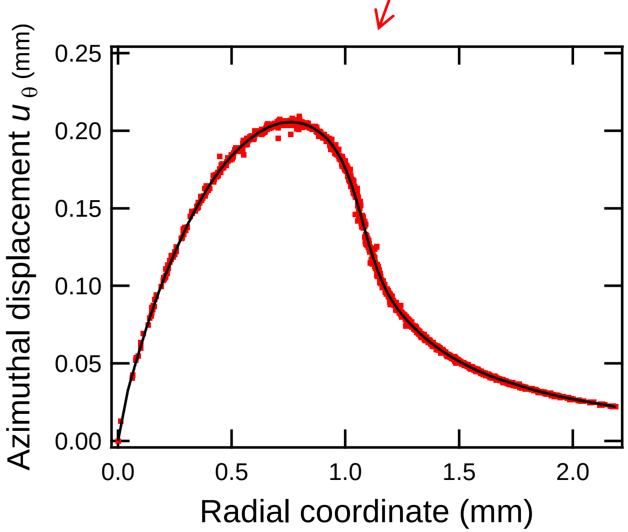


A. Chateauminois et al *Phys Rev E* ***81*** (2010)

Torsional contact : displacement & stress field

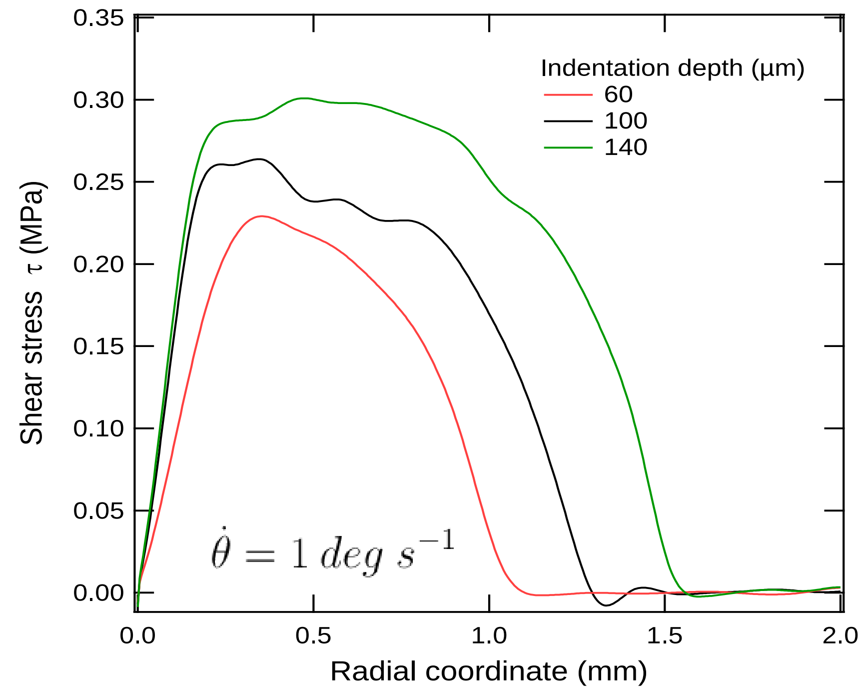
Azimuthal displacement u_θ

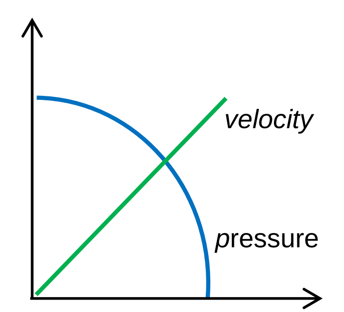




Inversion

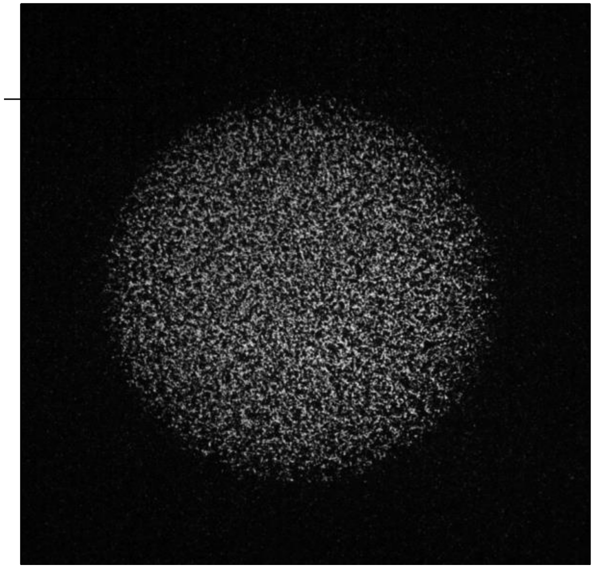
Frictional shear stress

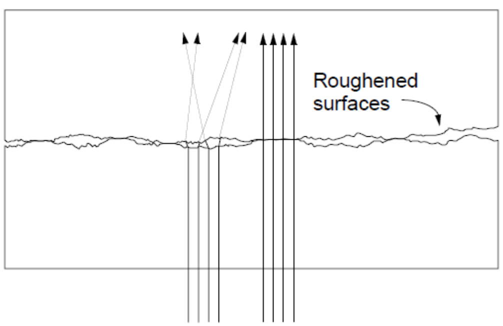




Light transmission through rough multi-contact interfaces

1 pixel = 5.1 µm

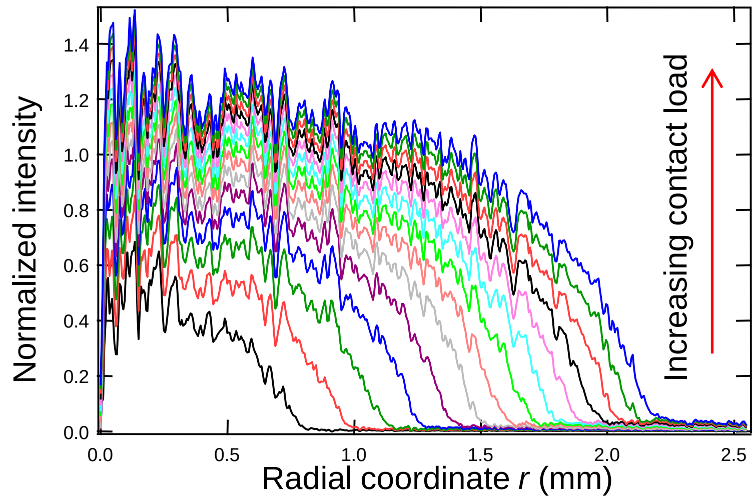


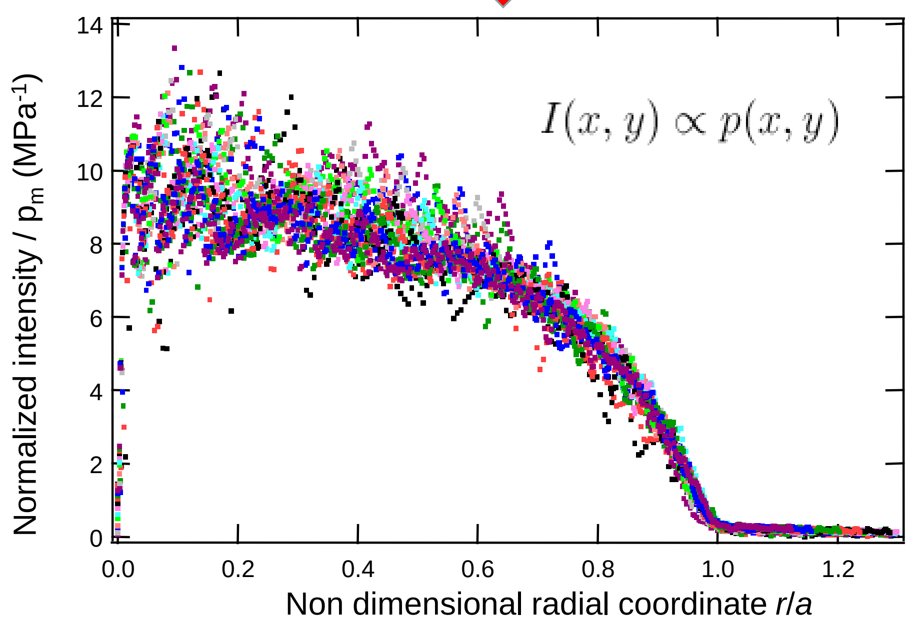


Dieterich *et al.* Pageoph,**143** (1994)

Light transmitted through the interface more efficiently when only one interface is present

Static indentation experiments

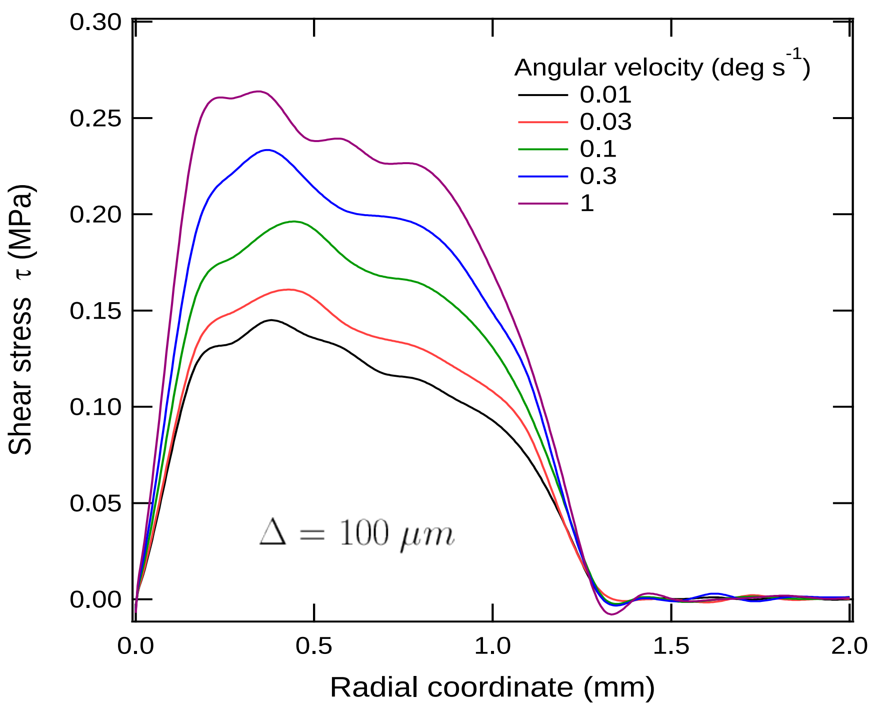




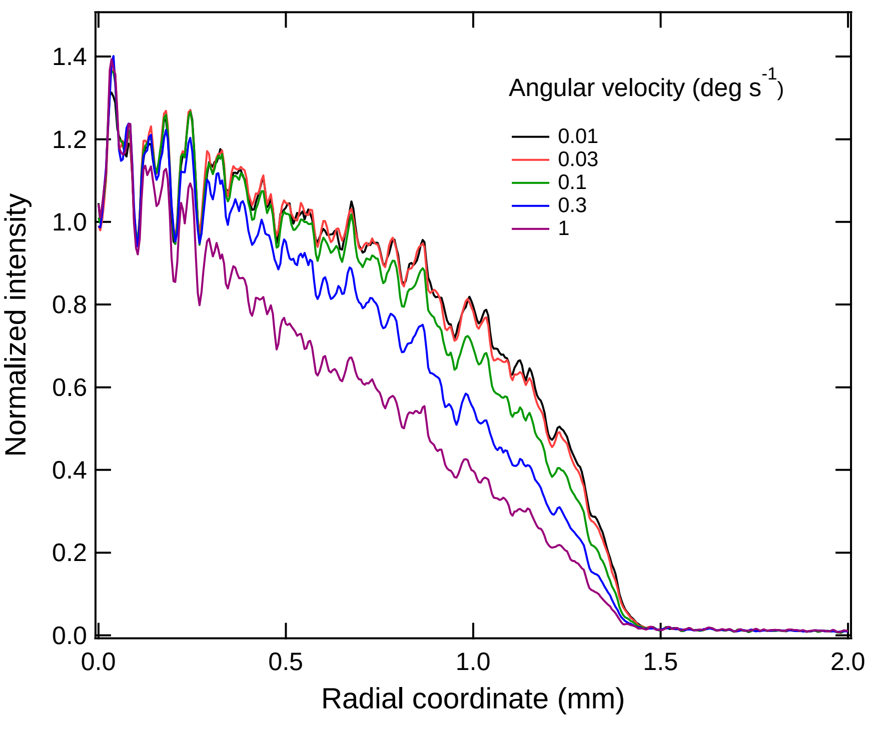
Transmitted light intensity *I(x,y)* ∝ Proportion of area in contact *A/Ao(x,y)*

Velocity dependence of the shear stress

Angular velocity



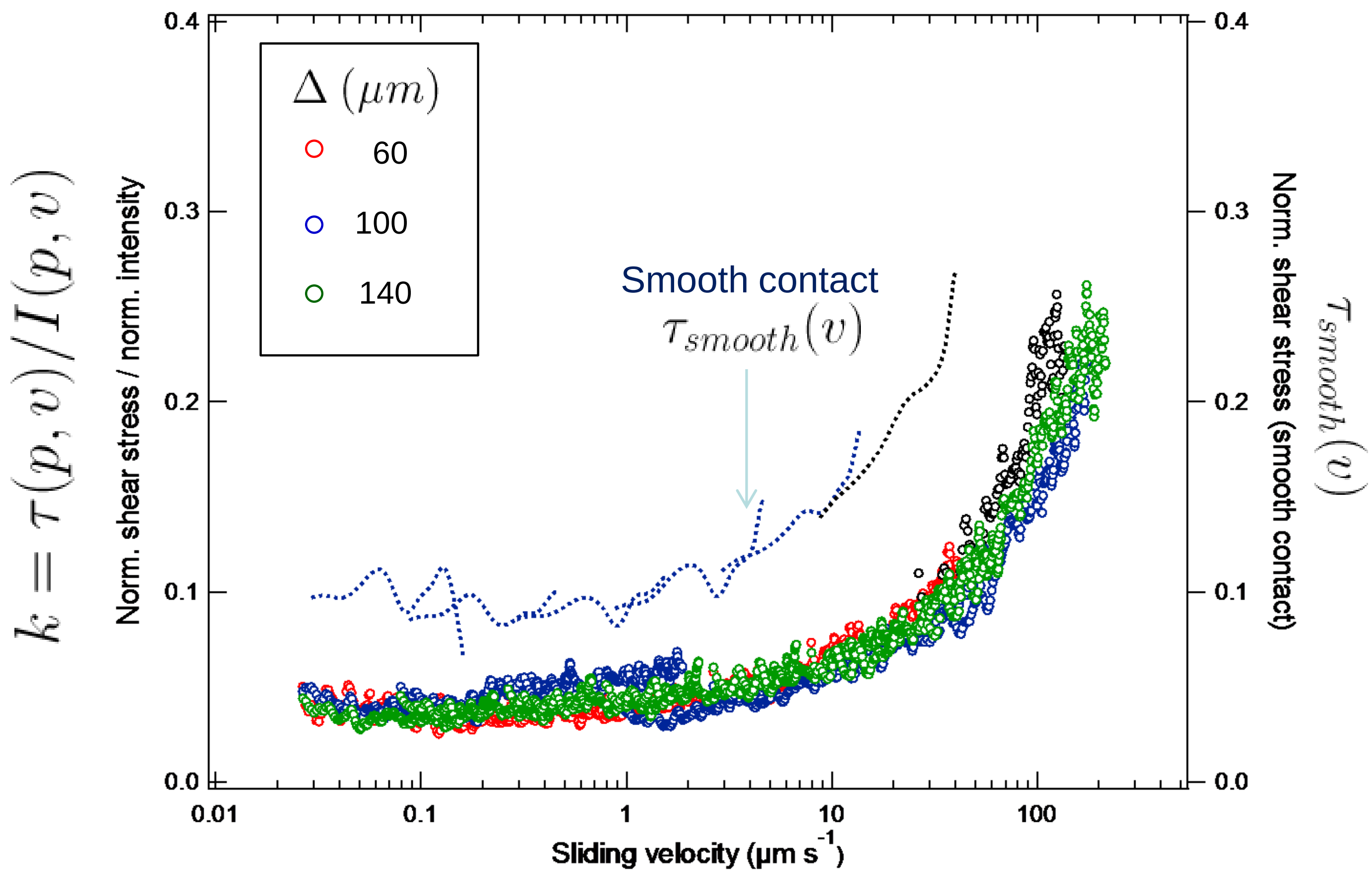
Transmitted light intensity



Dependence of the shear stress on the actual contact area :

$$\tau(p,v)/I(p,v) \quad ???$$

Pressure and velocity dependence of the frictional shear stress



$$\tau(p,v) \propto k(v)\ A/A_0(p,v)$$

Average shear stress within micro-asperity contacts

Real contact area: density of micro-contacts

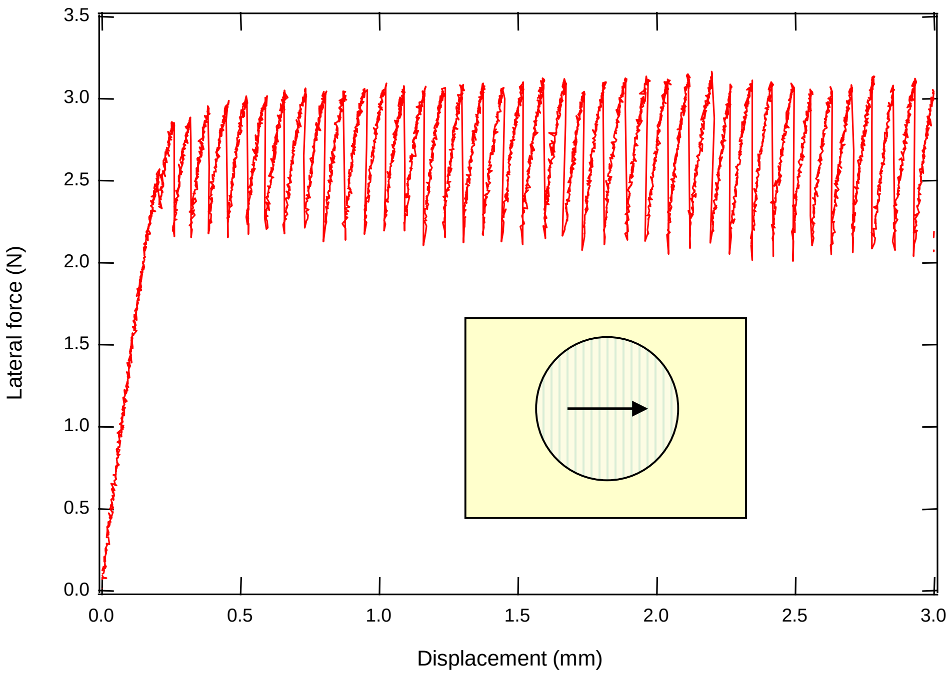
$k(v) \approx \tau_{smooth}(v)$ → Interface dissipation predominates over bulk viscoelastic dissipation

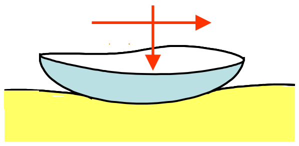
M. Trejo *Phys Rev E* (2013)

Unsteady state friction:

Stick-slip motions within patterned glass/PDMS contacts

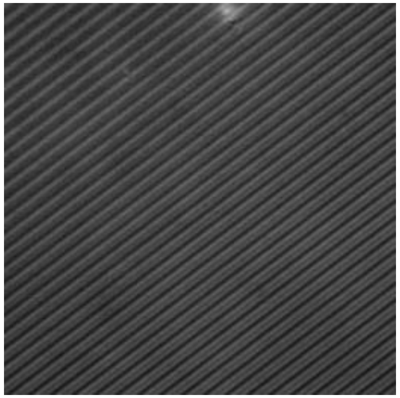
Stiction of patterned glass surfaces : stick-slip motions

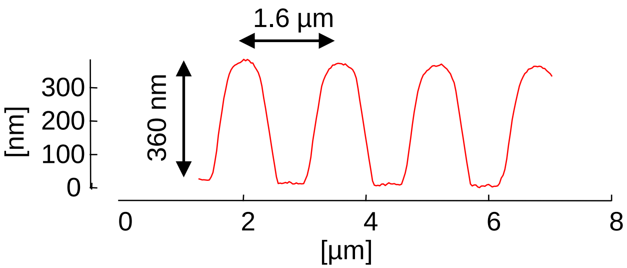




Patterned glass lenses

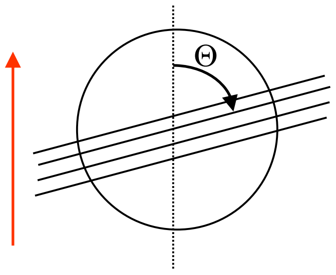
Sol-gel process, Saint Gobain



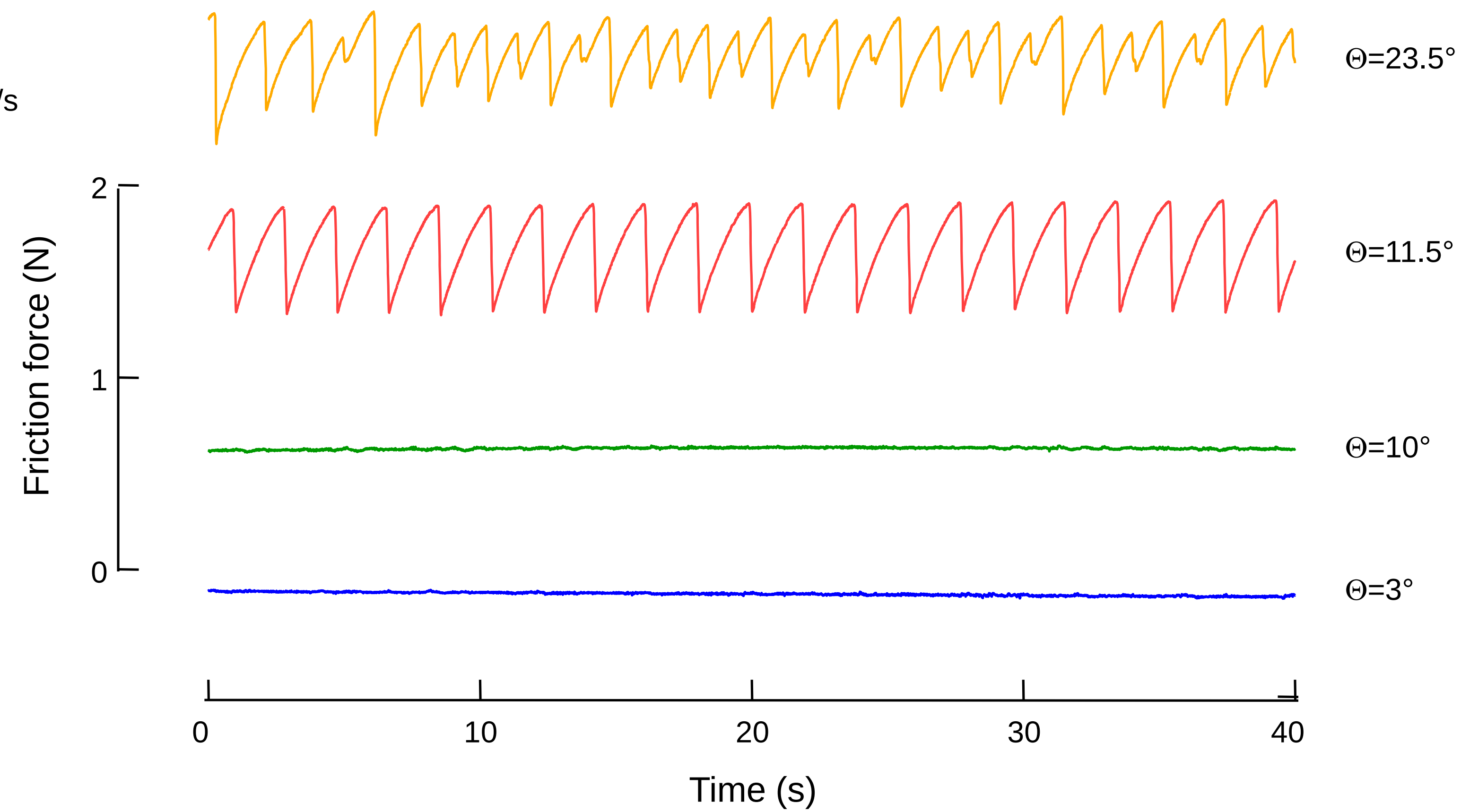


M.-C. Audry *EPJE* (2012)

Friction traces vs ridges orientation

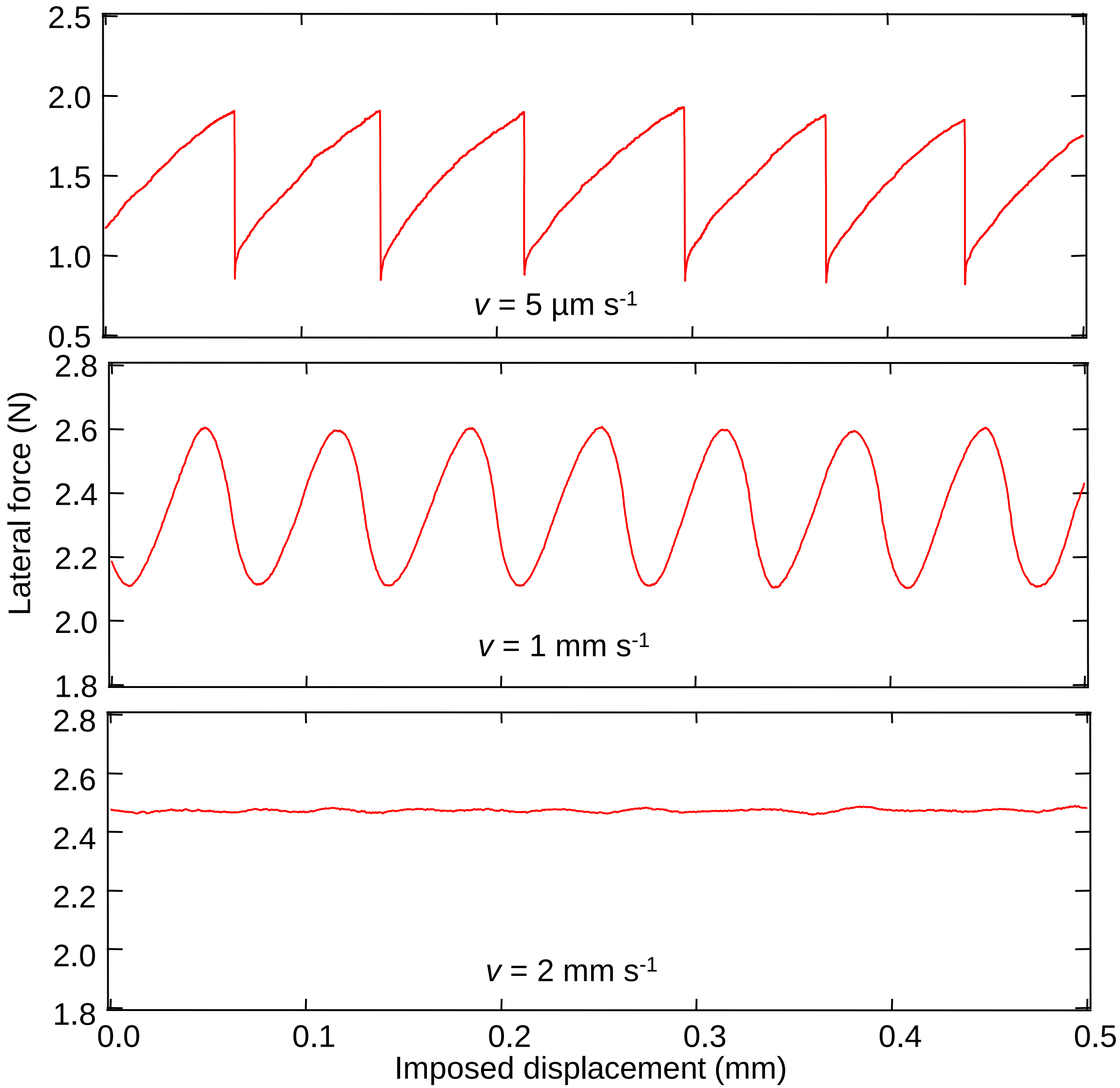


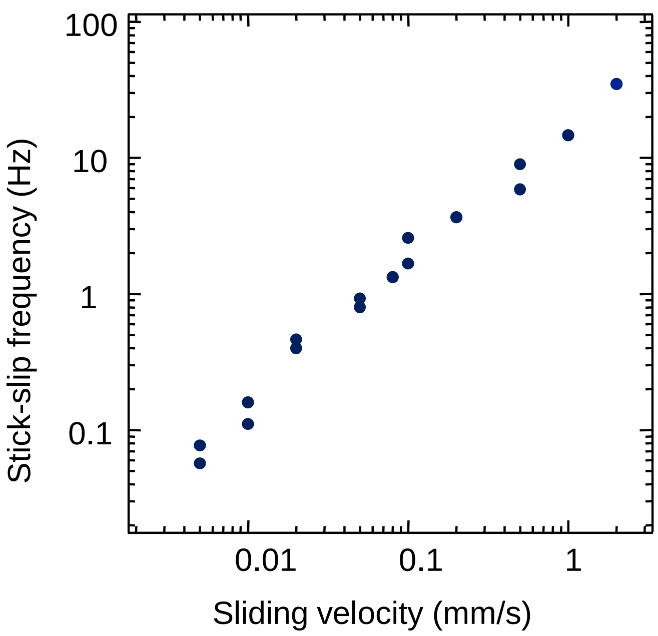
Critical angle for the occurrence of stick slip $\Theta_c \sim 11°$



Stick-slip generated by localized stress fluctuations

Friction traces : velocity dependence

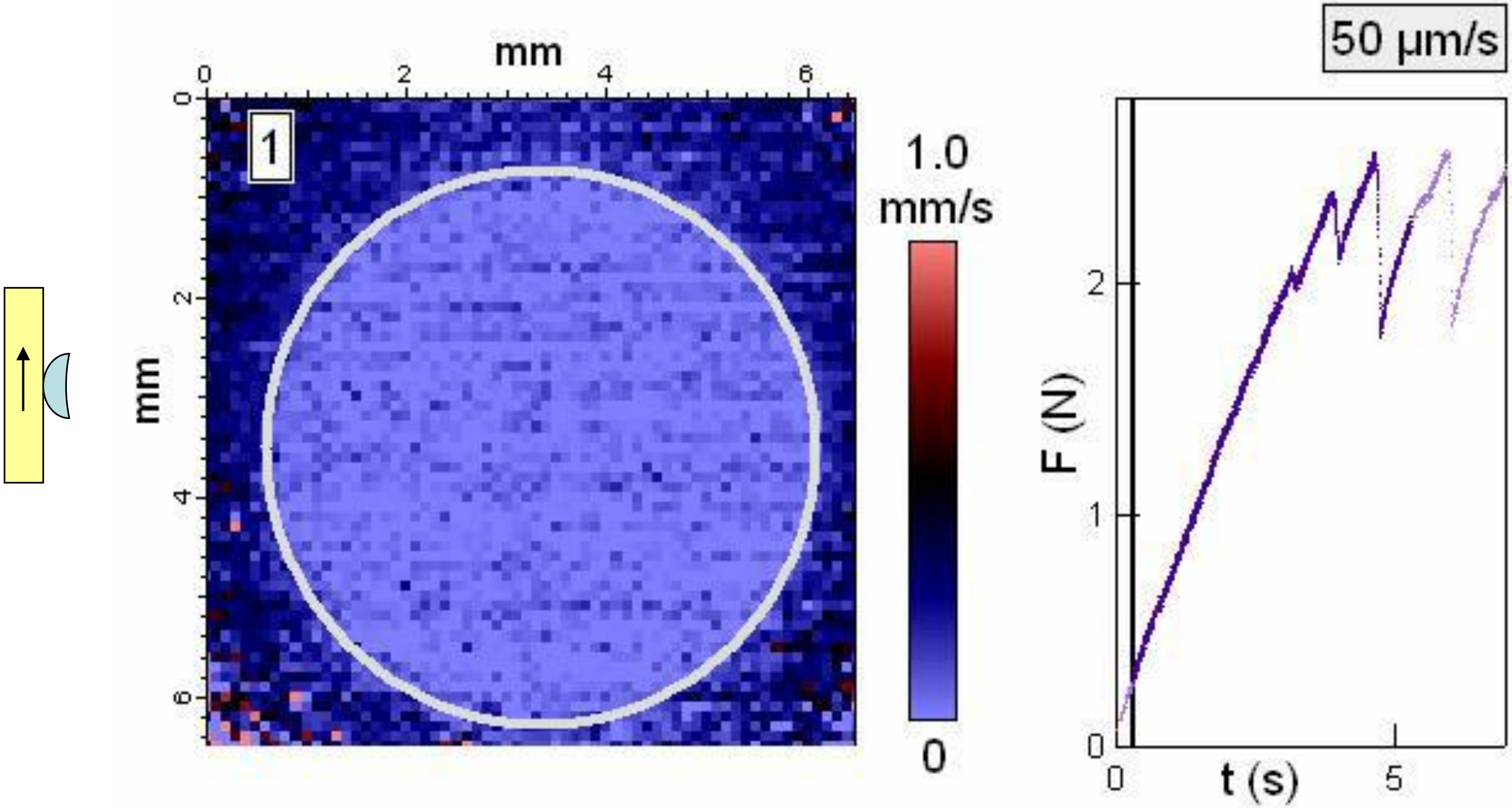




Characteristic length: $\lambda = v/F \sim 70\ \mu m$

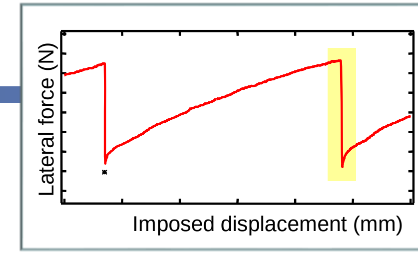
Stiction with patterned lenses

- Surface velocity field



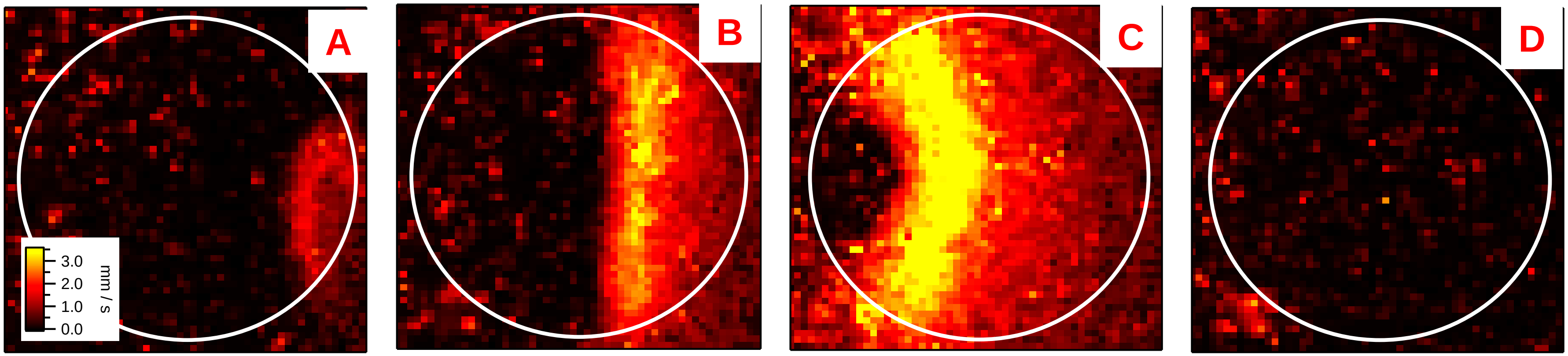
Crack-like precursors to friction

Established stick-slip regime : low velocity regime

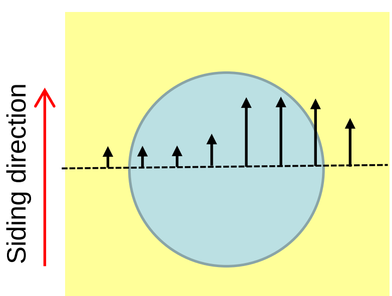


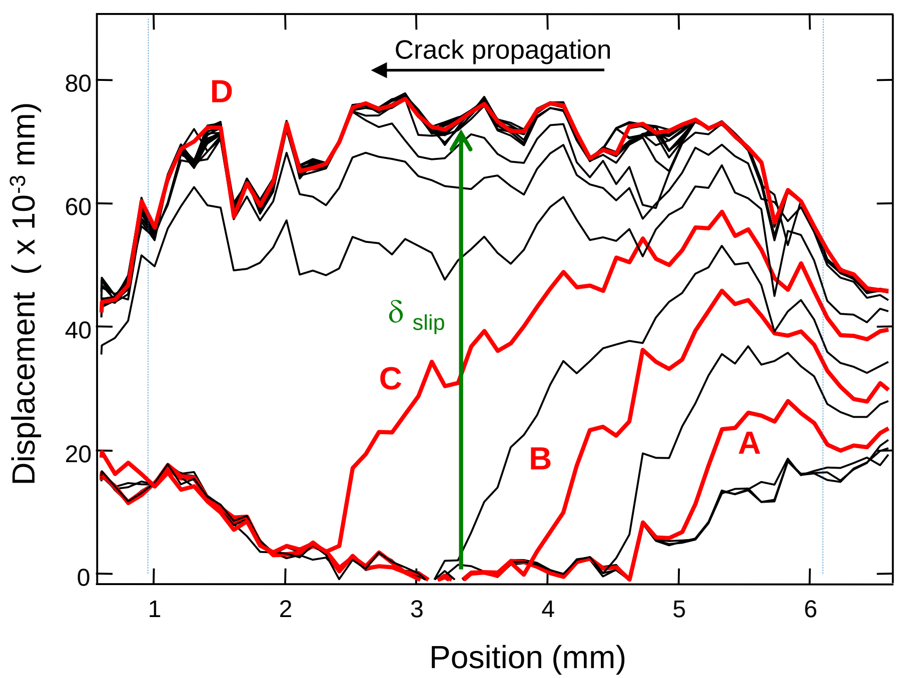
- 'Slip phase' - v=5 µm s^{-1}

Slip velocity field



Displacement profile



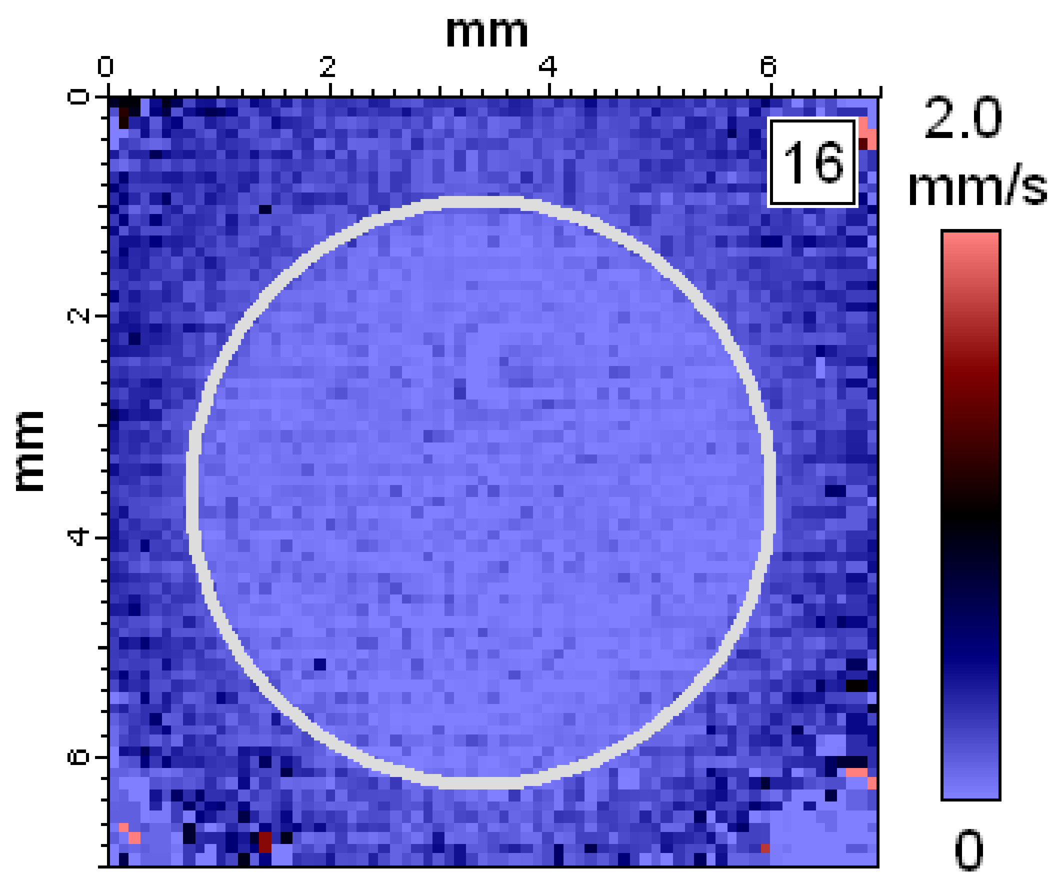


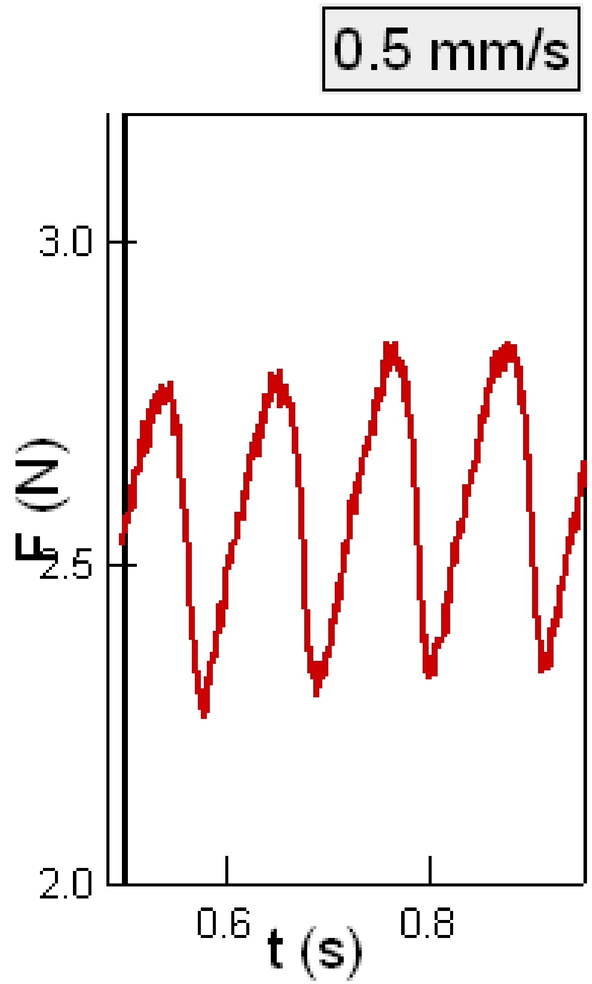
Crack velocity ~ 100 mm s^{-1}

δ_{slip} ~ 70 µm

Established stick-slip regime : high velocity regime

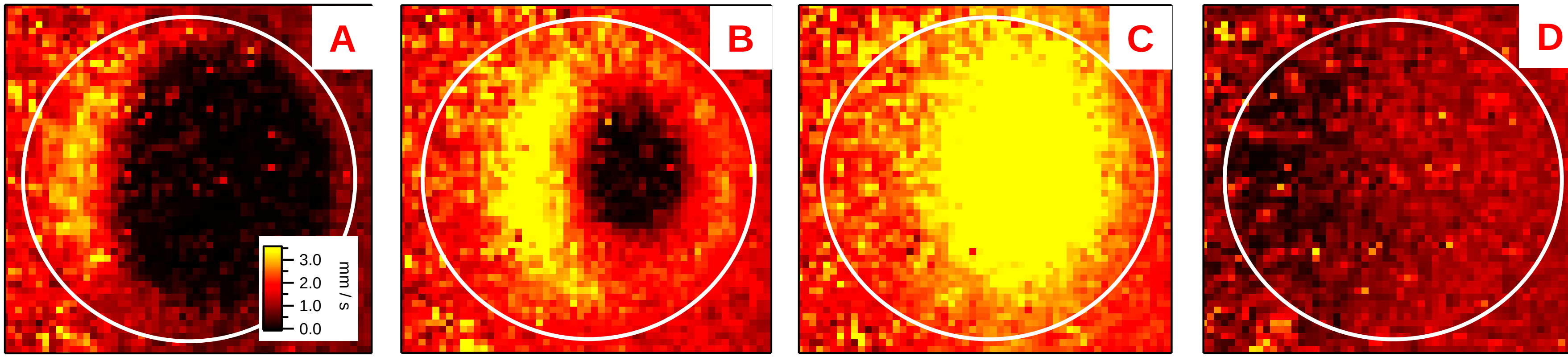
- Surface velocity field - v =0.5 mm s^{-1}



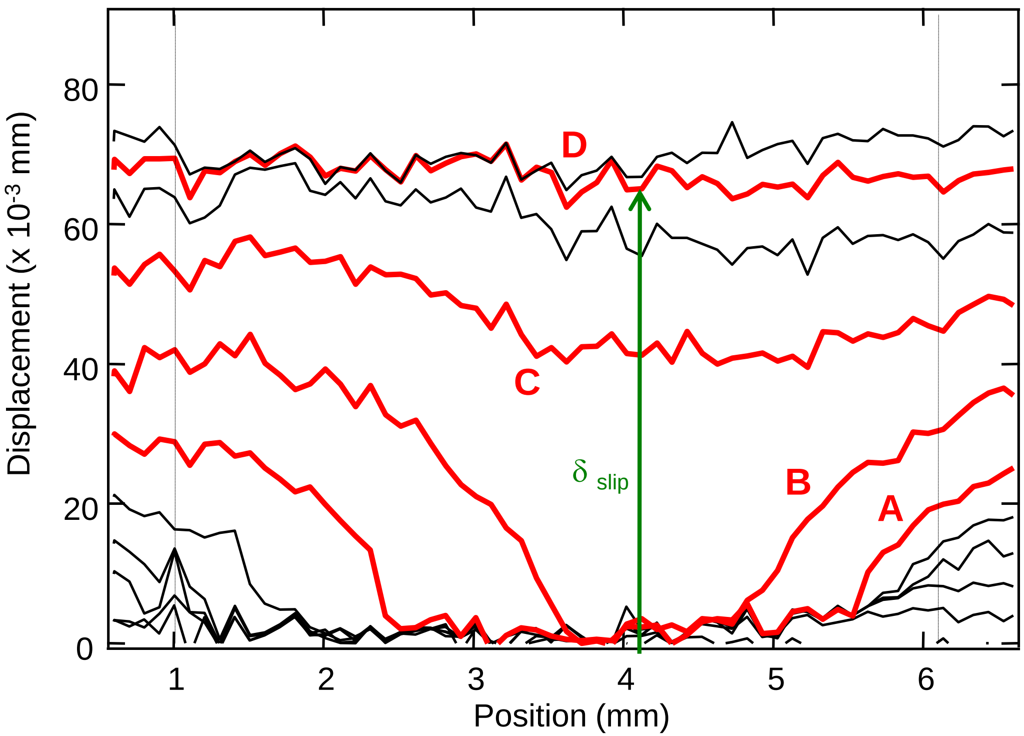


Stick slip regimes : high velocity

Slip velocity field



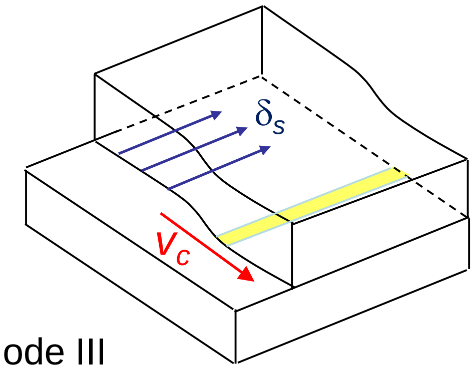
Displacement profile



Crack velocity ~ 100 mm s^{-1}

δ_{slip} ~ 70 µm

Stick-slip as a crack-like motion



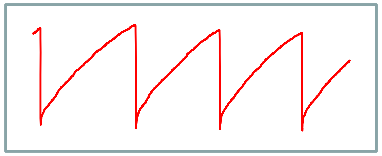
V_c & δ_s independent on the driving velocity

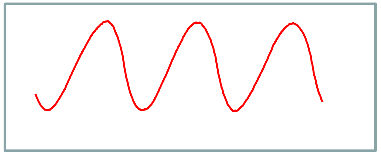
$v < v_c < V_{Rayleigh}$

- Typical propagation time: $t_p = 2a/v_c$

Low velocity : $t_p << T_{ss}$

High velocity: $t_p \approx T_{ss}$





- $\delta_s \approx$ cst $\longrightarrow$ Stick slip frequency linearly related to the driving velocity $v = \delta_s / T_{ss}$

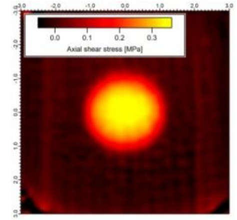
Parameters setting the slip length ?? How do the surfaces re-stick ??

- $V_c \approx$ cst $\longrightarrow$ Fracture energy G_c?

Threshold stress for crack nucleation >> Threshold stress for quasi-static crack propagation

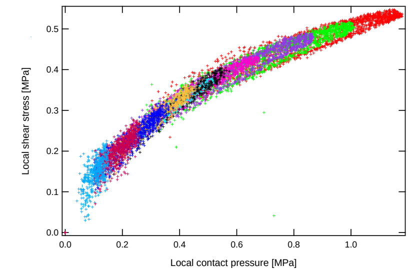
Reduced velocity dependence of G_c due to the interplay with friction ?

Conclusion /Outlook



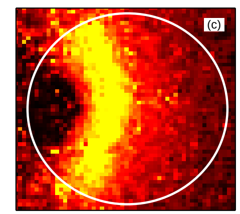
✓ Local friction law from displacement field measurements

✓ Multi-contact interface with rigid randomly rough surface



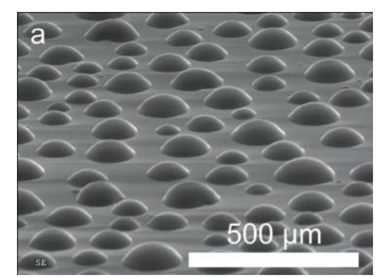
Non linear local friction law
Relevance of spectral description of surface topography ?
Contribution of viscoelasticity to friction

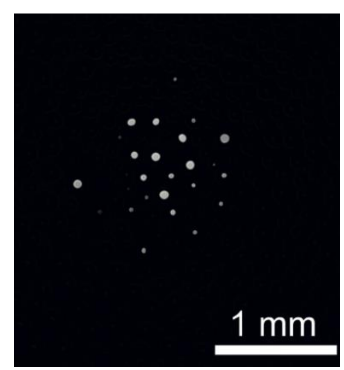
✓ Crack-like precursors to friction during stick slip regime



Ongoing work: friction of model randomly rough surfaces

with A. Prevost and E. Wandersman, Paris Univ
M. Chaudhury, Leighigh University





Elastic coupling between micro-asperity contacts ????