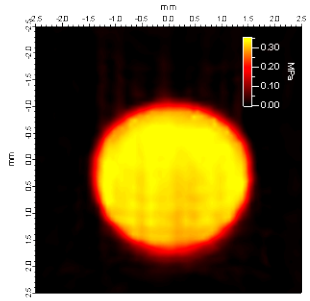
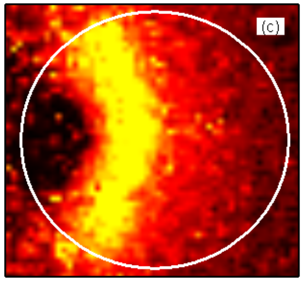
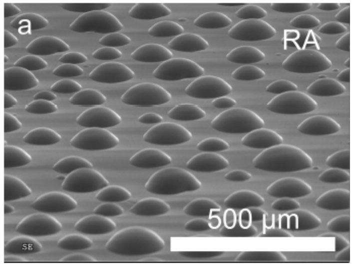
Local friction of soft materials on rough surfaces





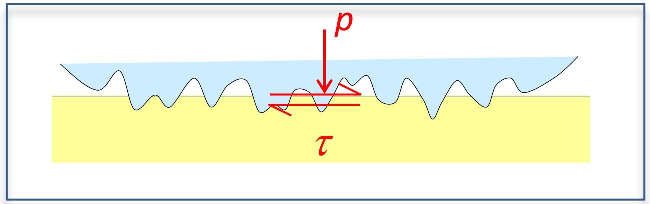


D.T. Nguyen, M. Trejo, C. Fretigny and A. Chateauminois
Soft Matter Science and Engineering Laboratory - SIMM
Ecole Supérieure de Physique et Chimie Industrielles (ESPCI), Paris, France

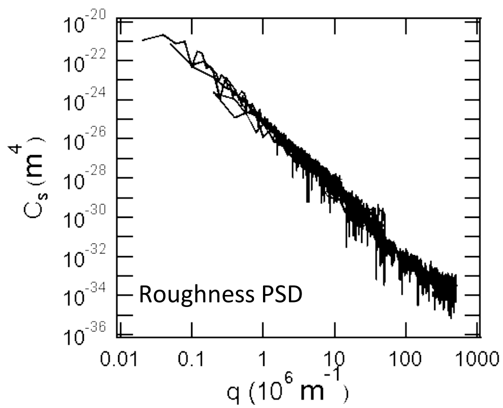
E. Barthel & J .Teisseire
Surface du Verre et Interfaces , CNRS – Saint Gobain, Aubervilliers

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

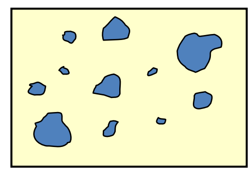
Dry friction of multi-contact interfaces



- **Surface geometry, contact mechanics**



Micro-contacts distribution

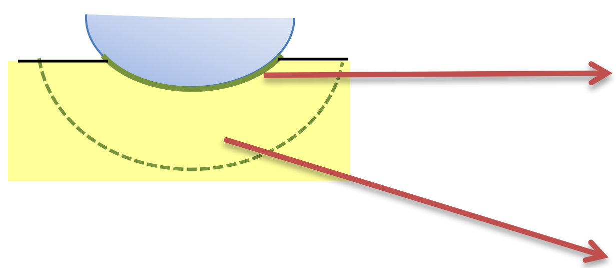


Real contact area ??

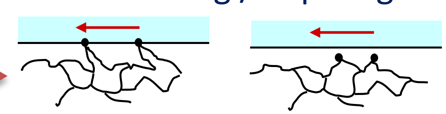
Persson, Müser, Robbins,…

Viscoelasticity
Non linear material response
Adhesion
….

- **Frictional energy dissipation mechanisms**



Pinning / depining



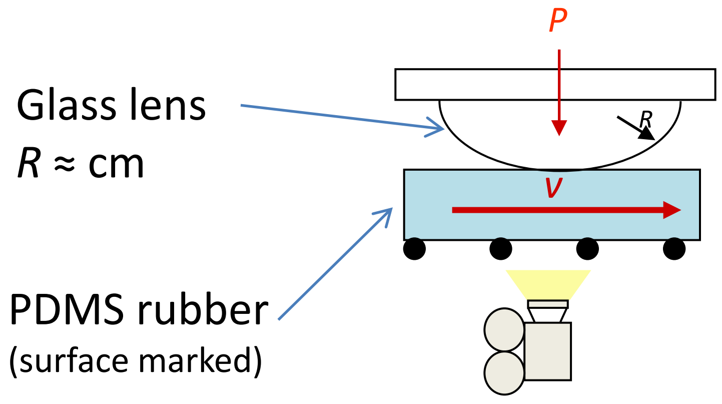
Schallamach, Chaudhury,..

Bulk viscoelastic dissipation

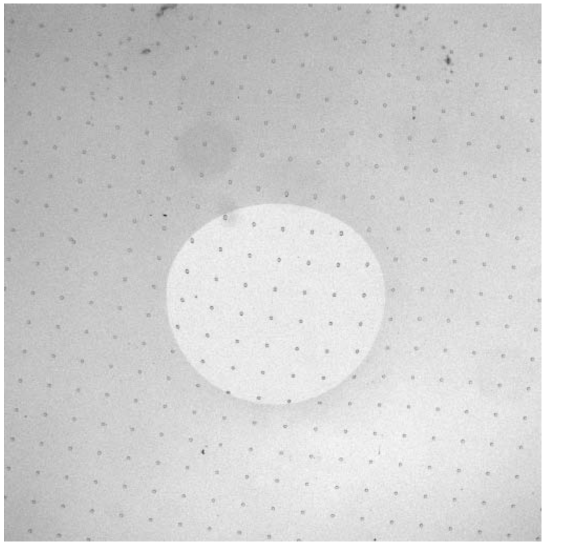
Grosch, Persson…

Local friction law τ(p) ??

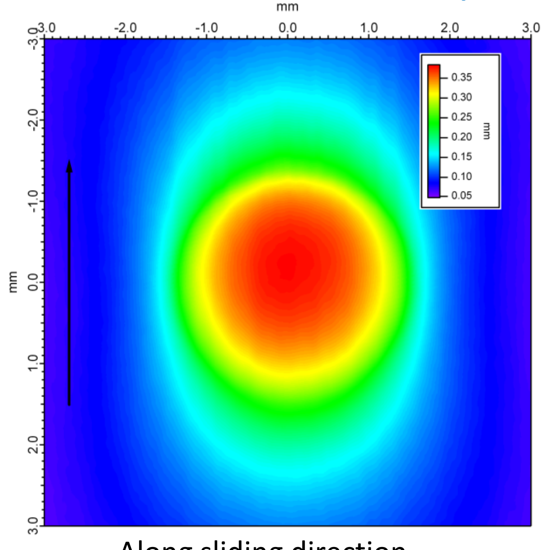
Displacement field measurements within contacts with rubbers



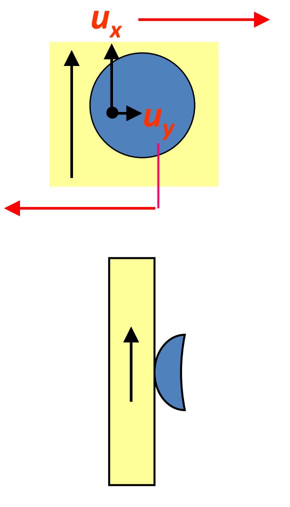
Imposed - normal load, *P*
- velocity, *v*

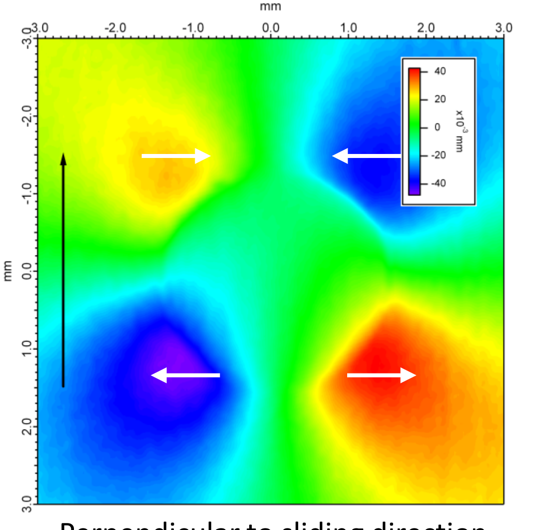


Surface displacements during steady state friction



Along sliding direction





Perpendicular to sliding direction

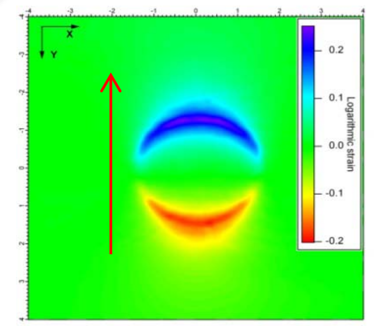
Spatial resolution ~ 10 x 10 µm²

A. Chateauminois *et al Eur. Phys. J. E* (2008)
D.T. Nguyen *et al J. Adhesion (2011)*

Contact stresses : inversion of the displacement field

Inversion???

Surface displacement → Surface stresses



contact strain

- Linear elasticity → Green's tensor

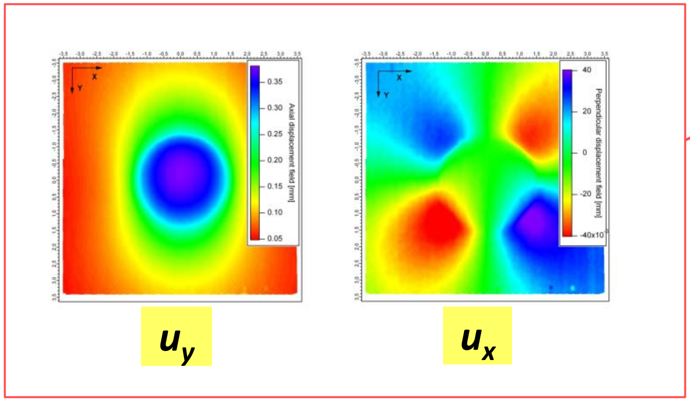
Incompressible materials, ν=0.5

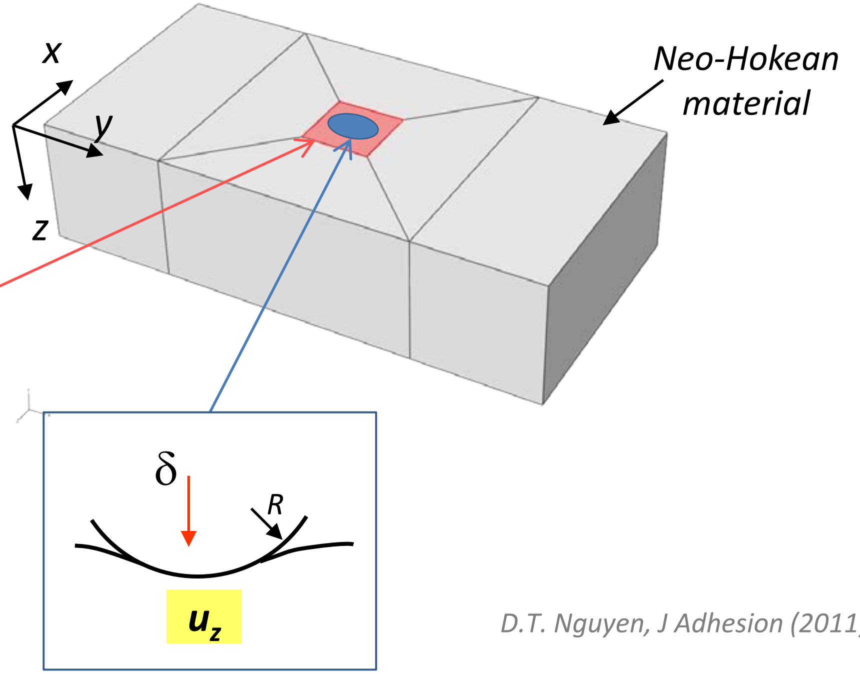
Lateral displacements $u_i = G_{ij} * \sigma_{jz}$

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

$i, j = x, y$

- Experimentally : large strains ! → Numerical inversion using FEM





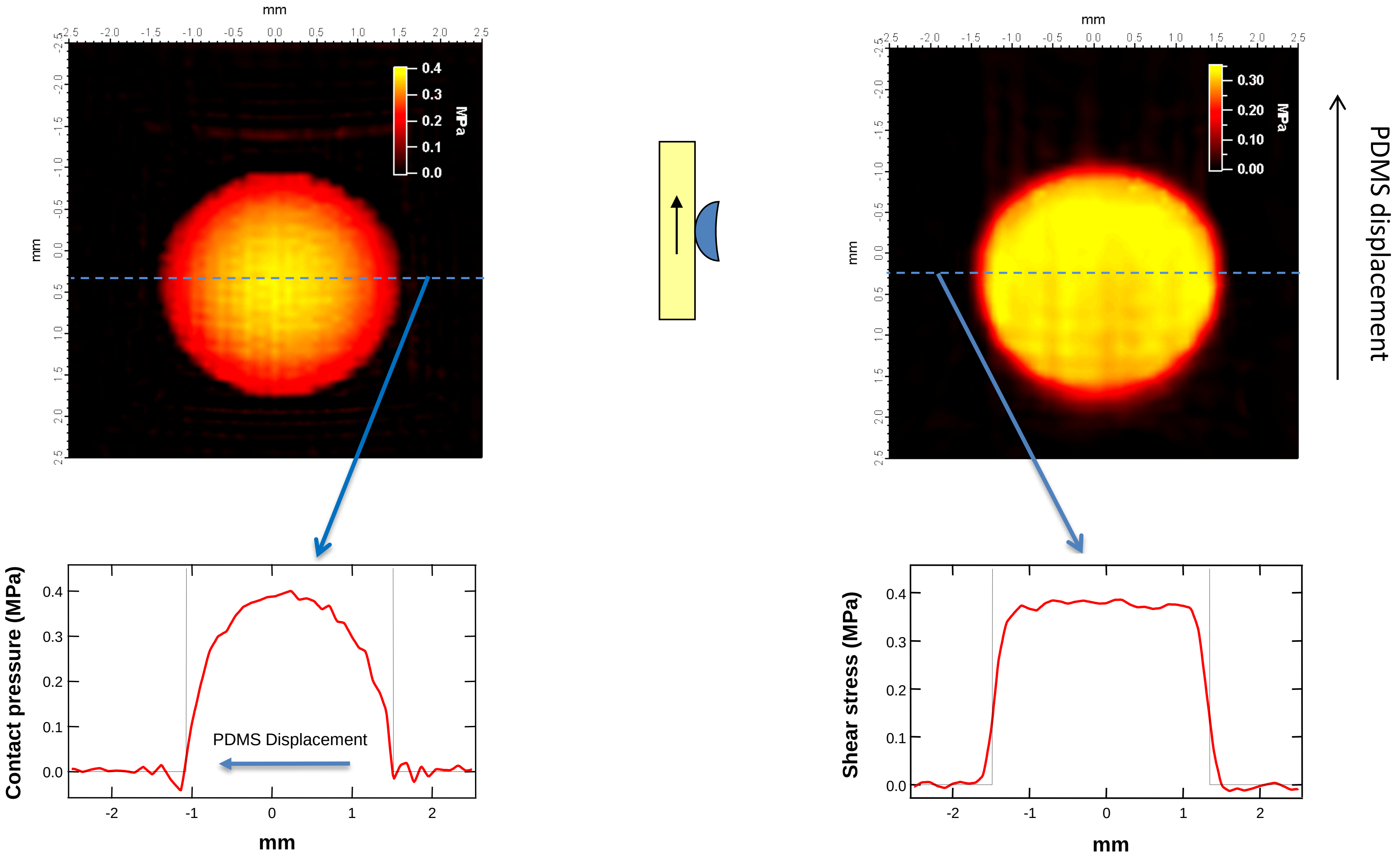
D.T. Nguyen, J Adhesion (2011)

Contact stresses: single asperity contact

Smooth Glass/PDMS contact

Contact pressure

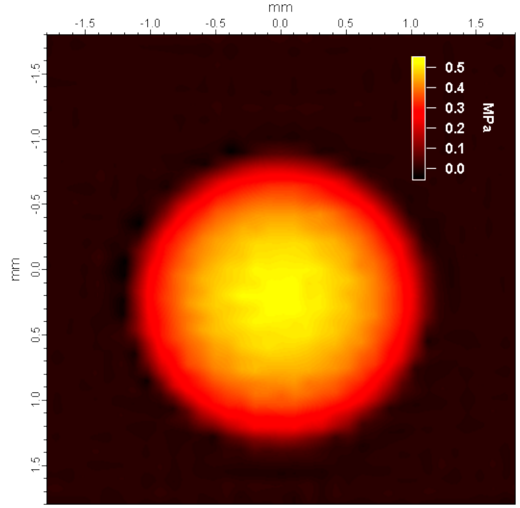
Surface shear stress



Pressure independent shear stress

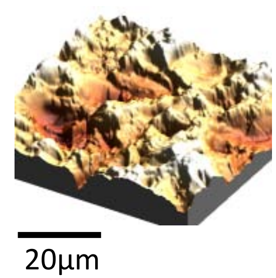
Contact stresses: randomly rough contact interfaces

Contact pressure



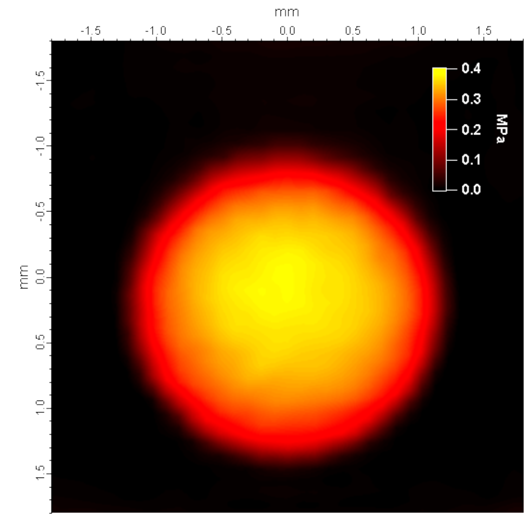
Gaussian roughness

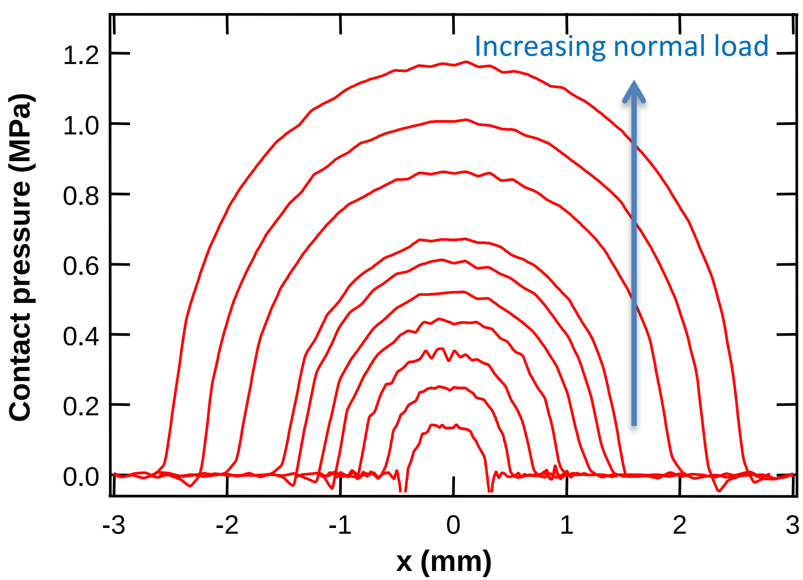
r.m.s roughness ~ 1 µm

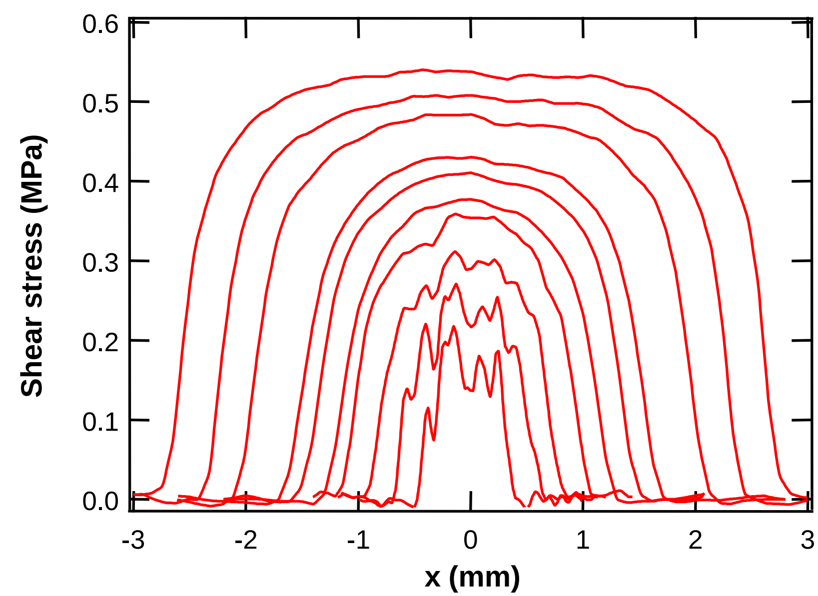


Sand blasted glass lens

Shear stress



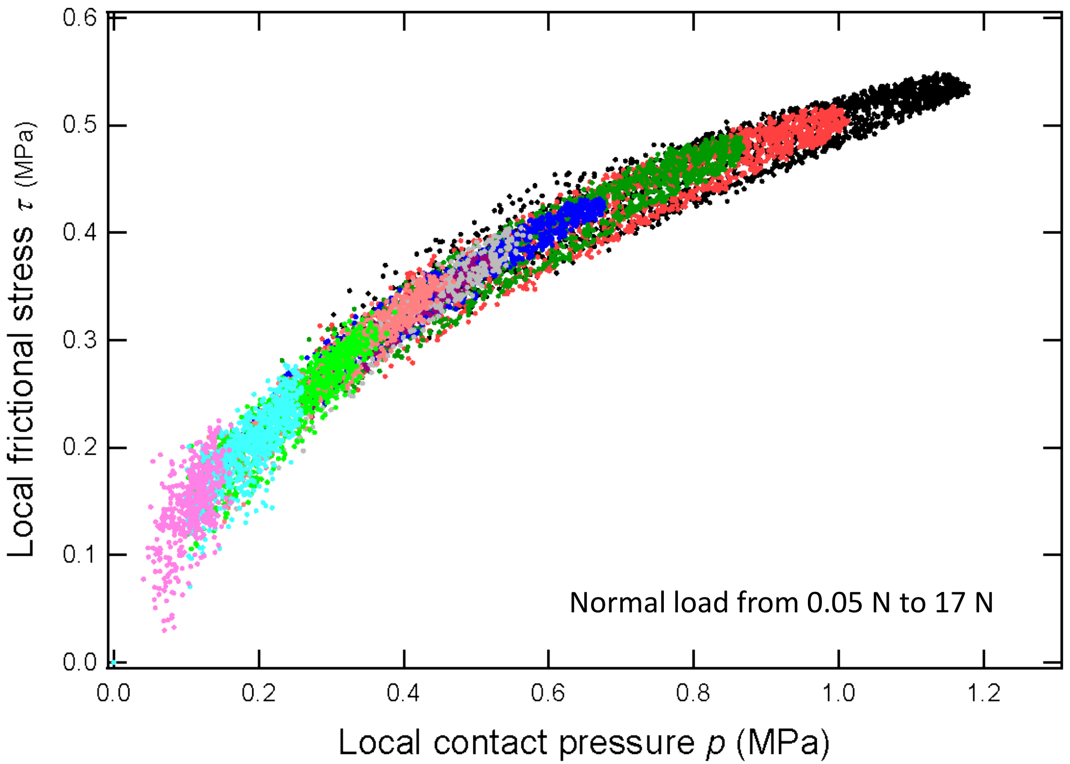




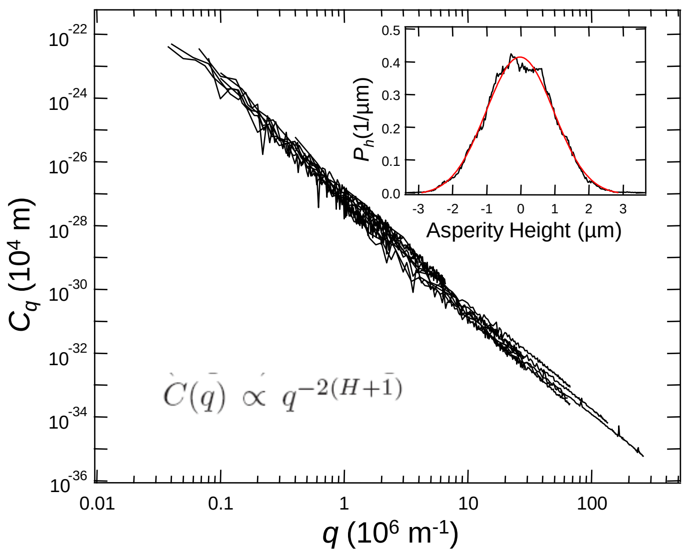
Pressure dependent shear stress

Local friction law

- PDMS / self affine rough glass surface



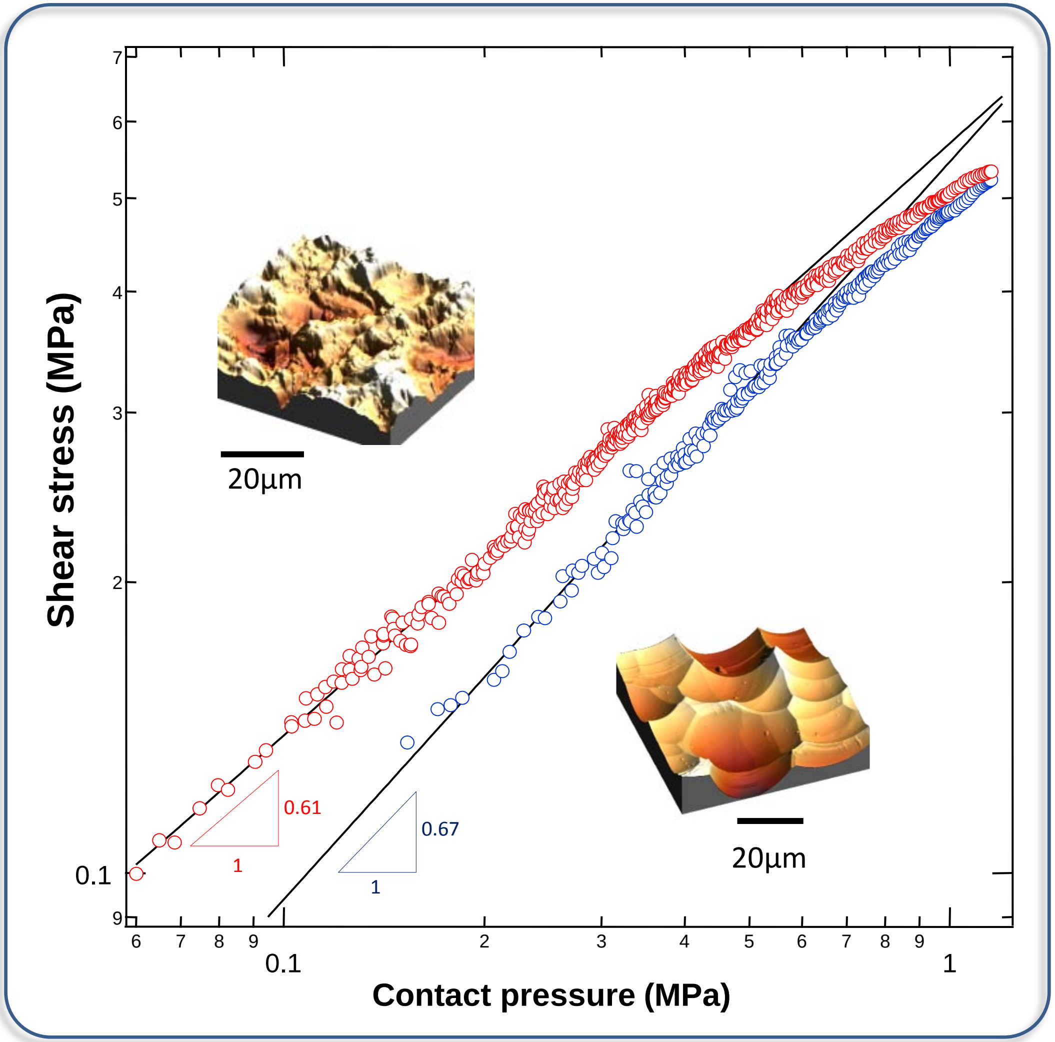
Roughness PSD



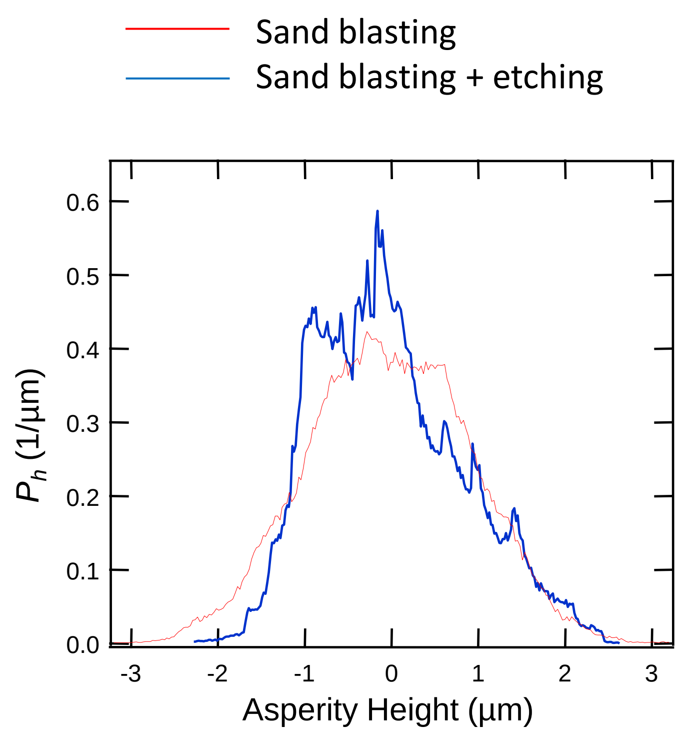
Non linear local friction law

D.T Nguyen *et al* EPL (2013)

Gaussian *vs* non Gaussian surface roughness

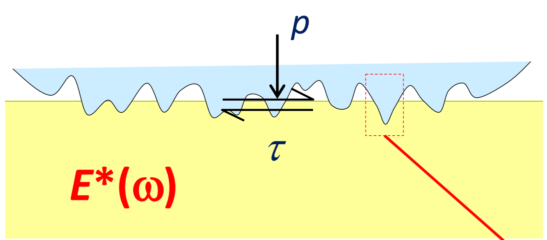


Local friction law

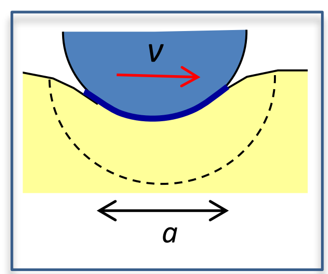


Height distribution

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



Multicontact interface



Characteristic frequency $\omega \sim v / a$

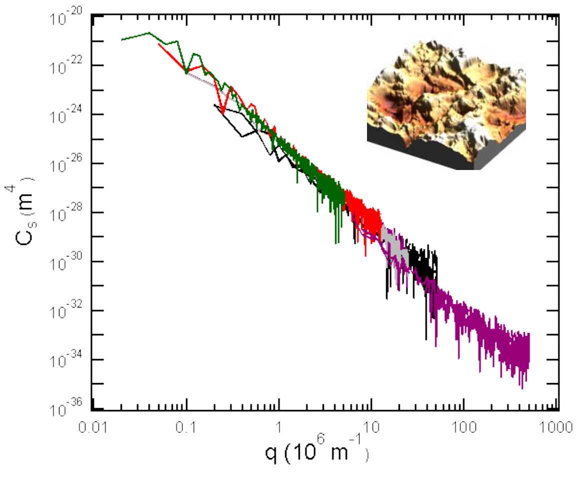
Single asperity contact

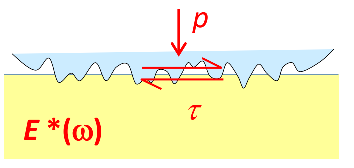
- Velocity and pressure dependence of the real contact area ?
- Viscoelastic losses at micro-asperity scale ?

→ Surface topography, patterning
Viscoelastic properties of the rubber

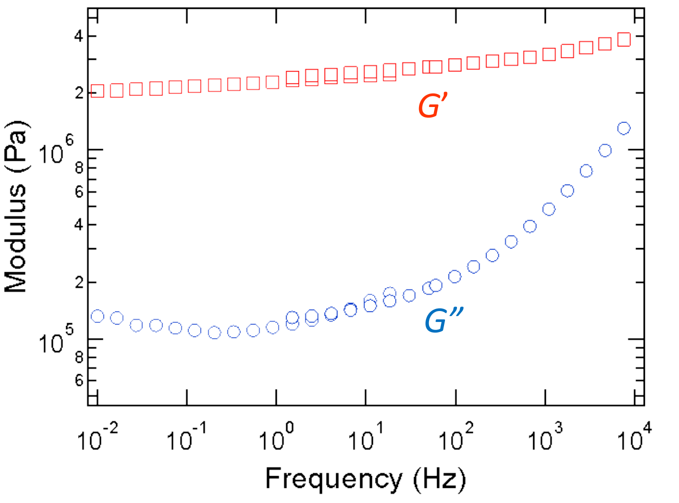
Local friction of viscoelastic rubbers with randomly rough surfaces

Sand blasted glass surface

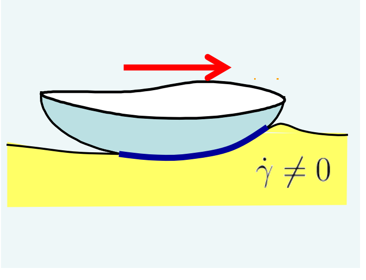




Epoxy rubber Tg = - 42°C

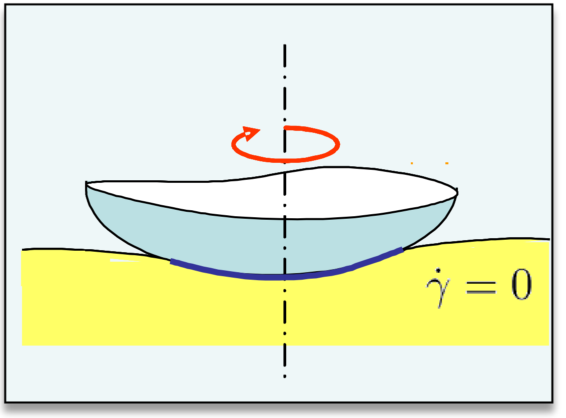


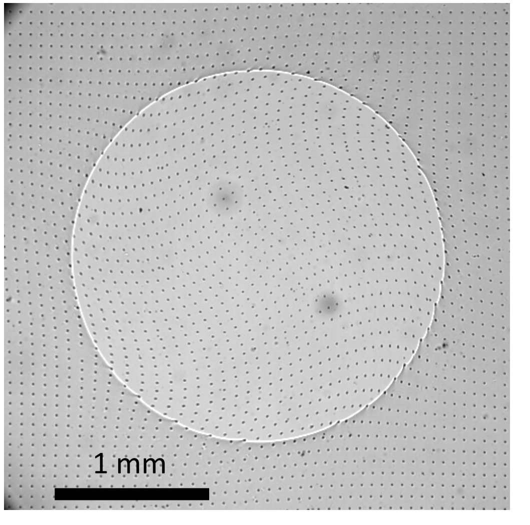
Torsional contacts



Linear sliding

Bulk viscoelastic dissipation at contact scale !

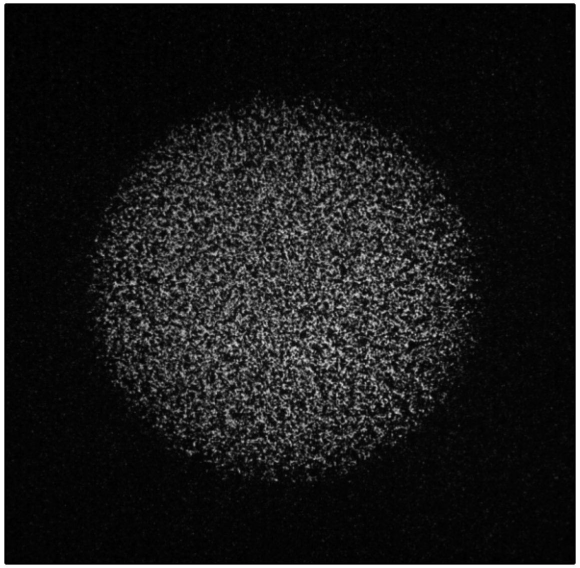


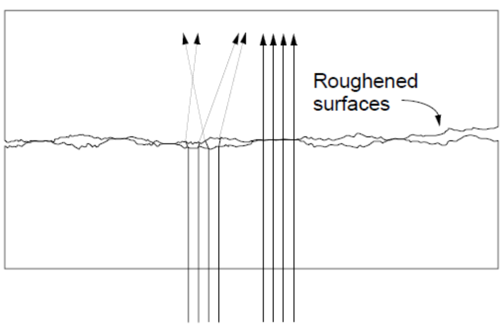


A. Chateauminois et al *Phys Rev E* ***81*** (2010)

Light transmission through rough contacts

1 pixel = 5.1 µm

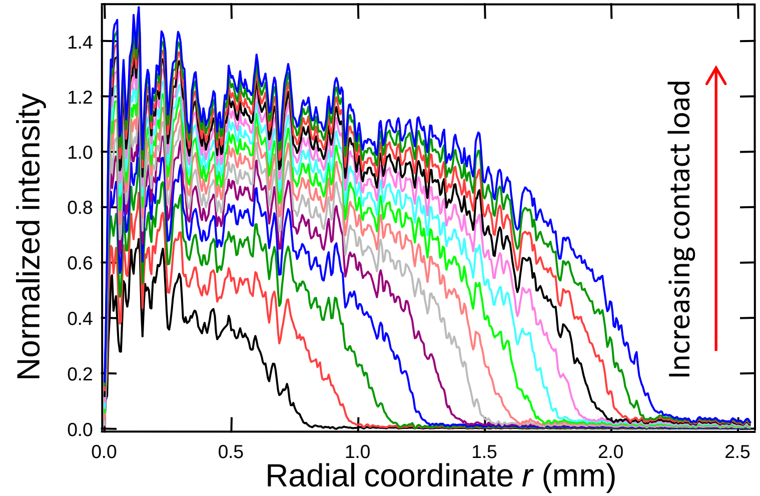


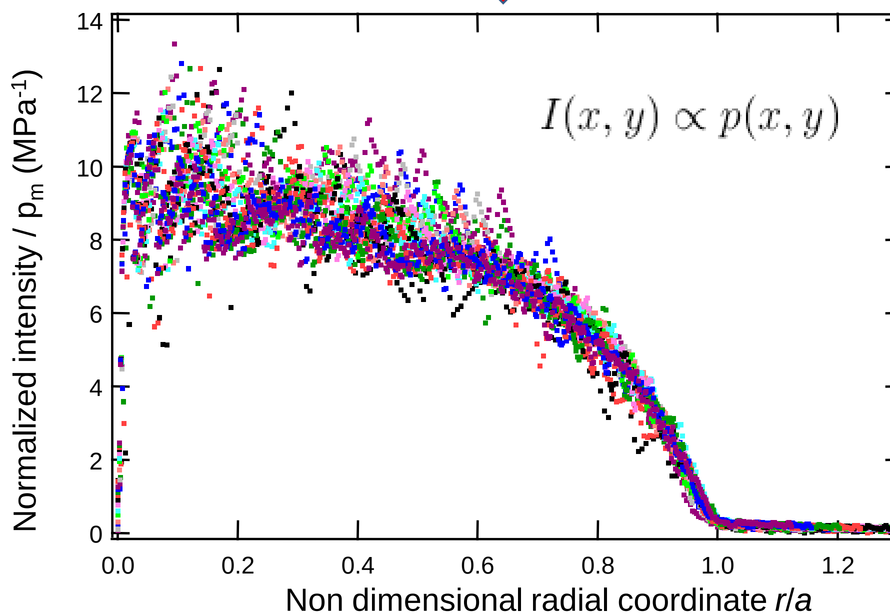


Dieterich *et al.* Pageoph, **143** (1994)

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

Static indentation experiments

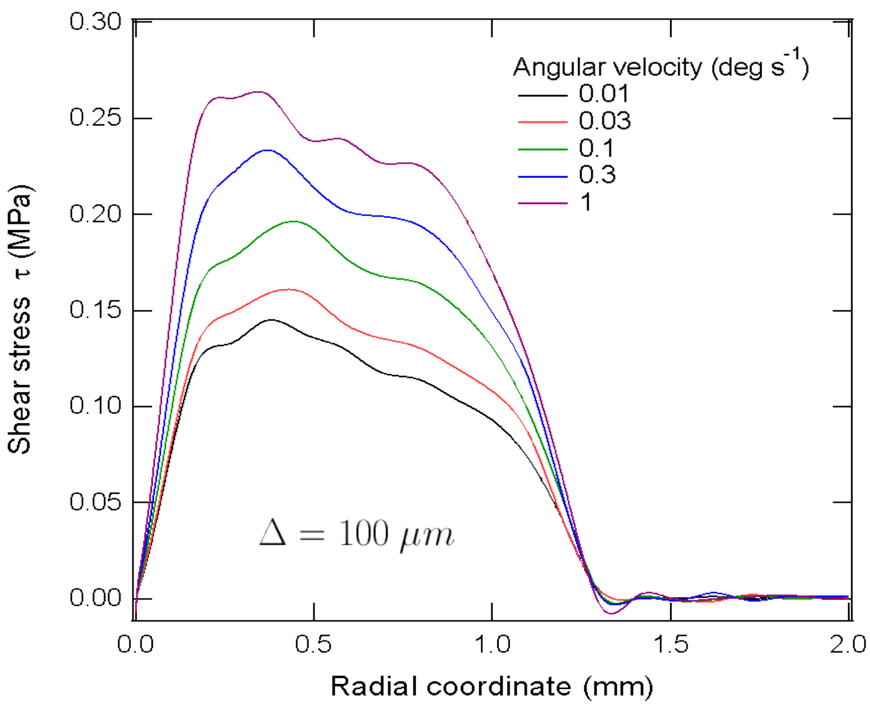




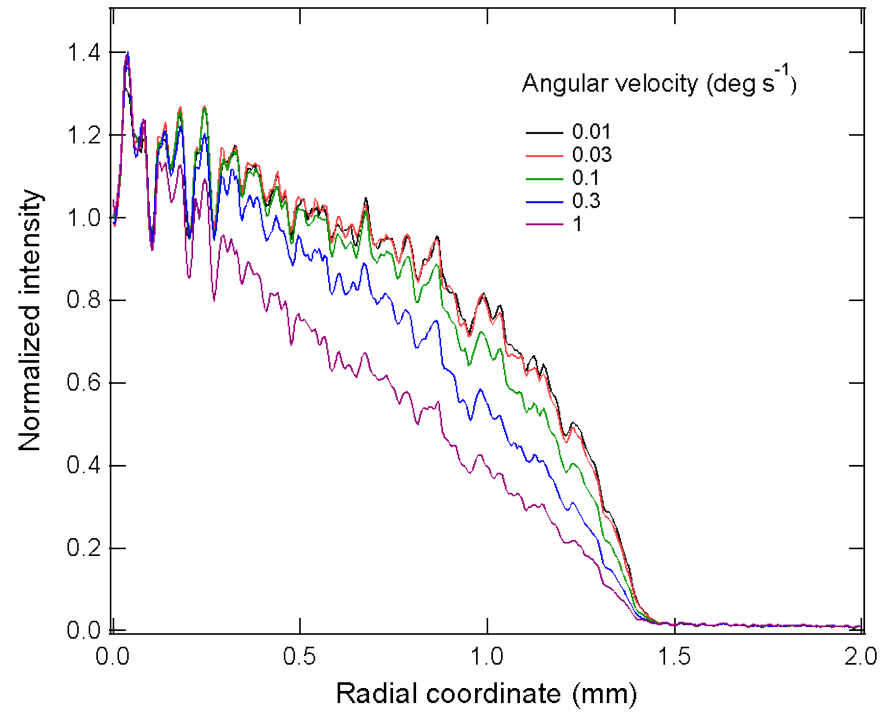
Transmitted light intensity *I(x,y)* $\propto$ Proportion of area in contact *A/Ao(x,y)*

Velocity dependence of the shear stress

Angular velocity



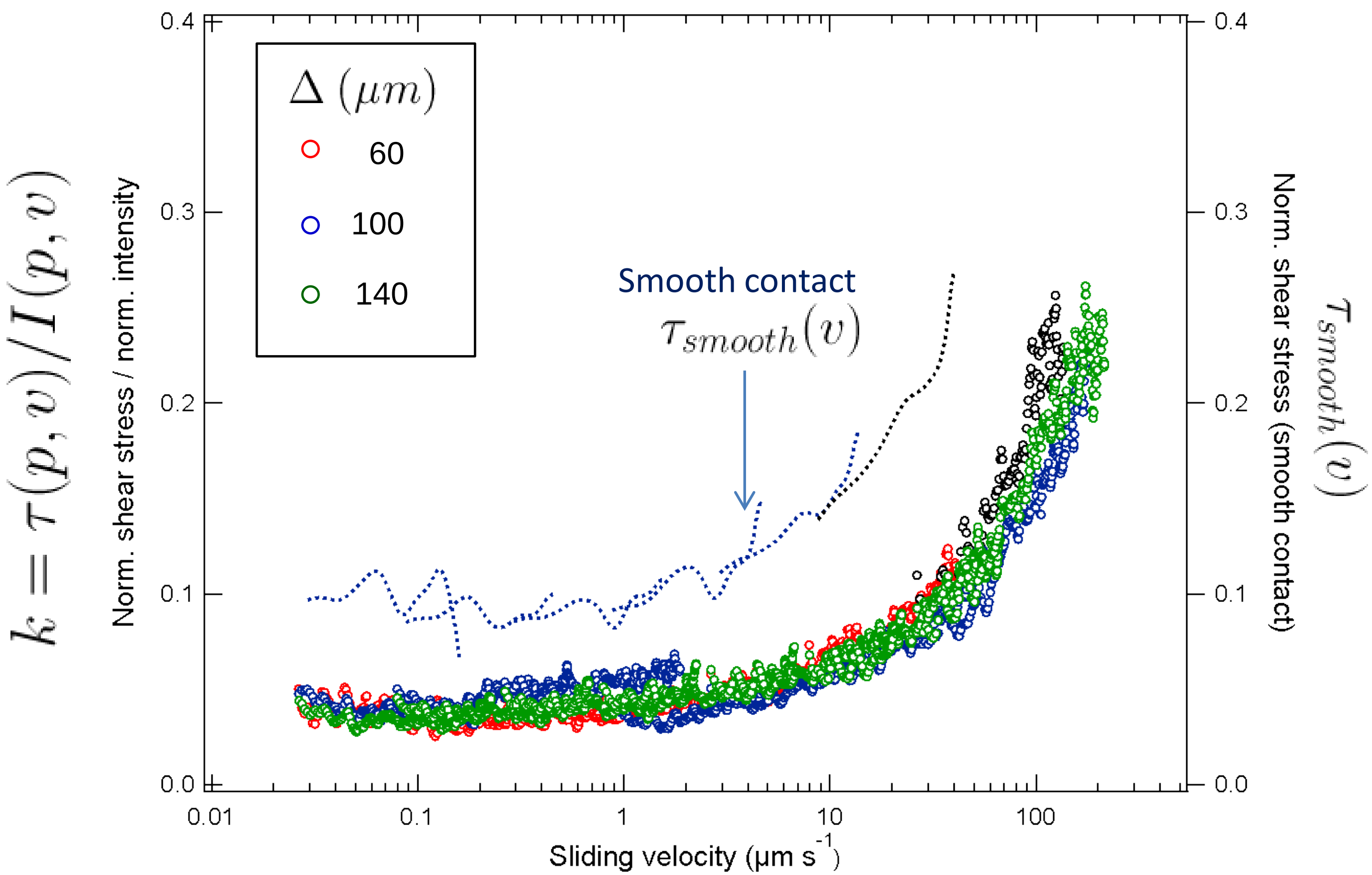
Transmitted light intensity



Dependence of the shear stress on the actual contact area :

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

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

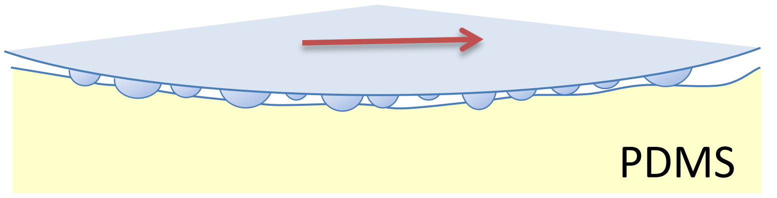
$k(v) \approx \tau_{smooth}(v)$ → Interface dissipation predominates over bulk viscoelastic dissipation

M. Trejo *Phys Rev E* (2013)

Friction of model randomly rough surfaces

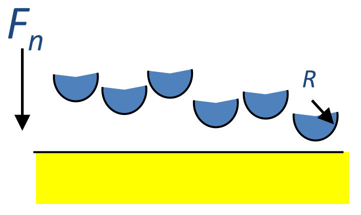
With Manoj Chaudhury and Shintaro Yashima

- Lens covered by a random distribution of rigid spherical micro-asperities

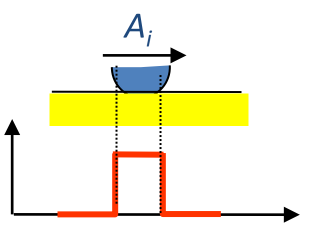


Distributed asperity heights and radius of curvature

- Experimental analog to the surfaces of the Greenwood and Williamson model



$\sum A_i \;\alpha\; F_n$



$\tau_i = \tau_0$

$F_t = \sum A_i \, \tau_i$

$F_t \;\alpha\; F_n$

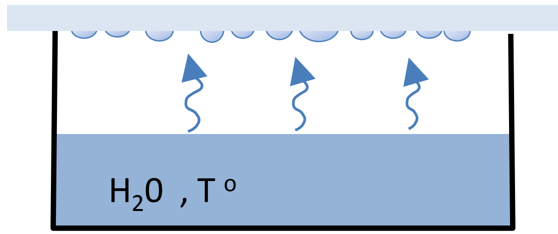
Coulomb's law retrieved
as a consequence of surface
roughness
$F_t = \mu \, F_n$

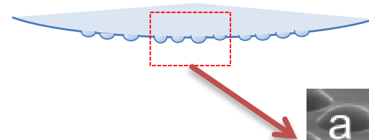
Greenwood & Williamson, 1965

Can we sum asperity contributions to friction ??
With a single value of the interface frictional stress ??

Fabrication of rigid asperities surfaces

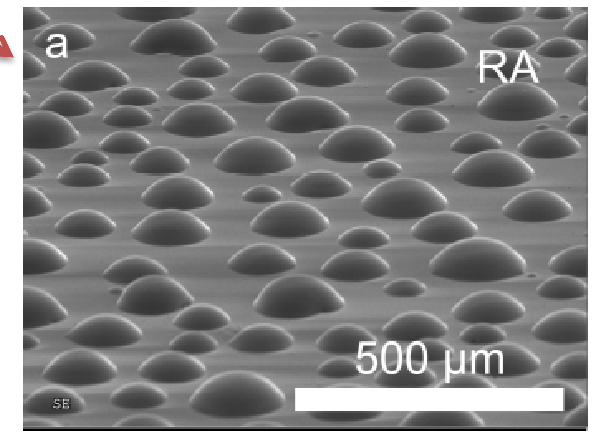
- 1. Water droplet condensation



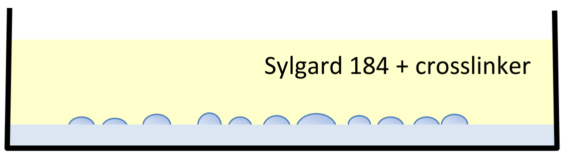


Surface density

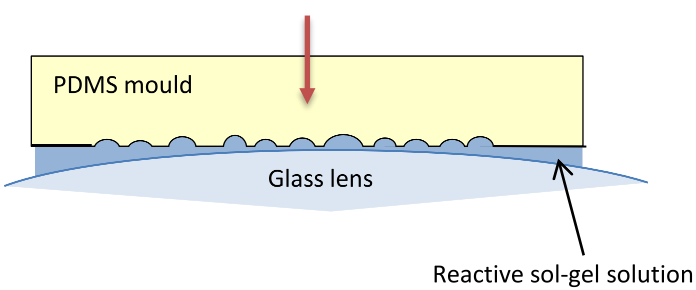
ϕ=0.41

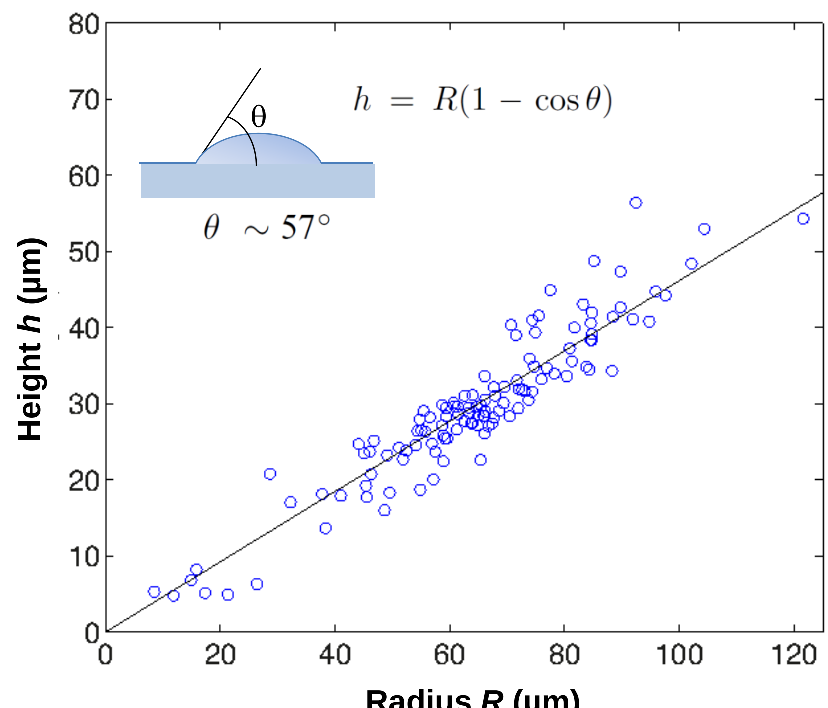


- 2. PDMS Replica

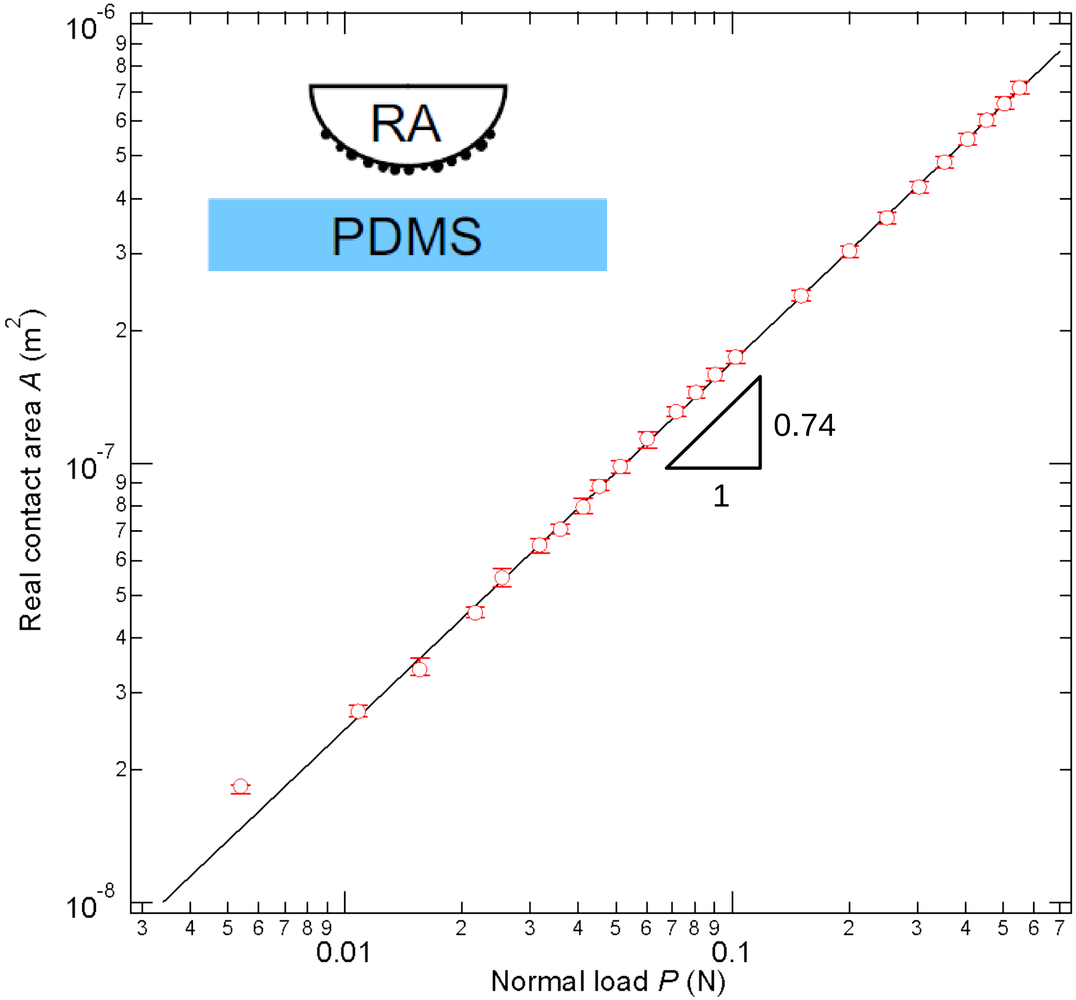


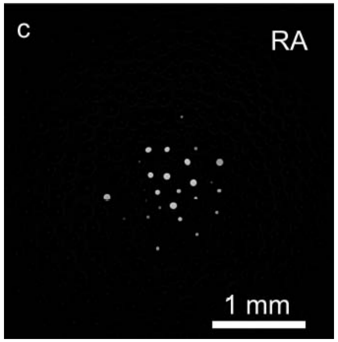
- 3. Sol gel replica on a glass lens



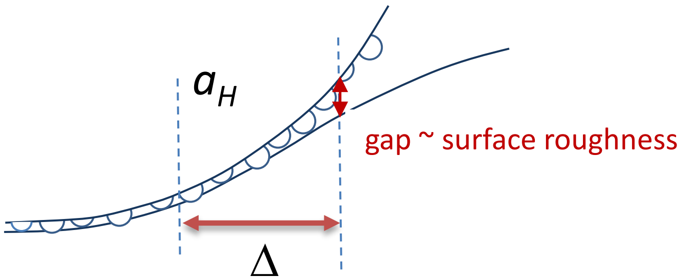


Normal loading: real contact area





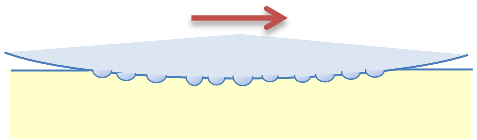
P=22 mN



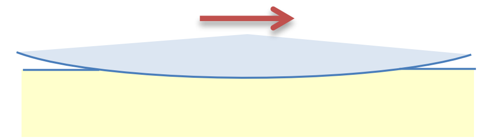
$$\Delta \propto R_l^{5/9} P^{-1/9}$$

- Only tops of micro-asperities make contact with the PDMS substrate
- Non linearity of the $A(P)$ relationship accounted for by lens curvature

Friction

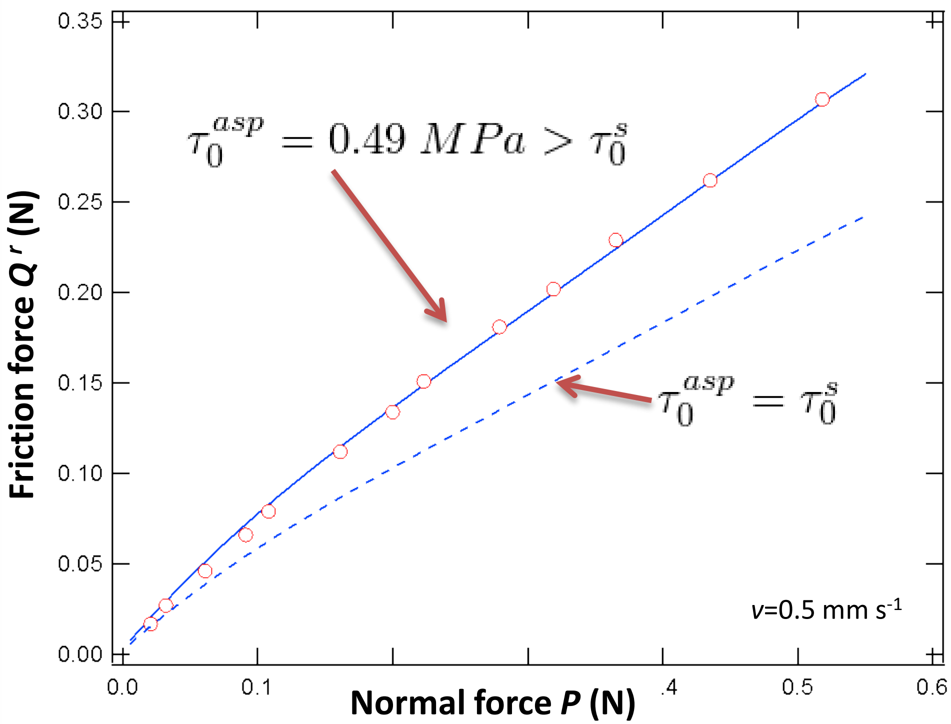


Rough lens with spherical micro-asperities

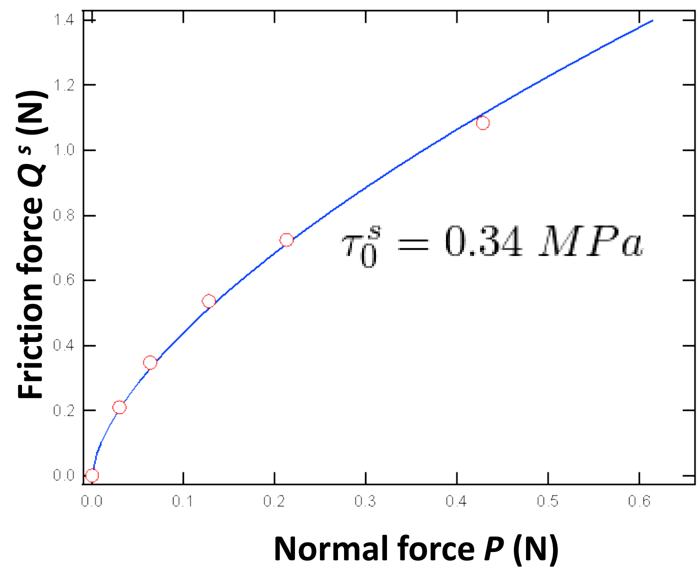


Smooth lens covered by a smooth sol-gel layer

- Velocity independent friction 0.01 < v < 5 mm s^{-1}



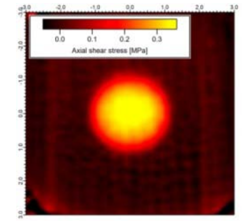
$$Q^r = \sum_i q_i = \tau_0^{asp} \sum_i (\pi a_i^2)$$



$$Q^s = \tau_0^s A \propto \tau_0 P^{2/3}$$

Frictional stresses at macroscopic length scales cannot be simply transposed to microscopic multi-contacts interfaces

Summary/ Outlook



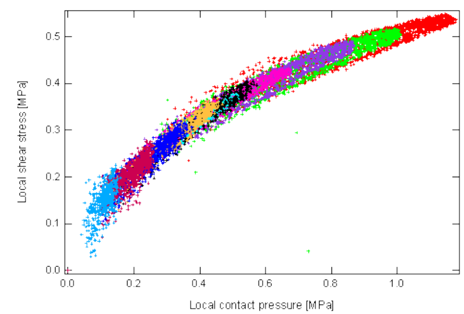
✓ Local friction law from displacement field measurements

✓ Multi-contact interface with rigid randomly rough surfaces

Non linear local friction law

dependence on the details of surface roughness

Contribution of viscoelasticity to friction



✓ Friction of model randomly rough surfaces

Contact mechanics of multi-contact interfaces

Contribution to friction of microasperities at various length scales