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Triggering frictional slip

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Triggering Frictional slip

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Vibration induced slip:
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see: Phys. Rev. Lett. 103, 085502 (2009)

Thermal induced slip:
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submitted to PNAS

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TRIGS

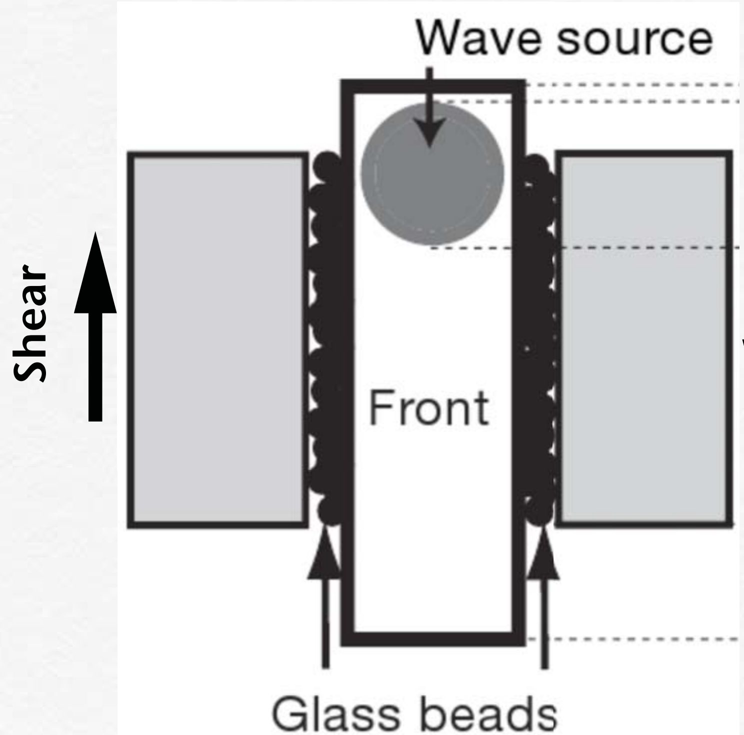
Questions

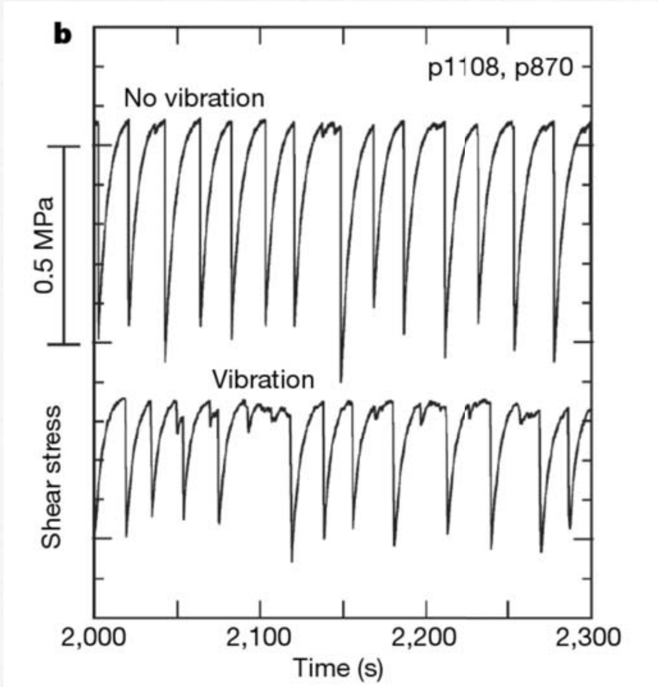
- Mechanical triggering:
  can we understand the role of vibration in stick-slip and friction?
- Thermal triggering:
  How does frictional slip occur in subcritical conditions?

Part I

Vibration induced slip

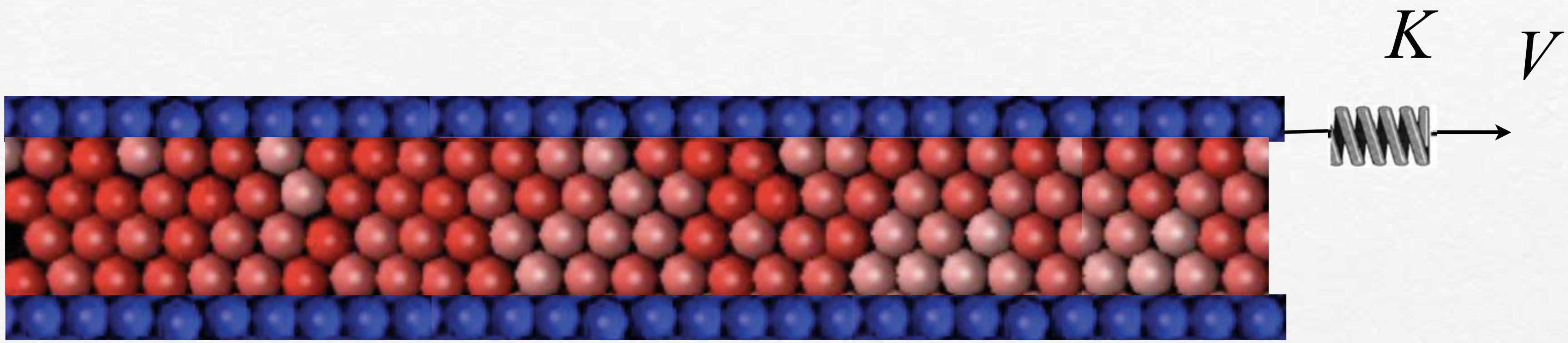
Suppression of stick-slip by vibration





Johnson, P., Savage, H., Knuth, M., Gomberg, J., and C. Marone, Nature, 451, doi:10.1038/nature06440, 2008.

Model

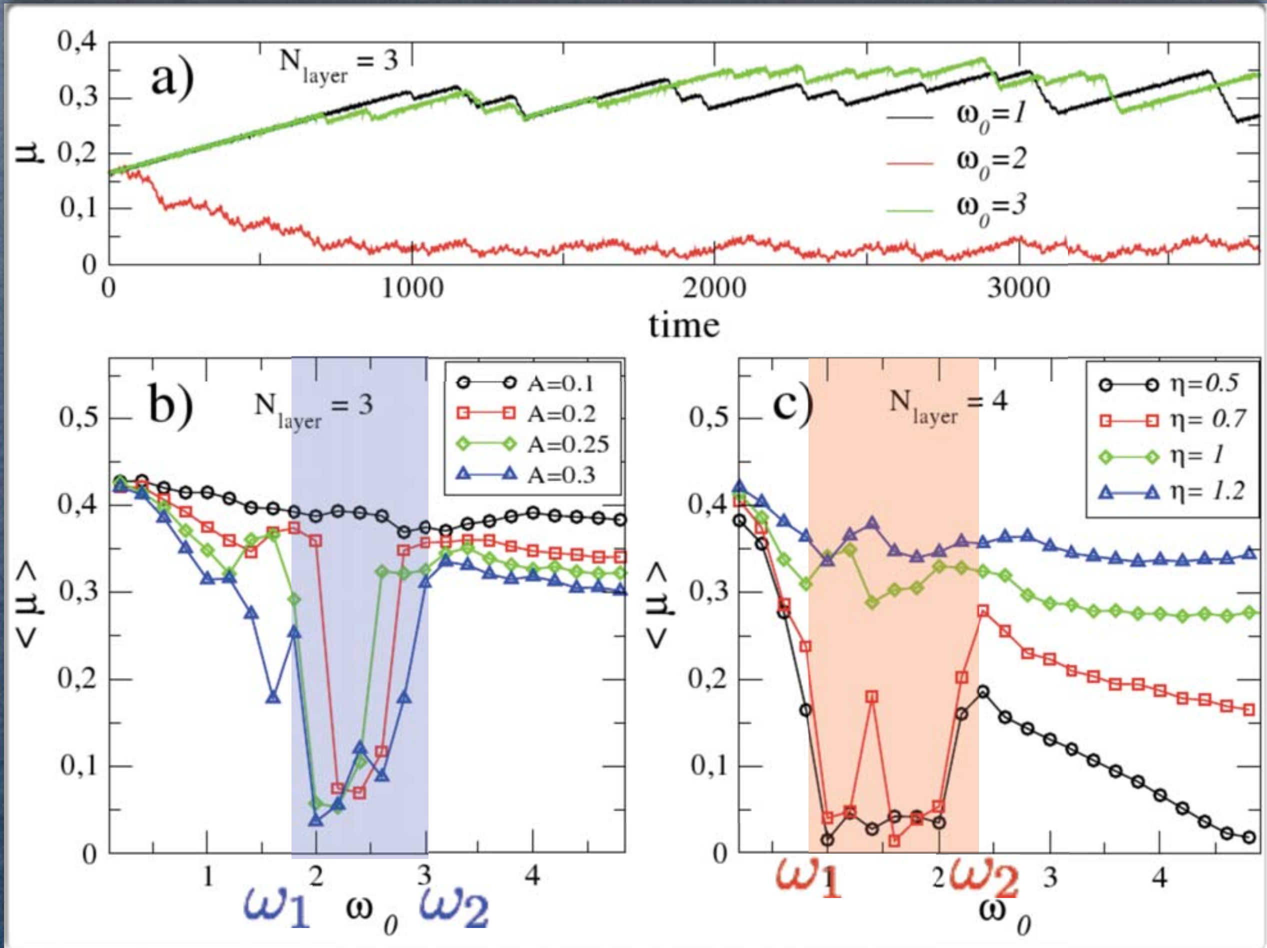


Langevin simulations
Repulsive particles
Normal load
Low driving velocity
Low temperature
Rigid top & bottom plates

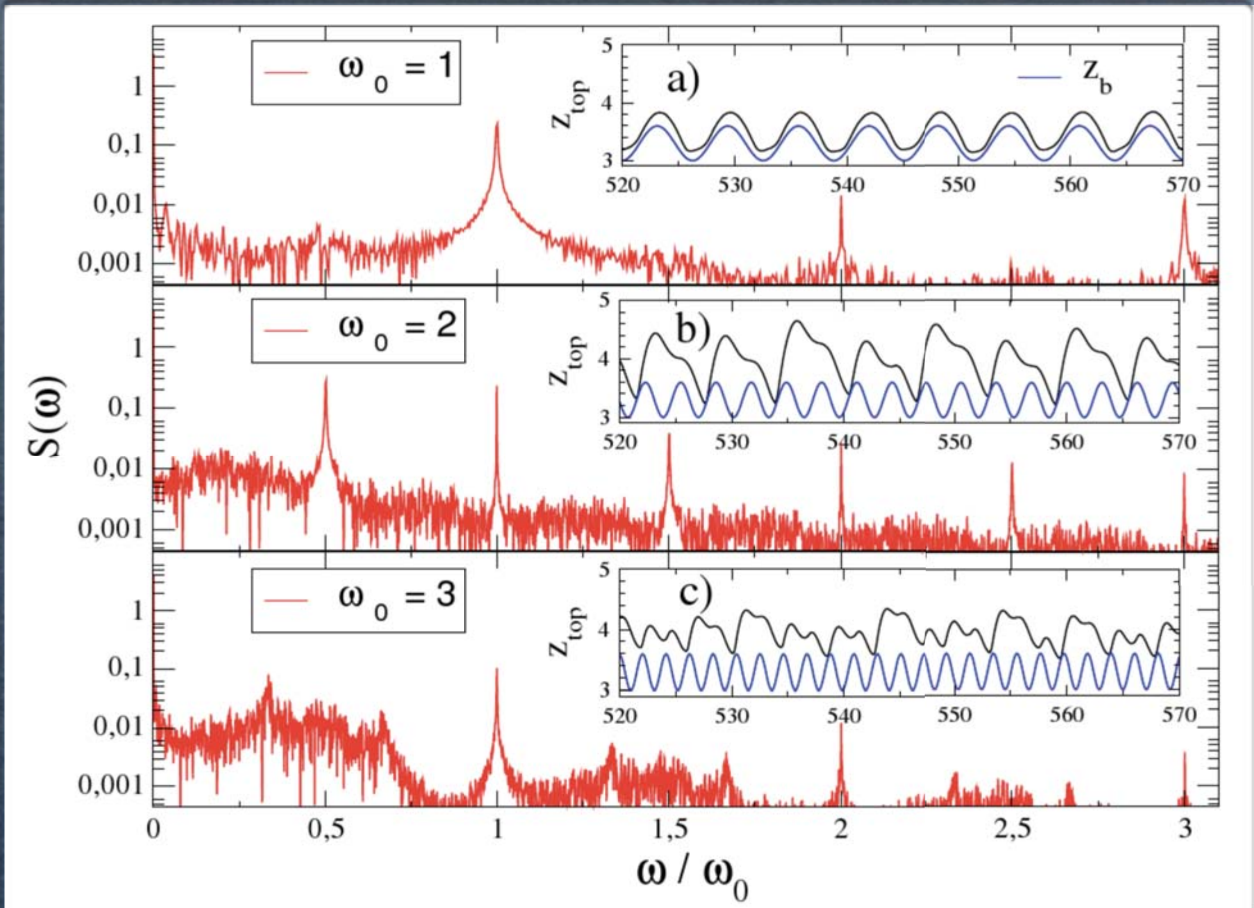
Sinusoidal vibration of the bottom plate

$$Z = A \sin(\omega_0 t)$$

Friction suppression



Spectral properties



Friction suppression

To compute the frequency ω_1 we compare the inertial force due to the vibration to the sum of the load and the damping

$$F_{in}(\omega_1) \simeq F_N(\omega_1) + F_{damp}(\omega_1).$$

M: is the total mass (particles+plates)
M_p: is the mass of the particles
F_N: is the load
: is the damping constant
A : is the vibration amplitude

$$M A \omega_1^2 = F_N + M_p \eta A \omega_1$$

Using dimensionless variables:

$$\tilde{f} \equiv \frac{F_N}{M A \eta^2} \quad \tilde{m} \equiv \frac{M_p}{M} \quad \tilde{\omega} \equiv \frac{\omega}{\eta}.$$

$$\tilde{\omega}_1 = \frac{1}{2}\left(\tilde{m} + \sqrt{\tilde{m}^2 + 4\tilde{f}}\right)$$

Friction recovery

Detachment time from the bottom substrate:

$$\Delta t \simeq \dot{Z}_b M / F_N \simeq A \omega_0 M / F_N$$

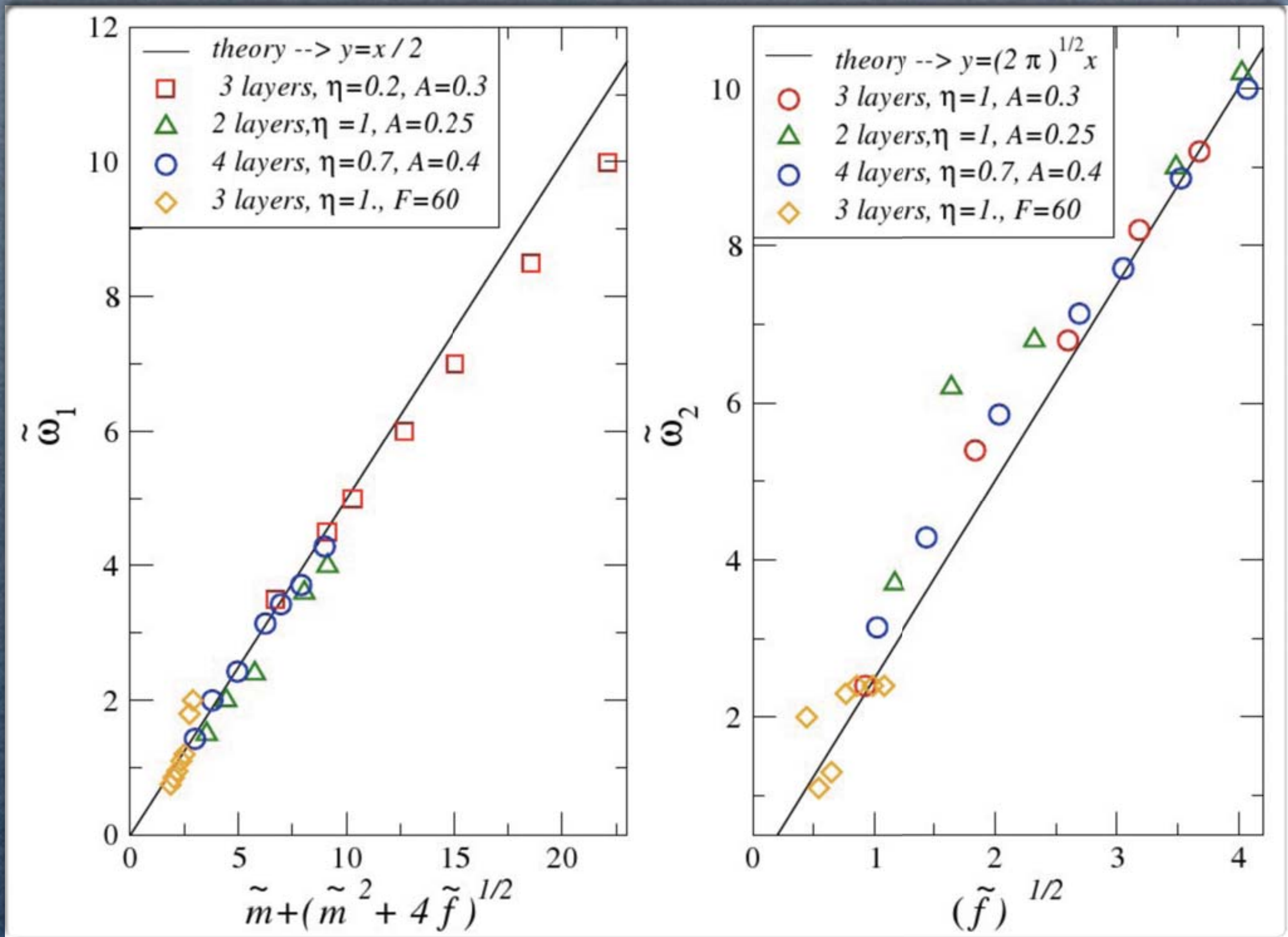
Rise time of the bottom substrate:

$$t_{rise} = \frac{2\pi}{\omega_0}$$

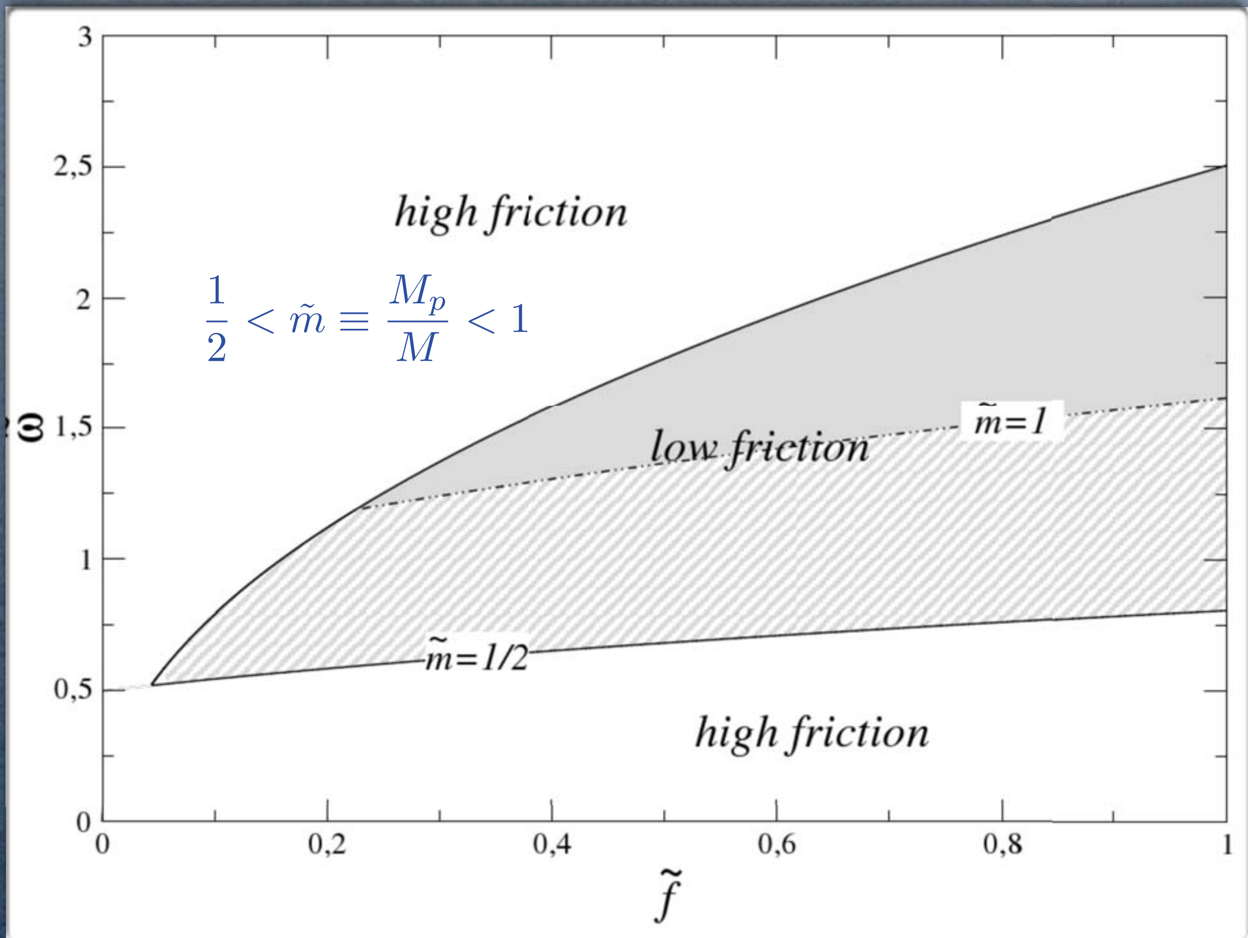
When the rise timeis equal to the detachment time friction is recovered:

$$\tilde{\omega}_2 = \sqrt{2\pi \tilde{f}}.$$

Comparison with simulations



Phase diagram



Part II

Thermally induced slip

Subcritical slip: creep

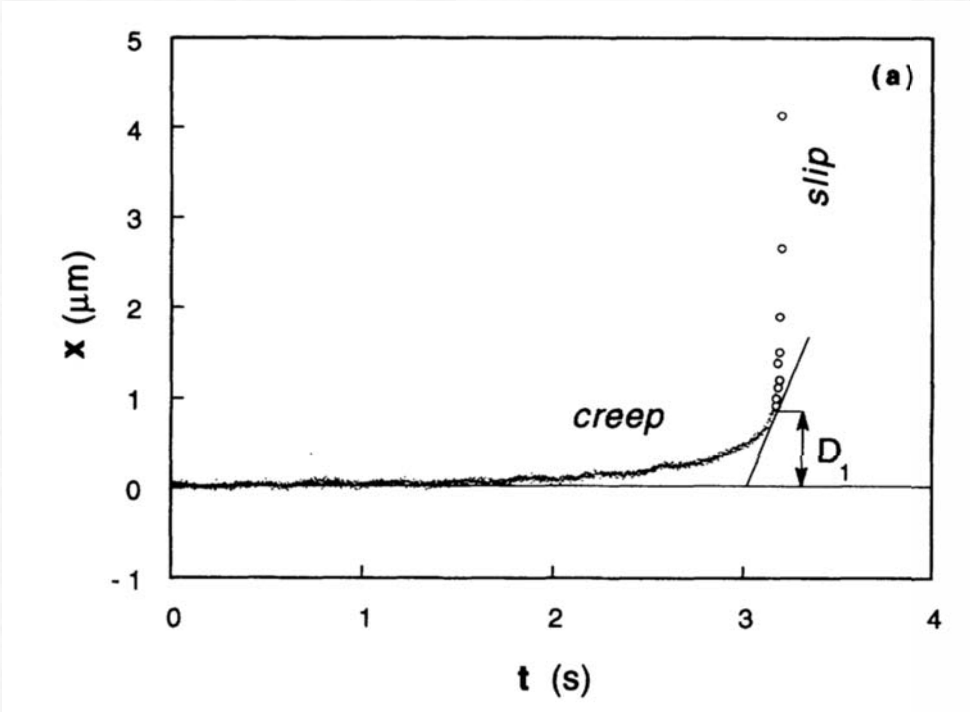
According to Amontons-Coulomb two surfaces in contact slide if the later force exceeds the static friction force:

$$F_L > F_s = \mu_s F_N$$

and when they move they are subject to the dynamic friction force:

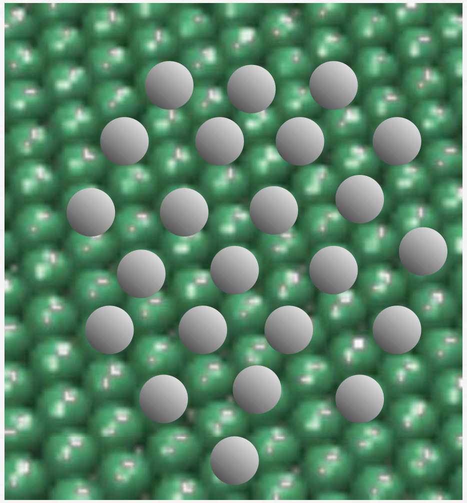
$$F_d = \mu_d F_N$$

but real interfaces creep even below the static limit.



F. Heslot, T. Baumberger, B. Perrin, B. Caroli and C. Caroli, Phys. Rev. E 49, 4973 (1994)

Onset of slip:
Xe monolayer on Cu substrate



Cu (111) surface
adsorbed Xe atom
form a commensurate
interface

Xe atoms interact
via LJ interactions:

$$\epsilon = 20\text{meV}$$

Xe-Cu potential
obtained from
ab-initio calculations:

$$V_0 = 1.9\text{meV}$$

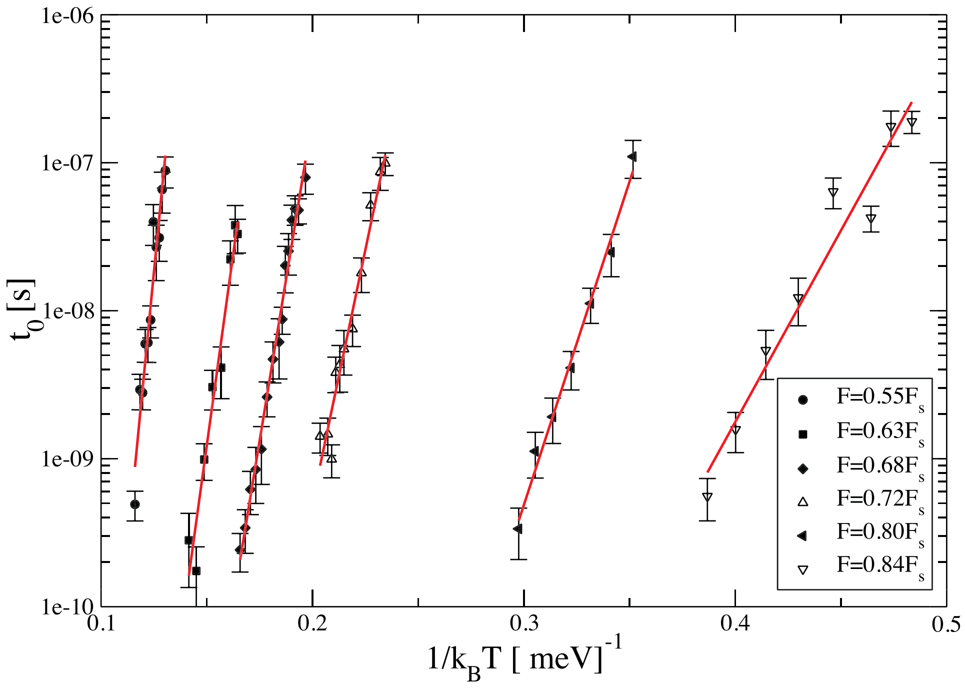
Constant temperature
MD simulations:

$$25^\circ\text{K} < T < 100^\circ\text{K}$$

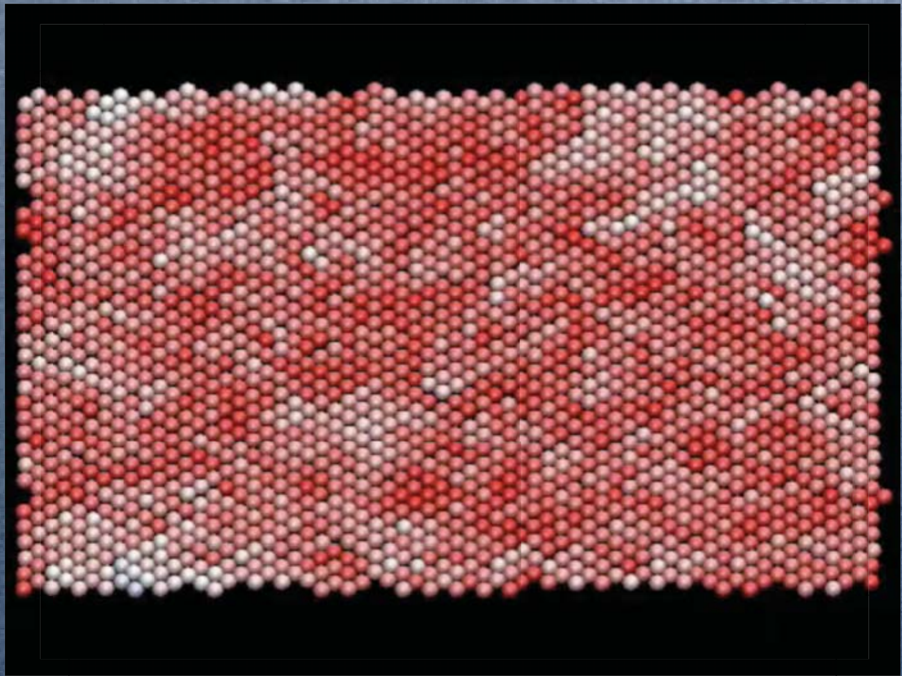
Apply a subcritical
force to Xe atoms:

$$F < F_s \simeq 2.4\text{meV}/\text{Å}$$

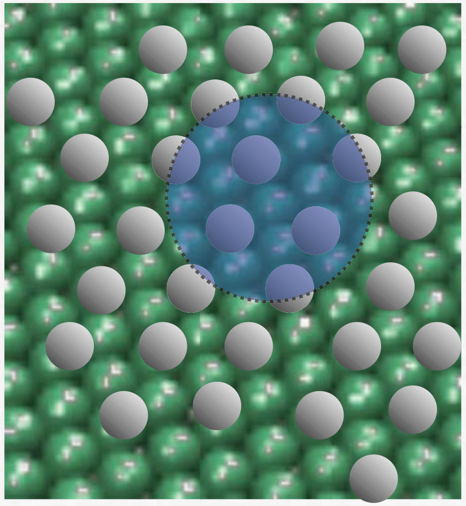
Slip activation time



Onset of slip



Nucleation theory



Energy cost of a commensurate domain:

$$\Delta E = 2\pi r \Gamma - \frac{2\pi r^2}{\sqrt{3} b^2} F a$$

domain wall energy — gain from the force

Critical domain size:

$$r_c = \frac{\Gamma \sqrt{3} b^2}{2aF}$$

Energy barrier:

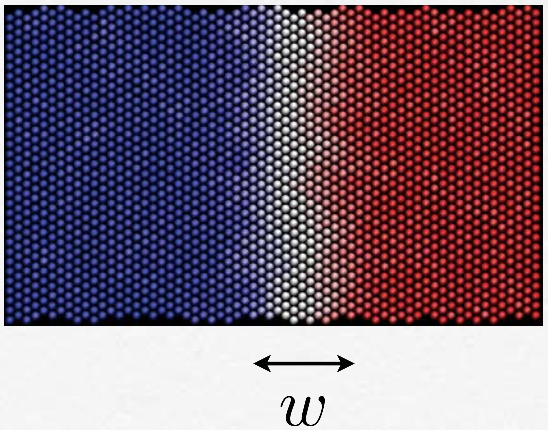
$$U = \frac{\sqrt{3}\pi \Gamma^2 b^2}{2aF} - E_s$$

Domain wall: theory

$$E = \int dxdy[\frac{1}{2}B(\nabla u)^2 + \rho V(u)]$$

$$B \simeq 57\epsilon/\sigma^2$$
$$V(u) \simeq \frac{V_0}{2}(1 - \cos(2\pi u/a))$$

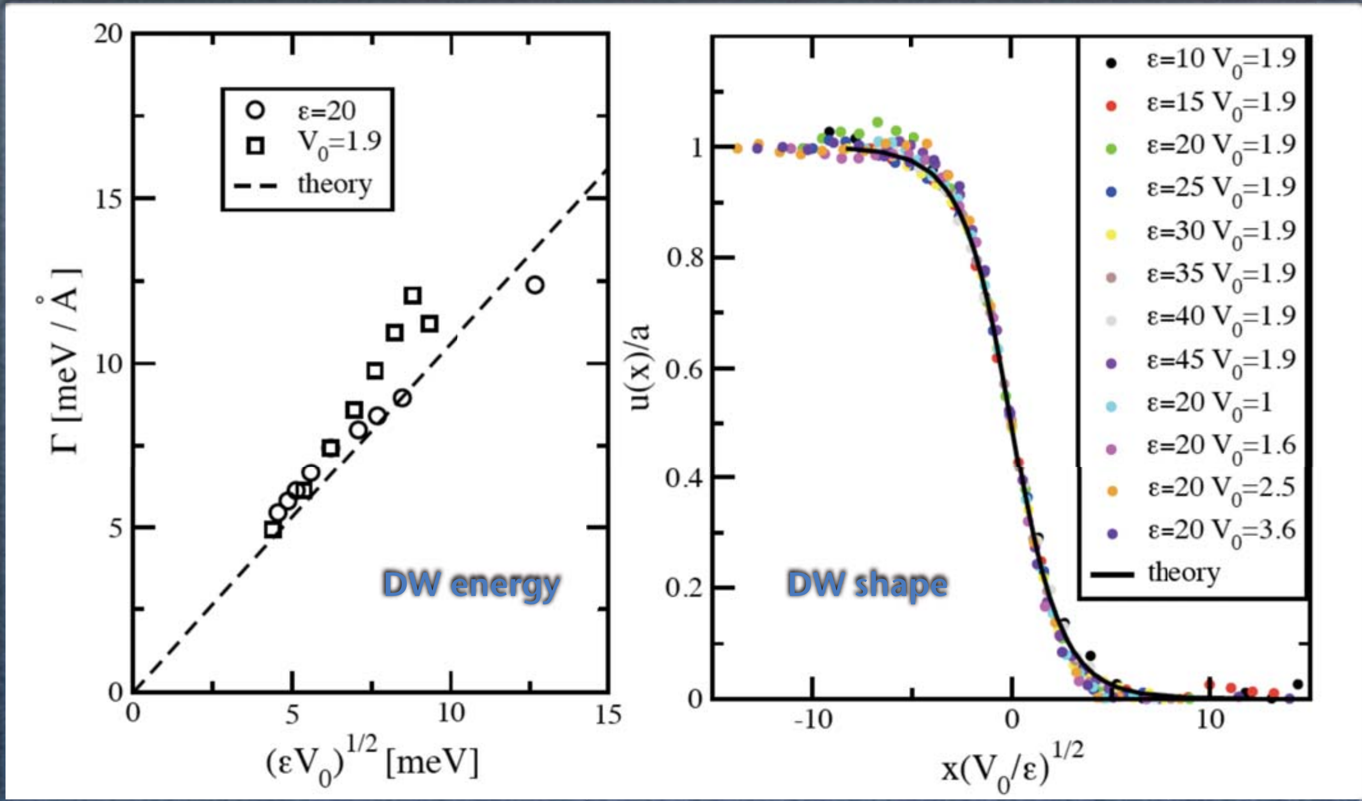
$$E_{el} \simeq Ba^2/w \qquad E_{sub} \simeq V_0 \rho w$$



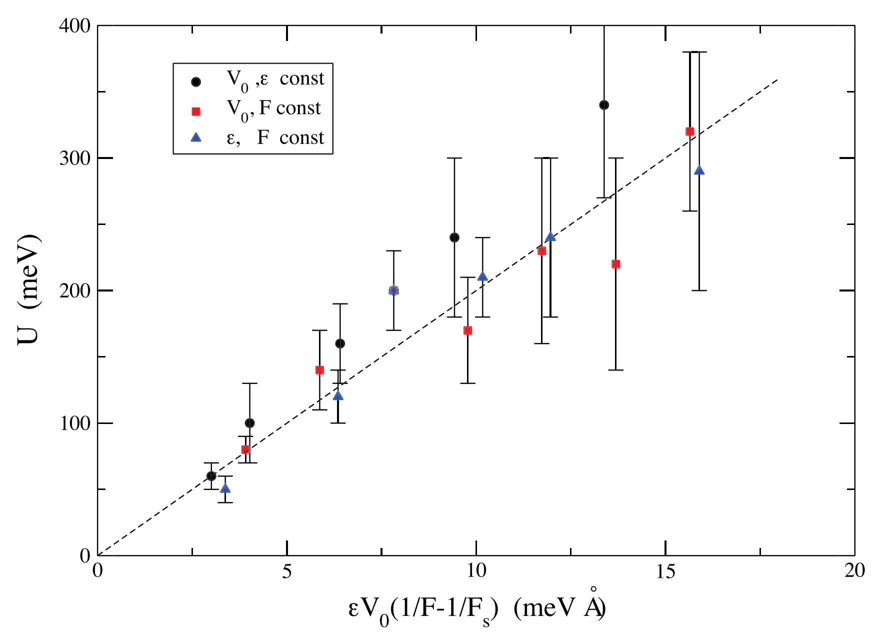
$$w \propto \sqrt{Ba^2/V_0\rho}$$

$$\Gamma \propto a\sqrt{\rho B V_0}$$

Domain walls: simulations

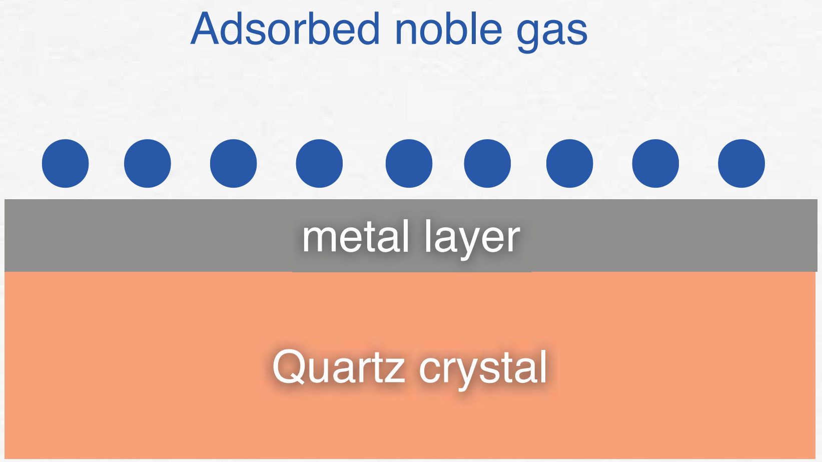


Nucleation barrier



Comparison with QCM experiments

Coffey & Krim Phys. Rev. Lett. 2005;95:076101.



A typical QCM operates at the resonance frequency of $\omega_0 \simeq 10^7\ \mathrm{s}^{-1}$

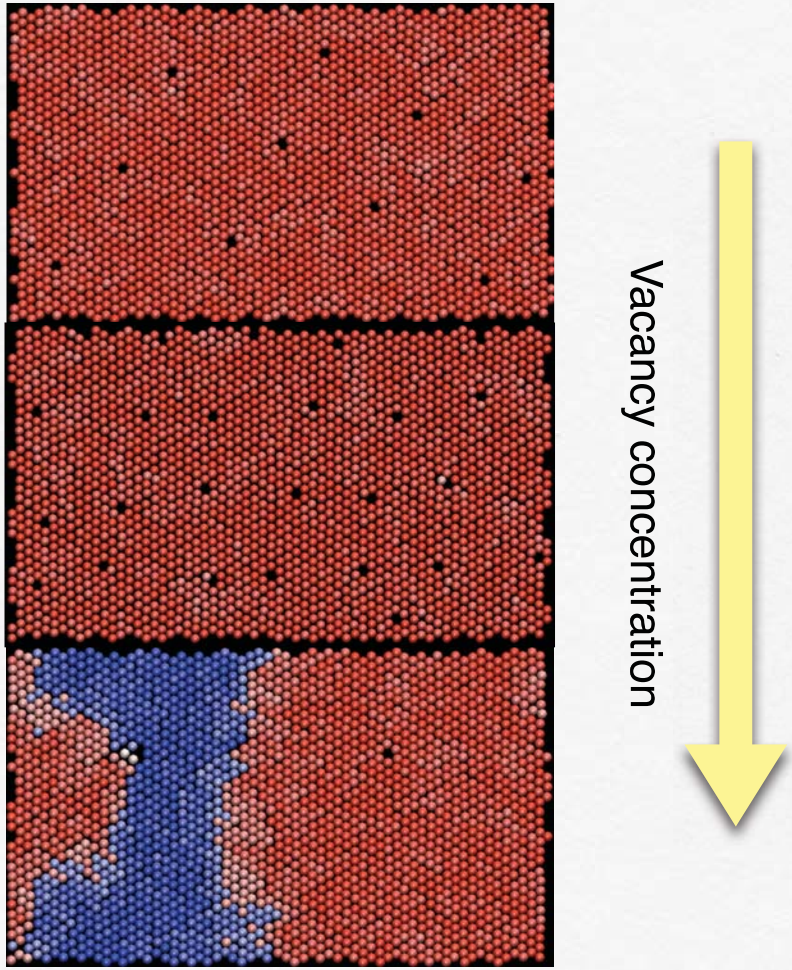
with an amplitude $A \simeq 100\text{Å}$ corresponding to a maximum lateral inertial force on the monolayer

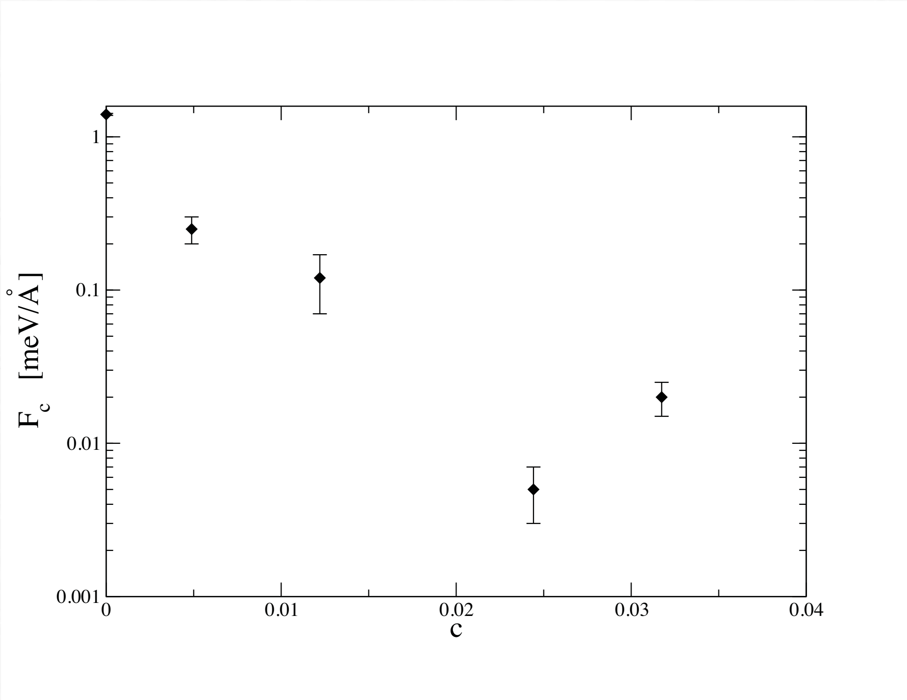
.

$$F_{QCM} = m\omega_0^2 A \simeq 10^{-7}\mathrm{meV}/\text{Å}$$

In order for the film to slide, the nucleation time should be smaller than the experimental time scale. This would be impossible for a perfect Xe/Cu interface where $F_s \simeq 2.4\mathrm{meV}/\text{Å}$

The role of defects





Defects could allow commensurate interfaces to slip in the QCM!

Conclusions

- Mechanical triggering:
  Under vibration friction is suppressed in a well defined frequency range.
- Thermal triggering:
  Creep in commensurate interface can be understood as a nucleation problem.
  Disorder induced nucleation could explain QCM experiments.

Thank you
for your attention!