TEL AVIV UNIVERSITY אוניברסיטת תל-אביב

Stabilizing stick-slip friction

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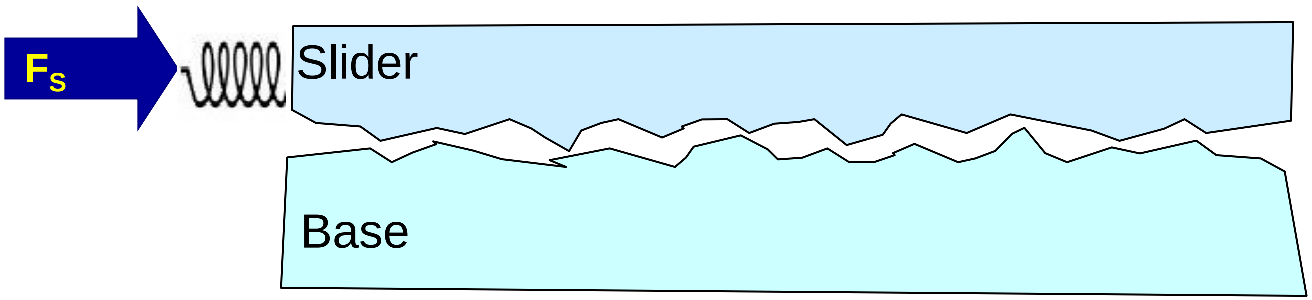
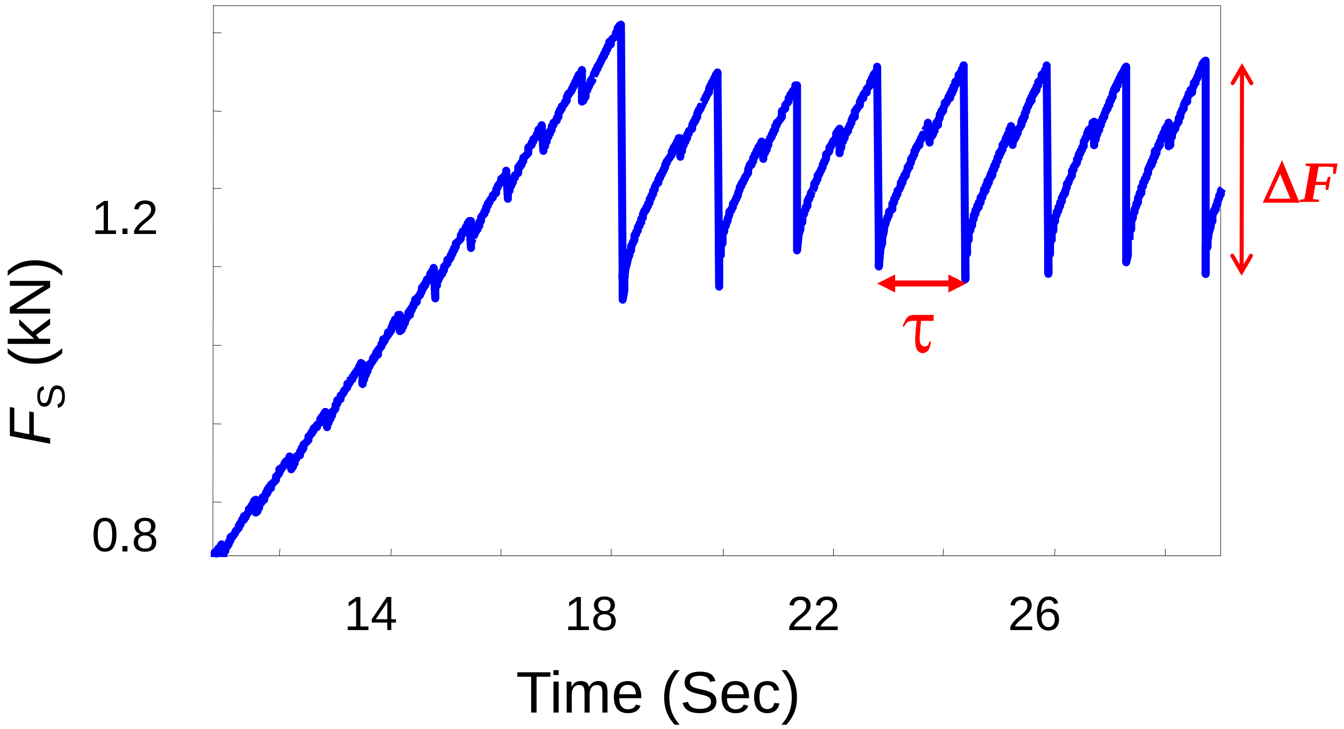
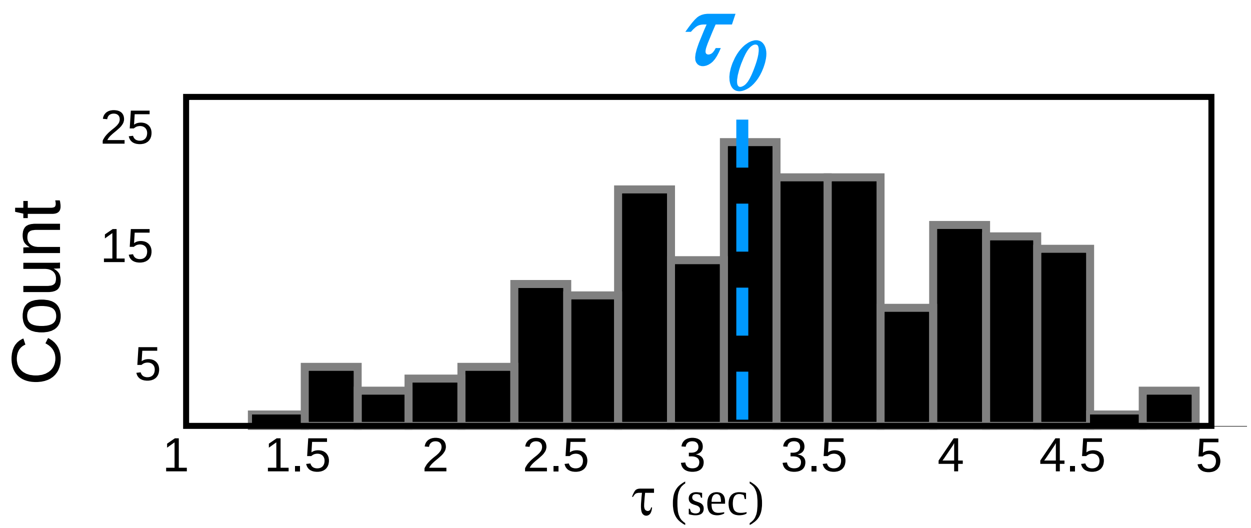
Jay Fineberg, HUJI

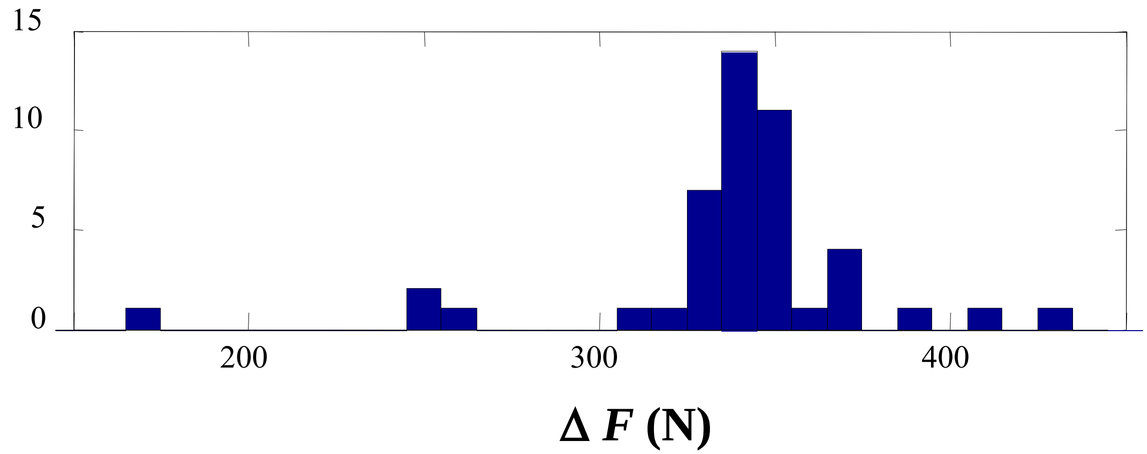
Shmuel M. Rubinstein, Harvard Un.

- stochasticity in the period between consecutive slip events
- irregularity in the size of the stress drops





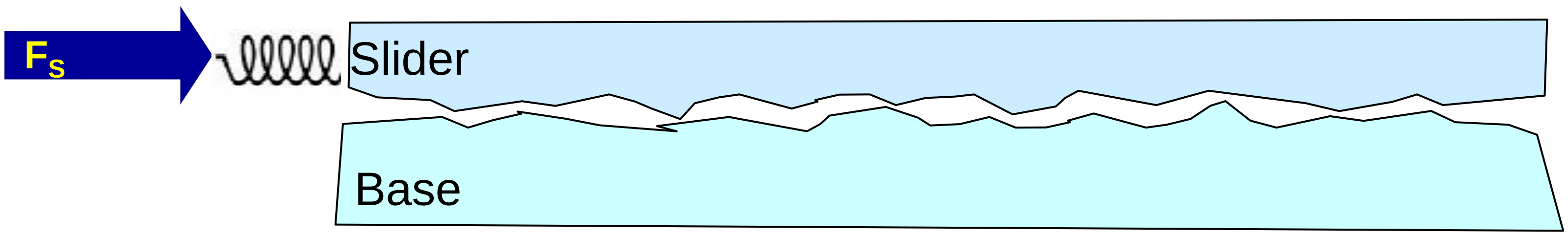


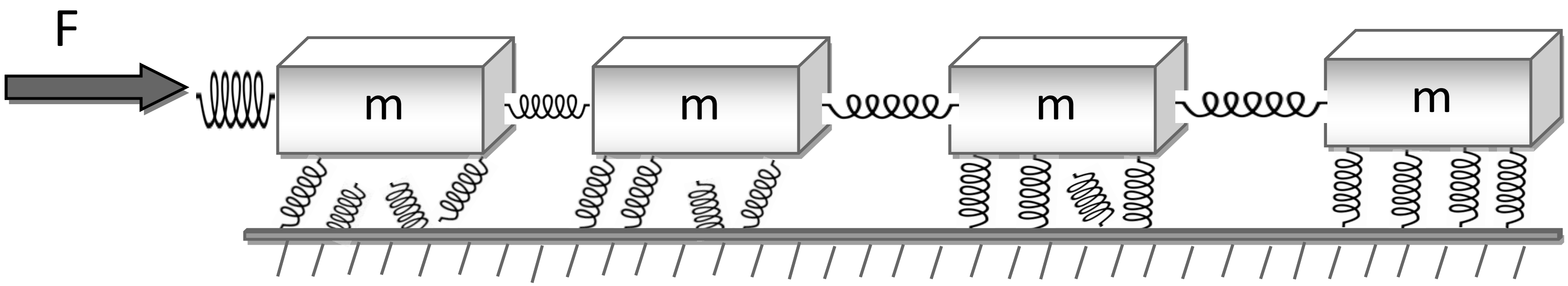


What is the origin of this stochasticity?

- A diversity of surface contacts
- Nonlinearity of interactions between the slider and the surface

The model





O.M. Braun, I. Barel and M. Urbakh, PRL, 2009

Parameters:

N – a number of rigid blocks,

N_s – a number of contacts between the block and track,

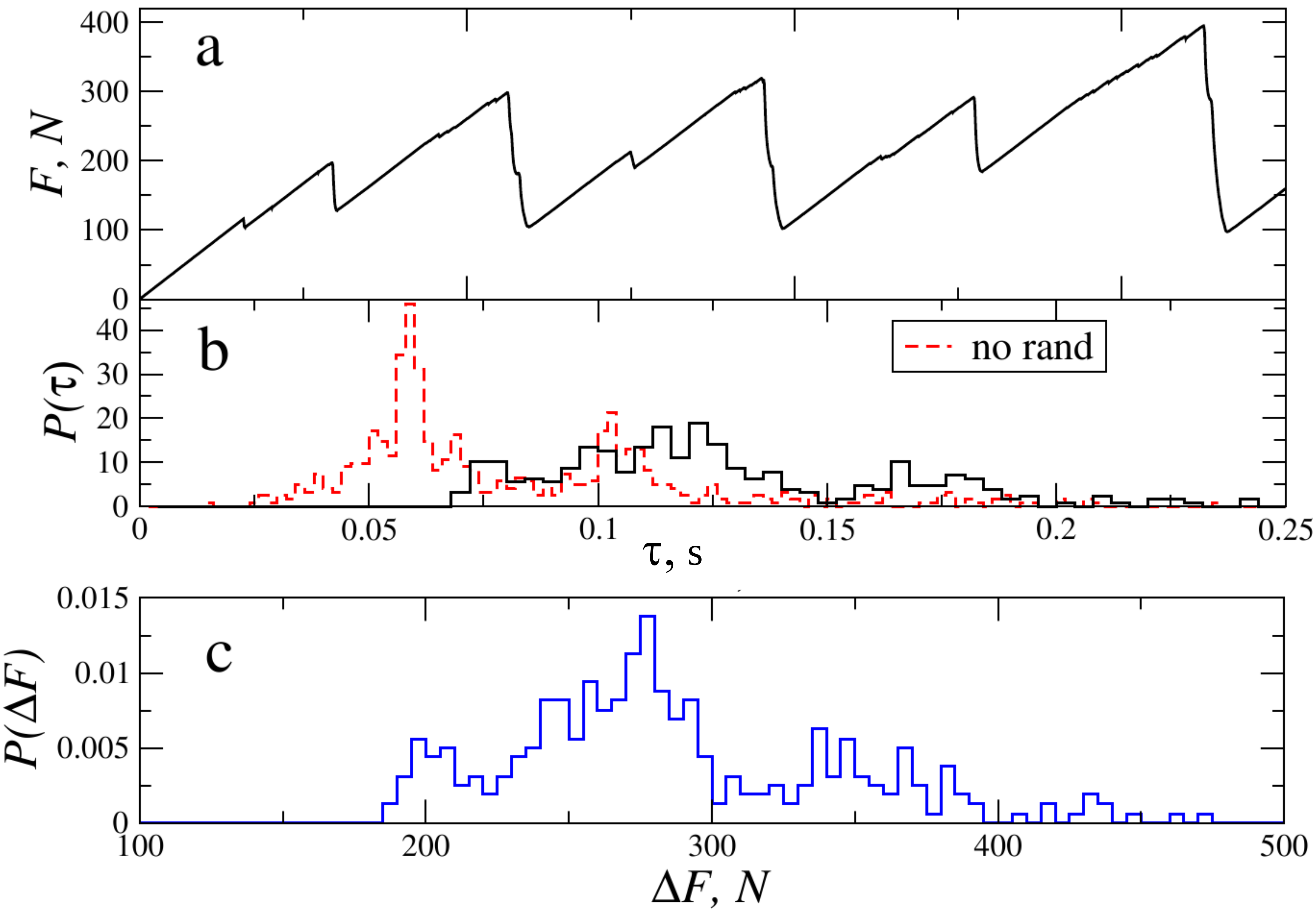
K_d – an elasticity of the driving spring,

K – a slider elasticity,

k_s – an elasticity of the contact,

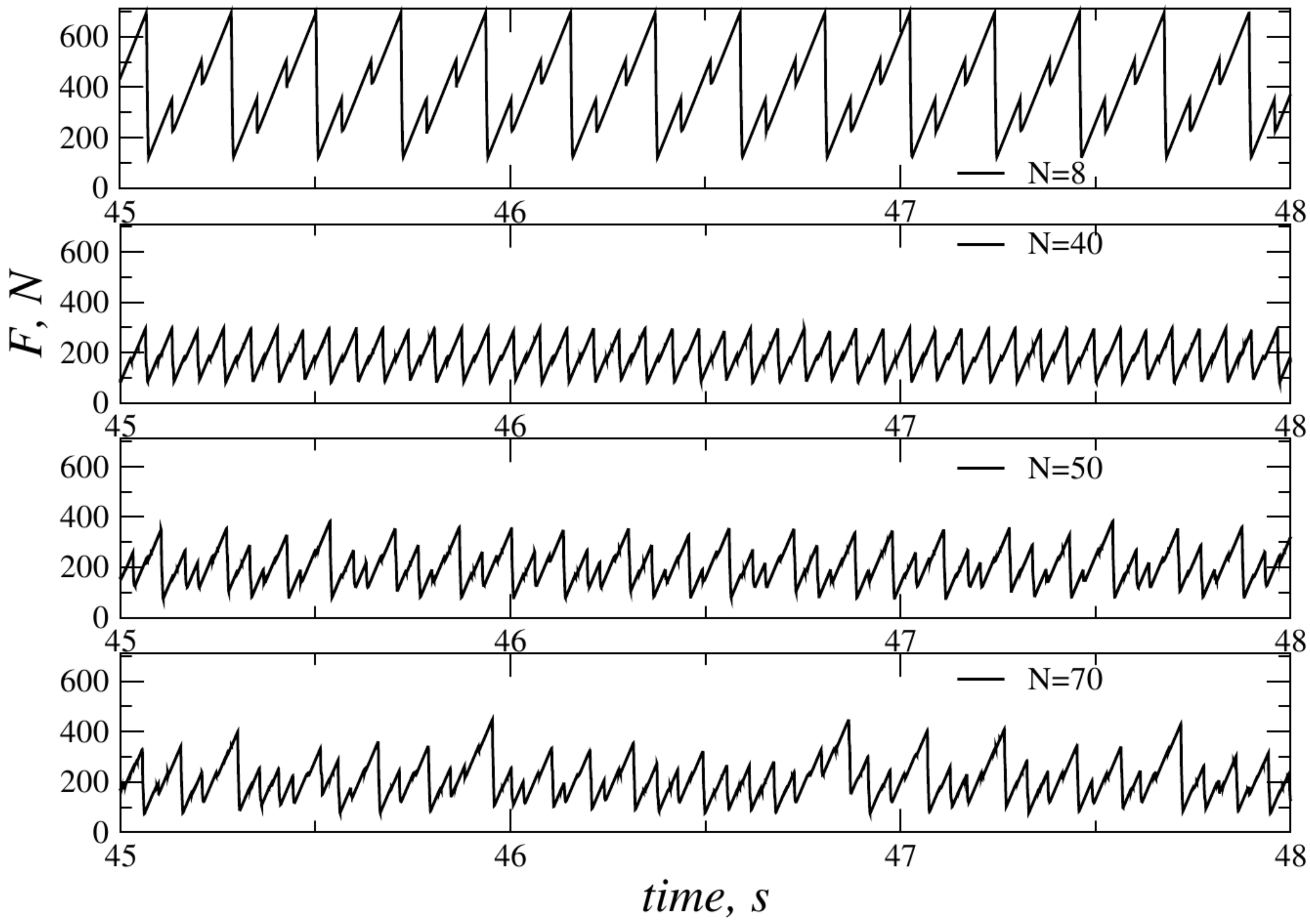
f_{si} – rupture forces which takes random values from a Gaussian distribution

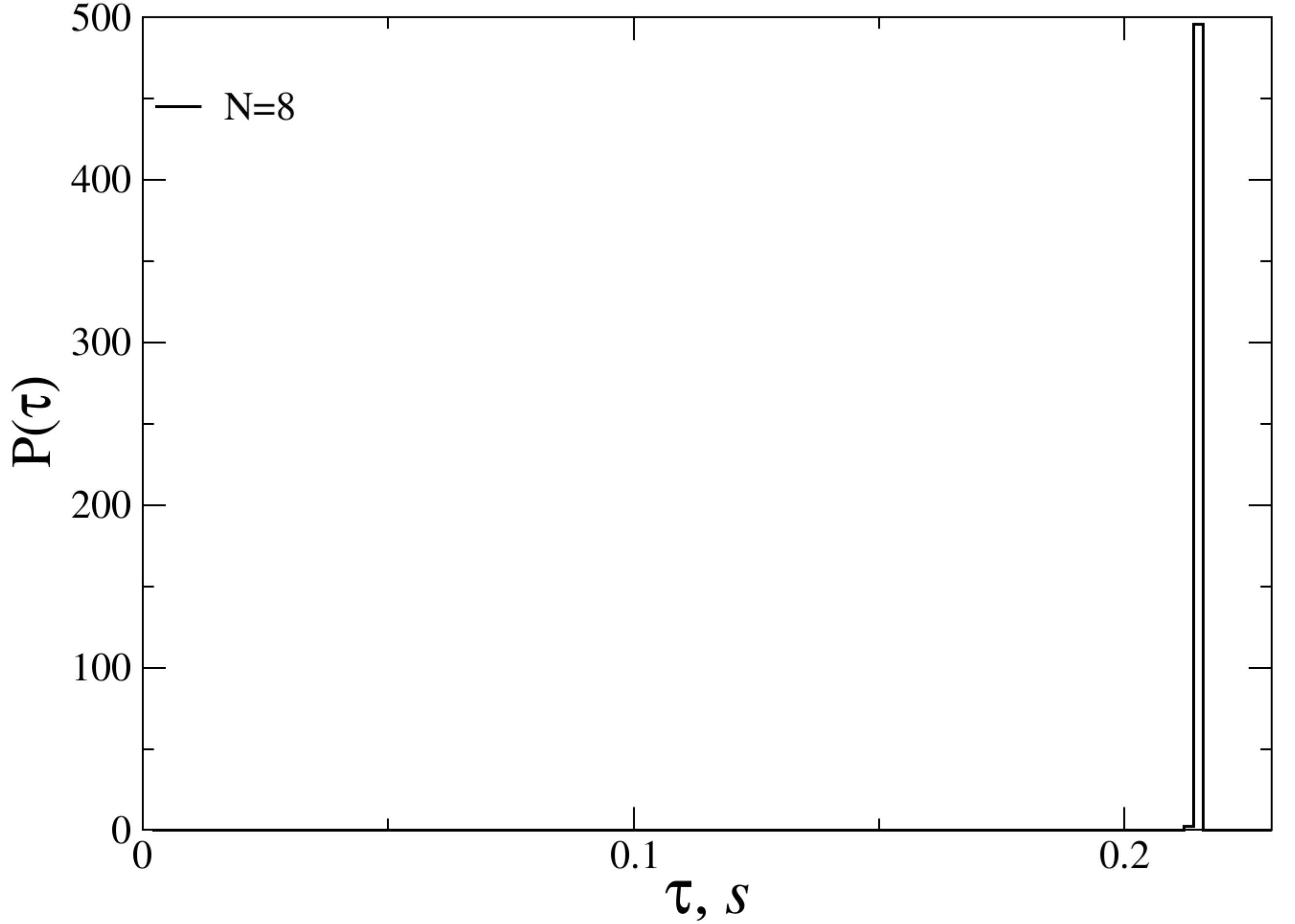
Results of simulations

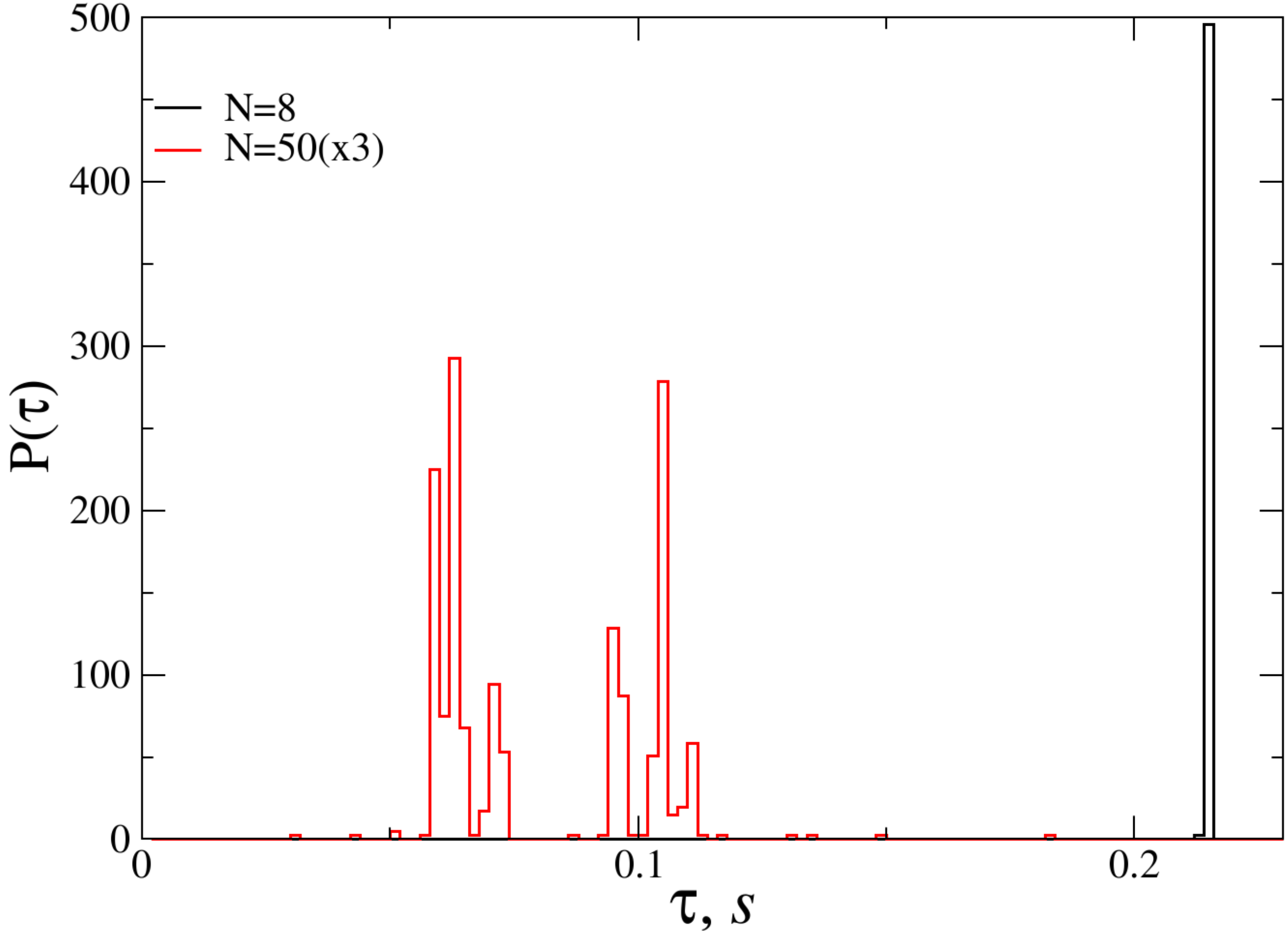


A broad distribution of stick times is retained even when all contacts are identical.

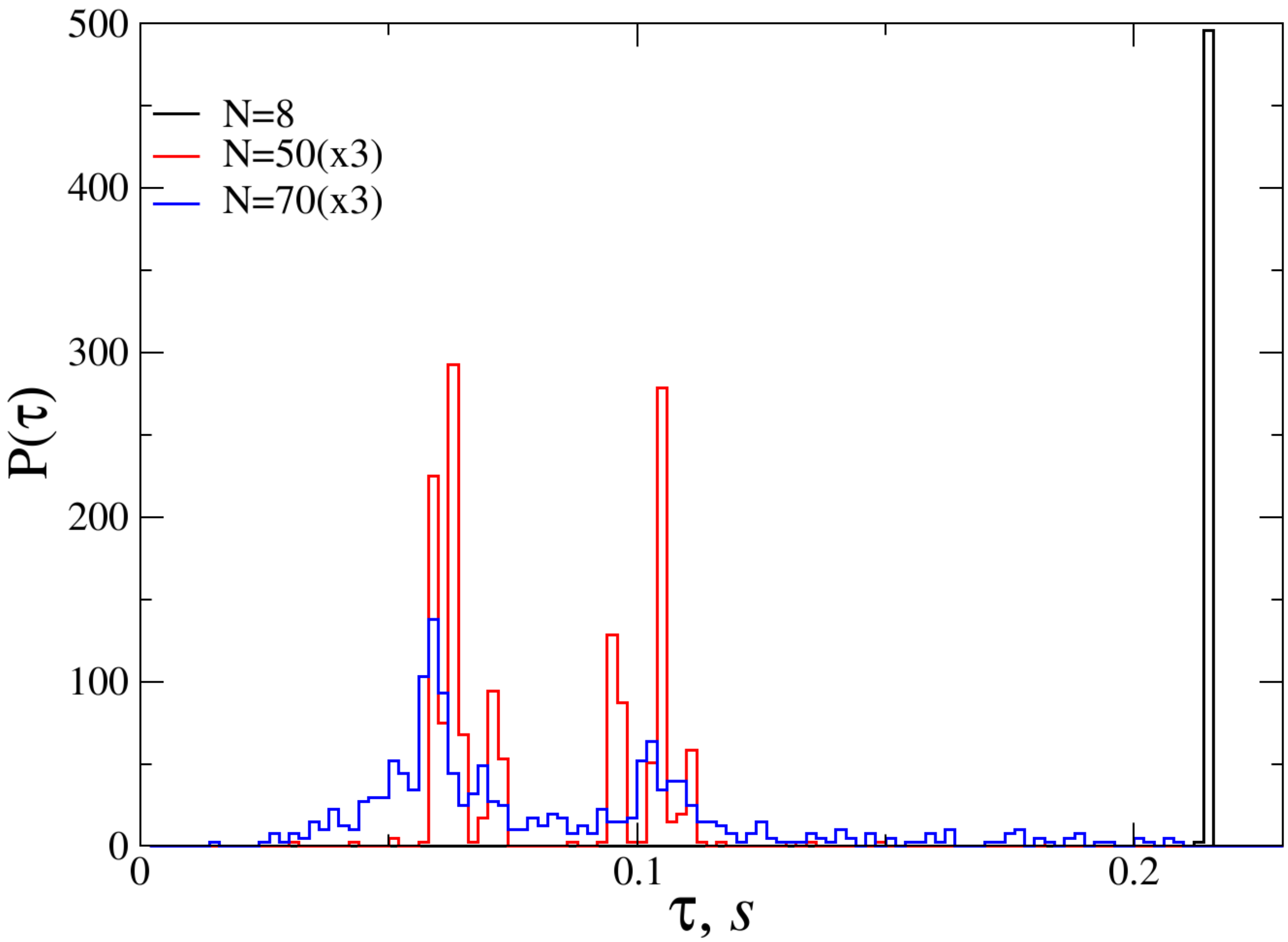
Force traces for different numbers of blocks




N=8
P(τ)
τ, s
0
100
200
300
400
500
0
0.1
0.2



N=8
N=50(x3)
P(τ)
τ, s
500
400
300
200
100
0
0
0.1
0.2

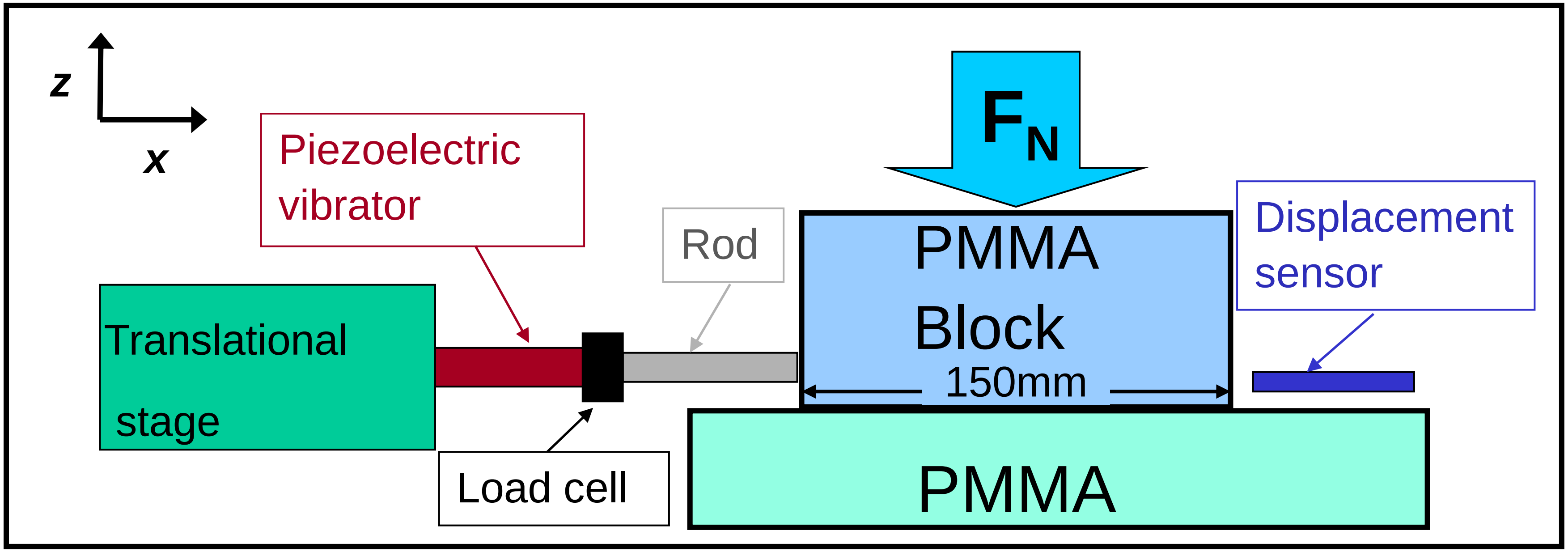


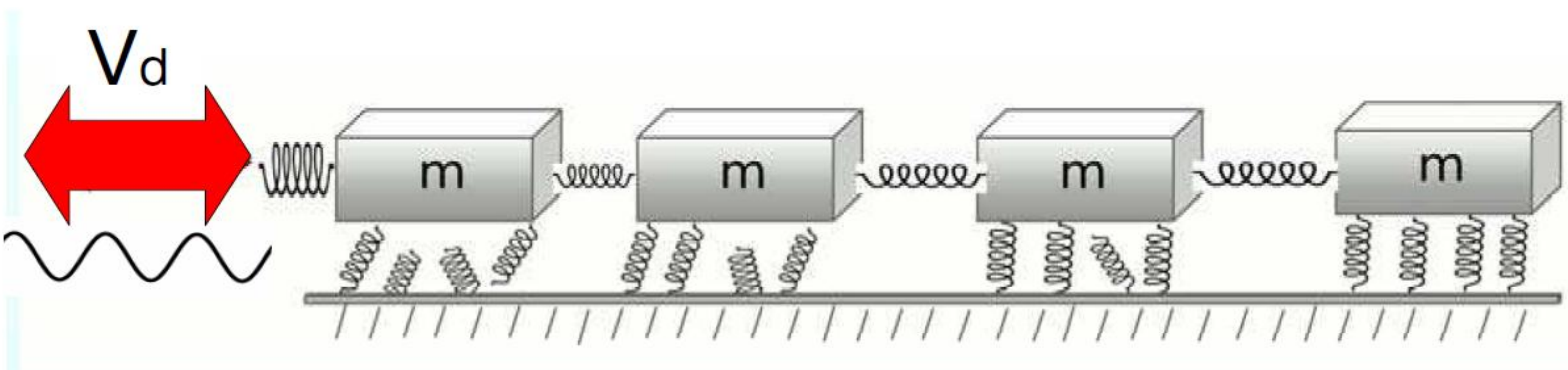
$$\Delta x_j = x_j - x_j^0 = \Delta x_1 \exp[-\sqrt{K_s/K_{\text{int}}}(j-1)]$$

Stochasticity: the nonuniformly stressed region involves more than one block, i.e.

$$N \gg \sqrt{K_{\text{int}}/K_s}$$

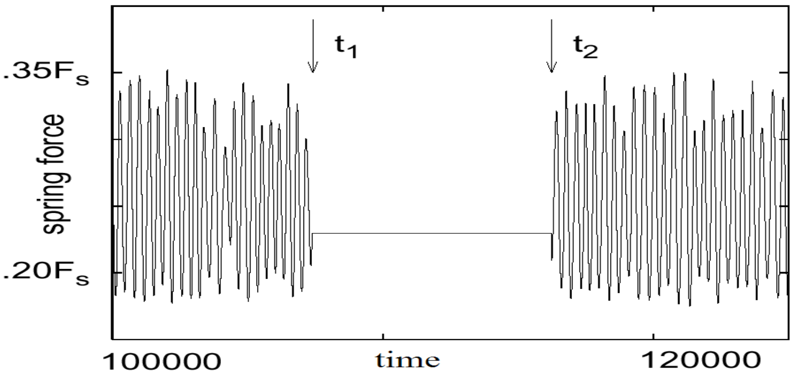
Is it possible to control the stochasticity?





$$V_d = V_0 - \frac{2\pi}{T} \Delta \sin(2\pi t / T),$$

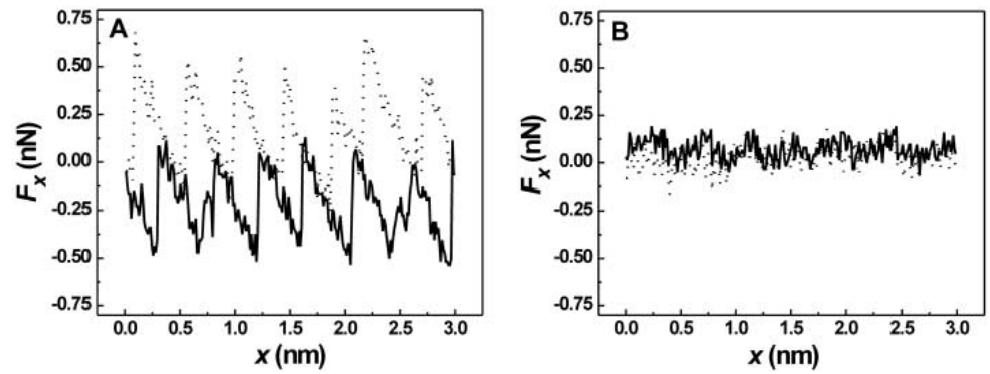
Control of Friction via Normal Oscillations



M.G. Rozman, M. Urbakh & J. Klafter, *Phys. Rev. E* 57, 7340 (1998);

M. Urbakh, J. Klafter, D. Gourdon & J. Israelachvili, *Nature*, 430, 525 (2004).

R.Capozza, A.Vanossi, A.Vezzani & S.Zapperi *Phys. Rev Lett.* 103, 085502 (2009)



Anisoara Socoliuc,[1*] Enrico Gnecco,[1] Sabine Maier,[1] Oliver Pfeiffer,[1] Alexis Baratoff,[1] Roland Bennewitz,[2] Ernst Meyer[1]

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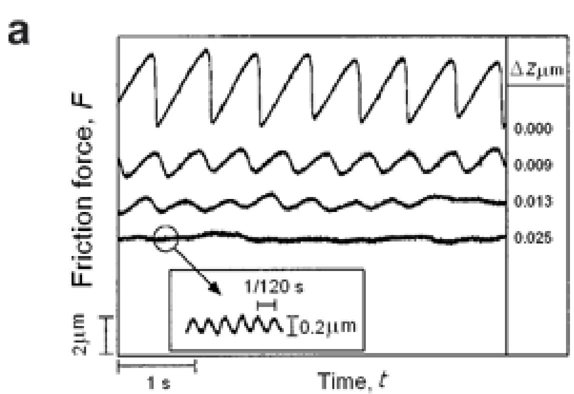
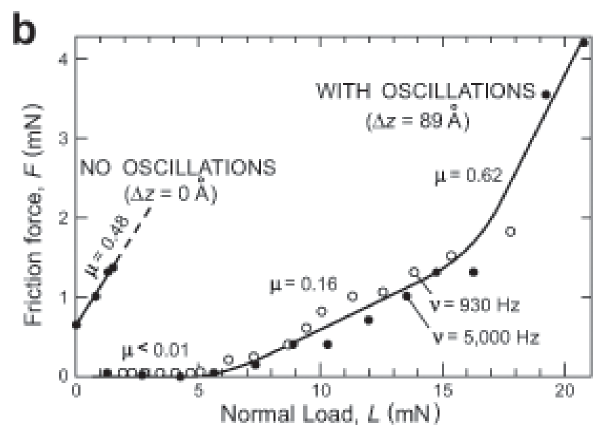
SFA Experiments

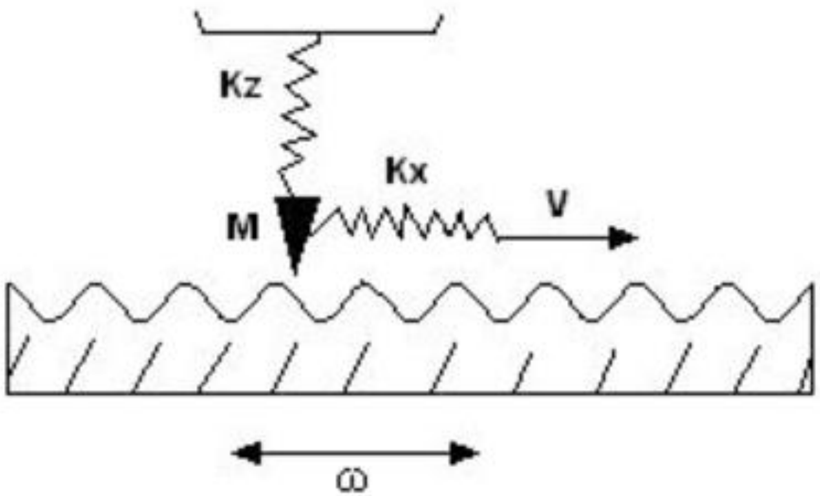


A. Cochard, L. Bureau & T. Baumberger, *Trans. ASME* 70, 220 (2003).



M. Heuberger, C. Drummond & J.N. Israelachvili, *J. Phys. Chem. B* 102, 5038 (1998).

Effect of lateral vibrations



Z. Tschiprut, A. E. Filippov & M. Urbakh, PRL 95, Art. No. 016101 2005.

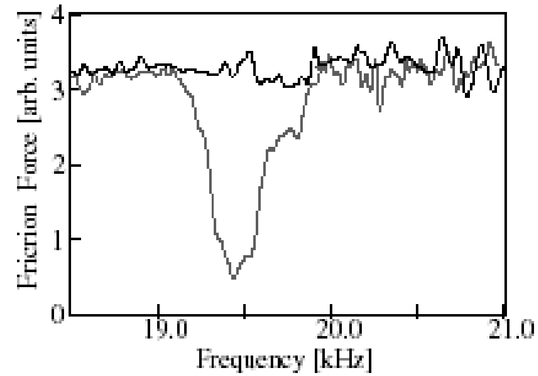
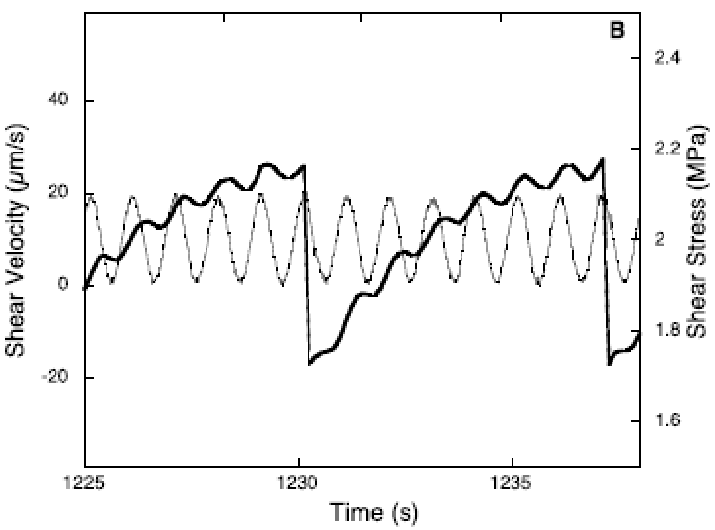


FIG. 3. Friction force vs frequency of the external oscillations at $v = 8\ \mu\mathrm{m/s}$ (continuous line) and $v = 150\ \mu\mathrm{m/s}$ (dashed line). The applied load is $F_N = 15$ nN in both cases.

E.Riedo, E.Gnecco, R.Bennewitz, E.Meyer, and H.Brune, PRL, 2003.

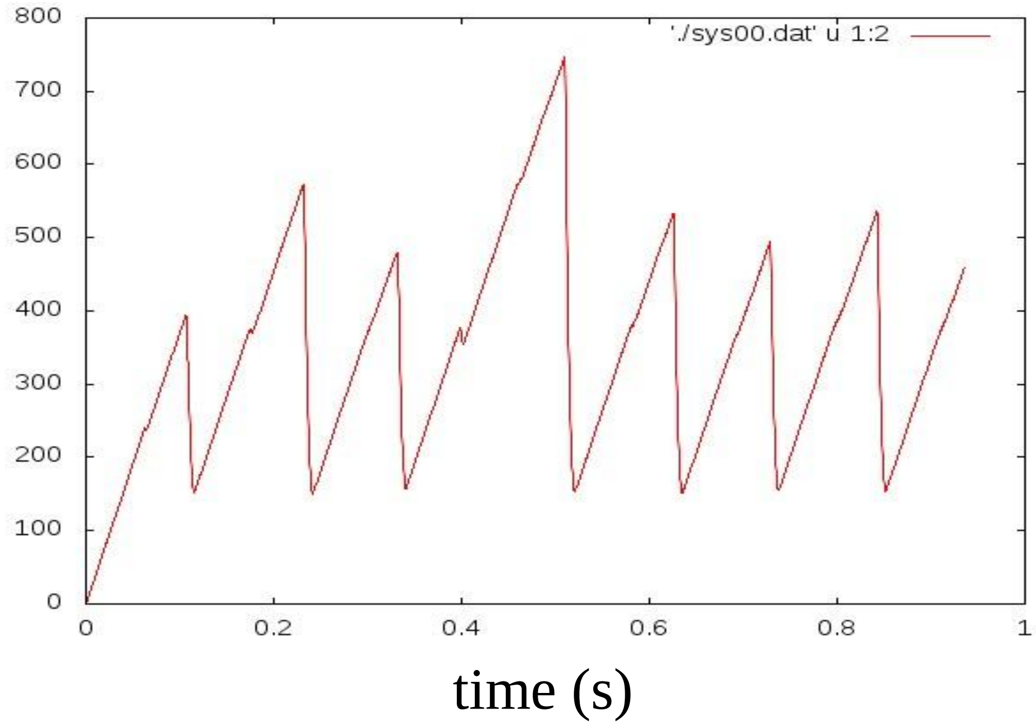
Shear velocity oscillations on stick-slip behavior on macroscale

Beeler, N. M., and D. A. Lockner, J. Geophys. Res., 108(B8), 2391, (2003)
H.M. Savage and C. Marone, J. Geophys. Res., 112(B0), 2301, 2007



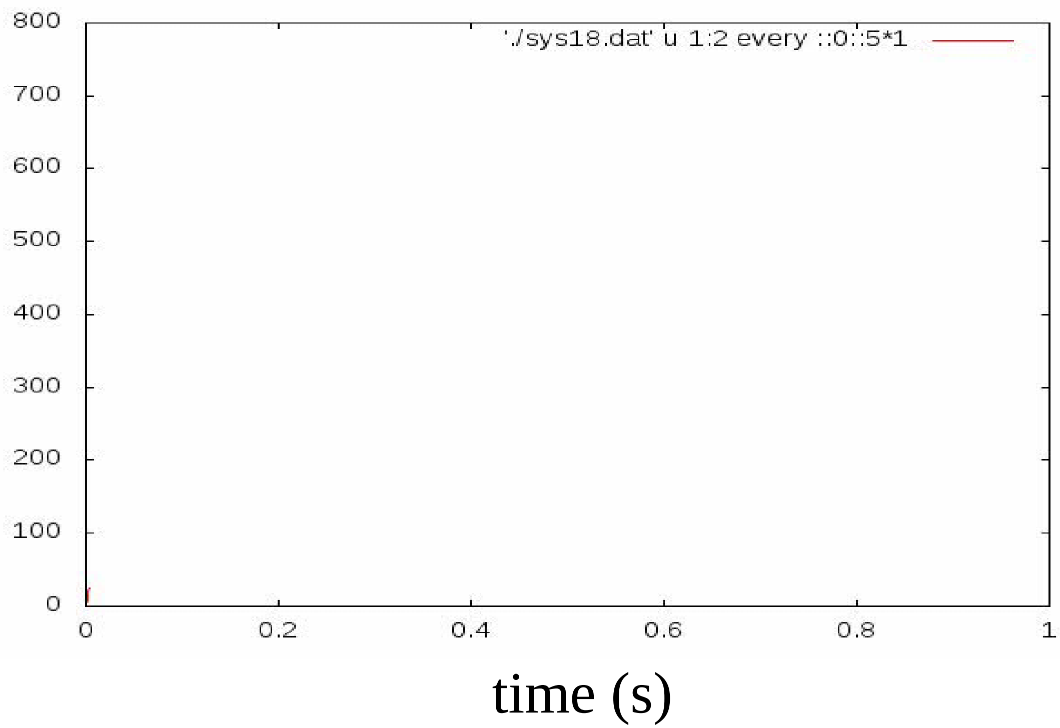
No control

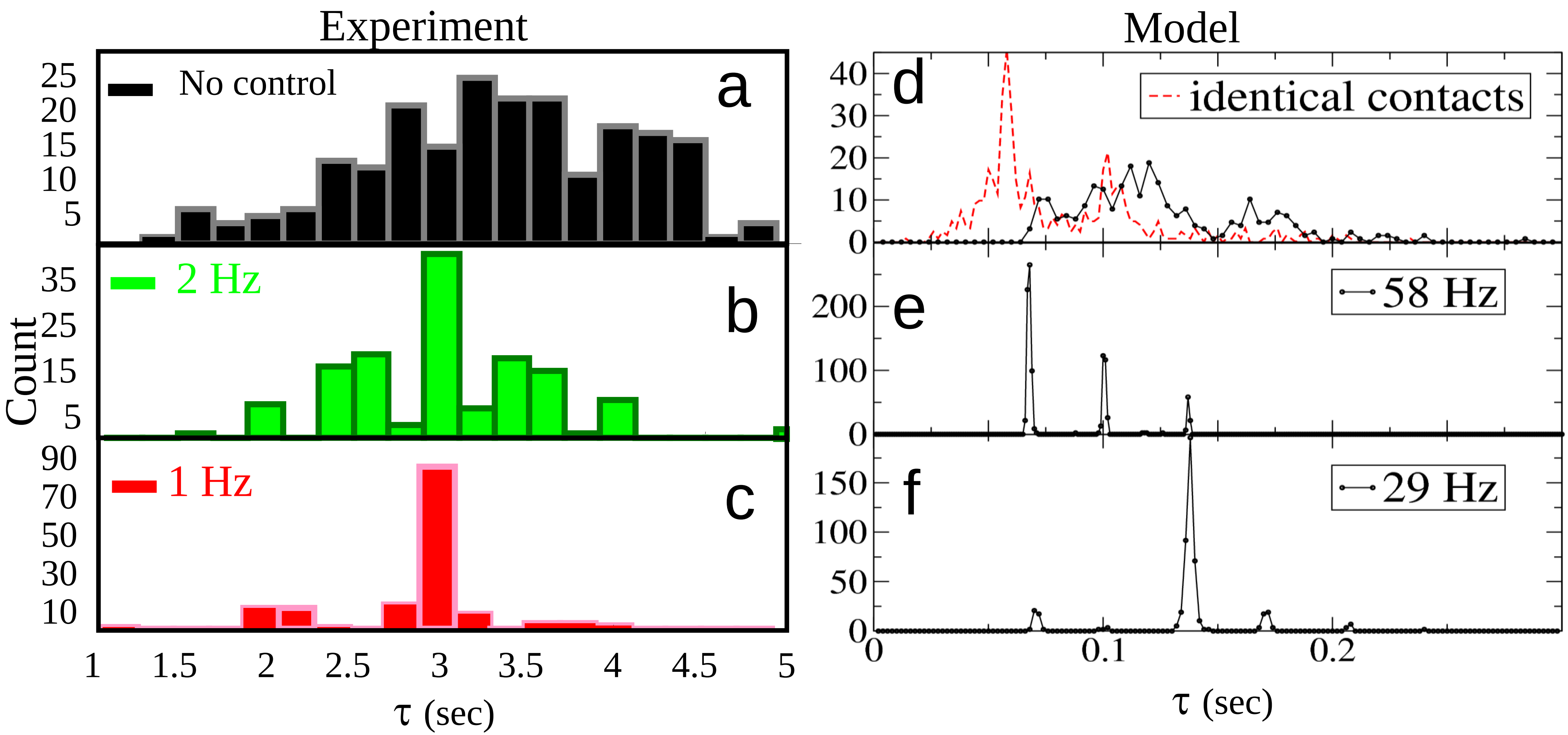
F_L



Control

F_L





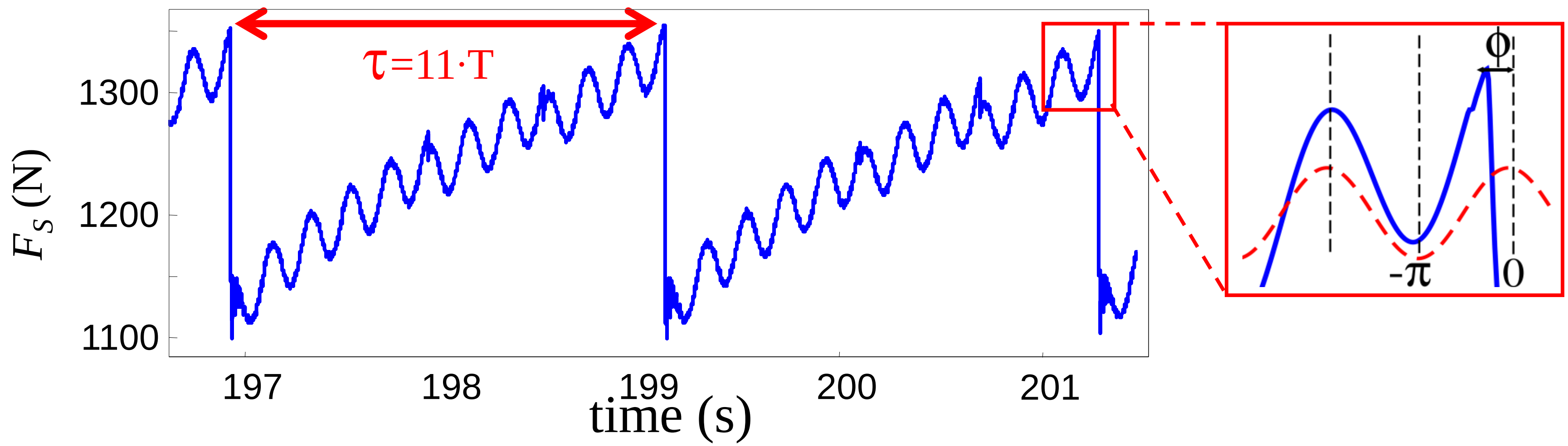
Phys. Rev Lett. 107, 024301(2011)

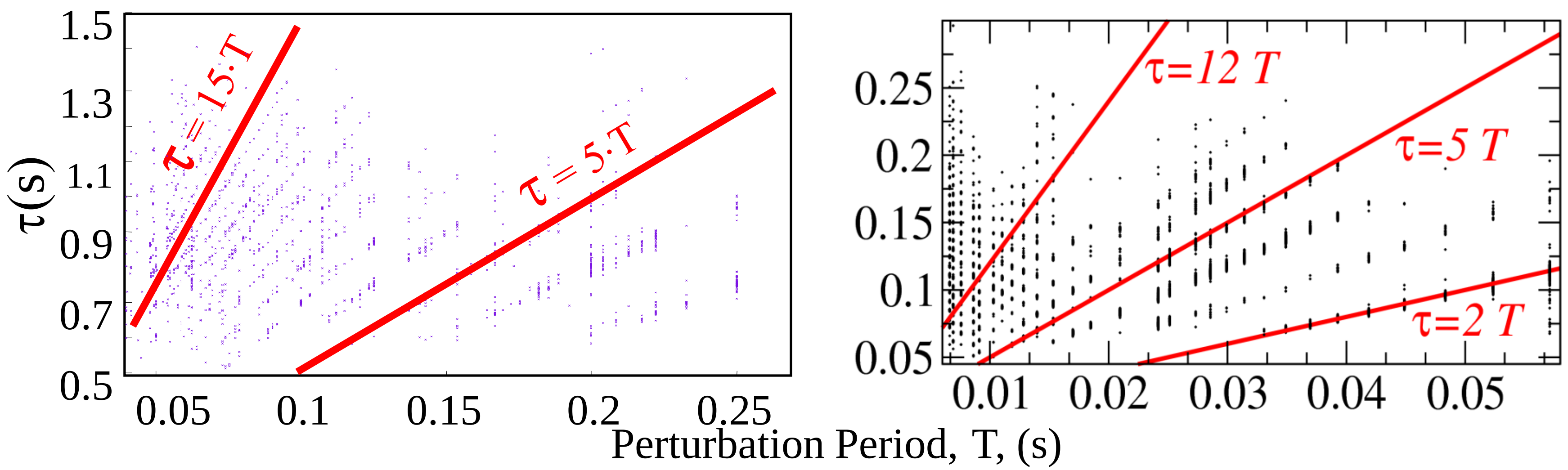
Even **relatively small** perturbations can cause the interval between successive stick-slip events to phase-lock to the perturbation frequency.

$$0.002 < \Delta F_S \; / \; F_S^m < 0.05$$

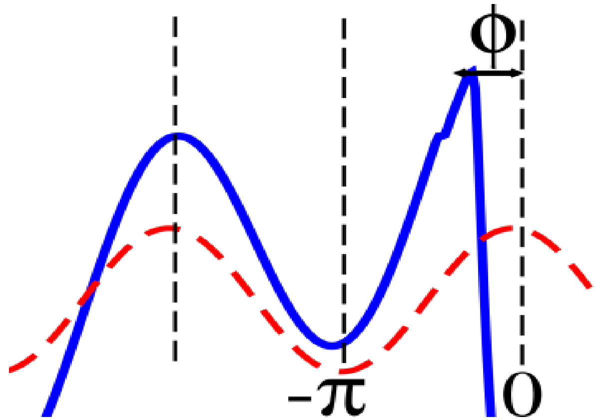
<u>Phase locking</u>: for frequencies much higher than the typical stick-slip frequency.
The stick time adapts itself to the value of T, such that $\tau = nT$

$\phi = 2\pi\Delta t / T$



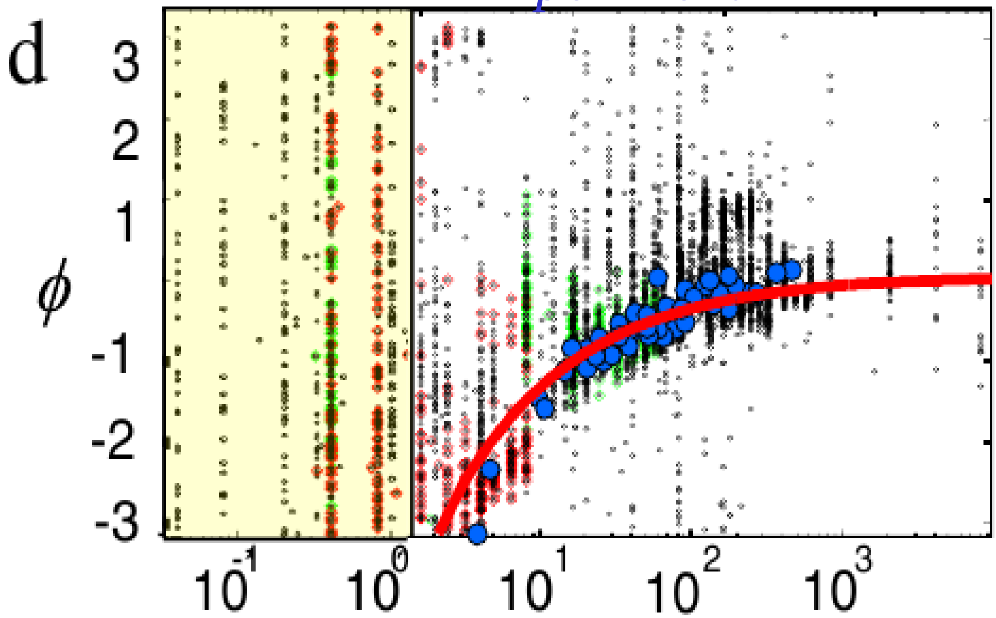


<u>Slip time relative to the forcing</u>: temporal shift, **Δt**, from the closest peak of the force modulation..

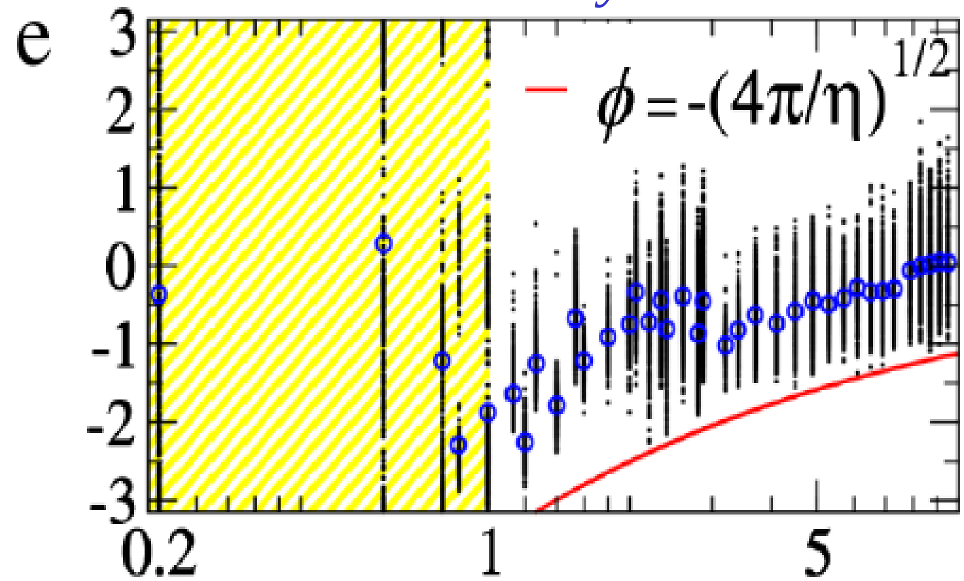


$$\phi = 2\pi\Delta t / T$$

Experiment



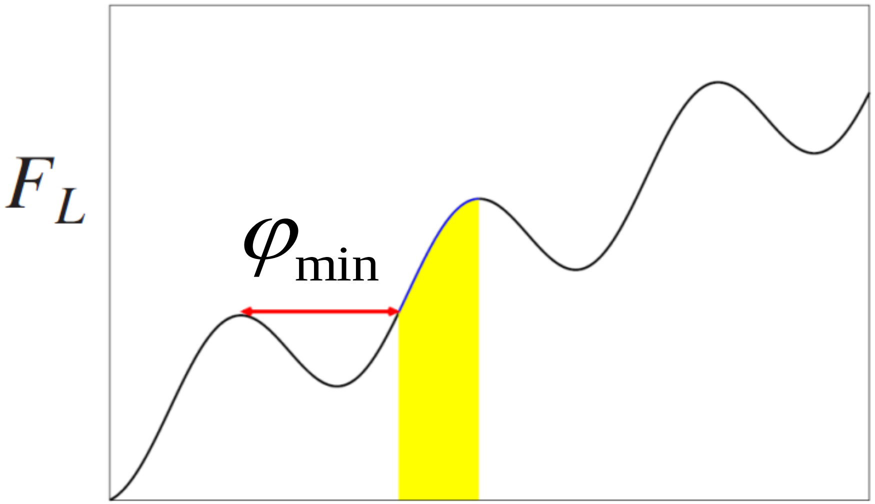
Theory



Phys. Rev Lett. 107, 024301(2011)

$$\eta = 2\pi\Delta / T\, V_0$$

Minimal possible value of the phase: the loading force associated with this phase is higher than the preceding maximum of F_L in the loading curve.



$$F_L = K_d[V_0 t + \Delta\cos(2\pi t/T)]$$

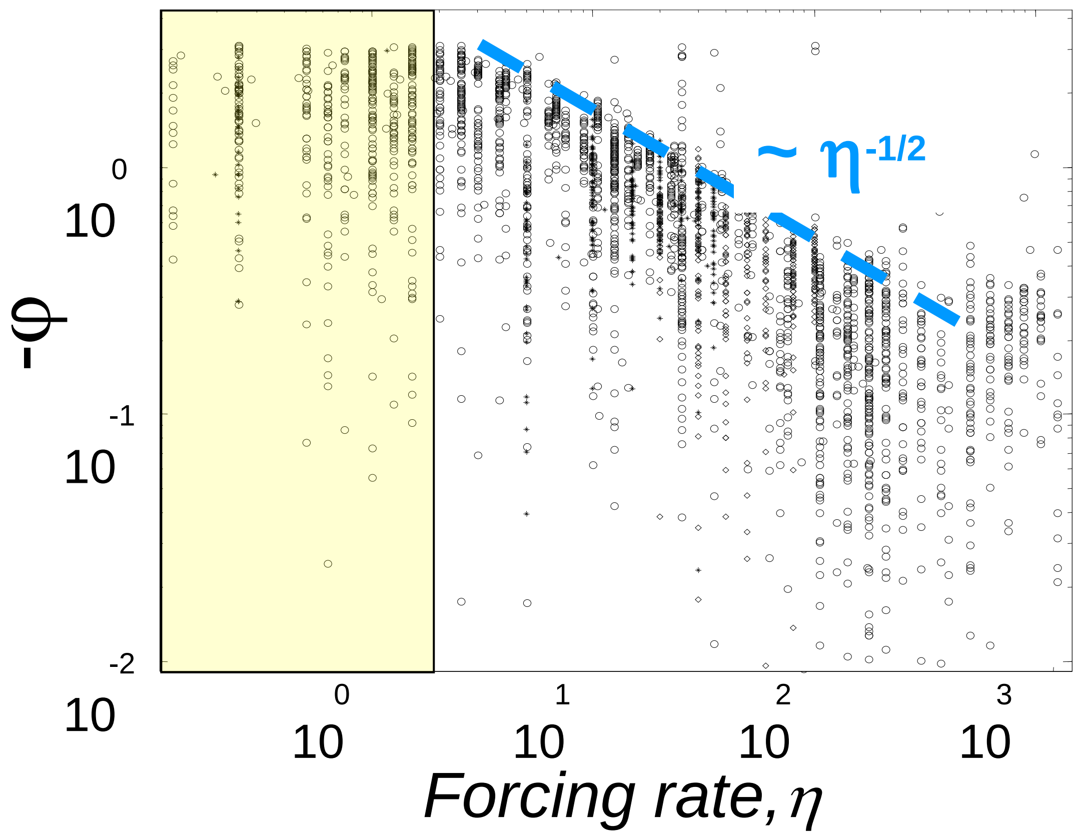
Controlling parameter

$$\varphi_{\min} + \eta\cos(\varphi_{\min}) = \Phi_{\max} + \eta\cos(\Phi_{\max}) \qquad \eta = \frac{2\pi\Delta}{TV_0}$$

- For values $\eta < 1$ the loading force changes monotonically with time and harmonic oscillations do not influence the stick-slip pattern.
- For $\eta >> 1$ we have the following asymptotic behavior of the phase:

$$\varphi_{\min} \approx -2(\pi/\eta)^{1/2}$$

Power law behavior of the phase



(i) ***η is indeed a relevant parameter that controls a frictional response to harmonic perturbations***

(ii) ***There exists minimum value of $\eta \sim 1$, below which no phase-locking is observed;***

(iii) ***When control is applied a well-defined "backbone" exists, below which the onset of stick-slip motion will (nearly) never occur;***

(iv) ***This backbone is described by the power law form: $\varphi \propto \eta^{-1/2}$.***

The data for stick-slip events are strongly clustered above this curve.

Conclusions

- Small oscillatory perturbations **synchronize** the periods between consecutive slip events.

- A **model** explains the experimental observations and elucidates the mechanism for phase locking.

- We have identified one of the **relevant dimensionless parameter** and shown how this functionally affects the locking phase.

- The main effect of perturbations on the detachment dynamics is the **elimination of slow fronts** which correspond to a **critical state**.