Avalanche phenomena in a sheared granular layer coupled to soft elastic plates

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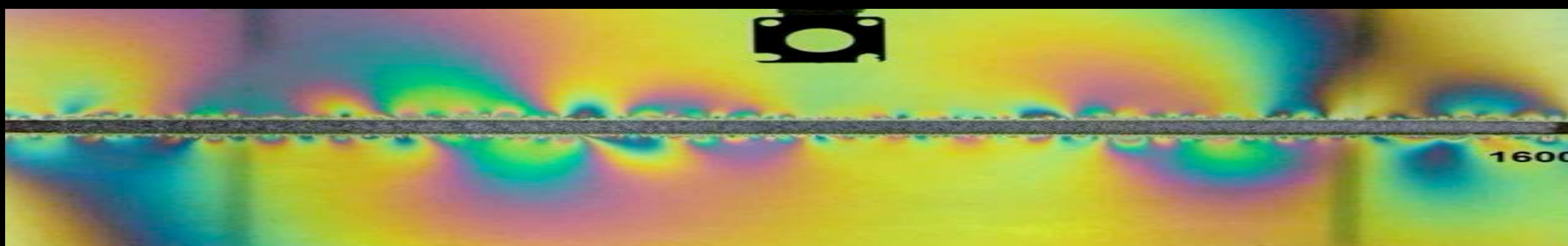
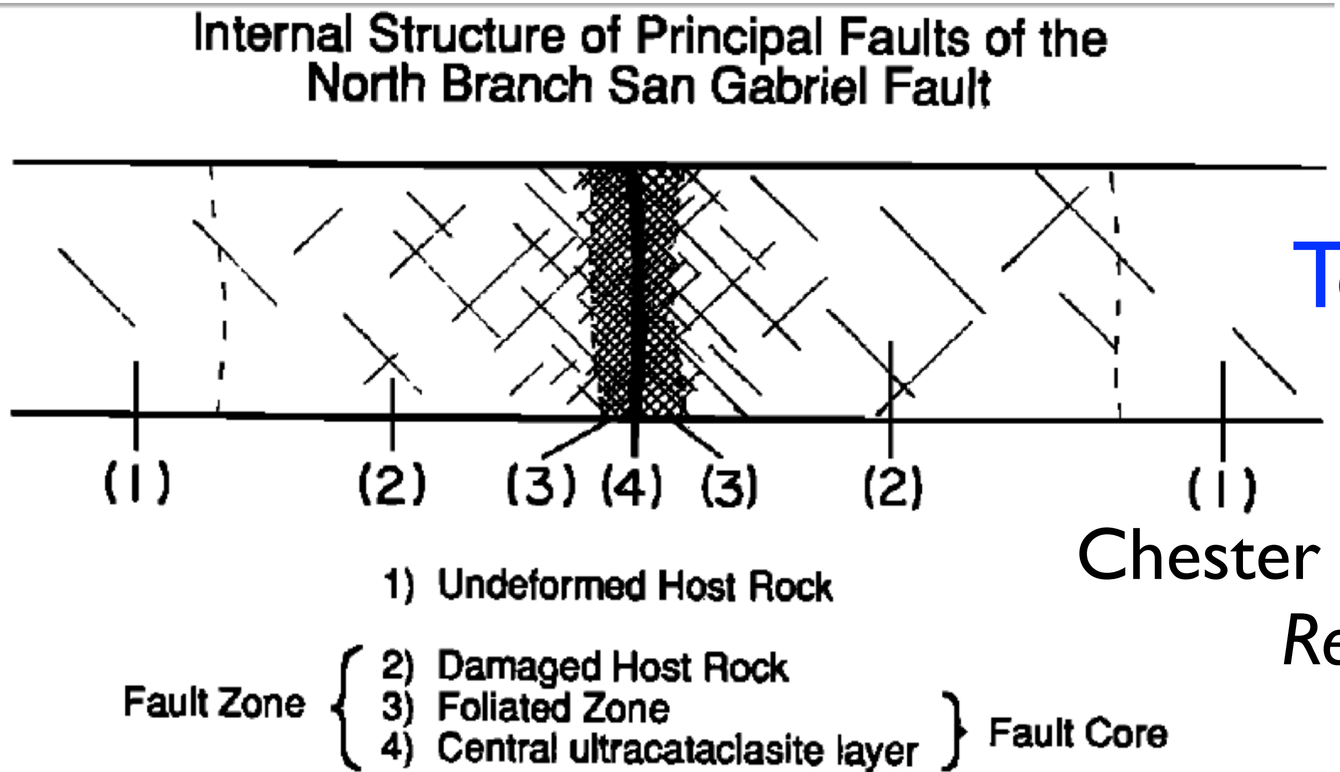


Center for Nonlinear Studies

Los Alamos

Earthquakes are complex and impactful - What are their essential ingredients?

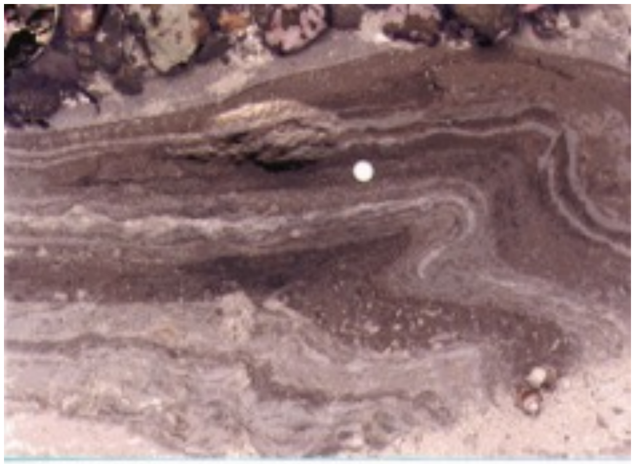
Fault zones contain gouge, a granular material



Top View

Chester et al., *J. Geophys. Res.* (1993)

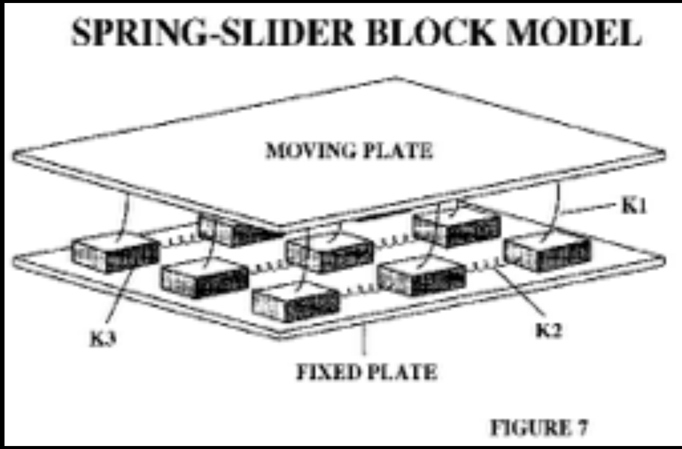
Granular Fault Gouge



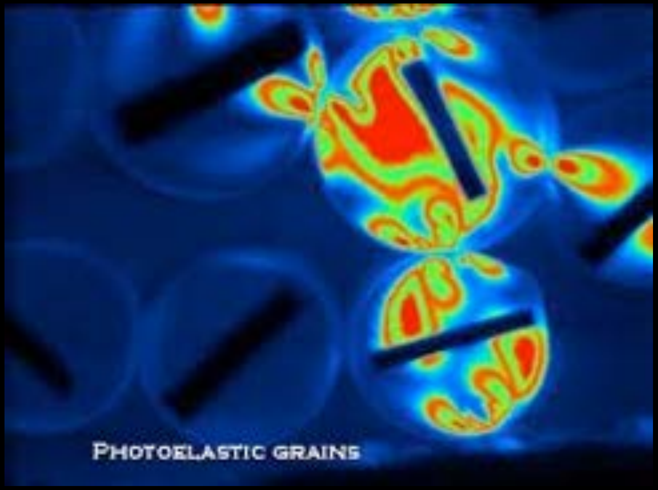
ref: http://crust.geol.vt.edu/asayed/research/Gouge.htm

Approaches to modeling and understanding earthquake phenomena using simulations and analog experiments

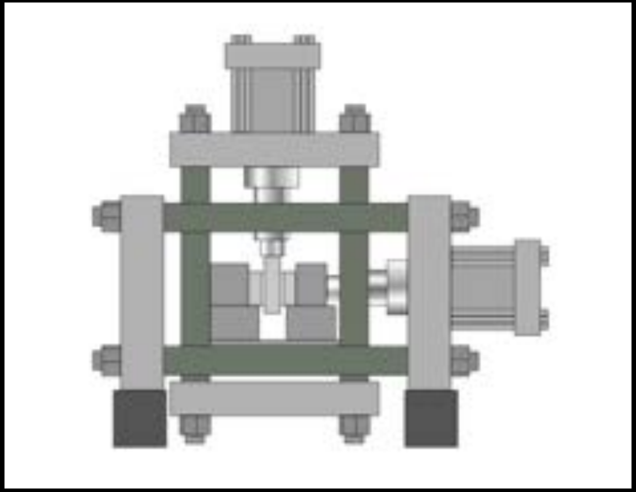
Burridge-Knopoff Models



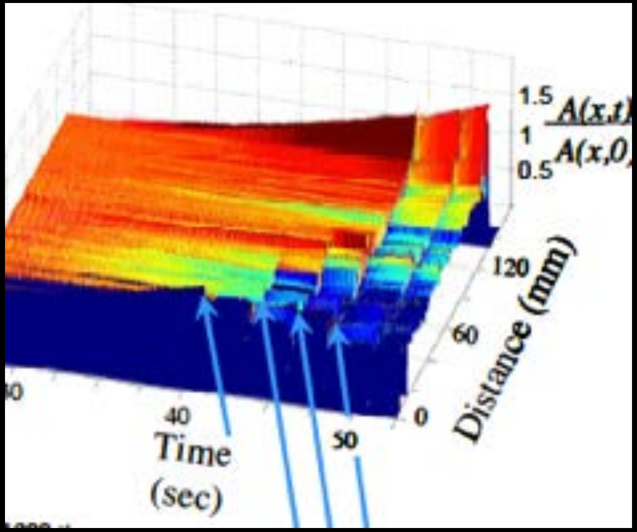
Granular Stick-Slip Behringer - Duke
Daniels - NC State



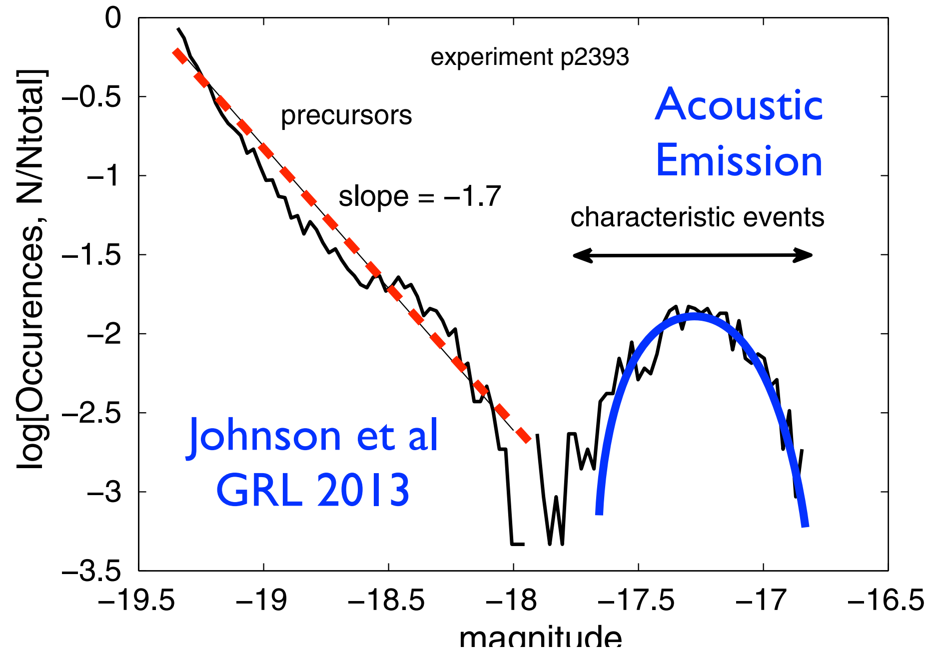
Granite Blocks w/ Glass
Granular - Marone PSU

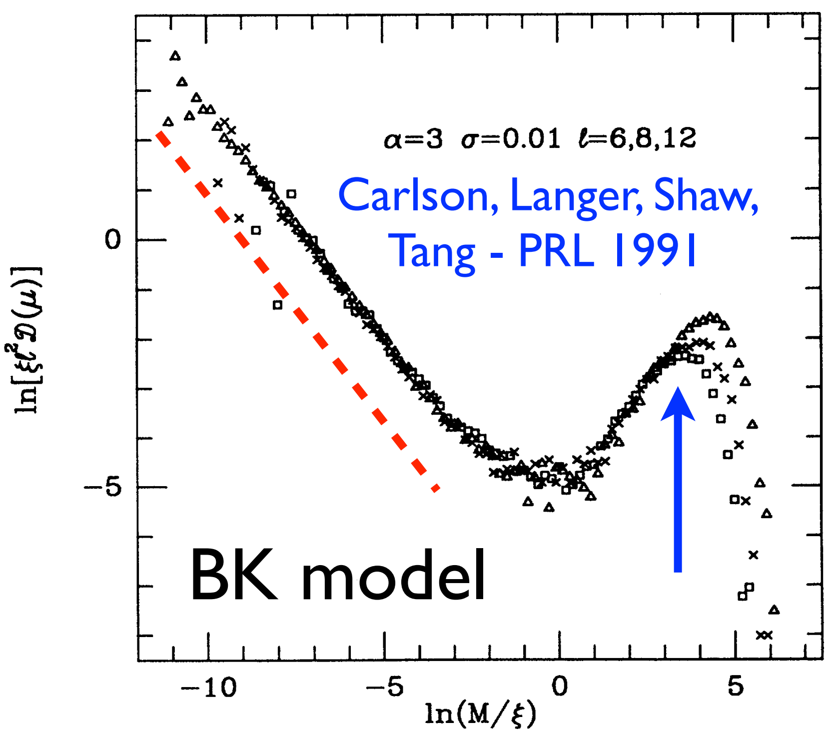


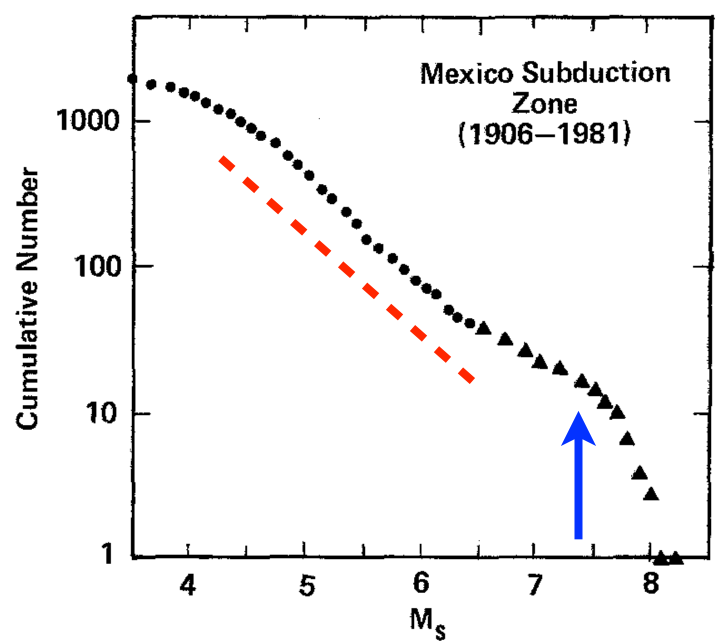
Block on Block Friction
Fineberg - Hewbrew U.



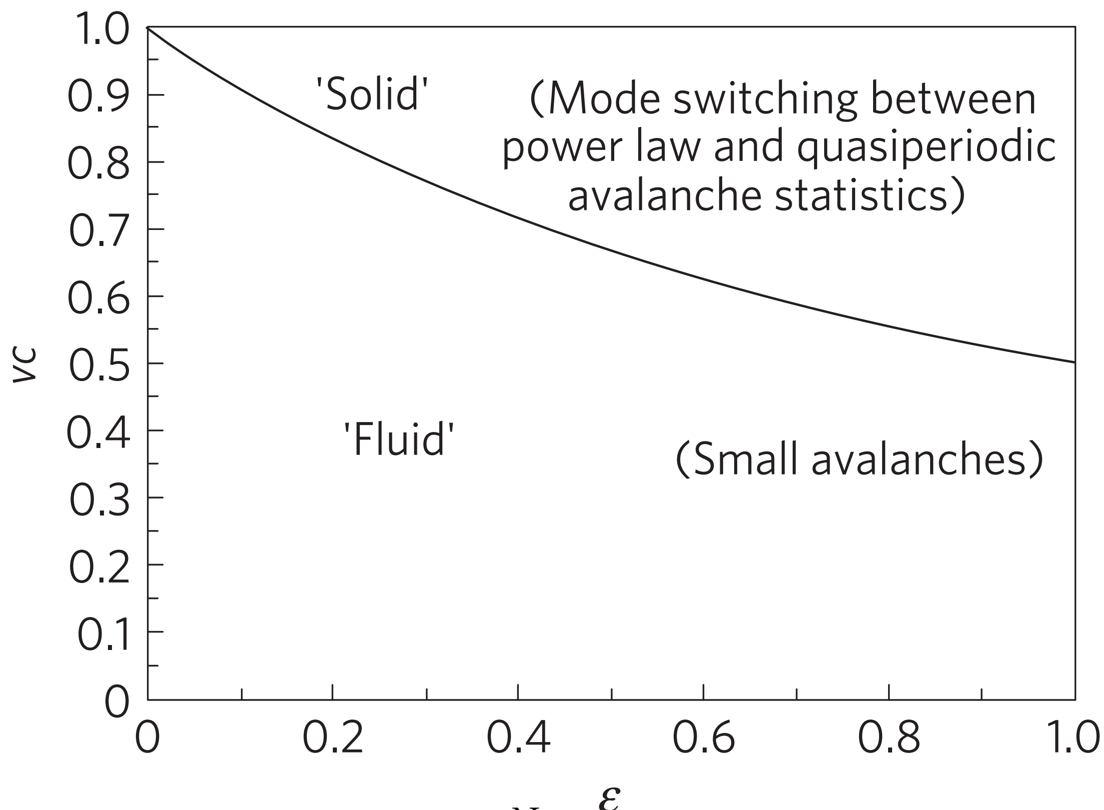
Some characteristics of models, measurements, and earthquakes

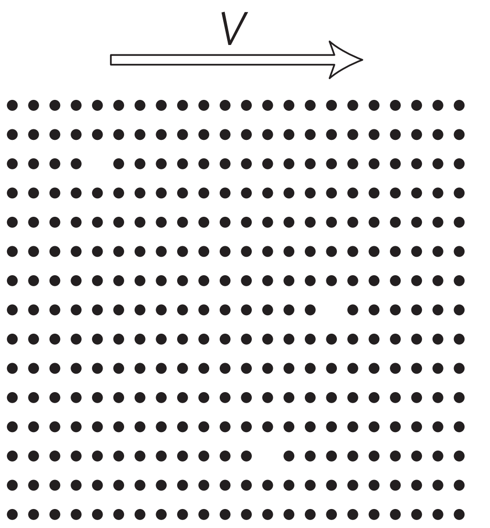






Mean-Field Models of Avalanches



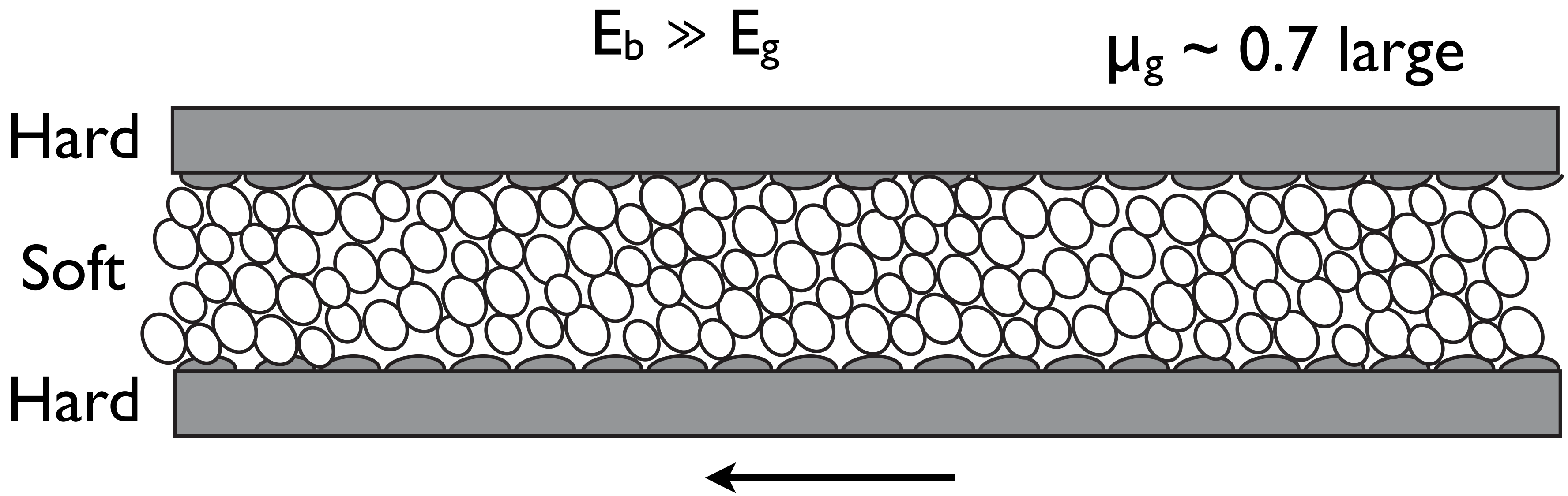


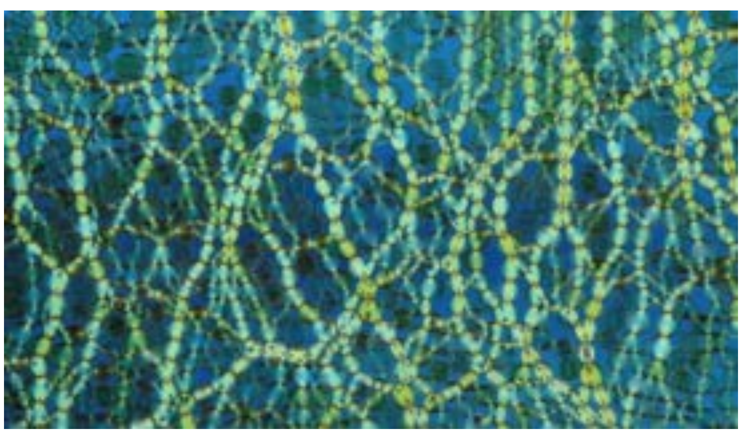
$$\tau_i(t) = Jo_i\left[\left(\sum_{m=1}^{N} o_m u_m(t)/N\right) - u_i(t)\right] + K_L(Vt - u_i(t))$$

Dahmen et al, Nat. Phys. 2011

D. Fisher/J. Sethna/J. Carlson/Rundle-Klein…

Sheared soft granular layers



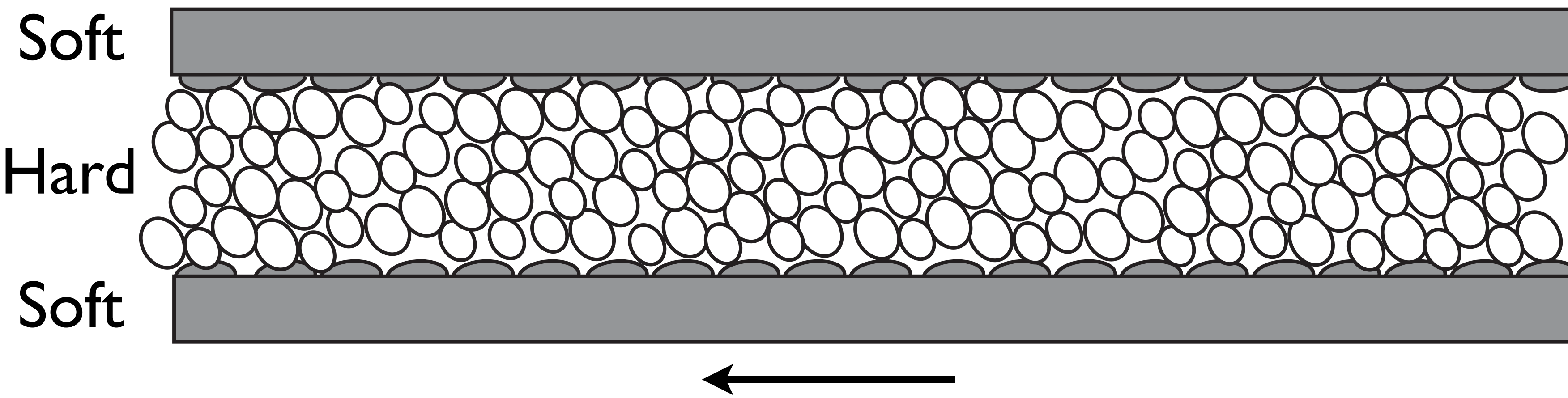


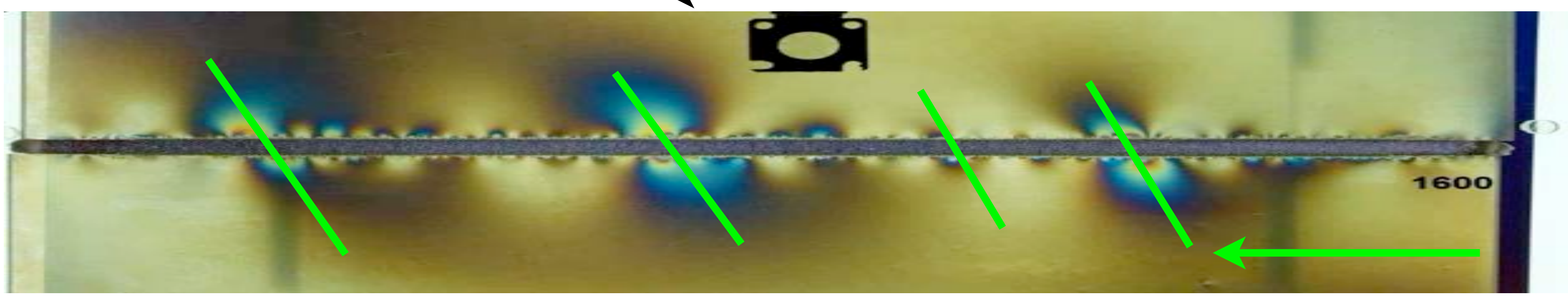
Behringer, Daniels, etc.

- Forces transmitted by heterogenous stress chain network
- Shear jamming
- Stick-slip behavior

Hard granular particles with soft boundaries

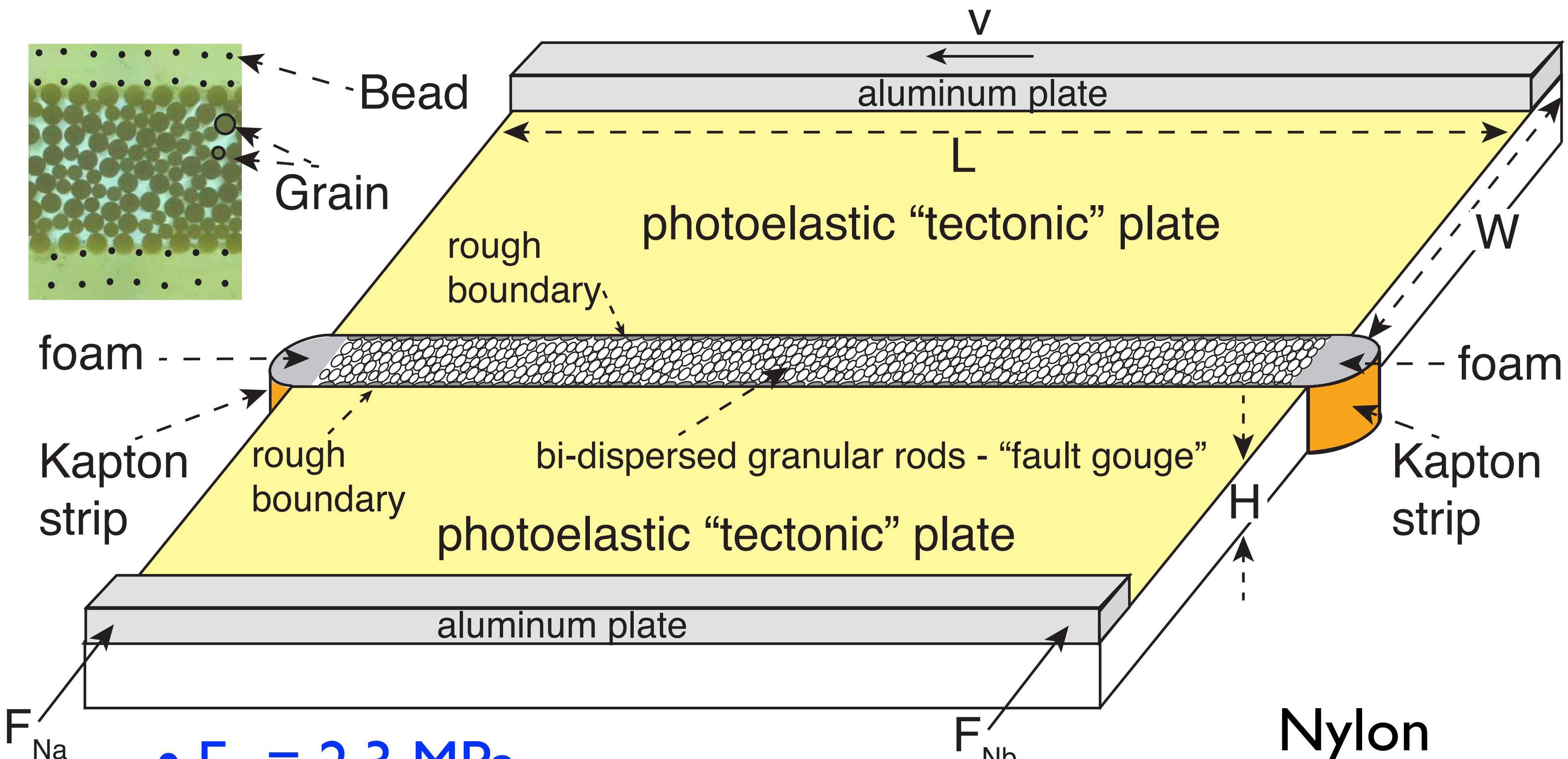
$E_g \gg E_b$ $\mu_g \sim 0.2$ small





Hard particles and soft boundaries self tune to jamming: $\phi \approx \phi_J \approx 0.7$

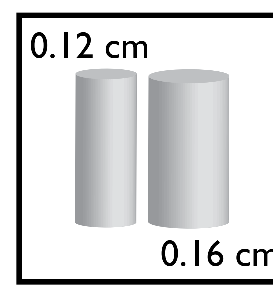
Apparatus: Soft spring drive, strain measurement



- E_p = 2.3 MPa
- E_g = 4 GPa

Nylon

Granular Rods



D. Geller, K. Dahmen, R. Ecke, S. Backhaus,
Phys. Rev E (R) (2015).

Experimental Apparatus

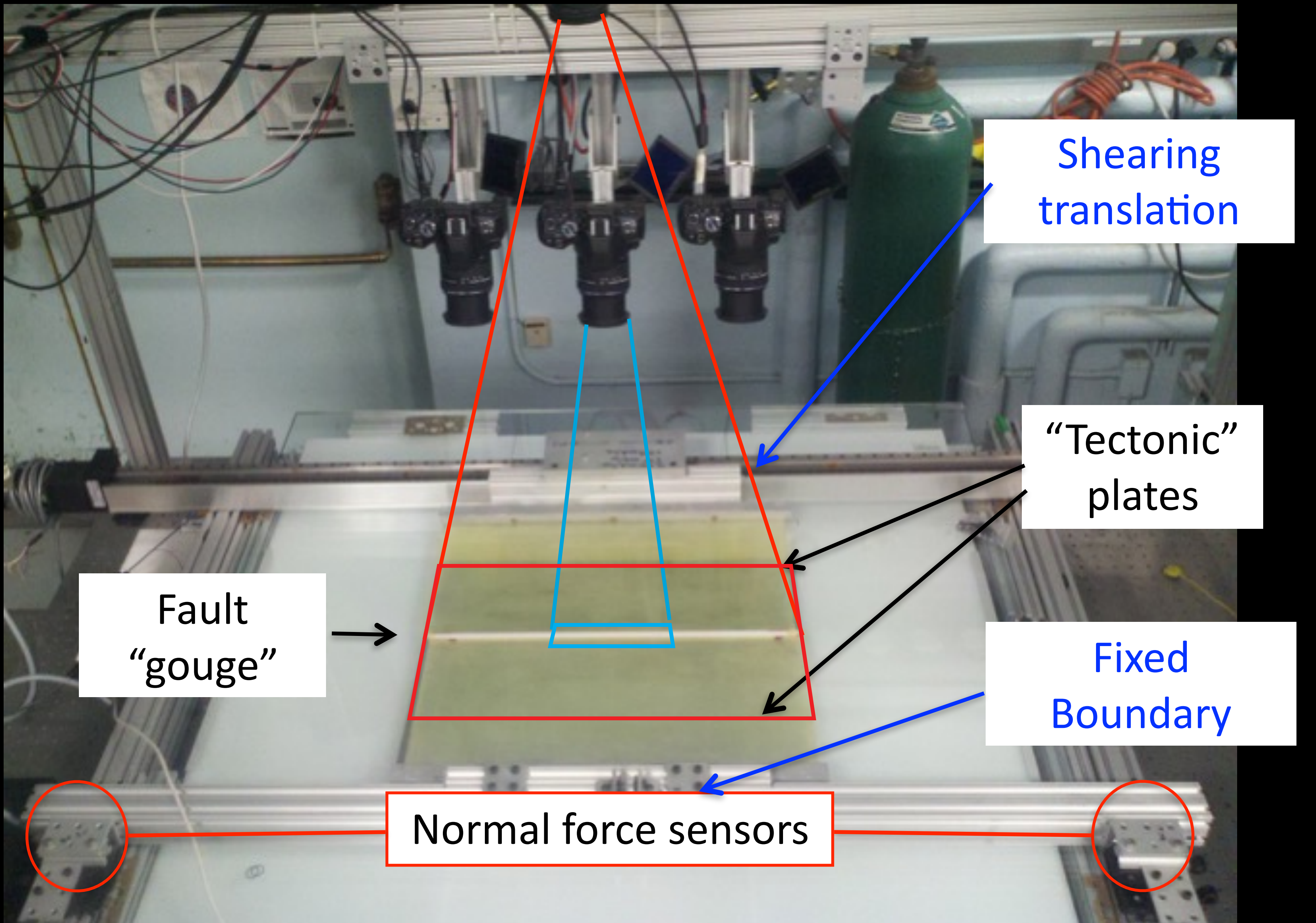
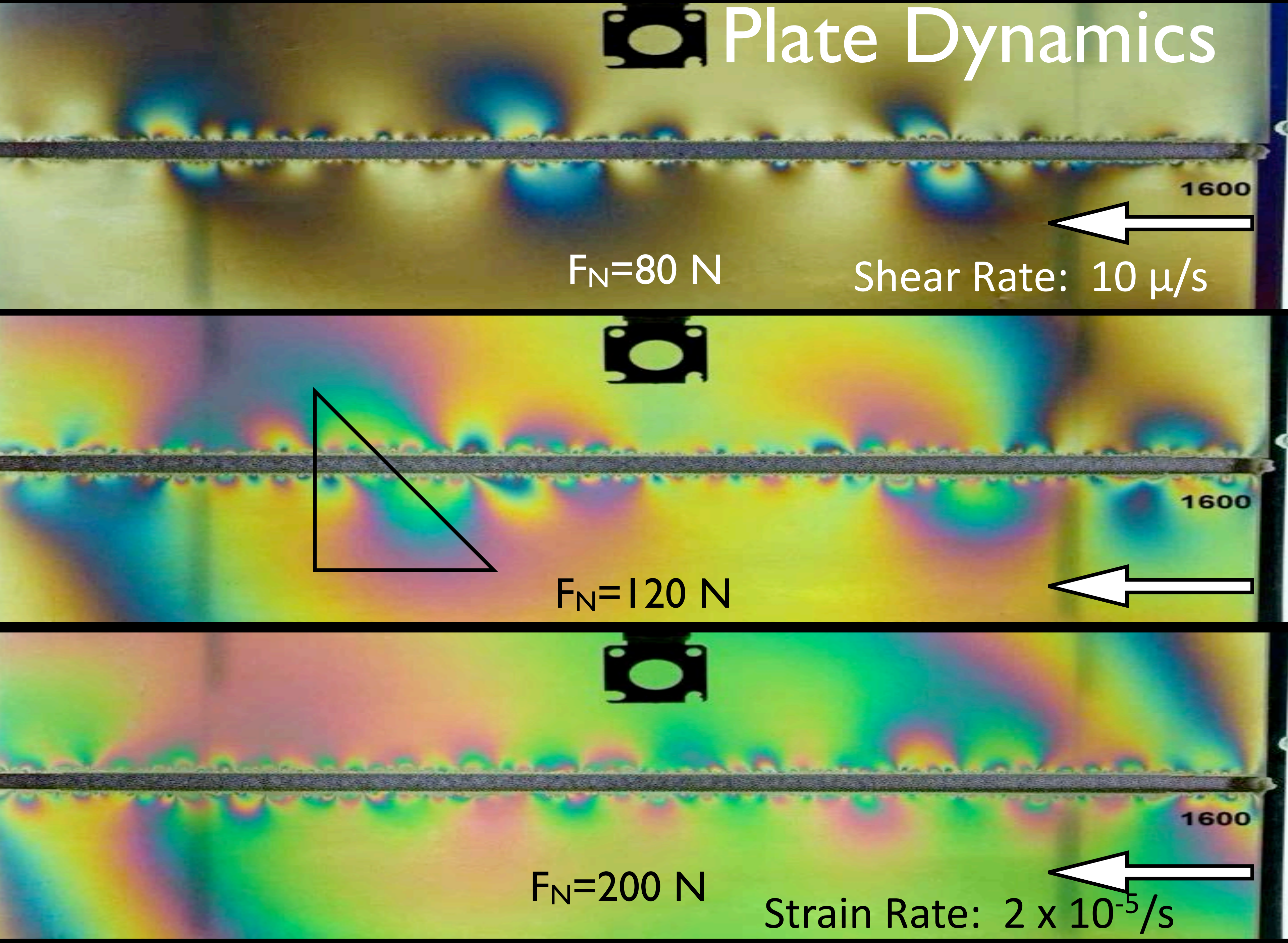
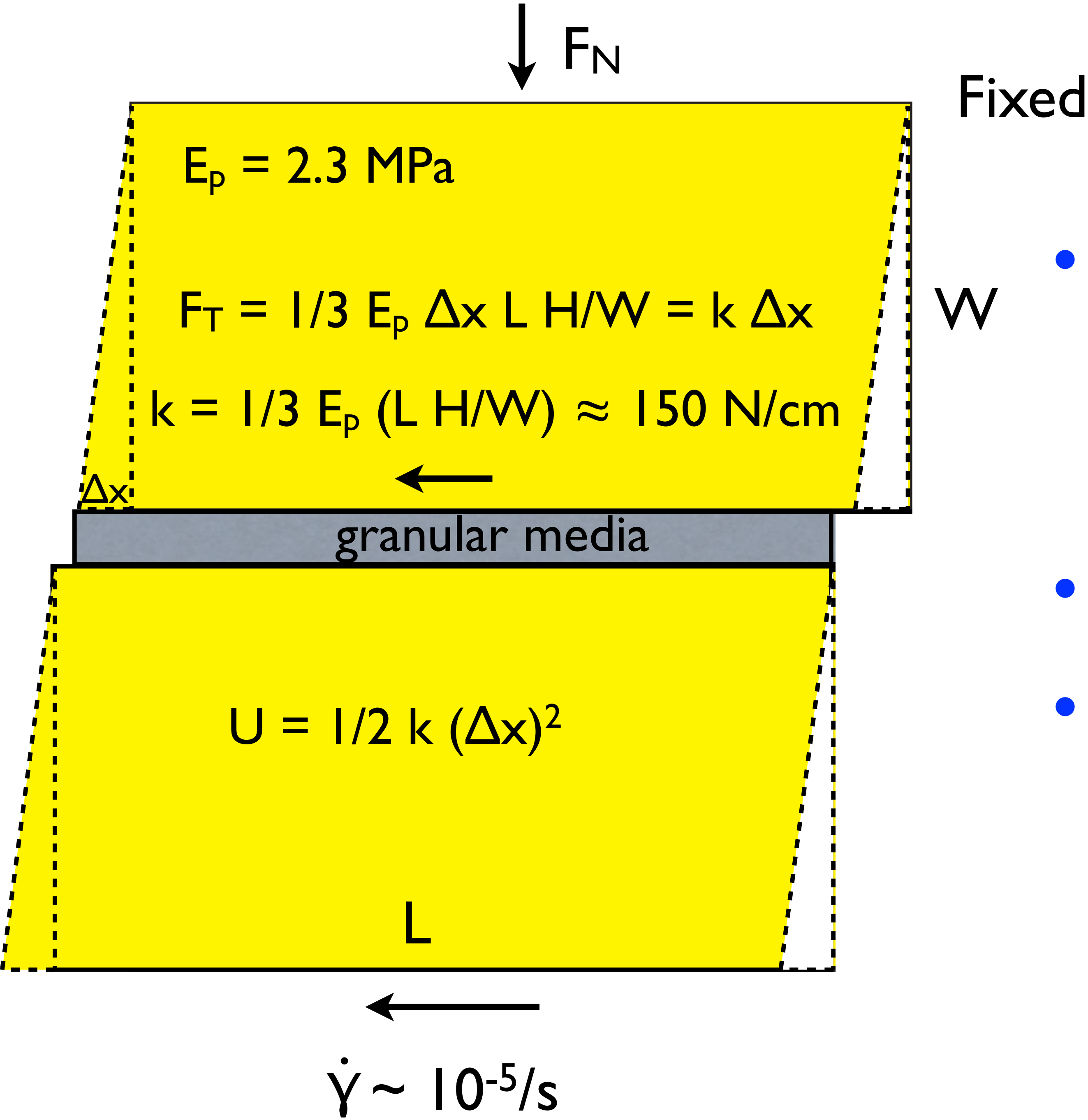
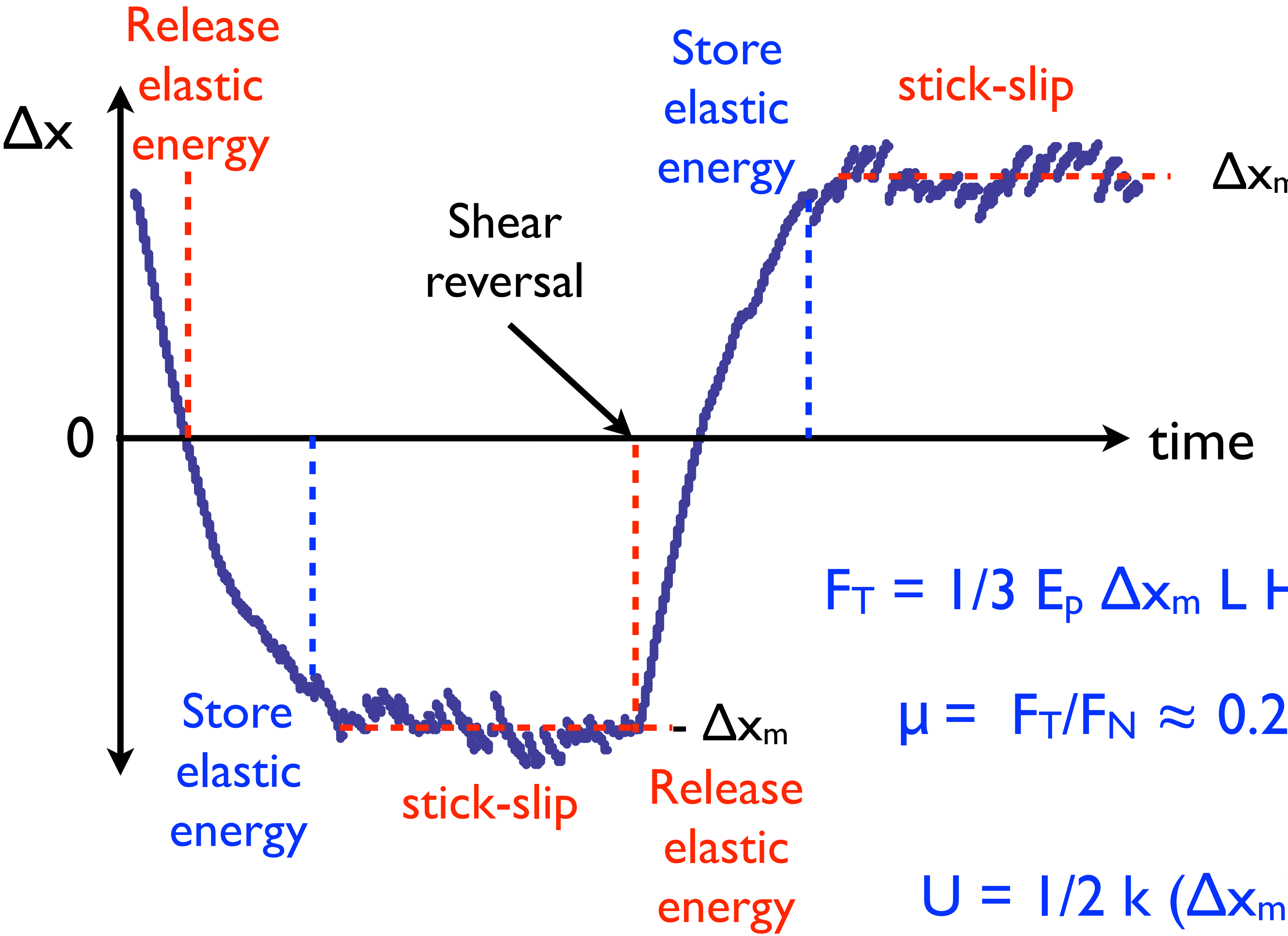


Plate Dynamics





- Stored elastic energy as plates deform under continuous shear
- Quasistatic
- Effective frictional coupling via stress chains

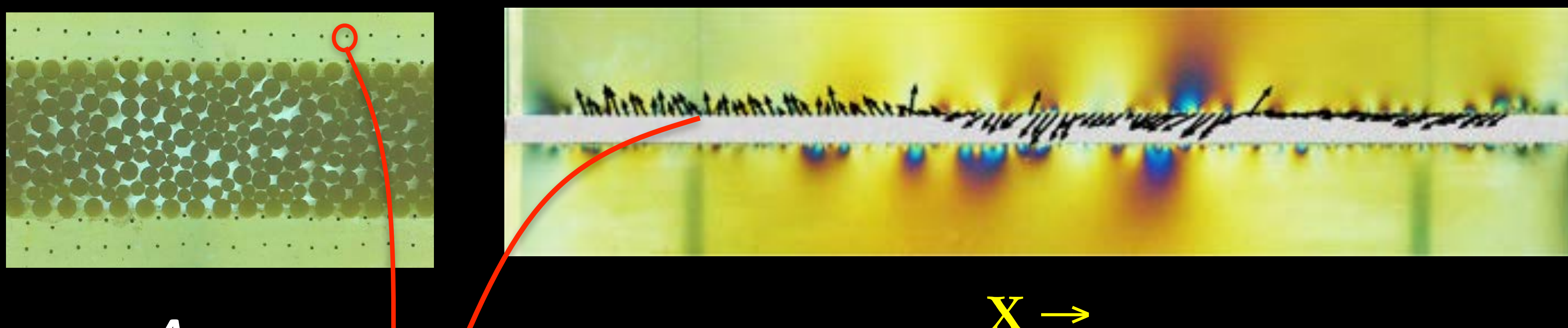


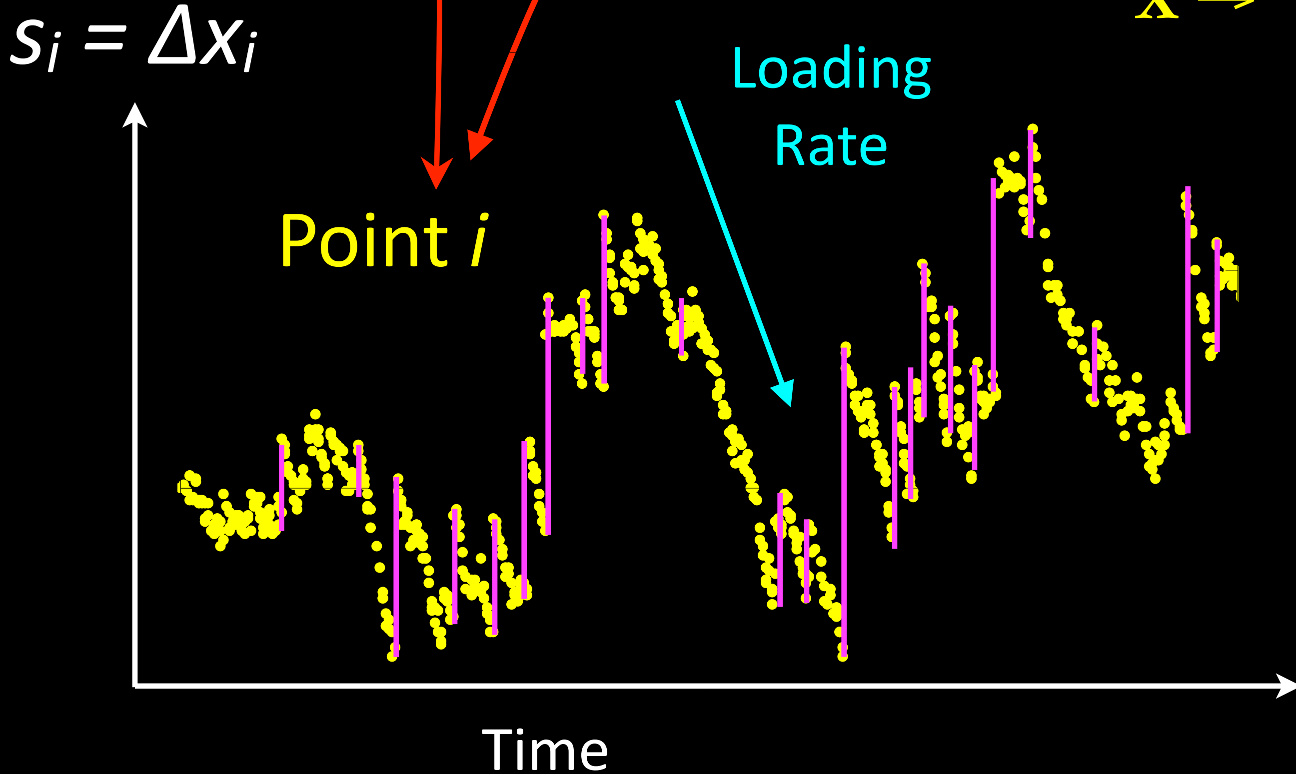
$F_T = 1/3\ E_p\ \Delta x_m\ L\ H/W$

$\mu = F_T/F_N \approx 0.22$

$U = 1/2\ k\ (\Delta x_m)^2$

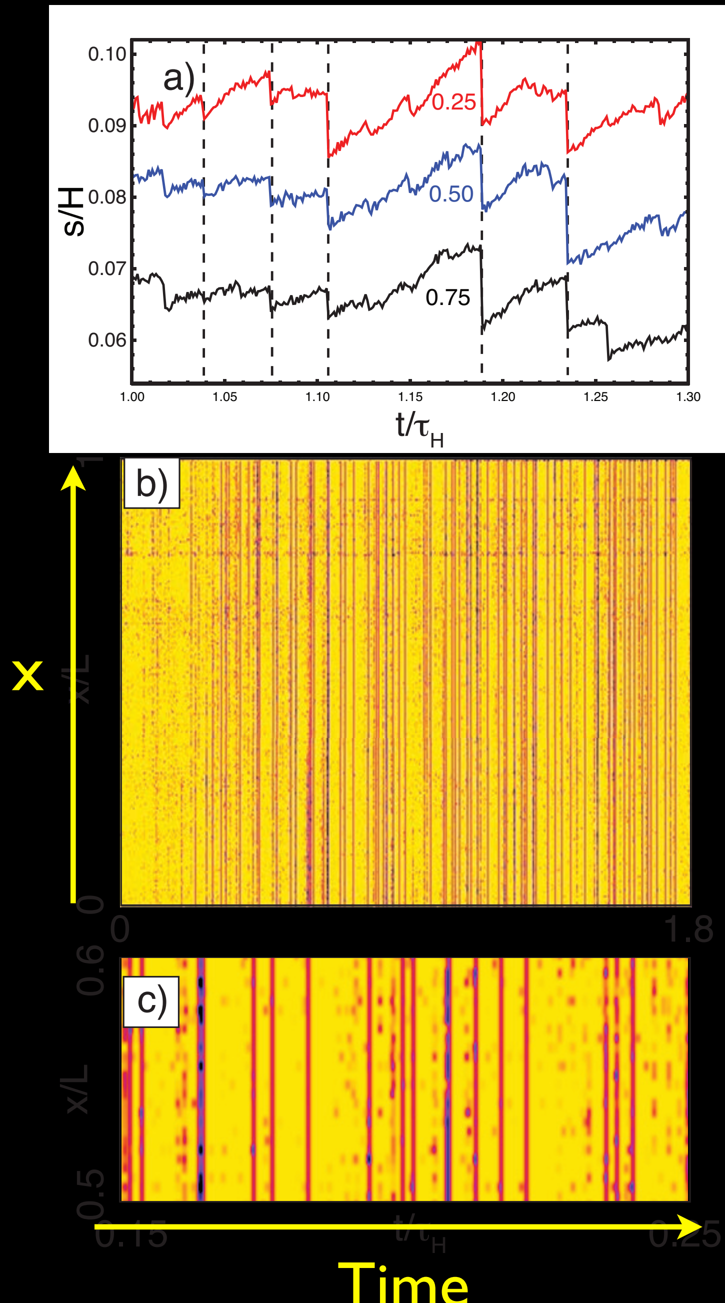
Detailed Interfacial Displacements





Moment of event j

$$M_j = \sum s_i^j$$



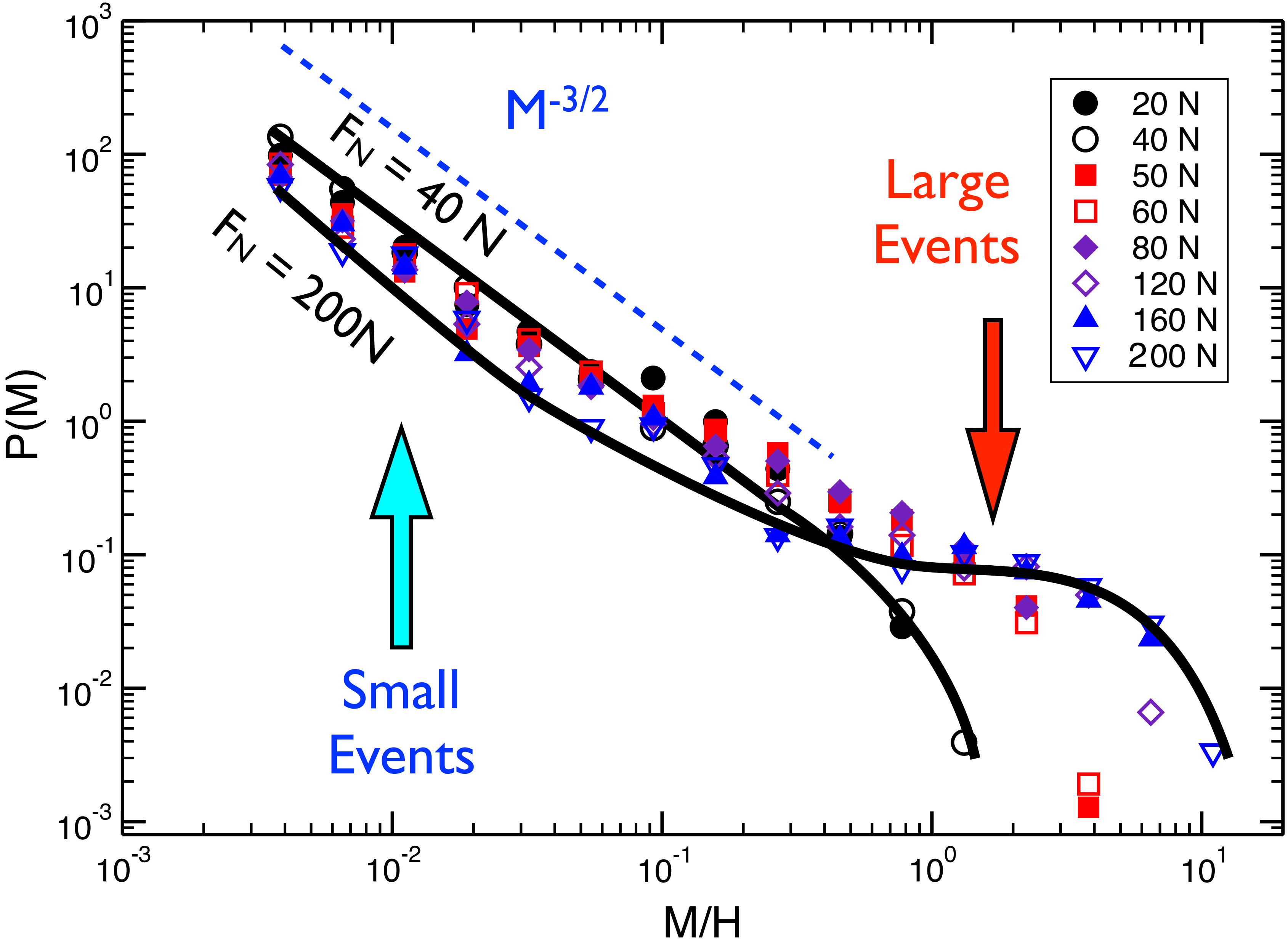
Spatial and Temporal Structure

System spanning events and mean recurrence

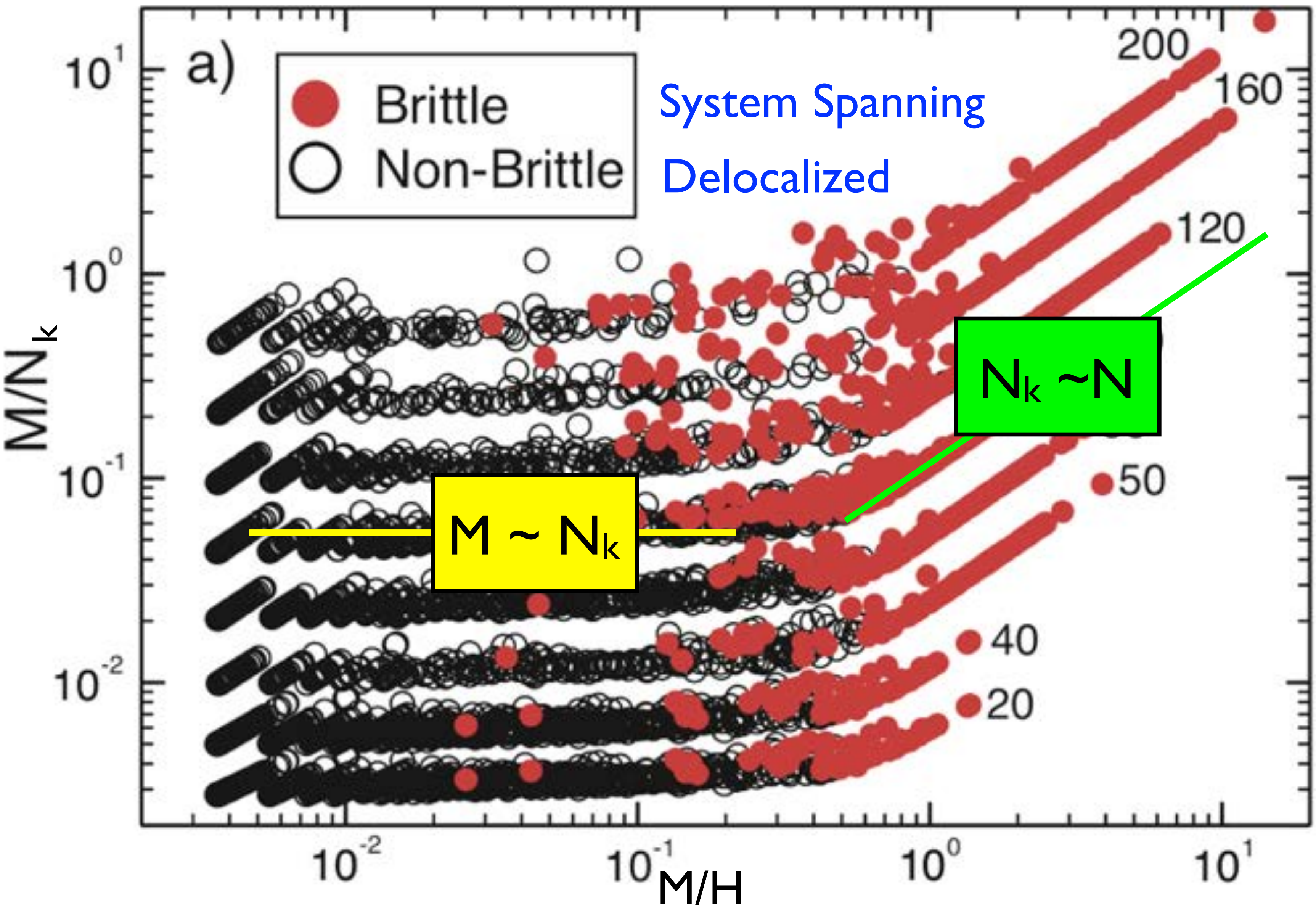
Compact & local events contrasted with delocalized events

Probability Distribution: Universal Feature?

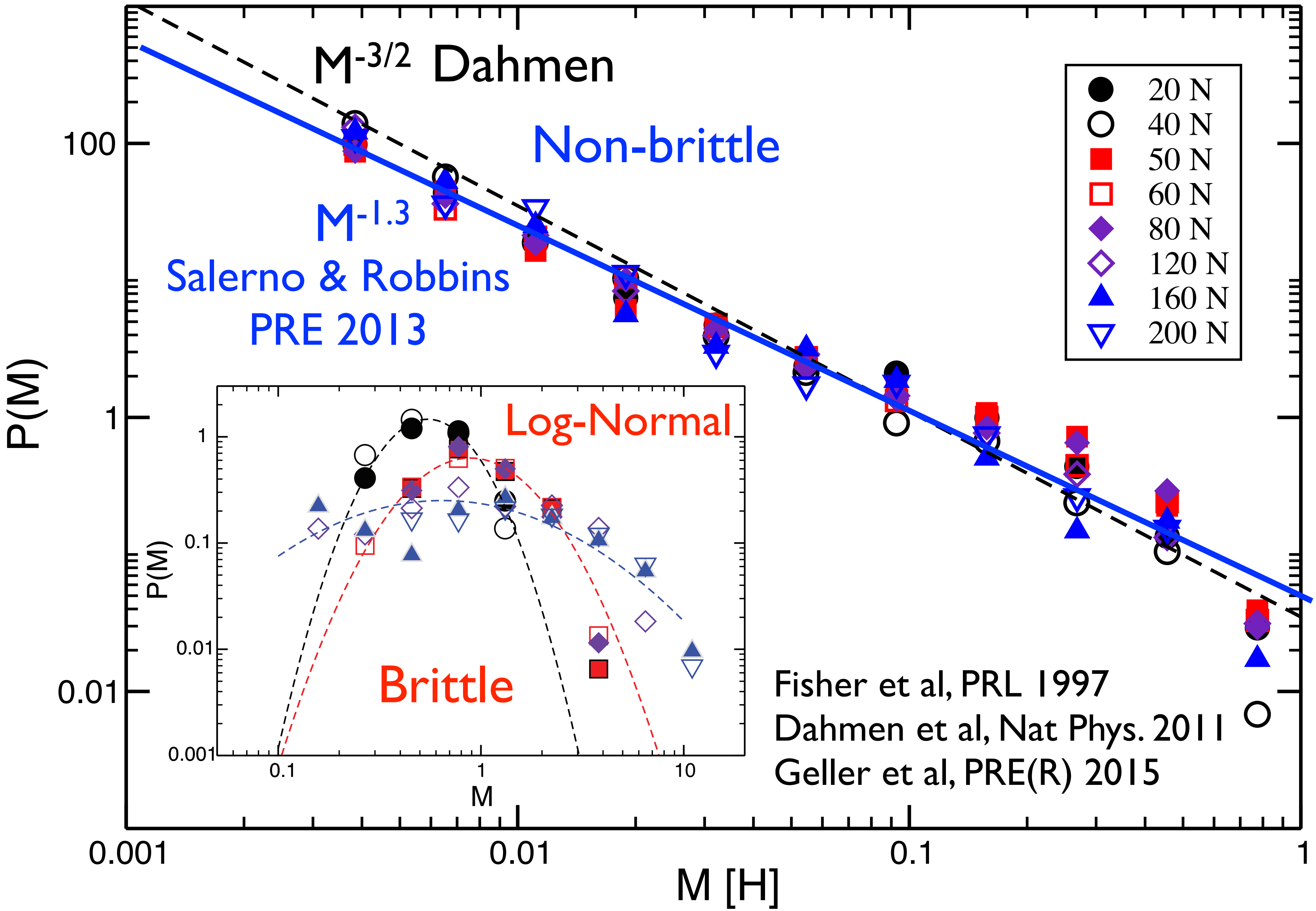
Moment Distribution



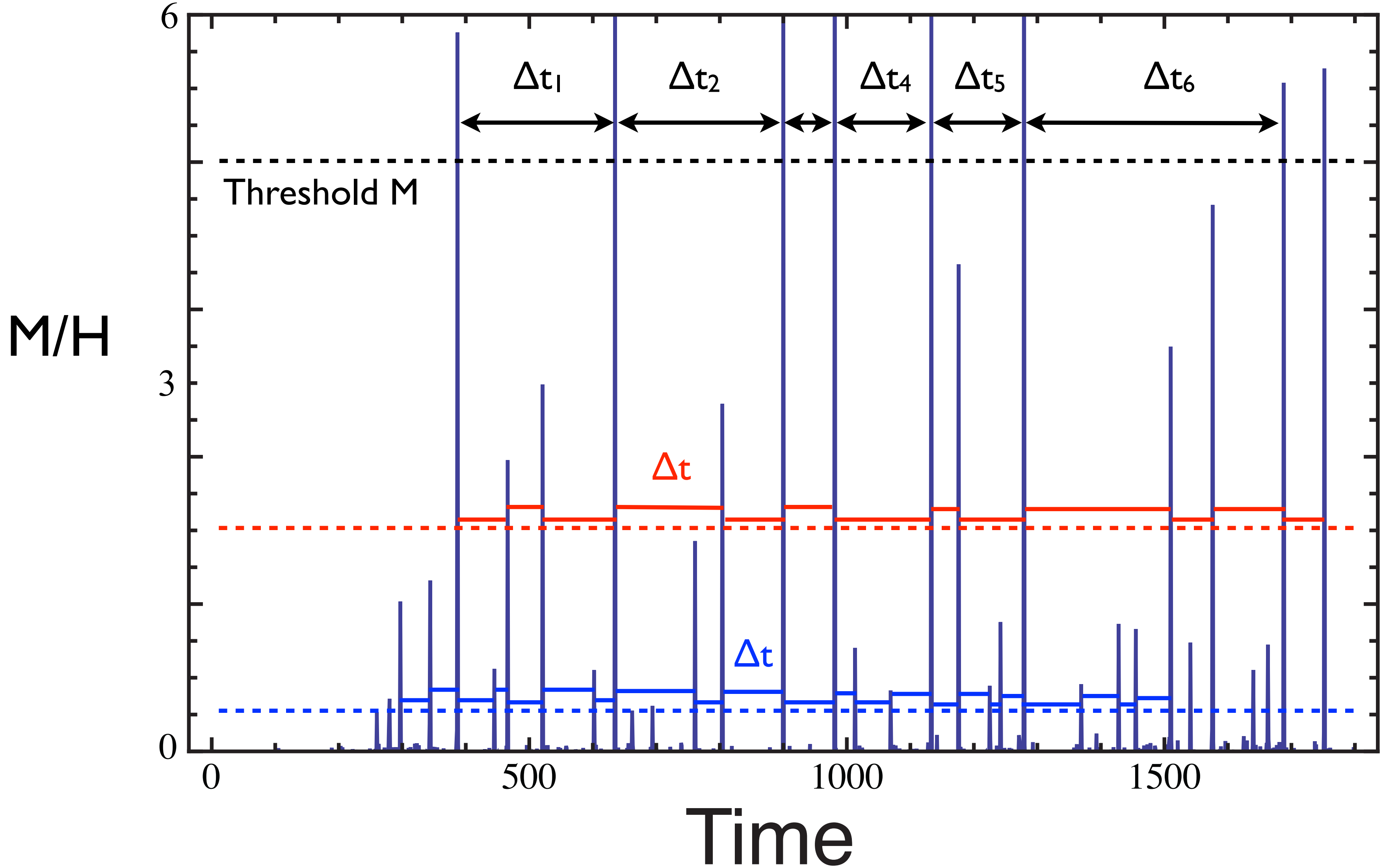
Moment per Number Moved N_k



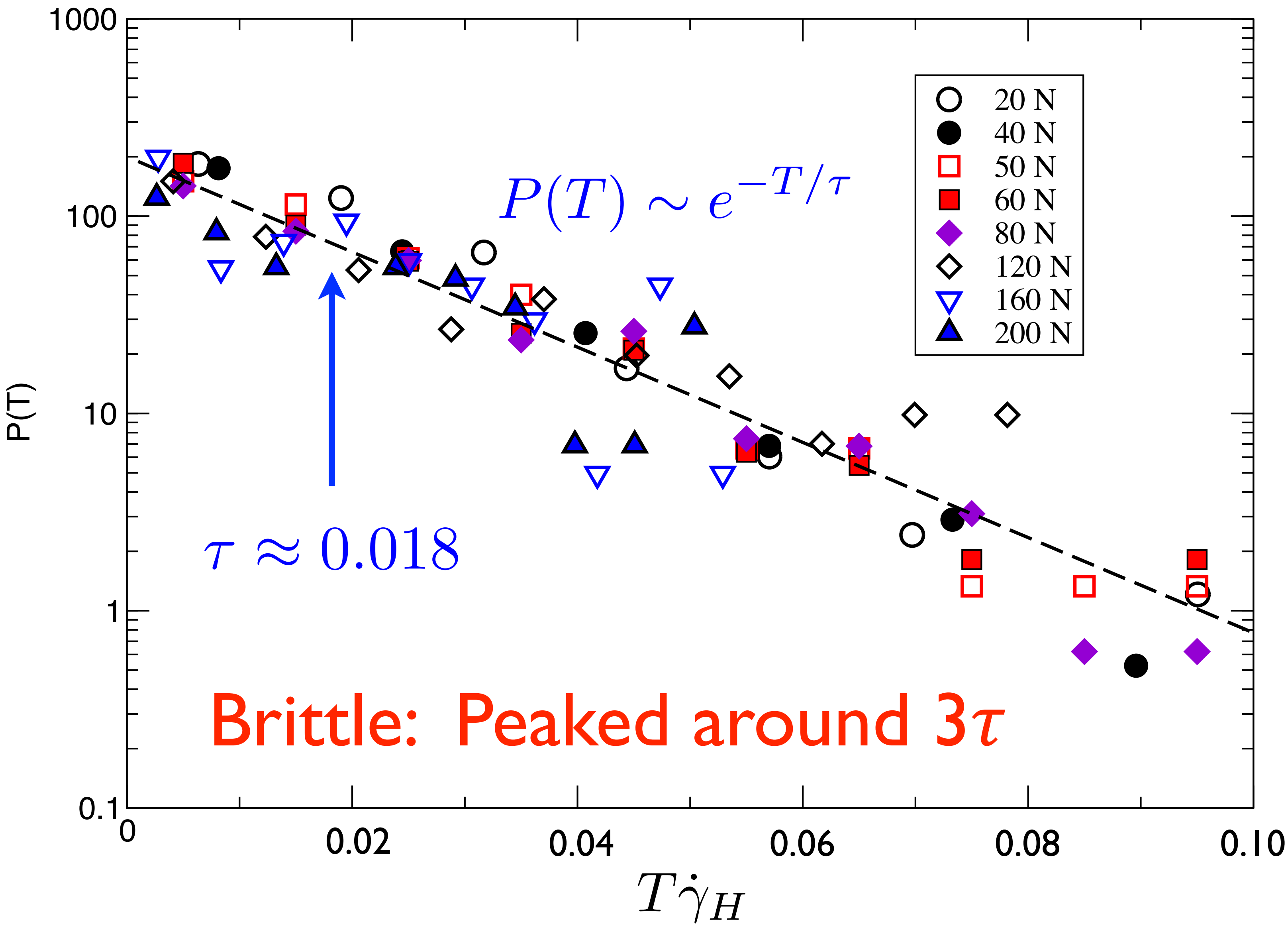
Large and Random Event Distributions



Recurrence Time Statistics



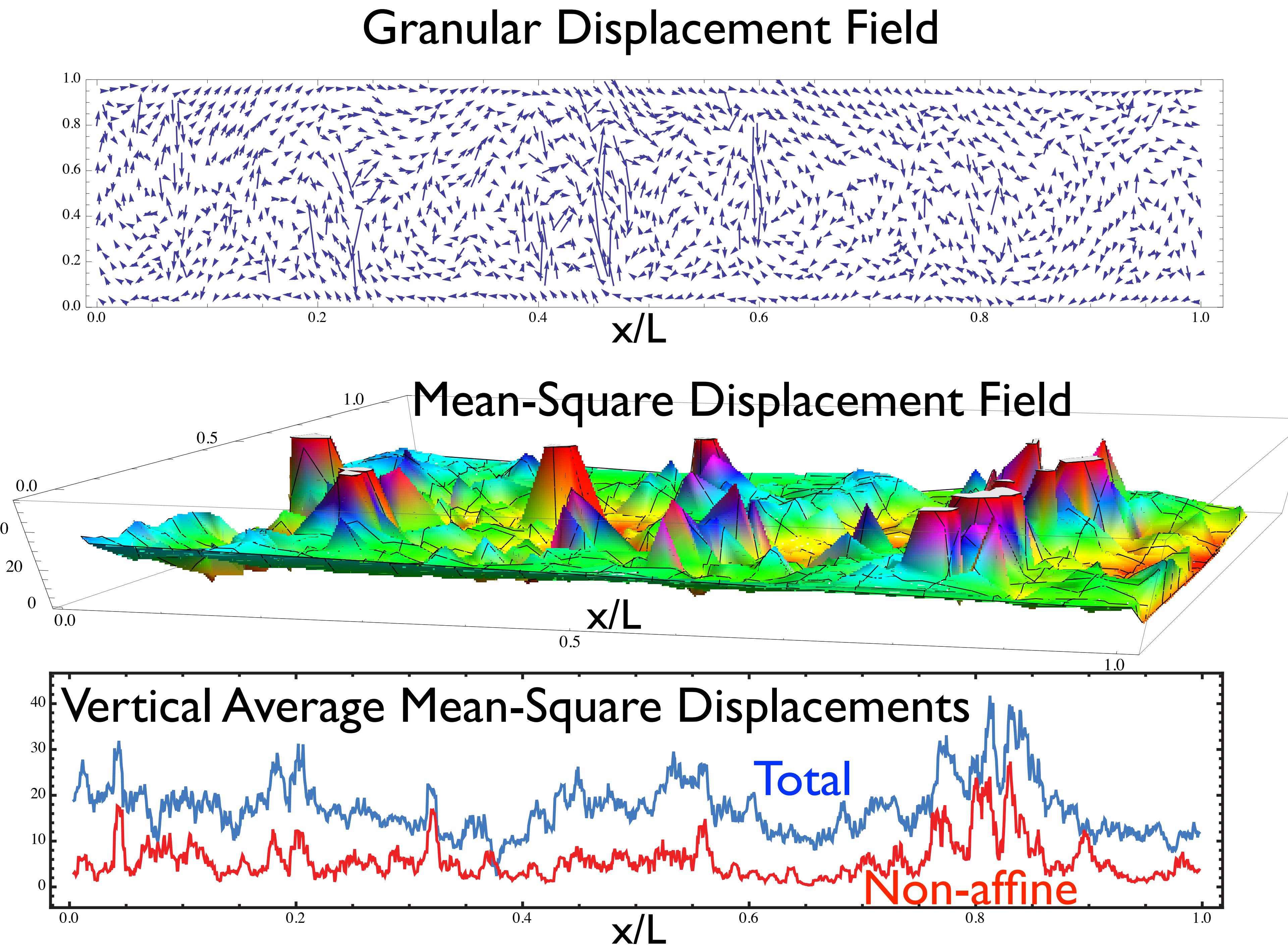
Non-Brittle: Poisson distributed



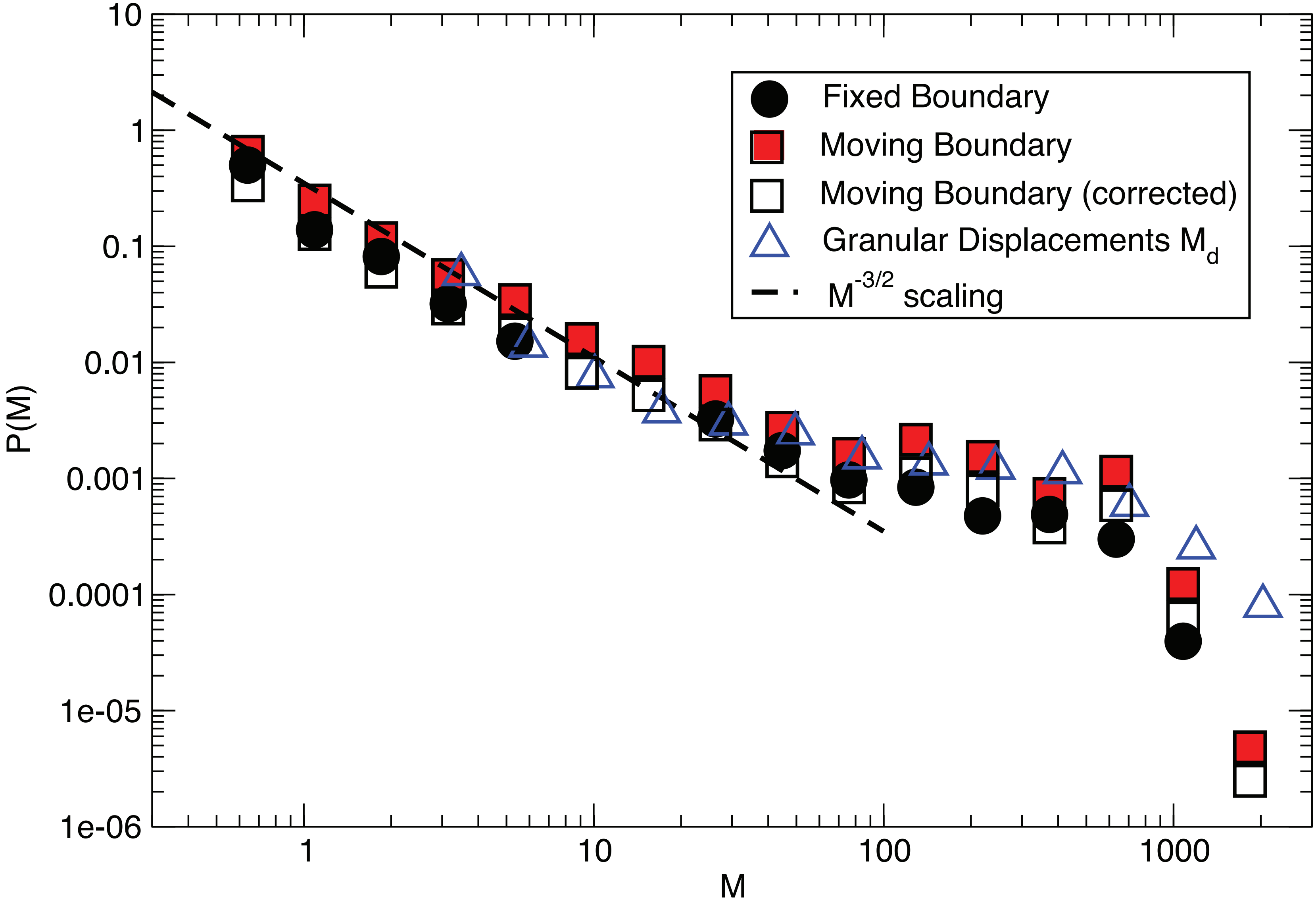
What is happening in the granular material?

F_N=200 N

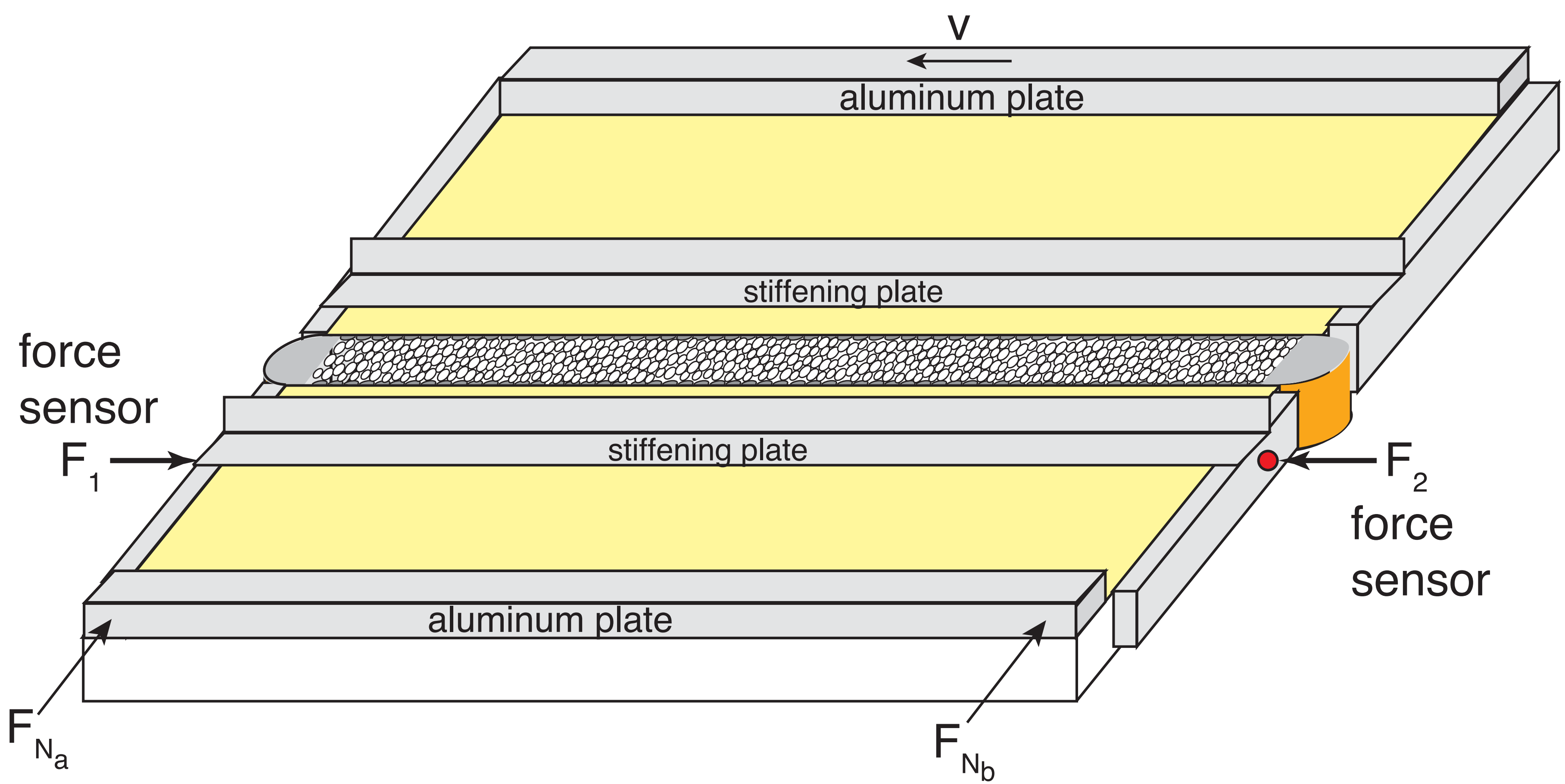
x 60000 speedup


Granular Displacement Field
x/L
Mean-Square Displacement Field
x/L
Vertical Average Mean-Square Displacements
Total
Non-affine
x/L

Where ever you look - it's the same

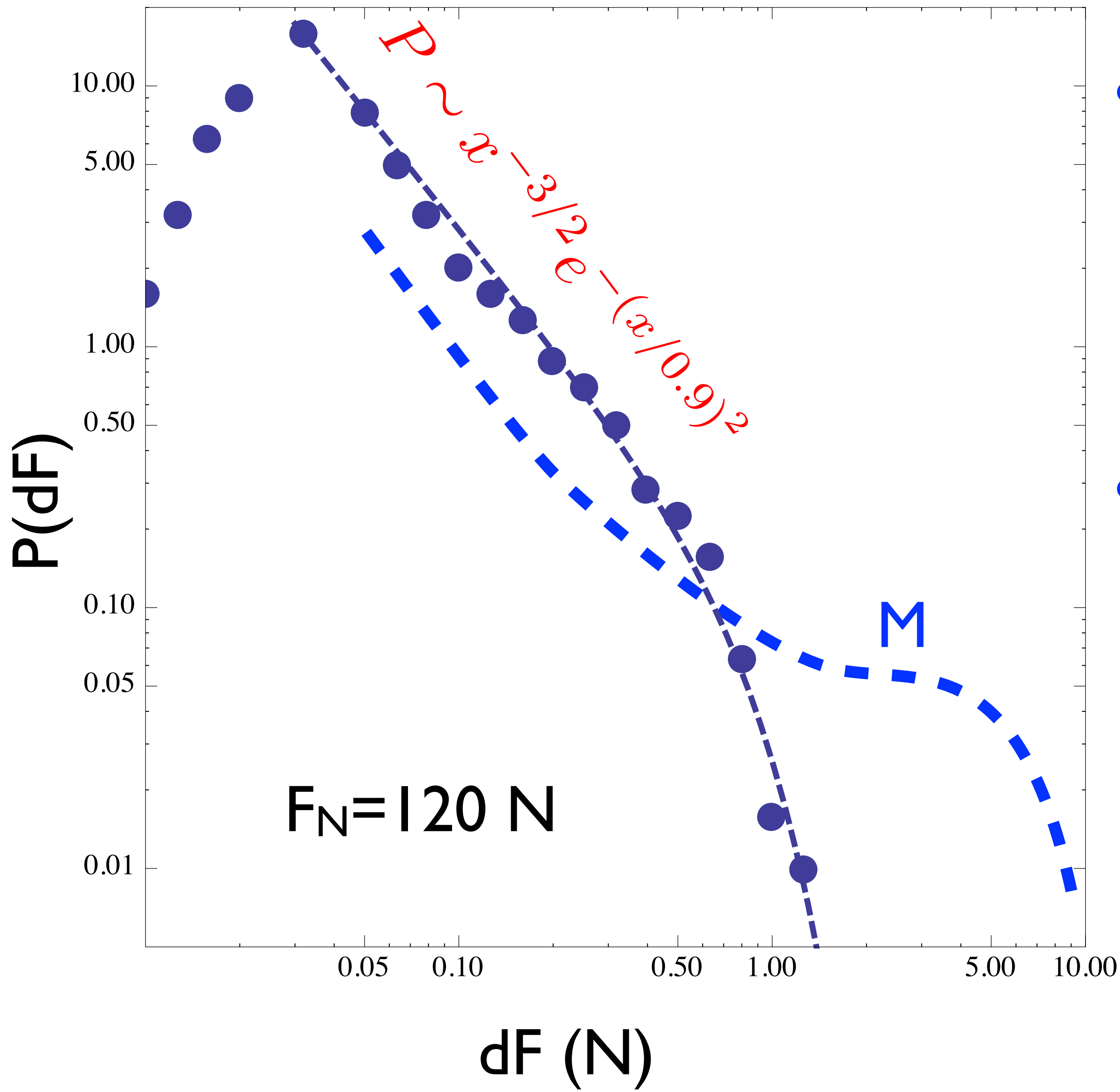


Apparatus: Stiffer spring drive, force measurement



Stiffened system and fixed plate constrained by force sensors

Probability distribution of force fluctuations



- Constraining the motion of fixed plate removes “large” events
- Large events result from stored elastic energy in the fixed plate

Summary

- Spatially determined moment P(M) as in an earthquake.
- Decompose into brittle and non-brittle events. Non-brittle $P(M) \sim M^{-\beta}$ $1.2 < \beta < 1.6$. Brittle - Log-Normal
- Poisson recurrence statistics for small events; large events have characteristic time.
- Large events - Finite size, stored elastic energy with granular “fracture”