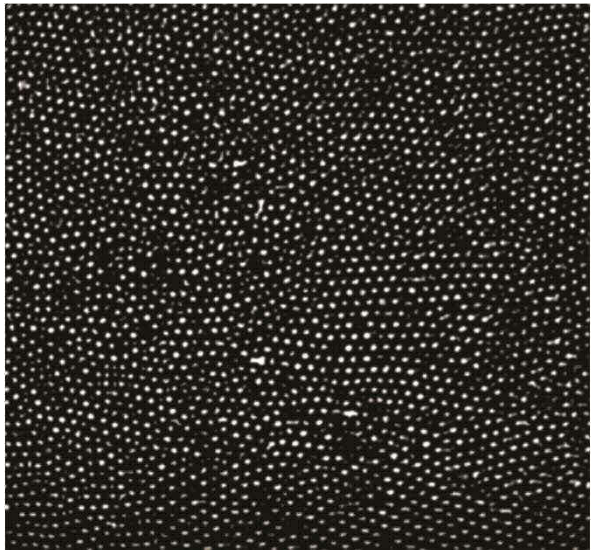
Amorphous-to-amorphous transition in compressed particle rafts

(*work in progress*)

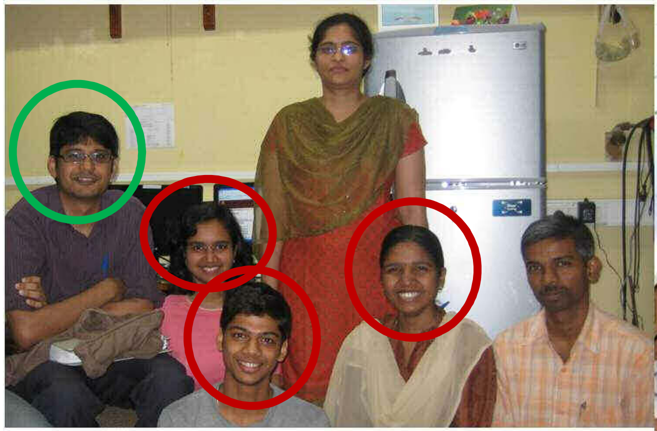
Atul Varshney*, Anit Sane, P. Aswathi, Shankar Ghosh* and SB
Tata Institute of Fundamental Research, Mumbai, India

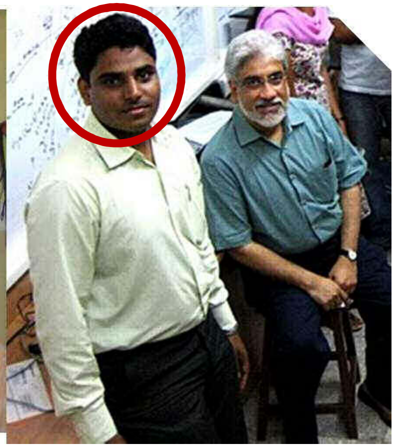


Outline

Soft matter (at) interfaces: examples
Sticking, Unsticking, Instabilities at interfaces,
New tools

Peeling of a colloidal film
Particle rafts (magic-sand films)





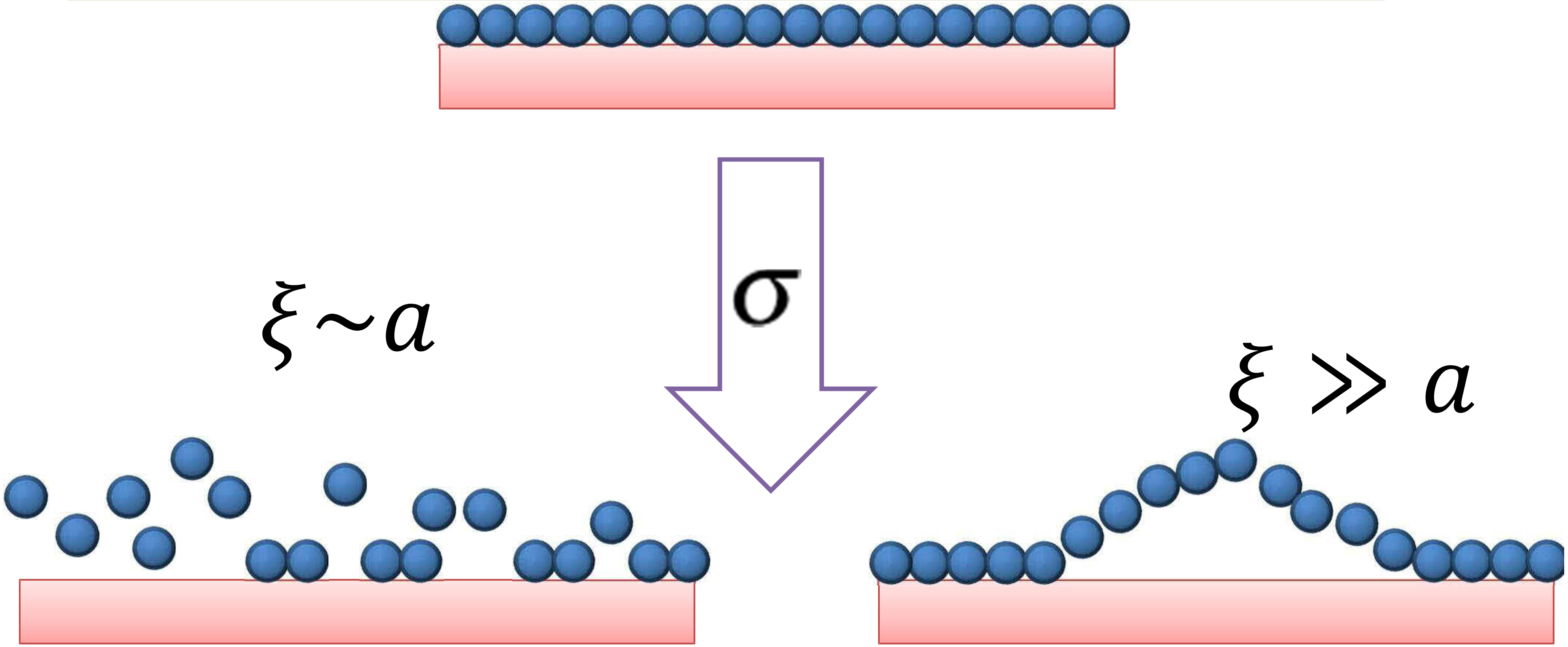
JAKS, Feb 7, 2012

Driven Dynamics of Detachment : Desorption to Delamination (Paint Peeling in Mumbai-Monsoon)

A. Varshney, P. Sharma, A. Sane, S. Ghosh, and S. B. , Phys. Rev. Lett., 105, 154301 (2010*)

Inspired by Kaushik Bhattacharya and G. Ananthkrishna

The generic process spans
17 orders of magnitude in L and 23 in t



Desorption

Atomic and molecular scale
e.g., gas desorption from metals

Delamination

Geological- Lithosphere
movement, plate tectonics

Aim is to:

Find a minimal system which captures the essential complexity of the various detachment processes seen in Nature.

Describe it by a few system parameters.

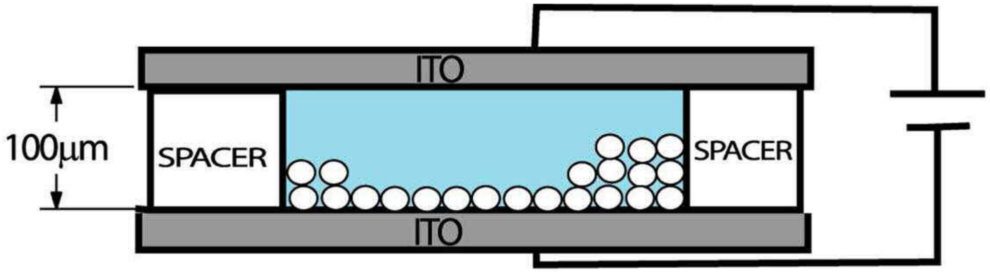
Control Stress (σ)

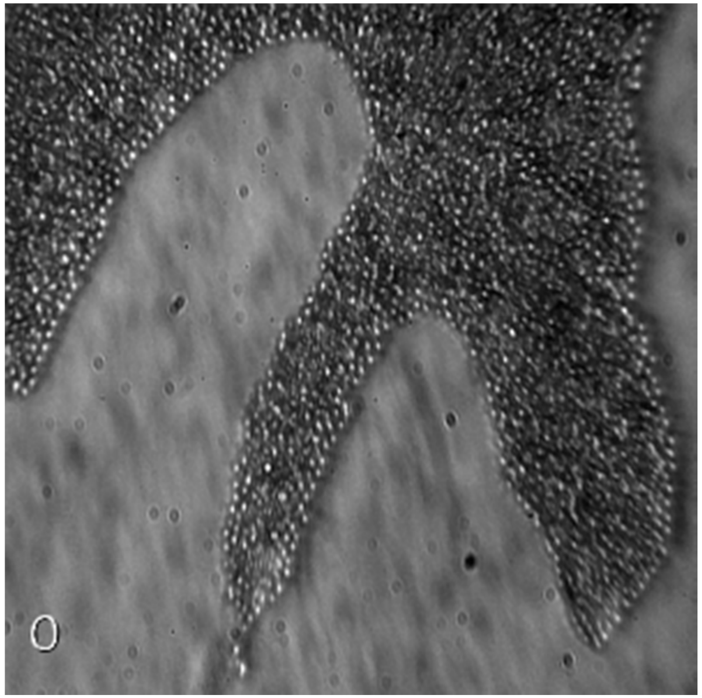
Alter rigidity (G) and Adhesion strength (f_p)

Observe events of failure over the entire length scale (ξ).

Get a model system

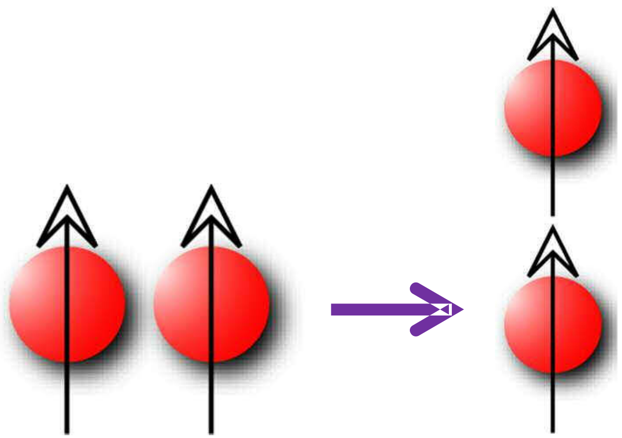
Electric field induced delamination (peeling) of particulate films: Individual vs. Collective Dynamics





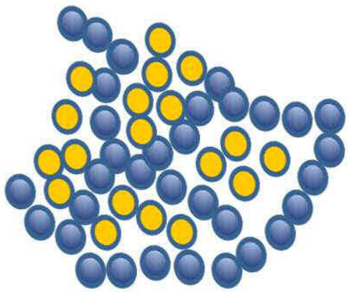
Two types of particles: silica and polystyrene
Variable silica fraction Φs : 0 to 1
Variation of dynamics from
Individual to Collective

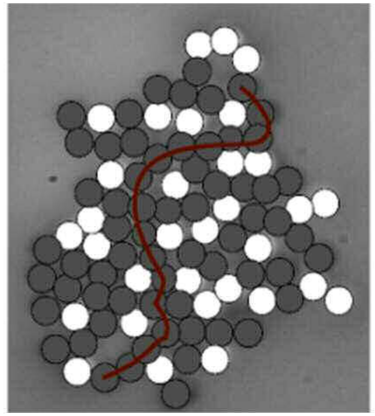
Origin of Stress in the system



Torque = P X E

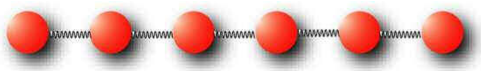
Creating percolating networks of silica particles





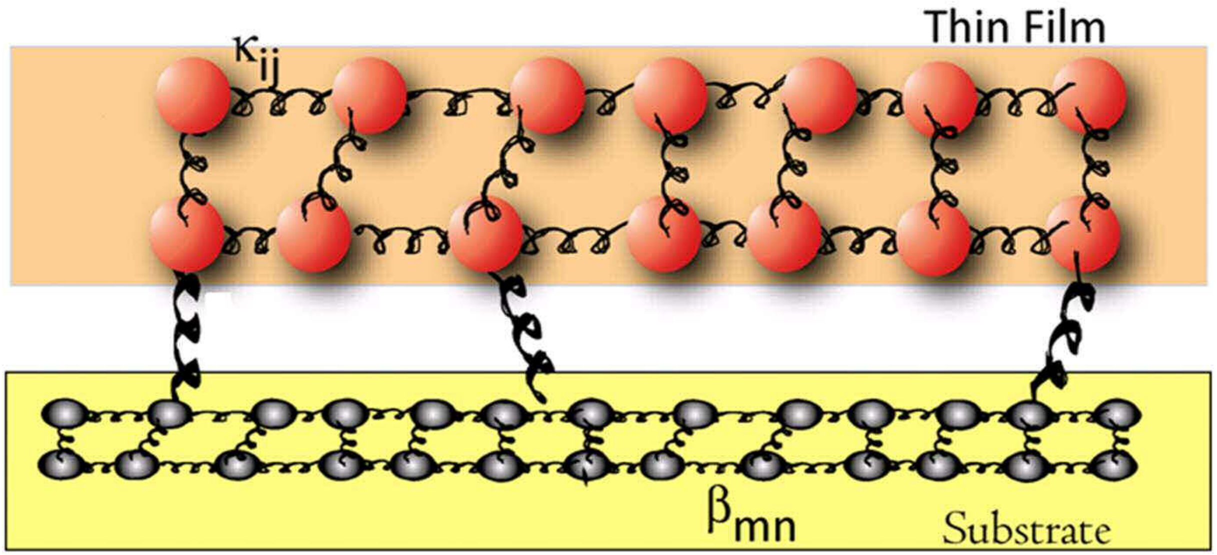
Volume fraction of silica particles

Tuning inter-particle interactions between spheres



Observable parameters

Length scale (ξ) over which the system fails
External stress at failure



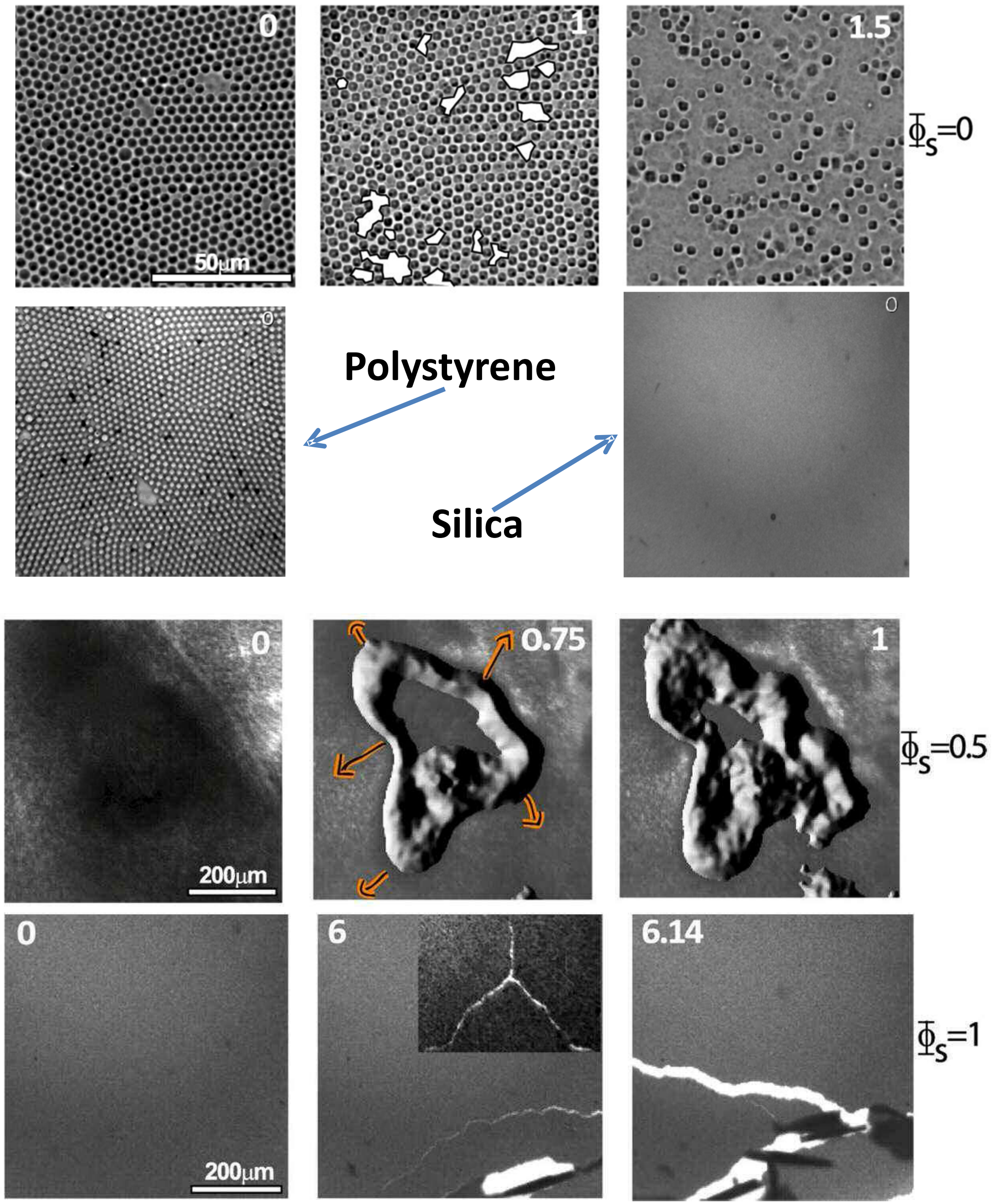
$G(Energy/Volume)$

$f_p(Energy/Area)$

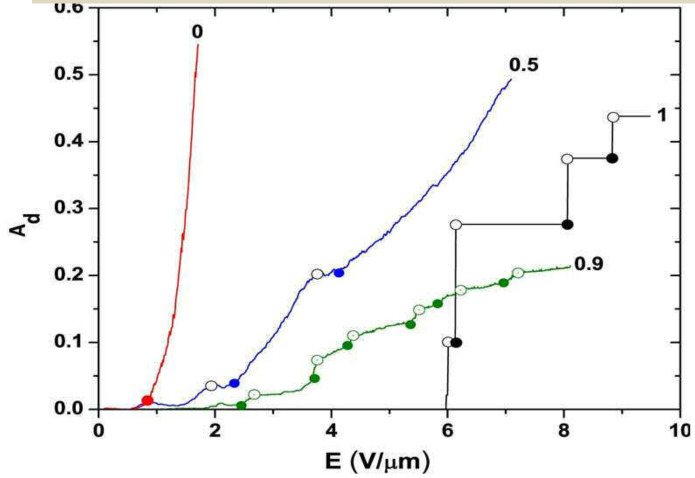
For a very rigid substrate, G-springs compete with fp- springs :

$$\xi = F(G, f_p)$$

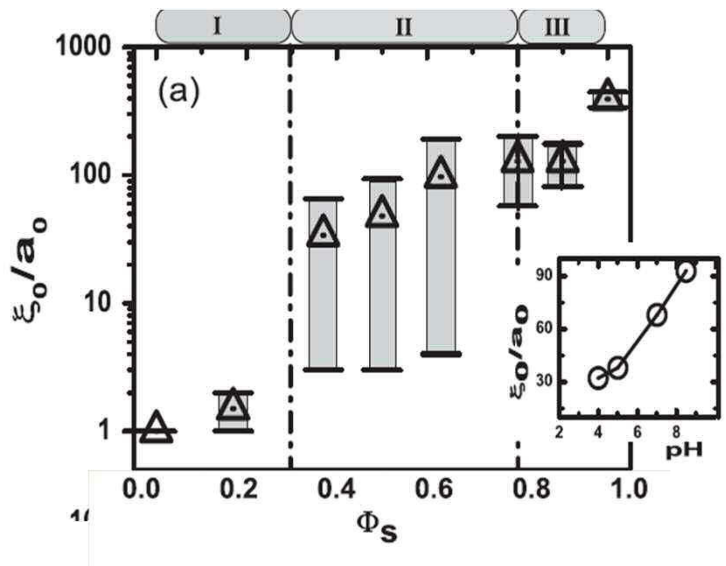
If f_p is large, ξ is small
If G is large ξ is large

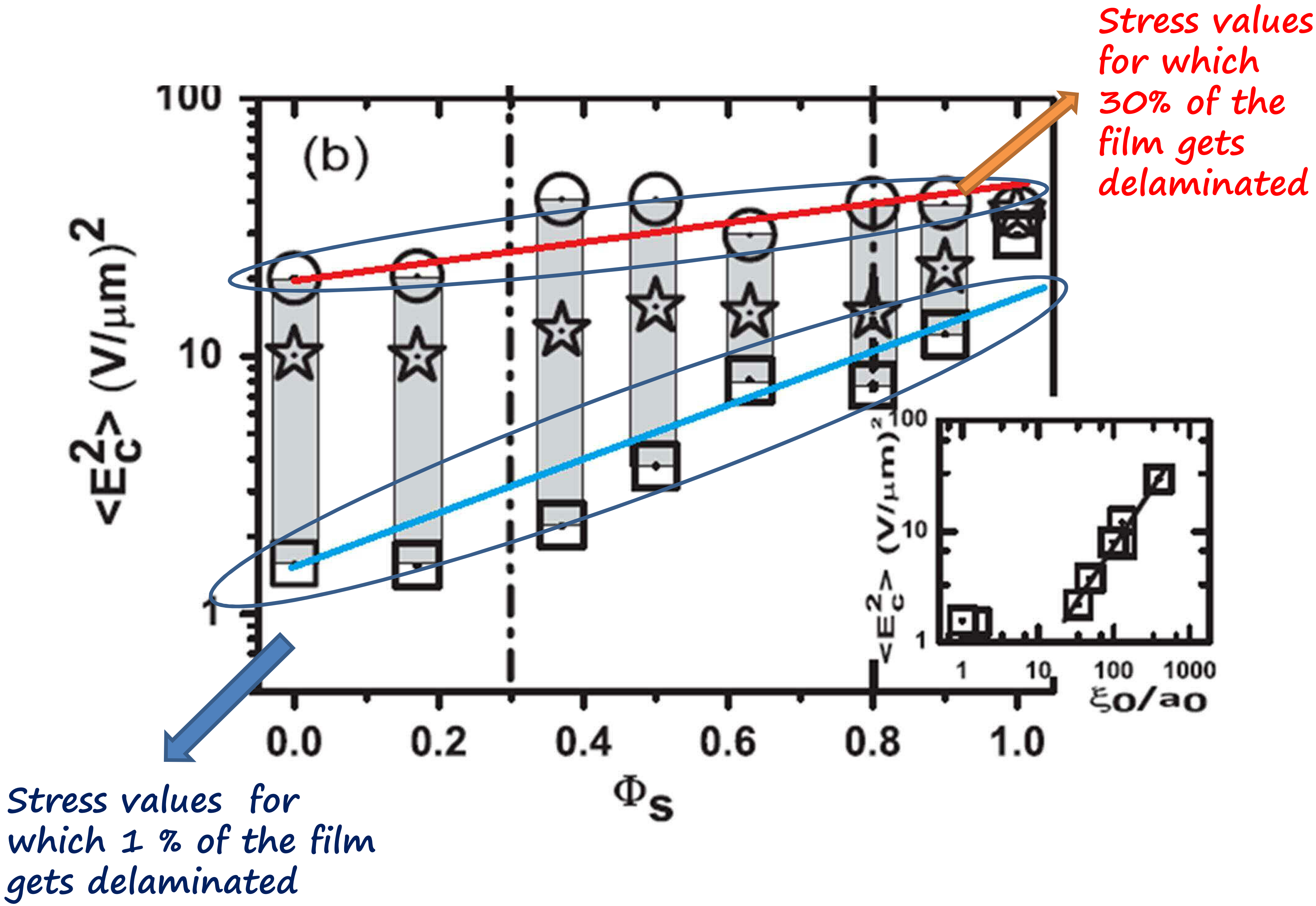


Area delaminated- E field curves



Individual, Mixed and Collective Dynamics

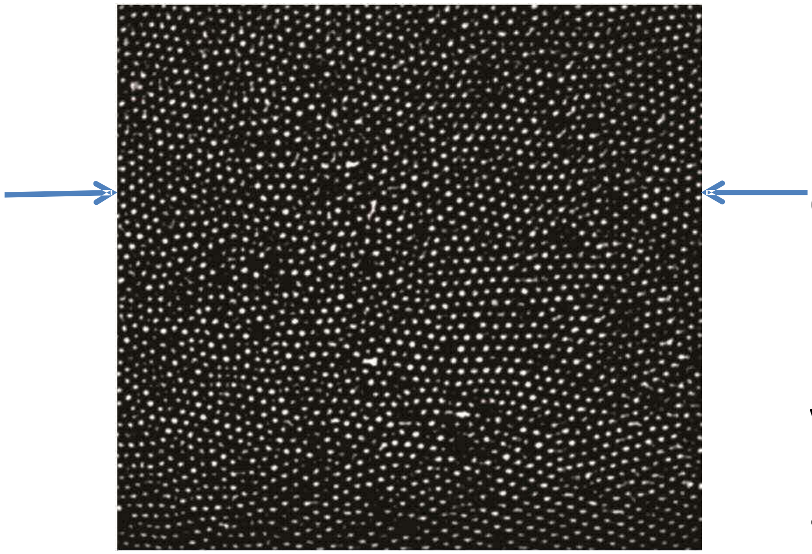




Individual-to-collective dynamics crossover & rigidity percolation ?

Particle Raft : A short introduction

Hydrophobic non-Brownian particles densely sprinkled on water
Gravity-driven dimples provide long-range attraction
Short range attraction or repulsion due to capillary interactions
Stable self-contained films, stable upon removal of stress
Buckles under compression, i.e, supports anisotropic stress
Unbuckles under expansion, ironing out wrinkles
This forms a solid, i.e., has Rigidity



Measure Elastic Moduli, both longitudinal and shear, under uniaxial compression or expansion
In a Langmuir Trough

Video Microscopy to look for structural changes

Europhysics Letters

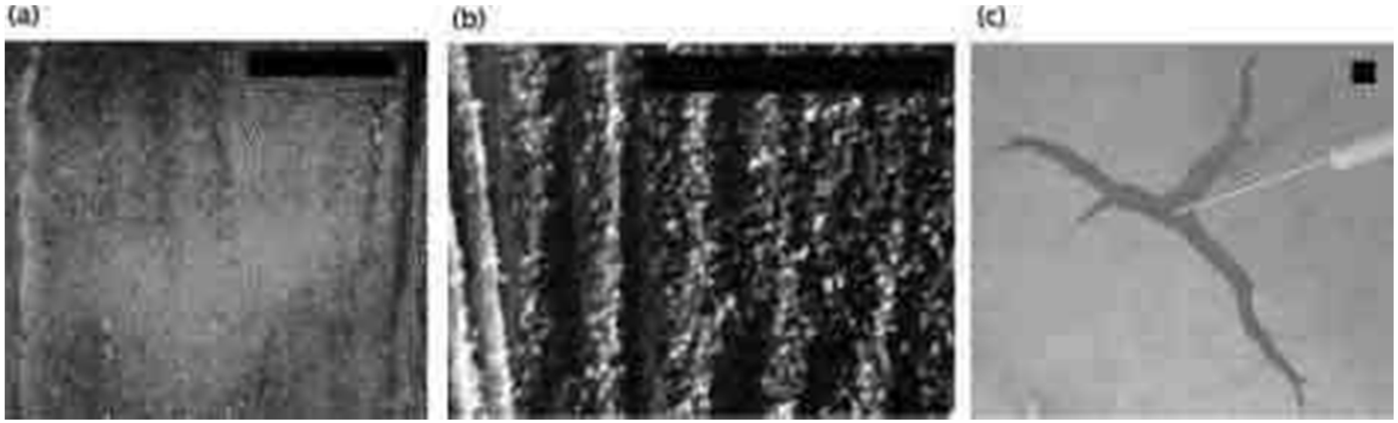
Elasticity of an interfacial particle raft

D. Vella1, P. Aussillous2 and L. Mahadevan1 ()

1 *Division of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA*

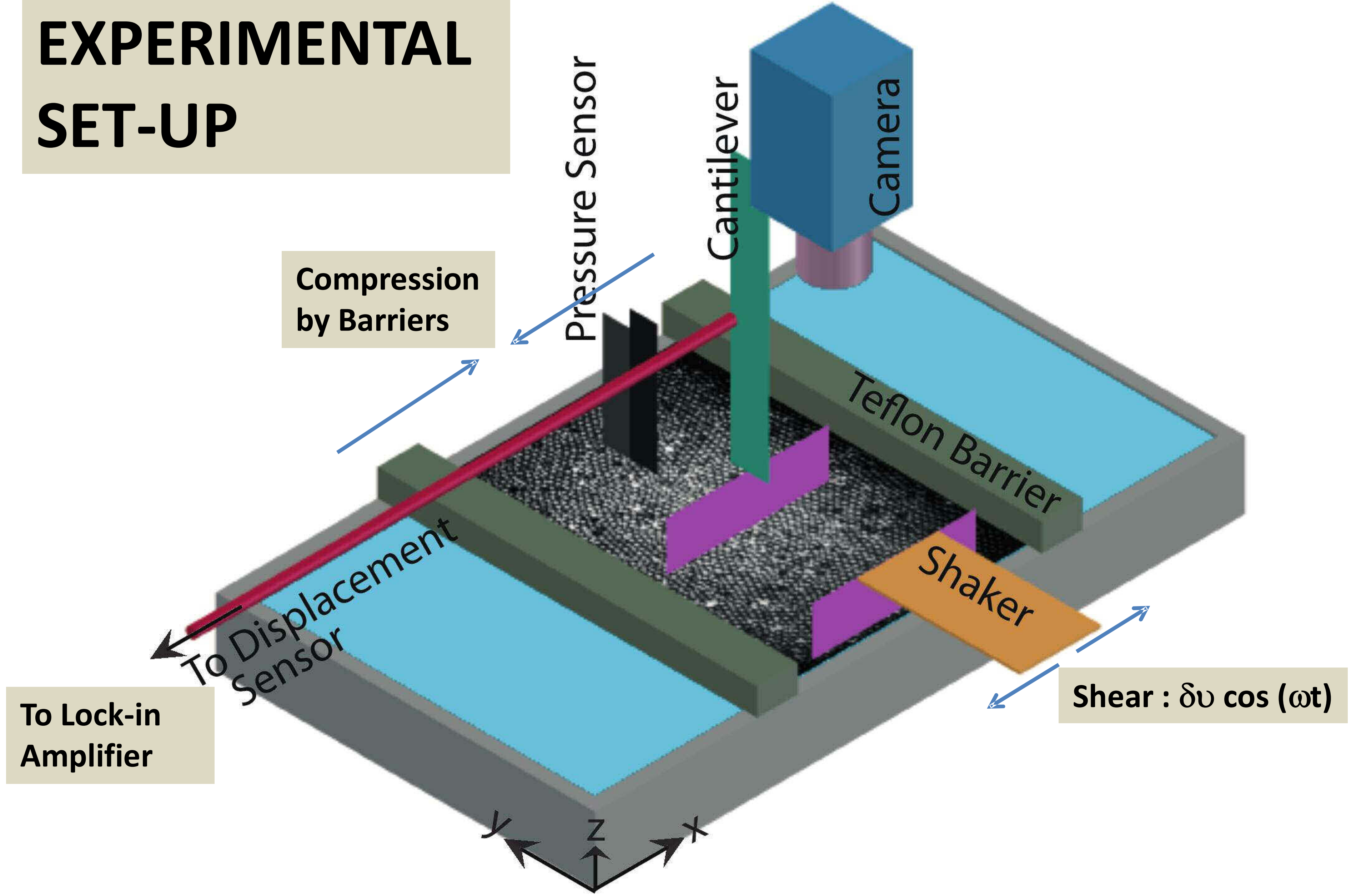
2 *Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Wilberforce Road, Cambridge, CB3 0WA, UK*

Abstract. We study the collective behaviour of a close packed monolayer of non-Brownian particles at a fluid-liquid interface. Such a particle raft forms a two-dimensional elastic solid and can support anisotropic stresses and strains, e.g. it buckles in uniaxial compression and cracks in tension. We characterise this solid in terms of a Young s modulus and Poisson ratio derived from simple theoretical considerations and show the validity of these estimates by using an experimental buckling assay to deduce the Young s modulus.

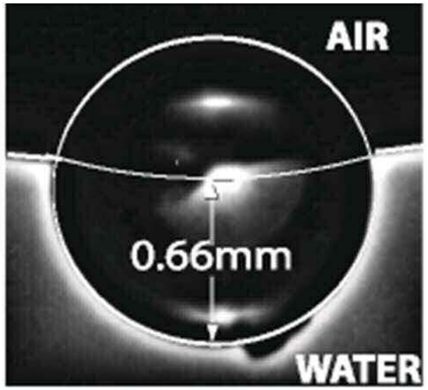


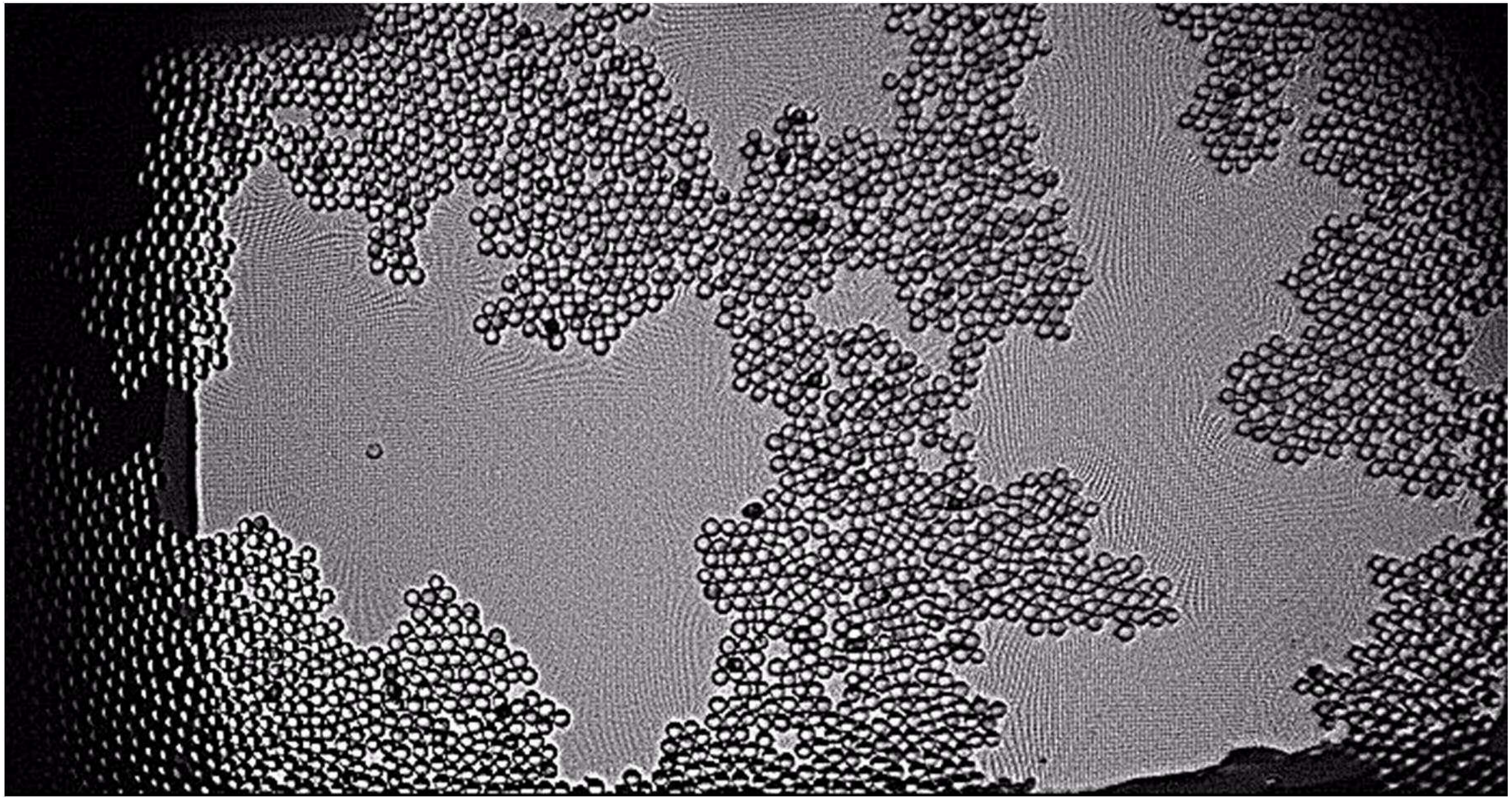
Cicuta and Vella : Particle rafts are granular media
Phys. Rev. Lett. 102, 138302 (2009)

EXPERIMENTAL SET-UP

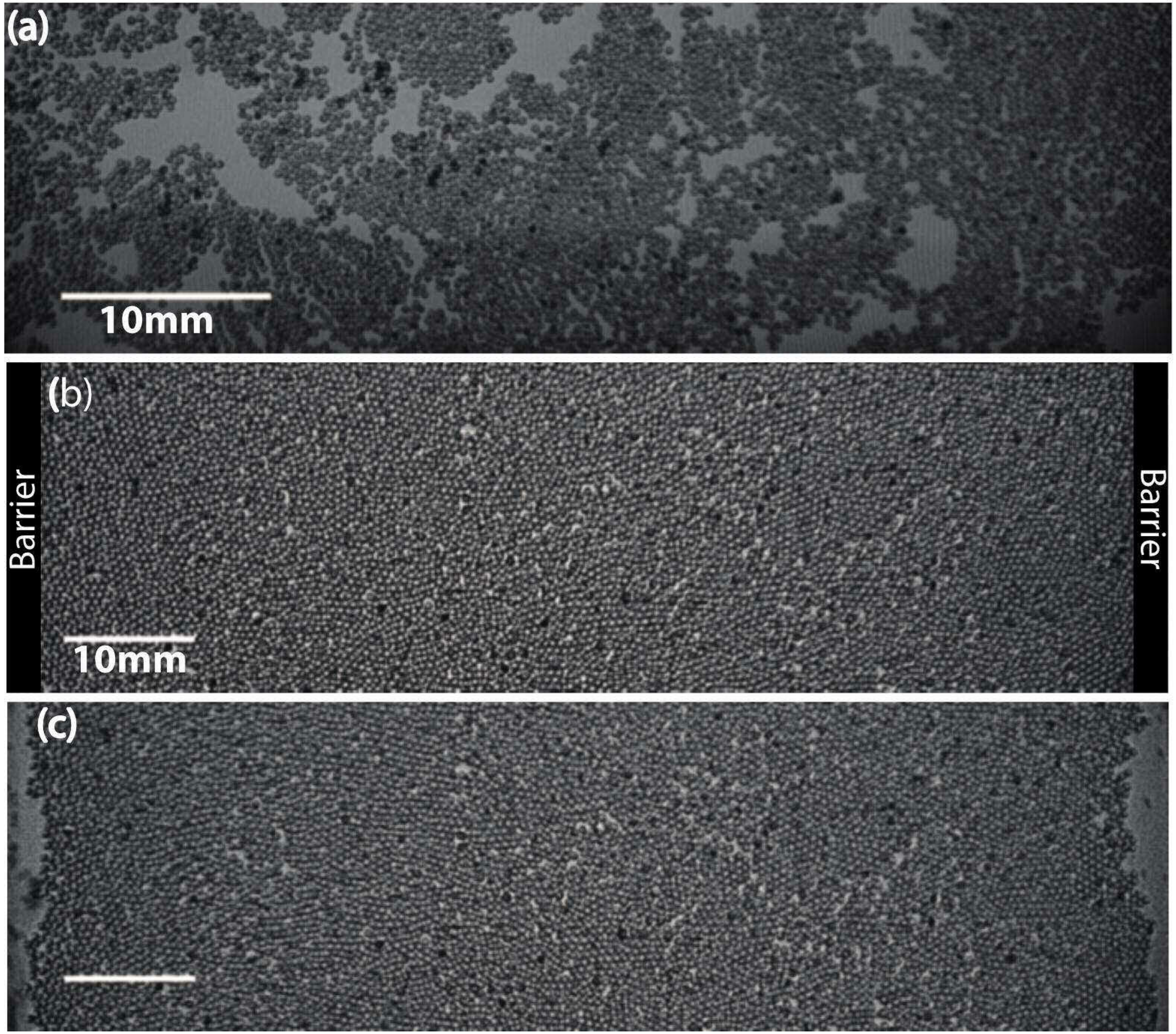


Formation of compressed and relaxed states starting from particulate clusters of 1mm particles

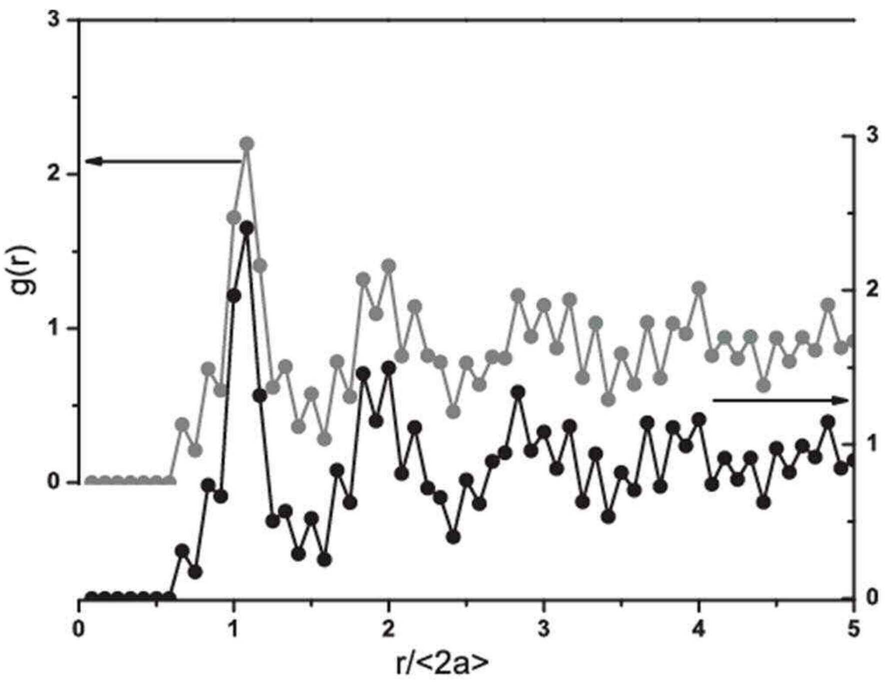




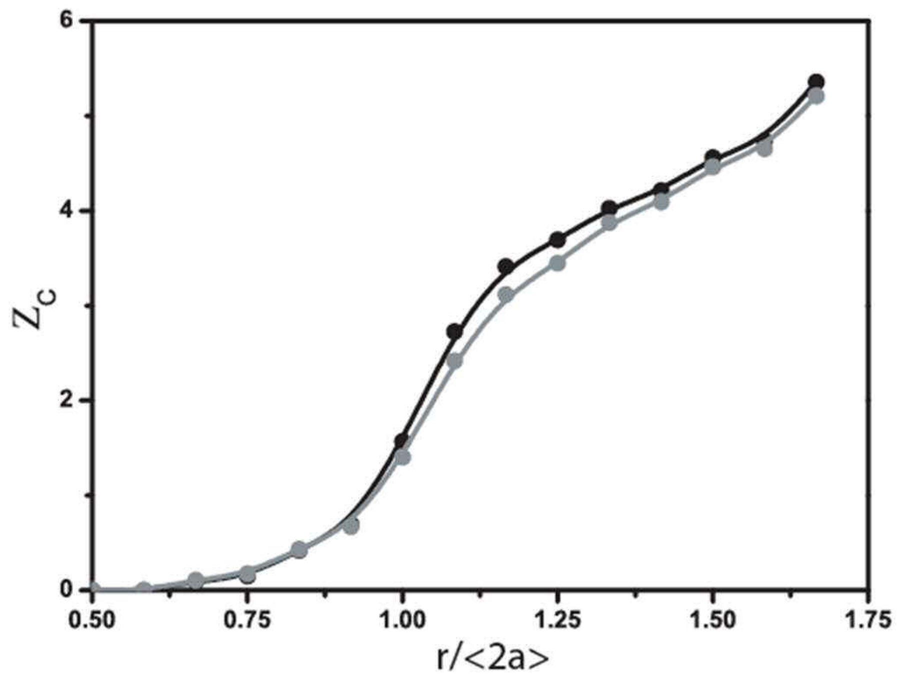
Compacition, Buckling/ Creasing-decreasing, Cracking under expansion
300 µm silica particles


(a)
10mm
(b)
Barrier
Barrier
10mm
(c)

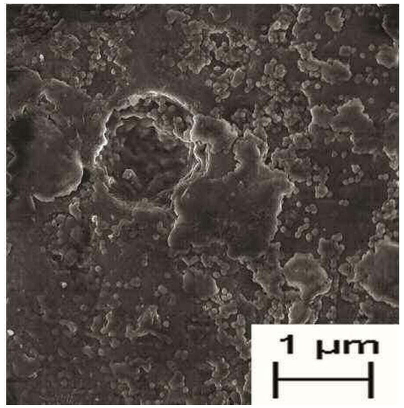
Radial Distribution Function
For compressed and expanded states
Amorphous!



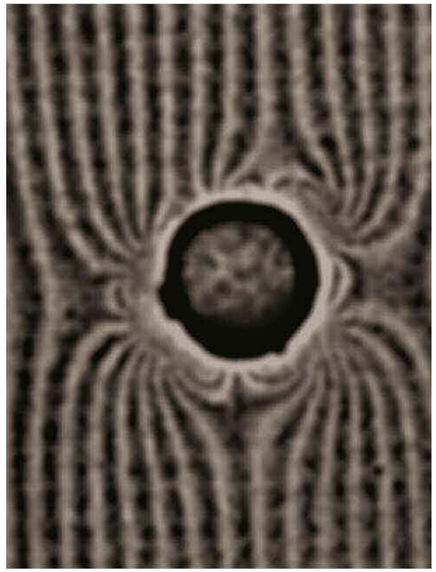
Cumulative Coordination Number
(Torquato)



Things one can see about the system

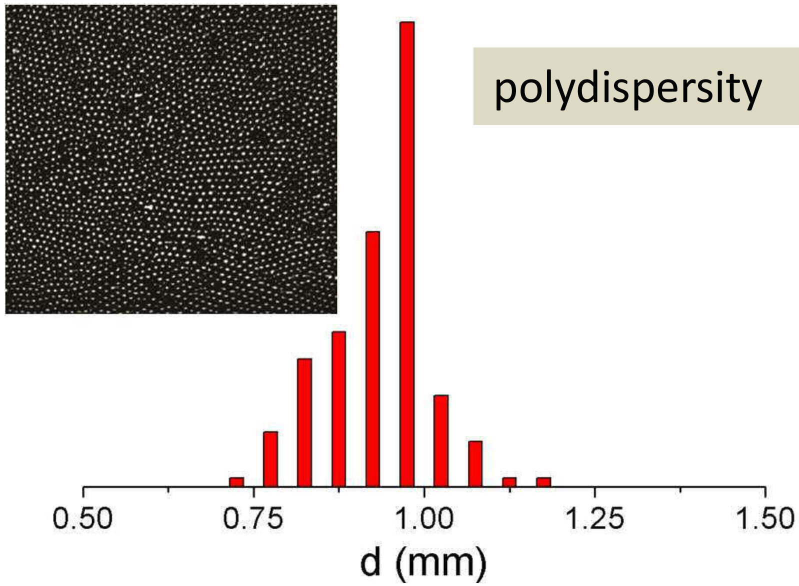


SEM scan of a particle



Rectangular grid below imaged from top

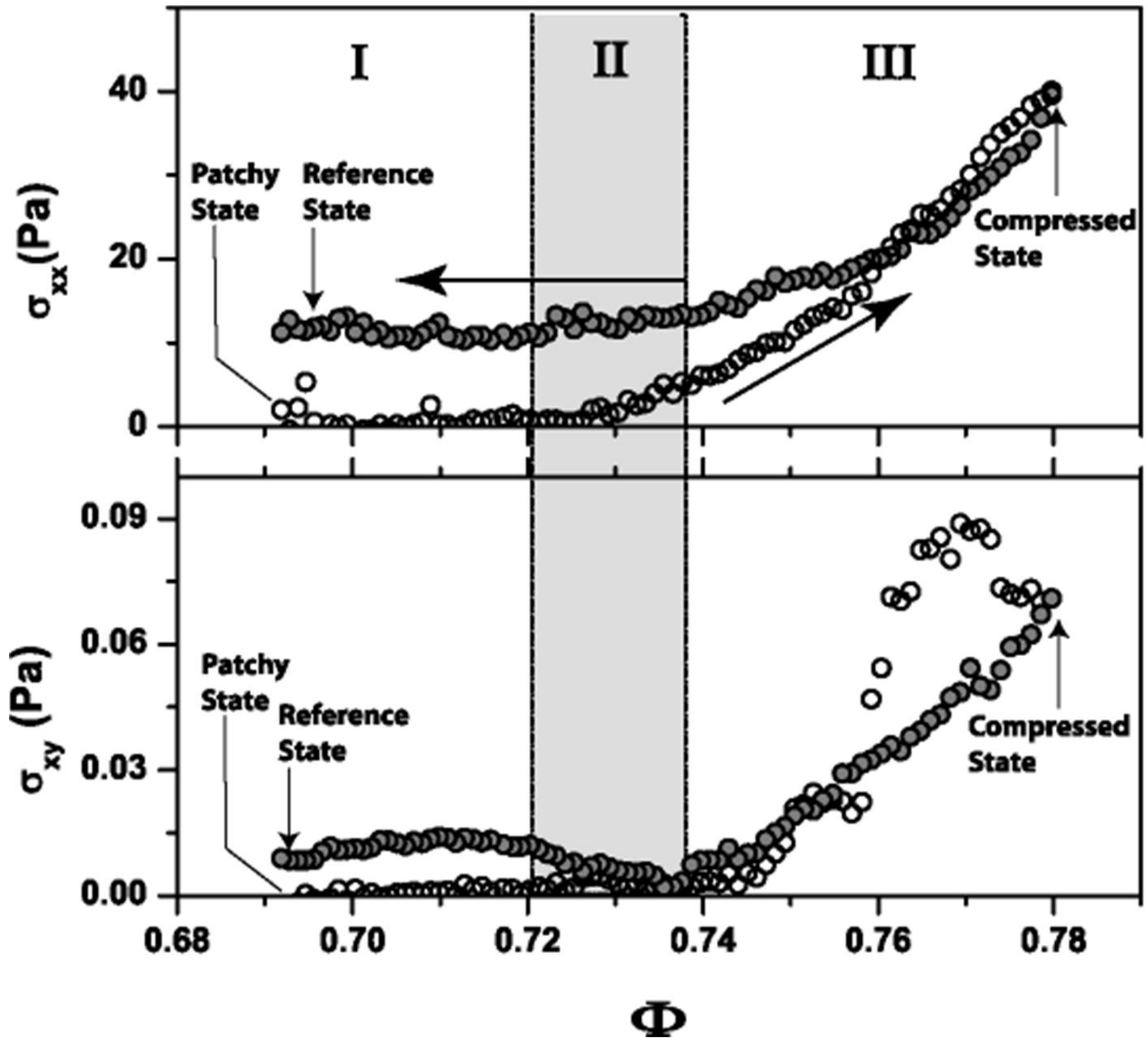
Capillary bridges across particles



polydispersity

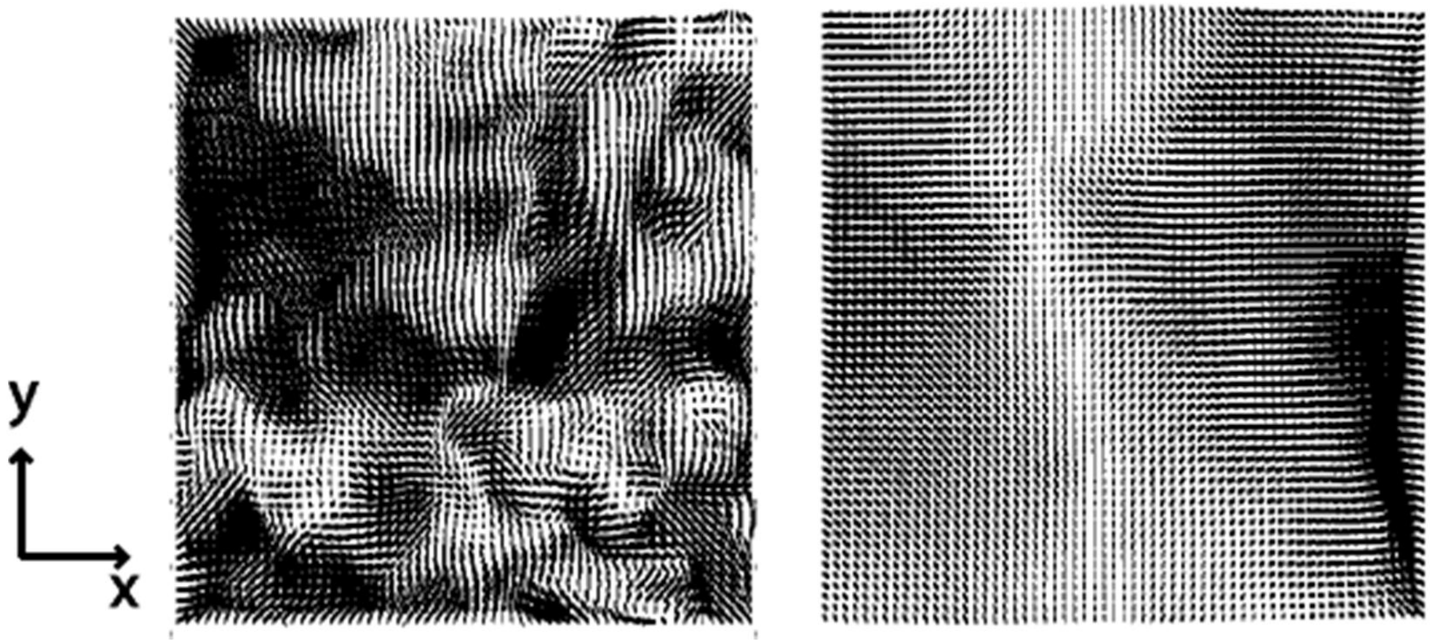
Things one can feel about the system

Preparation-Protocol and Creation of the Reference State: First-time Special



Soft, Relaxed state

Hard, Compressed State



Particle-Image Velocimetry (PIV): Strain Field

Quantities Determined:

From rheology:

Longitudinal and Shear Stress Σ_{xx}, Σ_{xy}

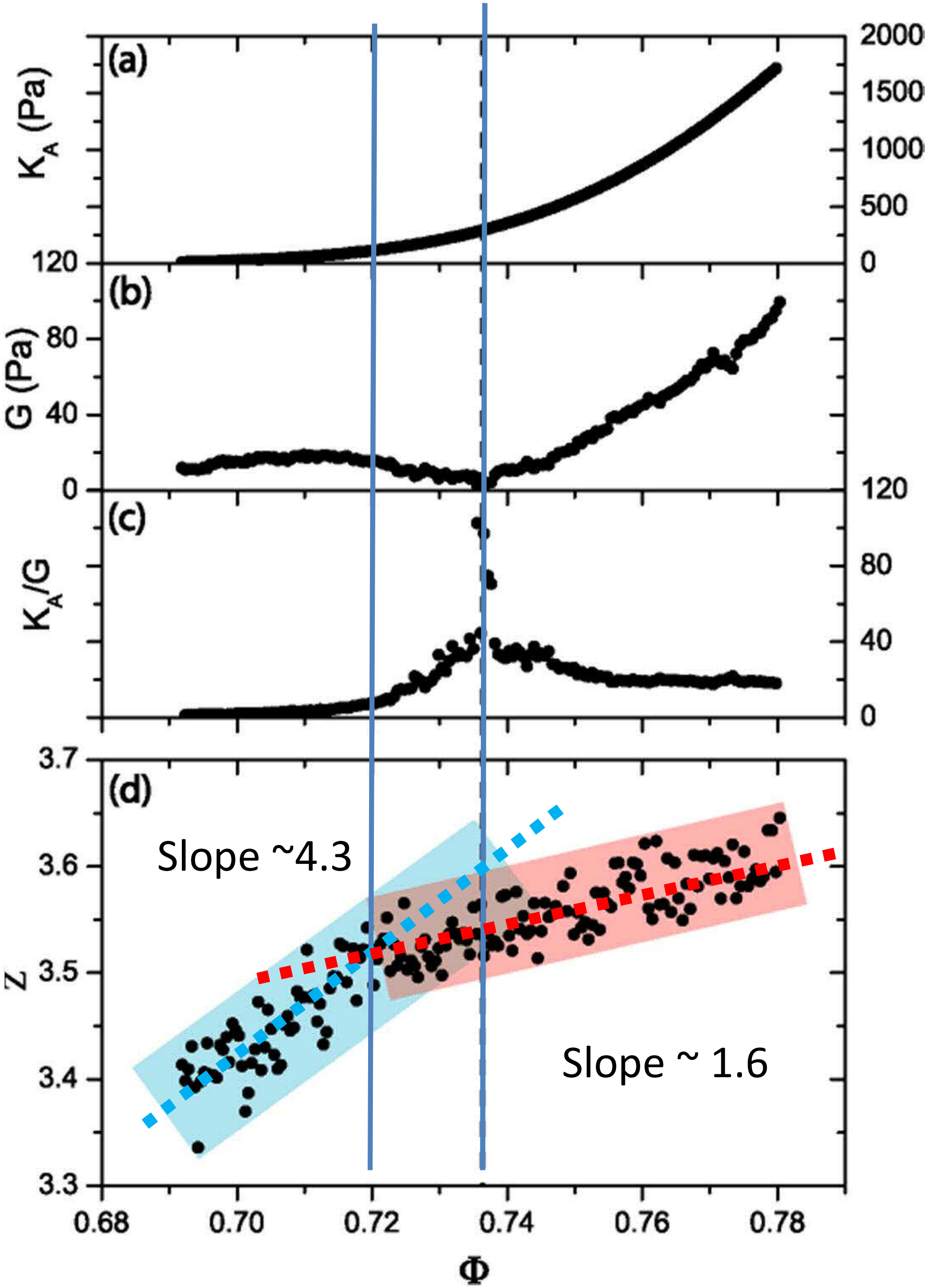
Infer the differential moduli :

$$K = \delta\Sigma/\delta\varepsilon$$
$$G = \delta\Sigma/\delta\upsilon$$

From Video Microscopy :

Coordination number Z at the first peak of g(r)

Floppy modes from " Pebble Algorithm" (?) (Thorpe et al.)



Quantities Determined:

From rheology:

Longitudinal and Shear Stress Σxx, Σxy

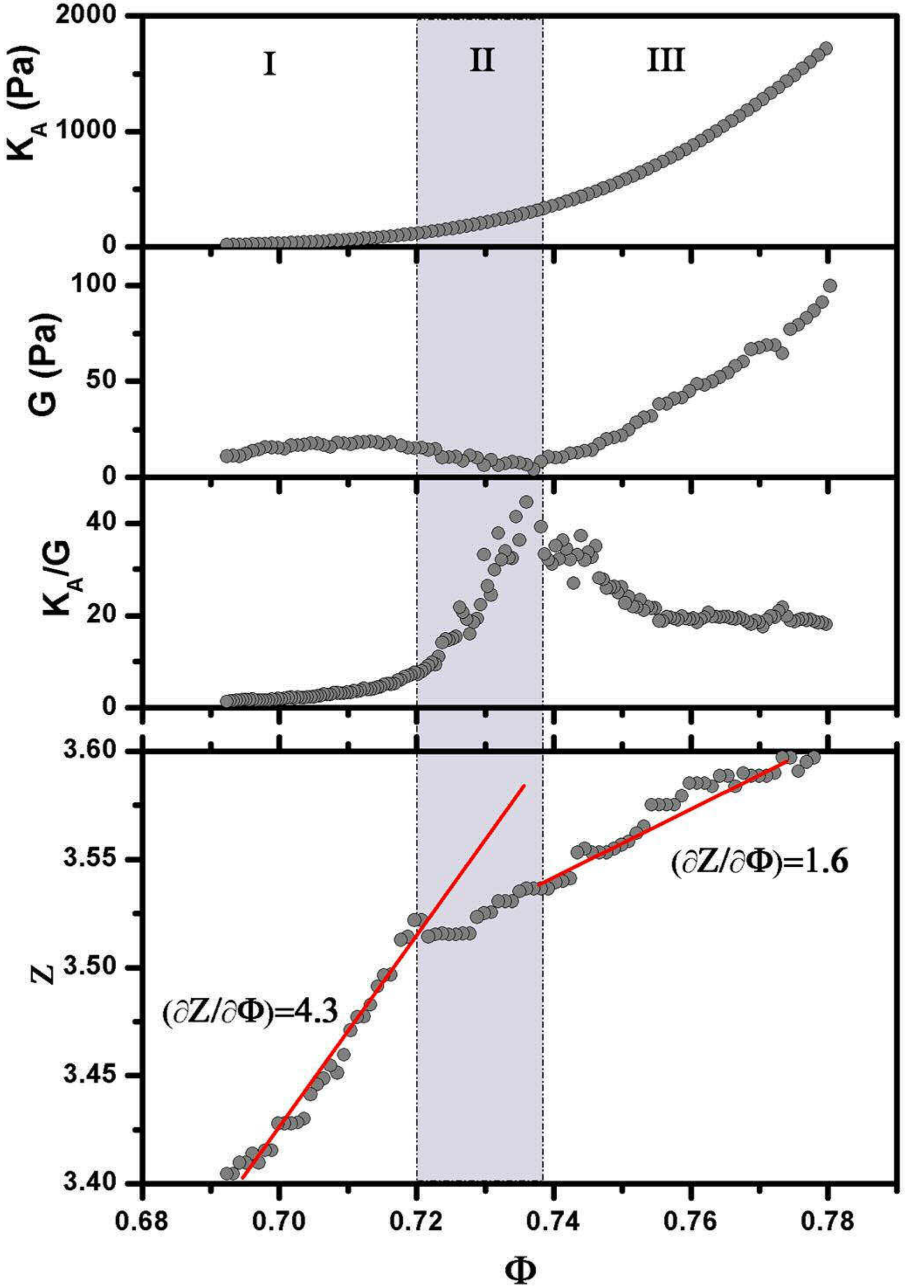
Infer the differential moduli :

$$K = \delta\Sigma/\delta\varepsilon$$
$$G = \delta\Sigma/\delta\upsilon$$

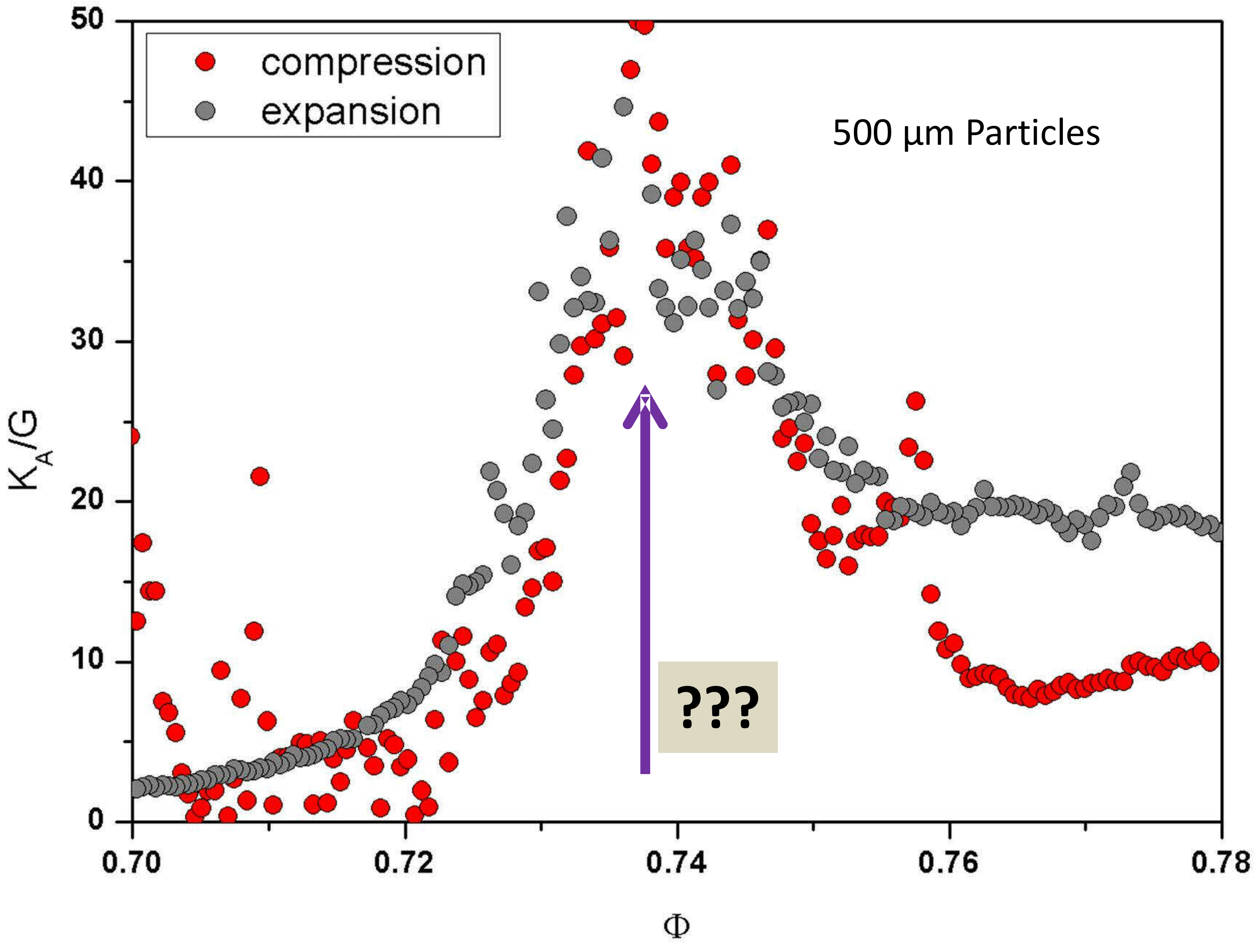
From Video Microscopy :

Coordination number Z at the first peak of g(r)

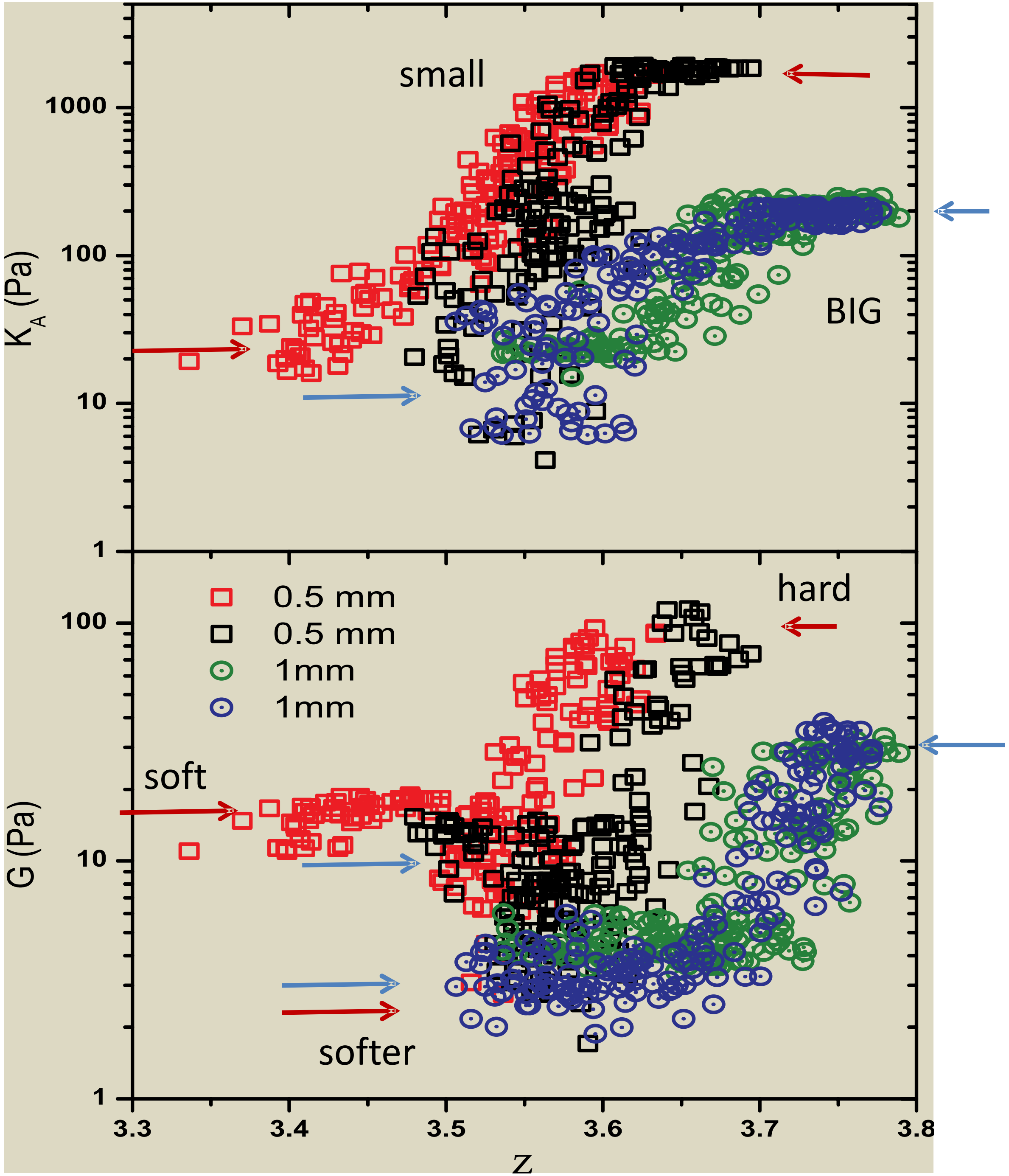
Floppy modes from " Pebble Algorithm" (?) (Thorpe et al.)



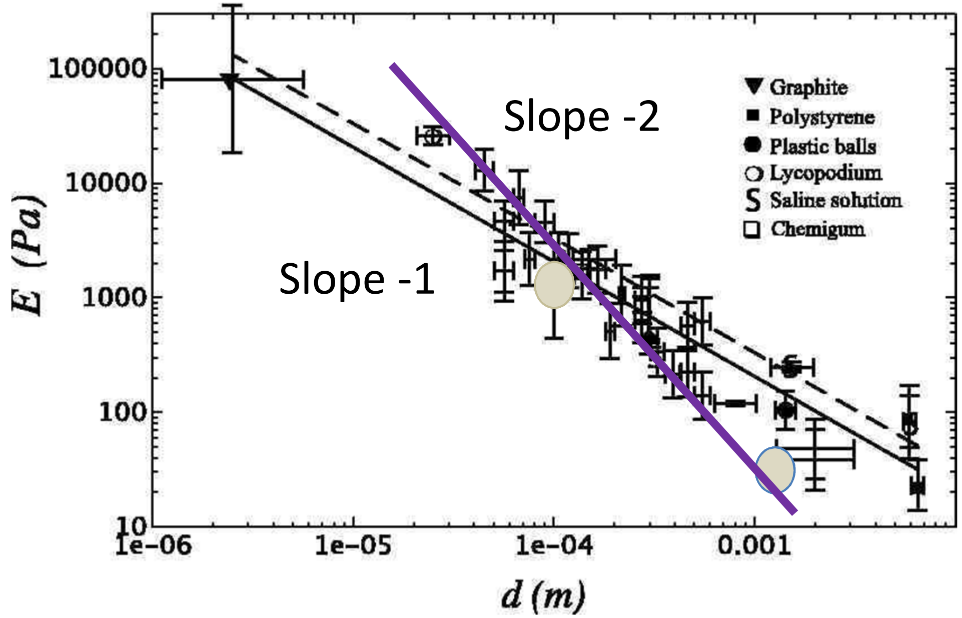
Reproducibility and Variability



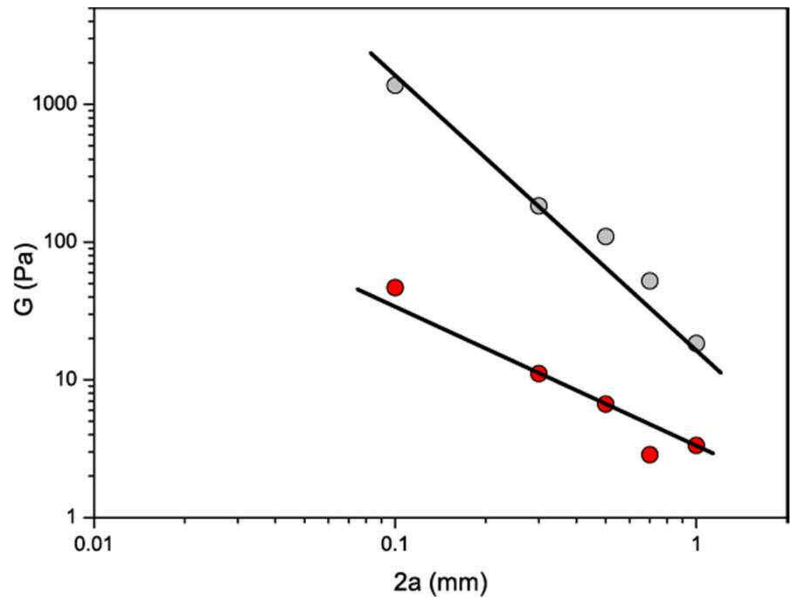
Variation of Moduli across "transition"

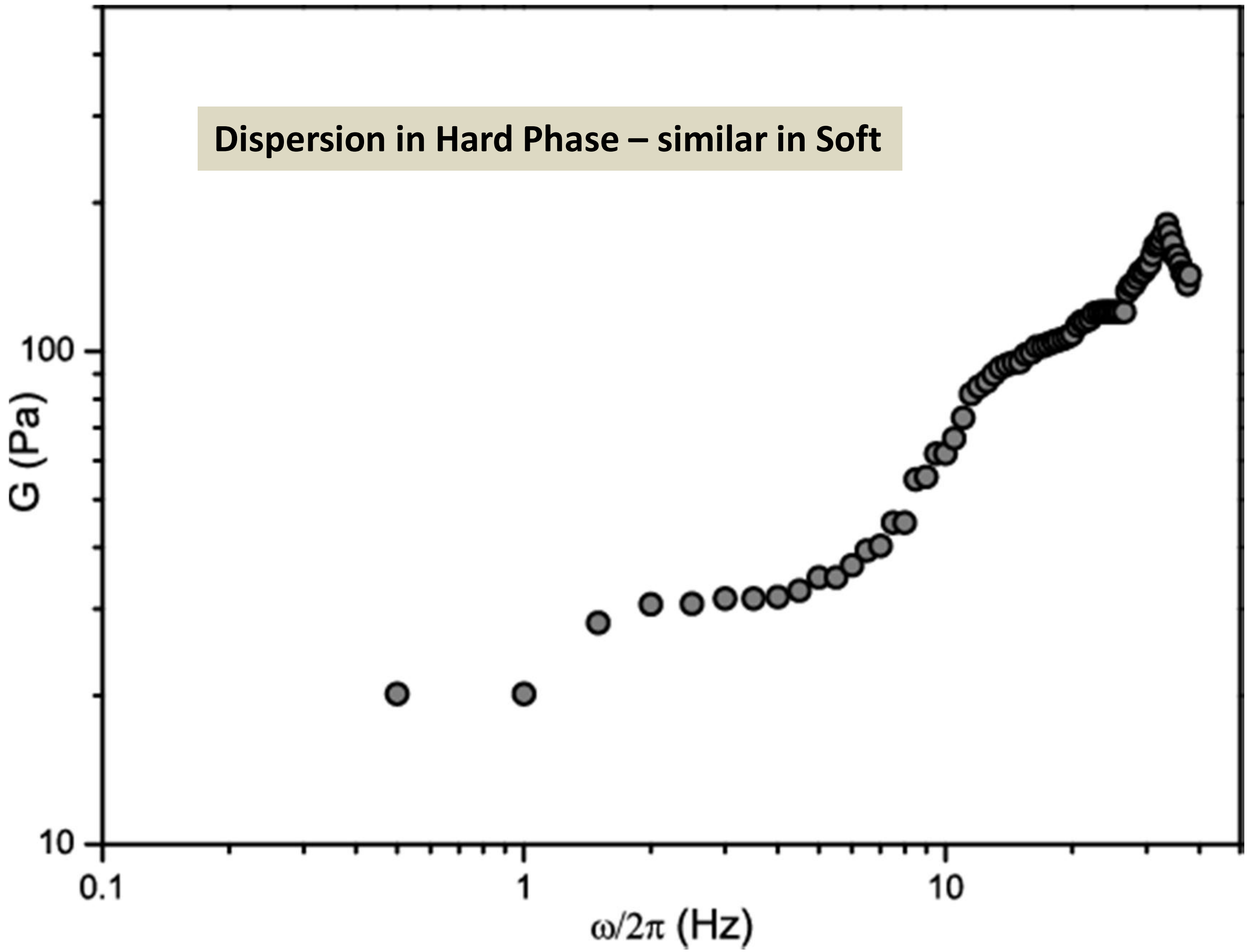


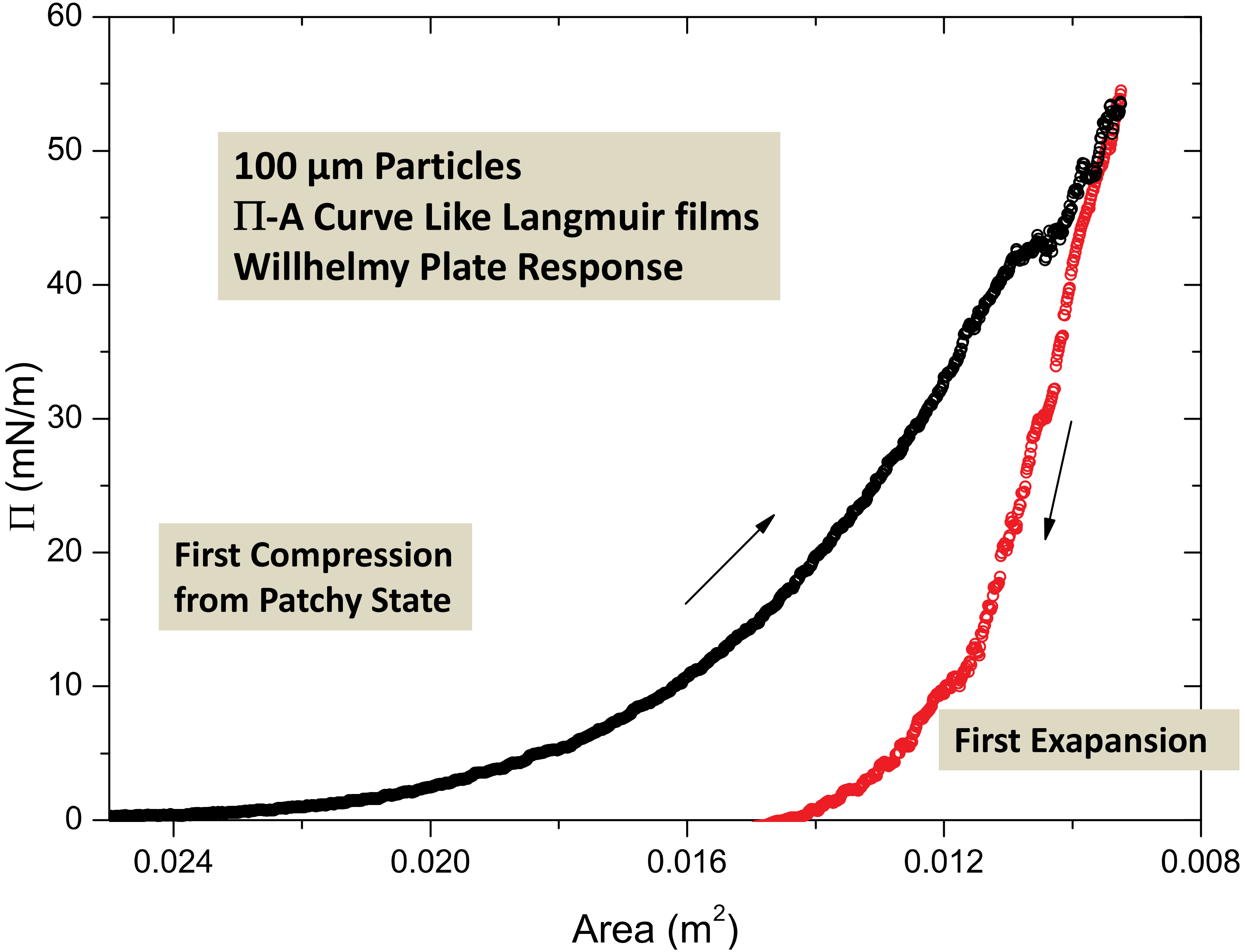
Young's Modulus from Vella et al



Shear moduli at soft and hard states from Varshney et al

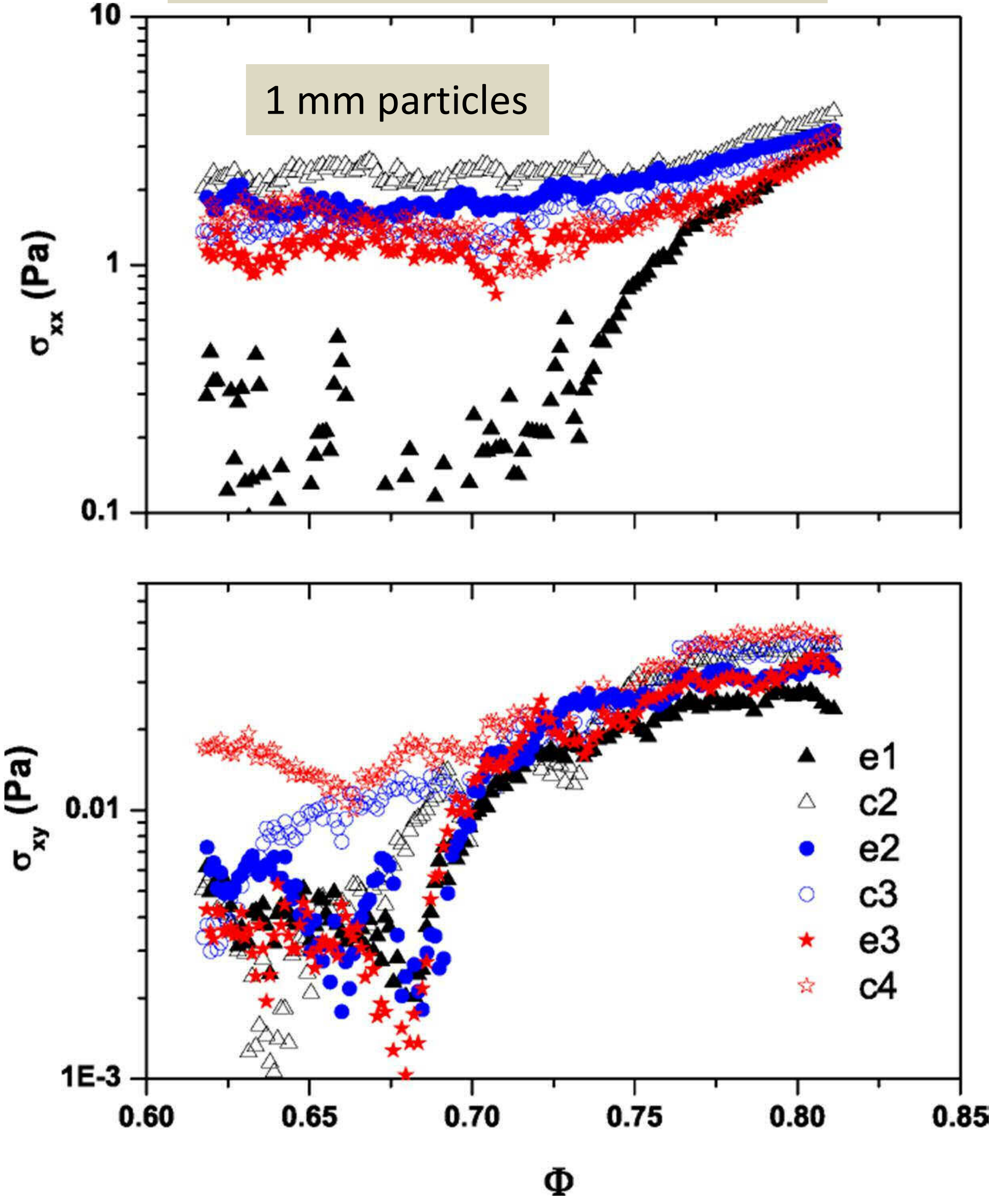



Dispersion in Hard Phase – similar in Soft
G (Pa)
100
10
0.1
1
10
ω/2π (Hz)

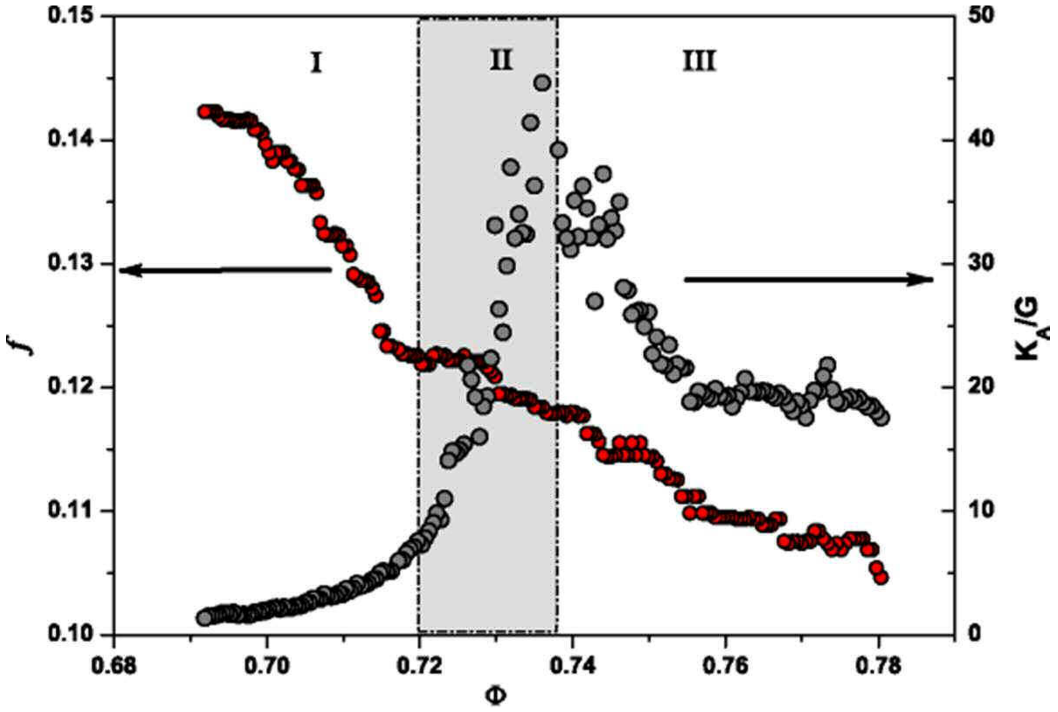


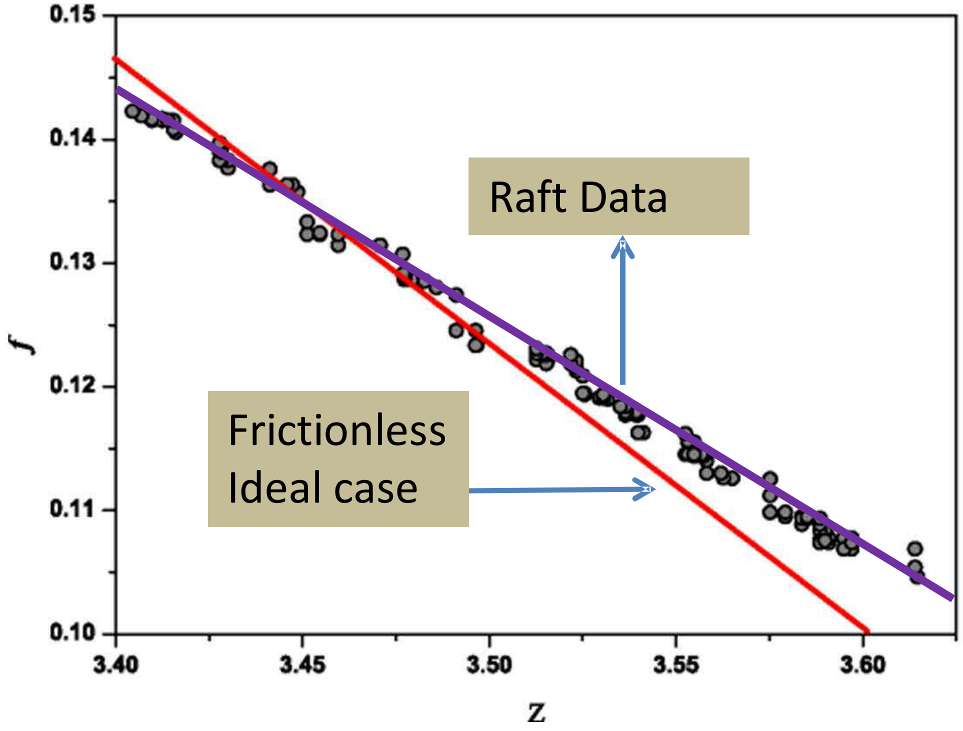
100 µm Particles
Π-A Curve Like Langmuir films
Willhelmy Plate Response
First Compression
from Patchy State
First Exapansion
Π (mN/m)
Area (m2)
0
10
20
30
40
50
60
0.024
0.020
0.016
0.012
0.008

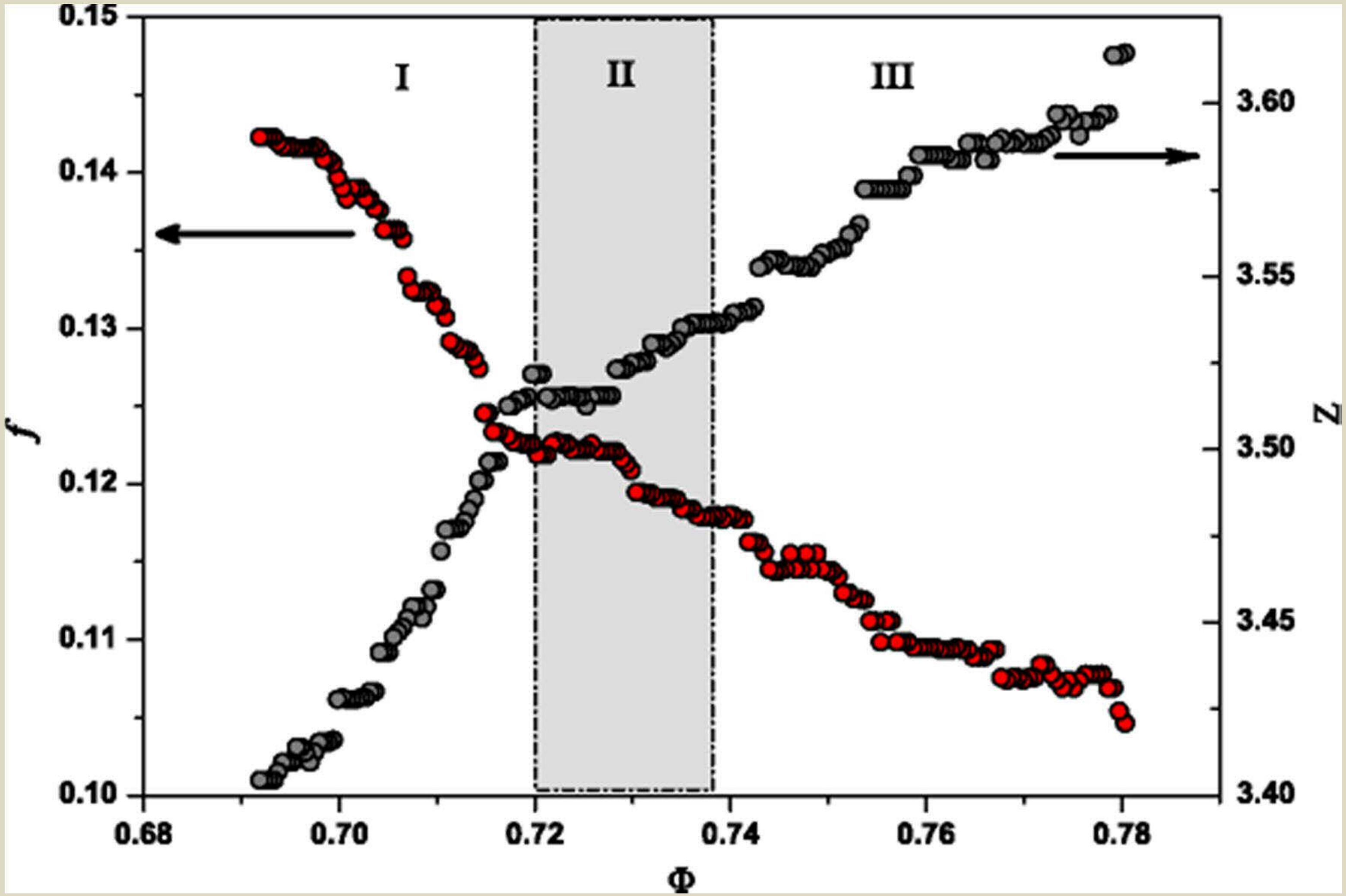
Variation with cycling



Floppy Modes and Moduli Ratio versus Areal Density







0.15
0.14
0.13
0.12
0.11
0.10
f
I
II
III
3.60
3.55
3.50
3.45
3.40
Z
0.68
0.70
0.72
0.74
0.76
0.78
Φ

Summary Scenario

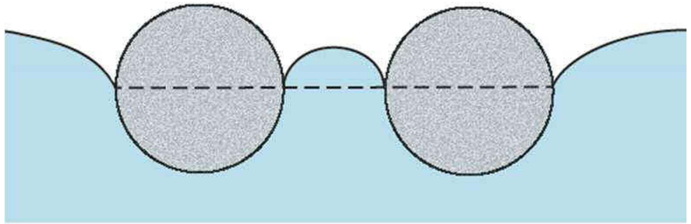
Two "metastable" amorphous phases
Tentatively : An amorphous-to-amorphous transition

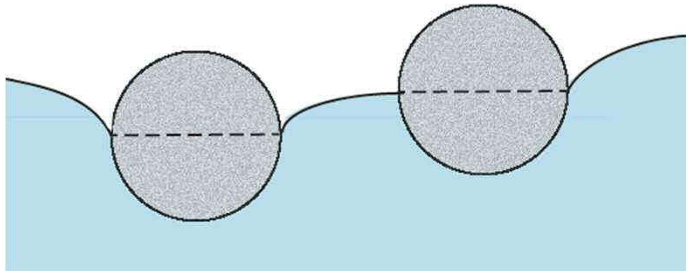
Different dependence on radius
Tentatively: Different mechanisms
"Capillary-Bridged Solid" and "Lubricated-Contact solid"

Crossover involves softening of shear – e.g., soft mode in structural transitions in crystals (shear is dispersive,...finite-frequency effect)
Tentatively: Depinning of contact lines - system specific?

Looking ahead:
Buckling, creasing , wrinkling, cracking : very rich but complex
Phenomenology would help: Pippard-Ehrenfest type signatures?
So would more incisive probes and protocols

Relation to granular-to-elastic medium? Jamming,…?

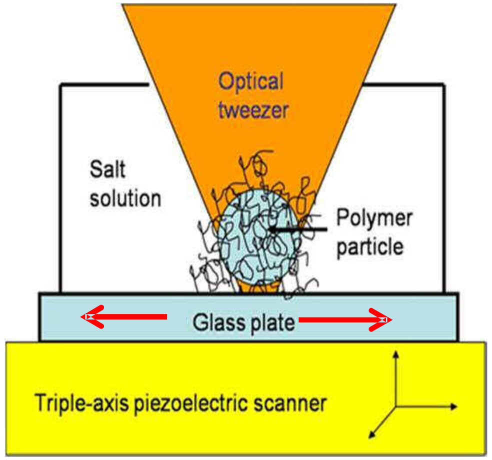




Thank you!

Sticking dynamics of a tethered colloidal particle:
A minimally glassy problem

P. Sharma, Shankar.Ghosh and SB
Nature Physics,4, 960 (2008)
J. Chemical Physics 133, 144909 (2010)
Appl.Phys.Lett, 97, 104101 (2010)

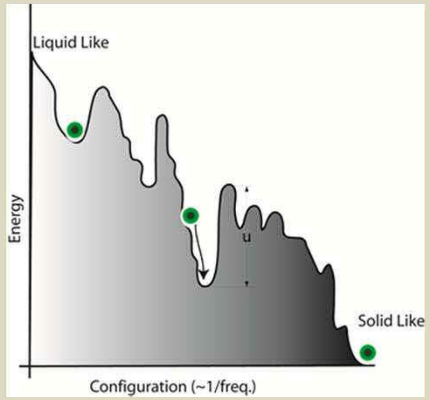


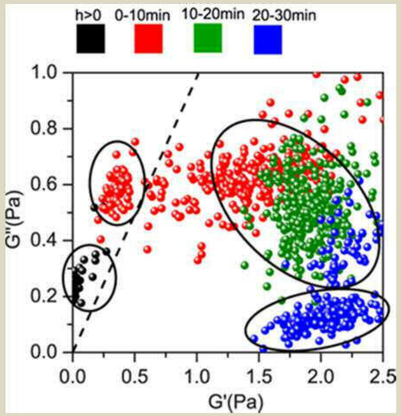
The process of sticking is always abrupt

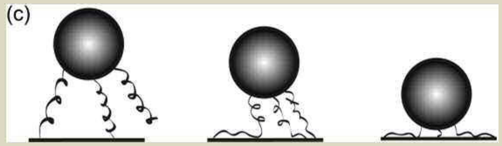
For stuck, non-stuck and aging

From a few degrees of freedom

Effectively a few-body problem one gets hopping down a few basins of attraction







Cartoon of tethers relaxing

A few effective degrees of freedom are enough to show aging & glassiness

Madhav Mani, Arvind Gopinath and L Mahadevan, Preprint (2012)