A microscopic view of the yielding transition in concentrated emulsions

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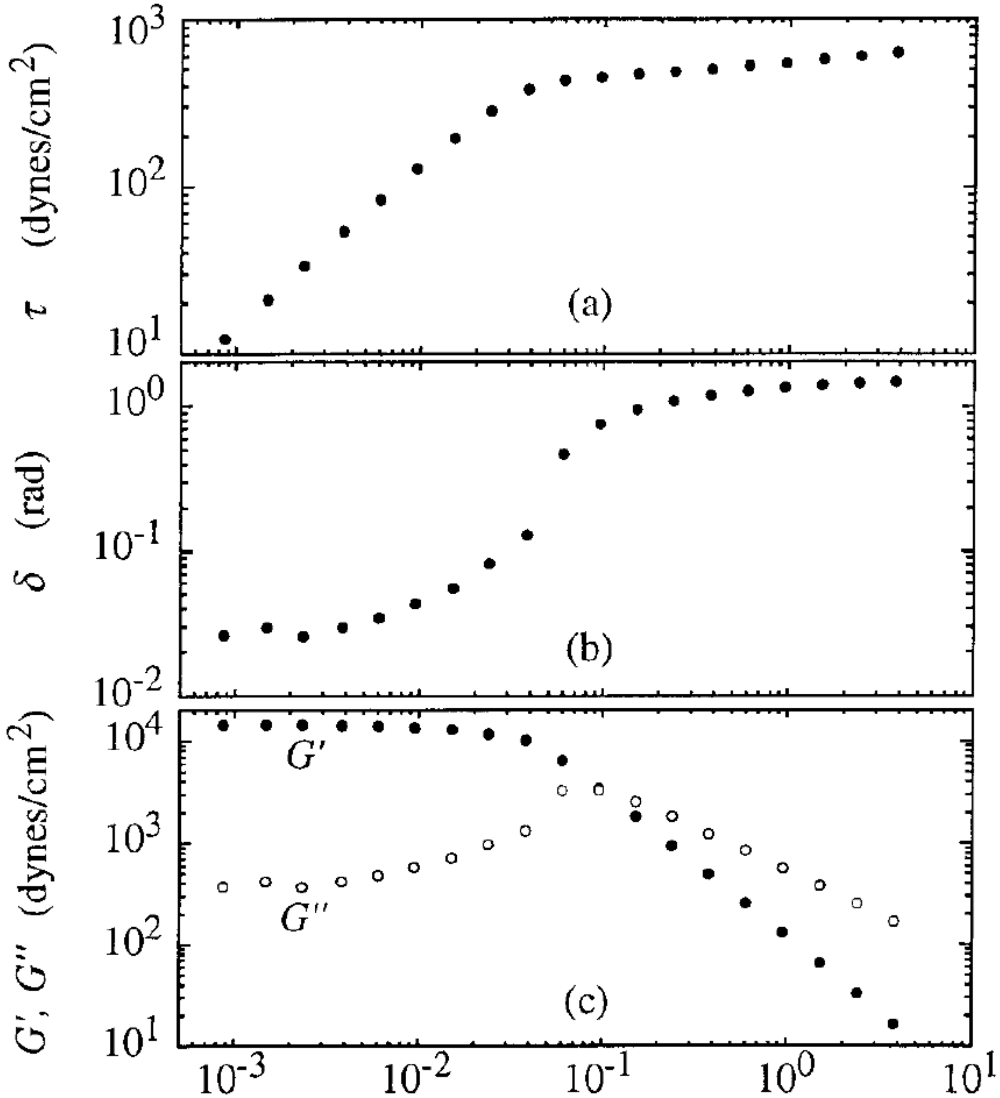
Elizabeth D. Knowlton[1], David J. Pine[1], Luca Cipelletti[2]

[1] Center for Soft Matter Research, New York University, NY 10003, USA
[2] L2C UMR 5221 Université Montpellier 2 and CNRS, Montpellier, France

Yielding of concentrated emulsions



stress

atan[G”/G’]

elastic and loss moduli

strain γ

Mason et al 1996.

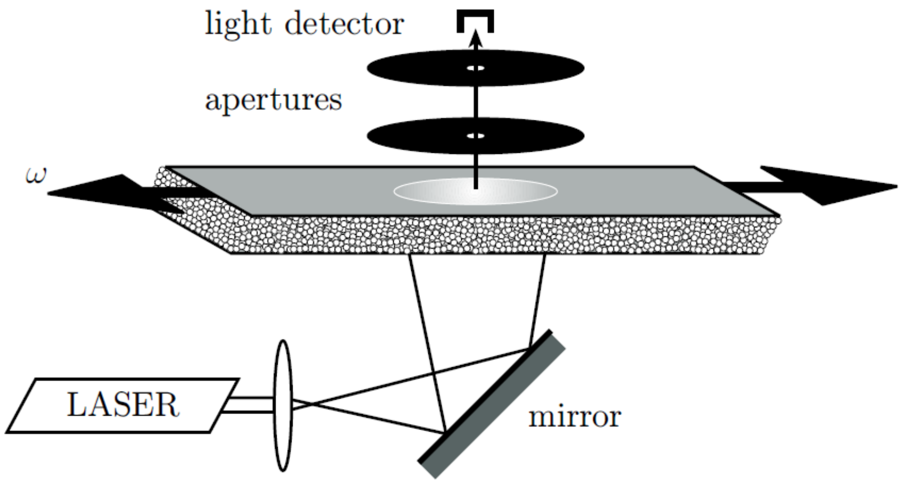
Questions

• Microscopic picture of yielding: cristalline solids OK (defects), what about amorphous solids?

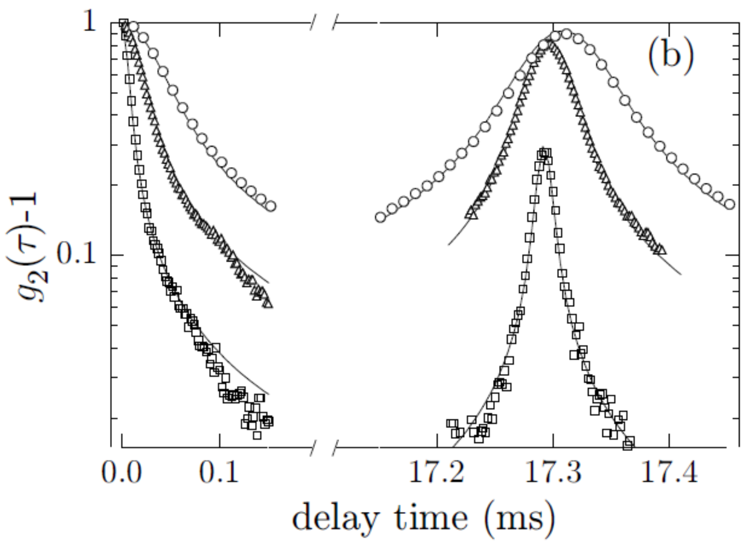
• Oscillatory drive: very few simulations and experiments! BUT relevant to rheology and fatigue tests, easier to detect irreversible rearrangements

• Relation to reversible-irreversible transition in complex fluids?

Oscillatory drive: DWS echo



Courtesy of D.J. Pine

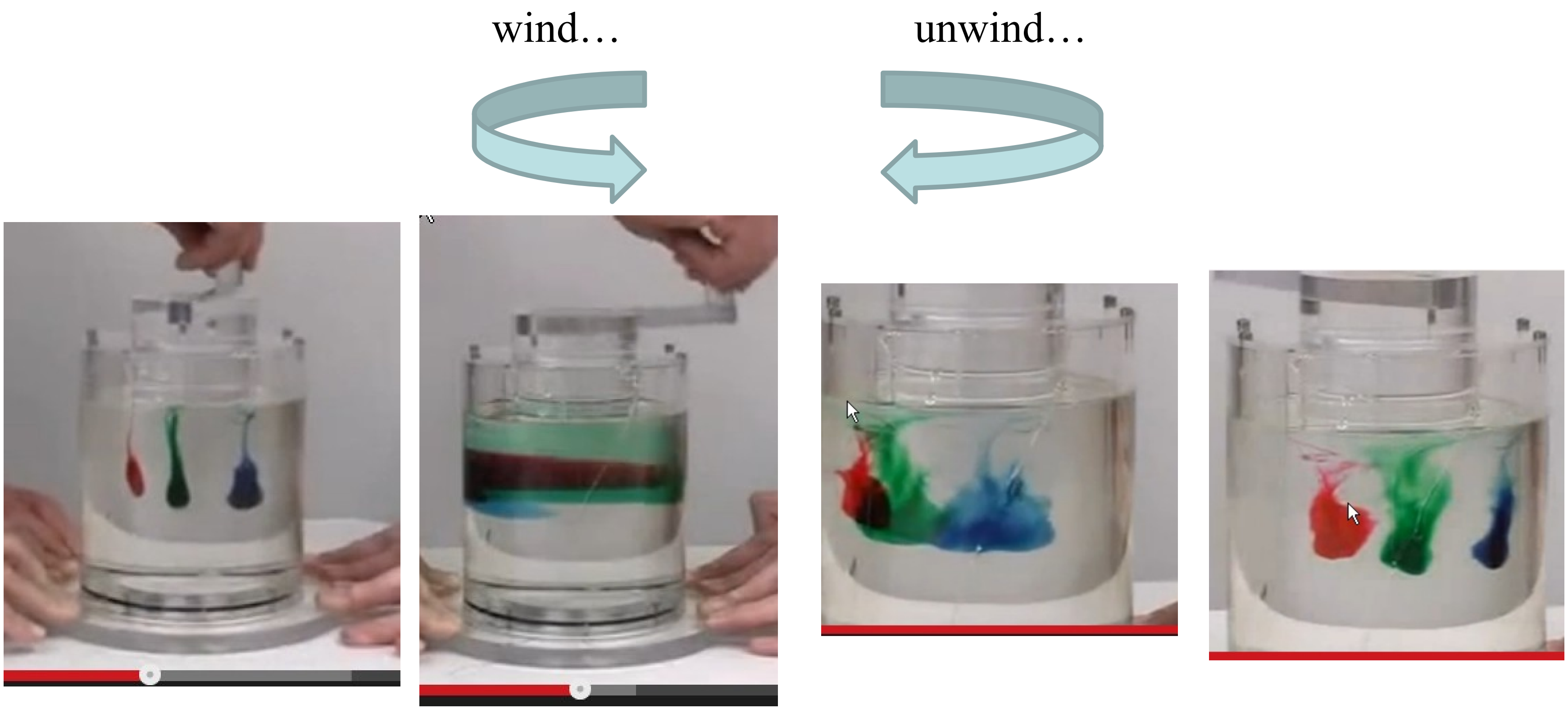


Hebraud et al., PRL 1997

- the same, small fraction of drops undergo irreversible rearrangements at each cycle
- the fraction of rearranged drops increases with γ
- at yielding, just a few % of drops undergo an irreversible rearrangement

- need to make (strong) assumptions on the nature of motion, no spatial/temporal resolution…

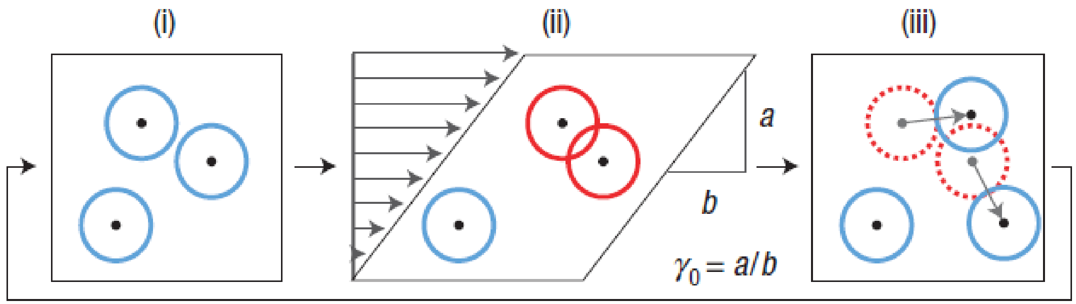
The reversible-irreversible transition: revisiting Taylor's experiment

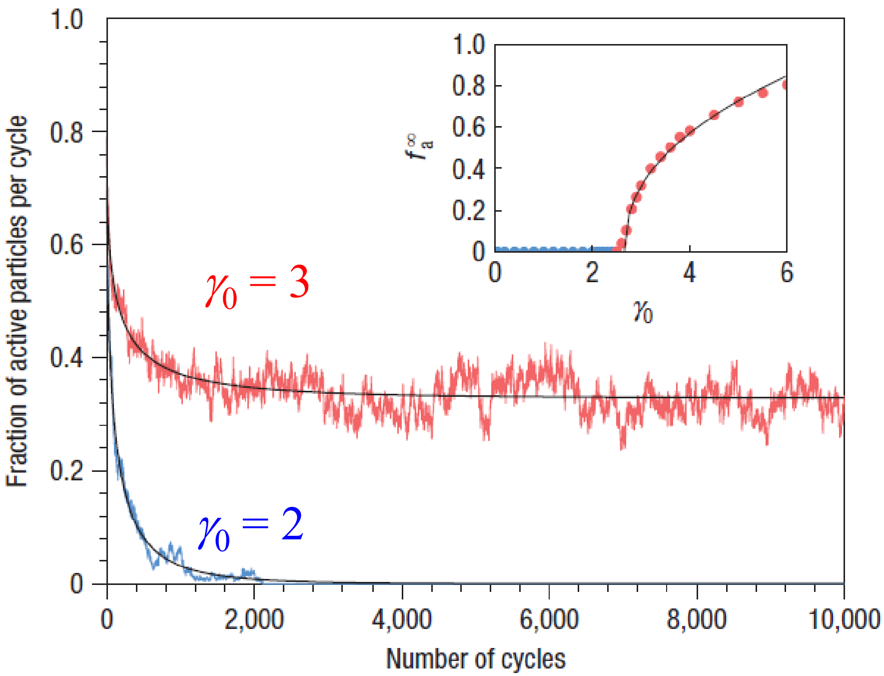


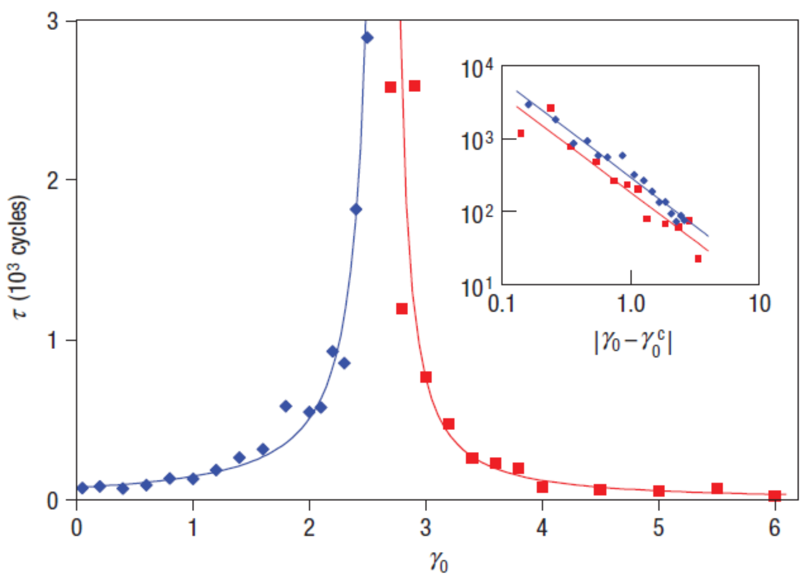
New Mexico University – http://youtu.be/p08_KlTKP50

Suspension of (non-Brownian) particles

Pine's group



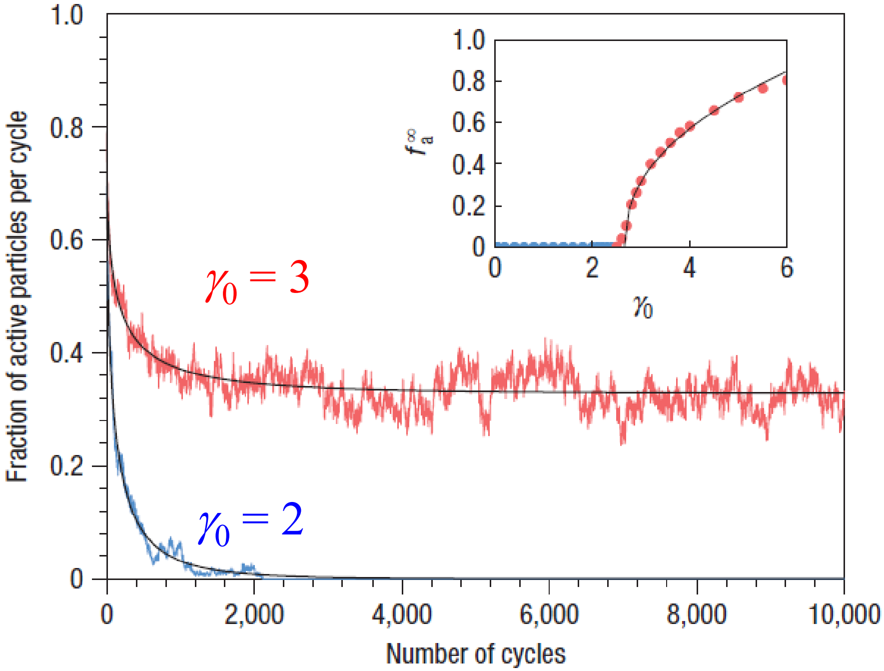


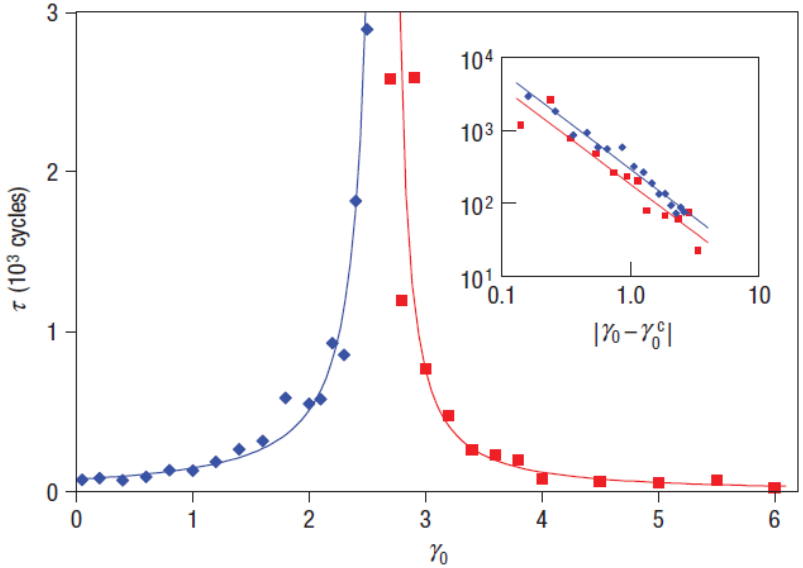


Corte et al, Nature Physics 2008

Suspension of (non-Brownian) particles

2^{nd} order dynamical transition





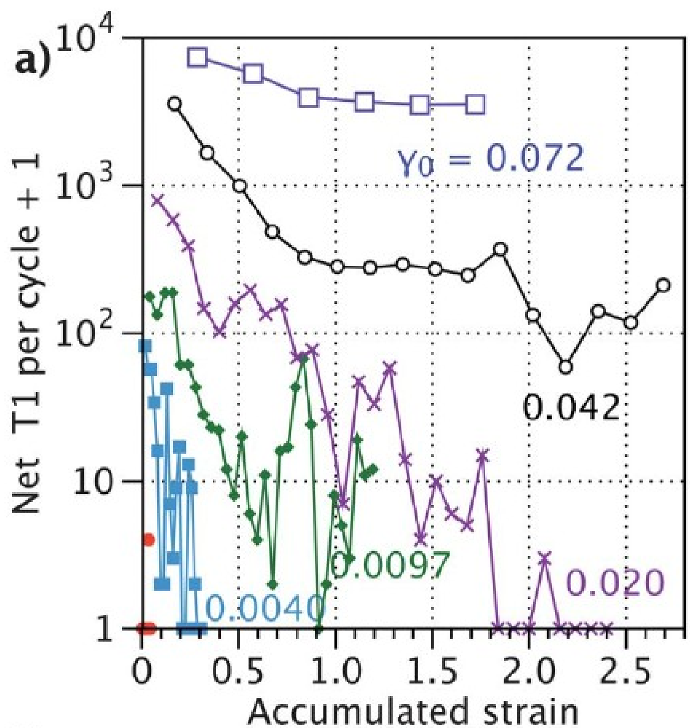
Corte et al, Nature Physics 2008

Dense/strongly interacting systems

Yielding and microstructure in a 2D jammed material under shear deformation†

Nathan C. Keim and Paulo E. Arratia*

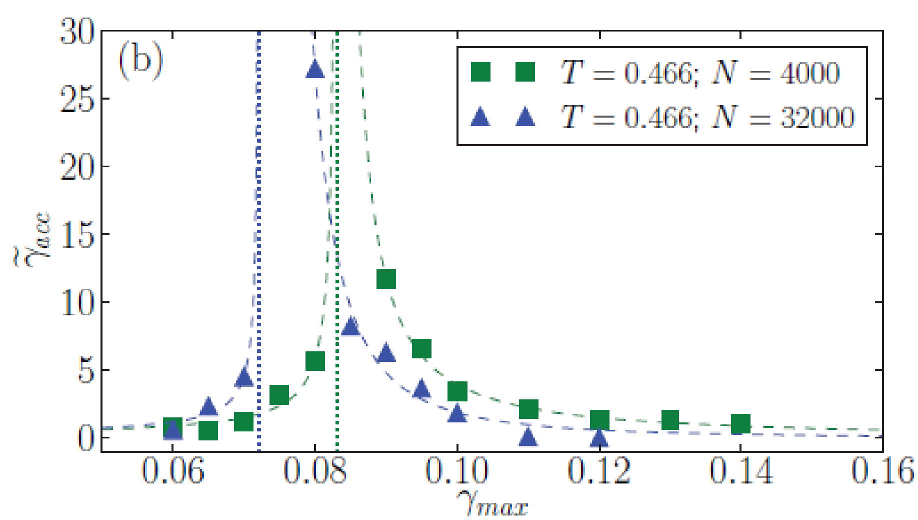
Soft Matter, 2013, **9**, 6222



PHYSICAL REVIEW E **88**, 020301(R) (2013)

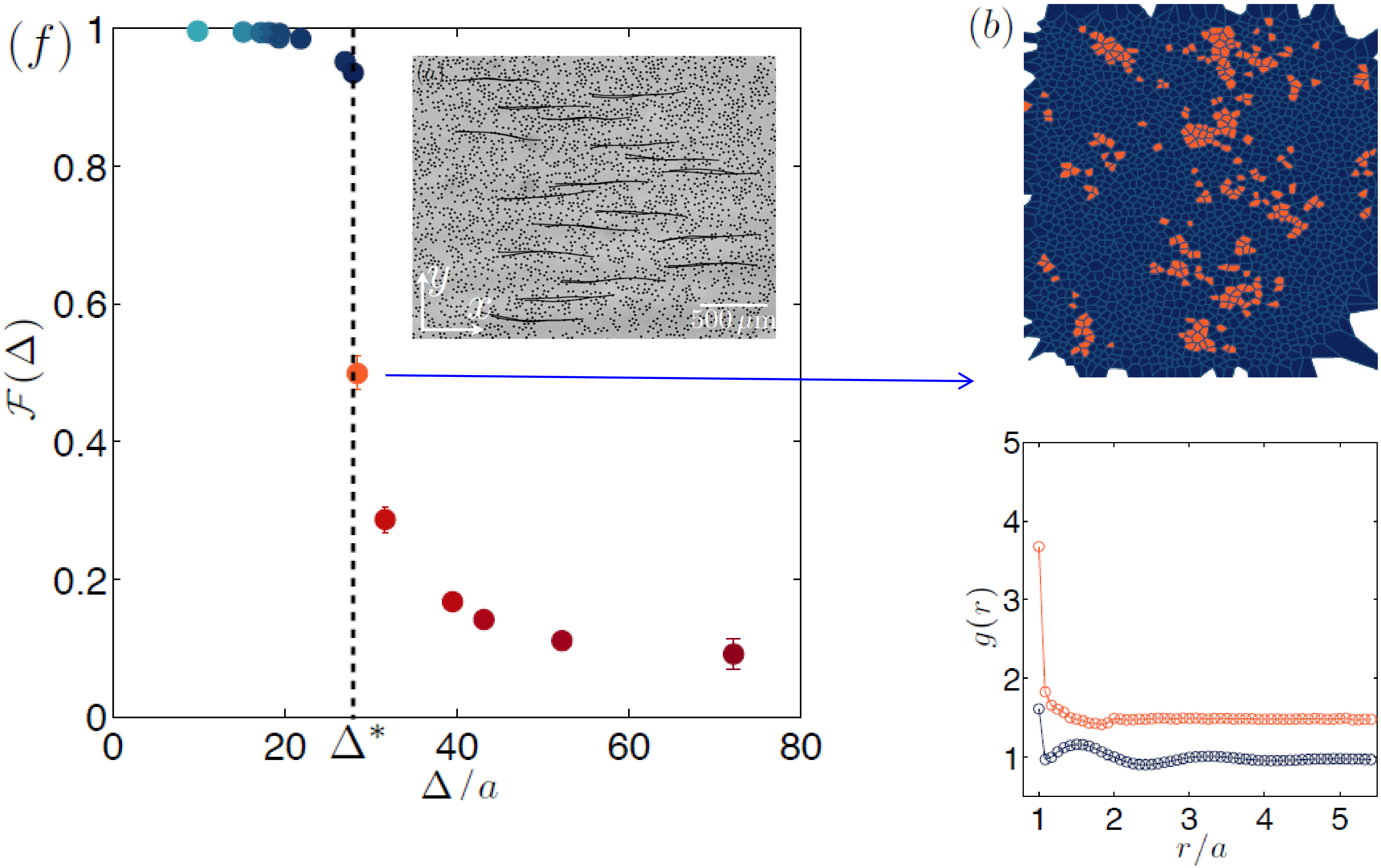
Oscillatory athermal quasistatic deformation of a model glass

Davide Fiocco,[1,*] Giuseppe Foffi,[1,2,†] and Srikanth Sastry[3,4,‡]



Same behavior as in Pine’s experiments??

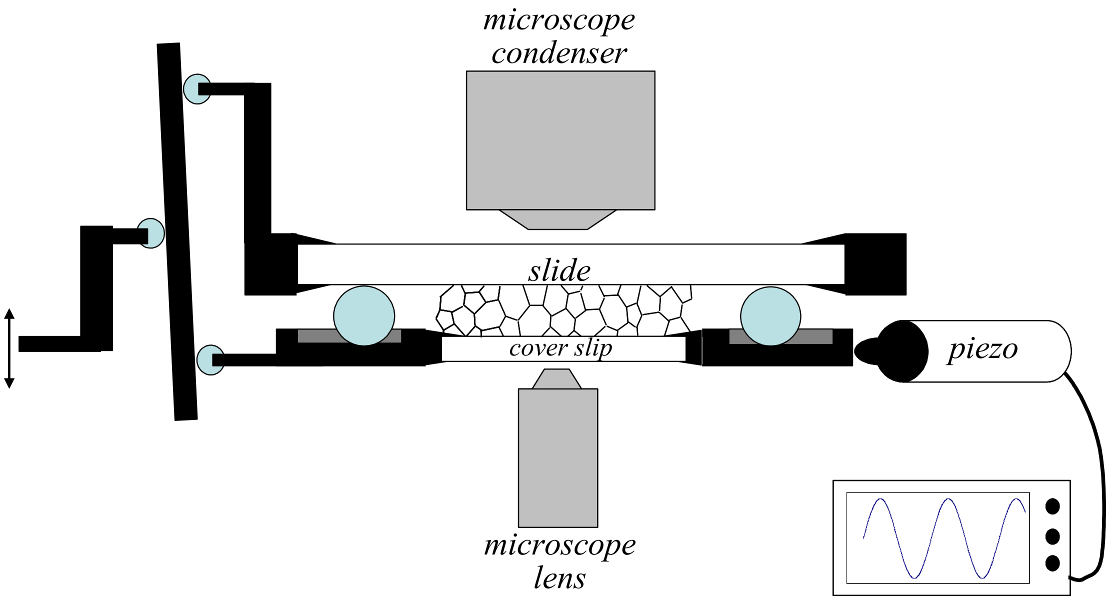
Confined colloids w/ hydrodynamic interactions: 1st order transition??



R. Jeanneret and D. Bartolo, Nature Comm. 2014

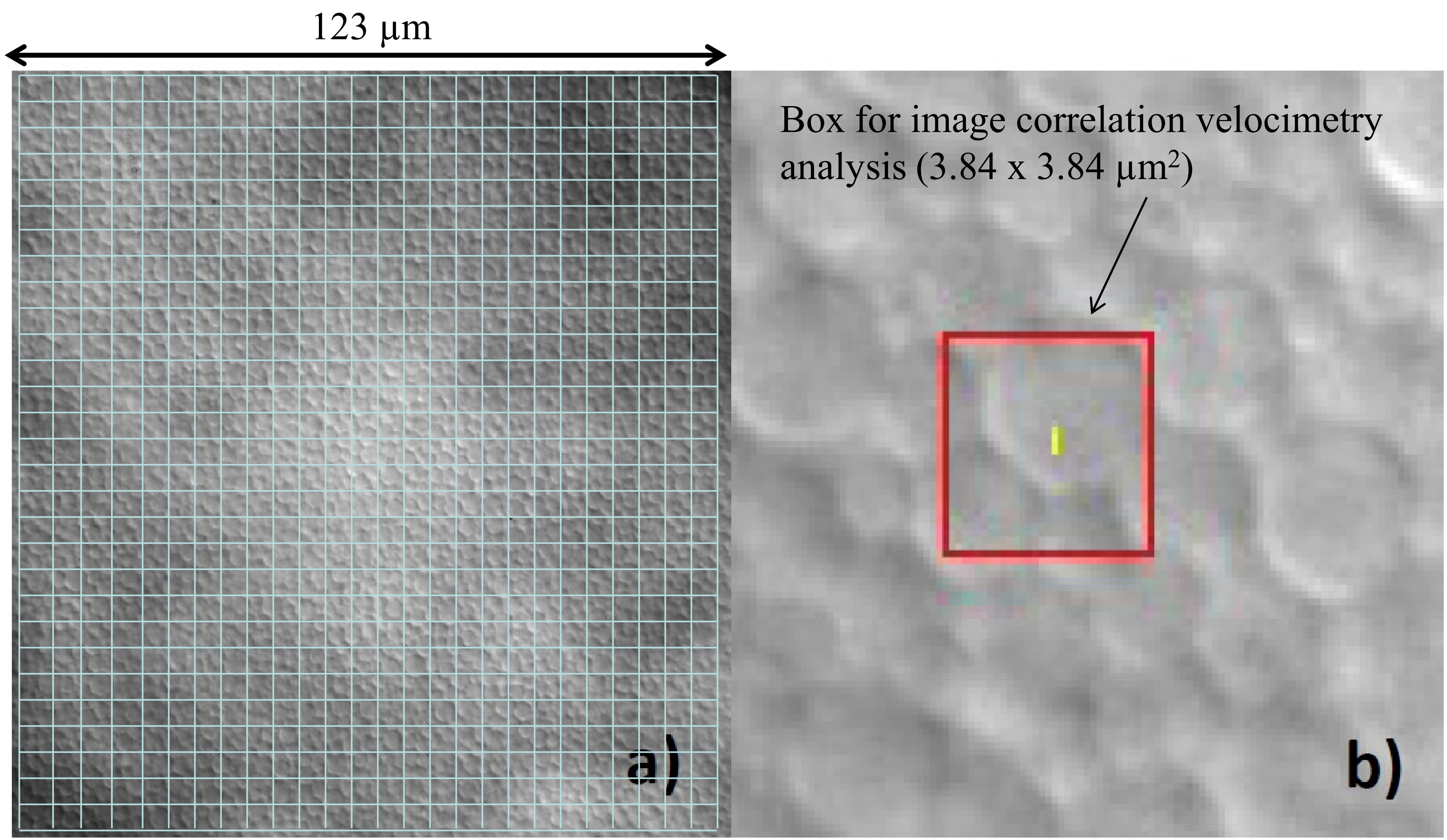
Back to our drops…

Emulsion : PDMS oil + TMN-10 in H_20 + glycerol
$2r$ = 2.4 µm, polidispersity = 20%
φ = 65 – 88%



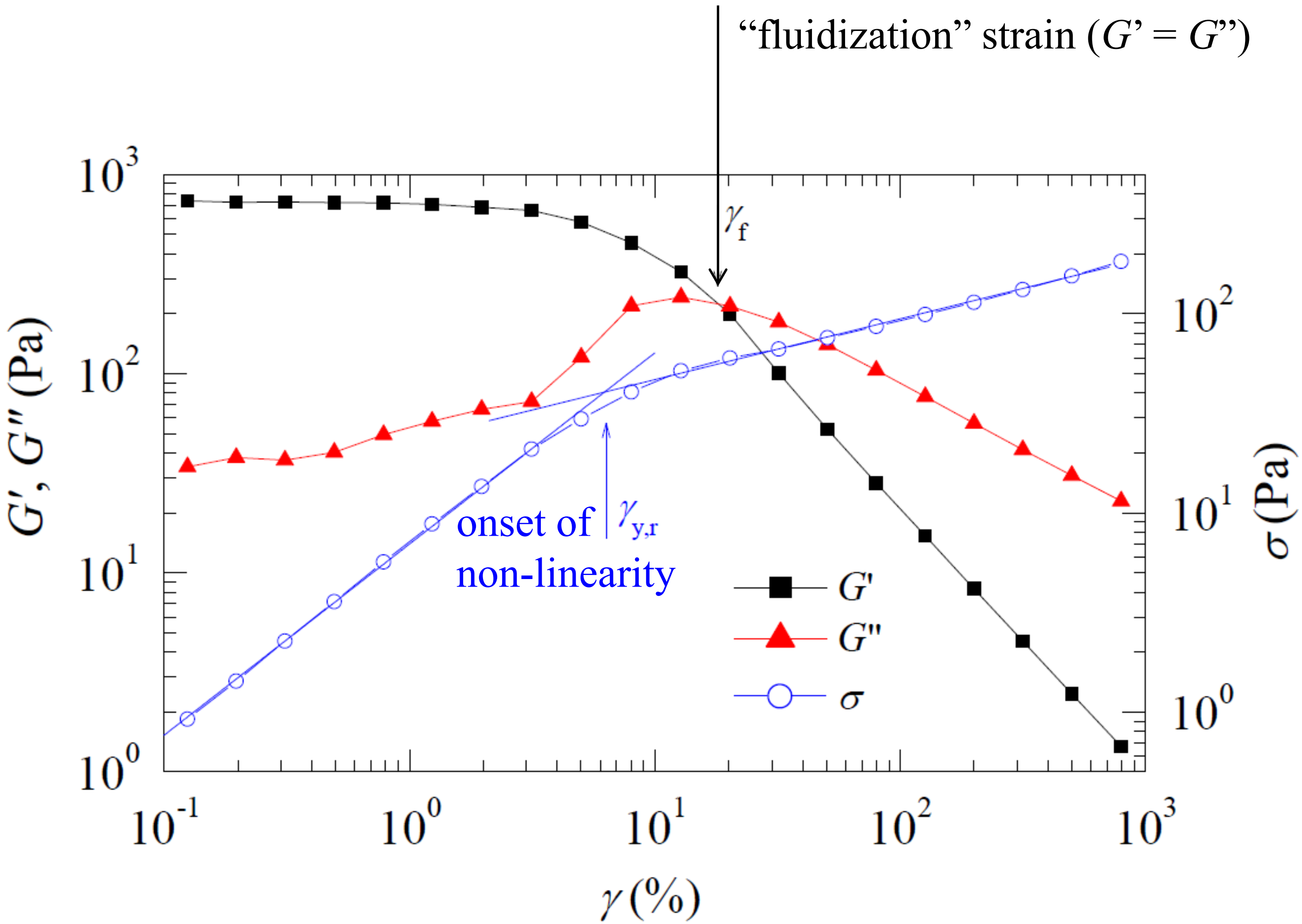
Microscopy : 100x DIC, gap ~100 µm

Visualizing the emulsion



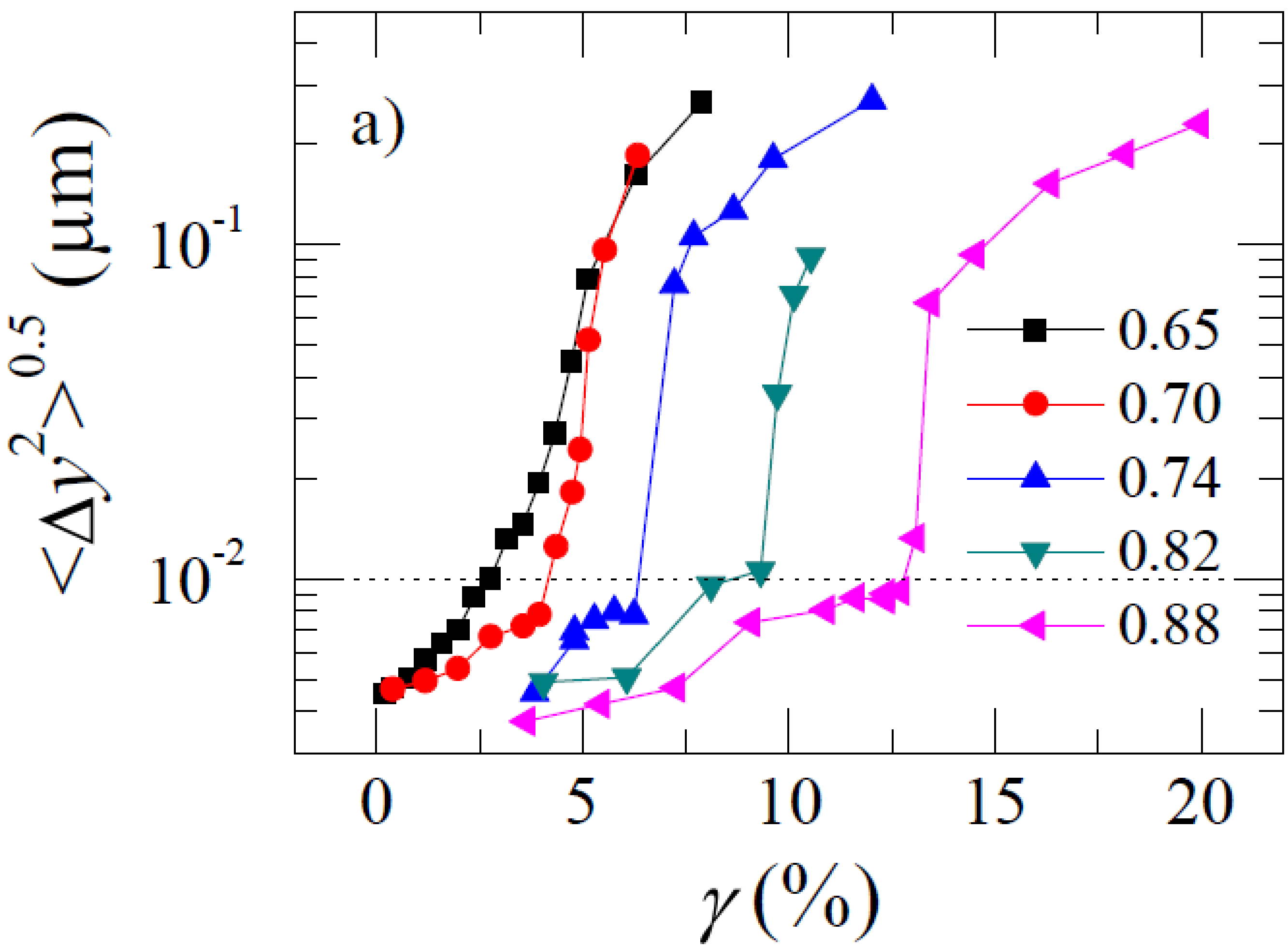
Motion analysis (over one cycle) : Image Correlation Velocimetry (PIV-like)
coarse graining ~ 3.8 μm, resolution ~ 10 nm

Rheology: strain sweep ($\varphi = 0.83$)



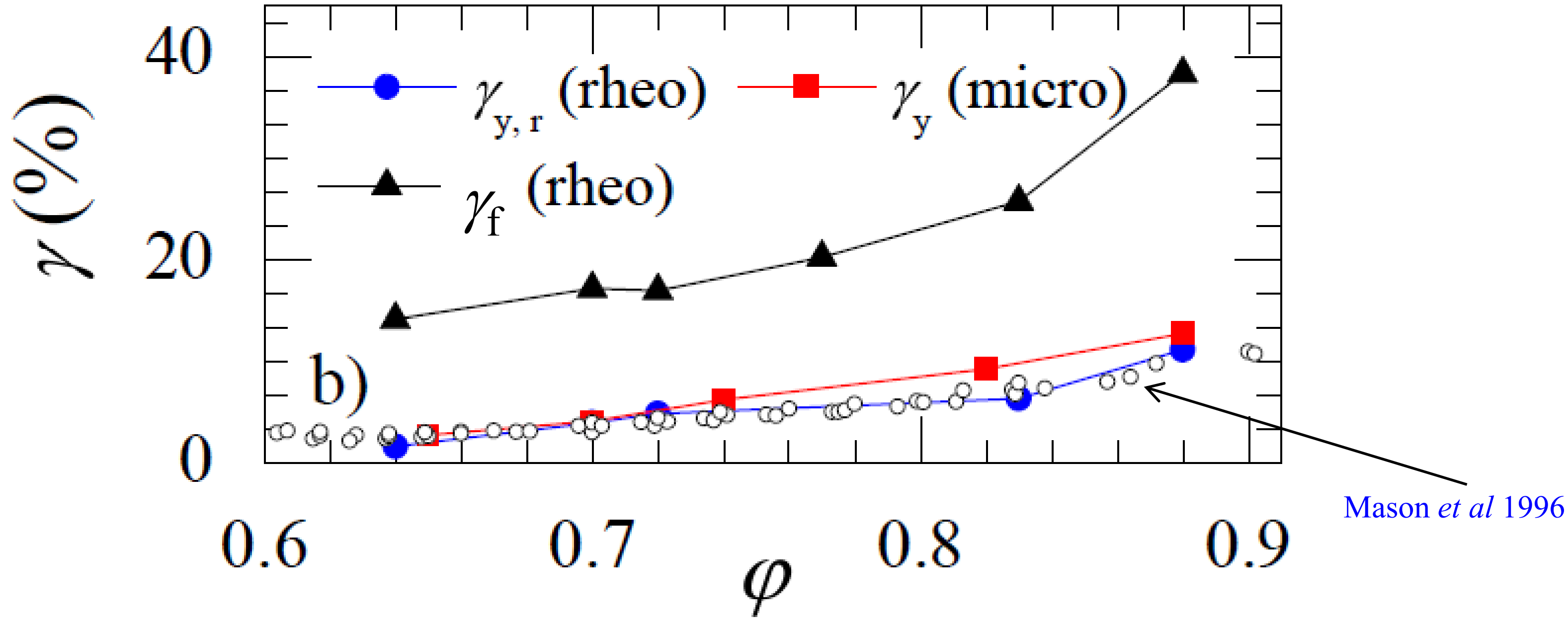
Yielding transition: very smooth!

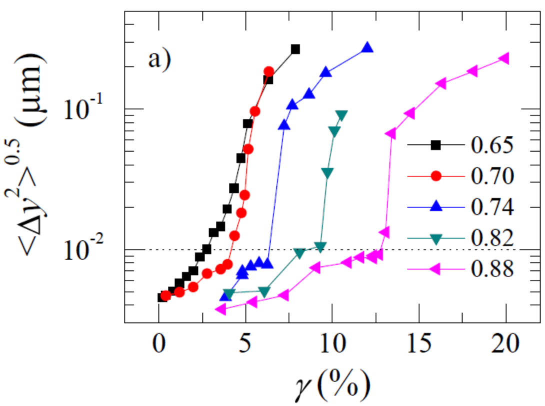
Microscopy: rms displacement

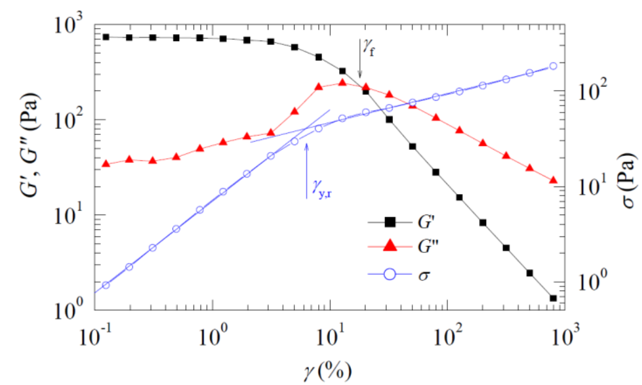


Yielding transition: quite sharp (especially at high φ)

Microscopic vs macroscopic yielding







Microscopic yielding corresponds to macroscopic onset of non-linearity

Motion is heterogeneous

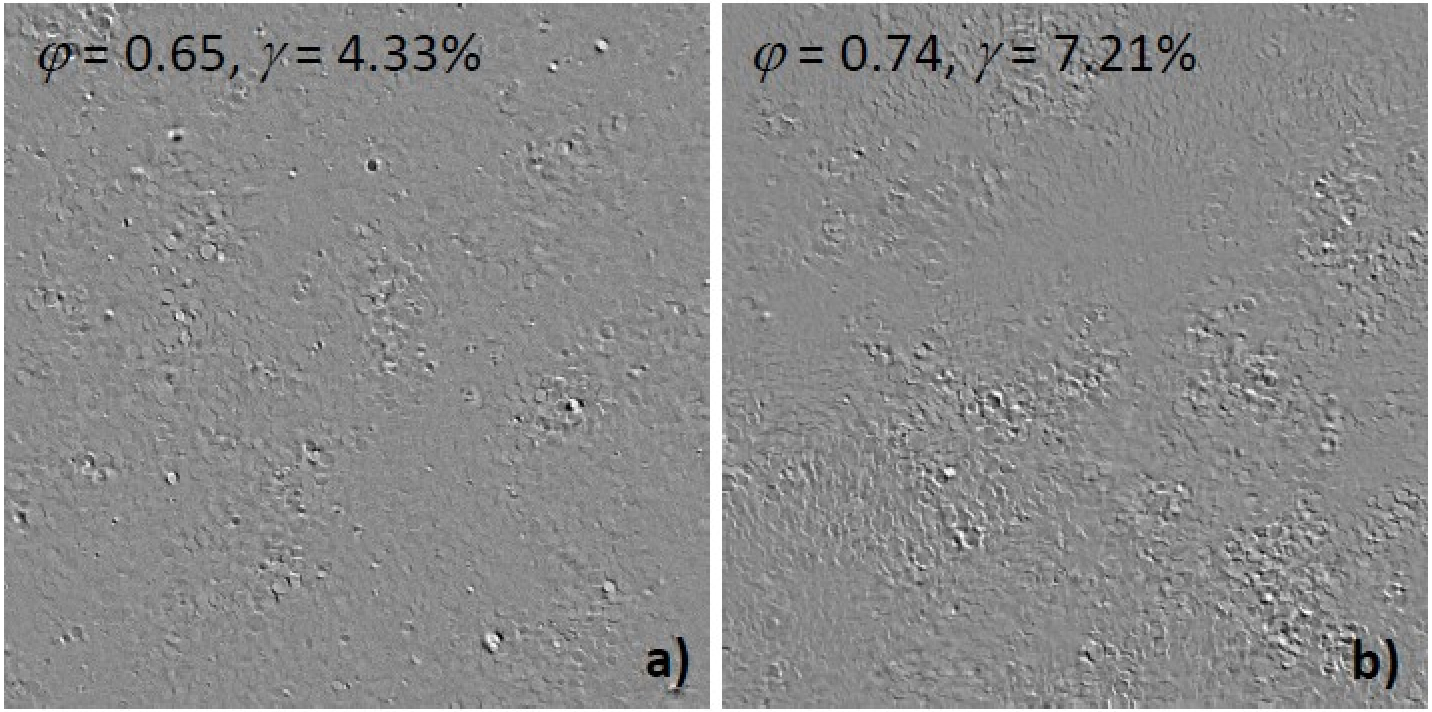
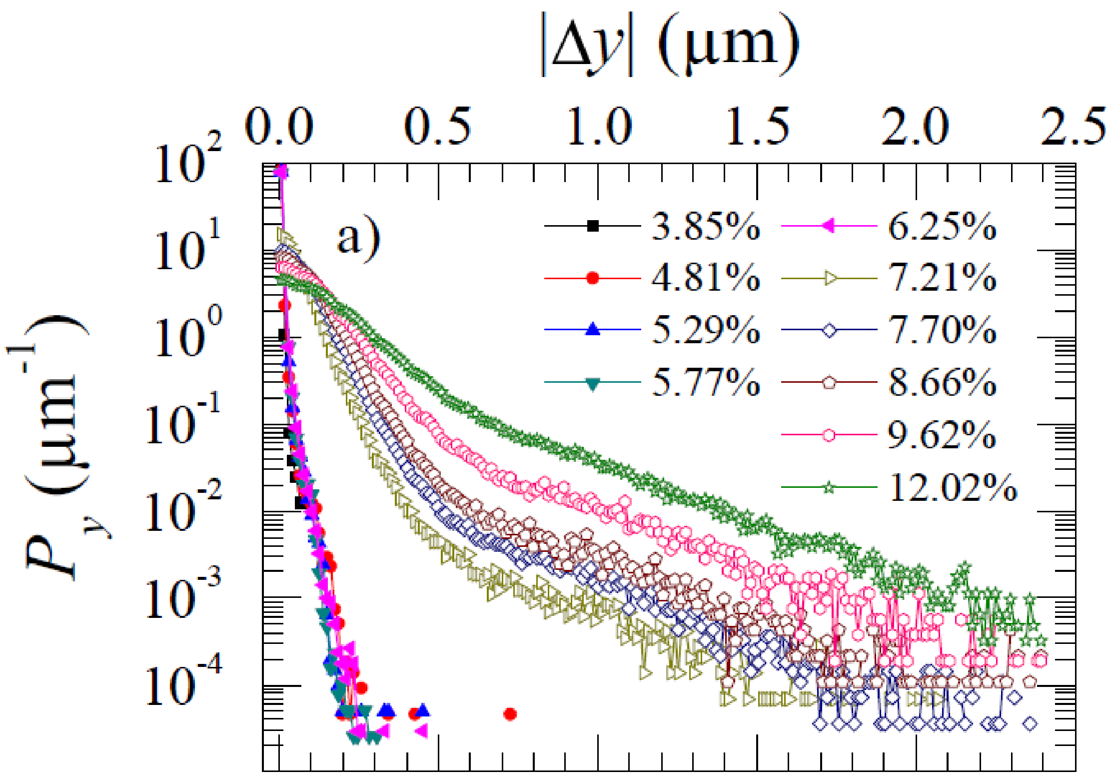


Fig. 4 Difference between two successive strobed images: regions where motion occurred show up as features brighter or dimmer than the average background, while immobile regions are featureless. For each sample, the applied strain is just above the yield strain γ_y.

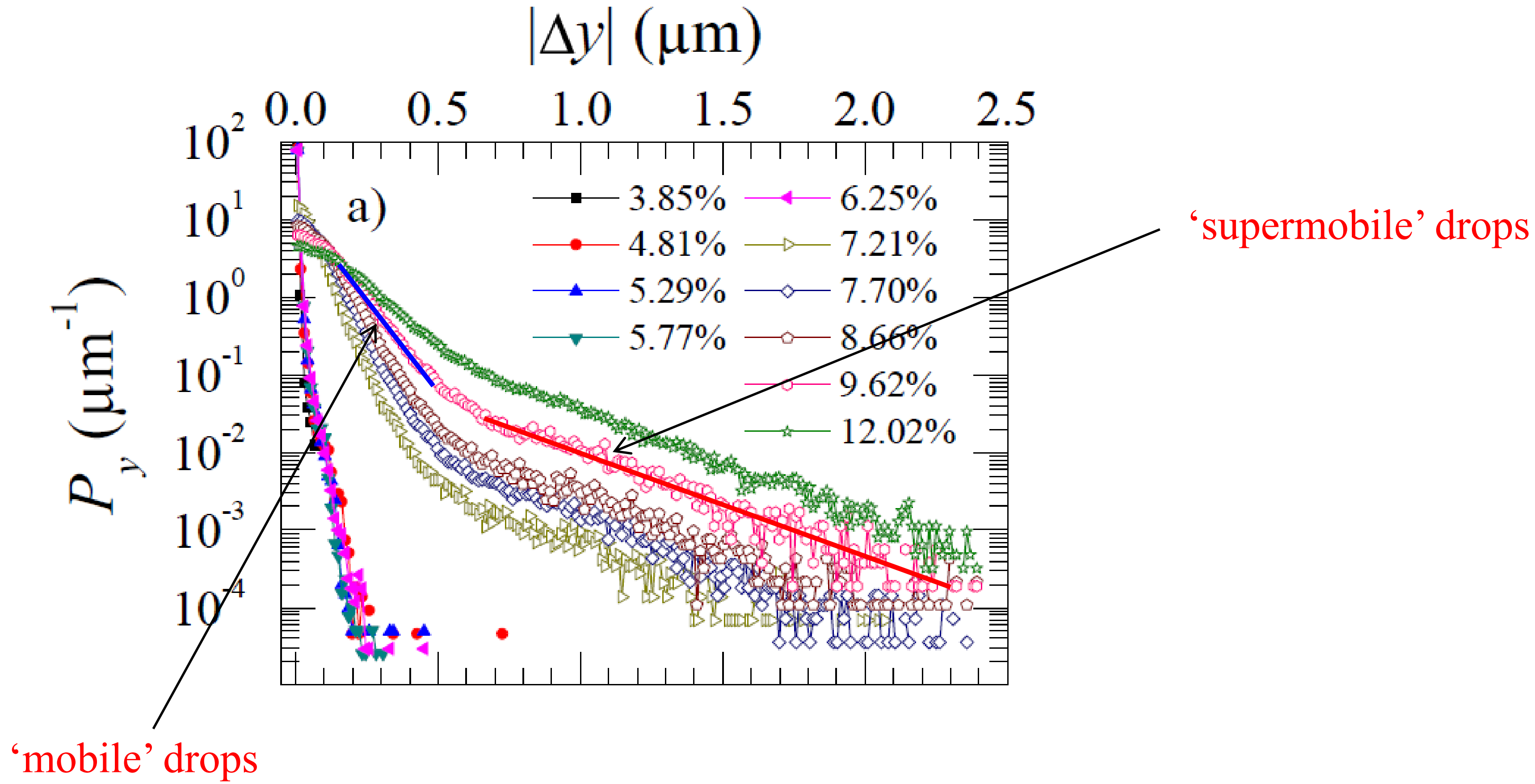
Probability distribution of drop displacements



$\varphi = 0.74$ (same at higher φ)

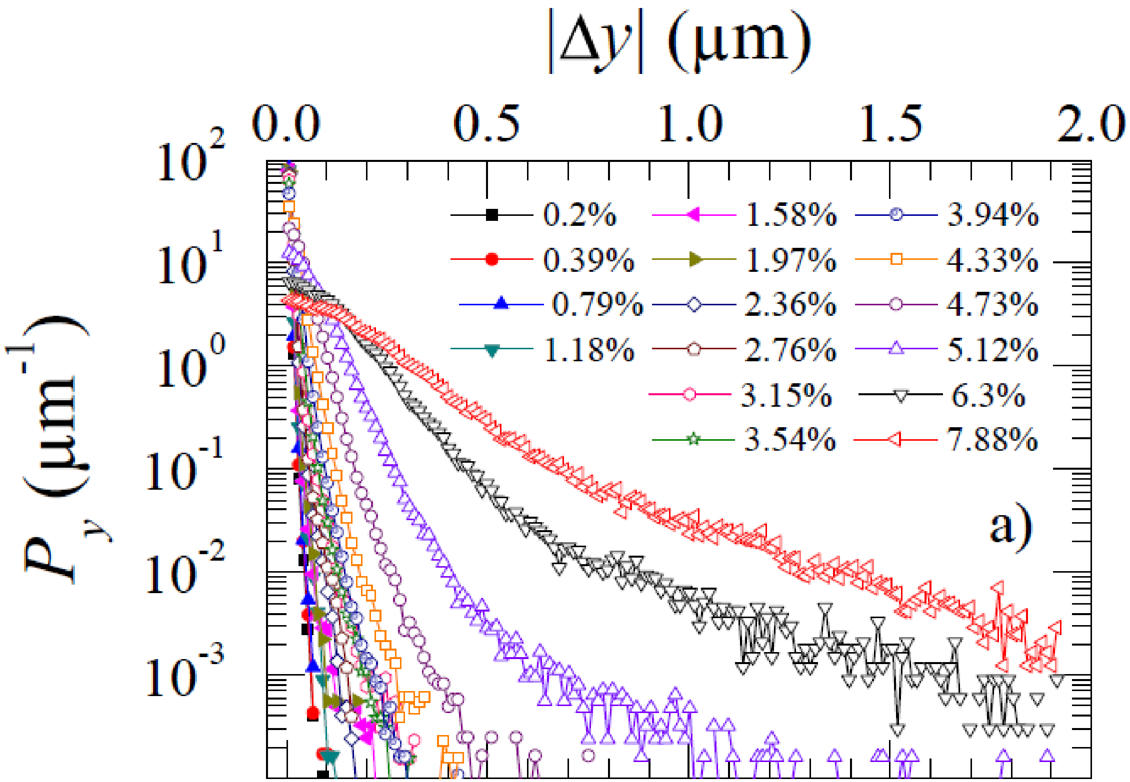
Abrupt change at the yielding transition (compare $\gamma = 6.25\%$ to $\gamma = 7.21\%$)

Probability distribution of drop displacements



Above γ_y: non-Gaussian pdf : ~ *double* exponential tails

Closer to the jamming transition…



$\varphi = 0.65$

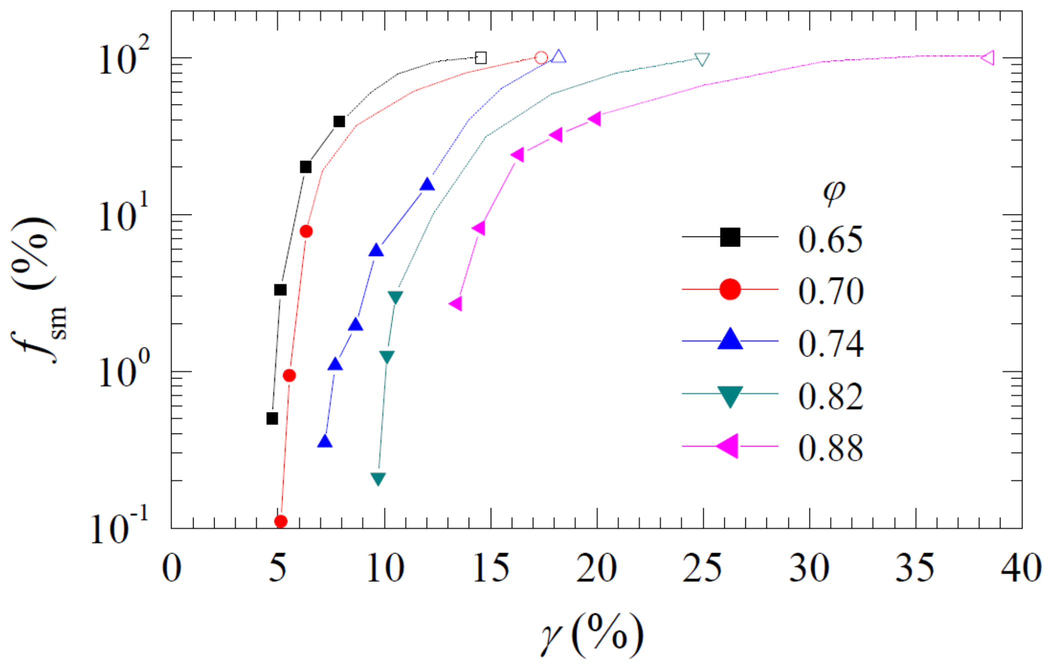
Smoother transition, but again‘mobile’ and ‘supermobile’ drops

A Lindemann's criterion for yielding?

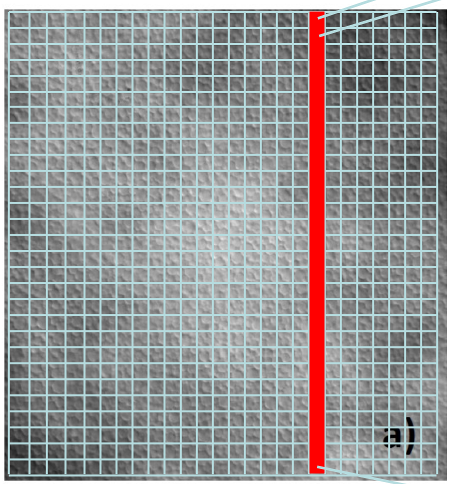
Jump size for 'supermobile' drops: ~11% of drop size (irrespective of φ and γ)

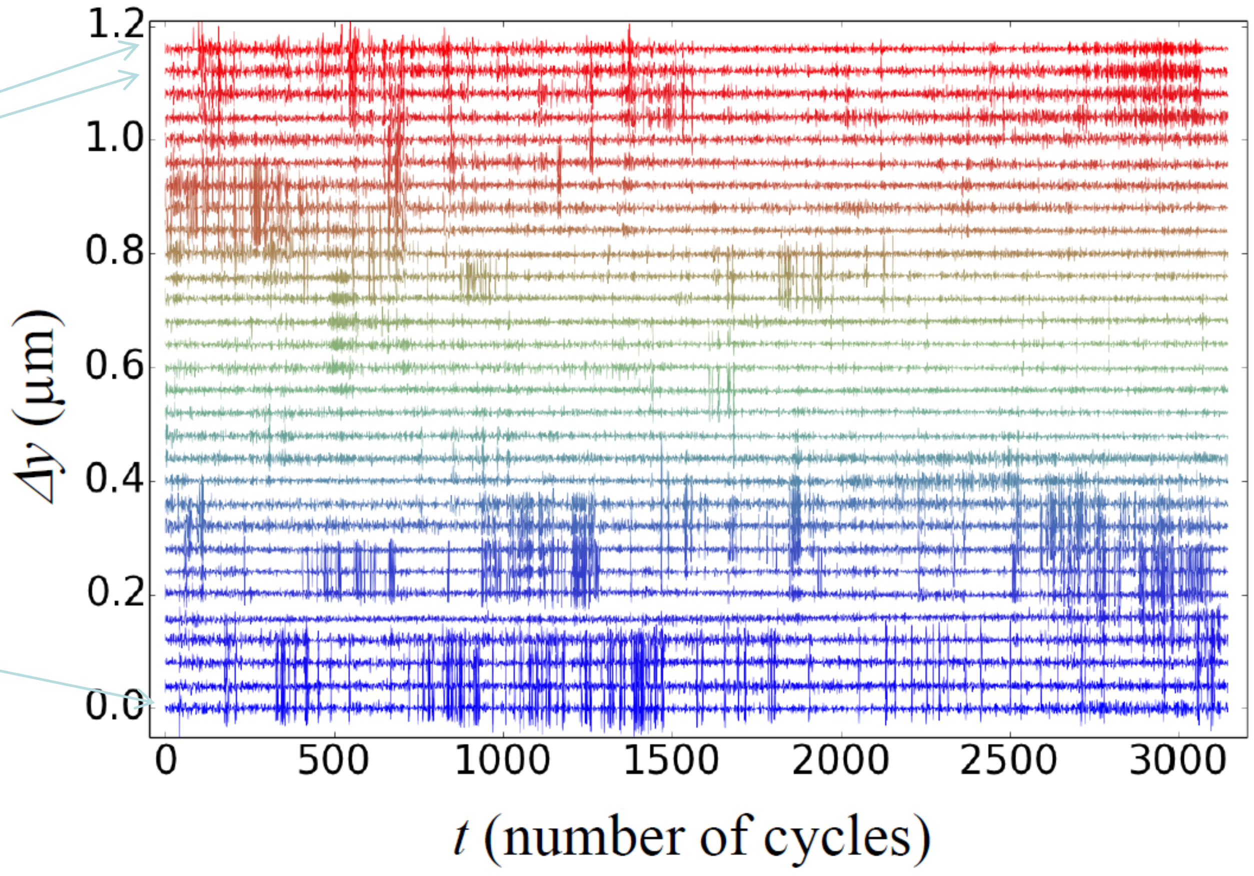
Lindemann's criterion for melting a crystal: particles 'jiggle' over ~15% of their size

→ Yielding transition when all particles become 'supermobile'??



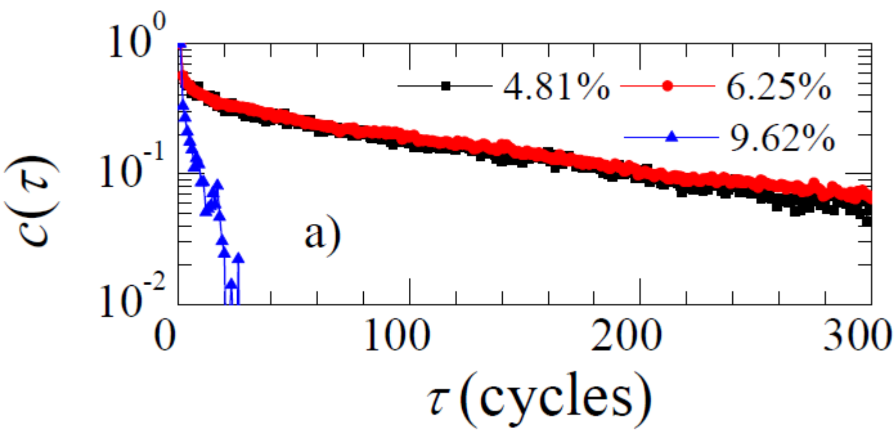
Dynamics: spatial and temporal organization



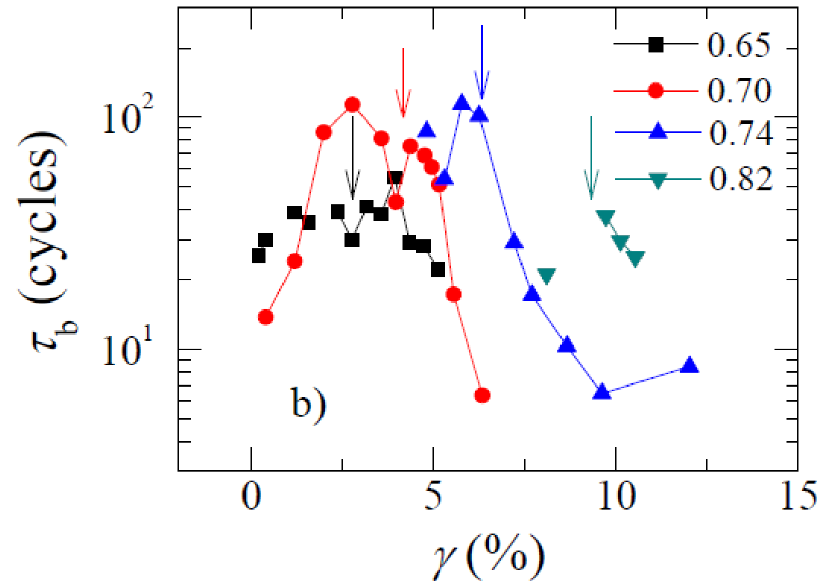


Temporal correlation: bursts of motion

$$c(\tau) = \langle\langle|\Delta y(t,\mathbf{R})||\Delta y(t+\tau,\mathbf{R})|\rangle_t\rangle_{\mathbf{R}}$$



$\varphi = 0.74$ ($\gamma_y = 6.5\%$)

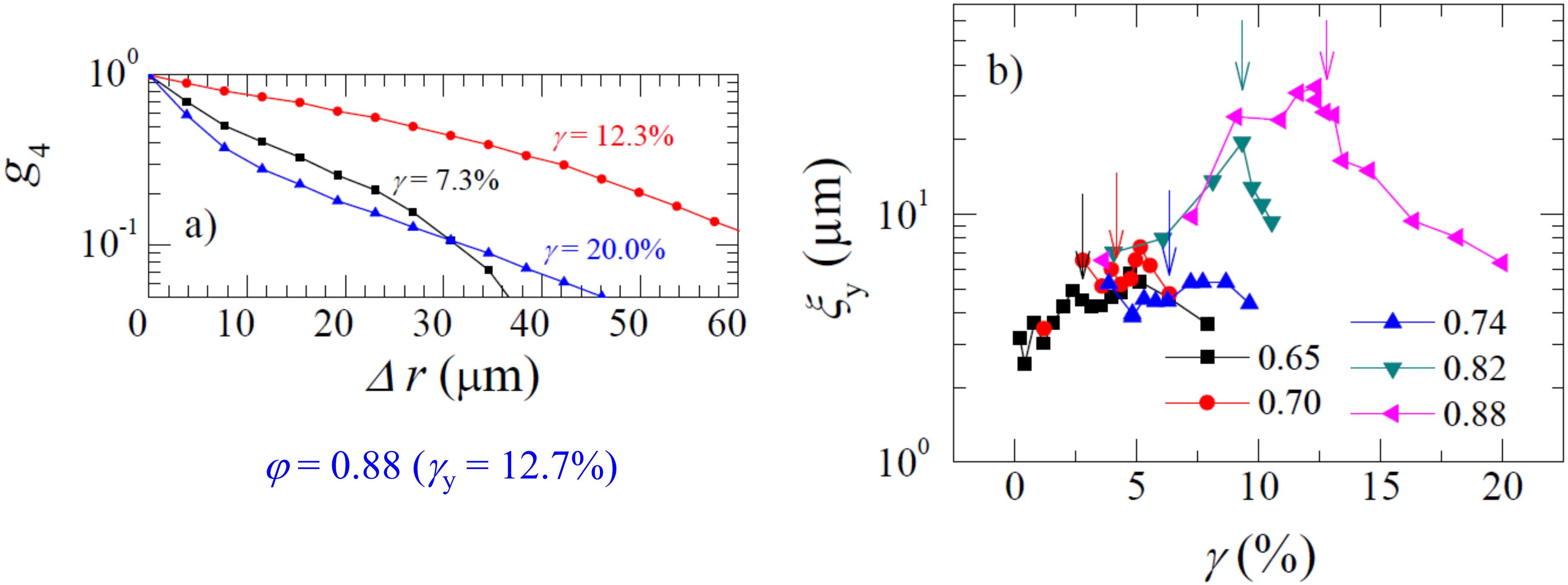


- Bursts of motion may last hundreds of cycles, but eventually mobile/quiescent drops do exchange

- No clear indication of divergence around γ_y: transition not so 2nd order…

Spatial correlation

$$g_4(\Delta\mathbf{r}) \sim \langle\langle \Delta y(\mathbf{R},t)\Delta y(\mathbf{R}+\Delta\mathbf{r},t)\rangle_t\rangle_{\mathbf{R}}$$



$\varphi = 0.88$ ($\gamma_y = 12.7\%$)

- Spatial correlations extend up to ~10-15 drops
- ξ_y larger at higher φ: stress transmission important ?
- Behavior around γ_y: varies with φ…

Conclusions

• Yield transition at a microscopic level quite sharp, as opposed to rheology

• Motion is heterogeneous: 'quiescent' , mobile and supermobile particles coexist

• extended spatio-temporal correlations of dynamics, but quiescent/mobile populations eventually do exchange

• A Lindemann's criterion for fluidization of amorphous systems?

• Nature of the transition unclear:
- Close to φ_J : smoother $\Delta y(\gamma)$, but no diverging length/time scales aroung γ_y
- At higher φ : sharp transition, but length/time scales grow significantly around γ_y

Thanks to…

NYU
Department
of Physics

You all!