Origin of two distinct stress relaxation regimes in shear jammed dense suspensions

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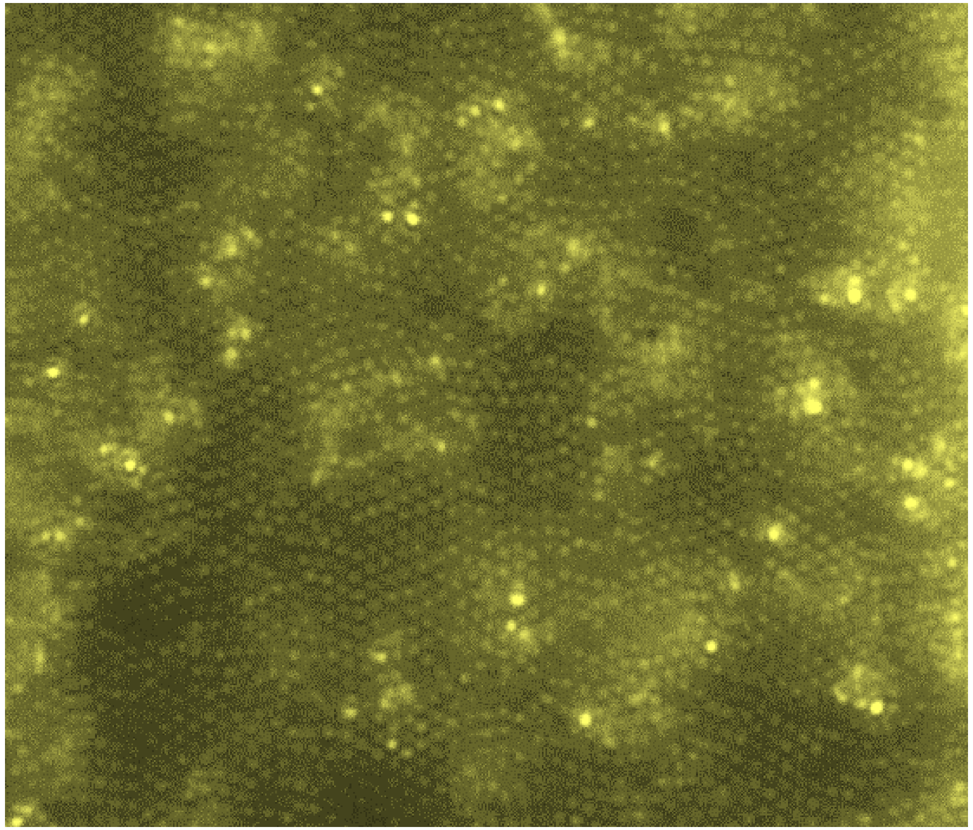
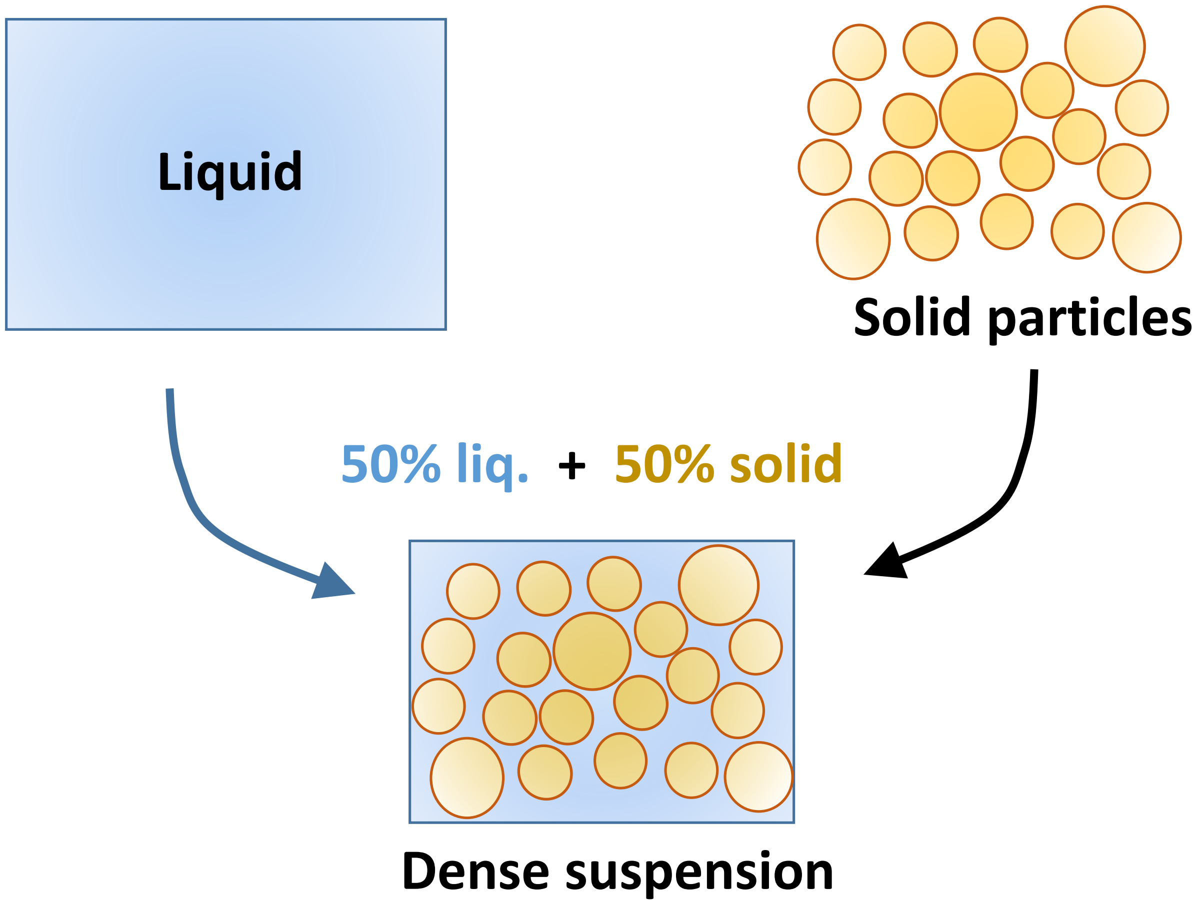


ISPCM 2023, ICTS

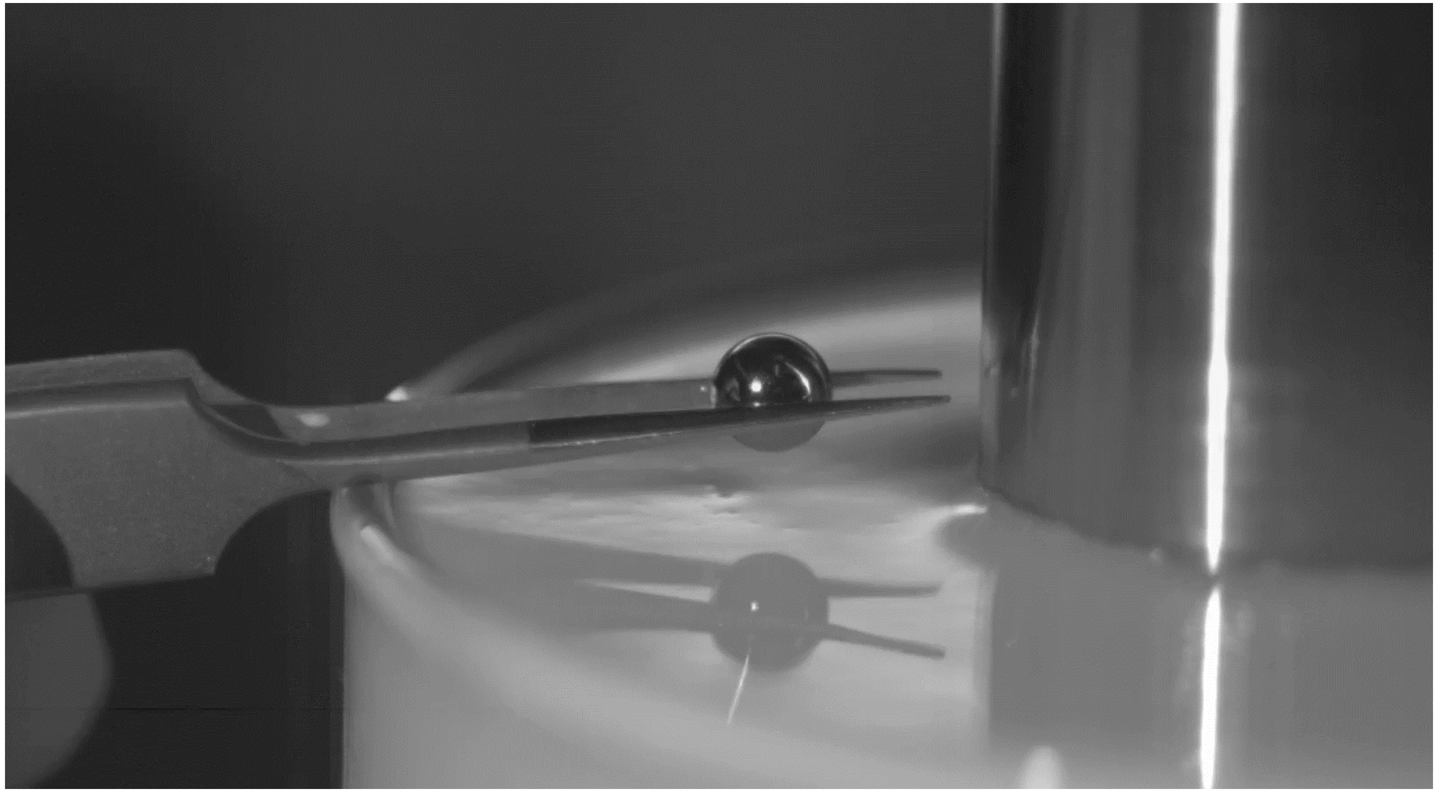
Force activated reversible liquid-solid transition



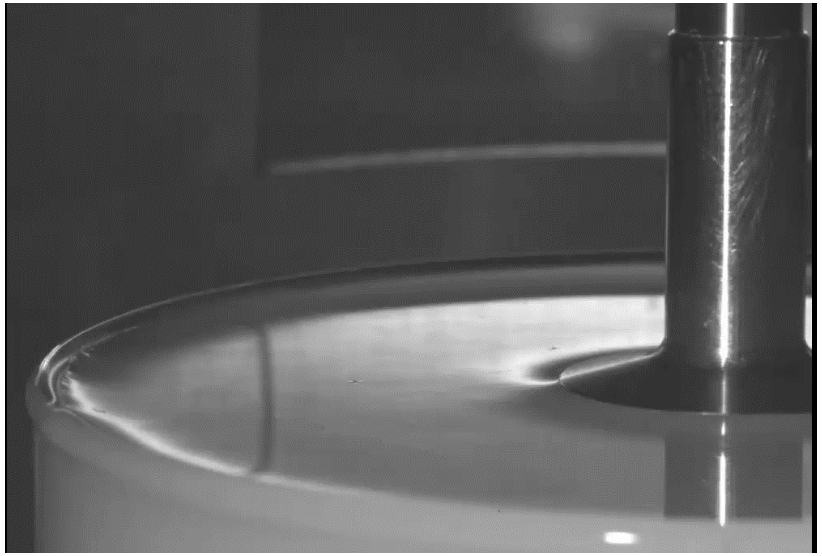
Force induced tuning of mechanical properties

Shear induced jamming transition

Ben Allen, Yale University



Peters, Majumdar and Jaeger, Nature (2016)

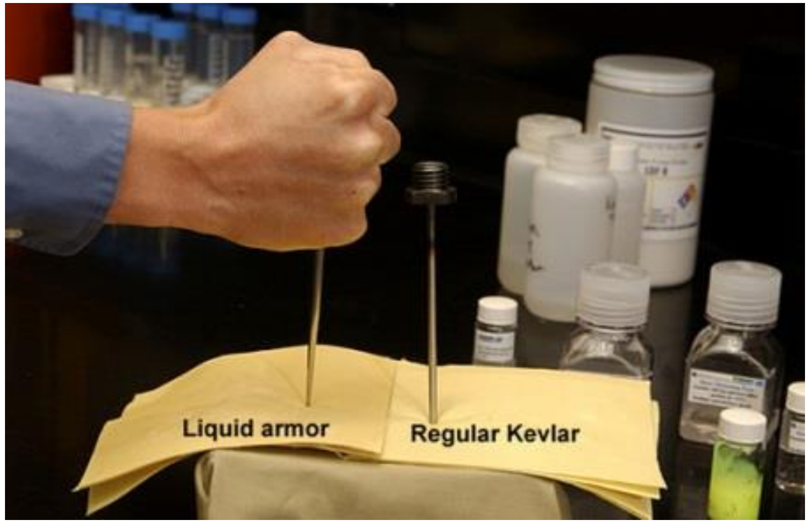


Majumdar et al., Phys. Rev. E (2017)

Shear induced jamming transition: why care?

These systems are being used in designing flexible shock absorbers:

Development of protective fabrics by improving the resistance of textile materials against ballistic impact and penetration



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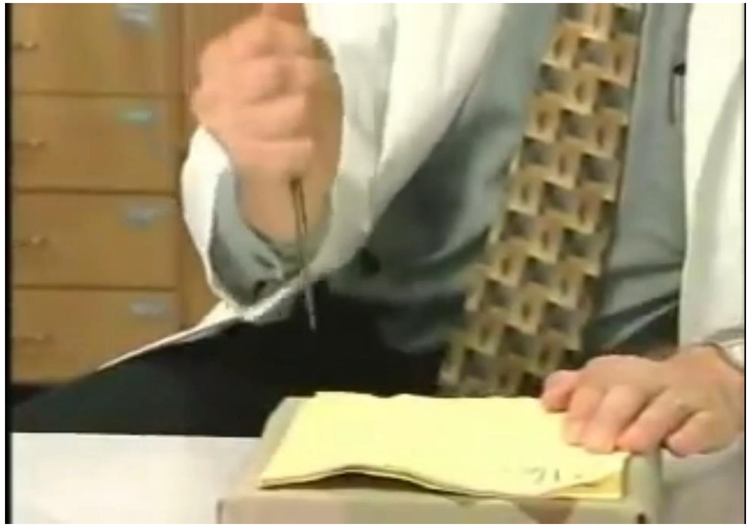

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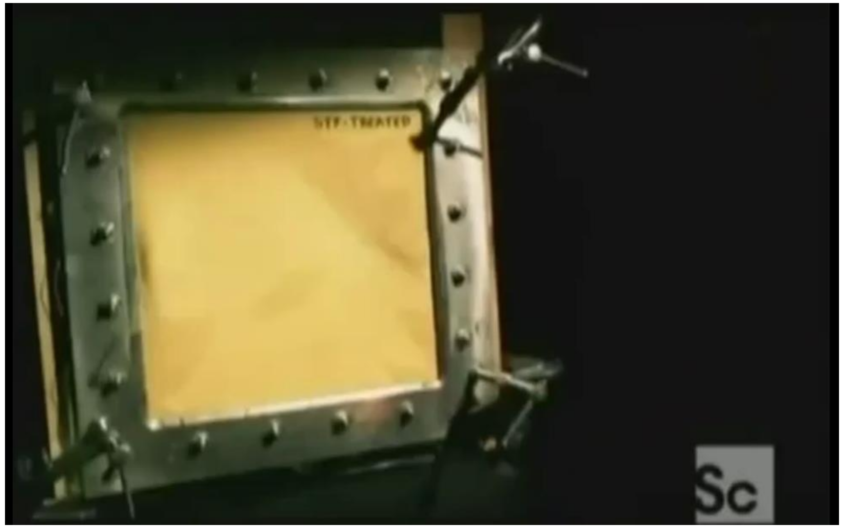


CPLAI

Fabric coated with SJ fluid (Silica particles in PEG)

- Automobile industry
- Stabilizing lithium-ion batteries
- Space technology (mitigating damage due to hypervelocity impacts in low-earth orbits)
- Preventing sports injury

Zarei et al., Journal of Materials Research and Technology (2020)

Fundamental aspects

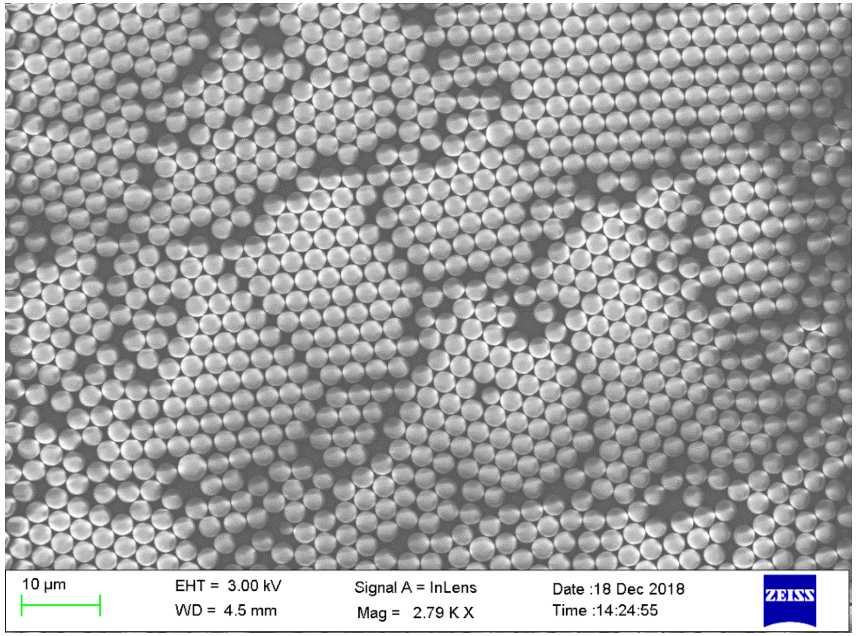
Microscopic dynamics of shear induced jamming poorly understood

- What sets the upper limit of stress response?
- How quickly SJ state goes back to initial liquid-like state?

We study transient stress relaxation in SJ dense suspensions

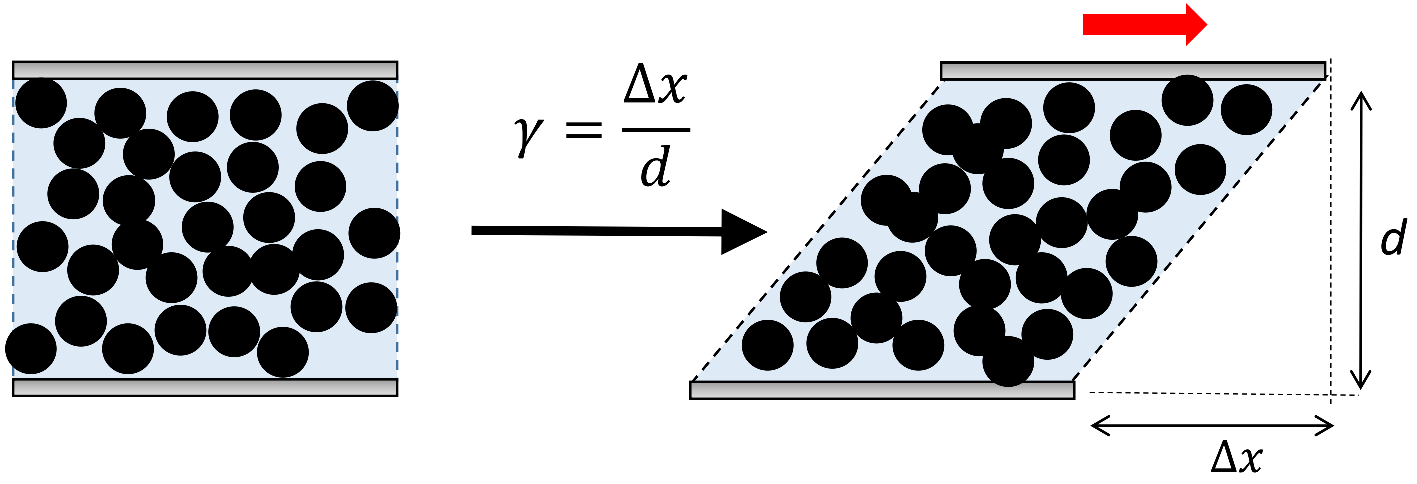
Microscopic particle-scale dynamics leading to stress relaxation

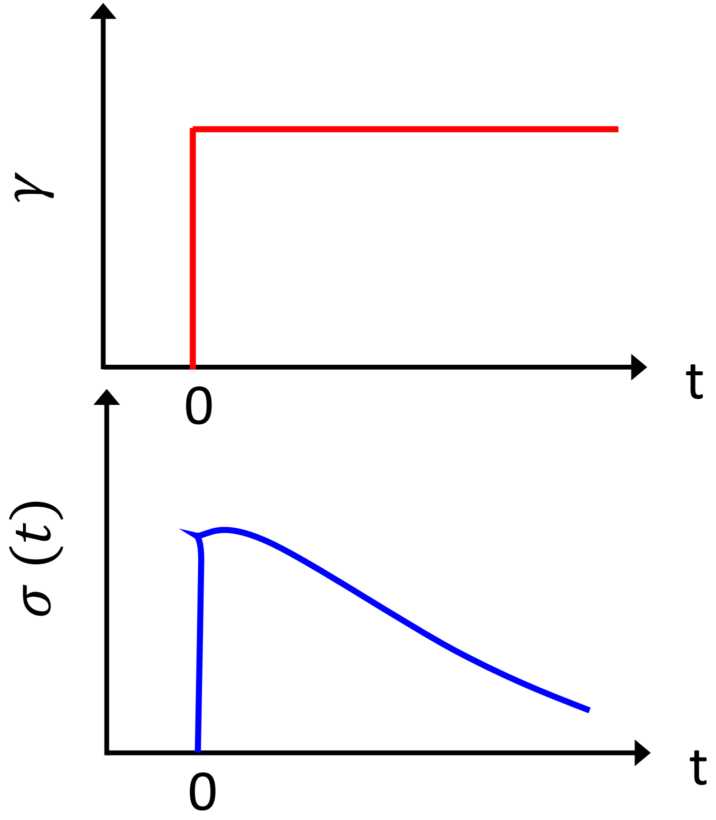
Transient stress relaxation experiments



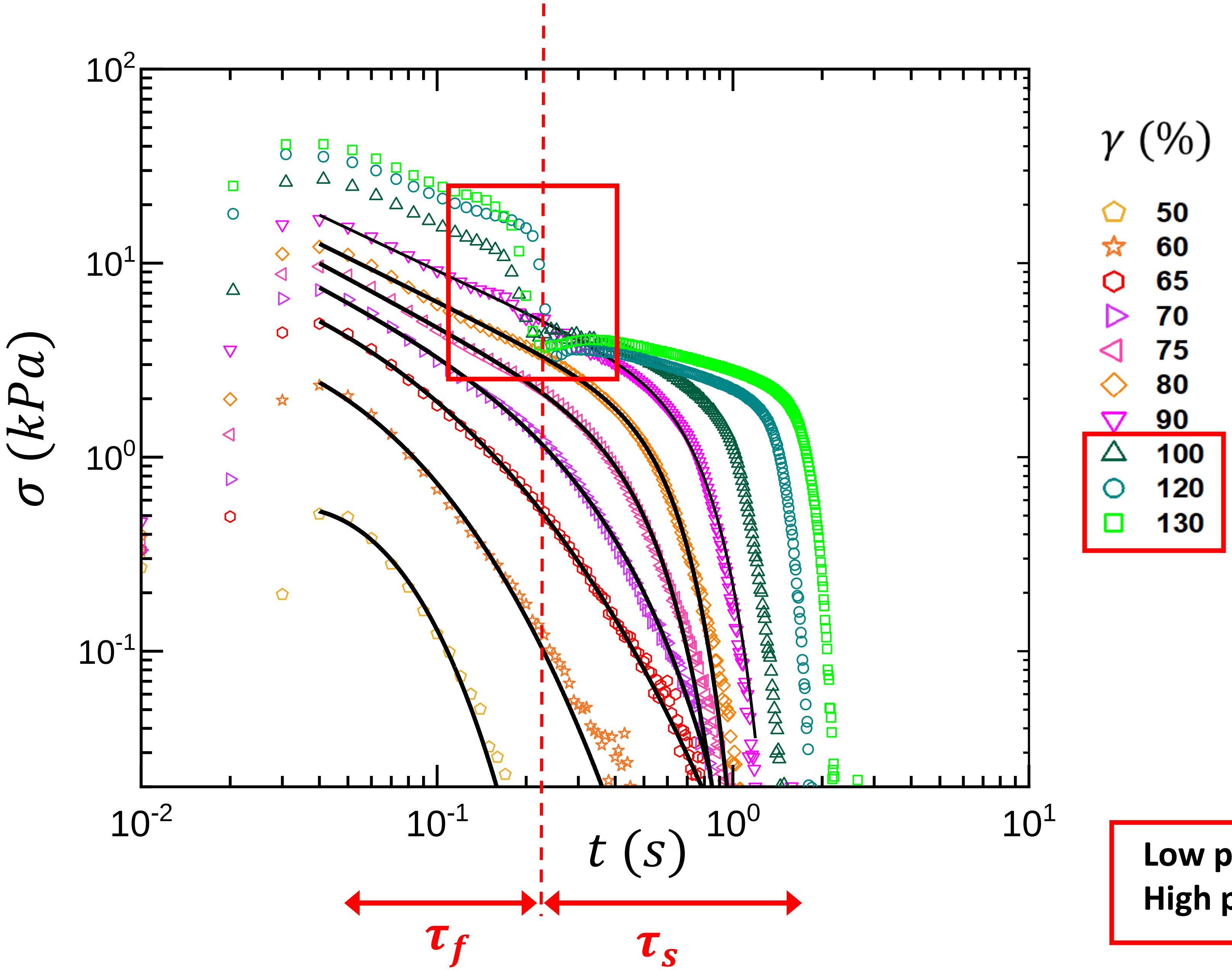
Dense suspension: polystyrene particles dispersed in PEG

Colloidal PS synthesised in large scale in our lab using dispersion-polymerization technique.





Transient stress relaxation under a step-strain perturbation



Fitting function:

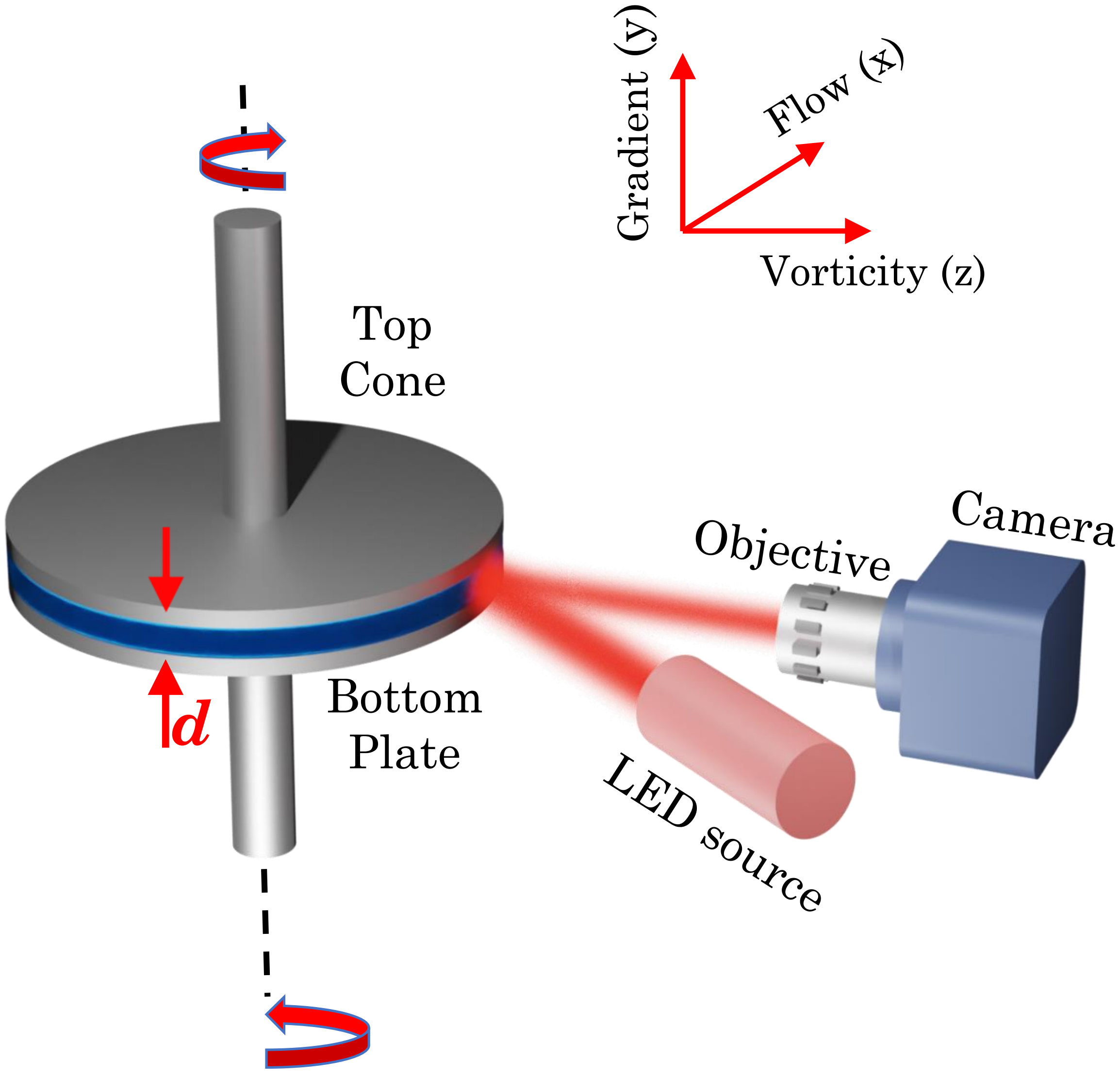
$$\sigma(t) \sim t^{-\alpha} e^{-(t/\tau)^{\beta}}$$

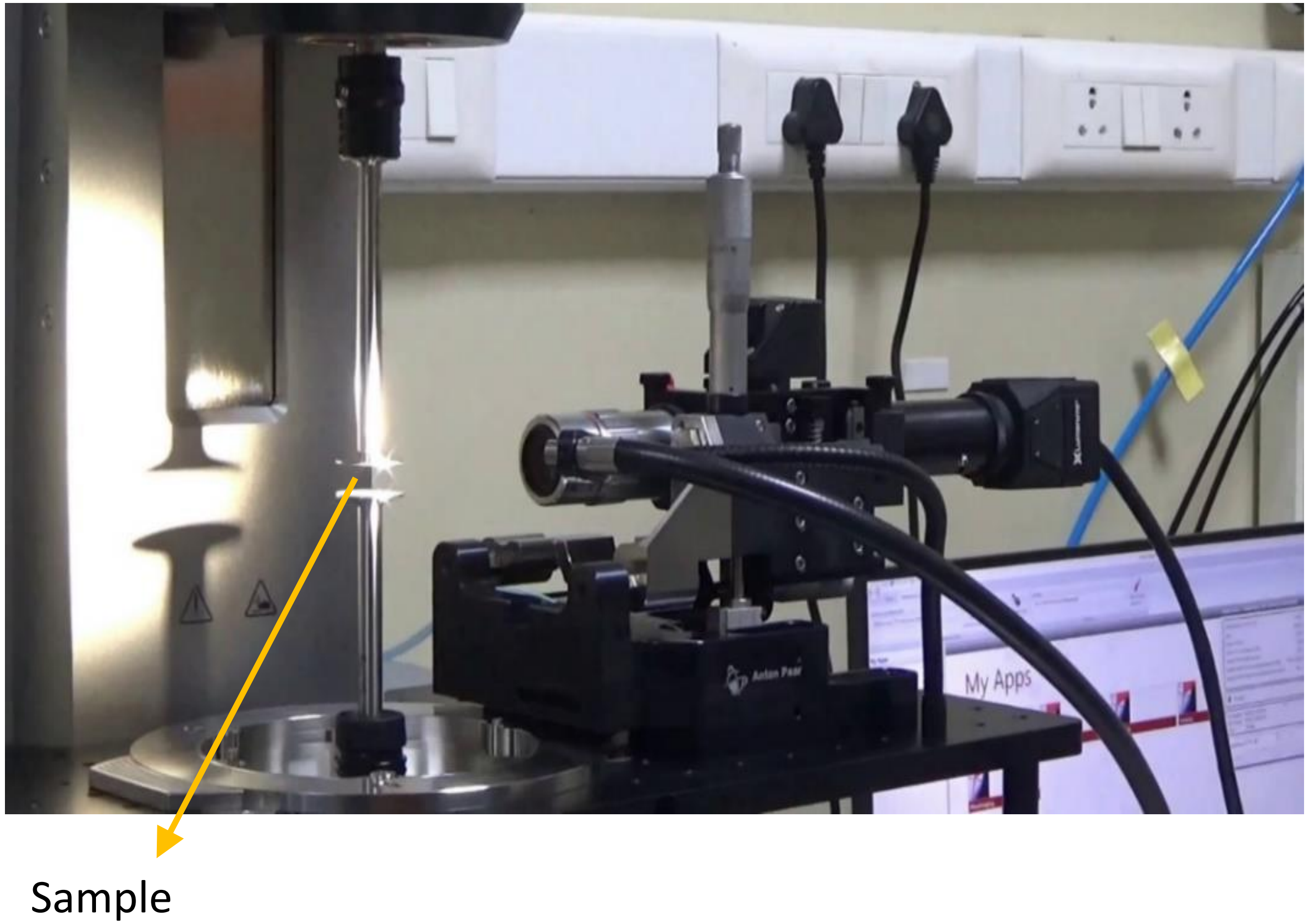
Similar functional form observed in simulations for dense frictionless suspensions close to jamming

Hatano; PRE (2009); Ikada et al.; PRL (2020)

Low peak-stress values: Continuous relaxation
High peak-stress values: discontinuous stress drop

Rheology and in-situ boundary imaging





Chattopadhyay, Nagaraja and Majumdar, Comm. Phys. (2022)

Strain :
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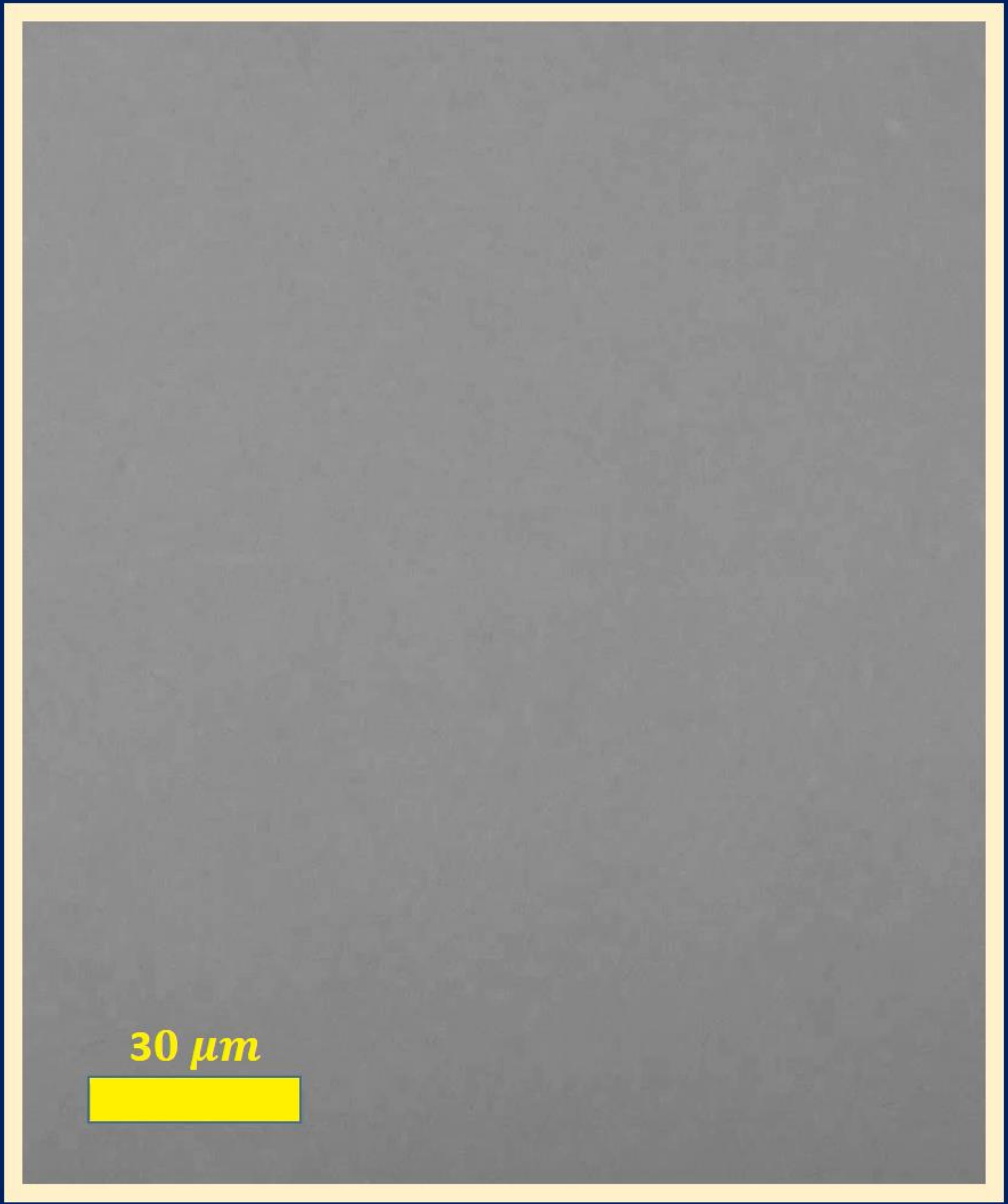
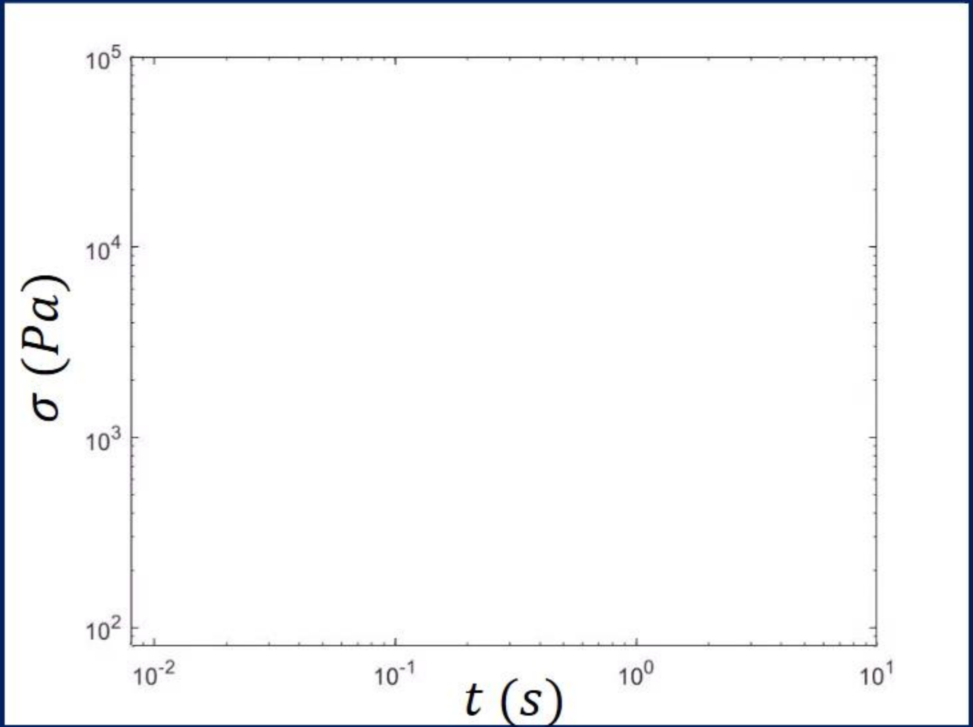
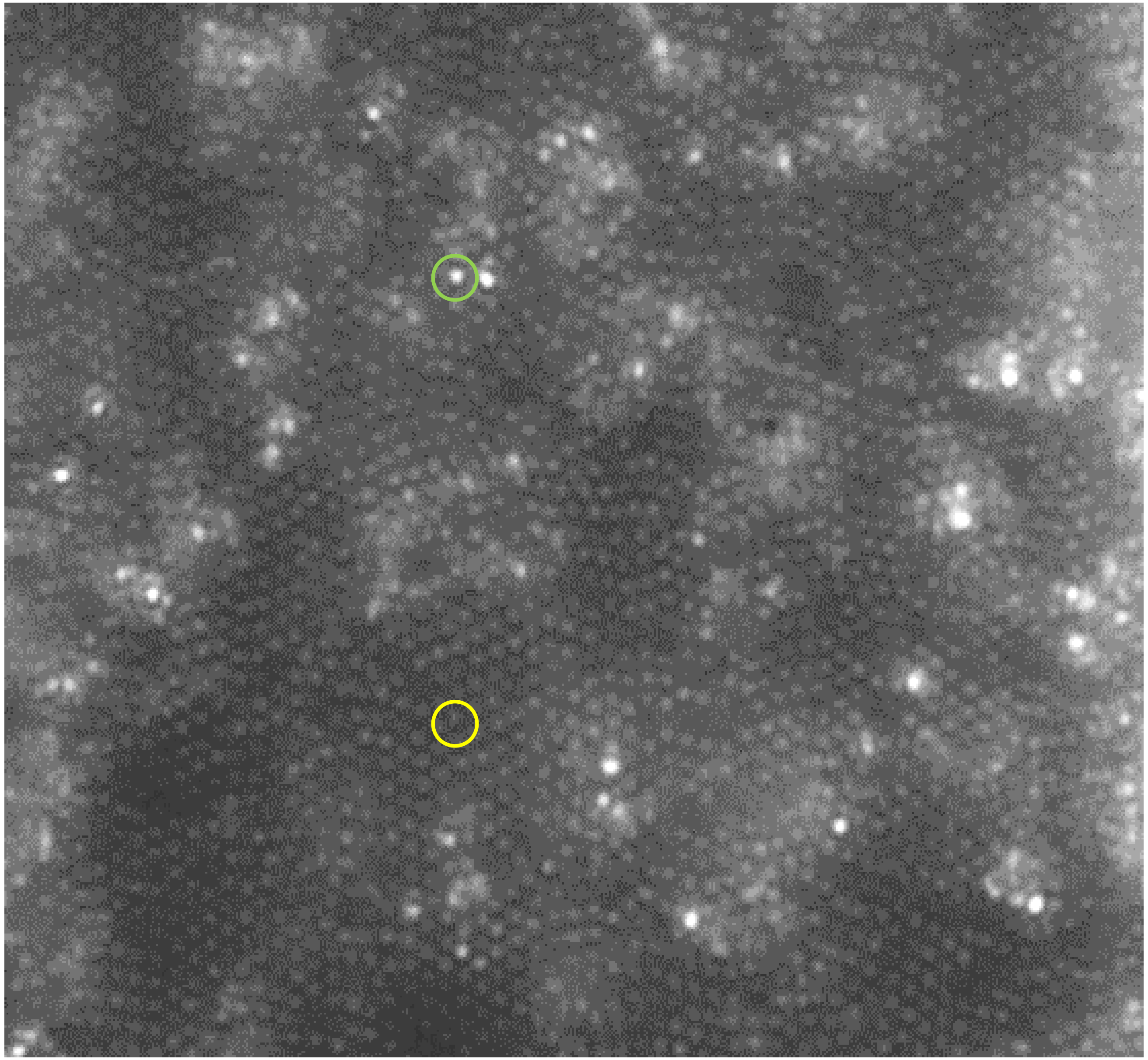
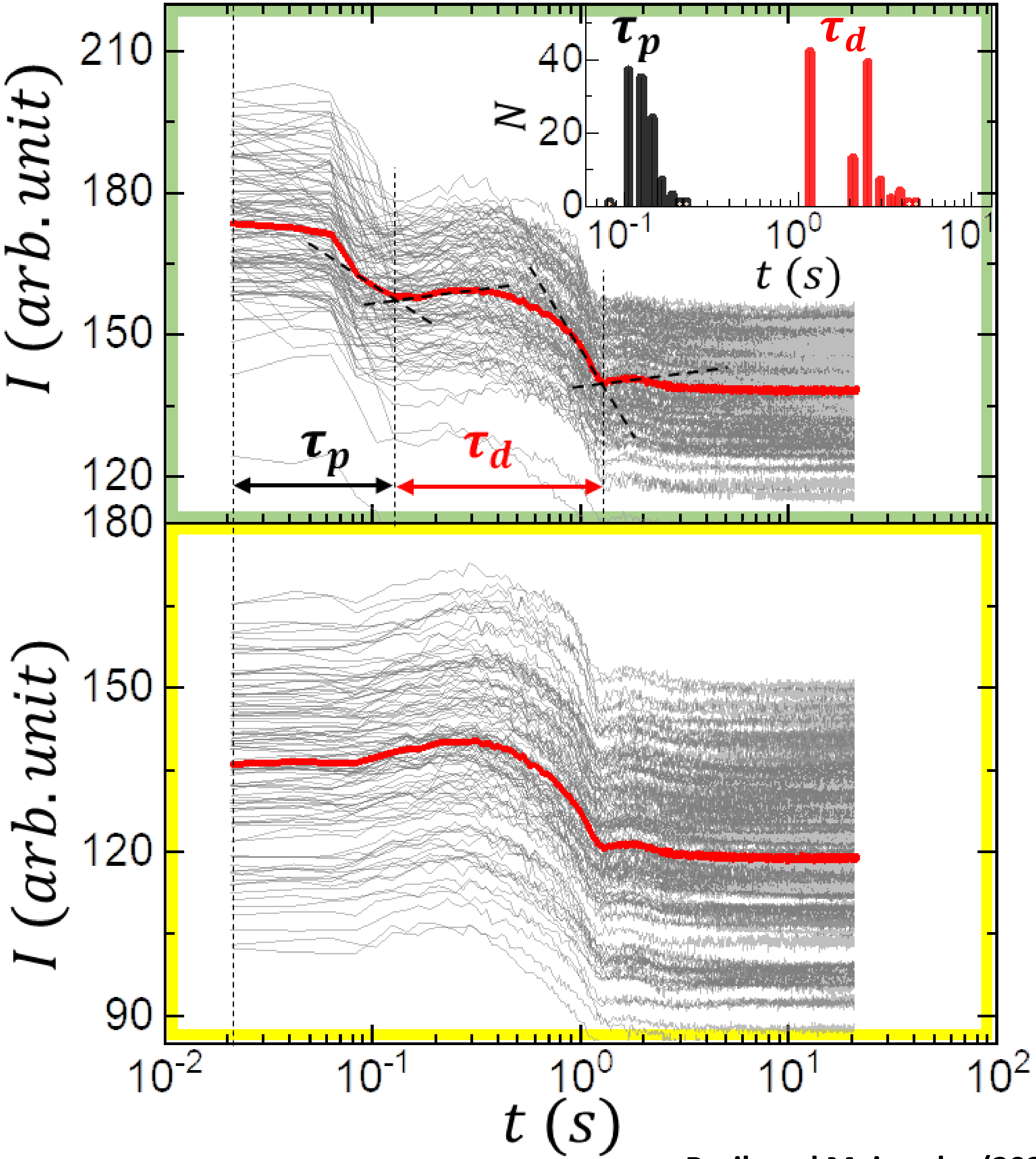




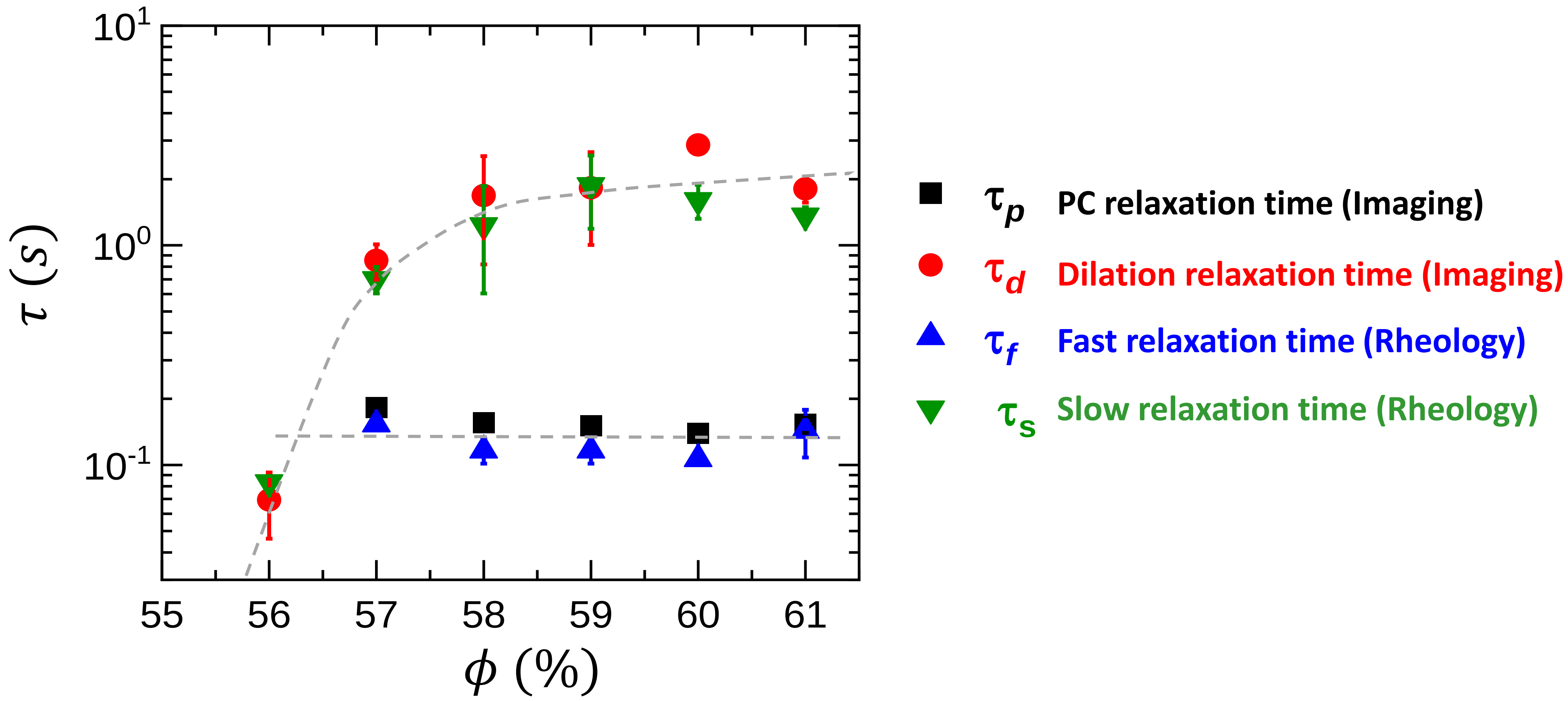
Plastic center and dilation relaxation





Barik and Majumdar (2022)

Origin of fast and slow relaxation times

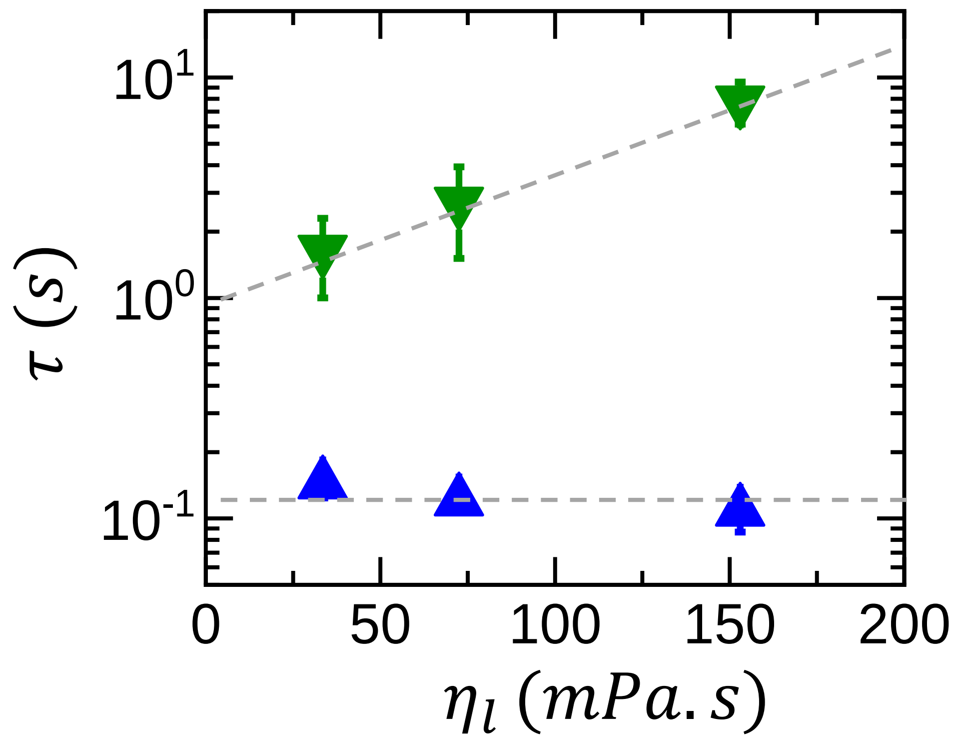


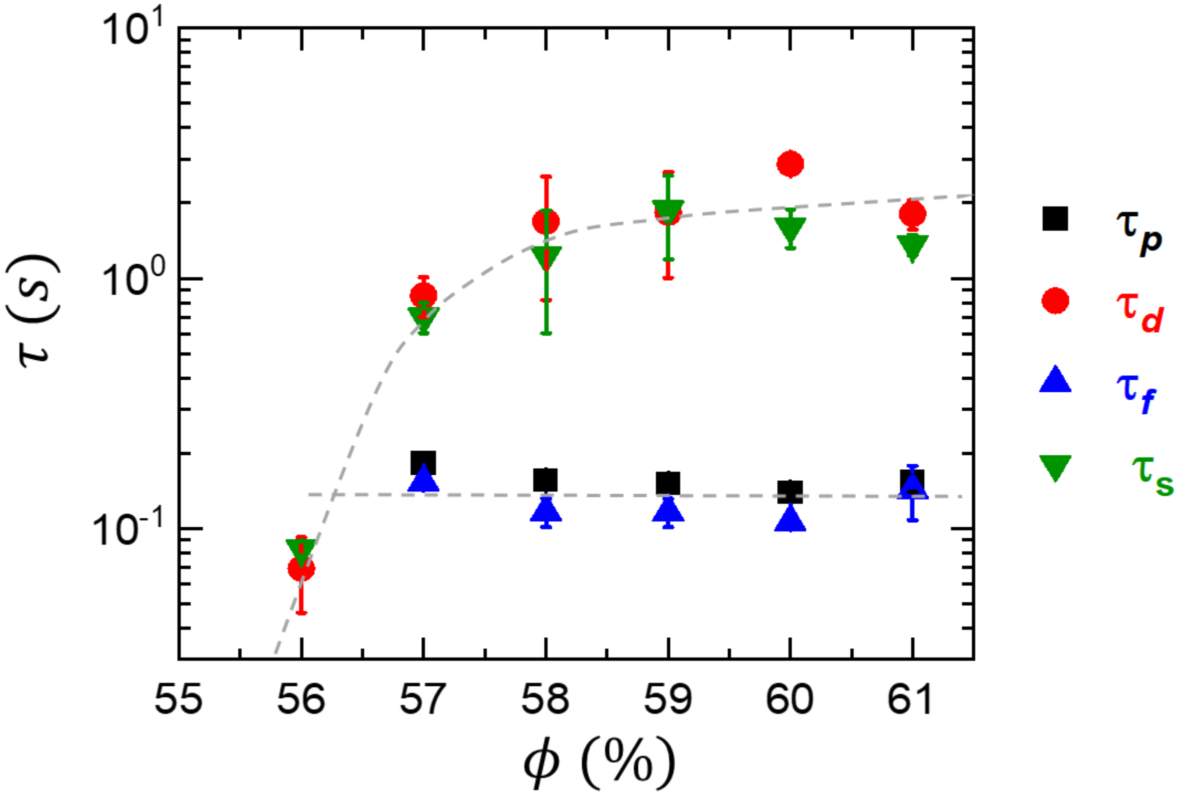
Excellent agreement between the time scales obtained from rheology and boundary imaging

Fast relaxation: localized PC relaxation
Slow relaxation: System spanning dilation relaxation

Barik and Majumdar (2022)

Effect of solvent viscosity and particle vol. fraction on relaxation time scales





Slow relaxation time: increases with increase in solvent viscosity and particle volume fraction

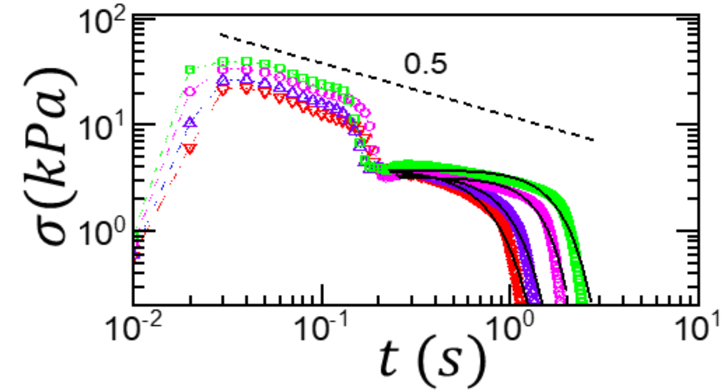
Fast relaxation time: remains unaffected by such variation

Supports the localized vs. system spanning particle rearrangement picture obtained from imaging.

Barik and Majumdar (2022)

Conclusions and outlook

1. Two distinct transient stress relaxation regimes in SJ dense suspensions.

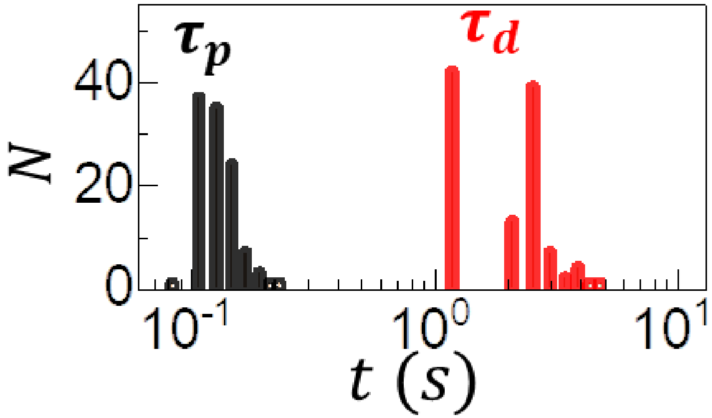


2. In-situ boundary imaging:

Localized plastic events ➡ Fast relaxation

System spanning dilation ➡ Slow relaxation

We have also indirectly confirmed such mechanism.



3. Interesting memory effect.

Connections with glassy relaxation:
strongly non-exponential relaxation over much longer time scales.

Acknowledgements

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<u>Current lab members</u>

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Raman Research Institute

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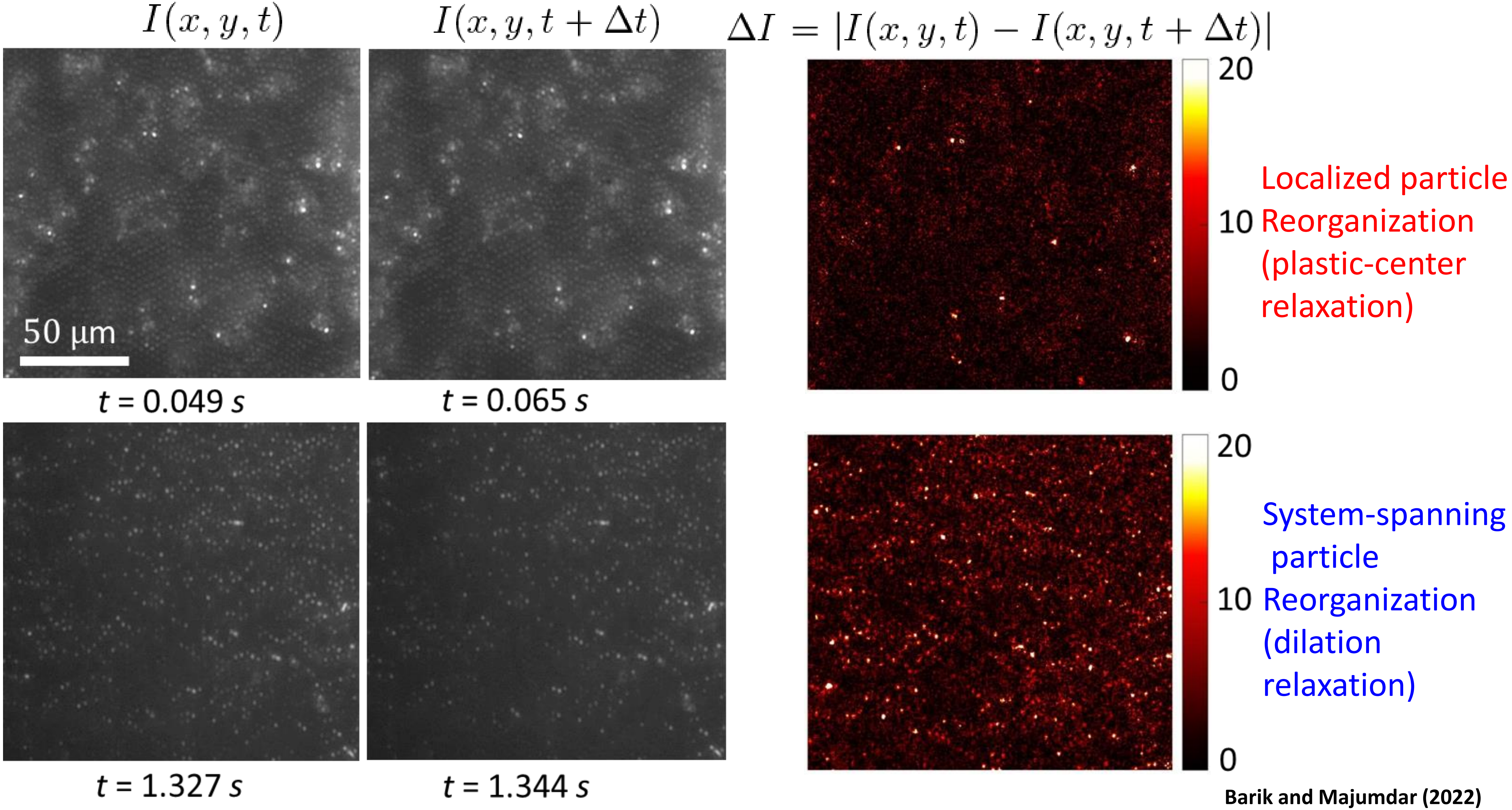
Reference

Origin of Two Distinct Stress Relaxation Regimes in Shear Jammed Dense Suspensions

Sachidananda Barik and Sayantan Majumdar
Phys. Rev. Lett. 128, 258002 (2022)

Thank you

Localized vs system-spanning particle rearrangements



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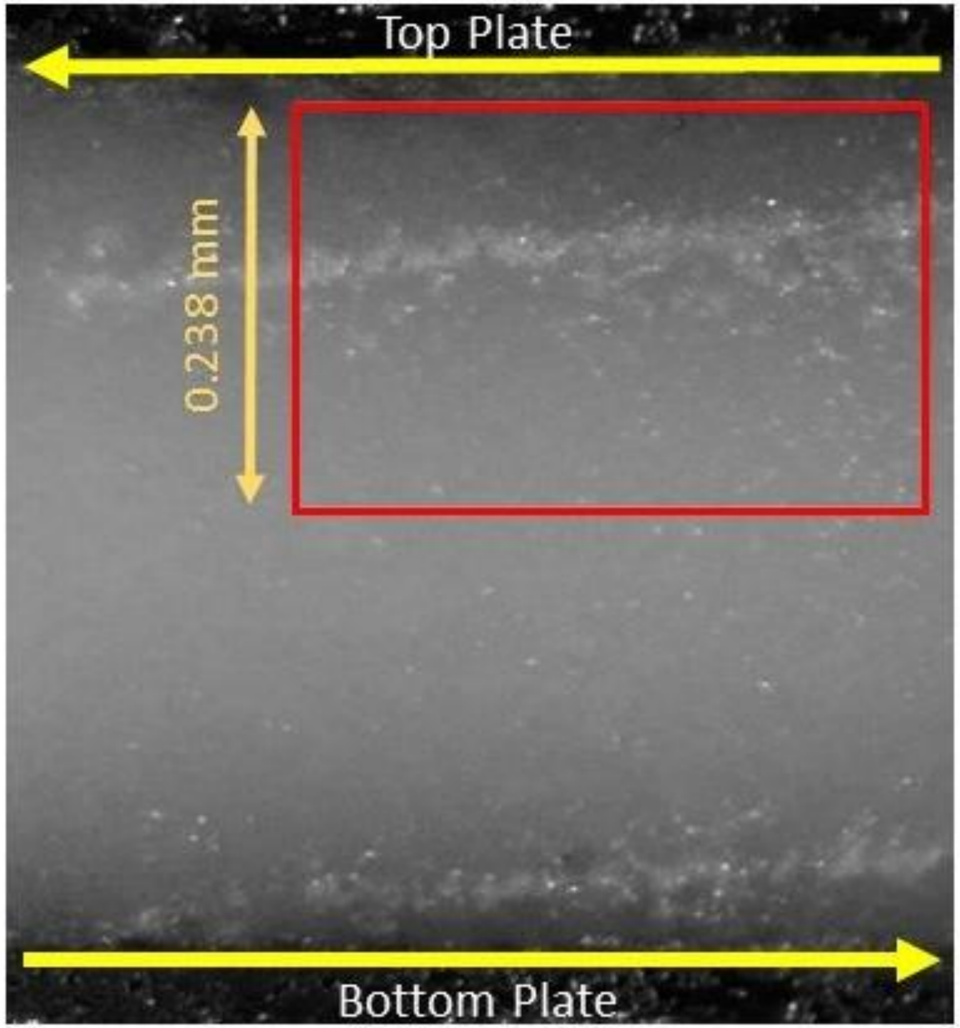
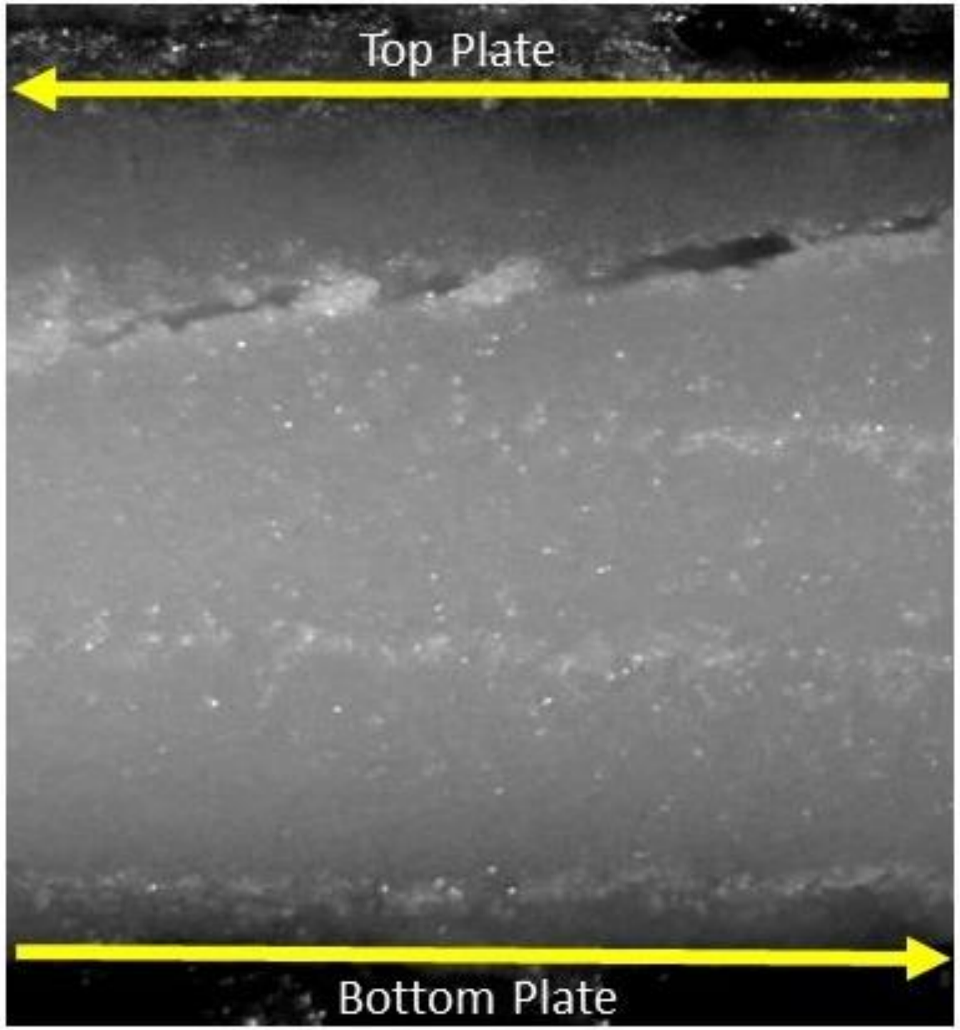
Relation between observed bright spots and plasticity





Accumulation many bright spots triggers plasticity and eventual material failure

Bright spots: Localized/particle scale plasticity

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