

# Predictive formulation of high-solid-content complex dispersions

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Wilson Poon and John Royer

Mark Haw



# Dense suspension



Cornstarch mixed with water at high solid concentration

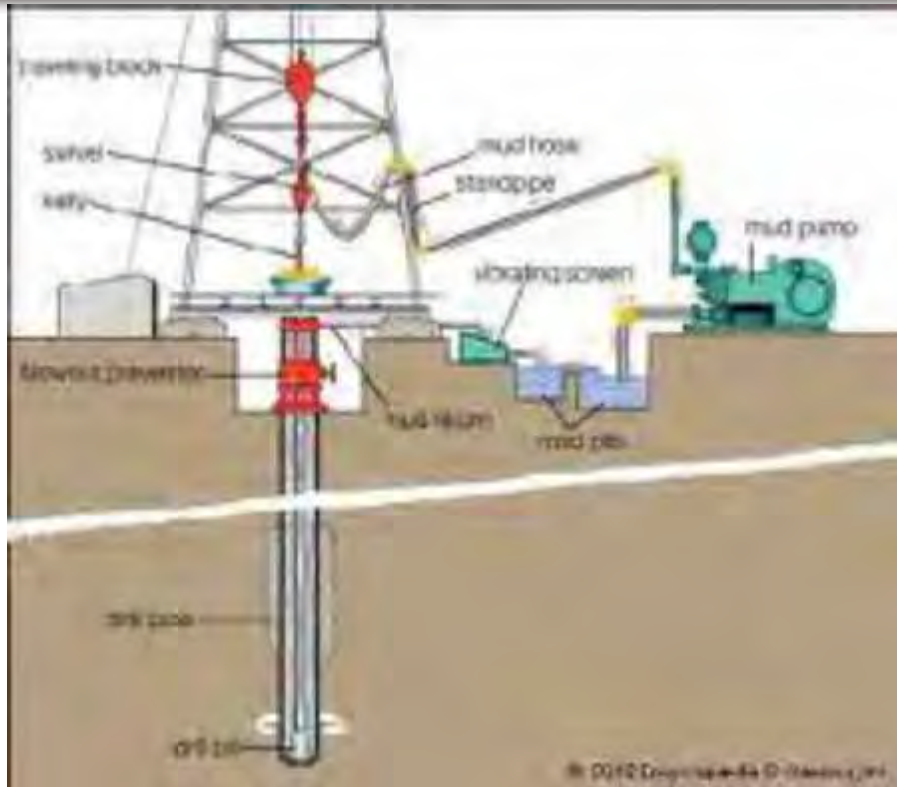


Video from ETH Soft Materials Youtube channel

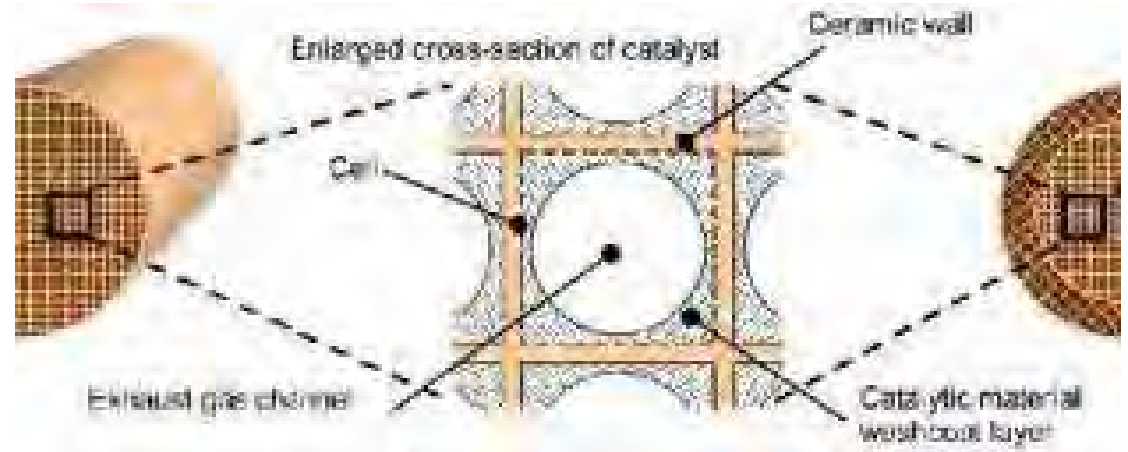
# Shear thickening



# Industrial importance



Drilling fluids



Washcoat on for catalyst



Paint

# Industrial importance

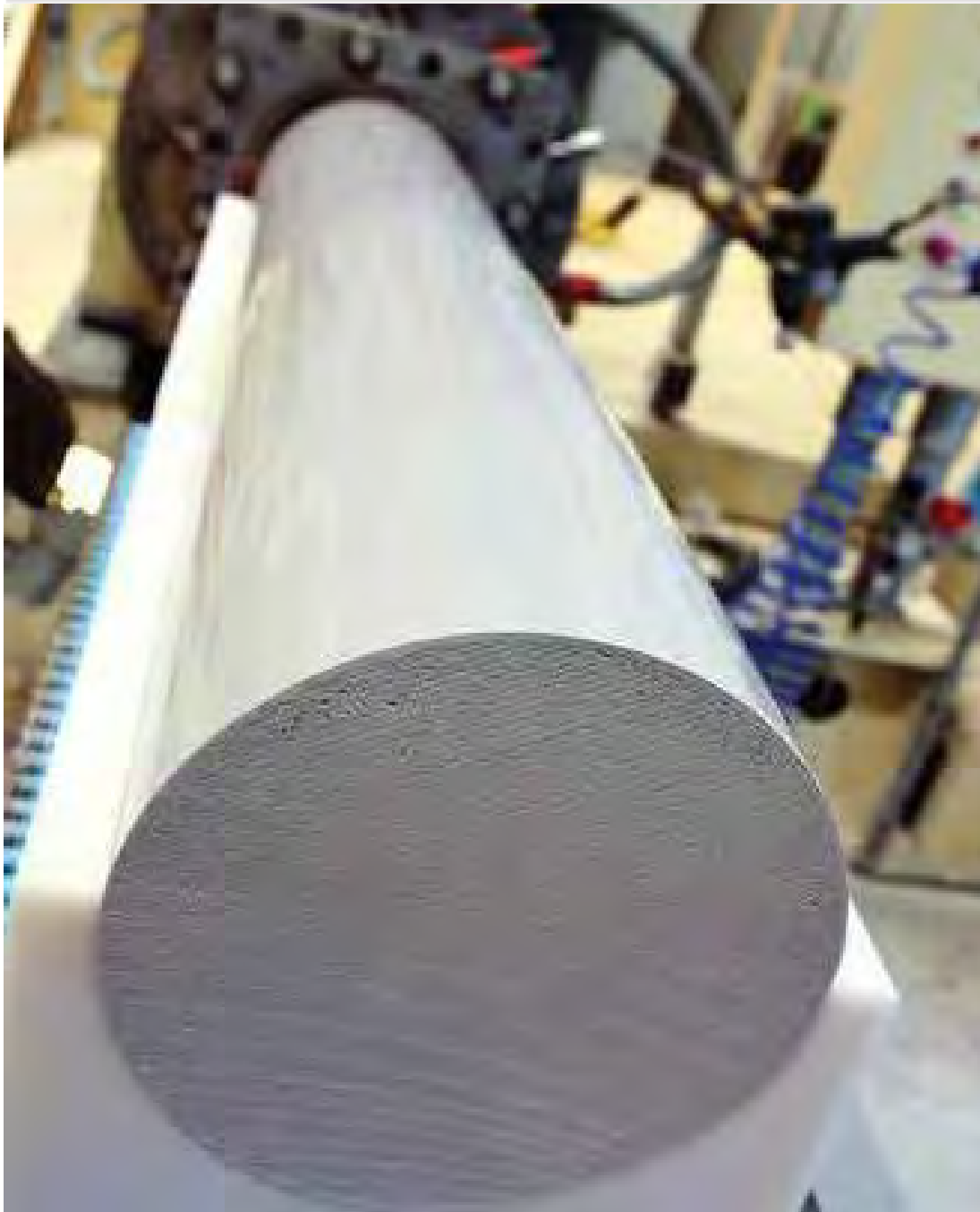


High solid contents  
and driving to higher...

Drilling

Paint

# Paste extrusion



Characterisation  
of particle and HSCD  
using rheometry



Prediction  
of flow and  
product properties



Control

Particle  
surface  
modification

Continuous  
phase  
properties

Formulation of  
High-Solid Content  
Dispersions

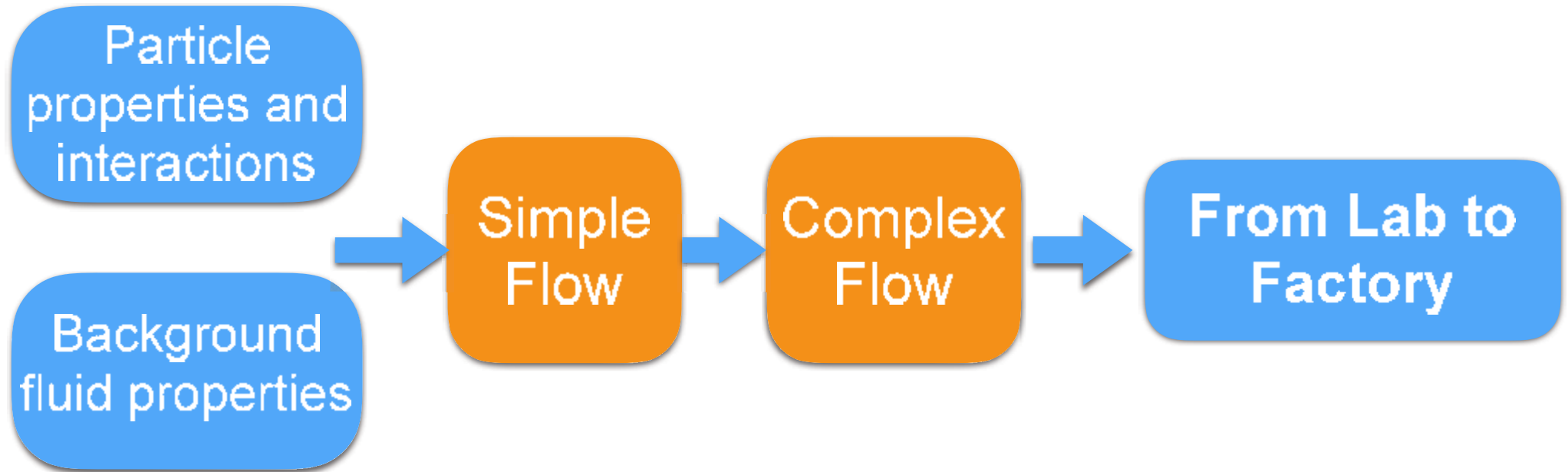
Industrial  
processes

Product

Designer HSCD  
Manufacturability



# Research programme







# High-solid-content dispersions

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# Future Formulations: Taming Dense Suspensions

**John Royer**

Future Formulations Meeting, Durham May 2017



# Shear thickening: Suspensions far from equilibrium



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Video from ETH Zurich Soft Materials youtube channel

# Shear thickening: Suspensions far from equilibrium



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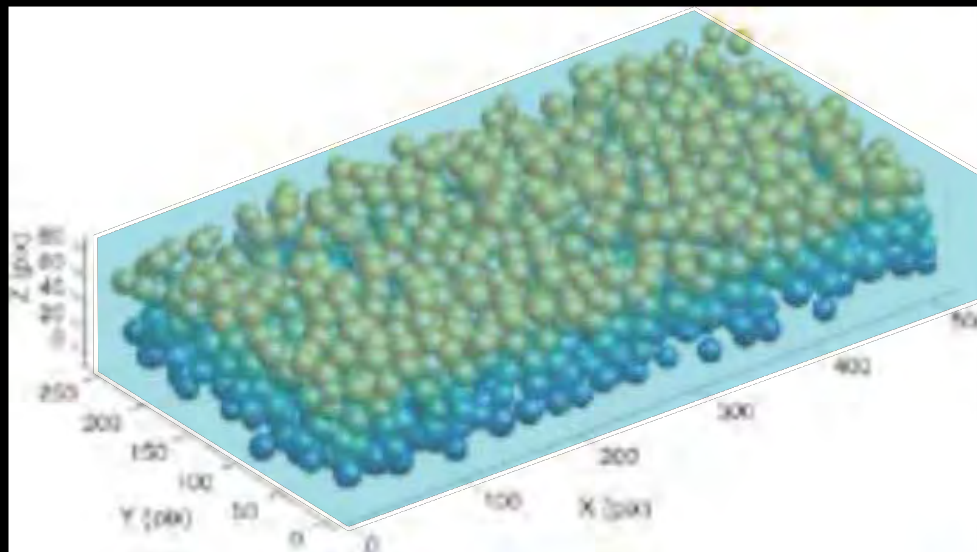
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Video from ETH Zurich Soft Materials youtube channel



Ubiquitous in dense suspensions of hard particles

**But until recently, poorly understood!**

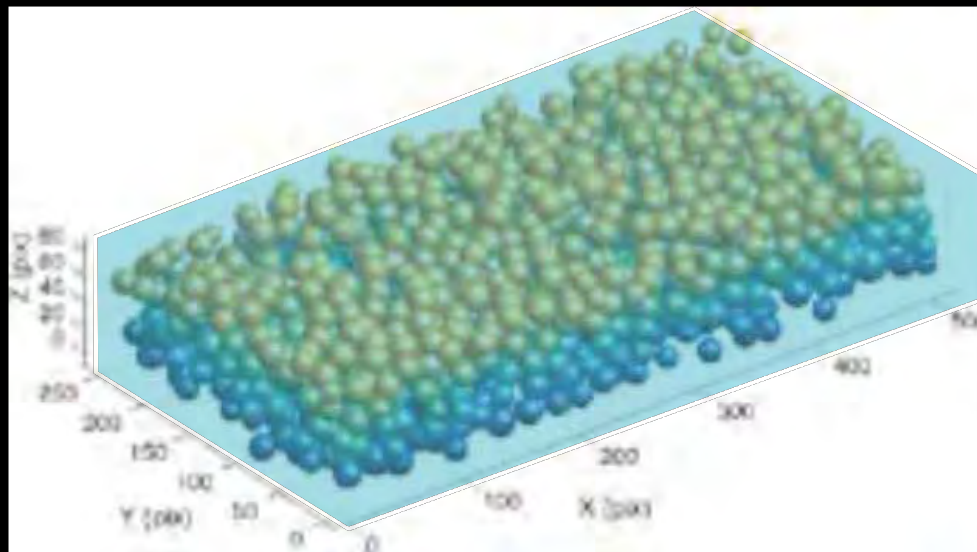
# Shear thickening: Suspensions far from equilibrium



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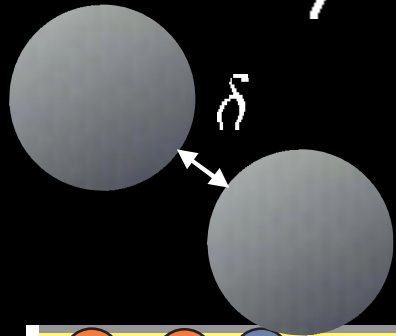


Ubiquitous in dense suspensions of hard particles

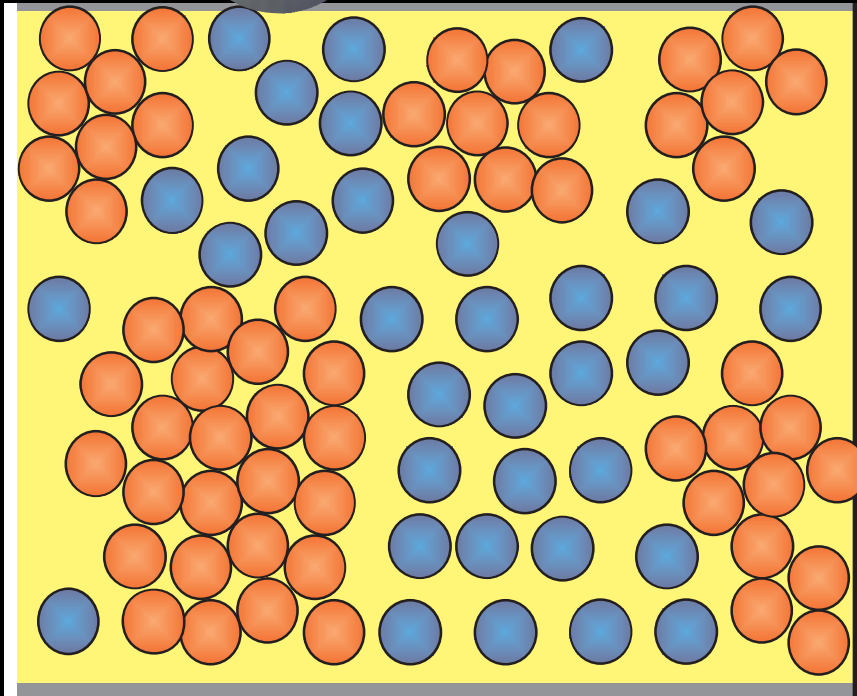
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# Previous focus - Hydrodynamics

'Hydroclusters'



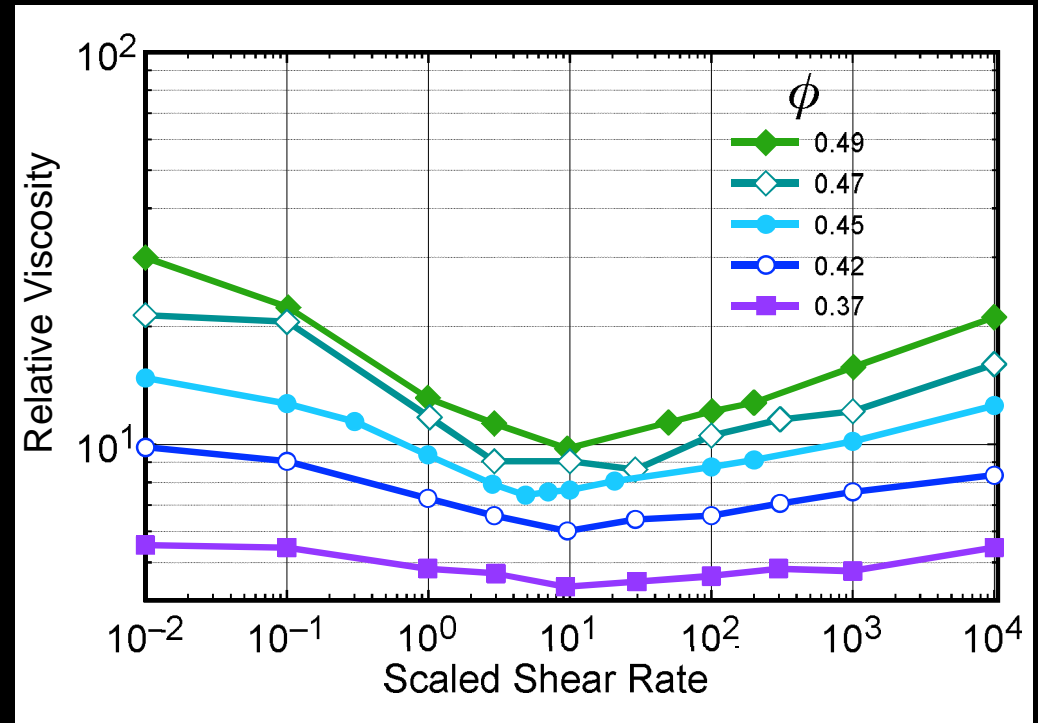
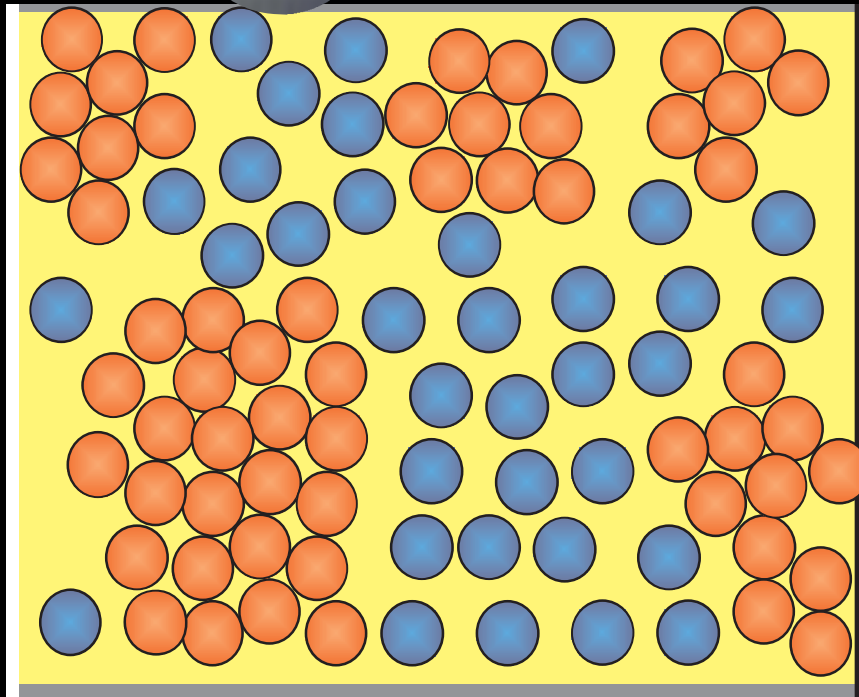
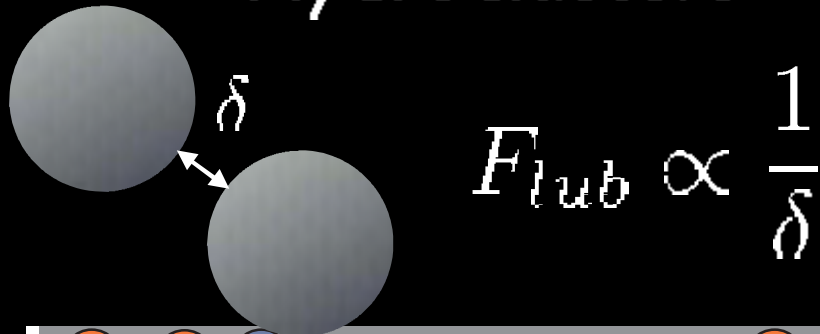
$$F_{lub} \propto \frac{1}{\delta}$$





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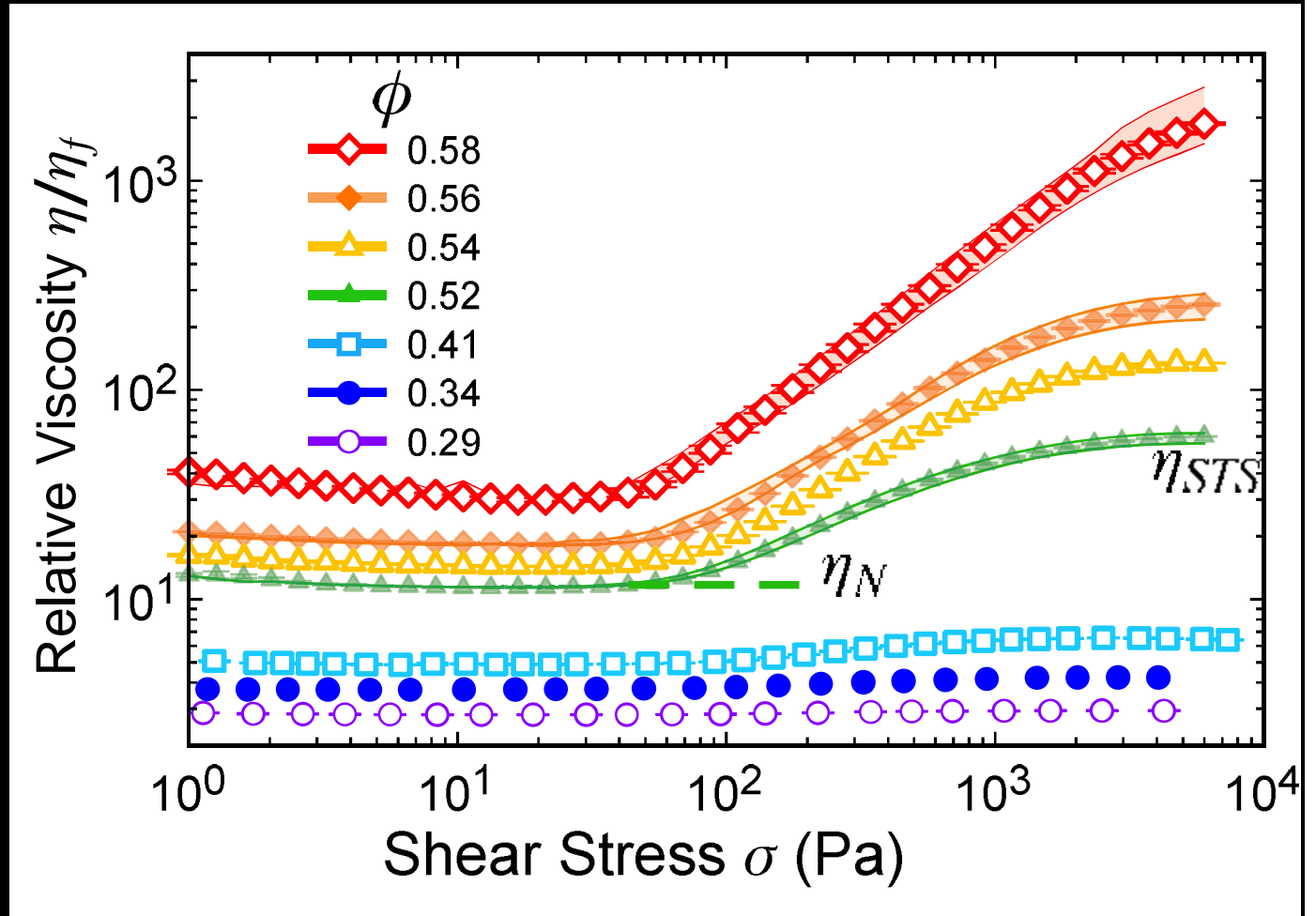
# Real Shear Thickening

Thickening increases strongly with solids concentration, becomes discontinuous.

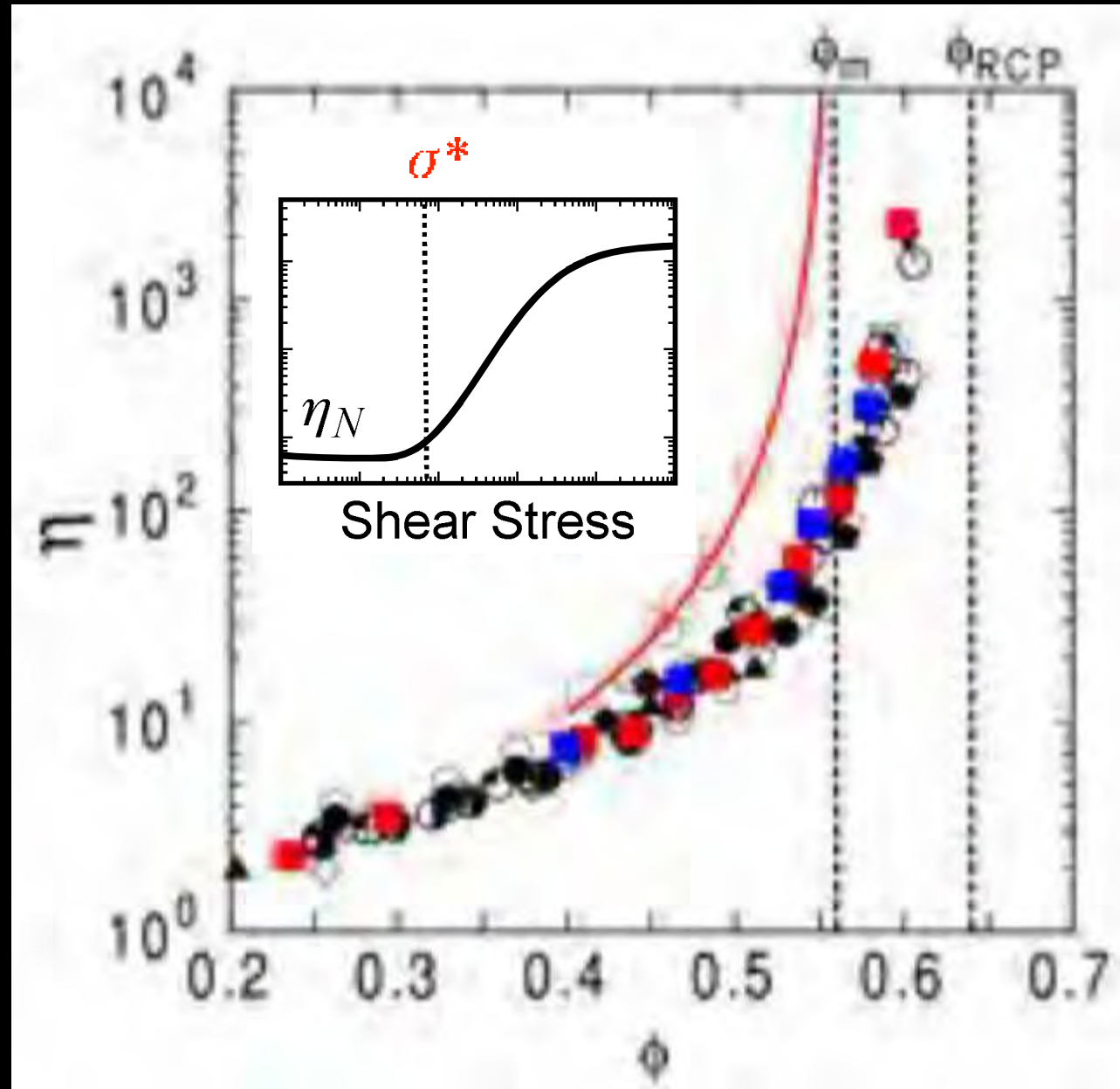
$$\eta = \frac{\sigma}{\dot{\gamma}}$$

Characteristic onset stress  $\sigma^*$  independent of solids concentration.

$$\phi = \frac{V_{part}}{V_{total}}$$

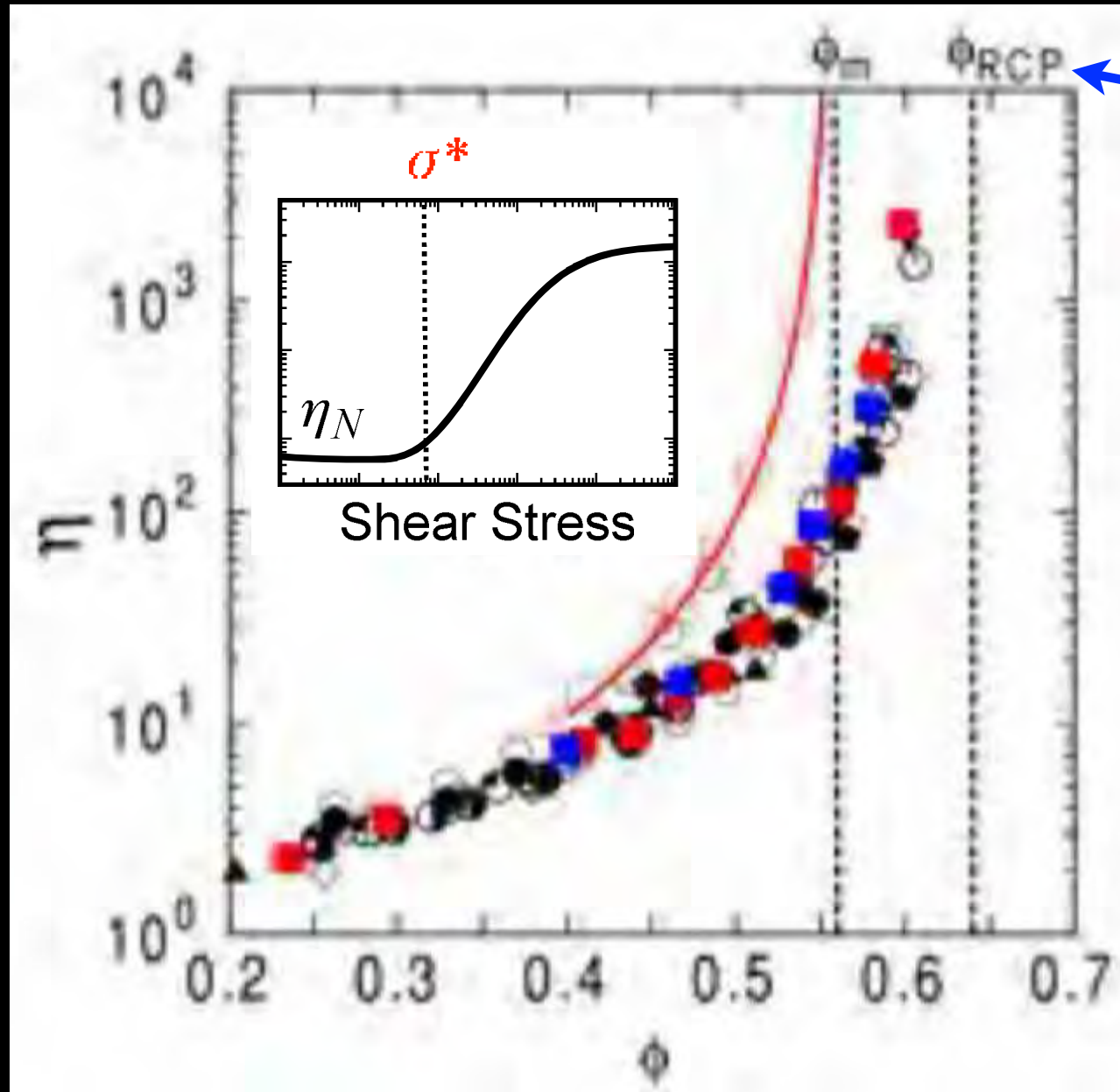


# Shear Thickening - Jamming below RCP



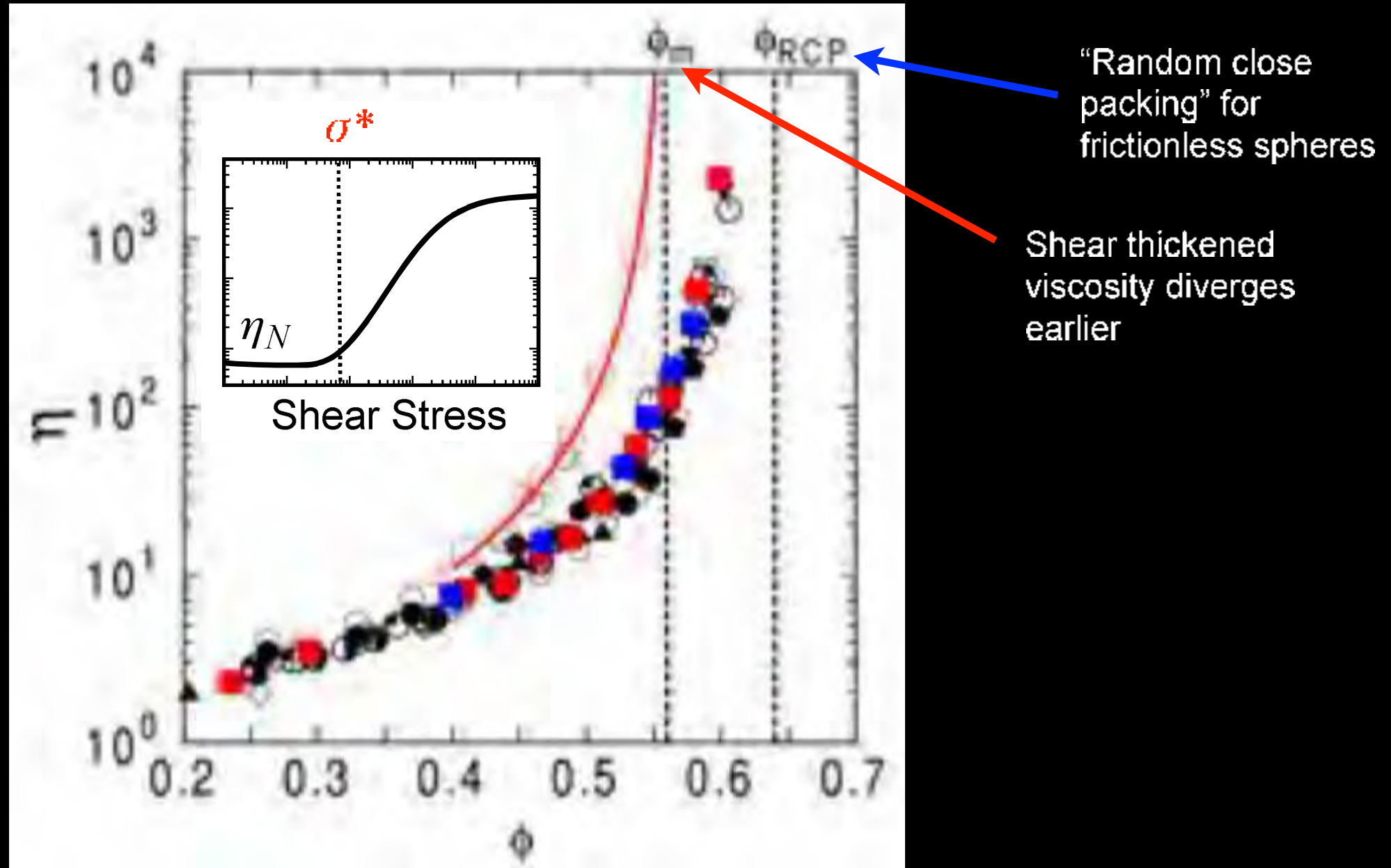
Guy, Hermes & Poon, PRL 2015  
Wyart and Cates, PRL 2014

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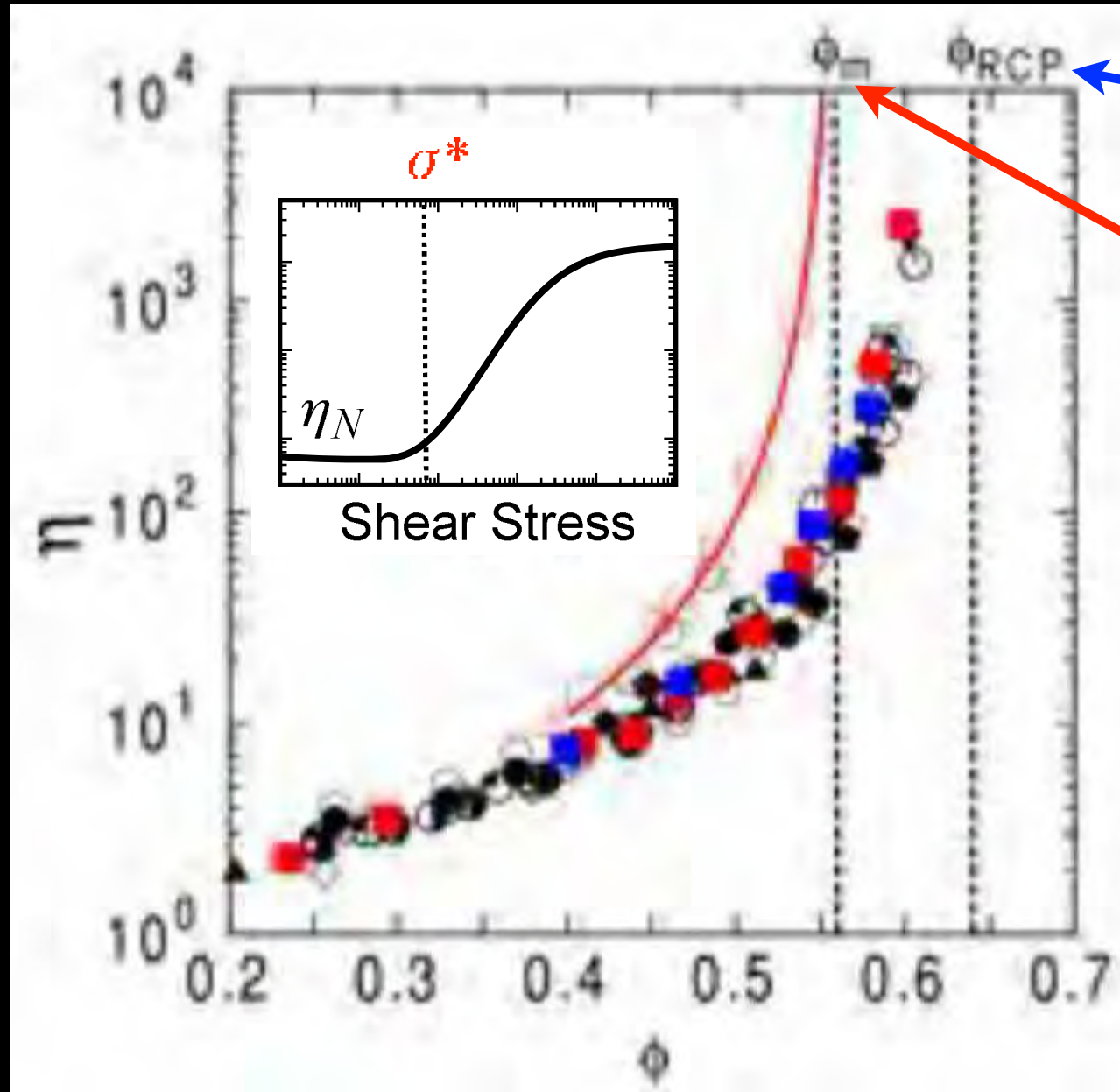
“Random close packing” for frictionless spheres

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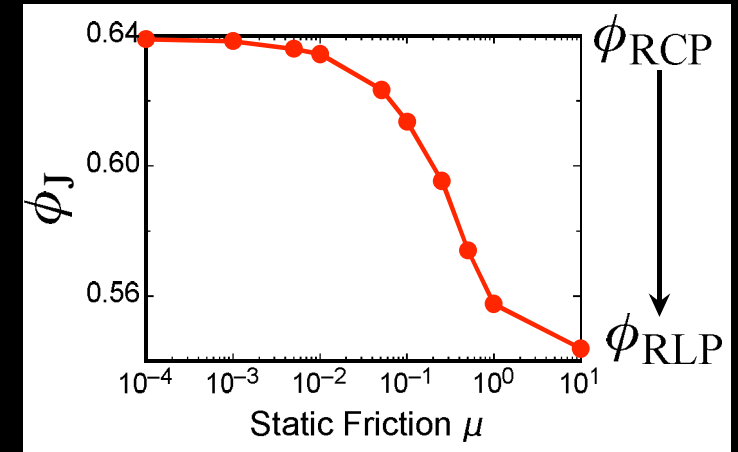
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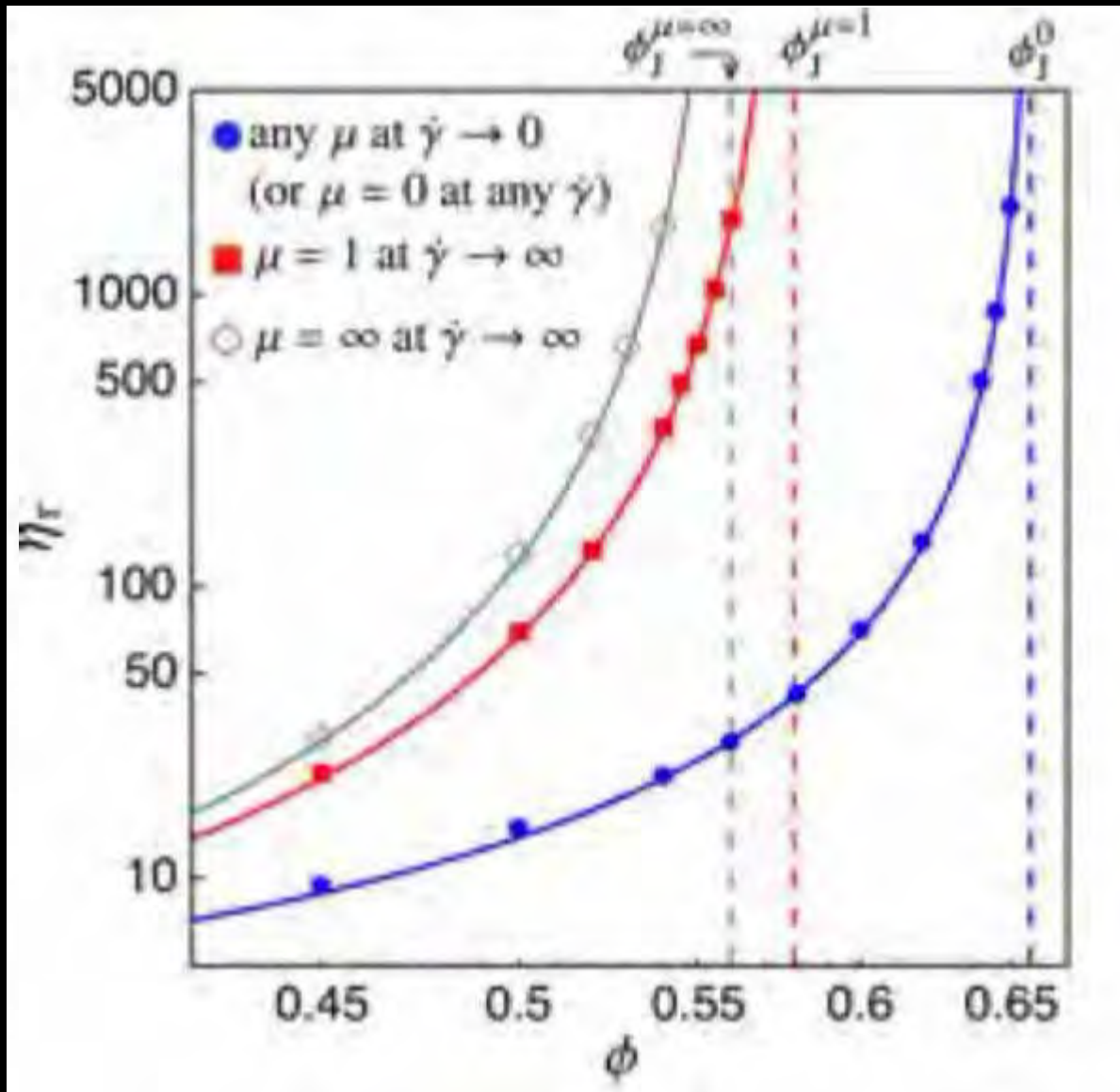
Shear thickened viscosity diverges earlier



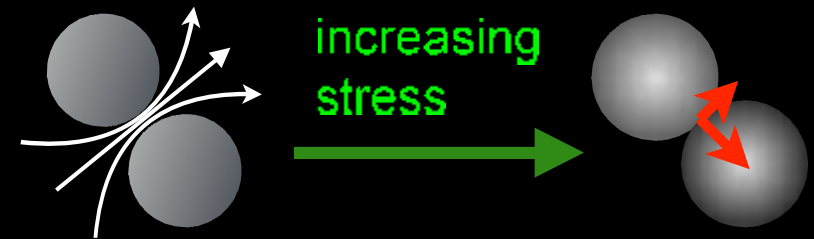
Silbert, Soft Matter 2010

Guy, Hermes & Poon, PRL 2015  
Wyart and Cates, PRL 2014

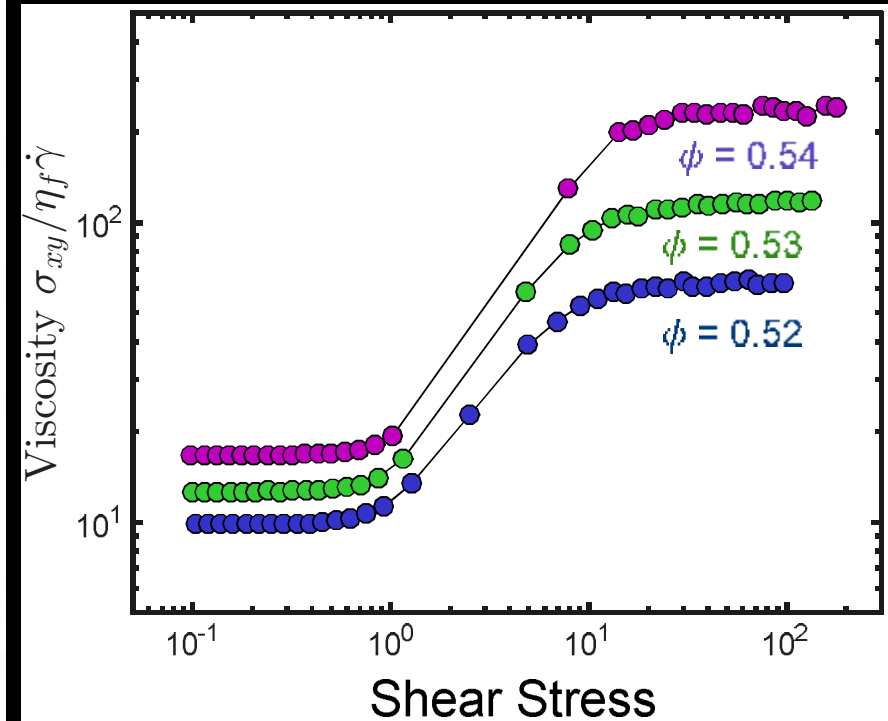
# Shear Thickening and Friction



Mari, Seto, Morris, JoR 2014



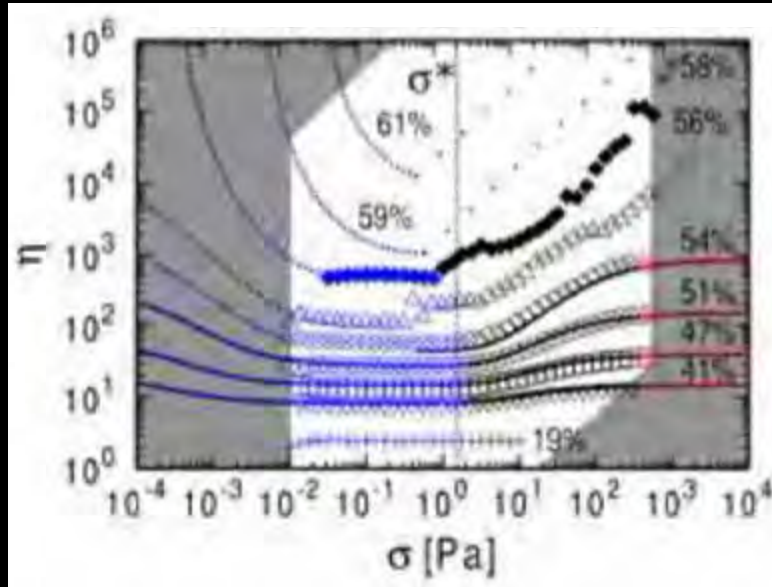
Simulations with stress activated frictional contacts



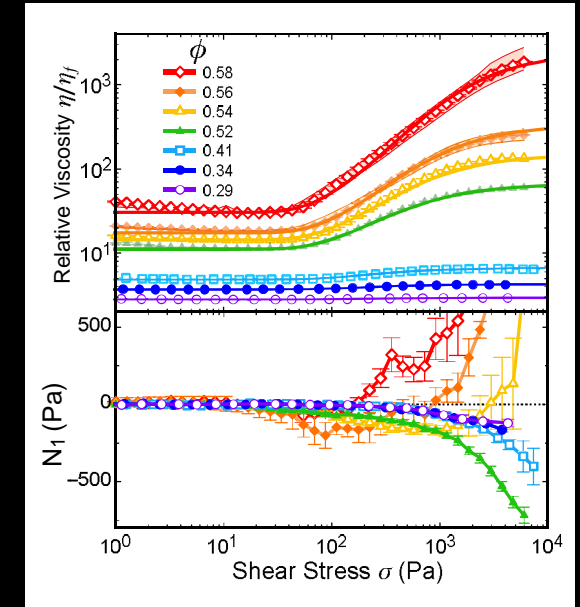
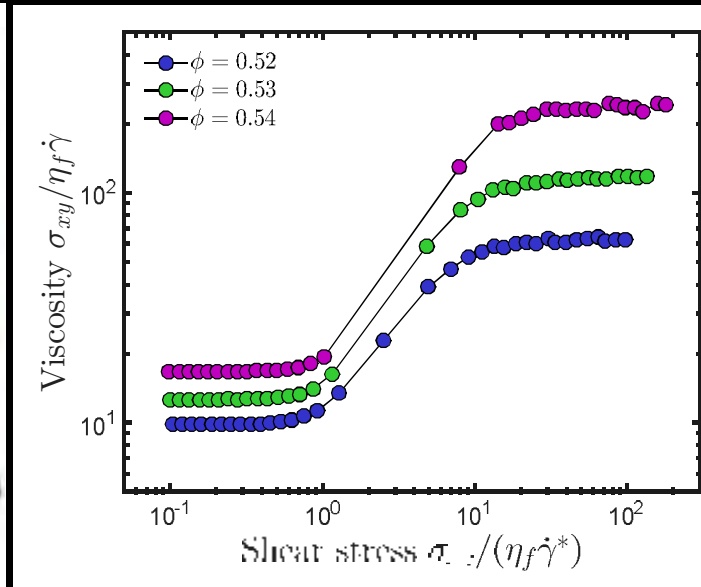
Ness and Sun, Soft Matter 2016

# Shear Thickening: A friction-driven transition

Agreement with analytical models



Agreement with simulations

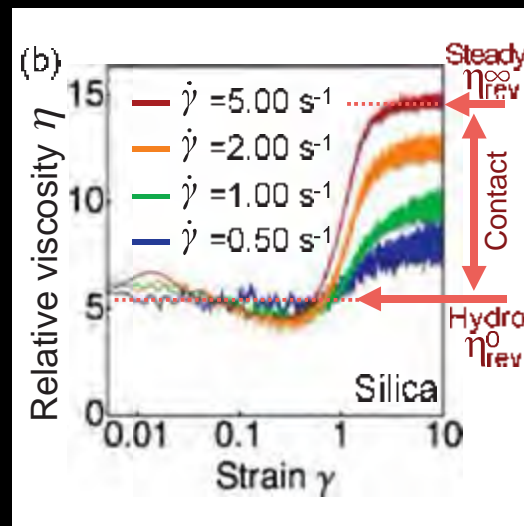


Wyart and Cates PRL, 2014

Guy, Hermes & Poon, PRL 2015

Ness and Sun, Soft Matter 2016

also work by R. Mari, R. Seto, J. Morris



Shear Reversal experiments show contacts dominate

Lin, Guy, Hermes, Ness, Sun, Poon, Cohen PRL 2015



# Current Core Team

## Experiments

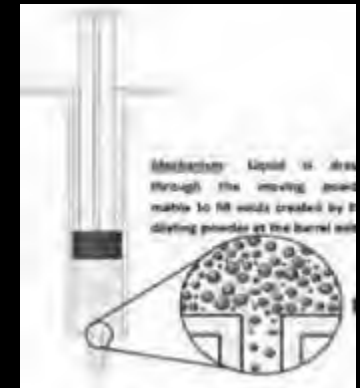
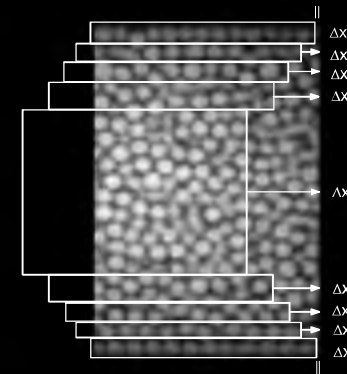
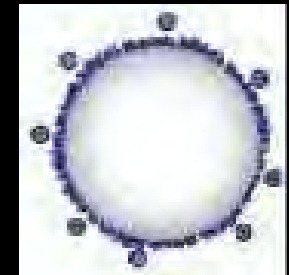
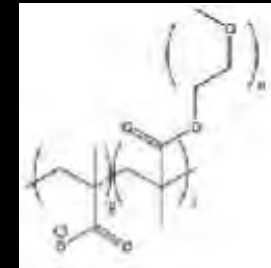
**John Royer** (CF): surface coatings, particle interactions

**James Richards** (PhD student): unsteady flow, attractive systems

**Yujie Jiang** (PhD student): suspensions in complex backgrounds

**Rory O'Neil** (postdoc): channel flows and extrusion

**Jose Ruiz Lopez** (Strathclyde): squeeze flow / extensional rheology

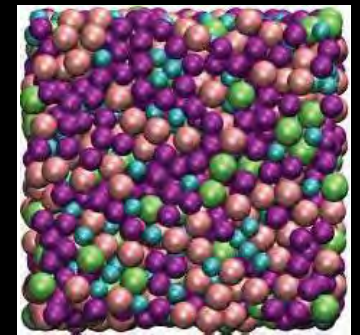
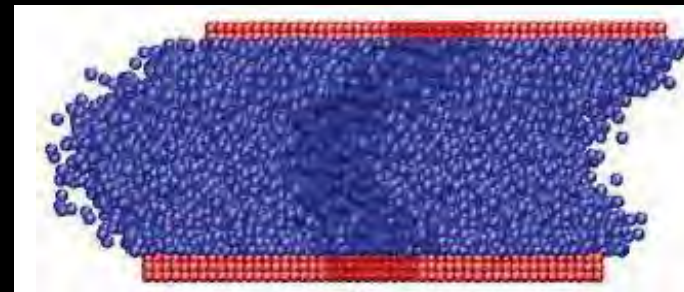


## Simulations

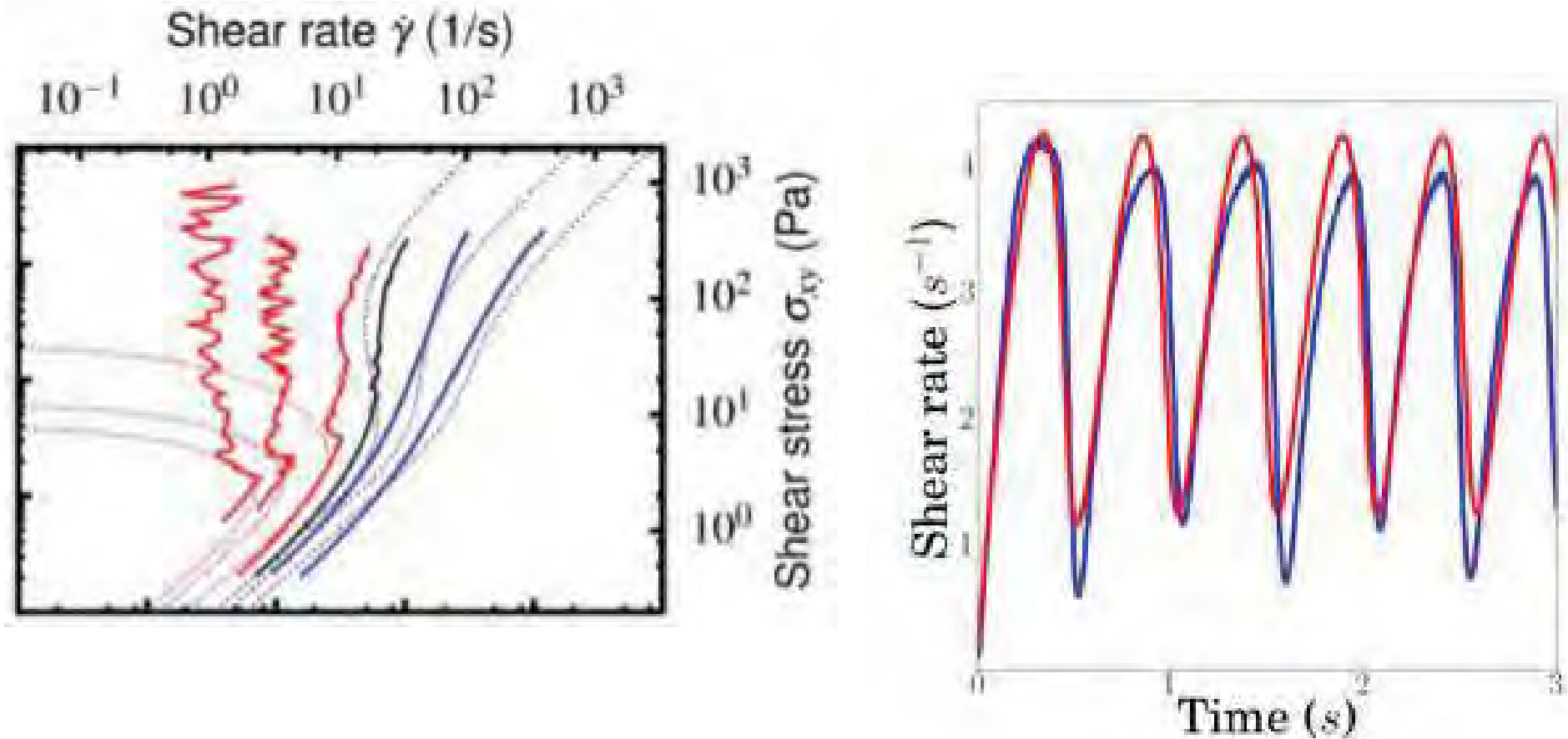
**Julien Sindt** (postdoc): attractive and poly-disperse systems

**Rangarajan Radhakrishnan** (postdoc):

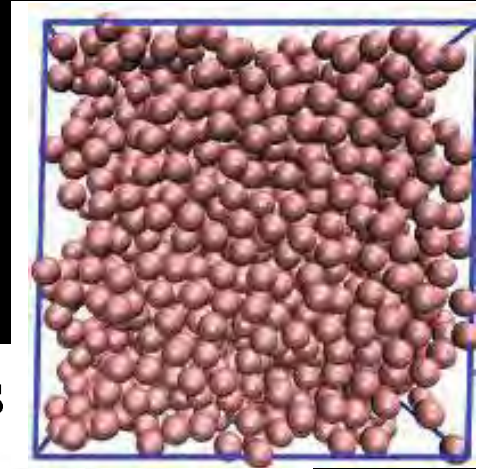
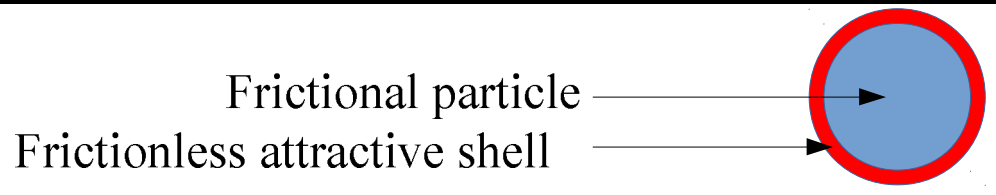
extensional/channel flow,  
shear thickening and LAOS



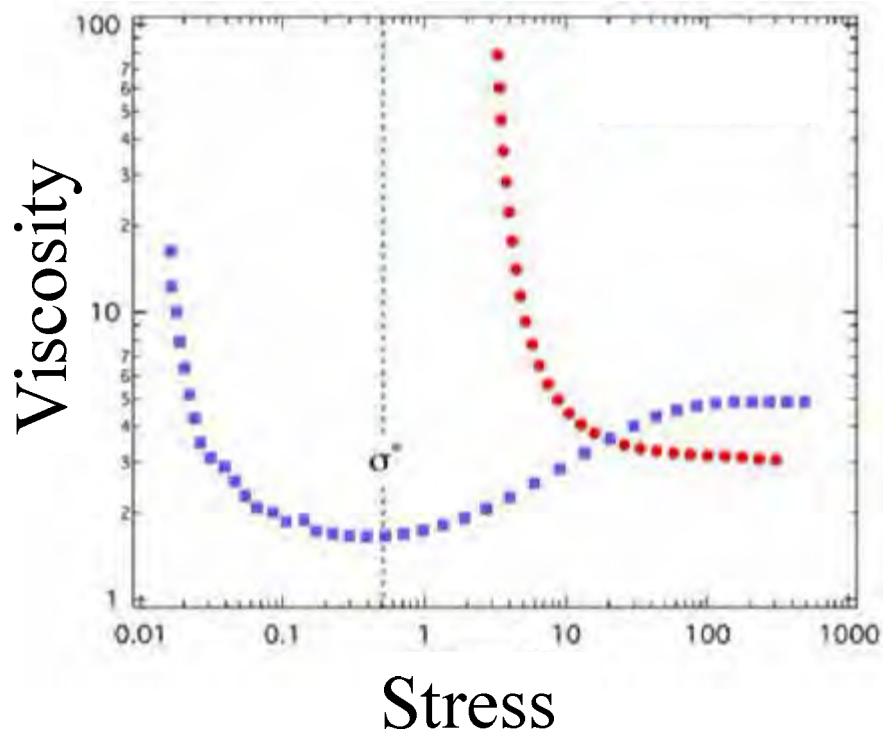
# Describing Time-Dependent and Unsteady Flows



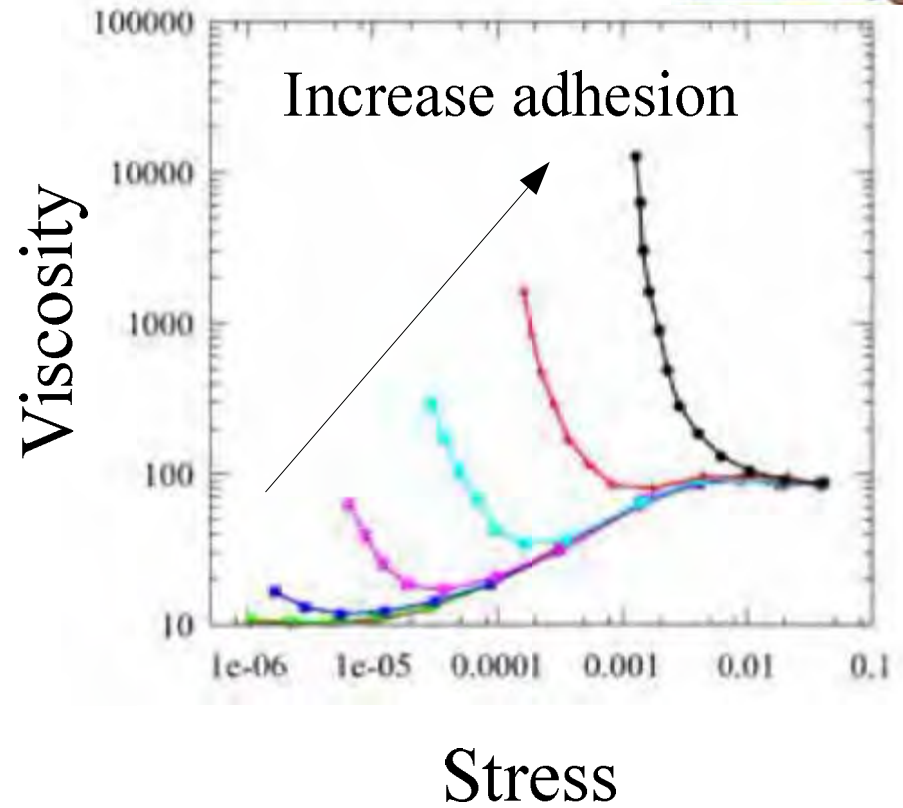
# Adding Attraction



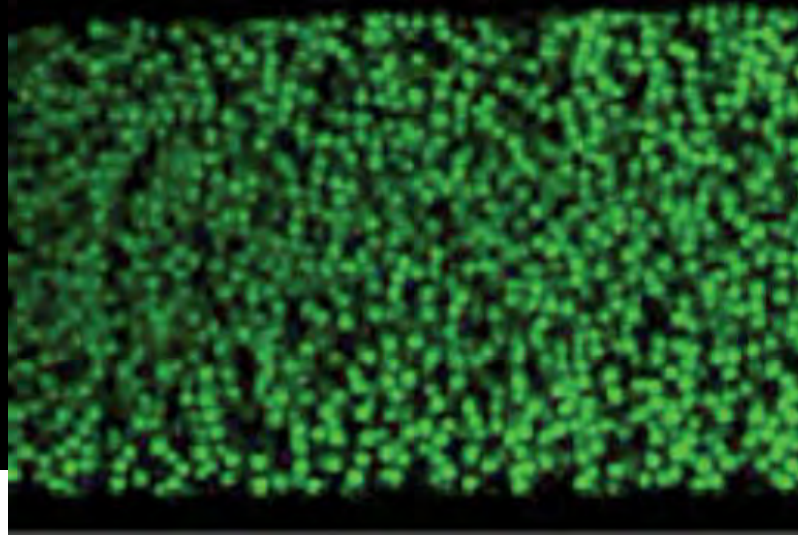
## Experimental results



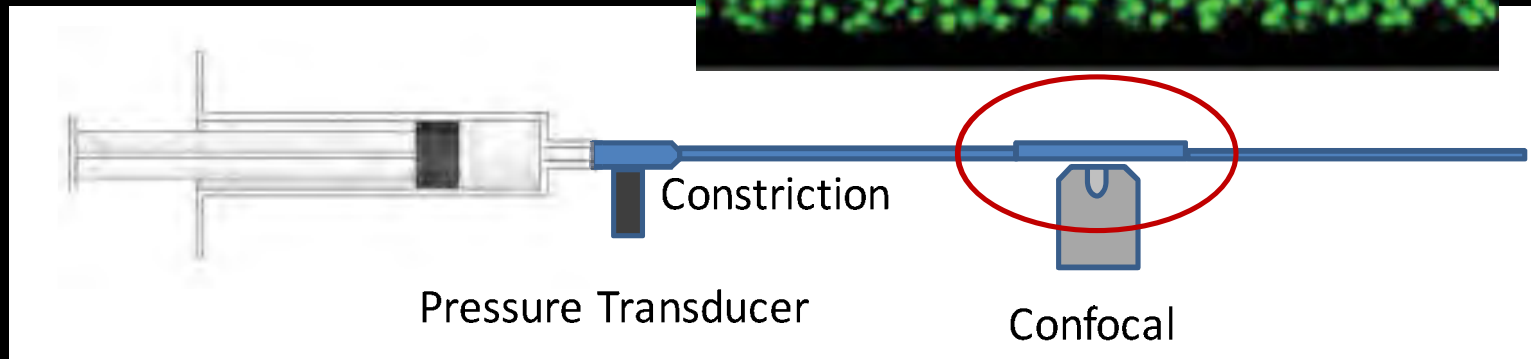
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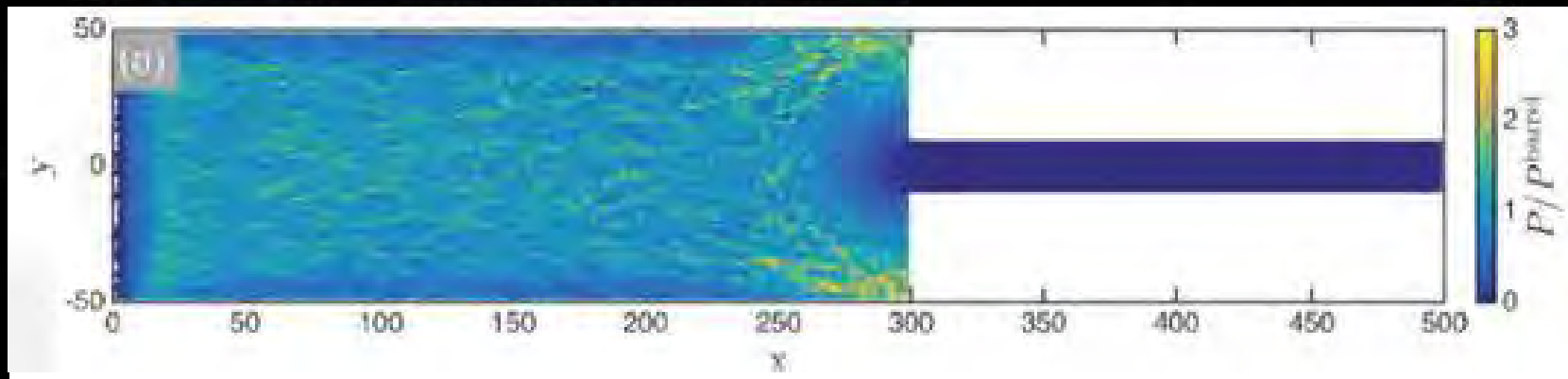
# Complex Flow Geometries



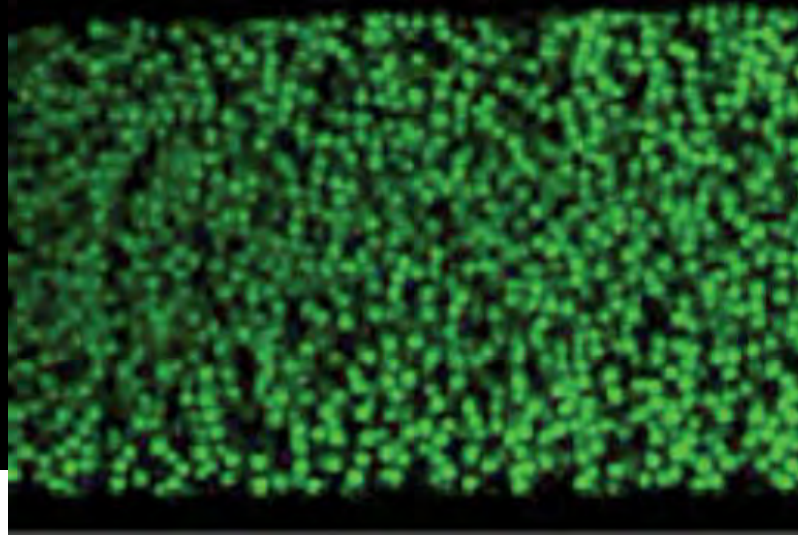
## Experiments



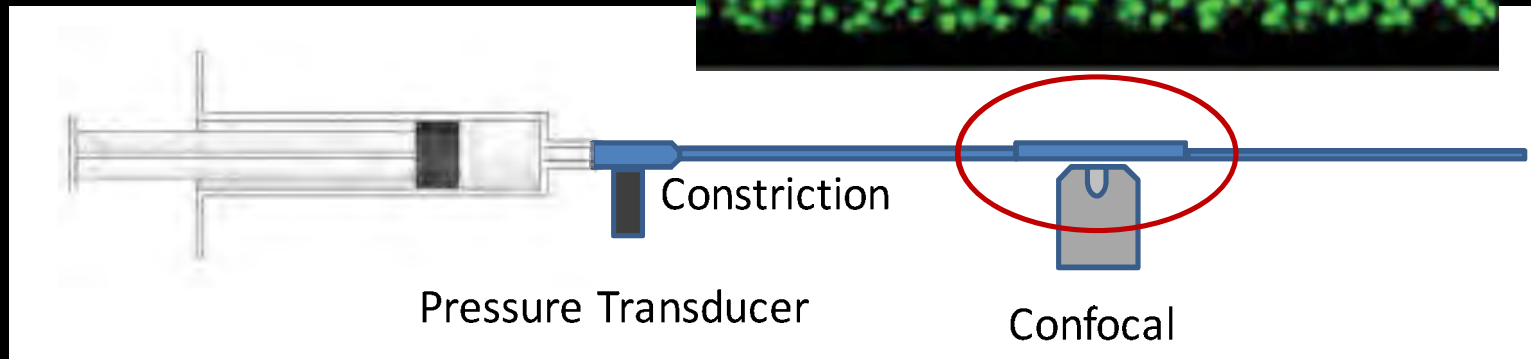
## Simulations



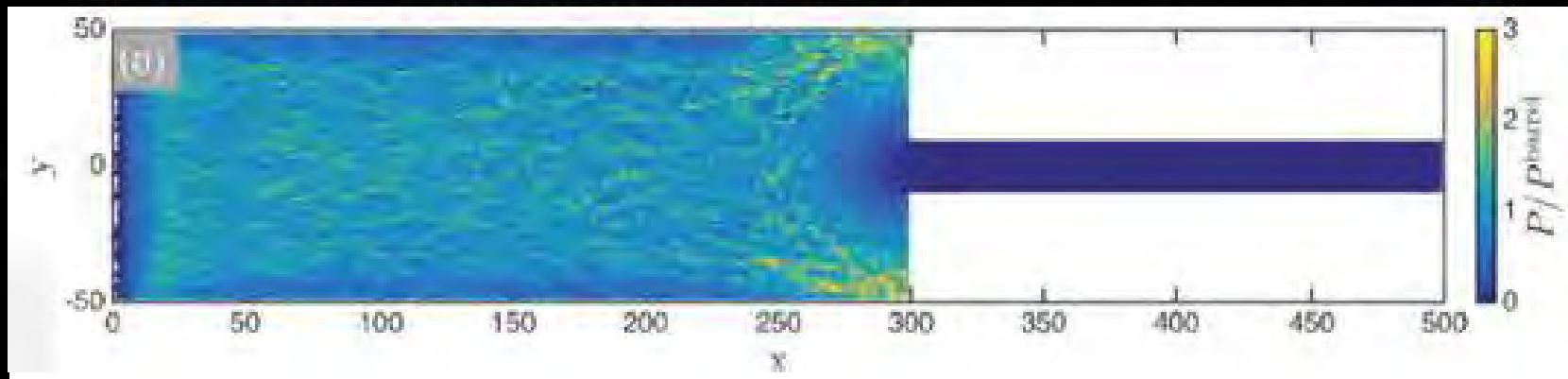
# Complex Flow Geometries



## Experiments



## Simulations



# Major Underlying Themes

- How to maximise  $\phi$
- Interplay between friction and attraction
- Building in complexity (flow geometry, polydispersity, shape, non-newtonian background ...)
- From lab to factory (extracting process-relevant information, developing predictive models ...)