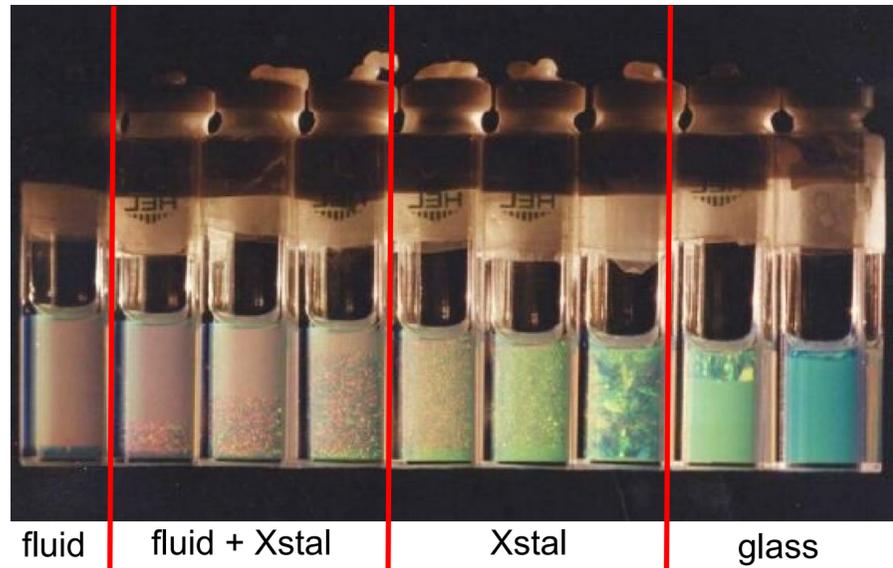


TRIBOLOGY, FRICTION, AND CONTACT MECHANICS IN WET SYSTEMS: A REVIEW

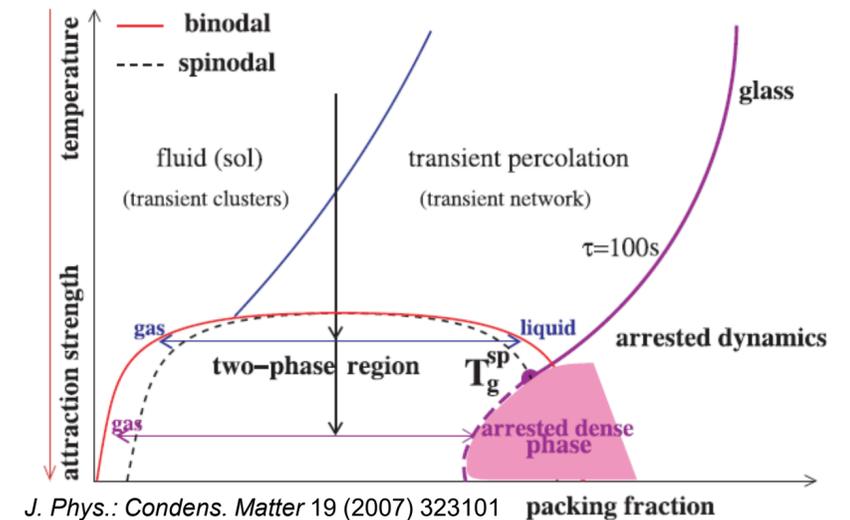
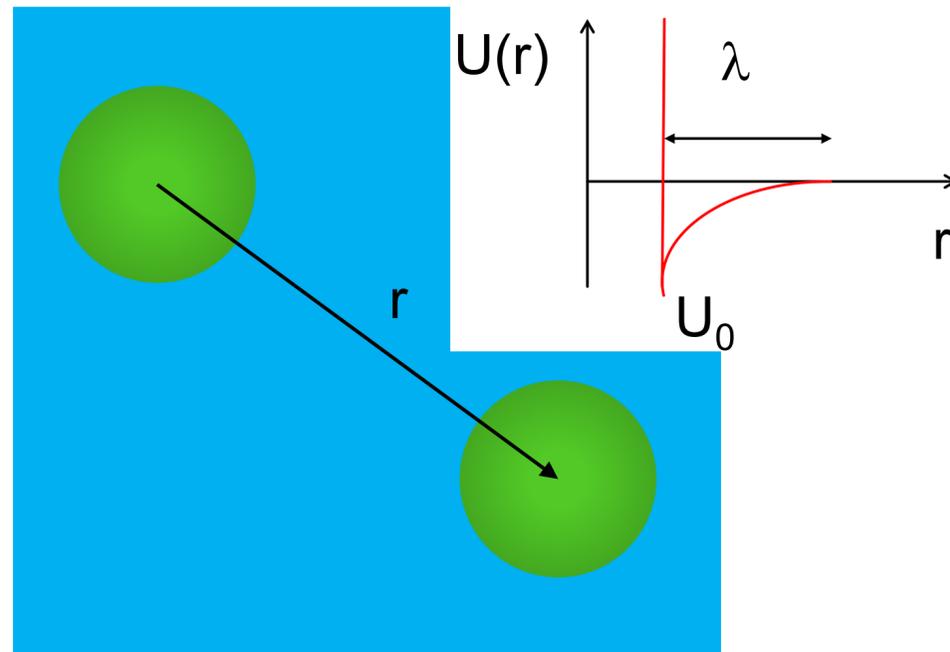


Table of Contents

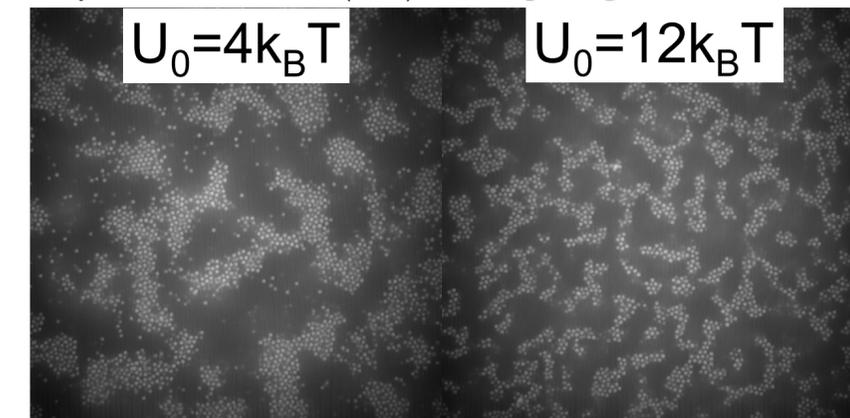
- Introduction and motivation: why do we need this review?
- General framework: Central vs non-central forces & contact mechanics
- Measuring friction and adhesion for particulate systems
- Modifying friction and adhesion for particles
- Case studies (to be discussed)
- Conclusions and outlook



Nature 320, 340–342 (1986)



J. Phys.: Condens. Matter 19 (2007) 323101



INTER-PARTICLE POTENTIAL + KINETICS

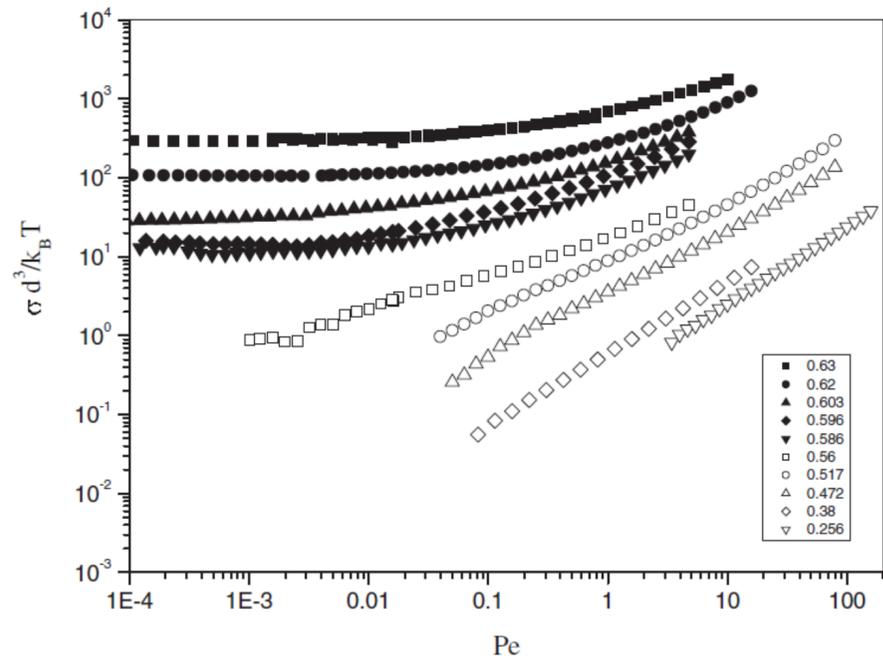


MICROSTRUCTURE

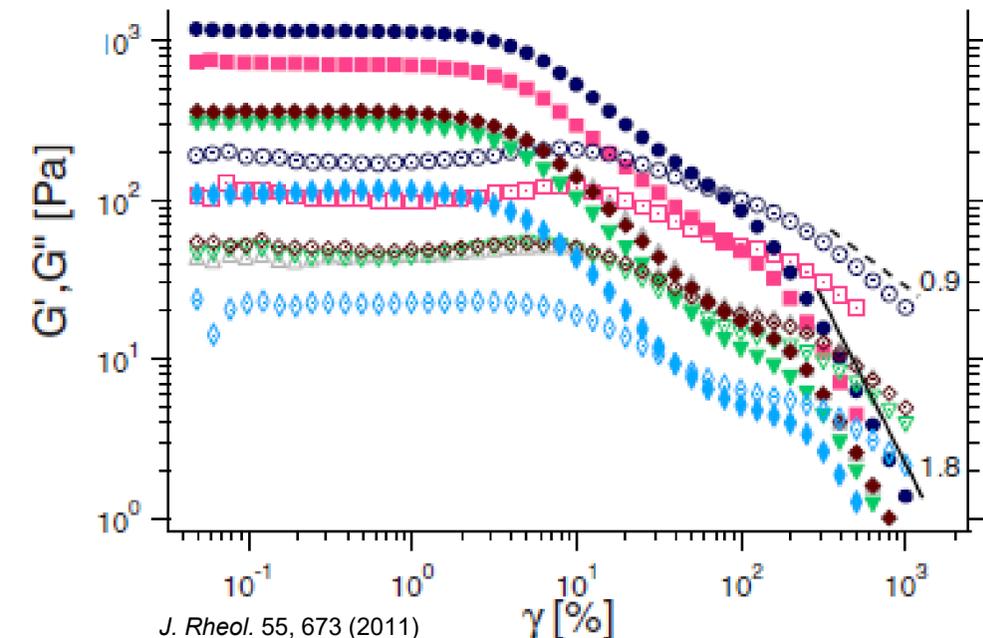


+ HYDRODYNAMICS

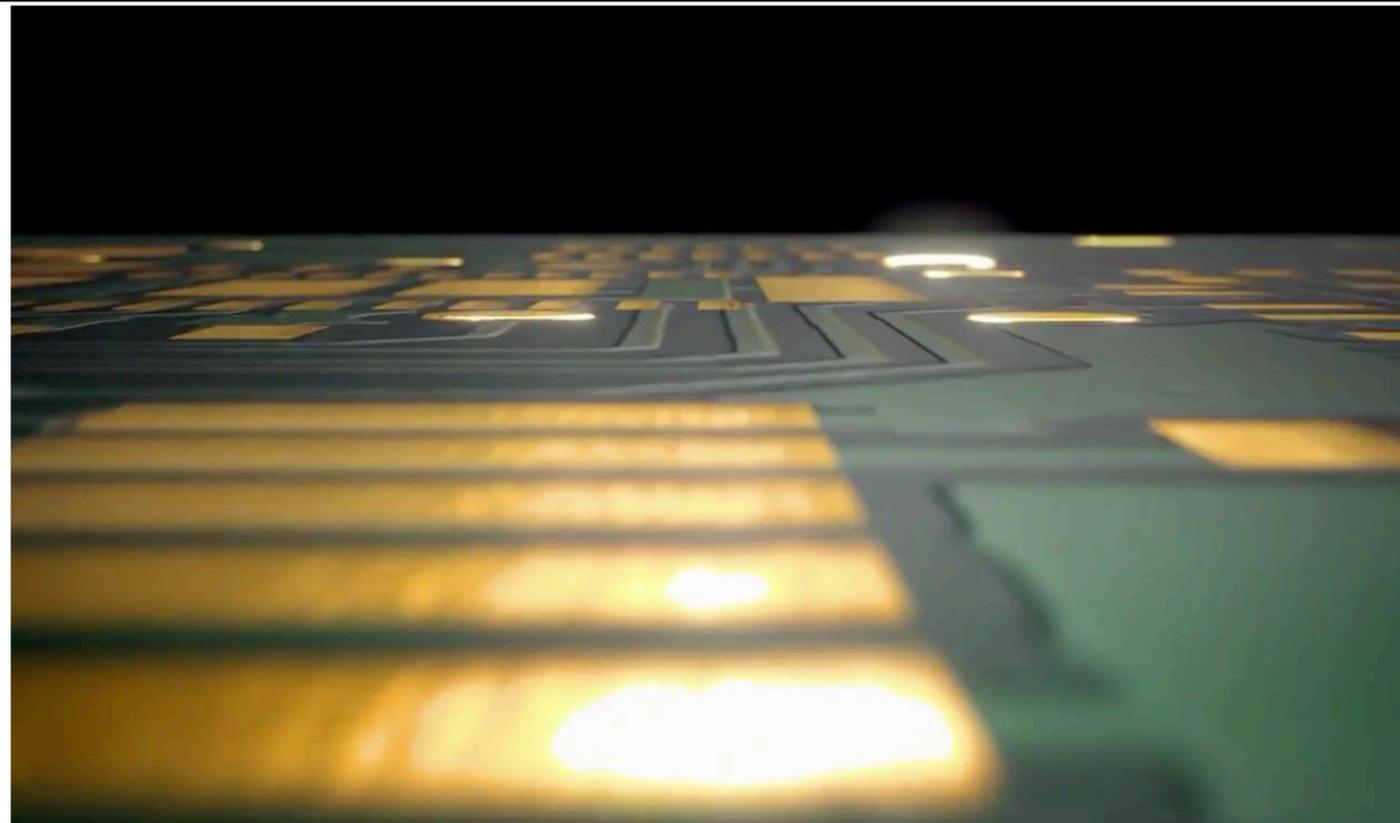
RHEOLOGY



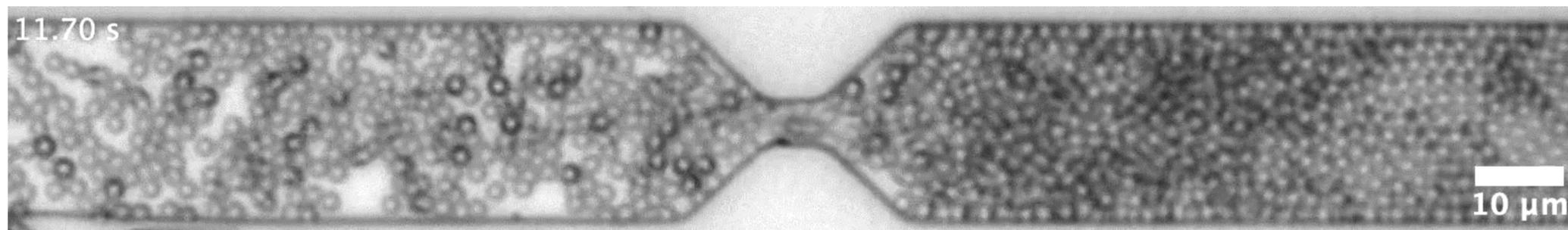
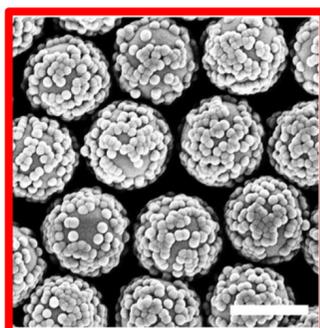
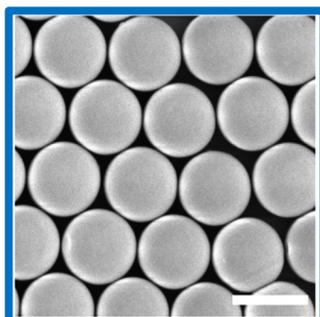
J. Phys.: Condens. Matter 16 S3955–S3963 (2004)



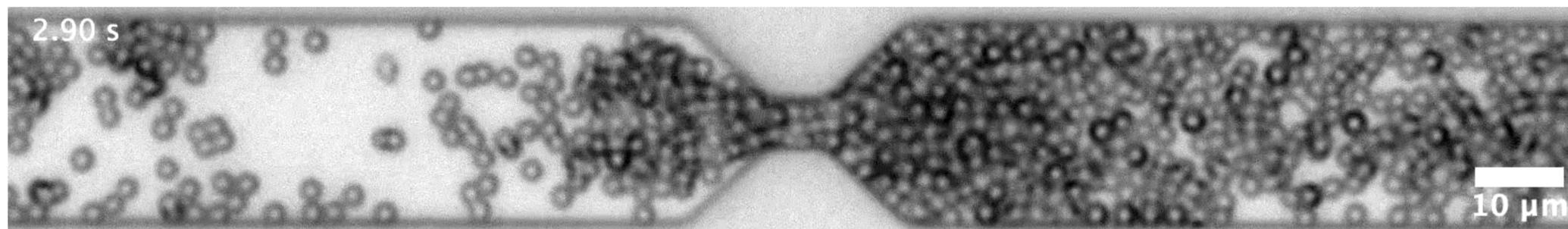
J. Rheol. 55, 673 (2011)



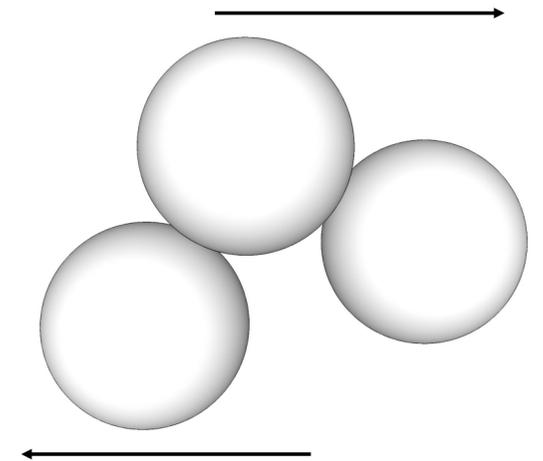
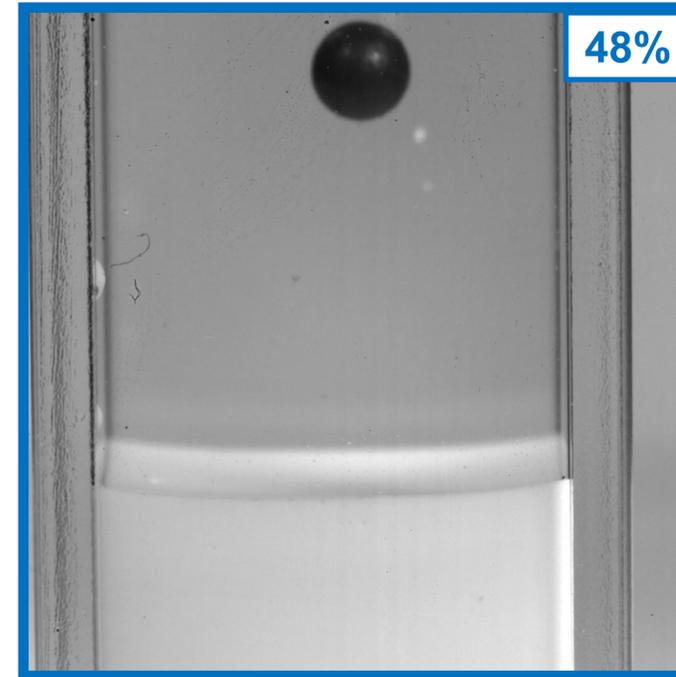
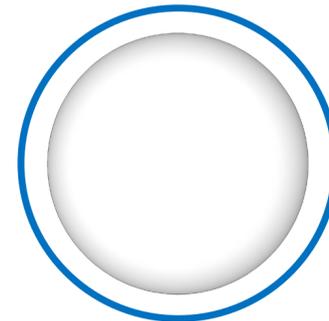
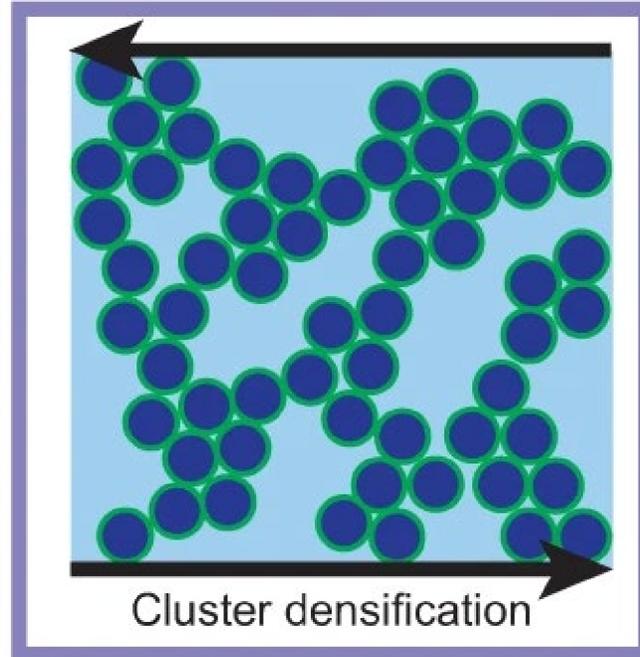
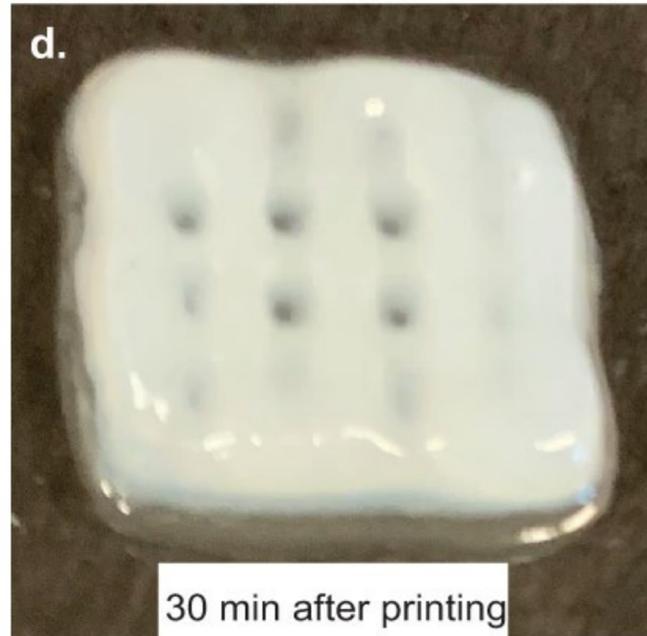
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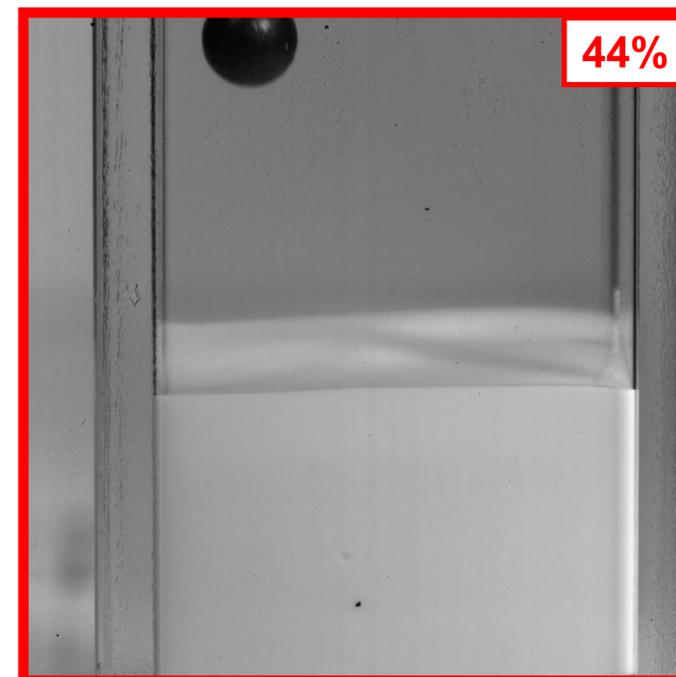
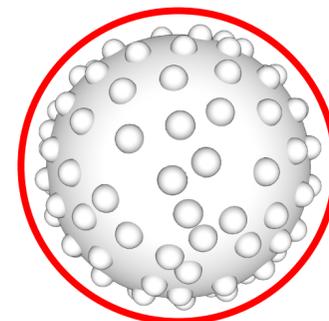
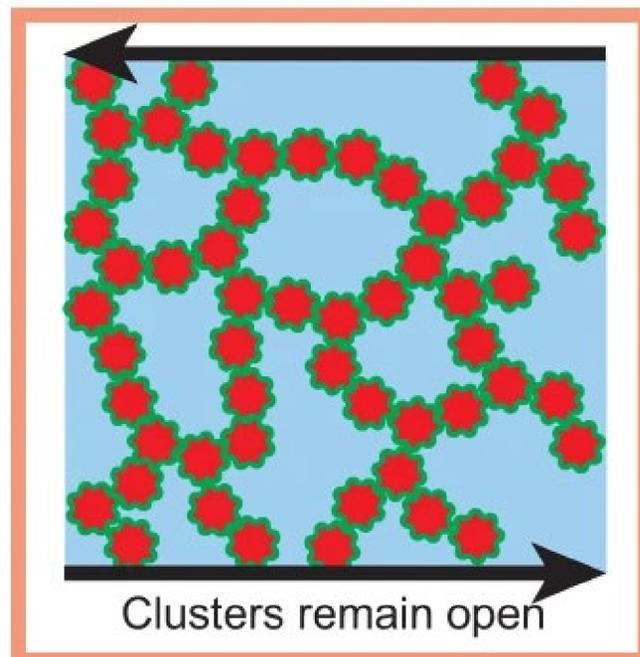
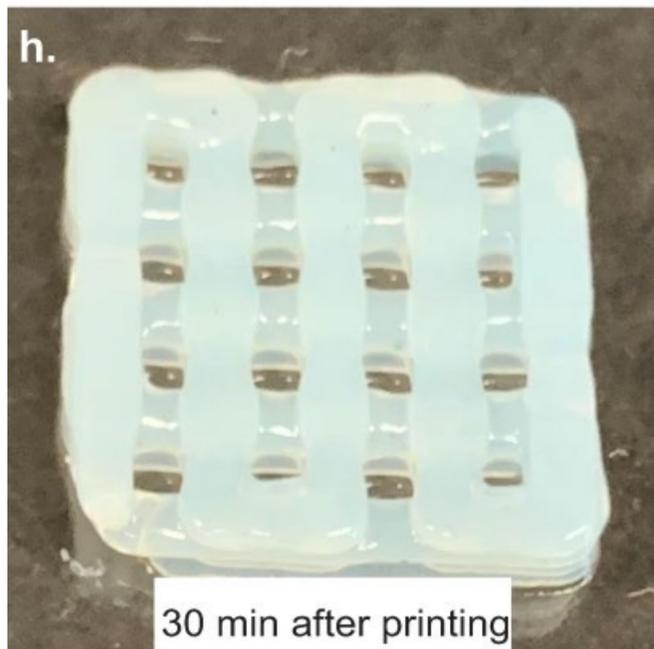
SMOOTH



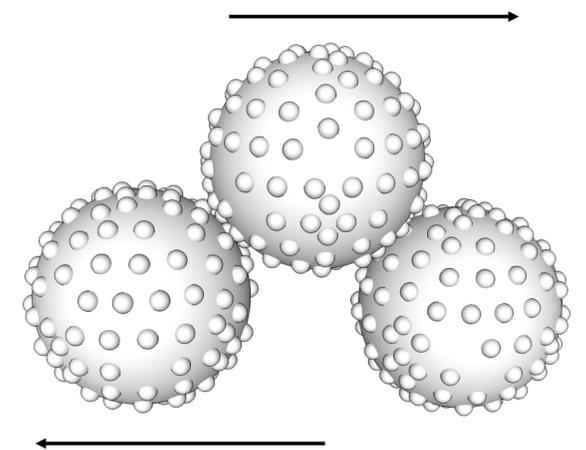
ROUGH



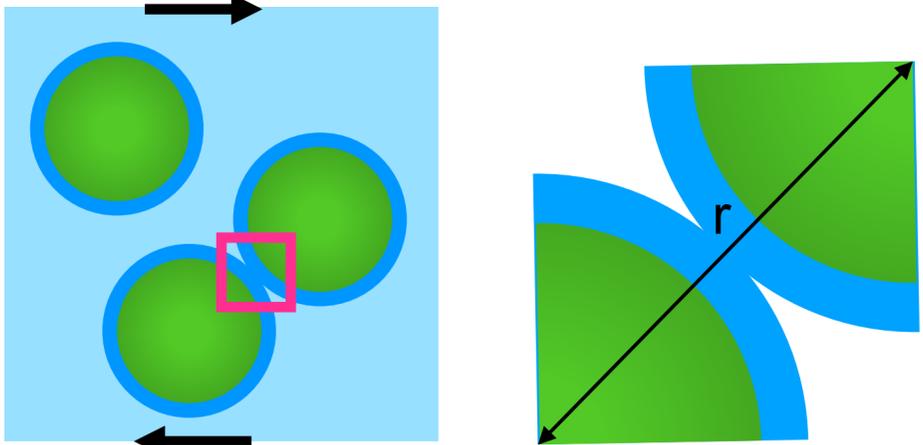
Müller, F.J., Isa, L. & Vermant, J. *Nat Commun* 14, 5309 (2023).



Asperity interlocking

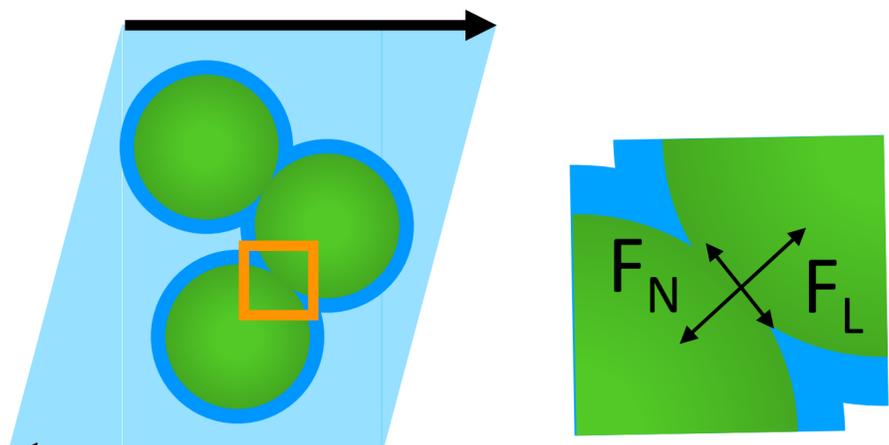


Low Shear / Non-aggregating Systems



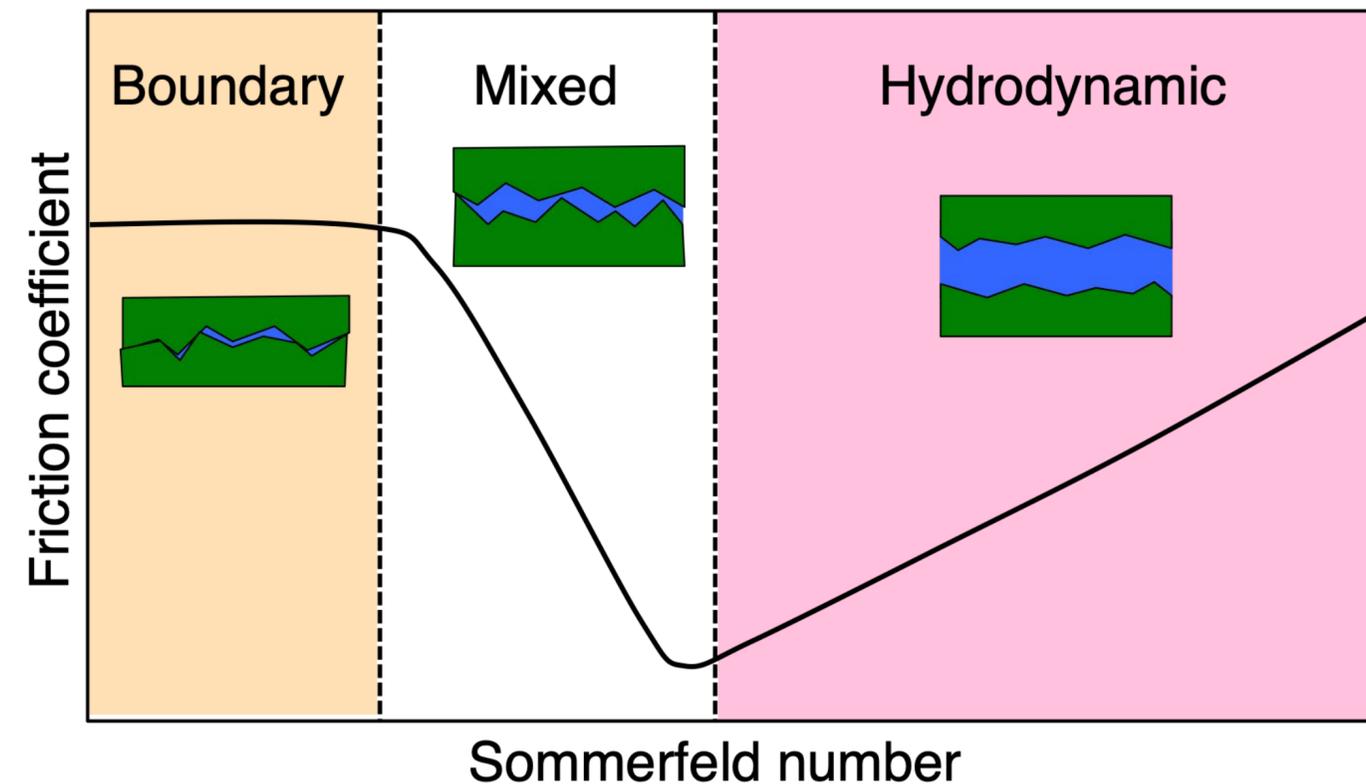
- Hydrodynamics
- $U(r)$

High Shear / Aggregating Systems

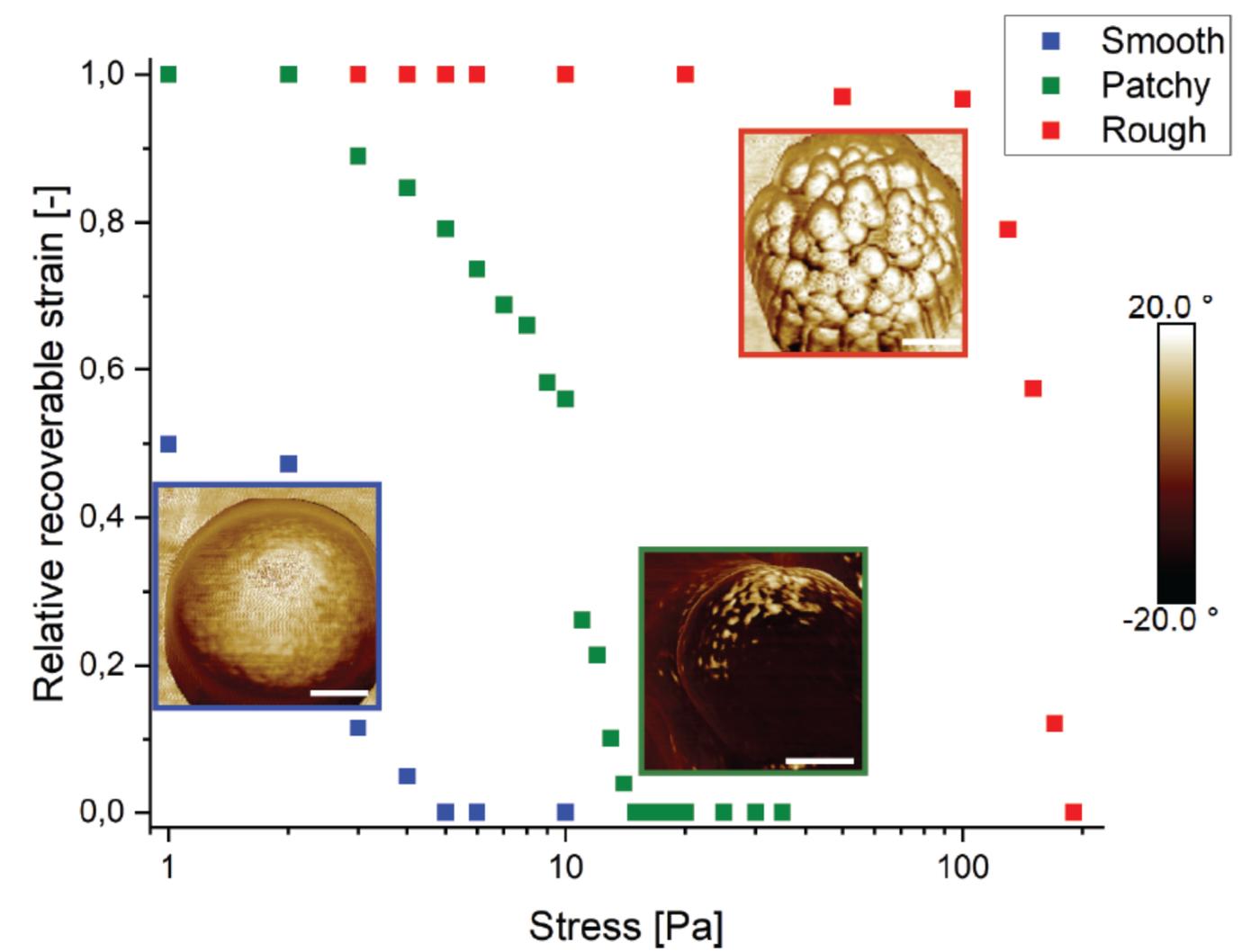
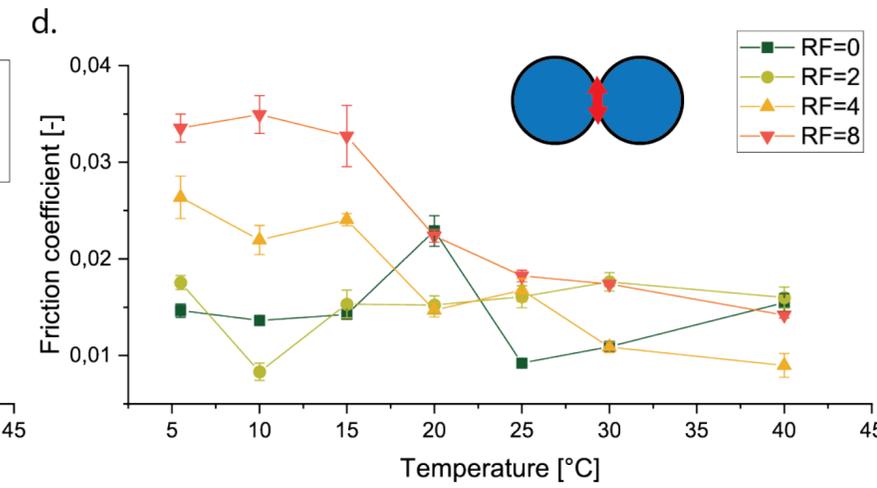
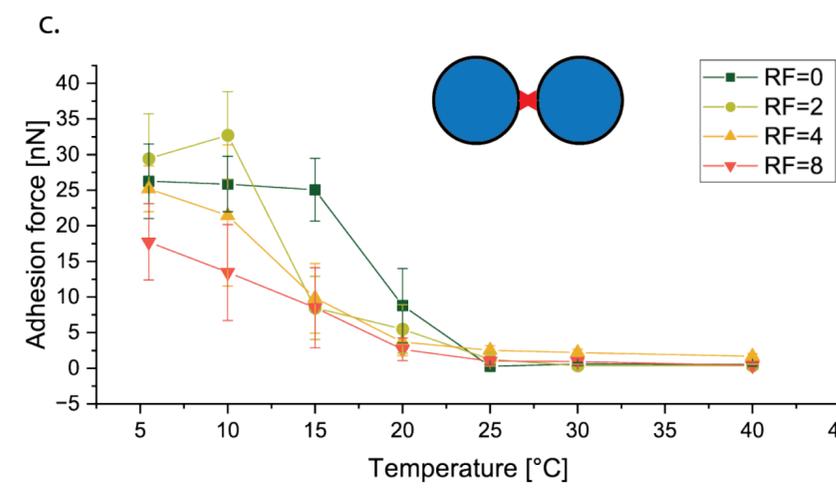
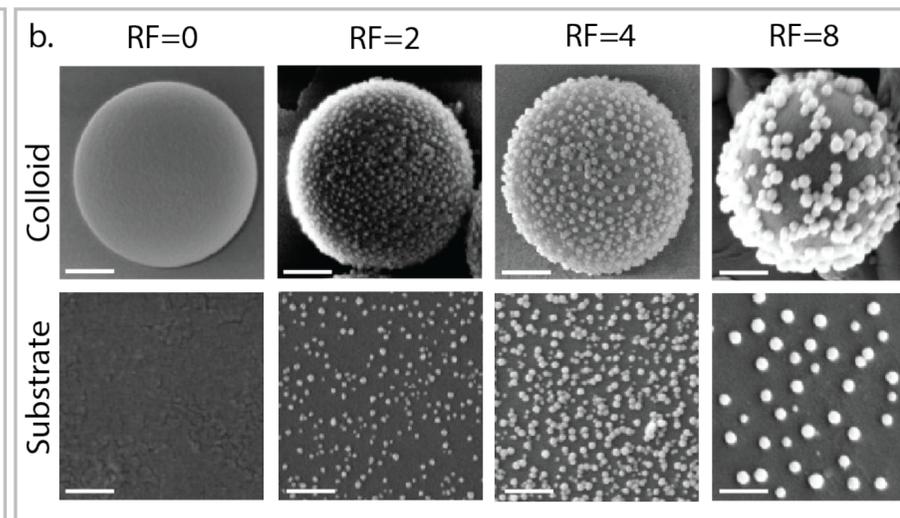
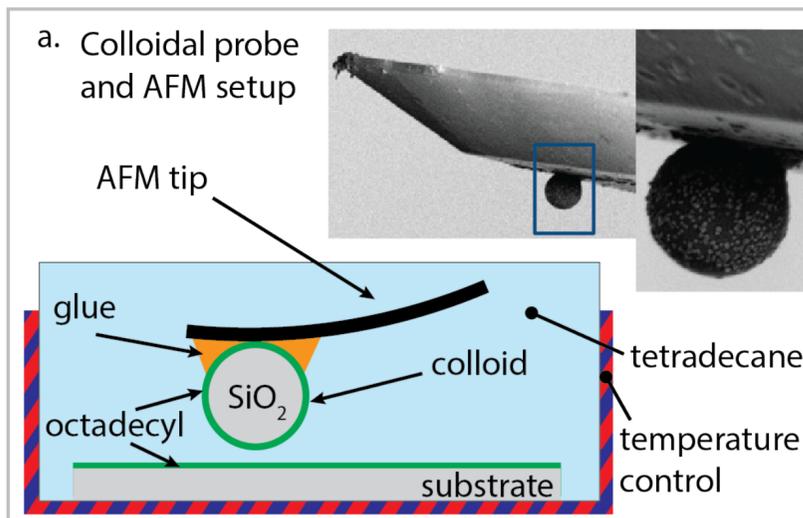


- Contact forces
- Adhesion & Friction
- Non-central forces
- Static & dynamic

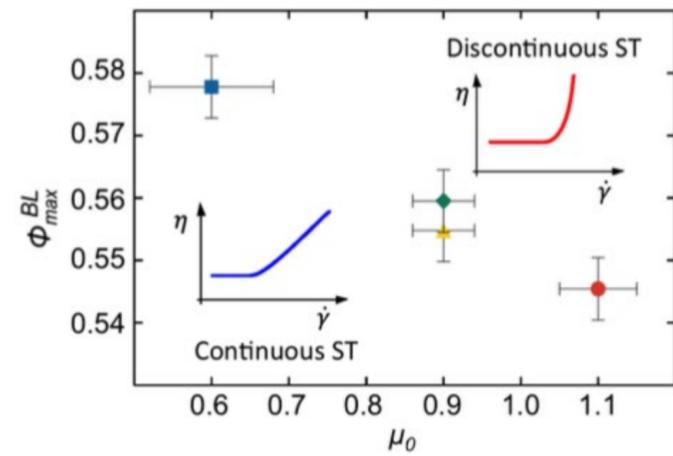
RHEOLOGY



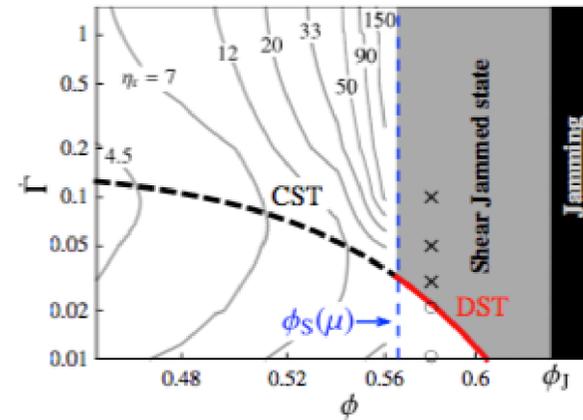
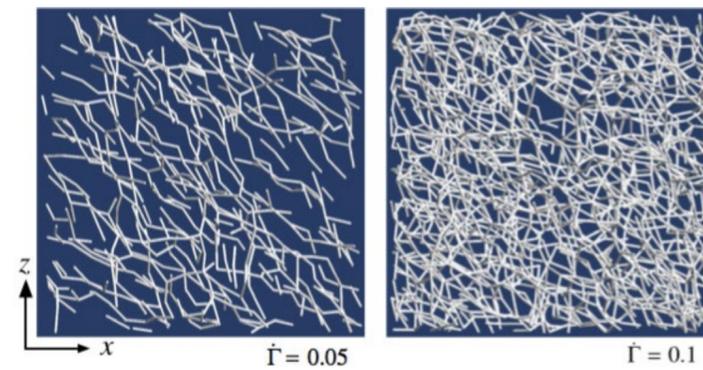
TRIBOLOGY



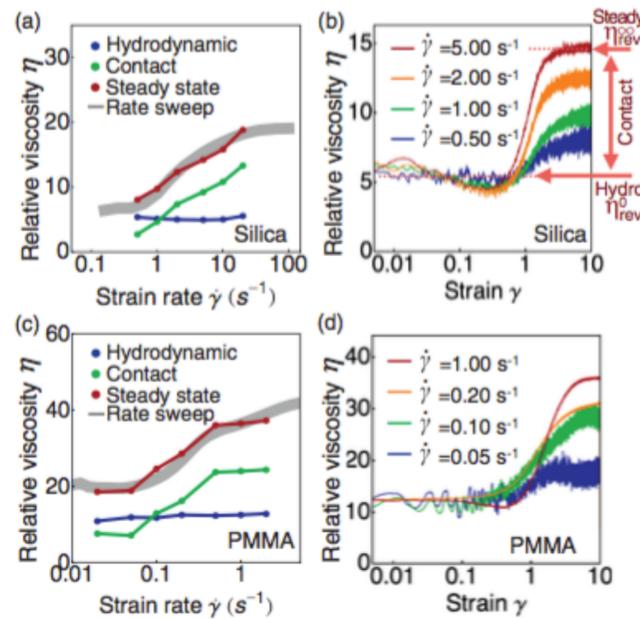
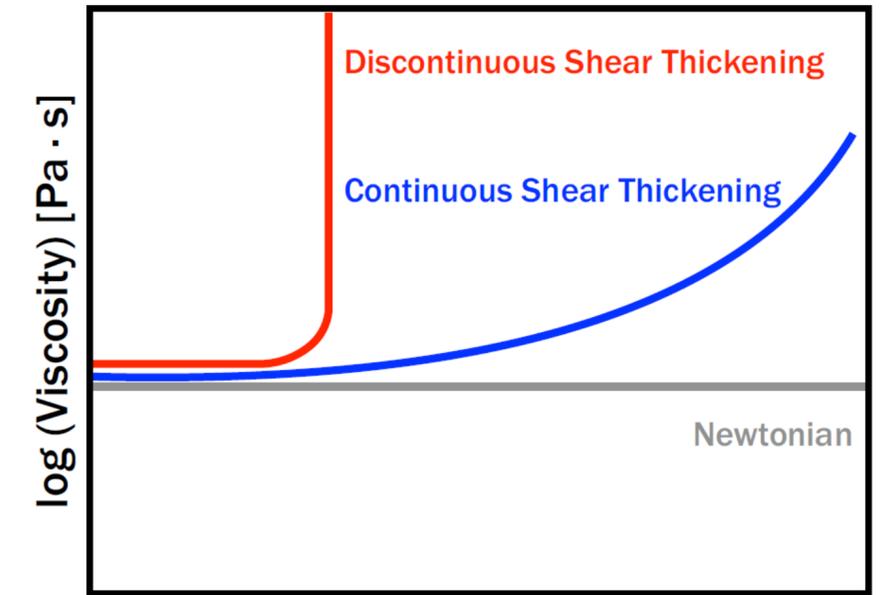
**INTER-PARTICLE CONTACTS
ARE IMPORTANT IN GELS**



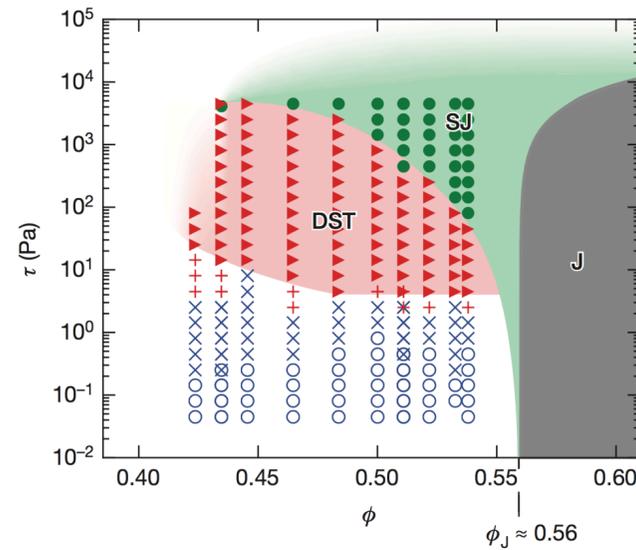
N. Fernandez et al., *Phys Rev Lett* 111, (2013).



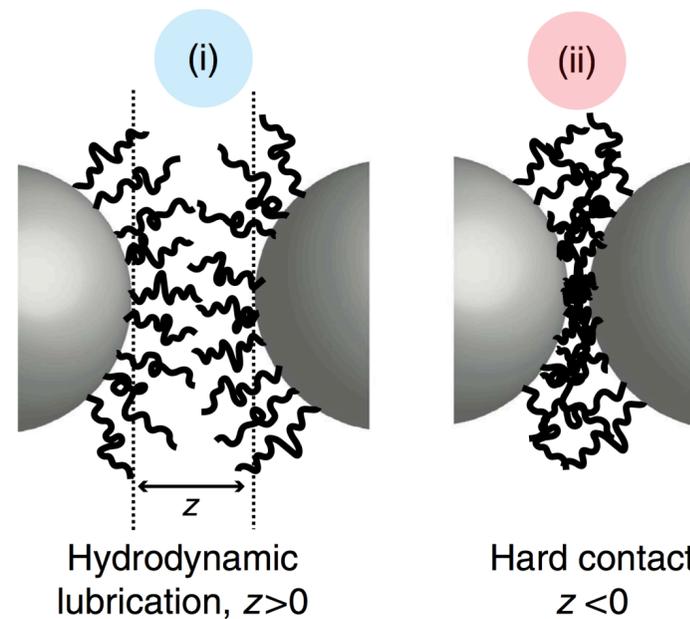
R. Seto, et al., *Phys Rev Lett* 111, (2013).



N. Y. C. Lin et al., *Phys Rev Lett* 115, (2015).

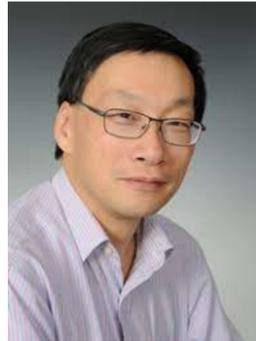


I. R. Peters, et al., *Nature* 532, 214-217, (2016).



Comtet, J. et al., *Nature Communications* 8, (2017).

INTER-PARTICLE CONTACTS ARE IMPORTANT IN DST



PHYSICAL REVIEW LETTERS 121, 128001 (2018)

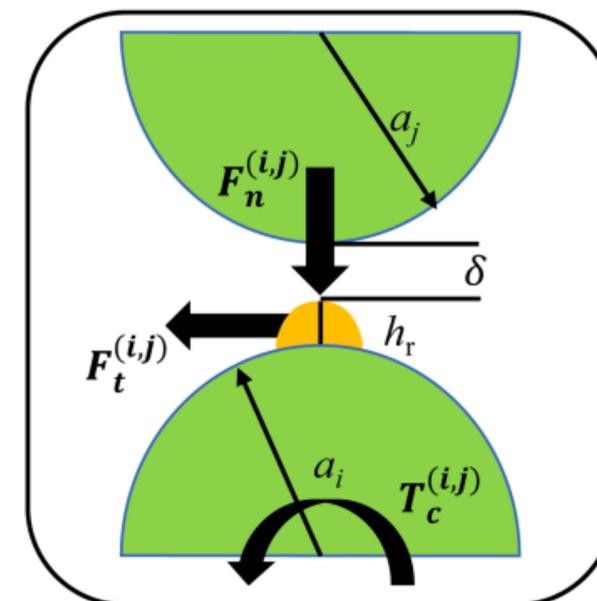
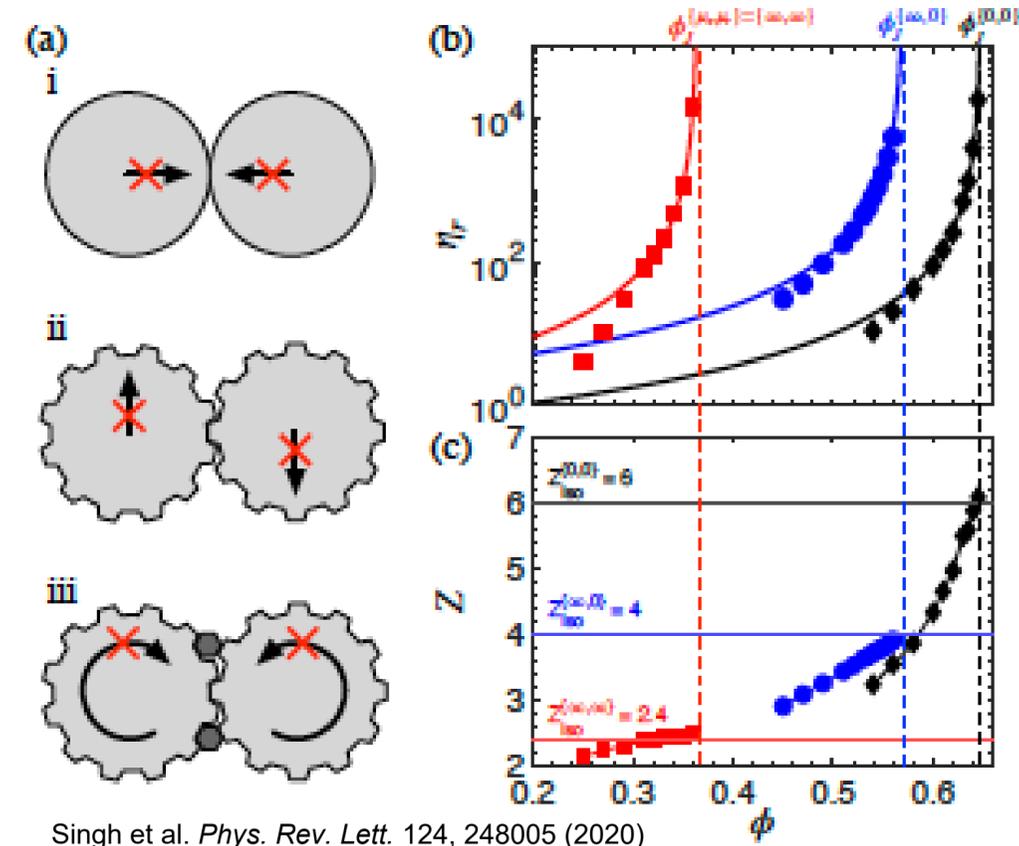
Constraint-Based Approach to Granular Dispersion Rheology

B. M. Guy,^{*} J. A. Richards,[†] D. J. M. Hodgson, E. Blanco, and W. C. K. Poon
 SUPA, School of Physics and Astronomy, The University of Edinburgh,
 King's Buildings, Peter Guthrie Tait Road, Edinburgh EH9 3FD, United Kingdom

(Received 10 May 2018; published 17 September 2018)

We present a phenomenological model for granular suspension rheology in which particle interactions enter as constraints to relative particle motion. By considering constraints that are *formed* and *released* by stress respectively, we derive a range of experimental flow curves in a single treatment and predict singularities in viscosity and yield stress consistent with literature data. Fundamentally, we offer a generic description of suspension flow that is independent of bespoke microphysics.

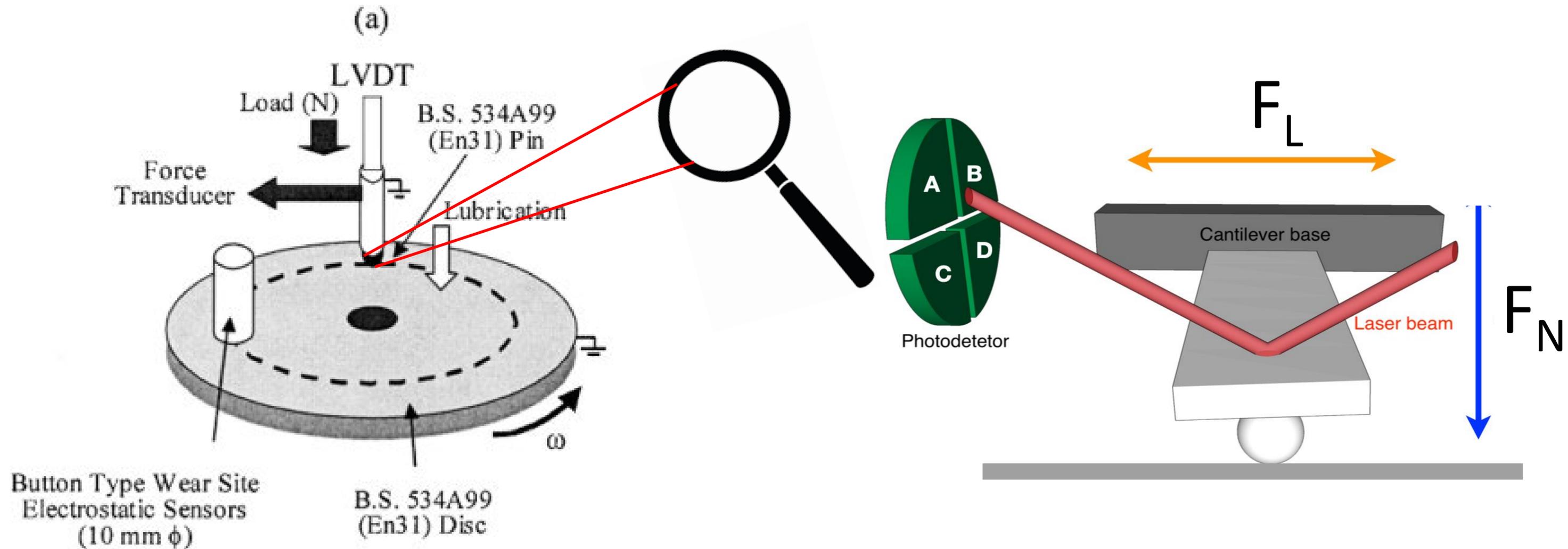
DOI: 10.1103/PhysRevLett.121.128001



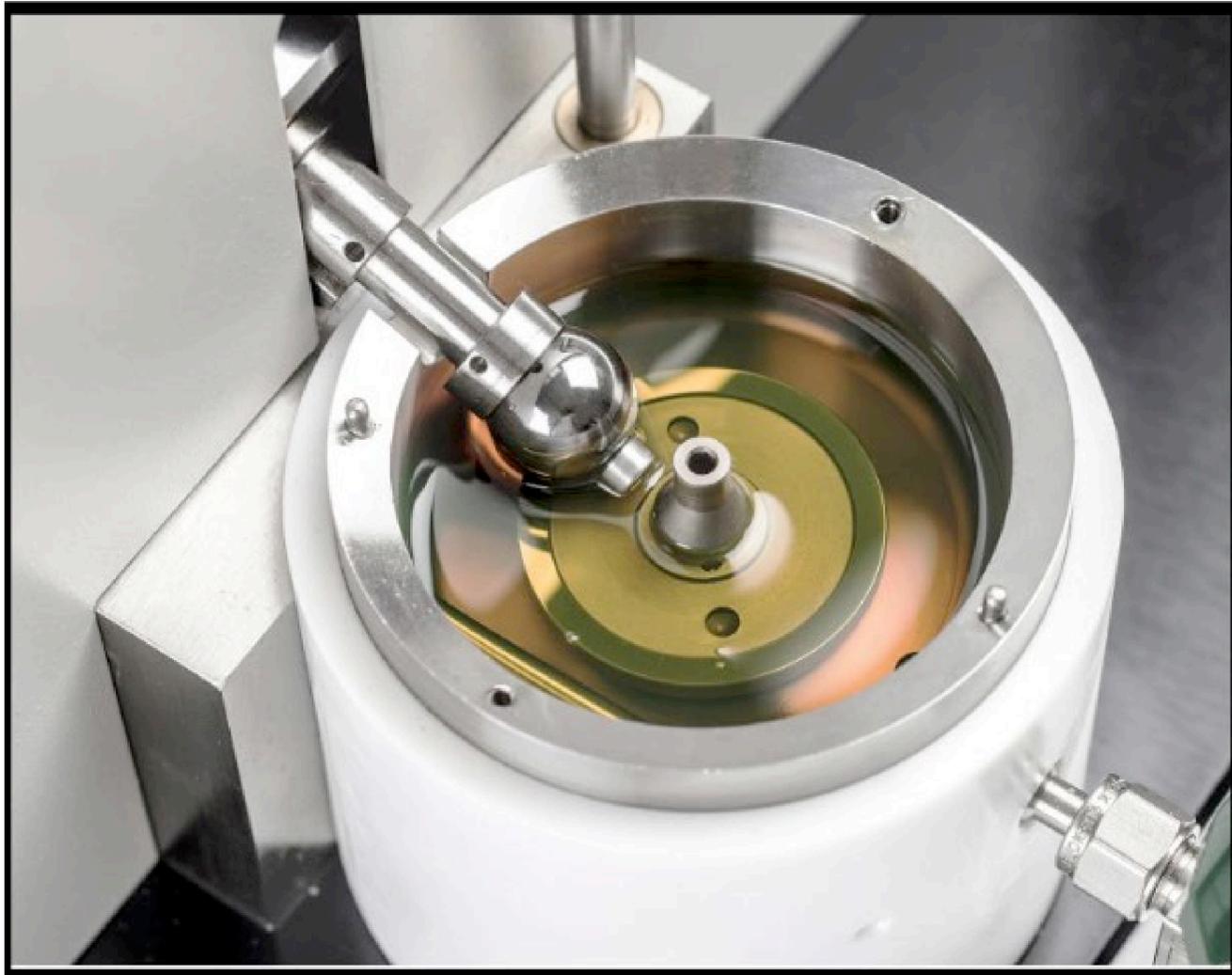
Moore and Ardekani, *J. Rheol.* 64, 1107 (2020)

MACRO

MICRO

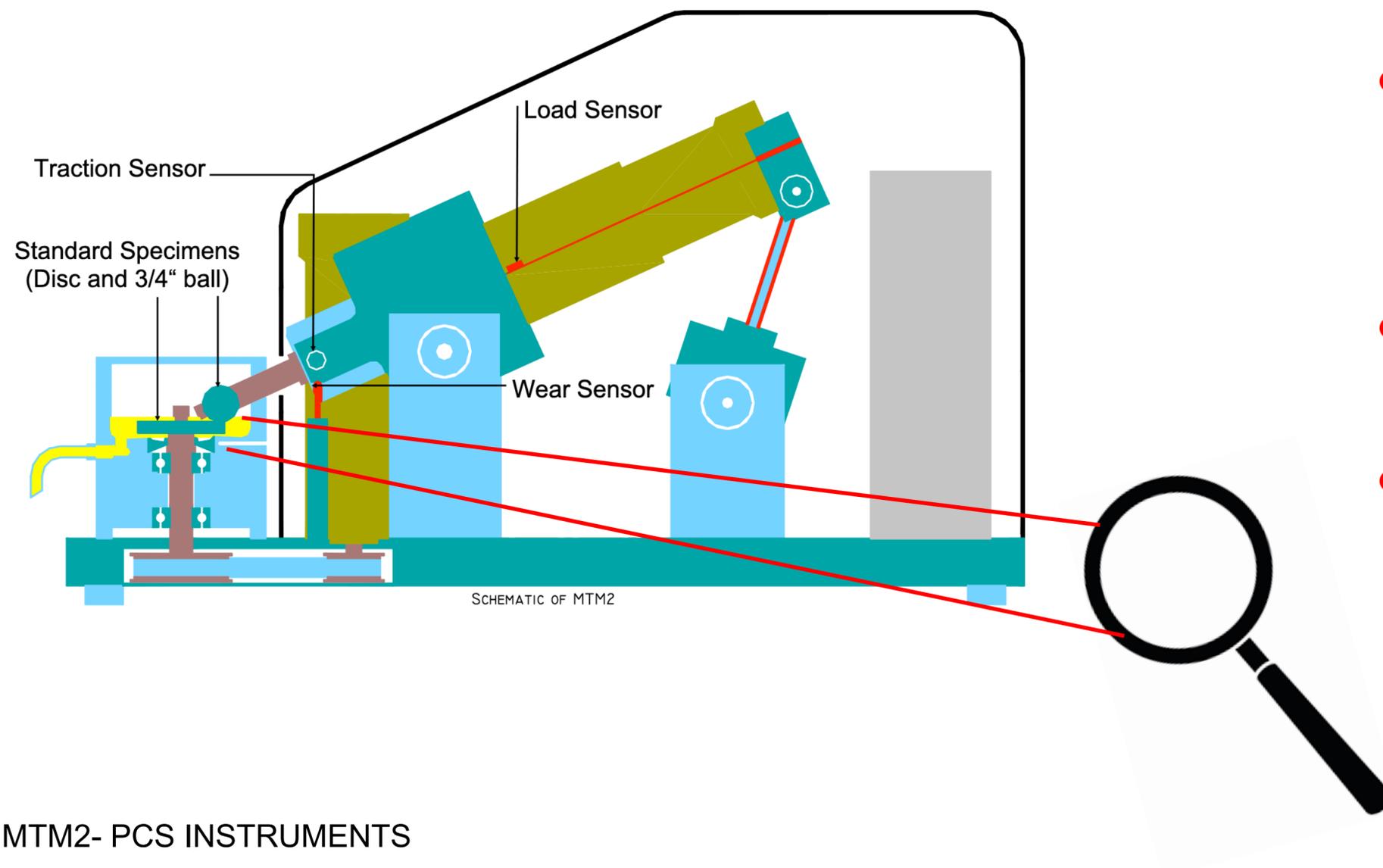


MACRO



MTM2- PCS INSTRUMENTS

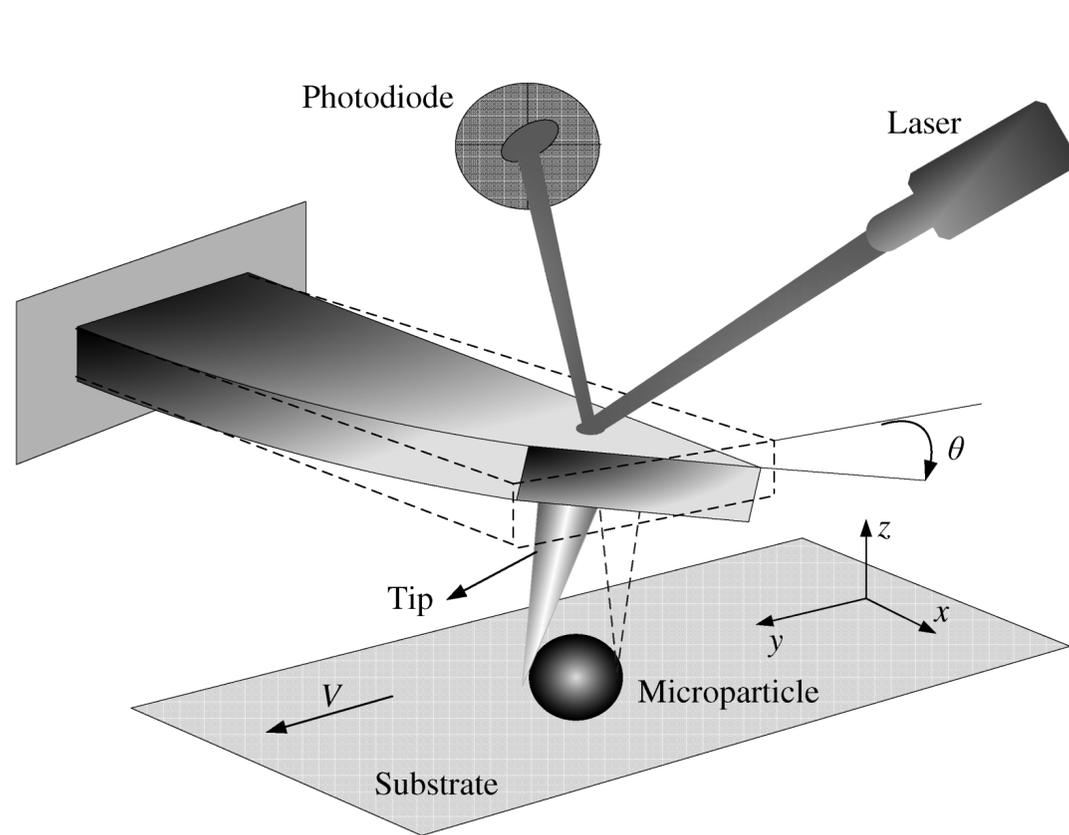
MACRO



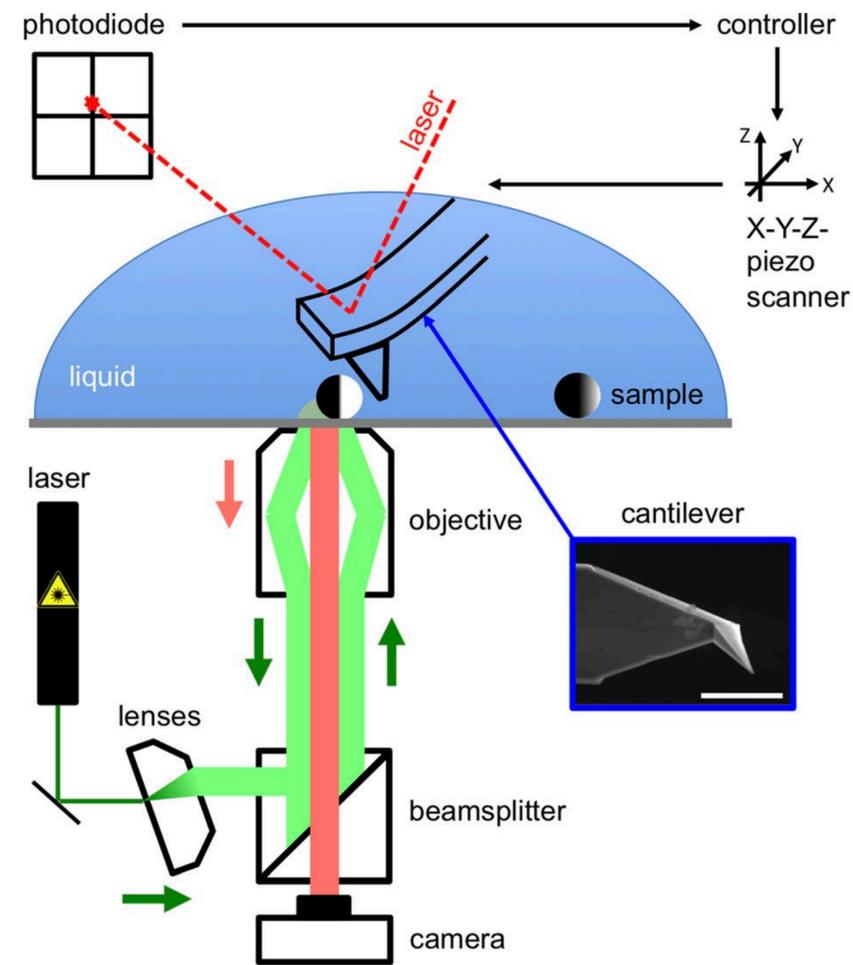
MICRO

- MEASUREMENT OF LATERAL/TRACTION FORCE
- ENABLING ROLLING CONTACT
- DETECTING ROTATION

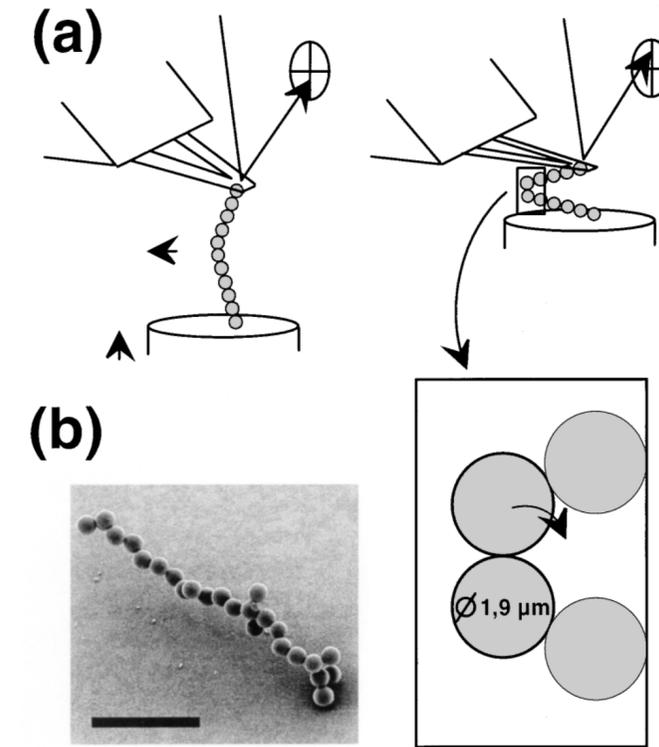




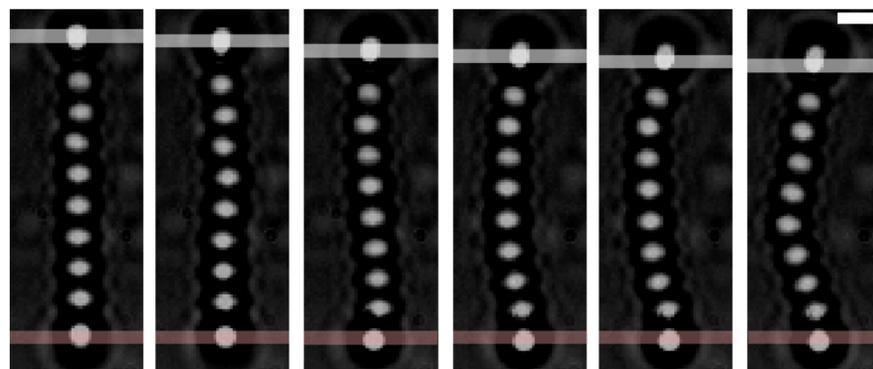
B. Sümer, M. Sitti, *Journal of Adhesion Science and Technology* 22 (2008) 481–506



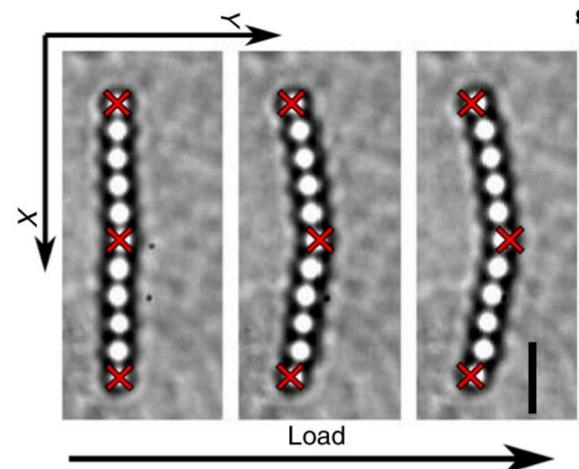
Schiwek et al. *J. Appl. Phys.* 119, 194304 (2016)



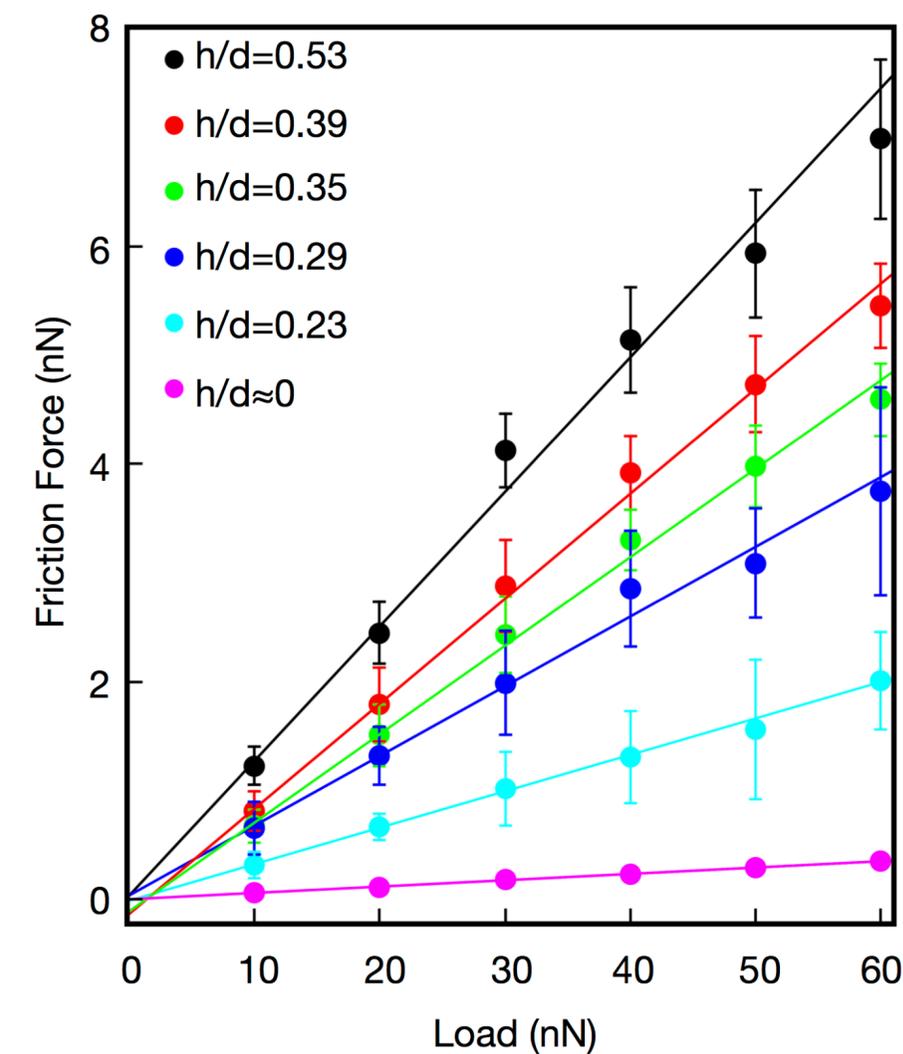
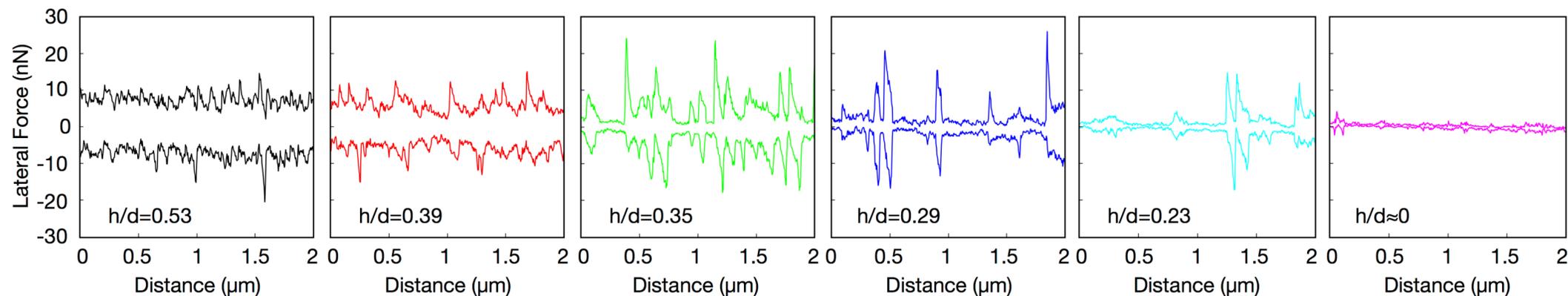
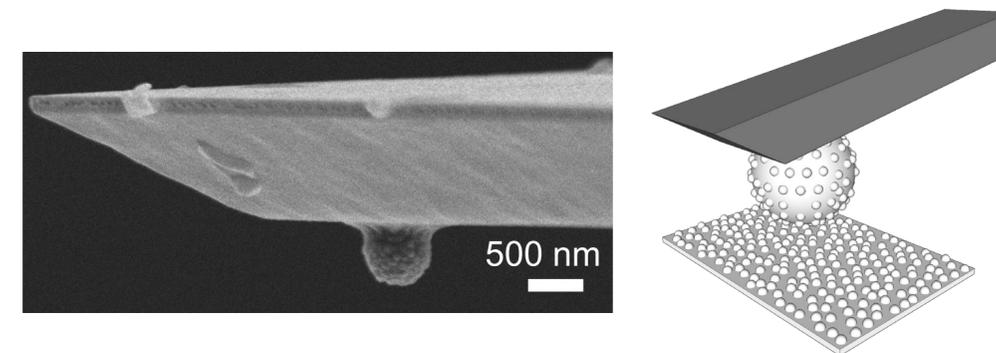
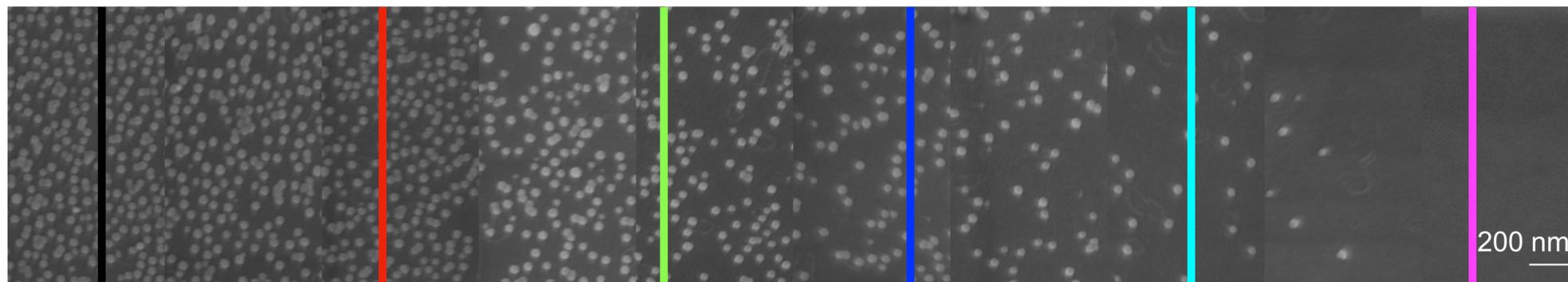
(c) AFM cantilever
particle chain
Heim et al. *Phys. Rev. Lett* 83(16), 3328 (1999)



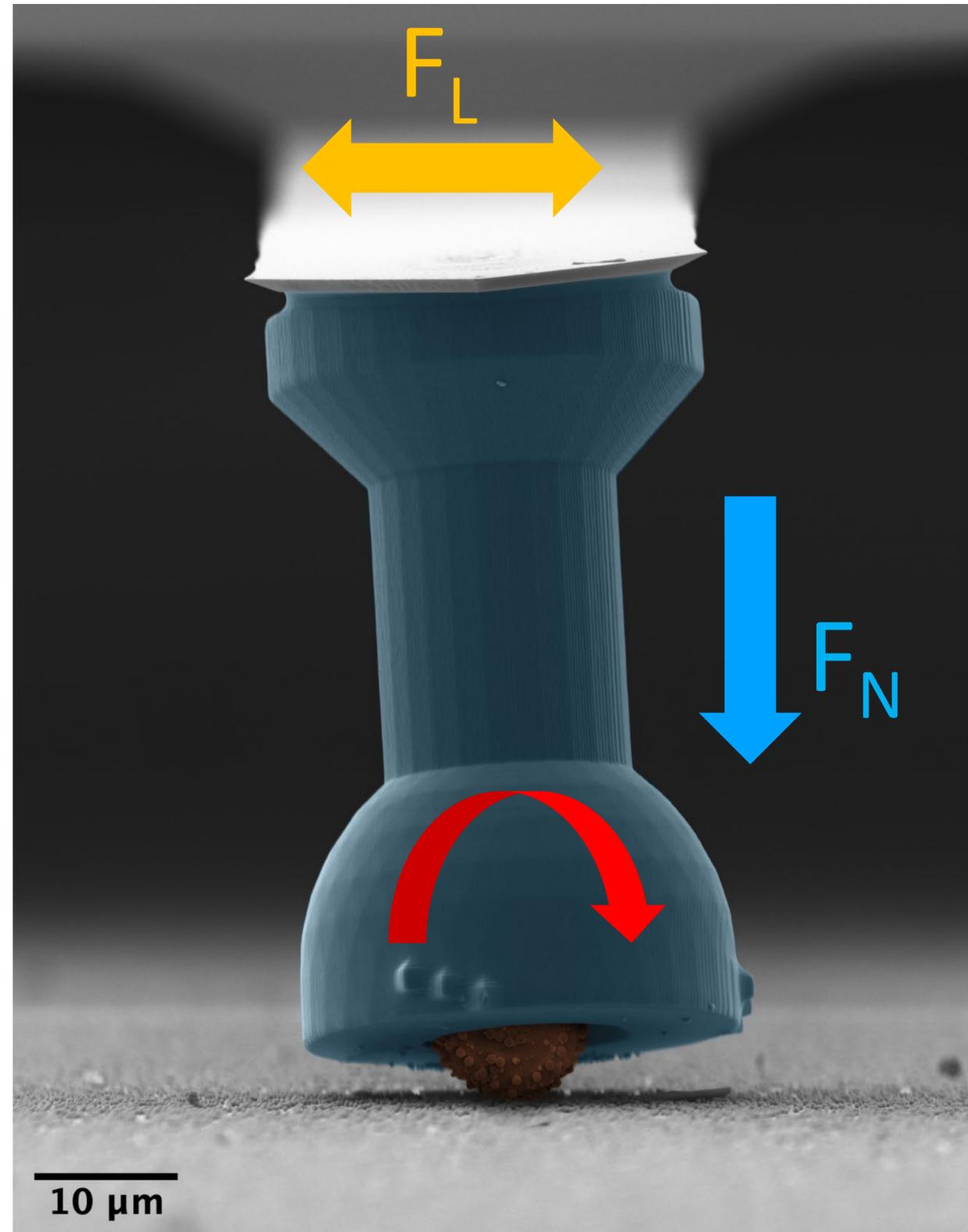
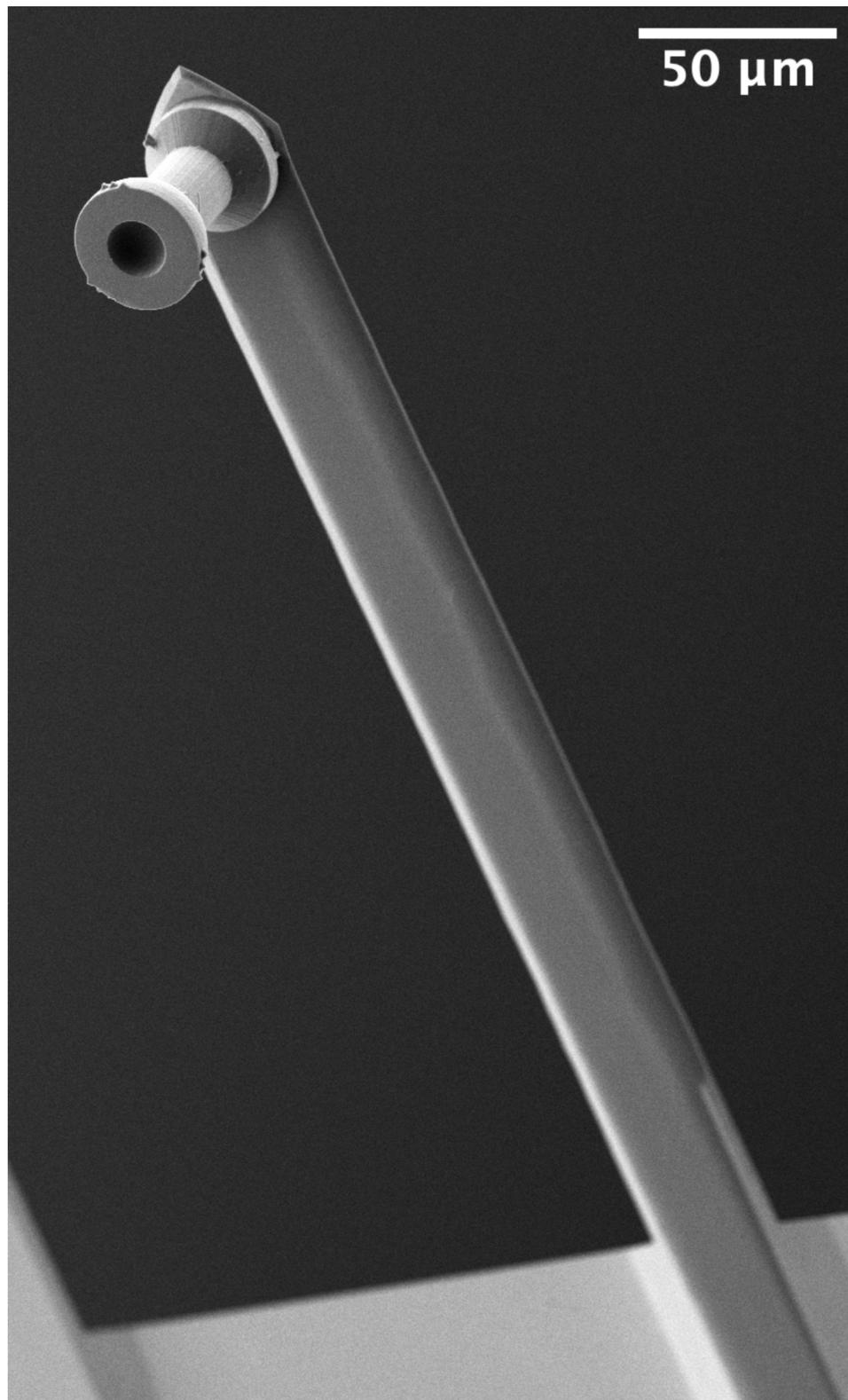
SIMON STUIJ et al. *PHYSICAL REVIEW RESEARCH* 1, 023033 (2019)



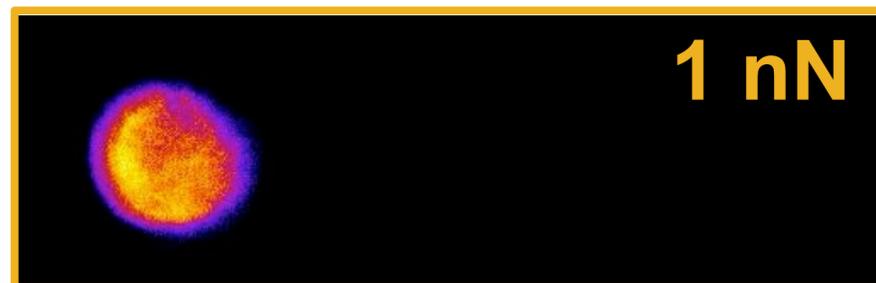
Bonacci et al. *Nat. Mater.* 19, 775–780 (2020)



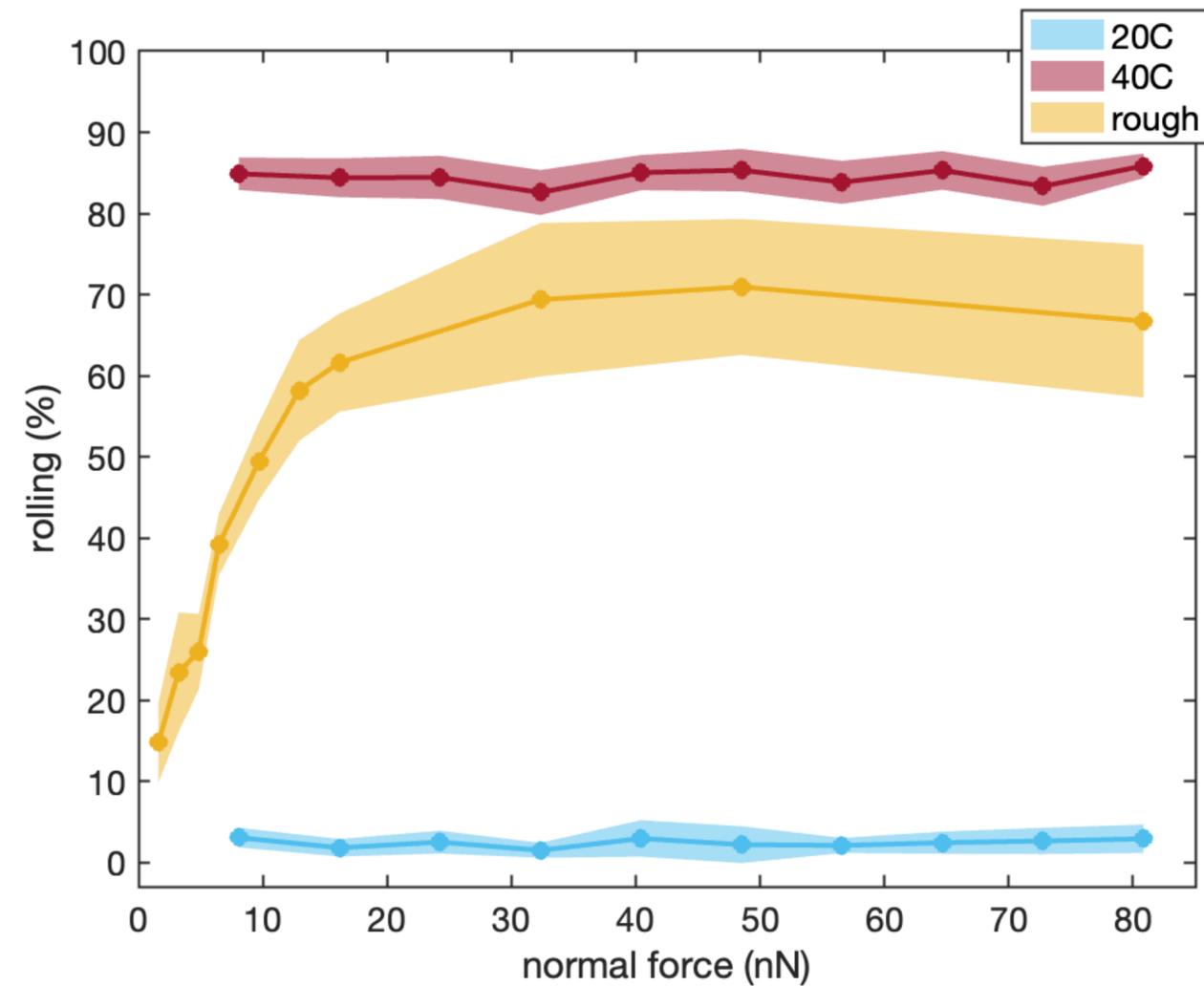
LATERAL FORCE
MICROSCOPY
✓



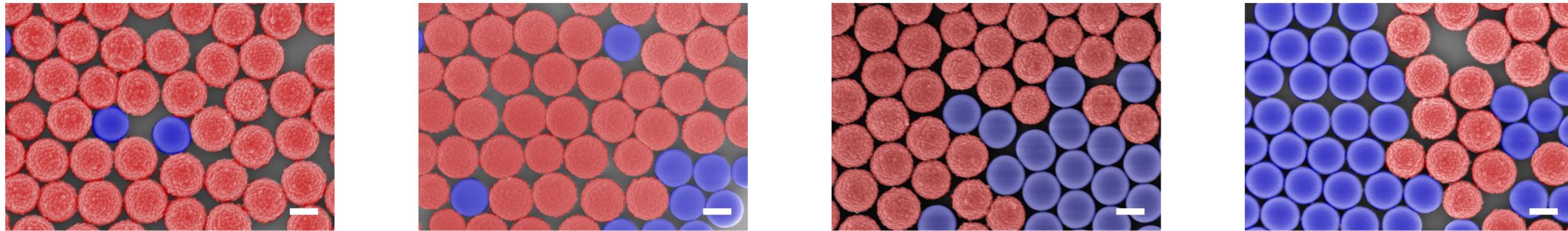
ROLLING CONTACT ✓



TRACTION TO ENABLE ROLLING

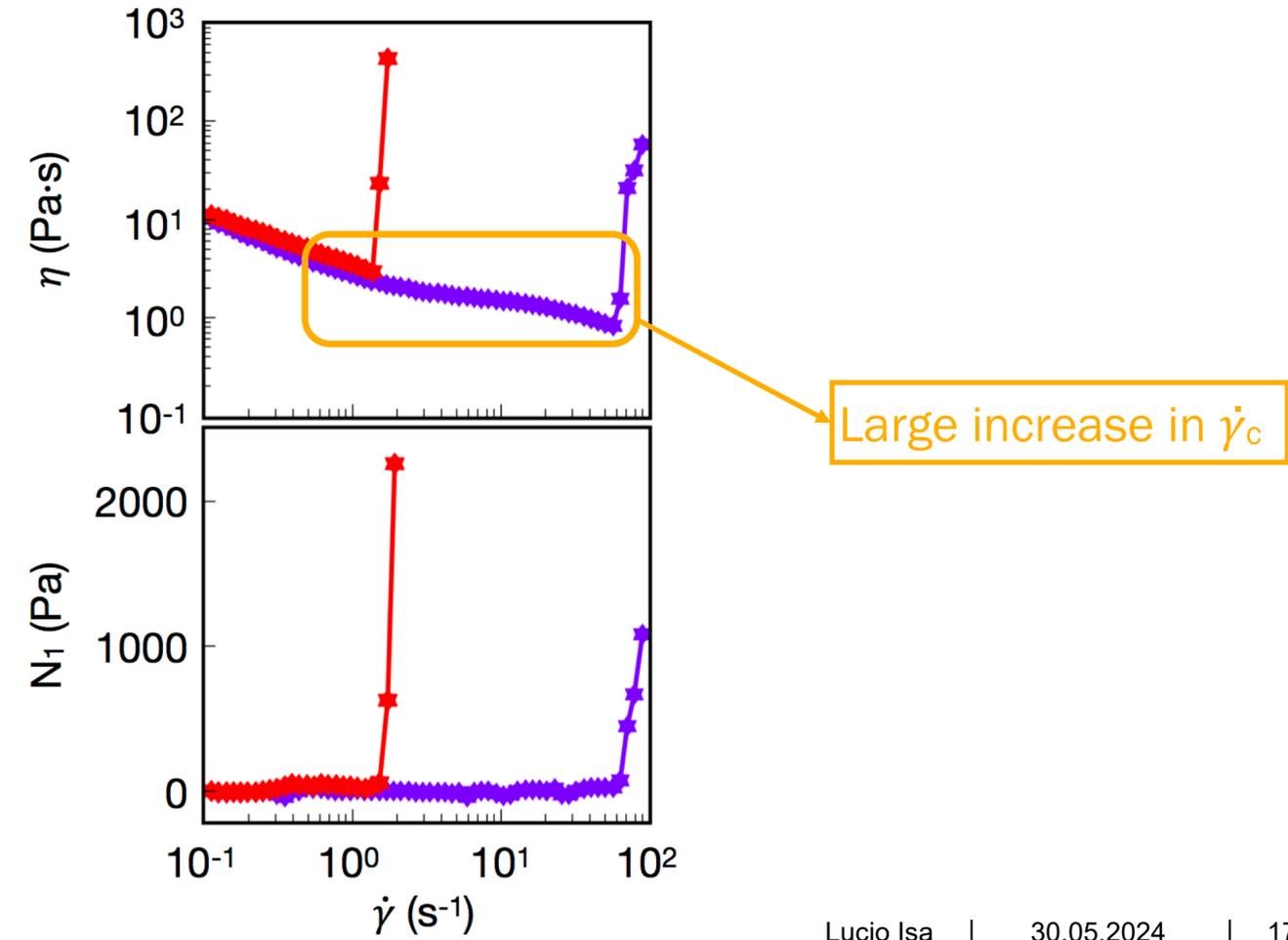
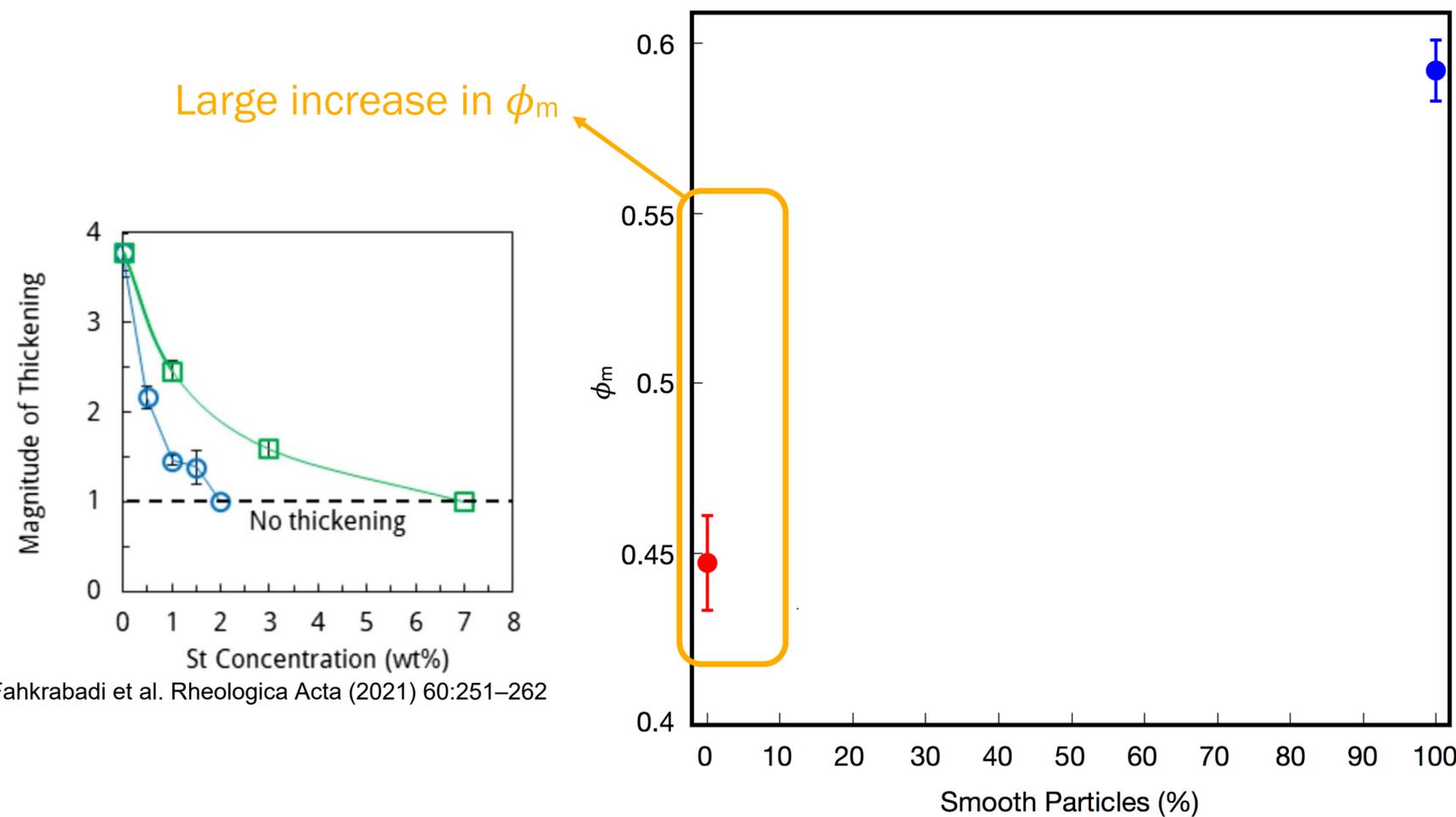


Friction between particles



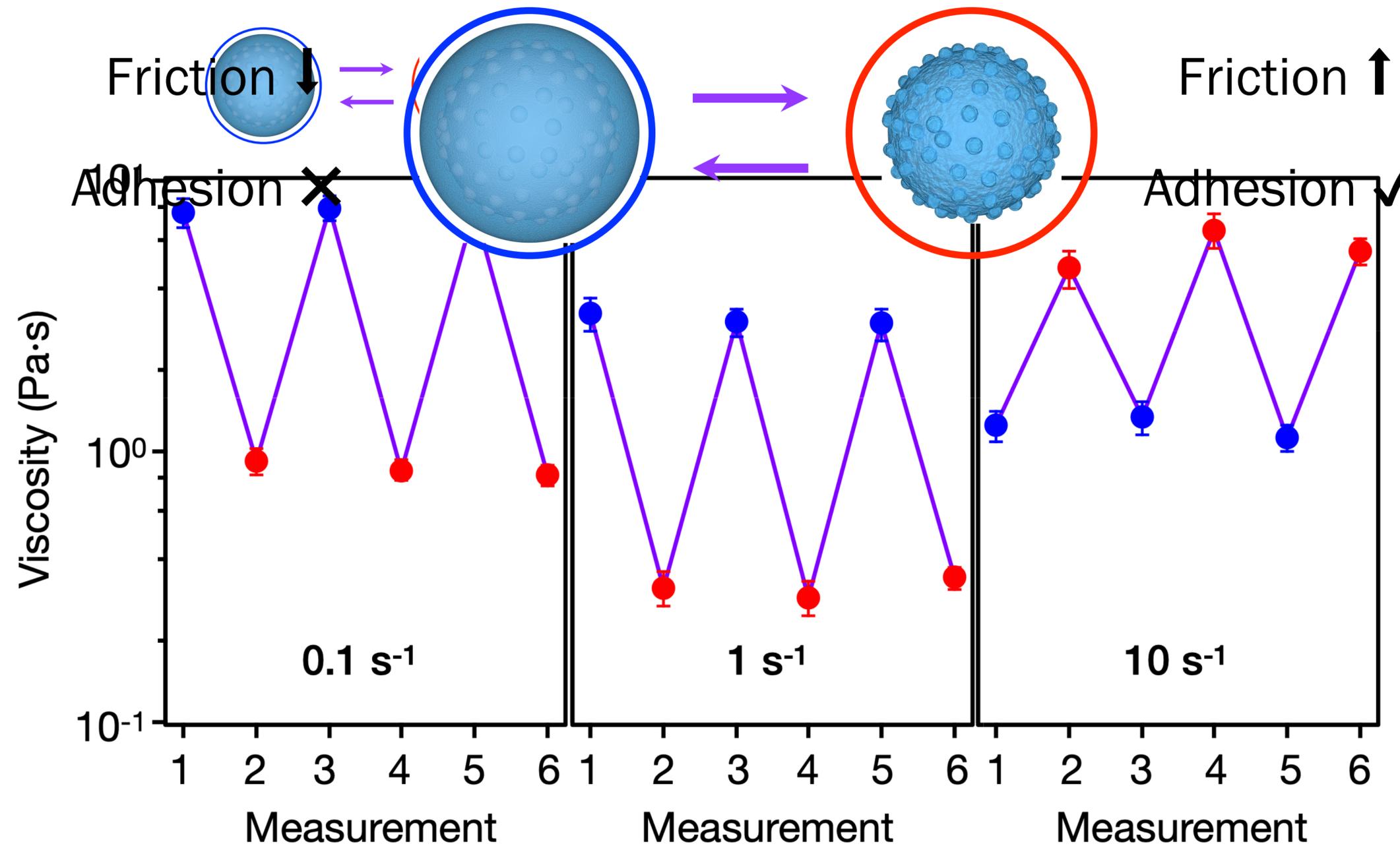
Scale bars = 500 nm

Vol% of smooth particles



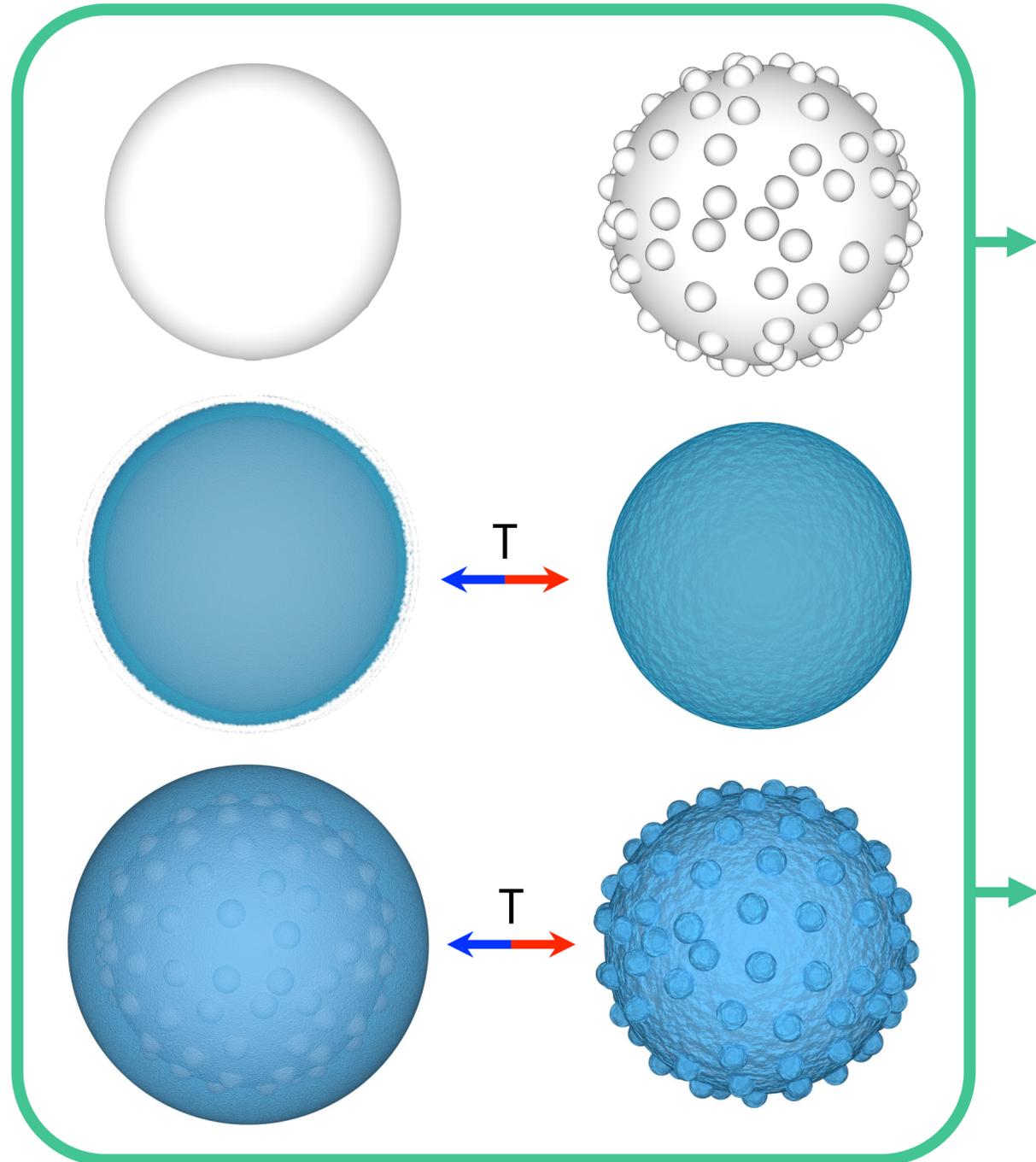
Fahkrabadi et al. Rheologica Acta (2021) 60:251–262

C. P. Hsu et al., PNAS 115, (2018).

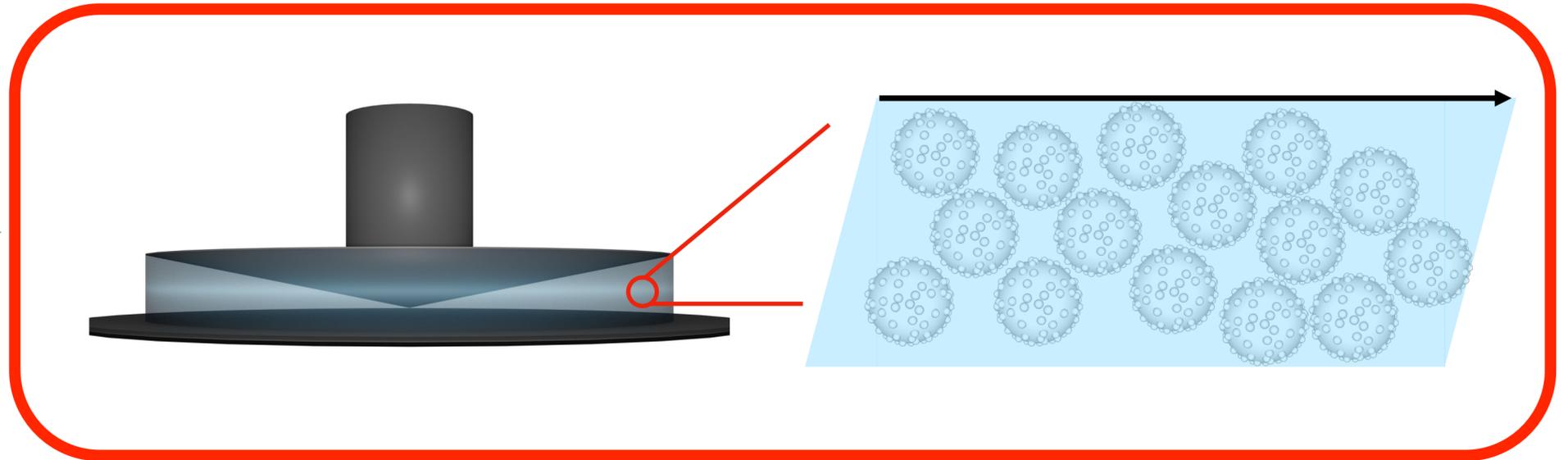


ENGINEER CONTACTS TO
ENGINEER RHEOLOGY

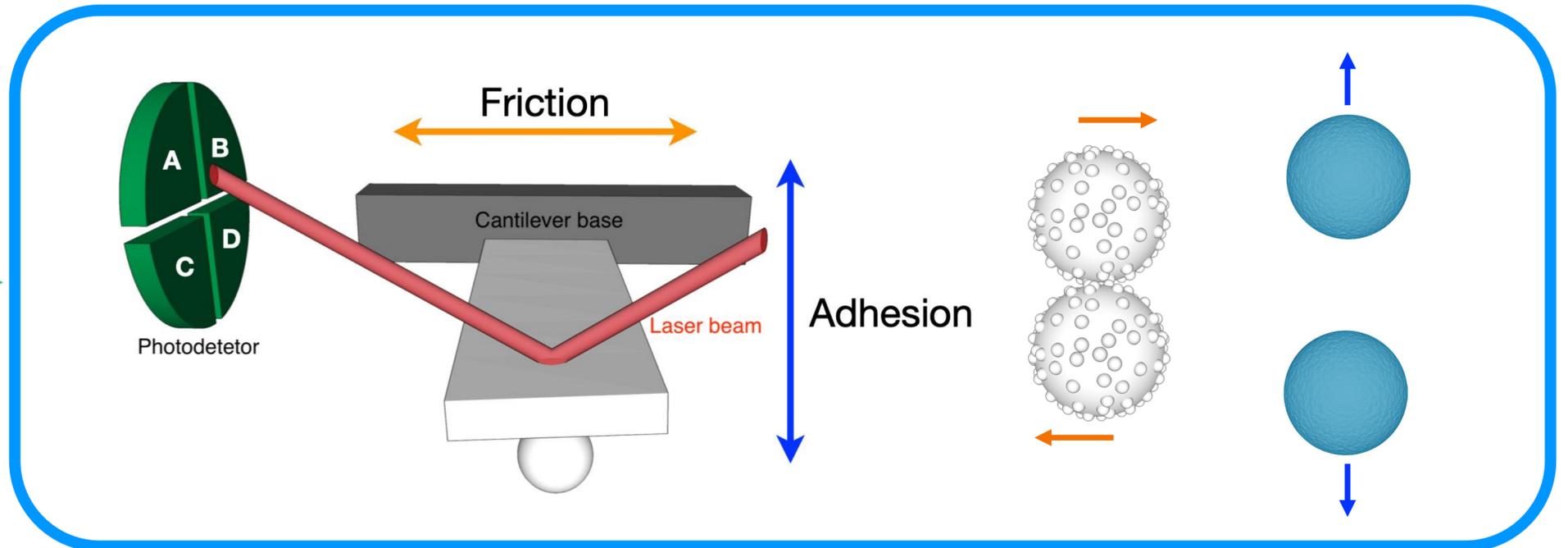
Colloidal Model Systems



Macroscopic Rheology



Nanotribological Contacts



- Case studies?

Outlook

- Elucidate the role of non-central forces in dense particulate suspensions
- Develop new tools to measure contact forces in realistic shear conditions
- Connect micro and macroscopic friction, and adhesion data to rheology
- Propose additives and sustainable solutions as rheology modifiers based on contact engineering
- Design rheology based on contact engineering



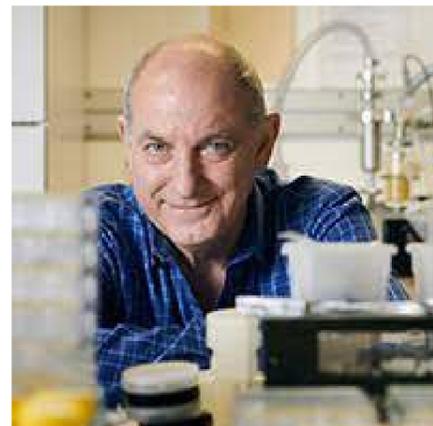
J. VERMANT



C-P. HSU



S. RAMAKRISHNA



N. SPENCER



S. SCHERRER

F. MÜLLER

V. NIGGEL