Tribology in Dry Granular Systems

T. Pöschel

FAU Erlangen-Nürnberg

tribology

- friction
- lubrication
- wear
- ...

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geology: granular lubrificatioon

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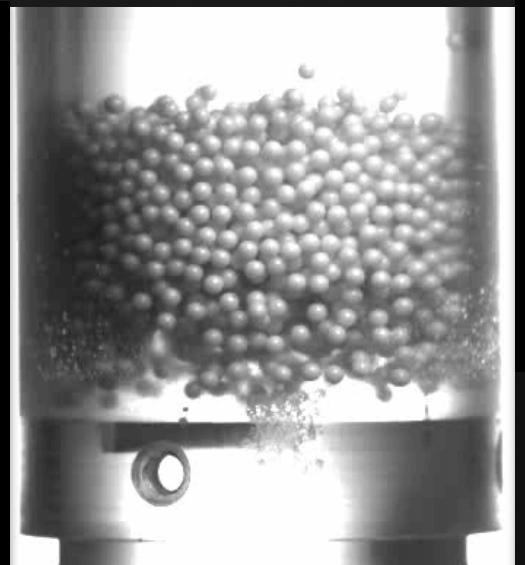

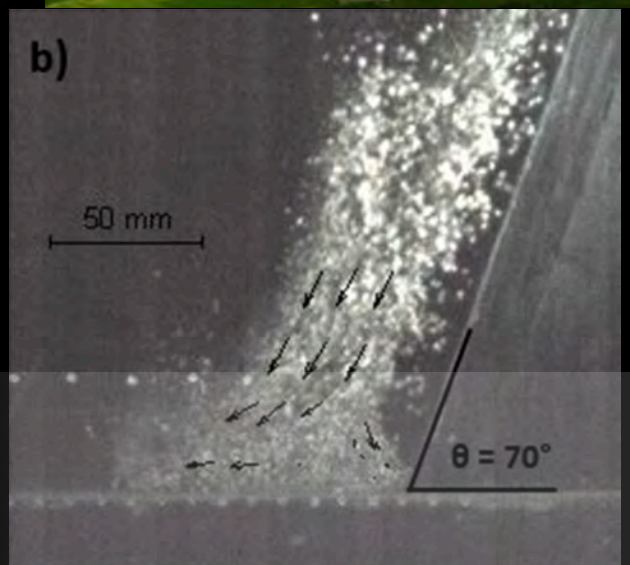

geology: granular lubrificatioon

idea: cushion of granular gas

shear induces (granular) temperature
soil supported by pressure (normal stress)
gas: no shear stress ➔ lubrification

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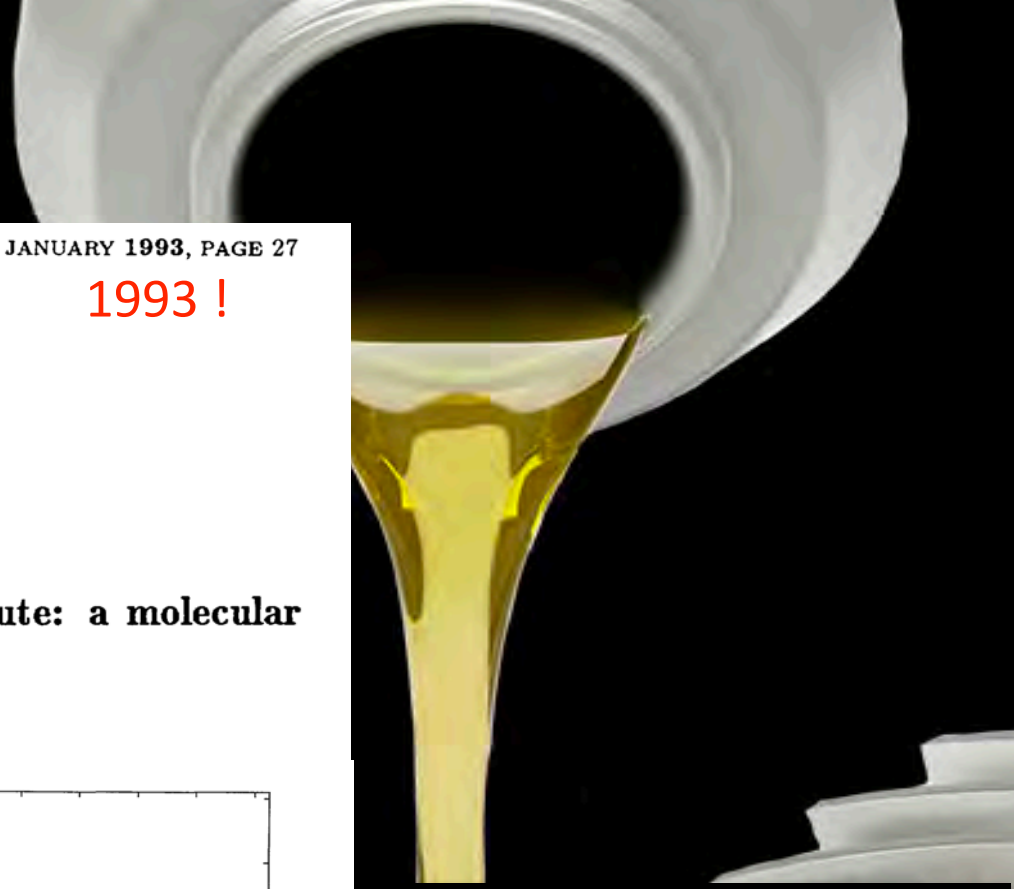


J. Phys. II France **3** (1993) 27–40

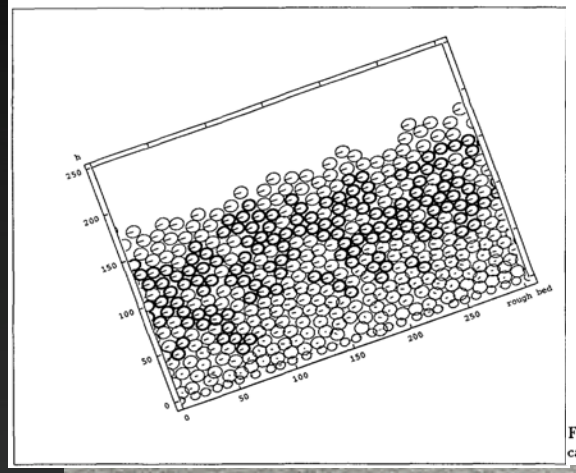
JANUARY **1993**, PAGE 27

1993 !

Classification
Physics Abstracts
05.60 — 46.10 — 02.60

Granular material flowing down an inclined chute: a molecular dynamics simulation

Thorsten Pöschel



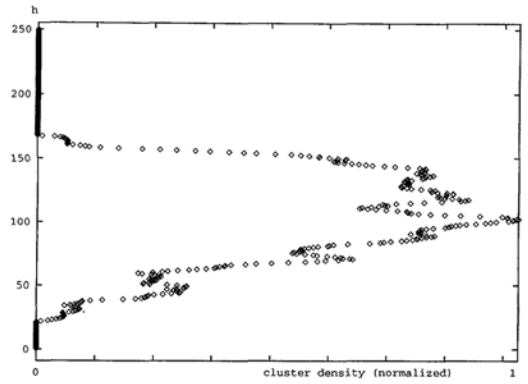


Fig.16. — Cluster density. There is a zone of significant higher cluster density. This region will be called block gliding zone.

Bryant '13

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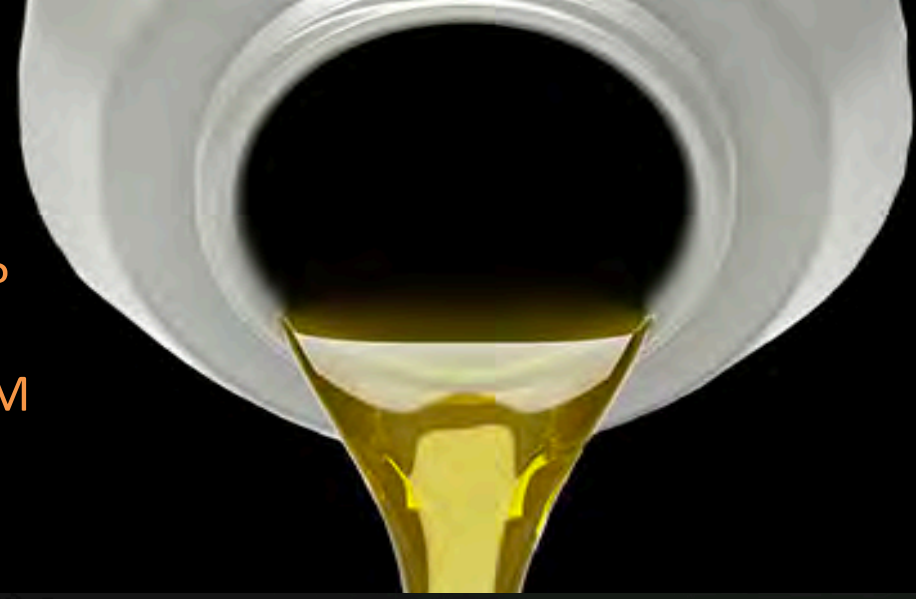
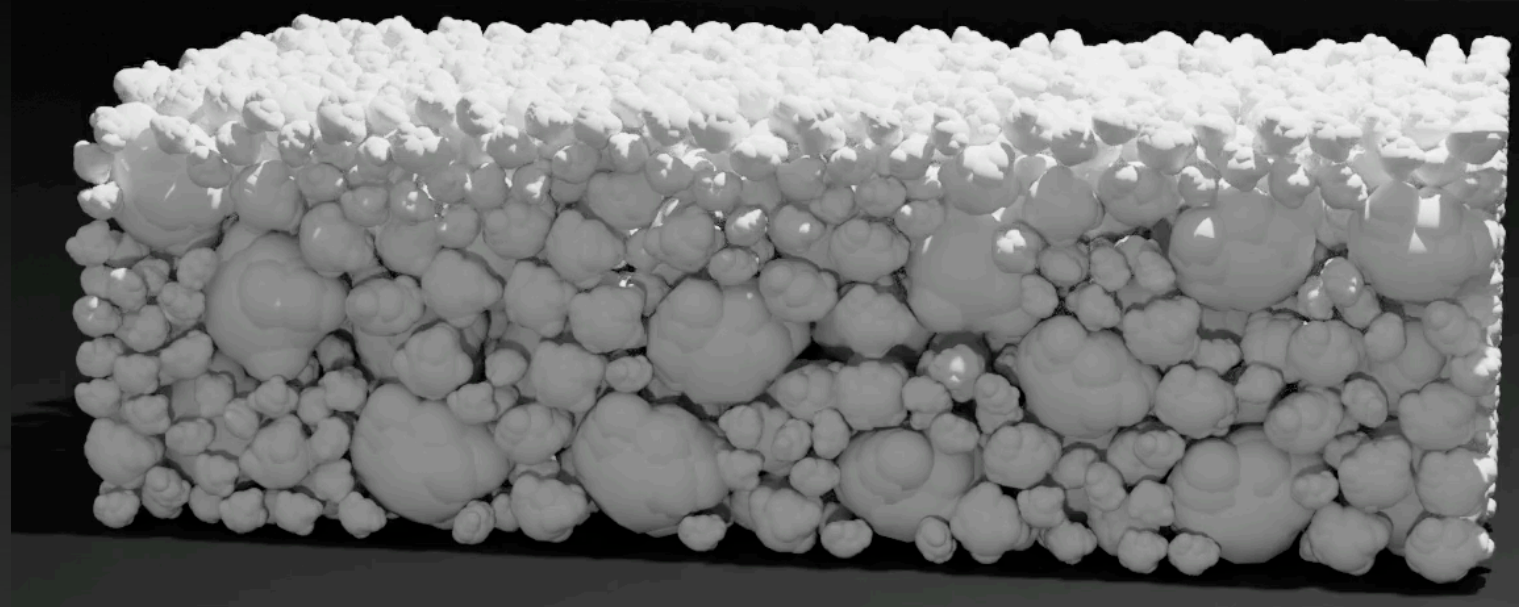
What is tribology in granular systems?

macroscopic bodies ➔ friction ➔ DEM



tribology

- friction
- lubrication
- wear
- ...



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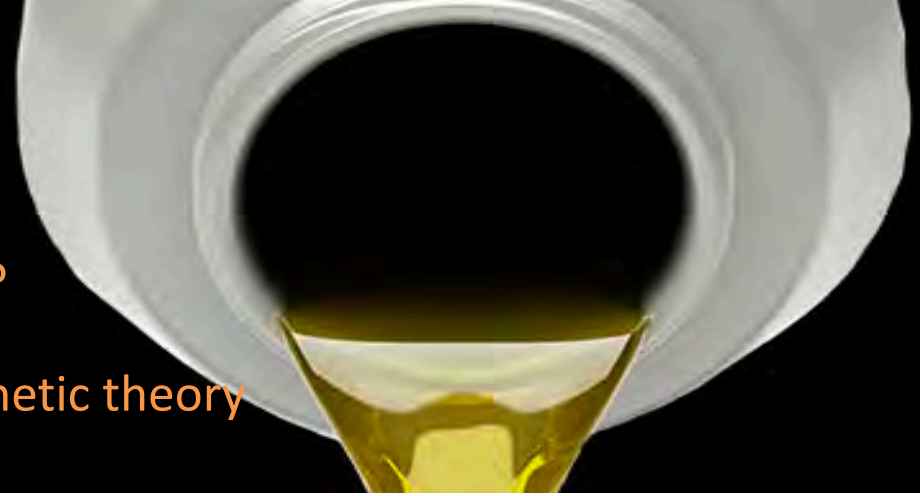
Tribology in Dry Granular Systems

T. Pöschel
FAU Erlangen-Nürnberg



What is tribology in granular systems?

dilute systems ➔ granular gases ➔ kinetic theory

tribology

- friction
- lubrication
- wear
- ...

Annu. Rev. Fluid Mech. 2003. 35:267–93
doi: 10.1146/annurev.fluid.35.101101.161114

RAPID GRANULAR FLOWS

Isaac Goldhirsch

Tribology in Dry Granular Systems

T. Pöschel
FAU Erlangen-Nürnberg

tribology

- friction
- lubrication
- wear
- ...

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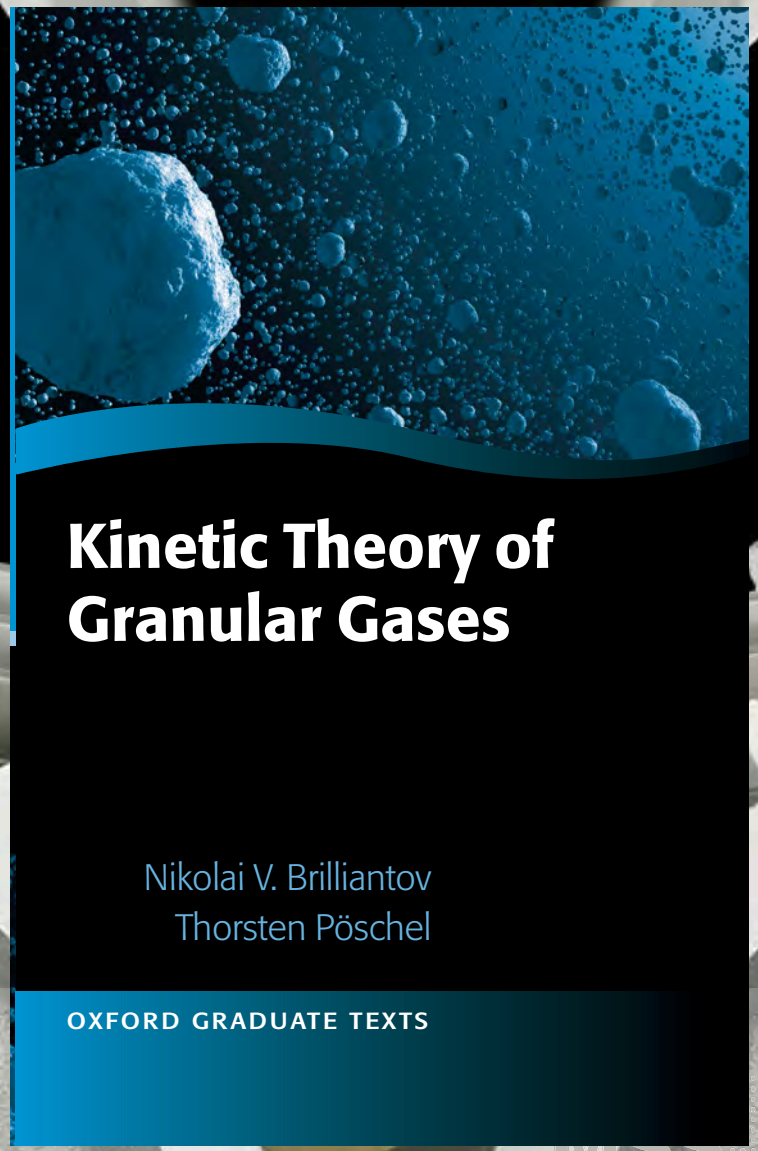

Tribology in Dry Granular Systems

T. Pöschel
FAU Erlangen-Nürnberg

tribology

- friction
- lubrication
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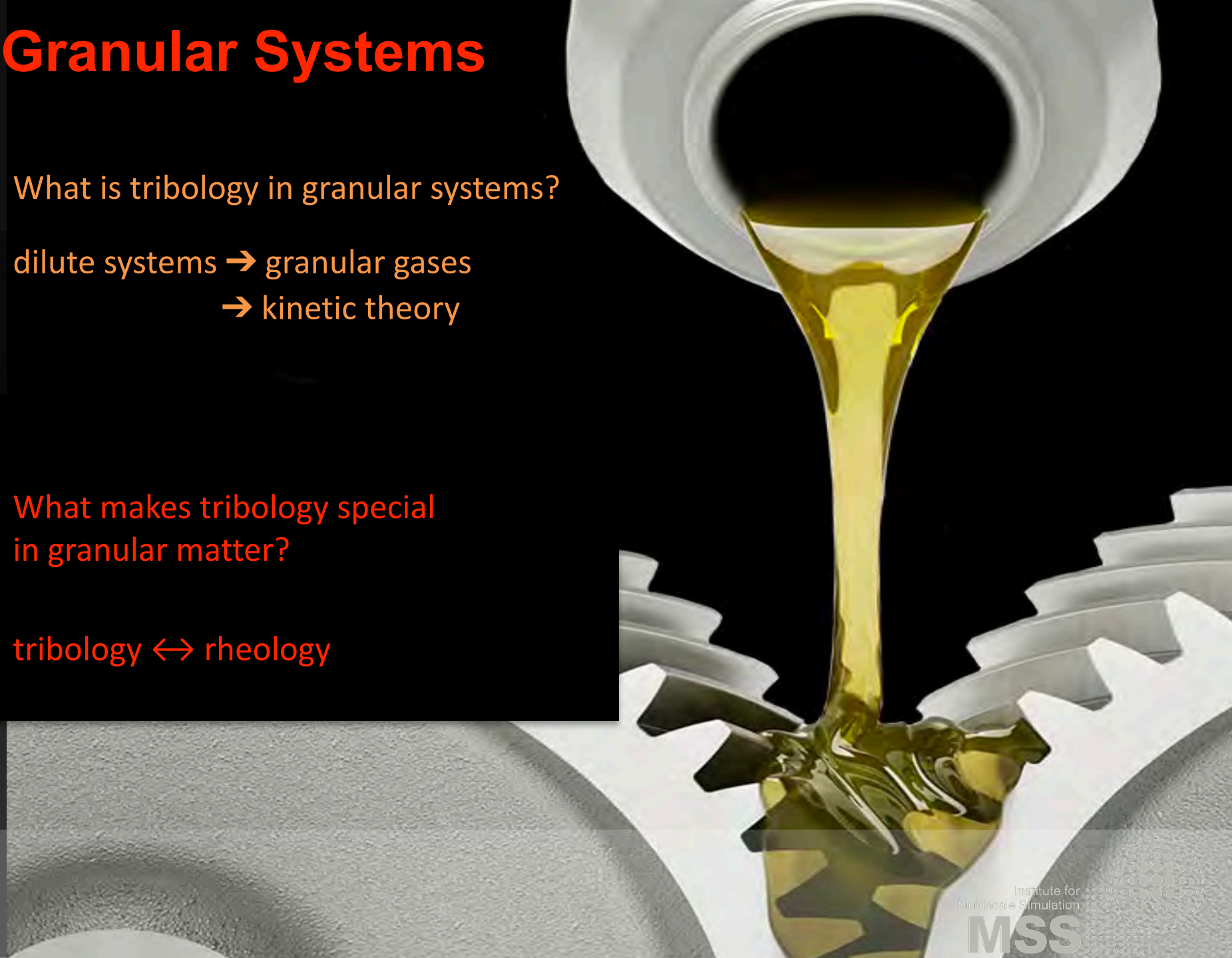
- …

What is tribology in granular systems?

dilute systems ➔ granular gases
➔ kinetic theory

What makes tribology special
in granular matter?

tribology ↔ rheology



Tribology and Flow in Dry Granular Systems

T. Pöschel

FAU Erlangen-Nürnberg

outline:

- large-scale anisotropy and non-local interaction due to history of the system (jamming)
- viscoelastic ↔ plastic
- fragmentation

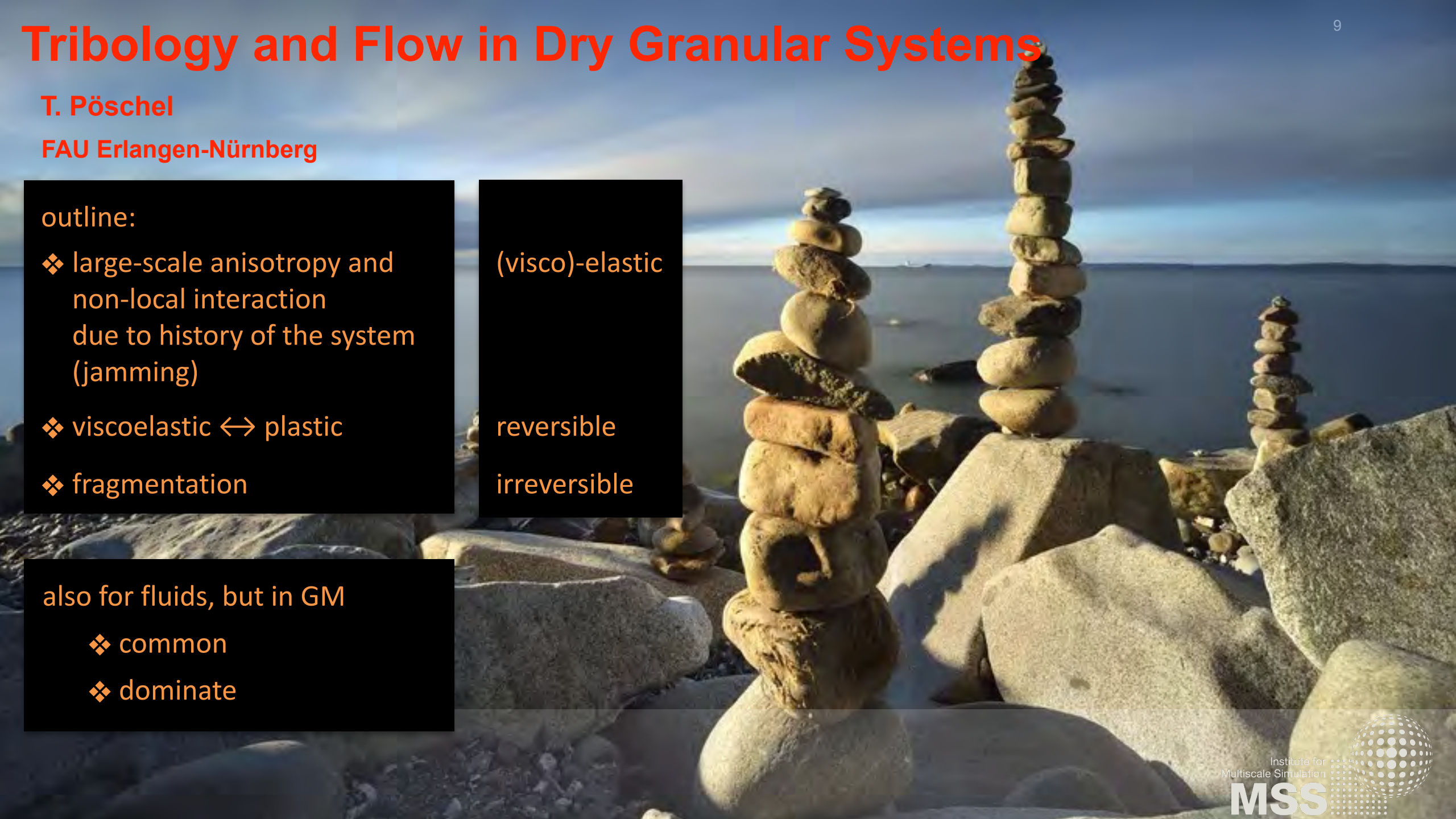
(visco)-elastic

reversible

irreversible

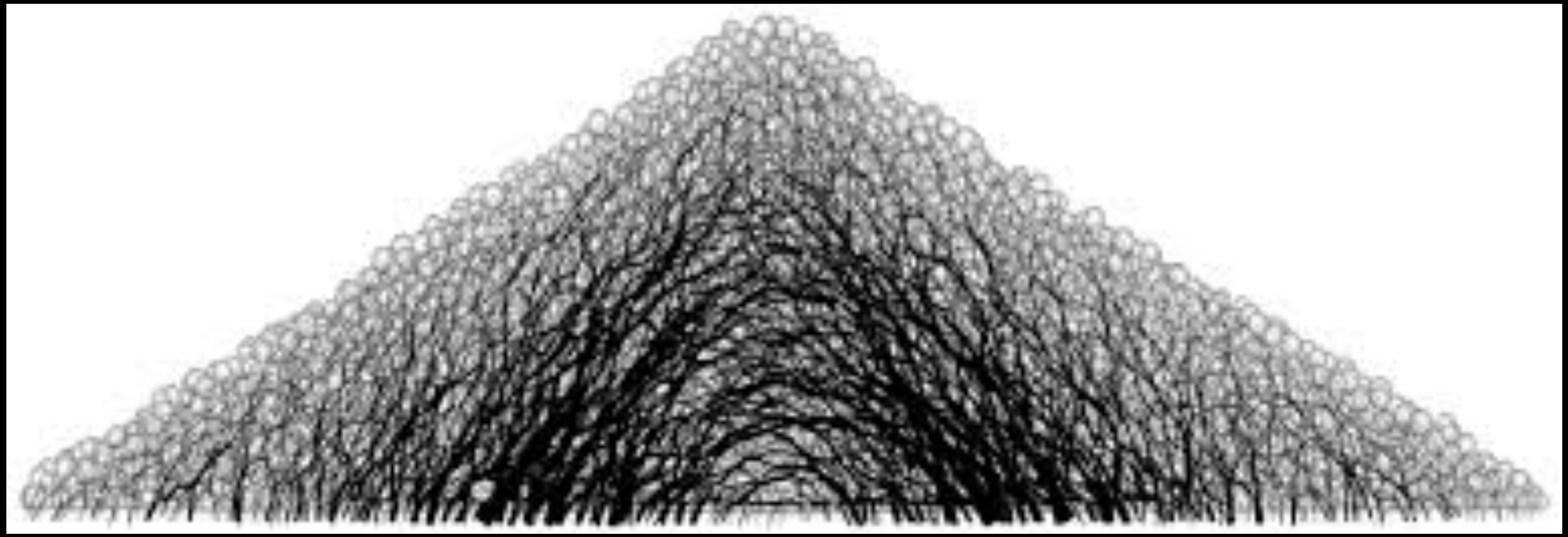
also for fluids, but in GM

- common
- dominate



large-scale anisotropy and non-local interaction due to history of the system

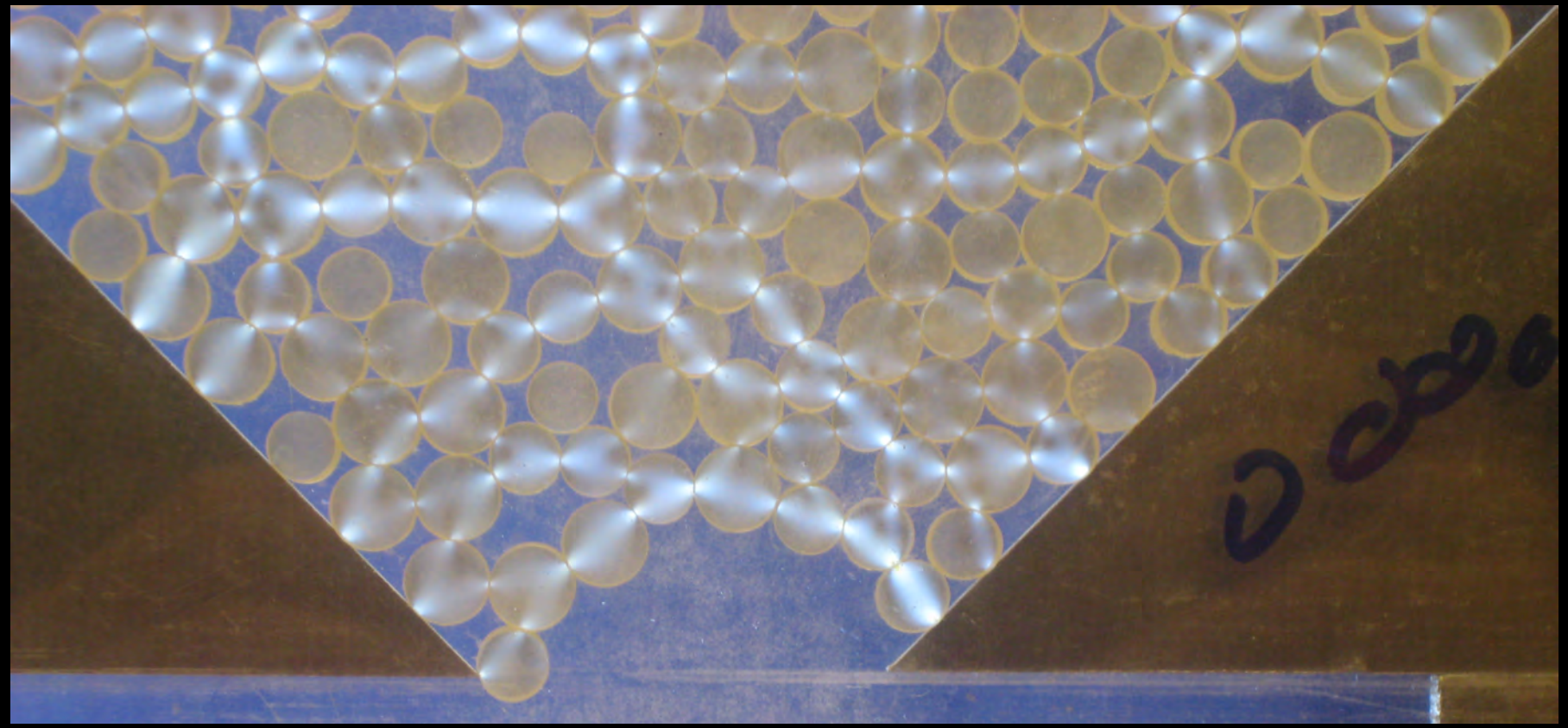
force chains



Nadukuru’12

large-scale anisotropy and non-local interaction due to history of the system

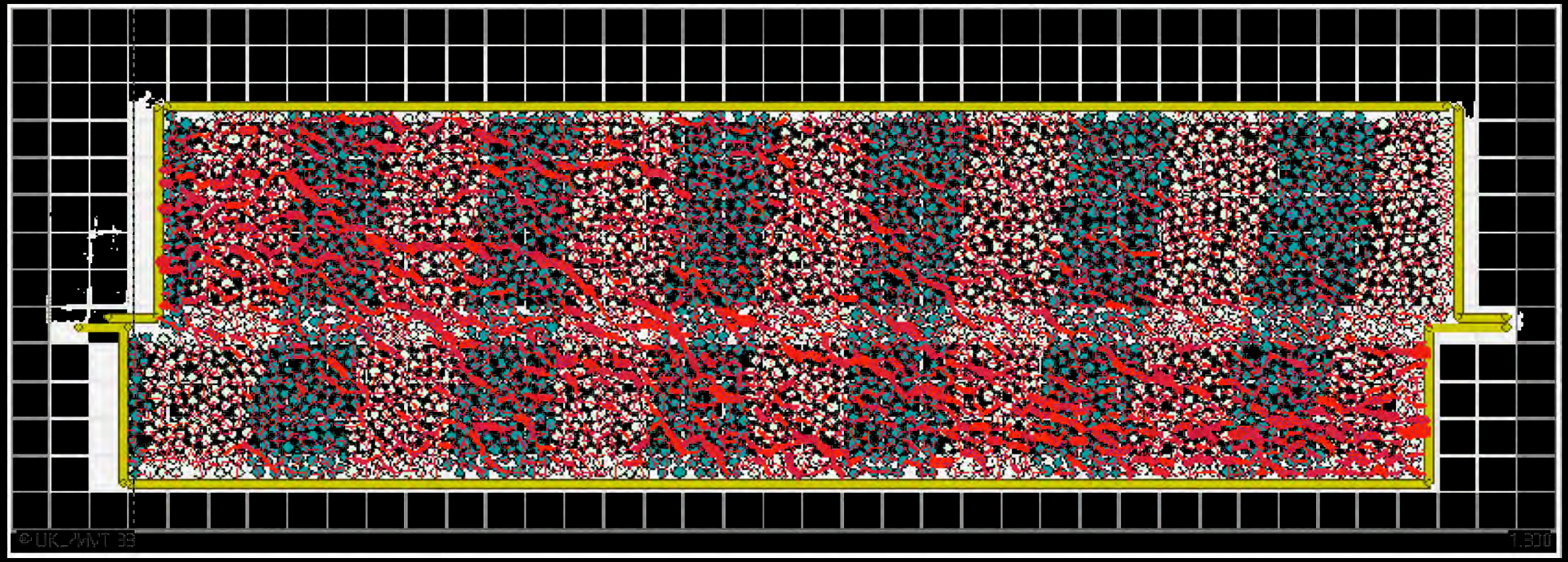
force chains



Tang'12

large-scale anisotropy and non-local interaction due to history of the system

force chains



large-scale anisotropy and non-local interaction due to history of the system

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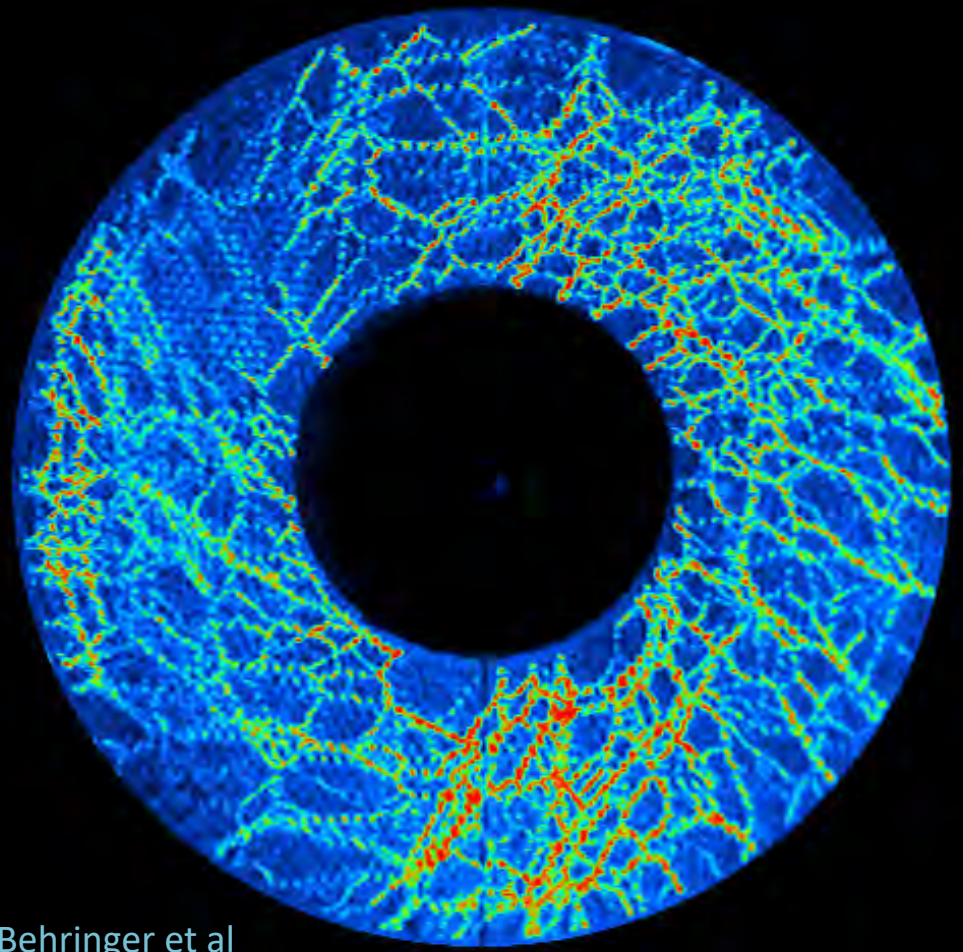
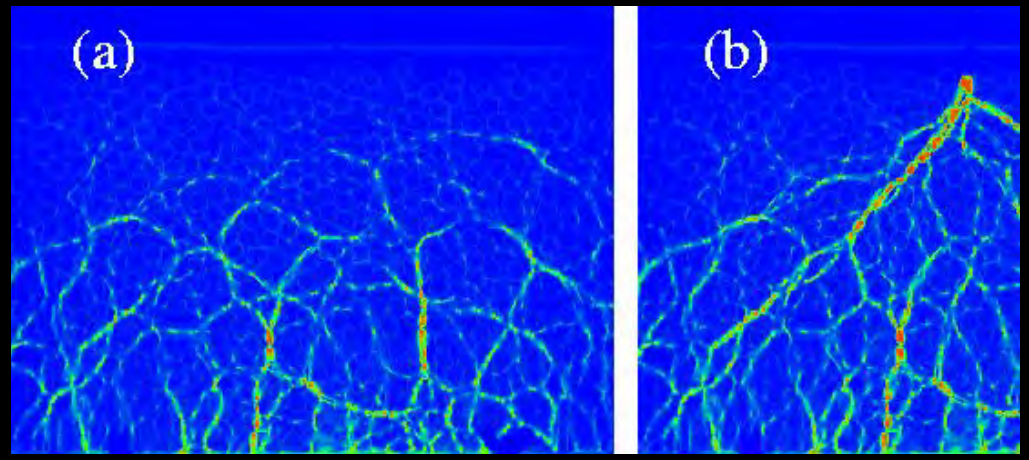


Behringer et al

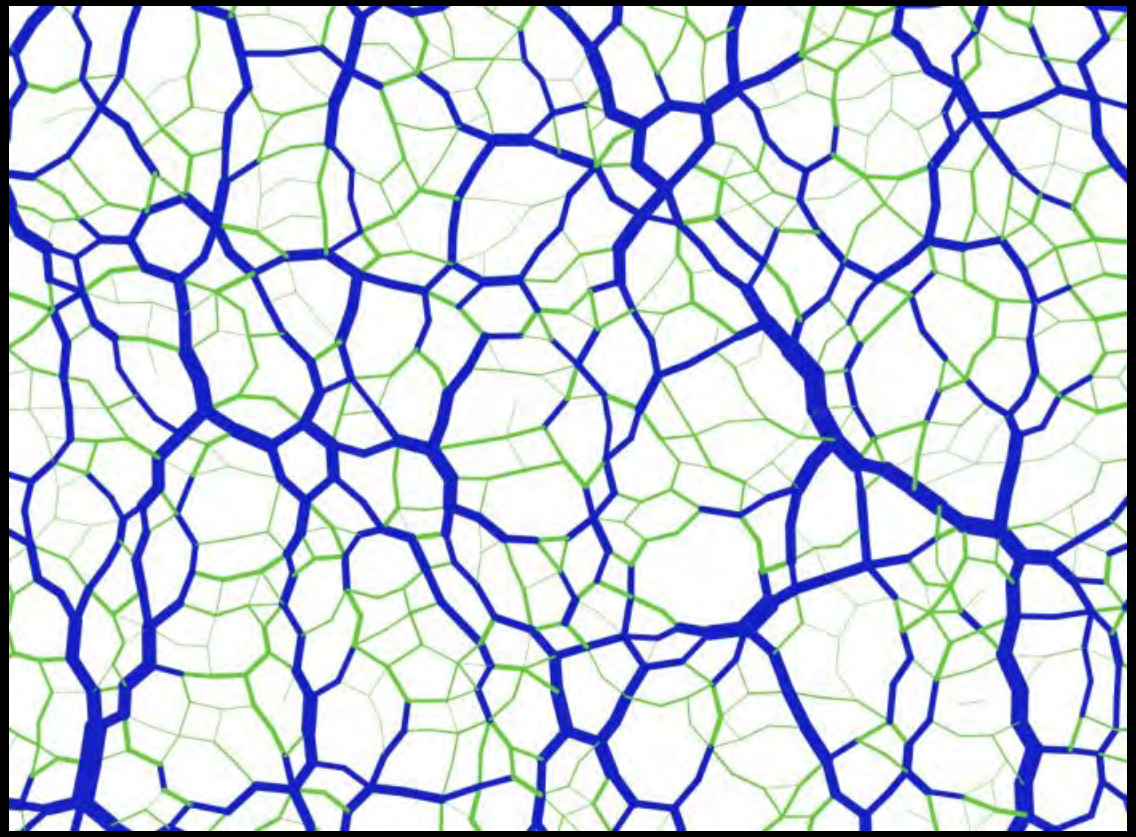


Behringer, Luding et al

Aste et al'01

large-scale anisotropy and non-local interaction due to history of the system

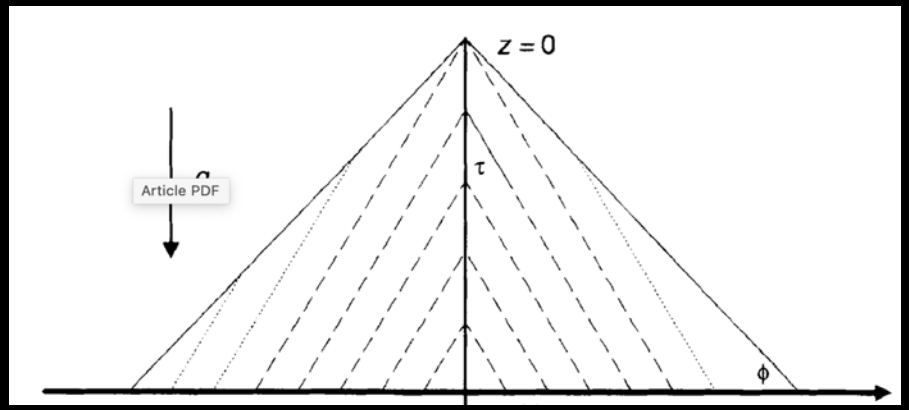
force chains



Radjai

statistics

theory - fixed principle axes



Wittmer, Cates et al'96

large-scale anisotropy and non-local interaction due to history of the system

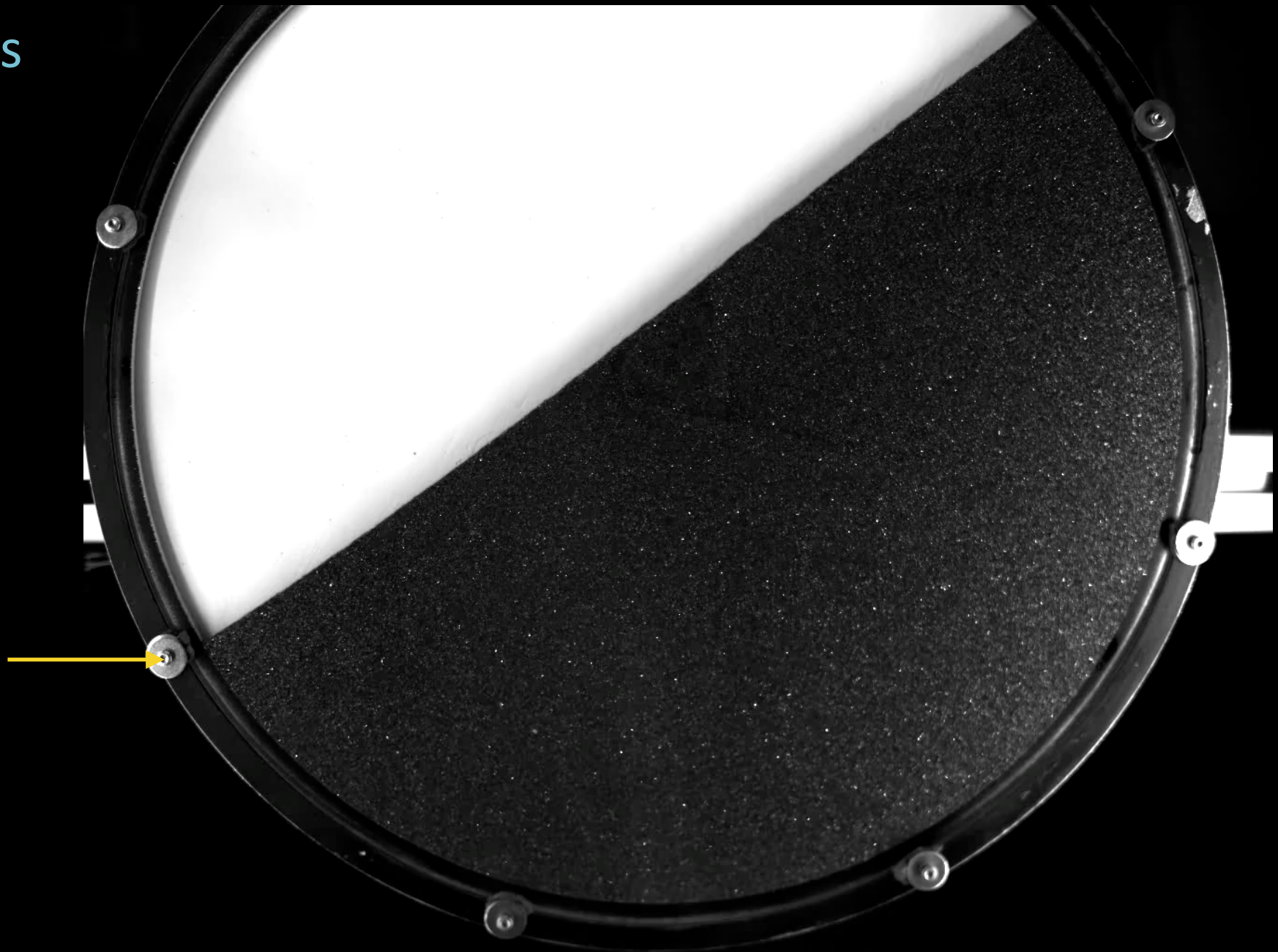
flow: dynamics

surface avalanches inflation-and-collapse regime S-shape flow

large-scale anisotropy and non-local interaction due to history of the system

flow: dynamics

no particle flow
in the bulk



large-scale anisotropy and non-local interaction due to history of the system

flow: dynamics

no particle flow
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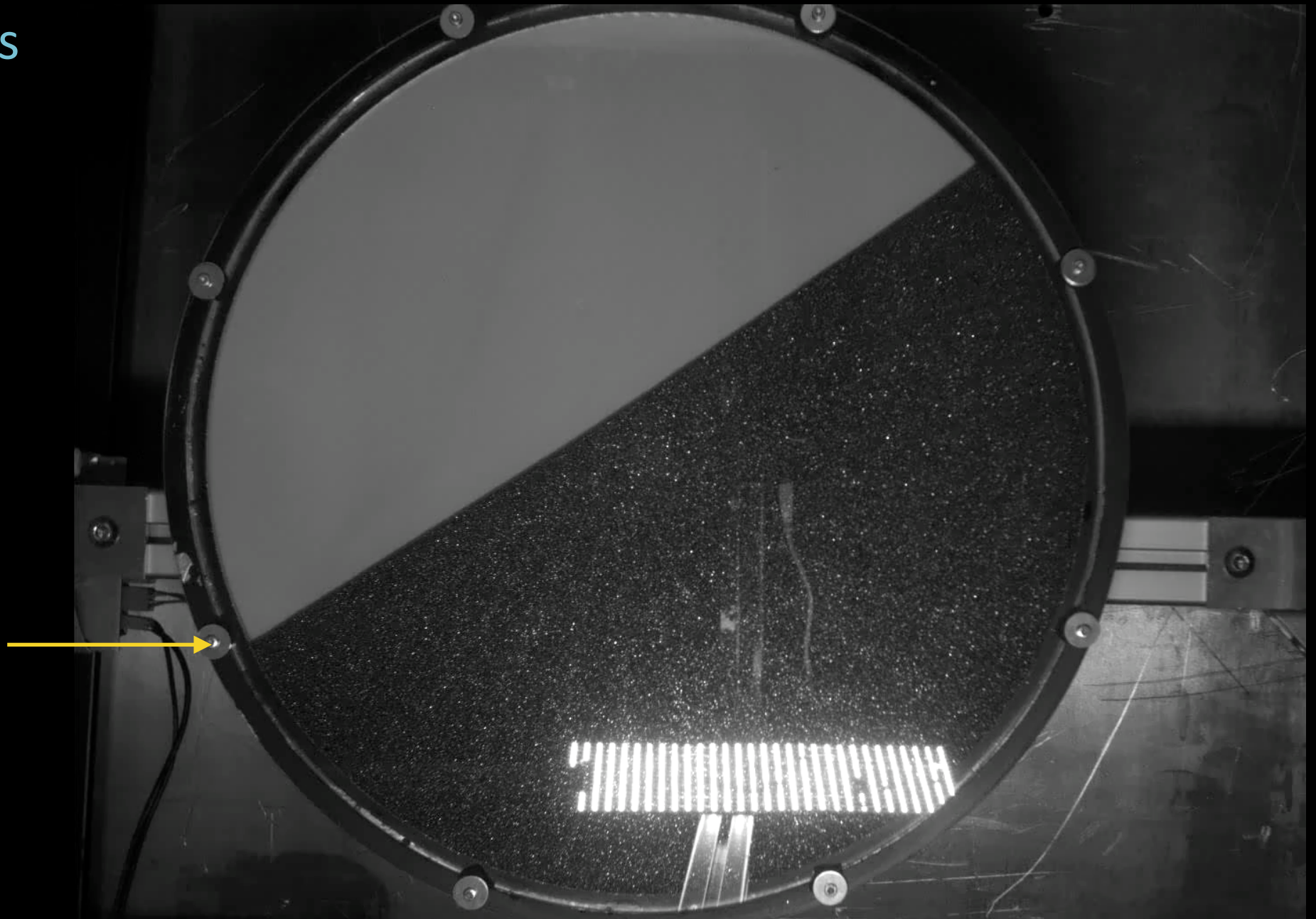
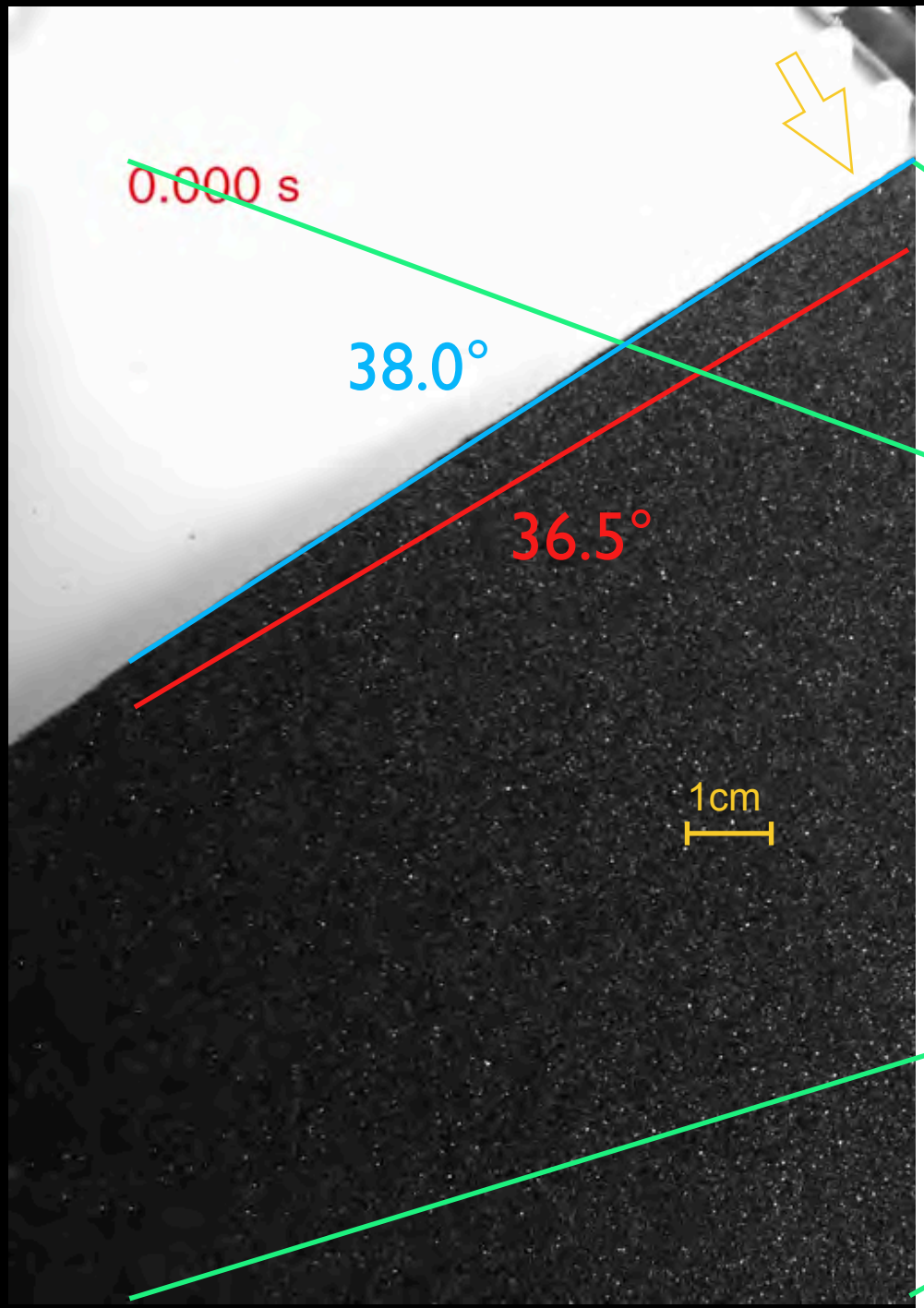
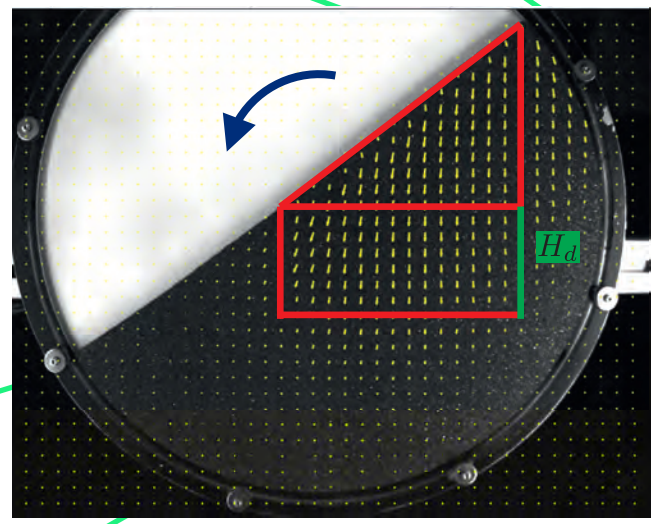


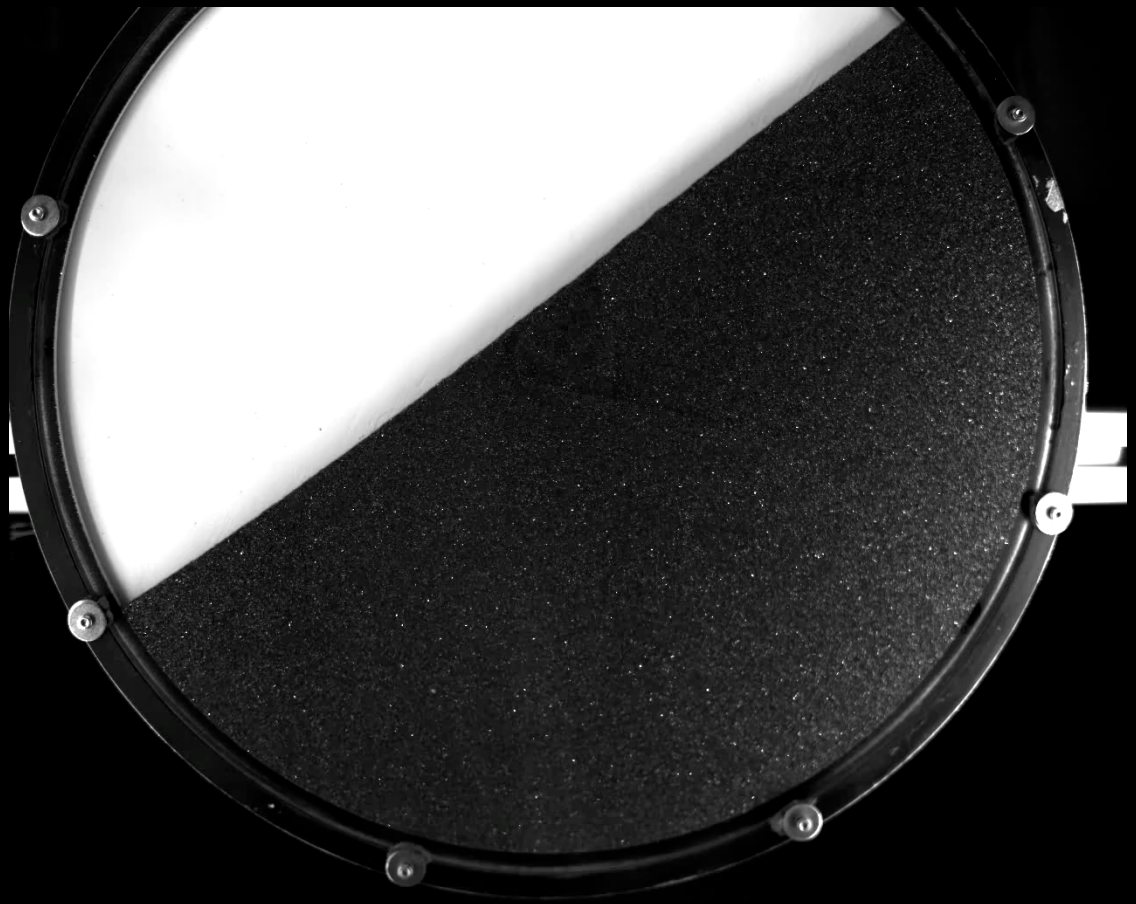


SiC Particles
125-150 μm



large-scale anisotropy and non-local interaction due to history of the system

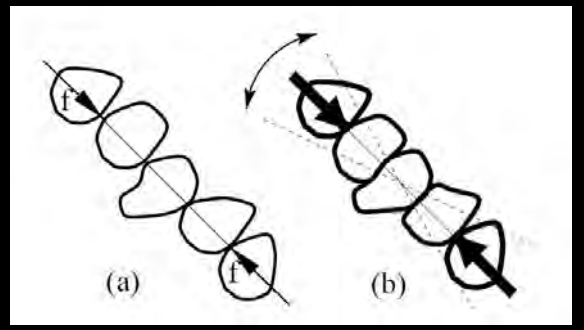
flow: dynamics

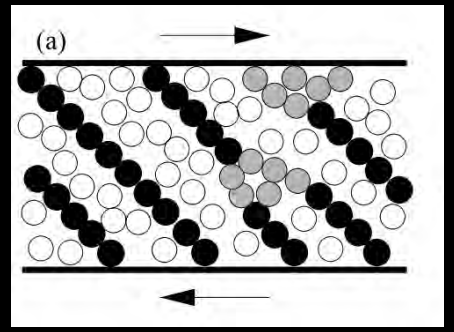


Zimber, Kollmer, TP'13

"fragile state" (Cates et al'98)

- elastic response to compatible loads
- plastic deformation if loaded incompatibly
- fragile state = special case of jammed state



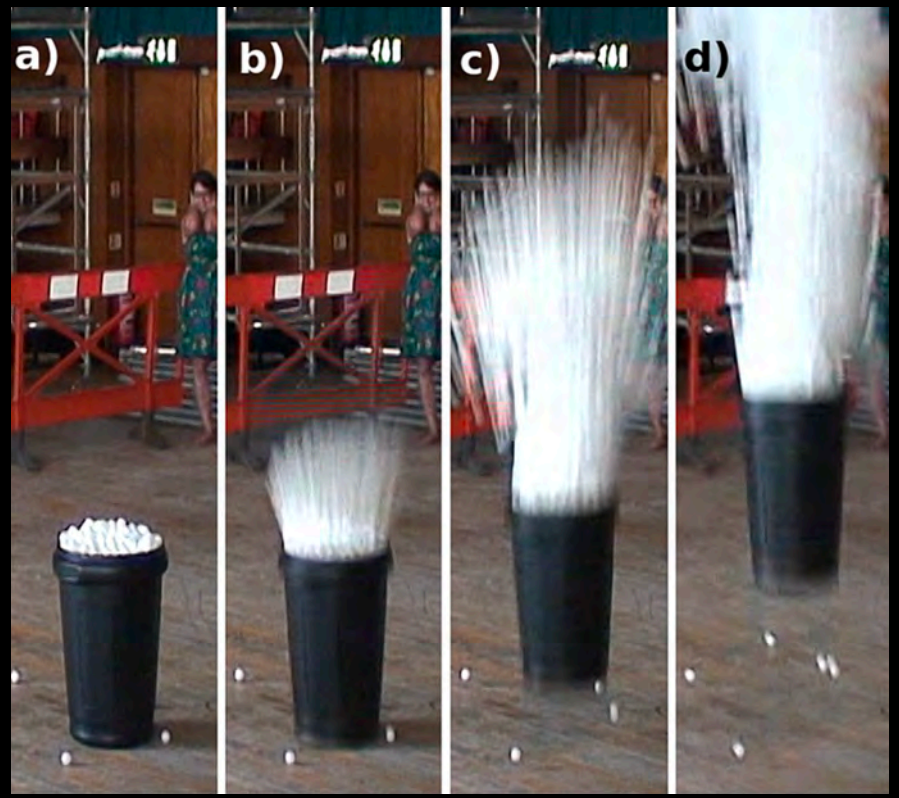


tribology ➔ non-locality ➔ rheology

large-scale anisotropy and non-local interaction due to history of the system

flow: dynamics

liquid nitrogen | in a closed bottle



Ping-pong ball cannon: Why do barrel and balls fly in the same direction?

Thorsten Pöschel and Daniel S. Nasato
Institute for Multiscale Simulations, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen 91058, Germany

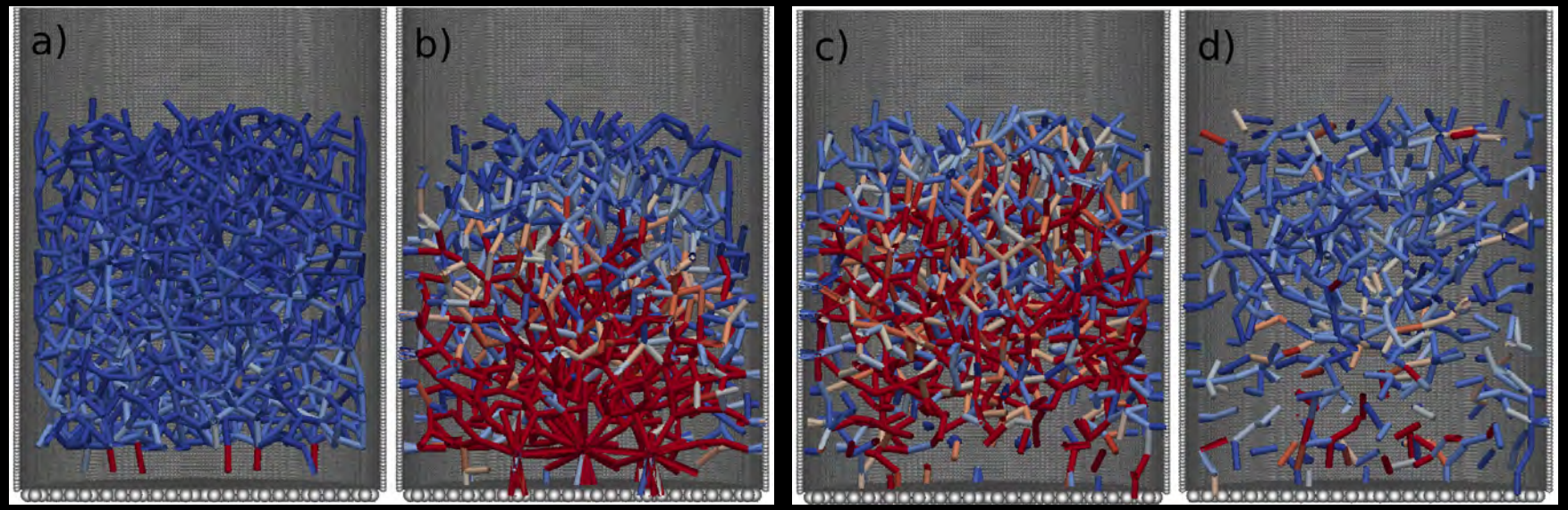
Lowry 2012, https://www.youtube.com/watch?v1⁄4mxwPfwwy878

large-scale anisotropy and non-local interaction due to history of the system

flow: dynamics

motion (dynamics) ➔ force chains ➔ large shear stress

➔ re-act creation mechanism



increase of volume (explosion)

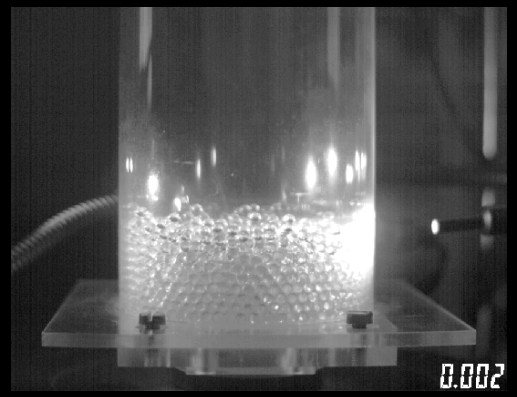
→ normal forces

→ shear forces (upward motion)

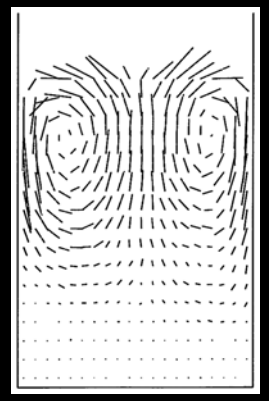
→ dilatation at the wall

large-scale anisotropy and non-local interaction due to history of the system

flow: dynamics: convection

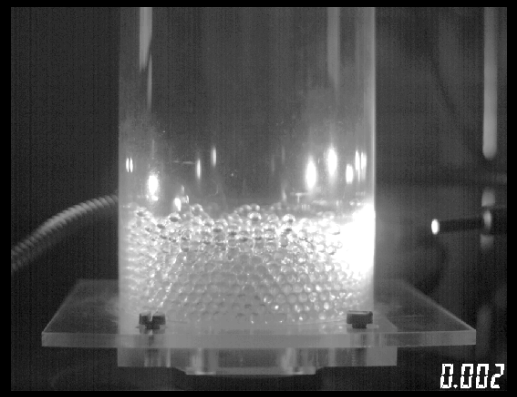


Krülle



large-scale anisotropy and non-local interaction due to history of the system

flow: dynamics: convection



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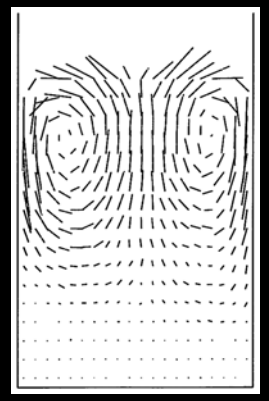
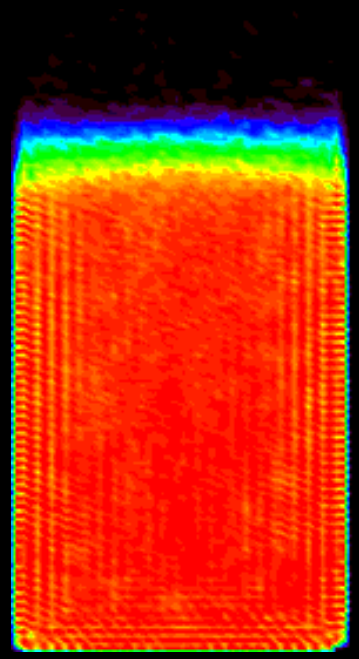
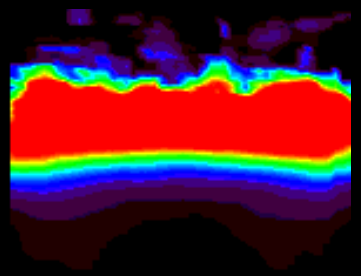


$$\ddot{z}(t) = A\cos(\omega t) > g$$

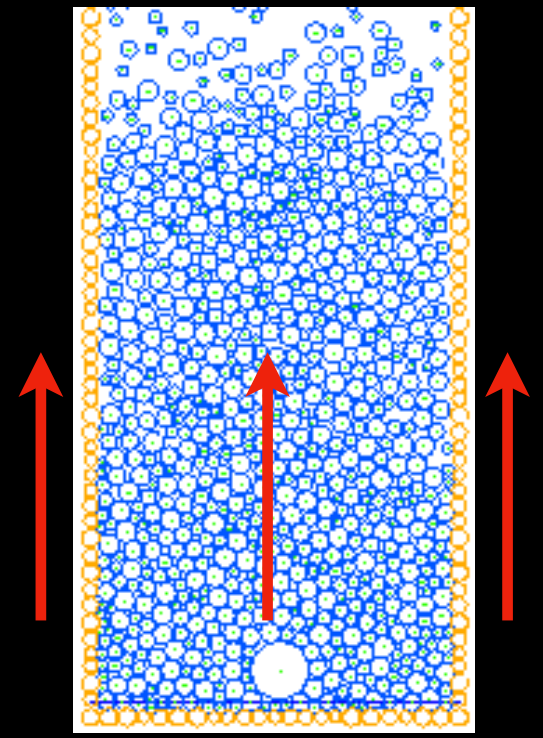


density



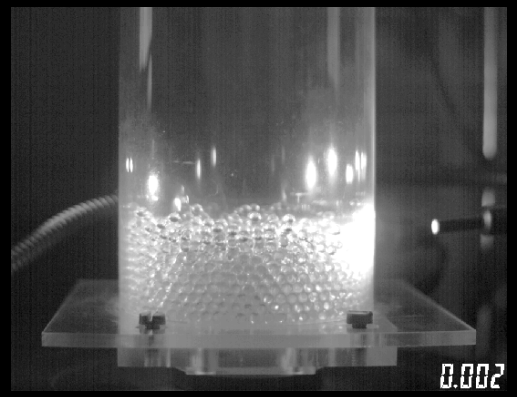
temperature

container and particles accelerated upward
→ container decelerates - sinus
→ shear → dilatation near wall



large-scale anisotropy and non-local interaction due to history of the system

flow: dynamics: convection



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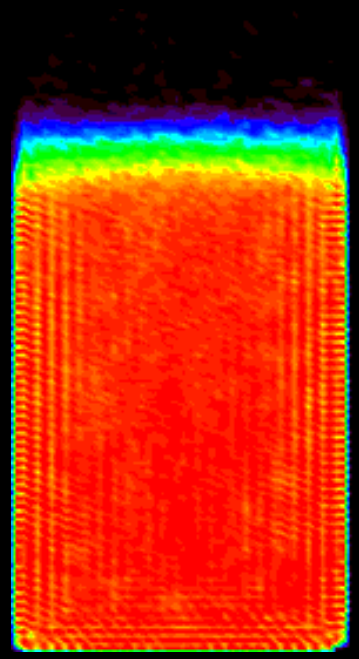

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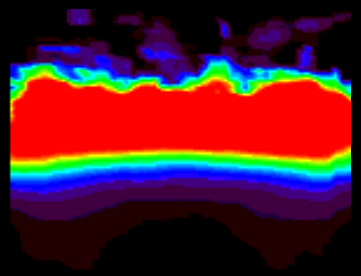
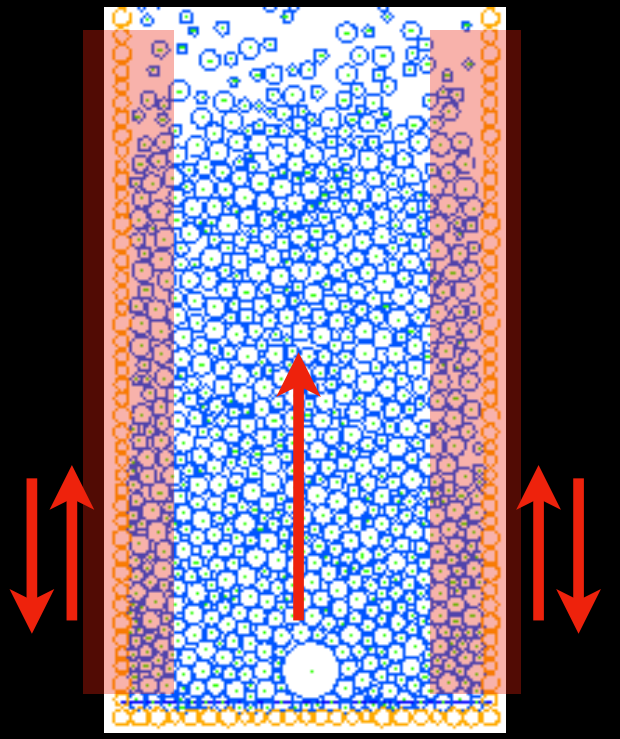


temperature

container and particles accelerated upward
→ container decelerates - sinus
→ jamming → shear → dilatation near wall
→ shock (=instantantaneous jamming)
→ shear stress (freezing)
→ CONVECTION

granular dynamics is
inherently supersonic

Esipov, TP' 97



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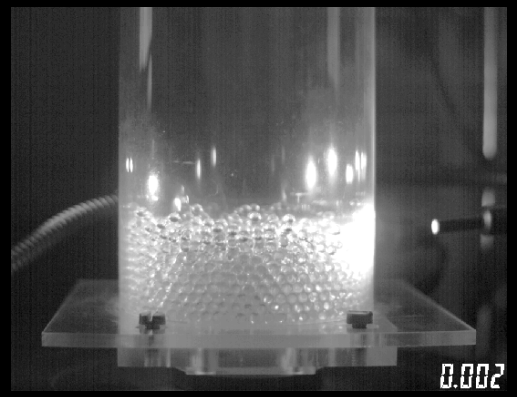

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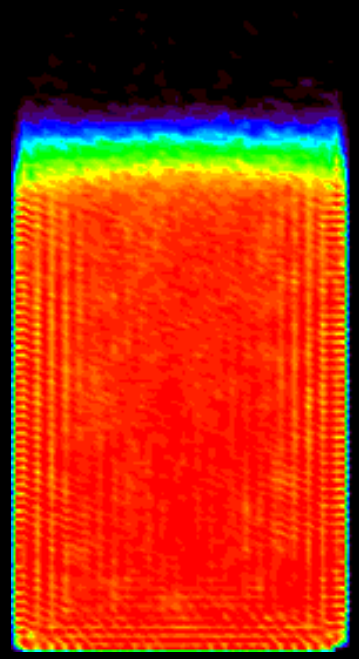

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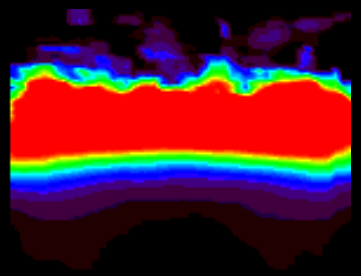

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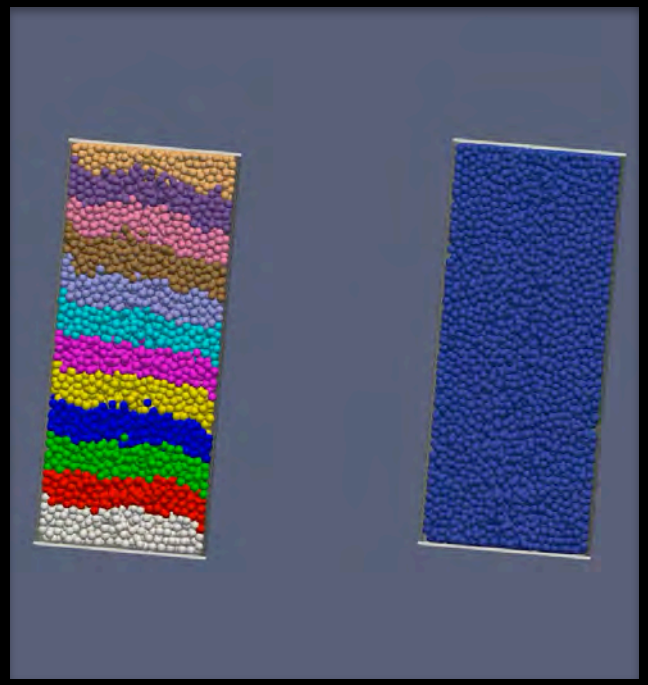

how important is this non-locality for the dynamics?

$$\ddot{z}(t) = A\cos(\omega t) > g$$

container and particles accelerated upward
→ container decelerates - sinus
→ jamming → shear → dilatation near wall
→ shock (=instantantaneous jamming)
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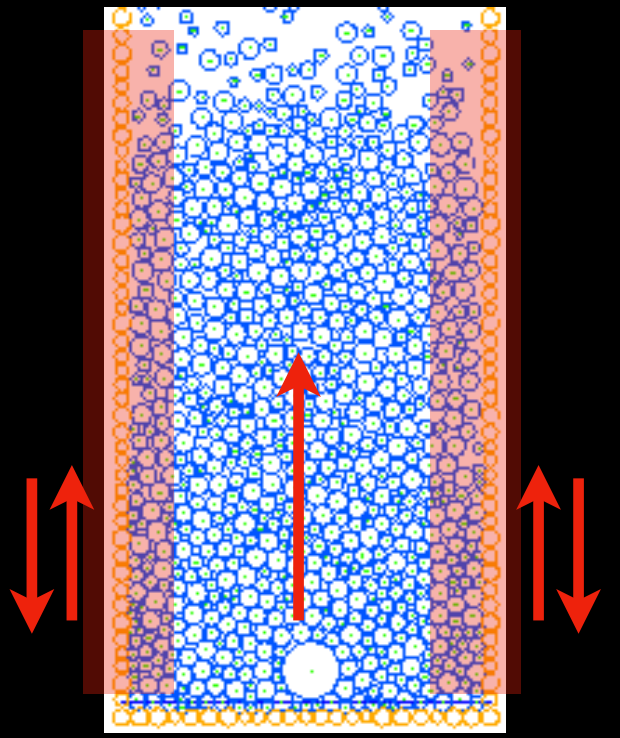
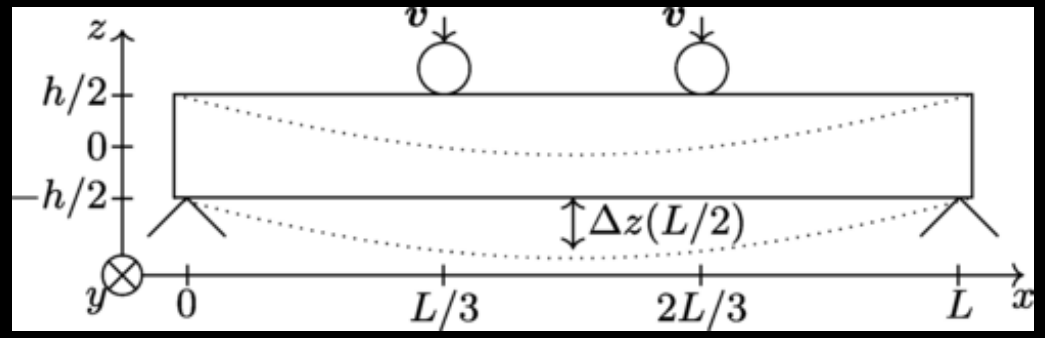
→ CONVECTION

granular dynamics is inherently supersonic

Esipov, TP' 97



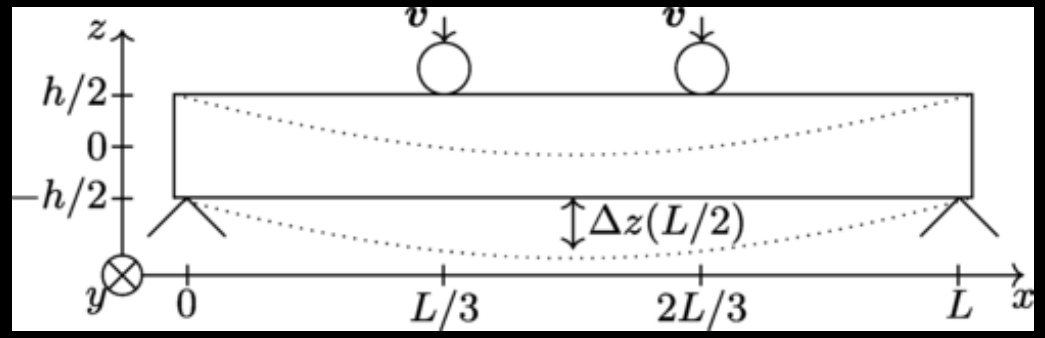
viscoelastic ➔ plastic transition: Granular meta-material



stress $\sigma = \dfrac{FL}{h^2 d}$ strain $\varepsilon = \Delta z \dfrac{108h}{23L^2}$

Götz, D'Angelo, TP'23

viscoelastic ➔ plastic transition: Granular meta-material



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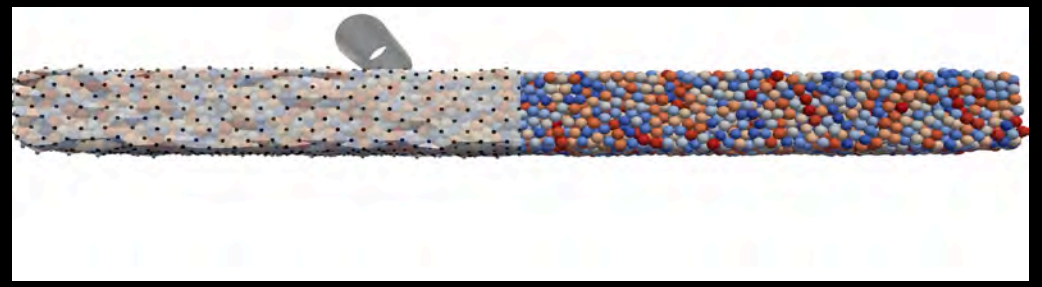
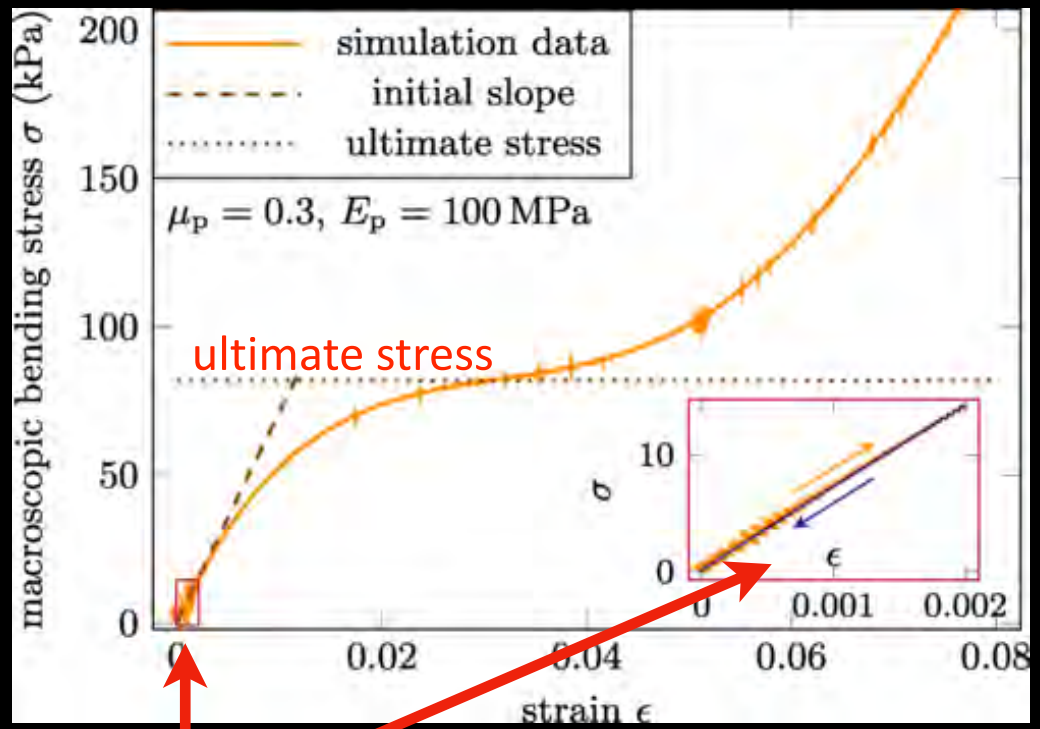
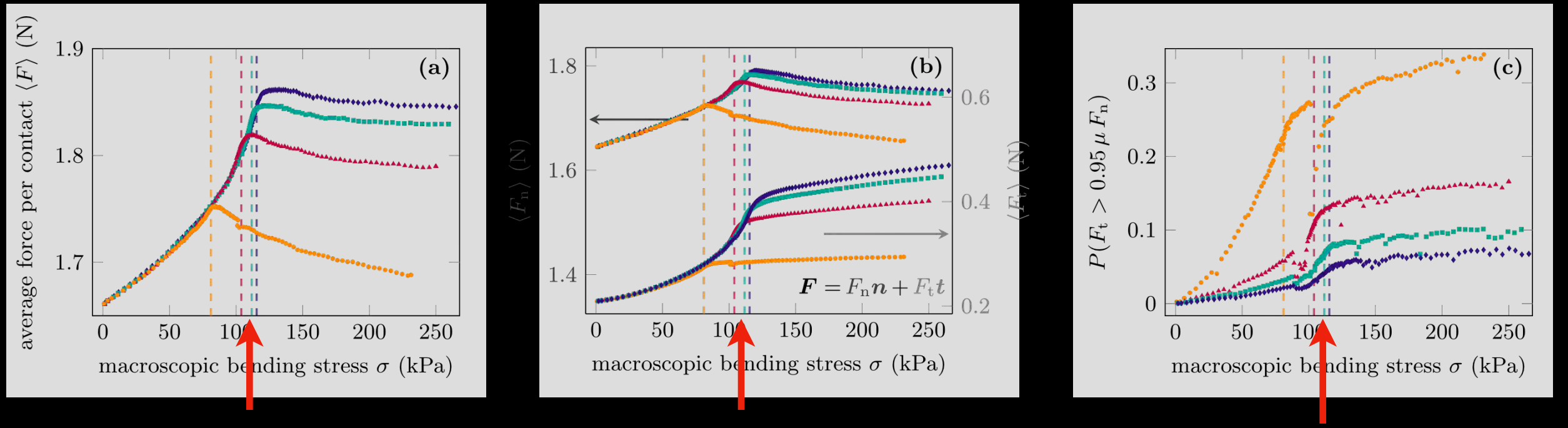




$\sigma = E_b \varepsilon$

Götz, D'Angelo, TP'23

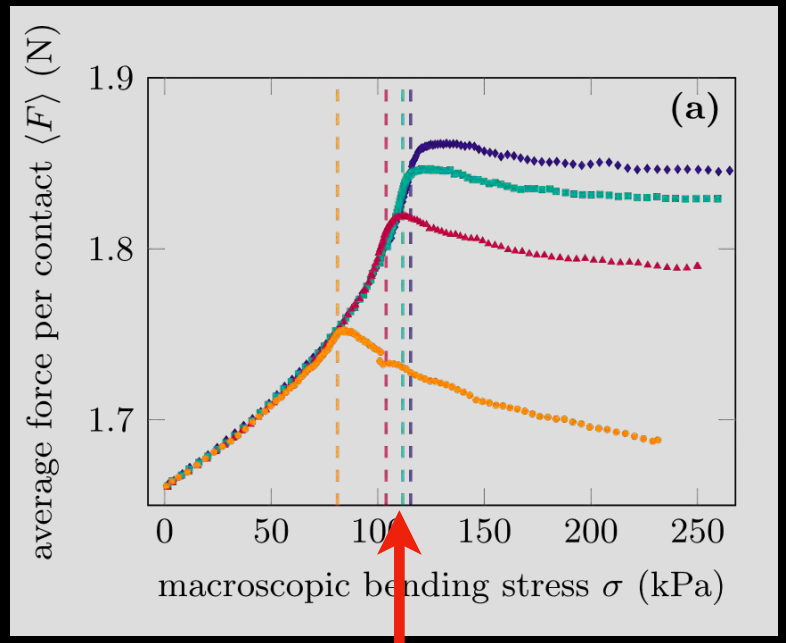
viscoelastic ➔ plastic transition: Granular meta-material

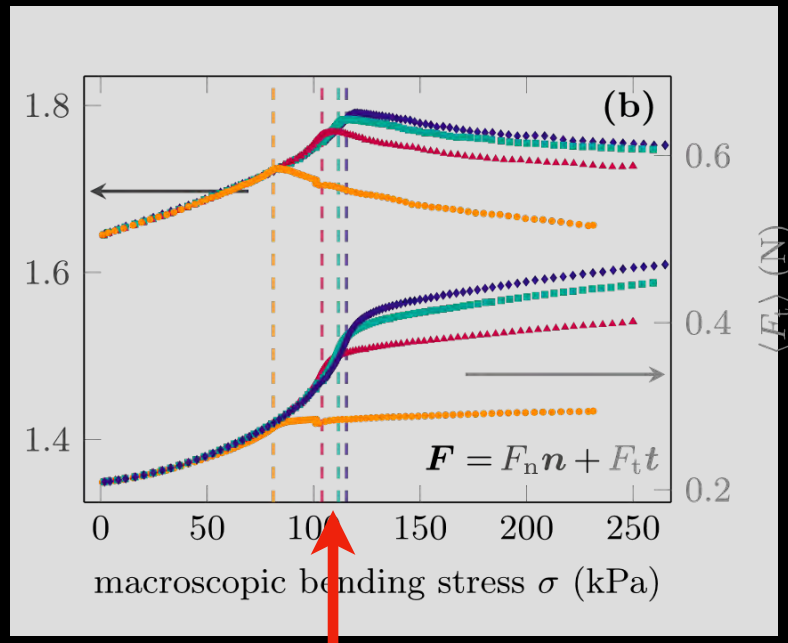


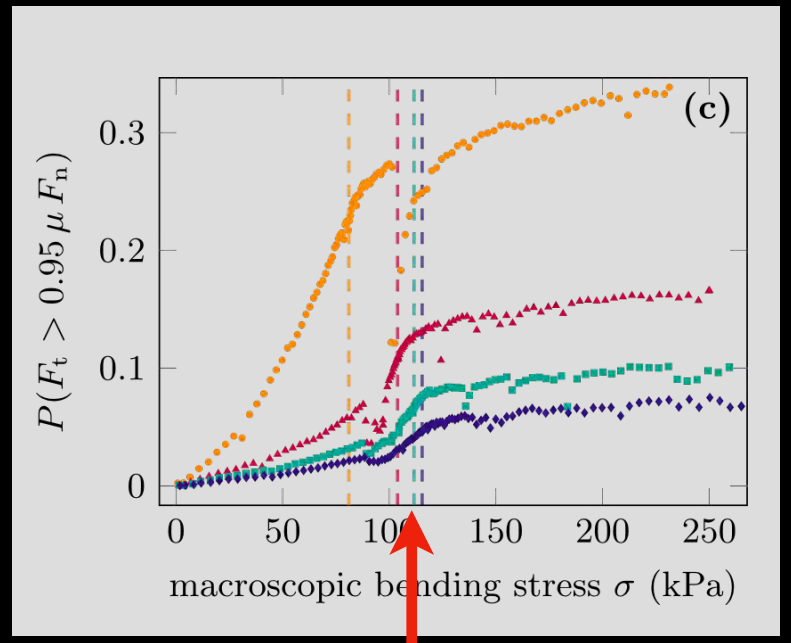
yielding of the force network — plastic deformation — history-dependent jamming state

Götz, D'Angelo, TP'23

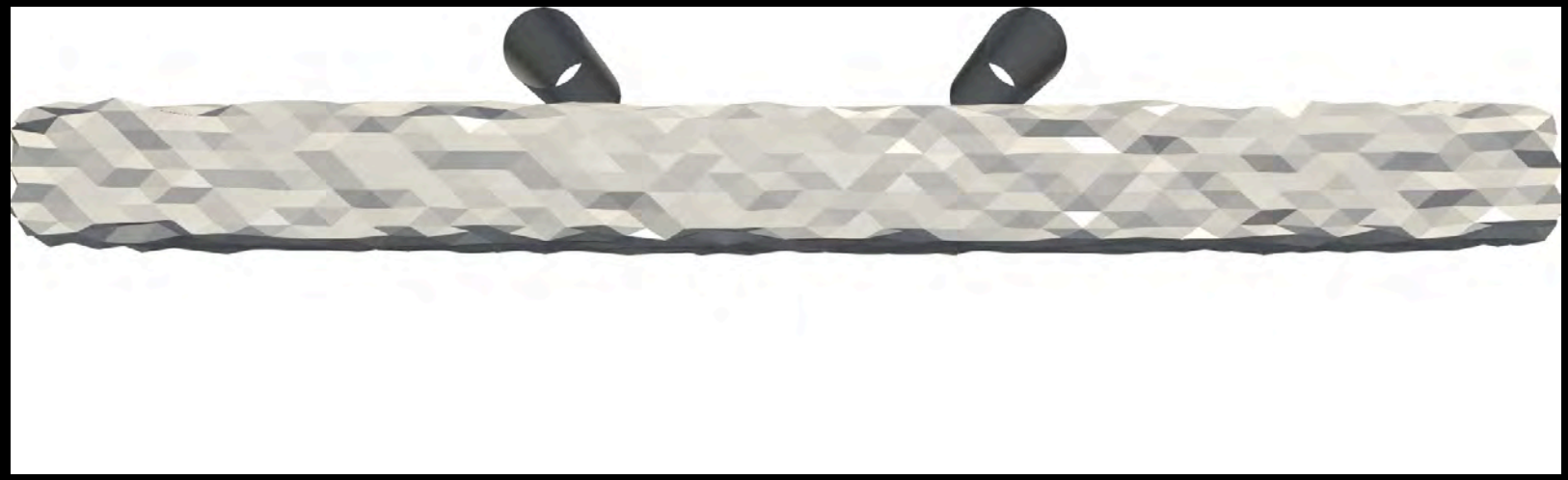
viscoelastic ➔ plastic transition: Granular meta-material





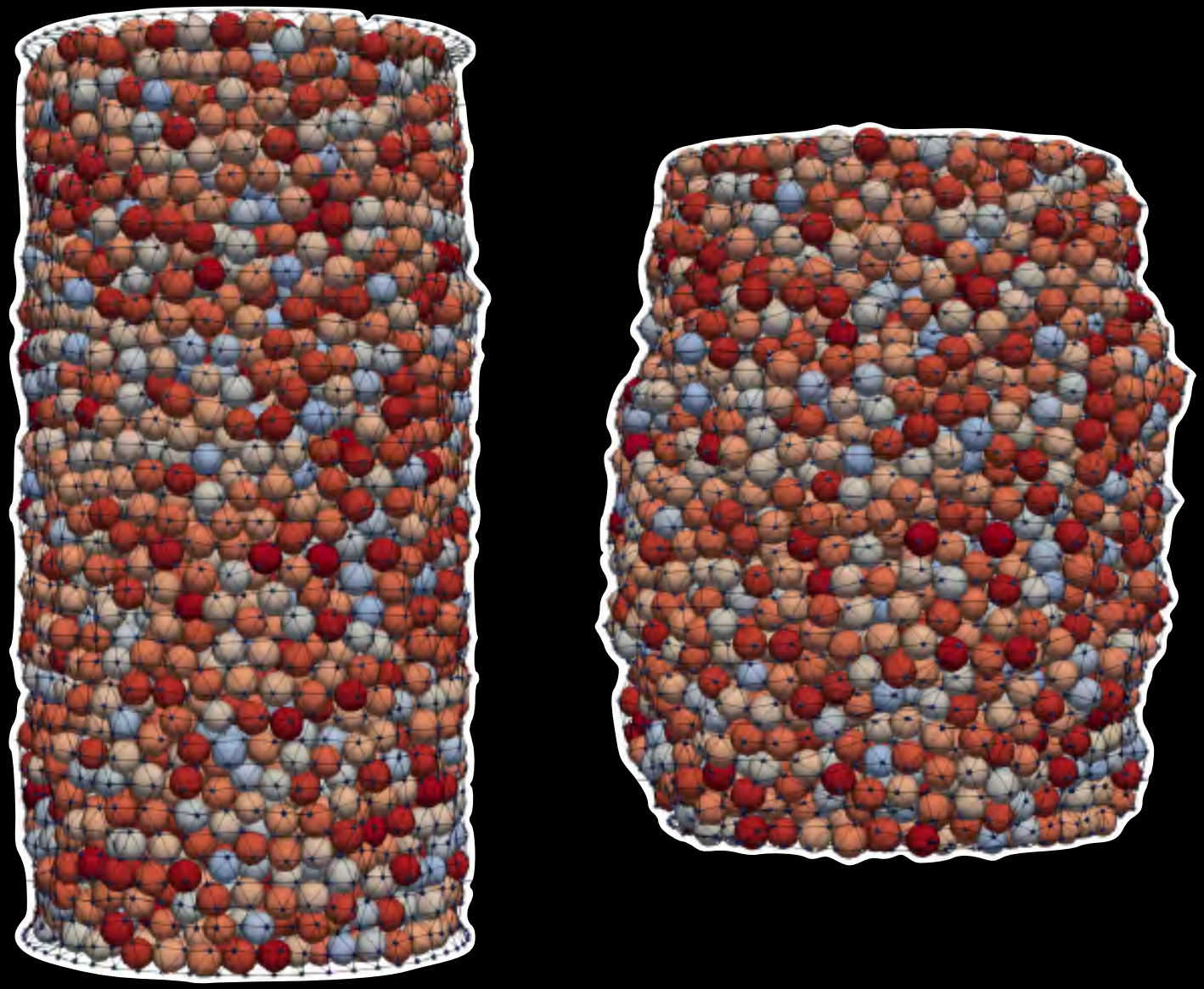


yielding of the force network — plastic deformation — history-dependent jamming state



Götz, D'Angelo, TP'23

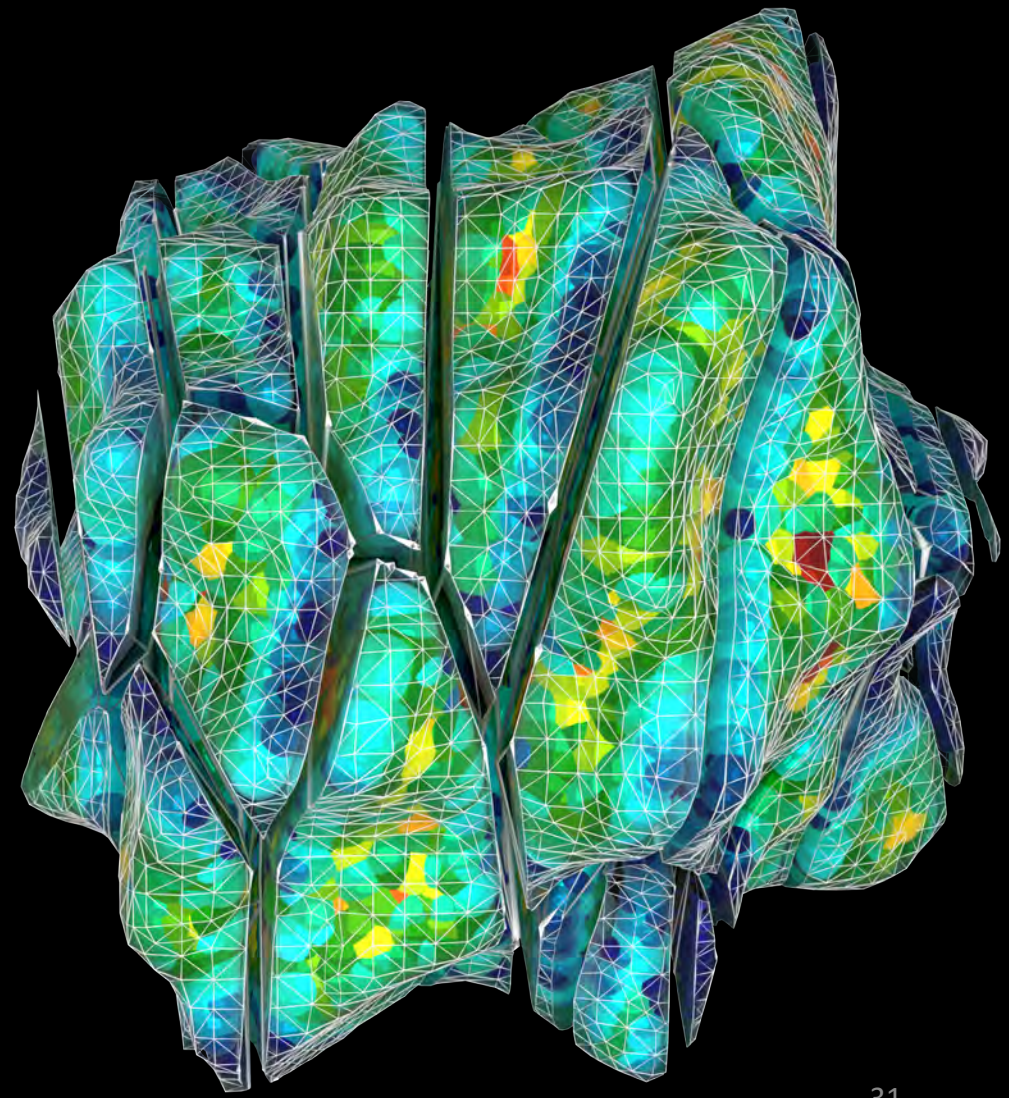
viscoelastic ➔ plastic transition: Granular meta-material



Götz, TP'23

fragmentation — irreversible

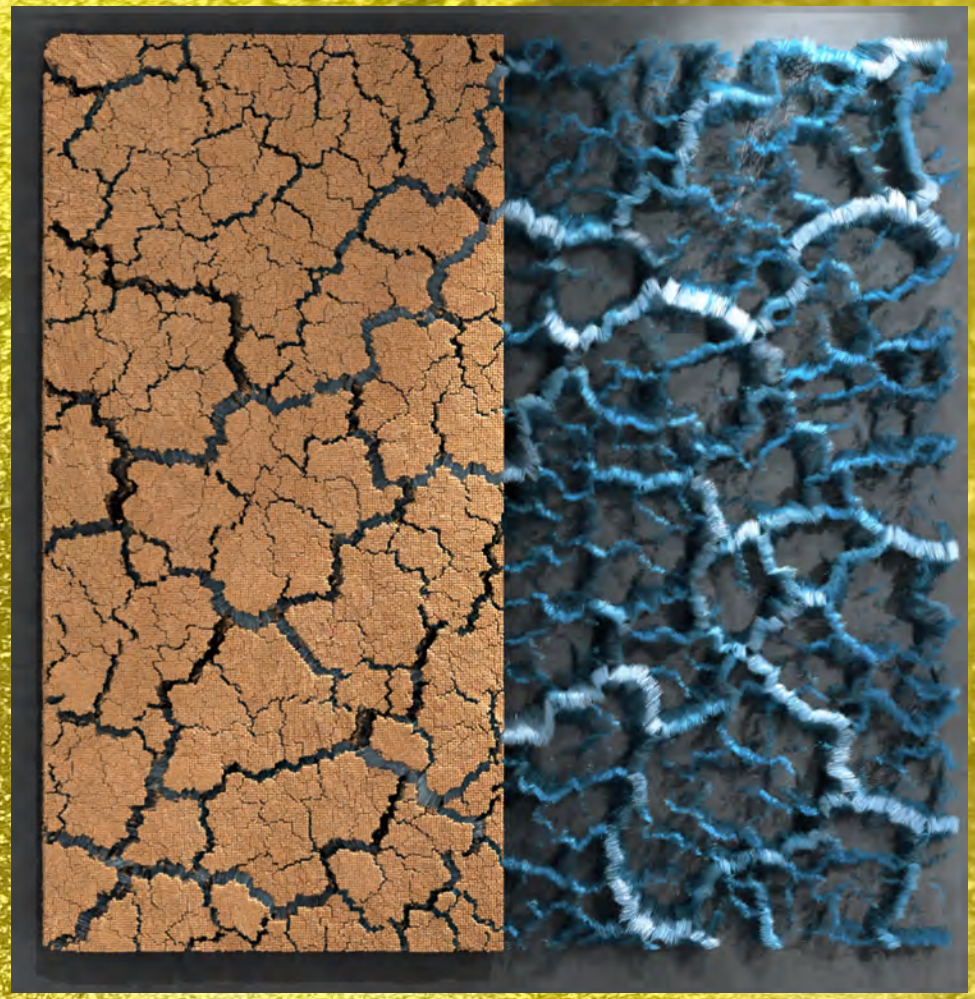
FRACTURE



Canbalot, TP'25

FRACTURE

brittle fracture / ductile



Bagheri, TP’26

FRACTURE - MSS

Tribology and Flow in Dry Granular Systems

T. Pöschel

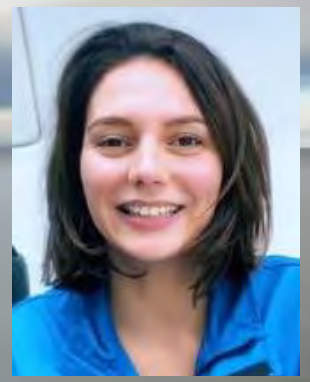
FAU Erlangen-Nürnberg

Conclusion:

Tribology and rheology are closely coupled in GM

- large-scale anisotropy and non-local interaction due to history of the system
- viscoelastic ↔ plastic
- fragmentation

(visco)-elastic
reversible
irreversible


Olfa D'Angelo


Meysam Bagheri


Felix Buchele

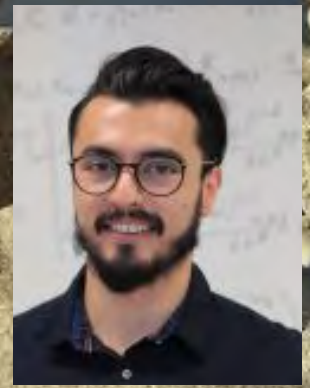

Utku Cambalot


Holger Götz


Jonathan Kollmer


Achim Sack


Sudeshna Roy


Mauricio Velasco


Fabian Zimber

Institute for Multiscale Simulation
MSS