Dry systems forward look

Michel Louge,
IFPRI AGM, Brussels
June 14, 2022

Dry systems portfolio

- Karen Daniels (dry rheology)   ending 2022
- Prabhu Nott (screw feeding)   until 2023
- Nott/Daniels (non-local model)   until 2023
- Kit Windows-Yule (round robin)   until 2023
- Casba Sinka (powder adhesion)   until 2023
- Arno Kwade (milling additives)   until 2023
- Ken Kamrin (air-induced defects/compaction until 2024
- Raj Dave (flow aids & cohesion)   until 2024

- Nico Gray   dynamic powder flow
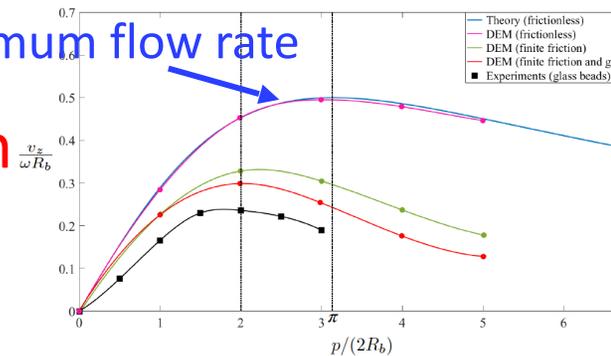- Farhang Radjai   beyond DEM

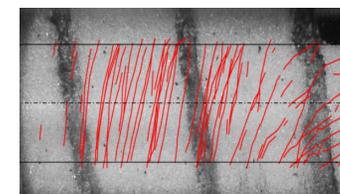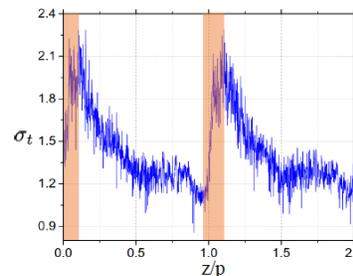# What we learned
screw feeders

Prabhu Nott
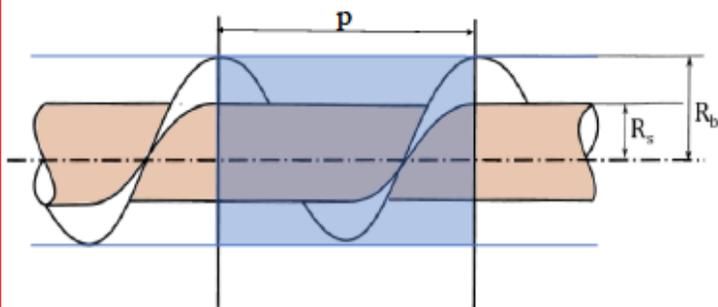
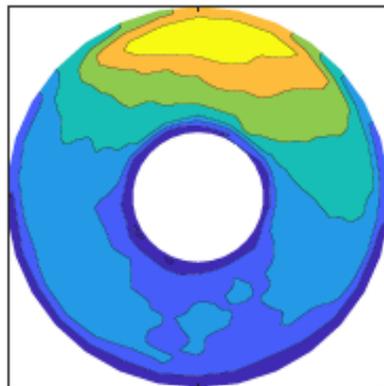formal calculation

Optimum flow rate

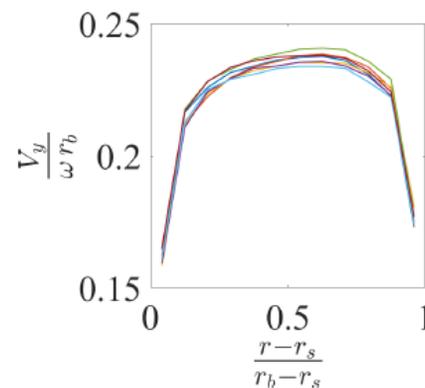instrumented experiments

Janssen-like effect for stress

no slip at the wall

DEM

role of cohesion

Upcoming collaboration
non-local rheology

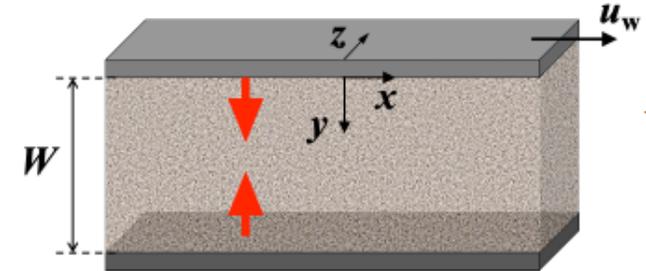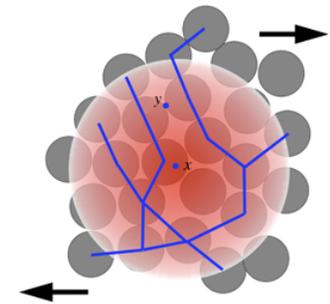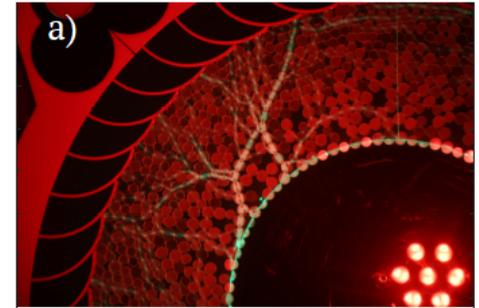## Prabhu Nott and Karen Daniels

JFM RAPIDS
journals.cambridge.org/rapids

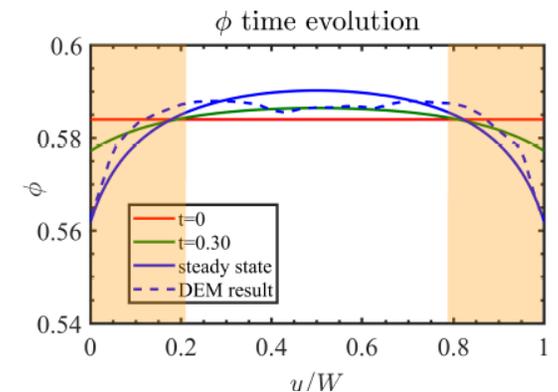### A non-local constitutive model for slow granular flow that incorporates dilatancy

Peter Varun Dsouza[1] and Prabhu R. Nott[1,†]

[1]Department of Chemical Engineering, Indian Institute of Science, Bangalore 560 012, India

unsteady, plane shear

$$\boldsymbol{\sigma} = -p\,\boldsymbol{\delta} + \frac{2\mu}{\dot{\gamma}}\left(p_{\mathrm{c}}\,\boldsymbol{D}' - \ell^2\,\Pi\,\nabla^2\boldsymbol{D}'\right), \qquad p = p_{\mathrm{c}}\left(1 - \frac{\mu_{\mathrm{b}}}{\dot{\gamma}}\boldsymbol{\nabla}\cdot\boldsymbol{u}\right) - \ell^2\,\Pi\,\frac{\mu_{\mathrm{b}}}{\dot{\gamma}}\nabla^2\boldsymbol{\nabla}\cdot\boldsymbol{u}$$

$$p_{\mathrm{c}} = \Pi - \ell^2\,\frac{\mathrm{d}\Pi}{\mathrm{d}\phi}\,\nabla^2\phi,$$

non-local terms

What we learned
challenge of predicting boundary conditions

Karen Daniels
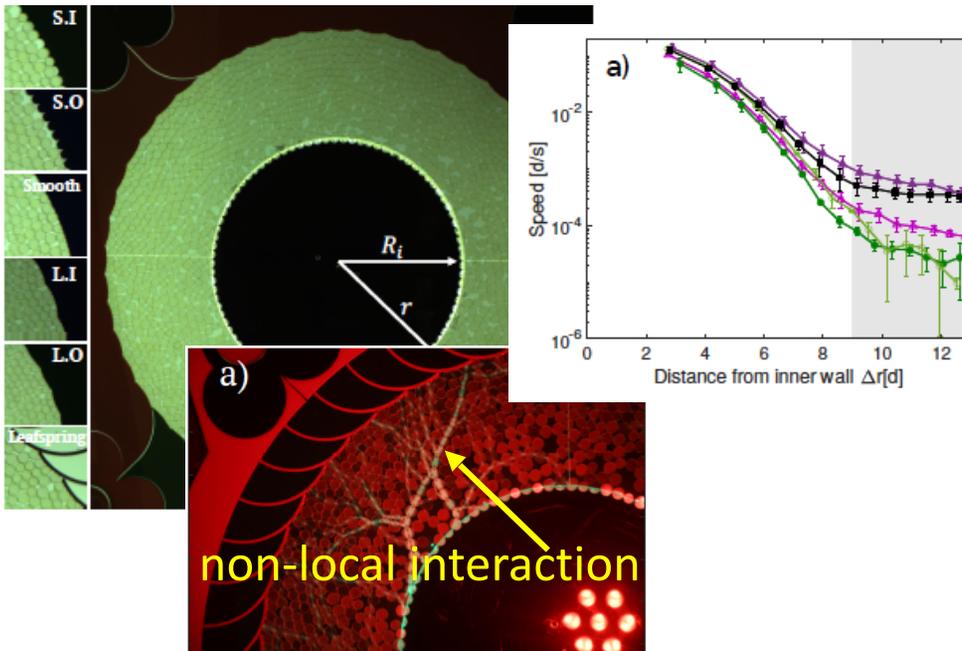
Boundaries are pervasive;
non-local rheology parameters capture data.
force fluctuations ⇔ roughness and low slip

non-local interaction

Kamrin, Claudin, et al

Pouliquen, Chevoir, Jop, et al

local   Inertial number I

$$\frac{S}{N} = \mu = f(I; \mu_s) \qquad I = \frac{d \times du/dr}{\sqrt{N/\rho}}$$

diameter d, velocity u, stresses S & N, density ρ

fluidity η, length scale ζ, friction μ

$$\mu = \frac{du/dr}{\eta} \qquad \nabla^2 \eta = \frac{1}{\zeta^2}(\eta - \eta_{local})$$

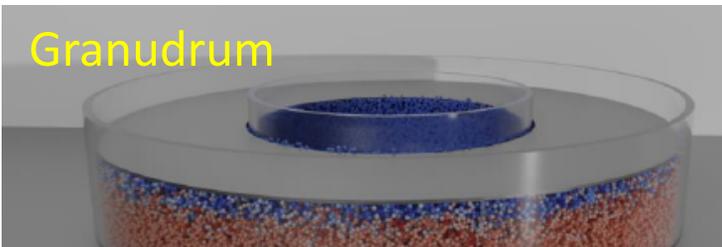$$\zeta = A \frac{d}{\lfloor \mu - \mu_s \rfloor^{1/2}}$$

non-local

Karen fits parameters A, μs and the function f to data

What we learned
from the round-robin

Kit Windows-Yule

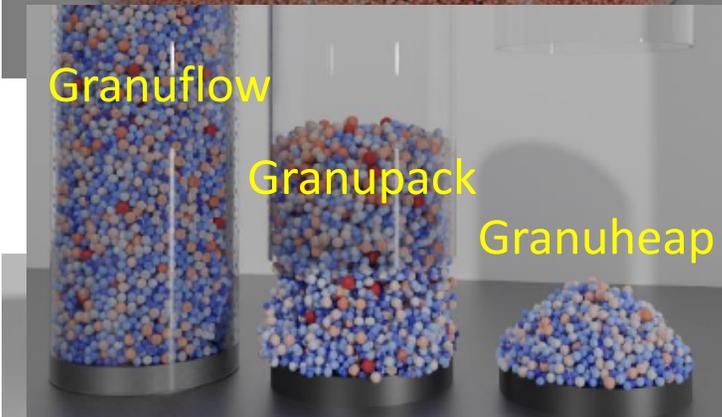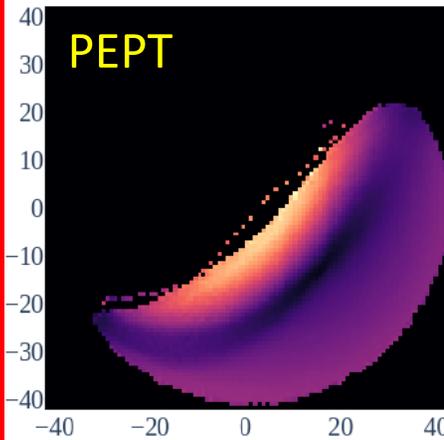Granudrum

Granuflow
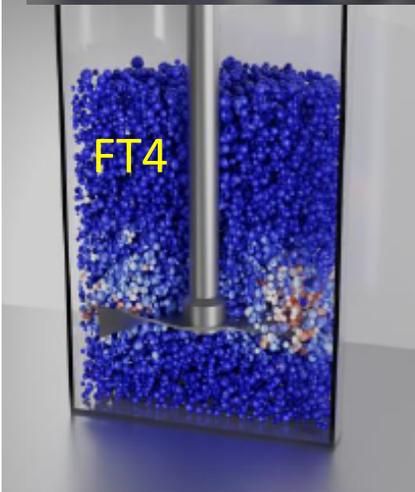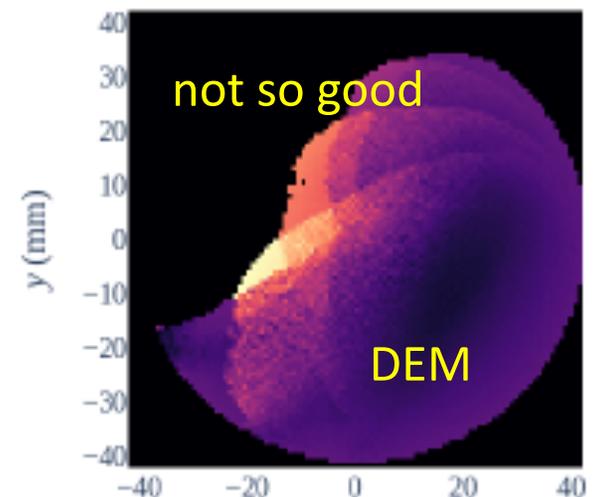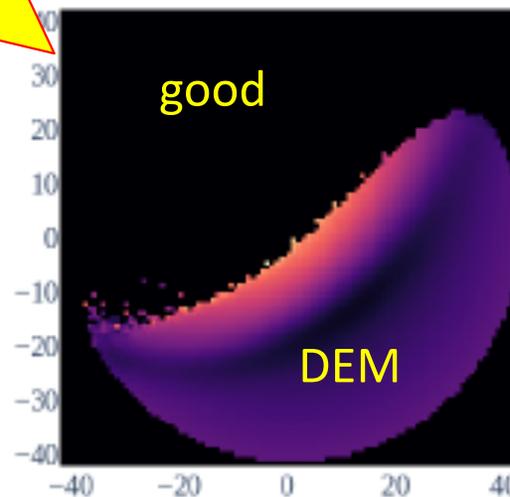
Granupack

Granuheap

FT4

digital twins

PEPT

good

DEM

not so good

DEM

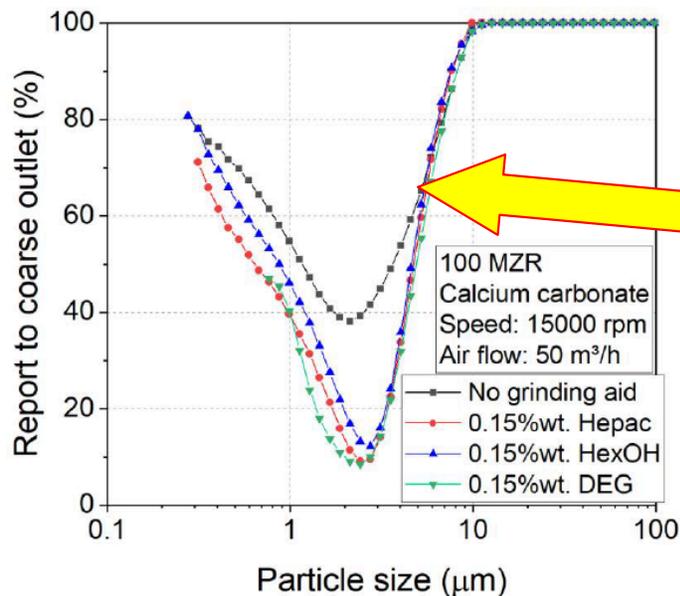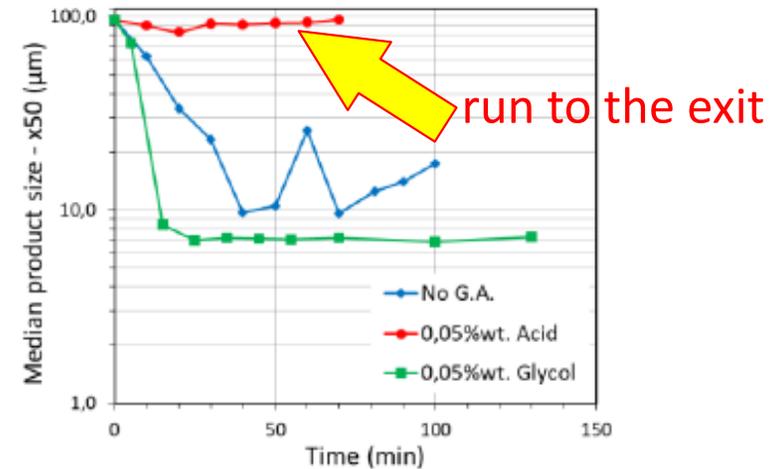rolling friction is a robust way to model angular particles

Next year: digital twin of Schultze shear tester and Anton-Parr rheometer, PEPT tests with resonant acoustic mixer

What we learned
## additives in continuous milling and classification

Arno Kwade

run to the exit
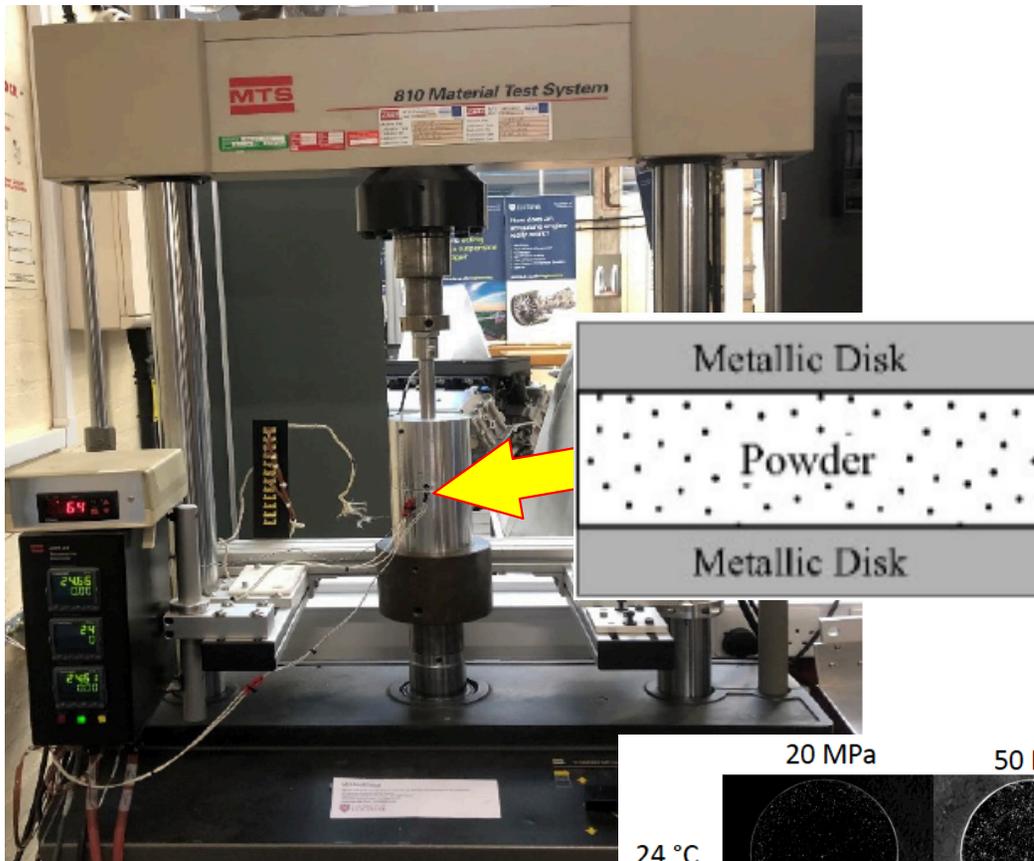
Trade-off of better flowability in mill:
less residence time ⇒ particles run to the exit...

"fish-hook" cumulative PSD:
fines hitch a ride on coarser particles in classifier

100 MZR
Calcium carbonate
Speed: 15000 rpm
Air flow: 50 m³/h

What we learned
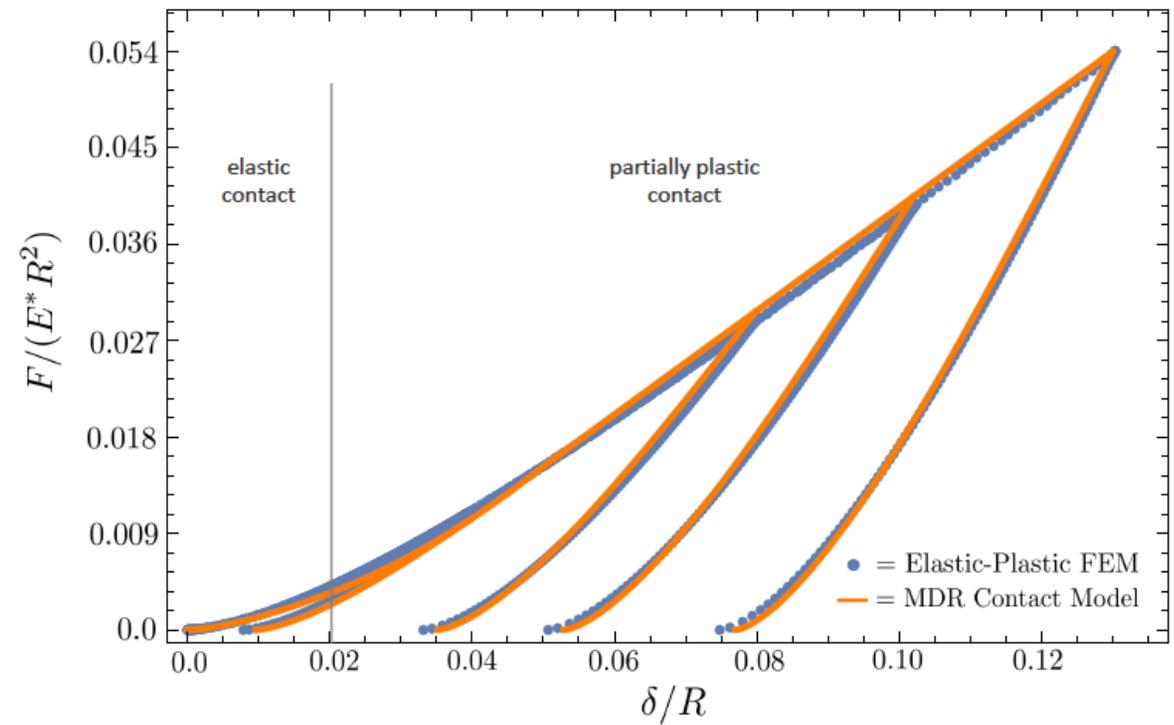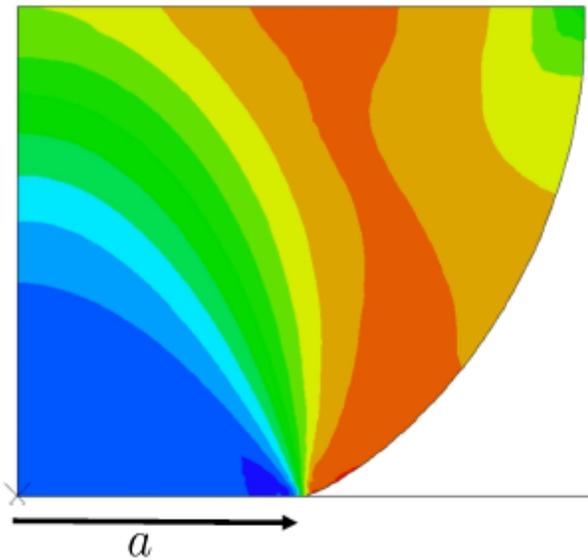## powder adhesion metal during compaction

Csaba Sinka
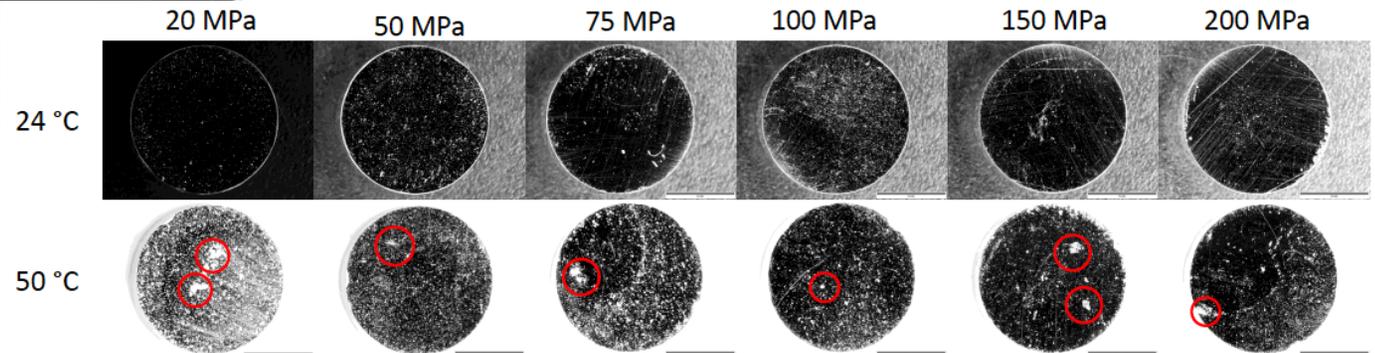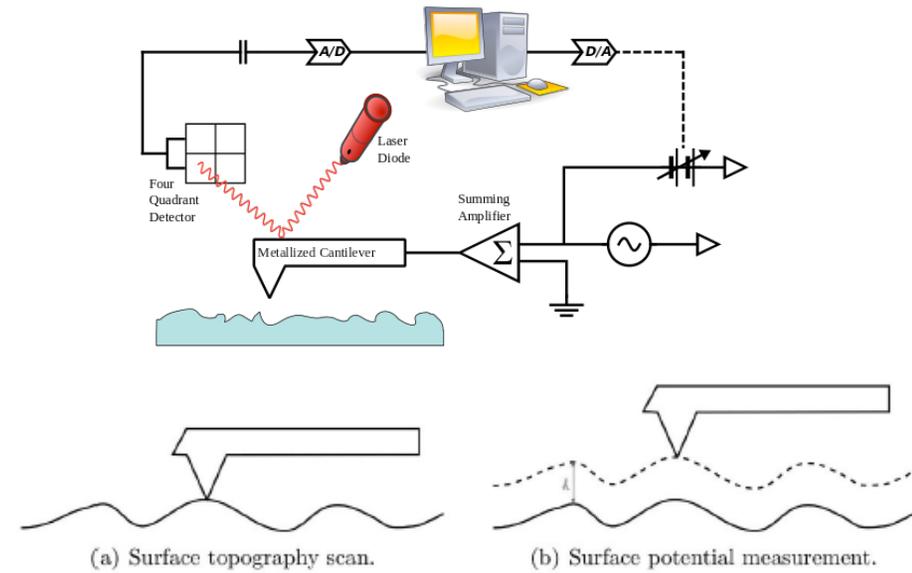
What we learned
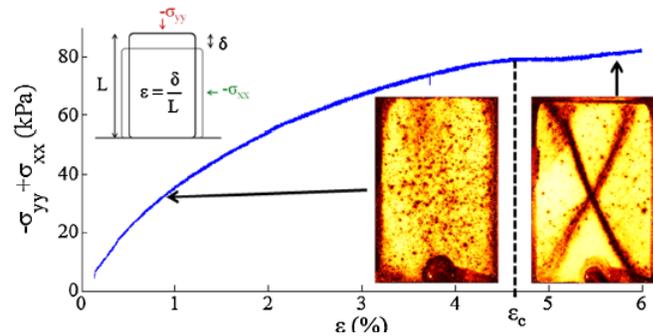## air-induced defects in compaction

Ken Kamrin

Modeled force-displacement relations and
validated against FEM simulations

Forward look
recruit scholars of wide scientific bandwidth
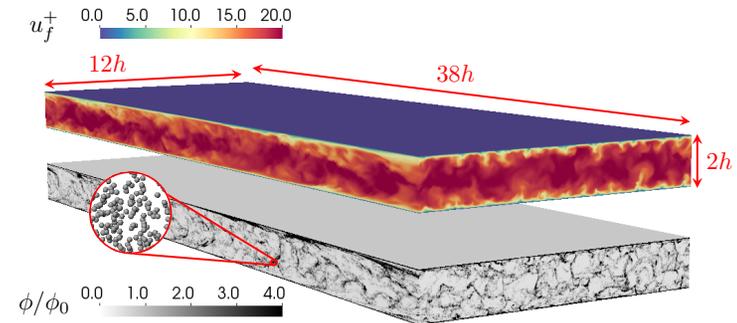
deployment of new instrumentation

Axelle Hamon (Rennes)

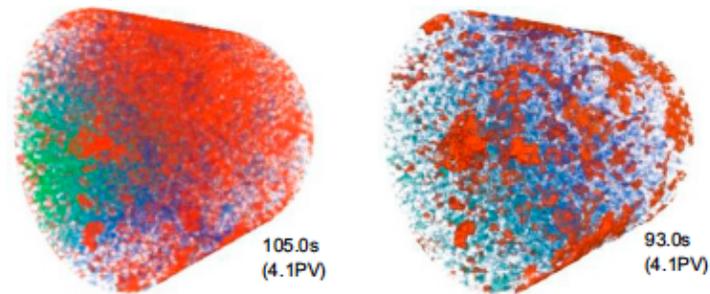stress-strain in granular materials

reintroduce gas-solid interactions

Houssem Kasbaoui (ASU):

turbulence with drag-reducing particles

wetting and drying: granulation, deliquoring

Vahid Nisar (Manchester):

synchrotron imaging of transport in unsaturated porous media

Suggested powder flow scientists

Heinrich Jaeger (Chicago): particle charging, granular impacts, dense suspensions.

Anil Misra (U. Kansas): granular theory.

Atieh Moridi (Cornell): thin flow with application to rapid prototyping.

Lucie Jezerska, (VSB-TU Ostrava): wet granulation experiments, DEM, friction.

Roberto Zenit (Brown): capillary interactions.

Ecevit Bilgili (NJIT): milling, granulation, extrusion, spray drying.

Paul Umbanhowar (Northwestern): granular physics.

Elisabeth Guazzelli (Paris-Diderot): granular suspensions.

Anthony Thornton (Twente): granular segregation.

Jesse Capecelatro (Michigan): multiphysics simulations of suspensions.

Mark Shattuck (CCNY): granular mechanics.

Jean-Christophe Géminard (ENS, Lyon): solid friction, sediment suspensions.

Antoinette Tordesillas (U. Melbourne): granular slides.