SAND2022-5401C

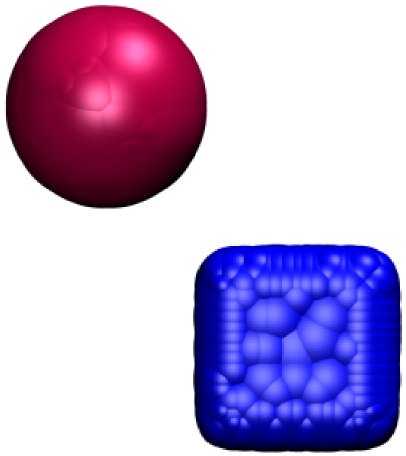
Sandia National Laboratories

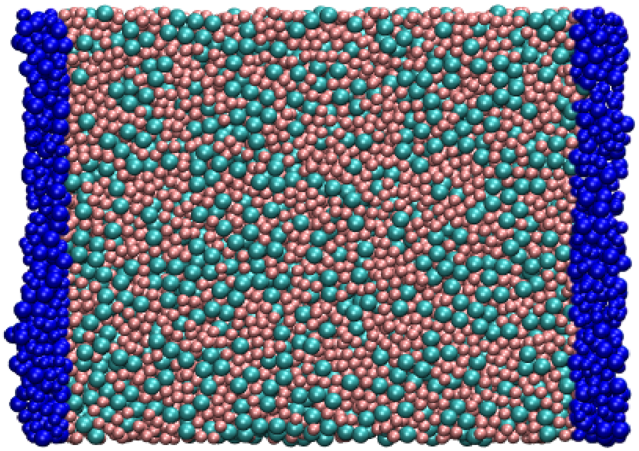
FLOW AND PACKING OF FRICTIONAL SHAPES FROM SPHERES TO CUBES

K. Michael Salerno, Dan Bolintineanu, Leo Silbert, Jeremy Lechman*, Gary Grest

*Sandia National Laboratories, * Southern Illinois University*

SIU Southern Illinois University CARBONDALE





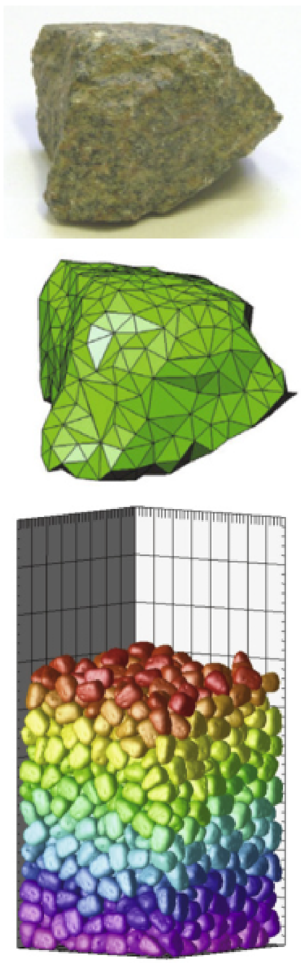
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

NNSA National Nuclear Security Administration

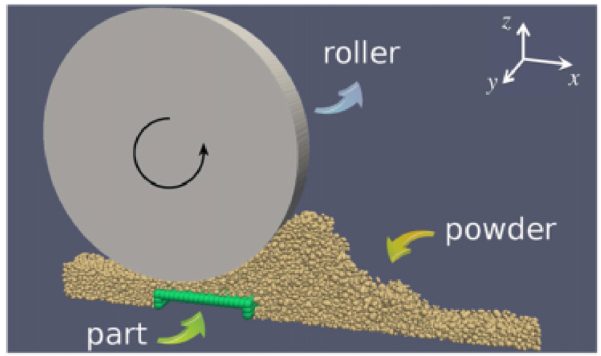
U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

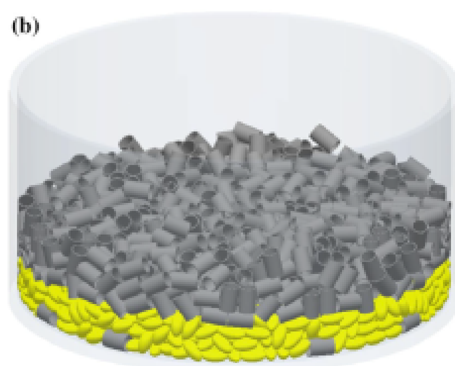
Why study granular shapes?



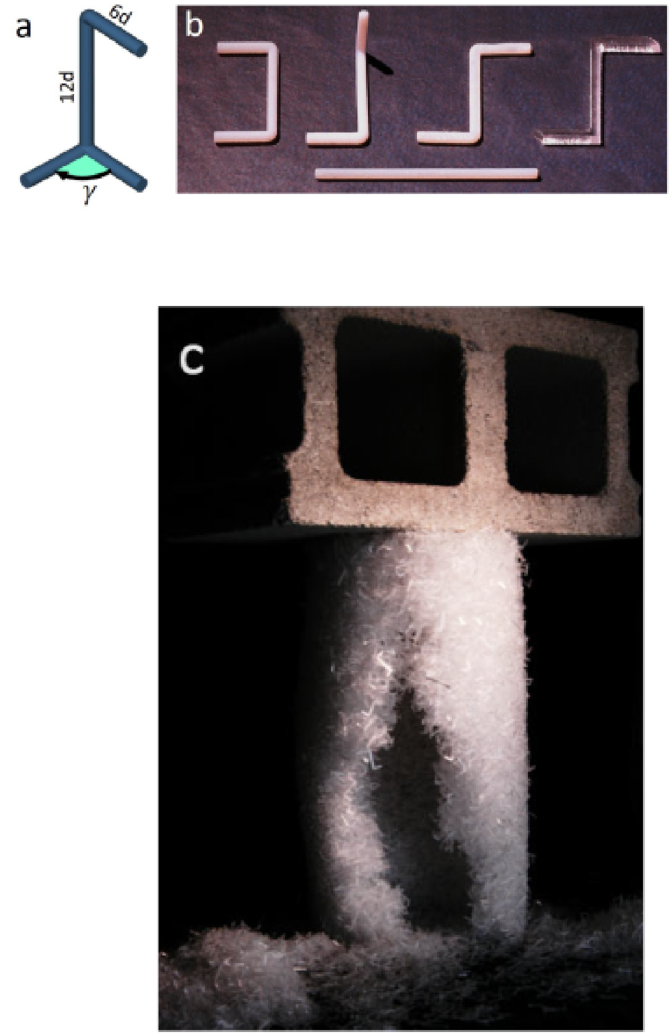
Latham, J. P., et al.
Miner. Eng. (2008)



Parteli, E. J. R. and Pöschel, T.
Powder Technol. (2016)



Ma, X-D, et al.
Gran. Mater. (2016)

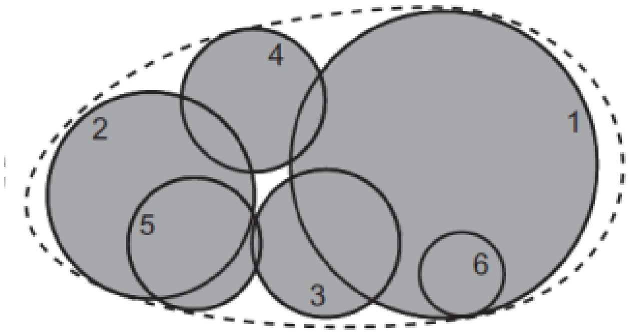


Muphy, K.A., et al.
arXiv:1510.05716

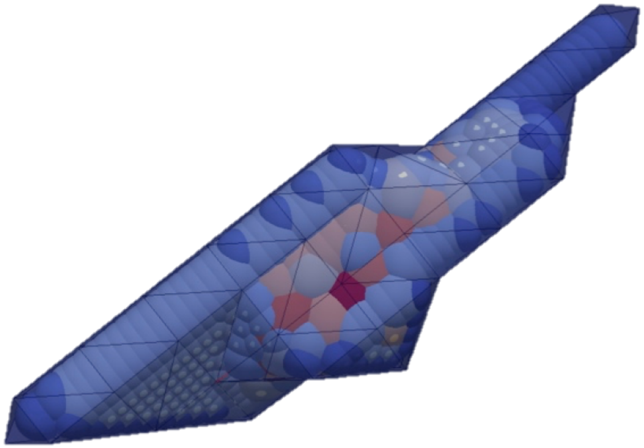
Representing granular shapes

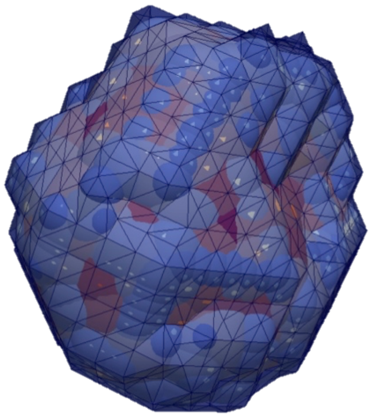
Clustered
Overlapping
Sphere

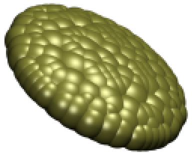
Garcia, X., et al. *Géotechnique* (2009).



(f)







Parameters

- Shape parameter ***s***

  $|x|^s + |y|^s + |z|^s \le 1 = a_0$

- Interaction stiffness

  $k_n = 2k_t = 2e5$

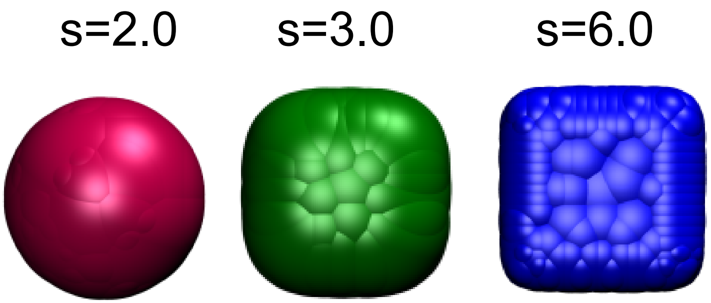
  - Time t_0

- Interaction damping

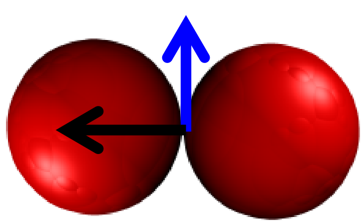
  $\gamma_n = 2\gamma_t = 365$ or 33.5

  - $e \approx 0.1$ or 0.85

- Microscopic friction coefficient μ



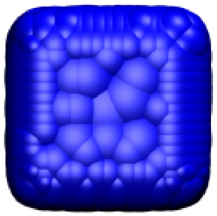
$$\mathbf{F}_{hk} = -k_n \boldsymbol{\delta}_{ij} - m_{\text{eff}} \gamma_n \mathbf{v}_{ij}^n$$
$$-k_t \mathbf{s}_{ij} - m_{\text{eff}} \gamma_t \mathbf{v}_{ij}^t$$
$$\delta_{ij} = r_{ij} - d_{ij} \quad r_{ij} < d_{ij}$$



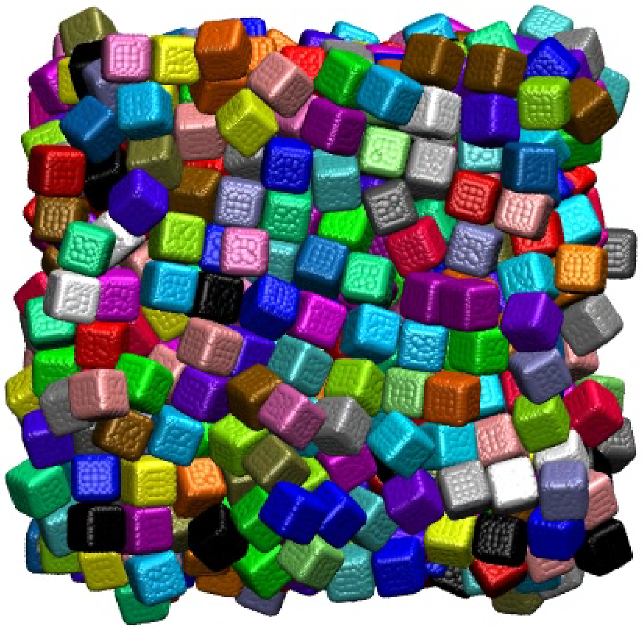
$F_t \le \mu F_n$

Packing Protocol

s=6.0



- Monodisperse samples N=1000
- Isotropic compression
- Strain rate $5\text{x}10^{-5}\,/t_0$
  - Compress when contacts $N_c/N < 4$
  - Wait/relax for $N_c/N > 4$

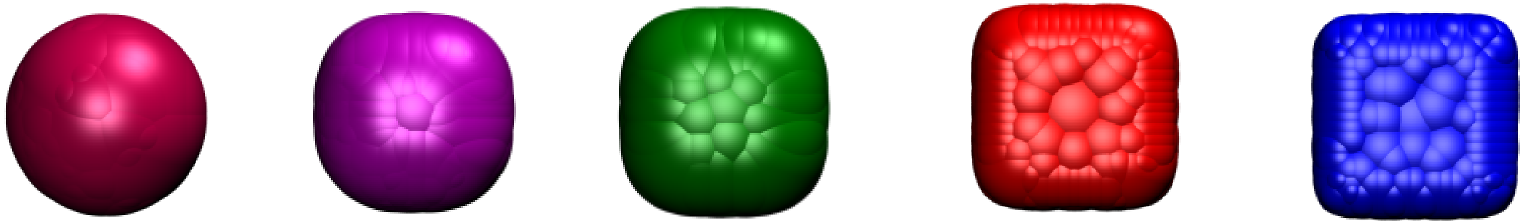


No Friction

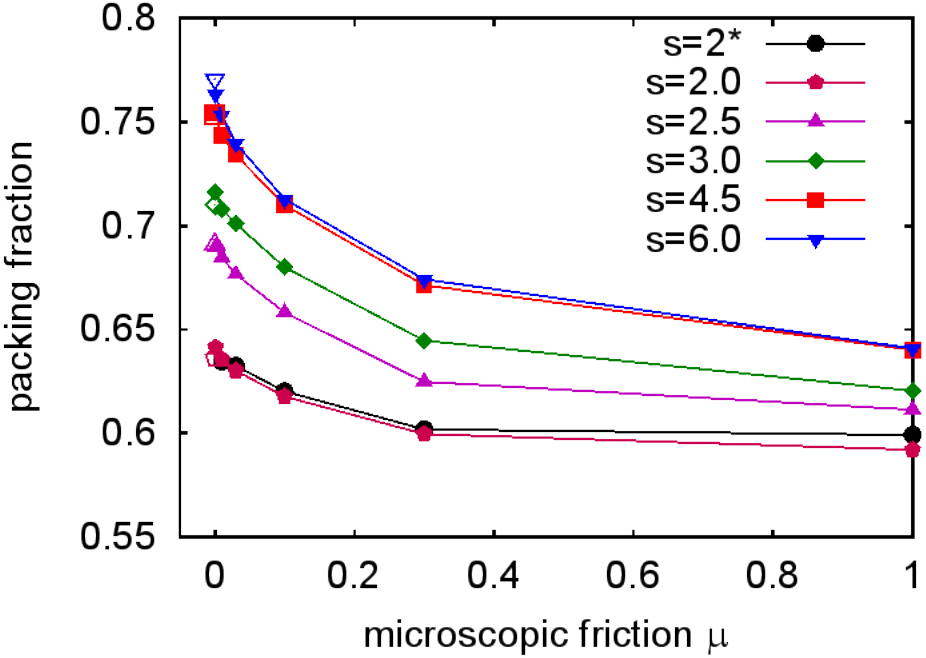
High Friction

Packing Results

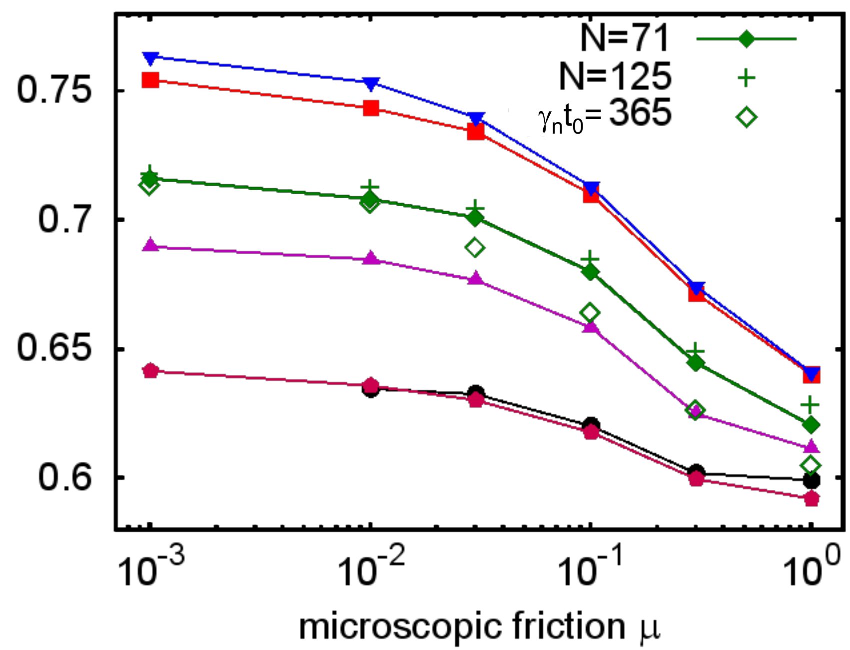
s=2.0 s=2.5 s=3.0 s=4.5 s=6.0



Jiao, Y., Stillinger, F. H., & Torquato, S. *PRE* (2010) open, $\mu = 0.0$



LES, Soft Matter (2010) $s = 2.0$



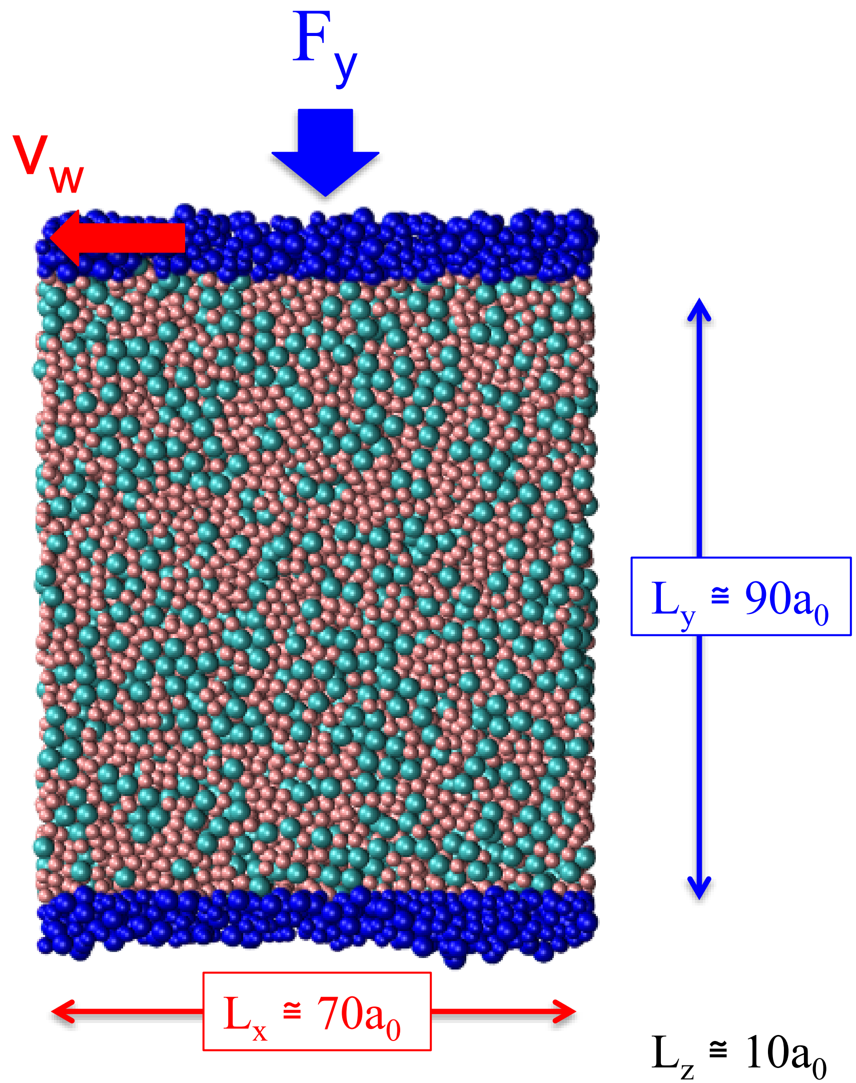
Rheology/Flow

- N=1000 bidisperse superballs
- Top and bottom rigid wall
  - Top wall pressure controlled $P_{yy} \cong 10^{-4} k_n$
  - Top wall constant x-velocity $v_w = 0.2\ a_0/t_0$ (F_x fluctuates)
  - Bottom wall fixed
- Granular Fluidity

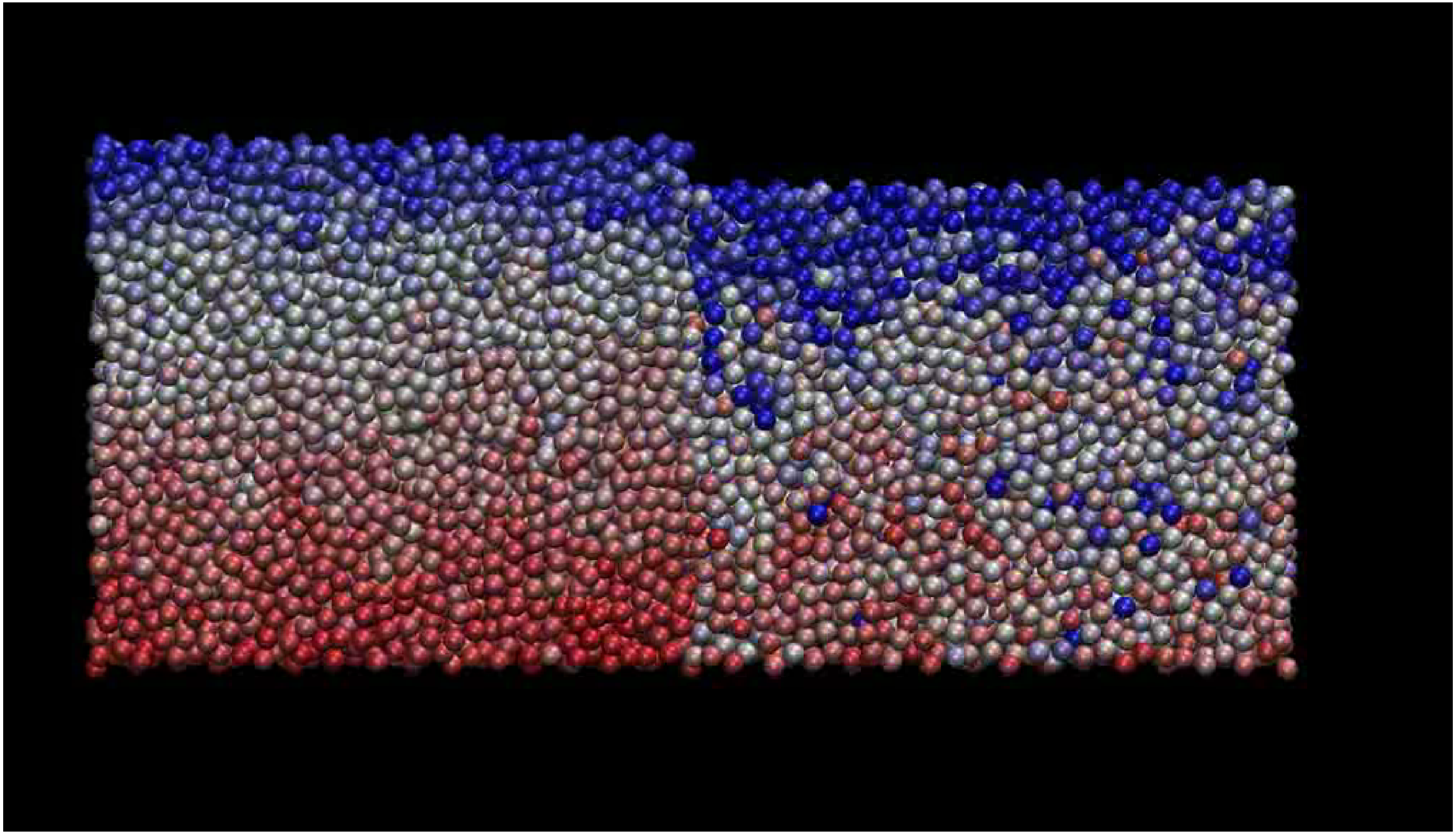
$$\mu^* = F_x / F_y$$

$$I = \dot{\gamma}\sqrt{m / P_{yy}}$$

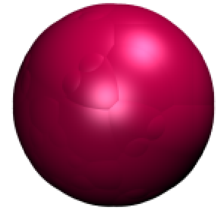
Kamrin, K., & Koval, G.
WCCM XI (2014)

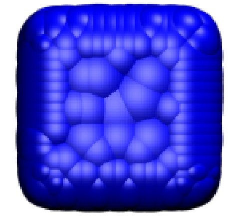


Rheology/Flow

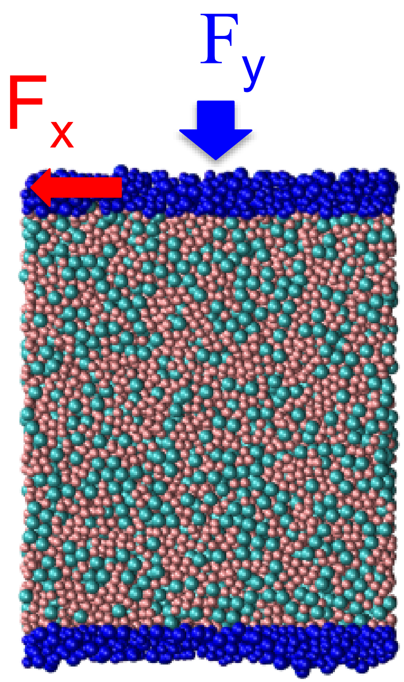


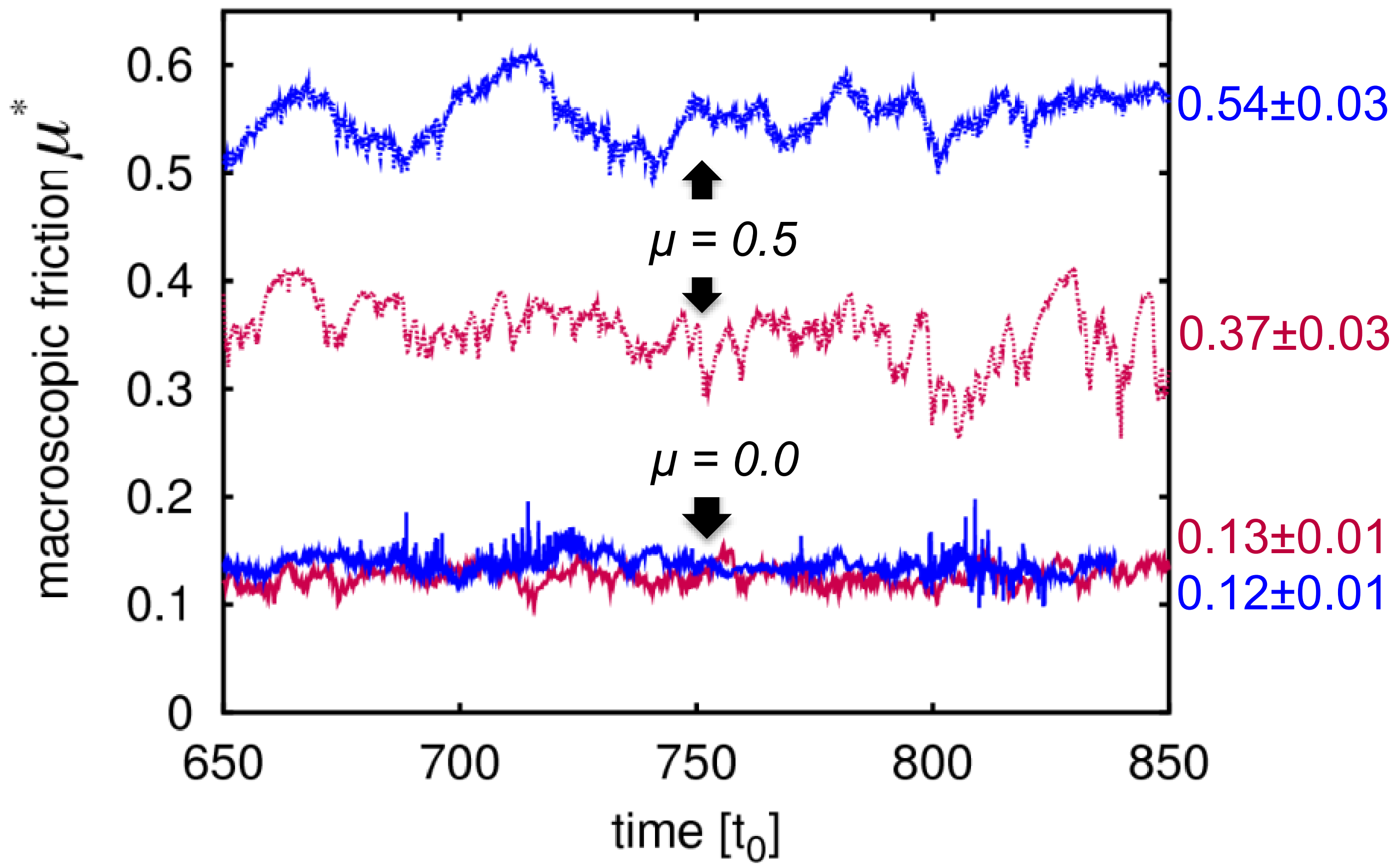
Rheology





- Measure F_x, F_y, calculate $\mu^*=F_x/F_y$

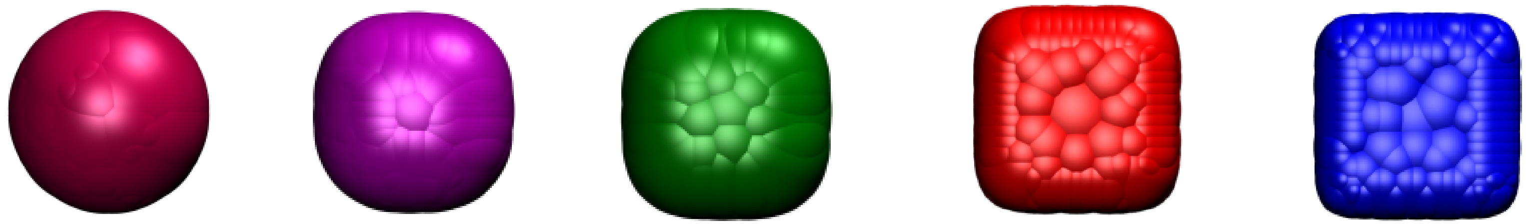




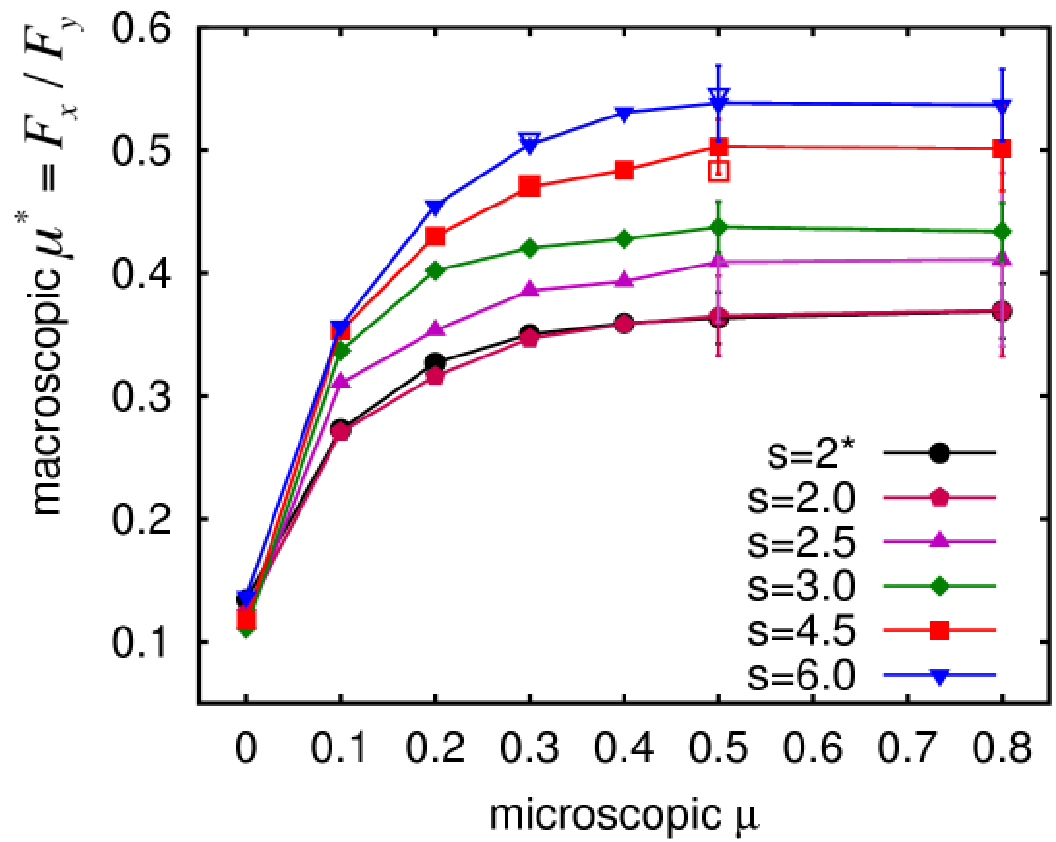
Rheology

Sandia National Laboratories

s=2.0 s=2.5 s=3.0 s=4.5 s=6



- Identical zero-friction (microscopic) limit
- Monotonic in shape parameter **s** for $\mu > 0$
- Saturates $0.3 > \mu > 0.5$
- μ^* saturation value 0.36 – 0.54
- Open $e = 0.85$
  Closed $e = 0.10$



Summary / Future Work

- Used COS algorithm to produce superballs
- Packing data agree with previous $\mu = 0$ results
- Smaller packing density variation for $\mu = 1.0$
- Macroscopic friction μ^* independent of s in zero-friction limit
- Macroscopic friction μ^* depends on *s* for finite μ
- Future plans for complex geometries, incline-plane flow, couette cell, etc.