Reversibility of granular rotations and translations under cyclic compression

Zackery Benson, Anton Peshkov, Lea Delance, Michelle Girvan, Derek C. Richardson, Wolfgang Losert

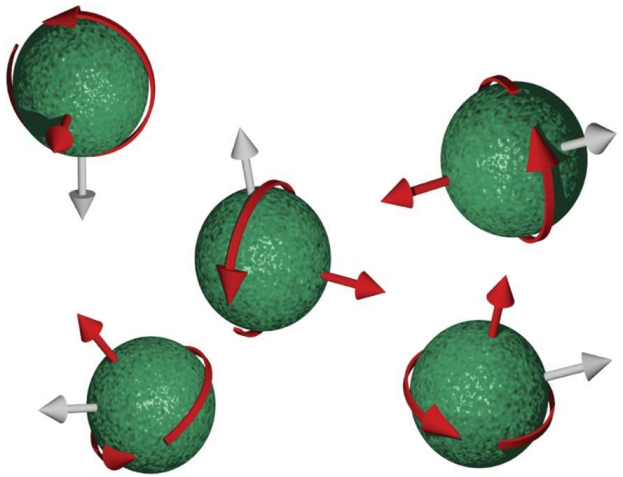
Granular rotations are crucial for the complete study of particle dynamics

Rotations motion is coupled to translations

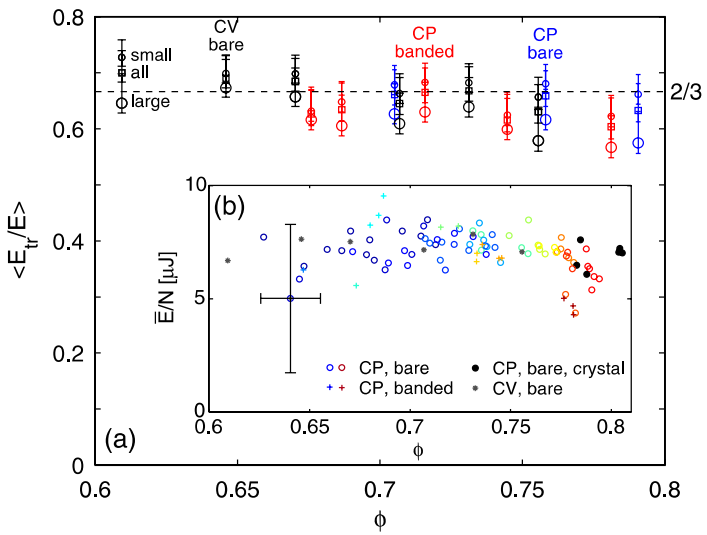
Rotations and translations have equipartition of KE

Collective rotations emerge from specific configurations of spheres

For dense systems, energy dissipation is dominated by frictional contacts instead of collisions



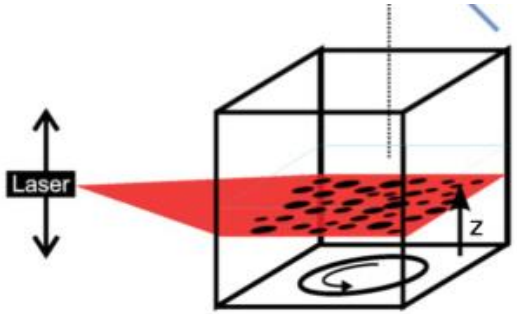
N. V. Brilliantov et. al. *PRL*, **98** (2007) 128001

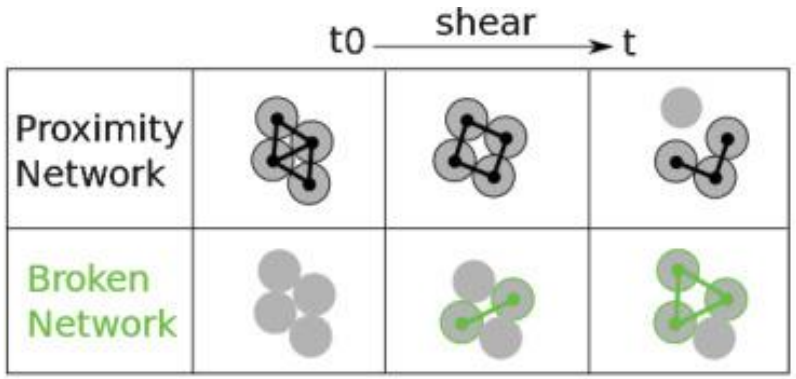


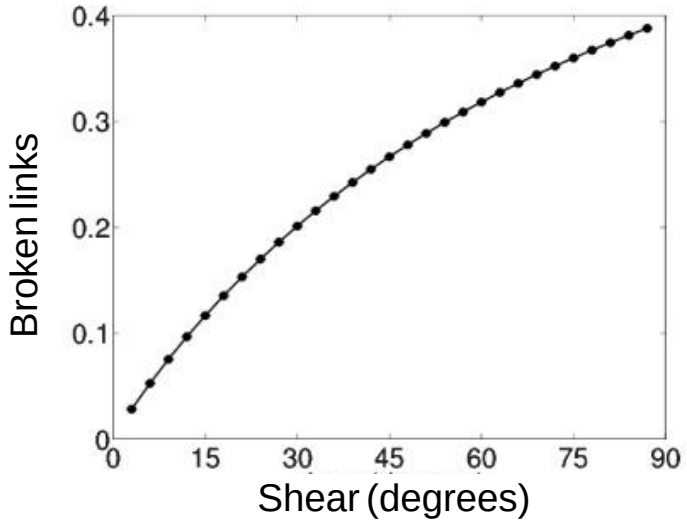
Kiri Nichol et. al. *PRL*, **108** (2012) 018001

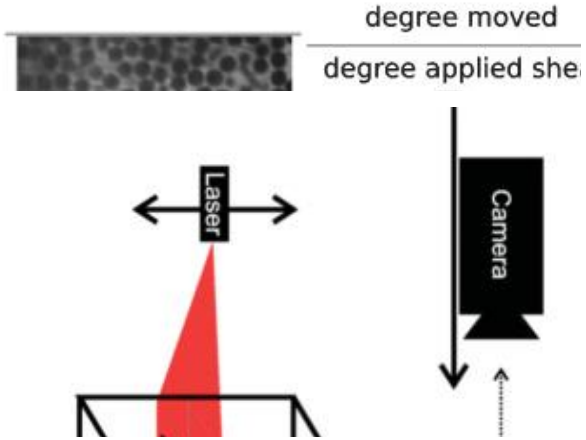
D. V. Stager et. al. *PRL*, **116** (2016) 254301

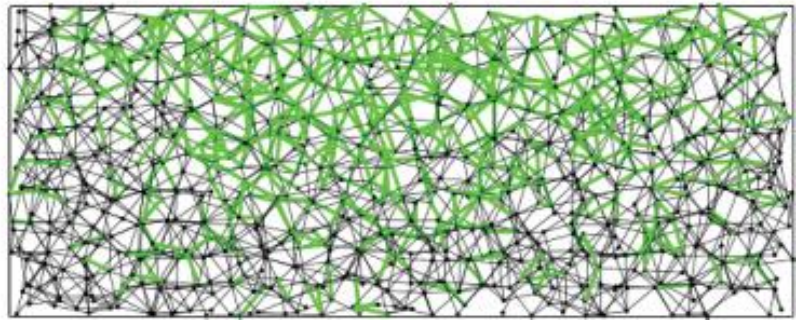
Previous work on Network Analysis

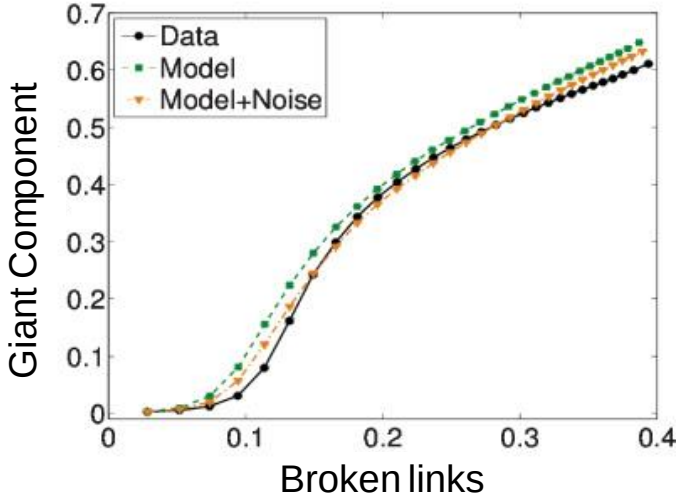






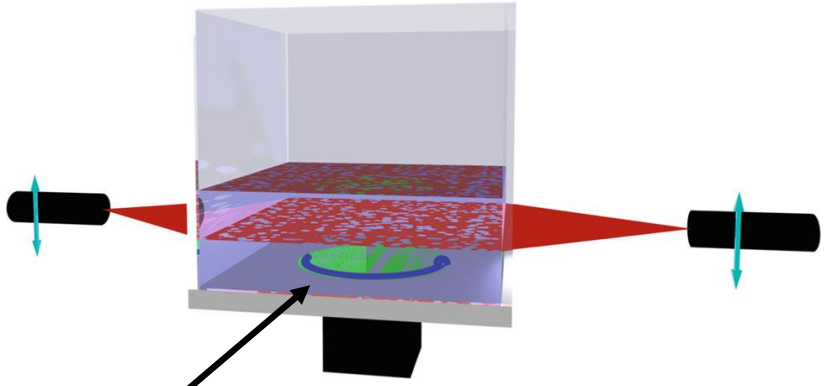




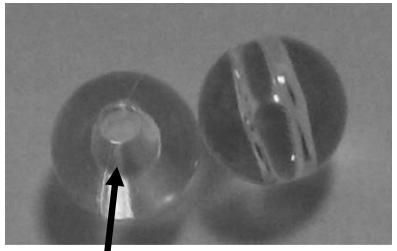


M Herrera et. al. *PRE*, **83** (2011) 061303

Capturing 3D rotational motion

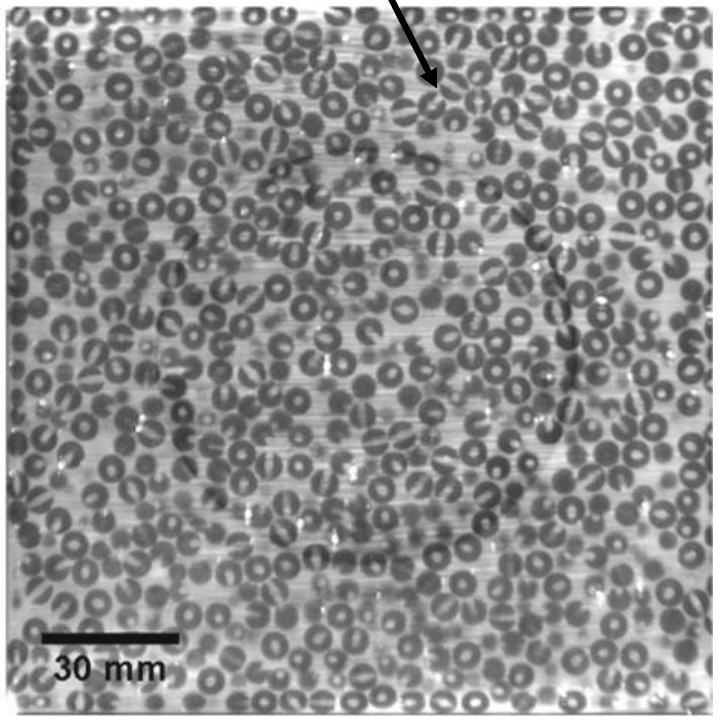


Rotating disk



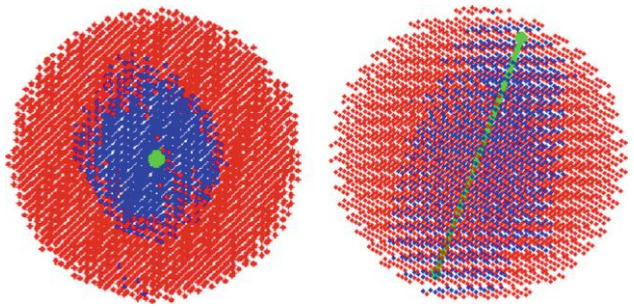
1.5 mm drilled hole

Fluid within hole lights up



Hole introduces 0.929 anisotropy

Extraction

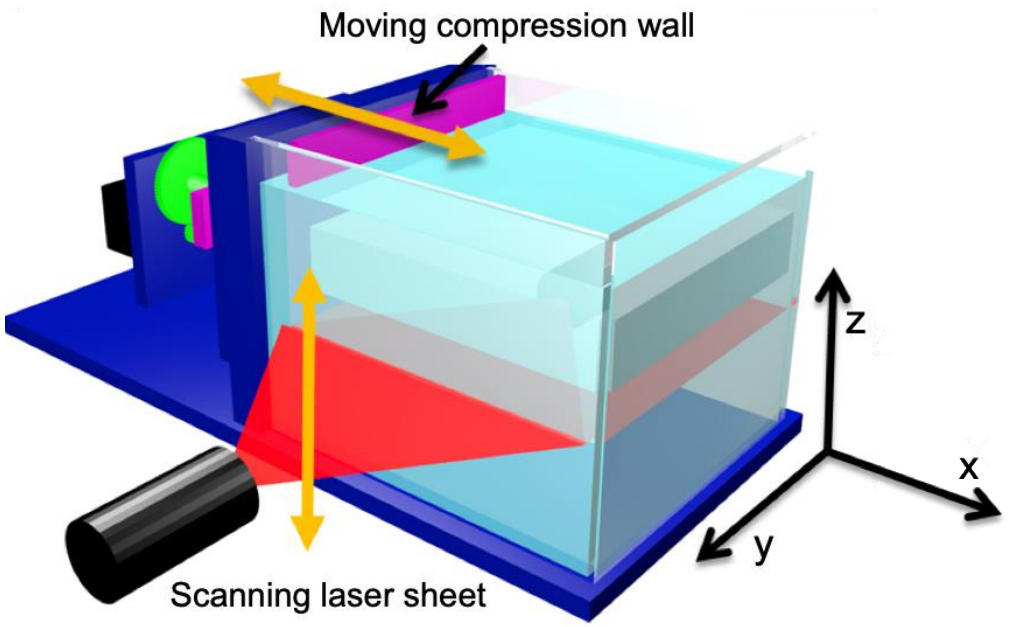


PCA analysis done on blue (bright) pixels of each bead gives orientation

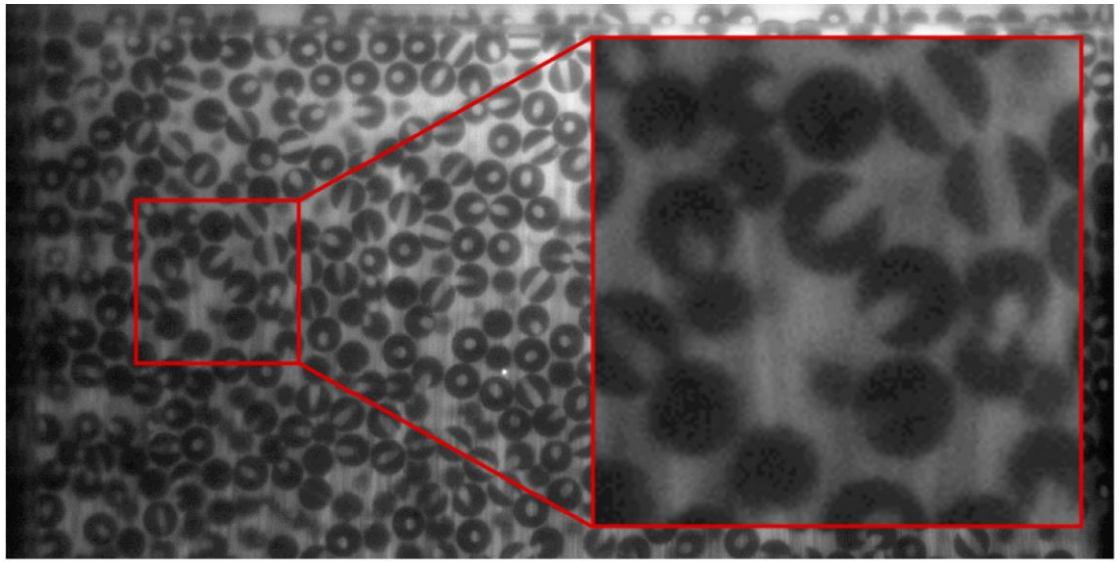
Green line -> extracted orientation

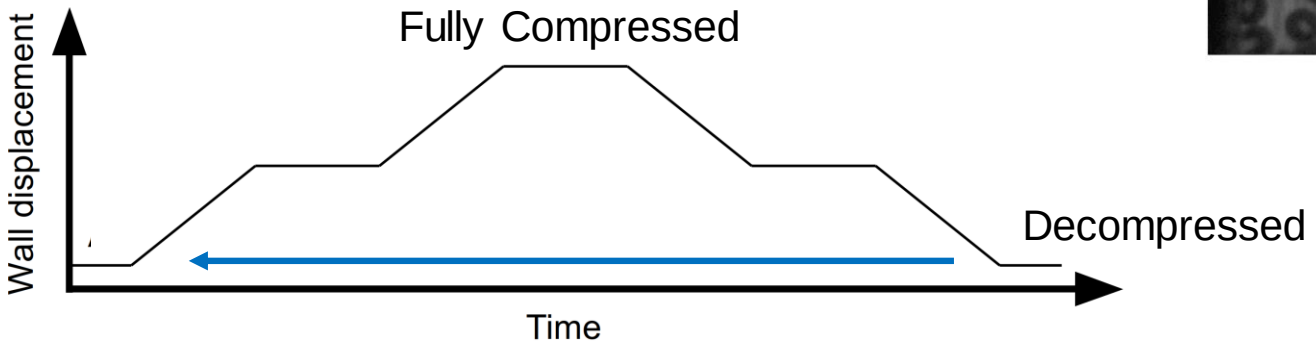
Matt Harrington et. al. *Granular Matter*, **16** (2014) 185-191

Capturing 3D rotational motion during cyclic compression



Material: 20,000 acrylic beads (n=1.49)
Fluid: Triton X100
Compression amplitude: 2% (~0.3cm)





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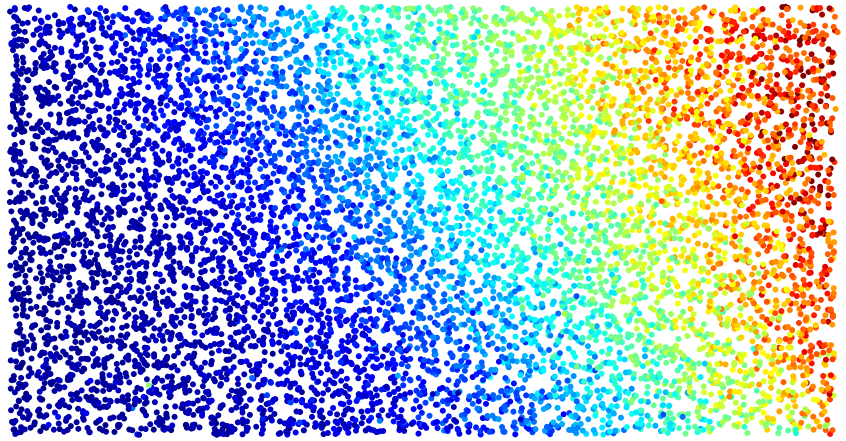
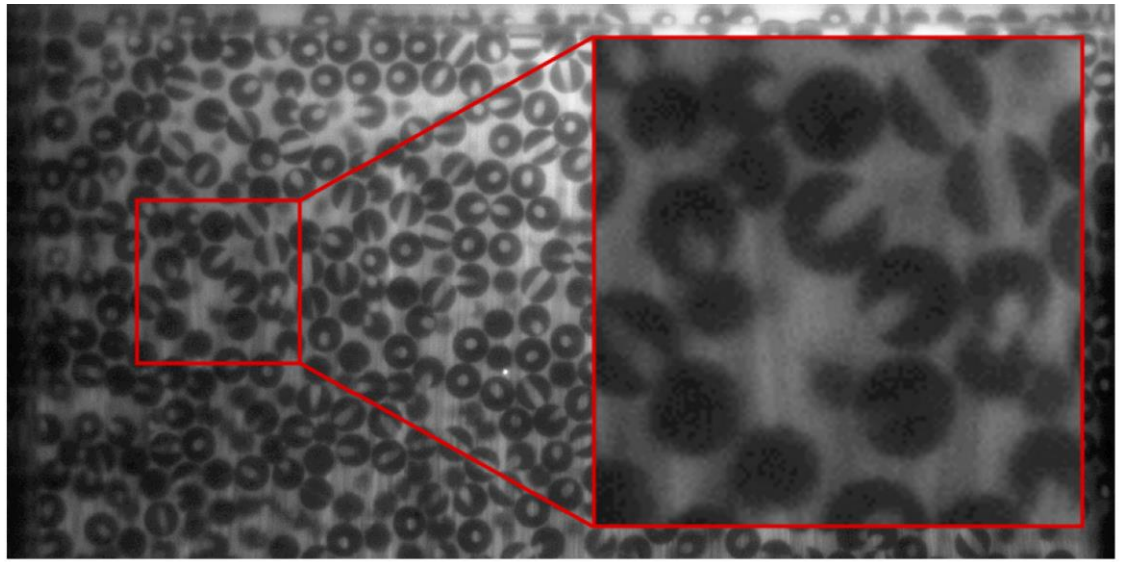
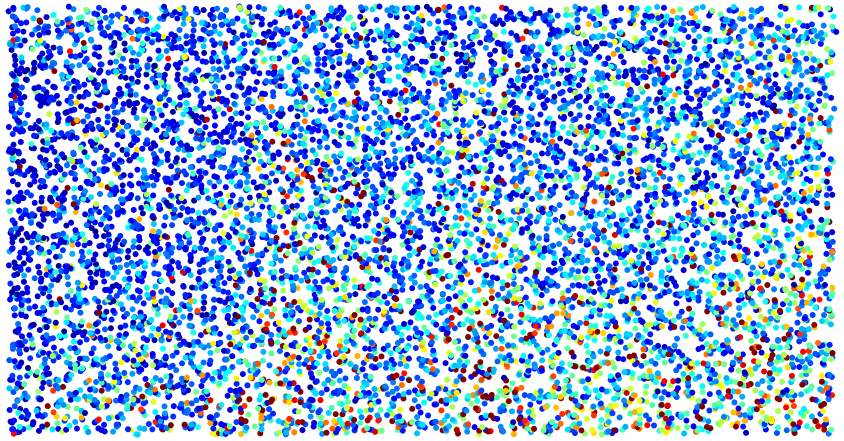
Mid Cycle Motion



Track positions



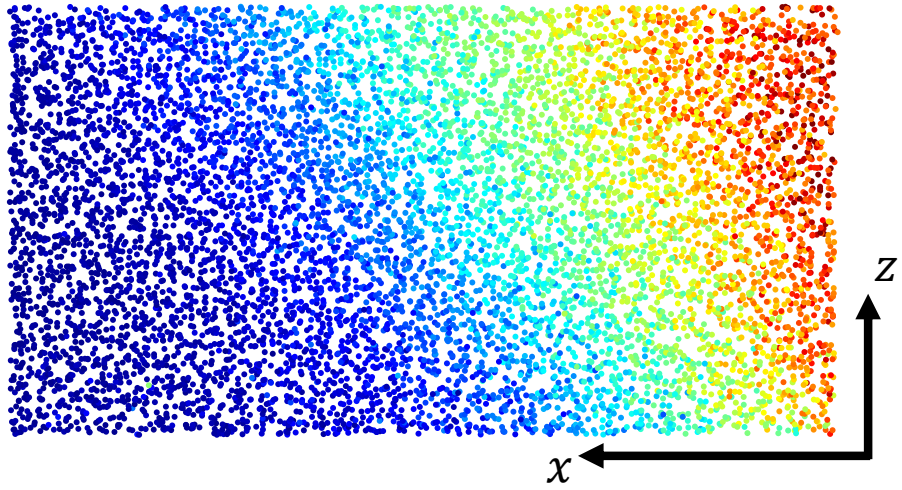
Mid Cycle Rotations

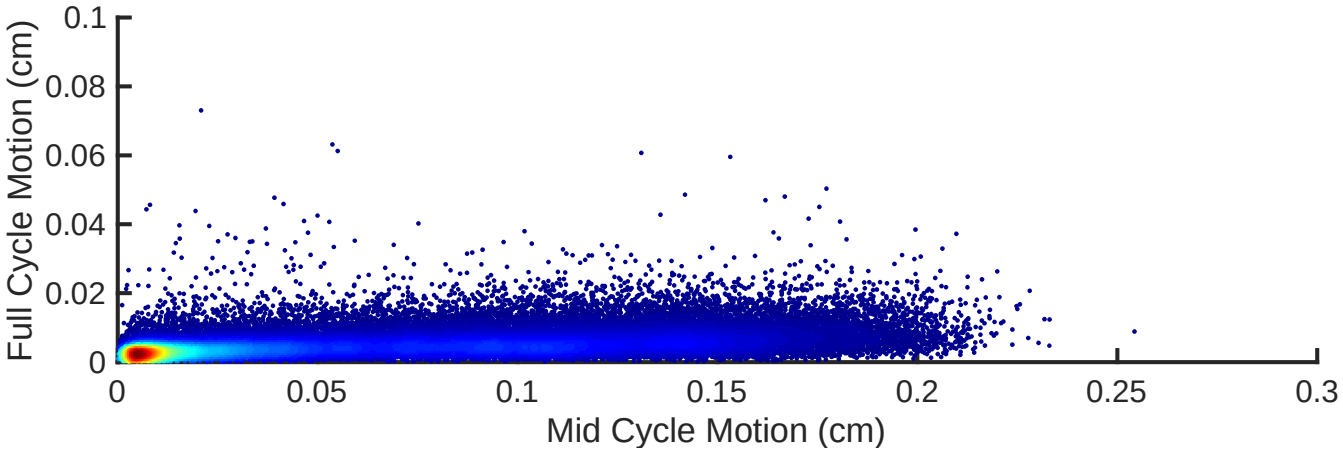


Track orientations

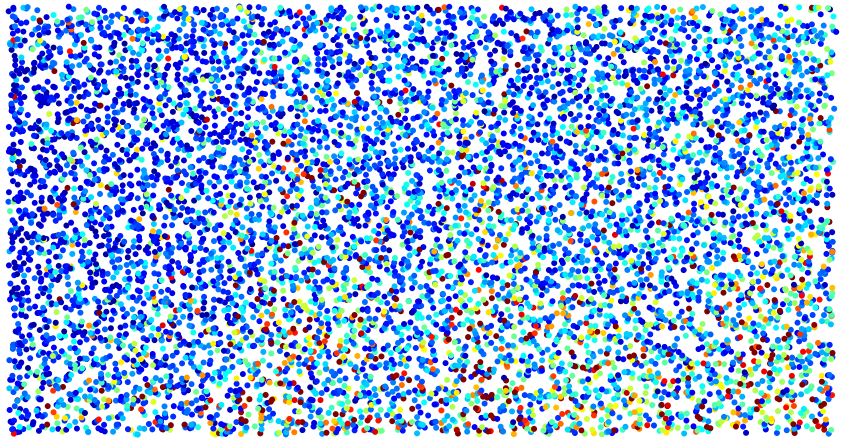
Tracking individual grains positions and orientations

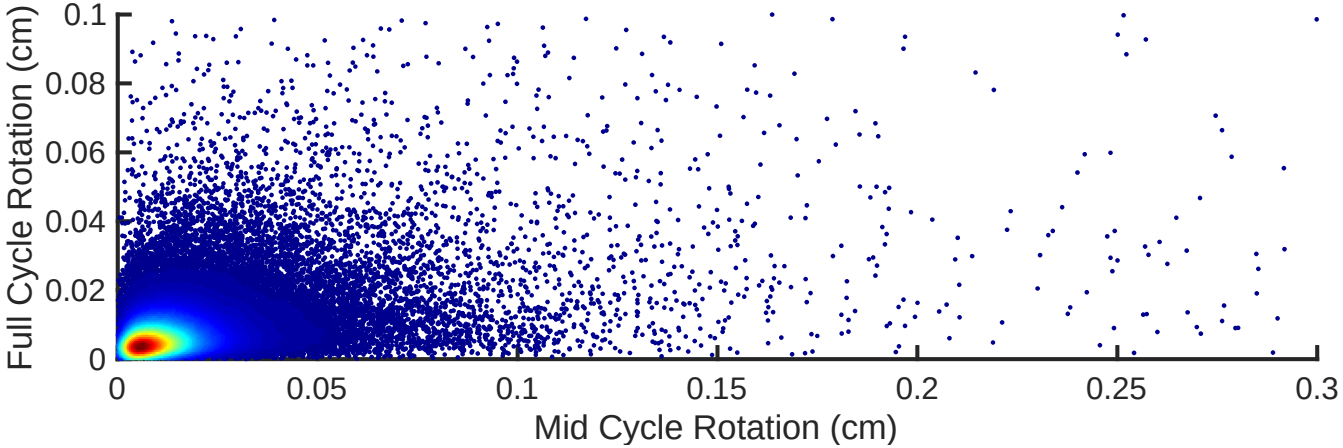
Mid Cycle Motion





Mid Cycle Rotations

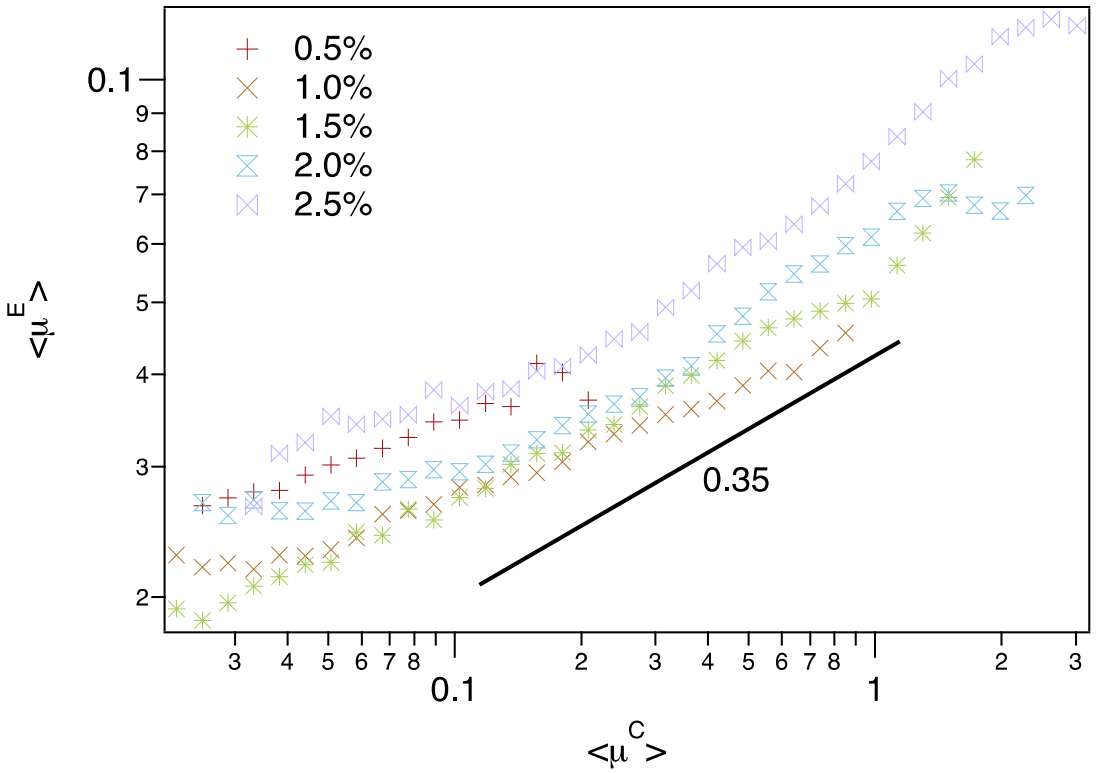




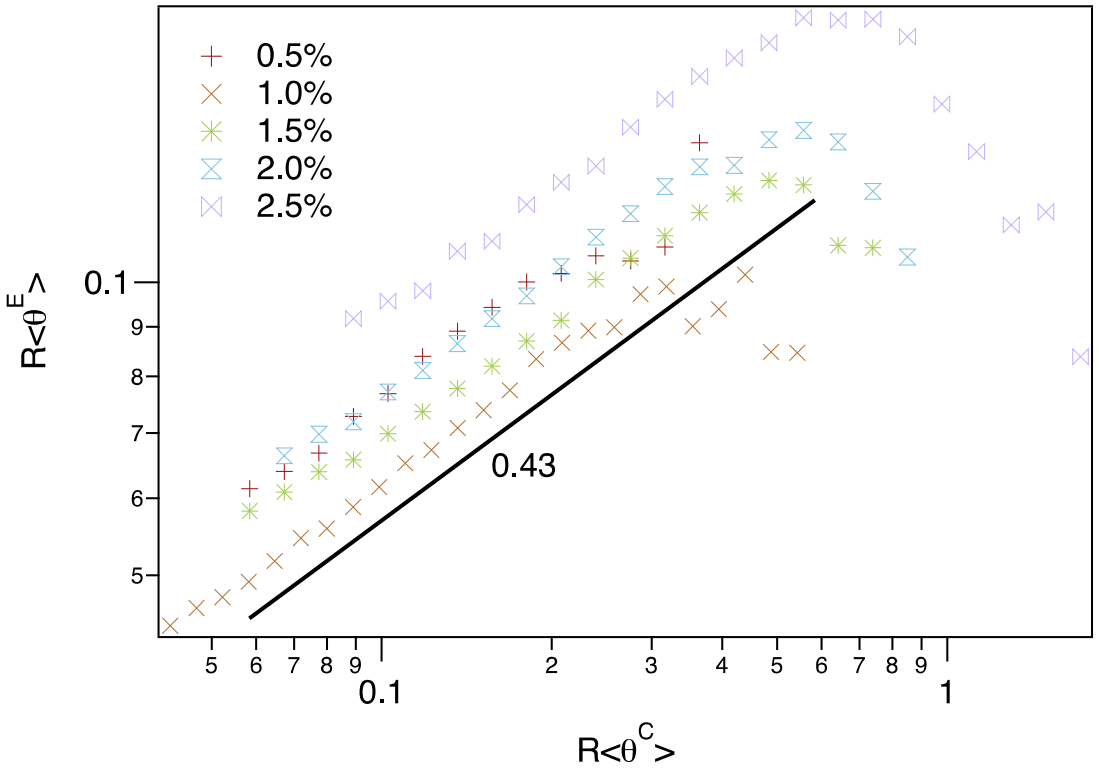
A. Peshkov et. al. https://arxiv.org/abs/1810.12985

Universal power law for different compression amplitudes

Translations

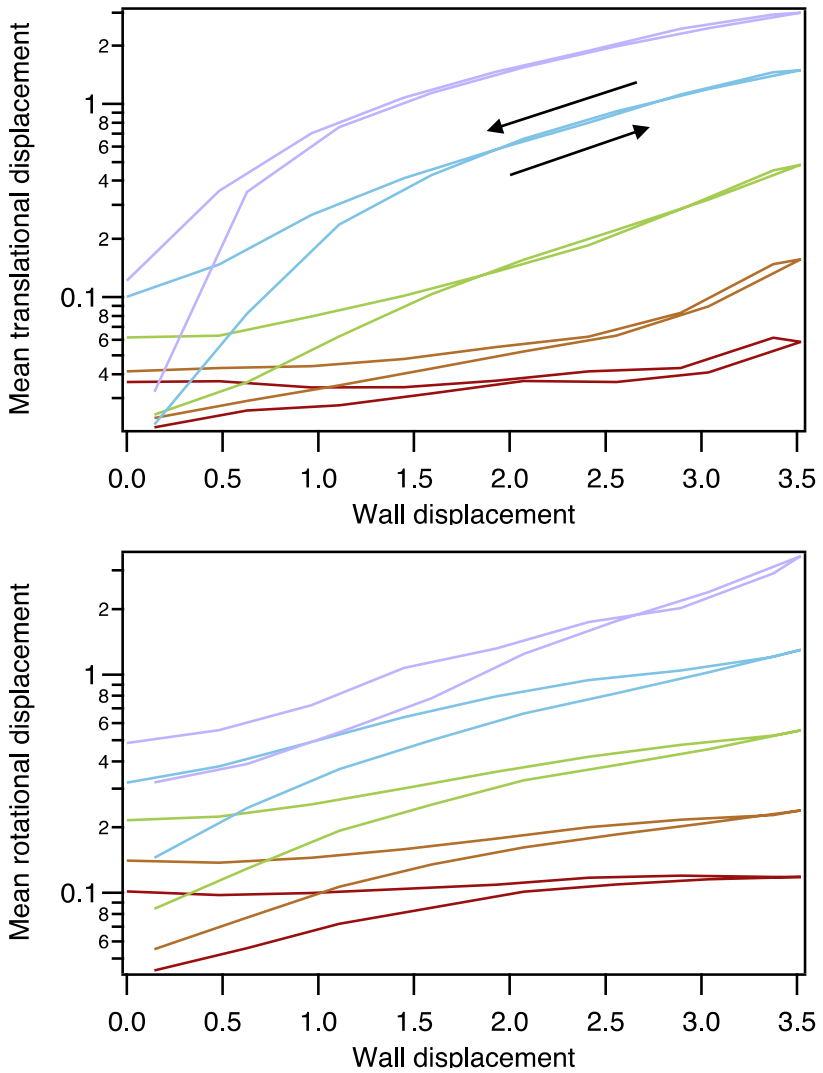


Rotations



Both exponents being <1 indicates more reversible motion the farther you move in the cycle

Network dynamics and hysteresis provide insight in irreversibility



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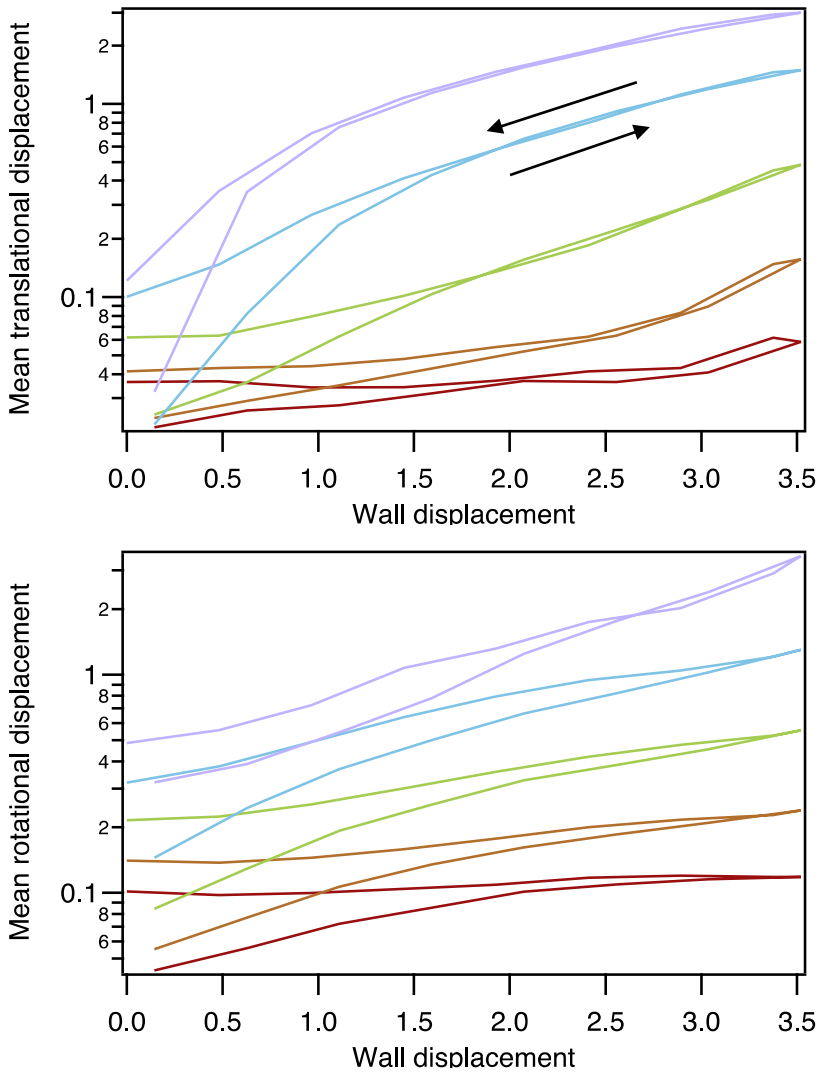

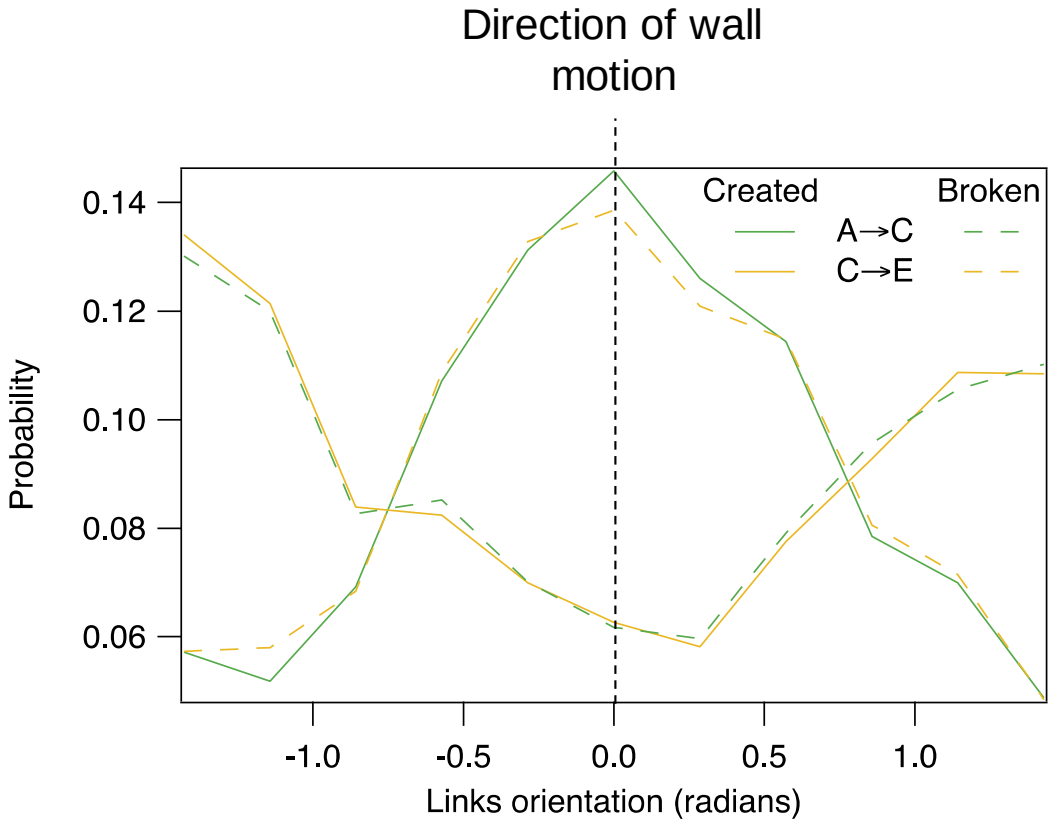

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Experimental setup and image

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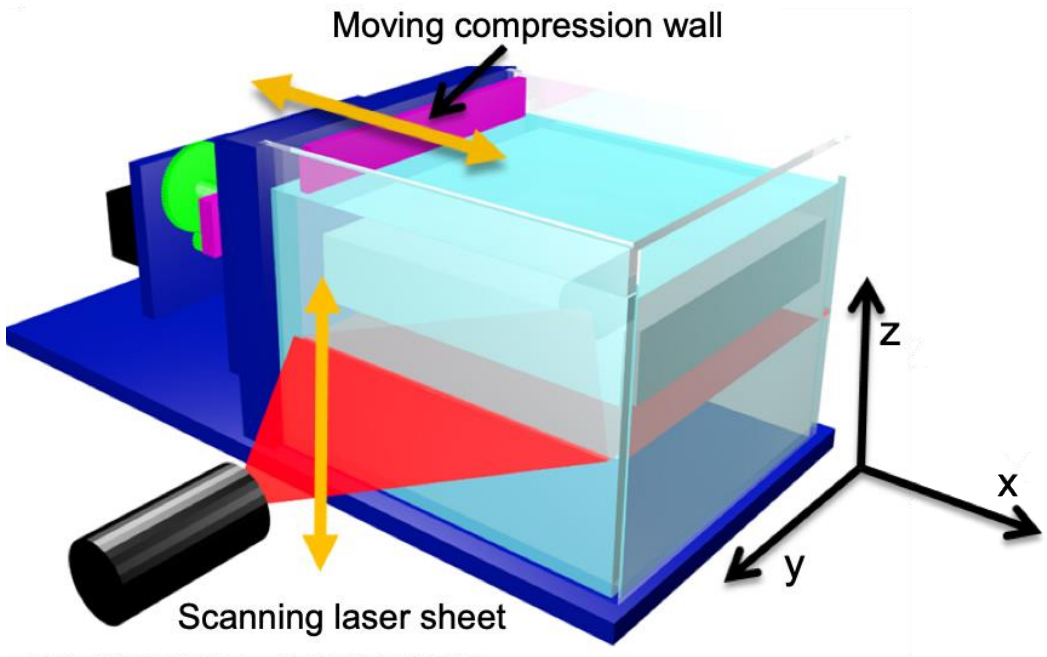
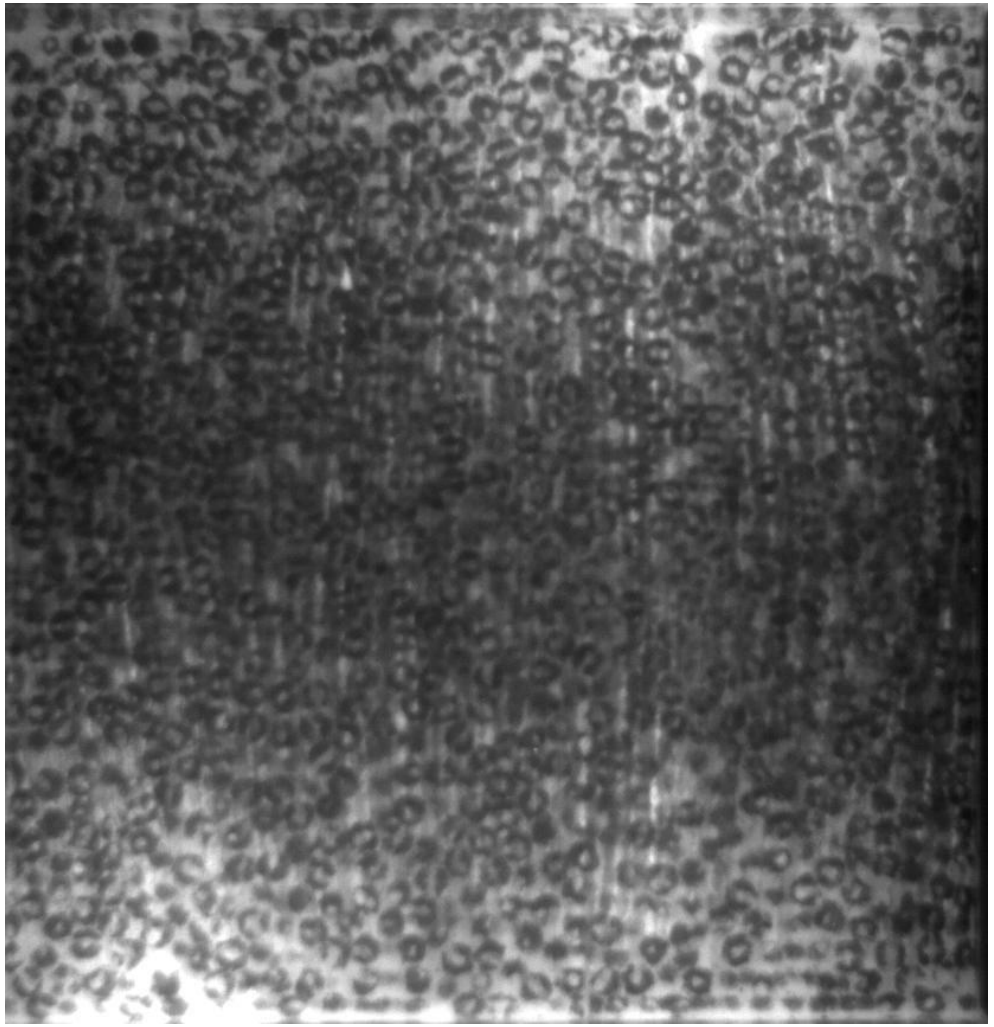
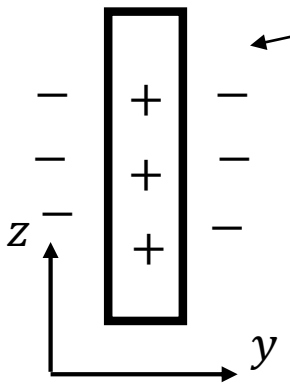


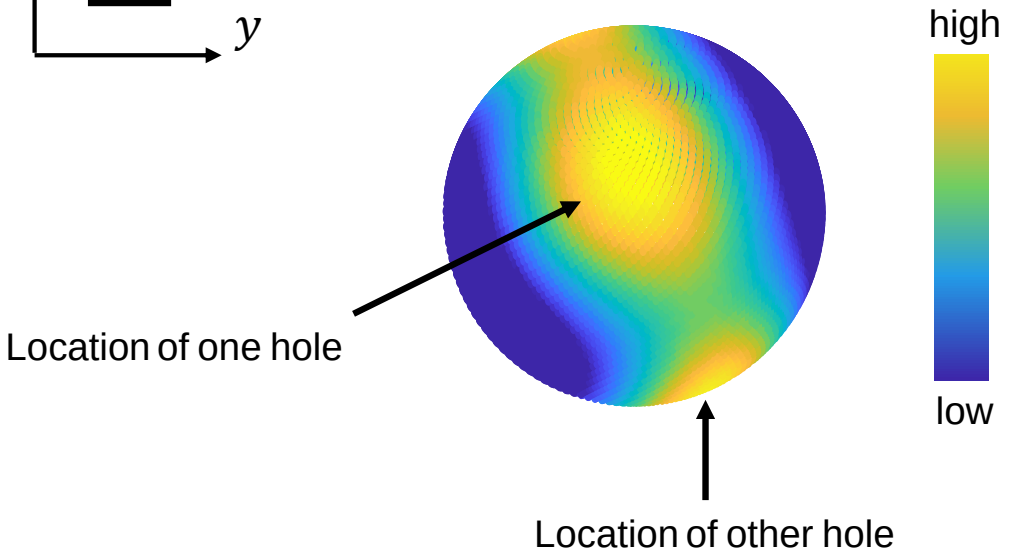


Experimental Analysis

$$f(\bar{x},\bar{y},\bar{z}) = (\bar{x}^2+\bar{y}^2-1)e^{-\frac{r^2}{2}}$$



$$\bar{x} = \frac{x}{r_{hole}} \qquad \bar{y} = \frac{y}{r_{hole}} \qquad \bar{z} = \frac{z}{r_{bead}}$$



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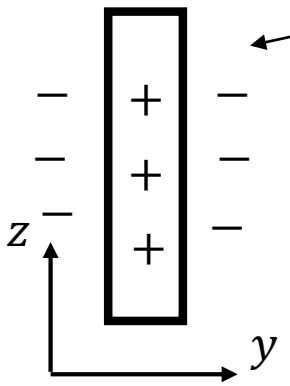

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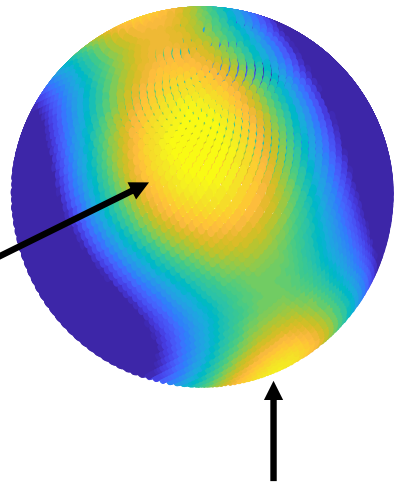

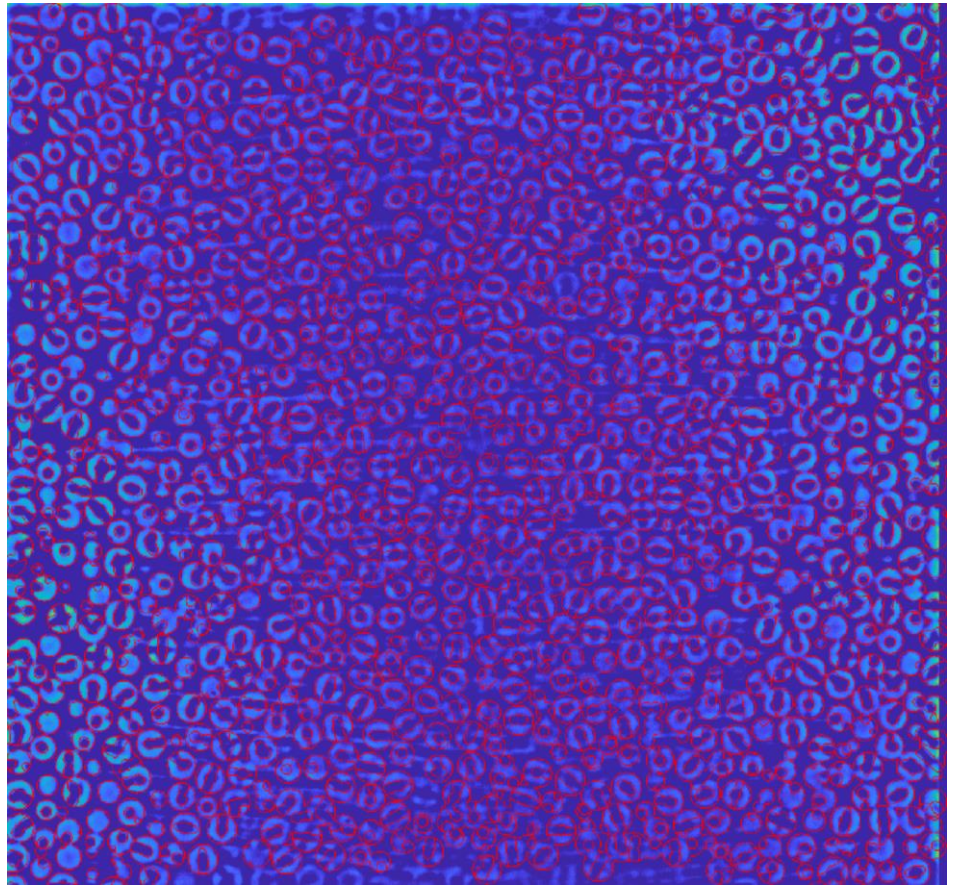

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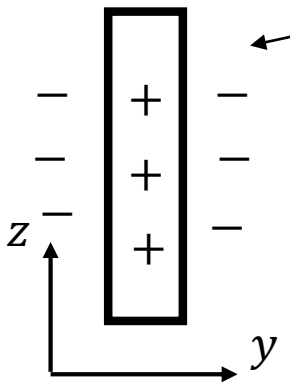

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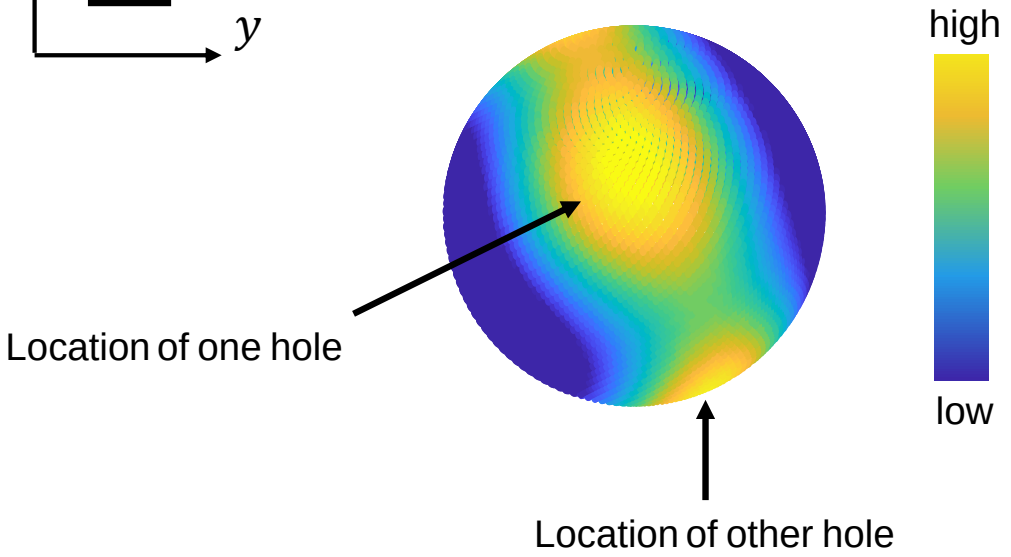
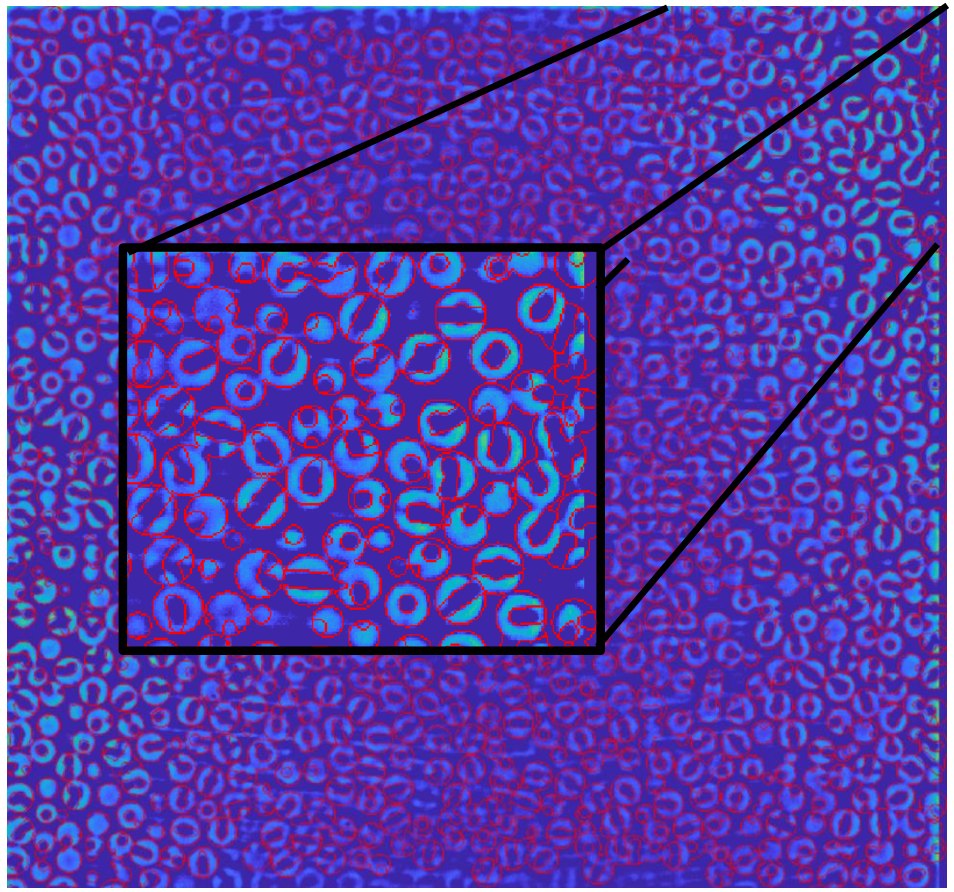
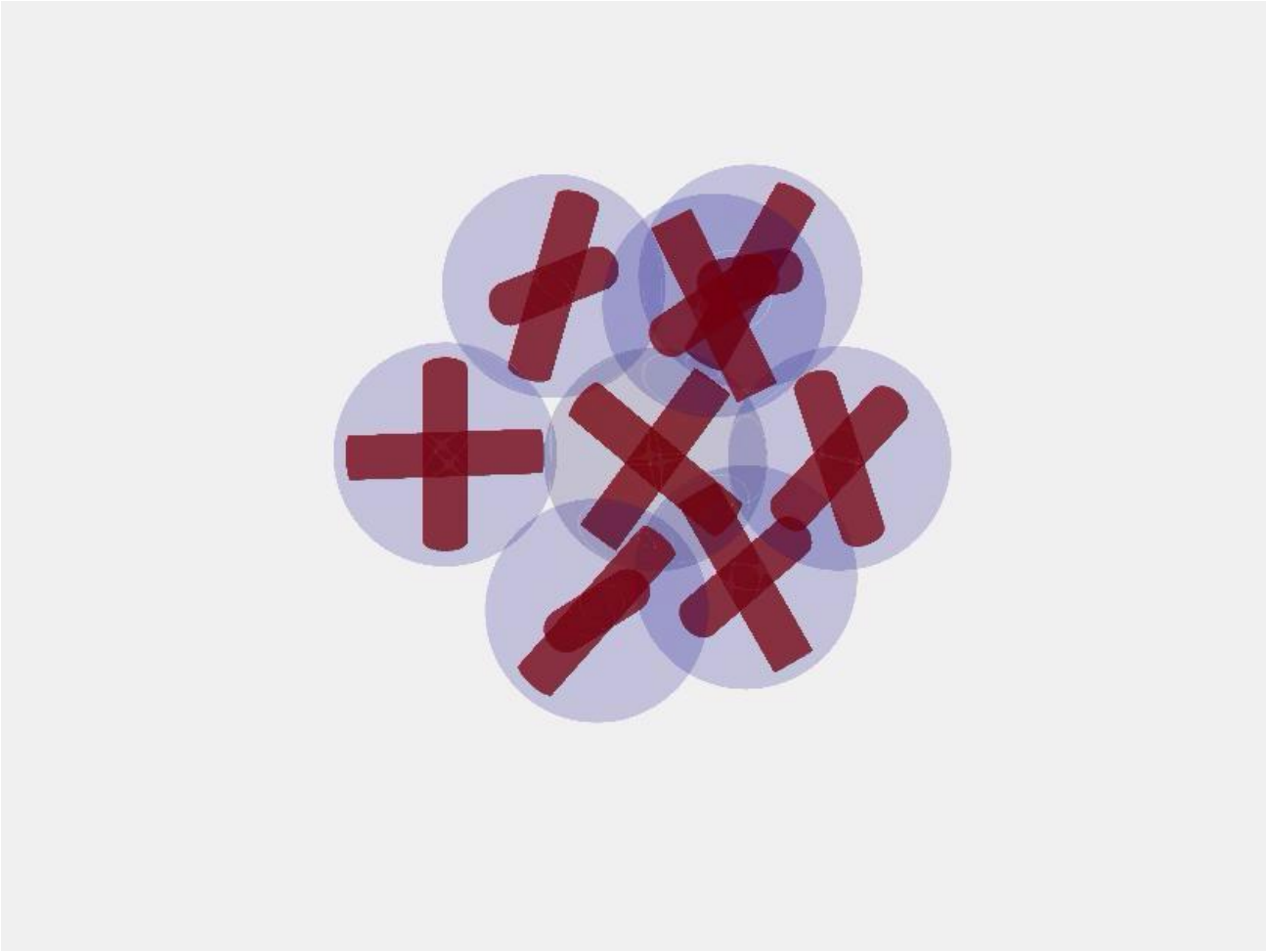




Visual reconstruction of collective rotations



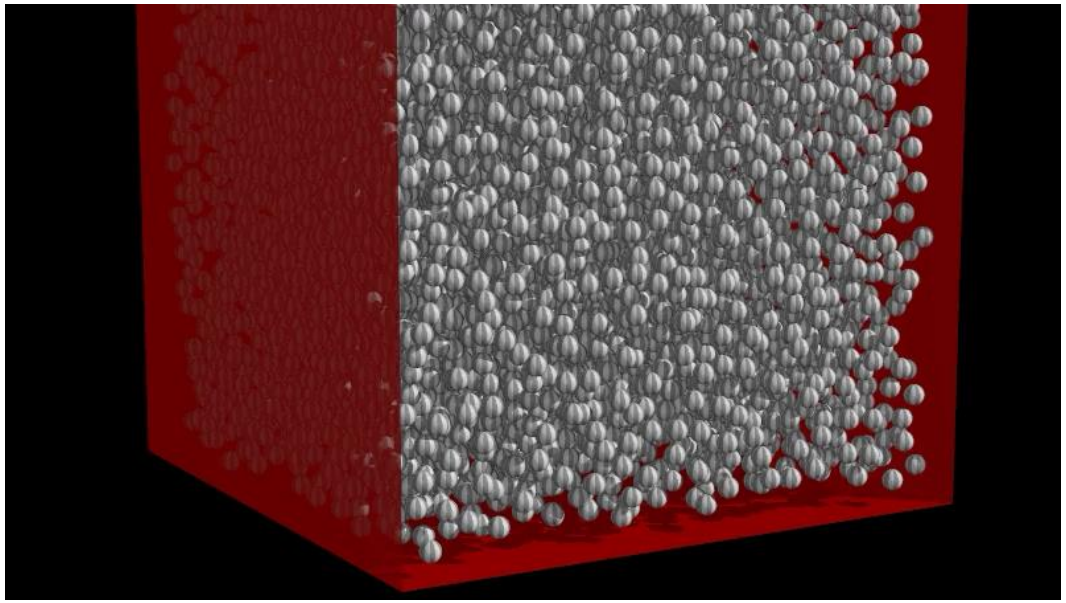
Simulation Setup

Soft spheres used with spring constants such that grains have < 1% overlap

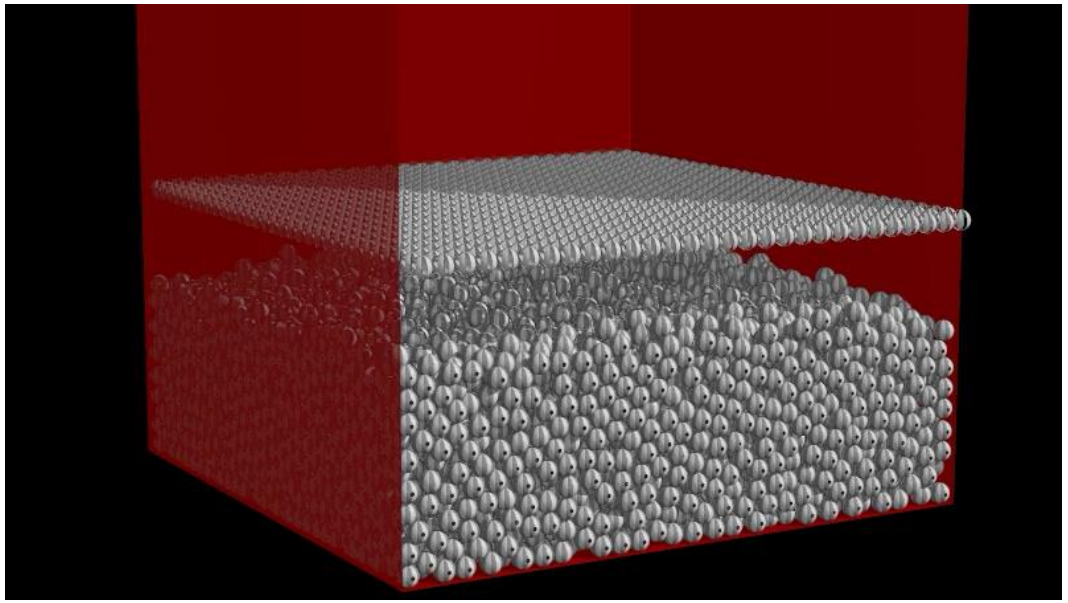
Rotational model includes static, rolling and twisting friction

Parameters:
- Spring constants
- Restitution
- Friction coefficients (μ_S, μ_R, μ_T)

Dropping beads for initial packing

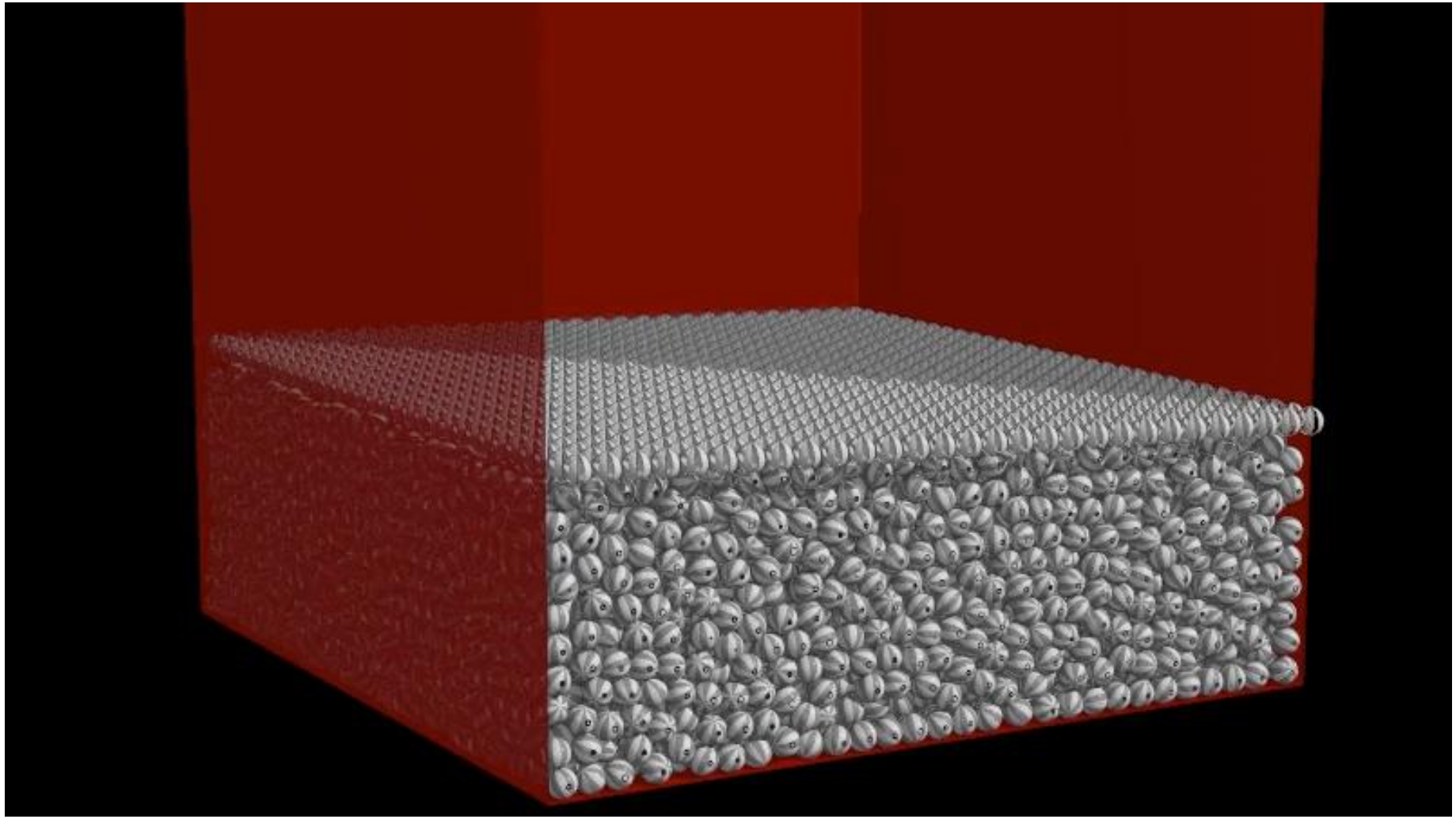


Dropping top weight for confining pressure

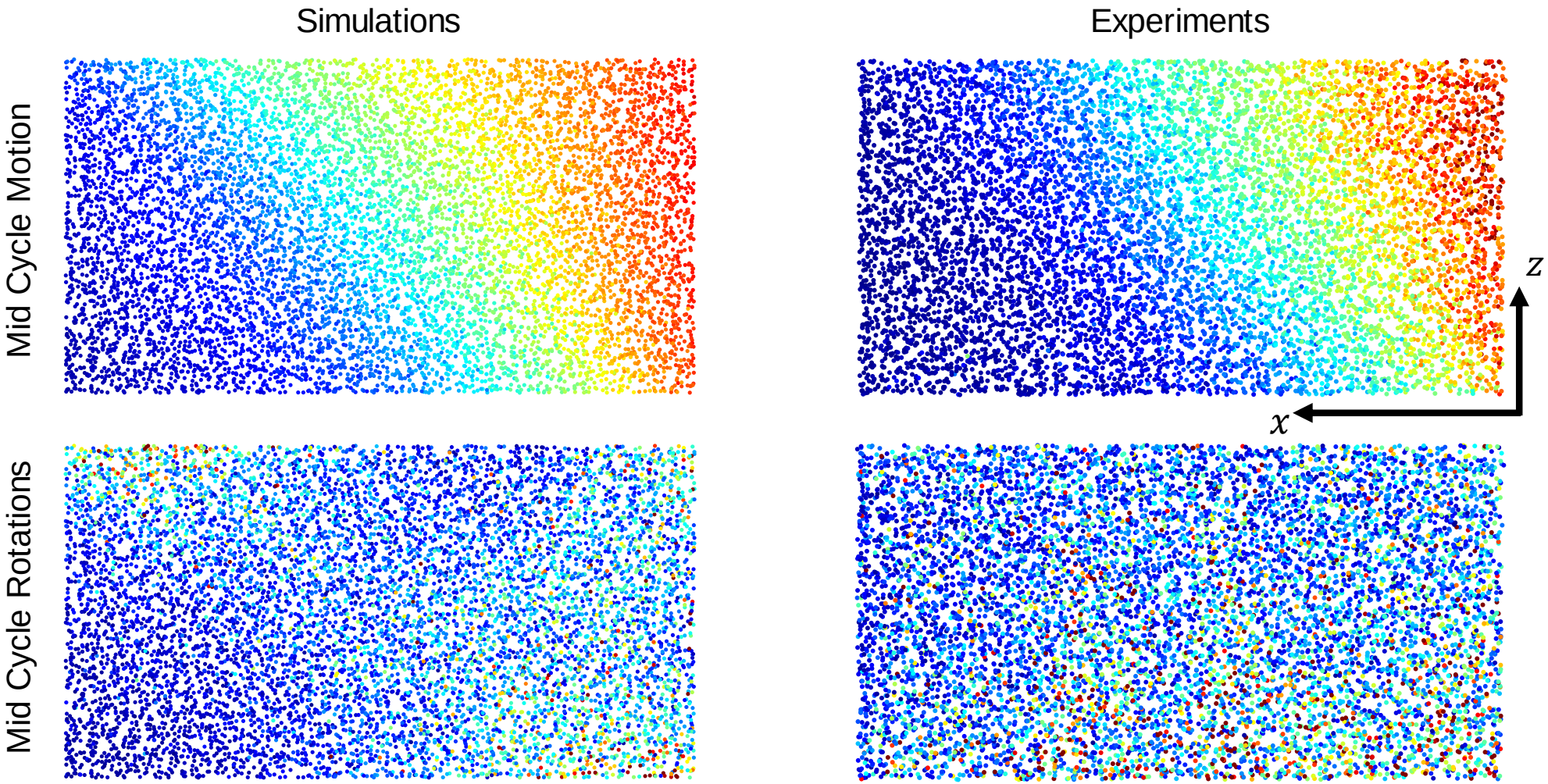


S. R. Schwartz, D. C. Richardson, P. Michel. *Granular Matter*. **14**. (2012). 363 - 380

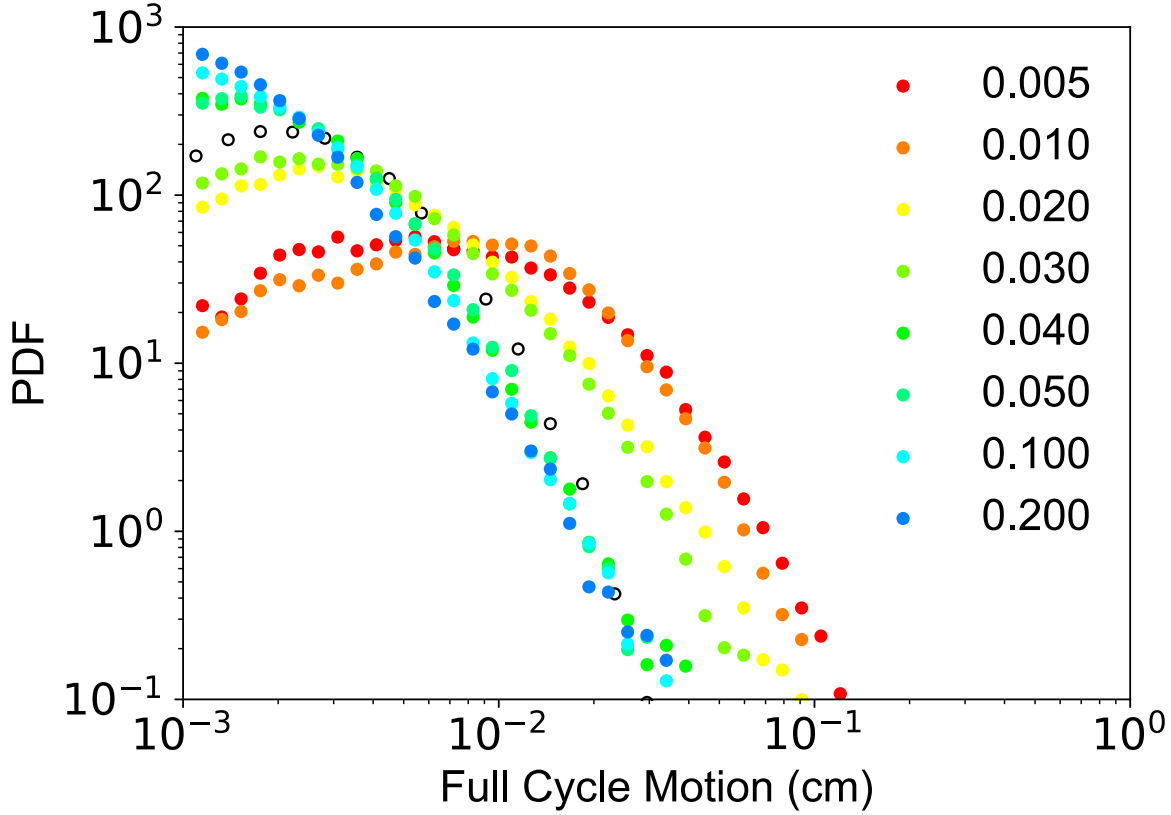
Simulation movie

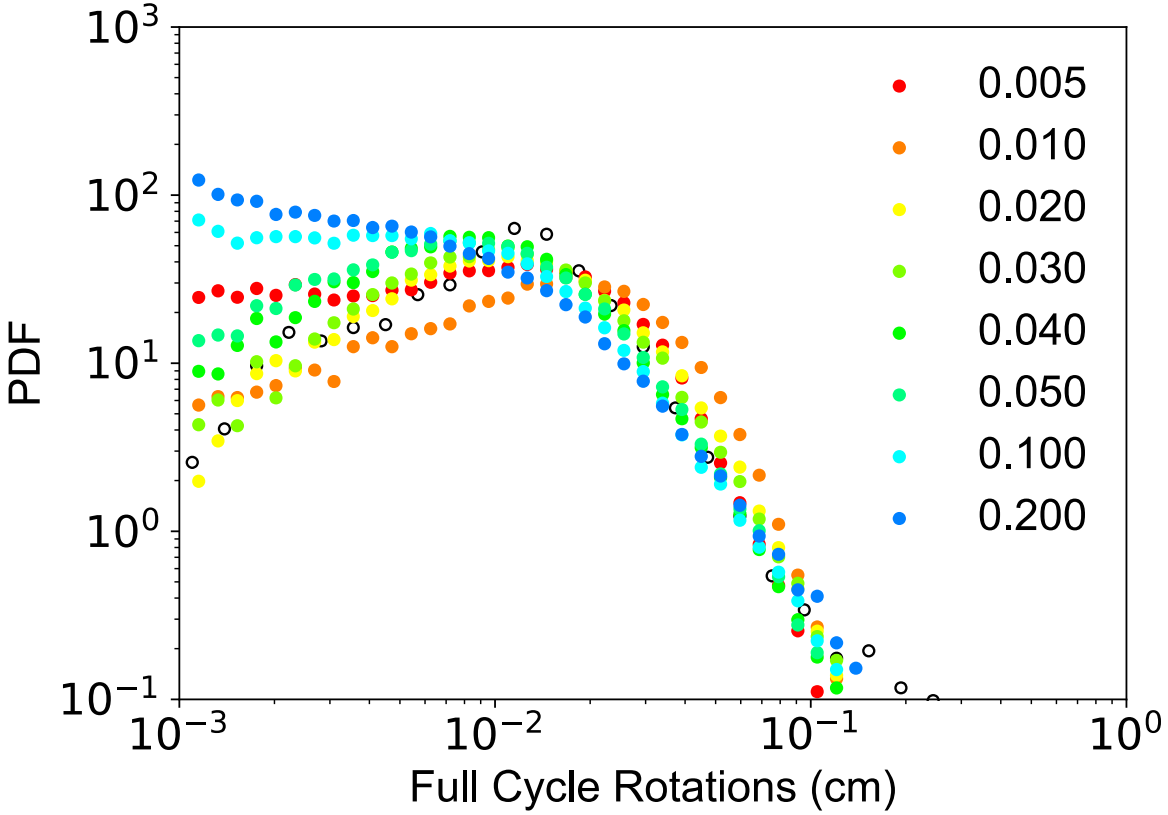


Experimental Results – tracking cycle motion and rotations



Comparing Reversibility vs Friction





Conclusion and Acknowledgements

Experimentally measured full 3D rotational motion of spherical grains during cyclic compression

Translations are reversible whereas rotations are not

Irreversibility could be due to asymmetry in contact network dynamics

Currently working on measures for collective rotations and their networks

Acknowledgements

Wolfgang Losert
Phillip Alvarez
Samira Aghayee
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Lea Delance
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