Characterizing Granular Material Dynamics in Micro-G

ASGSR Puerto Rico 2024

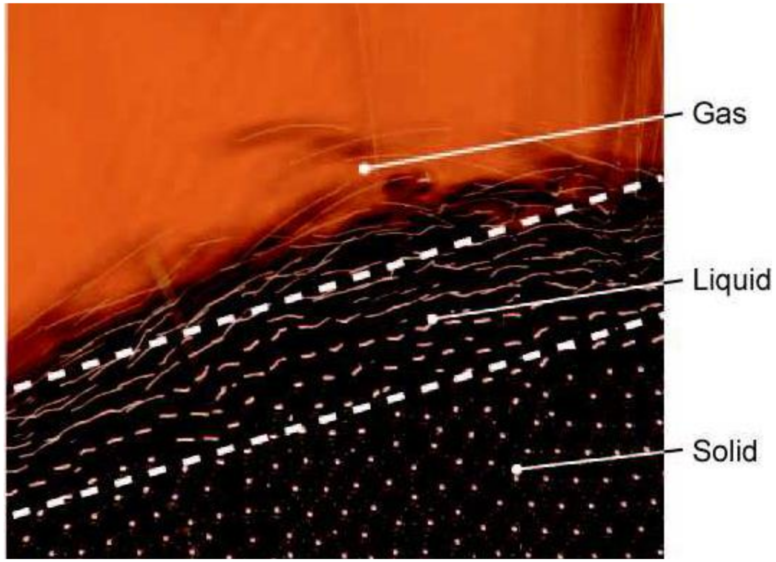
Ian Madden[1,3] , Amine Missaoui[1,3], Sathyashri Muruganandam[2,3], Emily Johnson[3] Suman Sinha Ray[1,3]

1- USRA, 2- University of Texas Austin, 3- NASA GRC ,

Granular Behavior is Highly Variable

Barale, L. *Int J Earth* (2015).

OSIRIS-Rex (Oct. 2020): NASA/Goddard/University of Arizona



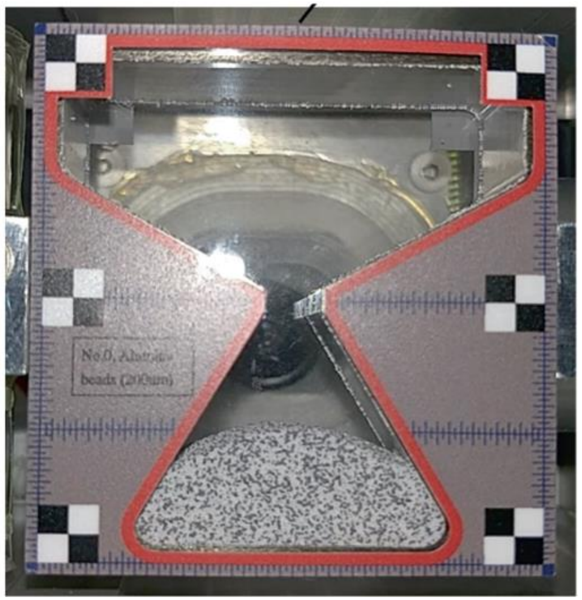
Forterre, Y. Flows of dense granularmedia. Annu. Rev. FluidMech (2008)

- Variability in part caused by the transition from static to dynamic behavior
- How does this transition from static to dynamic depend on material composition and gravity?

Simplified model of a granular material

Study the interplay between gravity and material properties in a simplified Molecular Dynamics (MD) model of a prototypical granular system

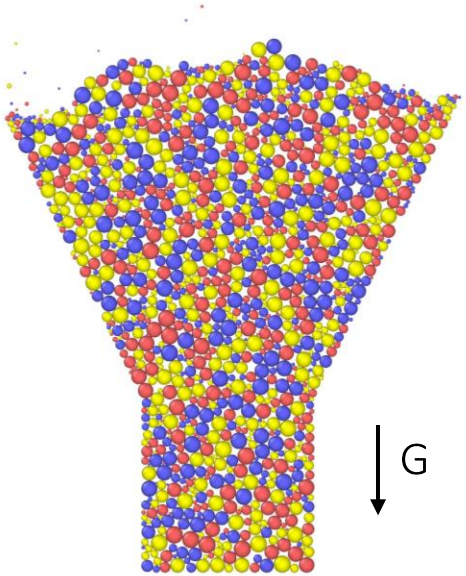
Prototypical experiment



Ozaki, S. npj Microgravity (2023)

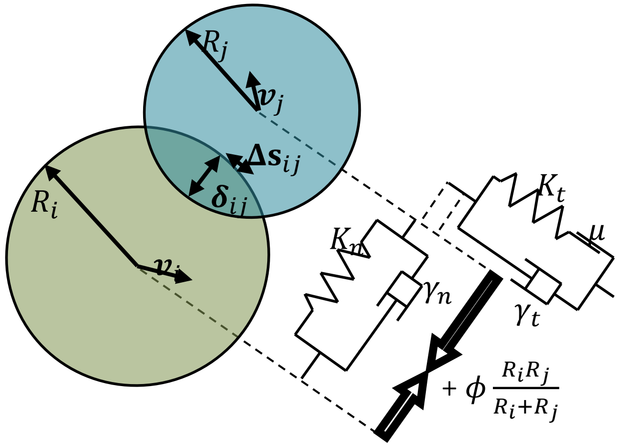
- Psuedo-2D hour-glass
- Filled with various sands
- Hour-glass is flipped and flows are recorded

Simple MD model



- 2D Funnel
- Filled with a monolayer of polydisperse spheres
- Funnel is unplugged and grains flow out

Simplified model of a granular material



Forces between particles i and j follow the DMT style:

$\mathbf{F_{ij}} = \mathbf{F_n} + \mathbf{F_t}$, *normal force + tangential force*

$$\mathbf{F_n} = \begin{cases} \mathbf{0} & \boldsymbol{r_i - r_j > R_i + R_j} \\ \mathbf{F_{spring}} - \mathbf{F_{damp}} - \mathbf{F_{VDW}} & \boldsymbol{r_i - r_j \leq R_i + R_j} \end{cases}$$

$\mathbf{F_t} = -\min(\mu\mathbf{F_n}, \mathbf{F_{t_{damp}}})$, *coulombic friction*

$\mathbf{F_{spring}} = -\mathrm{k}\mathbf{r_{ij}}^{\frac{3}{2}}$, normal spring

$\mathbf{F_{damp}} = -\gamma m_{ij}\mathbf{v_{ij}}$, normal dashpot damper

$\mathbf{F_{VDW}} = 4\pi\phi\boldsymbol{R_{ij}}$, cohesive VDW like force

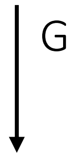
4 key variables : $\mathrm{k}, \gamma(\epsilon), \mu, \phi$

$\mathrm{k}, \gamma(\epsilon), \mu$ *are easily determined by material properties*

ϕ *is not so easily measured*

Simulation procedure

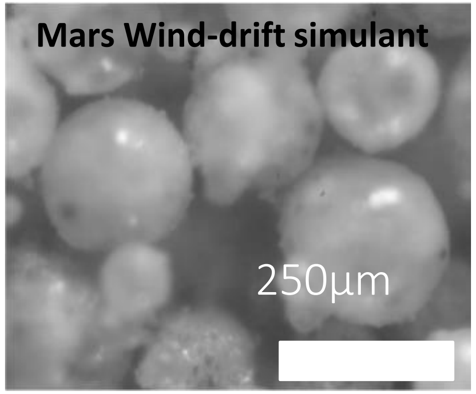
1. Funnel is empty and filled from top randomly with 1500 polydisperse spheres, R=(0.001mm-0.1mm).
2. Spheres pack randomly into plugged funnel
3. Plug is removed
4. Grains flow out
5. Flow pattern changes with variation in ϕ.

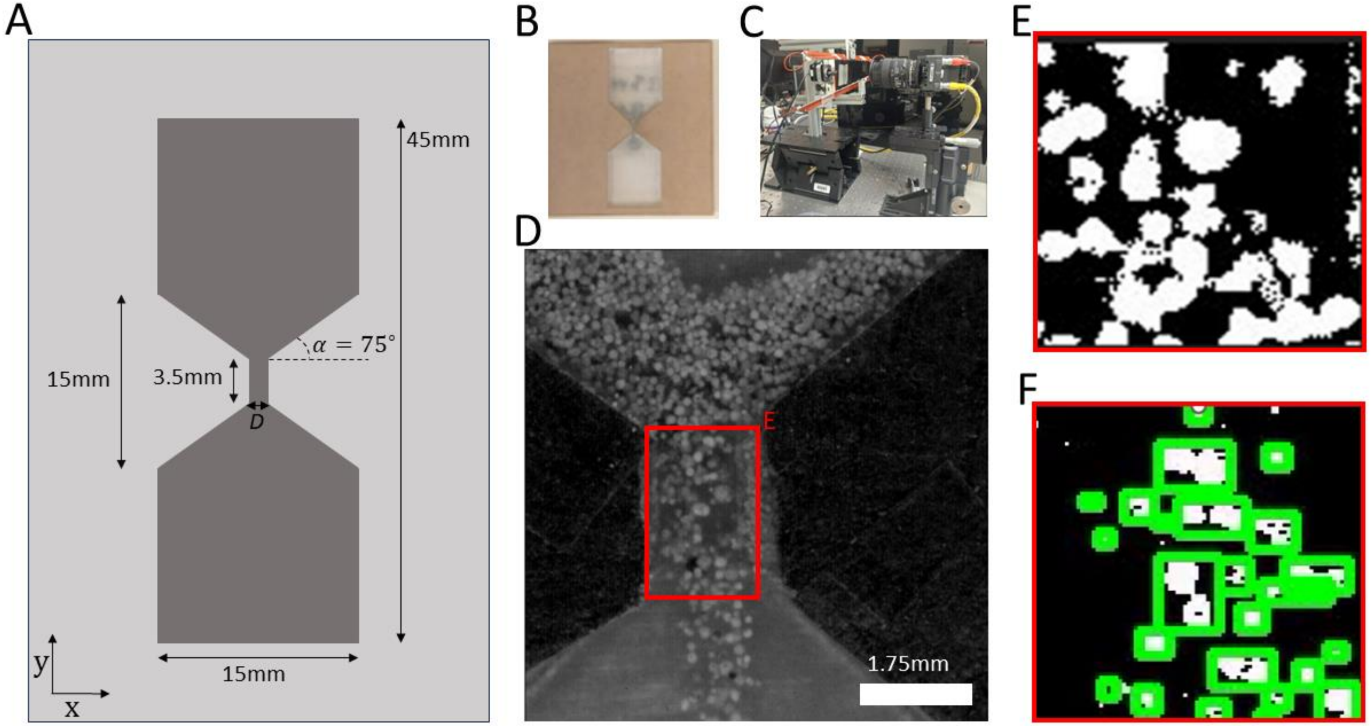


Calibrate ϕ with a simple experiment

Micro rheology experiment

1. Laser cut micro-2D hour-glass
2. Spherical regolith simulant: Mars Wind-drift
3. Grain detection and tracking algorithms
4. Match flow in experiment to simulation

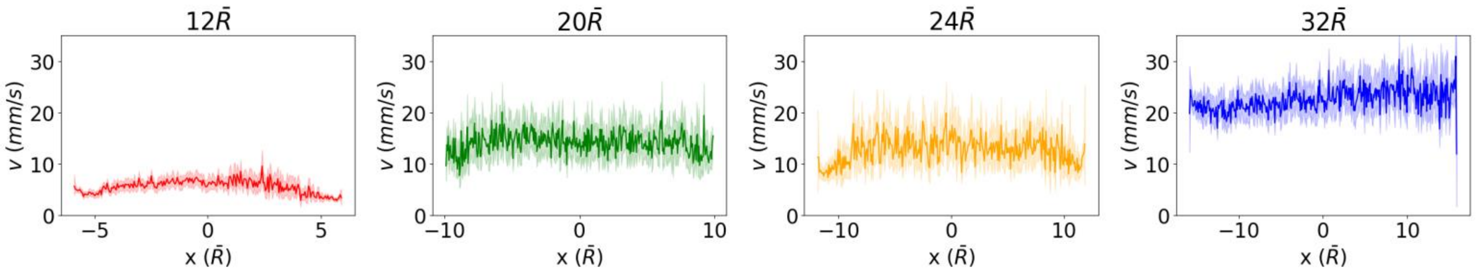




Flow profiles in experiment and simulation

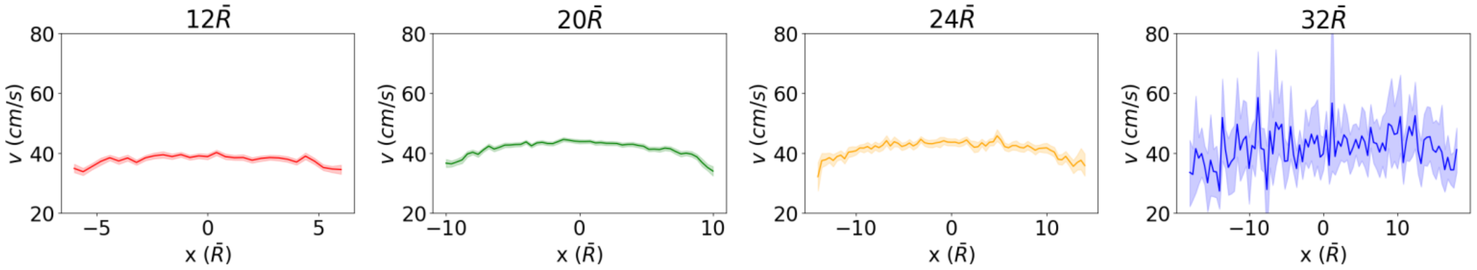
Experiment:

Particle flow profile changes in shape with variation in funnel opening diameter.



Simulation:

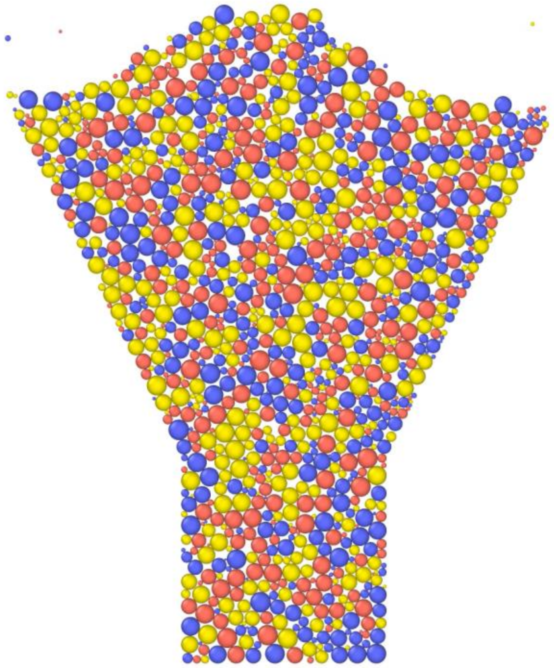
Materials with lower inter-particle cohesion shows a similar profile variation with varying funnel opening size *x*.



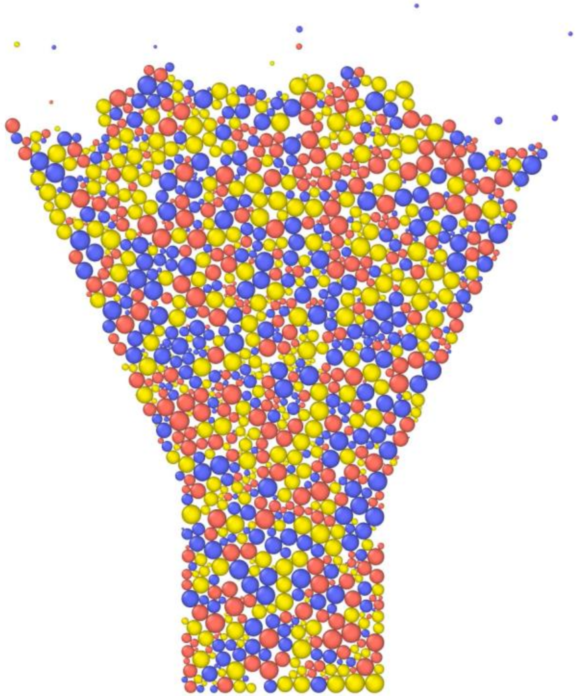
Extrapolate conditions in simulation.

With fixed ϕ we are free to vary G and other parameter in the simulation

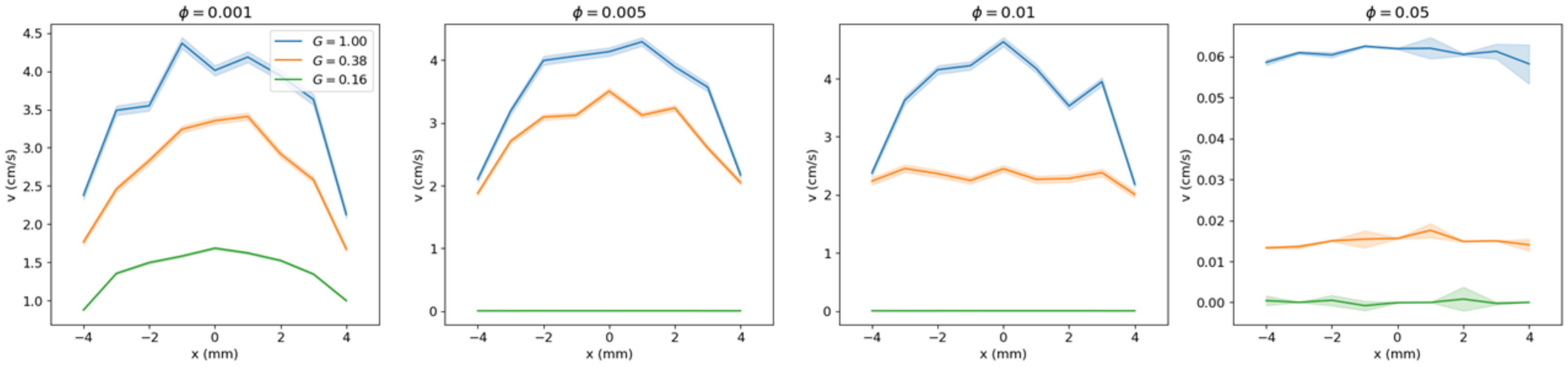
G=1.0

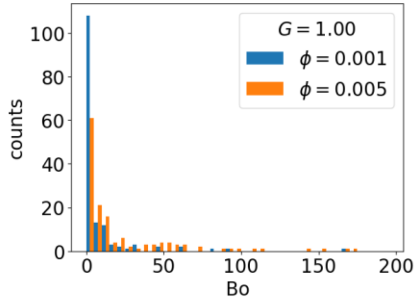


G=0.16

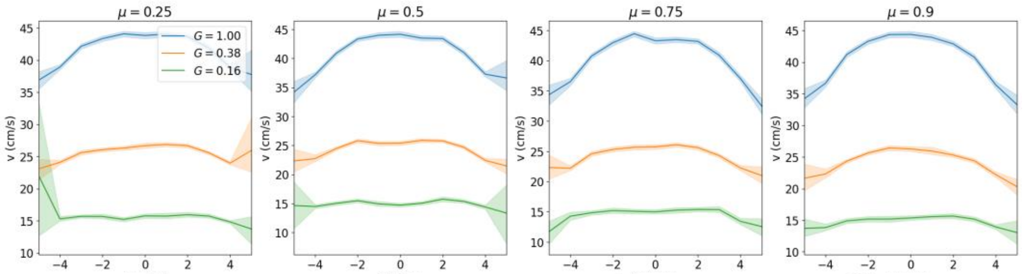


Tracking clogging/jamming onset

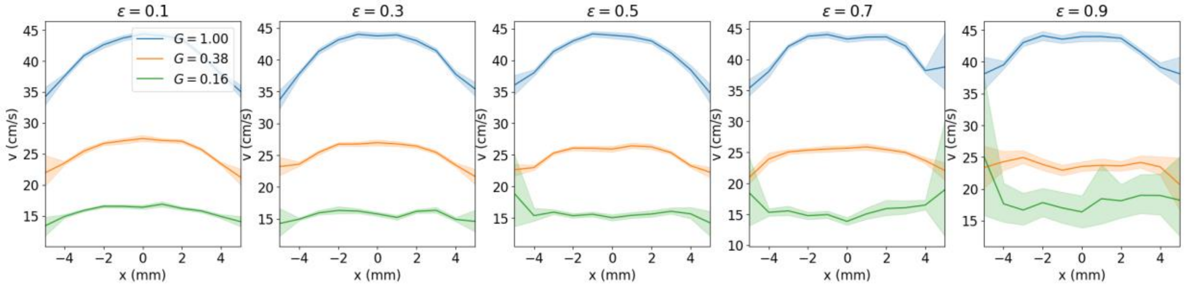




Flow is a function of cohesive force and G

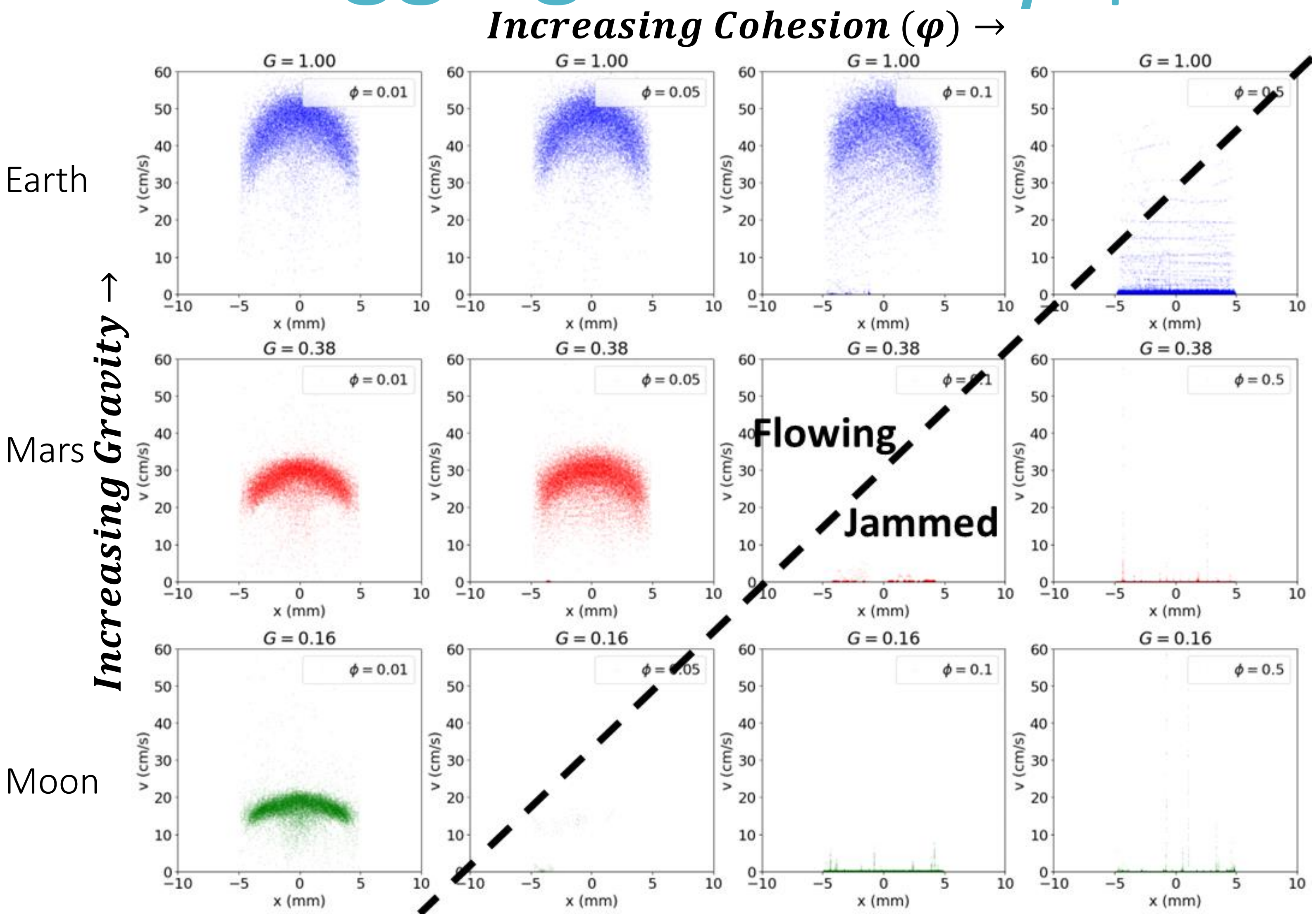


Friction: μ independent of variation in G

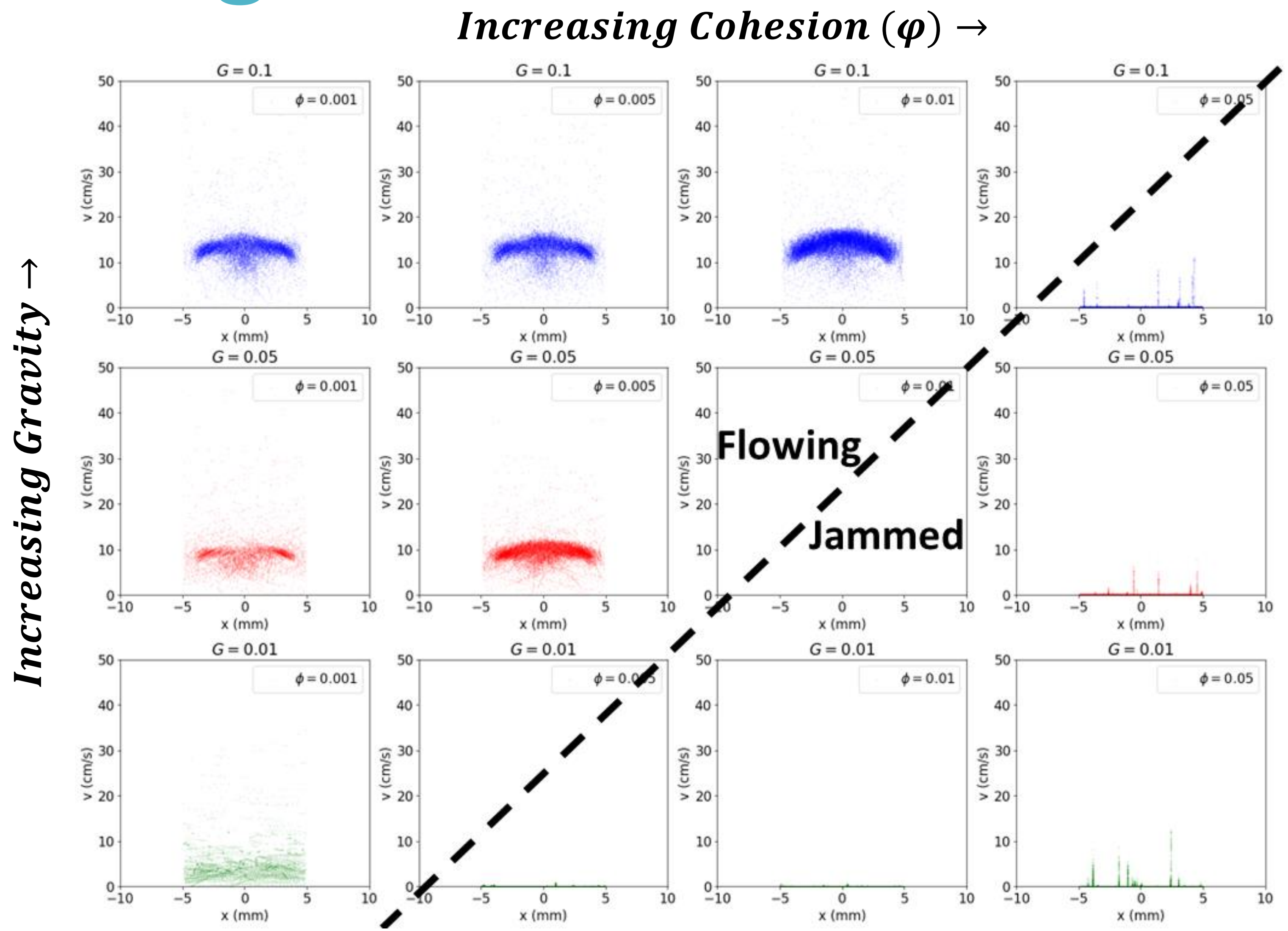


Coefficient of Restitution : $\gamma(\epsilon)$ weakly varies with G

Funnel clogging in the G-ϕ phase space



Trend is generalizable to lower G



Thank you

Acknowledgements:

- NASA Biology and Physical Sciences (BPS)
- NASA MUREP
- NASA's Office of STEM Engagement (OSTEM)

Dr. Amine Missaoui
(former post doc)

Sathya Muru
(Intern)

Dr. Suman Sinha Ray
(Lead Scientist)

Emily Johnson
(Ast, Eng. PM)