

Recent Advances in Soft Matter Characterization Capabilities Developed at NASA GRC for Lunar Exploration: Differential Dynamic Microscopy to Spectroscopy to Computer Vision

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Agenda

- Overview
 - ✓ Soft Matter Research at GRC
- Differential Dynamic Microscopy
- Computer Vision
- Conclusion & takeaways

NASA Centers



Glenn Research Center

Campuses

Lewis Field

1,500+ civil servants, 1,600+ contractors

Armstrong Test Facility

20+ civil servants, 100+ contractors



Our Focus of Soft Matter

We broadly focus on soft matter into two categories-

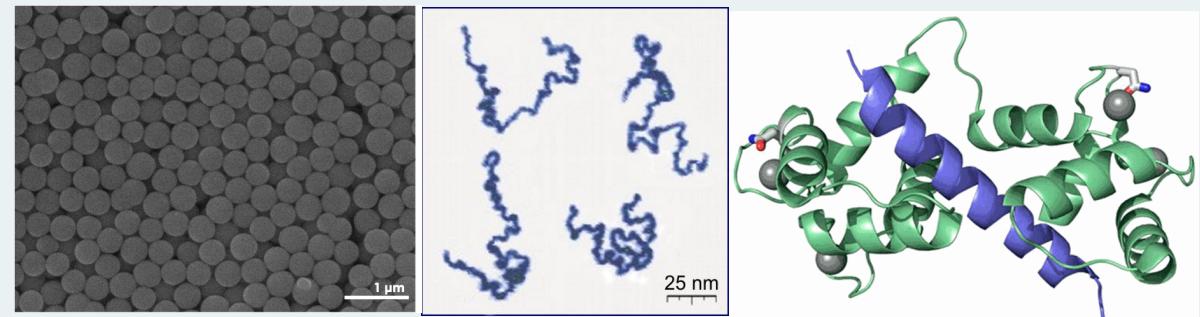
- ✓ Granular Media
- ✓ Active Matter

Granular Media



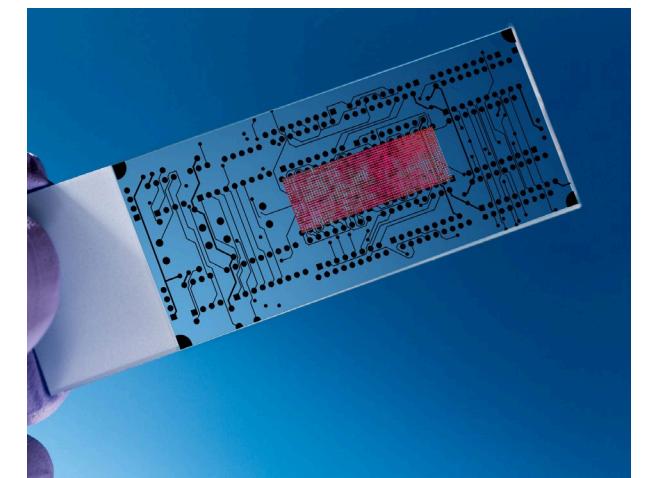
- ✓ Fundamental model describing rheology under different gravity conditions
- ✓ Understand impact of size, shape, electrostatic charge on flow behavior

Active Matter

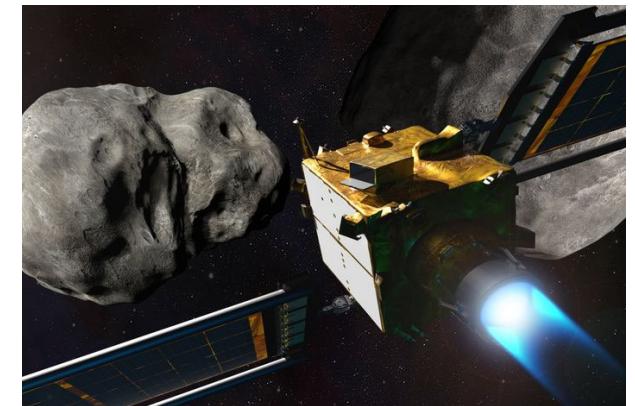


- ✓ Development of functional soft materials (e.g.- DNA functionalized colloidal particle)
- ✓ Understanding the interplay of competing microscopic forces in active matter

Fundamental soft active matter research is critical for diagnostics, affordable healthcare and food security



Fundamental
granular materials
research is critical
for exploration and
planetary defense





Micro and Reduced Gravity Platforms for Soft Matter Research

Challenges for soft matter research platforms are- footprint and upmass, complexity, data and lack of modularity

**Our focus is to
address the
shortcomings**

- Develop science-backed capabilities to improve scientific output for soft matter community
- Omni-platform (e.g.- ISS, CLD, Artemis etc.) capabilities
- AI/ML and computer- vision -based improved data analysis capability

Differential Dynamic Microscopy- Overview

DDM is an optical microscopy method that can use high speed imaging with data analysis to analyze soft active media (e.g.- colloidal particles, polymers, biological samples etc.)

Experimental Method

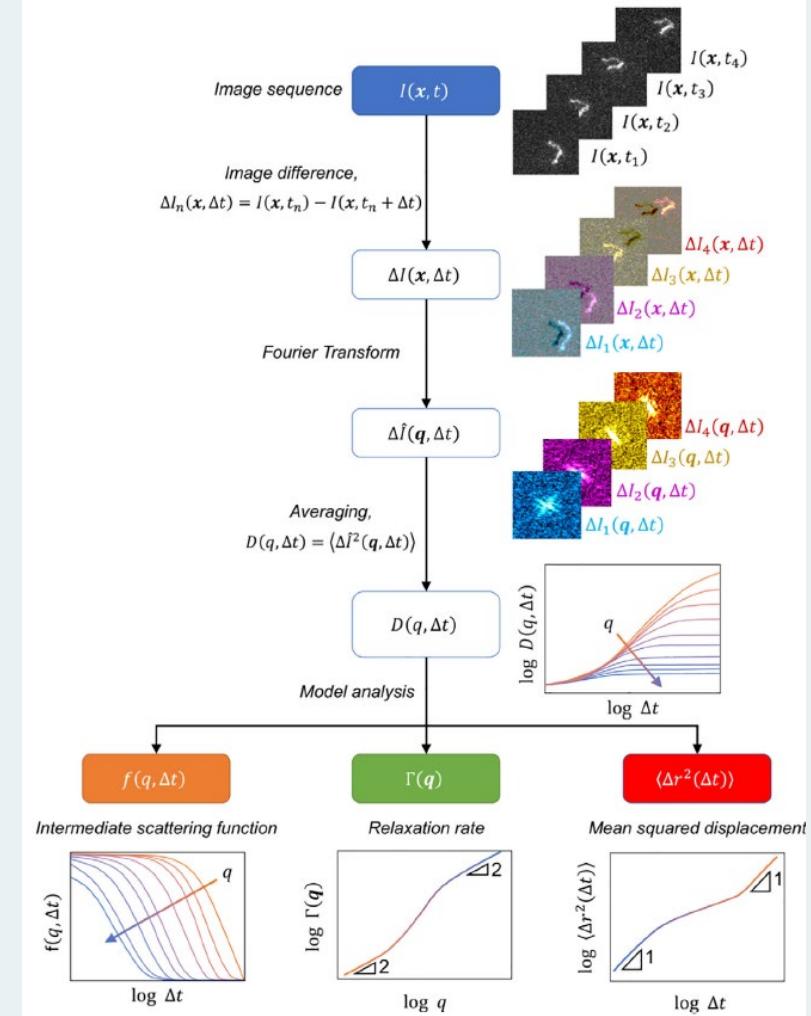
Series of images of the colloidal suspension samples are captured and resolved in the Fourier domain, providing image structure functions, $D(q, \Delta t)$, that correlate directly with soft matter dynamics

Analysis

- The Differential Intensity Correlation Function (DICF) is written as follows - $D(q, \Delta t) = A(q)[1 - f(q, \Delta t)] + B(q)$

- $A(q)$ is static amplitude term
- $B(q)$ accounts for noise.
- $f(q, \Delta t)$ is Intermediate Scattering Function

- In the case of colloidal particles in Brownian motion, $f(q, \Delta t)$, is expressed as $f(q, \Delta t) = e^{-\frac{\Delta t}{\tau(q)}}$, where $\tau = 1/D_m q^2$ and D_m is defined as $K_B T / 3\pi\mu d$.



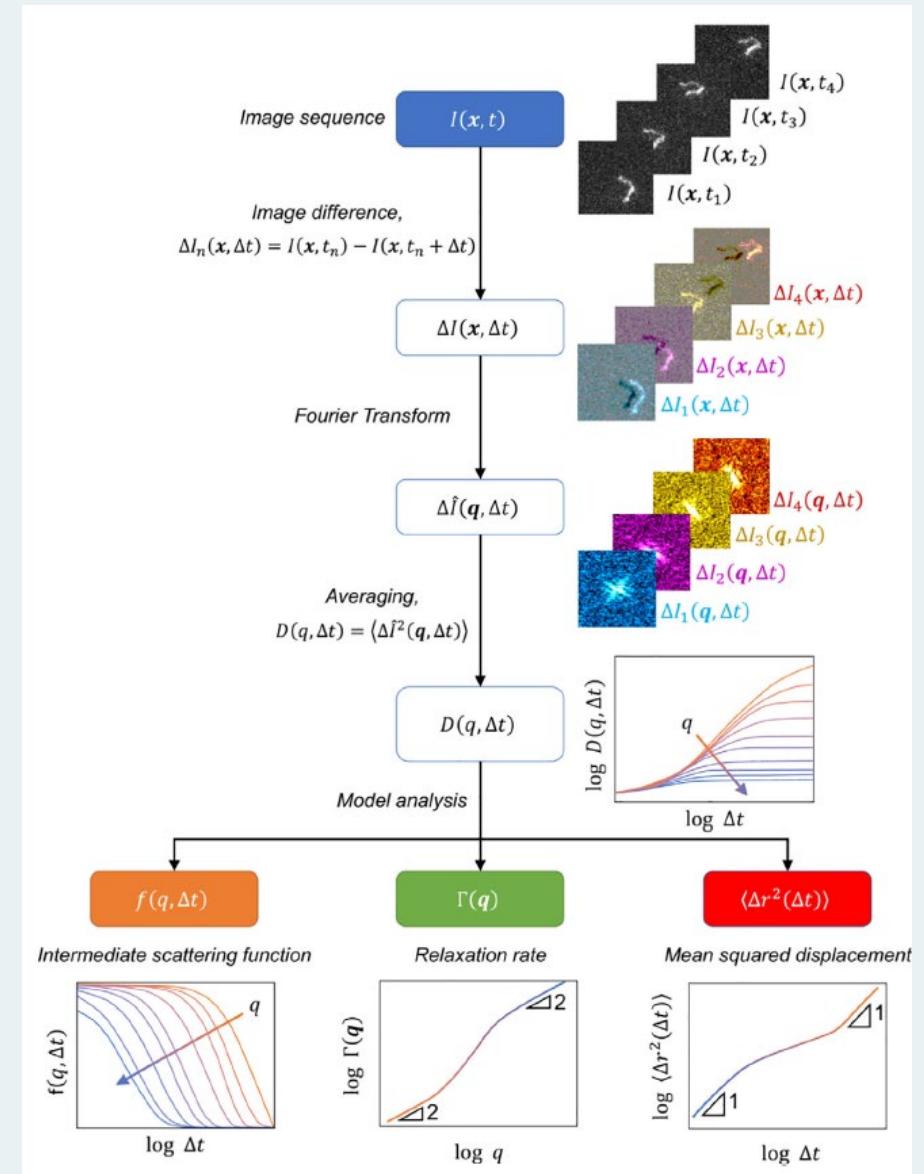
Differential Dynamic Microscopy

Our Goal. Implement DDM for soft matter research in space because-

- ✓ It only needs regular microscopy system (*resource light*)
- ✓ Can provide insight into ensemble behavior of soft and bio-soft materials

Accomplishment. We have developed DDM capability to be

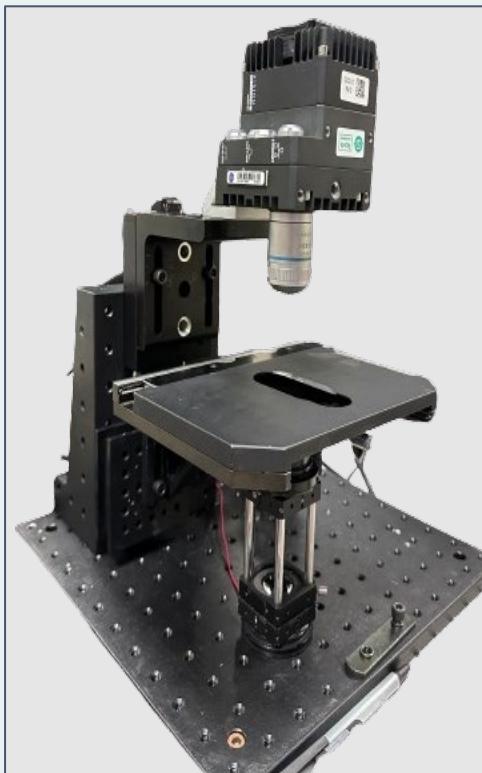
- ✓ Omni-platform ready and small form factor (form factor as small as a smartphone)
 - Would allow rapid execution of scientific experiment
- ✓ Modularize and integrate capability on demand in orbit



Differential Dynamic Microscopy- Prototype*



Traditional setup



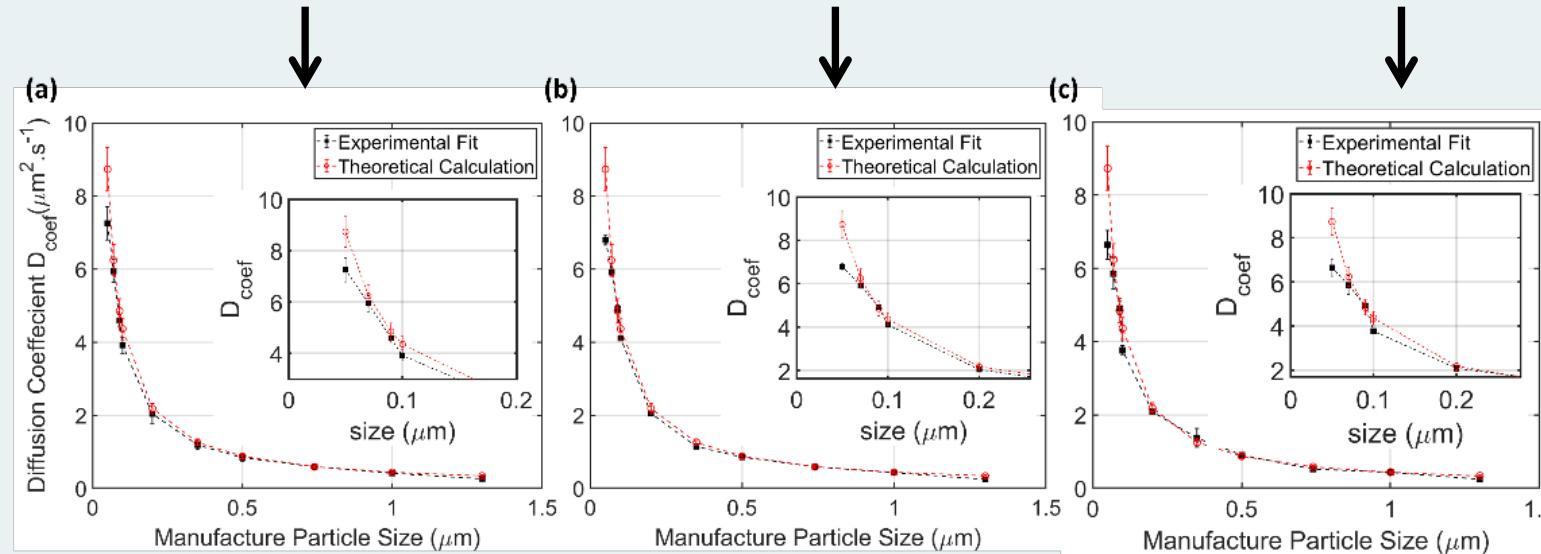
Modular prototype I



Modular prototype II

We have studied unimodal particle size within size range of 50 nm- 1.4 μ m

Differential Dynamic Microscopy- Results*



- ✓ We have studied unimodal particle size within size range of 50 nm- 1.4 μm
- ✓ Both of our small-scale prototypes work at par with commercial optical microscope (unto 70 nm)
- ✓ Commercial microscope tend to perform better for particle size 50 nm or less.

Next Steps

- Expand the capability to different active matter systems
- AI/ML-based improved data analysis capability
- Increase TRL level

AI/ML and Compute Vision aided Granular Materials Study

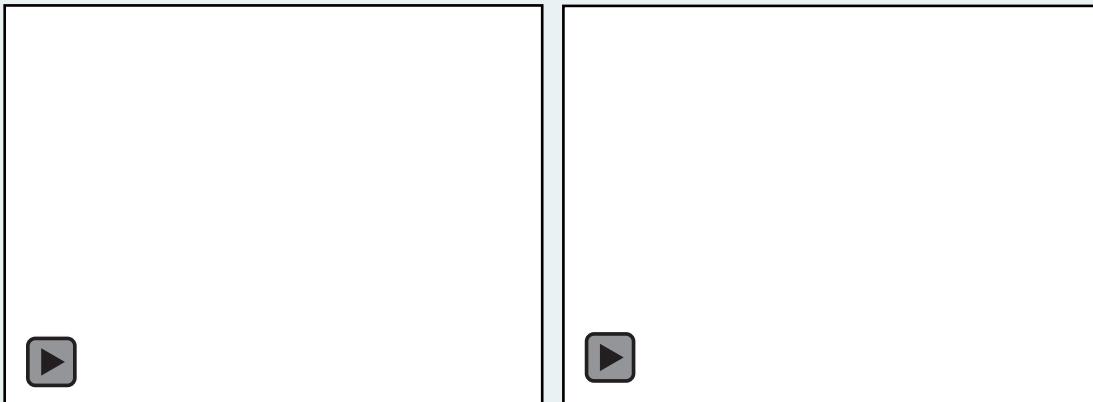
Develop a multi-scale (micro→ macro) experimental and theoretical platform to understand granular materials flow in variable gravity

Why this is important

Scalable approach towards understanding flow of granular materials in variable gravity condition under stress isn't understood with possible impact in Lunar Mission, Planetary Defense etc.

What is being done

- Discrete Element Method (DEM) simulations are being performed to provide us with insights into interparticle forces in granular media
- Develop multi-scale computer vision model –
 - ✓ 2D model to study particle-particle interaction
 - ✓ 3D reconstruction algorithm for bulk flow characteristic

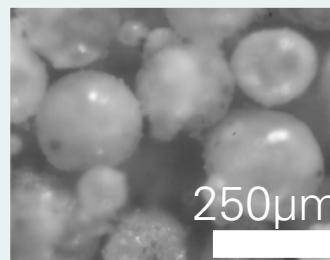


A low cohesion material flows through the funnel like a dry sand at 1G.

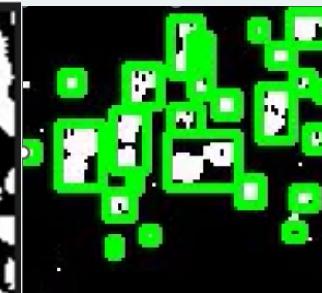
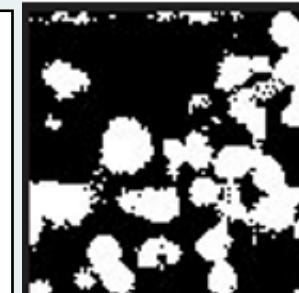
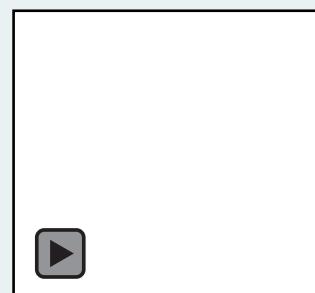
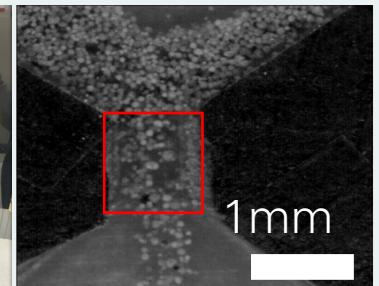
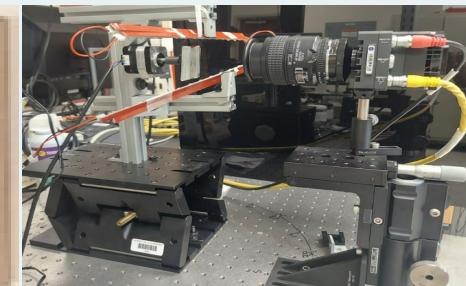
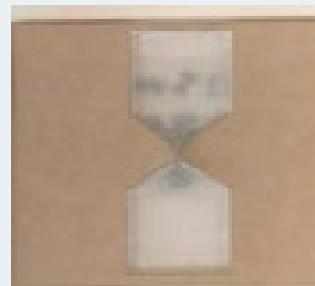
The same material but at Lunar gravity. Here the grains stick to each other, jamming the funnel, and arresting flow.

Experiment – 2D Micro-model*

- Mars wind-drift regolith simulant is studied as a **low cohesion polydisperse granular material** with a high degree of particle uniformity.
- A pseudo-2D hopper style hourglass of varying throat diameter is used to study the dynamic behavior of the simulant.
- Individual particle trajectories through funnel are tracked via particle recognition techniques.



Mars Wind-drift simulant under a microscope

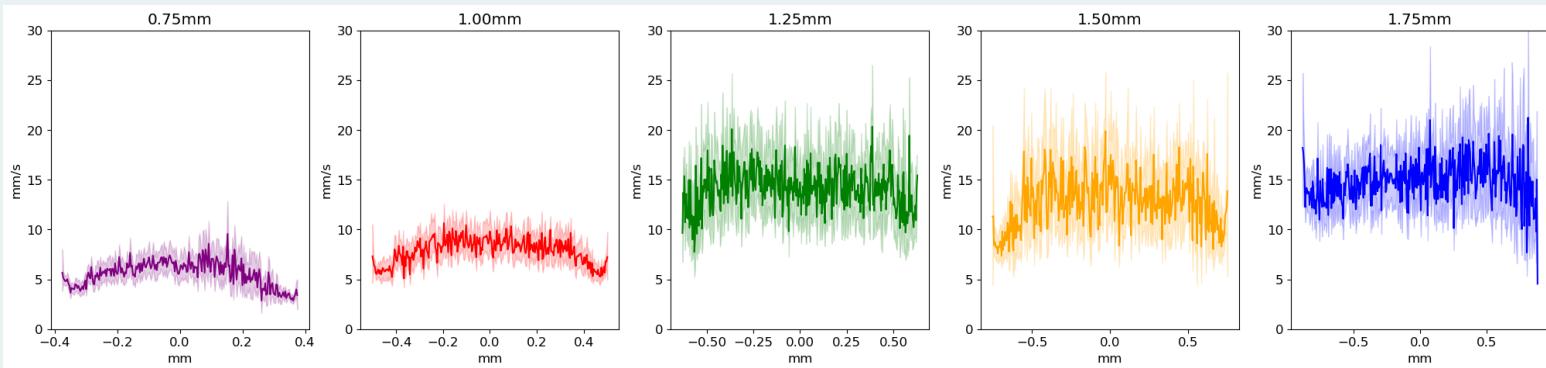


Cropped image J
masks of 2D
funnel, showing
simulant grains

Comparison of Experiments and Simulation*

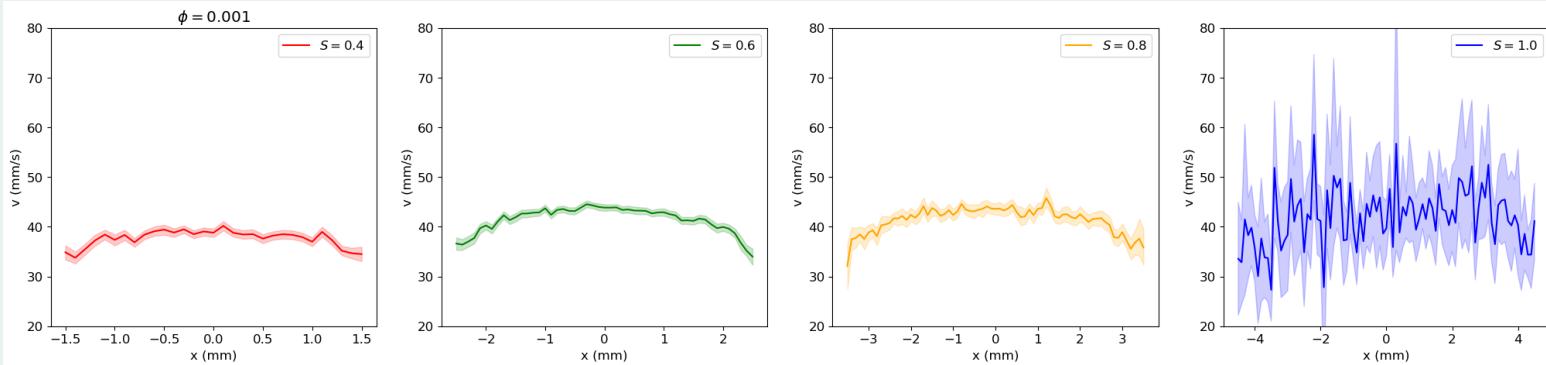
Experiment:

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



Simulation:

Materials with lower inter-particle cohesion shows a similar flow profiles as observed with varying funnel opening size S .



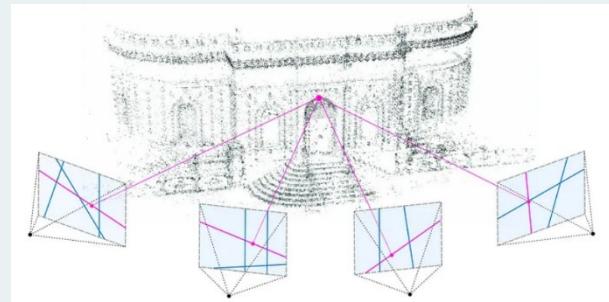
Experiment – 3D Macro-model

- Study multiple regolith simulants in a large-scale 3D funnel style geometry.
- Test if principles derived from 2D micro-model scale and can predict 3D macro flow of material.
- Contrast behaviors of different regolith types in different funnels against Finite Element Method (FEM) simulation models.

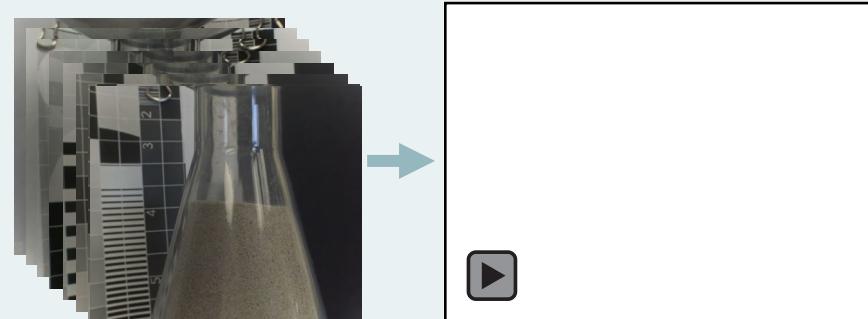


3D Reconstruction to Analyze Bulk Flow

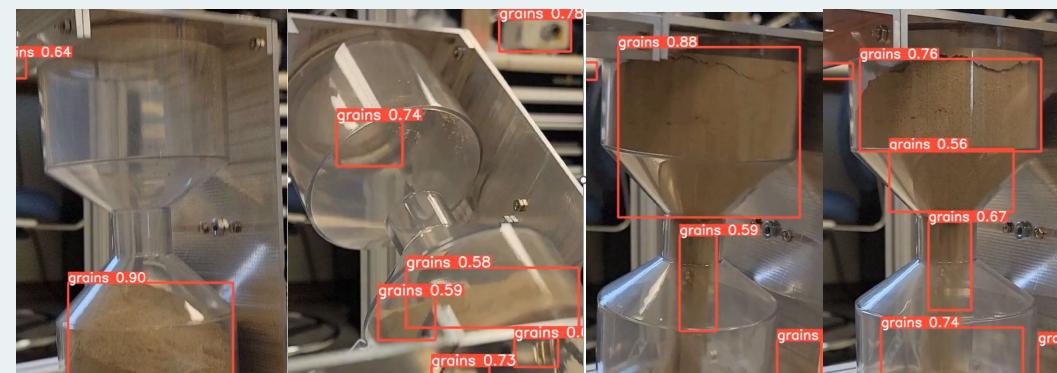
- Gaussian-splatting and Structure-from-Motion algorithm creates a 3D point cloud of a subject from 2D images.
- Use point cloud to reconstruct 3D bulk properties from 2D image sequence of funnel.
- Train image detection algorithm (YOLO) to track bulk material dynamics.



Point cloud
creation via SFM



Gaussian-splat
created from 2D
image stack

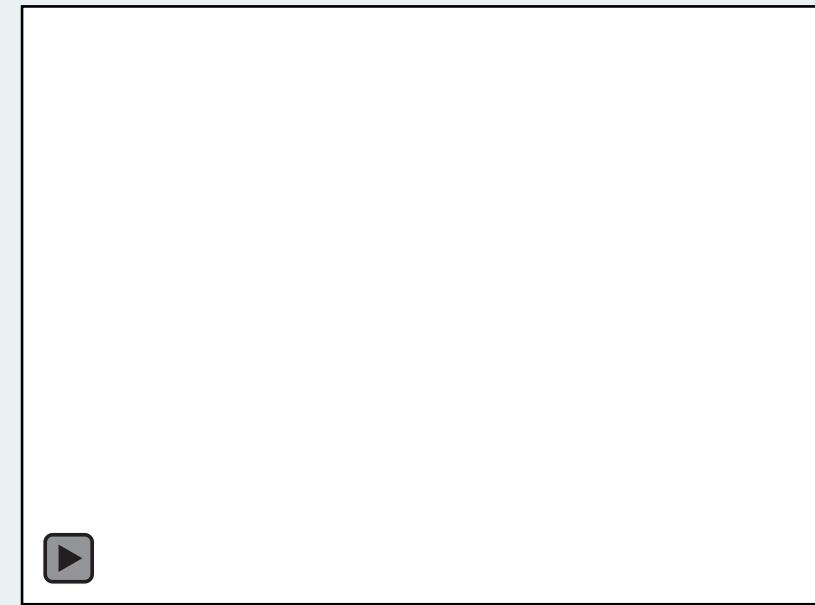


You-Only-Look-Once
(YOLO) detecting
bulk granular material

Remember this Simulation!!!



A low cohesion material flows through the funnel like a dry sand at 1G.



The same material but at Lunar gravity. Here the grains stick to each other, jamming the funnel, and arresting flow.

Acknowledgement

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Thank
you