Implementation of Charged Dust Dynamics in a Spacecraft Contamination Code

April 8th, 2022

Lubos Brieda[a,b], Elana Helou[b], Haroon Khan[b], Joseph Wang[b]

a) *Particle in Cell Consulting LLC, Westlake Village, CA*
b) *University of Southern California, Los Angeles, CA*

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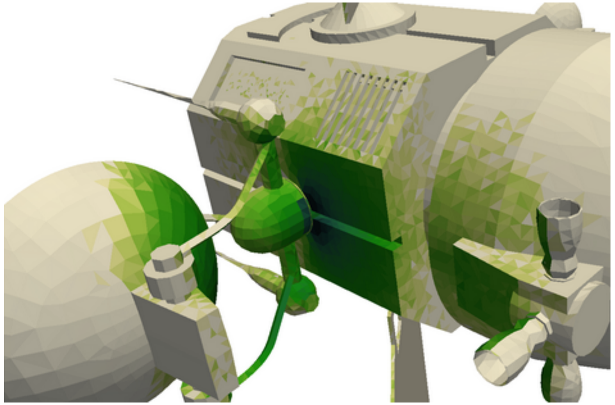
School of Engineering

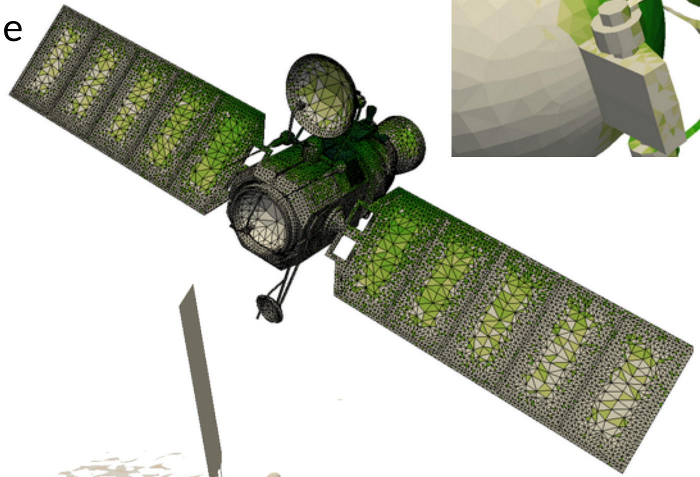
Background

- Since 2015, PIC-C has been developing a 3D “mesh-free” particle tracing code for modeing molecular and particulate transport called CTSP
  - Brieda, L., J. Spacecraft & Rockets, Vol. 56, No. 2, 2019
- CTSP can support highly realistic geometries represented using surface meshes, TSS assemblies, and (future work) CAD analytical surfaces
- Majority of work to date involved neutral, collisionless molecular and particulate flows, although the code supports loading external electric field and including DSMC collisions
- We have recently started new effort to expand code capability to simulate charge propagation and finite-sized dust grains

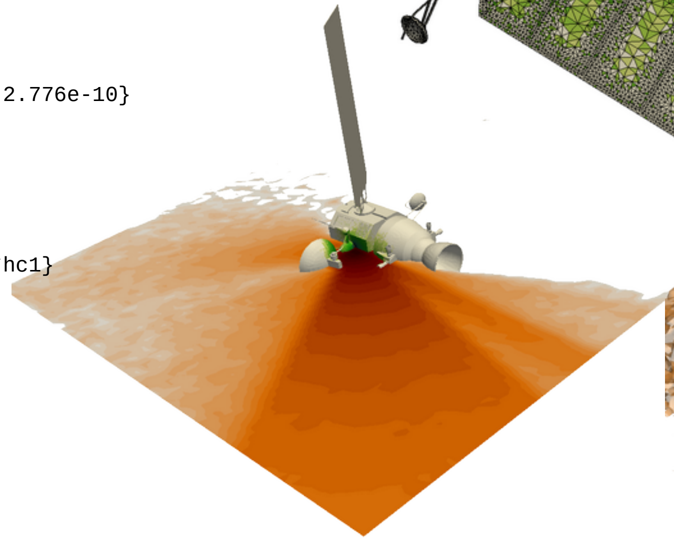
Hello World

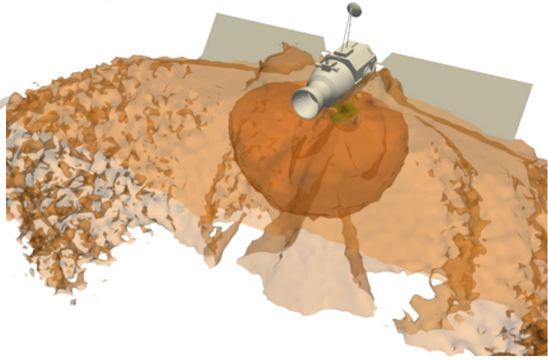
- A "Hello World" example of molecular transport on a generic satellite
- CAD model from GrabCAD, meshed in Pointwise
- Assigned outgassing source to antenna adapter
- Octree storage for surface mesh, mesh-free particle push
- Volumetric mesh used to visualize contamination plume





```
#simulation options
options{num_threads:1, file_diag_freq:1}

#load surface mesh
surface_load_unv{file_name:"satellite.unv",view:1}

#define volume mesh for computing contaminant plume
volume_mesh{dx:0.02,dy:0.02,dz:0.02,expand:[0.5,0.5,0.5]}

#specify materials
solid_mat{name:blanketing, weight: 100}
molecular_mat{name:hc1, weight: 54, mpw: 1e8, Ea:12, C_exp:100, r:2.776e-10}

#specify surface properties
surface_props{comps:/.*/, mat:blanketing, temp:260, c_stick:0.3}
surface_props{comps:source, temp:1000, c_stick:0}

#enable outgassing
load_molecules{comps:source, trapped_mass:1e-10, trapped_mats:1.0*hc1}
source_outgassing{model:"exp"}

#run simulation
run_sim{dt:1e-5,num_ts:5000,diag_start:5,diag_skip:5}

#save results
volume_save_vtk{skip:5000,file_name:"field",vars:[nd.hc1]}
surface_save_vtk{skip:5000,file_name:"surf"}
```





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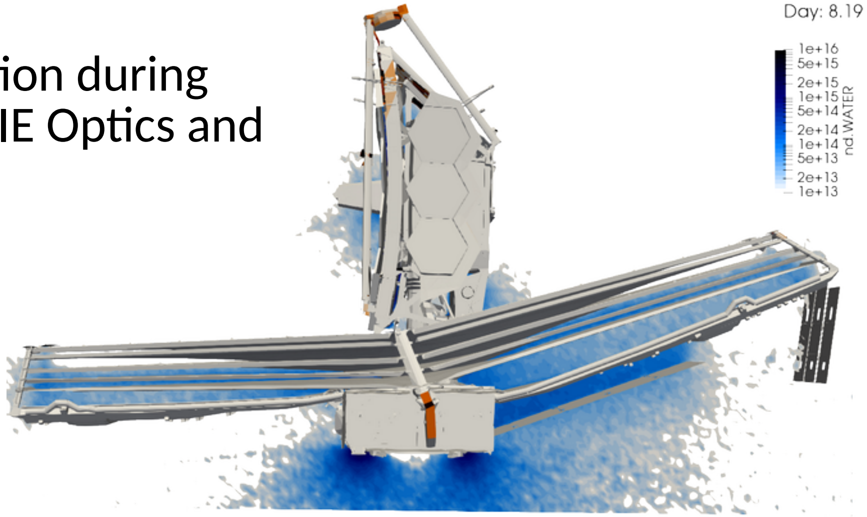
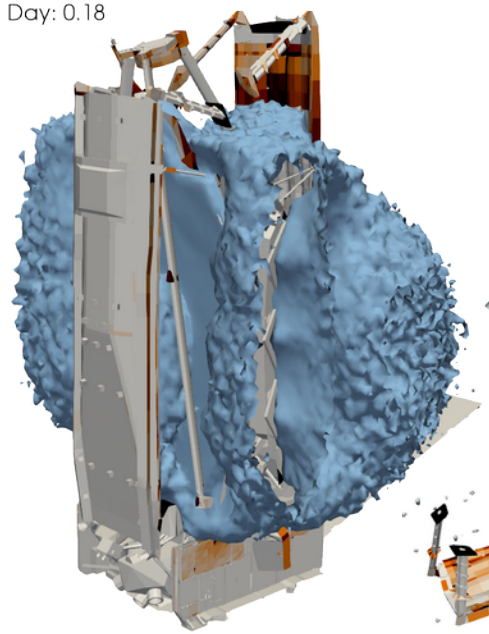
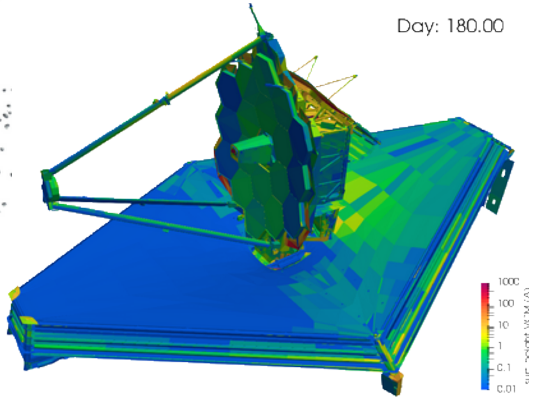
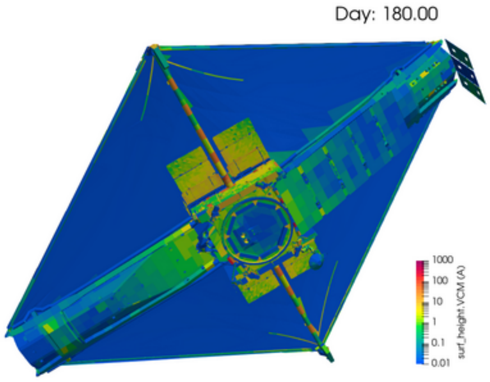
Deployment

- Recently also incorporated support to run analysis across varying geometrical configurations
- Allowed us to model evolution of water ice accumulation during JWST deployment: more details to be presented at SPIE Optics and Photonics in August 2022.









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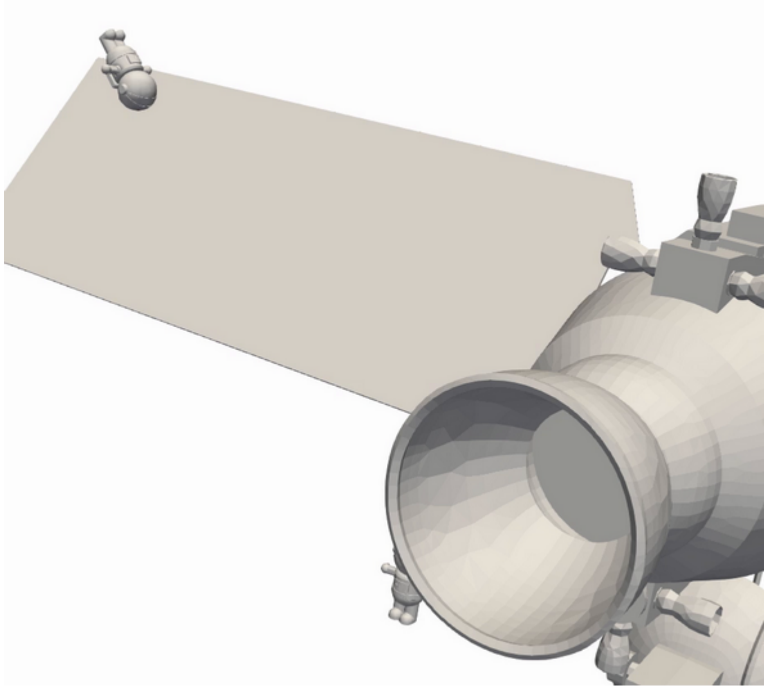
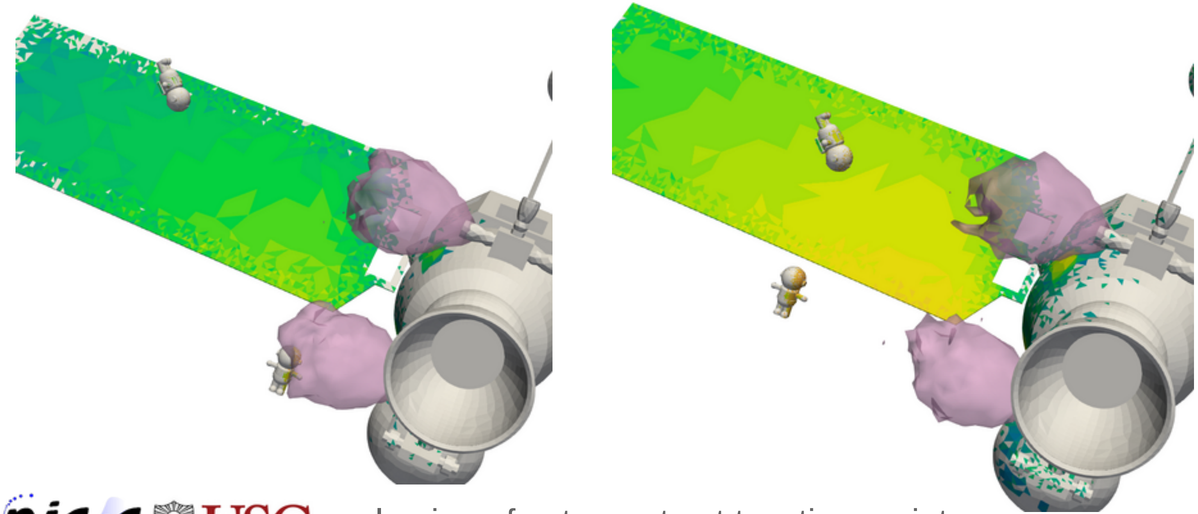
Surface Dynamics

- The JWST analysis considered 17 distinct geometries, restart file used to transfer solution between configuration changes
- Not robust enough to model servicing or lunar operations, recently implemented rudimentary support to include translating objects
- Each “actor” stored within own octree, transformation matrices map from global to local tree coordinates

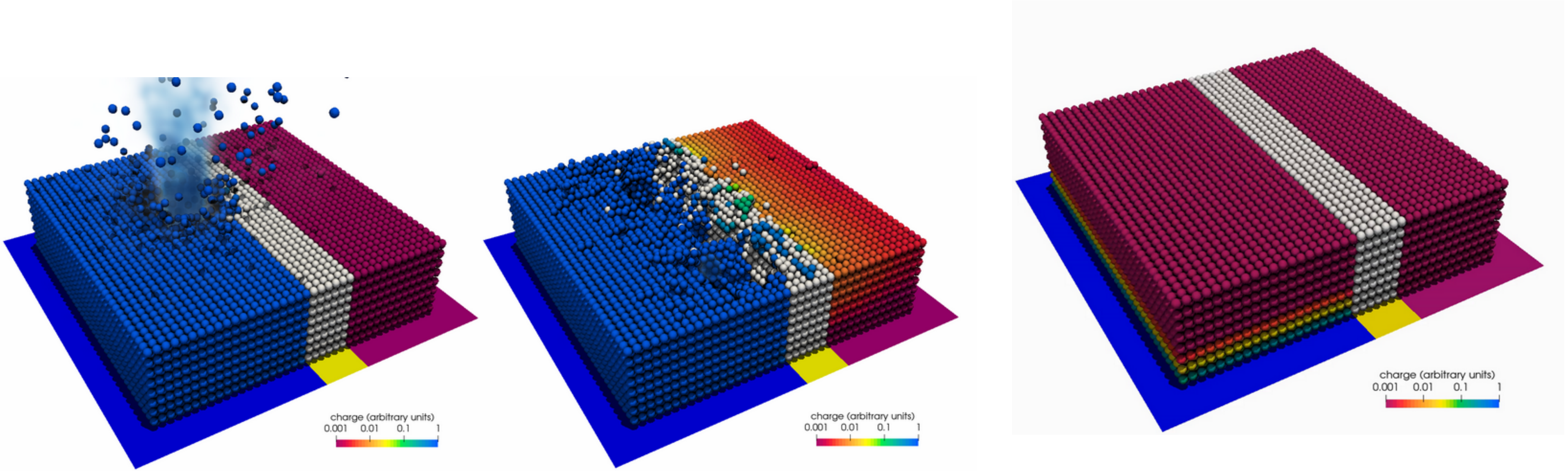




pluming of astronauts at two time points

Charge Propagation Model

- Also developed a standalone model of charge propagation and dynamic surface evolution due to plasma interaction
- Example shows build up of a conductive bridge across an insulator due to arc mass ejection

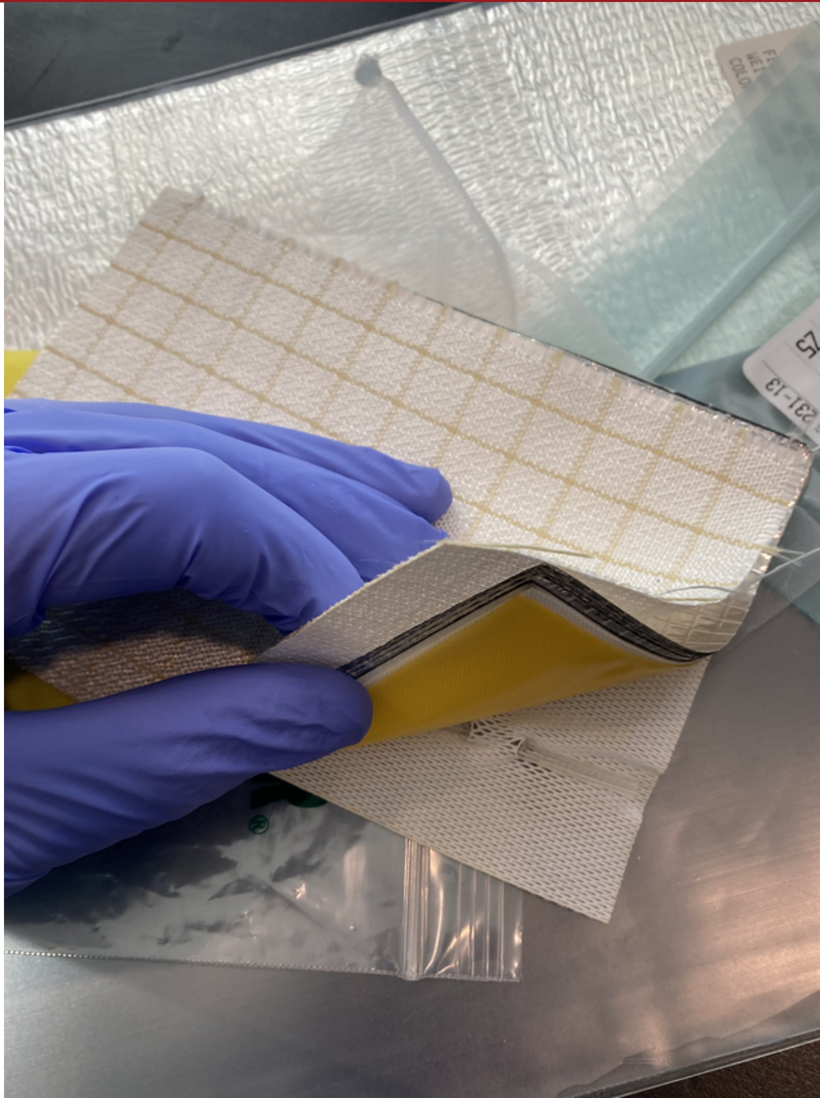


Motivation

- As demonstrated by others (including USC group), lunar regolith is expected to easily charge up due to photoelectron emission, with the charge profile being highly specific on the local environment

- Lunar regolith also sticky and may be hard to remove from surfaces, including astronaut spacesuits

- Our goal is to develop simulation capability that can resolve regolith accumulation and transport on engineering scales while retaining realistic level of detail and is backed by experimental validation



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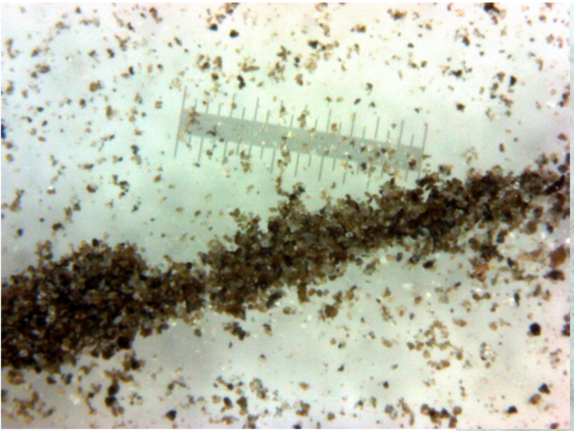
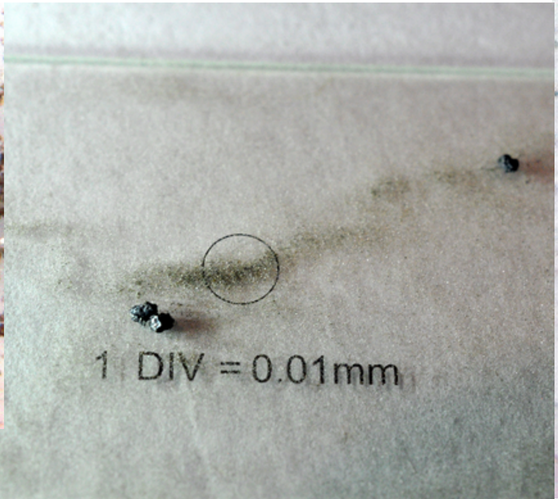
Regolith Sample

- Working with USC students to characterize regolith adhesion
- Utilizing JSC-1 simulant
- Microscope imaging indicates two distinct populations
- Fine dust ~ 50 micron





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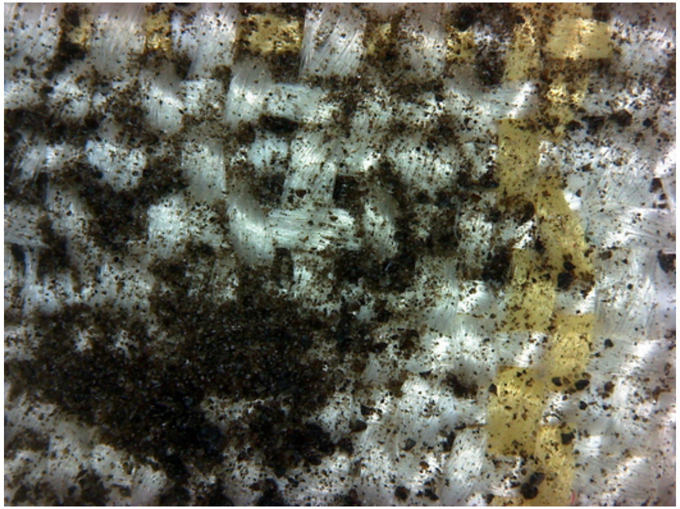
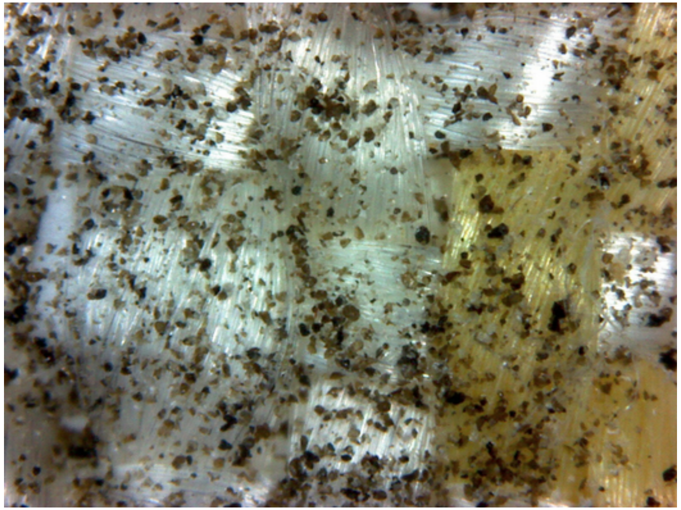
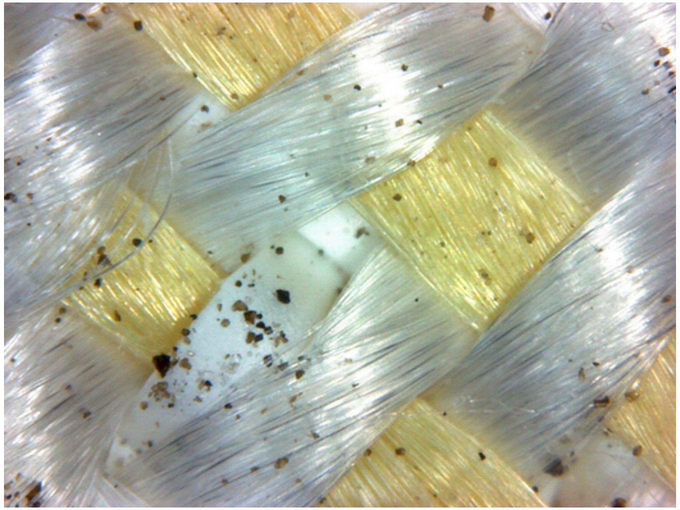
Desired Outcome

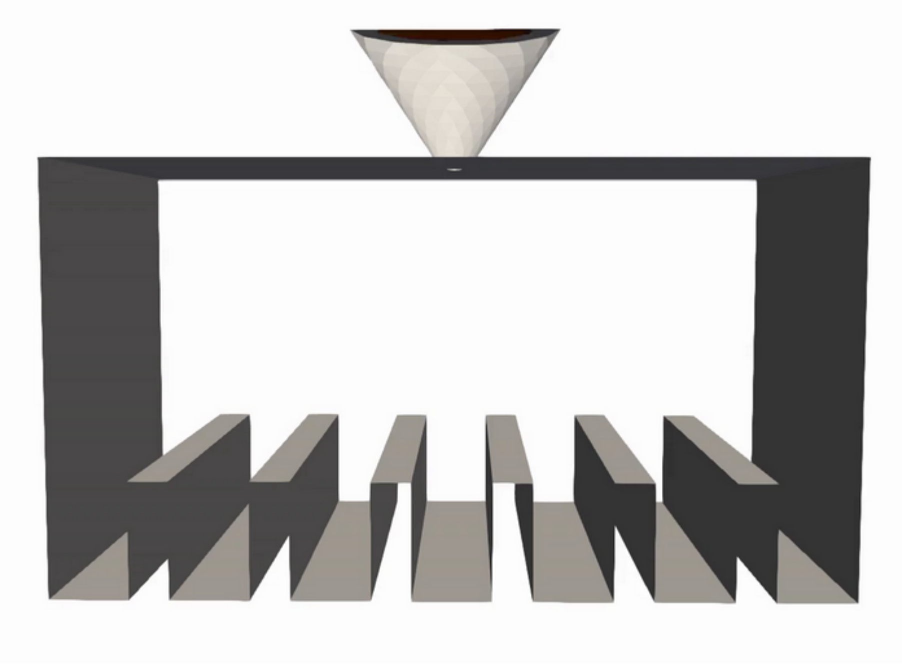

application

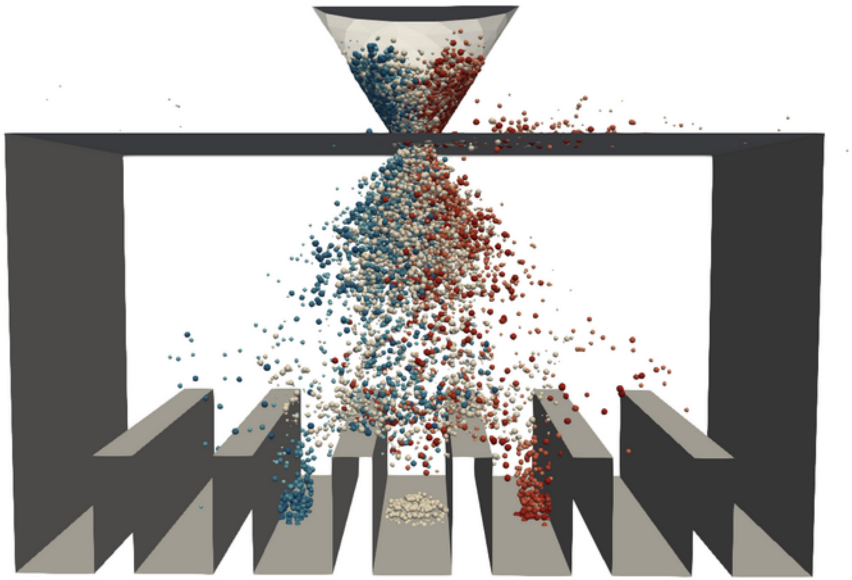

post shake


post brushing

Desired outcome: ability to simulate dynamic evolution of surface accumulation taking into account electrostatic attraction

Charged Dust Propagation

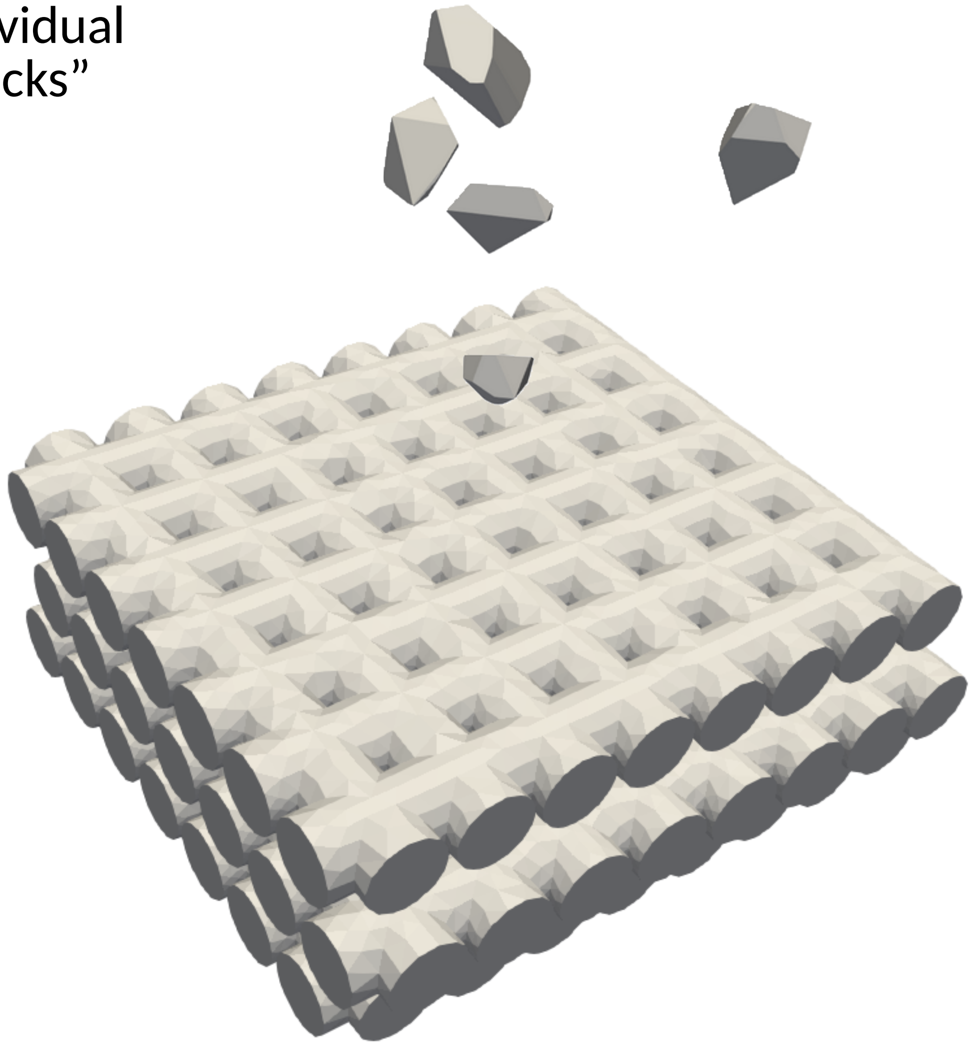




- CTSP already contains support to model dust propagation under external electric field. Above animation shows sorting of grains of different charge/mass ratios. “Particle leaks” due to mesh error.
- However, dust simulated as point-size particles of finite mass / volume, no grain-grain interactions
- Not robust enough to model dust grain interactions within engineering configurations

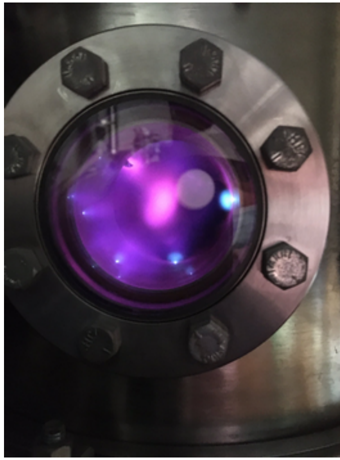
Numerical Details (Future Work)

- Implementing support to model grains as individual tessellated surfaces, generated as random “rocks”
- Each grain represented by individual actor
- Surface charge stored per surface cell, charge propagation within and between grains based on specified capacitance
- Velocity updated from Coulomb force (N^2 scaling to be addressed using octree)
- Grains moved by shifting center of mass position – translation matrix
- Angular velocity modifies rotation matrix
- Implementing triangle-triangle intersection algorithm to detect surface impacts
- Multithreading to speed up computation

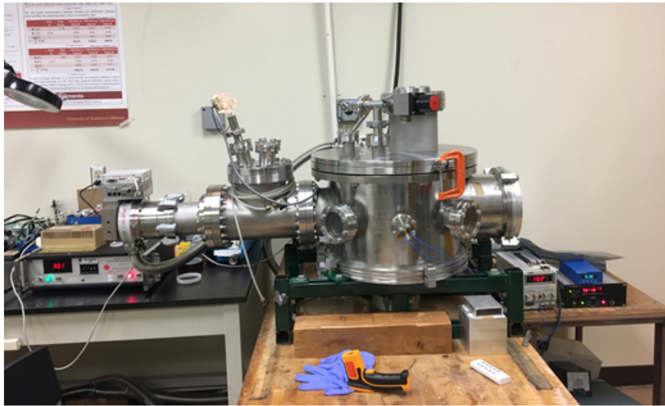


Conclusion

- New effort to expand capabilities of in-house contamination code to model transport of finite sized dust grains, specifically as applicable to lunar regolith space suite adhesion



- Complemented with experimental testing using JSC-1 and a space suite sample at atmospheric condition
- Future work involves experimental study of adhesion in vacuum environment with ambient plasma
- Numerical and experimental results to be presented at next SCTC



- Contact: lubos.brieda@particleincell.com

  brieda@usc.edu

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