Simulator for Planetary Interactions of Dust and Regolith (SPIDR):

A New Tool for Predicting Dust Transport from Lunar Surface Operations

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Space Resources Roundtable, June 7th-10th 2022

The Lunar Dust Problem

Dust mobilization methods:

- Interactions with surface electric fields
- Meteorite impacts
- **Human activities**

Apollo 16 LRV traverse (Credit: NASA)

The Lunar Dust Problem

- General problems
  - Highly cohesive
  - Retain charge in lunar vacuum
  - Damaging to humans tissue
- ISRU specific problems (International Agency Working group, 2016, Gaier, 2007)
  - Clogging mechanisms
  - Damage to rotating bearings/motors/drills
  - Seal failures
  - Abrasion
  - Compromising thermal control surfaces
  - Degrading solar panels
  - Contaminating extracted volatiles

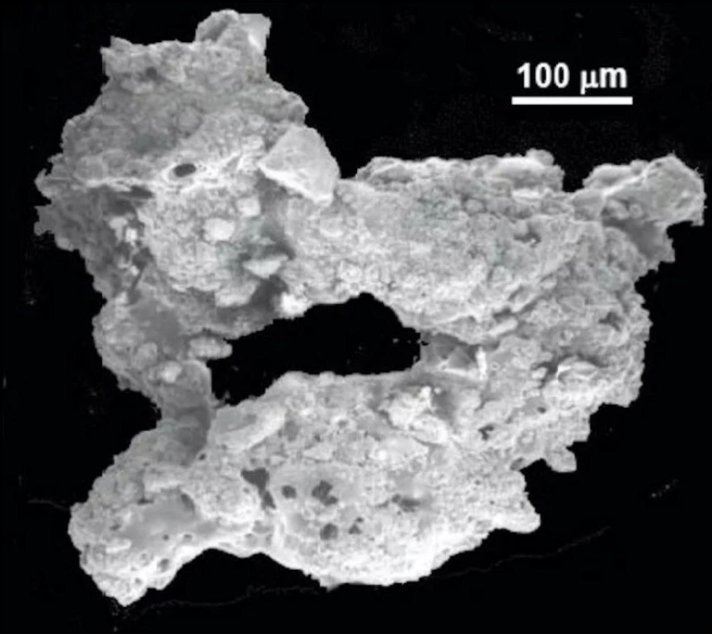
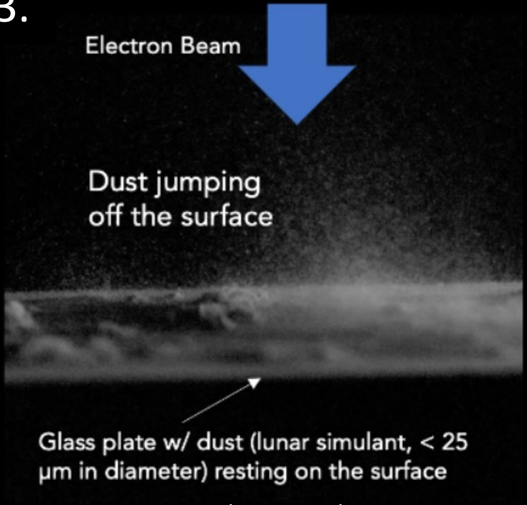


Image credit: David S. McKay/NASA/JSC

Dust Mitigation Techniques

1. Limit initial dust mobilization
    - E.g. fenders/sintered roads/vehicle speed
2. Prevent dust collection
    - E.g. filters/bellows/surface coatings
3. Dust removal
    - E.g. brushes/electrostatic precipitators/pressurized gas
4. Dust tolerance
    - E.g. ceramic bearings

3.



(Credit: I. Hahn/X. Wang/NASA)

1.

(Credit: Eugene A. Cernan/NASA)

Summary in Cannon et al., 2022

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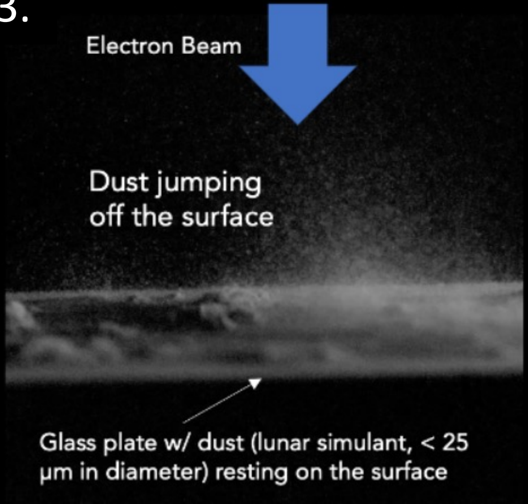


(Credit: I. Hahn/X. Wang/NASA)

1.

(Credit: Eugene A. Cernan/NASA)

Summary in Cannon et al., 2022

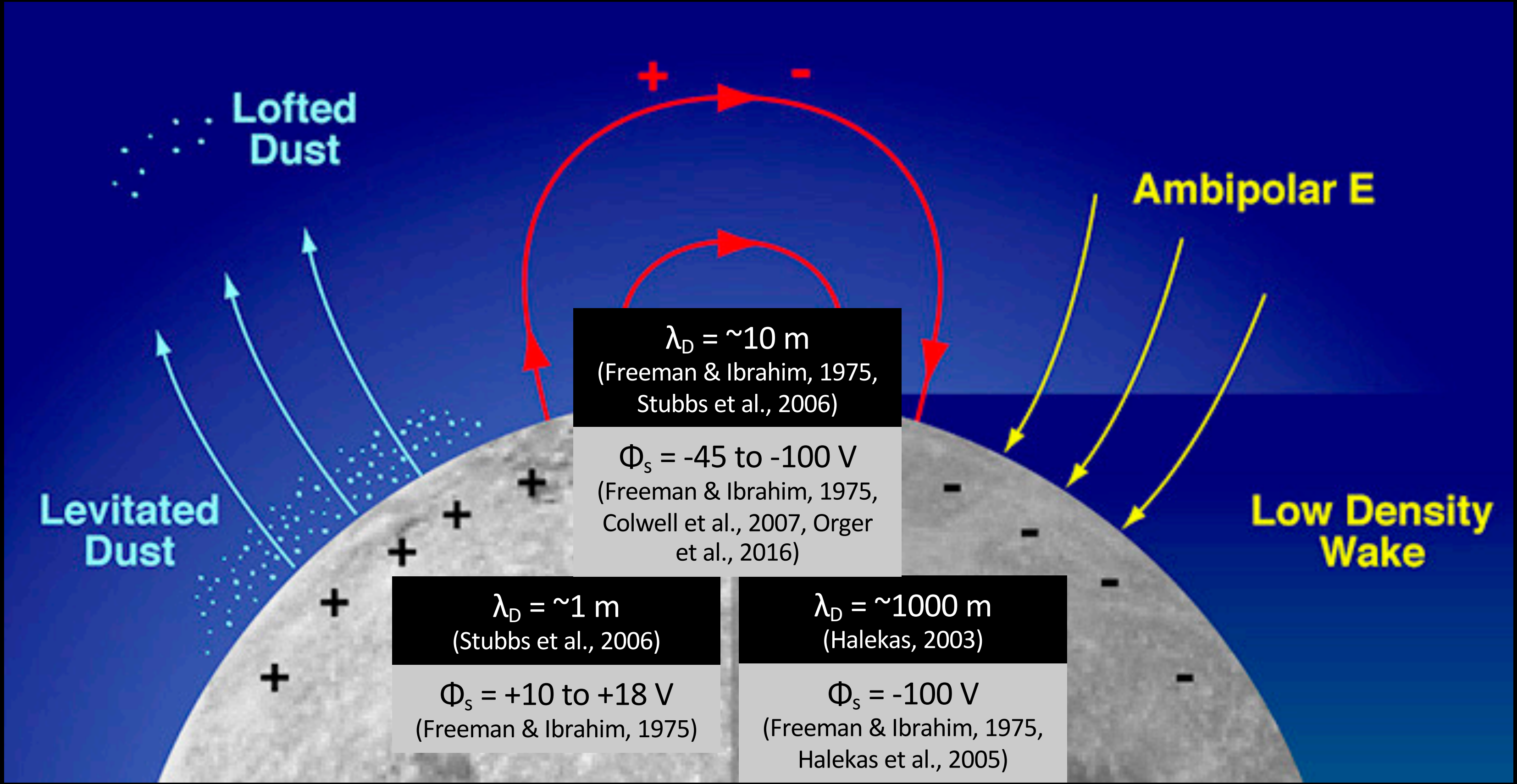
SPIDR

- A simulation that can be used to predict how dust is mobilized following interactions with planetary surfaces

- Questions we hope to answer:
    - What are the effects of lunar surface properties, regolith properties, and rover/excavator design on the formation of dust clouds?
    - How can we inform the design and operation of rovers/excavators to minimize dust mobilization and collection onto sensitive surfaces?

- Properties currently being considered in the development of the simulation:
    - Lunar surface environment
    - Grain size and bulk porosity
    - Grain charge
    - Cohesion and friction

Lunar Surface Environment



Lunar Surface Environment

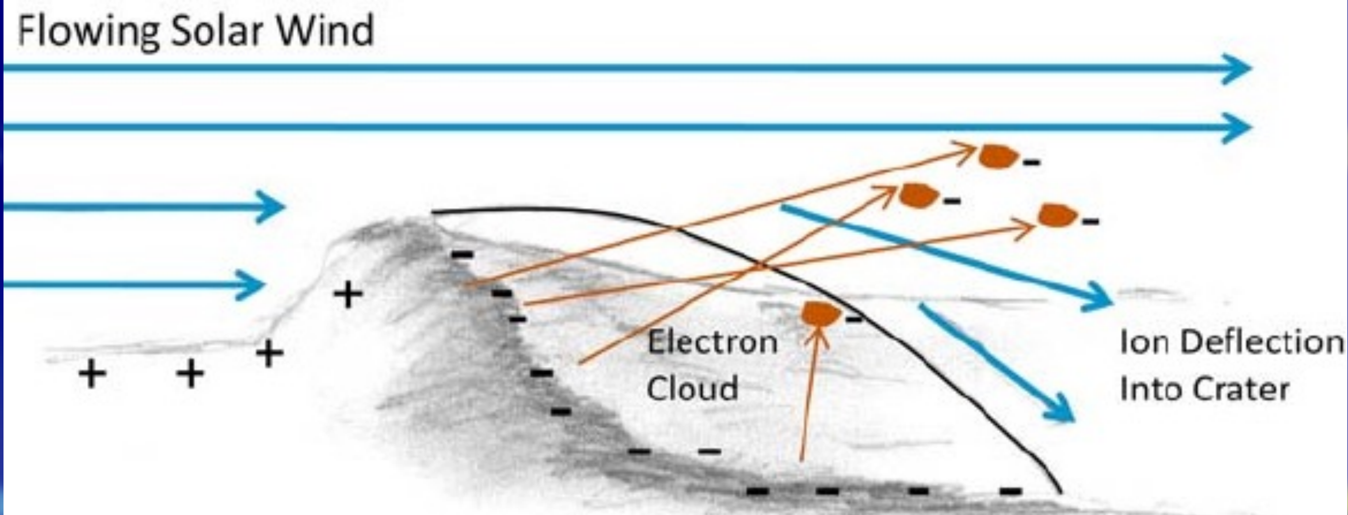


Illustration of the charging environment at lunar shadowed craters (Credit: Farrell et al., 2010)

Grain Size, density, and Bulk Porosity

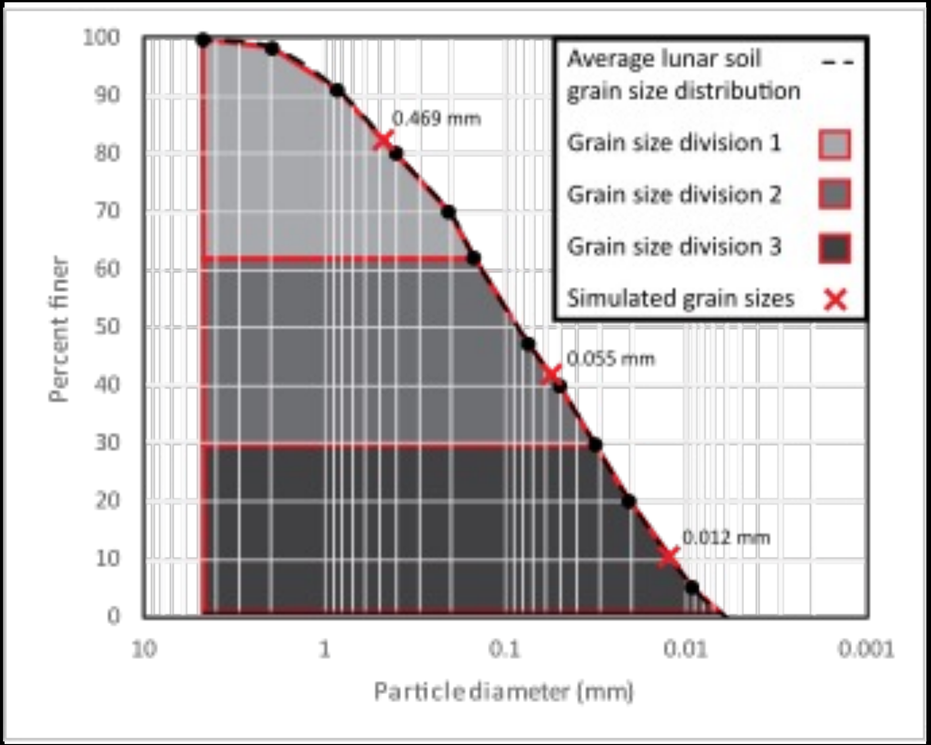
- Discrete grain sizes with weighted distributions

Grain size, d (mm)	Ratio of total mass (wt %)	Ratio of total number of grains (%)
0.469	38	0.0014
0.055	32	0.72
0.012	29	60
0.0001	0.00001	38

(Preliminary testing with single grain sizes)

- Density of lunar rock taken as 3365 kg m[3], as averaged from Kiefer et al. (2012)

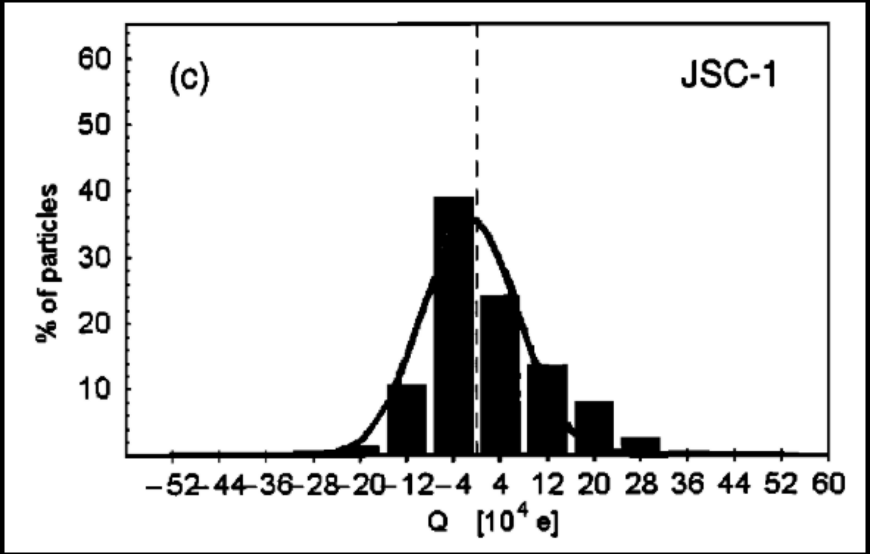
- Bulk porosity from upper 15 cm of lunar soils taken as 52 ± 2% (Carrier et al., 1991)



Average grain size distribution for lunar soils taken from Zeng et al. (2010).

Grain Charge

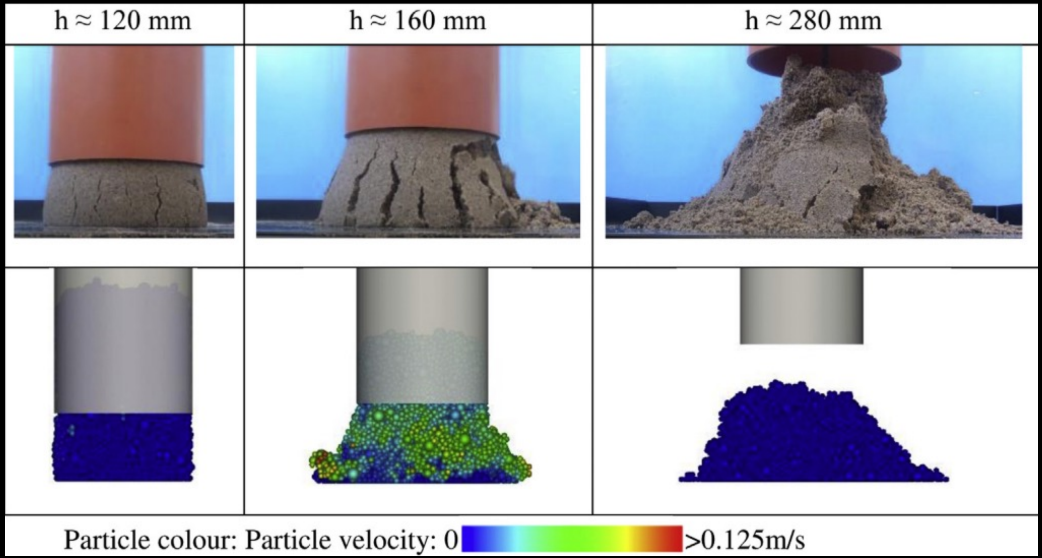
- Dust grains will become triboelectrically charged in a vacuum
- Sickafoose et al. (2001) measured the surface potentials built up in JSC-1A grains (r=50 μm) in vacuum
- Using $q = 4\pi\varepsilon_0 r_d \phi_s$ with Sickafoose et al.'s results, we predict the charge for different grain sizes



Surface potentials recorded for JSC-1A (Credit: Sickafoose et al., 2001)

Cohesion and Friction

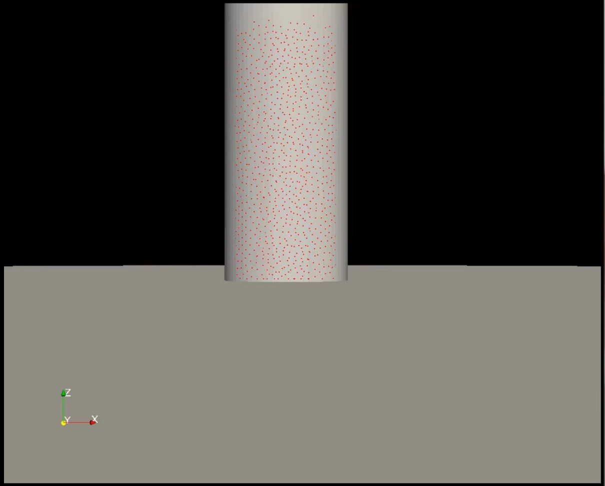
- Different cohesive mechanisms can be simplified into a DEM parameter, Cohesive Energy Density (CED).
- Bulk material flow behaviour is dependent on the coefficient of particle-on-particle friction, the coefficient of rolling friction, and CED.
- Roessler & Katterfeld (2019) devised an experiment to calibrate these parameters.



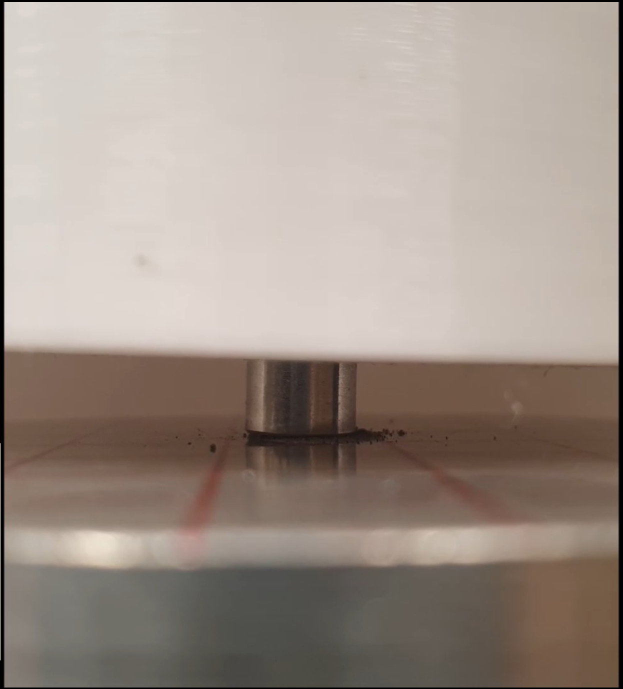
Comparison of the experiment and the best-fit DEM parameter combination (Credit: Roessler & Katterfeld, 2019)

Cohesion and Friction

Initial simulation for lunar soils



Experiment with LMS-1



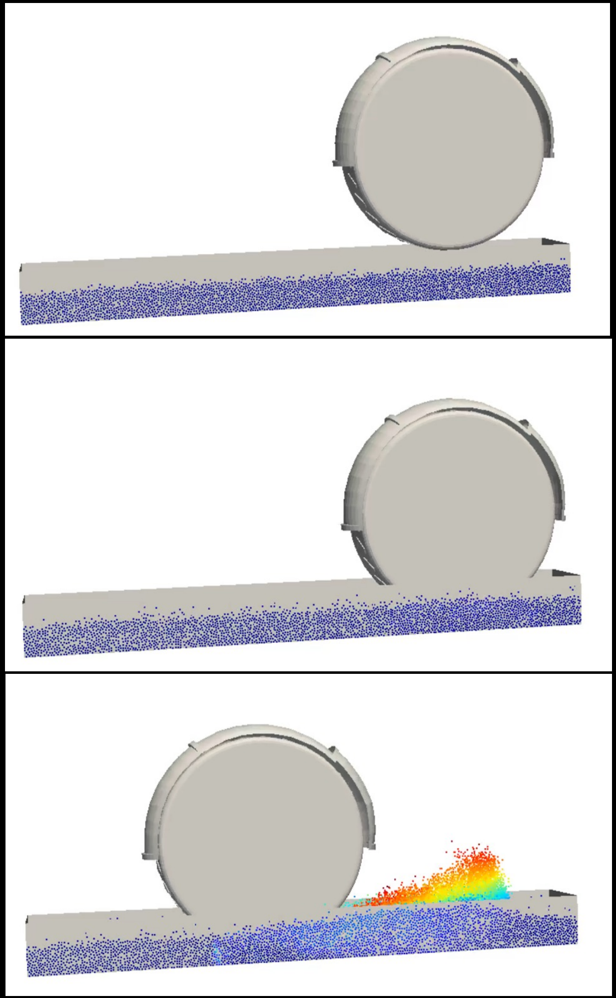
Building a Simulation

- LIGGGHTS (LAMMPS improved for general granular and granular heat transfer simulations)

- Create rover wheel
  - Simplified Apollo 16 wheel & fender
  - Can use any wheel design

- Defining Particles
  - Size, charge, cohesive properties

- Running Simulation
  - Insert particles into tray
  - Lower wheel into particles
  - Rotate wheel

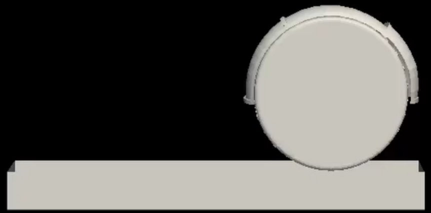


Initial Testing

Apollo 16 ‘Grand Prix’ (Credit: NASA)

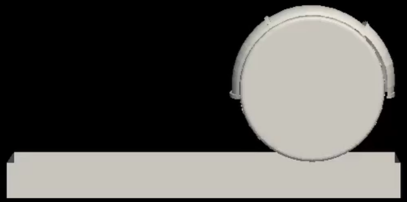
Initial Testing

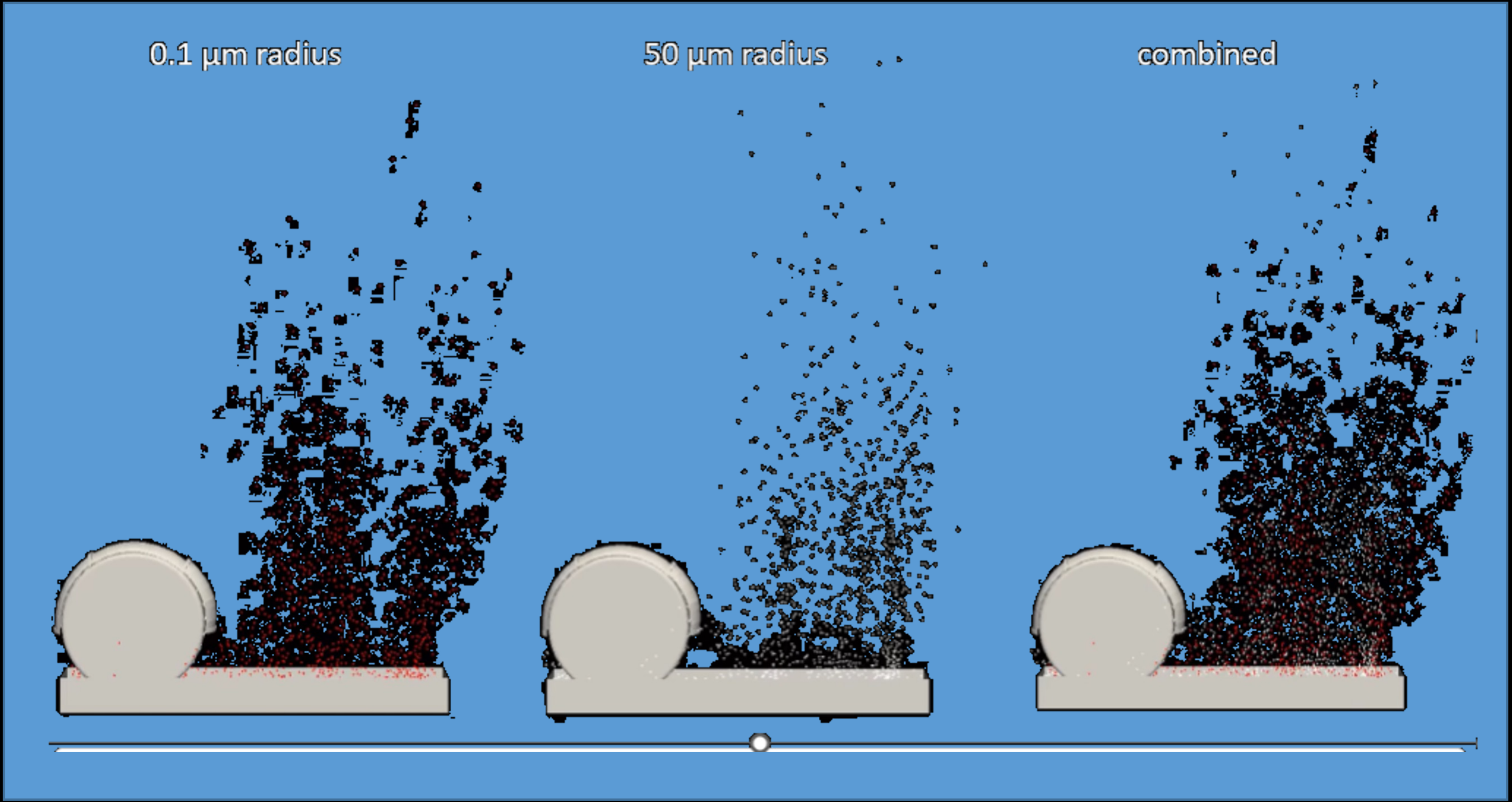
0.1 µm radius



50 µm radius

combined





0.1 µm radius
50 µm radius
combined

Next Steps

- Improve fidelity of simulation
  - Update soil properties with data from Apollo soil samples
  - Apply a particle size distribution

- Investigate effects of different lunar conditions
  - How does electric field impact dust distribution?

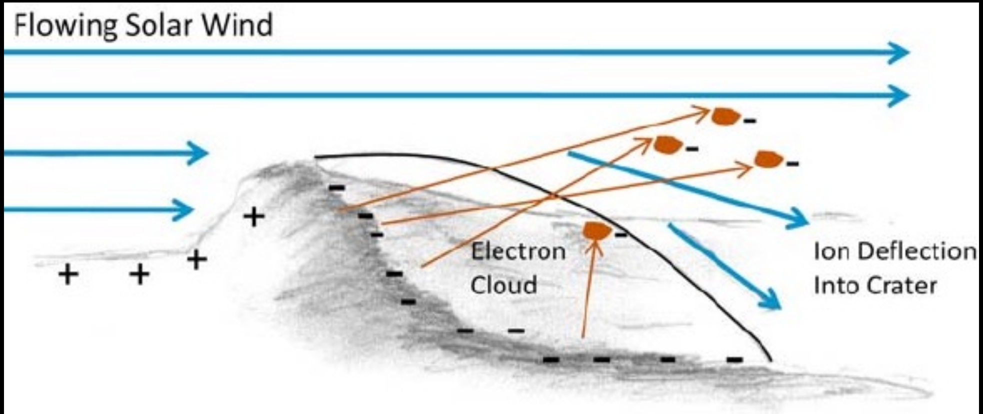
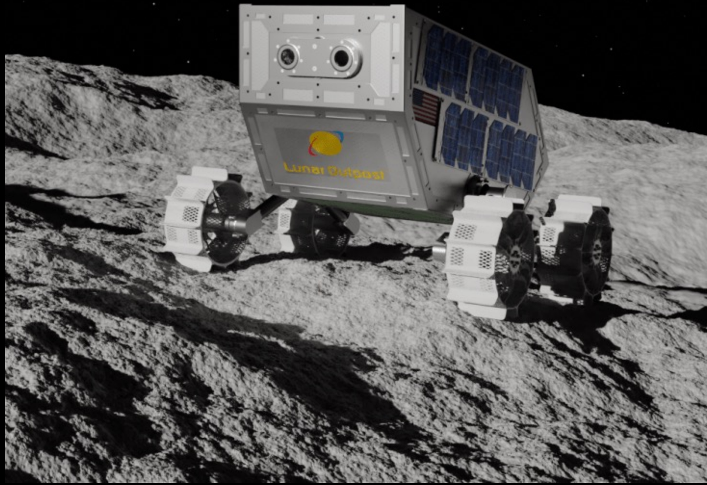


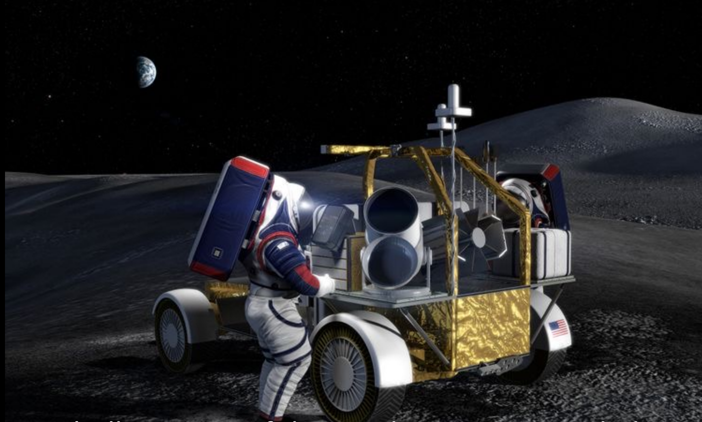
Illustration of the charging environment at lunar shadowed craters (Credit: Farrell et al., 2010)

Applications

- Upcoming Lunar Terrain Vehicle and other rover designs
  - SPIDR can helps assess different wheel and fender designs, and provide inputs into the most suitable location of sensitive components such as solar panels/radiators.
  - SPIDR can also estimate safe ‘speed limits’ that could keep dust mobilization down below a desired limit.
- ISRU Excavators
  - SPIDR could be used to trial different excavation tools and modes to predict how much dust will be mobilized and identify the most suitable tool/mode to protect sensitive components.



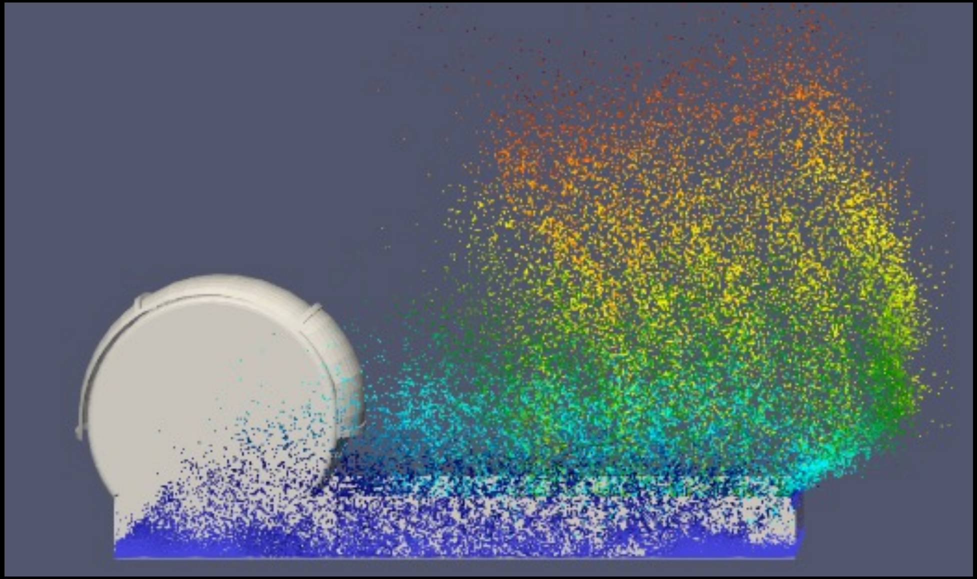
Lunar Outpost's MAPP Rover. (Credit: Lunar Outpost)



Artist's illustration of the Northrop Grumman-led Moon rover (Image credit: Northrop Grumman)

Summary

- We have created a DEM simulation to analyze lunar dust interactions with rover wheels
- We are using an Apollo LRV wheel design and lunar surface footage to help calibrate the model
- Preliminary results show that particles of different sizes will be distributed unevenly
- Further developments of the model are planned, and we hope to apply it to wheel designs for upcoming missions



Acknowledgements and References

We thank Ron Creel for providing CAD files and information on the LRV wheels and fenders. This work was initiated as part of the LUVMI-X project which is co-funded by the European Commission through its Horizon 2020 programme under grant agreement #822018. The continuation of this work is supported by CLASS under NASA cooperative agreement #80NSSC19M0214.

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