A Model for Tribocharging of Regolith Grains

DYLAN CARTER
CHRISTINE HARTZELL

University of Maryland 1856
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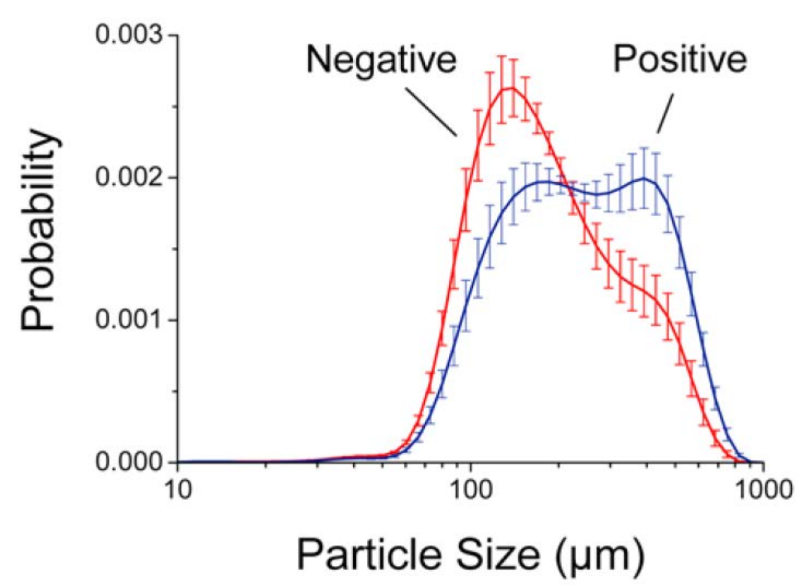
Introduction

Triboelectricity is the phenomenon by which surfaces exchange charge due to collisions or contact

- Occurs in nearly all materials
- Mechanism depends on environment and material properties



Known to occur in lunar regolith simulant

- Charge separation by particle size in regolith simulant (Forward, *et al,* 2009)
- Trigwell, *et al* (2013), used tribocharging to electrostatically filter regolith samples
- Determined feasible, but some questions about the process remain

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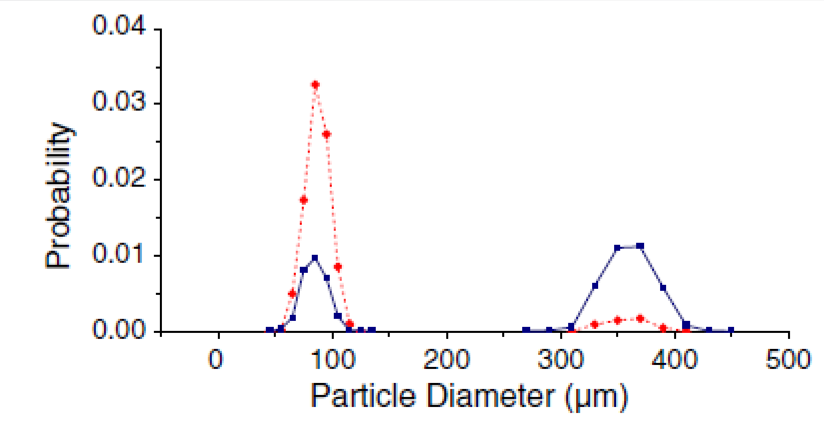
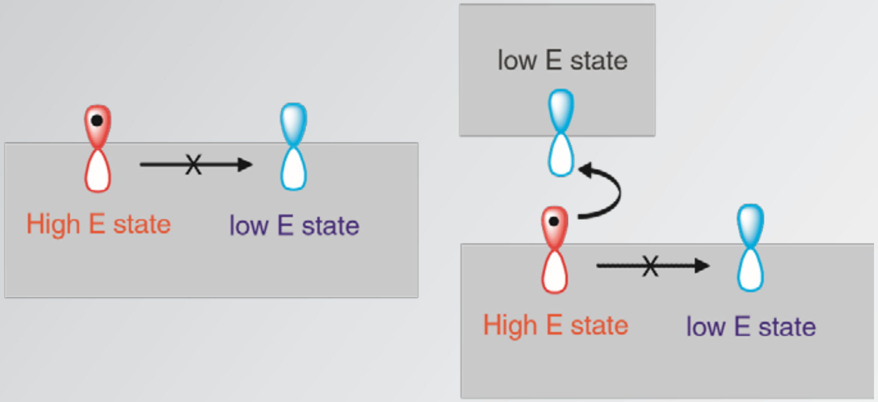
Same-Material Tribocharging

Tribocharging between identical granular materials is poorly understood

- Polarity follows size-dependent patterns (Forward, *et al*, 2009)
- Mechanism is unclear
- Atmosphere appears to have a significant effect





Lacks and Levandovsky (2006)

Lacks and Levandovsky developed a model for insulator tribocharging in bidisperse mixtures

- Excited electrons cannot reach lower energy states
- Predicts negative charge for small grains, positive for large grains

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Motivation

Presence of water vapor in air significantly alters the tribocharging process

- Testing in vacuum will be necessary to understand regolith charging *in situ*

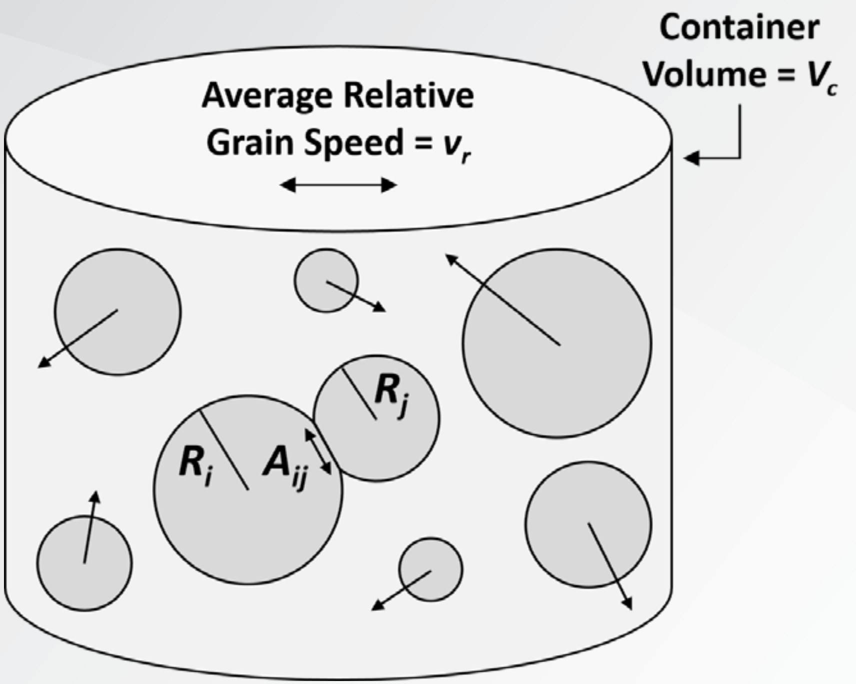
Knowledge gap in same-material dielectric tribocharging makes accurate models elusive

- Better models will have broad implications in fields of lunar ISRU, dust mitigation, and earth sciences
- Improving our understanding of this phenomenon is a critical first step

Collision Model

Assume grains move with constant speed against a uniform background

- Mixture contains n_0 grains
- Sizes distributed as $g(R)dR$
- Collision rate of grain with radius R_i against grains of radius R_j calculated as:



$$\omega_{ij} = \pi \frac{v_r n_0 g(R_j)}{V_c} \left(R_i + R_j\right)^2 dR_j$$

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Transfer Rates

- Relevant parameters:

ρ_0 (Initial electron density)

f_H (Transfer probability)

$$\alpha_i = \int_0^\infty \frac{f_H \omega_{ij} A_{ij}}{4\pi R_i^2}$$

(Exchange rate coefficient)

- High-energy electron density:

$$\frac{d\rho_{Hi}}{dt} = -\alpha_i \rho_0 e^{-\alpha_i t}$$

- Low-energy electron density:

$$g(R_i)\frac{d\rho_{Li}}{dt} = \rho_0 \int_0^\infty g(R_j)\frac{dR_j}{dR_i}\left[\frac{d\rho_{Hj}}{dt}\right]_i$$

- Charge rate:

$$\frac{dQ_i}{dt} = -4e\pi R_i^2 \left(\frac{d\rho_{Hi}}{dt} + \frac{d\rho_{Li}}{dt}\right)$$

Charging Model

Collision area estimated from Hertzian collision theory (Gugan, 2000):

$$A_{ij} \propto \frac{R_i^2 R_j^2}{\left(R_i^3 + R_j^3\right)^{2/5} \left(R_i + R_j\right)^{4/5}}$$

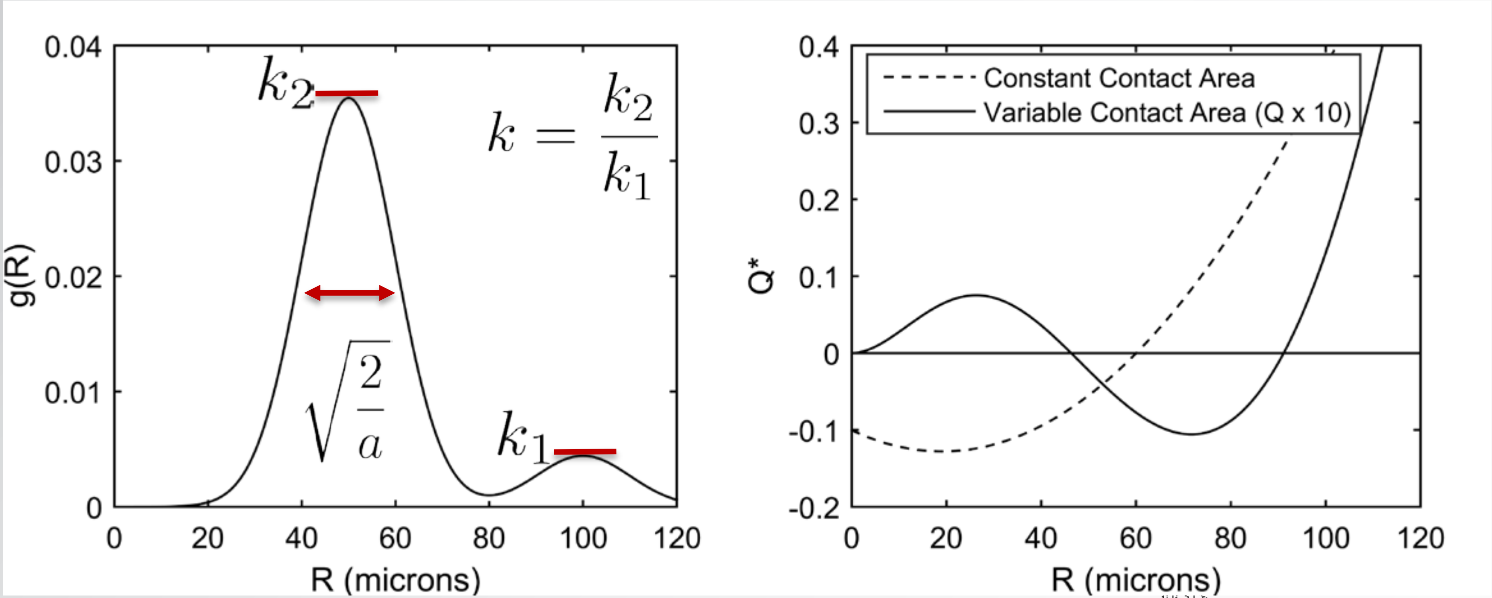
For single-material mixtures, integrating over collisions with all grain sizes gives average charge on a grain of some size R_i below:

$$Q(R_i) \propto R_i^2 - \int_0^\infty R_j^2 \frac{\left(R_i + R_j\right)^2 A_{ij} g(R_j)}{\int_0^\infty \left(R_j + R_k\right)^2 A_{jk} g(R_k) dR_k} dR_j$$

Results and Predictions

For normally distributed sizes:

$$g(R) \propto e^{-a(R-R_1)^2} + ke^{-a(R-R_2)^2} \qquad Q^*(R) = \frac{Q(R)}{4e\pi\rho_0 R_1^2}$$



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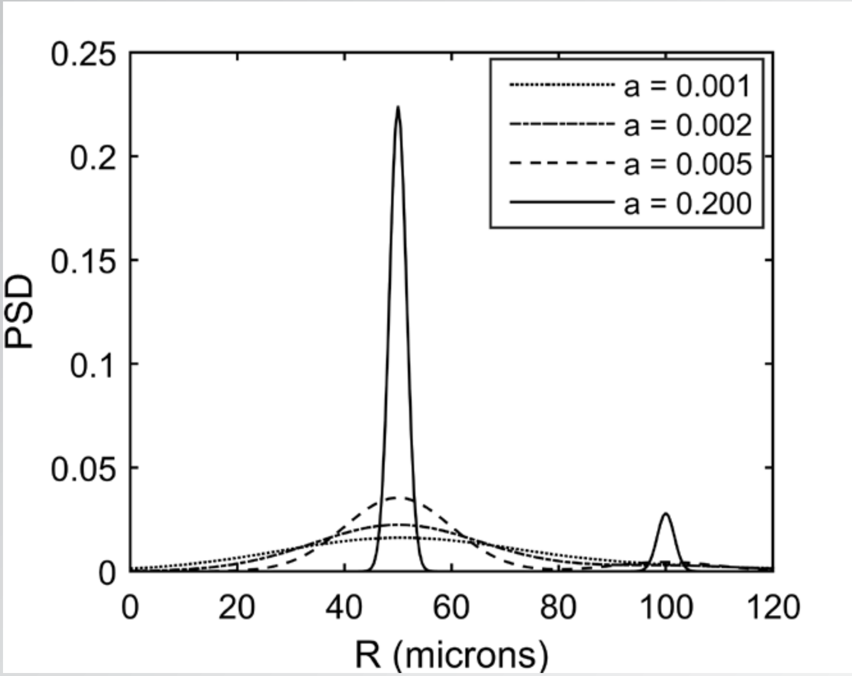
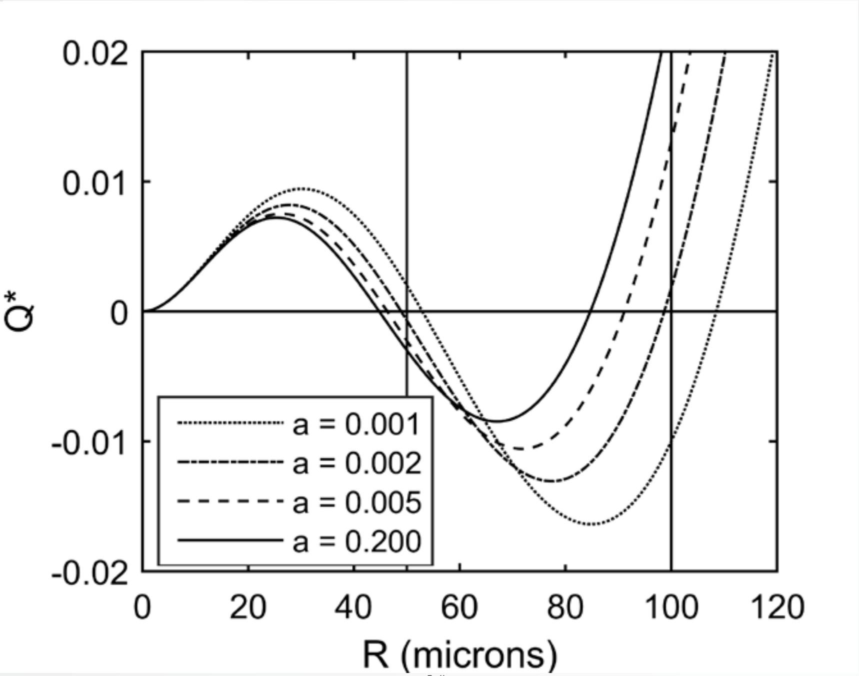
Polarity Variation

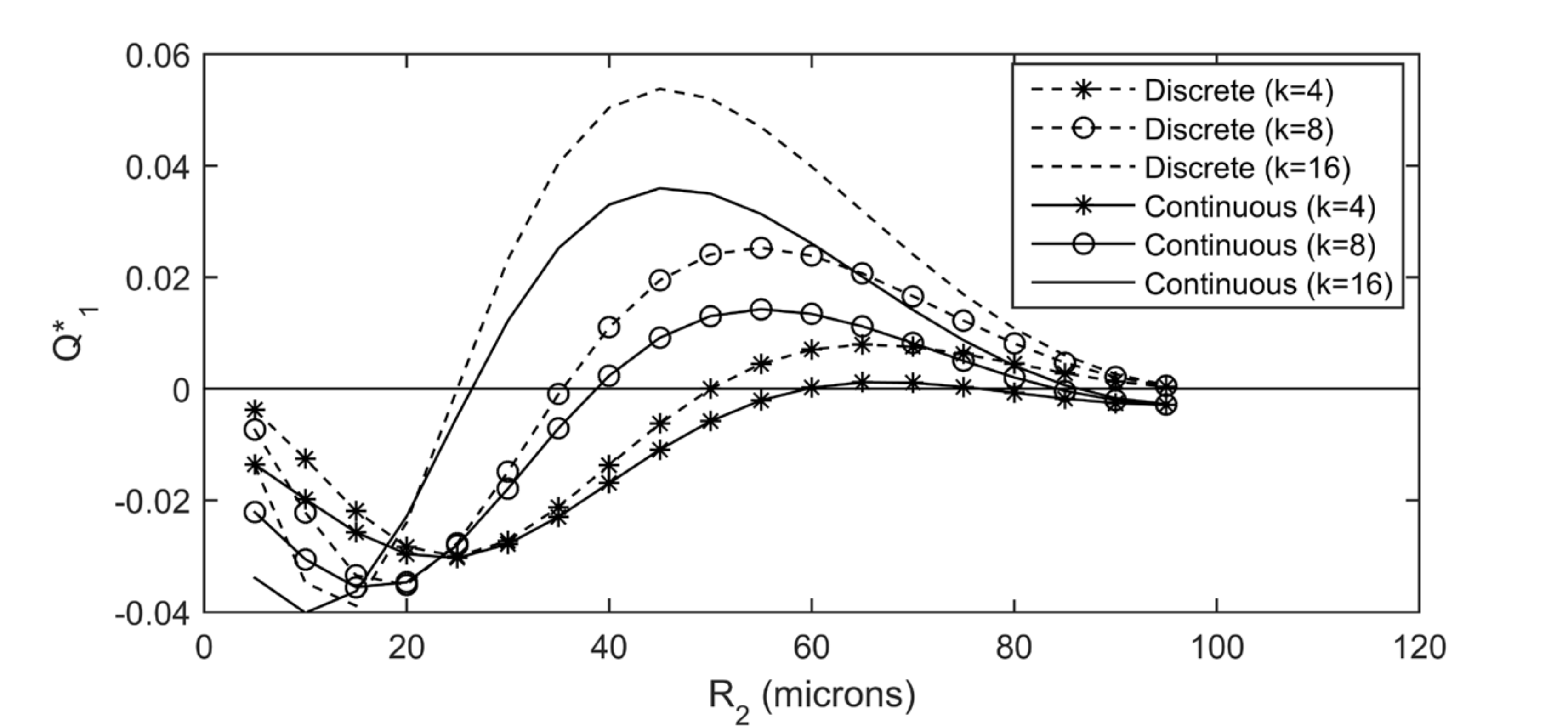
Charge polarity varies with width of size distribution





Polarity Variation

Size and mass ratios determine reversal conditions



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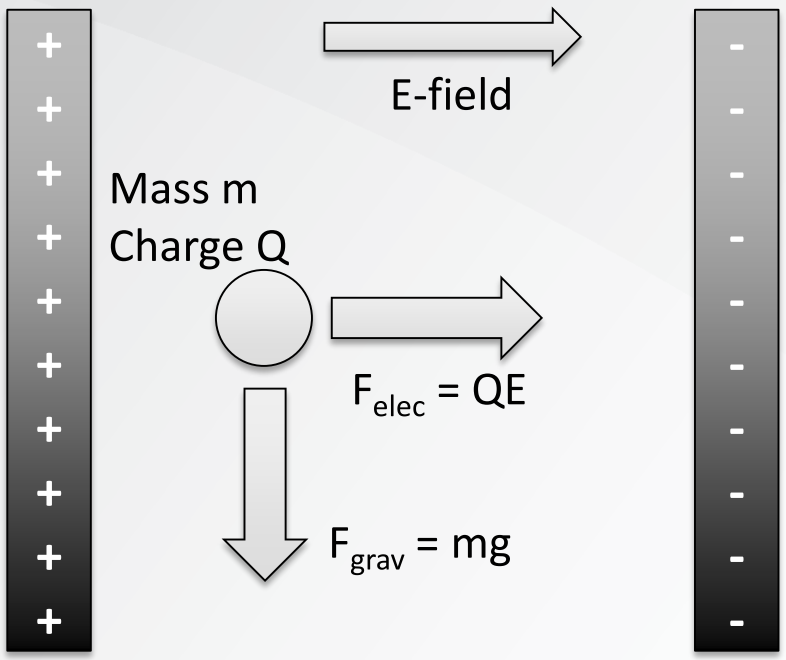
Experiment

Designing experiment to measure individual grain charge

- Grains shaken in vacuum to induce charge separation
- Dropped through transverse E-field
- High-speed camera records grain trajectory to measure charge
- See similar experiment by Jaeger and Waitukaitis, *et al*, 2014

Grain Charging Experiment



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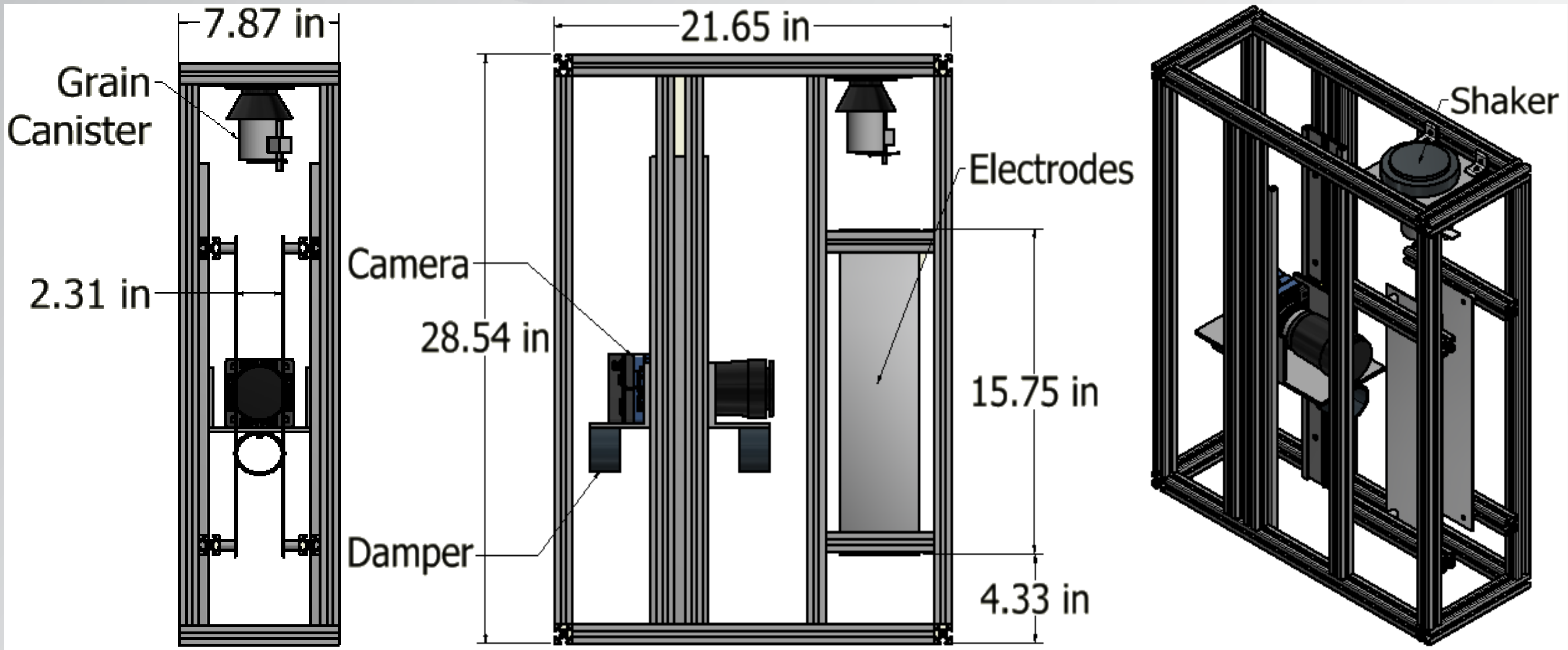
Experiment Setup



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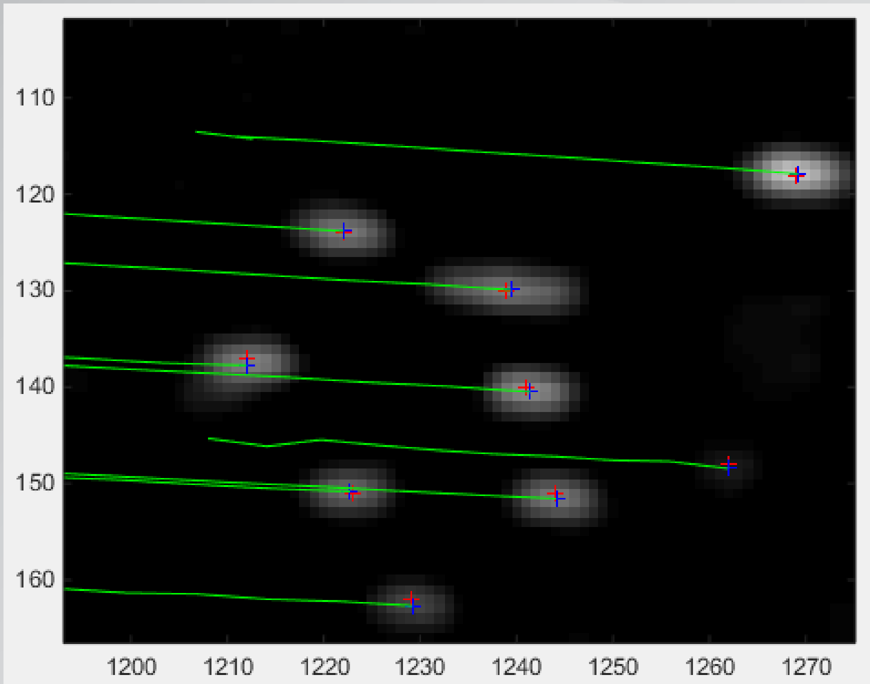
Grain Tracking



Developed preliminary grain tracking algorithm

- Sample taken at 1k fps over 10 frames
- 143 tracks with various degrees of accuracy
- Needs refinement for final setup

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Future Work

Model for same-material tribocharging can be integrated into existing models for different-material charging

- Monte Carlo simulations of granular mechanics incorporating our charge exchange model can illuminate charging trends in lunar regolith

Construction of experimental setup is underway

- Results will allow further refinement of our charging model

Currently awaiting results of small-scale vacuum tribocharging test

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Conclusions

- We know that significant, predictable charge separation occurs in lunar regolith
- Our model makes new testable predictions about charge polarity in vacuum conditions
- Our experiment will enable better modeling and prediction of grain charge by size and mixture properties in a variety of granular systems
- Predictive models have potential applications in lunar ISRU and dust mitigation techniques

Acknowledgments

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