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COMSOL Model of a Martian Electrostatic Precipitator

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SWAMP WORKS

NASA KENNEDY SPACE CENTER

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In-Situ Resource Utilization

1) Resource Acquisition

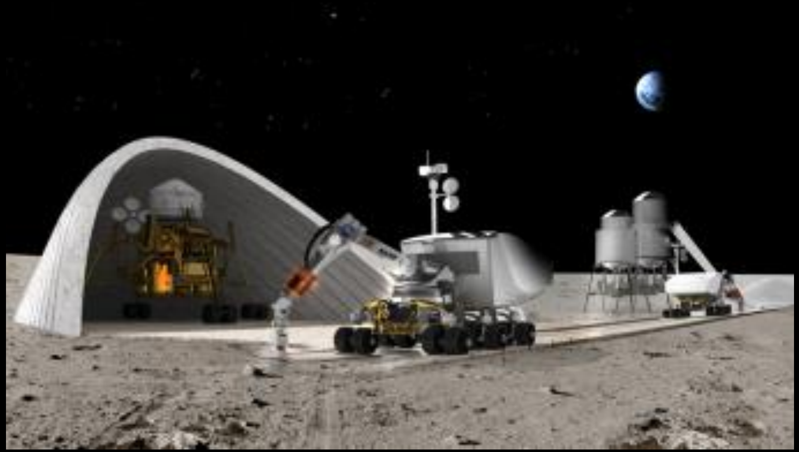
Prospecting and mining robots
Semi-autonomous

2) Resource Processing

Dust mitigation
Chemical conversion
Cryogenic storage

3) Fuel, Life Support, Infrastructure

Methane
Water
Oxygen
Research outpost and facility



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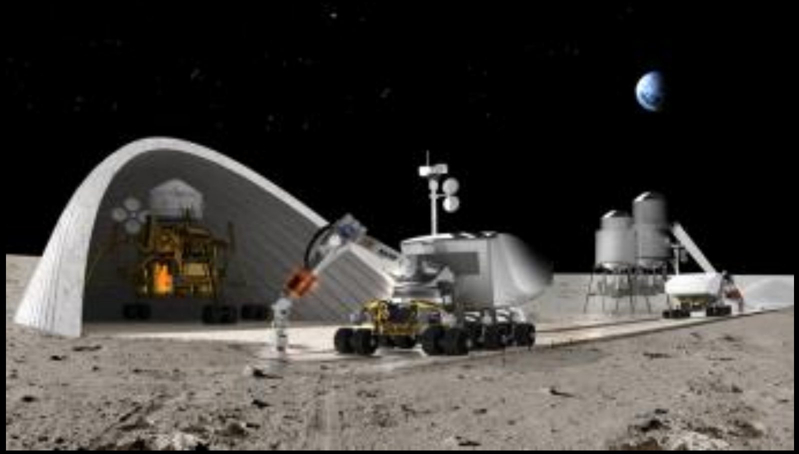
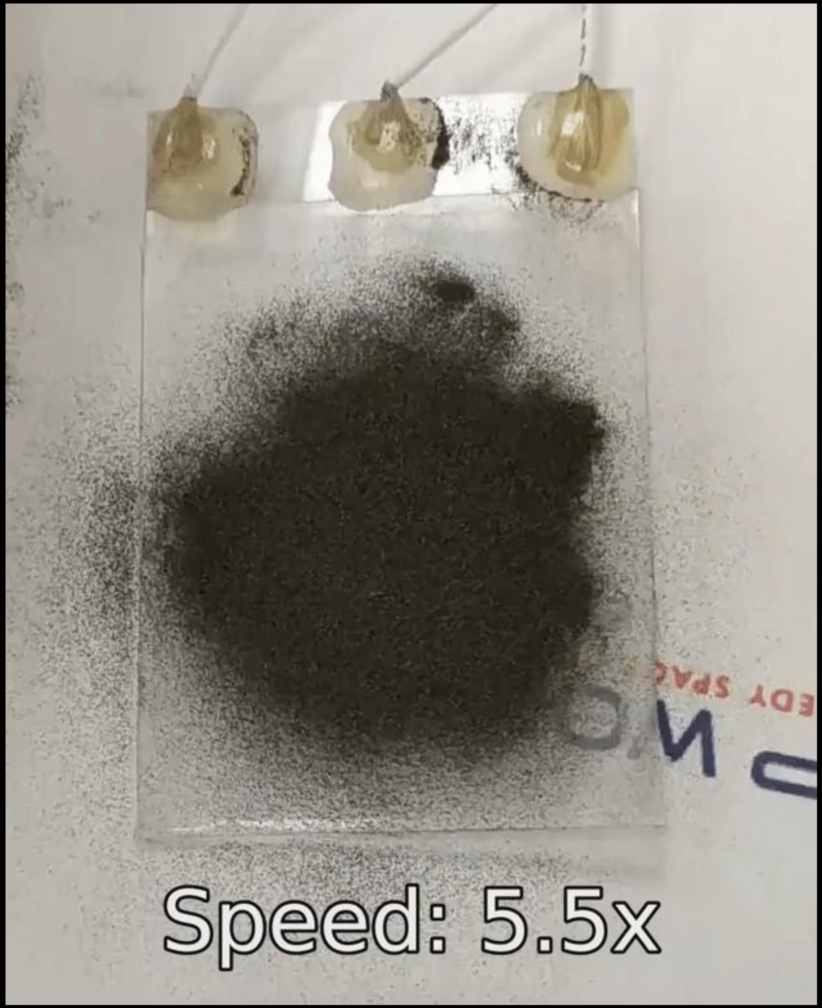


Dust

ESPL: Electrostatics and Surface Physics Laboratory

- Electrodynamic Dust Shield
  - Protect solar panels, astronaut visors, and camera lenses **(email us more use cases)**
  - Ruggedized version currently being exposed on ISS exterior
  - Tested with Apollo Lunar regolith



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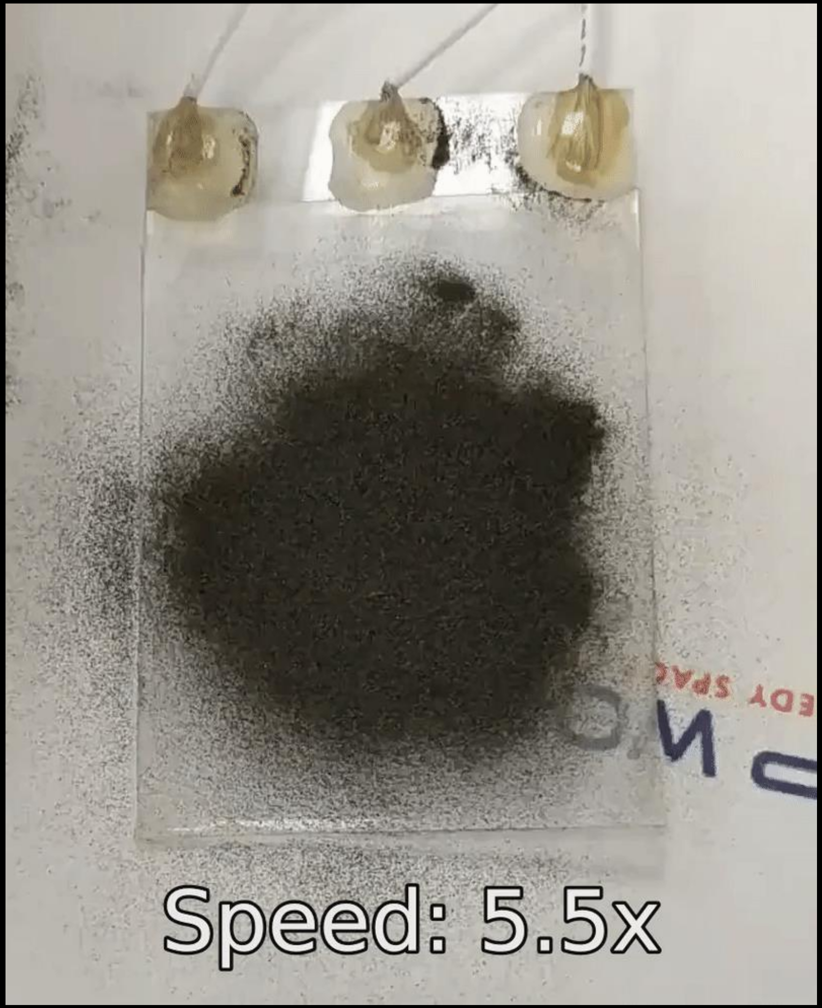

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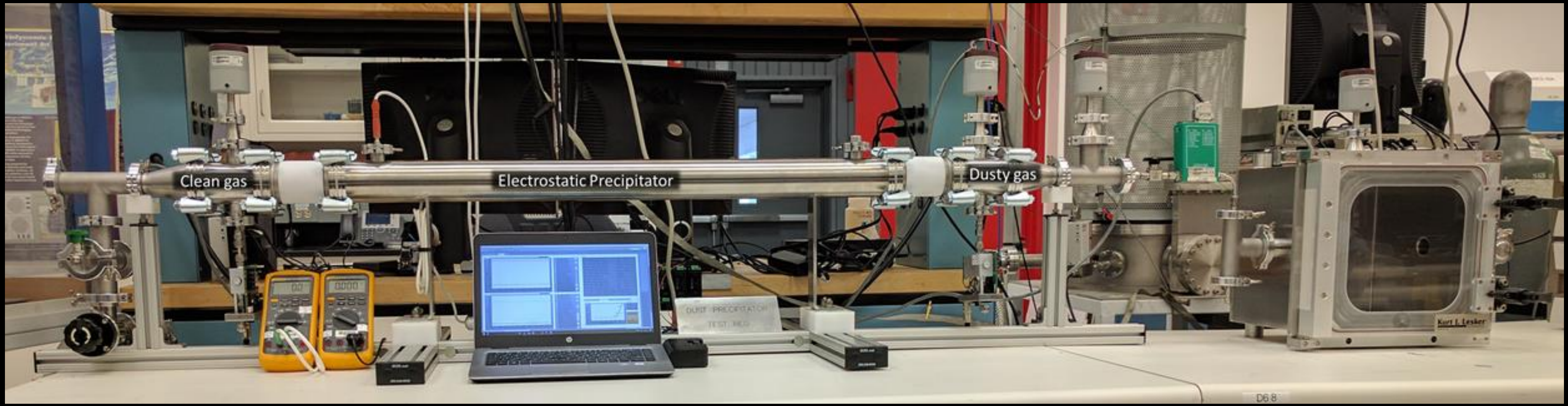
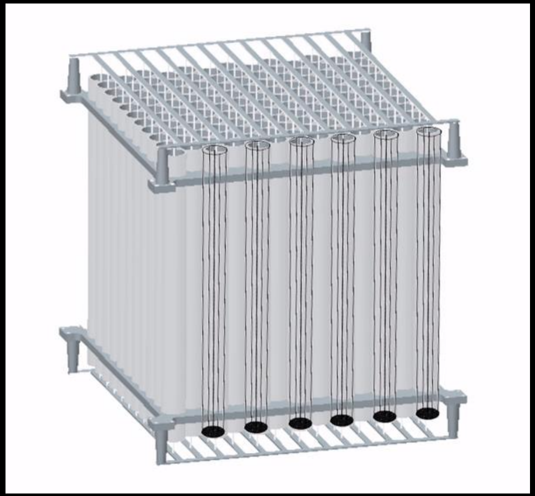
- Martian Electrostatic Precipitator



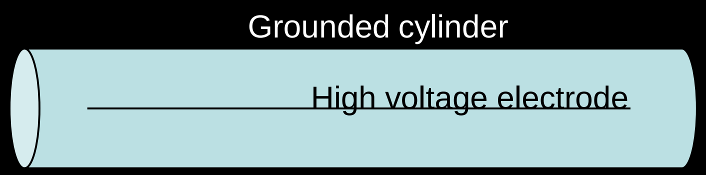


- Martian air → **precipitator** → CO_2 extractor…
  CO_2 extractor → Sabatier reactor + H_2 → **methane** & **water** → H_2 & $\mathbf{O_2}$
- Corona charging + radial electric field = media-less dust filter

Electrostatic Precipitator

- Particle density (nominal): 1 – 10 particles/cm^3
- Particle density (storm): 100 – 1000 particles/cm^3
- Particle diameter: 1 – 10 μm
- Pressure: 4 – 7 torr s

- Particle charging: **corona discharge**
- Corona ionizes gas, ions attach to dust, charged dust repelled out to ground
- Optimize collection length vs. diameter for smallest precipitator
- Scale in parallel for greater flows



Density Distribution (Plasma Module)

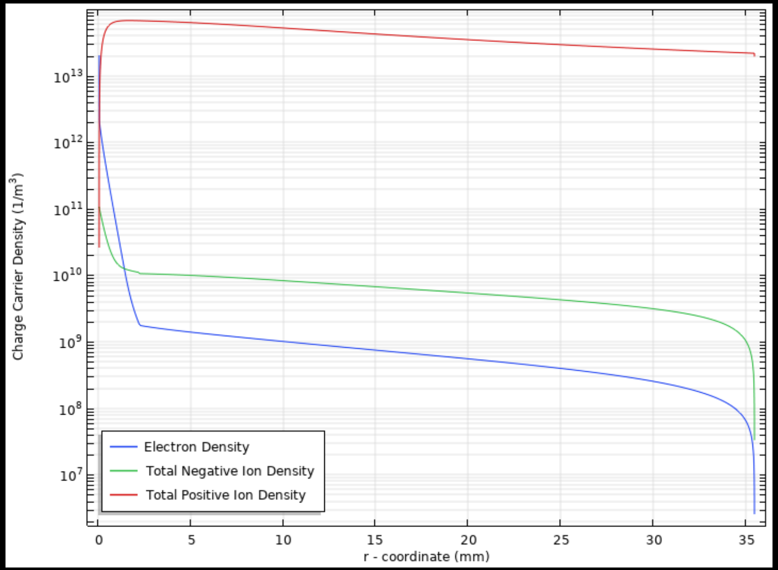


Figure 1. Semi-log density distribution

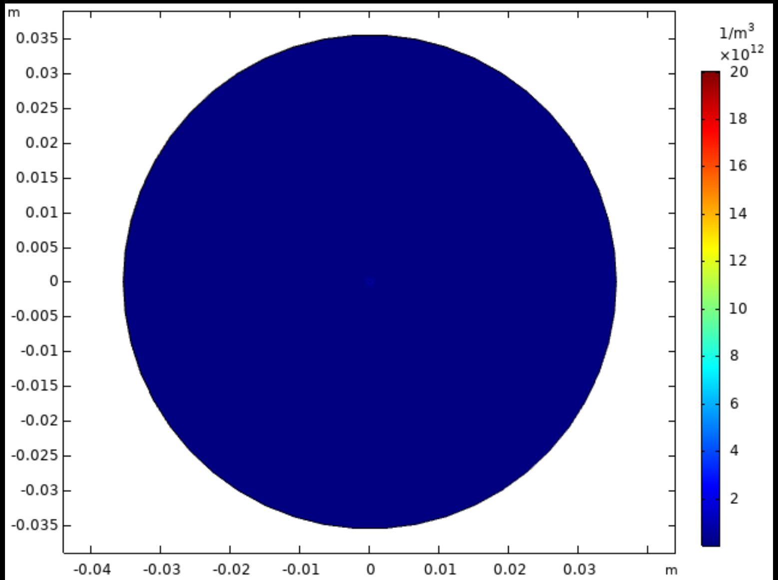


Figure 2. Electron density distribution

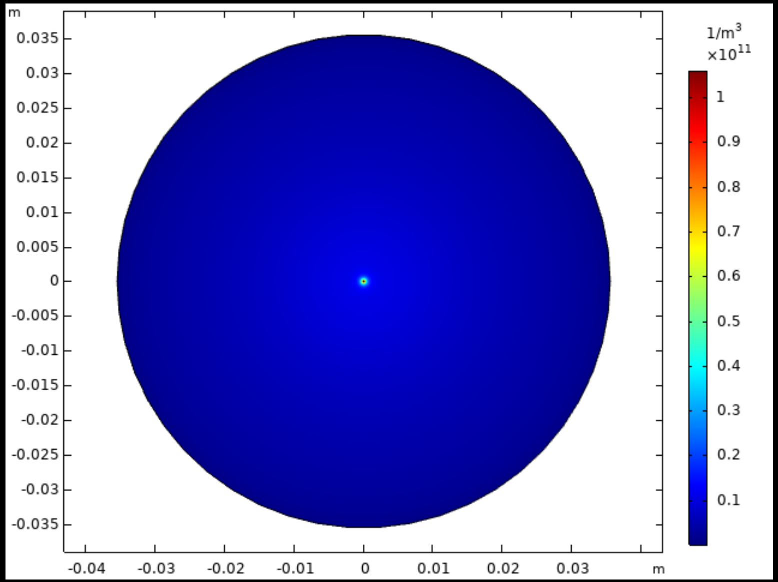


Figure 3. Negative ion density distribution

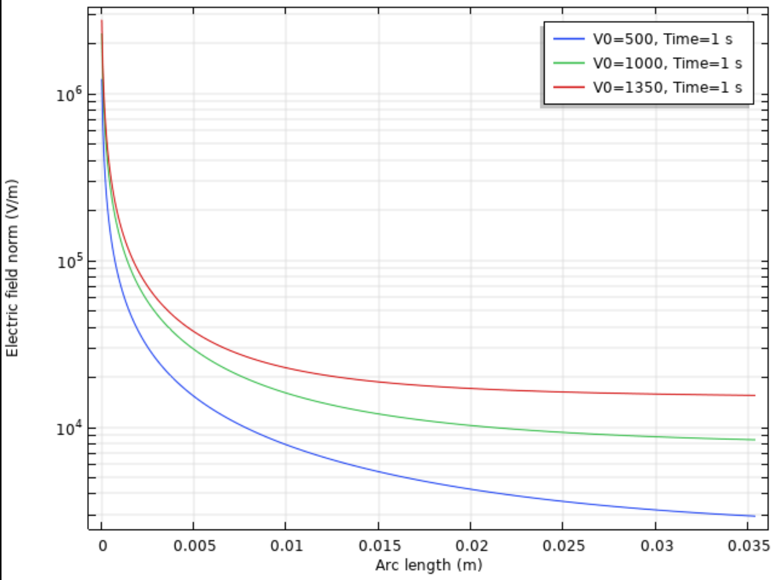


Figure 4. Electric field strength

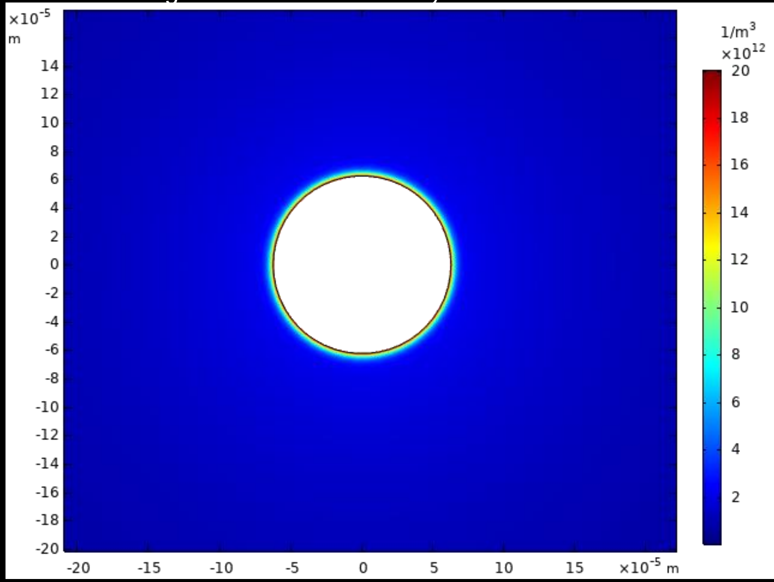


Figure 5. Electron density distribution zoom

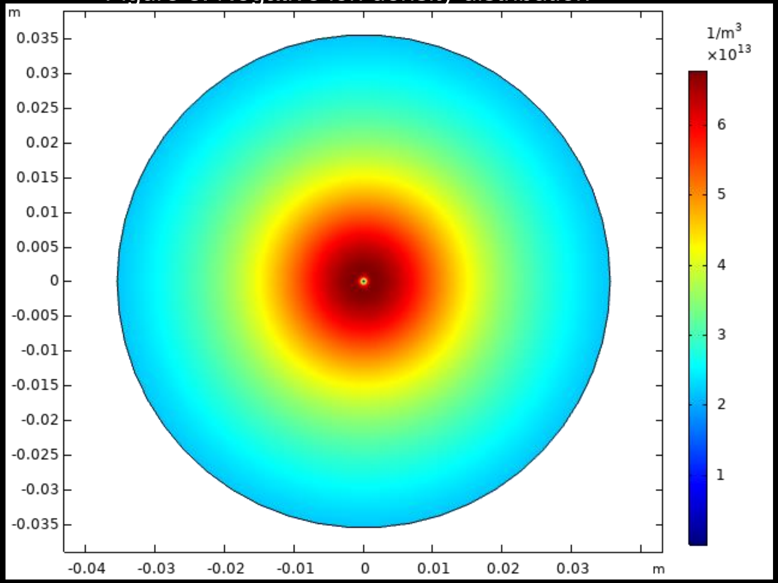


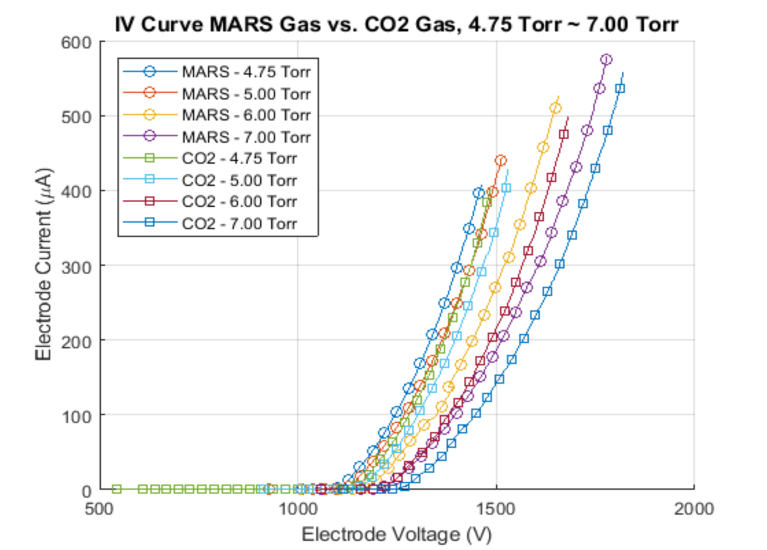
Figure 6. Positive ion density distribution

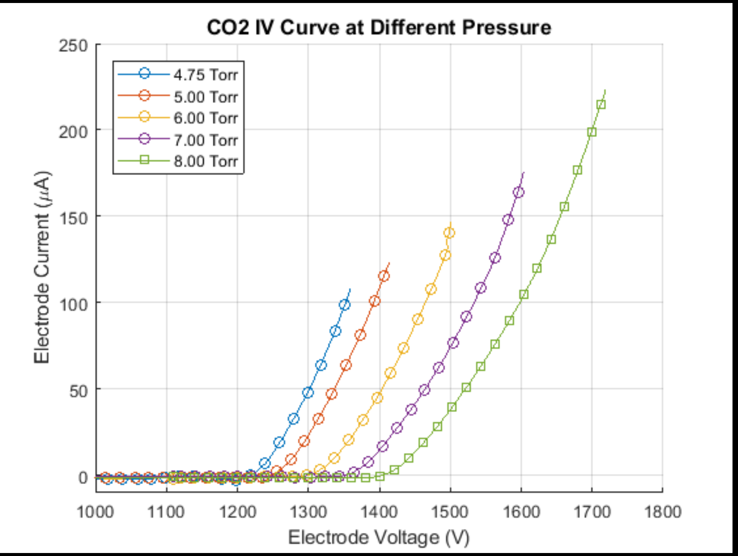
Model Objective

- Model positive corona discharge, determine accumulated charge on dust
- Characterize current vs. voltage (I-V curve) to compare to experiment
- Model particle trajectories
- Estimate collection efficiency and compare to experiment

$$\eta_{\mathrm{empirical}} = \left(1 - e^{\frac{-A*w}{V_f}}\right)$$

$$w = \frac{2 * \varepsilon_0 E_c E_p \left(\frac{d}{2}\right)}{\eta_{CO2}}$$





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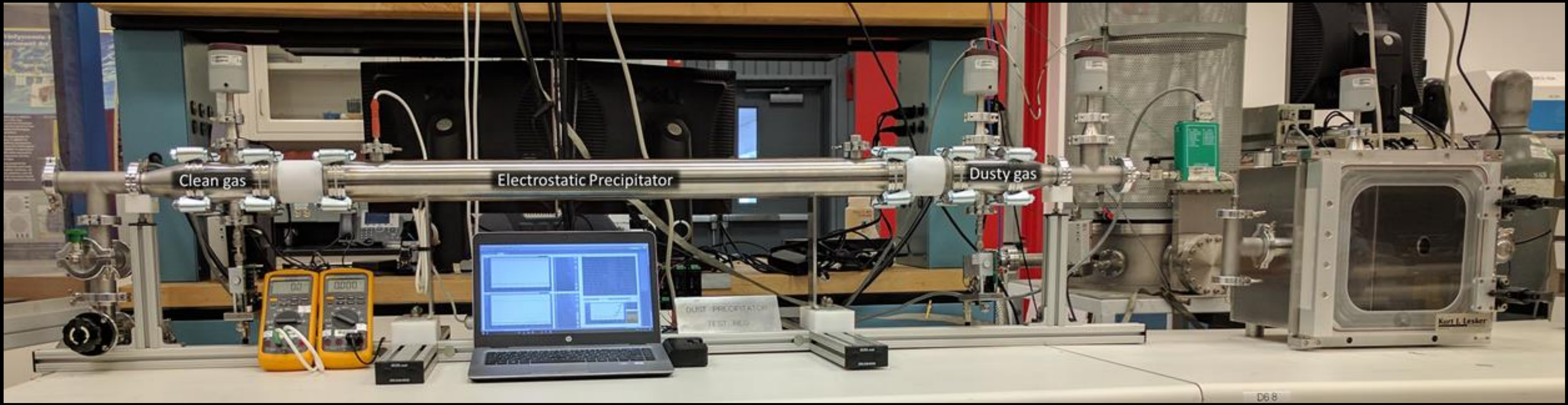
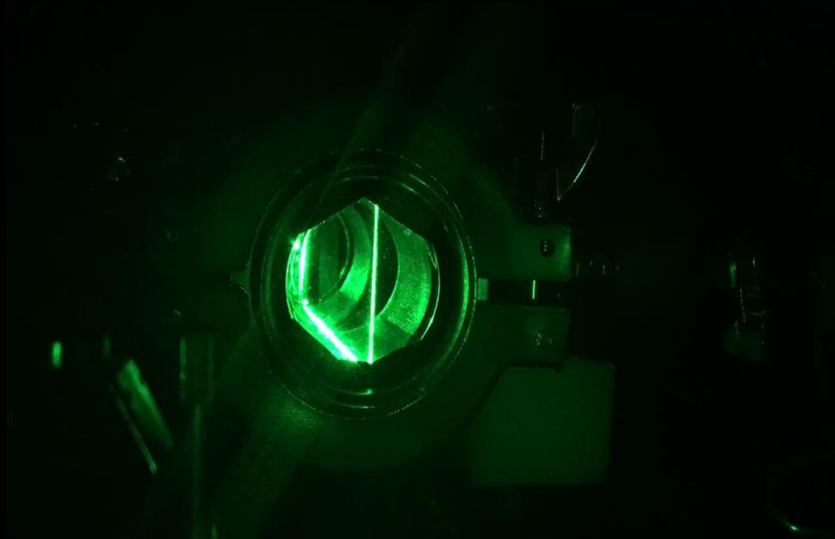
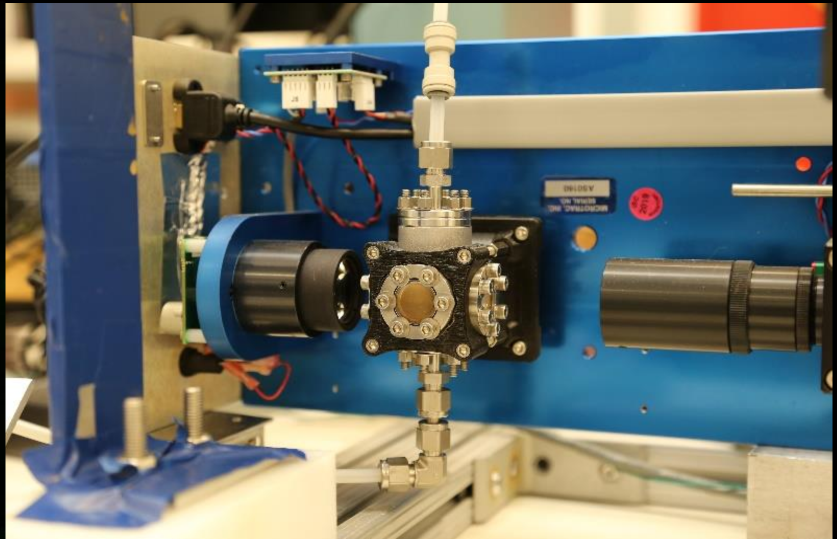
Hardware Setup







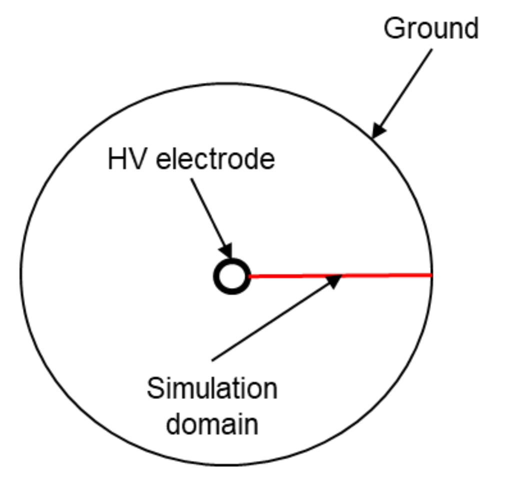
Model Setup

Boltzmann Equation

- Electron energy and cross-section data for different electron impact reactions
- Maxwellian shape function
- Townsend's coefficient, electron energy distribution function, and mean electron energy

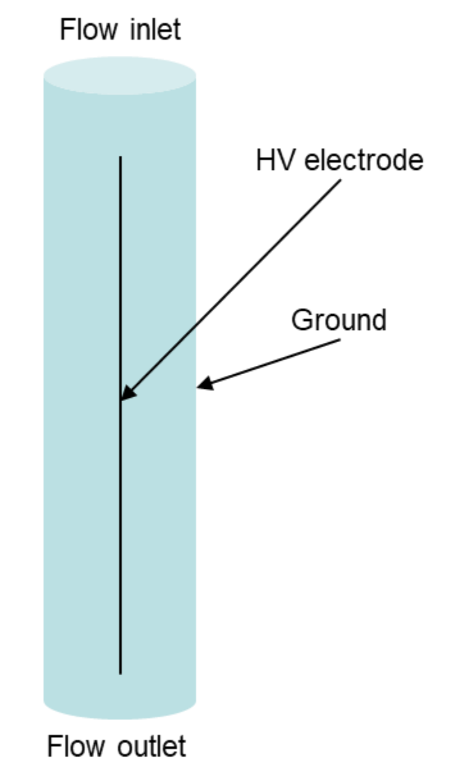
Table 1. Summary of all species included in the model.

Neutrals	CO_2, CO, O_2, O, C
Positive ions	CO_2^+, O_2^+, O^+,
Negative ions	O^-, O_2^-



DC Plasma Model

- Corona discharge
- Electron and ion density distribution
- Current-voltage relationship (IV curve)
- Particle charge estimation



Precipitator Model

- Laminar flow
- Electrostatics
- Particle tracing

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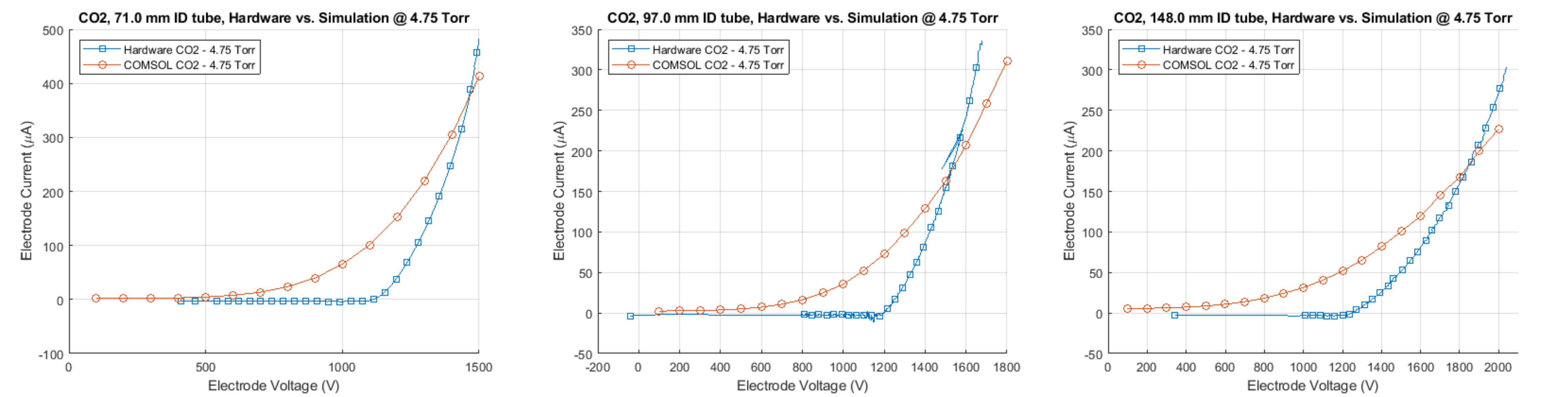
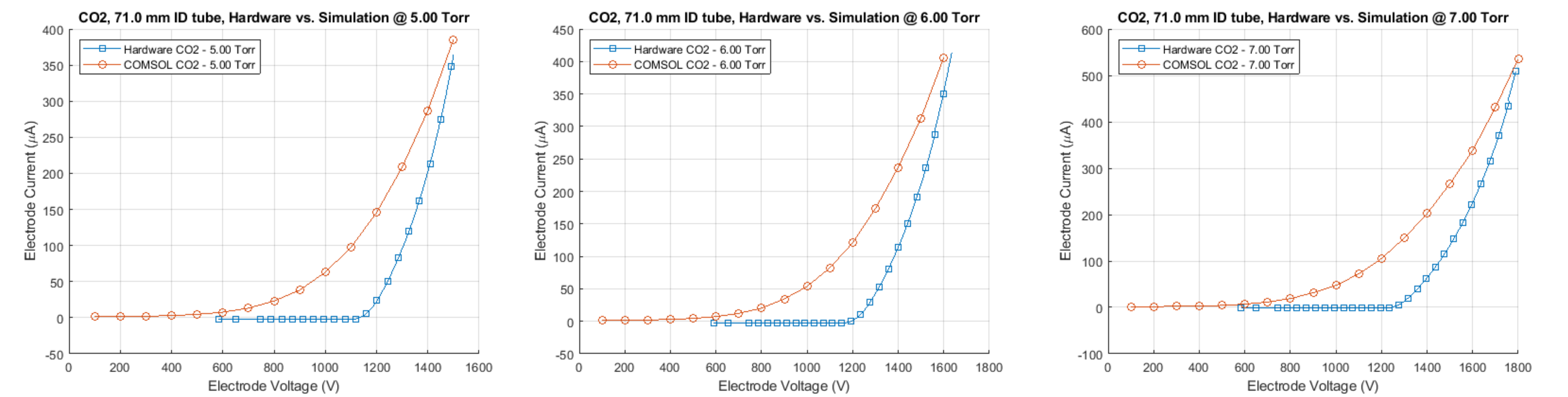
IV Curve: Simulation vs. Data





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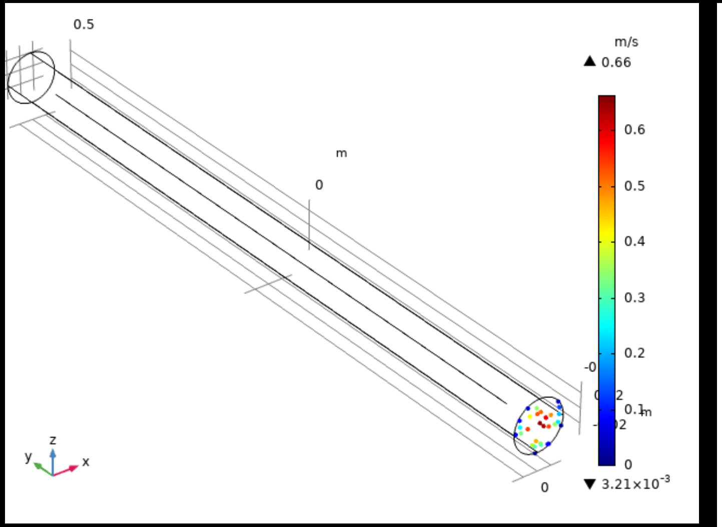
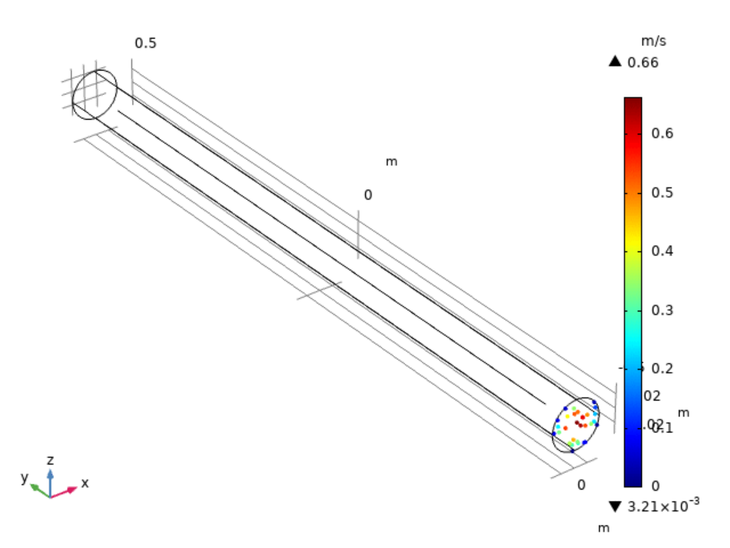
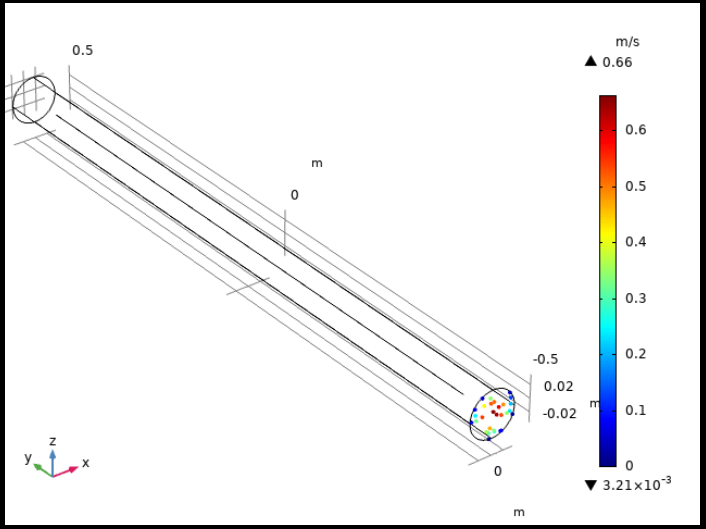
Particle Trajectory & Collection Efficiency



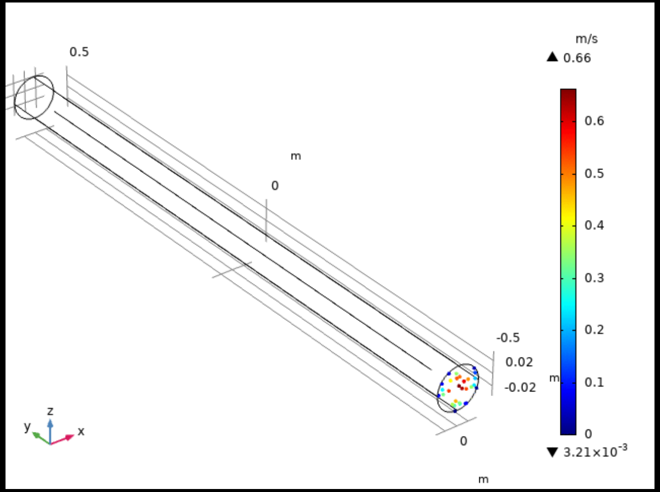
1 um particle 500 SCCM (0.214 fC)



3 um particle 500 SCCM (1.925 fC)



5 um particle 500 SCCM (5.349 fC)



10 um particle 500 SCCM (213.9 pC)

Diameter (μm)	$\eta_{empirical}$ (assumes air @ 1 atm)	η_{COMSOL}	η_{FPA}	η_{Laser}
1	77.8%	100.0%	99.6%	90.0%
3	98.8%	100.0%	99.5%	95.0%
5	99.9%	100.0%	99.7%	90.0%
10	100.0%	100.0%	99.0%	90.0%

Summary

- I-V curve partially approximated experiment (shape and magnitude)
  - Premature corona discharge onset voltage
  - Moderate agreement at higher voltages; Maxwellian distribution assumes high degree of ionization
- Literature: 1 fC/um, model: 0.1 fC/um
- Simulation: collection efficiency > 90% during dust storm
- Laser counter (side scattering): efficiency erroneously low, dust re-entrenchment (known issue)

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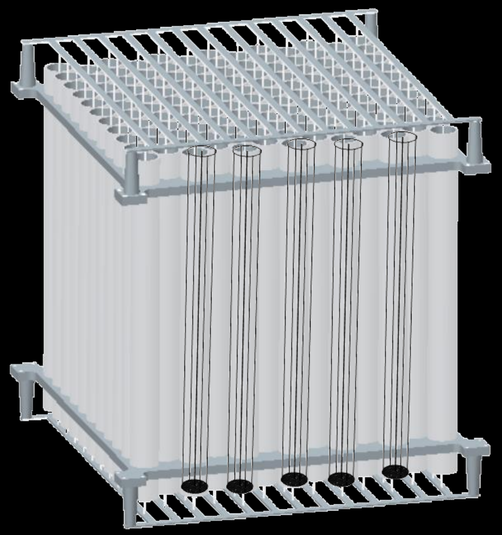

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Questions?

Joel Malissa
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Polarity

- HV is always positive because negative trials were less stable (electron mobility is higher than ion mobility, so negative electrode interacts more with charges than in positive field => more stable I-V corona curve (less steep slope for positive electrode)
- *also negative generates more ozone

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Collection Efficiency

$$\eta_{empirical} = (1 - e^{\frac{-A*w}{V_f}})$$

$$w = \frac{2 * \varepsilon_0 E_c E_p \left(\frac{d}{2}\right)}{\eta_{CO2}}$$

- Eq. from 1919 (100th anniversary)
- $\eta_{empirical}$ = dimensionless collection eff.
- A = collection area (m^2)
- w = migration velocity (m/s)
- V_f = average fluid velocity (m^3/s)
- ε_0 = vacuum permittivity constant
- E_c = E-field at wire (V/m)
- E_p = E-field at ground (V/m)
- η_{CO2} = dynamic viscosity (kg/(m s))
- d = particle diameter (m)

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Fine Particle Analyzer (FPA)

- One upstream
- One downstream
- Sampling error: only measures from center
- Flow controller & pressure transducer determine percentage of flow sampled