Touchless potential sensing model for active spacecraft charging scenarios

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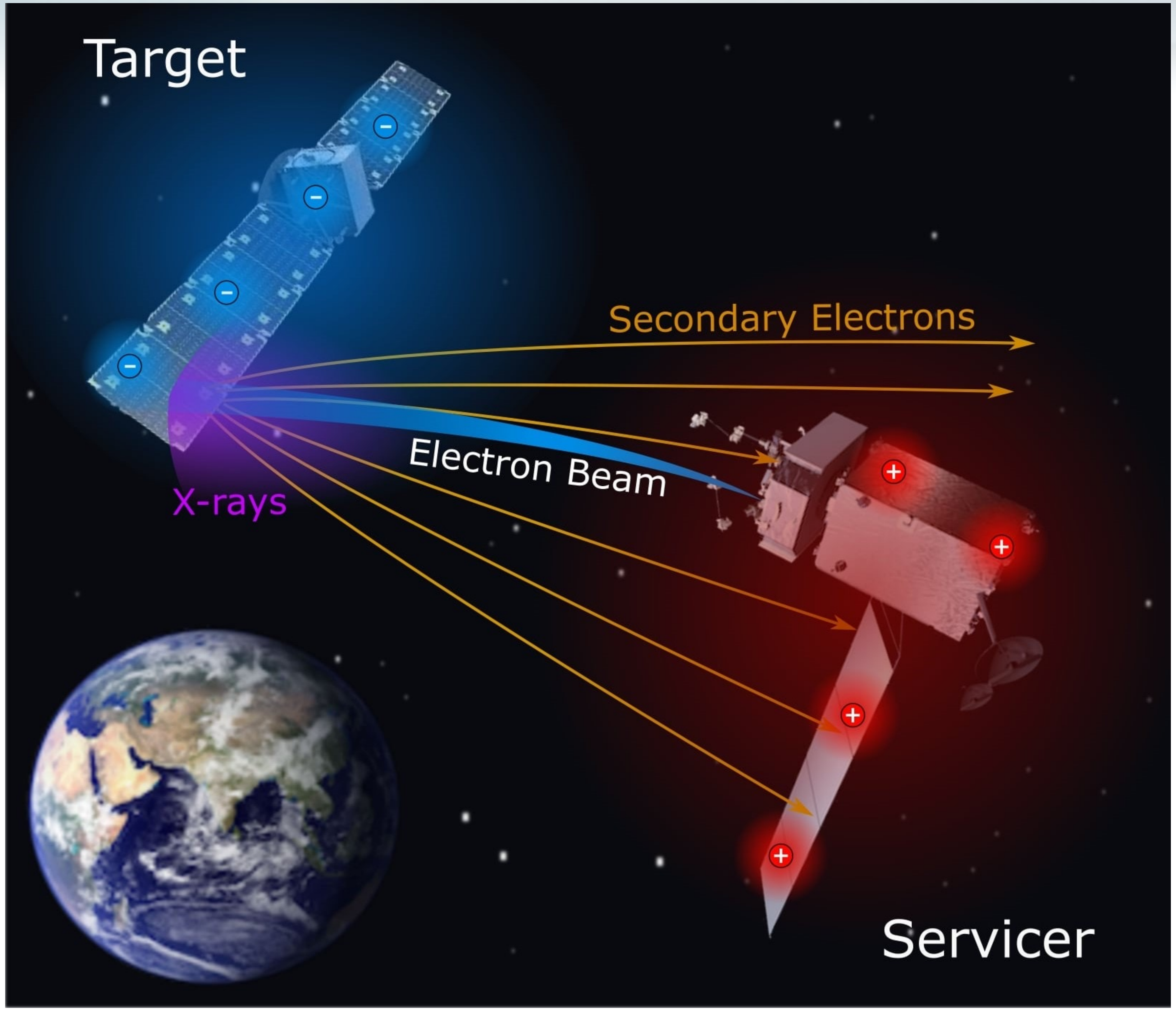
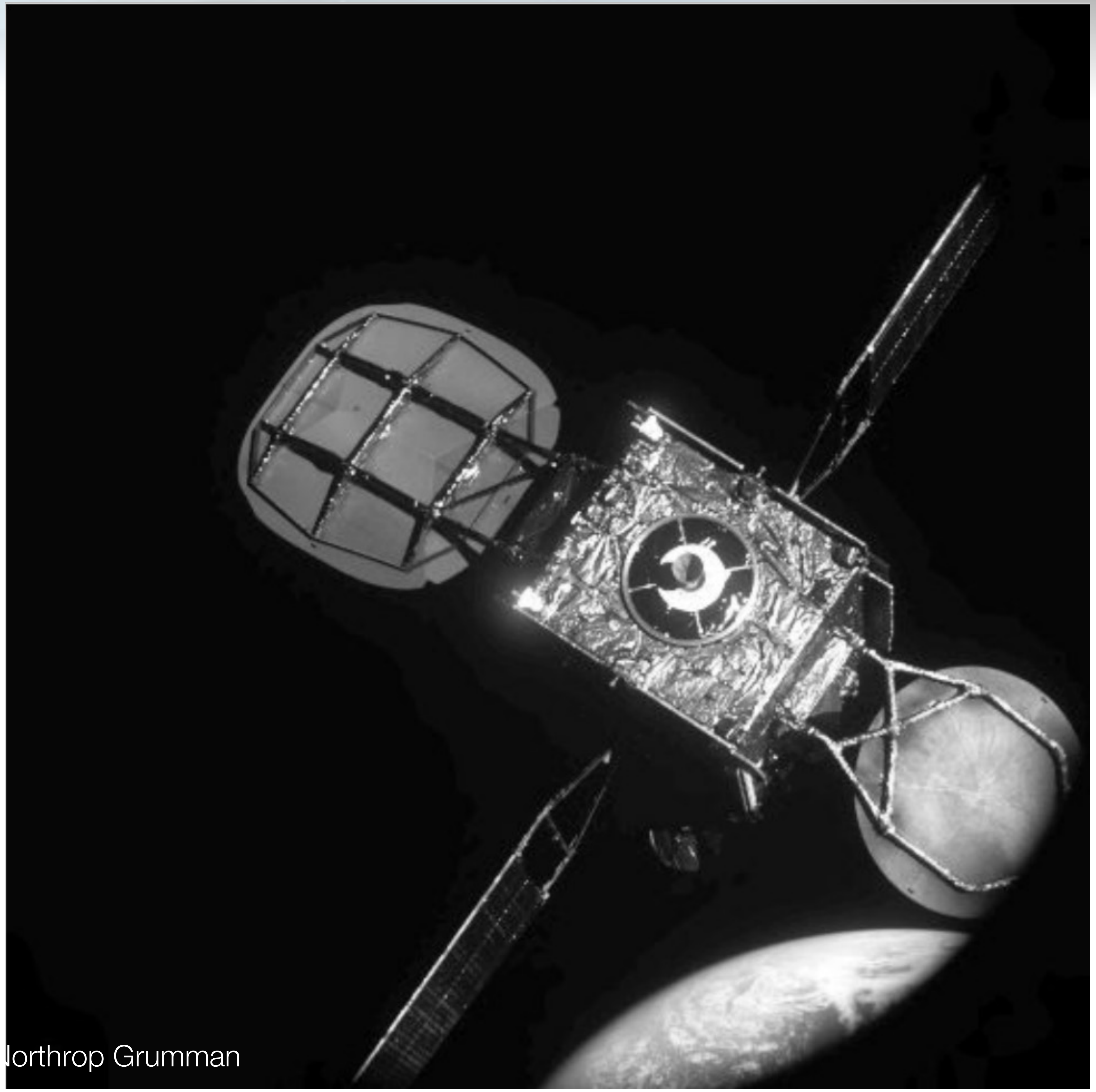
Introduction & Motivation

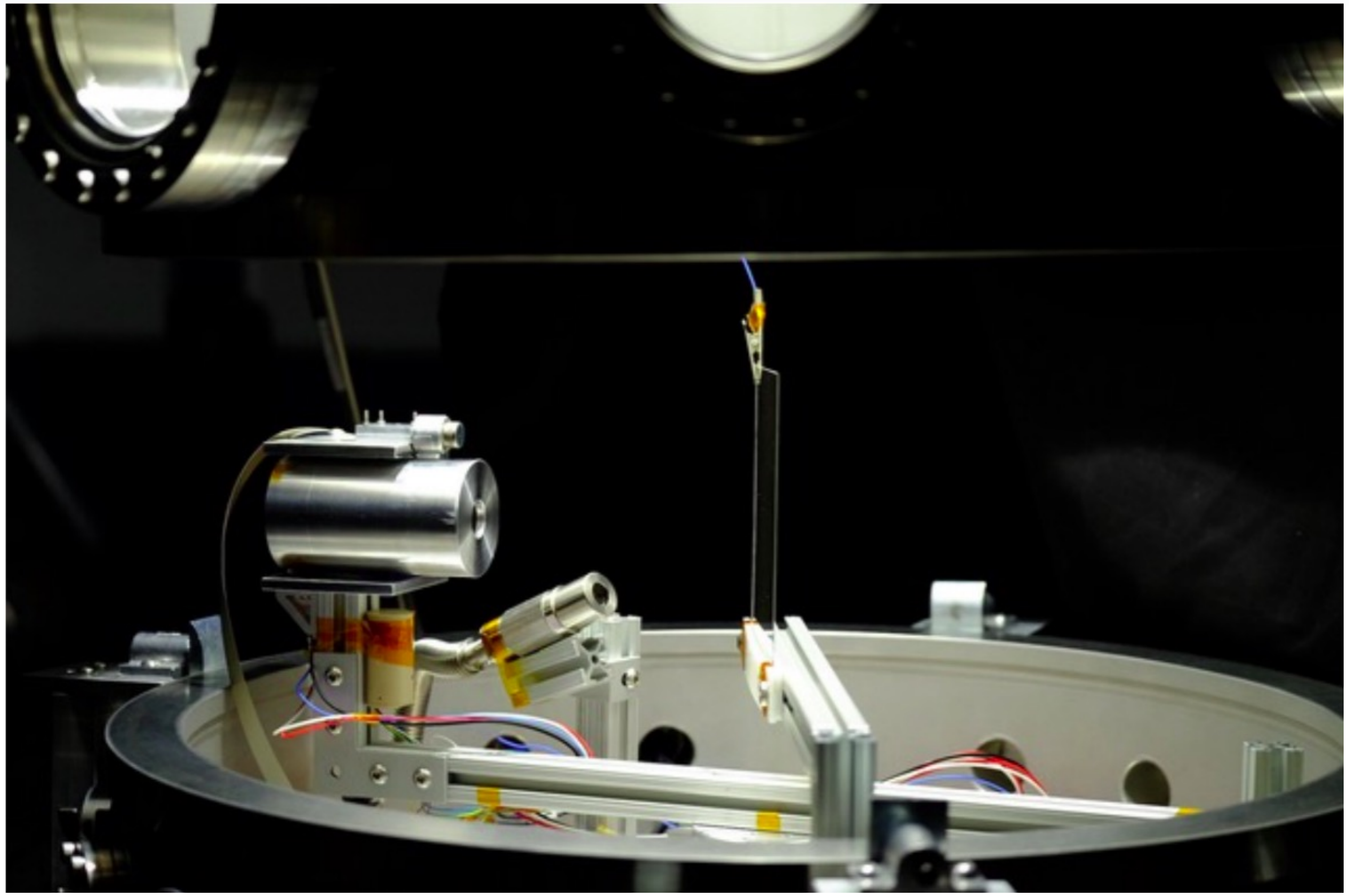
Introduction

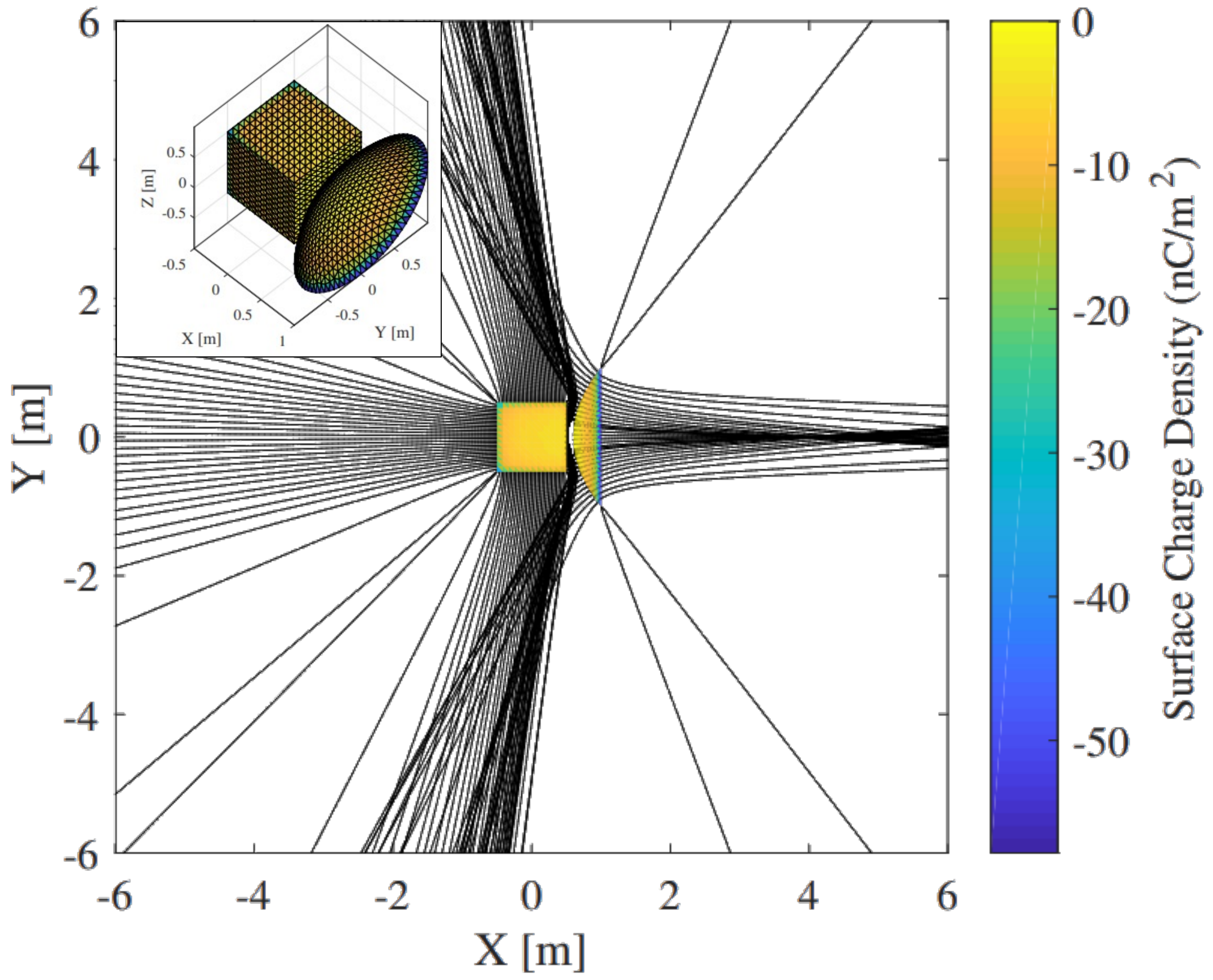




Bengtson, “Electron Method for Touchless Electrostatic Potential Sensing of Neighboring Spacecraft”, PhD thesis, 2020

Motivation

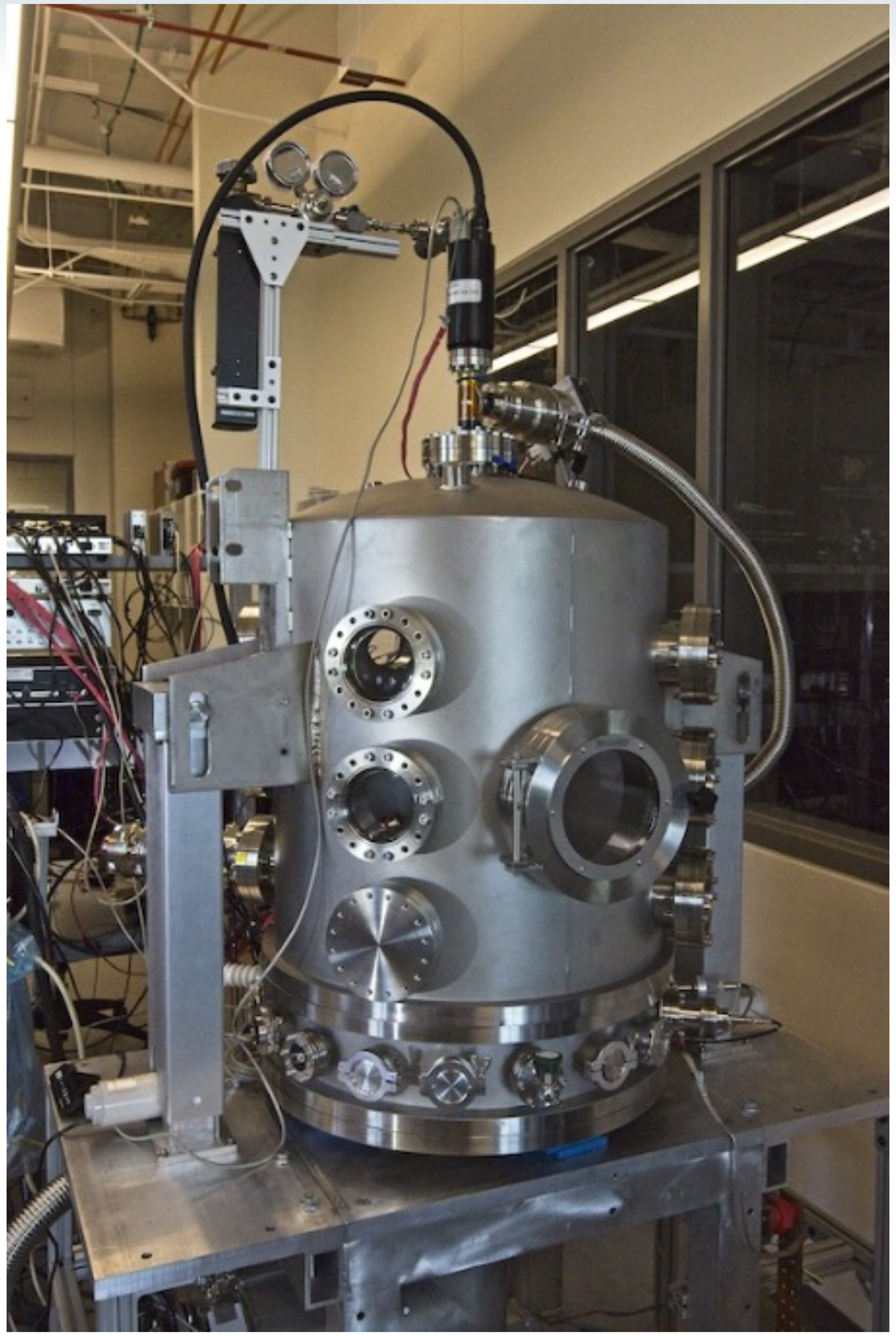


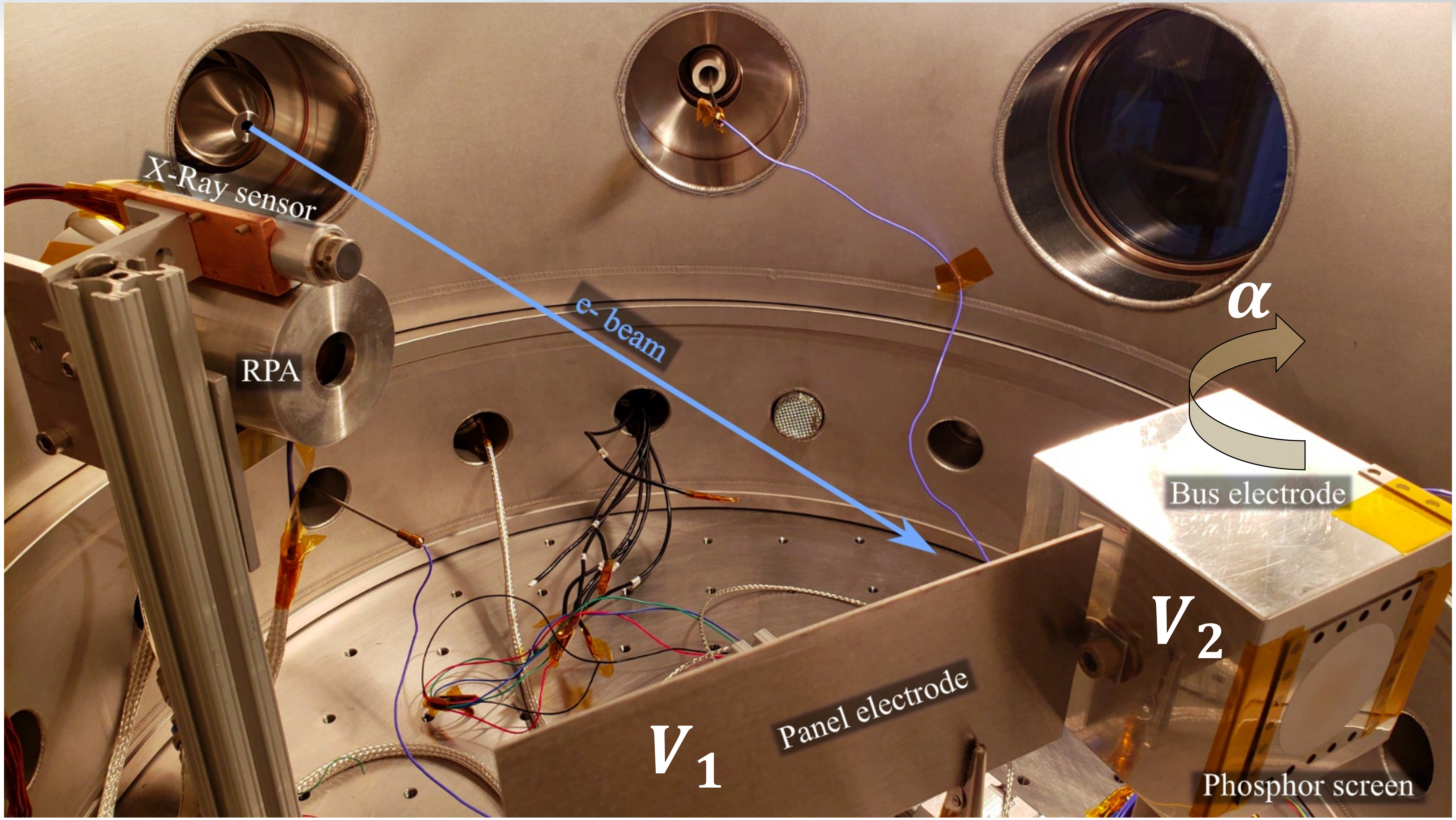


Bengtson, “Electron Method for Touchless Electrostatic Potential Sensing of Neighboring Spacecraft”, PhD thesis, 2020

Problem statement

Experimental setup

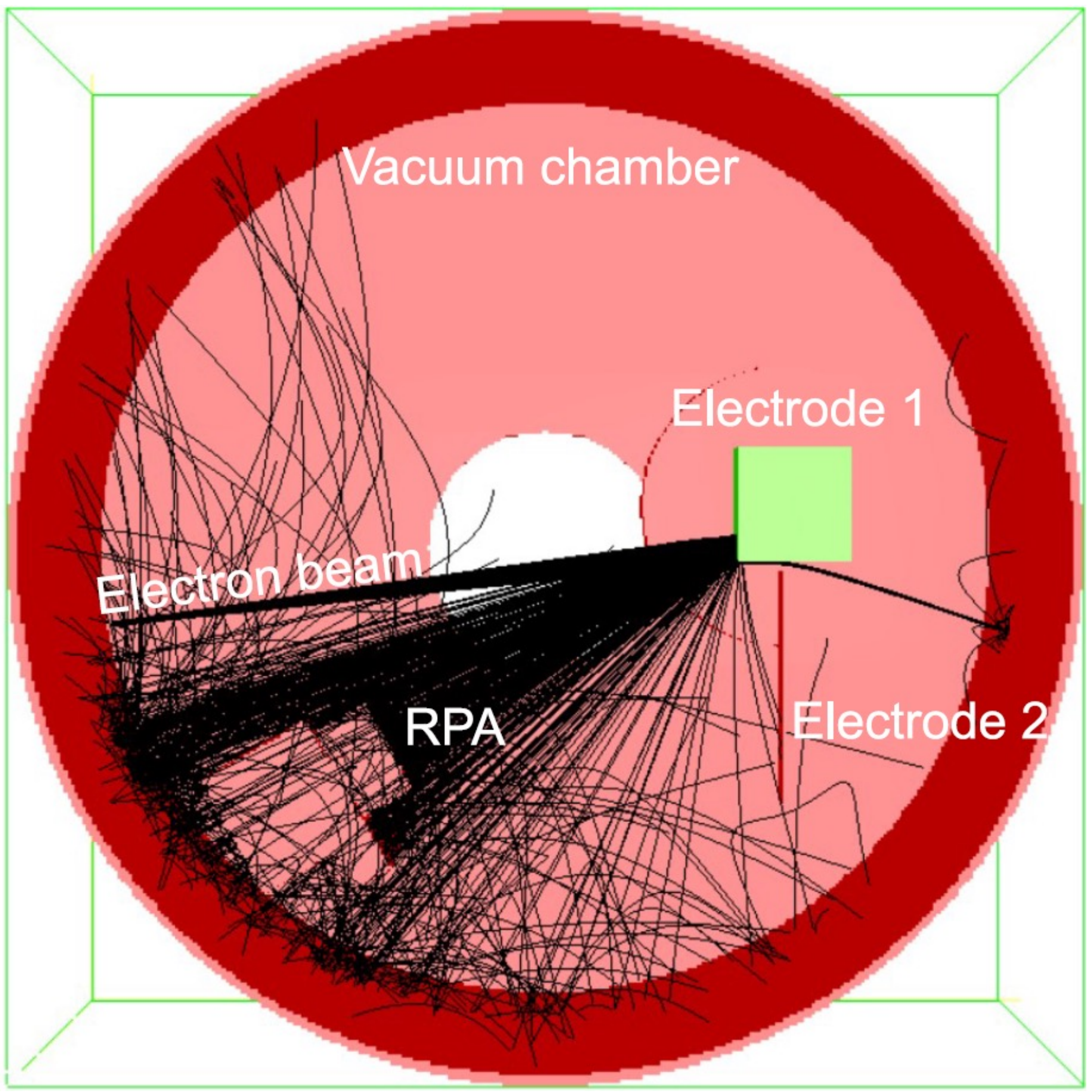




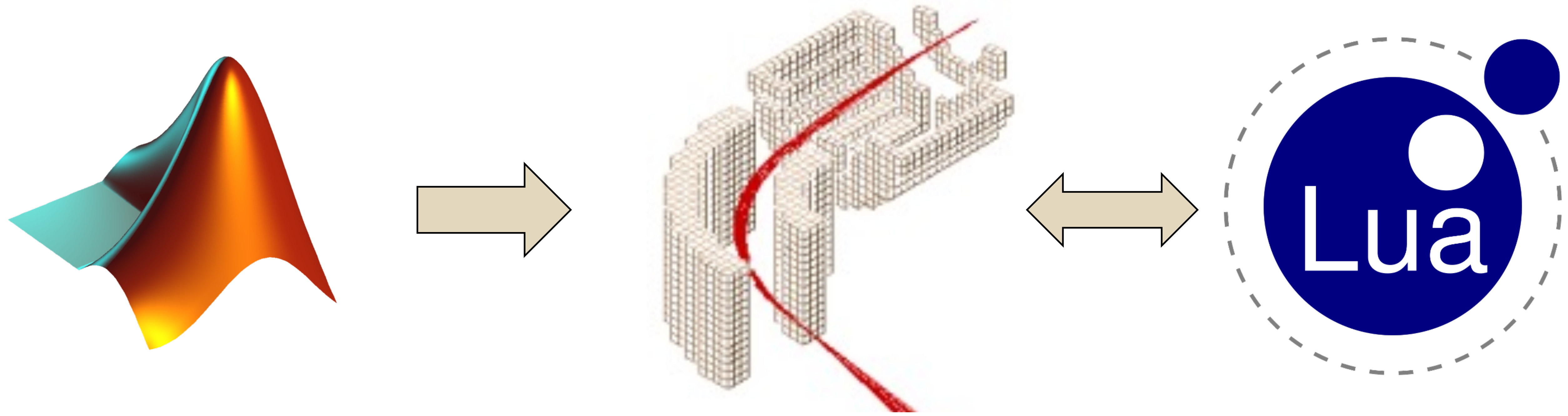
Numerical model

Overview

SIMION-based **particle tracing** model



- Built-in tools simplify analysis of complex shapes
- Custom LUA library for extended capabilities
  - **Lambertian reflectance** of SEs
  - Sanders and Inouye **emission probability** yield curve for SEs
  - Chung-Everhart distribution of **kinetic energies** for SEs
  - **Multiple emissions** of SEs
  - Integrated electron beam **expansion** and **steering** + **photoemission** + **NASCAP** plasma environment



SIMION Environment

Particle tracing based on Newton's 2nd law

$$\frac{d\boldsymbol{v}}{dt} = \frac{q}{m}\boldsymbol{E}$$

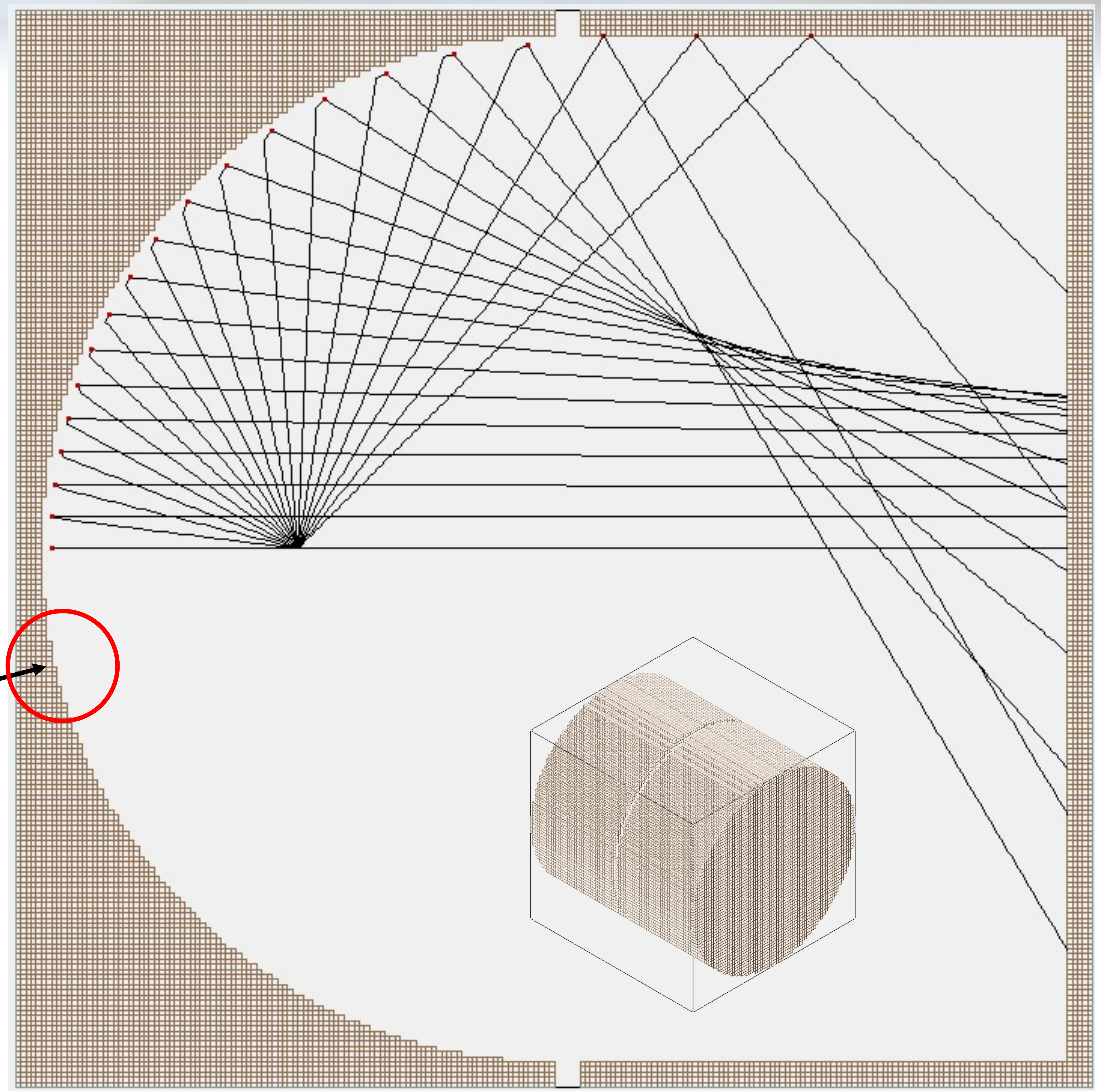
Electrostatic environment

$$\nabla^2 V = 0 \longrightarrow \boldsymbol{E} = \nabla V$$

Relativistic Correction: $\gamma = \sqrt{1 - v^2/c^2} < 10^{-10}$?

Numerical aspects:

- Cartesian grid → Surface jags
- Space-charge is neglected (no Poisson)
- Dirichlet & Neumann boundary conditions on V
- Superposition of electrode fields



SIMION's examples

Modeling of Secondary Electrons (custom LUA library)

- **Secondary electron yield** – Sanders and Inouye model

$$\delta(E,0) = c\left[e^{-E/a} - e^{-E/b}\right] \qquad a = 4.3E_{\max},\ b = 0.367E_{\max},\ \text{and}\ c = 1.37\delta_{\max}$$

- **Incident primary angle effect** – Darlington and Cosslett model

$$\delta(E,\phi) = \delta(E,0)e^{\beta_s(E)(1-\cos\phi)}$$

β_s from Laframboise and Kamitsuma

- **Angular distribution** – Lambertian

$$\theta = \frac{1}{2}\operatorname{acos}(1-2x)$$

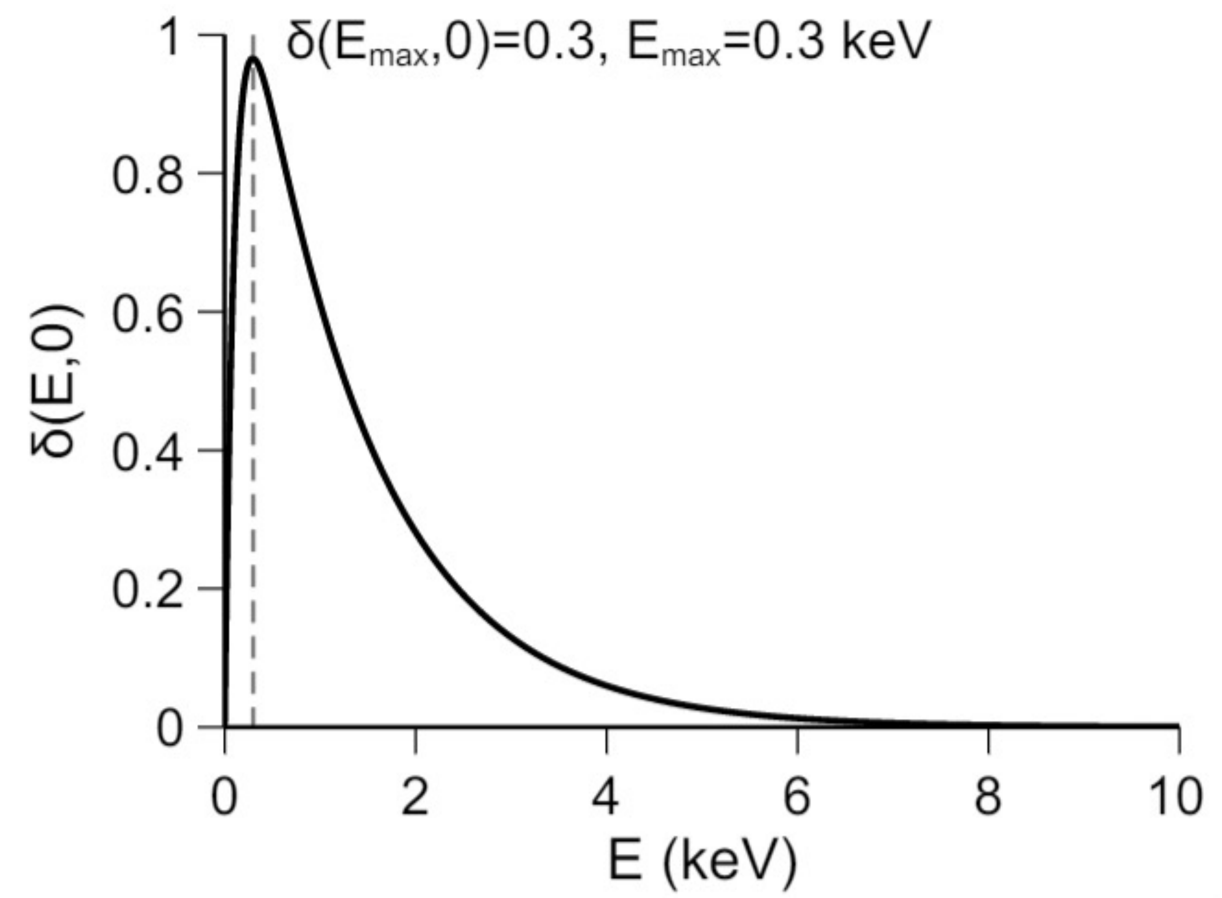
x is uniform random variable

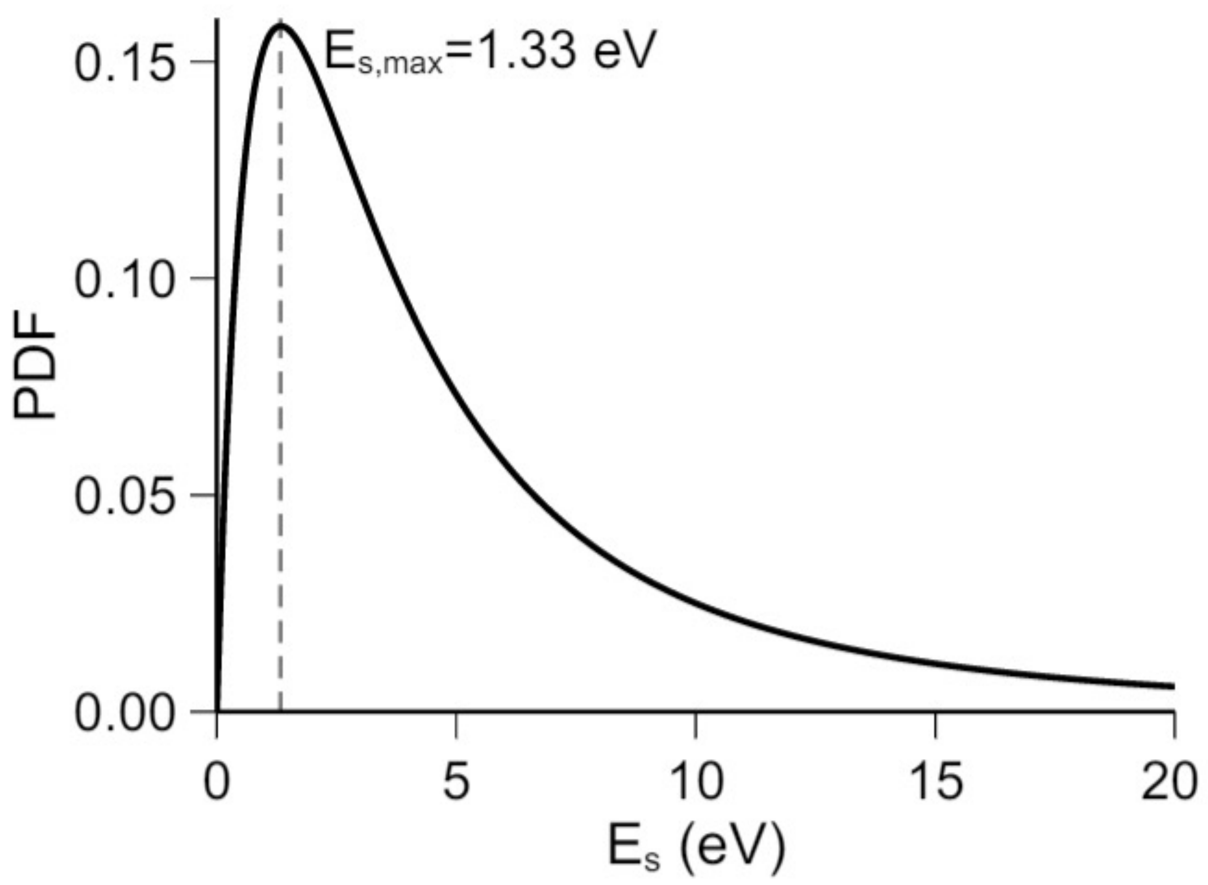
- **Energy distribution** – Chung-Everhart model

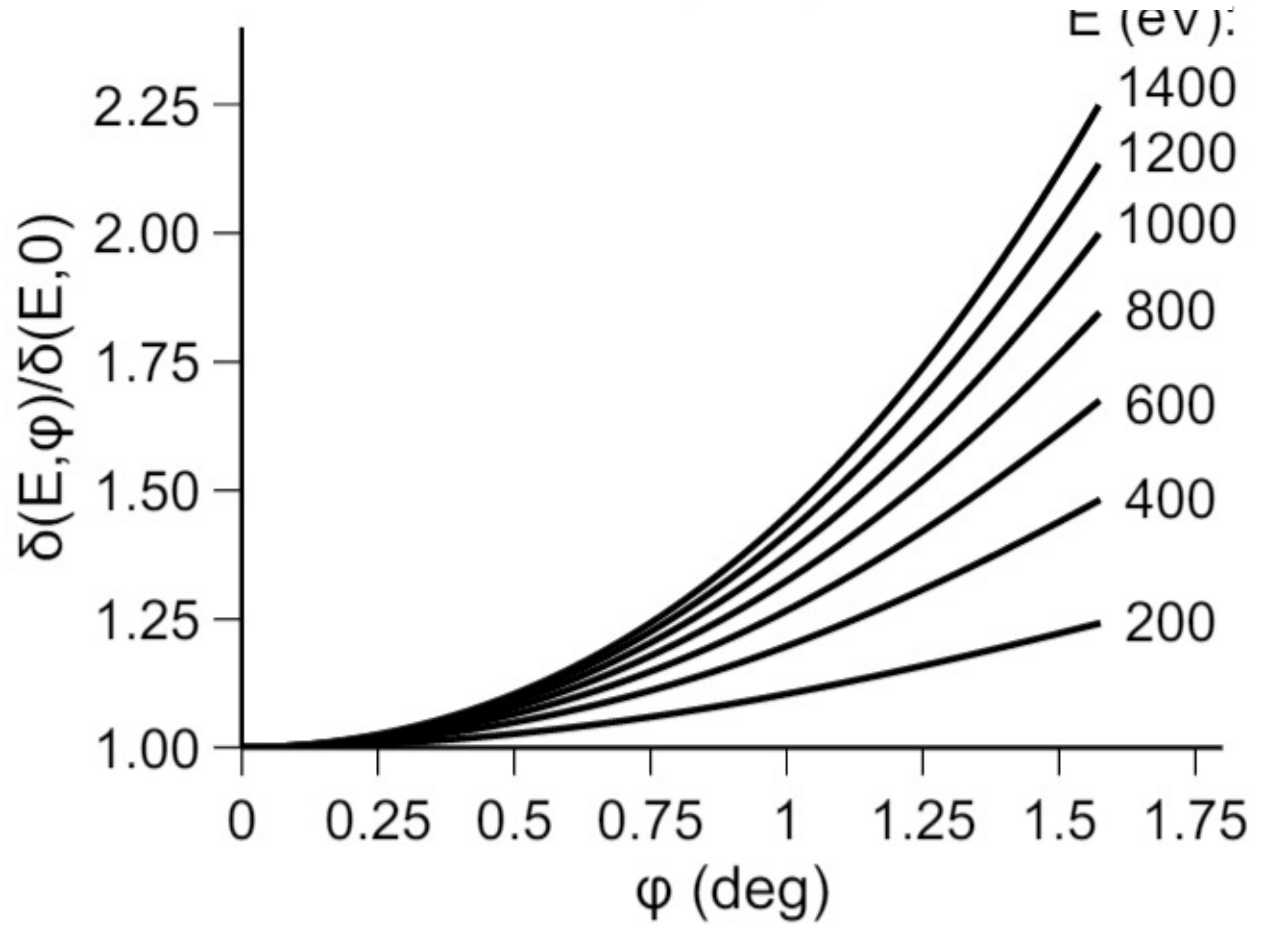
$$f(E_s) = \frac{6\varphi^2 E_s}{(E_s+\varphi)^4} \longrightarrow g(E_s) = \frac{\varphi}{3(E_s+\varphi)^3} - \frac{1}{2(E_s+\varphi)^2} + \frac{1}{6\varphi^2}$$

Inversion method with Newton solver

Aluminum

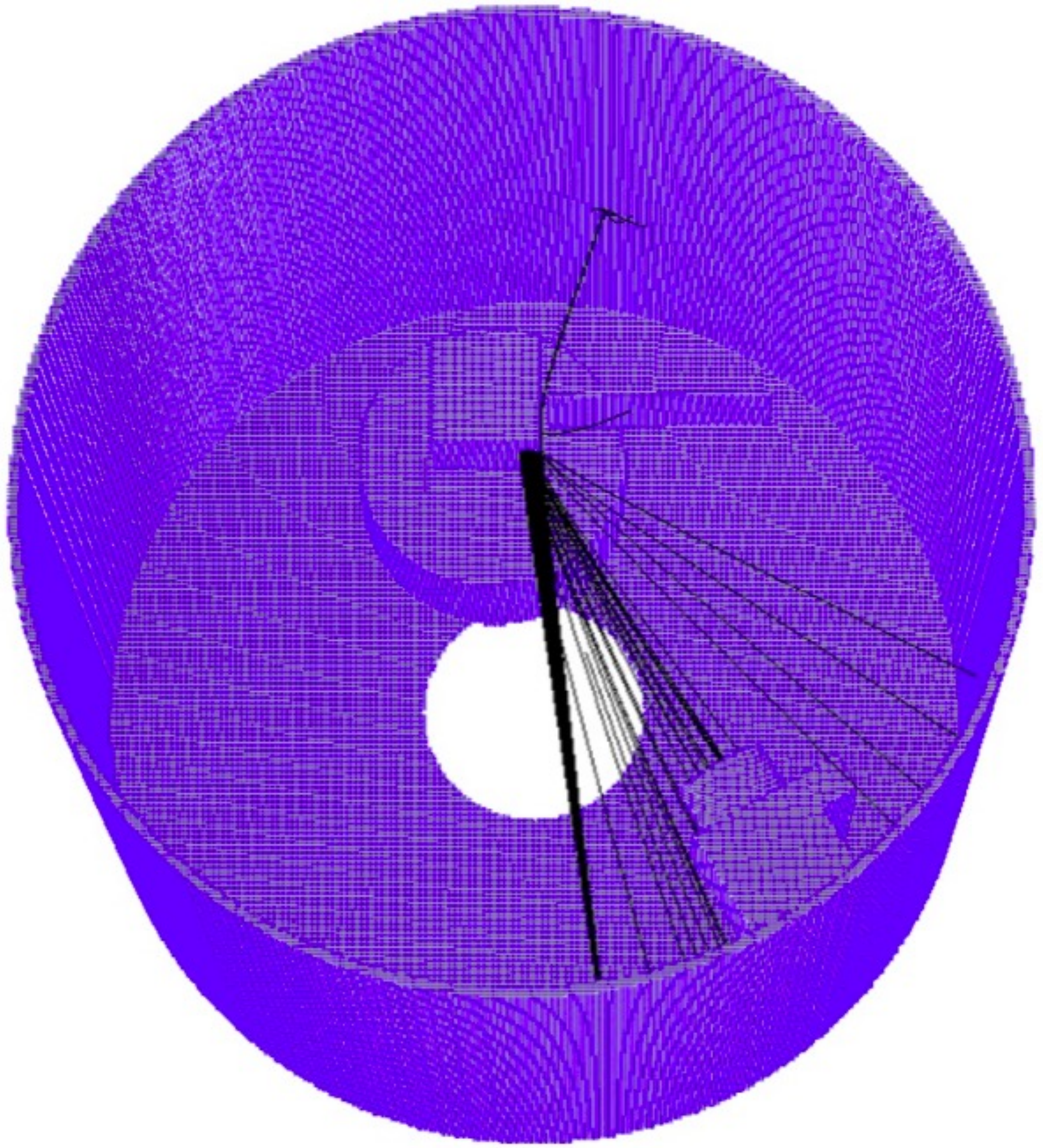




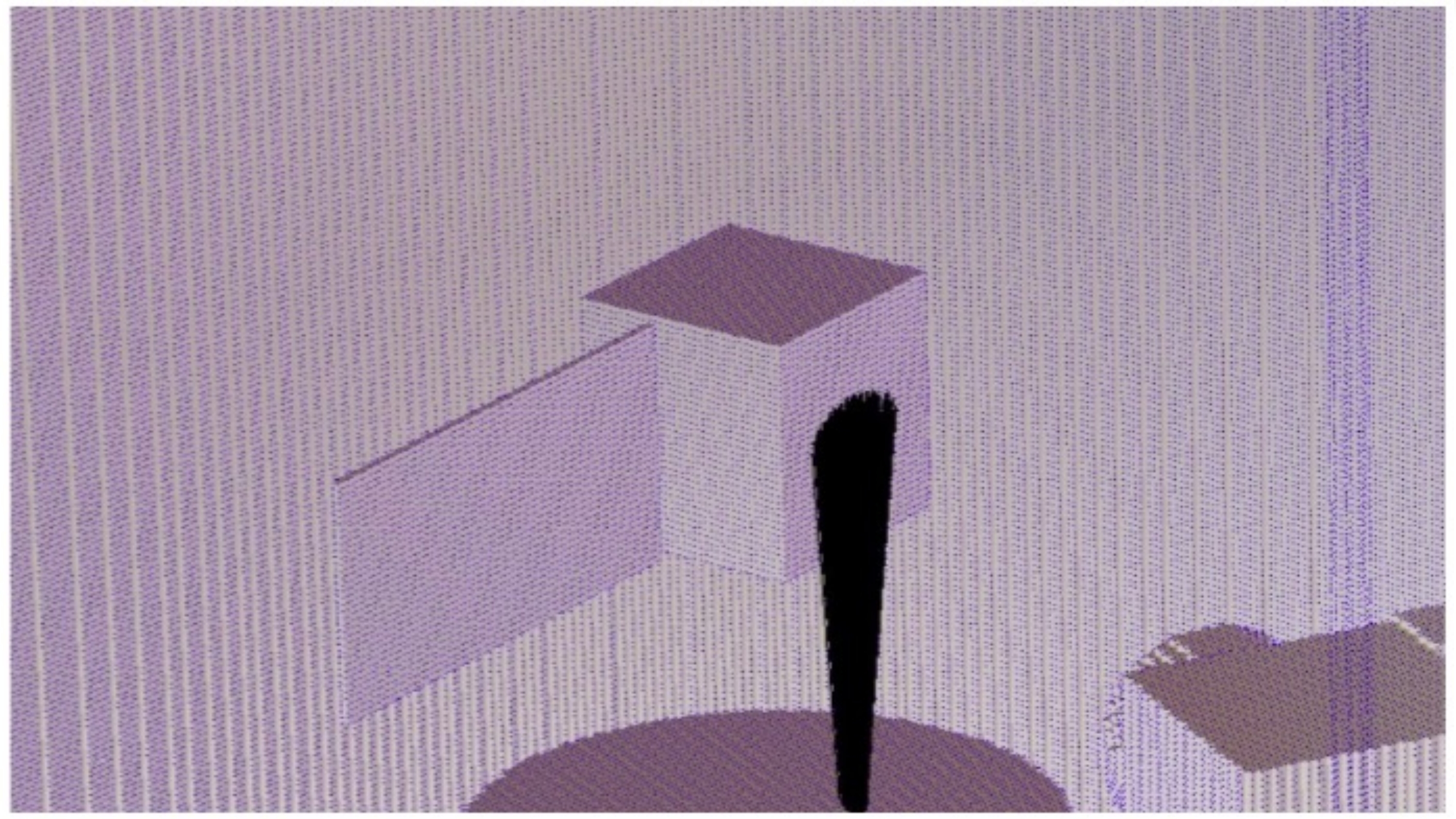


Implementation & Calibration

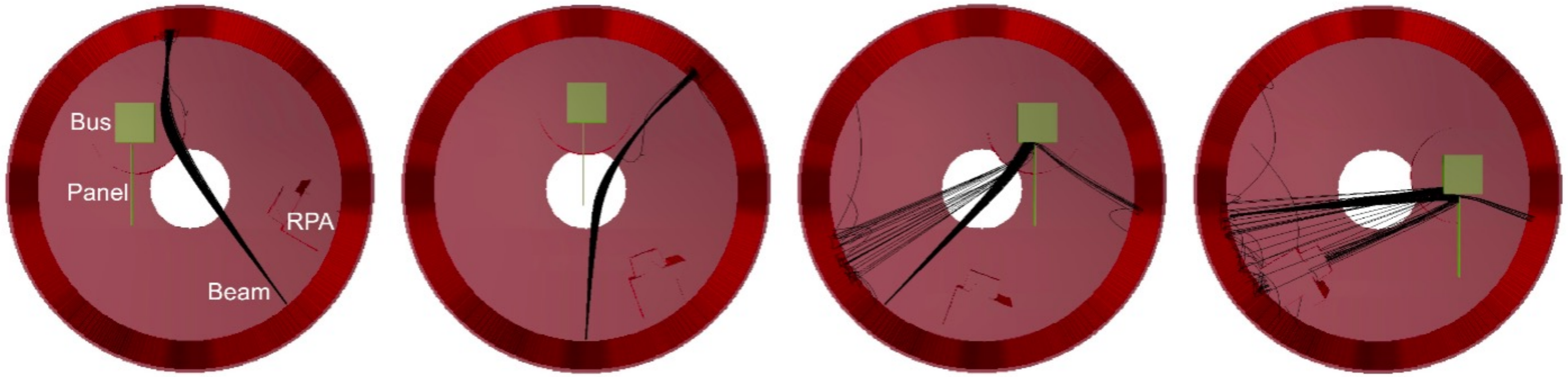
Mesh of simulation domain



Electron beam centering



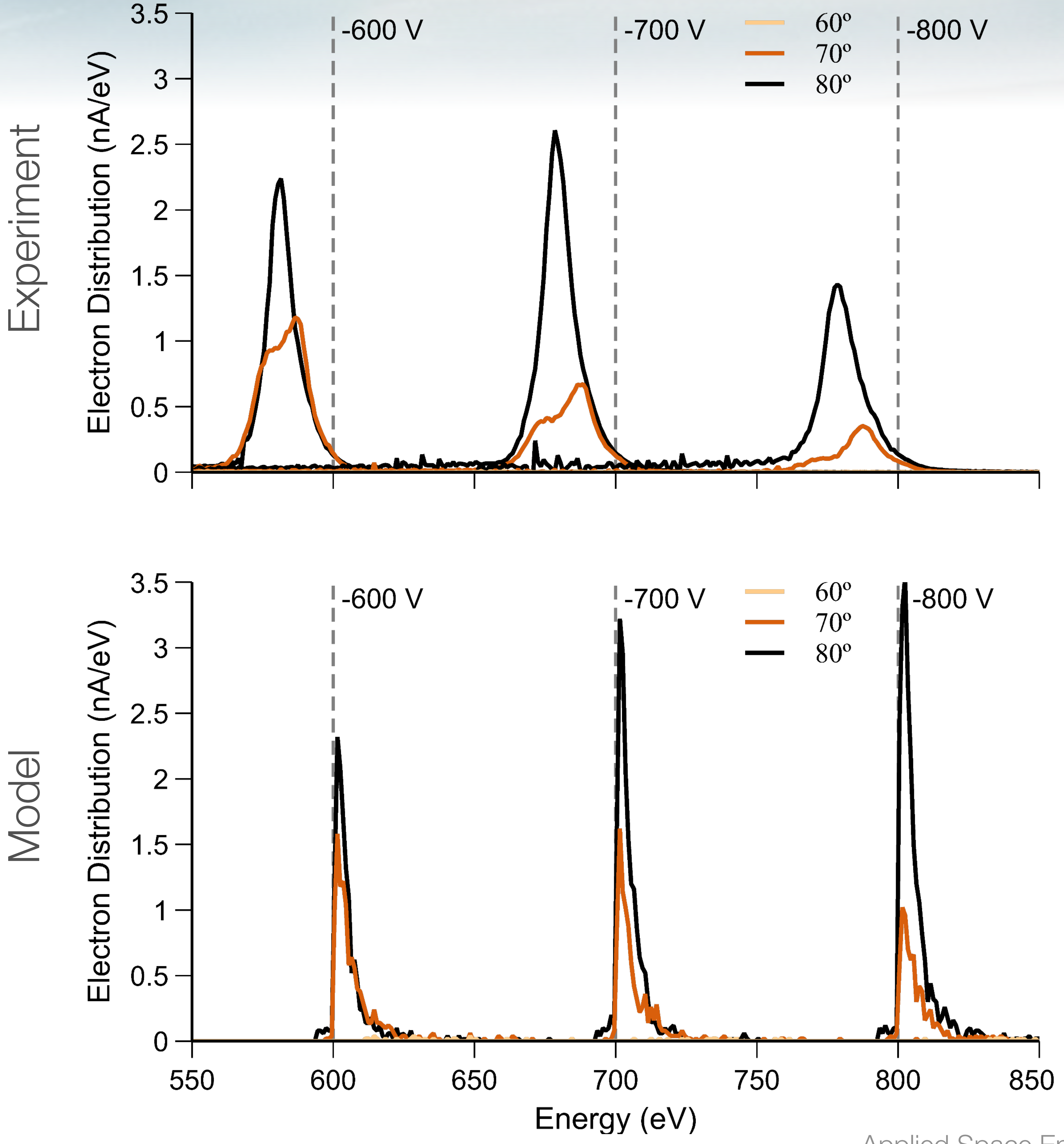
Strategy to **avoid surface jags**: keep electrodes aligned with axes



(a) −40° **(b)** 0° **(c)** 40° **(d)** 80°

Validation & Analysis

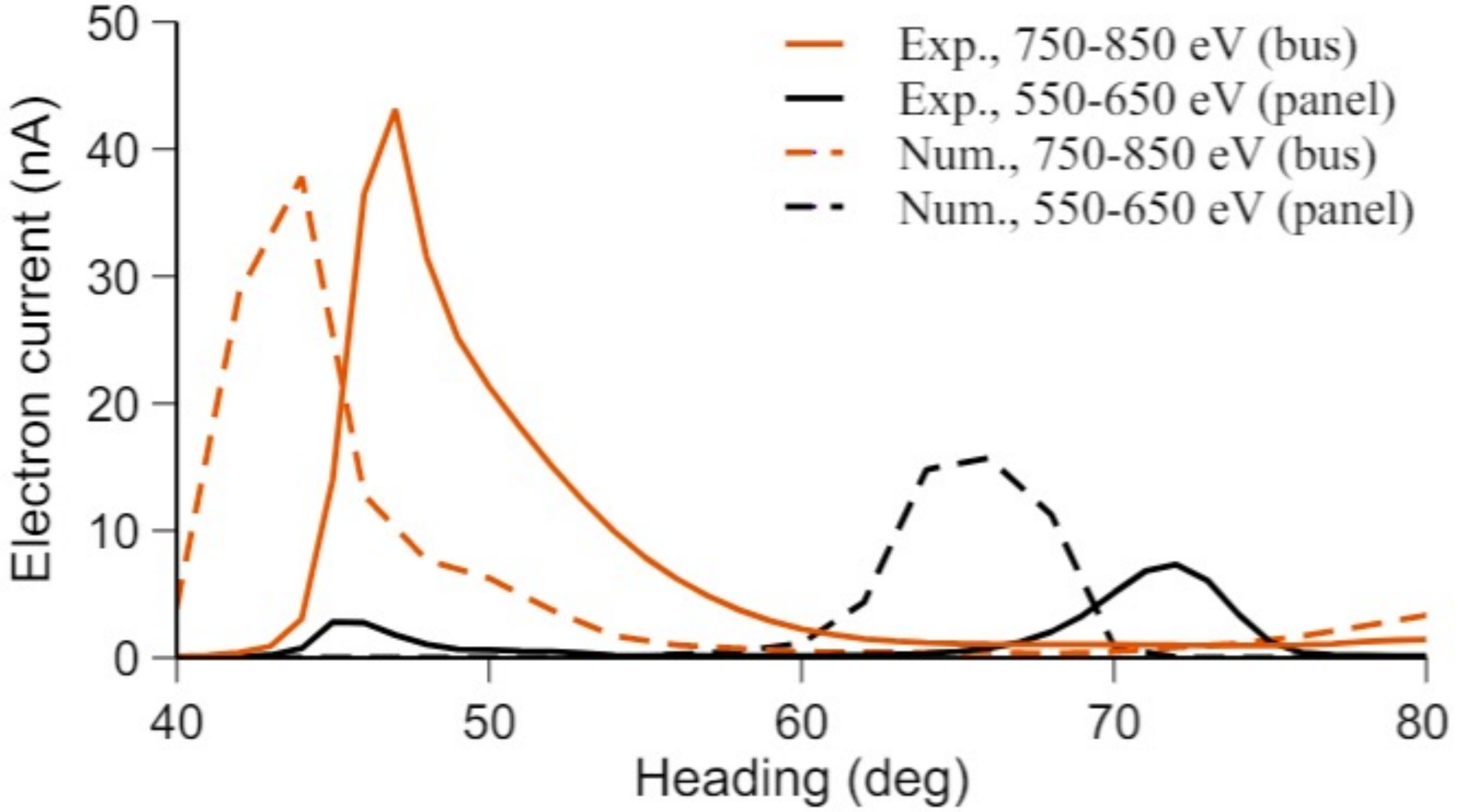
Equipotential surfaces



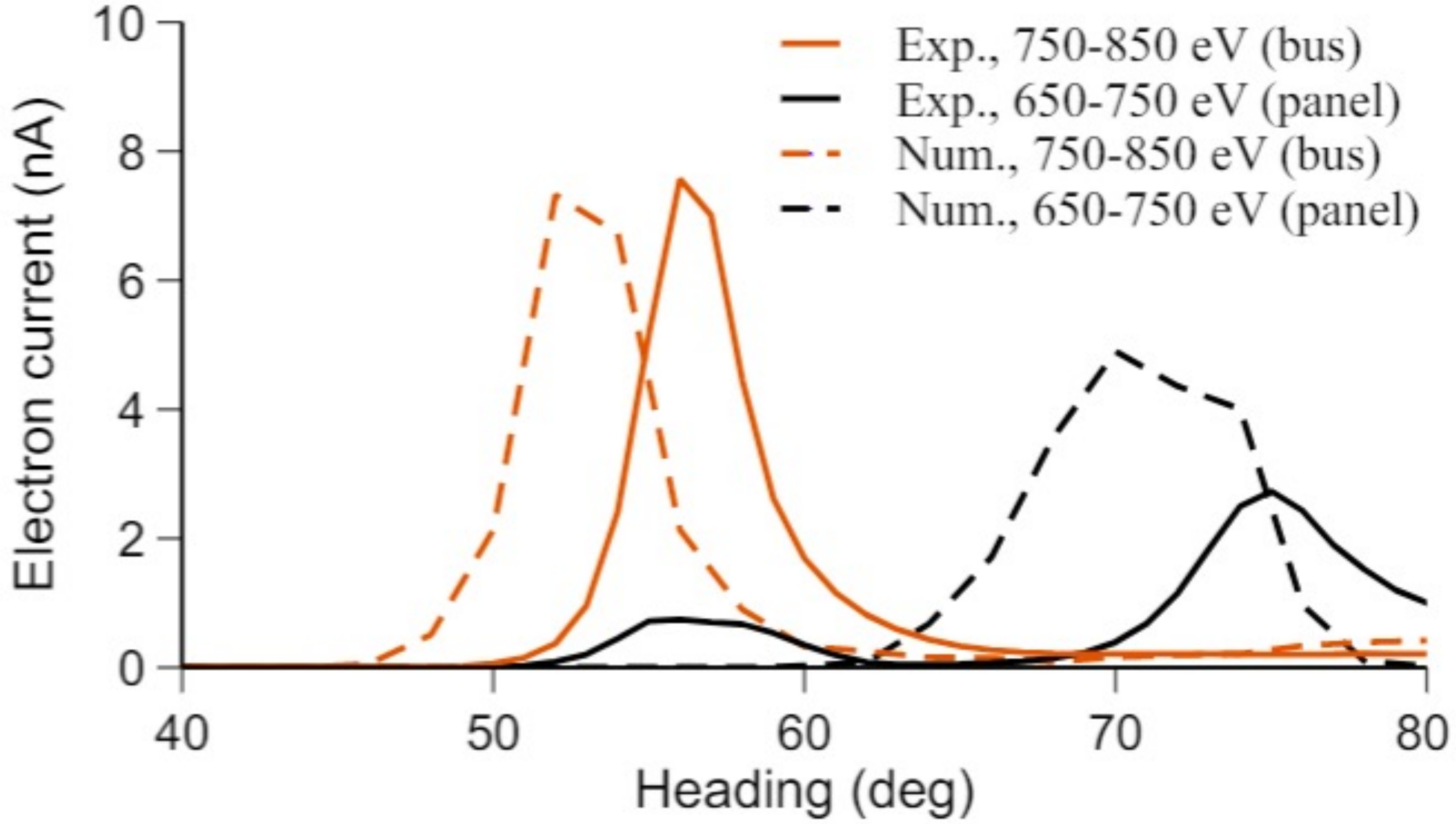
- Same potential at bus and panel
- Excellent agreement in **distribution** and **magnitude**
- Peaks are normal and shifted in the experiment
  - **Resistive layers** at the surface
  - RPA-related effects (plasma heating) & efficiency of ~20%

Heterogeneous potential

Panel at -600 V, Bus at -800 V



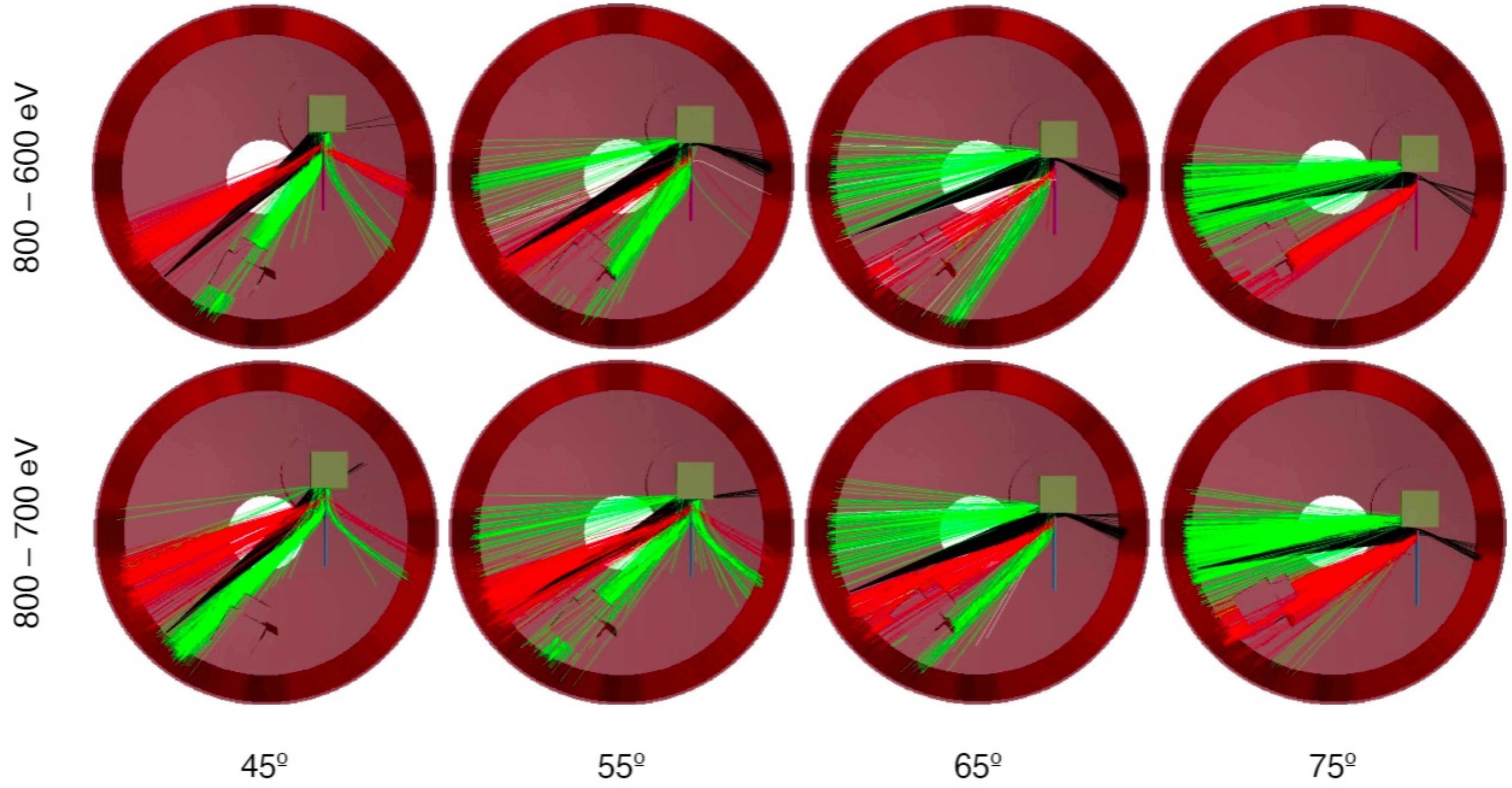
Panel at -700 V, Bus at -800 V



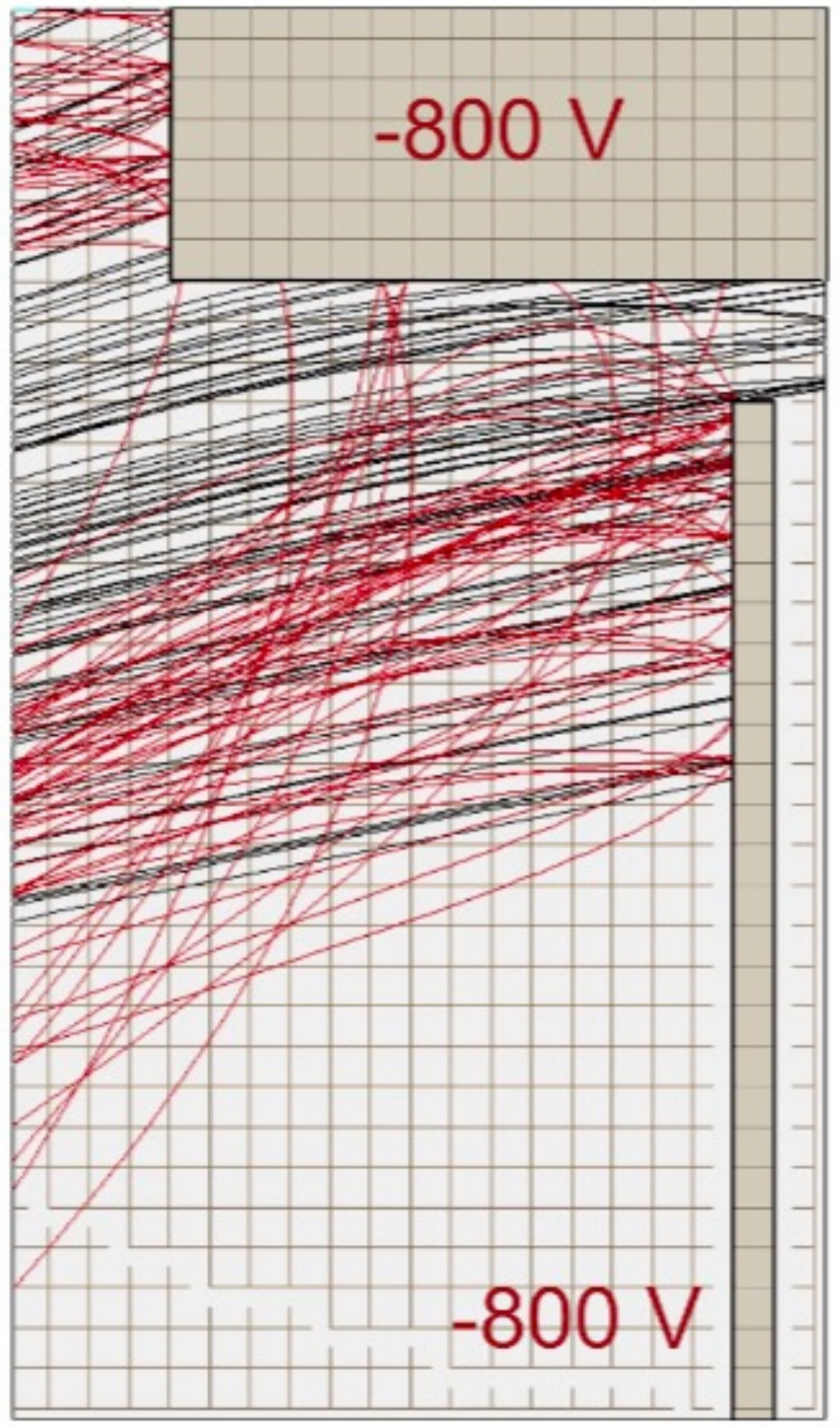
- Constant shift of ~3° between experiments and model attributed to **geometrical errors**
- **Unexpected features** in panel population → Why?

Heterogeneous potential

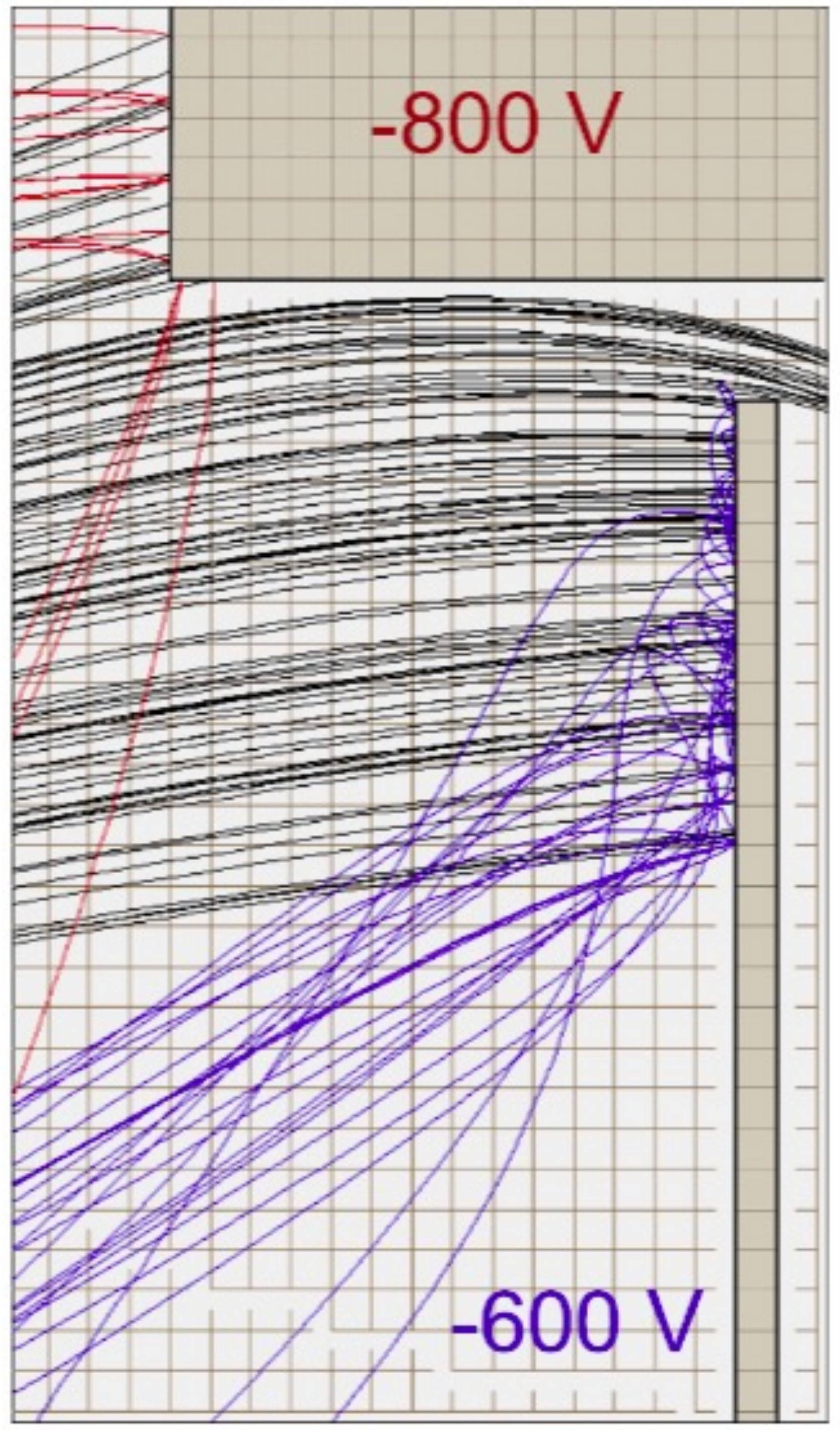
Green: Secondaries from hub (-800 V), Red: Secondaries from panel



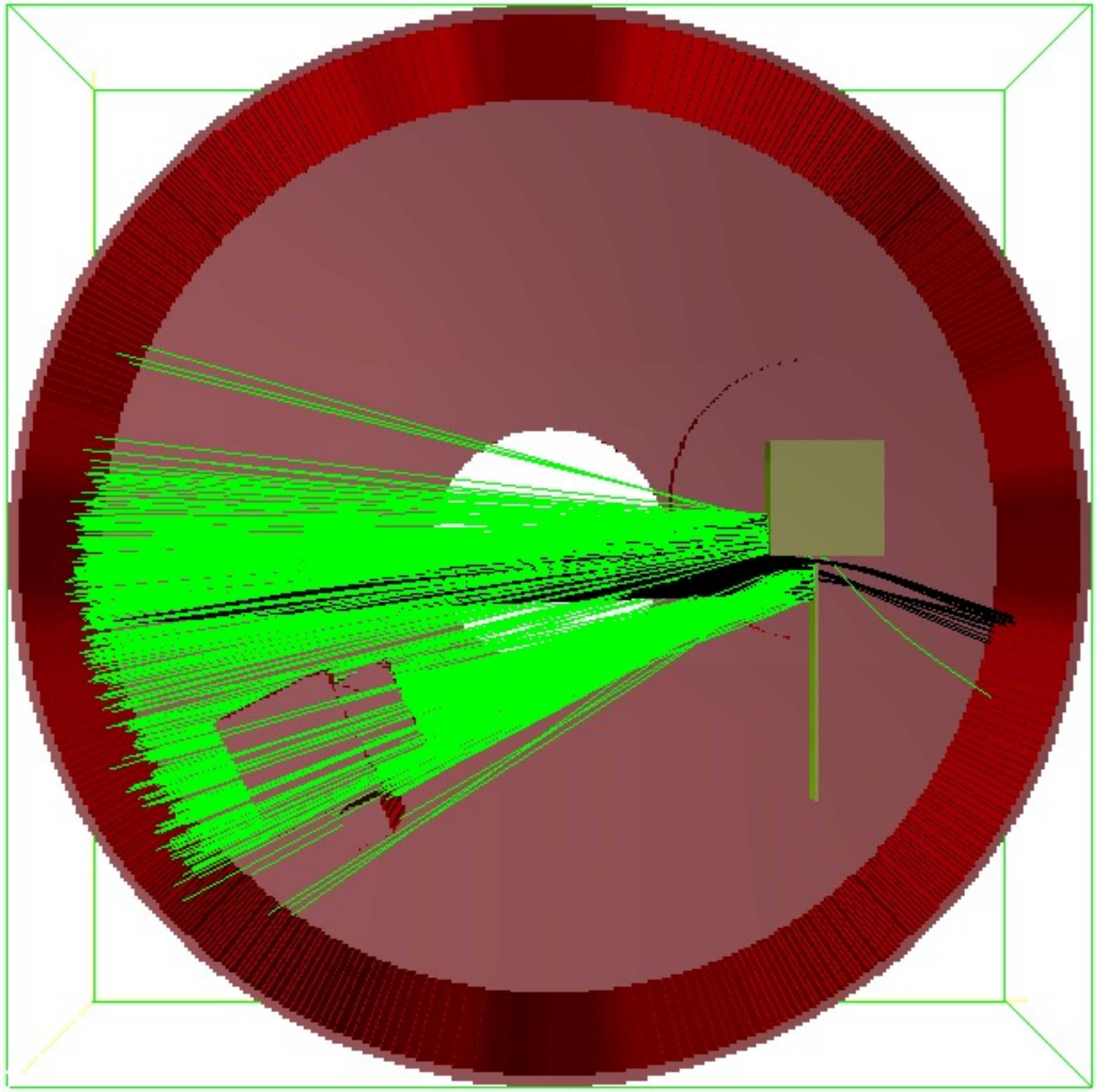
Equipotential

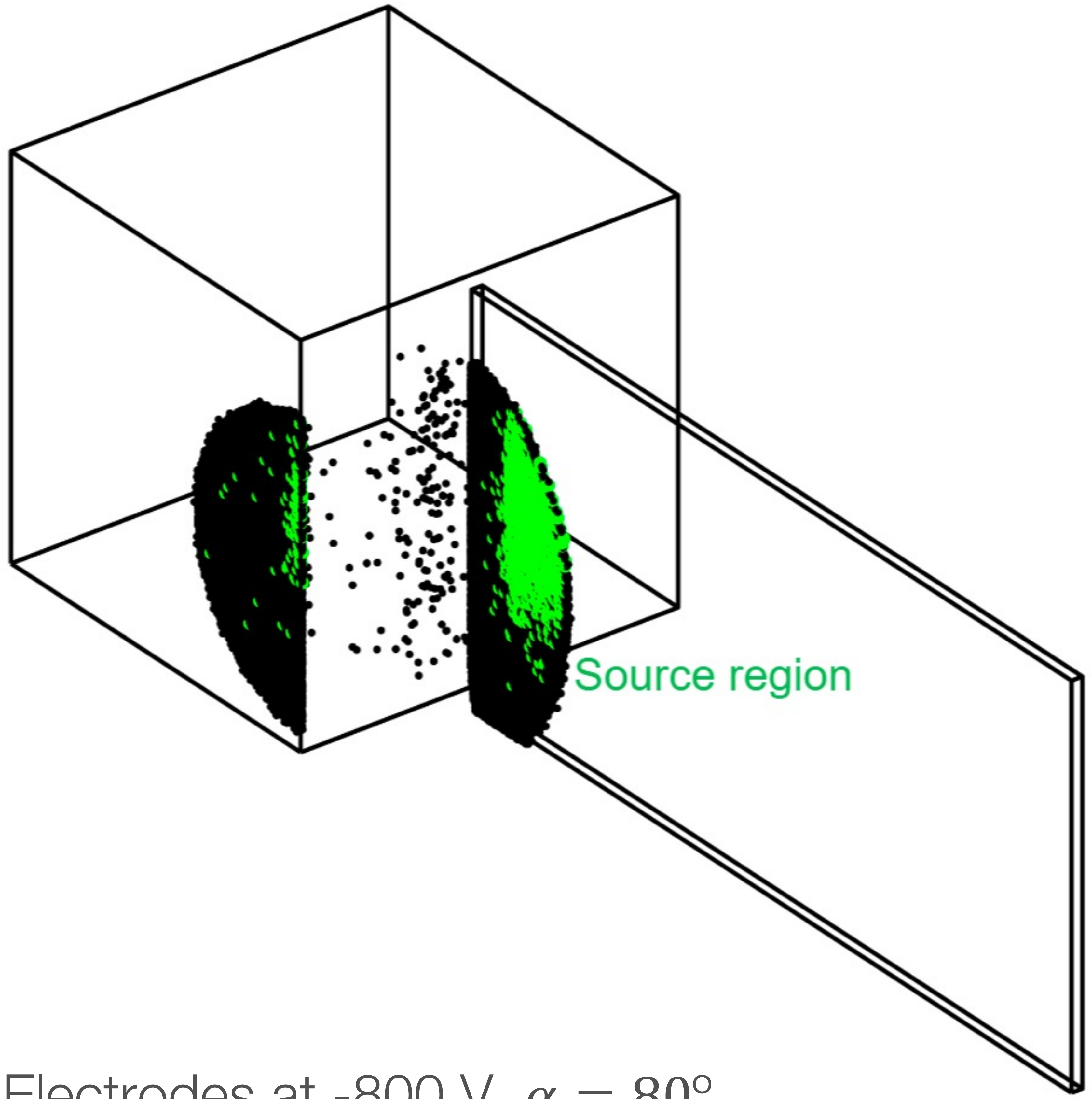


Electron trap



Source regions

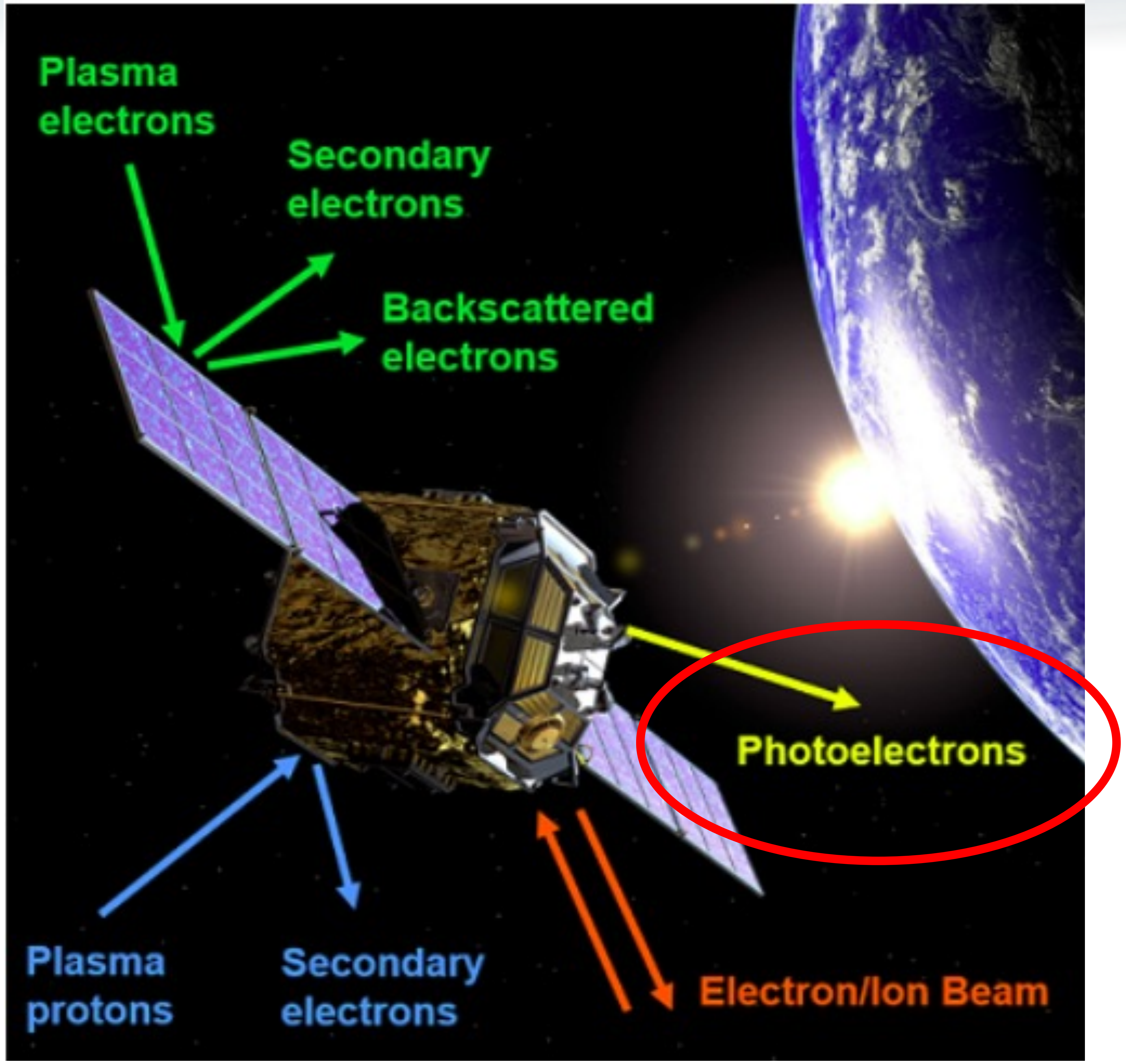




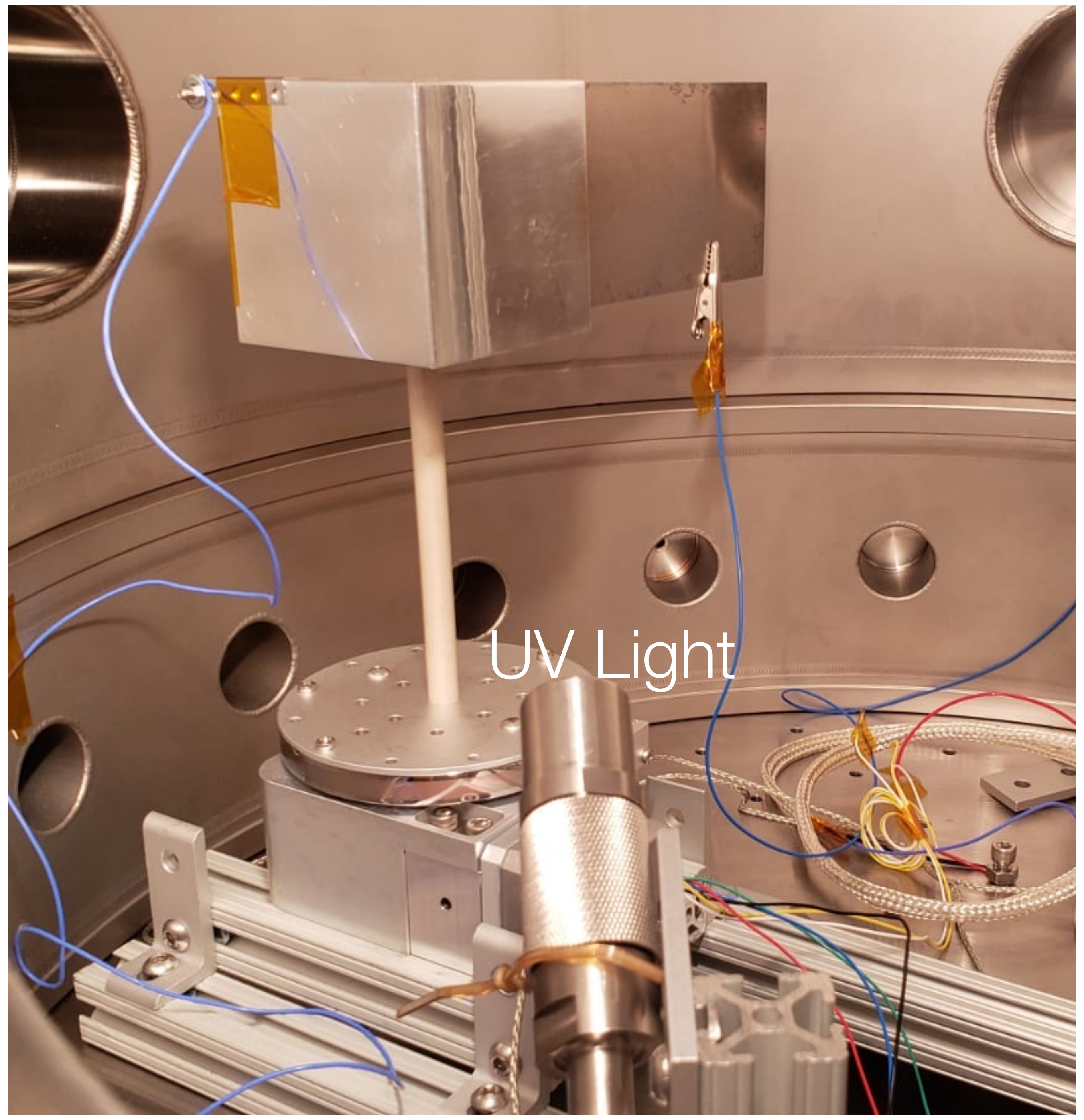
Electrodes at -800 V, $\alpha = 80°$

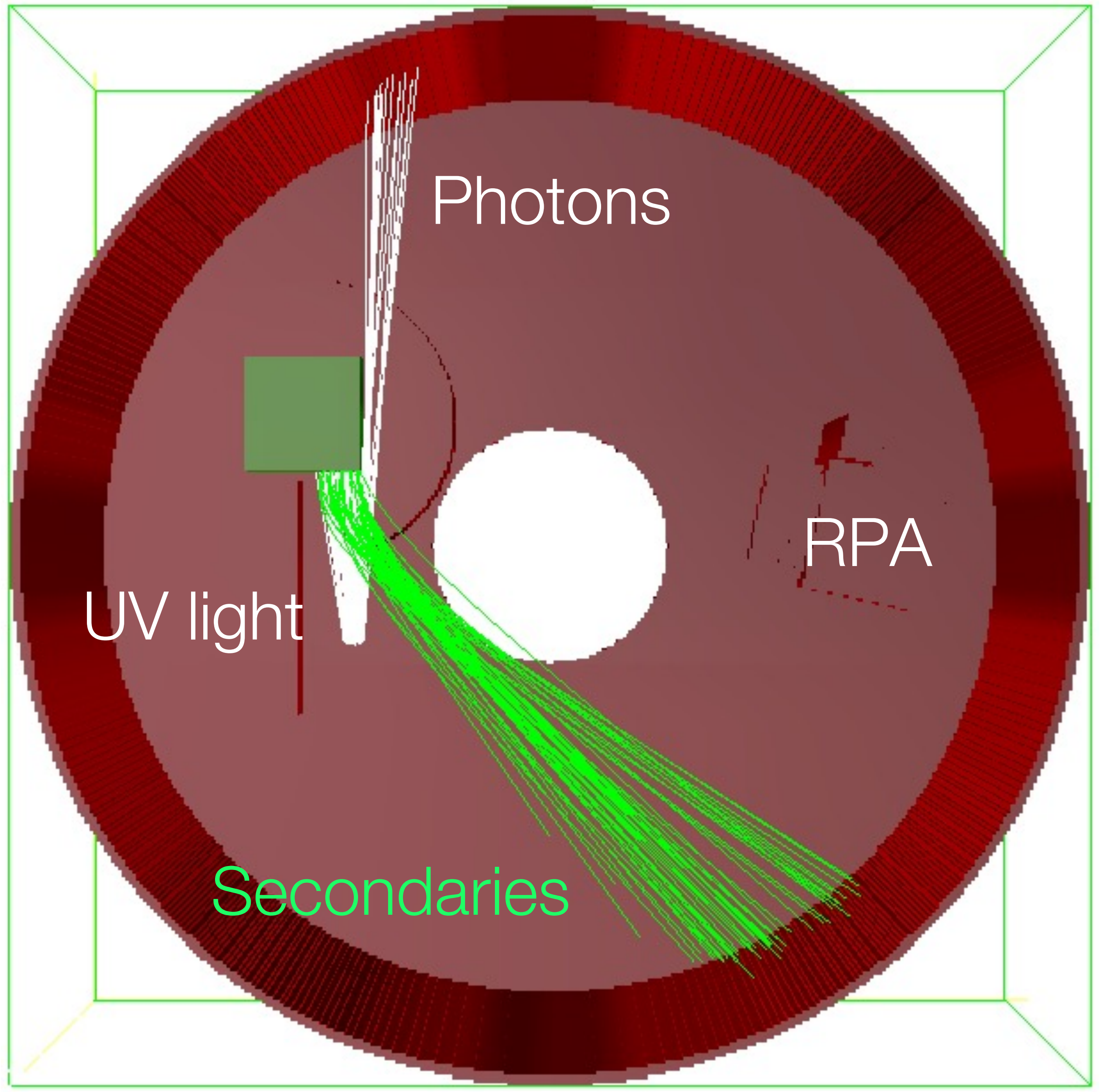
Ongoing work

Photoemission experiments and model



- Complicated reflection dynamics
- Photoemission yield between 10^{-7} and 0.1 → Super-photons needed

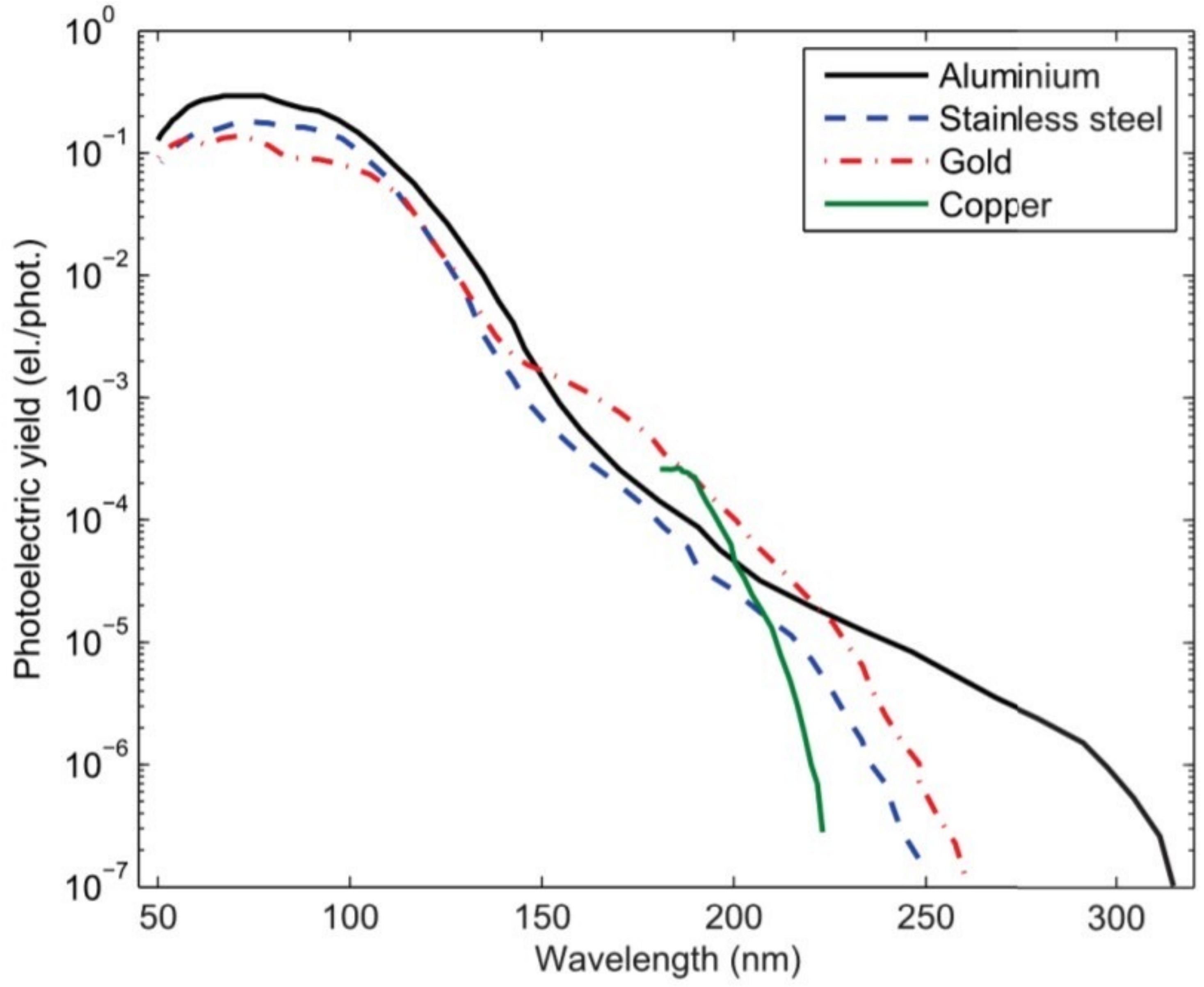


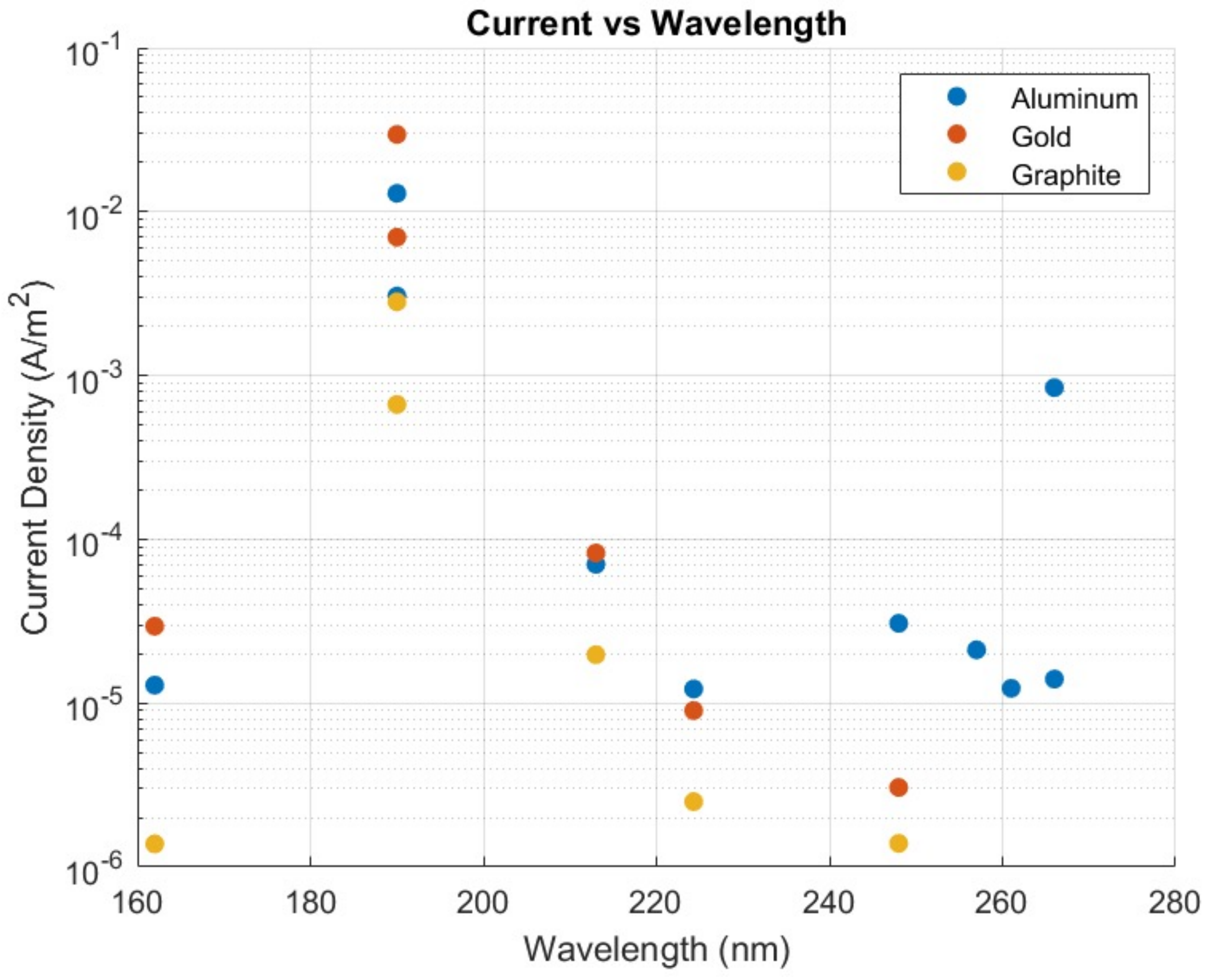


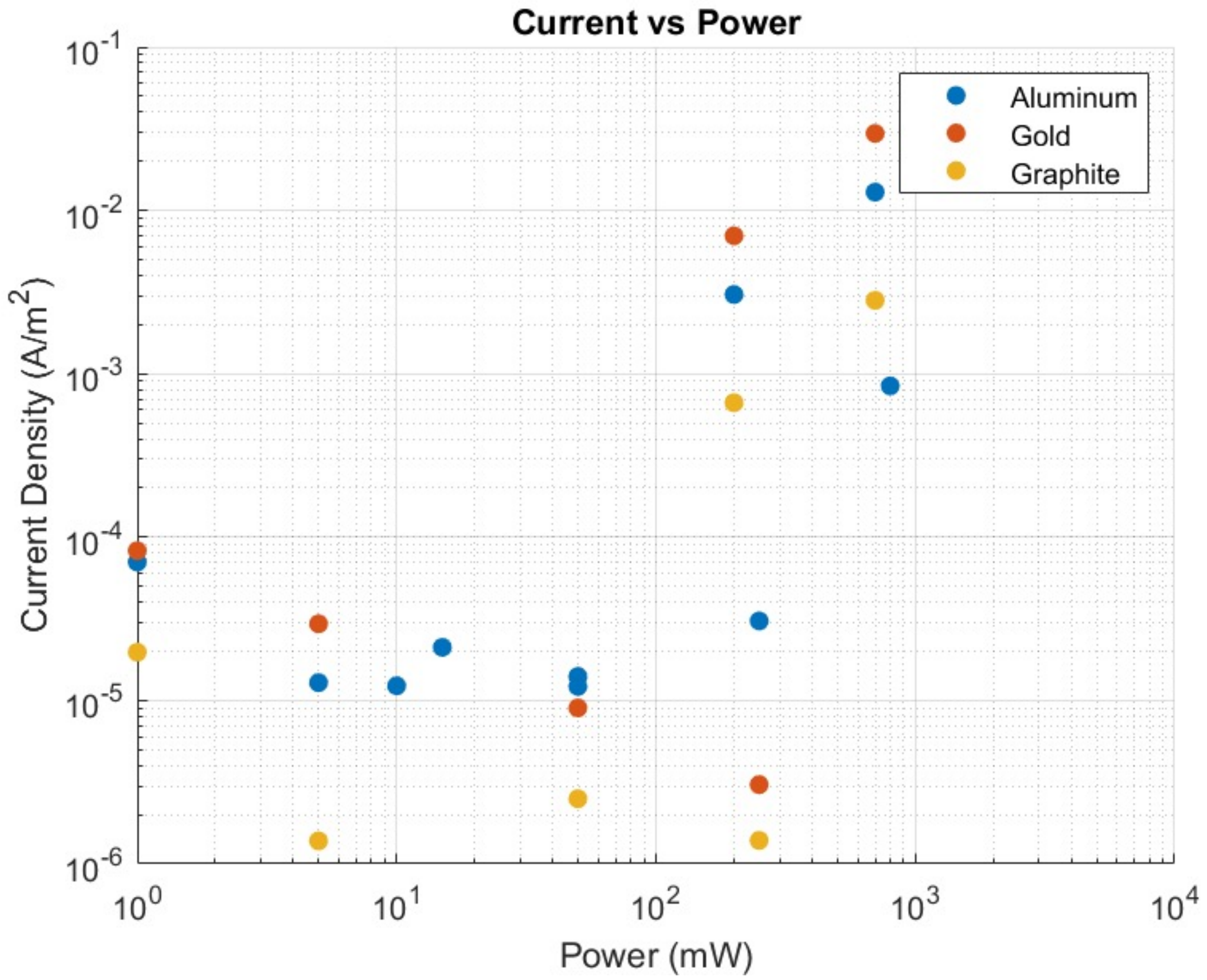
Active photoemission sensing strategy

- **Concept:** Induce the photo-generation of secondaries using UV lasers
  - Current density function of laser wavelength, power, and divergence angle
  - Narrow beams with wavelength < 300 nm and high-power output desirable for active photoemission

- Different commercial lasers are ranked depending on their induced current density:







Conclusions

Conclusions

1. Electron-beam-induced secondary electrons may be used to **touchlessly sense the potential** of a target spacecraft

2. The **complex geometry** of a spacecraft **focuses** the secondaries on specific paths and **complicates detectability** in realistic scenarios

3. An **advanced particle-tracing framework** is introduced and validated to study those scenarios

4. The model enables **high-fidelity analyses** of the spacecraft charging problem

5. Ongoing work involves studying **passive** (solar) and **active** (UV laser) photoemission

Questions?

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