# Developments in Spacecraft Charge Neutralization During Active Charged Particle Emission

**Grant Miars**[1]
Gian Luca Delzanno[2], Brian Gilchrist[1], Omar Leon[1]

1. The University of Michigan, Ann Arbor, MI, USA
2. Los Alamos National Laboratory, Los Alamos, NM, USA

# Beam-Induced Spacecraft Charging

$$\Sigma I_k = 0$$

- Beam emission perturbs satellite charge equilibrium
  - Other currents respond to maintain zero net current

- Largest balancing current term in LEO is electron current collected from the ambient plasma

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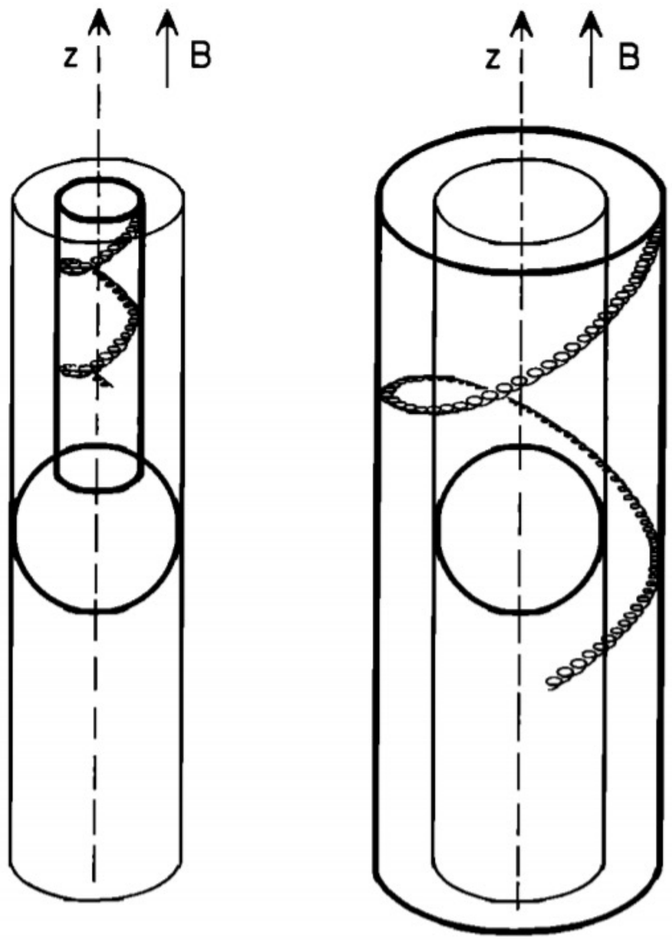


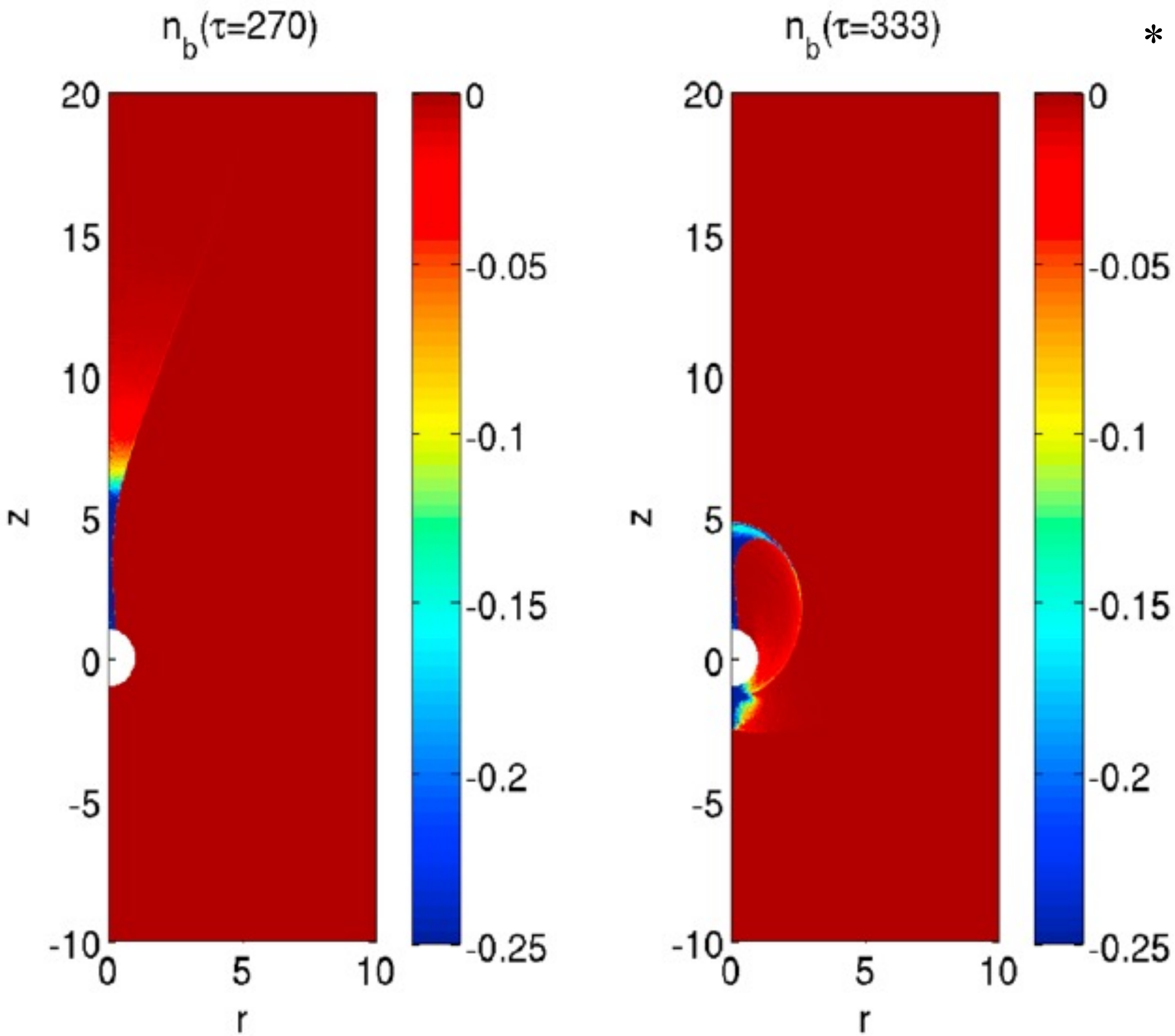

Fig. 1. Electron trajectories for small sphere potentials.



L. W. Parker, B. L. Murphy, Potential Buildup on an Electron-Emitting Ionospheric Satellite, JGR, 1967.

# The Need for Charge Mitigation

- Low plasma densities (~1 $cm^{-3}$) are insufficient to balance even 1 mA average beam current
- Beam pulled back electrostatically as spacecraft body charges positive
- Beam return can damage the spacecraft (failure of 3 payloads on SCATHA)

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G.L. Delzanno, J.E. Borovsky, M.F. Thomsen, J.D. Moulton, E.A. MacDonald, *Future beam experiments in the magnetosphere with plasma contactors: How do we get the charge off the spacecraft?*, Journal of Geophysical Research, 120 (5), 3647 (2015)

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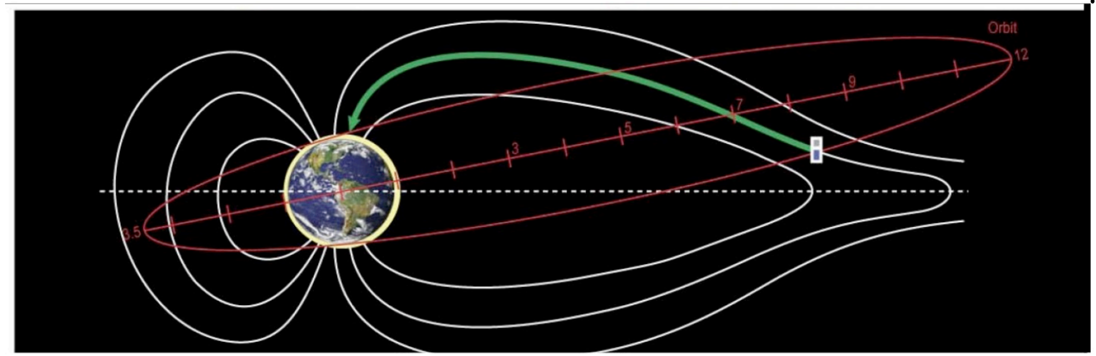
# The CONNEX Mission Concept

- Magnetosphere-Ionosphere Connections Explorer
- Establish connectivity by tracing the Earth's magnetic field in real time using an electron beam
- Addresses longstanding questions on coupling between ionosphere and magnetosphere
- Example: What drives the aurora?



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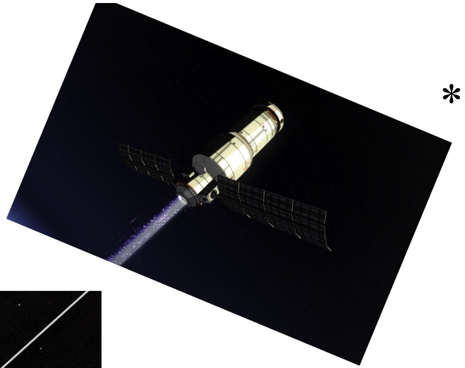
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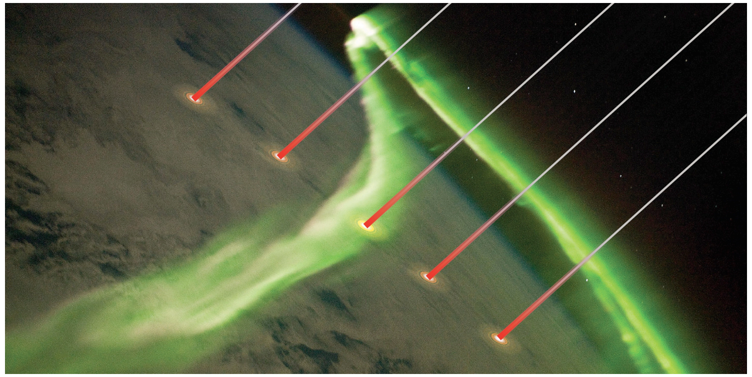
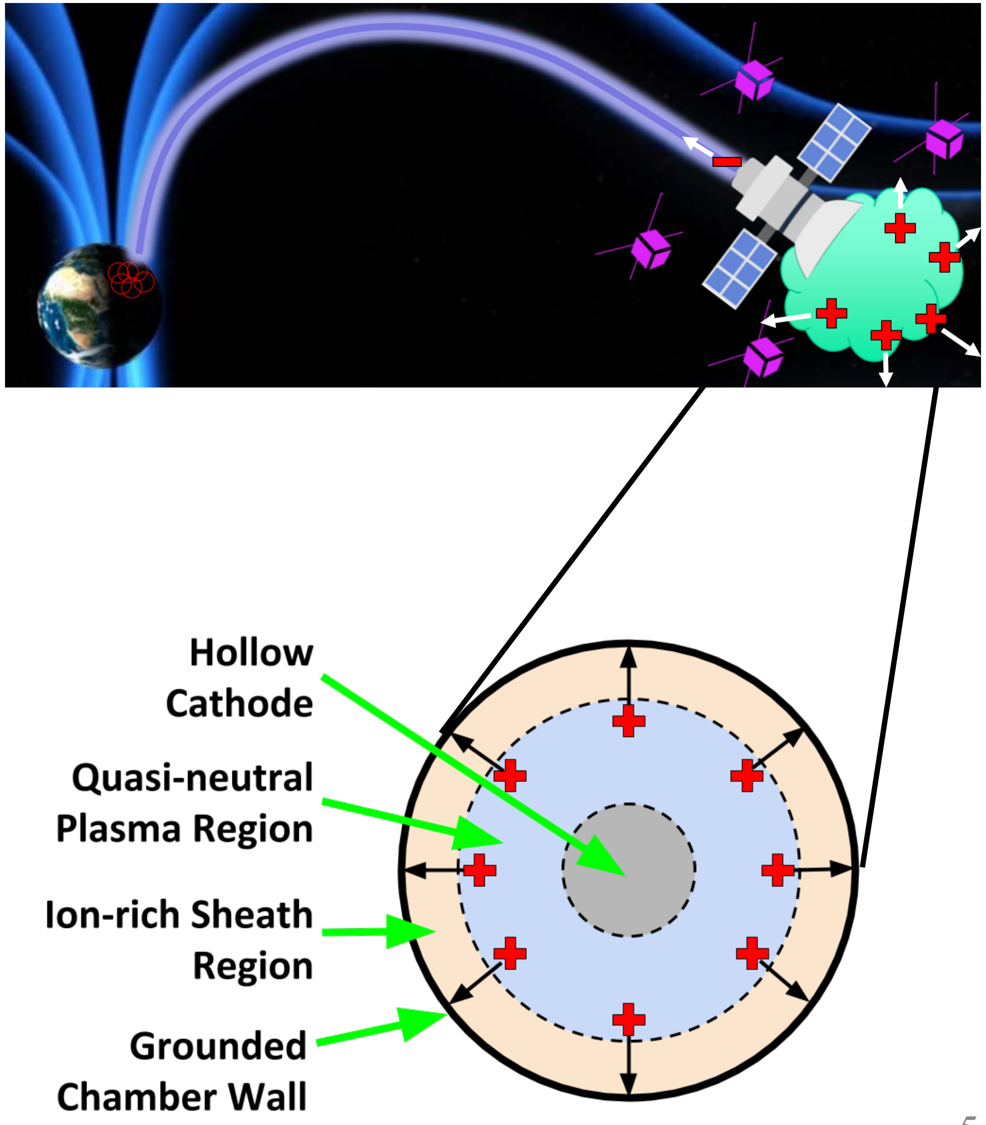


F. Lucco Castello, G.L. Delzanno, J.E. Borovsky, G. Miars, O. Leon, B. E. Gilchrist, *Spacecraft-charging mitigation of a high-power electron beam emitted by a magnetospheric spacecraft*, ICOPS, 2017.

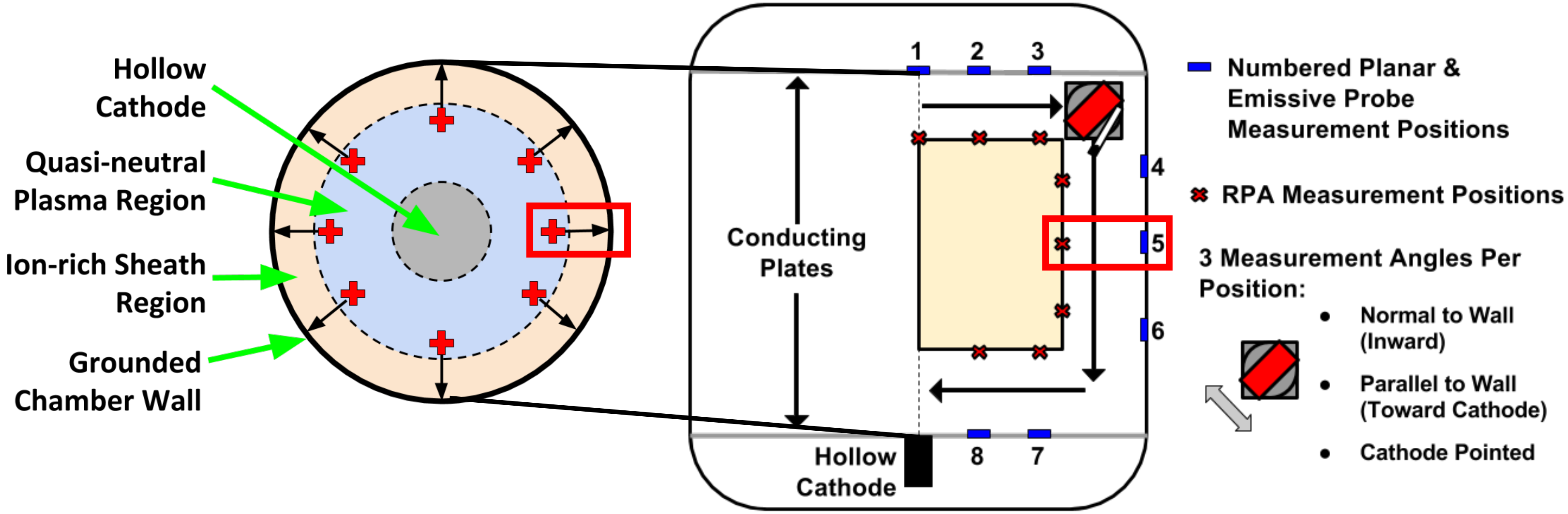
# The Ion Emission Model

- Net ion current is emitted from surface of a contactor plasma
- This current is able to balance electron emission without inducing significant spacecraft charging.
- Analytical model of ion emission successfully

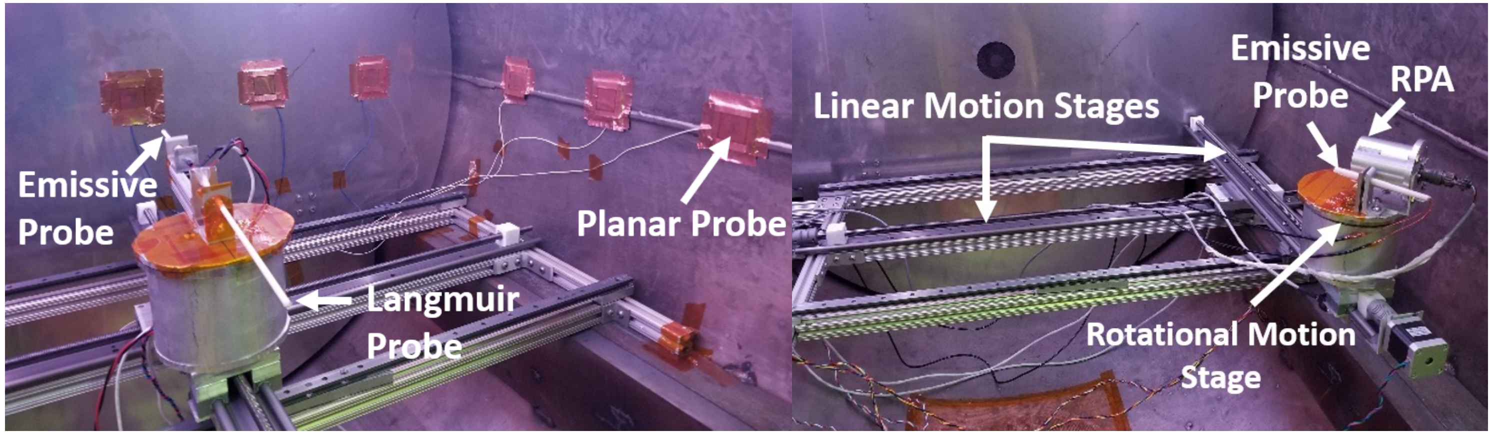


# Ion Emission Model Validation Experiments

Can we use vacuum chamber measurements to validate the ion emission model?




**Short Answer: Yes**

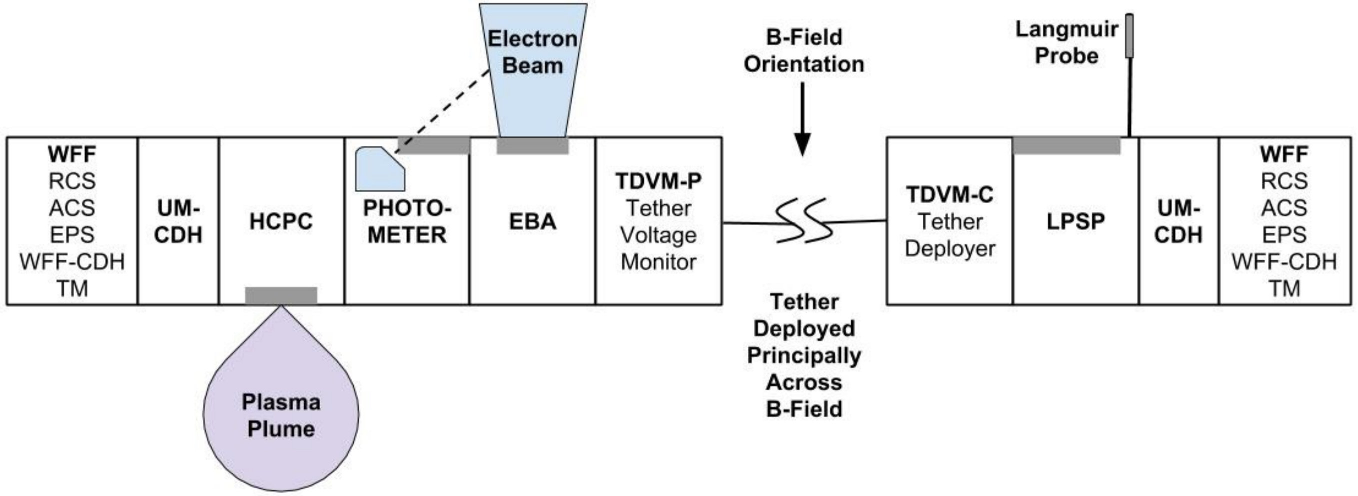


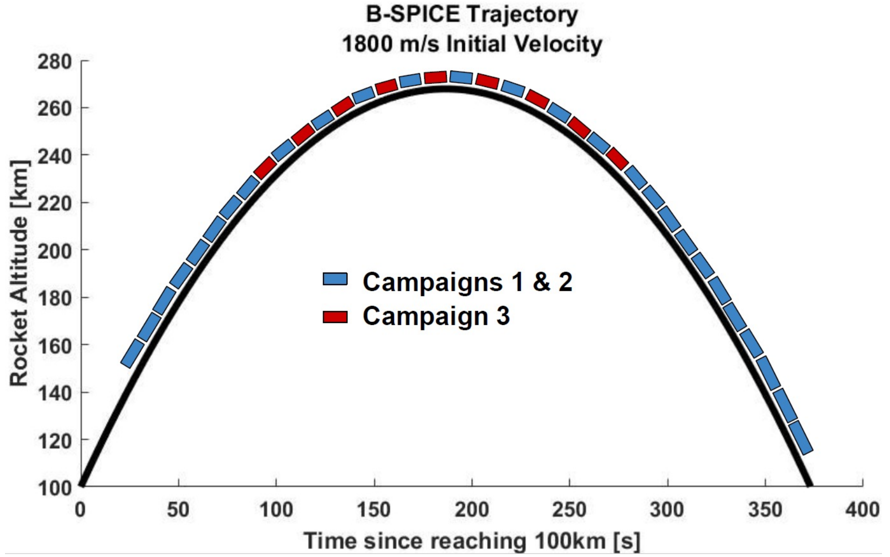
# The B-SPICE Mission Concept

- The Beam-Spacecraft Plasma Interaction and Charging Experiment

- Sounding rocket mission proposal resubmitted in the Fall

- Focus on validating the ion emission model in space
  - Technology demonstration mission
  - Validates modeling framework



# A Novel Spacecraft Potential Diagnostic

- Low cost
  - Can be board-mounted internally
- Easy to Use
  - Does not require complex/expert analysis
- Unlocks new measurement speeds
  - 100+ kHz sampling rate
- Unlocks new science capabilities
  - And other new capabilities…

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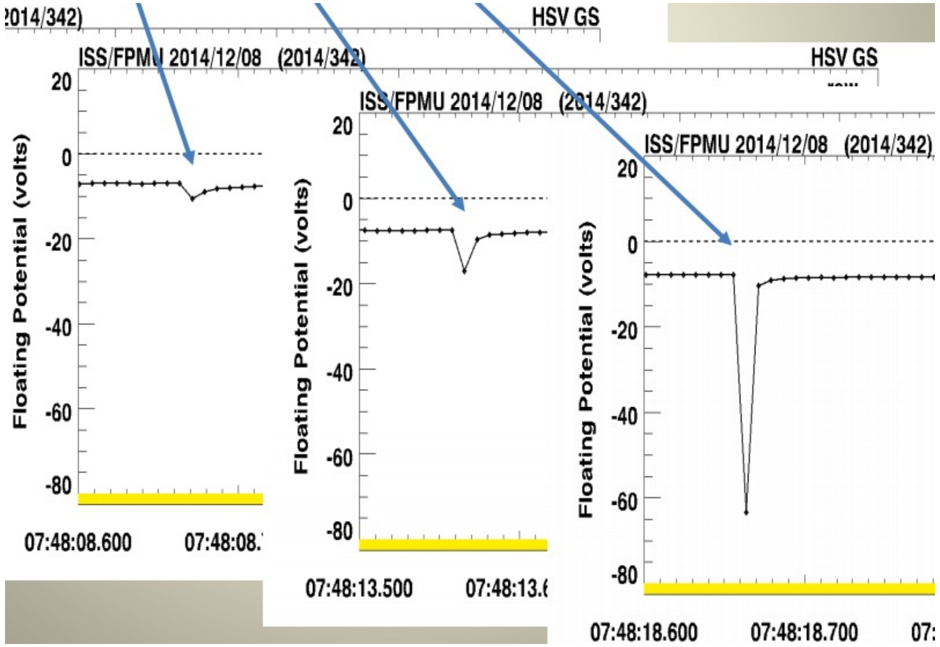





J. Minow & E. Willis, *Command Shunt/Unshunt Chit: Preliminary Analysis (update)*, NASA MSFC ISS Environments SPRT, 2014.

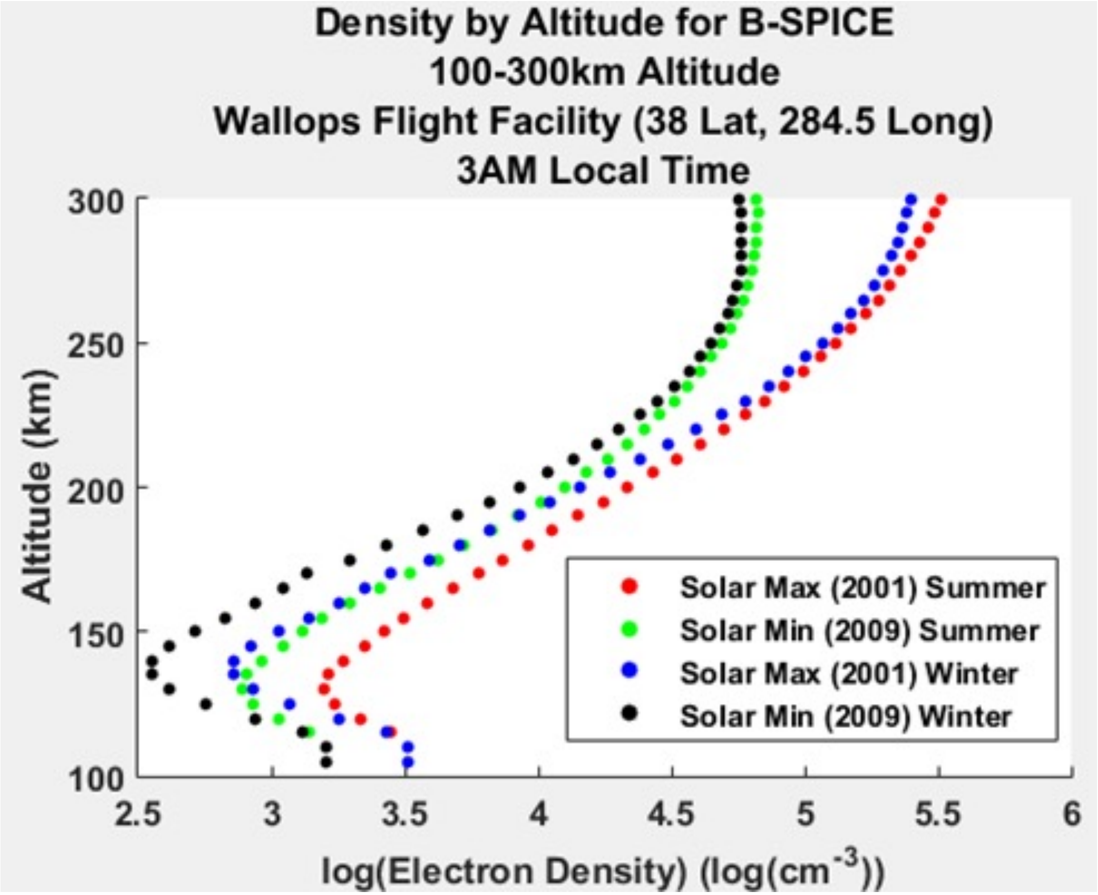
# Questions?

gmiars@umich.edu

# The B-SPICE Mission Concept

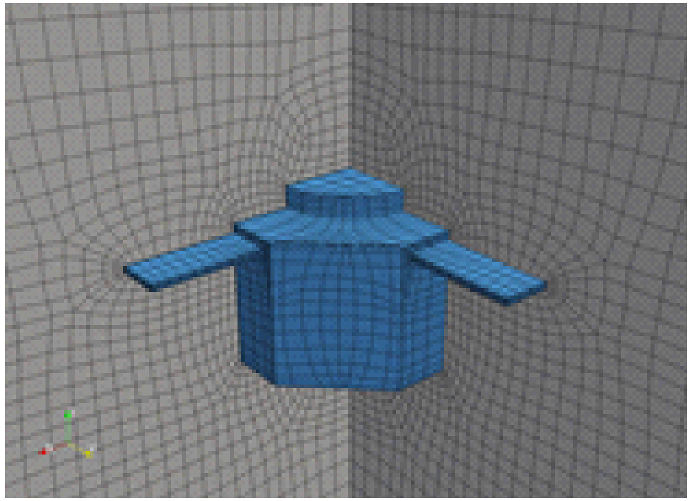
| Specific Mission Objectives | Science Measurement Requirements | | Instrument |
|---|---|---|---|
| | Physical Parameters | Observables | |
| Objective 1: Determine most efficient plasma contactor operating regime for spacecraft-charging mitigation.<br><br>Objective 2: Determine scaling law for spacecraft potential versus beam/contactor current.<br><br>Objective 3: Determine scaling law for spacecraft potential versus contactor expansion time.<br><br>Objective 4: Determine scaling law for spacecraft potential versus contactor expellant utilization. | Local Plasma Conditions | Plasma Density, Temperature | Langmuir Probe (LP) |
| | Conditions on Spacecraft | Spacecraft Potential, Collected Current | Tether Deployer & Voltage Monitor (TDVM) |
| | Electron Beam Conditions | Emitted Beam Current | Electron Beam Assembly (EBA) |
| | Beam Interactions (Atmos. & Plume) | Beam-Gas Optical Emission | Photometers (PM) |
| | Hollow Cathode Conditions | Keeper & RAA Potentials/ Currents | Hollow Cathode Plasma Contactor (HCPC) |
| | | Net Ion Emission Current | |

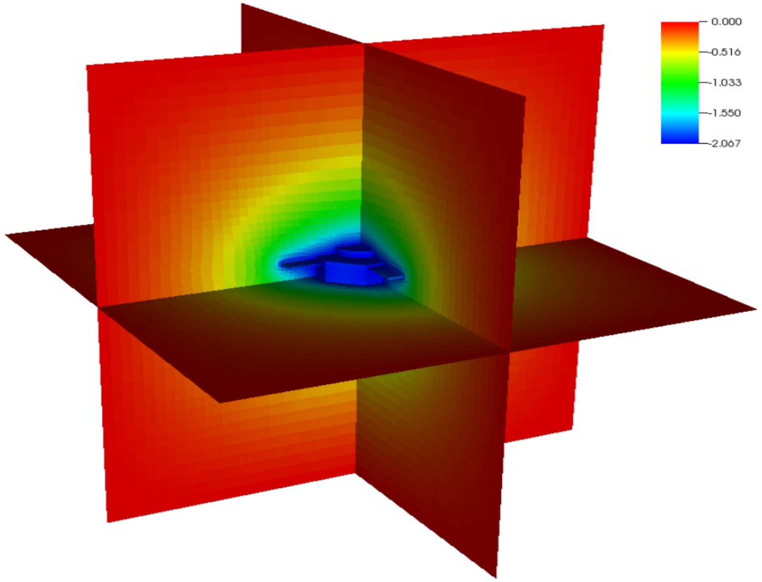
# The B-SPICE Mission Concept



# CPIC as a Plasma Physics Tool

- Curvilinear Particle-In-Cell
- Kinetic plasma modelling (PIC)
- Adaptive computational grid conforms to arbitrary shapes
- Designed for multiscale problems and complex objects






Example Van Allen Probe Model in CPIC

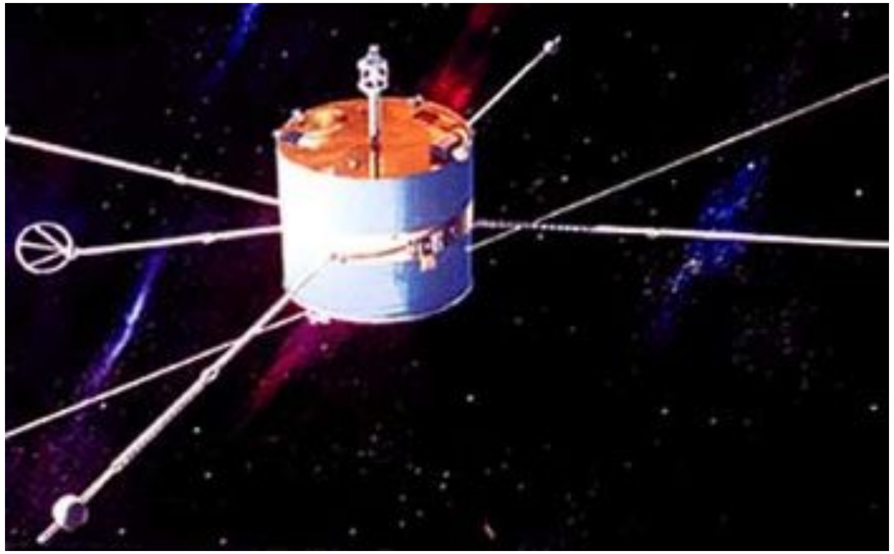
# A Brief History of Electron Beams in Space

- Numerous sounding rocket and LEO spacecraft have featured electron beams
- A useful tool for studying space plasmas and plasma physics
- Significantly fewer magnetospheric spacecraft (SCATHA is one example)

**Artificial Particle Beams in Space Plasma Studies**

Edited by
Bjørn Grandal

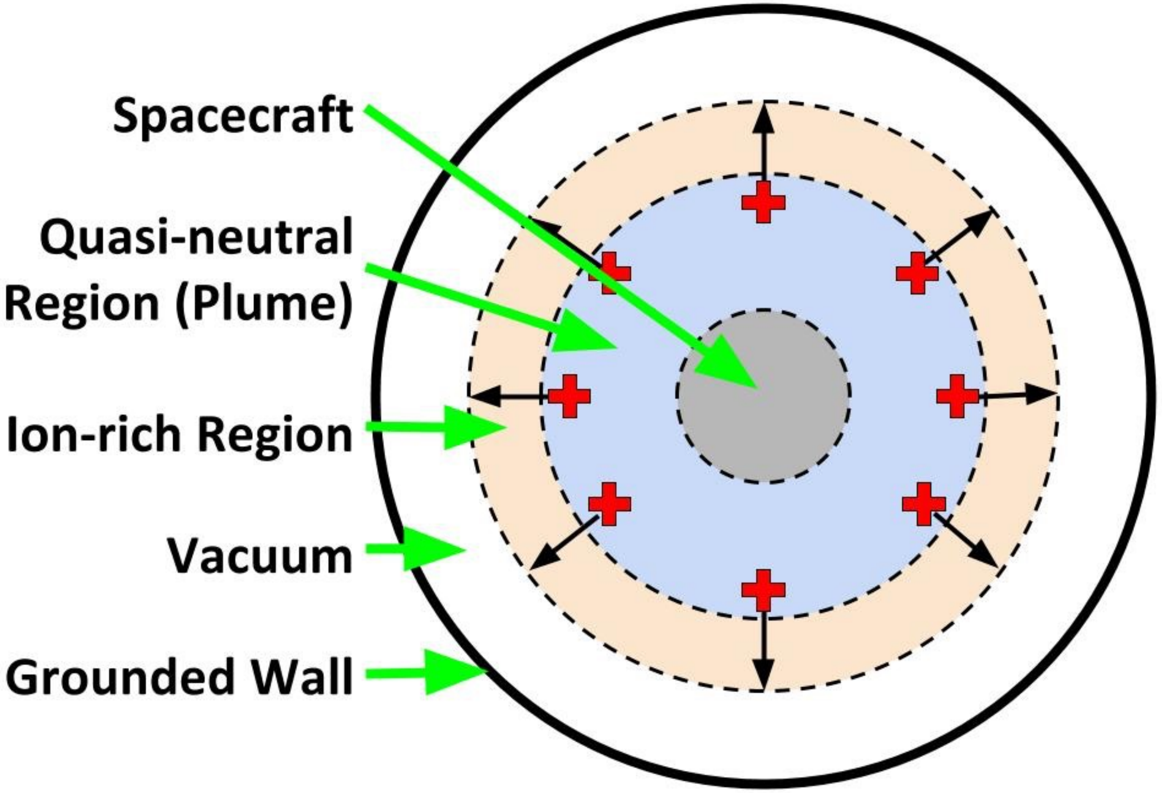
688 pages
1982

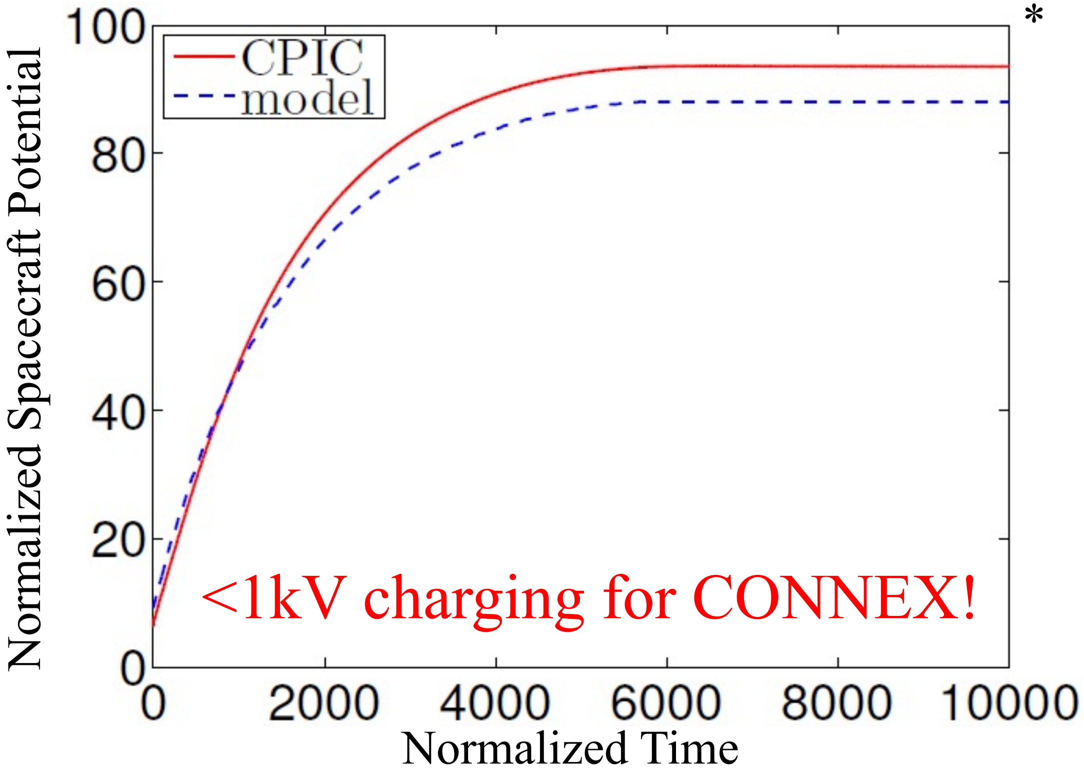


# Analytical Model of Ion Emission

Analytical model of ion emission successfully developed using space charge limit:

$$\mathbf{I^{emit} = I^{SCL}}\,\textbf{(plasma potential, plasma geometry, ion drift velocity)}$$

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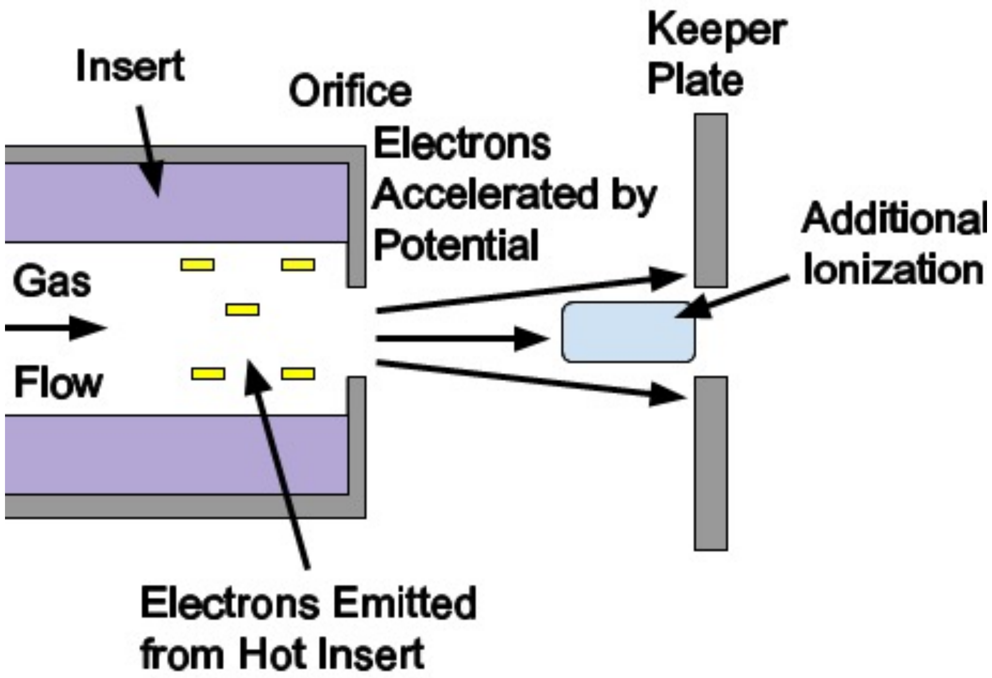
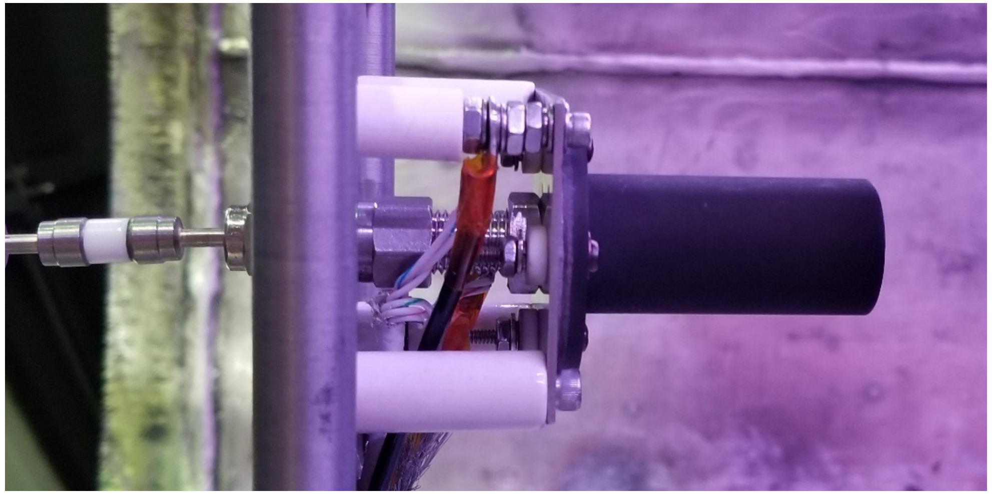
F. Lucco Castello, G.L. Delzanno, J.E. Borovsky, G. Miars, O. Leon, B. E. Gilchrist, *Spacecraft-charging mitigation of a high-power electron beam emitted by a magnetospheric spacecraft: Simple Theoretical model for the interpretation of the transient of the spacecraft potential*, JGR, 2018.

# Mimicking Space and Producing Plasma

- Ambient space potential = Chamber wall potential
- Spacecraft  potential = Hollow cathode potential
- Electron beam current = Power supply in constant current mode
- Hollow cathode biased positive w.r.t. chamber wall to emit ions



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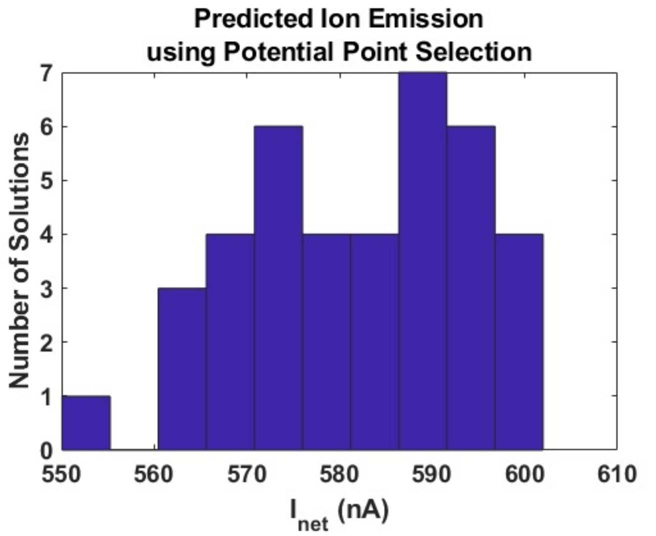
# Analytical Ion Emission Model Predictions

- Multiple possible solutions depending on which plasma potential points are picked as constraints




- Solutions match measured ion emission closely

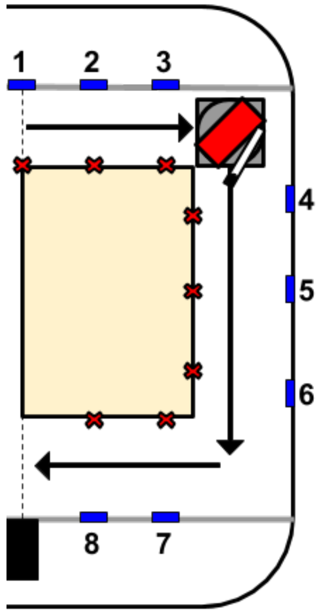


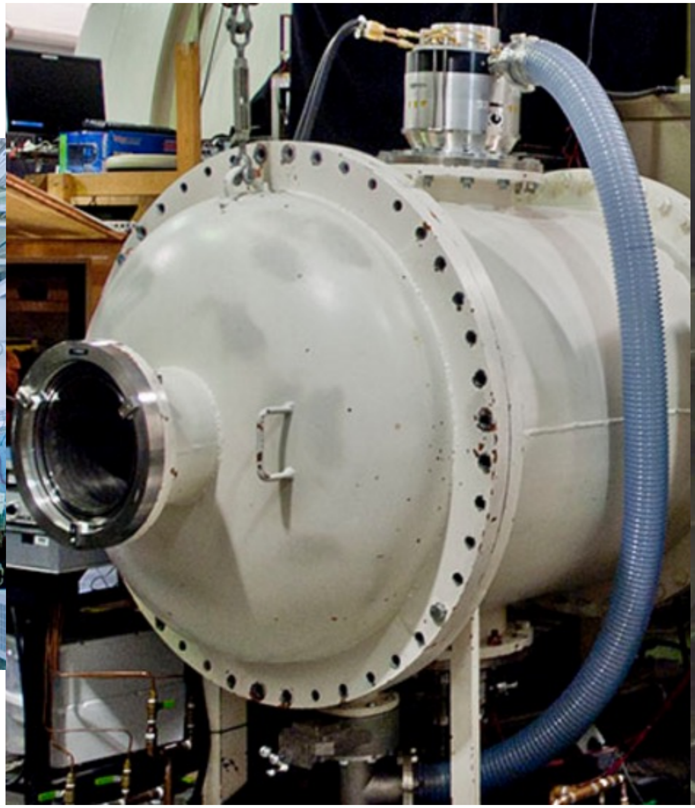

TABLE V. COMPARISON OF MEASURED EMISSION CURRENT AND ION EMISSION MODEL PREDICTION USING THE POTENTIAL POINT SELECTION TECHNIQUE AT A CATHODE POTENTIAL OF 30V

| Position | Measured Emission Current (nA) | Fit Used | Emission Current Prediction Range (nA) | Average Emission Current Prediction (nA) | % Error |
|---|---|---|---|---|---|
| 1 | 90 | None | 534-617 | 572 | 540% |
| 2 | 560 | None | 550-602 | 582 | 3.9% |
| 3 | 330 | None | 326-353 | 342 | 3.6% |
| 4 | 310 | Exponential | 267-289 | 282 | 9.0% |
| 5 | 200 | Exponential | 177-201 | 189 | 5.8% |
| 6 | 140 | Exponential | 243-271 | 256 | 83% |

# Vacuum Facilities

Large Vacuum Test Facility

Junior Test Facility



Cathode Test Facility


ElectroDynamic Applications Chamber