Satellite Instrument Shielding in the Strongly Coupled Plasmas

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Acknowledgments:

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Motivations

- CASSIOPE/e-POP high-resolution electron spectra measurements: **-6V** applied affecting **photoelectron deflection efficiency.**
- Swarm high negative (-3.5V) faceplate voltage applied to enable reliable estimation of the ion density.

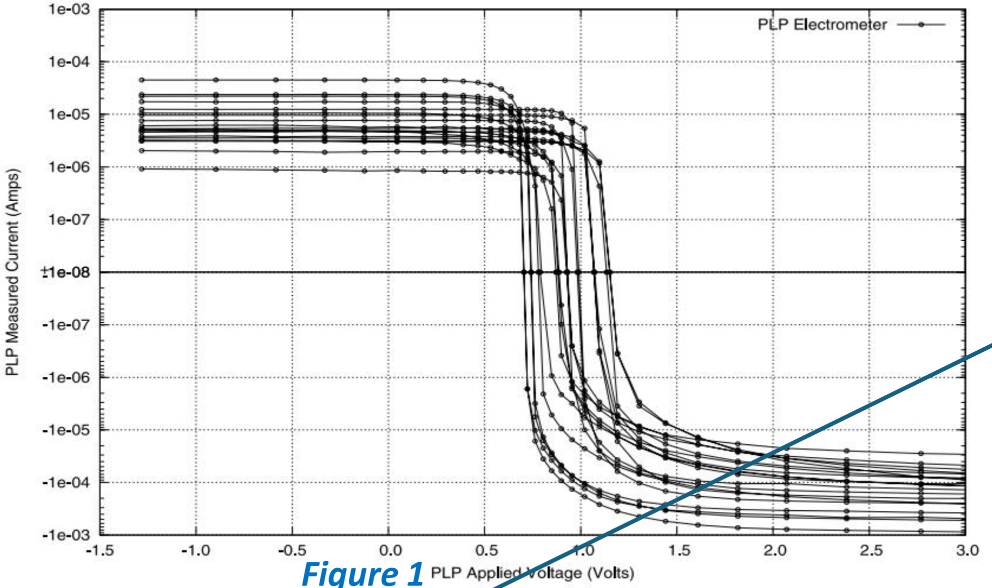
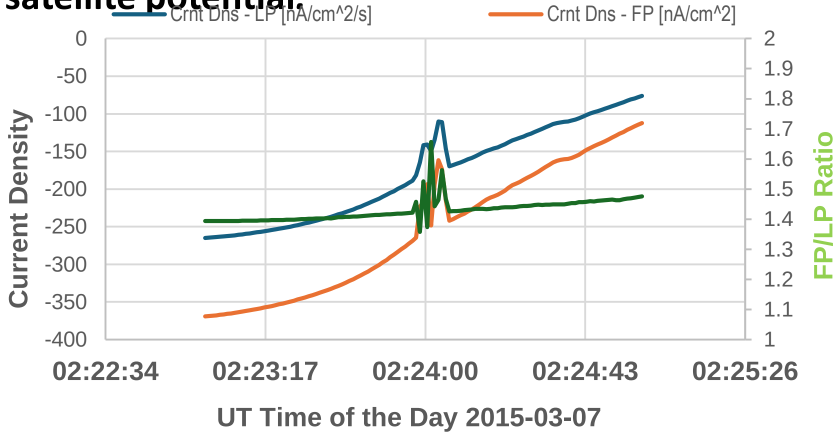


Figure 1

*"A collection of characteristic voltage-current sweeps from the PLP is shown in **Figure 1**. Notice that the ion current is extremely flat over a large range of voltage. This is consistent with our conceptual model of ion collection, which is simply that with an ion ram energy of about 5 eV, the PLP should see an undisturbed cross section of the ion flux when the potential is sufficiently negative as to eliminate the electron current. Furthermore, we argue that **if there were a more complicated interaction between the PLP and the environment, that interaction might be affected by the PLP potential**. Since **no such interaction had ever been observed,** and since the PLP current-voltage curves are indeed flat at negative voltage, **we have no reason to believe that the PLP is not seeing the representative flux caused by the relative motion of the spacecraft and ionospheric plasma".***

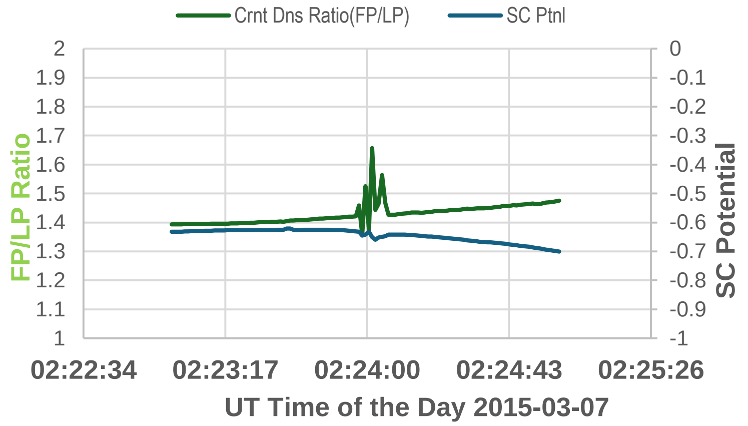
Mcnamara at. al, 2007: "*Comparison of CHAMP and Digisonde plasma frequencies at Jicamarca, Peru*"

In Swarm, we **do need a large negative floating faceplate bias (-3.5 V)** to enable reliable estimation of the ion density. Therefore, **we do have an evidence of a more complicated interaction between the Swarm and the environment**, because interaction is **strongly affected by the satellite potential.**



Face plate (in red) vs. Langmuir prob current densities (in blue) and their ratio (in green).

Face plate to Langmuir prob current densities ratio (in green) vs. Spacecraft potential (in blue).



Model: General

General Non-Stationary Continuity (Boltzmann-Vlasov) Equation for Electron Transport in Strongly Coupled Plasmas :

$$\frac{\partial f\left(\vec{r},\vec{v},t\right)}{\partial t}+div_{\vec{r}}\left[\vec{v}\cdot f\left(\vec{r},\vec{v},t\right)\right]+div_{\vec{v}}\left[\frac{\sum_i \vec{F}_i}{m_e}\cdot f\left(\vec{r},\vec{v},t\right)\right]=I_{Col}$$

$$I_{Col}=\sqrt{\frac{2w}{m_e}}\sum_s\int_{\vec{\Omega}'}\Sigma_s^{e\to N}\left(\vec{\Omega}'\to\vec{\Omega},w\right)f\left(\vec{r},\vec{\Omega}',w,t\right)d\vec{\Omega}'$$

<u>Where electron is accelerated by:</u>

- Strong instrument electric field: $\vec{F}_{\vec{E}}\left(\vec{r},t\right)=e\cdot\vec{E}\left(\vec{r},t\right)$
- Electron deflection by the geomagnetic field (weekly coupled plasma): $\vec{F}_L\left(\vec{r},\vec{v}\right)=e\cdot\left[\vec{v}\times\vec{B}\left(\vec{r}\right)\right]$
- Electron slowing down by the ambient electrons: $\vec{F}_{e\to e}\left(\vec{r},\vec{v},t\right)=\frac{\vec{v}}{\left|\vec{v}\right|}\frac{dW\left(\left|\vec{v}\right|\right)}{dl}\left(n_e\left(\vec{r},t\right),W\right)$
- Electron deflection by elastic collisions with neutral species: I_{Col}
- Set of Maxwell Equations to close the solution: $\left(\vec{E}(\vec{r},t),\vec{B}(\vec{r},t)\right)$

Numerical Simulations:

Spherical Probe

2-D Phase Space (Electron Radial Motion)

$$\frac{\partial f\left(\vec{r},\vec{v},t\right)}{\partial t} = -div_{\vec{r}}\left[\vec{v}\cdot f\left(\vec{r},\vec{v},t\right)\right] - div_{\vec{v}}\left[\frac{e}{m_e}\vec{E}\left(\vec{r},t\right) f\left(\vec{r},\vec{v},t\right)\right]$$ Continuity equation

$$div_{\vec{r}} E\left(\vec{r},t\right) = 4\pi e\left(n_e\left(\vec{r},t\right) - n_0\right); n_e\left(\vec{r},t\right) = \int_{\vec{v}} f\left(\vec{r},\vec{v},t\right) d\vec{v}$$ Gauss equation

Finite Element Scheme for the Instrument Shielding Dynamics in Spherical Radial and Velocity Coordinates:

Mac Cormack's predictor-corrector integration method has been implemented:

- Does not require explicit calculations of second derivatives,
- Accurate to second order.

Initial Conditions:

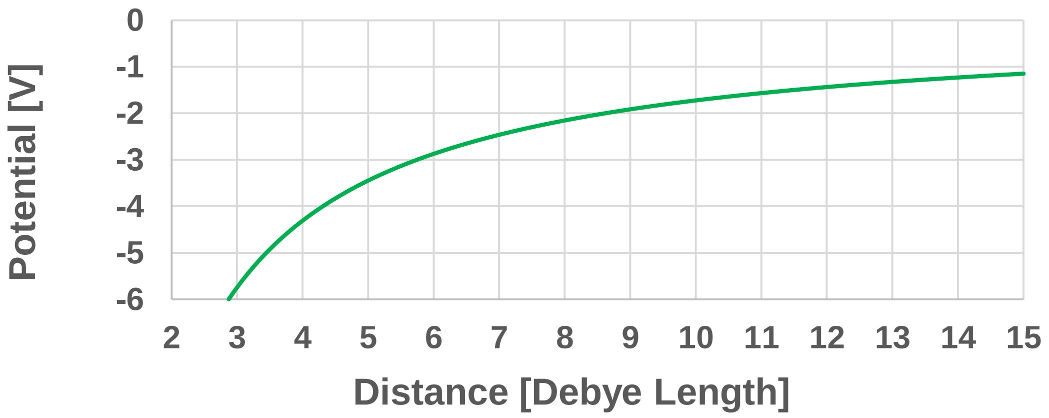
Electron velocities distribution: Maxwellian (T=900 K),10^5 [cm^{-3}]

Potential: Fixed at -6V

Phase space density: Time-independent **boundary conditions** are set on right and bottom boundaries:

- Left speed and left radial boundaries: $\varphi < 0.075 eV$ Zero input currents
- Right speed and right radial boundaries: Vacuum, means no input current from outside for potentials

Initial Potential Radial Profile:



Radial Probe Steady-State Shielding in the Strongly Coupled Plasmas

Poisson–Boltzmann equation in vector form:

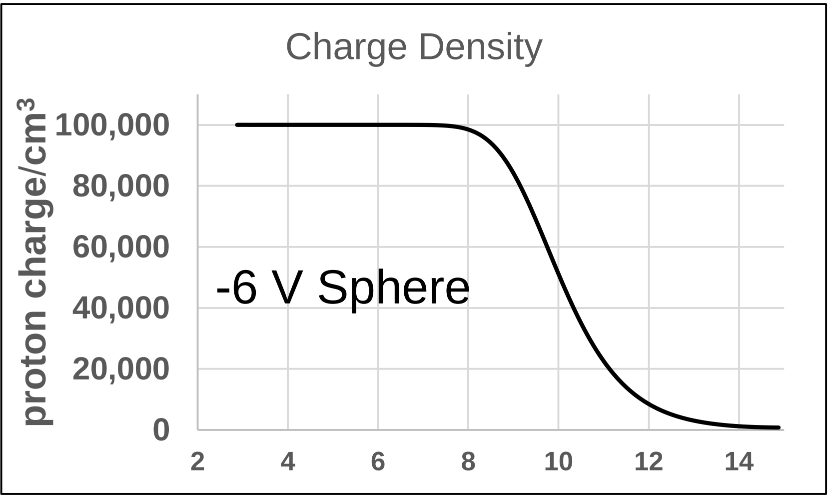
$$\nabla^2\varphi(\vec{r}) = 4\pi e n_0\left(\exp(\chi)-1\right), \chi = \frac{e\varphi(\vec{r})}{k_B T} < 0$$

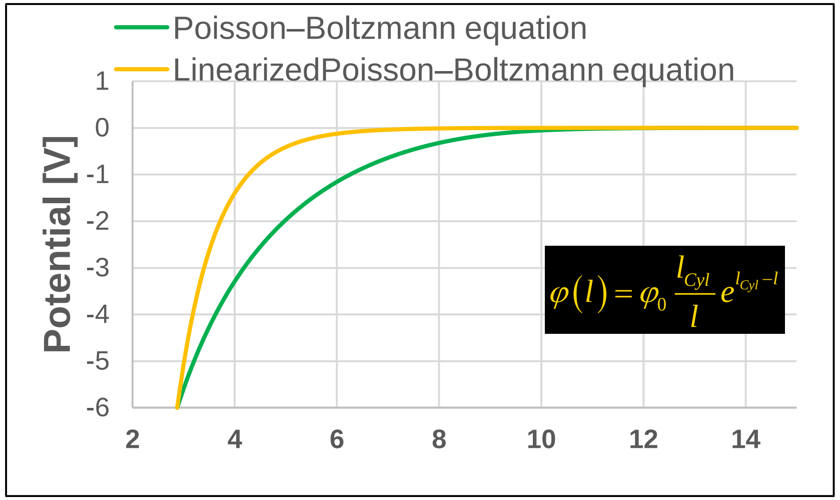
Parameter	Value
Electron Temperature	900 K
Plasma Density	100,000 cm-3
Debye Length	0.6547 cm
Sphere Radius	1.8825 cm
Sphere Potential	-6 Volt

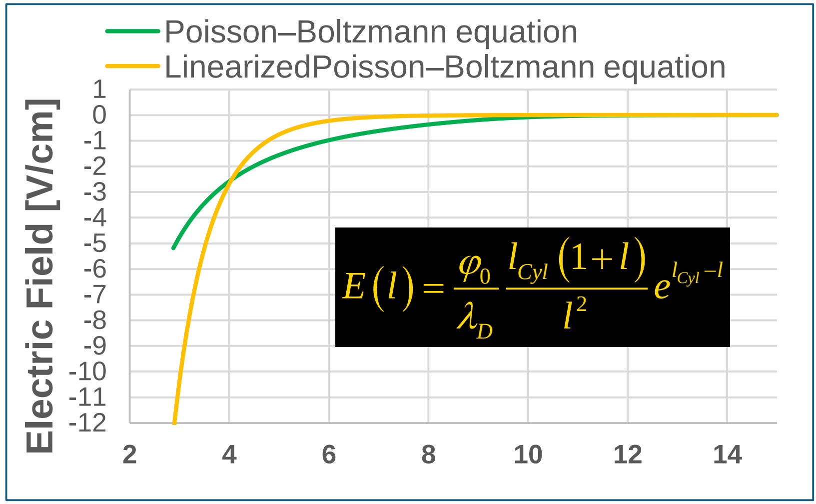
Poisson–Boltzmann equation in spherical coordinates

Debye-Huckel Potential:

$$\frac{d^2\chi(l)}{dl^2} + \frac{2}{l}\frac{d\chi(l)}{dl} = e^{\chi(l)} - 1; l = r / \sqrt{\frac{k_B T}{4\pi e^2 n_0}}$$







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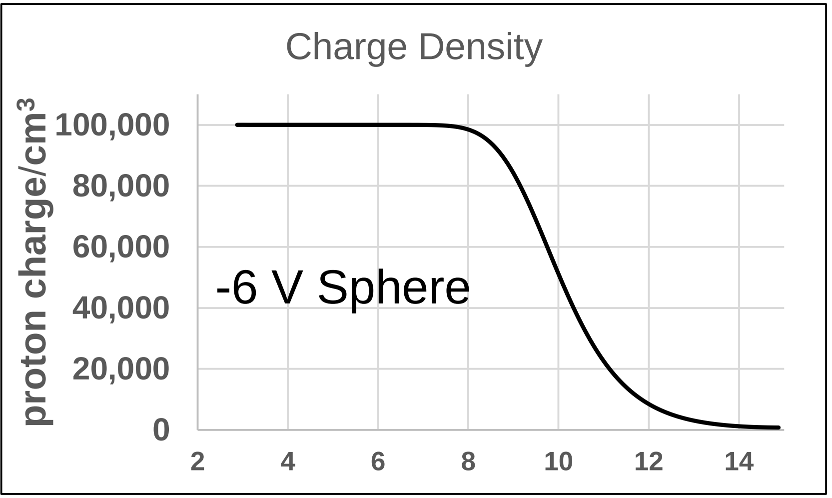
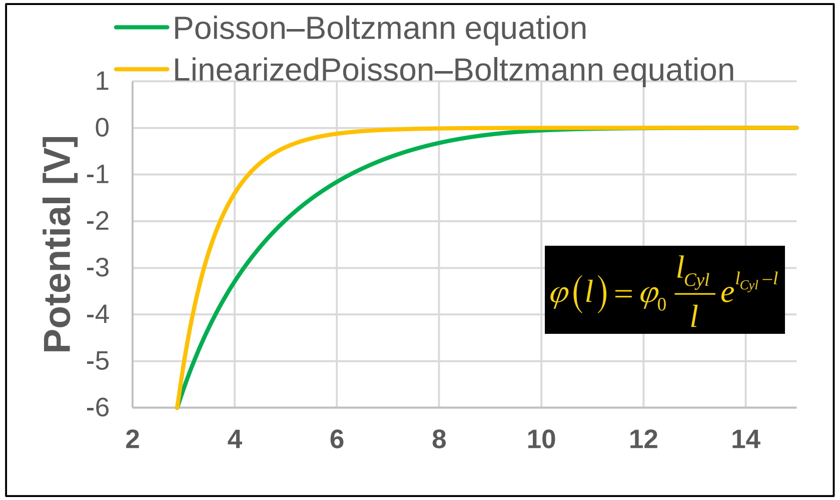
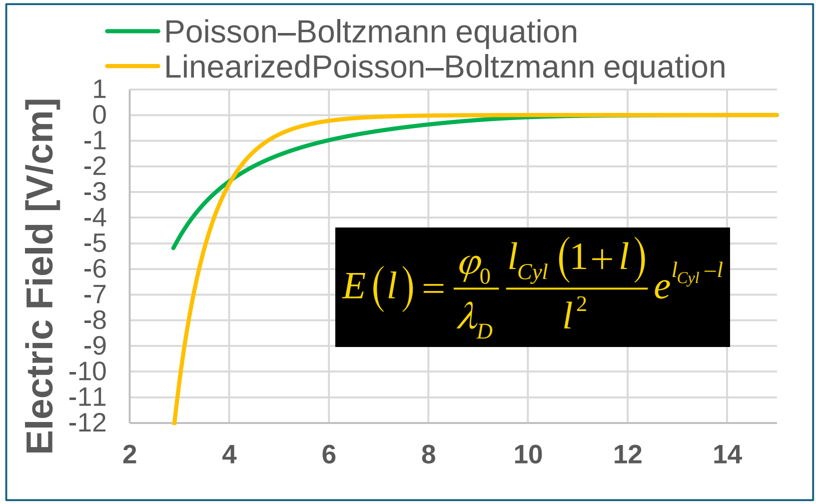
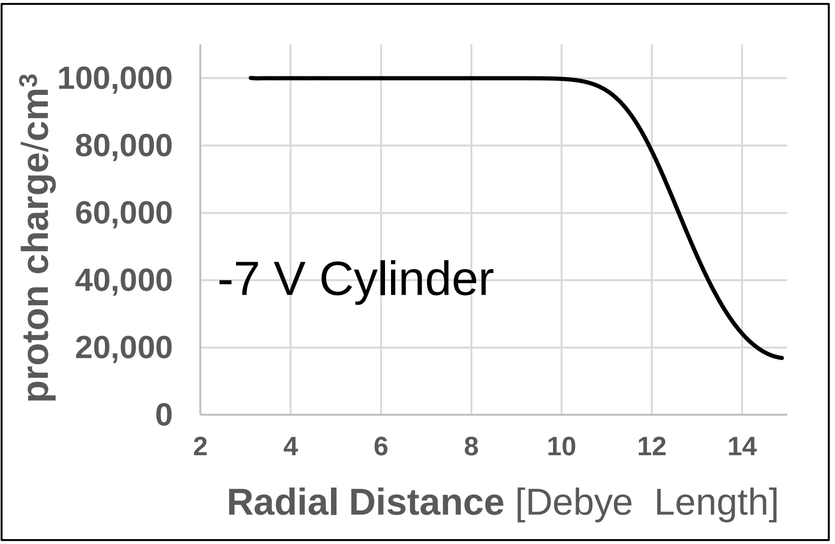
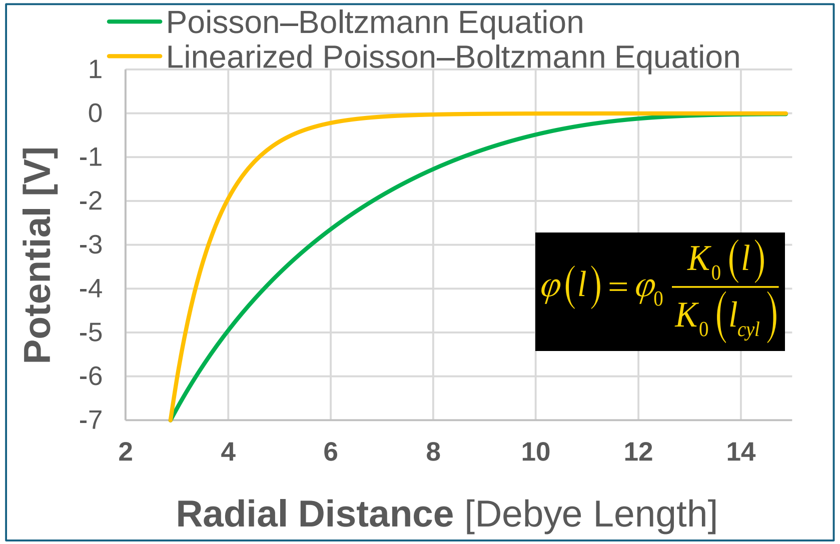
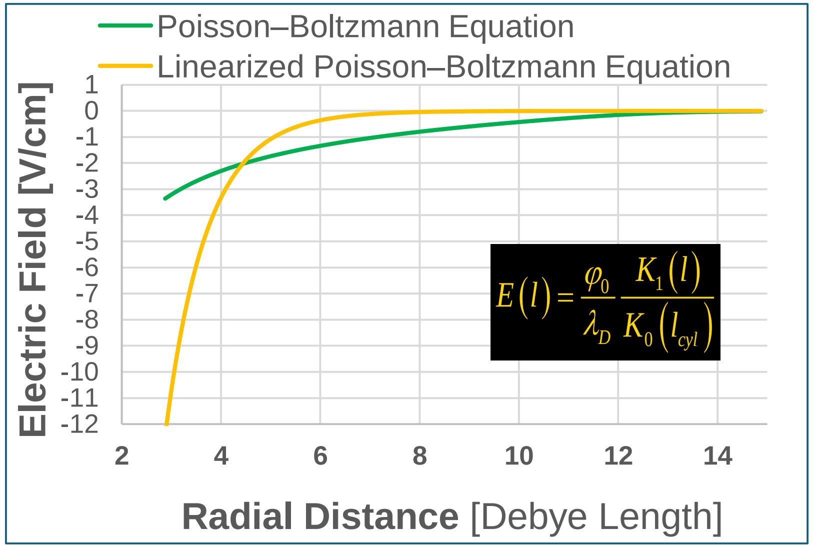


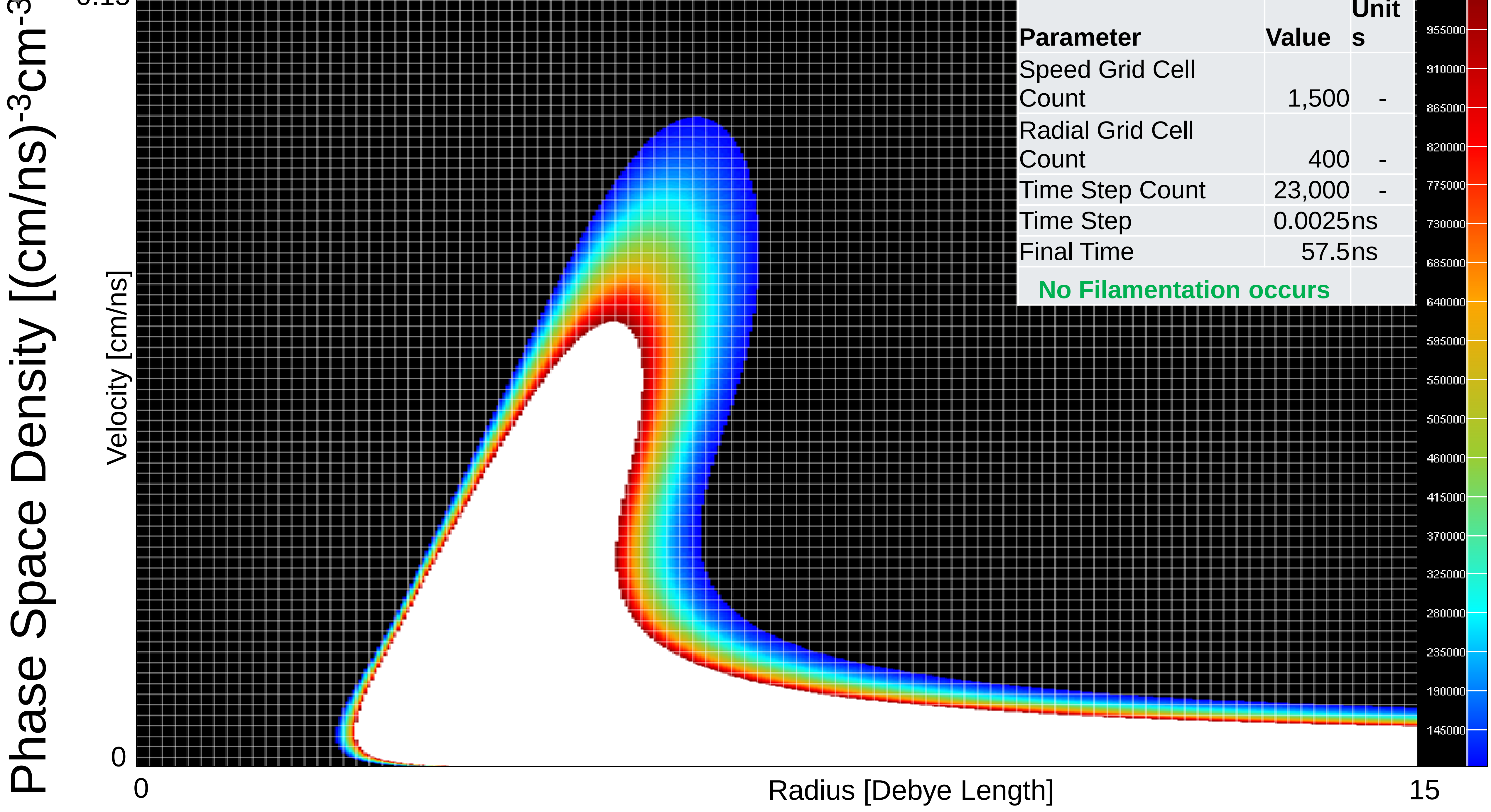




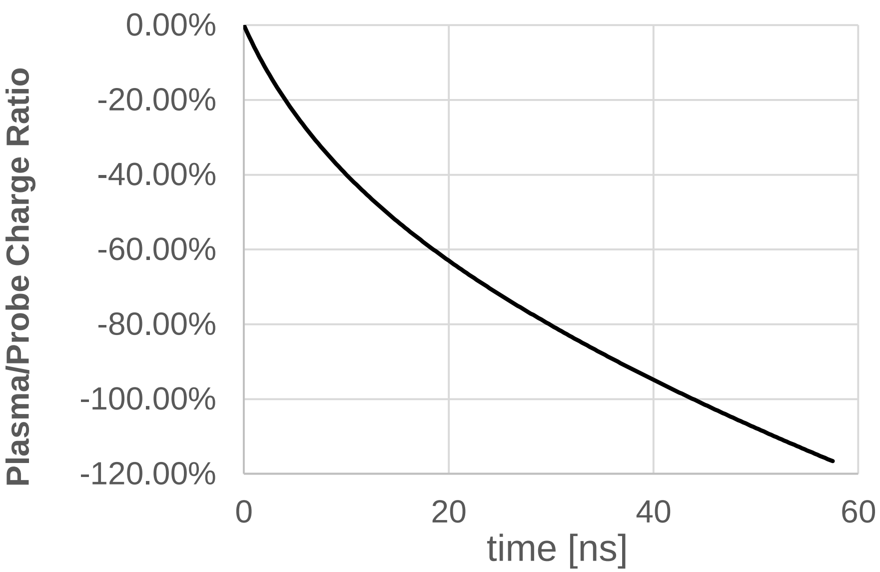


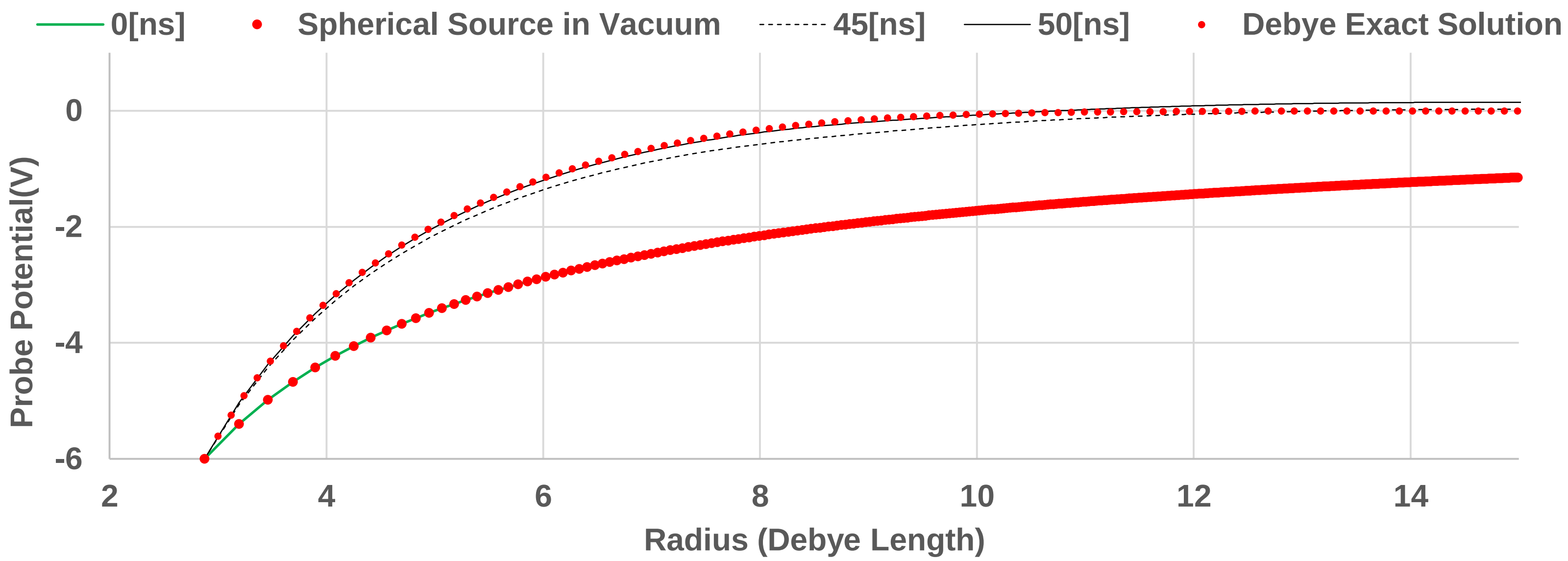


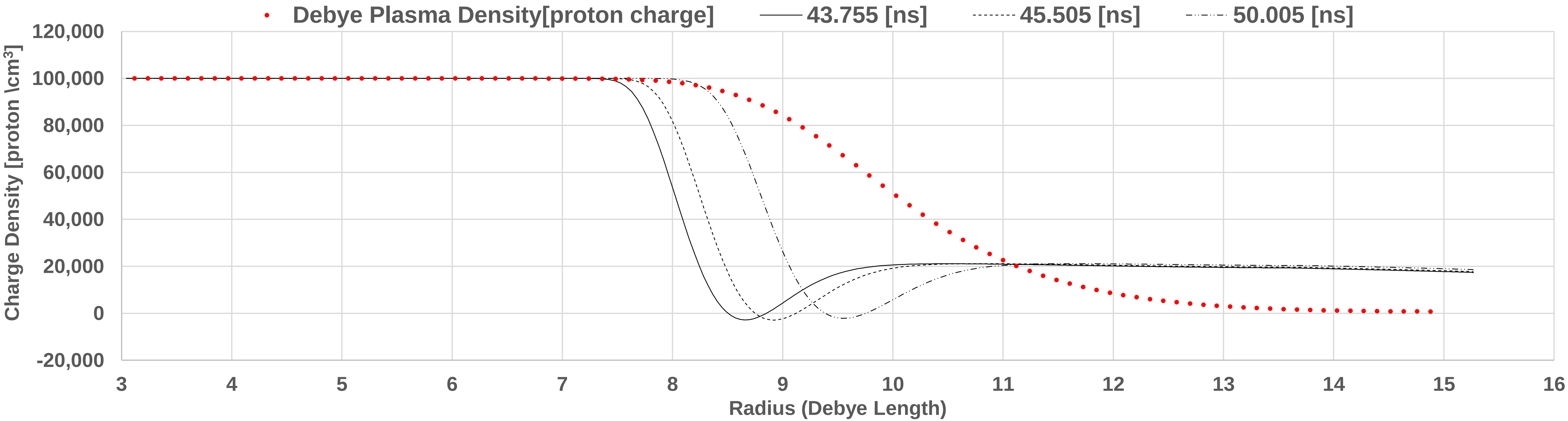



Phase Space Density [(cm/ns)-3cm-3]
0.15
Velocity [cm/ns]
0
0
Radius [Debye Length]
15
Parameter
Value
Units
Speed Grid Cell Count
1,500
-
Radial Grid Cell Count
400
-
Time Step Count
23,000
-
Time Step
0.0025
ns
Final Time
57.5
ns
No Filamentation occurs
955000
910000
865000
820000
775000
730000
685000
640000
595000
550000
505000
460000
415000
370000
325000
280000
235000
190000
145000

Radial Probe Shielding Dynamics in the Strongly Coupled Plasmas







Conclusions:

A steady-state solution for the stiff* Poisson–Boltzmann differential equation has been obtained.

Completed

**Electron density rapid change (in* $e^{\frac{-e\varphi=7eV}{k_B\cdot 900K=0.0776}}=e^{90.3}=1.6\times 10^{39}$ *times) on a distance of a few centimeters.*

A solution for the non-stationary Boltzmann-Vlasov equation has been utilized to validate the steady-state solution.

Completed

The obtained steady-state solution has been employed to calculate instrument shielding during the photoelectron spectrum deconvolution from SEI high-resolution electron measurements.

Completed

The non-stationary Boltzmann-Vlasov equation will be utilized to explain the need for large negative faceplate biases to enable reliable estimation of the ion density in Swarm faceplate current measurements.

Work in Progress