The Effect of Super-particle Weight Factor on Particle-in-Cell Simulations in Low-pressure Capacitively-Coupled Plasmas

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BACKGROUND AND MOTIVATION

Recent work reported that the plasma density of explicit electrostatic PIC/MCC simulations at steady state **does not converge** while decreasing the super-particle weight for low pressure CCPs [1].

METHODS

- xpdp1: a planar, one-dimensional electrostatic code [3].
- Gap: $2 \leq gap \leq 6.7\ cm$ • AC **250 V**, **13.56 MHz**.
- The argon at **0.076 Torr** and **0.026 eV**.
- $1.2 \times 10^4 \leq$ Super-particle Weight factor $\leq 1.0 \times 10^5$
- Density: the maximum time-averaged electron density.
- Temperature: the time-averaged electron temperature of the bulk.
- Sheath width: the location where $n_e/n_i = \frac{1}{2}$.
- Bulk width: $1/2(Gap\ Length - Sheath\ Width)$.
- Coulomb Collision Frequency: $\nu_e = 2.91 \times 10^{-6} n_e \lambda_{ee} T_e^{-3/2}$ [4].

RESULTS AND DISCUSSION

Time-Averaged Electron Density

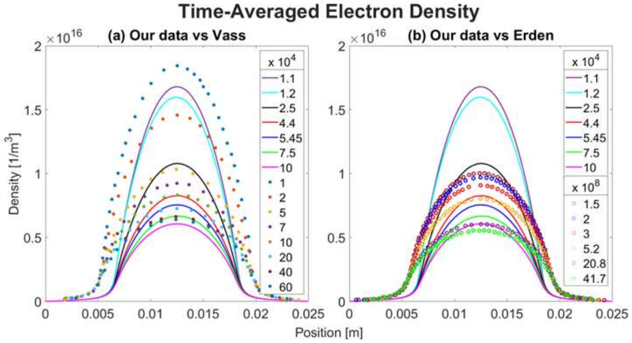

Fig. 1 Comparison to [1] and [2] of time-averaged electron density

Time Averaged Electron Density

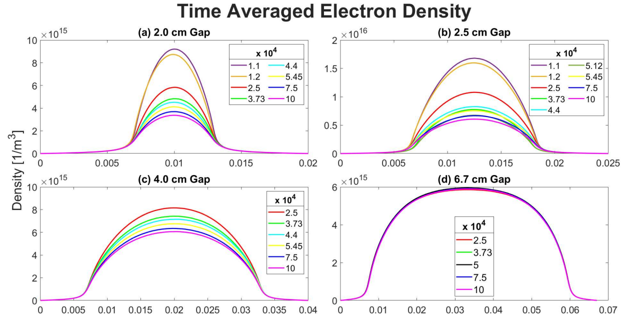

Fig. 2 Time-averaged electron density across the four gap sizes, displaying the convergence of larger gaps

Reverse Cumulative Integration of EEDF at Lower Energies

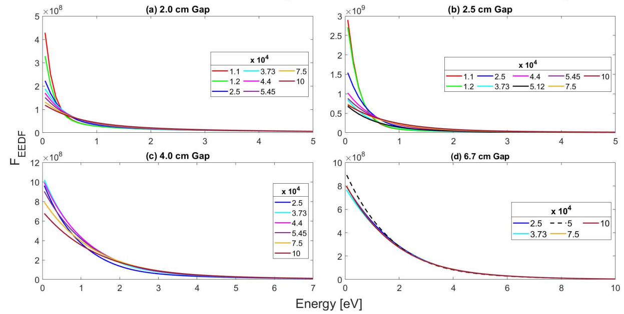

Fig. 3 Cumulative integration of electron energy distribution function, EEDF, for different weights from high to low energy.

- Our simulations have a narrower bulk than [1] and [2] partially due to the usage of different cross sections (*Fig 1*).
  - [1] diverges and [2] converges
  - However, [2] has a smaller range in super-particle weight factor
- The **gap size** (or cell width) **plays an effect in the convergence of the density** (*Fig 2*).
  - Most likely, it diminishes the effect of the absent physics.
- The **Debye Length resolution does not affect** the density **convergence** as several convergent cases are not well-resolved.
- **The density increases with decreasing super-particle weight factor, the opposite of the expected trend**.
- This **divergence is due to** accumulation of **cold particles**.

Time-Averaged Coulomb Collision Frequency

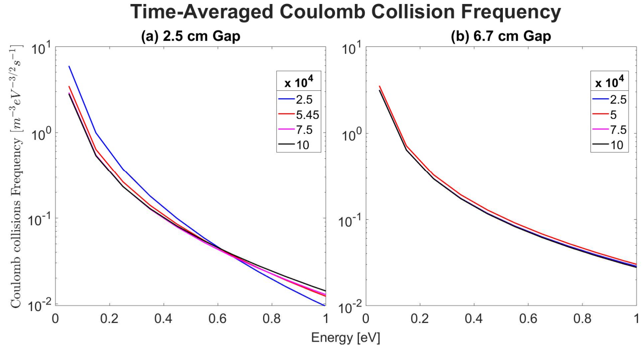

Fig. 4 Time-averaged Coulomb collision frequency for varying weights for energies between 0 and 1 eV.

COULOMB COLLISION MODEL

This Intra-cell Coulomb collision model is based on [4] with some modifications. The overall process is:

1. **Sort particles** by cell and position within cell
2. **Pair particles**: outside in, nearest neighbor
3. Calculate **relative velocities**, g_i
4. Calculate b_0**, s, and** A
5. Calculate **collision angle**
6. **Iterate velocities**

- Pairing is done like this since the strongest collision will be with nearest neighbors
  - If particles are odd, randomly pair middle particle
- Definitions:

b_0: collision parameter | *s*: isotropy | *A*: constant for collision probability

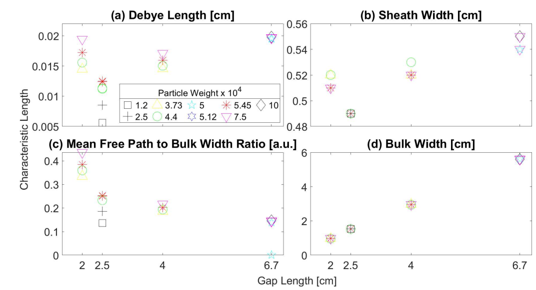

Fig. 5 Debye length, sheath width, mean free path, and mean free path to bulk width ratio, respectively, vs. gap length.

CONCLUSIONS AND FUTURE WORK

In revisiting xpdp1 for low pressure CCPs, the **divergence of plasma density at lower super-particle weight factors is found to be resultant of an accumulation of cold particles.** This effect diminishes at large electrode gap (6.7cm).

In future work, we will test the effectiveness of the intracell coulomb collision model.

ACKNOWLEDGEMENTS

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