Self-Consistent Dynamic Simulation of Ions around a Negatively Charged Dust Grain

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Overview

- Research Goal
- Code Development
- Current Code
  - Parameters
  - Forces
  - Ion Density
  - Electric Potential
  - Ion-Neutral Particle Collisions
- Results
- Conclusions

Objective

- Inspiration:
  - Alexander Piel
    - Developed MAD code to model N-ions in a plasma sheath
    - Models Ion density and electric potential

- Create a dynamic simulation to repeat Piel results

- Implement additional forces

Alexander Piel, "*Molecular dynamics simulation of ion flows around microparticles,*" IEAP, Christian-Albrechts-Universitat, D-24098 Kiel, Germany, 2017.

Model

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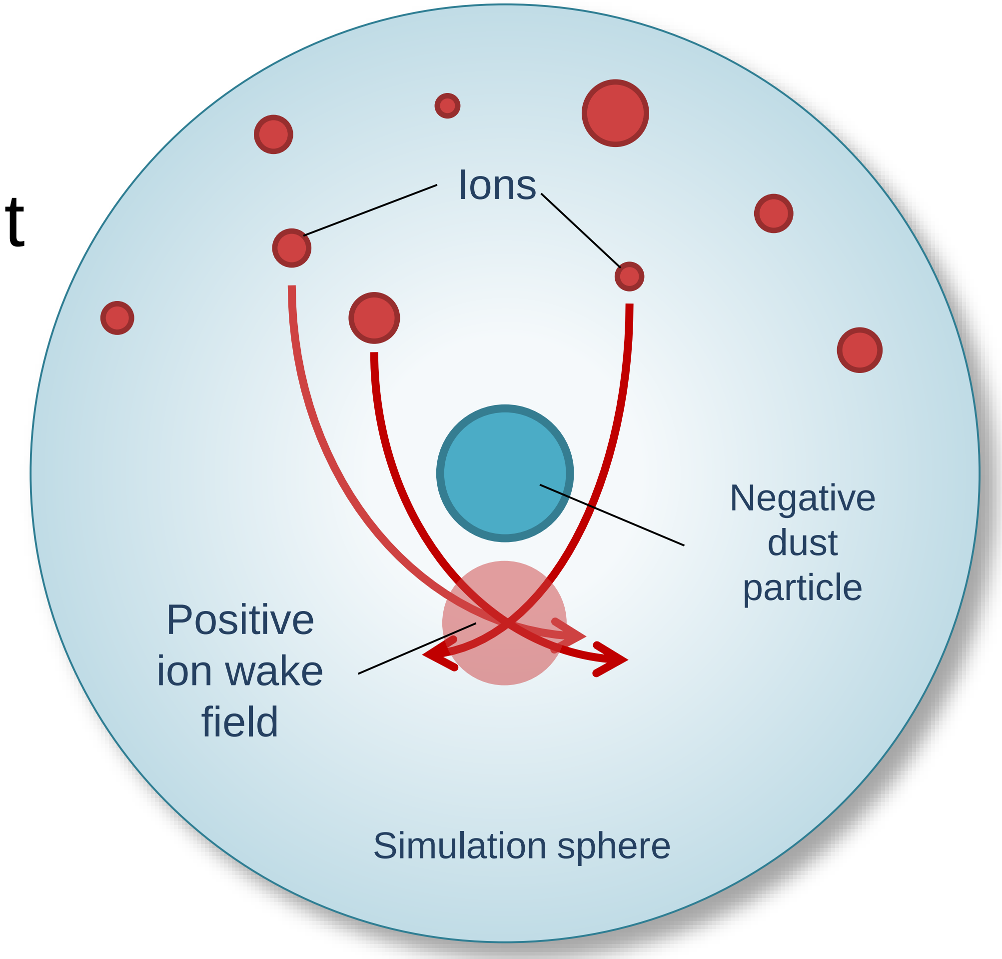
- Ions begin in positive Z
  - Given initial position and velocity
- Ions experience forces from environment
  - Other ions
  - Dust particle
  - External **E** field
  - Collisions
- Ions reset when leaving simulation
  - Boundaries



Parameters

- Dust
  - Charge = 30,000e
  - Radius = 8.89e-6 m
- Ions
  - Argon (mass = 6.63e-26 kg)
  - Charge = -e
  - Ion Temperature = 300 K
- Electron Temperature = 46000 K
- Mach = 1.1
- Plasma Density Far from Dust = 1e15 particles/m^3

Forces

- Ion/Ion Interactions
  - Ions treated as Yukawa Particles (shielded by thermal electrons)
- Ion/Dust Interaction
  - Dust treated as point charge
- Ion/Electric Field
  - $E(r) = \frac{e n_{i0} \lambda_{De}}{\epsilon_0} (\frac{R}{\lambda_{De}} + 1) \times \exp(-R/\lambda_{De}) \times \frac{\lambda_{De}}{r} \left[\sinh \frac{r}{\lambda_{De}} - \frac{\lambda_{De}}{r} \cosh \frac{r}{\lambda_{De}}\right]$

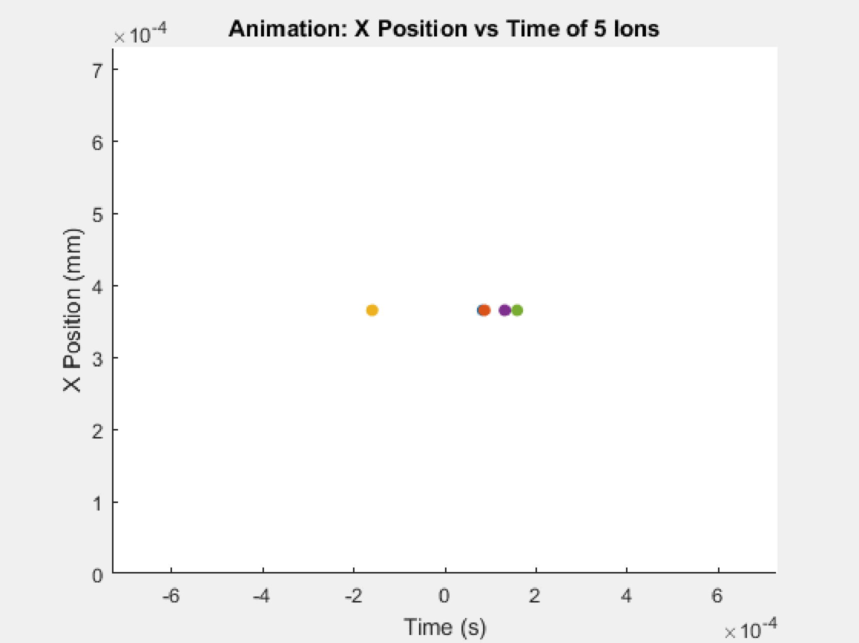
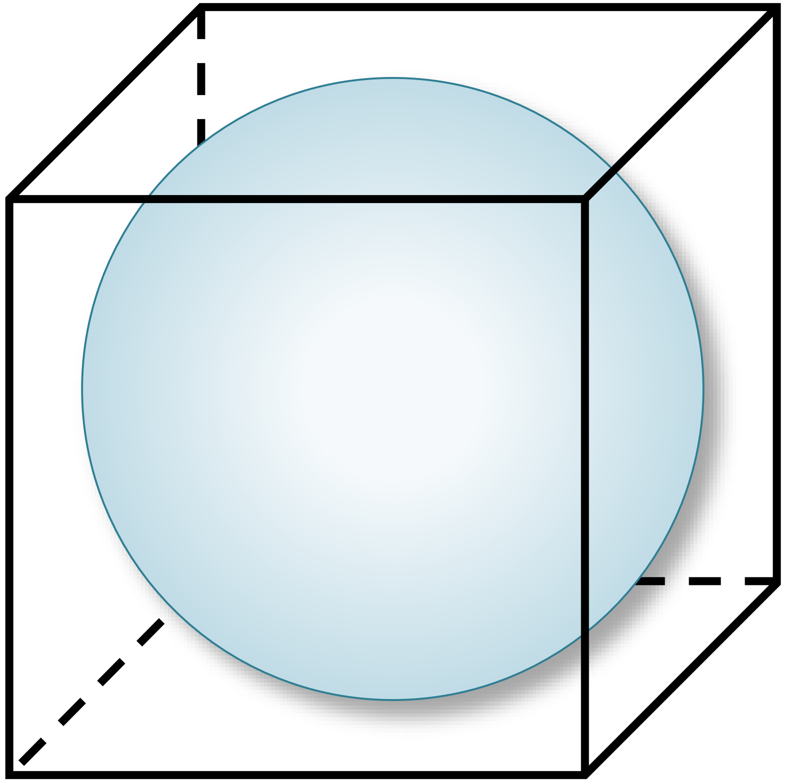


Figure Shielded ion/ion force shown between 5 ions

Ion Density and Electric Potential

- Simulation sphere divided into grid spaces
  - Grid records the location of each ion over time
- Electric potential summed using a 3D grid
  - Shielded ion potentials
    - $\Phi(\vec{r}) = \frac{1}{4\pi\epsilon_0}\sum_{i=1}^{N}\frac{\exp\left(-\frac{|\vec{r}-\vec{r}_i|}{\lambda_{De}}\right)}{|\vec{r}-\vec{r}_i|}$
  - Coulomb potential of dust particle
  - External potential due to plasma electric field



Ion-Neutral Particle Collisions

- Plasma has neutral atoms
- Resonant charge exchange between atom and ion
- Gas density is related to ion mean free path
  - Current mean free path approximated to 0.75*λ_{De}
- Ions velocity is randomized at end of path to simulate collision

Results

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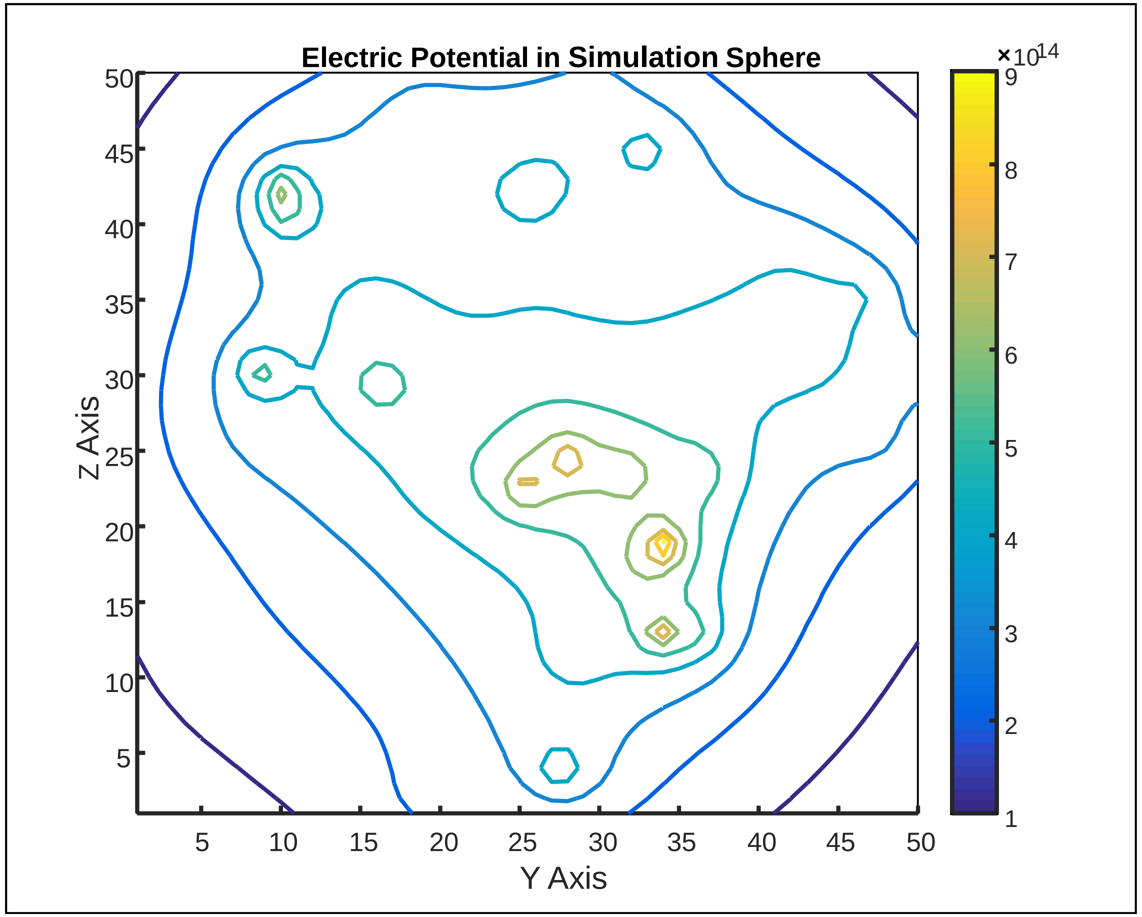
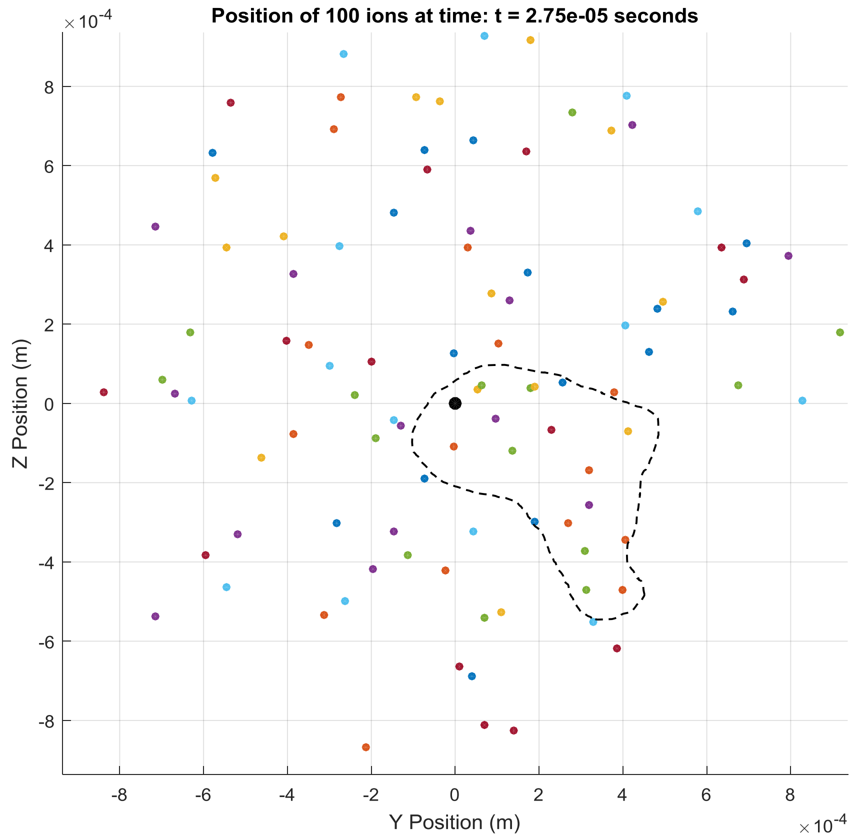
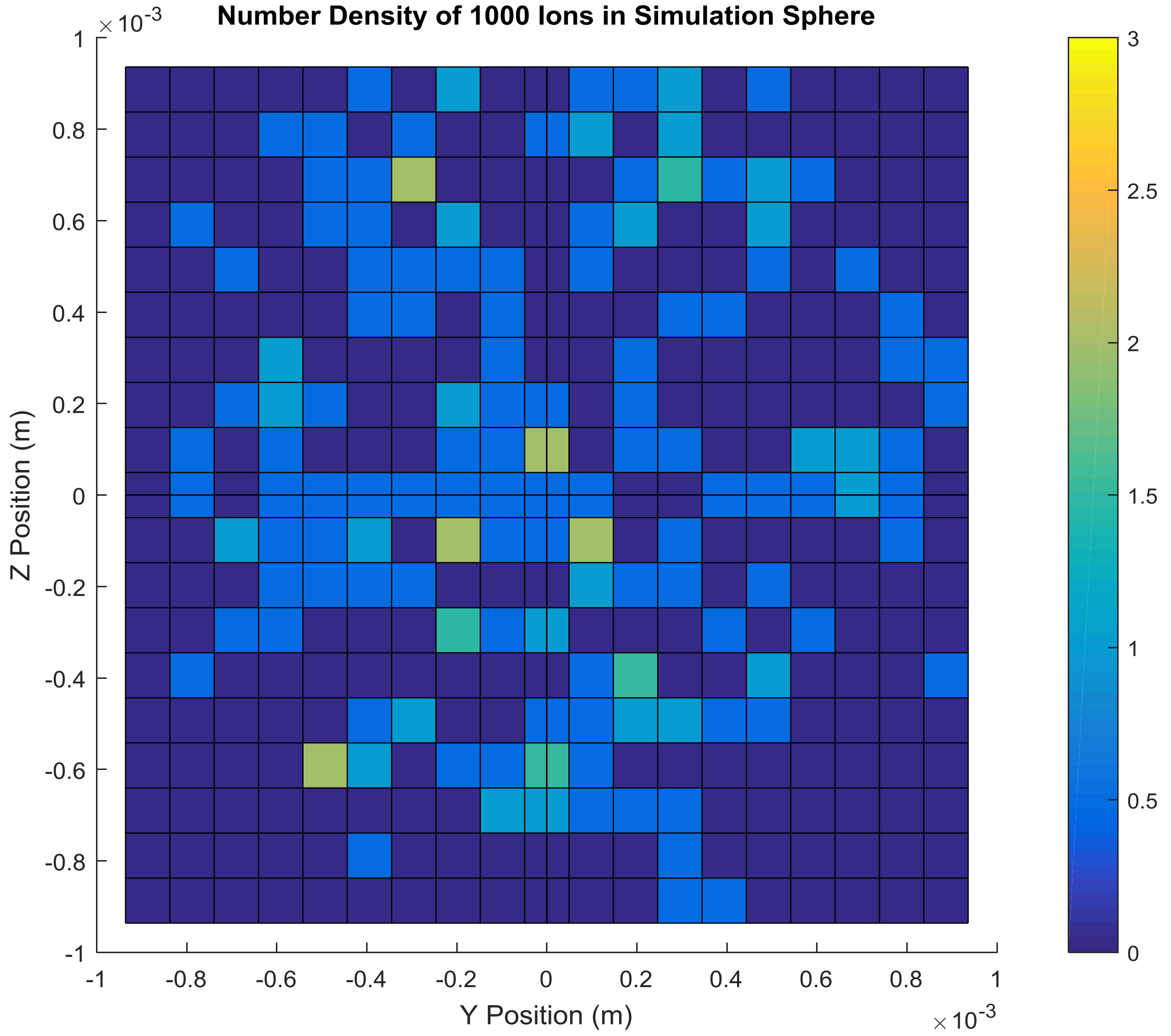
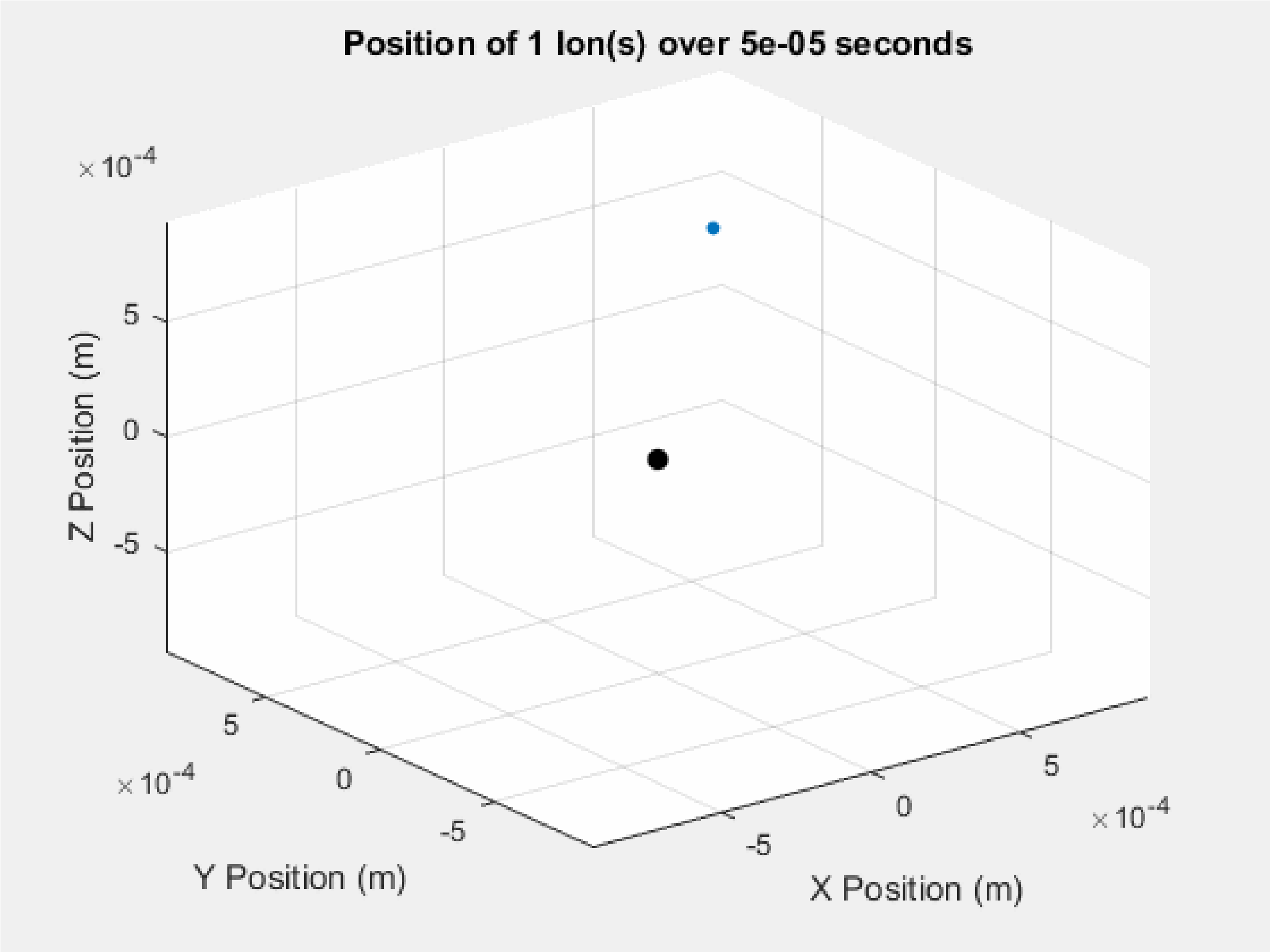




Results (cont.)



Results (cont.)



Results (cont.)

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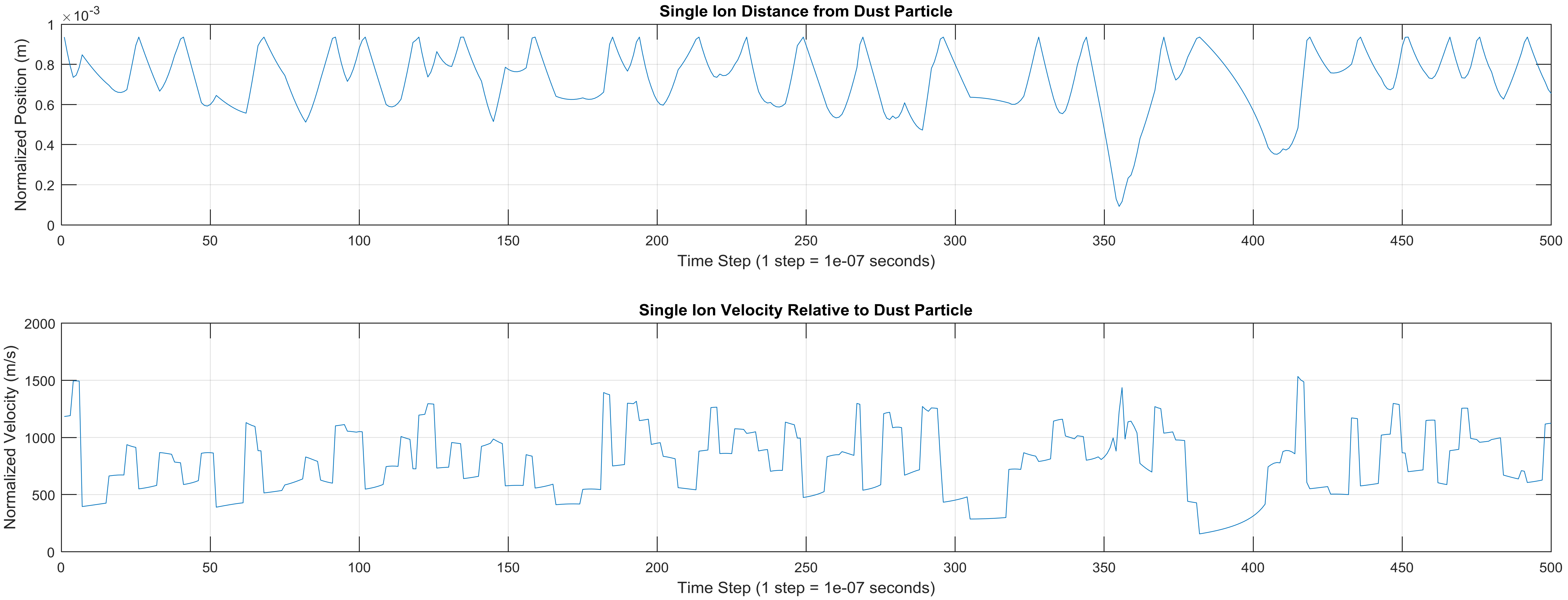

Discussion

- Electric potential values
- Ion density map
  - number of ions vs resolution
- Ion mean free path
  - $\bar{\lambda} = \frac{kT}{P\pi\sigma\sqrt{2}}$ where T is ion temperature, P is pressure, and σ is effective collisional cross section
    - Gives very small value on order of 10^{-16}

Conclusion

- Increased number of ions needed
  - Piel uses 2^{16} ions
- Dust charging as future implementation
- Code can be translated to C++ and run on GPU

Acknowledgements

- CASPER
- Baylor University Department of Physics
- NSF Grant No. 1414523
- B-TRUE

Works Cited

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