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

Model

- 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/m³**
Forces

◦ Ion/Ion Interactions
  • Ions treated as Yukawa Particles (shielded by thermal electrons)

◦ Ion/Dust Interaction
  • Dust treated as point charge

◦ Ion/Electric Field
  • \( E(r) = \frac{en_i0\lambda_{De}}{\epsilon_0} \left( \frac{R}{\lambda_{De}} + 1 \right) \times \exp(-R/\lambda_{De}) \times \frac{\lambda_{De}}{r} \left[ \sinh \frac{r}{\lambda_{De}} - \frac{\lambda_{De}}{r} \cosh \frac{r}{\lambda_{De}} \right] \)
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
    - \( \Phi(\vec{r}) = \frac{1}{4\pi\epsilon_0} \sum_{i=1}^{N} \exp\left(-\frac{|\vec{r}-\vec{r}_i|}{\lambda_{De}}\right) \)
    - 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 $0.75\lambda_{De}$
- Ions velocity is randomized at end of path to simulate collision
Results

Electric Potential in Simulation Sphere

Position of 100 ions at time: $t = 2.75 \times 10^{-5}$ seconds
Results (cont.)

Number Density of 1000 Ions in Simulation Sphere

Z Position (m)

Y Position (m)

10^{-3}

1

0.8

0.6

0.4

0.2

0

0.2

0.4

0.6

0.8

1

10^{-3}

0

0.5

1

1.5

2

2.5

3
Results (cont.)
Results (cont.)

![Graph of Single Ion Distance from Dust Particle](image)

![Graph of Single Ion Velocity Relative to Dust Particle](image)
Discussion

- Electric potential values

- Ion density map
  - number of ions vs resolution

- Ion mean free path
  - $\tilde{\lambda} = \frac{kT}{P \pi \sigma \sqrt{2}}$ where $T$ is ion temperature, $P$ is pressure, and $\sigma$ 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
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Works Cited

