



Chen Cui Research

- Development of Vlasolver
- Modeling of Electrospray Thruster
- Spacecraft/Asteroid Plasma Interaction

Chen Cui

Development of Vlasolver, a Grid-based Kinetic Code



$$\frac{\partial f_{\alpha}}{\partial t} + \mathbf{v} \cdot \nabla_{\mathbf{x}} f_{\alpha} + \mathbf{a} \cdot \nabla_{\mathbf{v}} f_{\alpha} = 0$$

$$\nabla \cdot (\epsilon_0 \nabla \Phi) = -e(Z_i n_i - n_e)$$

$$\mathbf{a} = \frac{F_{\alpha}}{m_{\alpha}} = \frac{q_{\alpha} \cdot \mathbf{E}}{m_{\alpha}} = \frac{-q_{\alpha} \nabla \Phi}{m_{\alpha}}$$

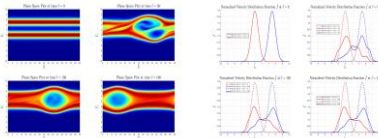
$$\langle M_n \rangle = \int_{-\infty}^{\infty} M_n \hat{f} dv$$

Vlasov-Poisson system -> control equations of electrostatic plasma system

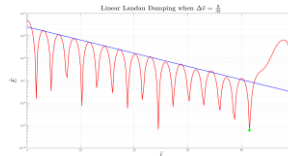
Particle Method: PIC, traditional and mature, however with inherent noise.

Grid-based Method: Vlasov, w/o noise, can be applied to higher order moments of Vlasov equations such like temperature and heat flux.

Validation of Vlasolver



Two-stream Instability



Landau Damping

Application: Searching for a New Electron Model for EP Plume Simulation

$$n_e = n_{b0} \exp\left(\frac{\Phi - \Phi_{p0}}{T_e}\right)$$

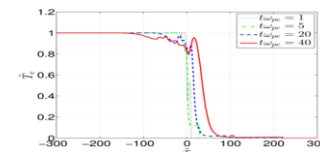
Electron assumed to be isothermal fluid.
VALID OR NOT?

Previous Study: 1. Anisotropic and non-isothermal, 2. Plume can be treated as semi-infinite expansion on axial direction.

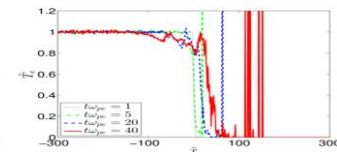
Semi-Infinite Expansion with ambient plasma load: theoretical work before, good validation of assumption.

Semi-Infinite Expansion vaccum inject: **NO** theoretical work before, more general model for this problem.

Comparison of Vlasov and PIC

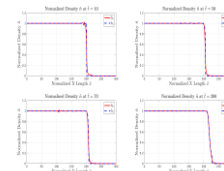


Temperature: Vlasov simulation

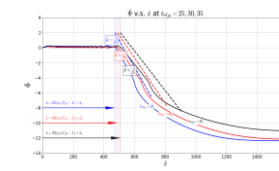


Temperature: PIC simulation

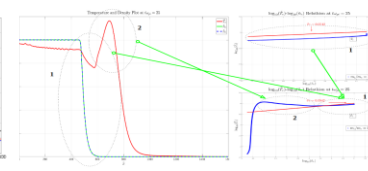
Semi-infinite expansion with ambient plasma load



Density Evolution

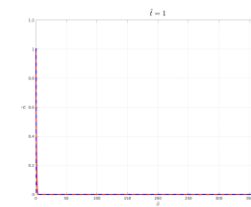


Potential Analysis

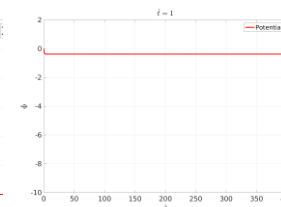


Temperature Analysis

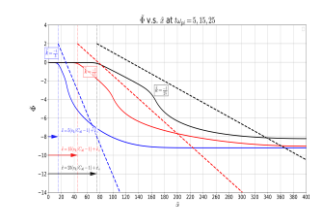
Semi-infinite expansion Vaccum Injection



Density Evolution



Potential Evolution



Potential Analysis

Modeling of Electrospray Thruster

Objective of this research:

- Develop a new simulation model which self-consistently simulates electrospray thruster plume (Taylor Cone -> Jet Breakup -> Plume) and provides accurate predictions for thruster design/fabrication

$$\rho \left(\frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u} \right) = -\nabla P + \mu \nabla^2 \vec{u} + \rho \vec{g} + \vec{F}_e$$

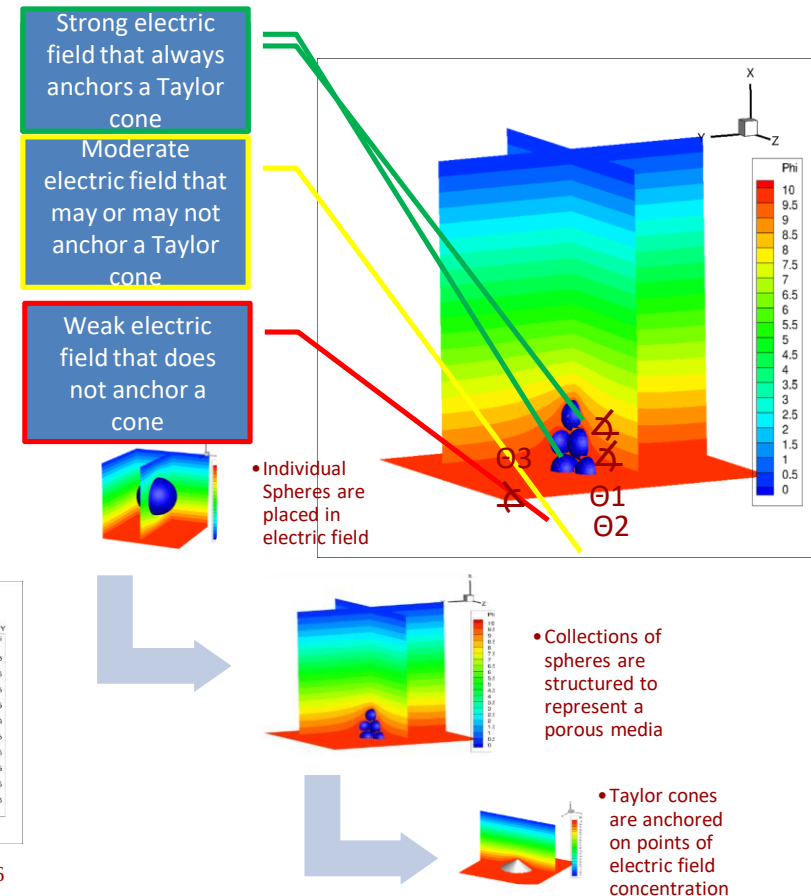
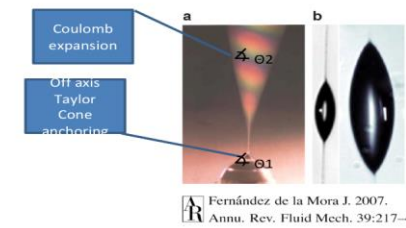
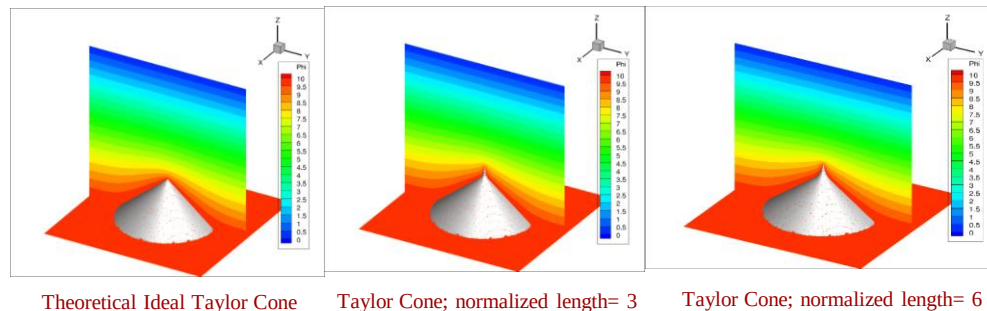
$$-\nabla \cdot \epsilon \nabla \Phi = \rho_e - (\epsilon_2 \vec{E}_2 - \epsilon_1 \vec{E}_1) \cdot \vec{n} = -\sigma_s$$

$$\vec{E}_{pp}^{(i)} = \frac{1}{4\pi\epsilon_0} \sum_{j=1, j \neq i}^N \frac{q_j}{|\vec{r}_{ij}|^3} \vec{r}_{ij}, \quad r_{ij} \geq 2R \quad m \frac{d^2 \vec{r}}{dt^2} = m \frac{d\vec{v}}{dt} = \vec{F} = \vec{F}_{pp} + \vec{F}_{acc} = q(\vec{E}_{pp} + \vec{E}_{acc}),$$

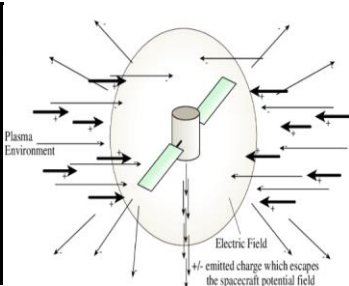
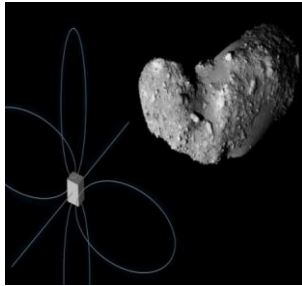
Modeling Approach:

- IFE-CFD (Immersed Finite Element – Computational Fluid Dynamics) simulation of Taylor Cone and dynamic jet breakup
- PP (Particle-Particle) and/or IFE-PIC simulation of downstream plume

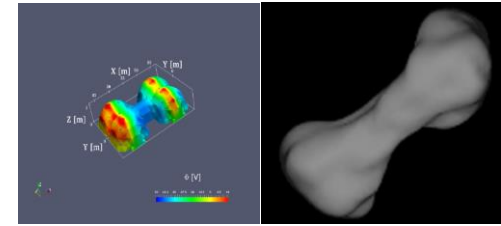
Taylor Cone-Jet Simulation



Spacecraft/Asteroid Plasma Interaction

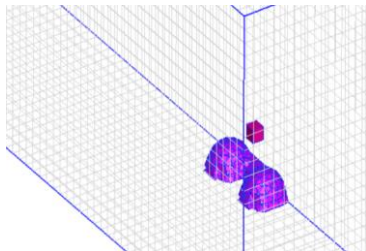


How is the spacecraft charged around the asteroids?
Irregular shape asteroid:
complex boundary condition

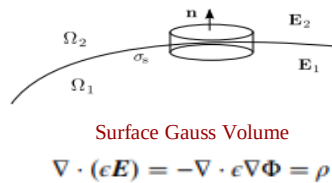


Asteroid Model

USC-IFE-PIC: Developed to deal with complex boundary



Mesh

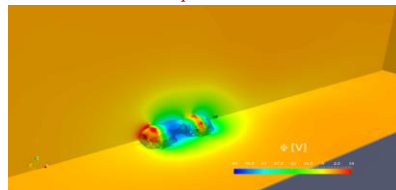


Surface Gauss Volume

$$\nabla \cdot (\epsilon E) = -\nabla \cdot \epsilon \nabla \Phi = \rho$$

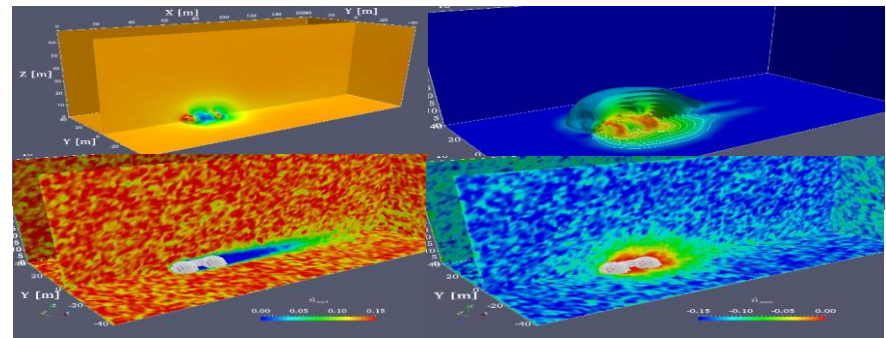
$$\rho(X) = \begin{cases} \rho_i - \rho_e - \rho_{pbe}, & X \in \Omega_2, \\ 0, & X \in \Omega_1, \\ 0, & X \in \Omega_0 \end{cases}$$

Control Equations



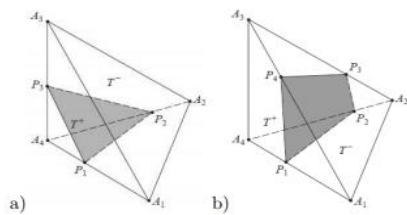
Potential when S/C in the wake

Plasma Environment around Irregular size Asteroid

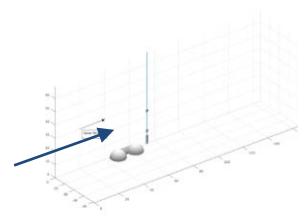


Plasma Environments

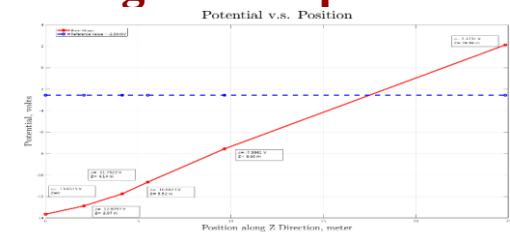
S/C Charging around Irregular Shaped Asteroids



Tetrahedral elements with object through



Trajectory



Potential v.s. Position