Development of a high resolution code for Hall effect thrusters

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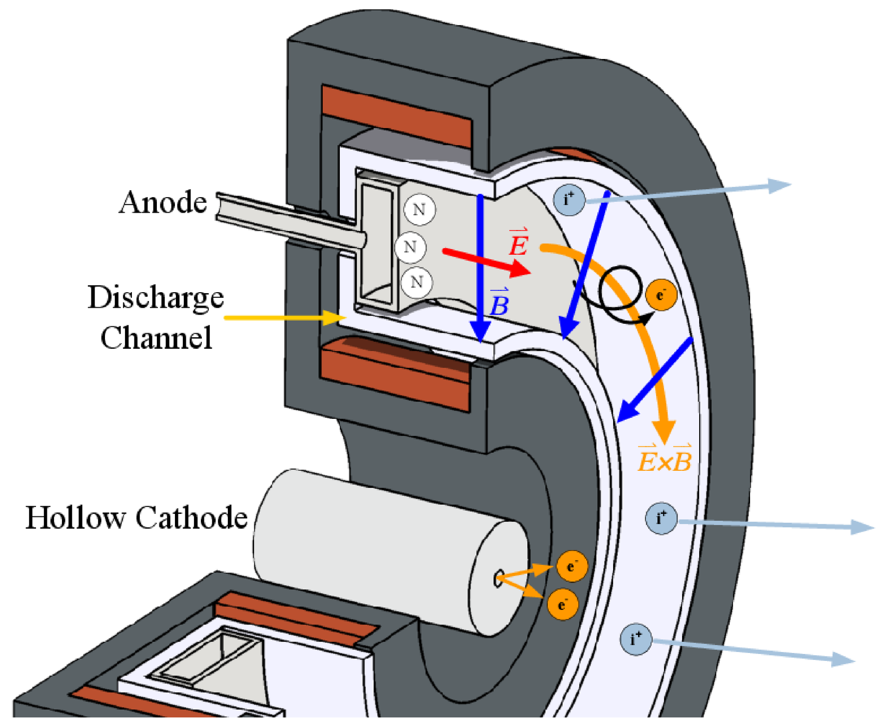
Electric Propulsion

Very high specific impulse
Flexible charge density

- **Applications:** Satellite positioning & long duration missions
- **Belgian industry:** power units Thales Alenia Space

Hall Effect Thrusters

Electron trapping and high speed $\sim$ $\mathbf{E}\times\mathbf{B}$ drift
$\rightarrow$ Electric potential
$\rightarrow$ In situ ionization



State of the Art

Simulation usually in 0d, 1D or 2D
Particle in Cell (PIC) is the most popular Model (high cost)

Model	Name	Collisions	Heat Tr.	Neutrals	Ionization
2D PIC	Villafana	×	N/A	×	×
	Lafleur	✓	N/A	×	✓
2D Hybrid	Dominguez	✓	✓	✓	✓
2D Fluid	Joncquieres	✓	×	×	✓
3D PIC	Villafana	×	N/A	×	×

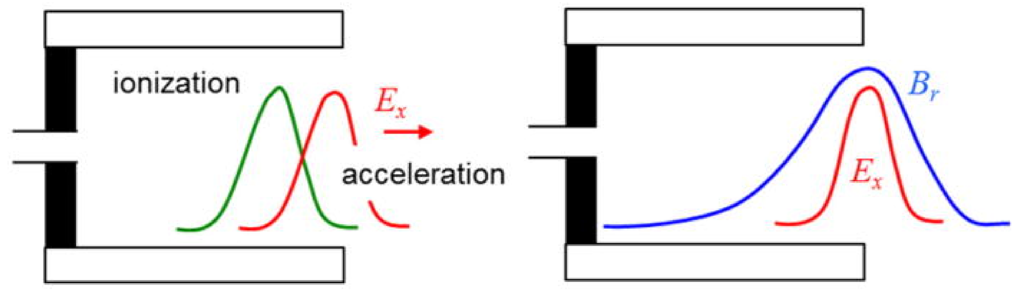
Towards: first principle simulation

1. Study flow field and estimate performance
2. Breathing Mode Instability
3. Electron Cyclotron Drift Instability (ECDI)
4. Wall and Particle Collisions
5. Anomalous Axial Drift

Breathing Mode

Oscillation in axial direction
Period of neutral depletion
Period of neutral replenishment
=> Variation of discharge current

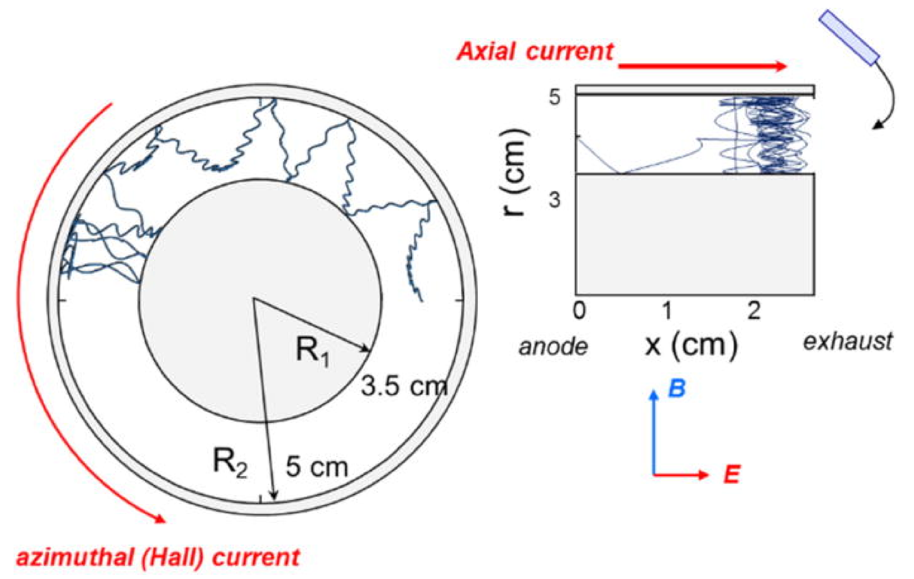
Requires chemical model



ECDI and MTSI

Density wave in azimuthal direction
Density wave in radial direction

Requires 3D domain



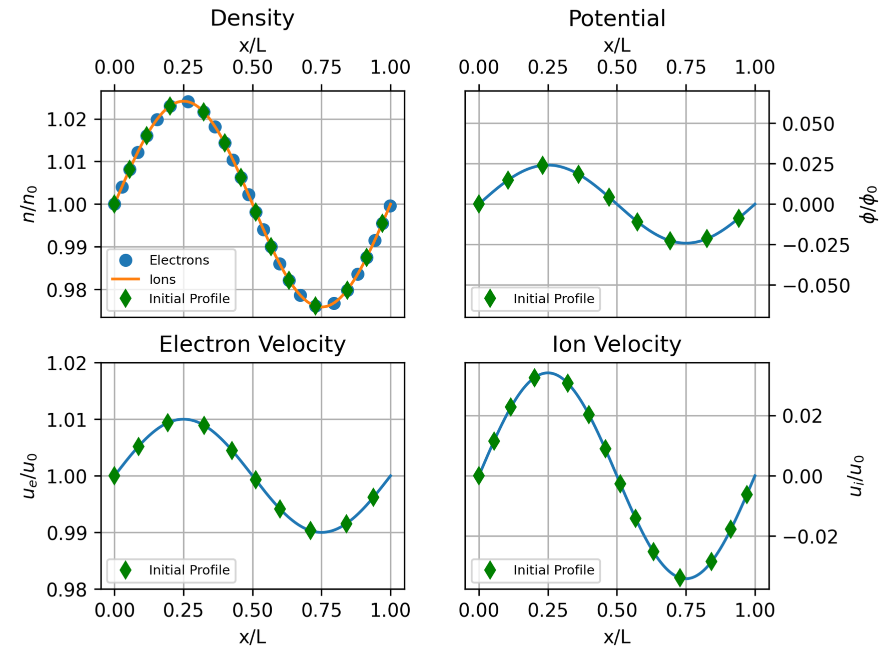
Requirements

- Collision modeling and constitutive law
- High precision numerics
- Lorentz Forces
- Heat Transfer
- Variable Time Scaling

Current State of the Model

Features that have already been added

- Riemann problem for 3 very different species
- Variable Time Scaling
- Electric potential computation



Future Developments

Features

- SOA models in 3D
- Magnetic Forces
- Thermal Diffusion
- Elastic Collisions
- Inelastic Collisions

Cases

- 2D Steady
- 2D Breathing Mode
- 3D Steady
- 3D Breathing Mode
- 3D ECDI & MTSI

Multi-Fluid Model

Boltzmann Equation

$$\partial_t f_\alpha + v\,\partial_x(f_\alpha) + \partial_v\left(\frac{F_\alpha}{m_\alpha} f_\alpha\right) = S_\alpha^{coll}$$

First 3 moments divided by particle mass

$$\partial_t n_\alpha + \partial_x(n_\alpha v_\alpha) = S_\alpha^{(n)}$$

$$\partial_t(n_\alpha v_\alpha) + \partial_x(n_\alpha v_\alpha^2 + \frac{p_\alpha}{m_\alpha}) = S_\alpha^{(m)}$$

$$\partial_t(n_\alpha e_\alpha) + \partial_x(n_\alpha v_\alpha h_\alpha) = -\frac{1}{m_\alpha}\partial_x q_\alpha + S_\alpha^{(e)}$$

Choice

- Neutral, ion & electron frame
- Moments
- Particle and wall collisions

ForDGe Software

High order Discontinuous Galerkin method

- stable for generic convection-diffusion-reaction
- low dispersion/dissipation error on arbitrary meshes
- hp-adaptation