Development of a high resolution code for Hall effect thrusters

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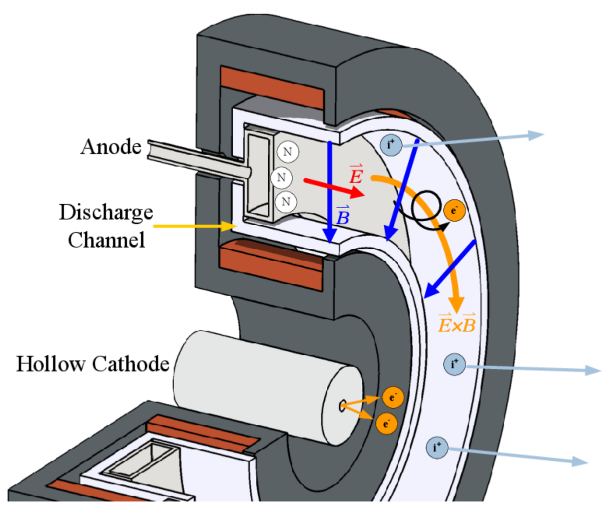
Hall effect thrusters

Very high specific impulse
Flexible charge density

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

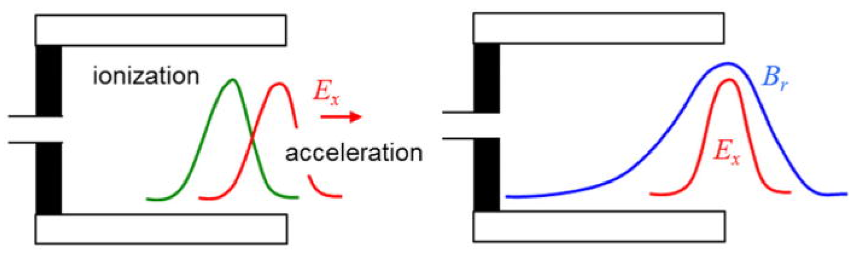
Operating principle

Electron trapping and high speed $\sim$ $\mathbf{E} \times \mathbf{B}$ drift
→ high electric potential
→ no charge density limitation
→ en situ ionization



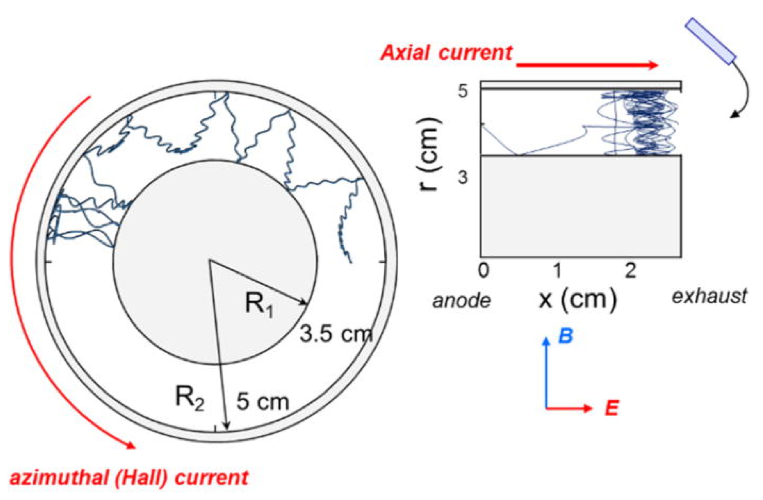
Instabilities

Breathing mode: Periodic axial oscillation of particle densities → operating limit, variation of discharge current



Requirement : acccurate collision model

ECDI and MTSI: Density waves in azimuthal and radial direction direction → operating limits, anomalous transport



Requirement: full 3D domain

Thesis Objectives

High Order Fluid Simulation of a HET

Lower computational cost than other methods
Enables the study of small scale phenomena

Towards: first principle simulation

Objectives: investigate

- flowfield and estimate performance
- flow non-uniformity and instabilitites
- anomalous transport of electrons

Numerical challenges

- allow variety of complex constitutive laws
- stiff problem to solve - conditioning
- large range of scales - high accuracy

In-house code: ForDGe

State of the Art

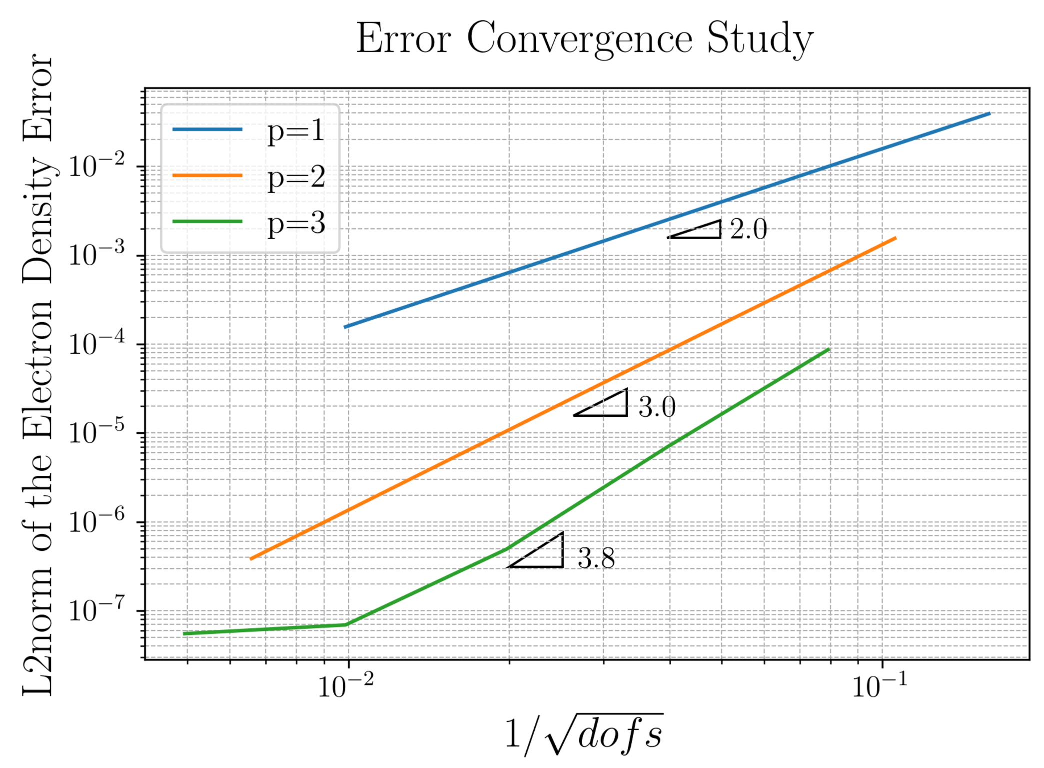
Simulation usaully in 0d, 1D or 2D
Particle in Cell (PIC) is the most popular Model (high cost)

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	×	×

Current State of ForDGe

High Order Accuracy

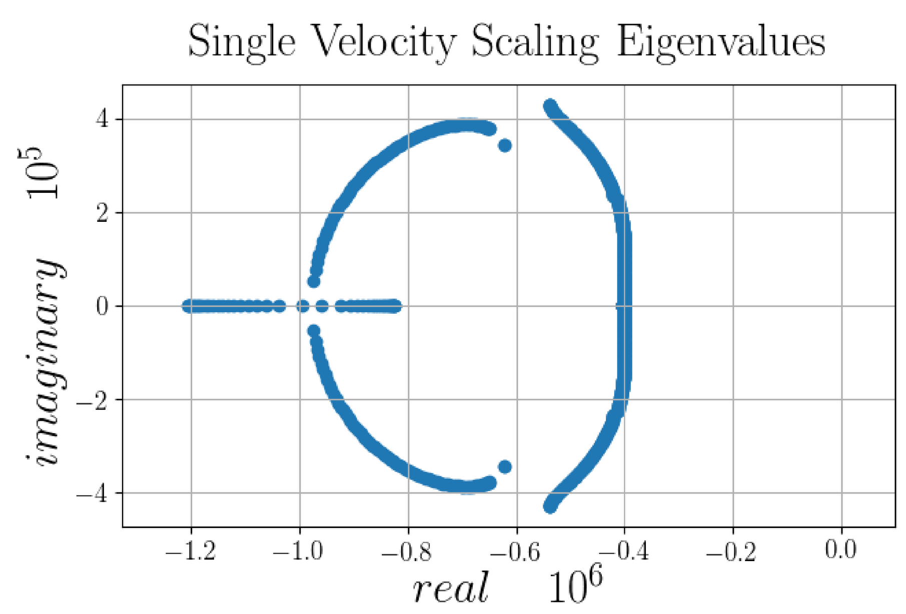
Required for small phenomena such as sheaths and instabilities

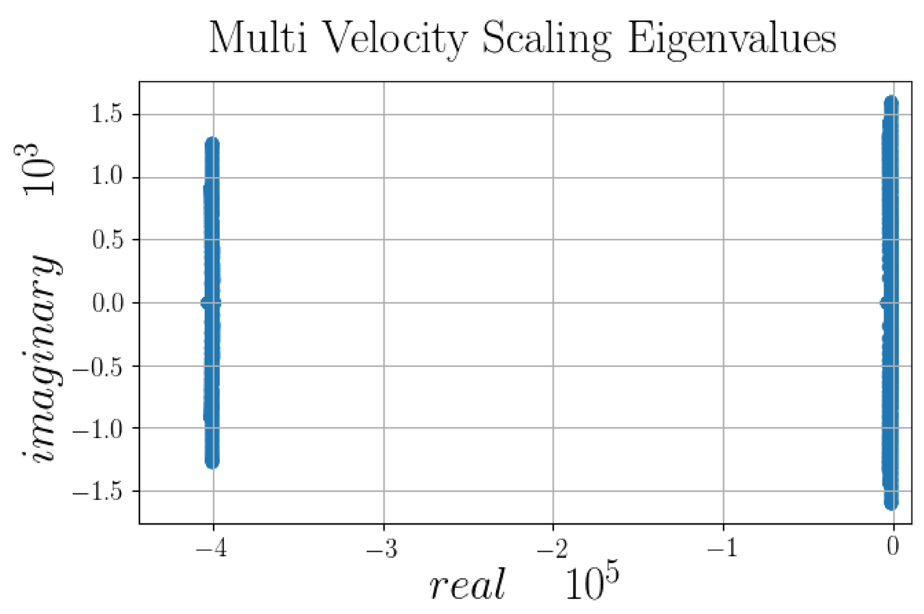


Variable Dependent Scaling

Better conditioning through variable dependent velocity scaling

Leads to variable dependent time scaling





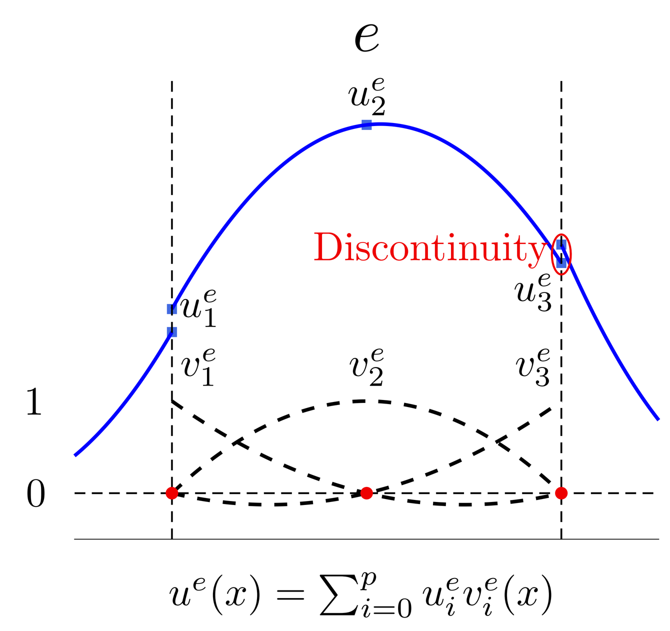
Future Developments

Polar Coord Formulation	→	Circular Channel
Added Dimension in Model	→	Axisymmetric Simulation
Collision Modeling	→	Ionization
Combined	→	High Resolution 3D Sim

ForDGe Software

High order Discontinuous Galerkin method

- Stable for generic convection-diffusion-reaction
- Low dispersion/dissipation error on arbitrary meshes
- HP-adaptation



Governing Equations

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

Electro-Magnetic Model

Electric Potential

$$\partial_x(\partial_x V) = -\frac{(n_+ - n_-)Q_0}{\epsilon}$$

Magnetic Field

Prescribed and not computed

Lorentz Forces

$$F = n_\alpha Q_0 \left(-\nabla V + v \times B\right)$$

First Year Objective

2.5D Axisymmetric Simulation of HET

Three species: e^-, Ar, Ar^+
Lorentz forces
Cylindrical coordinates