1D HYBRID-VLASOV SIMULATION FOR HALL THRUSTERS

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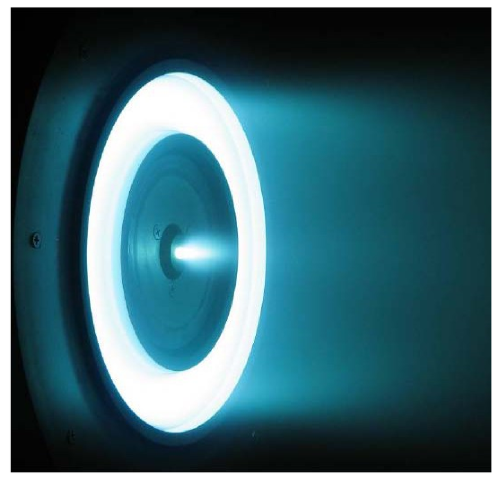
Hall Thrusters

A Hall thruster is an electric propulsion device that achieves high thrust efficiency, high specific impulse, and relatively long lifetime.

Due to the operation mechanism, the partially magnetized plasma in a Hall thruster is known to be in a non-equilibrium state. For example, wall reflections, ionization collisions, and cross-field transport are physical mechanisms that result in the velocity distribution function (VDF) of ions and electrons being neither isotropic nor Maxwellian.



6-kW Hall Thruster [1]

Hall thruster simulations have mainly used hydrodynamic and particle models. However, a fully-kinetic solver is needed to simulate the plasma with more physical accuracy and numerical efficiency.

1D1V Hybrid-Vlasov Simulation

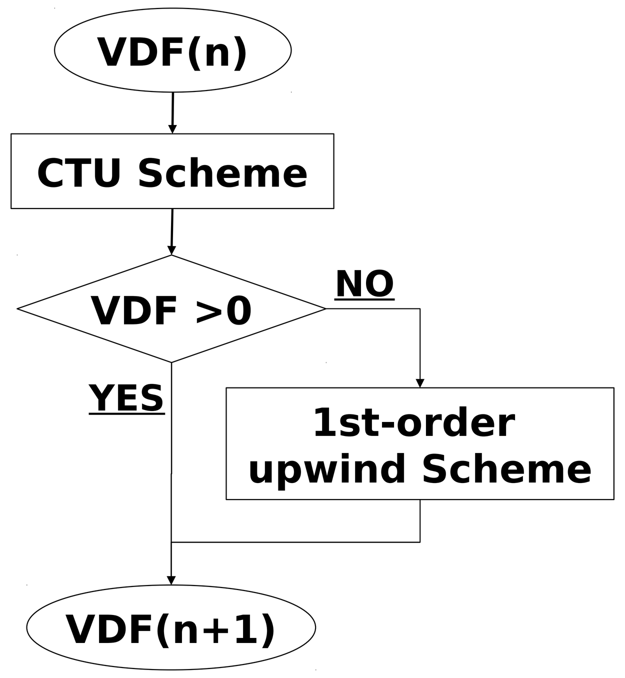
The plasma inside the channel of SPT-100 is investigated using a 1D1V Hybrid-Vlasov solver.

<u>Ions and Neutrals</u>

Solve the Vlasov equation for velocity distribution function (VDF) including ionization and charge exchange collisions: a Bounded Corner-Transport-Upwind (CTU) Scheme [2], which maintains the VDF to be non-negative, is developed.

<u>Electrons</u>

Use a hydrodynamic model. Calculate electrical field and electron temperature. [3]



Bounded-CTU Scheme

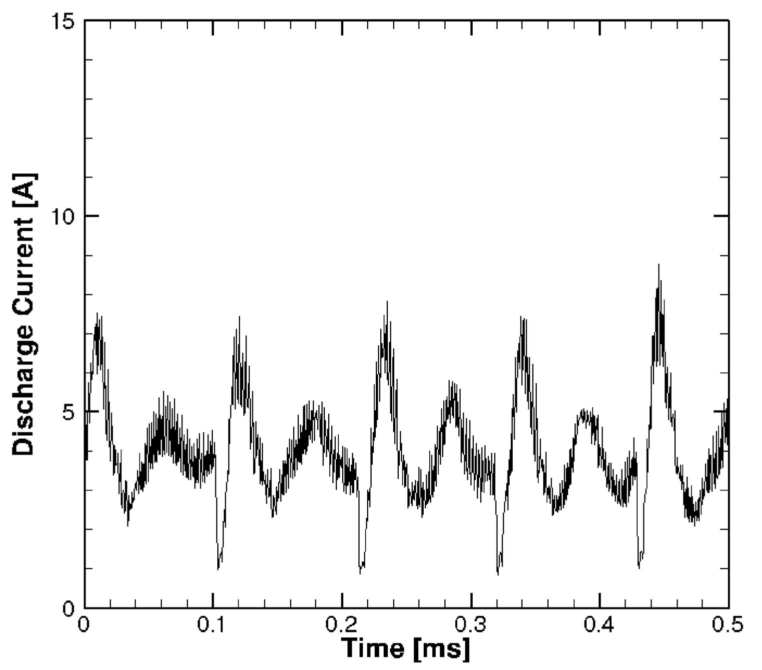
Numerical Setup

<u>**Calculation domain**</u>
- Axial Length: 4 cm (x= 0 cm: anode, x= 4 cm: channel exit)
- Velocity for ions and neutrals: from -10,000 m/s to 90,000 m/s
- Discretization: dx= 0.4 mm, dv= 300 m/s
- Time: T= 1ms, dt= 1 ns

<u>**Thruster operating conditions (SPT-100)**</u>
- Mass rate flow: 5.2 kg/s
- Inlet neutral velocity: 173 m/s [1]
- Discharge Voltage: 300 V
- Discharge current: 4.5 A
- Maximum magnetic field: 200 Gauss

Results

<u>**Thruster Performance**</u>

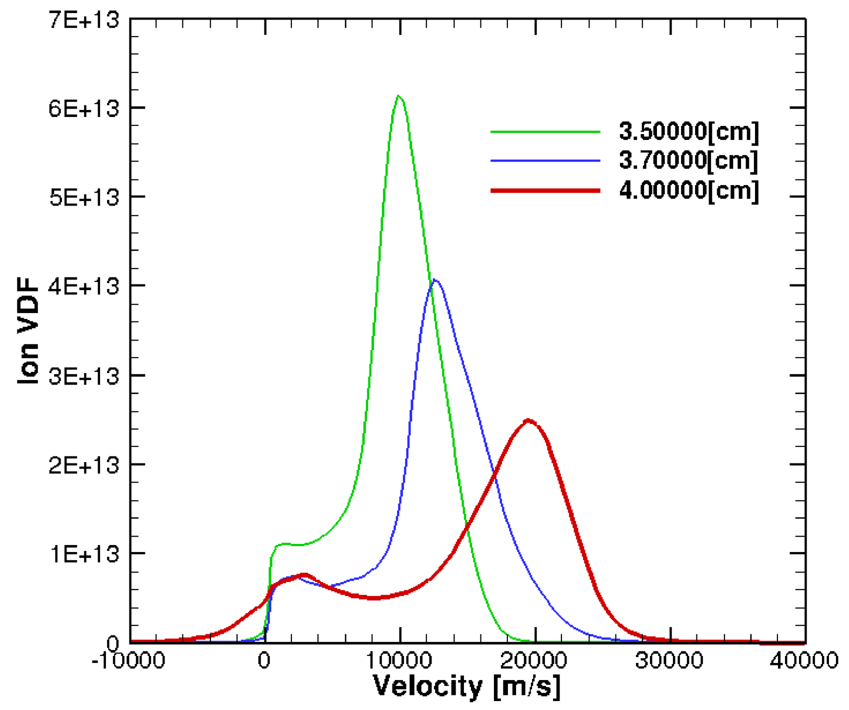


Evolution of the Discharge Current for SPT-100 calculated using the Hybrid-Vlasov simulation

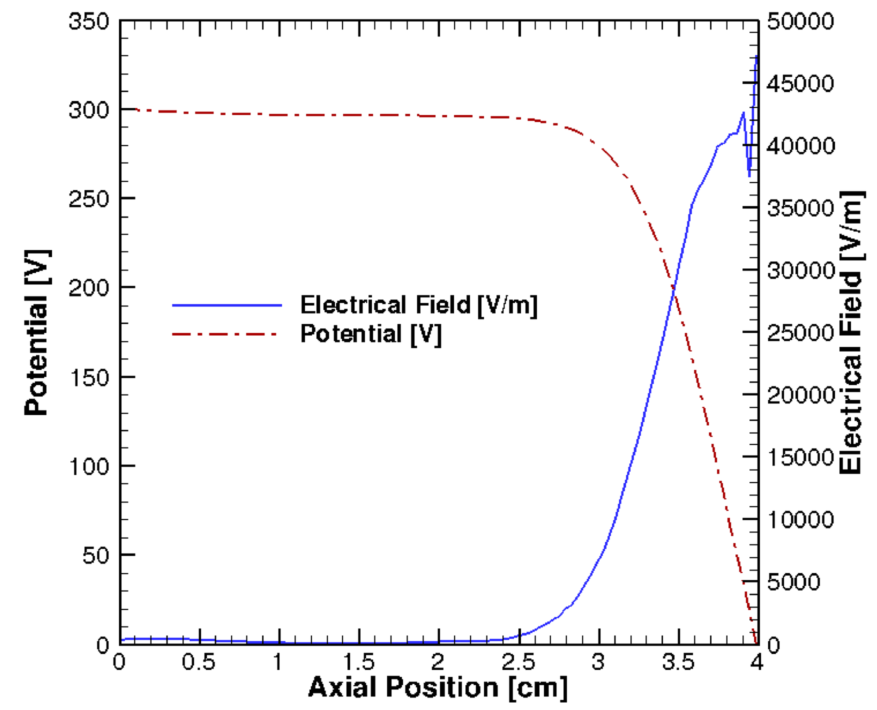
Variables	Hybrid-Vlasov	Hybrid-PIC[4]	Measured [5]
Id	3.94 A	3.76 A	4.5 A
Thrust eff.	0.55	0.53	0.5
Thrust	78.9 mN	79.0 mN	83 mN
Isp	1547 sec	1548 sec	1600 sec
Breathing mode freq.	18 kHz	20 kHz	17 kHz

Comparison of computed and measured performance for SPT-100

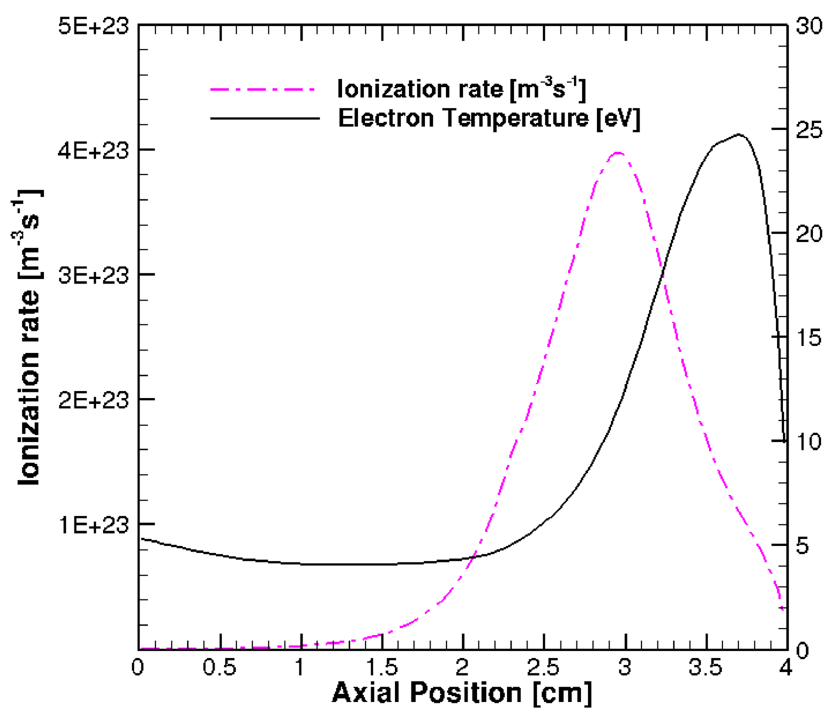
<u>**Plasma Properties**</u>



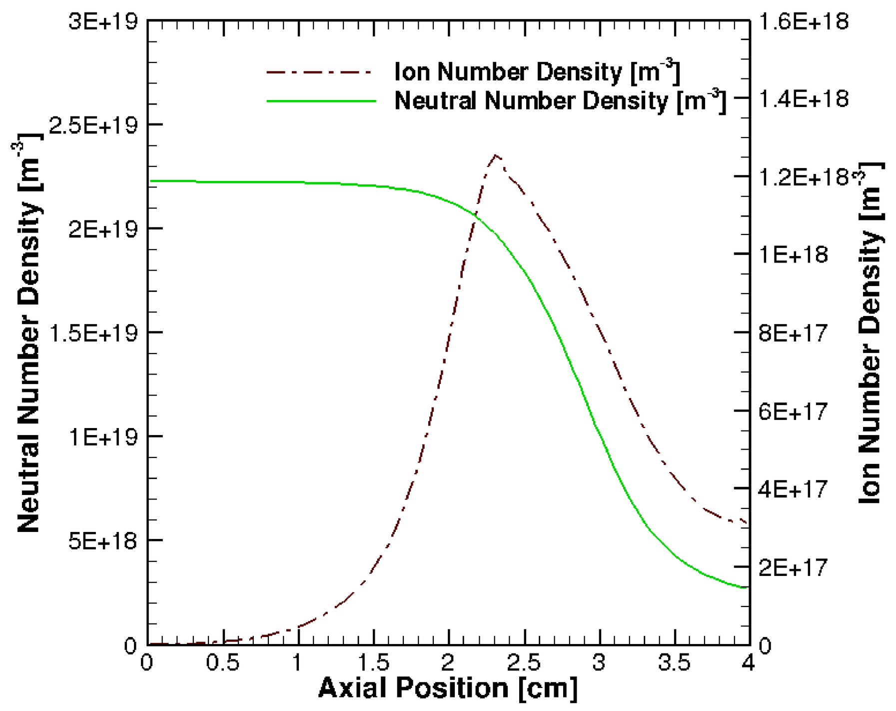
Time averaged Ion Velocity Distribution Function at x=3.5, 3.7 and 4cm (channel exit)



Time averaged solution of Potential and Electrical Field



Time averaged solution of Electron Temperature and Ionization Rate



Time averaged solution of Number Densities of Ions and Neutrals

Summary and Future work

This work represents a successful step towards a complete Vlasov simulation for Hall thrusters.

-Bounded Corner-Transport-Upwind Scheme is developed in order to maintain non-negativity of the VDF.

-The results including thruster performance and plasma properties show excellent agreement with the experimental data. Discharge oscillation (or "breathing mode") is also shown.

Future work involves

-implementation of double charged ions and other collision models,
-expansion to multi-dimensions (up to 3D3V),
-application of the Vlasov solver to plasma simulation in order to establish a theory of electron mobility.

References

[1] Reid, B. M., "The Influence of Neutral Flow Rate in the Operation of Hall Thrusters," Ph.D. Dissertation, Aerospace Engineering, University of Michigan, 2009.

[2] Herrmann, M, Blanquart, G. and Raman, V. "Flux Corrected Finite Volume Scheme for Preserving Scalar Boundedness in Reacting Large-Eddy Simulation," AIAA Journal, vol. 44, 2879-2886, 2006.

[3] Boeuf, J. P. and Garrigues, L., "Low frequency oscillations in a stationary plasma thruster", Journal of Applied Physics, vol. 84, 3541-3554, 1998.

[4] Garrigues, L., Boyd, I. D. and Boeuf, J. P., "Computation of Hall Thruster Performance," Journal of Propulsion and Power, vol. 17, 772-779, 2001.

[5] Mikellides, I.G., Katz, I. et. Al, "A 1-D Model of the Hall-Effect Thruster with an Exhaust Region," 37th AIAA Joint Propulsion Conference and Exhibit, July 8-11, 2001.

Acknowledgements

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