Hall effect thruster simulations through PIC and hybrid PIC/fluid codes

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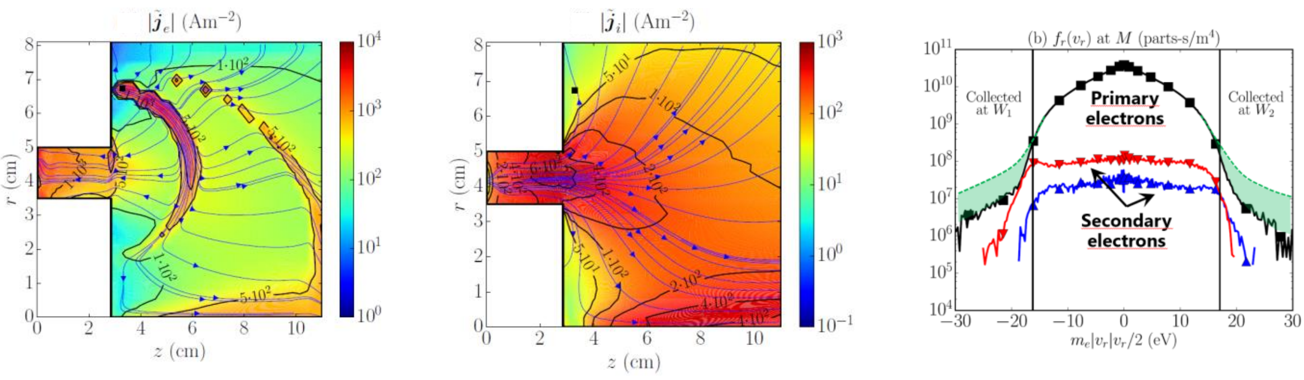
The development of reliable and versatile plasma discharges simulation codes is becoming of central importance, given the rapidly evolving electric propulsion landscape. These tools are essential for facilitating and complementing the design of new prototypes revealing optimization opportunities so as to improve the thruster performance and lifetime, and predicting the operational parameters at different regimes of interest.

This talk presents Hall effect thruster (HET) simulation results from two simulation codes developed by Dr. A. Domínguez-Vázquez during his PhD Thesis [1]. The first one, named HYPHEN, is a new two-dimensional axisymmetric hybrid, particle-in-cell (PIC)/fluid, OpenMP-parallelized multi-thruster simulation platform. The PIC module capabilities have been detailed and benchmarked in previous plasma plume expansion studies [2-4]. The main modeling novelties aim at both extending HYPHEN simulation capabilities and obtaining low-noise estimates of the heavy species macroscopic magnitudes at a limited computational cost and include: (i) dedicated computational lists for each ion and neutral species depending on its charge, mass or energy content; (ii) a new particle generation based population control that monitors the number of particles per cell of each species; and (iii) advanced volumetric and surface particle-mesh weighting algorithms operating in non-uniform, optimized structured meshes. Furthermore, an improved version of the HET electron-fluid module for the isotropic electron pressure case is presented. The major contributions are (i) the identification of the different electron anomalous transport contributions in the electron momentum, energy and heat flux equations; (ii) a preliminary treatment of the electron inertial effects through an electron drift velocity limiter; (iii) an improved treatment of the cathode source terms in the electron transport equations, which has permitted to simulate different cathode locations in the near plume region. Preliminary simulations of a SPT-100 HET have been carried out to demonstrate the code capabilities and reveal its limitations [5]. First, the well-known breathing mode oscillation in the range of 10-30 kHz characterizing the typical HET operation is identified and analyzed in a reference case. Second, the effects on the discharge of the cathode location in the near plume region are analyzed in order to assess the validity of the axisymmetric volumetric cathode model. Third, simulation results considering a unique electron turbulent parameter featuring different constant values and step-out profiles are presented.

The second code corresponds to a new version of the one-dimensional radial particle model of a HET discharge, originally developed by Dr. F. Taccogna. The major improvements are an ionization-controlled discharge algorithm, which enables sustaining a steady-state discharge, and an extended volumetric weighting algorithm which provides a more accurate macroscopic description of the low populated species, such as the wall-emitted secondary electrons. The radial dynamics of both the primary and secondary electron populations have been analyzed in detail, assessing the temperature anisotropy ratio of their velocity distribution functions and the asymmetries introduced by cylindrical geometry effects in the macroscopic laws of interest, thus aiming at a future improvement of the plasma-wall interaction module implemented in HYPHEN.



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