Sheath-Induced Instabilities in Magnetized Plasmas

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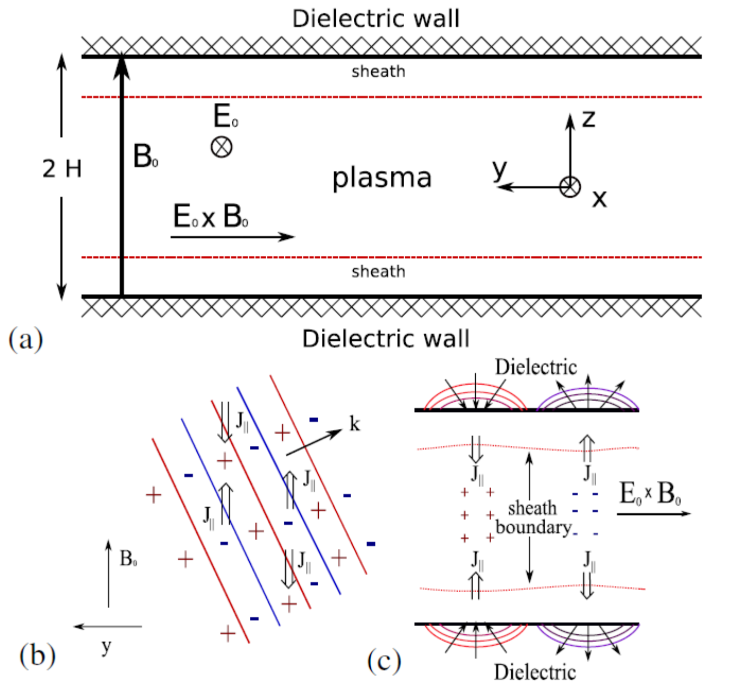


Fig. 1 – (a) Geometry of the plasma bounded by dielectric walls. (b) Perturbed parallel current in infinite plasma. The wave fronts are oblique with respect to the magnetic field. (c) Perturbed current in the bounded plasma. In (b) and (c) the instability is driven by the component of the perturbed parallel current that is directed into the regions of positive charge (shown with +), thus enhancing the initial perturbation.

Possible mechanisms of anomalous transport in Hall thrusters have been investigated by collaborators at the University of Saskatchewan (A. I. Smolyakov, W. Frias) and PPPL (I. D. Kaganovich, and Y. Raitses). The results of this investigation were recently published in Physical Review Letters in a paper titled "Sheath-Induced Instabilities in Plasmas with E×B Drift" [1]. Classical inter-particle collisions alone are too weak to explain experimentally observed electron currents across magnetic fields. A new instability was identified that may explain observations. It was shown that ion acoustic waves in plasmas of finite size with E×B electron drift become unstable due to the closure of plasma current at the chamber wall. (See Fig. 1.) Such unstable modes may enhance anomalous electron transport in plasma devices with E×B electron drift and unmagnetized ions. The instability is sensitive to the wall material. A high value of the dielectric permittivity of the wall material reduces the mode growth rate by an order of magnitude. This theoretical study may explain previous experimental findings that have shown that wall materials may strongly affect Hall thruster operation [2].

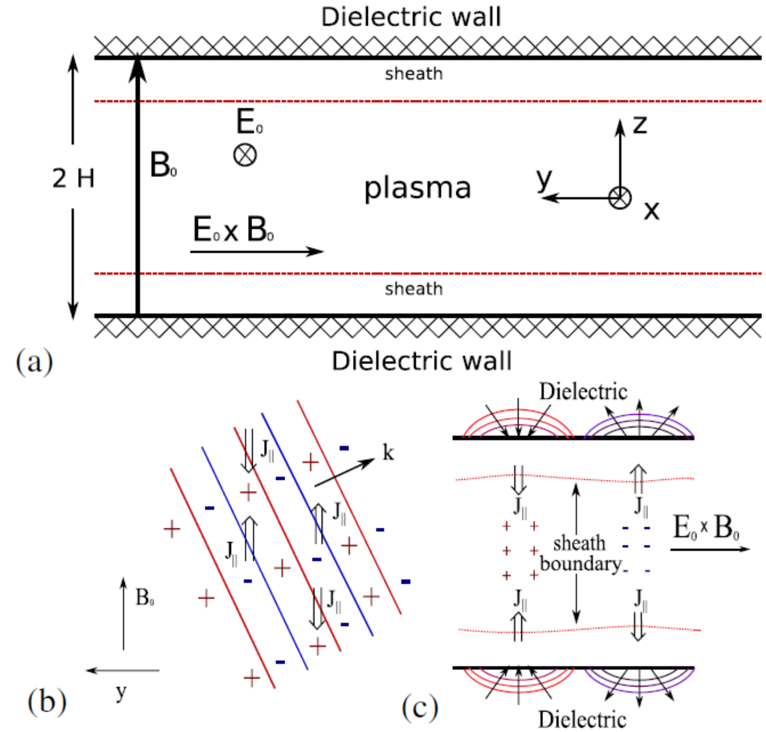
References

[1] A. I. Smolyakov, W. Frias, I. D. Kaganovich, and Y. Raitses, Phys. Rev. Lett. **111**, 115002 (2013). http://link.aps.org/doi/10.1103/PhysRevLett.111.115002

[2] Y. Raitses, I. D. Kaganovich, A. Khrabrov, D. Sydorenko, N. J. Fisch, and A. Smolyakov, IEEE Trans. Plasma Sci. **39**, 995 (2011).

SHEATH-INDUCED INSTABILITIES IN MAGNETIZED PLASMAS

- **A new instability was identified that may explain possible mechanisms of anomalous transport in magnetized plasmas.**
- **Ion acoustic waves in plasmas of finite size with E×B electron drift become unstable due to the closure of plasma current at the chamber wall.**
- **The instability is sensitive to the wall material: high values of the dielectric permittivity of the wall material reduces the mode growth rate by an order of magnitude.**
- **This theoretical study may explain experimental findings that wall material strongly affects Hall thruster operation.**



- **(a) Geometry of the plasma; (b) Perturbed parallel current in infinite plasma by an oblique wave with respect to the magnetic field; (c) Perturbed current in bounded plasma.**

PLSC_02_14 **HIGHLIGHT**

University of Saskatchewan

PPPL Princeton Plasma Physics Laboratory

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

PSC Department of Energy Plasma Science Center

DOE Plasma Science Center
Control of Plasma Kinetics

Kinetic Solvers with Adaptive Mesh in Phase Space: Application to Electron Kinetics in Capacitively Coupled Plasmas

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An Adaptive Mesh in Phase Space (AMPS) methodology has been recently developed to solve kinetic equations (Boltzmann, Vlasov, Fokker-Planck) for rarefied gas dynamics, radiation transport, and charged particle kinetics in plasmas [1]. Here, we illustrate the benefits of AMPS for studies of electron kinetics in capaciltively coupled plasma.

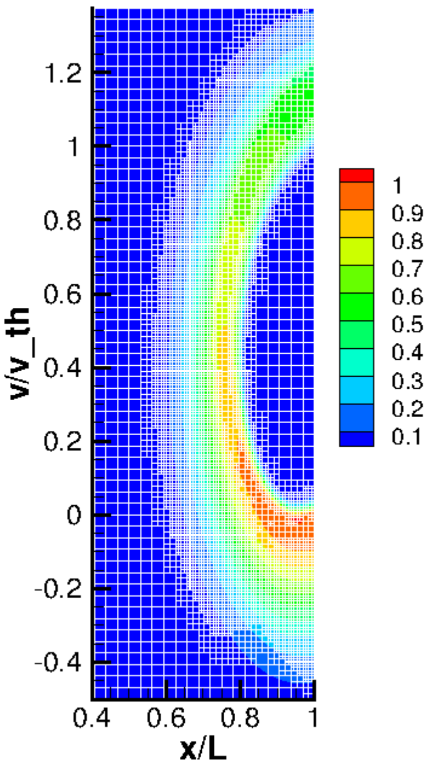


Fig. 1 - Adapted mesh and EDF contours (color) in a collisionless RF sheath.

The results of a numerical solution to the Vlasov equation for electrons in a collisionless RF sheath are shown in Fig. 1. At the sheath-plasma edge, at x/L=1, the Electron Distribution Function (EDF) is half-Maxwellian (at v<0) with a thermal velocity v_{th}. We use a prescribed distribution of the electric field:

$$E(x,t) = \frac{2U_0}{L^2}\left(x - s(t)\right),$$

where $s(t)$ is the sheath boundary position, and U_0 is the maximum value of the potential drop in the sheath ($U_0 >> mv_{th}^2/(2e)$). Electron dynamics are determined by the ratio of driving frequency, ω, and the characteristic frequency $\omega_0 = v_{th}/L$.

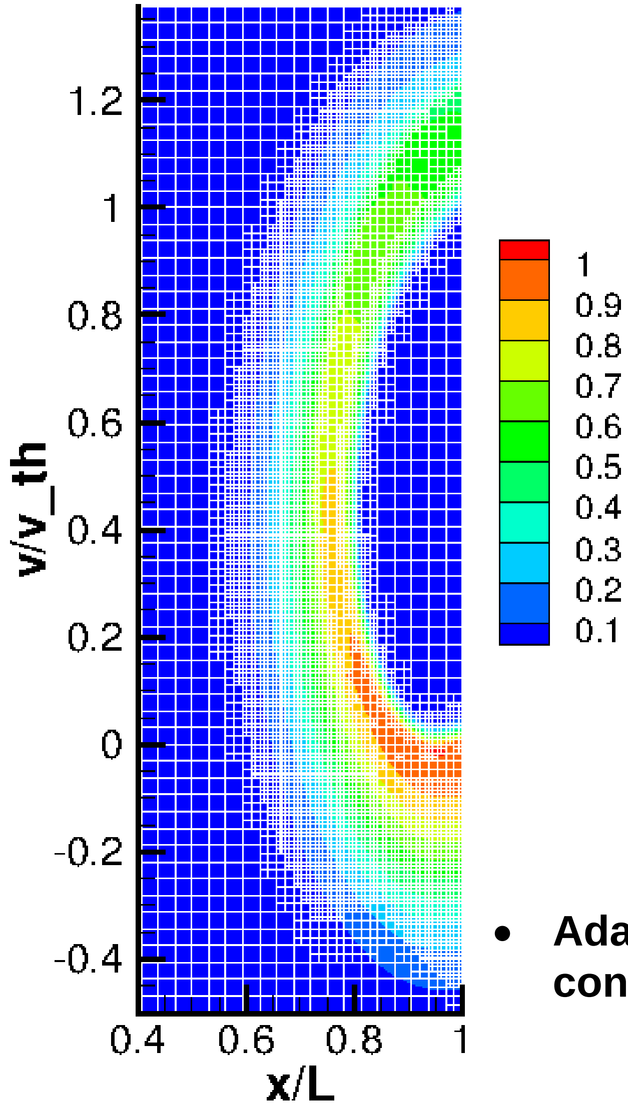
The AMPS method for the case of $\omega/\omega_0 = 0.1$ is illustrated in Fig. 1. Under these conditions, an electron "wave riding" effect is observed, when at some moments during the RF period electrons gain considerable energy after being repelled from the sheath. The mesh refinement/coarsening criteria for simulations, shown in Fig. 1, are based of gradients of the EDF in physical and velocity spaces. Using AMPS allows high-resolution of the EDF dynamics with minimum number of computational cells.

In future work, we plan on studying the effects of collisions (elastic and charge-exchange) and ionization processes on the electron and ion kinetics in RF sheaths under different regimes [2]. Kinetic solvers are being coupled to Poisson solvers for self-consistent simulations of the electric field.

References

[1] R.R. Arslanbekov, V.I. Kolobov, and A.A. Frolova, Phys. Rev. E **88**, 063301 (2013)
[2] V. I. Kolobov, Phys. Plasmas **20**, 101610 (2013).

KINETIC SOLVERS WITH ADAPTIVE MESH IN PHASE SPACE: APPLICATION TO ELECTRON KINETICS IN CCPs



- **An Adaptive Mesh in Phase Space (AMPS) methodology has been developed to solve kinetic equations [Phys. Rev. E 88, 063301 (2013)].**
- **We have illustrated the benefits of AMPS for studies of electron kinetics in a collisionless sheath for capaciltively coupled plasma.**
- **Using AMPS allows high-resolution of the EED dynamics with a mininum number of computational cells.**
- **In future work, we will study the effects of elastic and charge-exchange collisions, as well as ionization processes on electron and ion kinetics in RF sheaths under different regimes.**

- **Adapted computational mesh and instantaneous EDF contours (color) in a collisionless RF sheath**

PLSC_0214 ***HIGHLIGHT***

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