cnrs GDR Groupement de recherche
EMILI Étude des milieux ionisés
Plasmas froids créés par décharge et laser

Plasmas magnétisés

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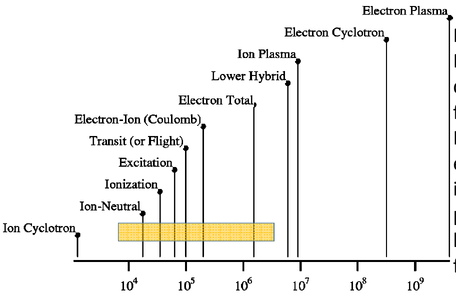
Instabilities in partially-magnetized ExB plasmas

Introduction

Plasma waves ranging from the **kHz-frequency** to the **MHz-frequency** range have been observed across a very wide range of low temperature plasmas when **electrons are strongly magnetized** (large Hall parameter) and adopt a closed-drift configuration under the influence of the applied magnetic field.



Frequency ranges in an ExB low pressure discharge, adapted from Ref. 1. Instabilities observed extend from ionization-scale phenomena to lower-hybrid frequency scales

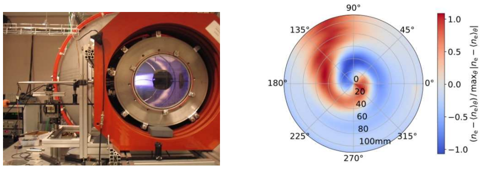
Destabilizing mechanisms

The difference in mobility between electrons and ions together with the action of the restoring force leads to a destabilization of the plasma. A large zoology of waves may develop because of **density, temperature, magnetic field, potential gradients, particle inertia**, etc. (generally a combination of the latter).

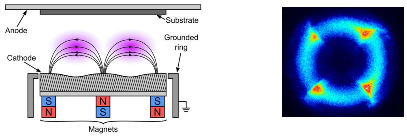
This is currently an active research topic, where the goal is to understand the plasma dynamics leading to the structuring at large and small scales observed in the nonlinear saturated regimes of many discharges.

Examples of device types and kHz-scale phenomena

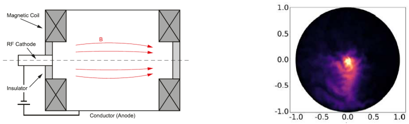
Several devices feature kHz-frequency rotating ionization instabilities broadly referred to as **spokes**:



(left): Mistral linear machine, Marseille (PIIM) (right): Observation of kHz counterclockwise rotating spoke (m = 1) mode in an Ar plasma [2]

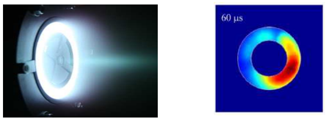


(left): planar magnetron crossed field configuration [3]
(right): fast camera imaging of rotating spoke formation in the planar magnetron [4]

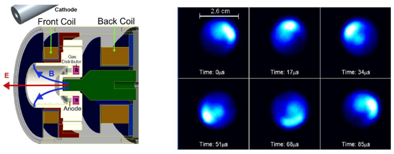


(left): cross-field configuration of a Penning discharge
(right): numerical simulation of rotating spoke formation in the Penning discharge [5]

(left): conventional Hall plasma thruster firing
(right): fast camera imaging of spoke formation in a Hall thruster [6]

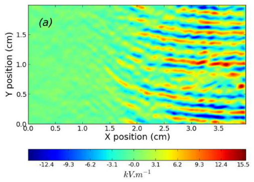


(left): cylindrical Hall plasma thruster architecture
(right): fast camera imaging of spoke formation in a cylindrical Hall thruster [7]

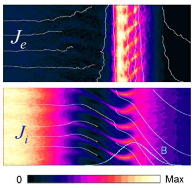


Evidence of MHz-scale instabilities

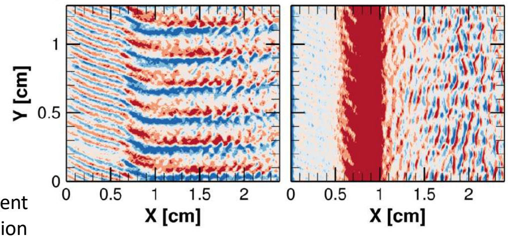
Camera imaging has been a key tool for the identification and study of kHz-scale rotating instabilities. Short scale (millimetric), MHz-frequency instabilities have been identified in simulations and in laser scattering and probe experiments.



electron cyclotron drift instability (ECDI) field development at the exit plane of a Hall thruster [8]



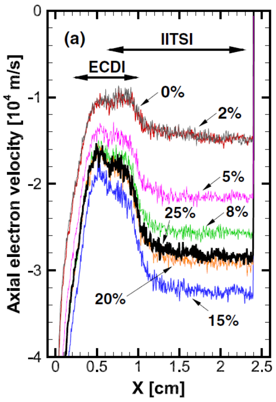
Drift waves generated by drawing a current across a magnetic filter in a closed-drift ion source in a 2D PIC-MCC calculation [9]



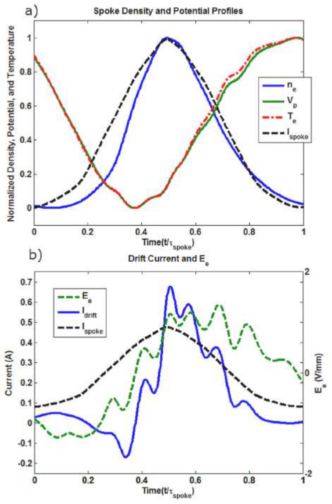
Coexistence of two small-scale modes in an ExB discharge configuration (2D simulation of a Hall thruster): MHz-frequency ECDI along y (azimuthal direction) and MHz-frequency ion-ion two stream instability (IITSI) along x (electric field direction) [10]

Importance of plasma instabilities in the ExB configuration

The presence of a range of instabilities in these magnetized discharges has important implications. They have been implicated in diverse features, including anomalous transport and ion trapping and heating.

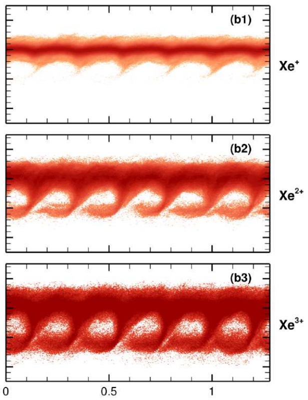


2D PIC simulation: Increased electron transport in the presence of both ECDI and IITSI. Transport is enhanced in the presence of multiply-charged ion species (% = fraction of doubly-charged ions in a Hall thruster) [10]



increased electron current observed in presence of spokes in Hall thrusters [7]

2D simulations: evidence of of trapping of ion species in the presence of instabilities, from examination of instantaneous ion velocity distribution function [11]



Open questions

Several questions surround instabilities in the ExB configuration and deserve further dedicated study. These include:

- The nature of transitions from linear to saturated regimes: what mechanisms are involved?
- What is the nature of coupling and potential energy transfer between instabilities at different length scales?
- What different mechanisms contribute to the formation of large-scale structuring in various plasmas?
- Existing codes are limited to 1D or 2D: what new insights can be gained from emerging 3D codes?

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