Seminar

Institute for Plasma Research

Title: Experimental Investigation of Nonlinear Interactions among Low-Frequency Instabilities in a Linear Magnetized Plasma

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Date: 24th March 2026 (Tuesday)

Time: 03:30 PM

Venue: Seminar Hall, IPR

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(Conference ID: 5992138016; Password: 232142)

Abstract

In many laboratory and space plasmas, several gradient-driven instabilities can coexist simultaneously. Among the most important are drift waves (DW) driven by density gradients, Rayleigh–Taylor (RT) modes driven by effective gravitational forces, and Kelvin–Helmholtz (KH) instability driven by velocity shear. While the linear characteristics of these individual instabilities are well established, experimental studies of their nonlinear interaction and energy exchange remain limited. Such interactions can lead to the generation of secondary instabilities, development of turbulence and enhanced cross-field transport in magnetized plasmas.

This work presents an experimental investigation of nonlinear coupling among low-frequency ($\omega < \omega_{ci}$) instabilities in a cylindrical linear magnetized plasma. Experiments are conducted on the Inverse Mirror Plasma Experimental Device (IMPED), which produces steady-state argon plasma using a hot-cathode discharge source under an externally applied axial magnetic field. To enable systematic exploration of instability parameter space, an integrated experimental framework was developed combining supervisory control, automated probe positioning, and structured data acquisition. Automated data management and parallelized analysis routines were implemented to efficiently process the large volumes of multi-channel data generated during the measurements.

Equilibrium plasma profiles were modified by varying the magnetic field ratio between the main chamber and the source chamber, as well as the neutral pressure. These parameters alter the density gradient and the radial electric field, which govern $E\times B$ flow and velocity shear in the plasma. Spatially resolved fluctuation measurements were analyzed using spectral techniques. As the equilibrium gradients were varied, distinct regimes dominated by DW, RT, KH instabilities were identified. When the spatial locations of these modes overlapped, strong nonlinear interactions emerged. The analysis revealed phase-coupled frequency triplets satisfying three-wave resonance conditions, while nonlinear energy transfer analysis quantified the direction of spectral energy exchange among the interacting modes.

The results demonstrate that the radial localization and relative strength of multiple instability drives can be systematically controlled in a linear magnetized plasma. The controlled coexistence of these drives leads to mutual competition among instability modes, resulting in nonlinear three-wave coupling and cross-spectral energy transfer. These findings provide new insight into the nonlinear dynamics of multi-mode interactions in magnetized plasmas.