Seminar

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Institute for Plasma Research

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Title: Fluid Simulation Framework for Debris-Induced Plasma Waves

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Date: 15th July, 2025 (Tuesday)

Time: 3:30 PM

Venue: Seminar Hall, IPR

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Abstract

The charged space debris, ranging from micrometres to millimetres, typically with supersonic speed in plasma, excites precursor solitons, which serve as promising tools to tackle the problem of space debris [1]. These nonlinear excitations have been predicted in numerical simulations [2] and observed in many laboratory dusty plasma experiments [3]. This presentation outlines a omprehensive fluid simulation framework developed to investigate the solitary structures induced by space debris, particularly focusing on pinned and precursor solitons. Both weakly and fully nonlinear regimes are explored using analytical and numerical techniques. The weakly nonlinear analysis employs reductive perturbation methods [4,5] to derive evolution equations such as the forced Korteweg-de Vries (fKdV) [1,4] in 1D and forced Kadomtsev-Petviashvili (fKP) [6] equations in 2D/3D, describing soliton dynamics. For fully nonlinear scenarios, a fluid model is simulated numerically using a flux-corrected transport method (LCPFCT) [5] for the continuity and momentum equations, along with Newton- based solvers for Poisson's equation. The study first validates the solver through standard equations like KdV, Burgers and fKdV then progresses to simulate 1D IAWs. Both small and large amplitude soliton dynamics are analyzed, confirming long-term stability. Introducing a source term to model moving charged debris reveals the formation of pinned solitons, wakes, and precursor solitons structures that vary depending on whether the driver speed is subsonic or supersonic. The framework is extended to 2D using the full set of cold-ion fluid equations, and the corresponding weakly nonlinear analysis leads to the fKP equation, capturing 2D soliton behavior. Simulated line solitons in 2D IAWs are presented as a proof of concept. Future work includes extending the model to electromagnetic (EM) wave interactions under magnetohydrodynamic (MHD) approximation [7,8]. Moreover, the soliton dynamics considering the self-consistent charging of the debris would be incorporated in near future.

References:

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