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Physical Regimes of Electrostatic Wave-Wave nonlinear interactions generated by an Electron Beam Propagation in Background Plasma

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Electron-beam plasma interaction has long been a topic of great interest. Despite the success of Quasi-Linear (QL) theory and Weak Turbulence (WT) theory, their validities are limited by the requirement of sufficiently dense mode spectrum and small wave amplitude. In this paper, by performing a large number of high resolution two-dimensional (2D) particle-in-cell (PIC) simulations and using analytical theories, we extensively studied the collective processes of a mono-energetic electron beam emitted from a thermionic cathode propagating through a cold plasma. We confirm that initial two-stream instability between the beam and background cold electrons is saturated by wave trapping. Further evolution occurs due to strong wave-wave nonlinear processes. We show that the beam-plasma interaction can be classified into four different physical regimes in the parameter space for the plasma and beam parameters. The differences between the different regimes are analyzed in detail. For the first time, we identified a new regime in strong Langmuir turbulence featured by what we call Electron Modulational Instability (EMI) that could create a local Langmuir wave packet growing faster than ion frequency. Ions do not respond to EMI in the initial growing stage. On a longer timescale, the action of the ponderomotive force produces very strong ion density perturbations, and eventually the beam-plasma wave interaction stops being resonant due to strong ion density perturbations. Consequently, in this EMI regime, electron beam-plasma interaction is a periodic burst (intermittent) process. The beams are strongly scattered, and the Langmuir wave spectrum is significantly broadened, which gives rise to the strong heating of bulk electrons. Associated energy transfer from the beam to the background plasma electrons has been studied. A resulting kappa distribution and a $E^2(k) \sim k^{-5}$ energy spectrum observed in the strong turbulent regime are also discussed.

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References

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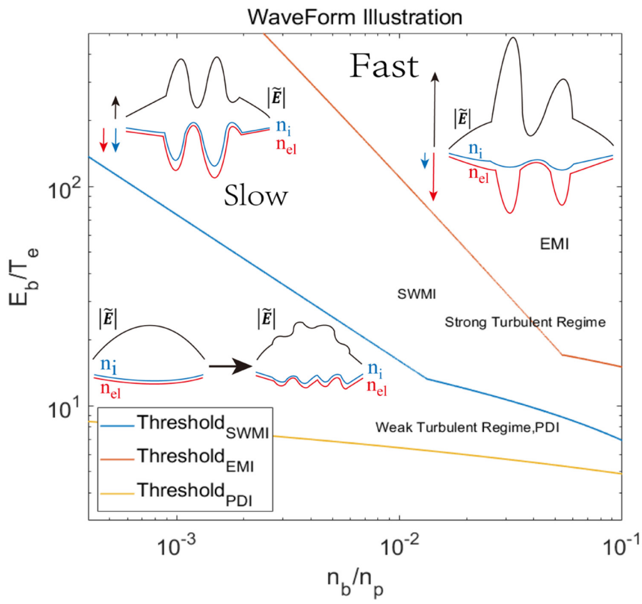

Figure 1: Schematic diagram of different regimes in the parameter space of ratio of the beam energy to the bulk electron temperature, E_b/T_e, versus the ratio of the beam to plasma density, n_b/n_p. The yellow line shows the threshold of Langmuir Parametric Decay Instability (PDI); the blue line - the threshold of Standing Wave Modulational Instability (SWMI); the red curve - the threshold of EMI. In the weak turbulence regime, the wave packet undergoes only slight modulations but doesn't grow locally. In the strong turbulent regime dominated by SWMI, the wave packet grows locally on the ion time scale and ion density perturbations grow together with the wave. Above the threshold of EMI, the wave localization is faster than the ion response and the wave grows locally before ions have time to move. Drawing for the ion density (bottom) and electric field amplitude (top) schematically show these processes for PDI, SWMI and EMI.