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Kinetic mode 'cloaking' of nonlinear waves in plasmas

Devendra Sharma[1], Debraj Mandal[1], Hans Schamel[2]

[1] Institute for Plasma Research, India, [2] Physikalisches Institute, Universität Bayreuth, Germany

e-mail (speaker) : devendra@ipr.res.in

Generic plasma modes, usually known to operate in their well-defined time scale regimes, can be rendered stable in highly unusual regimes by nonlinear kinetics effects, to propagate stably where all known plasma perturbations must phase mix and disqualify as normal plasma modes. Recent kinetic simulations of Vlasov-Poisson model and its nonlinear kinetic analysis uncover a continuum of characteristically fast electron phase-space structures that extends down to very slow time scales, or to almost vanishing structure velocities. A large stable ultra-slow region of this continuum is shown hidden or cloaked by a neutralizing plasma response to very slow perturbations, but reveals its nonlinear stable self in a previously unexplored parameter regime, accessible in modern fusion experiments and in space plasmas.

A special class of nonlinear propagating plasma excitations exists having no experimentally realizable existence of their linearly recoverable versions because of highly unstable distributions essential for their stable linear description. A more appropriate nonlinear kinetic description of them involves a single parameter analytic distribution to lowest order in the approximation. The resulting nonlinear nonlinear solutions are consequently identifiable with corresponding linear modes, reconciling the nonlinear continuum with the linear discreteness of the dispersions.

It was recently discovered [1] that the discreteness of the linear modes (distinct roots of linear dispersion function, separated by bands) also gets reflected in the nonlinear solutions space (as the corresponding band gaps), which was originally understood to be pure continuum. These bandgaps, or forbidden velocity ranges, were found admissible also by the Electron Hole (EH) [2] theory only after the simulations [1] could achieve no stably propagating EH structures in particular velocity ranges. In more specific terms, the nonlinear EH structures were noted as unstable (i.e., not propagating coherently but accelerating) below a critical velocity value, which ruled out existence of any electron holes slower than nearly the ion acoustic speed, analytically reaffirming several ununderstood observations in the past of only accelerating holes in the simulations [3–5]. This work presents even recent results, showing that ultraslow electron holes regain their stability at large enough ion temperature which exceeds electron temperature. The simulations thus uncover an unusual regime of EH stability, unexplored in any past study or simulations. Considering the correspondence existing between the nonlinear and linear solutions, this remarkably shows that the conventionally extreme supersonic electron acoustic-like excitations are capable of propagating with unconventionally slow velocities. The associated nonlinear analytics shows that the bandgap is a dynamical one and may indeed be buried with the changing ion temperature, showing no minimum cutoff velocity (e.g., the ion acoustic speed) for structures with no ion trapping nonlinearity. The new understanding from the discovery of stability of ultraslow electron hole is that a persistent dip in the electron density at the electron hole location is a result of the electron acoustic continuum which is cloaked by the ion response at the relatively colder ion temperatures.

The presentation will discuss the mechanism of EH stability which is achieved critically when the single (fully untrapped) ion population stops supplementing the response of cold electrons and instead begins to supplement the response of streaming Boltzmann electrons. This means the warm ions are rather rarefied at the hole location in full accordance with the Boltzmann-like response of positive ions to a positive potential. The corresponding behavior of ion density is as in the ion density profiles shown in Figs. 1(a) and 1(b) for large and small values, respectively, of the electron to ion temperature ratio, θ.

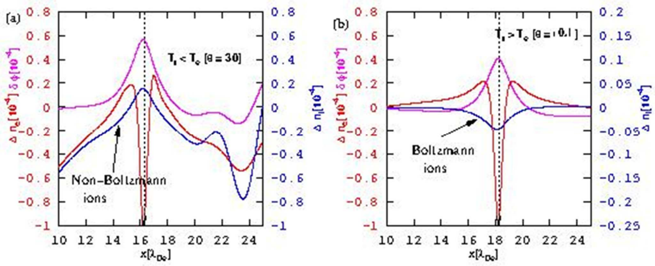

FIG. 1. Electron (red), ion density (blue) density and potential (magenta) for (a) θ = 30 and (b) θ = 0.1.

References

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