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ORIGINAL ARTICLE

Planar electron-acoustic solitary waves and double layers in a two-electron-temperature plasma with nonthermal ions

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Abstract A rigorous theoretical investigation of nonlinear electron-acoustic (EA) waves in a plasma system (containing cold electrons, hot electrons obeying a Boltzmann distribution, and hot ions obeying a nonthermal distribution) is studied by the reductive perturbation method. The modified Gardner (MG) equation is derived and numerically solved. It has been found that the basic characteristics of the EA Gardner solitons (GSs), which are shown to exist for α around its critical value α_c [where α is the nonthermal parameter, α_c is the value of α corresponding to the vanishing of the nonlinear coefficient of the Korteweg-de Vries (K-dV) equation, e.g. $\alpha_c \simeq 0.31$ for $\mu = n_{h0}/n_{i0} = 0.5$, $\sigma = T_h/T_i = 10$, n_{h0}, n_{i0} are, respectively, hot electron and nonthermal ion number densities at equilibrium, T_h (T_i) is the hot electron (ion) temperature], are different from those of the K-dV solitons, which do not exist for α around α_c, and mixed K-dV solitons, which are valid around $\alpha \sim \alpha_c$, but do not have any corresponding double layers (DLs) solution. The parametric regimes for the existence of the DLs, which are found to be associated with positive potential, are obtained. The present investigations can be observed in various space plasma environments (viz. the geomagnetic tail, the auroral regions, the cusp of the terrestrial magnetosphere, etc.).

Keywords Electron-acoustic waves · Modified Gardner equation · Gardner solitons · Double layers · Reductive perturbation method

1 Introduction

The idea of electron-acoustic (EA) mode had been conceived by Fried and Gould (1961) during numerical solutions of the linear electrostatic Vlasov dispersion equation in an unmagnetized, homogenous plasma. It is basically an acoustic-type of waves (Watanabe and Taniuti 1977) in which the inertia is provided by the cold electron mass, and the restoring force is provided by the hot electron thermal pressure. The ions play the role of a neutralizing background only. The spectrum of the linear EA waves, unlike that of the well-known Langmuir waves, extends only up to the cold electron plasma frequency $\omega_{pc} = (4\pi n_{c0} e^2/m_e)^{1/2}$, where n_{c0} is the unperturbed cold electron number density, e is the magnitude of the electron-charge, and m_e is the mass of an electron. This upper wave frequency limit ($\omega \simeq \omega_{pc}$) corresponds to a short-wavelength EA wave and depends on the unperturbed cold electron number density n_{c0}. On the other hand, the dispersion relation of the linear EA waves in the long-wavelength limit [in comparison with the hot electron Debye radius $\lambda_{dh} = (k_B T_h/4\pi n_{h0} e^2)^{1/2}$, where T_h is the hot electron temperature, k_B is the Boltzmann constant, and n_{h0} is the unperturbed hot electron number density] is $\omega \simeq k C_e$, where k is the wave number and $C_e = (n_{c0} k_B T_h/n_{h0} m_e)^{1/2}$ is the EA speed (Gary and Tokar 1985). Besides the well-known Langmuir and ion-acoustic waves, they noticed the existence of a heavily damped acoustic-like solution of the dispersion equation. It was later shown that in the presence of two distinct groups (cold and hot) of electrons and immobile ions, one indeed obtains a weakly damped EA mode (Watanabe and Taniuti 1977), the properties of which significantly differ from those of the Langmuir waves. Gary and Tokar (1985) performed a parameter survey and found conditions for the existence of the EA waves. The most important condition is $T_c \ll T_h$,

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