Large-amplitude electron-acoustic solitons in a dusty plasma with kappa-distributed electrons

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Abstract. The Sagdeev pseudopotential method is used to investigate the occurrence and the dynamics of fully nonlinear electrostatic solitary structures in a plasma containing suprathermal hot electrons, in the presence of massive charged dust particles in the background. The soliton existence domain is delineated, and its parametric dependence on different physical parameters is clarified.

Keywords: Nonlinear phenomena, solitons, electron-acoustic wave, dusty (complex) plasmas.
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Electron-acoustic (EA) waves occur in plasma which are characterized by a coexistence of two distinct type of electrons: cool and hot electrons. A large number of investigations have focused on electron acoustic solitary waves in such plasma configuration [1, 2]. Abundant observations suggest the presence of an excess population of suprathermal electrons/ions in astrophysical environments, which is efficiently modeled by a kappa-type distribution [3]. Recently, these investigations have been extended to study EA excitations in the presence of electrons modeled by a κ-distribution [4, 5, 6]. Furthermore, the presence of dust particles in space plasmas generates new modes, which modify the characteristics of ion-acoustic [7] and EA [8, 9] solitary waves.

We consider a four-component plasma, namely consisting of cold electrons, suprathermal hot electrons, stationary ions and charged dust particles. The cold electron fluid is described by the following normalized equations [6]

$$\frac{\partial n}{\partial t} + \frac{\partial (nu)}{\partial x} = 0, \quad \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} = \frac{\partial \phi}{\partial x}, \tag{1}$$

$$\frac{\partial^2 \phi}{\partial x^2} = -(\eta + s\delta) + n + (\eta + s\delta - 1)\left[1 - \frac{\phi}{\kappa - 3/2}\right]^{-\kappa+1/2}, \tag{2}$$

where n and u denote the density and velocity of the cool electron fluid normalized with respect to $n_{c,0}$ and the hot electron thermal speed $c_{th} = (k_B T_h/m_e)^{1/2}$, respectively. The wave potential ϕ is scaled by $k_B T_h/e$, time and space by the plasma period $\omega_{pc}^{-1} = \left(n_{c,0}e^2/\varepsilon_0 m_e\right)^{-1/2}$ and the characteristic length $\lambda_0 = \left(\varepsilon_0 k_B T_h/n_{c,0}e^2\right)^{1/2}$, respectively. We define the hot-to-cold electron charge density ratio $\gamma = n_{h,0}/n_{c,0}$, the ion-to-cold electron charge density ratio $\eta = Z_i n_{i,0}/n_{c,0}$, and the dust-to-cold electron charge density ratio $\delta = Z_d n_{d,0}/n_{c,0}$. Here, suprathermality is denoted by the spectral index κ, and $s = \pm 1$ for positive/negative dust. Charge neutrality at equilibrium yields $\eta + s\delta = 1 + \gamma$.

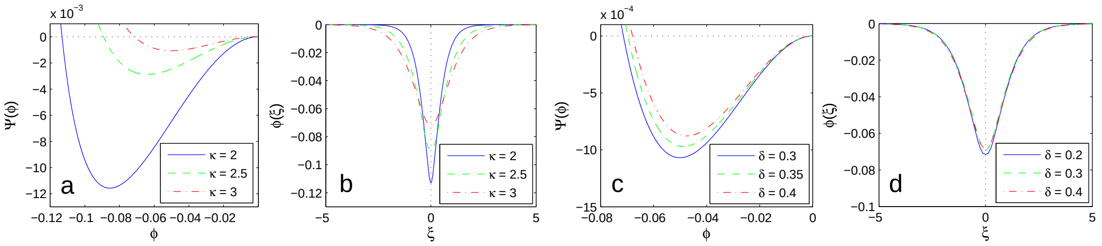

FIGURE 1. In panels: (a) the pseudopotential $\Psi(\phi)$ and (b) the resulting pulse profile ϕ are depicted, for different κ. (Here, $\delta = 0.3$, $s = -1$, $\eta = 5$, and $M = 0.5$.) Similarly, in panels (c) and (d), for different values of the dust concentration δ. (Here, $\kappa = 3$, $s = -1$, $\eta = 5$, and $M = 0.5$.)

Anticipating stationary profile excitations, we set $X = x - Mt$, where M is the soliton speed. Poisson's equation thus leads to the pseudo-energy-balance equation $\frac{1}{2}\left(d\phi/dX\right)^2 + \Psi(\phi, M, \kappa) = 0$, where the pseudopotential $\Psi(\phi, M, \kappa)$ is given as [10]

$$\Psi(\phi,M,\kappa) = (1+\gamma)\,\phi + M^2\left[1-\left(1+\frac{2\phi}{M^2}\right)^{1/2}\right] + \gamma - \gamma\left(1-\frac{\phi}{(\kappa-\frac{3}{2})}\right)^{-\kappa+3/2}. \quad (3)$$

The lower bound of the soliton speed (sonic limit) $M = M_s = \{(\kappa-\frac{3}{2})/[(\eta+s\delta-1)(\kappa-\frac{1}{2})]\}^{1/2}$ decreases with an increase in suprathermality (i.e., decrease in κ) but increases with the value of (dust concentration) δ. As shown in Fig. 1, the pseudopotential becomes deeper and wider with an increase in suprathermality and decrease in δ, for negative dusts. The pulse profile steepness also increases with decrease in κ and decrease in dust concentration. These effects are reversed in the presence of *positive* dust. We have only observed negative polarity solitons. For $\delta = 0$ (in the absence of dust), earlier results [6] are reproduced.

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