AIP | Conference Proceedings

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Citation: AIP Conf. Proc. **1397**, 305 (2011); doi: 10.1063/1.3659815
View online: http://dx.doi.org/10.1063/1.3659815
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1397&Issue=1
Published by the American Institute of Physics.

Electron beam - plasma interaction in a dusty plasma with excess suprathermal electrons

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Abstract. The existence of large-amplitude electron-acoustic solitary structures is investigated in an unmagnetized and collisionless two-temperature dusty plasma penetrated by an electron beam. A nonlinear pseudopotential technique is used to investigate the occurrence of stationary-profile solitary waves, and their parametric dependence on the electron beam and dust perturbation is discussed.

Keywords: Dusty (complex) plasmas, solitons, nonlinear phenomena, plasma interactions
PACS: 52.27.Lw, 52.35.Sb, 52.35.Mw, 52.40.-w

We have previously studied electron-acoustic solitary waves in the presence of a suprathermal electron component. [1] Our aim here is to investigate the effect of beam electrons and dust on the electrostatic solitary structures.

We consider a plasma consisting of cold inertial drifting electrons (the beam), cold inertial background electrons, hot suprathermal electrons modeled by a kappa-distribution, stationary ions, and stationary dust (of either positive or negative charge). The dynamics of the cold inertial background electrons and the beam electrons are governed by the following normalized one-dimensional equations:

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

$$\frac{\partial n_b}{\partial t}+\frac{\partial (n_b u_b)}{\partial x}=0, \quad \frac{\partial u_b}{\partial t}+u_b\frac{\partial u_b}{\partial x}=\frac{\partial \phi}{\partial x}, \tag{2}$$

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

Here, n and n_b denote the fluid density variables of the cool electrons and the beam electrons normalized with respect to $n_{c,0}$ and $n_{b,0}$. The velocities u and u_b, and the equilibrium beam speed $U_0 = u_{b,0}/c_{th}$ are scaled by the hot electron thermal speed $c_{th} = (k_B T_h/m_e)^{1/2}$, and the wave potential ϕ by $k_B T_h/e$. Time and space are scaled 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 $\alpha = n_{h,0}/n_{c,0}$, the beam-to-cold electron charge density ratio $\beta = n_{b,0}/n_{c,0}$, the

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AIP Conf. Proc. 1397, 305-306 (2011); doi: 10.1063/1.3659815

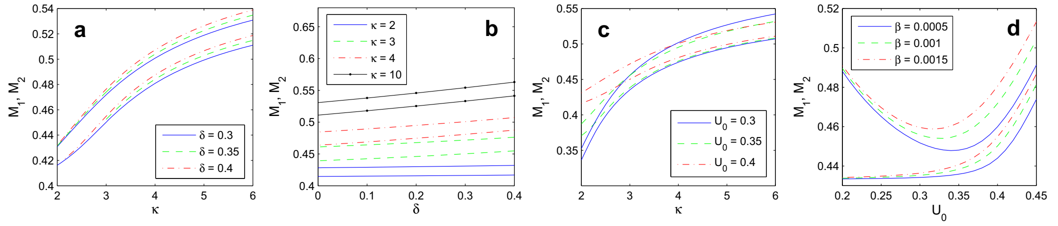

FIGURE 1. Soliton existence region ($M_1 < M < M_2$): (a) versus κ for different δ values; (b) versus δ for different κ values; (c) versus κ for different U_0 values; (d) versus U_0 for different β values. The remaining values are $\kappa = 4.5$, $\delta = 0.3$, $s = -1$, $\beta = 0.001$, $U_0 = 0.4$ and $\eta = 4.5$, unless values are given.

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 $s = \pm 1$ is the sign of the dust charge for positive or negative dust grains. At equilibrium, the plasma is quasi-neutral, so $\eta + s\delta = 1 + \alpha + \beta$.

Anticipating constant profile solutions of Eqs. (1)–(3) in a stationary frame traveling at a constant normalized velocity M, implying the transformation $\xi = x - Mt$, we obtain $n = (1 + 2\phi/M^2)^{-1/2}$ and $n_b = [1 + 2\phi/(M - U_0)^2]^{-1/2}$. Substituting in Poisson's equation and integrating yields a pseudo-energy balance equation $\frac{1}{2}(d\phi/d\xi)^2 + \Psi(\phi) = 0$, where the Sagdeev pseudopotential $\Psi(\phi)$ reads

$$\Psi(\phi) = (\eta + s\delta)\,\phi + M^2\left(1 - [1 + 2\phi/M^2]^{\frac{1}{2}}\right) + \beta(M - U_0)^2 \times$$
$$\left(1 - [1 + 2\phi/(M - U_0)^2]^{\frac{1}{2}}\right) + (\eta + s\delta - 1 - \beta)\left(1 - [1 - \phi/(\kappa - \tfrac{3}{2})]^{-\kappa + \frac{3}{2}}\right). \quad (4)$$

Reality of the density variable implies two limits on the electrostatic potential $\phi_{\max} = -M^2/2$ and $-(M - U_0)^2/2$ for $U_0 < 0$ and $U_0 > 0$, respectively. In order for solitary waves to exist, two constraints must be satisfied, i.e., $F_1(M) = -\Psi''(\phi)|_{\phi=0} > 0$ and $F_2(M) = \Psi(\phi)|_{\phi=\phi_{\max}} > 0$, which yield the solutions for the lower and upper limit in M.

As shown in Figure 1, the existence domain for solitons becomes narrower with increasing suprathermal excess (decreasing κ), increasing equilibrium beam speed, and decreasing beam density. Dust charge density shows little effect on the width of the existence domain, but for quasi-Maxwellian electrons, it weakly increases the typical values of M. It was found that both increasing κ and increasing negative dust charge density significantly reduce soliton amplitude at fixed M (not shown here).

ACKNOWLEDGMENTS

AD, NSS and IK thank the Max-Planck Institute for Extraterrestrial Physics for their support. IK acknowledges support from UK EPSRC via S&I grant EP/D06337X/1.

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