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Nonlinear electron-acoustic rogue waves in electron-beam plasma system with non-thermal hot electrons

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Abstract

The properties of nonlinear electron-acoustic rogue waves have been investigated in an unmagnetized collisionless four-component plasma system consisting of a cold electron fluid, non-thermal hot electrons obeying a non-thermal distribution, an electron beam and stationary ions. It is found that the basic set of fluid equations is reduced to a nonlinear Schrodinger equation. The dependence of rogue wave profiles on the electron beam and energetic population parameter are discussed. The results of the present investigation may be applicable in auroral zone plasma.

Keywords: Electron acoustic rogue waves; Nonlinear Schrodinger equation; Non-thermal electrons; Rogue waves

1. Introduction

Nonlinear electron acoustic solitary waves (EAWs) have been existed in laboratory devices when the plasma consisted of two temperature electrons, referred to as hot and cold electrons (Ikezawa and Nakamura, 1981). Electron-acoustic solitons have been observed in many regions of Earth' magnetosphere by various satellites, e.g. Viking, FAST etc. (Lakhina et al., 2011; Dubouloz et al., 1993; Cattell et al., 1998; Ergun et al., 1999; Pottelette et al., 1999; Miyake et al., 2000). The propagation of electron acoustic solitons in a four-component plasma system was examined (Singh et al., 2001). They applied their model results to discuss the Viking satellite observations in the dayside auroral zone. Furthermore, Lakhina et al. (2009) discussed the mechanism of electrostatic solitary waves generation of electrostatic solitary waves observed in the Earth's magnetosheath. Practically, hot electrons may not follow a Maxwellian distribution due to the formation of phase space holes caused by trapping of hot electrons in a wave potential (Mamun and Shukla, 2002; Shukla et al., 2004). Accordingly, Cairns et al. (1995) used the nonthermality of electrons to advised the nonlinear ion acoustic soliton structures observed by the FREJA satellite. El-Shewy (2007a,b) investigated the effects of non-thermal distribution of hot electrons and the contribution of higher-order corrections on the properties of nonlinear electrostatic EAWs. Later, Elwakil et al. (2007) examined the effect of both the relativistic electrons and energetic population parameter on the features of amplitude and width of EASWs in an unmagnetized collisionless plasma consisting of a cold relativistic electron fluid, nonthermal hot electrons obeying a non-thermal distribution, a relativistic electron beam and stationary ions. It was found that the presence of non-thermal electrons as well as the relativistic electron beam modified the basic properties of the EASWs. However, several studies on the nonlinear electron acoustic waves with nonthermal hot electrons have been

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discussed (Sahu and Roychoudhurya, 2006; Singh et al., 2004; Pakzad and Tribeche, 2010). Furthermore, Kakad et al. (2007) inspected electron-acoustic waves in a four-component unmagnetized plasma system consisting of cold background electrons, cold electron beam and two types of ion species. It was found that, the plasma system predicts the coexistence of rarefactive and compressive electrostatic modes for specific plasma parameters. Gill et al. (2007) studied the modulational instability of electron-acoustic waves in an unmagnetized plasma consisting of cold electron fluid and nonthermal electrons. It was showed that, the presence of nonthermality distributed electrons modified the domain of the modulational instability and solitary structures. Recently, several studies on the nonlinear planar, nonplanar electron-acoustic solitary waves and double layers in a two-electron-temperature plasma have been extensively investigated by many authors, see for examples (Mannan and Mamun, 2012; Shuchy et al., 2012; Borhanian and Shahmansouri, 2012). Abdelwahed (2012) investigated the obliquely nonlinear electron-acoustic solitons (EASWs) in a magnetized collisionless plasma using the Zakharov–Kuznetsov (ZK) and ZK-type equation. Elwakil et al. (2014), studied the electron-acoustic soliton energy of the Kadomtsev–Petviashvili (KP) equation at critical ion density in an unmagnetized collisionless plasma consisted of a cold electron fluid, low temperature ions and high temperature ions obeying Boltzmann type distributions. On the other hand, the rogue waves has been observed in astrophysical plasma environments (Moslem, 2011; El-Awady and Moslem, 2011; Moslem, 2011). These waves are a singular, rare, high-energy wave with very high amplitude that carries dramatic impact. It appears in the form of oceanic rogue waves, stock market crashes, propagation of acoustic-gravity waves in the atmosphere, atmospheric and plasma physics, communication systems, opposing currents flows, Bose–Einstein condensates (Moslem, 2011; El-Awady and Moslem, 2011; Moslem, 2011). Accordingly, several studies in different physical media used rational solutions of the nonlinear Schrödinger (NLS) equation which gives a suitable description of rogue waves, see Akhmediev and Ankiewicz (1997), Akhmediev et al. (2009) and Ruderman (2010). El-Labany et al. (2012) examined the existence of ion-acoustic (IA) rogue wave in a positive–negative ion plasma with electrons obeying isothermal distribution in Titan's atmosphere. Moreover, Abdelwahed and El-Shewy (2013) discussed the improved speed and shape of ion-Acoustic waves in a warm plasma and compared between the rational solutions of KdV and NLS equations. In this paper, we aim to study the electron acoustic (EA) rogue wave in an unmagnetized collisionless four-component plasma system composed of consisting of a cold electron fluid, non-thermal hot electrons obeying a non-thermal distribution, an electron beam and stationary ions. The organization of the paper is as follows. In Sec. II, we present the basic equations describing the dynamics of the nonlinear EA rogue waves. In Sec. III, we use the reductive perturbation method to derive the NLS equation and its rational solution. Section IV, is kept for results and discussions.

2. Basic equation

We consider a homogeneous system of an unmagnetized collisionless plasma consisting of a cold electron fluid, non-thermal hot electrons obeying a non-thermal distribution, an electron beam and stationary ions. For one dimensional propagation of a small-but finite amplitude nonlinear EAWs, the dynamics of an electron fluid can be written as (Berthomier et al., 1999; Elwakil et al., 2007):

$$\frac{\partial n_c}{\partial \tau} + \frac{\partial (n_c u_c)}{\partial \xi} = 0, \tag{1.a}$$

$$\frac{\partial u_c}{\partial \tau} + u_c \frac{\partial u_c}{\partial \xi} - \alpha \frac{\partial \phi}{\partial \xi} + \frac{3\alpha(1+\alpha+\beta)^2}{\theta} n_c \frac{\partial n_c}{\partial \xi} = 0, \tag{1.b}$$

$$\frac{\partial n_b}{\partial \tau} + \frac{\partial (n_b u_b)}{\partial \xi} = 0, \tag{1.c}$$

$$\frac{\partial u_b}{\partial \tau} + u_b \frac{\partial u_b}{\partial \xi} - \alpha \frac{\partial \phi}{\partial \xi} + \frac{3\alpha(1+\alpha+\beta)^2}{\sigma \beta^2} n_b \frac{\partial n_b}{\partial \xi} = 0, \tag{1.d}$$

$$\frac{\alpha}{(1+\alpha+\beta)} \frac{\partial^2 \phi}{\partial \xi^2} - n_c - n_h - n_b + \left(1 + \frac{\alpha}{(1+\alpha+\beta)}\right) = 0, \tag{1.e}$$

and the non-thermal hot electrons density n_h is given by (Cairns et al., 1995):

$$\frac{(1+\alpha+\beta)}{\alpha} n_h = (1 - \mu\phi + \mu\phi^2)\exp(\phi), \tag{1.f}$$

where

$$\mu = \frac{4\gamma}{1+3\gamma},$$

In the earlier equations $n_{c,h,b}$ are the densities of the three electron population, $u_{c,b}$ are velocities of the cold and beam electrons, respectively, and ϕ is the electrostatic potential. Eqs. (1.a)–(1.d) represent the inertia of cold and electron-beam and Eq. (1.e) is the poisson equation need to make the self consistent, the electrons is described by non-thermal distribution given by Eq. (1.f). In Eqs. (1) these quantities have been normalized to the total unperturbed density $n_0 = n_{c0} + n_{h0} + n_{b0}$, the electron acoustic velocity $u_{ea} = (n_{c0}/n_{h0})^{1/2} u_{Th}$, where $u_{Th} = (k_B T_h/m_e)^{1/2}$ is the hot electron thermal velocity and to $k_B T_h/e$, respectively. Time τ and space variables ξ are normalized, respectively, to the cold electron plasma period $\omega_{pc}^{-1} = (m_e/4\pi n_{c0} e^2)^{1/2}$ and the hot electron Debye length $\lambda_{Dh} = (k_B T_h/4\pi n_{h0} e^2)^{1/2}$, where k_B is Boltzmann's constant, m_e is the mass of electron and γ is a parameter which determines the population of energetic non-thermal hot electrons. We have introduced the following quantities, which will be used in our parametric study (Berthomier et al., 1999):