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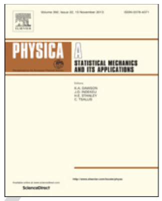

Q1 Modulation instability and rogue wave structures of positron-acoustic waves in q-nonextensive plasmas

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HIGHLIGHTS

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ABSTRACT

A theoretical investigation is made to study envelope excitations and rogue wave structures of the newly predicted positron-acoustic waves (PAWs) in a plasma with nonextensive electrons and nonextensive hot positrons. The reductive perturbation technique (RPT) is used to derive a nonlinear Schrödinger equation-like (NLSE) which governs the modulational instability (MI) of the PAWs. The NLSE admits localized envelope solitary wave solutions of bright and dark type. These envelope solutions depend upon the intrinsic plasma parameters. It is found that the MI of the PAWs is significantly affected by nonextensivity and other plasma parameters. Further, the analysis is extended for the rogue wave structures of the PAWs. The findings of the present investigation should be useful in understanding the acceleration mechanism of stable electrostatic wave packets in four components nonextensive plasmas.

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1. Introduction

Electron–positron–ion (e–p–i) plasmas exist in many astrophysical environments [1,2] and laboratory experiments [3–5]. Linear and nonlinear features of plasma waves in such plasma systems have attracted a good deal of interest over the last many years. It is well known that when positrons are introduced into a two-components electron–ion plasma, the response of the latter for the propagation of nonlinear waves changes significantly. Probably, Popel et al. [6] were the first to make an attempt to study nonlinear features of the ion-acoustic waves in a three components plasmas, whose constituents

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were ions, electrons and positrons. It has been found that the presence of the positron component reduces the amplitude of the ion-acoustic solitons. Further, Nejoh [7] showed that the ion temperature narrows the amplitude but increases the maximum Mach number of the soliton in an electron–positron–ion plasma. Some weakly relativistic effects were studied in such plasmas by Gill et al. [8]. They concluded that the relativistic effects increase the amplitude and decrease the width of the soliton. Later on, the same model was generalized to include the effects of a magnetic field [9]. There are many theoretical attempts that have been made for weakly nonlinear [10–13] and fully nonlinear [14–16] solitons in e–p–i plasmas.

Modulational instability (MI) of nonlinear waves in e–p–i plasmas attracted a good deal of attention due to its importance in stable wave propagation [17–19]. Salahuddin et al. [20] studied the envelope excitations of ion-acoustic soliton in an e–p–i plasma, and reported that a small fraction of ions in the electron–positron plasma can change significantly the dynamics of the system by involving slow time and long spatial scales in the plasma. Further, Jehan et al. [21] extended the same model to the magnetized plasma case. The range of the wave numbers where the instability sets in enlarges with an increase in the strength of the magnetic field and the positron density. Moreover, various theoretical attempts have been made to examine the effects of non-Maxwellian particles distributions on MI in e–p–i plasmas [22–26].

Recently, Tribeche et al. [27] made the first theoretical attempt to investigate the positron-acoustic waves (PAWs) in a plasma having cold fluid positrons, thermal hot positrons and electrons, and immobile positive ions. Since then a lot of studies on the propagation properties of this newly predicted mode gained the attention of many researchers during the last few years [28,19,29]. Some nonlinear theories have been extended and applied to the positron-acoustic waves in non-Maxwellian plasmas [30,29]. Alam et al. [30] studied the PAWs and associated double-layers (DLs) in an e–p–i plasma consisting of superthermal electrons and positrons. Very recently, an instability analysis of the positron-acoustic solitary waves in a magnetized plasma containing superthermal hot positrons and electrons has been conducted [29]. A nonlinear Zakharov–Kuznetsov (ZK) equation has been derived. It has been found that the instability criterion and growth rate are significantly modified by the external magnetic field, superthermality of the particles and propagation direction. Nevertheless and to the best of our knowledge, no theoretical investigation has been made on the modulational instability of the PAWs. Therefore, the aim of the present investigation is to study the modulational instability of PAWs in a four components plasma having cold positrons, immobile positive ions, and nonextensively distributed electrons and positrons. Let recall that the nonextensive theory of Tsallis has made remarkable progress and found wide applicability in different disciplines (see Ref. [31] and references therein for an actual view of the theory and its breadth of use). A one particular parameter, the entropic index q which measures the degree of nonextensivity, has been introduced ($q = 1$ corresponds to the standard, extensive, Boltzmann–Gibbs (BG) statistics). The q-nonextensive formalism has been successfully applied to systems endowed with long range interactions as usually happens in astrophysics and plasma physics. Since its introduction, the nonextensive statistics has been applied in various fields and has shown particular success especially in plasma physics [32–35]. Several observations seem to confirm the predictions of the Tsallis formalism. Among the various experimental verifications, the distribution characterizing the motion of cold atoms in dissipative optical lattices [36], the velocity distributions in driven dissipative dusty plasma [33], trapped ions interacting with a classical buffer gas [37], the fluctuations of the magnetic field in the solar wind [38], high energy collisional experiments at LHC/CERN [39,40], and RHIC/Brookhaven [41].

The organization of the paper is as follows: The basic equations of our theoretical model are given in the next section. A nonlinear Schrödinger equation (NLSE) is then derived in Section 3. Our results are presented and discussed in Section 4. The last Section is devoted to our conclusions.

2. Basic equations

Let us consider a four components plasma having cold positrons (pc), immobile positive ions (i), nonextensive electrons (e) and positrons (ph) of density n_{pc}, n_i, n_e and n_{ph}, respectively. Thus, at equilibrium, we have $n_{e0} = n_{pc0} + n_{ph0} + n_{i0}$, where the subscript "0" stands for unperturbed quantities.

To model the effects of the electron and hot positron nonextensivity, we refer to the following one-dimensional equilibrium velocity q-distribution given by [42]

$$f_e(v) = C_e \left\{ 1 - (q_e - 1) \left[\frac{m_e v^2}{2T_e} - \frac{e\phi}{T_e} \right] \right\}^{1/(q_e-1)}$$
$$f_p(v) = C_p \left\{ 1 - (q_p - 1) \left[\frac{m_e v^2}{2T_{ph}} + \frac{e\phi}{T_{ph}} \right] \right\}^{1/(q_p-1)} \quad (1)$$

where

$$C_{q,e} = \begin{cases} n_{e0} \dfrac{\Gamma\left(\frac{1}{1-q_e}\right)}{\Gamma\left(\frac{1}{1-q_e} - \frac{1}{2}\right)} \sqrt{\dfrac{m_e(1-q_e)}{2\pi T_e}}, & \text{for } -1 < q_e < 1 \\[2ex] n_{e0} \left(\dfrac{1+q_e}{2}\right) \dfrac{\Gamma\left(\frac{1}{q_e-1} + \frac{1}{2}\right)}{\Gamma\left(\frac{1}{q_e-1}\right)} \sqrt{\dfrac{m_e(q_e-1)}{2\pi T_e}}, & \text{for } q_e > 1 \end{cases}$$

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