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ORIGINAL ARTICLE

# Cylindrical Zakharov–Kuznestov equation for ion-acoustic waves with electrons featuring non-extensive distribution

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**Abstract** Cylindrical Zakharov–Kuznestov equation for ion-acoustic waves comprising of ions and electrons featuring non-extensive distribution are derived from the fluid equations through reductive perturbation technique. System of first order ordinary differential equations is obtained from Zakharov–Kuznestov equation through dynamical system approach and ultimately it is solved using numerical method. It is found that the electron to positron ratio parameter and the non-extensive distributed parameter due to electron play crucial role on the solution.

**Keywords** Nonlinear waves · Equilibrium point · Non-extensive distribution · ZK equation · Acoustic wave

## 1 Introduction

In accordance with the history of plasma literature, considerable attention has been paid to the study of nonlinear waves in various configurations of laboratory and space plasma (Washimi and Taniuti 1966; Ikezi 1973; Ikezi et al. 1970; Ghosh and Chatterjee 2013; Chatterjee and Ghosh 2011). The journey of the investigations is initiated with the propagation of ion acoustic solitary waves (IASWs) in cold plasma by Washimi and Taniuti (1966) through the derivation of Korteweg-de Vries (KdV) equation theoretically and by Ikezi (1973) experimentally. Electrons are often accelerated to energies of tens of MeV by the electric field induced during the disruptive instability in tokamaks Wesson et al. (1989). The resulting beam of runway electrons can carry up to about half of the original plasma current. At these high energies, electron-positron pairs can be created in collisions between the runaway electrons and background plasma ions and electrons. Helander and Ward (2003) estimated the number of such pairs and discussed the fate of the positrons created in this way. The experiments (Greaves et al. 1994; Greaves and Surko 1995; Surko et al. 1989; Tsytovich and Wharton 1978) have established the possibility of creating a non-relativistic electron-positron plasma in the laboratory. A natural extension of this research is to learn how to accumulate and store sufficient numbers of positrons so that they behave as a collective, many-body system. Surko et al. (1989) have developed a method to accumulate and store positrons in an electrostatic trap using a tungsten moderator and inelastic collisions with nitrogen gas. Indeed, electron-positron plasmas represent the larger class of equal-mass plasmas, a class of plasmas that may offer plasma physical properties quite different from those of conventional ion-electron plasmas. Clearly, the properties of wave motions in an electron-positron-ion plasma should be different from those in two-component electron-positron plasmas. KdV (Ko and Kuekl 1978; Gardner et al. 1967; Sharma 2009) equation in one dimension and Kadomtsev–Petviashvili (KP) (Senatorski and Infeld 1996) equation in two dimension describe the soliton structure in unmagnetized dissipation-less plasma where as the Korteweg-de Vries Burgers (KdVB) (Wang 2008) equation and Kadomtsev–Petviashvili–Burgers (KPB) (Masood et al. 2009) equation are deduced from the dissipative plasma system. To study such interesting behavior hidden within the nonlinear structures, many researchers have engaged them-

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