Physics Letters A 382 (2018) 1368–1373

Contents lists available at ScienceDirect

Physics Letters A

www.elsevier.com/locate/pla

Ion acoustic solitons in magnetized collisional non-thermal dusty plasmas

S. Sultana [a,b,*]

[a] Department of Physics, Jahangirnagar University, Savar, Dhaka-1342, Bangladesh
[b] Fakultät für Physik und Astronomie, Ruhr-Universittät Bochum, D-44780 Bochum, Germany

ARTICLE INFO

Article history:
Received 5 January 2018
Received in revised form 8 March 2018
Accepted 16 March 2018
Available online 20 March 2018
Communicated by F. Porcelli

Keywords:
IASWs
Dissipative solitons
dKdV equation
Oblique propagation
Superthermal electron

ABSTRACT

The oblique propagation of ion-acoustic solitary waves (IASWs) is considered, in a magnetized non-thermal collisional dusty plasma, composed of non-Maxwelian κ-distributed electrons, inertial ions, and stationary dust. The reductive perturbation approach is adopted to derive the damped Korteweg de-Vries (dKdV) equation, and the dissipative oblique ion-acoustic wave properties are investigated in terms of different key plasma parameters via the numerical solution of the dKdV equation. The collisional effect, describing the ion-neutral collision in the plasma, is taken into account, and seen to influence the dynamics of IASWs significantly. The basic features of IASWs are observed to modify, and the polarity of the wave is seen to change due to the variation of dust to that of ion number density and also due to the variation of the supethermality index κ in the considered plasma system.

1. Introduction

Localized structures of permanent profile (or solitary waves) in a dispersive plasma medium are formed due to the balance between the nonlinear and the dispersive effect. These solitary structures (or solitons) may suffer dissipation while propagating in the dissipative plasma medium, i.e., they may change their amplitude, width, speed, and eventually diminish with time. The nonlinear propagation of dissipative solitary waves (or dissipative solitons) have received a great deal of attention in plasma physics [1–8] and also in nonlinear optics [9–14], since most of the real physical systems in nature are far from equilibrium, and exhibit dissipative characteristics. In plasmas, the dissipation may arise due to the collisions of different plasma constituents (e.g., the electron-neutral collision [15], the ion-neutral collision [16], the dust-ion collision [16], the dust-neutral collision [15], etc.) or due to nonlinear landau damping [17] or due to kinematic fluid viscosity [18]. It is noted that the solitons are used for optical fiber communications [19] because of their excellent nature of stationary profile. In a dissipative system, an external source of energy (amplifier, amplitude modulator) [20] is needed to send the original information over a very long distances in fiber optic communications. The external energy balances the dissipation, and the initial solitary pulse maintains it's stability while propagating.

The nonlinear phenomena (solitary waves, shocks, double layers, vortices, etc.) in the presence excess energetic particles (e.g., electrons, ions, etc.) has received a great attention to the plasma physicists because of the availability of superthermal particles in space [21–23] and in laboratory [24–26] plasma environments. The excess superthermal particles, which are not in thermodynamic equilibrium [23,27,28], are successfully described via the κ (kappa) non-thermal distribution function than via the thermal Maxwellian distribution function [29,30]. It has already been studied a vast number of research to investigate the nonlinear dynamics of solitary waves [31–33], shock waves [34,35], double layers [36], and also to analyze the modulation dynamics of envelope solitary structures and their instability criteria [37,35] in multicomponent plasmas in the presence of κ non-thermal electrons or/and ions.

Ion acoustic waves (IAWs) [38–40], in which the inertia (the restoring force) is provided by the mass density (the thermal pressure) of the ion (electron) species and the dust species just maintains the background plasma neutrality, may exist in a three component dusty plasma system containing inertial ions, inertialess electrons, and static dust species. The nonlinear propagation of ion acoustic solitary waves (IASWs) in a collisionless unmagnetized plasma in the presence of superthermal electrons has been studied extensively [31,41,42] via different theoretical approaches. The propagation characteristics of IASWs in a collisional unmagnetized

* Correspondence to: Department of Physics, Jahangirnagar University, Savar, Dhaka-1342, Bangladesh.
E-mail address: ssultana@juniv.edu.

https://doi.org/10.1016/j.physleta.2018.03.027
0375-9601/

pair ion plasmas, and the role of dissipation on the dynamics of IASWs have been studied in Ref. [7]. The nonlinear characteristics of the small but finite amplitude high frequency electron acoustic solitary waves have been investigated via the KdV approach [8] in an unmagnetized collisional three component non-thermal plasma with two distinct temperature electron populations. It is essential to note that though the existing research in plasma physics [1–8] demonstrated the damping effects of solitons, we have noticed that no attempt has been taken to study the properties of the finite amplitude IASWs in a magnetized collisional dusty plasma system in the presence of excess superthermal electrons. Relying on our plasma model for cold ion fluid and on the existed research in the literature [38–40], we aim to investigate the characteristics of IASWs on the basis of different plasma composition parameters (especially the effect of dissipation, the superthermality effect, the effect of magnetic field, the effect of obliqueness, the effect of inertial cold ion concentration) in a three component magnetized collisional dusty plasma in the presence of superthermal electrons in which dust are assumed to maintain the background plasma neutrality with fixed charge on their surface and constant number density.

The manuscript is organized as follows. The basic formalism of our fluid model is presented in Section 2. The dissipative IASWs, modeled dKdV equation, and the ion acoustic solitary wave (IASW) properties relevant to different plasma configuration parameters are demonstrated in Section 3. Finally, a brief conclusion of our analytical and numerical results is given in the discussion Section 4.

2. The plasma model

To model the finite amplitude obliquely propagating IASWs, we consider a three-component magnetized, collisional, non-thermal plasma consisting of an inertial ion fluid (of mass m_i and charge z_ie), inertialess κ-distributed electron species (of mass m_e and charge $-e$), and stationary negatively charged dust species (of mass m_d and charge $-z_de$), where e is the magnitude of an electron charge and z_i (z_d) is the ion charge state (number of electrons residing onto the dust surface). We also consider a dusty plasma medium that may exist in many realistic system (e.g., Earth's mesosphere, the F-ring of Saturn's, supernova shells, etc.) [38,43] in which the absorption of ion species in the dust surface is assumed to be compensated by ion creation due to ionization. We, therefore, neglect the dissipation due to the ionization and absorption [44–46] of ion species, for simplicity. Moreover, the dust charging time scale is assumed as much smaller than the dust hydrodynamical time scale, i.e., the charge fluctuation of dust particles is neglected, while the ion-neutral collisional effect that might influence the propagation and evolution of IASWs is taken into account. Thus, the plasma neutrality condition in a dusty plasma where the dust can be thought of as stationary with its density and charge is assumed as constant reads: $z_in_{i0} - n_{e0} - z_dn_{d0} = 0$, where n_{i0}, n_{e0}, and n_{d0} are the unperturbed number density of the ion, electron, and dust, respectively. The dynamics of IAWs in such plasma medium, whose phase speed is far larger than the ion and dust thermal speed, but far smaller than the electron thermal speed, in the presence of an ambient magnetic field $\mathbf{B}_0 = \hat{z}B_0$, is governed by the following set of evolution equations

$$\frac{\partial N_i}{\partial T} + \nabla.(N_i\mathbf{U}_i) = 0\,, \tag{1}$$

$$\frac{\partial \mathbf{U}_i}{\partial T} + (\mathbf{U}_i.\nabla)\mathbf{U}_i = -\frac{z_ie}{m_i}\nabla\Phi + \frac{z_ieB_0}{m_i}\left(\mathbf{U}_i \times \hat{z}\right) - \nu_{in}\,\mathbf{U}_i\,, \tag{2}$$

$$\nabla^2\Phi = 4\pi e\left(N_e + z_dn_{d0} - z_iN_i\right)\,, \tag{3}$$

where N_i (U_i), Φ, N_e (n_{d0}), and ν_{in} are the number density (velocity) of the inertial ion fluid, the electrostatic wave potential, the electron (unperturbed dust) number density, and the ion-neutral collision frequency, respectively.

The presence of excess energetic (superthermal) electrons is considered, and we adopt a kappa (κ) non-thermal distribution. The electron number density therefore reads [30]

$$N_e = n_{e0}\left[1 - \frac{e\Phi}{(\kappa - \frac{3}{2})T_e}\right]^{-\kappa+\frac{1}{2}}\,, \tag{4}$$

where T_e is the electron temperature and κ is the superthermality index, measures the plasma nonthermality. One has to consider $\kappa \geq 1.5$ for a meaningful particle distribution function [30], and smaller κ indicates the stronger plasma nonthermality and larger κ indicates the weaker nonthermality, and the Maxwell–Boltzmann distribution is recovered for $\kappa \to \infty$.

We normalize all variables by appropriate quantities, and obtain the normalized continuity, momentum, and Poisson's equations in the form

$$\frac{\partial n}{\partial t} + \nabla.(n\mathbf{u}) = 0\,, \tag{5}$$

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}.\nabla)\mathbf{u} = -\nabla\phi + \Omega_{ci}\left(\mathbf{u} \times \hat{z}\right) - \nu_i\mathbf{u}\,, \tag{6}$$

$$\nabla^2\phi = \mu - n + b_1\phi + b_2\phi^2\,, \tag{7}$$

where $n = N_i/n_{i0}$, $u = U_i/C_0$ (in which $C_0 = (z_iT_e/m_i)^{1/2}$), $\phi = \Phi/\Phi_0$ (in which $\Phi_0 = T_e/e$), $\nabla = \nabla/\lambda_D$ (in which $\lambda_D = (T_e/4\pi e^2z_in_{i0})^{1/2}$), $t = T/\omega_{pi}^{-1}$ (in which $\omega_{pi} = (4\pi z_i^2e^2n_{i0}/m_i)^{1/2}$), $n_e = N_e/n_{e0}$, $\mu = z_dn_{d0}/z_in_{i0}$, $\nu_i = \nu_{in}/\omega_{pi}$, $\Omega_{ci} = \omega_{ci}/\omega_{pi}$ (in which $\omega_{ci} = z_ieB_0/m_i$), and the plasma nonthermality index κ is introduced via parameters

$$b_1 = \frac{(1-\mu)(\kappa - \frac{1}{2})}{\kappa - \frac{3}{2}}\,, \quad b_2 = \frac{b_1\,(\kappa - \frac{1}{2})}{2(\kappa - \frac{3}{2})}\,. \tag{8}$$

It is expected and also seen in (8), in absence of dust particles (i.e., for $\mu \to 0$) the Maxwellian limit is recovered for $\kappa \to \infty$, i.e., $b_1 \to 1$, $b_2 \to 1/2$ as $e^{\phi} = 1 + \phi + \phi^2/2 + \cdots$. It should be noted that one has to consider $\kappa \geq 3$ [30] to analyze the solitary wave characteristics via perturbative approach as the higher order terms in the Taylor expansion of equation (7) are large and can not be neglected in the range $3/2 < \kappa \leq 3$.

3. Dissipative IASWs

In search of finite amplitude ion acoustic solitary waves in a magnetized non-thermal collisional dusty plasma system, we proceed by assuming stretched coordinates as [47,48]

$$\xi = \epsilon^{1/2}\left(l_xx + l_yy + l_zz - \mathrm{v}_pt\right)\,, \quad \tau = \epsilon^{3/2}t\,, \tag{9}$$

where ϵ is a small parameter ($\epsilon \ll 1$), measures the strength of the nonlinearity, v_p is the phase speed of the ion acoustic waves in the considered plasma (normalized by the ion sound speed C_0), and l_x, l_y, and l_z are the directional cosines of the wave vector $\mathbf{k}$ along the x, y, and z axes, respectively, i.e., $l_x^2 + l_y^2 + l_z^2 = 1$. We should note that x, y, z are all normalized by λ_D, and τ is normalized by the ion plasma period ω_{pi}^{-1}. To model the dissipative IASWs, we consider the presence of small damping in the plasma due to the ion-neutral collision by assuming $\nu_i = \epsilon^{3/2}\,\nu$. The dependent variables n, $\mathbf{u}$, and ϕ are expanded around the equilibrium states in power series of ϵ as