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ScienceDirect

Advances in Space Research xxx (2018) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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Shocklike soliton because of an impinge of protons and electrons solar particles with Venus ionosphere

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Received 1 September 2017; received in revised form 25 November 2017; accepted 16 January 2018

Abstract

This paper introduces an investigation of shocklike soliton or small amplitude Double Layers (DLs) in a collisionless plasma, consisting of positive and negative ions, nonthermal electrons, as well as solar wind streaming protons and electrons. Gardner equation is derived and its shocklike soliton solution is obtained. The model is employed to recognize a possible nonlinear wave at Venus ionosphere. The results indicate that the number densities and velocities of the streaming particles play crucial role to determine the polarity and characteristic features (amplitude and width) of the shocklike soliton waves. An electron streaming speed modifies a negative shocklike wave profile, while an ion streaming speed modulates a positive shocklike wave characteristic.

Keywords: Small amplitude Double Layers; Venus ionosphere; Gardner equation; Solar wind

1. Introduction

Advancements in studying multicomponent plasma provide us with an in-depth understanding of many space observations and laboratory experiments. Multicomponent plasmas, including negative ions, dust grains, positrons, and streaming particles, have been observed in many space observations such as in an interplanetary medium, cometary comae and tail, Earth's magnetosphere, Titan atmosphere, white dwarfs, etc. (Grun et al., 1997; Shukla and Mamun, 2002; Horanyi et al., 2004; Vuitton et al., 2009; Sabry, 2009; Kashiyama et al., 2011; Sabry et al., 2011; Saleem et al., 2012; Wellbrock et al., 2013; Kaur et al., 2017; Carroll and Ostlie, 2017; Tolba et al., 2017; Mowafy et al., 2017; Abdelwahed and El-Shewy, 2017; Salem et al., 2017). The presence of these additional species to ordinary plasma affects on the plasma characteristics and behavior. For example, the presence of dust grains gives rise to propagation of new kind of modes called dust-acoustic waves and dust-ion-acoustic waves (Shukla and Mamun, 2002). Furthermore, the presence of negative ions and streaming particles (electrons and/or ions) introduces new collective behavior and instabilities. Motivation by the above findings, an interesting phenomenon appears because of an interaction of solar wind streaming particles with different planets. For example, an interaction of solar wind with magnetized (like Earth) and unmagnetized (like Venus) planets is quite different. At the Earth, an essential magnetic field is enough so that there is no direct contact between the solar wind and the planetary ionosphere. Indeed, solar wind carries its energy to the Earth's

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https://doi.org/10.1016/j.asr.2018.01.023
0273-1177/

Please cite this article in press as: Moslem, W.M., et al. Shocklike soliton because of an impinge of protons and electrons solar particles with Venus ionosphere. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2018.01.023

magnetosphere at the magnetopause region, i.e. this energy can dissipate in the ionosphere lastly. At Venus, there is little or no magnetic field, thus the solar wind particles interact directly with the dense ionosphere (Strangeway, 1991). The presence of different charged particles in Venus atmosphere was discussed by many authors (see e.g. Aplin, 2006; Michael et al., 2009). It was found that both positive and negative ions, as well as electrons can exist at Venus atmosphere. The negative ions can be formed by the attachment of electrons to the neutrals. Dynamics of these charged particles would lead to generate different plasma waves, one of these waves is an ion-acoustic wave. It was noticed that behind the planet; the plasma waves were observed at the magnetotail boundary. These waves have been identified as ion-acoustic waves, so the nature of this wave should be investigated. Furthermore, the observed plasma waves are associated with plasma clouds that cause relatively energetic electrons, which in turn may be accelerated in regions of anomalous resistivity, and so may produce aurora (Strangeway, 1991). An interaction of streaming protons and electrons solar particles with a plasma environment at Venus atmosphere is of critical interest, which is the motivation of present work.

2. Model equations

Let us consider a multicomponent plasma system consisting of positive and negative ions, nonthermal electrons, as well as solar wind streaming electrons and protons. The dimensionless basic set of fluid equations is governed by the following one-dimensional nonlinear differential equations for positive ions (Shukla and Mamun, 2002)

$$\frac{\partial n_{i+}}{\partial t}+\frac{\partial}{\partial x}(n_{i+}u_{i+})=0, \tag{1}$$

$$\frac{\partial u_{i+}}{\partial t}+u_{i+}\frac{\partial u_{i+}}{\partial x}+\frac{\partial \phi}{\partial x}=0, \tag{2}$$

for negative ions,

$$\frac{\partial n_{i-}}{\partial t}+\frac{\partial}{\partial x}(n_{i-}u_{i-})=0, \tag{3}$$

$$\frac{\partial u_{i-}}{\partial t}+u_{i-}\frac{\partial u_{i-}}{\partial x}-Q\frac{\partial \phi}{\partial x}=0, \tag{4}$$

for streaming electrons,

$$\frac{\partial n_{eb}}{\partial t}+\frac{\partial}{\partial x}(n_{eb}u_{eb})=0, \tag{5}$$

$$\frac{\partial u_{eb}}{\partial t}+u_{eb}\frac{\partial u_{eb}}{\partial x}+\frac{3\sigma_1}{\mu_1}n_{eb}\frac{\partial n_{eb}}{\partial x}-\frac{1}{\mu_1}\frac{\partial \phi}{\partial x}=0, \tag{6}$$

for streaming protons,

$$\frac{\partial n_{ib}}{\partial t}+\frac{\partial}{\partial x}(n_{ib}u_{ib})=0, \tag{7}$$

$$\frac{\partial u_{ib}}{\partial t}+u_{ib}\frac{\partial u_{ib}}{\partial x}+\frac{3\sigma_2}{\mu_2}n_{ib}\frac{\partial n_{ib}}{\partial x}+\frac{1}{\mu_2}\frac{\partial \phi}{\partial x}=0. \tag{8}$$

The plasma electrons obey a nonthermal distribution as (Cairns et al., 1995)

$$n_e=v(1-\beta\phi+\beta\phi^2)\exp\phi. \tag{9}$$

Eqs. (1)–(9) are closed by Poisson equation

$$\frac{\partial^2 \phi}{\partial x^2}=n_e+n_{i-}+n_{eb}-n_{i+}-n_{ib}. \tag{10}$$

In Eqs. (1)–(10) n_s, u_s, and ϕ represent the number densities normalized by $n_{i+}^{(0)}$, u_s indicates to the ions fluid velocities normalized by the ion acoustic speed $C_s=(k_B T_e/m_{i+})^{1/2}$, and ϕ is an electrostatic potential normalized by $k_B T_e/e$. Here, $s=i+, i-, eb, ib$, and e stands for positive ions, negative ions, electron beam, ion beam, and electrons, respectively. The time and space variables are normalized by the positive ion plasma period $\omega_{pi}^{-1}=(m_{i+}/4\pi e^2 n_{i+}^{(0)})^{1/2}$ and the Debye length $\lambda_{Di}=(k_B T_e/4\pi e^2 n_{i+}^{(0)})^{1/2}$, respectively. Furthermore, $n_{i+}^{(0)}$ is the unperturbed number density of positive ions and k_B is the Boltzmann constant. Here, $\mu_1=m_{eb}/m_{i+}$, $\mu_2=m_{ib}/m_{i+}$, $Q=m_{i+}/m_{i-}$, $\sigma_1=T_{eb}/T_e$, and $\sigma_2=T_{ib}/T_e$, where m_s and T_s are the mass and temperature of the s species ($s=i+, i-, eb, ib$, and e). At equilibrium, we have

$$v+\alpha+\gamma=\rho+1, \tag{11}$$

where $v=n_e^{(0)}/n_{i+}^{(0)}$, $\alpha=n_{i-}^{(0)}/n_{i+}^{(0)}$, $\gamma=n_{eb}^{(0)}/n_{i+}^{(0)}$, and $\rho=n_{ib}^{(0)}/n_{i+}^{(0)}$.

To study weakly nonlinear ion-acoustic waves, we use the reductive perturbation method. We introduce the stretched space-time coordinates (Watanabe, 1984)

$$\xi=\varepsilon(x-\lambda t) \quad \text{and} \quad \tau=\varepsilon^3 t, \tag{12}$$

where ε is a smallness parameter measuring the weakness of an amplitude or a dispersion and λ is the nonlinear phase speed normalized by C_s. All the physical quantities appearing in Eqs. (1)–(10) can be expanded as power series in ε around their equilibrium state as follows

$$F=F^{(0)}+\sum_{m=1}^{\infty}\varepsilon^m F^{(m)}, \tag{13}$$

where $F=(n_{i+}, n_{i-}, n_{eb}, n_{ib}, n_e, u_{i+}, u_{i-}, u_{eb}, u_{ib}, \phi)$ and $F^{(0)}=(1, \alpha, \gamma, \rho, v, 0, 0, u_{0eb}, u_{0ib}, 0)$.

Introducing the stretching (12) and expansion (13) into the basic Eqs. (1)–(10), we obtain to the lowest-order in ε

$$n_{i+}^{(1)}=\frac{1}{\lambda^2}\phi^{(1)}, \quad u_{i+}^{(1)}=\frac{1}{\lambda}\phi^{(1)}, \tag{14}$$

$$n_{i-}^{(1)}=-\frac{\alpha Q}{\lambda^2}\phi^{(1)}, \quad u_{i-}^{(1)}=-\frac{Q}{\lambda}\phi^{(1)}, \tag{15}$$

$$n_{eb}^{(1)}=-\frac{\gamma}{\lambda_1^2\mu_1-3\sigma_1\gamma^2}\phi^{(1)}, \quad u_{eb}^{(1)}=-\frac{\lambda_1}{\lambda_1^2\mu_1-3\sigma_1\gamma^2}\phi^{(1)}, \tag{16}$$

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