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Adiabatic Large Amplitude Double Layers in Positively Charged Dusty Plasma

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abstract

Large amplitude double layers are investigated in the case of positively charged dusty plasma. The dust grains provide the inertia and the background plasma is formed of two electron populations hot and cold in thermal equilibrium. Using fluid equations and the pressure balance equation the Sagdeev pseudo-potential is driven in the stationary frame for the adiabatic case. The dependence of the double layers amplitude and Mach number on various parameters such as the hot to cold electrons densities and temperatures ratios have been numerically examined. It is shown that the Mach number increases as the hot to cold electrons temperature increases and for a critical Mach number value the changes on the structure profile are also found.

Introduction

The basic reduced equation governing the pseudo-particles motion in a potential well was given firstly by Sagdeev. He shows that a plasma with cold ions and hot isothermal electrons supports a nonlinear waves[1]. From the suggestion that a nonequilibrium plasma with two or more distinct groups of electrons with different temperature can exists, there has been much interest in the field of dusty plasma with two electron populations. These two different temperatures can be seen as an anisotropic electrons distribution in two perpendicular directions. The electron dynamics characterize the wave higher frequency range of the electrostatic drift waves[2]. In the auroral latitude heating and injection give some time rise to hot electrons. It is possible to have in this plasma environment rarefactions as well as compressions associated with the solitary kinetic Alfven waves[3]. The large amplitude double layers has been investigated for both plasma with three and four components, where the fourth one is a dust grains[4][5]. It was shown that a dusty plasma with two electron populations supports a nonlinear electrostatic waves where the corresponding Mach number depends on both electrons density and temperatures ratios[6]. In this work the adiabatic large amplitude double layers are studied for a dusty plasma with positively charged grains

Basic Equations

Let us consider an unmagnetized dusty plasma with three-component in a collisionless regime. The two distinct electron groups hot and cold are respectively at the temperature T_h and T_c and follows the Boltzmann distribution,

$$n_{ec} = n_{oc}\exp\{\alpha_c\phi\}, \tag{1}$$

$$n_{eh} = n_{oh}\exp\{\alpha_h\phi\}, \tag{2}$$

Where $\alpha_j = T_{eff}/T_{ej}, j = h, c.$ and ϕ the normalized electrostatic potential. The effective temperature is given by $T_{eff} = n_{od}Z_d/(n_{oc}/T_c + n_{oh}/T_h)$. The dynamics of the dust is governed by the following set of normalized equations:

$$\frac{\partial n_d}{\partial t} + \nabla.(n_d v_d) = 0, \tag{3}$$

$$\frac{\partial v_d}{\partial t} + (v_d.\nabla)v_d = -\nabla\phi - \frac{\delta}{n_d}\nabla P, \tag{4}$$

$$\frac{\partial P}{\partial t} + v_d.\nabla P + \gamma P.\nabla v_d = 0. \tag{5}$$

where $\delta = T_d/Z_d T_{eff}$. n_{0j} is the density at equilibrium ($j = d$ dust, $j = c$ cold electrons and $j = h$ hot electrons) and Z_d is the dust charge at equilibrium.

The equation (5) stands for the dust balance pressure equation. We have considered the adiabatic case where $\gamma = 3$. The system is closed by Poisson's equation and the quasi-neutral assumption,

$$\nabla^2\phi = n_{ec} + n_{eh} - n_d, \tag{6}$$

$$n_{oc} + n_{oh} = Z_d n_{od} = n_o \tag{7}$$

We transform to the stationary frame $x = \xi - Mt$, where M is the Mach number, one obtains from Eq.(1-7) the pseudo-particle energy equation

$$\frac{1}{2}\left(\frac{\partial\phi}{\partial\xi}\right)^2 + V(\phi) = 0, \tag{8}$$

Where the Sagdeev potential is given by:

$$\begin{aligned} V(\phi) =& \frac{n_{0c}}{\alpha_c n_0}(1 - e^{\alpha_c\phi}) + \frac{n_{0h}}{\alpha_h n_0}(1 - e^{\alpha_h\phi}) - (M - v_0)^2\frac{\delta_1}{\sqrt{2}}\times \\ & \left\{\left[1 - \frac{2\phi}{(M - v_0)^2\delta_1^2} + \sqrt{(1 - \frac{2\phi}{(M - v_0)^2\delta_1^2})^2 - A}\right]^{1/2} - \left[1 + \sqrt{1 - A}\right]^{1/2}\right\} - B\times \\ & \left\{\left[1 - \frac{2\phi}{(M - v_0)^2\delta_1^2} + \sqrt{(1 - \frac{2\phi}{(M - v_0)^2\delta_1^2})^2 - A}\right]^{-3/2} - \left[1 + \sqrt{1 - A}\right]^{-3/2}\right\}. \end{aligned} \tag{9}$$

where $A = 4\delta_0^2/\delta_1^4$ and $B = 2\sqrt{2}\delta/\delta_1^3$.

The Latter result corresponds to the following boundaries conditions $|\xi| \to \pm\infty$: $n_d \to 1, P \to 1, \phi \to 0, v_d \to v_{od}$ where v_{od} is the equilibrium dust drift speed.

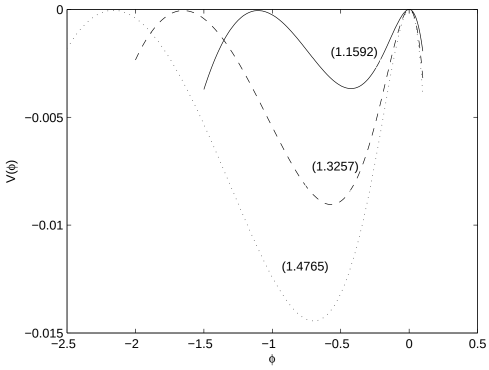

Figure 1: The large amplitude Sagdeev potential. The curves correspond to $T_h/T_c = 20$(—-), $30(---),\ 40(\cdots)$. The parameter labelling is the Mach number.

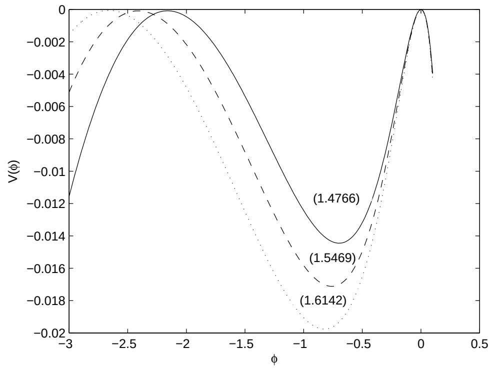

Figure 2: The same as Figure 1 but with $T_h/T_c = 40$(—-), $45(---),\ 50(\cdots)$.

Results and discussions

We seek the large amplitude double layers solution for the equation (8) when the hot electrons are the dominant species in the plasma, such as in the noctilucent clouds during polar summer mesopause. The standard numerical chosen initial values are, hot to cold densities ratio $n_{oc}/n_{oh} = 0.11$, dust charge $Z_d = 1000$ and dust velocity $v_{od} = 0$. In Figure 1 we plot the Sagdeev pseudo-potential versus the electrostatic potential for the different hot to cold temperature ratios. The double layers can be seen as a result of sudden change of the space charge distribution given rise to electrostatic potential with possible negative as well as positive structure. In the present case the negative double layers depends on the Mach number specific choice. The structures exist between two limited values one fixes $\phi_o = 0$ and the second negative limit depends on the temperatures ratio and increases as this ratio increases $|\phi_{max}| = 1,\ 1.5$ and 2.1. respectively for $T_h/T_c = 20,\ 30$ and 40. It is also possible to see the double layers structure for much higher temperature ratios (Fig 2). The dynamics of the grain and the dust pressure are responsible of the enlargement of the electrostatic interval and Mach number values. The result depends on the both hot and cold electron populations. In Figure 3 we have plotted the M^2 versus $|\phi_m|$, we have almost the same profile as the case where there is ion population instead of dust grains[8]. However, the mach number and the corresponding $|\phi_m|$ limit values are much higher in our case. There is no scaling parameters for both the two cases, the normalization is the same. The difference is due to the additional pressure term in which the dust fluid characteristics are introduced. Another significant result is obtained when we keep the same values for all other parameters except the hot (cold) initial density. We observe for the same Mach number the presence of soliton when $N_{oh} \neq 0.6$ (Fig.4)

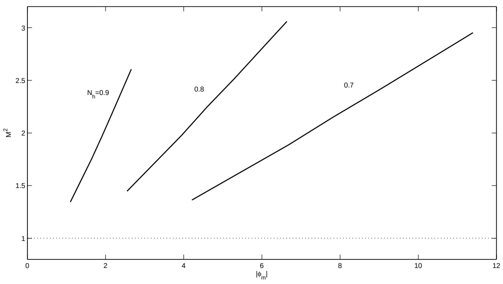

Figure 3: M^2 vs $|\phi_m|$. The parameter labelling the curves is n_{oh}.

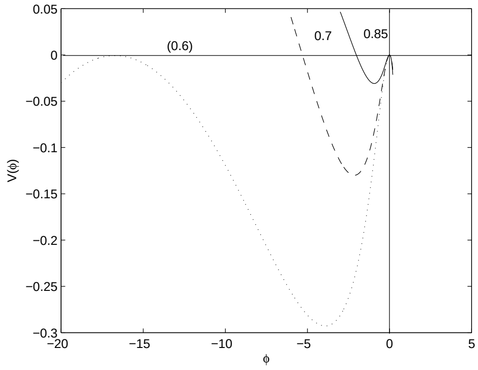

Figure 4: The same as Fig.1 but with $M = 1.598$.

Conclusion

We have investigated the electrostatic non linear waves for a dusty plasma with the presence of hot and cold electron populations. The pressure effect is consider by the pressure balance equation in the adiabatic case. We have found that there is an enlargement of the Mach number values. It is alos found the existence of a density ratio critical value where the double layares structure disepears giving rise to soliton.

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