Modulated Dust-Acoustic Wavepackets in a Kappa-Distributed Nonthermal Plasma Background

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Dust is a ubiquitous component of space and astrophysical environments occurring, for exam- ple, in planetary rings, comets, the Earth's ionosphere, interstellar molecular clouds etc. [1]. Dusty plasmas are known to support new electrostatic/electromagnetic modes, which were pre- dicted theoretically and confirmed experimentally [2, 3]. There are a number of observations which clearly indicate the presence of superthermal electron and ion structures as ubiquitous in a variety of astrophysical plasma environments. Both space and laboratory plasmas may contain a population of superthermal particles, due to which, a high-energy tail appears in the electron/ion distribution function that is conveniently modeled based by the κ-distribution function. The general form of the κ-distribution and its relation to the Maxwellian distribution was first discussed by Vasyliunas [4]. It is also observed that space plasmas can be modeled more effectively by the κ ?distribution than by a superposition of Maxwellian distributions. Therefore, not surprisingly, a large amount of research work has recently focused on the ef- fect of superthermal electrons obeying a κ-type distribution; see e.g. in [5, 6]; also in [7] for technical details. In contrast to earlier models for nonthermal plasmas [8, 9, 10], the dynamics of nonlinear wavepackets against a κ-distributed background have not yet been investigated. In this paper, we study the dynamics of the modulated dust-acoustic wavepackets in a dusty plasma composed of Maxwellian electrons and ions with kappa distribution function. We employ a standard one-dimensional fluid dust model, consisting of the continuity and momentum equations (for the scaled dust fluid reduced density n and velocity u variables) and an adiabatic equation of state for the pressure $p \propto n^3$, for dust-acoustic waves in a dusty plasma containing negative dust (charge $q_d = sZ_d e$, where s$= q_d/|qd| = \pm 1$ is the dust charge sign, either $+$ or $-$), Maxwellian electrons (temperature T_e) and nonthermal ions (charge $q_i = +Z_i e$, temperature T , nonthermality measured by κ). The system is closed by Poisson' s equation $\frac{\partial^2\phi}{\partial x^2} = -s(n-1) + c_1\phi + c_2\phi^2 + c_3\phi^3$ (for the scaled electric potential ϕ), where the right-hand side has been expanded near equilibrium. The coefficients c_1, c_2, c_3, incorporating the essential physics of the problem, are $c_m = -\frac{s}{(\mu-1)Z_d^m}\left(Z_i^m\beta_{im}\frac{T_{\text{eff}}^m}{T_i^m} - \frac{\mu}{m!}\frac{T_{\text{eff}}^m}{T_e^m}\right)$, where we have defined, using charge neutrality at equilibrium, the parameters:

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$$\mu = \frac{n_{e0}}{Z_i n_{i0}} = 1 + s\frac{Z_d n_{d0}}{Z_i n_{i0}}, \qquad \frac{1}{T_{\text{eff}}} = \frac{n_{i0} Z_i^2}{n_{d0} Z_d^2}\frac{1}{T_i} + \frac{n_{e0}}{n_{d0} Z_d^2}\frac{1}{T_e} \equiv \frac{s}{(\mu - 1) Z_d}\left(Z_i \frac{T_e}{T_i} + \mu\right). \quad (1)$$

The small-argument expansion of the κ-distribution [7] provides $\beta_{i1} = \left(\frac{1}{2\kappa_i} - 1\right)$, $\beta_{i2} = \left(\frac{1}{2} - \frac{9}{8\kappa_i^2}\right)$, and $\beta_{i3} = \left(-\frac{1}{6} - \frac{1}{4\kappa_i} + \frac{25}{24\kappa_i^2} - \frac{7}{16\kappa_i^3}\right)$. Note that in the Maxwellian limit, i.e. for $\kappa \to \infty$, $\beta_{im} = (-1)^m/m!(Z_i/k_B T_i)^m$. It is also noticed that $\mu < 1$ for negative dust and $\mu > 1$ for positive dust. Employing the multiple scales method for modulated slowly varying wavepackets [12], we obtain a solution in the form $A = A^{(0)} + \sum_{l=-\infty}^{\infty} \varepsilon^n A^{(n)}$, where harmonic generation is accounted for by assuming $A^{(n)} = \sum_{l=-\infty}^{\infty} \varepsilon^n A_l^{(n)}(X_m, T_m) \exp[il(kx - \omega t)]$. Here A is any of the state variables n, u and ϕ. The dust acoustic wave obeys the dispersion relation $\omega^2 = k^2/(k^2 + c_1) + 3\sigma k^2$. Combining the above, all relevant physical parameters (c_1, c_2, c_3) are expressed via lengthy functions of $\sigma (= T_d/T_{\text{eff}})$, μ, $\theta (= T_i/T_e)$ and κ_i, omitted here for brevity [11]. The appropriate limit is recovered for $\kappa_i \to \infty$ [13, 14]. The method [12] leads to a nonlinear Schrödinger equation

$$i\left(\frac{\partial \phi_1^{(1)}}{\partial T_2} + v_g \frac{\partial \phi_1^{(1)}}{\partial X_2}\right) + P\frac{\partial^2 \phi_1^{(1)}}{\partial X_1^2} + Q|\phi_1^{(1)}|^2 \phi_1^{(1)}, \quad (2)$$

where $P = 1/2\omega''(k)$ is the dispersive coefficient and Q is the nonlinearity coefficient [11]. Preliminary results (announced in this conference) suggest a non-negligible modification of the stability profile of dust-acoustic wavepackets and of associated envelope pulse characteristics. Details will be reported soon [11, 15].

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