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Landau damping of dust acoustic waves in a Lorentzian plasma

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The Landau damping of dust acoustic waves propagating in a dusty plasma modeled by a Lorentzian (kappa) distribution for electrons and ions, and by a Maxwellian distribution for the dust grains is kinetically investigated. The dust acoustic waves are found in the range of $kv_d \ll \omega \ll kv_i \ll kv_e$, where v_α is the thermal velocity of species $\alpha(=i,e,d)$. The damping rate is shown to be dependent on the spectral index κ as well as the ratio of ion density to electron. The maximum Landau damping rate is derived and found to be approximately $0.2\sigma_\kappa\omega_{pd}$ where ω_{pd} is the dust plasma frequency and σ_κ is a κ-dependent factor, which has the maximum value of 1.33 (for the smallest κ) and reduces to unity as the nonthermal effect disappears. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2716661]

I. INTRODUCTION

Non-Maxwellian plasmas are very common in space. Plasmas in space or laboratories can contain a substantial component of high energy particles which can be effectively modeled by a Lorentzian (kappa) distribution.[1,2] The physics of Lorentzian distribution has attracted much attention because of its interesting applications to space and laboratory plasmas that are far from thermal equilibrium. For instance, such distributions have been used to analyze the low-energy electrons in the magnetosphere,[3] electromagnetic ion-cyclotron waves in the equatorial ring protons,[4] Alfvén waves in the solar wind streams,[5] and whistler emission of Jupiter.[6] Numerous theoretical studies on the ion-acoustic mode,[7] electron-acoustic mode,[8] ion-cyclotron-sound mode,[9] and electrostatic surface mode[10] in Lorentzian plasmas have also been reported as well as experimental laboratory observations.[11,12]

Much of the work in this area has been devoted to the Lorentzian electron-ion plasma system without consideration of the effect of dust grains. Most plasma in space, however, coexists with dust grains that are not neutral in general. In the presence of charged dust grains, the modification of low-frequency plasma wave properties is essential because dusts exhibit a response to electric fields, thus producing very low frequency oscillations such as the dust acoustic (DA) mode. A review of dusty plasmas in the solar system has been published by Goertz.[13] The dust acoustic mode was first theoretically considered by Rao *et al.*[14] Subsequently, the low frequency electrostatic waves in magnetized dusty plasma,[15] dust drift waves in nonuniform magnetized dusty plasma,[16] excitation of dust acoustic waves,[17] and boundary effects on dust acoustic waves,[18] have been investigated. In recent years, studies on dusty plasmas in Lorentzian distributions have been reported.[19,20]

Among the many plasma wave phenomena, Landau damping is the most well known process in plasma physics.[21] The Landau damping of dust acoustic waves is well known for a Maxwellian velocity distribution.[22] The Landau damping in a Lorentzian electron-ion plasma has also been reported previously.[23,24] However, the Landau damping of dust acoustic waves in a dusty Lorentzian plasma has not yet been investigated. In this paper, an effort is made to obtain the kinetic modes of electrostatic dust acoustic waves propagating in a dusty plasma modeled by a Lorentzian distribution for electrons and ions, and by a Maxwellian distribution for dust grains.

II. DUST ACOUSTIC DISPERSION RELATION

In order to obtain a dust acoustic wave dispersion relation for Lorentzian electron-ion plasmas and Maxwellian dust grains, we assume a collisionless, unbounded, unmagnetized dusty plasma. The unperturbed state is neutral overall, so its internal electric field is zero. We assume that the curl of the electric field vanishes (i.e., electrostatic), and the perturbation about the equilibrium state is weak. The basic equation for the analysis is the familiar Vlasov equation for a species α with charge q_α and mass m_α given by

$$\frac{\partial}{\partial t}f_\alpha(\mathbf{r},\mathbf{v},t) + \mathbf{v}\cdot\frac{\partial}{\partial \mathbf{r}}f_\alpha + \frac{q_\alpha}{m_\alpha}\left(\mathbf{E}+\frac{1}{c}\mathbf{v}\times\mathbf{B}\right)\cdot\frac{\partial}{\partial \mathbf{v}}f_\alpha = 0 \tag{1}$$

where $\alpha(=e,i,d)$ denotes electron (e), ion (i) or dust particle (d). Now, we shall let our electrons and ions obey the Lorentzian distribution with the spectral index κ $(>3/2)$ which is given by

$$f_{\kappa,\alpha} = n_\alpha\left(\frac{m_\alpha}{2\pi\kappa E_{\kappa,\alpha}}\right)^{3/2}\frac{\Gamma(\kappa+1)}{\Gamma(\kappa-1/2)}\left(1+\frac{\frac{1}{2}m_\alpha v^2}{\kappa E_{\kappa,\alpha}}\right)^{-(\kappa+1)} \tag{2}$$

and dust grains obey the Maxwellian distribution

$$f_d = n_d\left(\frac{m_d}{2\pi T_d}\right)^{3/2} e^{-v^2/v_d^2}. \tag{3}$$

Here, $n_{\alpha(d)}$ is the number density, $v_d=\sqrt{2T_d/m_d}$ is the thermal velocity of the dust grain, $E_{\kappa,\alpha}=[(2\kappa-3)/2\kappa]T_\alpha$ is the characteristic energy, and Γ is the gamma function. The distribution $f_{\kappa,\alpha}$ is the so-called Lorentzian (kappa) distribution and has some interesting features. First, at high velocities, the distribution obeys an inverse power law, and second, for all velocities, the distribution becomes a simple Maxwellian velocity distribution in the limit of $\kappa \to \infty$; i.e., the larger (smaller) the value of κ, the larger (smaller) the proportion of high-energy particles. The equilibrium charge neutrality condition satisfies

$$q_d n_d + q_i n_i - e n_e = 0 \tag{4}$$

where $q_d = Z_d e$ and $q_i = Z_i e$ are the dust particle and the ion charges, respectively. Throughout this paper, we shall assume hydrogen ions, i.e., $Z_i = +1$.

Solving the Vlasov equation requires Poisson's equation:

$$\nabla^2 \phi = -4\pi \sum_{\alpha=e,i,d} q_\alpha n_\alpha. \tag{5}$$

In Eq. (2), no dust charge fluctuation is considered, i.e., $\partial q_d / \partial t = 0$ is assumed. We shall limit our investigation to small perturbation from the equilibrium conditions by writing $f_\alpha = f_{\alpha 0} + f_{\alpha 1}$ and $n_\alpha = n_{\alpha 0} + n_{\alpha 1}$ with $|f_{\alpha 0}| \gg |f_{\alpha 1}|$ and $|n_{\alpha 0}| \gg |n_{\alpha 1}|$, where the subscripts 0 and 1 denote the equilibrium and perturbation, respectively. The number density perturbation is

$$n_{\alpha 1} = \int f_{\alpha 1} d^3 v. \tag{6}$$

If we perform the Fourier transform for Eqs. (1) and (5) and combine them, we obtain

$$\varepsilon_\kappa(k,\omega)\phi = 0 \tag{7}$$

where the dielectric permittivity is given by

$$\varepsilon_\kappa(k,\omega) = 1 + \sum_{\alpha=i,e,d} \chi_\alpha. \tag{8}$$

The procedure for obtaining Eq. (8) is well known and straightforward.[25] The plasma dielectric susceptibility χ_α for the one-dimensional wave propagation in the x-direction can be written in the form

$$\chi_{\alpha(=i,e)} = \frac{\omega_{p\alpha}^2}{k^2} \frac{1}{n_{\alpha 0}} \int \frac{\partial f_{\kappa,\alpha 0}/\partial v_x}{\omega/k - v_x} d^3 v \tag{9}$$

$$\chi_d = \frac{\omega_{pd}^2}{k^2} \frac{1}{n_{d0}} \int \frac{\partial f_{d0}/\partial v_x}{\omega/k - v_x} d^3 v. \tag{10}$$

Using the distributions given by Eqs. (2) and (3), after some algebra, we can derive the longitudinal dielectric permittivity for the dusty plasma as

$$\varepsilon_\kappa(k,\omega) = 1 + \sum_{\alpha=i,e} \frac{1}{k^2 \lambda_\alpha^2} \left(\frac{\kappa}{\kappa - 3/2} \right) \left[\frac{\kappa - 1/2}{\kappa} + \zeta_\kappa Z_\kappa(\zeta_\kappa) \right]_\alpha + \frac{1}{k^2 \lambda_d^2} [1 + \zeta_d Z(\zeta_d)] \tag{11}$$

where $\lambda_\alpha = (T_\alpha / m_\alpha)^{1/2} \omega_{p\alpha}^{-1}$ is the Debye length, $\zeta_\kappa = \omega / \theta_{\kappa\alpha} k$ is the velocity ratio, $\theta_{\kappa\alpha} = [(2\kappa - 3)/\kappa]^{1/2} (T_\alpha / m_\alpha)^{1/2}$ is the thermal velocity in a kappa distribution plasma, and $\zeta_d = \omega / v_d k$.

Here, $Z_\kappa(\zeta_\kappa)$ is the modified plasma dispersion function first introduced by Summers and Thorne,[2]

$$Z_\kappa(\zeta_\kappa) = \frac{1}{\pi^{1/2}} \frac{\Gamma(\kappa+1)}{\kappa^{3/2}\Gamma(\kappa - 1/2)} \int_{-\infty}^{\infty} \frac{dx}{(x - \zeta_\kappa)(1 + x^2/\kappa)^{\kappa+1}}. \tag{12}$$

In the limit of $\kappa \to \infty$, it is easily seen with the aid of Sterling's formula that Z_κ reduces to Z, the usual Maxwellian plasma dispersion function. The asymptotic expansions of $Z_\kappa(\zeta_\kappa)$ are such that

$$Z_\kappa(\zeta_\kappa) = \frac{\kappa!\,\sqrt{\pi} i}{\kappa^{3/2}\Gamma(\kappa - 1/2)} \left[1 - \left(\frac{\kappa+1}{\kappa} \right) \zeta_\kappa^2 + \cdots \right] - \frac{(2\kappa-1)(2\kappa+1)}{2\kappa^2} \zeta_\kappa \left[1 - \left(\frac{2\kappa+3}{3\kappa} \right) \zeta_\kappa^2 + \cdots \right] \quad (|\zeta_\kappa| \ll 1), \tag{13}$$

$$Z_\kappa(\zeta_\kappa) = \frac{\kappa!\,\kappa^{\kappa-1/2}\sqrt{\pi} i}{\Gamma(\kappa - 1/2)} \frac{1}{\zeta_\kappa^{2(\kappa+1)}} \left[1 - \frac{\kappa(\kappa+1)}{\zeta_\kappa^2} + \cdots \right] - \left(\frac{2\kappa-1}{2\kappa} \right) \frac{1}{\zeta_\kappa} \left[1 + \left(\frac{\kappa}{2\kappa-1} \right) \frac{1}{\zeta_\kappa^2} + \frac{3\kappa^2}{(2\kappa-1)(2\kappa-3)} \frac{1}{\zeta_\kappa^4} + \cdots \right] \quad (|\zeta_\kappa| \gg 1). \tag{14}$$

The function $Z(\zeta)$ in Eq. (11) is the well known plasma distribution function defined by

$$Z(\zeta_d) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} \frac{e^{-q^2}}{q - \zeta_d} dq \tag{15}$$

which has the following asymptotic properties:

$$Z(\zeta_d) = -\frac{1}{\zeta_d} - \frac{1}{2\zeta_d^3} - \frac{3}{4\zeta_d^5} - \cdots \quad (|\zeta_d| \gg 1), \tag{16}$$

$$Z(\zeta_d) = -2\zeta_d + \frac{4}{3}\zeta^3 - \frac{8}{15}\zeta^5 + \cdots \quad (|\zeta_d| \ll 1). \tag{17}$$

Our concern is the investigation of dust acoustic modes and the nonthermal effects on the damping of waves. We consider plasma waves in the range where the phase velocity far exceeds the dust thermal velocity but is much less than those of the electrons and ions, i.e., $kv_d \ll \omega \ll kv_i \ll kv_e$. Then, we can use the large argument expansion of $Z(\zeta)$ for the dust grains and the small argument expansion of $Z_\kappa(\zeta_\kappa)$ for the electrons and ions to evaluate Eq. (11). Hence, we find, by the condition that ϕ be nonzero, that the dispersion relation for dust acoustic waves is

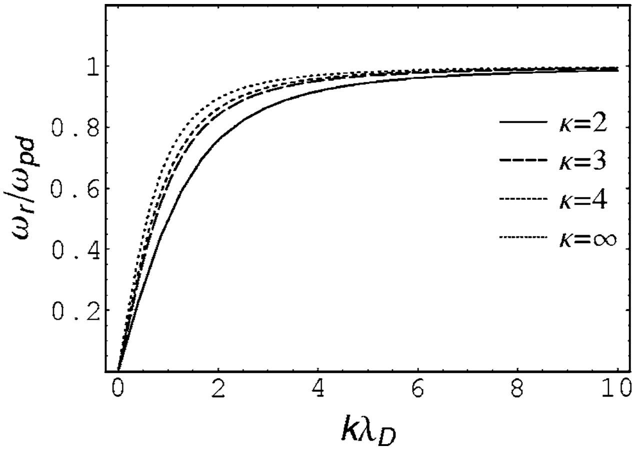

FIG. 1. Normalized frequency of the dust acoustic waves in a dusty Lorentzian plasma as a function of the normalized wave number ($kv_d \ll \omega_r \ll kv_i \ll kv_e$). Curves are drawn for $\kappa=2$ (solid), $\kappa=3$ (dashed), $\kappa=4$ (dotted), and $\kappa \to \infty$ (small dotted; Maxwellian). The Debye length of the dusty plasma is defined as $\lambda_D=(1/\lambda_i^2+1/\lambda_e^2)^{-1/2}$.

$$1+\sum_{\alpha=i,e}\frac{1}{k^2\lambda_\alpha^2}\left(\frac{2\kappa-1}{2\kappa-3}\right)\left[1-\left(\frac{2\kappa+1}{2\kappa-3}\right)\frac{2\omega^2}{k^2v_\alpha^2}+i\sqrt{\frac{2\pi}{(2\kappa-3)}}\frac{\kappa\Gamma(\kappa)}{\Gamma(\kappa+1/2)}\frac{\omega}{kv_\alpha}\right]-\frac{\omega_{pd}^2}{\omega^2}\left(1+\frac{3k^2v_d^2}{2\omega^2}\right)=0. \tag{18}$$

III. LANDAU DAMPING

To obtain the Landau damping rate of a dust acoustic wave, we let $\varepsilon_\kappa(k,\omega)=\varepsilon_\kappa^{\rm re}(k,\omega)+i\varepsilon_\kappa^{\rm im}(k,\omega)$ where $\varepsilon_\kappa^{\rm re}(k,\omega)$ and $\varepsilon_\kappa^{\rm im}(k,\omega)$ are the real and imaginary parts of the dielectric permittivity, respectively. We also let $\omega=\omega_r+i\gamma$, where ω_r and γ are the real and imaginary parts of the frequency, respectively. We assume that $|\varepsilon_\kappa^{\rm re}(k,\omega)| \gg |\varepsilon_\kappa^{\rm im}(k,\omega)|$ and $|\omega_r| \gg |\gamma|$. Then the real part of the dielectric permittivity can be reduced to

$$\varepsilon_\kappa^{\rm re}(k,\omega_r)\approx 1+\sum_{\alpha=i,e}\frac{1}{k^2\lambda_\alpha^2}\left(\frac{2\kappa-1}{2\kappa-3}\right)-\frac{\omega_{pd}^2}{\omega_r^2-3k^2v_d^2/2}. \tag{19}$$

The real part of ω is obtained from $\varepsilon_\kappa^{\rm re}(k,\omega_r)=0$ and is given by

$$\omega_r^2=\frac{\omega_{pd}^2k^2\lambda_D^2}{k^2\lambda_D^2+\left(\dfrac{2\kappa-1}{2\kappa-3}\right)}+\frac{3}{2}k^2v_d^2 \tag{20}$$

where the dusty plasma Debye length is defined as

$$\lambda_D^2=\left(\frac{1}{\lambda_i^2}+\frac{1}{\lambda_e^2}\right)^{-1}=\lambda_i^2\left(1+\frac{n_{e0}T_i}{n_{i0}T_e}\right)^{-1}. \tag{21}$$

Equation (20) is the dispersion relation of dust acoustic waves for Lorentzian electron ion plasmas. The degree of nonthermality corresponds to the values of the spectral index κ. When $\kappa \to \infty$, the result reduces to the well known Maxwellian plasma dispersion relation.[2] For low values of the κ, Eq. (20) is plotted in Fig. 1. We can see that the phase velocity of the wave decreases as the nonthermal characteristics of the distribution increases (i.e., κ decreases); the dust acoustic wave in a dusty Lorentzian plasma is slow compared to that in a dusty Maxwellian plasma. For low values of wave number (long wavelength) the phase velocity v_ϕ of the wave becomes proportional to $\omega_{pd}\lambda_D$ with a κ-dependent factor μ_κ defined by $\mu_\kappa=(2\kappa-3)/(2\kappa-1)$, i.e.,

$$v_\phi=\sqrt{\mu_\kappa}\omega_{pd}\lambda_D. \tag{22}$$

When $\kappa \to \infty$, the value of μ_κ becomes unity to give $v_\phi \approx \omega_{pd}\lambda_D$ which is the Maxwellian case. For high values of the wave numbers (short wavelength), the wave simply oscillates with the frequency $\omega_r \approx \omega_{pd}$.

The imaginary part of dielectric permittivity can take the form

$$\varepsilon_\kappa^{\rm im}(k,\omega_r)\approx\frac{\sqrt{2\pi}\kappa\Gamma(\kappa)\omega_{pd}\left(1+\sqrt{\dfrac{m_eT_i^3}{m_iT_e^3}}\dfrac{n_{e0}}{n_{i0}}\right)}{\Gamma(\kappa+1/2)(2\kappa-3)^{1/2}\left[\mu_\kappa k^2\lambda_i^2+1+\dfrac{n_{e0}T_i}{n_{i0}T_e}\right]kv_i} \tag{23}$$

since $\omega_r \gg kv_d$. Then, the Landau damping of the dust acoustic wave is obtained as

$$\gamma=-\frac{\sqrt{\pi}\mu_\kappa\kappa\Gamma(\kappa)\omega_{pd}^2k^2\lambda_i^2\left(1+\sqrt{\dfrac{m_eT_i^3}{m_iT_e^3}}\dfrac{1}{\delta}\right)}{2\Gamma(\kappa+1/2)(\kappa-3/2)^{1/2}\left(\mu_\kappa k^2\lambda_i^2+1+\dfrac{T_i}{T_e}\dfrac{1}{\delta}\right)^2kv_i} \tag{24}$$

where $\delta=n_{i0}/n_{e0}$ is introduced to replace the ion-electron density ratio. Again, as the spectral index κ goes to ∞, γ reduces to the Maxwellian Landau damping

$$\gamma(\infty)=-\frac{\sqrt{\pi}\omega_{pd}^2k^2\lambda_D^2}{2(k^2\lambda_D^2+1)^2kv_i}\left(1+\sqrt{\frac{m_eT_i^3}{m_iT_e^3}}\frac{1}{\delta}\right) \tag{25}$$

which agrees well with the previous result. If we use the charge neutrality condition given by Eq. (4), the ratio of dust plasma frequency ω_{pd} to ion plasma frequency ω_{pi} can be expressed in terms of δ, so that

$$\frac{\omega_{pd}}{\omega_{pi}}=\left(\frac{m_in_i}{m_dn_d}\right)^{1/2}\left|1-\frac{1}{\delta}\right|. \tag{26}$$

Then the Landau damping rate is rewritten as

$$\gamma=-\sqrt{\frac{\pi}{8}}M_\kappa\left(1+\sqrt{\frac{m_eT_i^3}{m_iT_e^3}}\frac{1}{\delta}\right)\times\left|1-\frac{1}{\delta}\right|\omega_{pd}\frac{k\lambda_i}{\left(\mu_\kappa k^2\lambda_i^2+1+\dfrac{T_i}{T_e}\dfrac{1}{\delta}\right)^2}. \tag{27}$$

If we assume that the dust is negatively charged and $\delta \gg 1$ (high Z_d), the damping rate is simplified to

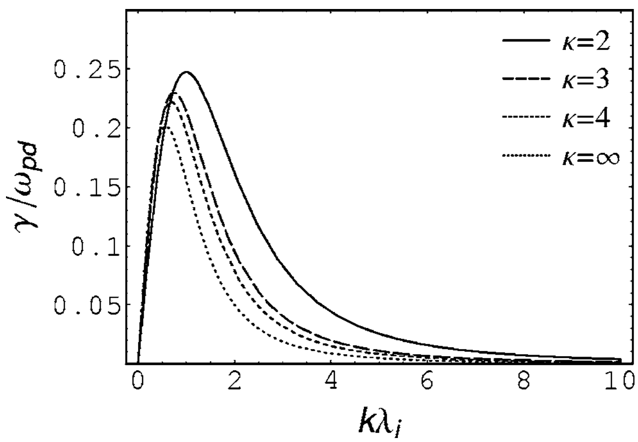

FIG. 2. Normalized Landau damping rate of the dust acoustic waves in a dusty Lorentzian plasma as a function of the normalized wave number ($kv_d \ll \omega_r \ll kv_i \ll kv_e$). Curves are drawn for $\kappa=2$ (solid), $\kappa=3$ (dashed), $\kappa=4$ (dotted), and $\kappa \to \infty$ (small dotted; Maxwellian). In this plot, $\delta=100$, $T_i/T_e=0.1$, $m_i/m_d=10^{-5}$, and $n_i/n_d=10^5$ are assumed.

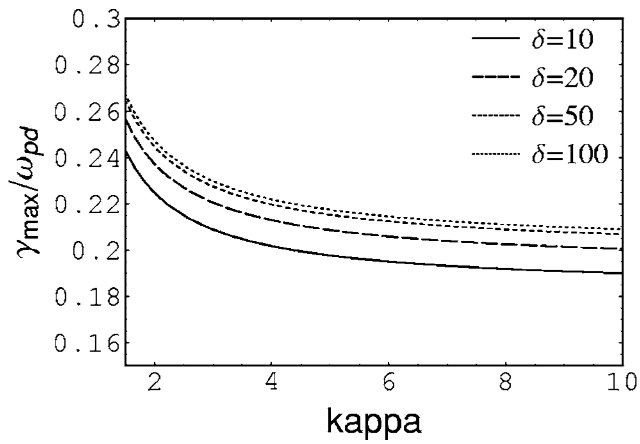

FIG. 3. Normalized Landau damping rate of the dust acoustic waves in a dusty Lorentzian plasma as a function of the spectral index κ. ($kv_d \ll \omega_r \ll kv_i \ll kv_e$). Curves are drawn for $\delta=10$ (solid), $\delta=20$ (dashed), $\delta=50$ (dotted), and $\delta=100$ (small dotted). In this plot, $T_i/T_e=0.1$, $m_i/m_d=10^{-5}$, and $n_i/n_d=10^5$ are assumed.

$$\gamma \approx -\sqrt{\frac{\pi}{8}}\frac{M_\kappa \omega_{pd} k\lambda_i}{(\mu_\kappa k^2\lambda_i^2+1)^2} \quad (28)$$

where M_κ is the κ-dependent factor defined by

$$M_\kappa = \frac{\mu_\kappa \kappa \Gamma(\kappa)}{\Gamma(\kappa+1/2)(\kappa-3/2)^{1/2}}. \quad (29)$$

We note that $0 < M_\kappa < 1$ and $M_\kappa \to 1$ ($\kappa \to \infty$) corresponds to a Maxwellian plasma. For $\delta=100$, $T_i/T_e=0.1$, $m_i/m_d=10^{-5}$, and $n_i/n_d=10^5$, the normalized Landau damping rate, γ/ω_{pd}, as a function of normalized wave number, $k\lambda_i$, is depicted in Fig. 2. The Landau damping increases linearly with $k\lambda_i$ in the long wavelength limit, but it decreases as $(k\lambda_i)^{-3}$ in the short wavelength limit. In this figure, we can compare the dependencies of κ on damping rate vividly. One can observe the tendency where the damping is enhanced as the nonthermality of the distribution increases. The maximum damping rate can be obtained by taking the derivative of γ with respect to the wave number. The result is simple in the case of $\delta \gg 1$,

$$\gamma_{\max} \approx -\sqrt{\frac{\pi}{24}}\frac{9}{16}\frac{M_\kappa}{\sqrt{\mu_\kappa}}\omega_{pd} = -0.203\sigma_\kappa \omega_{pd} \quad (30)$$

where $\sigma_\kappa = M_\kappa/\sqrt{\mu_\kappa}$ is the κ-dependent factor in the range of $1 < \sigma_\kappa < 1.33$.

The maximum value of the damping rate also moves to a larger region of $k\lambda_i$ as the nonthermality increases. In Table I, the values of $k\lambda_i$ and γ/ω_{pd} were calculated for $T_i/T_e = 0.1$, $\delta=100$, and $\kappa=2,3,4,\infty$. The dependence of the maximum Landau damping rate on nonthermality is depicted in Fig. 3 as a function of κ for $T_i/T_e=0.1$, $m_i/m_d=10^{-5}$, $n_i/n_d = 10^5$, and $\delta=10,20,50,100$. In this figure, we observe that the maximum damping is enhanced as the population of the electron density decreases (δ increases), i.e., as the depletion of electron number density due to the charging of the dust grains.

TABLE I. Maximum Landau damping rates ($T_i/T_e=0.1$ and $\delta=100$).

κ	$k\lambda_i$	$\gamma_{\max}/\omega_{pd}$
2	1.04	−0.25
3	0.78	−0.22
4	0.71	−0.22
∞	0.61	−0.20

IV. CONCLUSIONS

We have considered the dust acoustic wave modes propagating in a dusty plasma modeled by a Lorentzian (kappa) distribution for electrons and ions, and by a Maxwellian distribution for dust grains. The dispersion relation of such modes was kinetically investigated by using Vlasov-Maxwell equations. The dust acoustic waves are found in the range of $kv_d \ll \omega \ll kv_i \ll kv_e$. The phase velocities of the dust acoustic waves were obtained for various values of the spectral index κ and the effects of nonthermality were observed. It was found that as nonthermality increases, i.e., κ decreases, the phase velocity of the wave decreases. However, the phase velocity disappears for all values of κ as the wave number increases and the mode simply exhibits the dusty plasma oscillation, ω_{pd}. The Landau damping rate of the dust acoustic mode is derived and investigated for various values of κ. It has been found that the damping is enhanced by the increase of nonthermality, i.e., by the decrease of κ (see Fig. 2). The maximum damping rate is also derived in terms of the spectral index κ and was found to be approximately $0.2\sigma_\kappa\omega_{pd}$ where σ_κ is a κ-dependent factor that reduces to unity as the nonthermal effect disappears (i.e., $\kappa \to \infty$; Maxwellian) and approaches 1.33 as $\kappa \to 3/2$. The maximum damping rates can be enhanced by the decrease of the electron density (see Fig. 3). As can be seen in this work, the Lorentzian plasma distribution can support a greater number of dust acoustic waves than a Maxwellian distribution can. Since dust particles appear to be almost omnipresent in the space, the result can be useful for understanding the nonthermal effects on Landau damping of the dust acoustic waves in dusty Lorentzian plasma regions of planetary rings, comets, or any other space plasma environments. The result can also be applied to interpret the damping of dust acoustic modes or very low frequency noises in laboratory dusty plasmas.

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