

NON-THERMAL EFFECTS ON THE DUST ION-ACOUSTIC SURFACE WAVES IN A SEMI-BOUNDED COMPLEX PLASMA CONTAINING POSITIVE DUST PARTICLES

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Propagation of surface waves on the interface between a vacuum and plasma is kinetically investigated. Since most plasmas encountered in geophysics and astrophysics are not Maxwellian [1], the effects of the superthermal particles on the dust ion-acoustic surface wave are investigated by employing kappa velocity distribution function for the semi-bounded complex plasma containing positively charged dust particles. We assume that the equilibrium plasma is uniform, isotropic, collisionless, unmagnetized, and occupied by the region $z > 0$ (vacuum for $z < 0$). For a species α ($=i, e, d$) containing the superthermal particles, the unperturbed distribution can be effectively modelled by so called kappa velocity distribution function [2]:

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

where n_{α} is the number density, m_{α} is the particle mass, and v_{α} is the velocity of the plasma. $E_{\kappa\alpha} = (1 - 3/2\kappa)T_{\alpha}$ is the characteristic energy with T_{α} being the plasma temperature. Γ is the gamma function and κ ($>3/2$) is the spectral index of the distribution.

If the characteristic lengths of the plasma are much greater than the scale length of the density inhomogeneity, a sharp boundary between a plasma ($z>0$) and a vacuum ($z<0$) can be established so that the specular reflection condition in which the charged particles undergo a mirror reflection such that $f_{\alpha 1}(v_x, v_y, v_z, t, z = 0) = f_{\alpha 1}(v_x, v_y, -v_z, t, z = 0)$, where $f_{\alpha 1}$ is the perturbed plasma distribution of species α , can be utilized for the study of the surface waves. Under this condition, the dispersion relation for dust ion-acoustic surface wave propagating in the x direction (hence $k_y = 0$) whose phase velocity is such that $v_d, v_i \ll \omega/k \ll v_e$, where $v_{\alpha(d,i,e)}$ is the thermal speed of species α , can be obtained as

$$\pi + k_x \int_{-\infty}^{\infty} \left[\left(1 - \frac{\omega_{pd}^2}{\omega^2} - \frac{\omega_{pi}^2}{\omega^2} + \frac{1}{\mu_k k^2 \lambda_e^2} \right)^{-1} - i \frac{\beta_k \omega}{\mu_k k^3 \lambda_e^3 \omega_{pe}} \left(1 - \frac{\omega_{pd}^2}{\omega^2} - \frac{\omega_{pi}^2}{\omega^2} + \frac{1}{\mu_k k^2 \lambda_e^2} \right)^{-2} \right] \frac{dk_z}{k^2} = 0$$

where $\omega_{p\alpha}$ is the plasma frequency of species α , λ_e is the electron Debye length, and the symbols μ_k and β_k are kappa dependent factors defined as

$$\mu_k = \frac{2\kappa-3}{2\kappa-1} \quad \text{and} \quad \beta_k = \sqrt{\frac{\pi}{2\kappa-3}} \frac{\kappa!}{\left(k-\frac{1}{2}\right)!}.$$

We note that $\mu_k = 1$ and $\beta_k = \sqrt{\pi/2}$ correspond to a Maxwellian plasma ($\kappa \rightarrow \infty$).

In the long wavelength limit ($k_x \lambda_e \rightarrow \text{small}$) the wave frequency can be found as $\omega_r \approx \sqrt{\mu_k \left[1 + \frac{\rho_i}{\rho_d} \left(1 - \frac{1}{\delta} \right)^2 \right]} \omega_{pi} k_x \lambda_e$ where ρ_i and ρ_d are the ion and the dust mass density, respectively, and δ is the ion-to-electron number density, i.e., $\delta = n_i/n_e$. If $\delta = 1$, then there is no charged dust particles and we obtain $\omega_r \approx \sqrt{\mu_k} \omega_{pi} k_x \lambda_e$ which agrees to the previous result [3]. In the short wavelength limit ($k_x \lambda_e \rightarrow \text{large}$), we obtain the resonant frequency $\omega_r \approx \sqrt{\frac{1}{2} + \frac{\rho_i}{2\rho_d} \left(1 - \frac{1}{\delta} \right)^2} \omega_{pi}$ which reduces to Alexandrov et al.'s result [4] in the case of no dust. If the dust is positively charged, there will be ion density deficit, thus the value of δ must be less than the unity. Figure 1 shows the scaled phase velocity $(\omega_r/\omega_{pi})/k_x \lambda_e$ of dust ion-acoustic surface waves as a function of the ion-to-electron density ratio δ and the spectral index κ . Here, the scaled wavelength $k_x \lambda_e$ and the ion-to-dust mass density ratio ρ_i/ρ_d are both assumed to be the unity. We observe that as δ decrease, the phase velocity increase. However, the velocity is less sensitive to the spectral index κ especially for $\kappa \gtrsim 5$.

The Landau damping rate also can be obtained by examining the dispersion relation. In the long wavelength limit, the Landau damping rate is linear to the wave number:

$$\gamma \approx -\frac{\mu_k \beta_k}{2} \sqrt{\frac{\delta m_e}{m_i}} \left[1 + \frac{\rho_i}{\rho_d} \left(1 - \frac{1}{\delta} \right)^2 \right] \omega_{pi} k_x \lambda_e$$

which can be further reduced to $\gamma \approx -\sqrt{\pi m_e/8m_i} \omega_{pi} k_x \lambda_e$ that agrees with the previous result [4]. In the short wavelength limit, the dispersion relation gives

$$\gamma \approx -\frac{\beta_k}{8\pi} \sqrt{\frac{\mu_k \delta m_e}{m_i}} \left[1 + \frac{\rho_i}{\rho_d} \left(1 - \frac{1}{\delta} \right)^2 \right] \frac{\omega_{pi}}{\left(\sqrt{\mu_k} k_x \lambda_e\right)^3}$$

which shows that the damping is proportional to the inverse cube of the wave length. Figures 2 and 3 display the variation of the damping rate with δ , κ , and $k_x \lambda_e$.

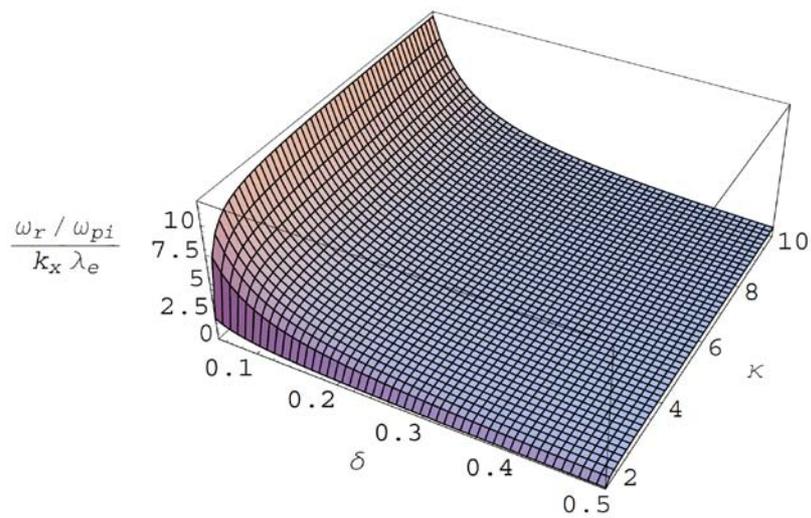


Fig. 1. The scaled phase velocity $(\omega_r/\omega_{pi})/k_x\lambda_e$ of dust ion-acoustic surface waves as a function of the ion-to-electron density ratio δ and the spectral index κ . ($k_x\lambda_e = 1$ and $\rho_i/\rho_d = 1$ are assumed.)

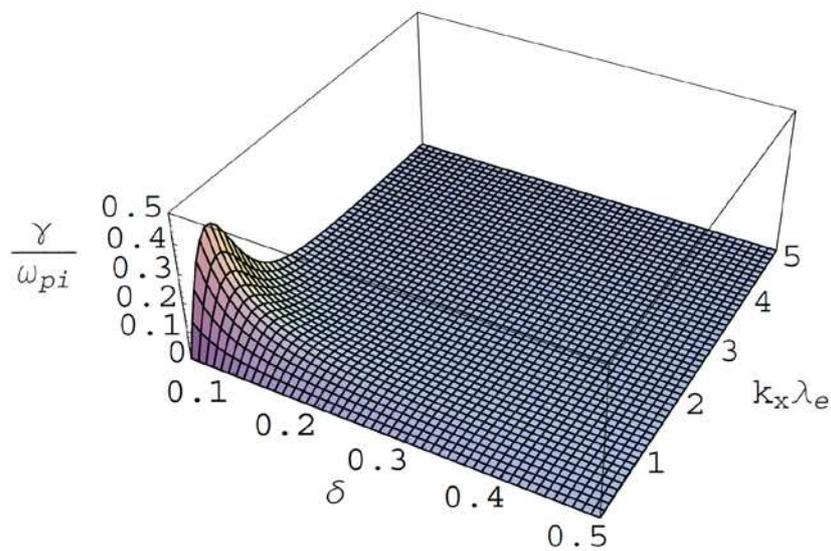


Fig. 2. The scaled phase velocity γ/ω_{pi} of dust ion-acoustic surface waves as a function of the ion-to-electron density ratio δ and the scaled wave number $k_x\lambda_e$. ($\kappa = 3$ and $\rho_i/\rho_d = 1$ are assumed.)

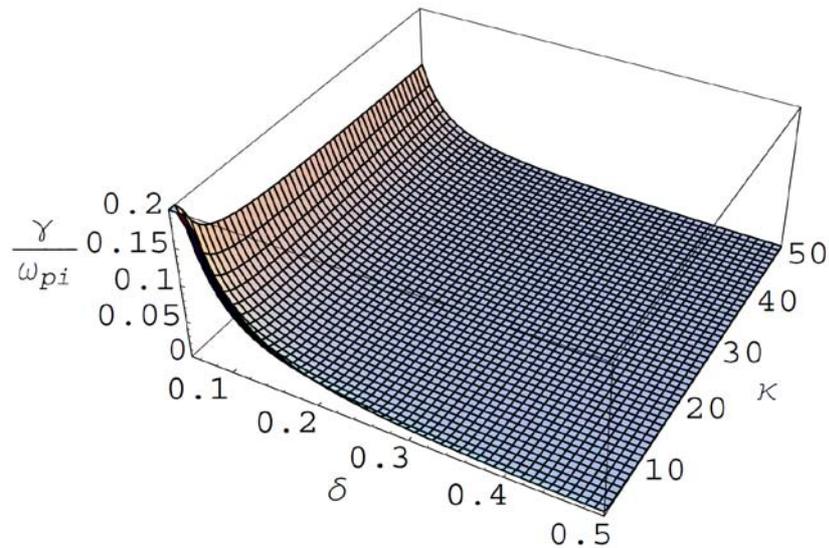


Fig. 3. The scaled phase velocity γ/ω_{pi} of dust ion-acoustic surface waves as a function of the ion-to-electron density ratio δ and the spectral index κ . ($k_x\lambda_e = 1$ and $\rho_i/\rho_d = 1$ are assumed.)

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