Dust grain rotation effects on the dust-acoustic surface wave damping

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The dust grain rotation effects on a damping of the dust-acoustic surface wave are investigated for the semi-bounded kappa plasma including the elongated and rotating dust grains. The growth rate is kinetically derived by employing the Poisson-Vlasov equations and numerically solved for various physical parameters such as the dust rotation angular frequency, the wave number, etc. The result shows that the dust-acoustic surface wave is stable against perturbation.

1. Dispersion relation and the damping rate

Dust grains in astrophysical environments or terrestrial laboratories are of micrometer or submicrometer size and are often negatively charged with a large amount of captured electrons on their surfaces. [1-3] In many literature, dust grains were often assumed to be point charges, hence their geometrical features were neglected. However, the dust grains in space or laboratory are typically non-spherical and sometimes elongated or flattened. The non-spherical dusts can have non-zero dipole moment and can acquire a rotational motion due to the oscillating electric field or due to their interaction with photons or particles of surrounding gas. [4] Therefore, the dispersive properties of dusty plasma should be modified by the influence of the dust rotation.

Meanwhile, plasmas encountered in space and laboratories are not in thermally equilibrium states and often well described by a kappa distribution function because it can effectively represent the properties of the superthermal plasma particles in the high energy tail. [5] The kappa distribution function takes the form:

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

where $n_{0\alpha}$, m_α, v_α, $E_{\kappa,\alpha}$ are the density, the mass, the velocity, and the characteristic energy of species α, respectively. The symbol κ (>3/2) is the spectral index of the kappa distribution and Γ is the gamma function.

For the semi-bounded plasma, we employ the specular reflection boundary condition for the perturbed distribution function:

$$f_{1,\alpha}\left(v_x, v_y, v_z, t, z=0\right) = f_{1,\alpha}\left(v_x, v_y, -v_z, t, z=0\right)$$

Then, the disperion relation for a surface wave propagating along the interface of a plasma occupying z>0 and a vacuum can be obtained from [6]

$$\left(\frac{k_x^2 c^2}{\omega^2} - 1 \right)^{\frac{1}{2}} + \frac{\omega}{\pi c} \int_{-\infty}^{\infty} \frac{dk_z}{k^2} \left[\frac{k_z^2 c^2}{\omega^2 \varepsilon_l(\omega,k)} - \frac{k_x^2 c^2}{k^2 c^2 - \omega^2 \varepsilon_t(\omega,k)} \right] = 0$$

where ω is the wave frequency, c is the speed of light, $k = (k_x^2+k_z^2)^{1/2}$ is the wave number, ε_l and ε_t are the longitudinal and transverse dielectric permittivities, respectively.

The longitudinal dielectric permittivity for a plasma including rotationg dust grain is found as [7]

$$\varepsilon_l = 1 - \frac{1}{k^2 \lambda_D^2 \mu_\kappa} - \frac{\omega_{pd}^2}{\omega^2} - \frac{k_z^2}{k^2} \frac{\Omega_r^2}{\left(\omega - \Omega_0\right)^2}$$

where λ_D is the Debye length, ω_{pd} is the dust plasma frequency Ω_0 is the dust angular frequency, Ω_r is a constant related to the inertial moment of dust and $\mu_\kappa = (2\kappa-3)/(2\kappa-1)$ is a parameter of kappa plasma. Assuming the electrostatical limit and $\omega = \omega_r + i\gamma$ where ω_r and γ is the real and imaginary parts of the wave frequency, respectively, we obtain the dust acoustic surface wave damping rate as

$$\gamma = -\frac{1.538\pi k_x \beta_\kappa \left(\omega_{pi}^2 + \omega_{pd}^2\right) \phi^{-\frac{4}{5}}}{5\mu_\kappa \lambda_e^3 \omega_{pe} \sqrt{\beta^2 - 4\alpha} \left(1 - \frac{2\alpha}{-\beta + \sqrt{\beta^2 - 4\alpha}} + 2\frac{\Omega_r^2}{\Omega_0^2} \right)^2}$$

where

$$\phi = k_x^5 \frac{\left(1 - \frac{2\alpha}{-\beta + \sqrt{\beta^2 - 4\alpha}} + \frac{1}{\mu_\kappa k_x^2 \lambda_e^2}\right)^2}{\left(1 - \frac{2\alpha}{-\beta + \sqrt{\beta^2 - 4\alpha}} + 2\frac{\Omega_r^2}{\Omega_0^2}\right)^2}$$

$$\alpha = -2\frac{\Omega_r^2}{\Omega_0^2} + \frac{1}{\mu_\kappa k_x^2 \lambda_e^2}\left(1 - 2\frac{\Omega_r^2}{\Omega_0^2}\right)$$

$$\beta = -2 - 2\frac{\Omega_r^2}{\Omega_0^2} - \frac{1}{\mu_\kappa k_x^2 \lambda_e^2}$$

$$\beta_\kappa = \sqrt{\frac{\pi}{2\kappa - 3}}\left(\frac{\kappa!}{\kappa - 1/2}\right).$$

2. Numerical results

In this work, the damping rate of electrostatically perturbed dust-acoustic surface wave propagating in a kappa plasma containing elongated and rotating dust grains is investigated. We have found that the wave is stable against the linear perturbation for the full spectrum of the wave number. We also have found that the increase of angular frequency of rotating dust grains can enhance the damping of the wave. Figure 1 illustrates the scaled damping rate (γ/ω_{pd}) for various dust rotational frequencies where the spectral index κ is set to 2. The solid, dotted, dashed, dot-dashed lines are for Ω_r/Ω_0 = 2, 3, 4 and 5, respectively. We observe that as the rotational frequecy is increased, the damping rate is enhanced.

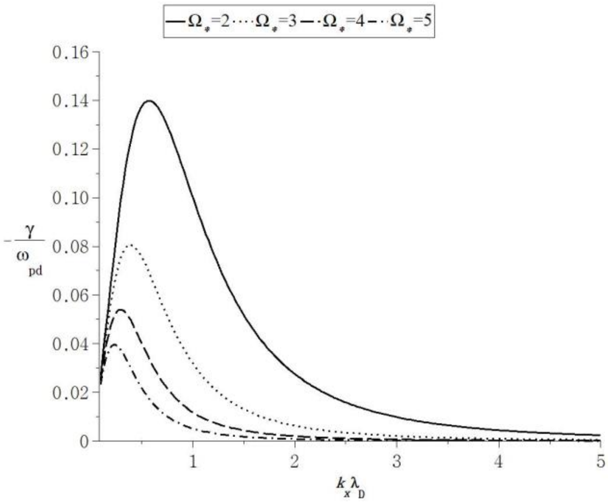

FIG 1. The scaled damping rate of the dust acoustic surface wave are plotted for various dust rotation angular frequencies. The solid, dotted, dashed, dot-dashed lines are for Ω_r/Ω_0 = 2, 3, 4 and 5, respectively, and the spectral index is given as $\kappa = 2$.

3. References

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