Effect of Weakly Nonthermal Ion Velocity Distribution on Jeans Instability in a Complex Plasma in Presence of Secondary Electrons.

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Abstract

In this paper we have investigated the effect of weak nonthermality of ion velocity distribution on Jean's instability in a complex plasma in presence of secondary electrons and negatively charged dust grains. The primary and secondary electron temperatures are assumed equal. Thus plasma under consideration consists of three components: Boltzman distributed electrons, non-thermal ions and negatively charged inertial dust grains. From the linear dispersion relation we have calculated the real frequency and growth rate of the Jean's mode. Numerically we have found that secondary electron emission destabilizes Jean's mode when ion nonthermality is weak.

Introduction.

Dusty or complex plasma has become an emerging field of plasma research for last two decades. Properties of such plasmas have been studied by several authors in laboratory, industrial, space and astrophysical situation [1-3].

Jean's instability in space and astrophysical plasmas is a well known phenomenon. In a self gravitating dusty plasma it has been studied by several authors considering different physical effects[4-8]. Effect of secondary electron emission on Jean's instability in a dusty plasma was first considered by Sarkar et al for both negatively and positively charged dust grains[9-11].

When very small dust grains in cosmic plasmas are irradiated by ultraviolet radiation, sufficiently high energy electrons hit a single dust grain and ionize the dust material resulting in ejection of electrons producing the secondary electron current. This is equivalent to the flow of positive current to the dust surface and is an important phenomenon of astrophysical plasmas where Jean's instability also plays important role [12-14].

In the study of Jean's instability in a dusty plasma in presence of secondary electrons by Sarkar etal both electron and ion behavior were modeled through a Maxwellian [9] or drifted Maxwellian distribution [10,11]. But deviation of ion velocity distribution from Maxwellian is another important characteristic of space and astrophysical plasmas. Jean's instability in presence of non-thermal ion fluxes was first reported by Pillay and Verheest [7] showing that increasing values of critical Jeans wave number, correspond to an increase in the space scale, over which Jean's instability exists but they did not consider the presence of secondary electrons in their study.

In this paper we have investigated Jean's instability in a complex plasma in presence of both secondary electrons and non-thermal ions. Primary and secondary electron temperatures are considered equal. Meyer-Vernet [15] and Goretz [16] proposed that in a Maxwellian plasma due to secondary electron emission from a static dust grain three equilibrium dust charge states exist out of which two are stable and one is unstable. Of these two stable equilibrium charge states one is negative and the other is positive. In this paper electron velocity distribution has been assumed Maxwellian but ions follow nonthermal velocity distribution. So the negative equilibrium value of the dust charge will be shifted towards positive value due to the presence of fast energetic ions, increasing the ion flux to the dust grains. For weak ion nonthermality this shift is small which we have considered in the present paper.

The investigation shows that for weak ion non-thermality Jean's mode decays but magnitude of decay reduces with increasing grain charge fluctuation. For strong secondary electron emission this reduction is faster. Thus increasing rate of secondary electron emission destabilizes Jean's mode when ion nonthermality is weak.

II. Formulation of The Problem:

As the equilibrium dust charge is negative, secondary electrons are emitted without any barrier of attracting potential. Hence primary and secondary electron temperatures are equal. Thus plasma under consideration consists of three components: Boltzmann distributed electrons, nonthermal ions and negatively charged inertial dust grains. The charge neutrality condition then reads as,

$$n_{i0} - n_{eo} - z_{d0} n_{d0} = 0 \tag{1}$$

Where n_{i0}, n_{e0}, n_{d0} are equilibrium number densities of ions, electrons and dust grains and z_{d0} is the number of electrons on dust grain surface.

As the ions are assumed to be nonthermally distributed, a three dimensional equilibrium state ion velocity distribution function satisfying Vlasov equation with population of fast particle is,

$$F_i(v_i) = (\, n_{i0}/(1+3a))(1/2\pi V_{thi}^2)^{3/2}[1 + 4a(v_x^2/2V_{thi}^2 + \Phi/\sigma_i)^2] \exp\left((-(v_x^2 + v_y^2 + v_z^2)/2V_{thi}^2) - \Phi/\sigma_i\right) \tag{2}$$

Where a is the ion nonthermal parameter that determines the number of fast (energetic) ions v_x, v_y, v_z are the three components of ion velocity v_i, $v_{thi} = \sqrt{T_i/m_i}$ is the ion thermal velocity, $T_i(T_e)$ is the ion(electron) temperature, m_i is the ion mass and $\Phi = e\varphi/T_e$, $\sigma_i = T_i/T_e$, φ is the electrostatic potential. In the presence of nonzero potential Φ, integration of the distribution function (2) gives the following ion number density [17],

$$n_i = n_{i0}[1 + (4a/(1+3a))(\Phi/\sigma_i + \Phi^2/\sigma_i^2)]\exp(-\Phi/\sigma_i) \tag{3}$$

The electrons are assumed to follow Maxwellian velocity distribution, so the electron number density is,

$$n_e = n_{e0}\, exp(\Phi) \tag{4}$$

The warm dust fluid component is modeled by the one dimensional continuity and momentum equations,

$$(\partial n_d/\partial t) + \partial(n_d v_d)/\partial x = 0 \tag{5}$$

$$(\partial v_d/\partial t) + v_d\,(\partial v_d/\partial x) = -(q_d/m_d)(\partial\phi/\partial x) - (T_d/m_d n_d)(\partial n_d/\partial x) - (\partial\psi/\partial x) \tag{6}$$

Here n_d, m_d, v_d, q_d and T_d represent dust number density, mass, velocity, charge and temperature of dust grains, ψ represent the gravitational potential.

The variable dust charge q_d satisfies the grain charging equation,

$$(\partial q_d/\partial t) + v_d(\partial q_d/\partial x) = I_e + I_i + I_e^s = I_{tot} \tag{7}$$

Where I_e and I_i are respectively the dust charging currents due to due to flow of Boltzmann distributed primary electrons and nonthermal ions to the dust surface and I_e^s is the secondary electron current flowing out of the dust surface.

$$I_i = \pi r_0^2 e(8\mathrm{Ti}/\pi m_i)^{1/2}(n_{i0}/(1+3a))[((1+24a/5) + 16a\Phi/3\sigma_i + 4a\Phi^2/\sigma_i^2) - eq_d/r_0 T_e\sigma_i((1+8a/5) + 8a\Phi/3\sigma_i + 4a\Phi^2/\sigma_i^2)]\exp(-\Phi/\sigma_i) \tag{8}$$

$$I_e = -\pi r_0^2 e(8T_e/\pi m_e)^{1/2} n_{e0}\exp(\Phi)\exp(eq_d/r_0 T_e) \tag{9}$$

$$I_s^e = \pi r_0^2 e 3.7\delta_M(8T_e/\pi m_e)^{1/2} n_{e0}\exp(\Phi)\exp(eq_d/r_0 T_e)F_5(E_M/4T_e) \tag{10}$$

where r_0 is the grain radius.

Equilibrium dust charge state is given by, $I_{tot}(q_d = q_{d0}, \Phi = 0) = 0$, where $q_{d0} = -z_{d0}e$ is the equilibrium charge on the dust surface and ϕ is the plasma potential. Substituting $(I_i)_{eq}$, $(I_e)_{eq}$ and $(I_e^S)_{eq}$ from [8]-[10] with $q_{d0} = -z_{d0}e$, $n_i = n_{i0}$, $n_e = n_{e0}$ at $\Phi = 0$, we obtain

$$(n_{i0}/n_{e0}) = (m_i/m_e\sigma_i)^{1/2}(((5+15a)/(5+8a))/((z_0/\sigma_i)+((5+24a)/(5+8a)))e^{-z_0}\alpha_{1s} \tag{11}$$

where $\alpha_{1s} = 1 - 3.7\delta_M F_5(x)$, $z_0 = z_{d0}e^2/aT_e$, $x = E_M/4T_e$ and δ_M is the maximum secondary electron yield.

The dust charging frequency $\nu_{ch} = (\partial I_{tot}/\partial q_d)_{eq}$ we have been calculated in the form,

$$\nu_{ch} = (r_0/\sqrt{2\pi})(\omega_{pi}^2/V_{thi})((5+8a)/(5+15a))[1+z_0+((5+24a)/(5+8a))\sigma_i] \tag{12}$$

where ω_{pi} is the ion plasma frequency. Other parameters are already defined. The equations [3]-[7] are closed with the following poisson equations satisfied by the electrostatic potential Φ and the gravitational potential ψ ,

$$(\partial^2\Phi/\partial x^2) = -(1/\epsilon_0)(en_i - en_e + q_d n_d)\,, \quad (\partial^2\psi/\partial x^2) = 4\pi G m_i(n_d - n_{d0}) \tag{13}$$

We have neglected the gravitational effects of ions and electrons. It is to be noted that for a gravitational plasma, the assumption of an equilibrium value n_{d0} of the dust number density n_d is a consequence of what is known as Jean's swindle.

III. Dispersion Relation:

Considering perturbation $(\delta n_e, \delta n_i, \delta n_d, z_{d0}eq_1) \sim exp i(kx - \omega t)$ about the equilibrium state $(n_{e0}, n_{i0}, n_{d0}, -z_{d0}e)$ equation [7] along with [8)]-[10] yields,

$$q_1 = (\beta_d/(1 - i\omega/\nu_{ch}))((\alpha + \beta z_0/\sigma_i)/(z_0 + ((5+24a)/(5+8a)))\Phi \tag{14}$$

where $\beta_d = [z_0 + ((5+24a)/(5+8a))]/[z_0(1 + z_0 + ((5+24a)/(5+8a))]$ (15a)

$$\alpha = ((8a - 15) - (15 + 72a)\sigma_i)/(15 + 24a)\ , \ \beta = ((16a - 15) - (15 + 24a)\sigma_i)/(15 + 24a) \tag{15b}$$

From [3] ion density fluctuation δn_i , from [4] electron density fluctuation δn_e and from [5], [6], [13]. dust density perturbation δn_d are given by,

$(\delta n_i/n_{i0}) = ((a-1)/(1+3a))(\Phi/\sigma_i)$, $n_e/n_{e0}) = \Phi$, $(\delta n_d/n_{d0}) = -k^2c_{da}^2\Phi/(\omega^2 + \omega_{Jd}^2 - k^2V_{td}^2)$ (16)

Here $c_{da} = \sqrt{z_{d0}T_e/m_d}$ is the dust acoustic speed, $\omega_{Jd} = \sqrt{4\pi G m_d n_{d0}}$ is the Jean's frequency and $V_{td} = \sqrt{T_d/m_d}$ is the dust thermal speed.

Substituting [14]and [16] in the linearized Poisson equation we obtain the following dispersion relation in the long wavelength limit $k^2\lambda_e^2 \ll 1$ for dust acoustic waves in a self gravitating complex plasma in presence of non thermal ions and secondary electrons.

$$(\omega^2 + \omega_{Jd}^2 - k^2V_{td}^2)[1 + ((1-a)/(1+3a))(n_{i0}/n_{e0})(1/\sigma_i) - (z_{d0}n_{d0}/n_{e0})(\beta_d/(1 - i\omega/\nu_{ch}))((\alpha + \beta z_0/\sigma_i)/(z_0 + ((5+24a)/(5+8a))\sigma_i) - (z_{d0}n_{d0}/n_{e0})k^2c_{da}^2] = 0 \quad (17)$$

This shows that real part ω_r of the wave frequency $\omega = \omega_r + i\omega_i$ is given by,

$$(\omega_r^2/k^2c_{da}^2) = \sigma_d - (\omega_{Jd}^2/k^2c_{da}^2) + [(z_{d0}n_{d0}/n_{e0})/(1 + (1-a)/(1+3a))(n_{i0}/n_{e0})(1/\sigma_i) - \overline{\beta_d})] \quad (18)$$

$$\sigma_d = (V_{td}^2/c_{da}^2)\ ,\ \overline{\beta_d} = (z_{d0}n_{d0}/n_{e0})(\beta_d((\alpha + \beta z_0/\sigma_i)/(z_0 + ((5+24a)/(5+8a))\sigma_i)) \quad (19)$$

Which can be written in the form, $\omega_r^2 = \Omega_{\mathrm{d}}^2k^2c_{da}^2 - \omega_{Jd}^2$

where

$$\Omega_{\mathrm{d}}^2 = \sigma_d + [((n_{i0}/n_{e0}) - 1)/(1 + (1-a)/(1+3a))(n_{i0}/n_{e0})(1/\sigma_i) - \overline{\beta_d})] \quad (20)$$

The decay rate or growth rate of the dust acoustic mode being,

$$W_i = (z_{d0}n_{d0}/n_{e0})^2\beta_d\ /[(1 + (1-a)/(1+3a))(n_{i0}/n_{e0})(1/\sigma_i) - \overline{\beta_d})^2(z_0 + ((5+24a)(5+8a))\sigma_i)] \quad (21)$$

Where $W_i = \nu_{ch}\omega_i/k^2c_{da}^2$

IV. Numerical Estimation:

For negatively charged dust grains equation [1] gives us the condition $(n_{i0}/n_{e0}) > 1$. From equation [11] we have obtained the range of z_0 for the non-thermal parameter a =0.5 and ion-electron temperature ratio $\sigma_i = .01$. Numerical values of $\alpha_{1s} = 1 - 3.7\delta_M F_5(x)$ have been chosen 1 for $\delta_M = 0$ and 0.7, 0.4 for $\delta_M \neq 0$. Decreasing values of α_{1s} indicate increasing strength of secondary electron emission. The graphs of $W_i = \nu_{ch}\omega_i/k^2c_{da}^2$ and Ω_d^2 have been plotted against $z_0 = (z_{d0}e^2/aT_e)$. Fig. [1] shows that for a=0.5, Jean's mode decays. Magnitude of decay reduces with increasing values of z_0. This reduction is faster when $\alpha_{1s} = 0.4$. Moreover magnitude of decay is lower for lower values of α_{1s} i.e. for higher values of secondary electron yield δ_M. Ω_d^2 has been plotted against z_0 in fig. [2] with same parameters and $\sigma_d = 0.15$ which shows that Ω_d^2 and hence ω_r^2 is lower for lower values of α_{1s}. This indicates destabilization of Jean's mode with increasing secondary electron emission when ion nonthermality is weak.

V. Concluding Remark:

Effect of secondary electron emission on Jean's instability has been investigated in this paper in presence of nonthermal ions and negatively charged dust grains. Real frequency and growth rate of the Jean's mode have been calculated. Numerically it has been shown that for weak ion nonthermality secondary electron emission destabilizes Jean's mode when equilibrium dust charge is negative.

VI. References:

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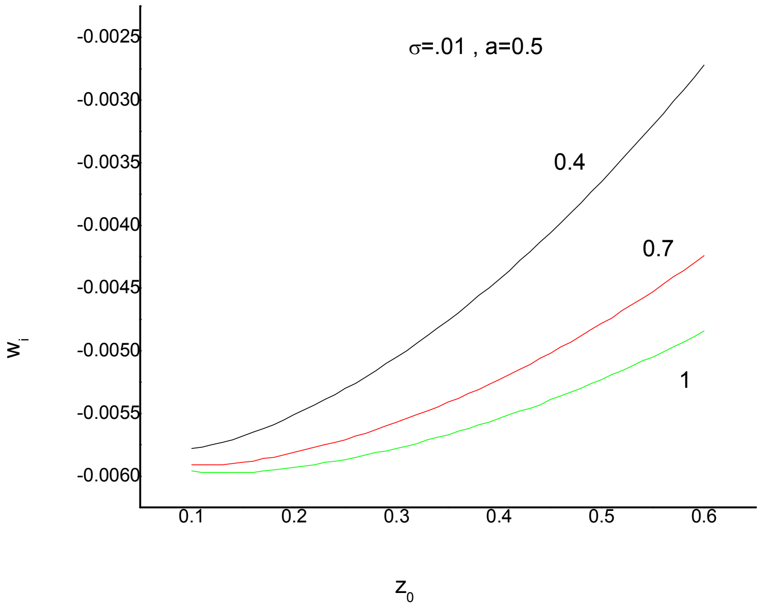

Fig. 1. Plot of the normalized imaginary frequency w_i against z_0 for different plasma parameters.

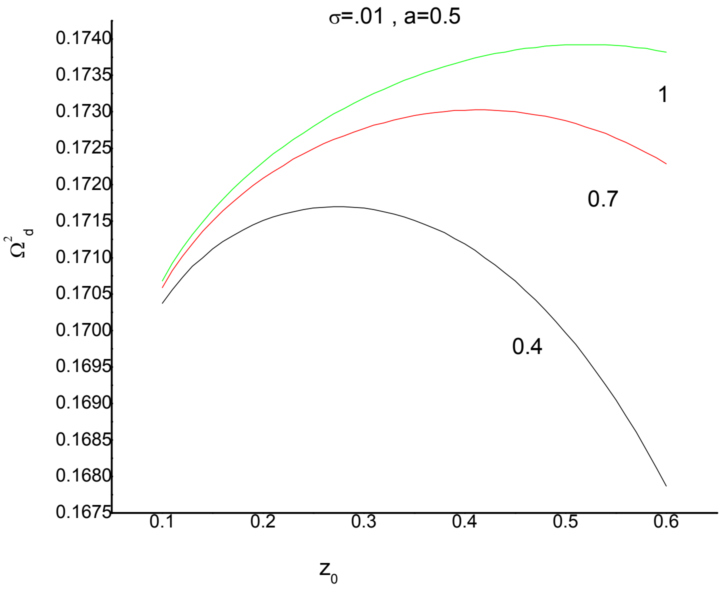

Fig. 2. Plot of Ω_d^2 against z_0 for different plasma parameters.