Effect of Photoelectron Current on Jeans Instability of Rotating Quantum Dusty Plasma

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Abstract. The influence of Photoelectron current and rotation of dusty plasma is studied with the inclusion of Quantum effect. The fluid model of dusty (complex) plasma is considered with the dynamics of charged dust along with the Boltzmann distributed ions. The General dispersion relation is derived analytically using the plane wave solution. The Joint effect of Photoelectron current (depends upon irradiated frequency) and rotation is examined on the modified Jeans instability. The Growth rate of the system is analysed with graphical presentation. It is observed that Photoelectron current has destabilizing influence while rotation has stabilizing influence on the growth rate of instability.

INTRODUCTION

A Dusty plasma is a complex system because of the variation of dust grain charge, mass and size with space and time. It exhibits new and unusual behavior, and provides a possibility for modified or entirely new collective modes of oscillation and instabilities. In astrophysics, dusty plasma has application in understanding the formation of dust clusters and structures, planetary rings, interstellar media(ISM), protostar formation, cometary tails, nebulae and magnetospheres,etc.[1-4].Complex system has exciting features dealt with the instabilities and wave modes.[5,6].

The dusty plasma is a recent branch of plasma physics with various application [7].In complex plasma the variation in dust charge produces charging current which is responsible for the modifications of the dynamics of dust particles. There are large numbers of complex plasma systems where dust charge fluctuation occurs due to different plasma processes. In this direction Pandey et al. [8] have discussed the instabilities in the presence of grain charge fluctuation. Schneider et al.[9] have derived dispersion relation of electrostatic waves in a Maxwellian dusty plasma with variable charge on dust particles.

However, when dusty plasma is cooled to extremely low temperatures the de Broglie wavelength of the charge carriers could be comparable to the dimension of the system and so quantum mechanical effects are expected to play an important role in the behavior of charged particles. The importance of quantum mechanical effects in dense astrophysical systems has been recognized [10].In Verheest and Meuris[11] work, they have observed Whistler-like instability due to dust charge fluctuation in dusty plasma. Dust acoustic waves in quantum plasma studied by Shukla et al.[12]Therefore, the consideration of dust charge fluctuation and quantum mechanical effects in gravitating, astrophysical dusty plasma could be important to discuss.

In addition to this ,in space, photoelectron emission is often the dominant charging mechanism from dust grains exposed to UV rays[13].In this direction recently Prajapati et al.[14] has discussed the effect of dust charging on the Jeans instability. Also Zainab A. Mankhi[15] have studied the effect of UV rays on dust charging process. But none of the above authors has discussed the effect of photoelectron current on growth rate of instability of dusty plasma. So in present work we have considered the combined effects of photoelectron current and rotation of self gravitating quantum dusty plasma. The results are useful in understanding the formation of dense dusty molecular clouds.

FORMULATION OF THE PROBLEM

We consider three component plasma having charged dust grain with Boltzmann distributed thermal ions and electrons

At the slow dust time scale, the ion densities are expressed by Maxwell-Boltzmann relation

$$n_i = n_{i0} exp\left(\frac{-e\phi}{T_i}\right) \tag{1}$$

The dynamics of inertialess electrons are expressed as

$$-\nabla p_e + e n_e \nabla\phi = 0 \tag{2}$$

The modified dust fluid momentum equation is

$$m_g n_g \frac{d\boldsymbol{v}_g}{dt} = -T_g \nabla n_g - Q n_g \nabla\phi - m_g n_g \nabla\psi + 2 m_g n_g (\boldsymbol{v}_g \times \Omega) + \frac{\hbar^2}{4 m_g} \nabla(\nabla^2 n_{g1}) \tag{3}$$

Where $\boldsymbol{v}_g, m_g, T_g, \phi, \psi$ *and* Ω denotes the fluid velocity, dust mass, Temperature, electrostatic and gravitational potential and rotation of dust grains. The last term in equation (3) is due to the quantum effect.

The mass transfer or the continuity equation can be expressed as

$$\frac{\partial n_g}{\partial t} + \nabla.(n_g \boldsymbol{v}_g) = 0 \tag{4}$$

The poisons equations for electrostatic and gravitational potential are

$$\nabla^2\phi = 4\pi e[n_e - n_i] - 4\pi Q n_g \tag{5}$$

Where Q is grain charge, and

$$\nabla^2\psi = 4\pi G m_g n_g \tag{6}$$

The current balance equation for charge fluctuation is

$$\frac{dQ}{dt} = I_e(Q,\phi) + I_i(Q,\phi) + I_{pe} \tag{7}$$

WhereI_e, I_i are the electron and ion equation and $I_{pe}$is the photoelectron current expressed as

$$I_{pe} = \pi a^2 e n_e \sqrt{\frac{2\,(h v_p - e W_0)}{m_e}} \tag{8}$$

Where W_0 is the work function , a is grain radius and v_p is the irradiated frequency.

LINEARIZED EQUATIONS AND DISPERSION RELATION

The perturbation is subjected to the oscillating wave function which is described using the normal mode analysis. The physical variables are represented as sum of their equilibrium(subscript'0') and perturbed(subscript'1') part as vg =vg0+vg1,ng=ng0+ng1,ϕ=ϕ0+ϕ1 and ψ=ψ0+ψ1,Q=Q0+Q1.Thus the linearized form of the momentum equation and perturbed dust charge are

$$\frac{\partial \boldsymbol{v}_{g1}}{\partial t} = -C_g^2 \frac{\nabla n_{g1}}{n_{g0}} - \frac{Q_0}{m_g}\nabla\phi_1 - \nabla\psi_1 - \frac{Q_1 \nabla\phi_1}{m_g} + 2(\boldsymbol{v}_g \times \boldsymbol{\Omega}) + \frac{\hbar^2}{4 m_g n_{g0}} \nabla(\nabla^2 n_{g1}) \tag{9}$$

Let us substitute the values of $n_{i1}, Q_1, n_{g1}, n_{e1}$ from equation (1)-(9) in following equation

$$\nabla^2\phi_1 = 4\pi e[n_{e1} - n_{i1}] - 4\pi Q_1 n_{g0} - 4\pi Q_0 n_{g1} \tag{10}$$

to yields the following dispersion relation

$$\omega^2 - C_g^2 k^2 + \omega_j^2 - 2ik\left(\frac{\omega}{\boldsymbol{k}} \times \boldsymbol{\Omega}\right) = \frac{4\pi n_{g0} k^2 Q_0^2}{m_g\left(\frac{1}{\lambda_D^2} + 4\,\pi n_{g0} \frac{|I_{Pe0}|}{\eta T_{e0}} e\right)} \tag{11}$$

Where

$$\lambda_D^2 = \lambda_e^2 \lambda_i^2 / \lambda_e^2 + \lambda_i^2 \text{ and } C_g^2 = T_g / m_g$$

Equation (11) represents the modified dispersion relation of gravitating dusty plasma incorporating effects of dust charge fluctuation due to irradiated frequency of photons with rotation.It is clear from the term Ipe0 in equation (11) that photoelectron current plays an important role in dust charge fluctuation hence in Jeans instability.

DISCUSSION OF DISPERSION RELATION

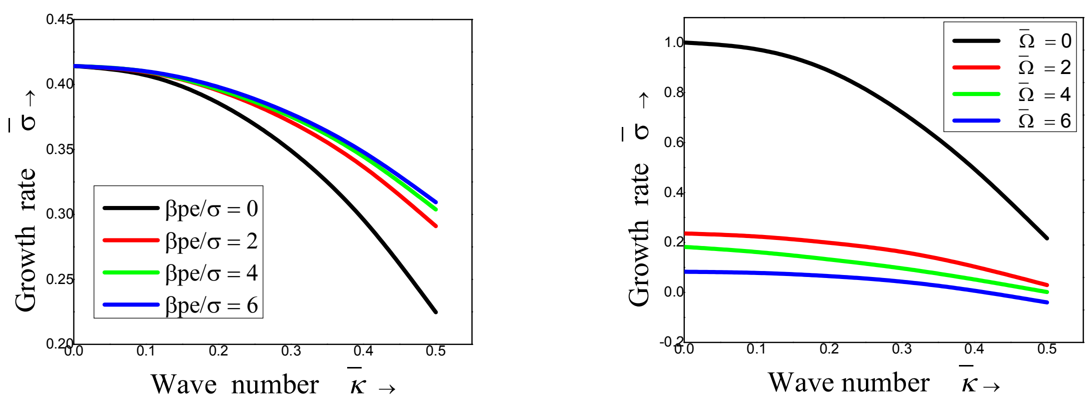
The modified form of equation(11) after substituting iω=σ is

$$\sigma^2 + 2\sigma\Omega\sin\theta + \left[C_g^2 + \frac{\omega_{pd}^2}{\frac{1}{\lambda_D^2} + \frac{1}{\lambda_{De}^2}.\frac{\beta_{pe}}{\sigma}}\right]k^2 - 4\pi G n_{g0} m_g = 0 \qquad (12)$$

Where ω2pd=4πng0Qo2/mg and βpe= IIpe0Ingo/ene0.

The expression of critical Jeans wavenumber modified due to photoelectron current is given by

$$k < k_j = \sqrt{4\pi G n_{g0} m_g}\left[C_g^2 + \frac{\omega_{pd}^2}{\frac{1}{\lambda_D^2} + \frac{1}{\lambda_{De}^2}.\frac{\beta_{pe}}{\sigma}}\right]^{-1/2} \qquad (13)$$



(a)

(b)

FIGURE 1. Figure 1(a)-Growth rate of Jeans instability$(\bar{\sigma})$ versus normalized wavenumber $(\bar{k})$ for $\beta_{pe0}/\sigma =$ 0.0,2.0,4.0,6.0 respectively. The constant parameters are chosen as $\bar{C}_g = \bar{C}_S = \bar{\Omega} = 1.0$.Figure1(b) - Growth rate of Jeans instability$(\bar{\sigma})$ versus normalized wavenumber $(\bar{k})$ for $\bar{\Omega} =$ 0.0,2.0,4.0,6.0 respectively. The constant parameters are chosen as $\bar{C}_g = \bar{C}_S = 1.0, \frac{\beta_{pe}}{\sigma} = 0$.

The nondimensional form of equation(12) is given by following equation

$$\bar{\sigma}^2 + 2\bar{\sigma}\bar{\Omega} + \left[\bar{C}_g^2 + \frac{\bar{C}_s^2}{1 + \frac{\beta_{pe}}{\sigma}}\right]\bar{k}^2 - 1 = 0 \qquad (14)$$

Where

$$\bar{\sigma} = \frac{\sigma}{\omega_j}, \bar{\Omega} = \frac{\Omega}{\omega_j}, \bar{C}_g = \frac{C_g k_j}{\omega_j}, \bar{C}_s = \frac{C_s k_j}{\omega_j}, \bar{k} = \frac{k}{k_j}$$

In Figure.1 (a), the real roots of growth rate $(\bar{\sigma})$ are plotted against normalized wavenumber $(\bar{k})$ for different values of βpe0/σ. where βpe0 is the effective detachment frequency of photo electrons from the dust grains. It is clear from the graph that as the ratio β_{pe0}/σ increases the growth rate of Jeans instability also increases. Thus dust charging effects due to photoelectrons have destabilizing influence on the growth rate. Hence gravitational collapse is affected due to the presence of dust charge fluctuation. Also in Figure1 (b) a graph between real roots of growth rate ($\overline{\sigma}$) and normalized wavenumber ($\overline{k}$) is plotted for different values of $\overline{\Omega}$.It can be seen from Figure 1(b) that roataion has stabilizing influence on growth rate of instability.

CONCLUSION

We have analyzed the combined influence of photoelectron current and rotation on self gravitating quantum dusty plasma. The normal mode analysis technique is used to derive a dispersion relation which is modified owing to the inclusion of photoelectron current, rotation and other prameters.We find that condition of Jeans instability and expression of critical Jeans wavenumber both have been modified due to these parameters. The photoelectron current increases the critical Jeans wavenumber(decreases the critical Jeans length).From the graphical representations, it is observed that the photoelectron current have destabilizing influence while rotation has stabilizing influence on the growth rate of Jeans instability.

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