Low Frequency Waves and Instability in Magnetized Radiative Dusty Plasma

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Abstract. The wave modes and the stability of a magnetized viscous self-gravitating plasma system with Maxwellian distribution of ions and radiative effect of electrons, charge gradient force and polarization force is theoretically analysed. The investigation is carried out with a theoretical model dealing with ions, electrons and dust grains to bring forth a dispersion relation defining the characteristics of the plasma by the normal mode analysis method. The dispersion relation is examined to understand the wave modes propagating longitudinally and transversely (along the direction of the magnetic field) with their significance. Numerical calculations and graphical interpretations are also included to support the results. Applications based on the interstellar clouds can utilize the result from the study.

I INTRODUCTION

The radiative heat-loss mechanism has a significant role in the structure formation and condensation process, proved by the observations of the interstellar medium phenomena [1].The heat loss by the radiative mechanism can be defined by the radiative heat-loss function that shows heat loss from an embedded system in comparison with the local temperature and density. [2] Moreover the relation between the X-ray luminosities and the temperature shows a steep increase towards the lower temperatures implying the effect of the non-gravitational processes such as radiative cooling,which progressively affects the structure of the ambient medium as the decline of the confining gravitational potential takes place as observed by Voit et al. [3]. Avinash et al. [4] showed that the charged dust grains play a major role to make the system stable. If the critical mass is greater than the mass of the cloudthen the collapse does not take place due to self-gravitation, but the structure formation process is fastened by radiative cooling[5].Gilden[6] has discussed about radiative effect and thermal instability in the study of small scale structure formation. Kopp and Shchekinov [7]analysed the radiative effect in multi-fluid dusty plasma.The effect of polarization, effects of radiative coolingof electronand self-gravitation have been done by Sharma and Jain[8] to study instability of partially ionized dusty plasma. These works of radiative condensation and self-gravitation have considered the charge to remain constant on the dust particles. But the highlymobile plasma species can accumulate over thelarge dust grains and gradually increase the charge on the dust particulates.Khrapak et al., [9] has pointed out that if the dust charge is not constant then there arises a force termed as charge gradient force. Consequently the influence of a charge-gradient force, associated with variations of the particle charge in response to external perturbations, on the propagation of low-frequency waves in weakly coupled dusty plasmas was documented by Khrapak et al.[10]. Many investigators have based their study on the polarization force effect on the dust grains however the charge gradient force effect was neglected but magnitude of these forces become comparable in some systems. In this paper we focus our investigation on the effect of the charge-gradient and polarization forces,with radiative effect on Jeans instability.

IIGOVERNING EQUATIONS

A system of inhomogeneous magnetized dusty plasma with radiative electron, Maxwellian ion distribution and self-gravitating polarized dust grains with negative charge is considered. The external magnetic field is in the z-direction i.e. ($\boldsymbol{B}=B_0\hat{z}$). The dust grains are assumed to be with variable charge, constant mass and size such that the charge gradient force has a significant influence. The equation of continuity and the equation of momentumare

$$\frac{\partial n_d}{\partial t}+(\nabla . n_d \boldsymbol{u}_d)=0 \tag{1}$$

$$\frac{\partial \boldsymbol{u}_d}{\partial t}+(\boldsymbol{u}_d.\nabla)\boldsymbol{u}_d=-\nabla\psi-\frac{V_{Td}^2\nabla n_d}{n_d}-\frac{q_d\nabla\phi(1-\wp_p)}{m_d}-\frac{q_d}{m_d}(\boldsymbol{u}_d\times\boldsymbol{B})+\frac{q_d\nabla q_d}{\lambda_D m_d}+\frac{\eta\nabla^2\boldsymbol{u}_d}{m_d n_d} \tag{2}$$

The symbols used such as n_d q_d, m_d, $\boldsymbol{u}_d$, ϕ , η, $\wp_p$ and T_d indicate the dust density, dustcharge, dust mass, dust velocity, electrostatic potential, coefficient of viscosity, dust polarization force, and dust temperature respectively. The radiative electron modifies the dust polarization force parameter ($\wp_p$) which can be expressed as $\wp_p=(1/4)(|q_d|e/\lambda_D T_i)\exp(-e\phi/T_i)$. The electrons are considered to be inertia less and having finite thermal conductivity, hence the electron' distribution portrays radiative effects as it deviates from normal Maxwellian distribution. Thus, to analyze the radiative effect of electron the heat loss functions are introduced in energy transfer equation. The basic equations that describe the electron dynamics is given as

$$0=en_e\nabla\phi-\nabla p_e \,(3)\; \frac{3n_e}{2}\frac{\partial T_e}{\partial t}+p_e\nabla\boldsymbol{u}_e=\chi_e\nabla^2 T_e-L(n_e,T_e)\,(4)\; \frac{\partial n_e}{\partial t}+\nabla\cdot(n_e\boldsymbol{u}_e)=0 \tag{5}$$

where χ_e is the thermal conductivity of the electron and $L(n_e,T_e)$ denotes thefunction of radiative heat loss, $p_e=n_eT_e$ shows the electron pressure.The gravitational potential ψ is given by $\nabla^2\psi=4\pi Gm_dn_d$, where G is gravitational potential. The Poisson's equation is represented as $\nabla^2\phi=-4\pi(en_i-en_e+n_dq_d)$

III LINEARIZATION AND DISPERSION RELATION

To find the dispersion relation the above basic equations are linearized taking the first order perturbation of each variable separately. The perturbation influid velocityis written as $\boldsymbol{u}_d=\boldsymbol{u}_{d0}+\boldsymbol{u}_{d1}$, dust charge is $q_d=q_{d0}+q_{d1}$,fluid density is $n_\alpha=n_{\alpha 0}+n_{\alpha 1}$ $(\alpha=e,i)$, gravitational potential is $\psi=\psi_0+\psi_1$ and electrostatic potential is $\phi=\phi_0+\phi_1$. The denotations with subscript '0','1' standsfor the equilibrium and perturbed parts respectively.Now the linearized equation of dust charge number that depends upon charging frequency can be written as

$$Z_1=-\frac{J_0}{\Omega_{ch}}\left(\frac{e\phi_1}{T_{e0}}+\frac{e\phi_1}{T_{e0}}\wp_{rad}\right) \tag{6}$$

where $\wp_{rad}=(L_{Te}+\chi_ek^2/n_{e0}-3i\omega/2)/(L_{Te}+\chi_ek^2/n_{e0}-L_{ne}-5i\omega/2)$the radiative cooling parameter , $L_{Ne}=1/T_{e0}\,(\partial L/\partial n_e)_{n_{e0}}$ and $L_{Te}=1/n_{e0}\,(\partial L/\partial T_e)_{T_{e0}}$ are the functions of heat loss. The linearized Eqs of (1) - (6)are taken for dispersion relation.

$$\begin{aligned}&\left\{\left(\sigma^2+\omega_{cd}^2+\eta_ck^2\sigma\right)\left[k^2\left(\sigma^2+\eta_ck^2\sigma\right)+k_z^2\left(k^2v_{td}^2-\omega_{Jd}^2\right)\right]+k_x^2\left(k^2v_{td}^2-\omega_{Jd}^2\right)\left(\sigma^2+\eta_ck^2\sigma\right)\right\}\ell\\&+\omega_{pd}^2k^2k_x^2\Re_c\left(\sigma^2+\eta_ck^2\sigma\right)+\omega_{pd}^2k^2k_z^2\Re_c\left(\sigma^2+\omega_{cd}^2+\eta_ck^2\sigma\right)=0\end{aligned} \tag{7}$$

where $v_{Td}=(T_d/m_d)^{1/2}$ is the thermal velocity of the dust, $\eta_c=\eta/m_dn_d$, $\omega_{cd}=q_{d0}B_0/m_d$ is the cyclotron frequency of the dust, $\omega_{Jd}=(4\pi Gm_dn_{do})^{1/2}$ is the dust Jeans frequency, $\lambda_{di(e)}=\left(T_{i(e)}/4\pi e^2n_{i(e)o}\right)^{1/2}$ is the dust Debye length, $\omega_{pd}=\left(4\pi Z_d^2e^2n_{d0}/m_d\right)^{1/2}$ is the dust plasma frequency and $\Re_c=1-\Re_p+J_0e^2/\lambda_D\Omega_{ch}T_{i0}+J_0e^2\wp_{rad}/\lambda_D\Omega_{ch}T_{e0}$ is the overall effect of polarization force and charge-gradient force.

The equation (7) shows the dispersion relation for modified low frequency wave modes in radiative dusty plasma with magnetization. The modifications observed can be attributed to radiative cooling of electrons, viscosity effect, thermal dust velocity, polarization force and charge gradient force in gravitatingviscous magnetized dusty plasma.

IV ANALYSIS OF MODES

A. Mode of propagation in Parallel ($k_x = 0, k_z = k$)

The dispersion relation for the mode of propagation in parallel can be derived by using $k_x = 0,\ k_z = k$ in expression (7). The parallel mode of propagation in algebraic polynomial form can be represented as

$$\ell(\sigma^2 + \eta_c k^2 \sigma - \omega_{Jd}^2 + k^2 v_{td}^2) + \omega_{pd}^2 k^2 \Re_c = 0 \tag{8}$$

The dispersion relation (8)shows the electrostatic dust wave in the parallel mode while propagating in radiative self-gravitating plasma with the combined effect of polarization force, charge gradient force and radiative electrons. The influence of the magnetic field vanishes so radiative gravitating viscous mode is independent of the magnetic field. If the system is considered non viscous then the expression (8) gives the radiative gravitating mode and the roots of the Eq. (8) becomes

$$\sigma = \pm\left\{\left(-\omega_{pd}^2 k^2 \Re_c\right)/\ell + \omega_{Jd}^2 - k^2 v_{td}^2\right\}^{1/2} \tag{9}$$

Equation (9) shows that the positive root will make the system stable. On removing the effect of charge gradient force and polarization force the dispersion relation is given as

$$\sigma^2 = -\omega_{pd}^2 k^2 (1/\lambda_{Di}^2 + 1/\lambda_{De}^2) + \omega_{Jd}^2 - k^2 v_{td}^2 \tag{10}$$

Equation (10) shows the electrostatic dust acoustic wave mode modified by gravitational effect and resembles the result obtained by Rao and Verheest [11].On ignoring the radiative effect and the self-gravitational effect the Eq. (8) takes the form of the relation obtained by Khrapak et al.[10] which is a low frequency wave mode modified by charge gradient force. This shows the dispersion relation obtained in Eq.(7) is a modified low frequency wave mode.

B. Mode of propagation in Perpendicular ($k_x = k, k_z = 0$)

In order to find out the parameters that influence the stability criteria of the system or influence the growth rate of perturbations, we make the following analysis. If we substitute $k_z = 0$ and $k_x = k$ in Eq. (7) then we get the dispersion relation forlow frequency mode travelling in perpendicular directionas compared to the magnetic field applied externally.

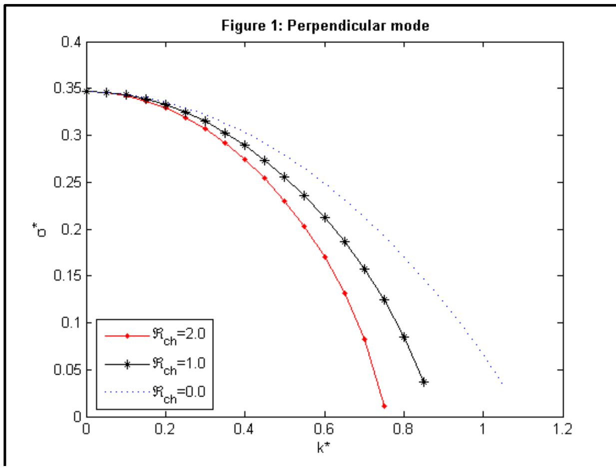
$$\ell(\left(\sigma^2 + \omega_{cd}^2 + \eta_c k^2 \sigma\right) - \omega_{Jd}^2 + k^2 v_{td}^2) + \omega_{pd}^2 k^2 \Re_c = 0 \tag{11}$$

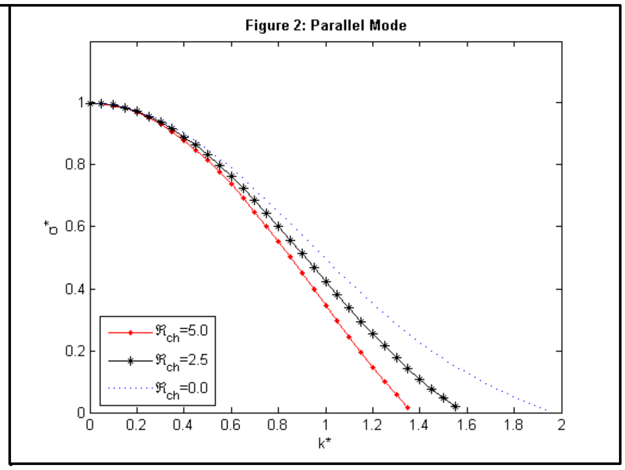
The dispersion relation (11) clearly shows that the perpendicular propagation in magnetized radiative self-gravitating dusty plasma depends on charge gradient force and polarization force, dust thermal velocity and the radiative cooling of the electron. When we neglect the effect of polarizing force, self-gravitation, magnetic field and charge gradient force then, Eq. (7) shows the dust acoustic mode which resembles with the results obtained by Mamun et al. [12].For the gravitational instability condition, we find radiative Jeans mode in magnetothermal plasma which is modified by the presence of radiative electrons and charge gradient force due to the parameter $\Re_c$

$$\left\{\omega_{cd}^2 + k^2 v_{td}^2 + (\omega_{pd}^2 k^2 \Re_c / \ell)\right\}^{1/2} < \omega_{Jd} \tag{12}$$

The dispersion relation (10) is normalized in such a way that frequency terms are made dimensionless by plasma dust frequency, while the wave vector k is normalized by dust Debye length, coefficient of viscosity and dust thermal velocity is normalized by dividing it with plasma dust frequency and dust Debye length. The parametersare $\wp_p^* = 0.5$, $\omega_{Jd}^* = 0.4$ $V_c^* = 0.5$, $V_{td}^* = 0.3$, $J_0 n_{d0} / \Omega_{ch} n_{i(e)0} = 0.8$ $\omega_{cd}^* = 2.0$, $\wp_{rad}^* = 5.0$ in Fig. 2 $\wp_{rad}^* = 2.0$ in Fig. 1and $\lambda_{Di(e)}^* = 0.1$. Figure1 shows the plot of the normalized wave vector against the normalized real roots of the growth rate of instability.The comparison of the growth rates with the dotted curve, starred curve and dotted solid curve shows the effect of decreasing charge gradient force in radiative magnetized dusty plasma. The dotted curve corresponds to the absence of charged gradient force. Even in the presence of radiative effect which is destabilizing, if the effect of the charge gradient force is increasing in thesystem, it tends to stabilize the system and decreases the growth rate of instability.

In Fig. 2 the growth rate of instability is plotted against the wave vector in the parallel mode of propagation. The effect of the charge gradient force shows a steeper curve showing a weaker influence when the normalized radiative effect value is kept at 5.0 in the absence of the magnetic effect.If we compare both the perpendicular mode and the parallel mode of propagation plots, it is evident in the perpendicular mode that the dust cyclotron frequency which is an effect of the magnetic field influences the growth rate towards stability.





Figures:The dimensionless growth rate of gravitational instability versus the dimensionless wave number for different charge gradient force in(Figure 1) perpendicular mode and (Figure 2) in Parallel mode of propagation.

VI CONCLUSION

The workis focused on the effect of the charge gradient force, polarization force, viscosity in magnetized radiative dusty plasma.Jeans instability in the perpendicular mode depends upon the polarization parameter, charge gradient force, radiative cooling and magnetic field whereas the parallel mode is unaffected by magnetic field. The polarization force and radiative effect of cooling of electrons stimulate the growth rate of instability further and sustains the self-gravitational collapse. The magnetic field and charge gradient force together decreases the growth rate of the Jeans mode. The resultscan be useful to explain the astrophysical phenomena taking place in the interstellar medium and for industrial applications where the condensationof dust grains needs to be minimized.

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