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EFFECT OF TWO DIFFERENT ELECTRON TEMPERATURES IN AURORAL IONOSPHERE

We have investigated the effect of two different electron temperatures in an auroral ionosphere in the presence of ions and obtained a modified electron-acoustic and modified lower-hybrid drift dissipative modes which will not be affected much due to the presence of cold electrons. However, in the drift dissipative case, the growth rate of the electron-acoustic wave depends on the number density of cold electrons.

Keywords: auroral plasma, electron temperature, electron-acoustic wave, lower-hybrid wave.

1. Introduction

The auroral zone is one of the most intriguing regions in the Earth's atmosphere. A variety of plasma physics processes occur on auroral field lines, from large-scale MHD phenomena to the micro-physics of plasma instabilities, solitary waves, and radio emissions. It is well known that the aurora occurs on magnetic field lines and causes the acceleration of field-aligned electrons, which is related to the formation of the aurora. Theories to explain the formation of parallel electric fields and the auroral acceleration have fallen into two categories, kinetic models that follow the adiabatic motions of auroral electron populations and fluid models that describe the time development of the parallel electric fields.

The main features of the classic "inverted-V" particle acceleration can be well described by a quasistatic potential drop [1]. However, some aspects of the auroral acceleration cannot be understood in the context of these quasisteady models. In particular, a number of rocket and satellite observations have identified nearly field-aligned electron beams precipitating into the auroral zone. It is well known that, in many kinds of plasmas, the ion temperature (T_i) is often much higher than the electron temperature (T_e) in various situations like in fusion machines and in space. This condition is favorable for certain plasma instabilities. Among these, the electron-acoustic instability is heavily Landau damped under this particular situation which is driven by the electron pressure and the ion inertia. In fact in plasma with $T_i > T_e$, the electron-acoustic instability is only an acoustic wave, which can propagate inside the plasma. From the stability analysis of the electrostatic electron cyclotron wave in a multiion plasma in the low latitude boundary layer, it was found that plasma can support electron cyclotron waves with a frequency slightly greater than the electron cyclotron frequency. However, when the drift velocities of both the ions are greater than the phase velocity, these waves can be the driven unstable [2].

The existence of plasma with two distinct types of electrons viz., hot and cold has been reported in the auroral ionosphere, as well as fusion devices. Waves in the plasma with two temperatures of electrons have been initiated by Jones *et al.*, [3]. Yu and Shukla [4] have shown that, in a plasma with two distinct, hot and cold, electron components, a modified electron-acoustic mode exists. Lichtenberg and

Meuth [5] have observed the hot electron instability in a mirror machine. Refractive ion-acoustic solitons have been observed in a two-electron temperature plasma by Nishida and Nagasawa [6]. For electron-acoustic and lower-hybrid waves, of a multiion species plasma, the drift dissipative instabilities was investigated by Bose *et al.*, [7] and found that the electron-acoustic drift dissipative instability appears at moderately high ion-viscosity and also found another electron-acoustic drift dissipative mode due to the second ion species.

Broadband plasma waves have wide range of frequencies from the lower-hybrid to electron plasma frequency and observed by many satellites on the auroral and cusp field lines. The amplitude of the electric field of these waves arranged from a few tens to hundreds of mV/m. These large amplitude waves can decay into kinetic Alfven waves (KAWs) through parametric processes. The three wave interaction process electron-acoustic wave (EAW), kinetic Alfven wave and another electron acoustic wave is studied in the auroral region by using multi-fluid approach [8]. In the linear limit it is found that sheared equilibrium flows can be the cause of the instability of Alfven-like electromagnetic waves and electron-acoustic waves in magnetospheric measurements. It is also shown that electromagnetic waves and sheared flows may cause the formation of street vortex and its size are sufficiently small than the scale lengths of the equilibrium density and velocity gradients [9].

The response of ionospheric electron temperatures to the geomagnetic activity has been simulated using the Thermosphere–Ionosphere Nested Grid (TING) model. It is found that electron temperatures are significantly increased in regions of depleted electron densities. The electron temperatures are decreased as a result of enhanced energy loss to the ion. Ion frictional heating increases ion temperatures at high-latitude F-region during geomagnetic storms, causing the ions to transfer energy to the electrons and thus enhancing electron temperatures and there are no significant electron temperature increases in the E-region during the storm because of the rapid energy loss from the electrons to the neutrals [10]. In a partially ionized plasma for a low density of neutrals the ion acoustic mode is damped. Upon increasing the neutral density, the modem first disappears and then reappears for a larger number of neutrals. A similar behavior is obtained by varying the mode wavelength. In an in-homogeneous plasma placed in an external magnetic field, and for magnetized electrons and unmagnetized ions, the ion acoustic mode propagates in any direction and the collisions make it growing on the account of the energy stored in the density gradient [11].

The linear mode structure of electron-acoustic (EA) waves have been studied for the modulational instability and rogue wave profiles also in four-component plasma system consisting of stationary ions, cold electron fluid, hot electrons and an electron beam. The dispersion relation obtained, depends on various parameters such as beam density, beam velocity, beam-temperature and nonextensivity. Depending on the phase velocities, two electron-acoustic (EA) modes have been extracted, which are real. The non linearity and dispersion coefficients affect the stability characteristics of EA waves for both the modes [12].

The lower hybrid instability is driven by cross field currents in the presence of a density gradient in fairly narrow sheaths and is favored by $T_i > T_e$. Both in Ionosphere as well as in fusion plasmas the collisions as well as density inhomogeneity plays an important role and therefore, the drift-dissipative instabilities evolves in such plasmas. These instabilities have been studied in the frequency regime of $\omega < \omega_{ci}$ and $k_z V_{i\theta} < k_z V_{e\theta}$ where, ω_{ci}, $V_{i\theta}$ and $V_{e\theta}$ are ion-cyclotron frequency, ion & electron thermal velocities respectively [13].

In this paper, we have tried to investigate the effect of two different electron temperatures in an auroral Ionosphere where we have obtained a modified electron acoustic as well as a modified lower-hybrid drift dissipative mode under the same condition as that of Arefev [13].

2. Calculation of Dispersion Relations

In our calculations, we have considered the electrons as magnetized particles whereas the ions are un-magnetized. The magnetic field is assumed to be fixed along the z-direction and approximately equal to the magnetic dipole field so, this model is electrostatic and the electric field is equal to the potential gradient $\mathbf{E} = -\boldsymbol{\nabla}\phi$ [14]. With the help of continuity equation, equation of motion and the Poisson's equation for each species, i.e. hot and cold electrons as well as ions, we obtained the expressions for the number densities for different type of particles as follows:

$$n_h = \frac{c}{\omega B_0}\left(\mathbf{k}\times\hat{z}\,\boldsymbol{\nabla} n_{0h}\right)\phi + \\ + \frac{c}{\omega_c B_0} n_{0h} k_\perp^2 \phi - \frac{e n_{0h}}{m_e \omega^2} k^2 \phi, \quad (1)$$

$$n_c = \frac{e n_{0c}}{m_e[\omega\omega_{ce} + k^2 V_{c\theta}^2]} k^2 \phi, \quad (2)$$

$$n_i = \frac{e k^2 n_{0i}}{m_i \omega(\omega + i\nu_i)}\left[1 - \frac{kv}{\omega(\omega + i\nu_i)}\right]^{-1}\phi, \quad (3)$$

where, the subscripts c, h, i and θ represents the cold electrons, hot electrons, ions and thermal terms respectively and n_{0h}, n_{0c}, n_{0i} are the equilibrium density of hot electrons, cold electrons and ions. ν_i is the electron-ion collision frequency. For the sake of simplification, we have neglected the viscosity terms. The electron-ion collision frequency is neglected in comparison with the electron-cyclotron frequency. The hot electrons satisfy the drift approximation to give

$$\frac{\partial^2 n_h}{\partial t^2} - \frac{c}{B_0}\frac{\partial}{\partial t}\left(\boldsymbol{\nabla}\phi\times\mathbf{z}\right)\boldsymbol{\nabla}\, n_{0h} + \\ + \frac{c n_{0h}}{B_0 \omega_c}\frac{\partial^2}{\partial t^2}\nabla_\perp \phi + \frac{e n_{0h}}{m_e}\frac{\partial^2 \phi}{\partial t^2} = 0. \quad (4)$$

Where, the electron temperature is neglected as the term containing temperature does not depend upon space. Using equations (1), (2), (3) and (4) alongwith the Poisson's equation, we get

$$\omega^2 k^2 \lambda_i^2 + \frac{n_{0h}}{n_{0i}}\left[\frac{\omega^2 k_\perp^2 T_i}{m_e \omega_{ce}^2} - \frac{T_i k_z^2}{m_e} - \omega\omega^*\right] + \\ + \frac{\omega^2 k^2 T_i}{m_e[\omega\omega_{ce} + k^2 V_{c\theta}^2]}\frac{n_{0c}}{n_{0i}} - \frac{\omega^2 k^2 T_i}{m_i(\omega\omega_{ci} - k^2 V_{i\theta}^2)} = 0 \quad (5)$$

here, ω^* is the ion drift frequency. Considering the effect of cold electrons are very less, as well as the system is dissipationless and uniform, i.e. for $\omega^* = 0$ and $\nu_i = 0$, the dispersion relation, equation (5) for single ion species reduces to

$$\omega^2 = \frac{c_s k_z^2}{b} \quad \text{and} \quad \omega^2 = \frac{a\omega_{pi}^2}{b}$$

here, $a = k^2\lambda_i^2\alpha$, $\alpha = 1 + \left(\frac{\omega_{pe}}{\omega_{ce}}\right)^2$, $c_s^2 = \frac{T_i}{m_e}$ and $b = \left(1 + \frac{m_i k_z^2}{m_e k_\perp^2} + a\right)$ at, $T_i \gg T_e$ and $\frac{m_i k_z^2}{m_e k_\perp^2} \ll 1$, we get the electron-acoustic wave from the first root. Similarly, the lower-hybrid wave can be obtained by considering $a \ll 1$ in the second root and the ion drift wave appears at $k_z \to 0$. Thus the dispersion relation given by equation (5) gives electron acoustic, lower-hybrid and ion-drift wave.

Since we are interested in the dissipative and homogeneous density case, the dispersion relation for the modified electron acoustic wave is obtained as

$$\omega^2 = \frac{c_s^2 k_z^2\left(\frac{n_{0h}}{n_{0i}}\right)}{1 + a + \frac{k_z^2 m_i n_{0h}}{k^2 m_e n_{0i}} + \frac{i\nu_i\omega^* n_{0h}}{k^2 V_{i\theta}^2 n_{0i}} + \frac{k^2\lambda_i^2\omega_{pc}^2}{(\omega_{ce}^2 - k^2 V_{c\theta}^2)}}. \quad (6)$$

3. Calculation of Growth Rates

Here, the frequency of the excited wave is considered to be a complex quantity and can be expressed as, $\omega = \omega_r + i\gamma$ and the growth rate (γ) is obtained as

$$\gamma = \frac{|\,k_z\,|\,c_s\left(\frac{n_{0h}}{n_{0i}}\right)^{1/2}(S-1)^{1/2}}{\sqrt{2}S\left[1 + a + \frac{k_z^2 m_i n_{0h}}{k^2 m_e n_{0i}} + \frac{k^2\lambda_i^2\omega_{pc}^2}{(\omega_{ce}^2 - k^2 V_{c\theta}^2)}\right]^{1/2}} \quad (7)$$

under the approximation $\omega_r \gg \gamma$ equation (6), gives

$$\gamma = \frac{\nu_i\,|\,k_z\,|\,c_s\omega^*\left(\frac{n_{0h}}{n_{0i}}\right)^{3/2}}{2Sk^2 V_{i\theta}^2\left[1 + a + \frac{k_z^2 m_i n_{0h}}{k^2 m_e n_{0i}} + \frac{k^2\lambda_i^2\omega_{pc}^2}{(\omega_{ce}^2 - k^2 V_{c\theta}^2)}\right]^{3/2}}, \quad (8)$$

where,

$$S = \left\{1 + \frac{\nu_i^2(\omega^*)^2\left(\frac{n_{0h}}{n_{0i}}\right)^2}{k^4 V_{i\theta}^4\left[1 + a + \frac{k_z^2 m_i n_{0h}}{k^2 m_e n_{0i}} + \frac{k^2\lambda_i^2\omega_{pc}^2}{(\omega_{ce}^2 - k^2 V_{c\theta}^2)}\right]^2}\right\}^{1/2}. \quad (9)$$

In the absence of cold electron species, the relation for growth rate reduces to that of Mohan and Yu [15], i.e.

$$\gamma = \frac{\nu_i\,|\,k_z\,|\,c_s\omega^*}{2k^2 V_{i\theta}^2\left[1 + a + \frac{k_z^2 m_i}{k_\perp^2 m_e}\right]^{3/2}} \quad (10)$$

i.e.

$$\gamma = \frac{\nu_i\,|\,k_z\,|\,c_s\omega^*}{2k^2 V_{i\theta}^2 b^{\frac{3}{2}}}$$

Now the dispersion relation for the lower-hybrid drift dissipative instability, which is also modified due to the presence of the cold species of electrons, can be obtained from equation (5)

$$\omega^2 = k^2 V_{i\theta}^2 + \frac{k^2 V_{i\theta}^2 + k_z^2\lambda_i^2\omega_{ph}^2 + i\nu_i\omega^*\left(\frac{n_{oh}}{n_{oi}}\right)}{\left[a + \frac{k^2\lambda_i^2\omega_{pc}^2}{(\omega_{ce}^2 - k^2 V_{c\theta}^2)}\right]} \quad (11)$$

and the growth rate is found to be

$$\gamma = \frac{kV_{i\theta}(S-1)^{1/2}\left[1+a+\frac{k_z^2 m_i n_{0h}}{k^2 m_e n_{0i}}+\frac{k^2\lambda_i^2\omega_{pc}^2}{(\omega_{ce}^2-k^2V_{c\theta}^2)}\right]^{1/2}}{\sqrt{2}\left[a+\frac{k^2\lambda_i^2\omega_{pc}^2}{(\omega_{ce}^2-k^2V_{c\theta}^2)}\right]^{1/2}}. \quad (12)$$

In absence of cold species of electrons with approximation equation (11) shows the expression for lower hybrid wave

$$\gamma = \frac{v_i\omega^*}{2\sqrt{b}\alpha\omega_{pi}\lambda_i^2 k^2}.$$

This expression for the growth rate is also in agreement with one of the expression obtained by Mohan and Yu [15].

4. Discussion

For a nonmagnetized plasma, Yu and Shukla [4] concluded that the evolved electron acoustic waves are strongly dependent to the number density of cold electrons. For drift dissipative case, the growth rate for electron acoustic wave equation (7) also depends on the number density of cold electrons, whereas this dependency is not that strong as in the case of Yu and Shukla [4]. It was also shown that drift modes associated with lower-hybrid and electron-acoustic waves become stable via ion collisional damping by the cold electrons but that unstable waves can exist when the electrons are warm [16].

Here, our calculation shows that the lower hybrid drift dissipative wave will not be affected much in the presence of cold electrons. In other words, the greater injection of high energetic particles in ionospheric plasma, which generates the luminous glow of an electron acoustic drift dissipative wave, becomes unchanged. This concludes that when the solar activity will be very high the aurora generates in ionosphere will affect more through the electron acoustic drift-dissipative wave

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ЕФЕКТ ДВОХ РІЗНИХ
ЕЛЕКТРОННИХ ТЕМПЕРАТУР
У ПОЛЯРНОМУ СЯЙВІ ІОНОСФЕРИ

Досліджується ефект двох різних електроних температур у полярному сяйві іоносфери за присутності іонів. Отримано модифіковані електронну акустичну та нижньогібридну дрейфову дисипативну моди, на які слабко впливає присутність холодних електронів. Проте, у разі дисипативного дрейфу, швидкість зростання електронної акустичної хвилі залежить від густини холодних електронів.

Ключові слова: плазма полярного сяйва, температура електронів, електрон-акустична хвиля, нижньогібридна хвиля.