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Effect of Plasma Densities on Alfven Waves in Multi-Component Magnetized Plasma

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Abstract

The aim of this study is to look the effect of plasma densities on Alfven waves in auroral acceleration region. We develop the dispersion relation of Alfven waves in isothermal and homogeneous magnetized plasma. We estimate the dispersion relation, growth/damping rate and growth length of Alfven waves in multi-component magnetized plasma by using the method of kinetic approach and different plasma parameters. In this research communication, we are present some results of earlier work on Alfven waves in multi component magnetized plasma. Here one component is electron (e) and other three components are the hydrogen (H^+), helium (He^+) and oxygen (O^+) ions are mixed. The interaction of the wave with thermal ions is one of the most important features in many spaces and astrophysical region. The waves are assumed to propagate along to the magnetic field with the parallel wave vector k_{II} (cm^{-1}). The Alfven wave's emissions may interact with communication signal; therefore, the study may be applicable in communication system. An Alfven waves is an important electromagnetic wave that transports electromagnetic energy in many space and astrophysical regions. It is observed that the frequency of Alfven waves increase with increase the plasma density. The results are discussed the applications of Alfven waves in multi-component magnetized plasma in the auroral acceleration region of interplanetary space plasma as well as the magnetospheric plasma and astrophysical plasmas.

Keywords: Kinetic approach; Auroral acceleration region; Magnetosphere; Alfven waves; Multi-component magnetized plasma.

1. Introduction

We start with the discovery of Alfven waves are fundamental low-frequency electromagnetic wave in magnetized plasma [1]. The Alfven waves are found to be prevalent in the nature and laboratory plasmas. The Alfven waves are fundamental physical phenomenon in magnetized plasma that contribute to a wide variety of physical processes in space plasmas, i.e., turbulence plasma heating and acceleration along the magnetic field lines, wave particle-interactions and generation of geomagnetic perturbations.

An Alfven wave in the magnetosphere observed by satellite and ground magnetometers as Pc 3-5 pulsations, and is usually classified according to the predominant polarization in the plane transverse to geomagnetic field [2]. The magnetic pulsations are explained as a consequence of the precipitation changing the ionospheric conductivity and hence causing changes in both the position and strength of ionospheric currents which appear as a magnetic signal on the ground [3].The resulting dispersion behavior is directly related to heat and energy transport in magnetized plasmas [4]. A magnetosphere is formed when a stream of charged particles, such as the solar wind, interacts with and is deflected by the magnetic field of a planet or similar body.

However, Satellite observations, both FAST and Polar satellites are very well suited for studies of auroral acceleration processes: field aligned currents, plasma flow and Alfven waves [5]. These satellite observations of intense Alfven bursts over auroral arcs motivated researchers to suggest that this Alfven wave's activity does provide energy to the auroral arc intensification. This satellite orbits between the topside ionosphere and the lowest reaches of the auroral acceleration region and is ideally located for performing this study. In the auroral acceleration processes, aurora's are produced by electrons and protons string earth's atmosphere, when oxygen, hydrogen, helium and nitrogen atoms are hit by these energetic particles, they become excited as they relax to their original state, the emit light is of a characteristic colors. Moreover, the auroral zone is one of the most intriguing regions in the Earth's magnetosphere. The most important aspect of Alfven waves observed in the auroral oval, and more recently in the high latitude magnetosphere is their ability to accelerate electrons to energies and in fluxes sufficient to cause visible aurora [6].

Landau damping describes any collision-less resonant interaction between waves and particle motions which transfers energy from the waves to the particles. Resonance with the gyro, bounce and drift motion of particles is all possible in the magnetosphere [7]. The Alfven waves can transfer the wave energy to electrons via Landau damping, which is the collision less damping of low-frequency waves that occurs when thermal electrons travel along the magnetic field lines. In this process the particles gain kinetic energy at the expense of the wave if the distribution function has a negative slope in the range ω/k and it results in the heating of plasmas or acceleration of electrons along the magnetic field direction [8]. In many space and astrophysical regions, the wave properties such as the wave dispersion and the onset of Landau/cyclotron damping are dependent on the plasma beta [9].

The dissipation of Alfven waves by electron Landau damping has been suggested to play a significant role in the damping of interplanetary magnetic field fluctuations and to explain the slope of the magnetic turbulence spectrum where the spectral is believed to cause the collision less damping at short scales, which converts the turbulent energy into thermal energy. In most of the theoretical investigations reported so far, the particle velocity distribution function has been assumed to be bi-Maxwellian. The consistency is attributed to the proper estimation in this study we adopt the kinetic approach as the mathematical model based upon computational analysis to explain the observations in auroral acceleration regions. The observations of various rockets and satellites will be undertaken to explain our theoretical findings. The present studies on the

Alfven waves in multi-component including (H+, He+, O+) ions at the sub-storm events and in the auroral acceleration region. In the present paper, we have explain the introduction in section 1, section 2 represent the basic mathematic model of calculation of particle trajectories. Section 3 described the dispersion theory and isothermal dispersion relation of Alfven waves in multi-component plasma described in section 4. Section 5and 6 damping rate and growth length of Alfven waves in multi-component plasma are evaluated. In section 7 we discuss the results for the Alfven waves in auroral acceleration. In section 8 is conclusion of the paper.

2. Basic Mathematic Model

We begin with the collision less Vlasov-Maxwell equations in which the multi particle distribution function of the species α, f(r, v, t) is described by the Vlasov equation and from [10].

$$\left[\frac{\partial}{\partial t}+\vec{v}\frac{\partial}{\partial r}+\frac{e_\alpha}{m_\alpha}\{\vec{E}(r,t)+v\times\vec{B}(r,t)\}\frac{\partial}{\partial v}\right]f_\alpha(r,v,t)=0 \tag{1}$$

Here, **E**(r, t) and **B**(r , t) are the electric and magnetic fields and e_α and m_α are the charge and mass respectively of particle α. Moreover, the electric and magnetic fields are determined self consistently from Maxwell equations in term of the plasma current density and charge density.

$$J(r,t)=\sum_\alpha e_\alpha\int d^3v\vec{v}f_\alpha(r,\vec{v},t) \tag{2}$$

$$\rho(r,t)=\sum_\alpha e_\alpha\int d^3vf_\alpha(r,\vec{v},t) \tag{3}$$

3. Dispersion Theory

Our starting point is the dispersion relation for plane wave in homogeneous plasma which can be written as:

$$\det D_{II}\left(\omega,\vec{K}\right)=0$$

Using Maxwell equations (4-7)

$$\nabla\times\vec{E}=-\frac{1}{c}\frac{\partial\vec{B}}{\partial t} \tag{4}$$

$$\nabla\times\vec{B}=\frac{4\pi}{c}J-i(\frac{\omega}{c})\vec{E} \tag{5}$$

$$\nabla\cdot B=0 \tag{6}$$

$$\nabla\cdot\vec{E}=4\pi\rho \tag{7}$$

From equation (2, 4- 6), we gate

$$k\times(k\times E)+\frac{\omega^2}{c^2}E+\frac{4\pi i\omega}{c^2}\sum_\alpha e_\alpha\int d^3v\vec{v}f_\alpha(k,v,\omega)=0 \tag{8}$$

We obtain the components of the plasma dispersion tensor following matrix

$$\begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix} \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} = 0 \tag{9}$$

Where

$$D_{xx}(k,\omega) = 1 - \frac{c^2 k_{II}^2}{\omega^2} + \sum_{\alpha} \frac{\omega_{p\alpha}^2}{\omega} \sum_{n=-\infty}^{\infty} \int d^3 v v_{\perp} \frac{(\frac{n^2}{b_\alpha^2}) J_n^2(b_\alpha)}{\omega - n\omega_{c\alpha} - k_{II} v_{II}} \times \{\frac{\partial F_\alpha}{\partial v_\perp} - \frac{k_{II} v_{II}}{\omega}(\frac{\partial F_\alpha}{\partial v_\perp} - \frac{v_\perp}{v_{II}}\frac{\partial F_\alpha}{\partial v_{II}})\} \tag{10}$$

$$D_{xy}(k,\omega) = i \sum_{\alpha} \frac{\omega_{p\alpha}^2}{\omega} \sum_{n=-\infty}^{\infty} \int d^3 v v_{\perp} \frac{(\frac{n^2}{b_\alpha^2}) J_n^2(b_\alpha)}{\omega - n\omega_{c\alpha} - k_{II} v_{II}} \times \{\frac{\partial F_\alpha}{\partial v_\perp} - \frac{k_{II} v_{II}}{\omega}(\frac{\partial F_\alpha}{\partial v_\perp} - \frac{v_\perp}{v_{II}}\frac{\partial F_\alpha}{\partial v_{II}})\} \tag{11}$$

$$D_{xy}(k,\omega) = -D_{yx}(k,\omega) \tag{12}$$

$$D_{xz}(k,\omega) = \frac{c^2 k_{II} k_\perp}{\omega^2} + \sum_{\alpha} \frac{\omega_{p\alpha}^2}{\omega} \sum_{n=-\infty}^{\infty} \int d^3 v v_{\perp} \frac{(\frac{n}{b_\alpha}) J_n^2(b_\alpha)}{\omega - n\omega_{c\alpha} - k_{II} v_{II}} \times \{\frac{\partial F_\alpha}{\partial v_{II}} + \frac{n\omega_{c\alpha}}{\omega}(\frac{v_\perp}{v_{II}}\frac{\partial F_\alpha}{\partial v_\perp} - \frac{\partial F_\alpha}{\partial v_{II}})\} \tag{13}$$

$$D_{yy}(k,\omega) = 1 - \frac{c^2 (k_{II}^2 + k_\perp^2)}{\omega^2} + \sum_{\alpha} \frac{\omega_{p\alpha}^2}{\omega} \sum_{n=-\infty}^{\infty} \int d^3 v v_{\perp} \frac{[J_n^{'}(b_\alpha)]^2}{\omega - n\omega_{c\alpha} - k_{II} v_{II}} \times \{\frac{\partial F_\alpha}{\partial v_\perp} - \frac{k_{II} v_{II}}{\omega}(\frac{\partial F_\alpha}{\partial v_\perp} - \frac{v_\perp}{v_{II}}\frac{\partial F_\alpha}{\partial v_{II}})\} \tag{14}$$

$$D_{yz}(k,\omega) = -i \sum_{\alpha} \frac{\omega_{p\alpha}^2}{\omega} \sum_{n=-\infty}^{\infty} \int d^3 v v_{\perp} \frac{J_n(b_\alpha) J_n^{'}(b_\alpha)}{\omega - n\omega_{c\alpha} - k_{II} v_{II}} \times \{\frac{\partial F_\alpha}{\partial v_{II}} + \frac{n\omega_{c\alpha}}{\omega}(\frac{v_\perp}{v_{II}}\frac{\partial F_\alpha}{\partial v_\perp} - \frac{\partial F_\alpha}{\partial v_{II}})\} \tag{15}$$

$$D_{zx}(k,\omega) = \frac{c^2 k_{II} k_\perp}{\omega^2} + \sum_{\alpha} \frac{\omega_{p\alpha}^2}{\omega} \sum_{n=-\infty}^{\infty} \int d^3 v v_{II} \frac{(\frac{n}{b_\alpha}) J_n^2(b_\alpha)}{\omega - n\omega_{c\alpha} - k_{II} v_{II}} \times \{\frac{\partial F_\alpha}{\partial v_{II}} + \frac{n\omega_{c\alpha}}{\omega}(\frac{v_{II}}{v_\perp}\frac{\partial F_\alpha}{\partial v_\perp} - \frac{\partial F_\alpha}{\partial v_{II}})\} \tag{16}$$

$$D_{zy}(k,\omega) = i \sum_{\alpha} \frac{\omega_{p\alpha}^2}{\omega} \sum_{n=-\infty}^{\infty} \int d^3 v v_{\perp} \frac{J_n(b_\alpha) J_n^{'}(b_\alpha)}{\omega - n\omega_{c\alpha} - k_{II} v_{II}} \times \{\frac{\partial F_\alpha}{\partial v_\perp} - \frac{k_{II} v_{II}}{\omega}(\frac{\partial F_\alpha}{\partial v_\perp} - \frac{v_\perp}{v_{II}}\frac{\partial F_\alpha}{\partial v_{II}})\} \tag{17}$$

$$D_{zz}(k,\omega) = 1 - \frac{c^2 k_\perp^2}{\omega^2} + \sum_{\alpha} \frac{\omega_{p\alpha}^2}{\omega} \sum_{n=-\infty}^{\infty} \int d^3 v v_{II} \frac{J_n^2(b_\alpha)}{\omega - n\omega_{c\alpha} - k_{II} v_{II}} \times \{\frac{\partial F_\alpha}{\partial v_{II}} + \frac{n\omega_{c\alpha}}{\omega}(\frac{v_{II}}{v_\perp}\frac{\partial F_\alpha}{\partial v_\perp} - \frac{\partial F_\alpha}{\partial v_{II}})\} \tag{18}$$

Where,

$$\int d^3 v = 2\pi \int_0^\infty dv_\perp v_\perp \int_{-\infty}^\infty dv_{II}, \quad b_{i\alpha} = \frac{k_\perp v_{\perp\alpha}}{\omega_{ci\alpha}}, \quad \omega_{p\alpha}^2 = \frac{4\pi n_\alpha e_\alpha^2}{m_\alpha}$$

4. Dispersion Relation

Later, we consider a plasmas with external magnetic field (B), since the AW's propagate parallel to the magnetic field in z-direction with parallel wave vector in the x-z plane, we can write.

$$\begin{vmatrix} D_{xx} & D_{xz} \\ D_{zx} & D_{zz} \end{vmatrix} = 0 \tag{19}$$

Using plasma dispersion relation, we get

$$D_{xx}(k,\omega) = \varepsilon_{\perp} - \frac{c^2 k_{II}^2}{\omega^2}, \quad D_{xz}(k,\omega) = \frac{c^2 k_{II} k_{\perp}}{\omega^2}, \quad D_{zx}(k,\omega) = \frac{c^2 k_{II} k_{\perp}}{\omega^2}$$

$$D_{zz}(k,\omega) = \varepsilon_{II} - \frac{c^2 k_{\perp}^2}{\omega^2}$$

Where $\epsilon_{\perp}$ and ϵ_{II} refer to the dielectric tensor elements along and across the magnetic field, respectively, with the help of above determinant, we obtain the isothermal dispersion relation for Alfven waves in multi-component magnetized plasma using auroral acceleration region as

$$\omega^2 = k_{II}^2 v_A^2 k_{\perp}^2 [\frac{v_{\perp H^+}^2}{\Omega_{H^+}^2} + \frac{v_{\perp He^+}^2}{\Omega_{He^+}^2} + \frac{v_{O^+}^2}{\Omega_{O^+}^2}] \tag{20}$$

5. Growth/Damping Rate

The AW's can transfer the wave energy to electrons via landau damping, which is the collision less damping of low frequency waves that occurs when thermal electrons travel along the magnetic field lines. In this process the particle gain kinetic energy at the expense of the wave if the distribution function has a negative slope in the range $\upsilon=\omega/k$ and it results in the heating of plasmas or acceleration of electrons along the magnetic field in the direction z.

We assuming $\omega \rightarrow \omega_r + i\gamma$, with $\gamma<\omega$, to obtain the damping rate from [11] as

$$\gamma = -\frac{\operatorname{Im} D(\omega,k)}{\frac{\partial}{\partial\omega}\operatorname{Re} D(\omega,k)} \tag{21}$$

We obtain an expression for the collision less damping rate of the AW's in multi-component magnetized plasma as

$$\gamma = -(\frac{m_e}{m_{H^+} + m_{He^+} + m_{o^+}})\sqrt{\frac{\pi}{8}}\frac{c^2 k_{\perp}^2}{v_{Te}^2}(\omega_{pH^+}^2 + \omega_{pHe^+}^2 + \omega_{po^+}^2) \times [\frac{v_{TH^+}^2}{\omega_{pH^+}^2} + \frac{v_{THe^+}^2}{\omega_{pHe^+}^2} + \frac{v_{To^+}}{\omega_{po^+}^2}]^2 \tag{22}$$

6. Growth Length

The growth length γ_L of the Alfven waves (AW's) is derived from [12] as

$$\gamma_L = \frac{v_g}{\gamma} \tag{23}$$

$$v_g = \frac{d\omega}{dk_{II}} \tag{24}$$

We evaluated growth length by equation (20, 23 and 24) as

$$\gamma_L = \frac{m_{H^+} + m_{He^+} + m_{O^+}}{m_e} \times \sqrt{\frac{8}{\pi}} \times \frac{v_{TIIe}^3}{k_\perp k_{II} v_A} \times \frac{\left(\frac{v_{TH^+}^2}{\Omega_{H^+}^2} + \frac{v_{THe^+}^2}{\Omega_{He^+}^2} + \frac{v_{TO^+}^2}{\Omega_{O^+}^2}\right)^{\frac{1}{2}}}{\left(\frac{\omega_{PH^+}^2}{\Omega_{H^+}} + \frac{\omega_{PHe^+}^2}{\Omega_{He^+}} + \frac{\omega_{PO^+}^2}{\Omega_{O^+}}\right)^2 \times \left(\frac{v_{TH^+}^2}{\omega_{PH^+}^2} + \frac{v_{THe^+}^2}{\omega_{PHe^+}^2} + \frac{v_{TO^+}^2}{\omega_{PO^+}^2}\right)^2} \tag{25}$$

7. Discussion and Analysis of Results

In the present analysis, the expression for modified isothermal dispersion relation, growth/damping rate and growth length are numerically evaluated for the AW's in multi-component magnetized plasma. We have used the following parameters appropriate to the auroral acceleration region [13-14].

$$B_0 = 4300nT, k_{II} = 10^{-10} cm^{-1}, k_\perp = 10^{-6} cm^{-1}, v_A = 3\times10^{10} cms^{-1},$$
$$\Omega_{H^+} = 412 s^{-1}, \Omega_{He^+} = 103 s^{-1}, \Omega_{O^+} = 26 s^{-1}, v_{TIIe^+} = 8.38\times10^7 cms^{-1},$$
$$\omega_{PH^+} = 9.31\times10^4 s^{-1}, \omega_{PHe^+} = 3.292\times10^4 s^{-1}, \omega_{Po^+} = 1.646\times10^4 s^{-1},$$
$$v_{TH^+} = 4.37\times10^7 cms^{-1}, v_{THe^+} = 4.01\times10^6 cms^{-1}, v_{TO^+} = 3.9\times10^6 cms^{-1}$$

Equation (20), (22) and (25) have been evaluated numerically using the Mathcad Software to solve the dispersion relation for wave frequency ω (cm^{-1}), damping rate (γ) and growth /damping length (γ_L) at different plasma density.

Figure (1) shows the variation of AW's frequency ω (s^{-1}) versus the parallel wave's vector K_{II} (cm^{-1}). It is seen that the wave frequency increases linearly with increases parallel wave vector K_{II} (cm^{-1}) and the variation shown by the straight line.

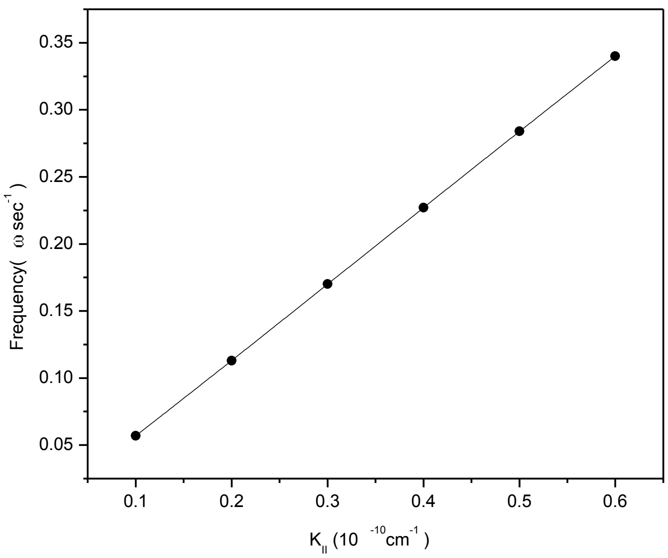

Figure 1: Variation of wave frequency (ω) versus wave vector (k_{II}).

Figure (2) shows the variation of growth/damping rate (γ) versus the parallel wave vector K_{II} (cm^{-1}) for different values of hydrogen plasma densities n_H^+ (cm^{-3}). It is seen that the damping rate increases with the parallel wave vector for each value (n_H^+) with multi species (α). Figure (3) shows the variation of growth/damping (γ) versus the parallel wave vector K_{II} (cm^{-1}) for different values of helium plasma densities n_{He}^+ (cm^{-3}). It is seen that the damping increases with the parallel wave vector for each value (n_{He}^+) with multi species (α). Figure (4) shows the variation of growth/damping rate (γ) versus the parallel wave vector K_{II} (cm^{-1}) for different values of oxygen plasma densities n_O^+ (cm^{-3}). It is seen that the damping increases with the parallel wave vector for each value (n_O^+) with multi species (α).

In figures (2),(3) and (4), the observed growth/damping rate of the AW's may be due to Landau damping of the wave through the wave particle-interaction and the energy of the wave is transferred to the particles or it may be due to the interaction of the waves with an electrons leading to their acceleration.

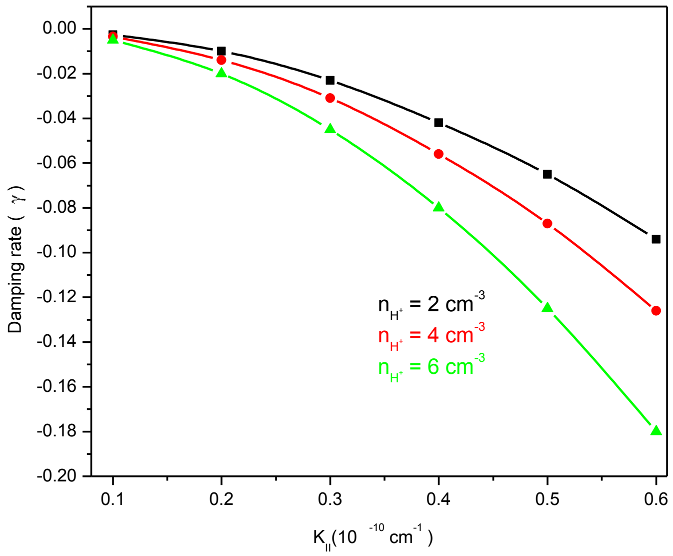

Figure 2: Variation of damping rate (γ) versus the parallel wave vector (K_{II}) for different values of hydrogen plasma densities n_H^+ (cm^{-3}).

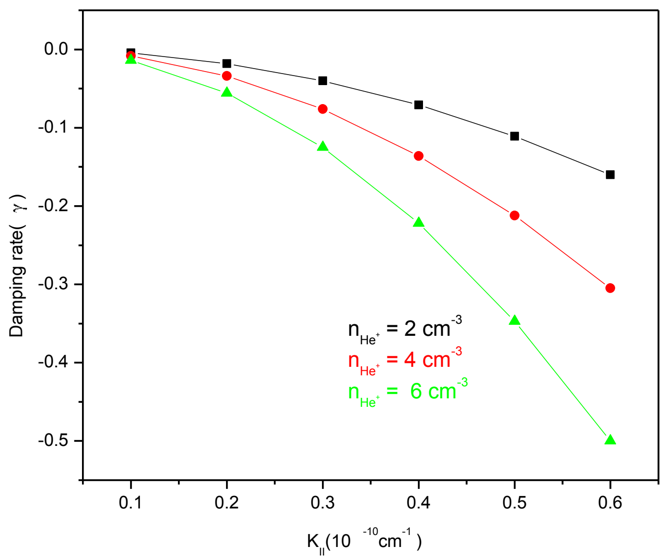

Figure 3: Variation of damping rate (γ) versus the parallel wave vector K_{II} (cm^{-1}) for different values of helium plasma densities n_{He}^+ (cm^{-3}).

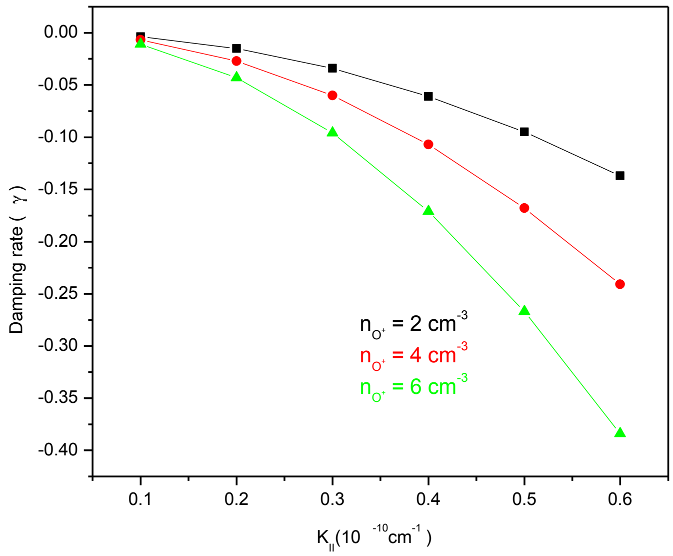

Figure 4: Variation of damping rate (γ) versus the parallel wave vector K_{II} (cm^{-1}) for different values of oxygen plasma densities n_O^+ (cm^{-3})

Figure (5) shows the growth length (γ_L) of Alfven waves with respect to the parallel wave vector K_{II} (cm^{-1}) for different values of hydrogen plasma densities n_H^+ (cm^{-3}). It is found that the growth length exponential decreases with increases the parallel wave vector and multi species (α). Here, it is notice that the growth length becomes less than $1R_E$ on the lower value of K_{II} (cm^{-1}).The nature of wave's frequency for the different values of hydrogen densities is same.

Figure (6) shows the growth length (γ_L) of waves with respect to the parallel wave vector K_{II} (cm^{-1}) for different values of helium plasma densities n_{He}^+ (cm^{-3}). It is found that the growth length exponential decreases with increases the parallel wave vector and multi species (α). Here, it is notice that the growth length becomes less than $1R_E$ on the lower value of K_{II} (cm^{-1}). The nature of wave's frequency for the different values of helium densities is same.

Figure (7) shows the growth length (γ_L) of wave's with respect to the parallel wave vector K_{II} (cm^{-1}) for different values of oxygen plasma densities n_O^+ (cm^{-3}). It is found that the growth length exponential decreases with increases the parallel wave vector and multi species (α). Here, it is notice that the growth length becomes less than $1R_E$ on the lower value of K_{II} (cm^{-1}). The nature of AW's frequency for the different values of oxygen densities is same.

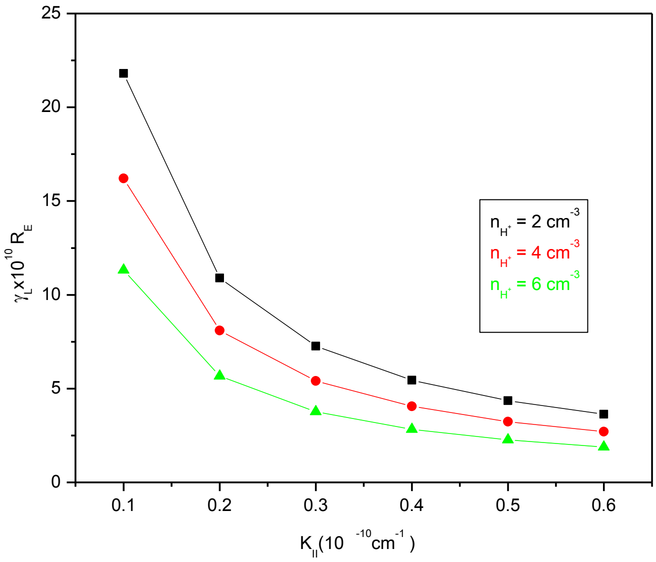

Figure 5: Variation of growth length (γ_L) of AW's with respect to the parallel wave vector K_{II} (cm^{-1}) for different values of hydrogen plasma densities n_H^+ (cm^{-3}).

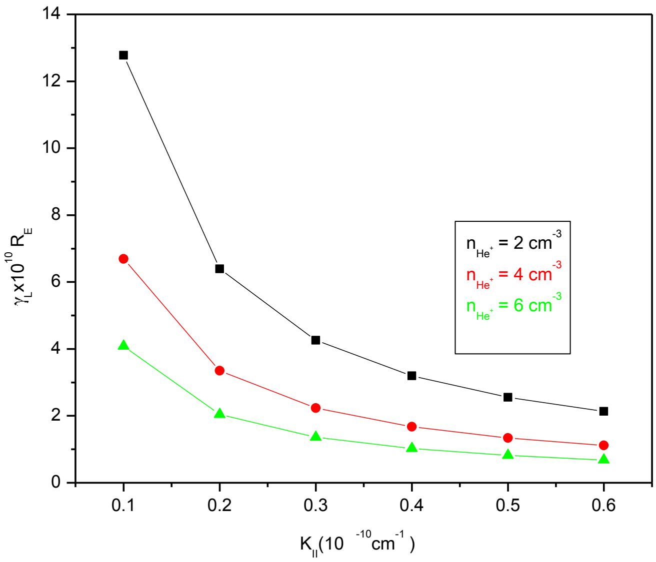

Figure 6: Variation of growth length (γ_L) of AW's with respect to the parallel wave vector K_{II} (cm^{-1}) for different values of helium plasma densities n_{He}^+ (cm^{-3}).

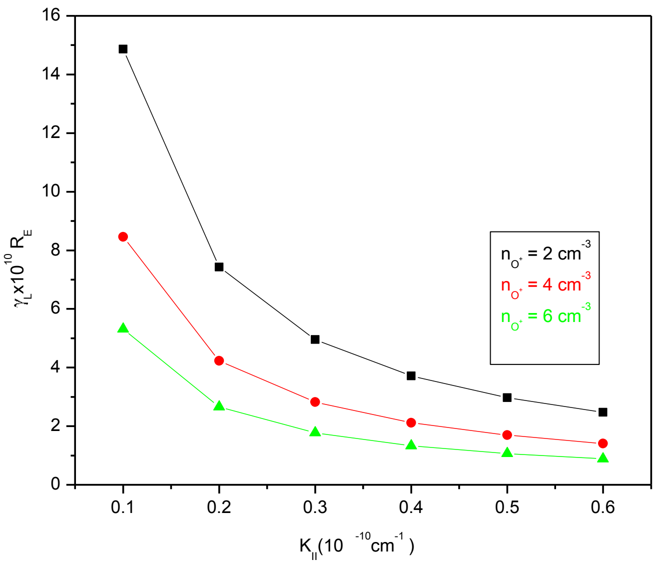

Figure 7: Variation of growth length (γ_L) of AW's with respect to the parallel wave vector K_{II} (cm^{-1}) for different values of oxygen plasma densities n_O^+ (cm^{-3}).

8. Conclusion

In this research communication, the Alfven wave has been studied in auroral acceleration region. The wave dispersion relation, growth/damping rate and growth length are evaluated for Alfven waves in multi-component magnetized plasma. It is observed that the Alfven waves are landau damped depending upon the parallel wave number electron plasma density and ions plasma density. Thus the Alfven waves may be due to landau damping of the wave through the wave particle-interaction and the energy of the wave is transferred to the particles. In summary, we demonstrated, both analytically and numerically, the heating of ions and electron acceleration in plasma by low frequency Alfven waves of finite amplitude. This is contrary to the linear theory, according to which ions can only be heated through resonant interactions with Alfven waves. In our model, the frequency of the Alfven wave is much lower than the ion cyclotron frequency. The results show that ions can be significantly heated and electrons accelerated by Alfven wave.

We also reviewed some applications in space and astrophysical plasma. Showing the importance of Alfven waves in multi-component plasma these studies.

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