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Beam effect on EMIC waves in presence of parallel electric field with different plasma densities by particle aspect approach

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Electromagnetic ion-cyclotron (EMIC) waves have been studied by single particle approach. The effect of ion beam on EMIC instability in the presence of parallel electric field at different plasma densities is evaluated. The dispersion relation, growth rate parallel and perpendicular resonance energies of the electromagnetic ion-cyclotron waves in a low β (ratio of plasma pressure to magnetic pressure), homogeneous plasma have been obtained. The wave is assumed to propagate parallel to the static magnetic field. The whole plasma is considered to consist of resonant and non-resonant particles. It is assumed that resonant particles participate in energy exchange with the wave whereas; non-resonant particles participate in the oscillatory motion of the wave. The effect of ion beam on EMIC waves in the presence of parallel electric field at different plasma densities is to enhance the growth rate of EMIC waves. The results are interpreted for the space plasma parameters appropriate to the auroral acceleration region of the earth's magneto-plasma.

Keywords: Electromagnetic ion-cyclotron waves, Auroral acceleration region, Solar plasma, Beam, Parallel electric field, Plasma density

1 Introduction

Electromagnetic ion cyclotron (EMIC) waves generated in the equatorial region of earth's magnetosphere as left-hand circularly (LHC) polarized waves propagate field-line guided towards the ionosphere. EMIC waves energy propagates bidirectional both away and towards the equator for events observed below 11° [M Latitude], but unidirectional away from the equator for all events located at latitudes greater then 11° [M Latitude] (Ref. 1). When observed on the ground, EMIC waves are usually measured with frequencies in the P_C1-2 or 0.1-5.0 Hz range. The theoretical studies of ion heating and acceleration perpendicular to the magnetic field are common features in the auroral region. These ions acquire energies of up to several KeV and then move up the field line, adiabatically exchanging perpendicular and parallel energy to produce ion conics. It is found that an inverted-V electron beam with energy of KeV can excite electromagnetic ion cyclotron (EMIC) waves propagating parallel to the magnetic field with a frequency below the hydrogen gyro-frequency.

The parallel electric field is known to be primary acceleration mechanism in the upward current region of the aurora. They have been inferred from observations on sounding rockets and satellites and direct measurements have been reported. The S3-3 satellite mission established that auroral acceleration is a near earth process, often less than 8000 km in altitude. Subsequent missions verified this finding. FAST observation also suggests both high and low-altitude acceleration regions. The polar observations now conclude that the majority of auroral acceleration is below 2 R_E in altitude[2].

The ionosphere and magnetosphere are electro-dynamically coupled by electric field and the existences of electric fields therein significantly change the electrodynamics energization and transport of charged particles in both the regions[3]. The large parallel electric field structure associated with ion cyclotron waves in the upward currents region were seen in association with an ion beam[4]. These structures can carry hundreds of volts and are associated with electron flux modulation typically developed from electromagnetic waves or above the H^+ cyclotron frequency. Similar structures have been observed by the polar satellite. The electric field structures seen in the downward current region are distinct from those typically seen in the upward current region[2]. The perpendicular component typically consists of brief (~100 μs) unipolar spikes and the parallel component is bipolar. The association with ion cyclotron waves is seen in the power spectra, which show depletions rather than enhancements at H^+ cyclotron harmonics.

The ion beam in the direction of the wave motion may damp these waves; however, the ion beam opposite to the wave motion may excite the waves as reported in this paper. In the present paper, we have considered the electro-dynamics of the auroral ionospheric region by an EMIC wave study. Lund *et al*.[5] predicted some observational evidences through satellite data. Ion conics may enhance the growth rate of EMIC waves at the ionospheric region, which provides the potential of our theoretical model to study EMIC wave's characteristics in the auroral acceleration region[4,6].

2 Observations of EMIC Waves

The large-amplitude electric fields represent a common feature on auroral field lines at altitudes above a few thousand kilometers, as shown by a number of spacecraft such as Dynamics Explorer 1, Viking, Polar and FAST and in the return current region at altitudes as low as 800 km, as was first shown by Freja satellites.

Observations evidence of H_{e+} energization by electromagnetic ion cyclotron (EMIC) waves in the magnetosphere has been reported. Ion beams waves, at or just above $f_{\mathrm{CH}+}$ are observed. These waves are of narrow-band with additional harmonics. The electromagnetic ion cyclotron (EMIC) waves at about $f_{CH+/2}$ are measured both inside and outside the ion beam region. The enhanced field-aligned flux at the inverted-V spectral peak is similar to the flux in the ion beam region but with a broader parallel temperature for the electron beam indicating greater parallel heating has taken place.

Resonant ion energies are also lowered by the increase in plasma density inside the plasma-pause and the guidance of electromagnetic ion cyclotron (EMIC) waves by density gradients near the plasma-pause can substantially enhance the net path integrated gain, the waves propagate across the equator. The dynamic pressure of the solar wind can cause an increase in the thermal anisotropy of trapped ring current ions, which enhances the growth rate of EMIC waves. The analysis of particle and field data on the AMPTE/CCE satellite in the dayside magnetosphere indicates that enhancements in solar wind pressure can excite electromagnetic ion cyclotron (EMIC) waves driven by changes in the energetic proton population. The micro-pulsations near noon on ground-based magnetometers are associated with sudden impulses. The excitation Pc-1 band waves observed both on the ground and on the polar spacecraft pulses[7]. Here we concentrate upon the excitation of EMIC waves by an up flowing ion beam at different plasma densities in the converging magnetic field of the auroral acceleration region and the energy exchange of the ions with the EMIC waves along and perpendicular to the magnetic field.

Observations made by the Freja satellites revealed detailed characteristics of the ion heating and corresponding wave phenomena at an altitude around 1700 km. It had been found that broadband waves around the ion cyclotron frequencies are the main energy source for the transversely accelerated ions and that the other mechanism, such as lower hybride wave or a slowly varying electric field, are less important at an altitude around 1700 km. Here we stated that the perpendicular heating is reduced by EMIC waves in the presence of an ion beam in a mirror-like structure of the auroral ionosphere[6]. These events are well correlated with the occurrence of electromagnetic ion cyclotron (EMIC) waves and are associated with inverted-V electron distribution. Transverse acceleration of ions which leads to the formation of ion conics is a ubiquitous feature of the aurora [8].

The main advantage of this approach is to consider the energy transfer between wave and particles, along with the discussion of wave dispersion and the growth/damming rate of the wave. The method may be suitable to deal with the auroral electrodynamics where particle acceleration is also important along with wave emissions. The results obtained by this approach is the same as those derived using the kinetic approach. Effects of the general distribution function with the parallel electric field and ion beam have been widely studied by researchers concerning electrostatic waves, electromagnetic waves, drift waves, Alfven waves and kinetic Alfven waves and electrostatic ion cyclotron waves[9,10].

In this paper, the combined effect of the parallel electric field $E_{\parallel}$ with ion beam velocity at different plasma densities on EMIC waves has been studied. The main objective of the present study is to examine the effect of parallel electric field $E_{\parallel}$ with beam and plasma densities on EMIC waves at zero of general loss-cone distribution index J in view of the observations in the auroral acceleration region. The present study is based on Dawson's theory of Landau damping which was further extended by Dwivedi *et al.*.[9], Mishra & Tiwari[10] and Ahirwar *et al*[4,6].

3 Mathematical Considerations/Evaluation

3.1 Basic trajectories

We find the following set of equations[4,6]:

$$\delta V_{\perp i^{+}} = \frac{h\Omega_i\left(V_{\Pi 0i} - \frac{\omega}{k}\right)}{kV_{\Pi 0i} - (\omega - \Omega_i)}[\cos(kz - \omega t - \psi) - \varepsilon\cos\{kz - \omega t - \psi - \{kV_{\Pi 0i} - (\omega - \Omega_i)\}t\}] \quad \ldots(1a)$$

$$\delta V_{\Pi i} = \frac{-hV_{\perp 0i}\Omega_i}{kV_{\Pi 0i} - (\omega - \Omega_i)}[\cos(kz - \omega t - \psi) - \varepsilon\cos\{kz - \omega t - \psi - \{kV_{\Pi 0i} - (\omega - \Omega_i)\}t\}] \quad \ldots(1b)$$

where $z = z_0 + V_{\parallel}\, t$ and $\psi = \psi_0 - \omega\, t$ and $\varepsilon = 0, 1$ for the non-resonant and resonant particles.

3.2 Density variation

To determine the dispersion relation and the growth rate, we consider a bi-Maxwellian plasma with density distribution as:

$$N(y, \bar{V}) = N_0 f_{\perp}(V_{\perp}) f_{\Pi}(V_{\Pi}) \quad \ldots (2)$$

We consider a general loss-cone distribution function for $f_{\perp}(V_{\perp})$ as[4,6]:

$$f_{\perp i}(V_{\perp i}) = \left(\frac{V_{\perp i}^{2J}}{\pi V_{T\perp i}^{2(J+1)} J!}\right)\exp\left(-\frac{V_{\perp i}^{2}}{V_{T\perp i}^{2}}\right) \quad \ldots (3)$$

and $f_{\Pi}(V_{\Pi})$ which is defined by the drifting Maxwellian [4,6]:

$$f_{\Pi i}(V_{\Pi i}) = \left(\frac{1}{\sqrt{\pi} V_{T\Pi ci}}\right)\exp\{-m(V_{\Pi i} - V_{Di})^2 / V_{T\Pi ci}^{2}\} \quad \ldots (4)$$

and $V_{T\Pi ci} = \left(1 - \frac{ieE_{\Pi}}{k(KV^{2}_{TIIi})}\right)^{1/2} . V_{TIIi}$.

This procedure was further adopted by Mishra & Tiwari[10] and Ahirwar *et al*[4,6]. V_{Di} defines the ion beam velocity of the particles and J is the distribution index and measures the steepness of the loss-cone feature. In the case of J=0 this represents a bi-Maxwellian distribution $V_{T\Pi ci}^{2} = \frac{2T_{\Pi ci}}{m_i}$ and $V_{T\perp i}^{2} = (J+1)^{-1}\frac{2T_{\perp i}}{m_i}$, which are the squares of parallel and perpendicular thermal velocities with respect to the external magnetic field. We evaluate the density perturbation associated with the particle velocity as[4,6]:

$$\frac{dn_1}{dt} = -N(V)(\nabla . u) \quad \ldots (5)$$

Transforming the r.h.s of Eq. (5) as the function of t and by Eqs (1) and (5) we get the solution for perturbed density [4,6] as:

$$n_1 = \frac{hV_{\perp 0i}\Omega_i kN(V)}{[kV_{\Pi 0i} - (\omega - \Omega_i)]^2}[\cos\chi - \varepsilon\cos\chi_0 + \varepsilon t\Lambda\sin(\chi - \Lambda t)] \quad \ldots (6)$$

where $\chi = k\,z - \omega t - \Psi$ and $\Lambda = (kV_{\parallel 0} - (\omega - \Omega_i))$

3.3 Dispersion relation

We consider the cold plasma dispersion relation for the EMIC wave[4,6] as:

$$\frac{c^2k^2}{\omega^2} = \left(\frac{\omega_{pi}^{2}}{\Omega_i^{2}}\right)\left(1 - \frac{\omega}{\Omega_i}\right)^{-1} \quad \ldots (7)$$

where $\omega_{pi}^{2} = \frac{4\pi N_0 e^2}{m_i}$ is the plasma frequency for the ions. N_0 is the plasma density of particles. In the present study we have the parallel electric field with ion beam velocity, introduced through the modification of thermal velocity parallel to the magnetic field which modifies the ion beam velocity parallel to the magnetic field. A beam of ions of the low density, in constant velocity along the magnetic field is considered.

4 Wave Energy and Growth Rate

The wave energy density W_w per unit wavelength is the sum of the pure field energy and the changes in the energy of the non-resonant particles i.e. the total energy per unit wavelength is given as:

$$W_w = U + W_i \quad \ldots (8)$$

where U is the energy of electromagnetic wave as defined by the expression[4,6] as:

$$U = \left(\frac{1}{16\pi}\right)\left[\left(\frac{d}{d\omega}\right)(\omega\varepsilon_k)E_1^{*}E_k + |B|^2\right] \quad \ldots (9)$$

where ε_k is the dielectric tensor. After the calculation, the electromagnetic wave energy per unit wavelength is given by:

$$U = \left(\frac{\lambda B^2}{8\pi}\right)\left(\frac{(2\Omega_i - \omega)}{(\Omega_i - \omega)}\right) \quad \text{… (10)}$$

and

$$W_i = \int_0^{\lambda} dz \int_0^{2\pi} d\psi \int_0^{\infty} V_{\perp i} dV_{\perp i} P \int_{-\infty}^{\infty} dV_{\Pi i} \frac{m}{2}[(N + n_1) \times (V_i + \delta V_i)^2 - NV_i^2] \quad \text{… (11)}$$

4.1 Non-resonant energy

With the help of Eqs (1), (6) and (11) with $\varepsilon = 0$ we find the parallel non resonant energy as[4, 6]:

$$W_{\Pi i} = \frac{-\lambda B^2}{8\pi} \frac{C_{Ji}}{V^2_{T\Pi ci}} \frac{\omega^2_{pi}}{c^2 k_{\Pi}^2}\left[\frac{1}{2} Z_1\left(\zeta - \frac{V_{Di}}{V_{T\Pi c}}\right) + \frac{\omega - \Omega_i}{k_\Pi V_{T\Pi ci}} Z_2\left(\zeta - \frac{V_{Di}}{V_{T\Pi c}}\right)\right] \quad \text{… (12)}$$

and perpendicular non-resonant energy as:

$$W_{\perp i} = \frac{\lambda}{2}\frac{B^2}{8\pi}\frac{\omega_{pi}^2}{c^2 k_\Pi^2}\left[D_J\left\{1 - \frac{2\Omega_i}{k_\Pi V_{T\Pi ci}} Z\left(\zeta - \frac{V_{Di}}{V_{T\Pi ci}}\right) + \frac{\Omega_i^2}{k_\Pi^2 V_{T\Pi ci}^2} Z_1\left(\zeta - \frac{V_{Di}}{V_{T\Pi ci}}\right)\right\} + \frac{2C_J}{V_{T\Pi ci}^2}\left\{Z_1\left(\zeta - \frac{V_{Di}}{V_{T\Pi ci}}\right) - \frac{\Omega_i}{k_\Pi V_{T\Pi ci}} Z_2\left(\zeta - \frac{V_{Di}}{V_{T\Pi ci}}\right)\right\}\right] \quad \text{…(13)}$$

4.2 Perpendicular resonant energy

The role of the EMIC wave particle interaction in the auroral acceleration region is examined in the present analysis. The perpendicular (transverse) energy and the parallel resonant energy of the resonant ions are calculated with the help of Eqs (1), (6) and (11) with $\varepsilon = 1$ as:

$$W_{r\perp i} = \frac{\pi^{3/2} B^2}{C^2 K_\Pi^2}\frac{\omega_{pi}^2 \Omega_i^2}{\omega k_\Pi^2 V_{T\Pi ci}}\left[(J+1)\frac{T_{\perp i}}{T_{\Pi i}}\left(\frac{\omega' - \Omega_i}{\Omega_i}\right) + 1\right] \times \exp\left(-\frac{(\omega' - \Omega_i)^2}{k_\Pi^2 V_{T\Pi ci}^2}\right) \quad \text{… (14)}$$

4.3 Parallel resonant energy

$$W_{r\Pi i} = \frac{\pi^{3/2} B^2}{C^2 K_\Pi^2}\frac{\omega^2_{pi}\Omega_i^2}{\omega k_\Pi^2 V_{T\Pi ci}}\left[(J+1)\frac{T_{\perp i}}{T_{\Pi ci}}\left(\frac{\omega' - \Omega_i}{\Omega_i}\right)^2\right] \times \exp\left(-\frac{(\omega' - \Omega_i)^2}{k_\Pi^2 V_{T\Pi ci}^2}\right) \quad \text{… (15)}$$

where $\omega' = (\omega - K_\Pi V_{Di})$

$$C_J = \frac{2\pi}{V_{T\perp}^{2(J+1)} J!}\int_0^\infty dV_\perp{}^2 V_\perp^{2(J+1)} \exp\left(-\frac{V_\perp^2}{V_{T\perp}^2}\right)$$

$$D_J = \frac{2\pi}{V_{T\perp}^{2(J+1)} J!}\int_0^\infty dV_\perp{}^2 V_\perp^{2J} \exp\left(-\frac{V_\perp^2}{V_{T\perp}^2}\right)$$

and

$$f_r(V_r) = \left(\frac{m_i}{2\pi T_{\Pi c}}\right)^{1/2} \exp\left(-\frac{m_i(\omega' - \Omega_i)^2}{2T_{\Pi c} k_\Pi^2}\right)$$

$$f'(V_r) = -2\left(\frac{m_i}{2\pi T_{\Pi c}}\right)^{1/2}\left(\frac{\omega' - \Omega_i}{k_\Pi V_{T\Pi c}^2}\right)\exp\left[-\left(\frac{\omega' - \Omega_i}{k_\Pi V_{T\Pi ci}}\right)^2\right]$$

$$Z_n(\xi) = \frac{1}{\sqrt{\pi}} p \int_{-\infty}^{\infty} \frac{\exp(-x^2)}{(x - \xi)^{n+1}} dx$$

$$\xi = \frac{\omega - \Omega_i}{k_\Pi V_{T\Pi ci}}$$

Using the law of conservation of energy

$$\frac{d}{dt}(W_r + W_w) = 0 \quad \text{… (16)}$$

The growth/damping rate γ is derived as[4, 6]:

$$\frac{\partial U}{\partial t} = 2\gamma U \quad \text{… (17)}$$

where

$$\frac{dW_r}{dt} = -2\frac{\partial U}{\partial t}$$

and

$$\frac{dW_i}{dt} \sim \frac{\partial U}{\partial t}$$

Those particles with velocities near the phase velocity of the waves give up energy $2U$ to the waves. Half of this goes to potential energy and the other half goes into kinetic energy of oscillation of the bulk of the particles.

Hence the growth rate of EMIC waves is obtained as:

$$\frac{\gamma}{\omega} = \frac{\dfrac{\Omega_i}{kV_{T\amalg i}.s^{1/2}}\left(\dfrac{(\Omega_i-\omega)}{\Omega_i}\dfrac{(J+1)V_{T\perp i}{}^2}{V_{T\amalg i}{}^2.S}-1\right)\exp\left[-\dfrac{1}{V_{T\amalg i}{}^2.S}\left(\dfrac{\omega'-\Omega_i}{k_\amalg}\right)^2\right]}{\left(\dfrac{ck}{\omega_{pi}}\right)^2\left(\dfrac{2\Omega_i-\omega}{\Omega_i-\omega}\right)+\dfrac{1}{2}\dfrac{\omega^2}{(\Omega_i-\omega)^2}} \quad \ldots (18)$$

where $S=[1+\dfrac{e^2.E_{II}^2}{K^2(KV_{TIIi})^2}]$

using the value of $V_{T\perp i}{}^2=(J+1)^{-1}\dfrac{2T_{\perp i}}{m_i}$ and $V_{T\amalg ci}{}^2=\dfrac{2T_{\amalg ci}}{m_i}$.

Here it is noticed that the parallel electric field $E_\parallel$ with ion beam V_{Di} has affected the growth rate through plasma densities and change in the energy for the electromagnetic waves propagating parallel to the magnetic field.

5 Results and Discussion

The characteristics of the EMIC waves were derived by using auroral acceleration region parameters[4,6,10].

B_0 = 4300 nT, Ω_i = 412 sec^{-2}
$V_{T\parallel i} = 2\times10^9$cm/s, $\omega_{pi}{}^2 = 1.732\times10^6$ s^{-2}

Figures 1 and 2 predict the variation of the growth rate (γ/ω) with the wave vector $K_\parallel$ (cm^{-1}) for different values of parallel electric field $E_\parallel$ and distribution index J = 1, 2, respectively. The steepness of loss-cone distribution i.e. for the Maxwellian distribution the growth rate slightly increases with the particular value of wave number ($K_\parallel$). The steepness of loss-cone distribution also introduced a peak in the growth rate which may be due to wave-particle resonance interaction at $K_\parallel$ = 0.7, 0.9. Further increase in the steepness of the loss-cone distributions shifts the resonance condition towards the lower side of the wave number ($K_\parallel$) and the peak value of the growth rate also decreases. Under this condition for the increasing magnetic activity, magnetospheric convection is enhanced and the location of the flow separator moves rapidly earthward. In such conditions, the outer plasma sphere becomes strongly structured, and plasmaspheric material will appear beyond the plasma pause.

Figures 3 and 4 predict the variation of the growth rate (γ/ω) with the wave vector $K_\parallel$ (cm^{-1}) for different values of ion beam velocity V_{Di} and parallel electric field $E_\parallel$ = 10, 20, respectively. The increasing on the growth rate and the resonant energy transferred in the presence of ion beam velocity V_{Di} and parallel electric field $E_\parallel$ = 10, 20 mV/m and the peak is the growth

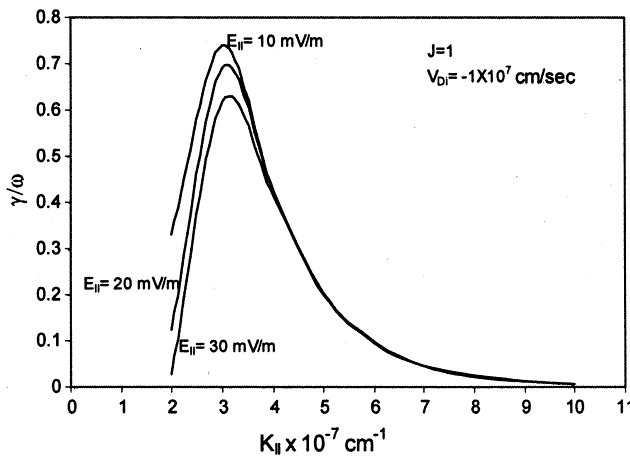

Fig. 1 — Variation of growth rate (γ/ω) versus wave vector $K_\parallel$ (cm^{-1}) for different values of parallel electric field $E_\parallel$ and distribution index J=1

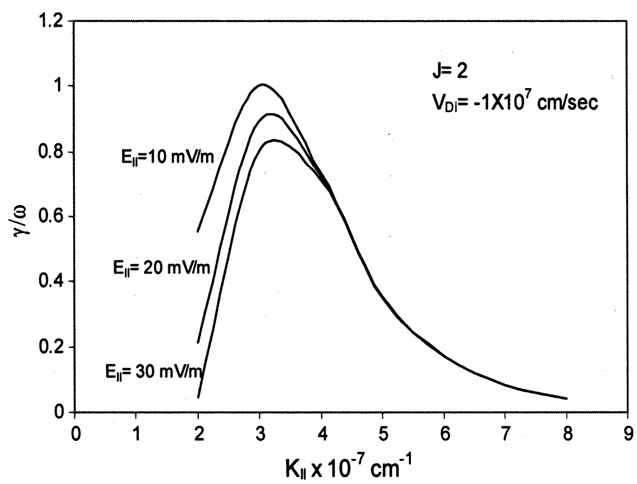

Fig. 2 — Variation of growth rate (γ/ω) versus wave vector $K_\parallel$ (cm^{-1}) for different values of parallel electric field $E_\parallel$ and distribution index J=2

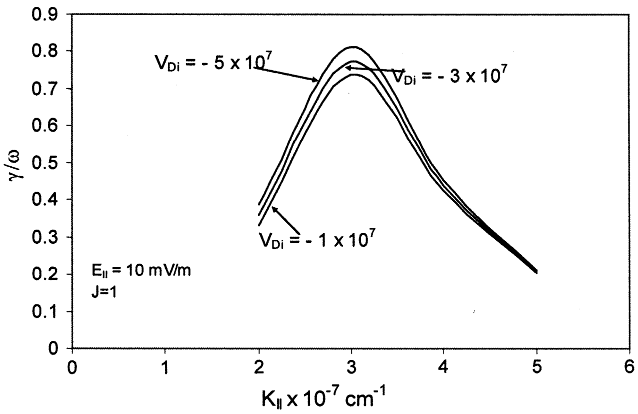

Fig. 3 — Variation of growth rate (γ/ω) versus wave vector $K_{\|}$ (cm^{-1}) for different values of ion beam velocity V_{Di} and parallel electric field $E_{\|}$ = 10 mV/m

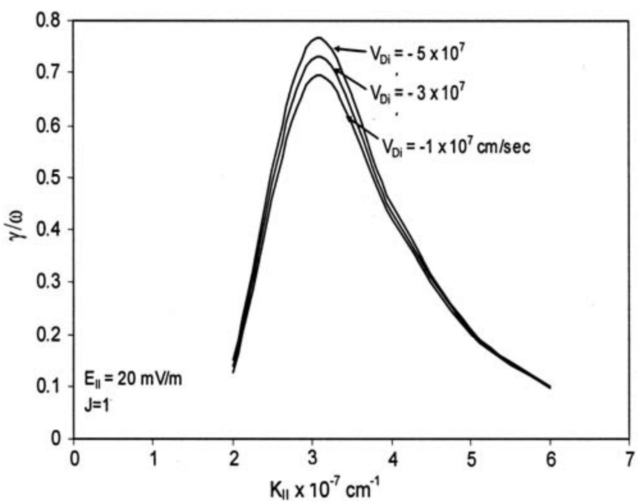

Fig. 4 — Variation of growth rate (γ/ω) versus wave vector $K_{\|}$ (cm^{-1}) for different values of ion beam velocity V_{Di} and parallel electric field $E_{\|}$ = 20 mV/m

rate which shifts towards the lower side of the parallel wave number ($K_{\|}$) and the growth rate also decreases. The decrease in the transverse and parallel resonant energies is supported by the increases in the growth rate of the wave which is in accordance to the conservation of energy in mirror like devices.

Figures 5 and 6 depict the variation of growth rate (γ/ω) with the wave vector $K_{\|}$ cm^{-1} for different values of plasma density n_i and ion beam velocity V_{Di} $=-1\times10^7$ cm/sec parallel electric field $E_{\|}$ = 10, 20 mV/m and J = 1. It is assumed that the ion beam is directed from the ionosphere towards the magneto-tail and therefore, the ion beam velocity is negative. It is observed that the effect of increasing the parallel electric field $E_{\|}$ with plasma density and ion beam velocity is to enhance the growth rate.

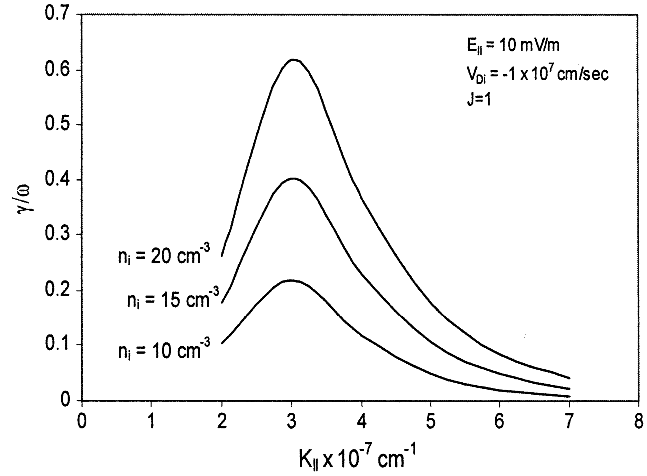

Fig. 5 — Variation of growth rate (γ/ω) versus wave vector $K_{\|}$ (cm^{-1}) for different values of plasma densities n_i and ion beam velocity V_{Di} =-1×10^7cm/sec, parallel electric field $E_{\|}$ = 10 mV/m and J=1

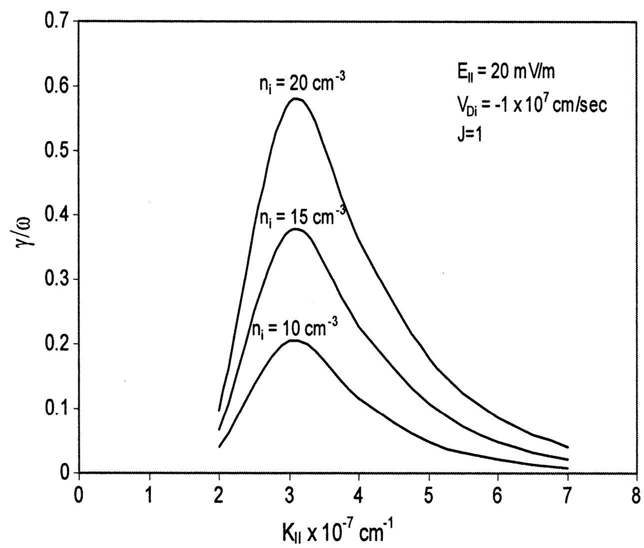

Fig. 6 — Variation of growth rate (γ/ω) versus wave vector $K_{\|}$ (cm^{-1}) for different values of plasma densities n_i and ion beam velocity V_{Di} =-1×10^7cm/sec, parallel electric field $E_{\|}$ = 20 mV/m and J=1

The resonance value of the growth rate increase markedly with the increasing ion beam velocity V_{Di} and plasma densities n_i that may be due to the Doppler-shifting of frequency in the resonance interaction. Thus the parallel electric field in the presence of ion beam, parallel electric field with plasma densities, and steepness of loss-cone distribution modifies the wave-particle resonance condition and leads to lowering of the growth rate of the EMIC wave and enhanced acceleration of ions transverse to the magnetic field. The wave-particle interaction and the energy of the parallel potential drop extracted through the ions cyclotron wave cause the transverse acceleration of the ions.

Figure 7 depicts the variation of transverse resonant energy $Wr_{\perp}$ erg cm with the wave vector $K_{\|}$ (cm^{-1}) for different values of plasma densities n_i and ion beam velocity V_{Di} =-1×10^7, parallel electric field $E_{\|}$ = 10 mV/m and J=1. The negative W_{r1} indicates that the particles energy is transferred to the waves. Thus, wave emissions occur by extracting energy from the ions moving perpendicular to the magnetic field. It is observed that the effect of increasing V_{Di} is to enhance the transfer of the particle's energy perpendicular to the magnetic field to the waves. Thus the perpendicular deceleration of ions is noticed through the EMIC wave by ion beam energy. The effect of increasing values of the distribution indices is to increases the reduction in resonant energy. Thus the steep loss-cone distribution of the magnetosphere decreases the transverse resonant energy in the presence of EMIC waves.

It is also seen that the transverse resonant energy $W_{r\perp}$ increase with the decreases value of $K_{\|}$. Thus at higher $K_{\|}$ the growth rate and reduction in perpendicular energization are both enhanced as the ion beam energy is being transferred to the waves.

Figure 8 shows the variation of parallel resonant energy $W_{r\|}$ erg cm with $K_{\|}$ (cm^{-1}) for different values of plasma densities n_i and ion beam velocity V_{Di} =-1×10^7 cm/sec, parallel electric field $E_{\|}$ and J = 1. It is seen that the effect of V_{Di} is to increase the parallel resonant energy. Thus, the ion beam may enhance the heating of resonant ions parallel to magnetic field. The effect of increasing values of the distribution indices is to increase the parallel resonant energy. Thus, the steep loss-cone distribution of the magnetosphere enhances the parallel resonant energy by the EMIC waves. It is also seen that the parallel resonant energy $Wr_{\|}$ increase with the decreases value of $K_{\|}$. The process occurs at the cost of ion beam energy. The enhancement of $Wr_{\|}$ due to steep loss-cone distribution has been reported previously by Ahirwar *et al*[6]. The steep loss-cone structures are analogous to mirror-like devices with a higher mirror ratio which may accelerate the charged particle moving along the magnetic field[9]. Thus, the ion acceleration along the magnetic field is predicted by EMIC waves along the auroral field lines.

Figure 9 shows the variation of perpendicular resonant energy $W_{r\perp}$ erg cm, with $K_{\|}$ (cm^{-1}) for different values of ion beam velocity V_{Di}, parallel electric field $E_{\|}$ = 10 mV/m and J = 1. It is observed that the effect of increasing the values of the parallel electric field ($E_{\|}$) is to enhance the transverse resonant energy of the ions. The effect of increasing the values of the distribution index J = 1, 2, is to decrease transverse resonant energy of the ions as the growth rate is enhanced. Thus the steepness of the loss-cone distribution decreases the transverse resonant energy of the ions in the presence of EMIC waves.

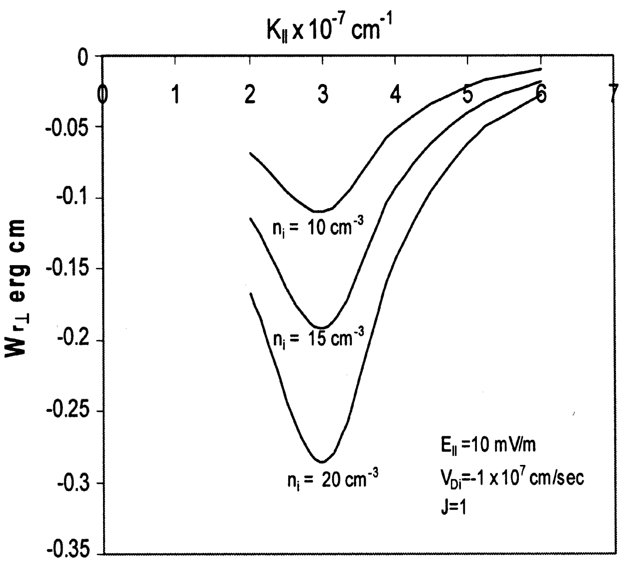

Fig. 7 — Variation of perpendicular resonant energy $W_{r\perp}$ erg cm versus wave vector $K_{\|}$ (cm^{-1}) for different values of plasma densities n_i and ion beam velocity V_{Di} =-1×10^7 cm/sec, parallel electric field $E_{\|}$ = 10 mV/m and J=1

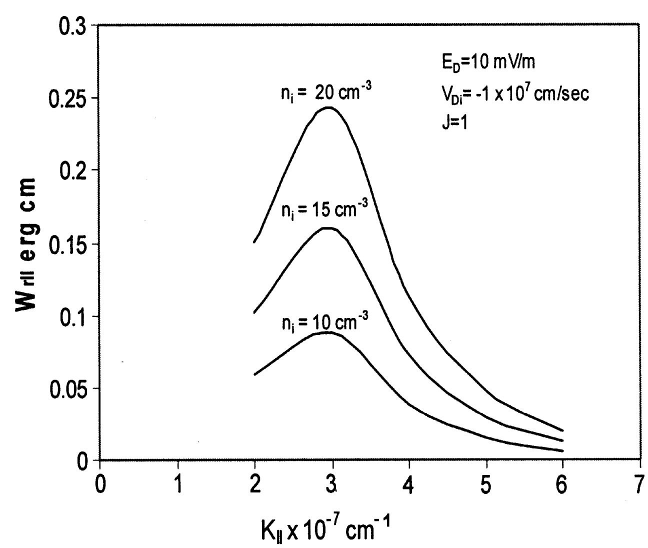

Fig. 8 — Variation of parallel resonant energy $W_{r\|}$ erg cm versus wave vector $K_{\|}$ (cm^{-1}) for different values of plasma densities n_i and ion beam velocity V_{Di} =-1×10^7 cm/sec, parallel electric field $E_{\|}$ = 10 mV/m and J=1

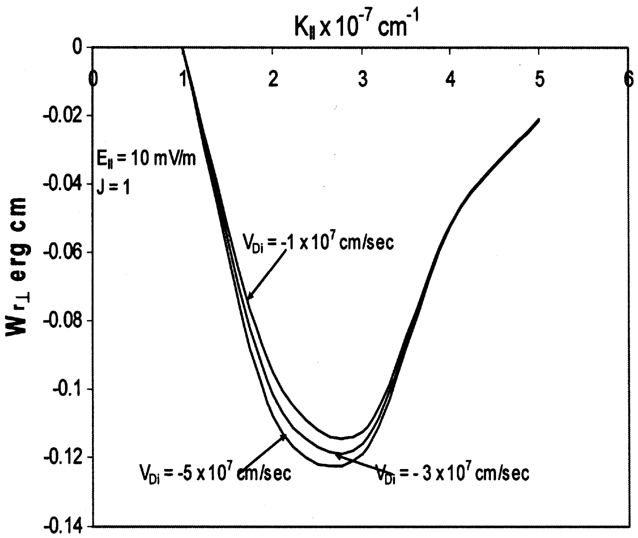

Fig. 9 — Variation of perpendicular resonant energy $W_{r\perp}$ erg cm versus wave vector $K_{\parallel}$ (cm^{-1}) for different values of ion beam velocity V_{Di}, parallel electric field E_0 = 10 mV/m and J=1

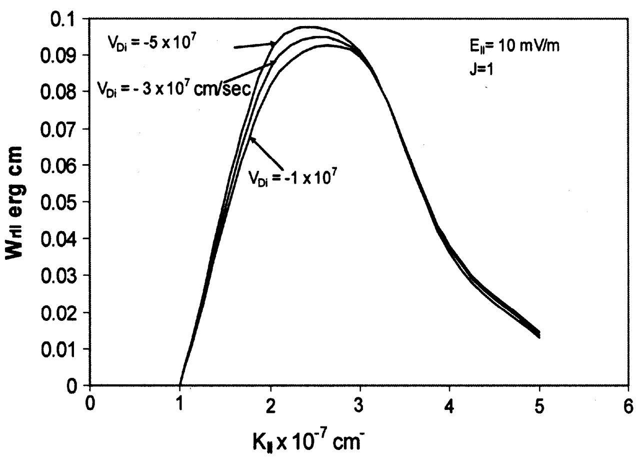

Fig. 10 — Variation of parallel resonant energy $W_{r\parallel}$ erg cm versus wave vector $K_{\parallel}$ (cm^{-1}) for different values of ion beam velocity V_{Di}, parallel electric field $E_{\parallel}$ = 10 mV/m and J=1

Figure 10 predicts the relation between the parallel resonant energy $W_{r\parallel}$ erg cm, and wave vector $K_{\parallel}$ (cm^{-1}) for different values of the ion beam velocity V_{Di}, parallel electric field $E_{\parallel}$ = 10 mV/m and J = 1. The effect of increasing values of the parallel electric field $E_{\parallel}$ is to decrease the parallel resonant energy due to the EMIC wave, which causes the increase in the transverse resonant of the ions. The effect of increasing the values of the distribution index J is to show the increasing effect of the parallel resonant energy of the ions. Thus, the steepness of the loss-cone distribution is to increase the parallel resonant energy $W_{r\parallel}$ by the presence of EMIC wave.

Ergun *et al.*[11] observed the Fast Auroral Snapshot (FAST) satellite which measures electromagnetic fields and charged particle distribution of the aurora. The FAST satellite is in a near-polar orbit (83° inclinations) with a 350 km perigee and a 4175 apogee. Instruments include electron and ion spectrographs and three-axis electric field and magnetic field instruments. The visible auroral arcs are known to come from energetic (~10 k_eV) electrons that are accelerated earthward by magnetic-field-aligned (parallel) electric fields. In this region, parallel electric fields ($E_{\parallel}$) arises from a combination of strong upward currents and a substantial magnetic mirror ratio (~ 400) between the source electron population in the tail of the Earth's magnetosphere and the visible arc in the ionosphere. Direct observations of $E_{\parallel}$ in the upward current region have been reported.

Ahirwar *et al.*[4], stated that the measurement of the parallel electric field is a recent aspect of rocket and satellite experiments in space plasma[12,13]. Theoretical and experimental studied have indicated the presence of parallel electric fields in the range from several microvolt per meter to several milivolts per meter. The electric field observed along the auroral field lines in the presence of EMIC wave may govern the behaviour of auroral electrodynamics. The electrical energy may be transferred to the ions by the EMIC wave. The EMIC waves may be excited in the auroral acceleration regions, as predicted by the enhancement of growth rate with various parameters. The role of the observed electric field is to control the growth rate in the linear limit. The particle aspect analysis developed may be applicable to laboratory plasma as well as to estimate the heating rates, along with the study of emissions of EMIC waves.

6 Conclusions

A comprehensive mathematical analysis has been done and it has been found how an electromagnetic ion-cyclotron wave may grow through the inverse Landau damping with parallel electric field as well as ion beam with plasma densities. The effects of a general loss cone distribution are also incorporated in the auroral acceleration region to discuss EMIC wave's emission.

The effect of increasing parallel electric field, ion beam velocity and plasma densities is found to enhance the growth rate may be due to a shifting of the resonance condition. The effect of higher distribution indices is to enhance the growth rate. The mirror-like structure of the magnetosphere with a steep loss-cone distribution may be unstable for the EMIC wave emission. The growth rate increases with $K_{||}$ in all cases. The effect of increasing the values of the distribution indices is to increase the parallel resonant energy, along with an increase by n_i. The electric field plays an important role in the dynamics of the plasma in the ionosphere as well as in the magnetosphere and solar wind. The behaviour studied for the EMIC waves may be important in the electromagnetic emission in the auroral acceleration region. The result of the study is also applicable to the plasma devices that have the steep loss-cone distribution. The effect of ion beam, parallel electric field and plasma densities during his substorm periods is to enhance the EMIC wave's emission. The energy of ions in the presence of parallel electric field of EMIC waves depends upon the plasma densities of the ions and loss cone distribution indices in the presence of an up flowing ion beam. The increasing values of the distribution indices are to increase the parallel resonant energy along with an increase by ion beam. The findings may be applicable to explain the EMIC wave's emissions and ion heating in the solar corona as well as auroral acceleration region and the acceleration of the solar wind.

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