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Study of General Loss-Cone Distribution Function on EIC Waves with Multi-Ions Plasma in PSBL Region-Particle Aspect Approach

BD Raikwar, P Varma and MS Tiwari*

Department of Physics, Dr. H.S. Gour Vishwavidyalaya, Sagar, Mandhya Pradesh, 470003, India

***Corresponding Author:** MS Tiwari, Department of Physics, Dr. H.S. Gour Vishwavidyalaya, Sagar Mandhya Pradesh, 470003, India, E-mail: tiwarims@yahoo.co.in

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Abstract

Electrostatic ion-cyclotron waves are investigated with multi-ion plasma (H^+, He^+ and O^+) using particle aspect analysis. The plasma is considered to consist of resonant and non-resonant particles. The resonant particles participate in energy exchange while the non-resonant particles support the oscillatory motion of the wave. The wave is assumed to propagate obliquely to the static magnetic field. Dispersion relation, growth rate, parallel and perpendicular resonant energy have been investigated for electrostatic ion-cyclotron waves with multi-component plasma. The effect of general loss-cone distribution function with varying plasma density is to enhance the growth rate of EIC waves with multi- component plasma (H^+, He^+ and O^+). The loss-cone distribution acts as source of free energy. The results are interpreted for the space plasma parameters appropriate to the plasma sheet boundary layer region around the earth's magnetosphere. The study may explain the EIC waves observed in this region and play a major role of particle density variation in particular region.

Keywords: Earth's Magnetosphere; Electrostatic ion-cyclotron wave; Particle aspect approach; Plasma sheet boundary layer; Loss-cone distribution function; Multi-component plasma

1. Introduction

The Electrostatic ion cyclotron waves were first discovered by D` Angelo and Motley Drummond and Rosenbluth in 1962 [1]. These waves are normal mode of magnetized plasma. It is propagates almost perpendicularly to the magnetic field with a small, but finite parallel wave number $K_{\|}$ so that electrons can maintain Boltzmann distribution by moving along the magnetic field, thus the ratio of parallel to perpendicular wave number is less than one. These waves are very narrowing banded and consequently turn out to be highly coherent over several oscillation periods. The excitation mechanism of these waves is the instabilities caused by electron currents, ion beams and loss-cone distribution of energetic ions. The EIC waves can be generated by wave particle interactions in the magnetosphere and can be separated into narrow band and broad band spectral types. Narrow band EIC waves typically exhibit frequencies just above the proton cyclotron frequency and its harmonics. In a different way we can say an EIC wave is a longitudinal oscillation of ions and electrons in a magnetized plasma propagating nearly (but not exactly) perpendicular to the magnetic field.

During the last decade substantial progress has been made towards understanding the influence of heavy ionospheric ions on the dynamics of the terrestrial magnetosphere. The major source of O^+ in the ring current is the near-earth plasma sheet, but some internal sources and acceleration mechanisms have also been identified, and their importance is unclear. Excitation of waves, and details of wave-particle interactions depend on the heavy ion composition which provides an additional link between the dynamics of heavy ions and electron/ ion populations of the ring current and the radiation belts. The Plasma Sheet Boundary Layer (PSBL) (Figure1; http://static-content.springer.com/image/chp%) is often the most active plasma region of the magnetotail. This is a temporally variable transition region located between the magnetotail lobes and the central plasma sheet. It can be separated from the tail lobes by the plasma sheet boundary layer (PSBL). It is probably located on closed field lines, and the densities are only little smaller than in central plasma sheet.

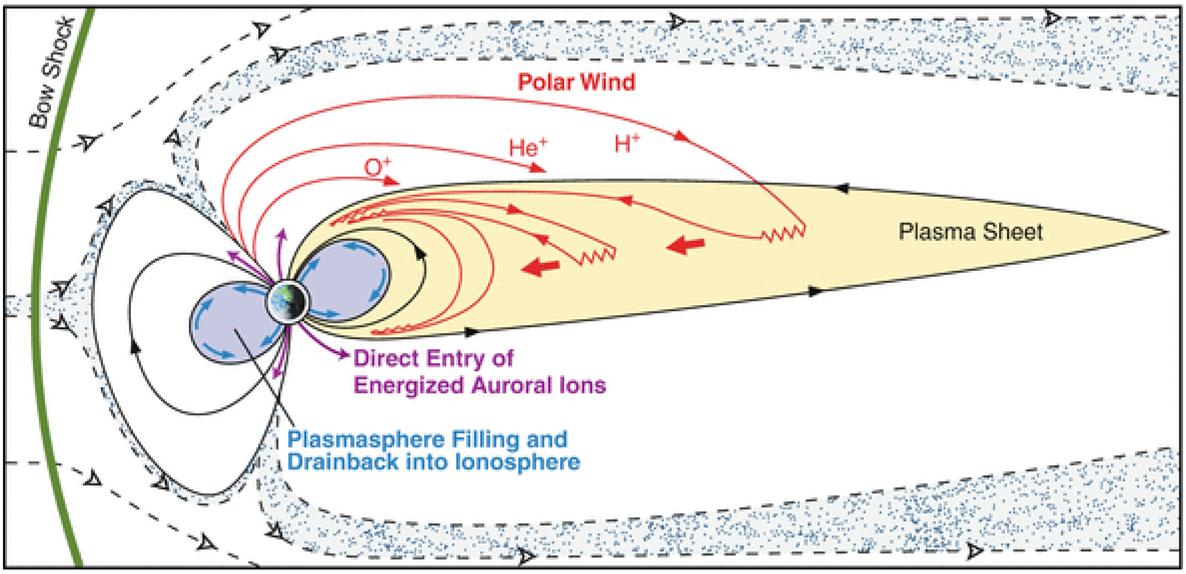

Figure 1: Schematic diagram of PSBL region with multi-ions

EIC waves are able to resonate with the ions and electrons available in the magnetosphere over a broad range of energies. Here source of EIC wave excitation is considered the pitch angle distribution of ions and most of the interaction leads to pitch-angle scattering and energy diffusion. The EIC waves are considered as one of the more important loss mechanisms or energization of ions may take place via wave particle resonance. In present study the EIC waves are studied with general loss-cone distribution function and multi-ions plasma i.e. H^+, He^+ and O^+ ions. Since the Earth's magnetic field is converging at the magnetic poles, as a consequence of the conservation of energy and magnetic moment, a particle approaching the Earth's magnetic dipole will be repelled by a magnetic mirror force. if it doesn't have a small enough original pitch angle; or it reaches the ionosphere, collides with the neutrals, and loses its energy by ionizing or exciting them. Particles with pitch angles smaller than the loss cone angle will be able to reach the ionosphere. Thorne & Horne [2] and Xue [3] have provided explanation for O^+ ion energization at outer ionosphere by He^+ cyclotron wave instability and concluded that O^+ achieves more energy by He^+ ion cyclotron interaction. Vogiatzis [4] studied magnetosphere during substorms and made conclusions about plasma transport in the Earth's magnetotail and various magnetic structures detected in the magnetosphere.

Present study is made sequentially to study the growth rate and resonant energies of Electrostatic ion-cyclotron waves with multi component plasma and loss-cone distribution function. This study can help to understand the transport of plasma in the magnetosphere and electrodynamics of plasma sheet boundary layer region. Satellites dedicated to the study of the Earth's magnetosphere, such as Cluster Escoubet [5], the Geomagnetic Tail Lobe (GEOTAIL) Nishida [6], Double Star, Liu [7] or the Time History of Events and Macro scale Interactions during Substorms (THEMIS) Angelopoulos [8]. These all satellites provided us very useful data which can help to make a better understanding about magnetosphere, earth environment and related mysteries.

For present analysis we are using particle aspect analysis which is the simplest approach for the single particle motion description it describes the motion of a particle under the influence of the external electric and magnetic fields. This paper is divided into 6 sections, in section 1 represents introduction and Section 2 represents the basic trajectories following the velocities of the charged particles. Section 3 describes the dispersion relation of EIC waves. In section 4 growth rate of EIC waves with multi-component plasma and general loss-cone distribution is evaluated. Section 5 describes the result and discussions and section 6 explains the conclusion of the study.

2. Basic Trajectory

An EIC wave is assumed to start at t = 0 when the resonant particles are not disturbed. The trajectories of particles are then evaluated within the framework of linear theory. The wave is assumed to have the form and (fig. 2) satisfying the condition of wave propagation,

$$K_{\Pi} E, k = (k_{\perp}, 0, k_{\Pi}), E = (E_X, 0, E_Z)$$

With

$$E_X(r,t) = E_1 \cos(k_{\perp} x + k_{\Pi} z - \omega t),$$
$$E_Z(r,t) = \kappa E_1 \cos(k_{\perp} x + k_{\Pi} z - \omega t)$$

And

$$\kappa = \left(\frac{k_{\Pi}}{k_{\perp}}\right) < 1$$

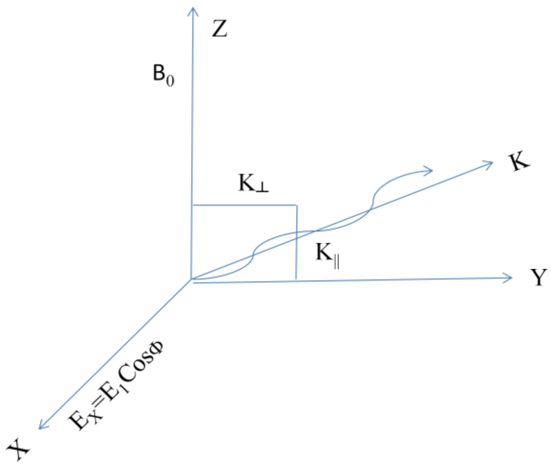

Fig. 2 Propagation of EIC waves

Where, $\Phi = k_{\perp} x + k_{\|} z - \omega t$

The amplitude E_1 is slowly varying function of **t** i.e.

$$\frac{1}{E_1}\left(\frac{dE_1}{dt}\right) << \omega$$

Here k_{Π} and $k_{\perp}$ are the components of the wave vector along and across the magnetic field, respectively and ω represents the wave frequency.

Trajectories and velocities of the Particles;

The trajectories of particles are evaluated within the framework of linear theory. The equation of motion of a particle is given by:

$$m\left(\frac{dv}{dt}\right) = q\left[E + \left(\frac{1}{c}\right) v \times B_0\right] \qquad (1)$$

If E is considered to be a small perturbation i.e., $E = E_0 + E_1$, velocity v can be expressed in terms of unperturbed velocity V and perturbed velocity u.

Then the trajectory of the free gyration is obtained as;

$$X(t) = \frac{V_{\perp}}{\Omega_{\alpha}}\left[\sin(\theta - \Omega_{\alpha} t) - \sin\theta\right] + X_0,$$
$$Y(t) = \frac{V_{\perp}}{\Omega_{\alpha}}\left[\cos(\theta - \Omega_{\alpha} t) - \cos\theta\right] + Y_0, \qquad (2)$$
$$Z(t) = V_{\Pi} t + Z_0$$

The perturbed velocity u is determined by:

$$\frac{du_{\perp}}{dt} + i\Omega_{\alpha} u_{\perp} = \frac{qE_1}{m}\sum_{-\infty}^{+\infty} j_l(\mu)\cos(\mathrm{A}_{\lambda} t + \psi_{\lambda}{}^{0})$$
$$\frac{du_{\Pi}}{dt} = \frac{qE_1}{m}\sum_{-\infty}^{+\infty} j_l(\mu)\cos(\mathrm{A}_{\lambda} t + \psi_{\lambda}{}^{0})$$
(3)

Where $u_{\perp} = u_X + iu_y$ represents the perturbed velocity in transverse direction and u_{Π} represents the velocity in parallel direction. The resonance criteria are given by:

$$\mathrm{A}_{\lambda}(V_{\Pi} = V_r) = k_{\Pi} V_{\Pi} - \omega + \lambda\Omega_{\alpha} = 0; \lambda = \pm 1, \pm 2, \pm 3, \ldots\ldots\ldots$$

Here, V_r is the resonance velocity of the particles

The oscillatory solution of u (t) is given by:

$$u_X(r,t) = \frac{qE_1}{m}\sum_{-\infty}^{+\infty} J_n(\mu)\sum_{-\infty}^{+\infty} J_{\lambda}(\mu)\times\left[\frac{\mathrm{A}_{\lambda}}{\mathrm{A}^2{}_{\lambda} - \Omega^2{}_{\alpha}}\sin\chi_{nl} - \frac{\delta}{2\mathrm{A}_{\lambda+1}}\sin(\chi_{nl} - \mathrm{A}_{\lambda+1}t) - \frac{\delta}{2\mathrm{A}_{\lambda-1}}\sin(\chi_{nl} - \mathrm{A}_{\lambda-1}t)\right]$$
$$u_y(r,t) = \frac{qE_1}{m}\sum_{-\infty}^{+\infty} J_n(\mu)\sum_{-\infty}^{+\infty} J_{\lambda}(\mu)\times\left[\frac{\mathrm{A}_{\lambda}}{\mathrm{A}^2{}_{\lambda} - \Omega^2{}_{\alpha}}\cos\chi_{nl} - \frac{\delta}{2\mathrm{A}_{\lambda+1}}\cos(\chi_{nl} - \mathrm{A}_{\lambda+1}t) - \frac{\delta}{2\mathrm{A}_{\lambda-1}}\cos(\chi_{nl} - \mathrm{A}_{\lambda-1}t)\right]$$
$$u_z(r,t) = \frac{q\kappa E_1}{m}\sum_{-\infty}^{+\infty} J_n(\mu)\sum_{-\infty}^{+\infty} J_{\lambda}(\mu)\frac{1}{\mathrm{A}_{\lambda}}\left[\sin\chi_{nl} - \delta\sin(\chi_{nl} - \mathrm{A}_{\lambda}t)\right]$$

Here, $\chi_{nl} = k.r - \omega t + (n-\lambda)(\Omega_{\alpha} t - \theta)$

$\delta = 0$ for non-resonant particles and $\delta = 1$ for resonant particles

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Density Perturbation

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

$$N(v) = N_0 f_{\perp}(v_{\perp}) f_{\Pi}(v_{\Pi}) \qquad (5)$$

$$f_{\perp}(v_{\perp}) = \left[\frac{v_{\perp}{}^{2J}}{\pi v_{T_{\perp}}{}^{2(J+1)} J!}\right]\exp\left(\frac{-v^2{}_{\perp}}{v^2{}_T}\right) \qquad (6)$$

$$f_{\Pi}(v_{\Pi}) = \left(\frac{1}{\sqrt{\pi} v_{T\Pi}}\right)\exp\left(\frac{-v^2{}_{\Pi}}{v_{T_{\Pi}}{}^2}\right) \qquad (7)$$

Where J is distribution index and measures the steepness of loss-cone feature. It characterizes the width of loss cone distribution. Tiwari & Varma [9], Mishra & Tiwari [10]. In case J = 0, this represents a bi-Maxwellian distribution, $J = \infty$, this reduces to Dirac delta function. $v_{T_{\Pi}}{}^2 = \frac{2T_{\Pi}}{m_{\alpha}}$, and $v_{T_{\perp}}{}^2 = (j+1)^{-1}\frac{2T_{\perp}}{m_{\alpha}}$ are the squares of parallel and perpendicular velocities of multi ions with respect to the external magnetic field.

The quasi-neutrality condition yields to the equation:

$$n_e = n_{H^+} + n_{O^+} + n_{He^+}$$

Thus we evaluate the density perturbation associated with the particle velocity as:

$$\frac{dn_1}{dt} = -N_{H^+}(v_{H^+})(\nabla.u)_{H^+} + (-N_{He^+}(v_{He^+})(\nabla.u)_{He^+}) + (-N_{O^+}(v_{O^+})(\nabla.u)_{O^+}) \qquad (8)$$

Transforming the r. h. s. of equation (8) as the function of **t** and integrating we get the solution of equation for perturbed density

$$n_1(r,t)=\frac{qE_1N(v_\alpha)}{m_\alpha}\kappa^2k_\perp\sum_{l,n=-\infty}^{+\infty}J_\lambda(\mu)J_n(\mu)\left[\frac{k_\perp}{\mathrm{A}^2{}_\lambda-\Omega^2{}_\alpha}+\frac{\kappa^2k_\perp}{\wedge^2{}_{\lambda^+}}\right]\sin\chi_{nl}$$

And

$$n_1(r,t)=\frac{qE_1N(v_{H^+})}{m_{H^+}}\kappa^2k_\perp\sum_{l,n=-\infty}^{+\infty}J_l(\mu)J_n(\mu)\frac{1}{\wedge^2{}_{lH^+}}\{\sin\chi_{nl}-\sin(\chi_{nl}-\wedge_{lH^+}t)-\wedge_{lH^+}t\cos(\chi_{nl}-\wedge_{lH^+}t)\}$$
$$+\frac{qE_1N(v_{He^+})}{m_{He^+}}\kappa^2k_\perp\sum_{l,n=-\infty}^{+\infty}J_l(\mu)J_n(\mu)\frac{1}{\wedge^2{}_{lHe^+}}\{\sin\chi_{nl}-\sin(\chi_{nl}-\wedge_{lHe^+}t)-\wedge_{lHe^+}t\cos(\chi_{nl}-\wedge_{lHe^+}t)\} \quad (9)$$
$$+\frac{qE_1N(v_{O^+})}{m_{O^+}}\kappa^2k_\perp\sum_{l,n=-\infty}^{+\infty}J_l(\mu)J_n(\mu)\frac{1}{\wedge^2{}_{lO^+}}\{\sin\chi_{nl}-\sin(\chi_{nl}-\wedge_{lO^+}t)-\wedge_{lO^+}t\cos(\chi_{nl}-\wedge_{lO^+}t)\}$$

Where

$$\chi_{nl}=k.r-\omega t+(n-l)(\Omega_\alpha l-\theta) \quad \text{and} \quad \alpha=H,^+He^+,O^+$$

3. Dispersion Relation

The Poisson equation is,

$$\nabla.E=-\kappa_\perp(1+\kappa^2)E_1\sin(\kappa.r-\omega t)=4\pi e(n_\alpha-n_e) \quad (10)$$

Where $n_{\alpha,e}$ is integrated perturbed density of the non resonant particles of the respective species given by,

$$n_{\alpha,e}=\mp\int dvN(v)\frac{eE_1k_\perp}{m_{\alpha,e}}\sum_{nl}\left\{J_n(\mu)J_l(\mu)\times\left(\frac{1}{\wedge^2{}_n-\Omega_\alpha{}^2}+\frac{\kappa^2}{\wedge^2}\right)\sin\chi_{nl}\right\}_{i,e} \quad (11)$$

Where $\mu=\frac{k_\perp V_\perp}{\Omega_{\alpha,e}},\wedge_n=k_\Pi V_\Pi-\omega+n\Omega_{i,e}$ and $\chi_{nl}=k.r-\omega t+(n-l)(\Omega_\alpha l-\theta)$

Where, $\alpha=H,^+He^+,O^+$

Using expression for unperturbed density for the non resonant ions Mishra & Tiwari [11 - 13] and equation (5) the integrated perturbed densities for the non resonant particles after applying these solutions for multi-ions is derived as:

$$n_e\cong\left(\frac{1}{k_\perp d^2{}_{\|e}}\right)\frac{E_1}{4\pi e}\sin(\kappa r-\omega t) \text{ and } n_\alpha\cong-\frac{k_\perp\kappa^2\omega^2{}_{p\alpha}}{[\omega-\lambda\Omega_\alpha]^2}\langle J^2{}_\lambda\rangle\frac{E_1}{4\pi e}\sin(\kappa r-\omega t)$$

$$\langle J^2{}_\lambda\rangle=\int_0^\infty 2\pi V_\perp dV_\perp J^2{}_l(\mu)f_{\perp\alpha}(V_\perp)$$

Where, $\alpha=H,^+He^+,O^+$ $\omega_{p\alpha}{}^2=\frac{4\pi N_\alpha e^2}{m_\alpha}$ is plasma frequency for the multi ions and N_α the multi ions plasma density.

Then the dispersion relation is,

$$1+\left(\frac{1}{1+\kappa}\right)\left(\frac{1}{k_{\perp}{}^{2}d^{2}{}_{\Pi e}}\right)-\left(\frac{\kappa^{2}}{1+\kappa}\right)+\left(\frac{\omega_{p\alpha}{}^{2}}{(\omega-\lambda\Omega\alpha)^{2}}\right)<\left(J^{2}{}_{\lambda-1}-J^{2}{}_{\lambda+1}\right)>\cong 0 \qquad (12)$$

For λ =1, $\left\langle\left(J^{2}{}_{0}+J^{2}{}_{2}\right)\right\rangle=1-(j+1)\frac{k^{2}{}_{\perp}\rho^{2}{}_{\alpha}}{2}$;

$$\left\langle\left(J_{0}+J_{2}\right)^{2}\right\rangle=1-(j+1)\frac{k^{2}{}_{\perp}\rho^{2}{}_{\alpha}}{2}$$

For J = 0 this dispersion relation reduces to that given by Terashima [14].

4. Growth Rate

The wave energy per unit wavelength can be defined as

$$W_{w}=\frac{\lambda E_{1}{}^{2}}{8\pi}+W_{e}+W_{\alpha}\ \text{where,}$$

$$W_{\alpha,e}=\int_{0}^{\lambda}ds\int dV\,\frac{m_{e,\alpha}}{2}\left\{(N+n_{1})(V+u)^{2}-NV^{2}\right\}_{\alpha,e},$$

$$W_{w}\approx\frac{\lambda E^{2}{}_{1}}{8\pi}+\frac{\lambda E^{2}{}_{1}}{16\pi}\frac{\omega^{2}{}_{p\alpha}}{\left\{\omega-\lambda\Omega_{\alpha}\right\}^{2}}\kappa^{2}\frac{1}{2}\left\langle J_{\lambda-1}{}^{2}+J_{\lambda+1}{}^{2}\right\rangle+\frac{\lambda E^{2}{}_{1}}{16\pi}\left(\frac{1}{k^{2}{}_{\perp}d^{2}{}_{\Pi e}}\right) \qquad (13)$$

Rate of energy transfer:

The changes in energy of the resonant particles are,

$$W_{r}=\sum_{i,e}(W_{r\perp}+W_{r\Pi})$$

$$W_{r\perp}=\int_{0}^{\lambda}ds\int_{0}^{\infty}V_{\perp}dV_{\perp}\int_{0}^{2\theta}d\theta\int_{v_{r}-\Delta r}^{v_{r}+\Delta r}dV_{\Pi}\,\frac{m_{\alpha}}{2}\left\{(N+n_{1})(V_{\perp}+u_{\perp})^{2}-NV_{\perp}{}^{2}\right\}, \qquad (14)$$

$$W_{r\Pi}=\int_{0}^{\lambda}ds\int_{0}^{\infty}V_{\Pi}dV_{\Pi}\int_{0}^{2\theta}d\theta\int_{v_{r}-\Delta r}^{v_{r}+\Delta r}dV_{\Pi}\,\frac{m_{\alpha}}{2}\left\{(N+n_{1})(V_{\Pi}+u_{\Pi})^{2}-NV_{\Pi}{}^{2}\right\} \qquad (15)$$

For the resonant particles $\delta=1$ and the resonant velocity V_{r} defined as

$$V_{r}=\frac{\omega-l\Omega_{i}}{k_{\Pi}},$$

$$W_{r\perp}=\left(\frac{\lambda E^{2}{}_{1}}{8\pi}\right)\left(\frac{\omega^{2}{}_{p\alpha}}{\Omega^{2}{}_{\alpha}}\right)\left(\frac{\omega}{k_{\Pi}V_{th\alpha}}\right)\frac{\Omega_{\alpha}t}{\sqrt{2\pi}}\exp\left\{-\frac{1}{2}\left(\frac{\omega}{k_{\Pi}V_{th\alpha}}\right)^{2}\left(1-\frac{\lambda\Omega_{\alpha}}{\omega}\right)^{2}\right\}$$
$$\times\frac{1}{2}\left\langle J_{\lambda-1}{}^{2}+J_{\lambda+1}{}^{2}\right\rangle\left[1-\left(\frac{R\left(\frac{\lambda\Omega_{\alpha}}{\omega}-1\right)}{\frac{\lambda\Omega_{\alpha}}{\omega}}\right)\frac{T_{\perp\alpha}}{T_{\Pi\alpha}}\right] \qquad (16)$$

$$W_{r\Pi} = \left(\frac{\lambda E^2{}_1}{8\pi}\right)\left(\frac{\omega^2{}_{p\alpha}}{\Omega^2{}_\alpha}\right)\left(\frac{\omega}{k_\Pi V_{th\alpha}}\right)\frac{\Omega_\alpha t}{\sqrt{2\pi}}\exp\left\{-\frac{1}{2}\left(\frac{\omega}{k_\Pi V_{th\alpha}}\right)^2\left(1-\frac{\lambda\Omega_\alpha}{\omega}\right)^2\right\}$$
$$\times\frac{1}{2}\left\langle (J_{\lambda-1}+J_{\lambda+1})^2\right\rangle\left[\frac{\left(1-\frac{\lambda\Omega_\alpha}{\omega}\right)}{\frac{\lambda\Omega_\alpha}{\omega}}\right]\frac{T_{\perp\alpha}}{T_{\Pi\alpha}} \tag{17}$$

Where,

$$R = \frac{(J_{l+1}+J_{l-1})^2}{\langle J_{l+1}{}^2 + J_{l-1}{}^2\rangle}$$

$$\langle J_l{}^2(\mu)\rangle \approx \langle (J_{l+1}(\mu)+J_{l-1}(\mu))^2\rangle(\mu^2/4l^2)$$

Using the law of conservation of energy the growth rate is obtained to be

$$\left|\frac{dW^\alpha{}_{r\perp}}{dt}\right\rangle\frac{dW^\alpha{}_{r\Pi}}{dt}$$

Hence the growth rate is,

$$\frac{\gamma}{\omega} = \sqrt{\frac{\pi}{2}}\left(\frac{\omega}{k_\Pi V_{th\alpha}}\right)\left(1-\frac{\lambda\Omega_\alpha}{\omega}\right)^2\exp\left\{-\frac{1}{2}\left(\frac{\omega}{k_\Pi V_{th\alpha}}\right)^2\left(1-\frac{\lambda\Omega_\alpha}{\omega}\right)^2\right\}$$
$$\times\left[R\left(\frac{\frac{\lambda\Omega_\alpha}{\omega}-1}{\frac{\lambda\Omega_\alpha}{\omega}}\right)\frac{T_{\perp\alpha}}{T_{\Pi\alpha}}-1\right] \tag{18}$$

For J = 0 the growth rate reduces to that given by Terashima [14].

5. Result and Discussions

We have evaluated the dispersion relation, transverse energies and growth/damping rate of EIC waves in multi-component plasma. A graphical representation of the expressions is shown by figures 3 to 5. The following parameters relevant to the plasma sheet boundary layer region Agarwal [15] and Mishra & Tiwari [13].

B_0 = 400nT; $\Omega_H{}^+$ = 412 s^{-1}; $\Omega_{He}{}^+$ = 206 s^{-1}; $\Omega_0{}^+$ = 51.50 s^{-1}; λ = 300m; E_1 = 50mV/m;

$$\frac{T_{ll\alpha}}{T_{\perp\alpha}} = 5eV$$; d_{lle} =52.55m

Using these data in derived expression for dispersion relation (Eq. 12), perpendicular resonant energy (Eq. 16), parallel resonant energy (Eq. 17) and growth rate (Eq. 18), we obtain the graphical representations.

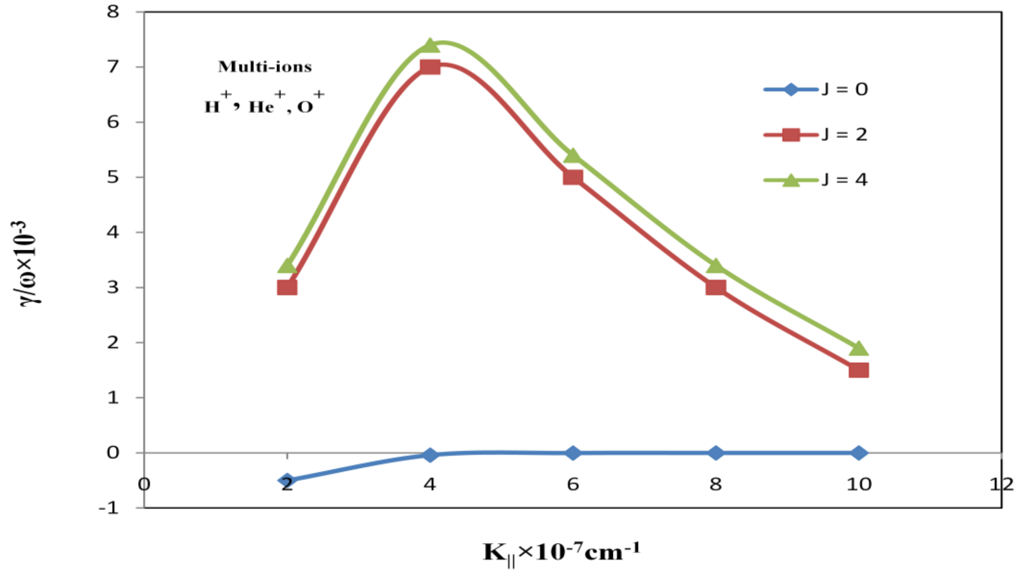

Figure 3: Variation of growth rate (γ/ω) versus wave vector $K_{||}$ (cm^{-1}) for different values of distribution indices J=0, 2 & 4

Figure 3 depicts the variation of growth rate versus wave vector for different values of distribution indices for multi ions. It is observed that distribution index enhance the growth rate for multi-ions plasma. This may be due to more energetic particles may be available to provide energy to the wave via wave particle interaction due to landau damping and the wave will start to grow. Thus steep loss-cone distribution of magnetosphere can act as a free source of energy for wave generation.

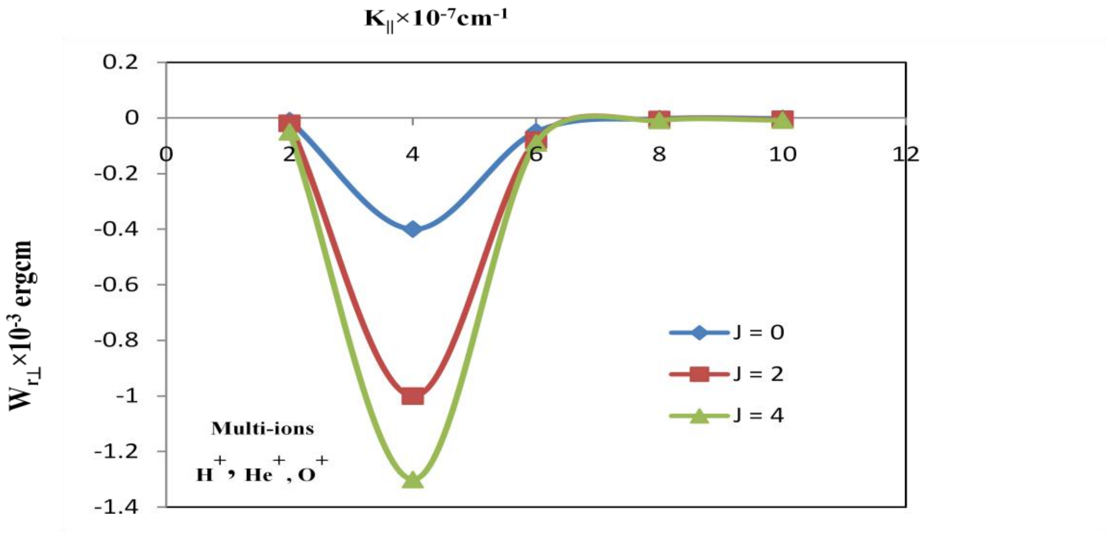

Figure 4: Variation of perpendicular resonant energy $W_{r\perp}$ erg cm versus wave vector $K_{||}$ (cm^{-1}) for different values of distribution indices J=0, 2 & 4.

Figure 4 shows the Variation of perpendicular resonant energy $W_{r\perp}$ erg cm versus wave vector $K_{||}$ (cm^{-1}) for different values of distribution indices J with multi-component plasma. It is observed that perpendicular resonant energy decreases with higher distribution index for multi component plasma which implies that perpendicular heating of resonant ions decreases at a particular wave number at which energy is decreased. Perpendicular heating earlier studied Hamrin [16] and Albert [17]. Transverse acceleration of ions may be due to damping of the EIC waves not by the amplification.

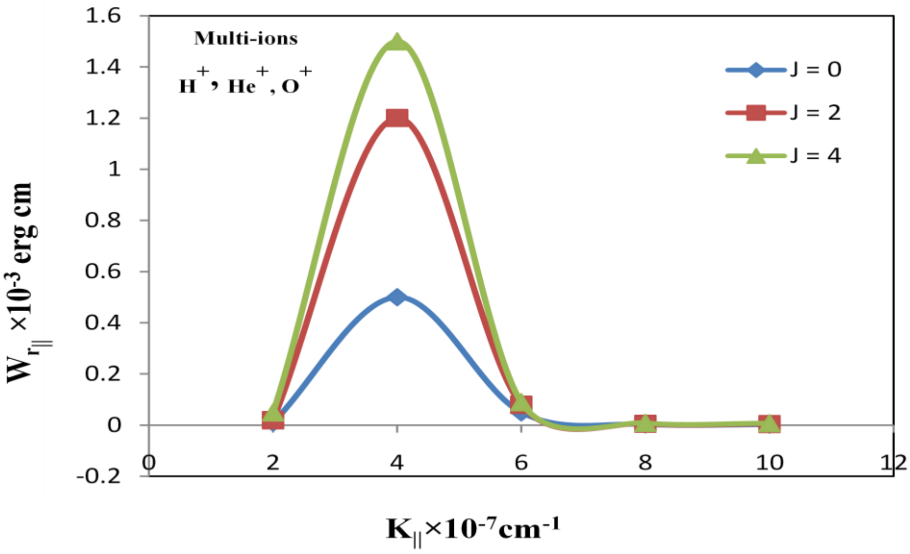

Figure 5: Variation of parallel resonant energy $W_{r||}$ erg cm versus wave vector $K_{||}$ (cm^{-1}) for different values of distribution indices J= 0, 2 & 4

Figure 5 depicts the variation of parallel resonant energy $W_{r||}$ erg cm versus wave vector $K_{||}$ (cm^{-1}) for different values of distribution indices J with multi component plasma. It can be concluded that parallel resonant energy increases with increasing the loss-cone distribution index. The loss-cone distribution index enhances the parallel resonant energy with multi-ions plasma which supports the wave emission and controls the heating of ions to parallel and perpendicular resonant energy to the magnetic field. Mirroring force may also be useful in the generation of EIC waves and controlling the heating of ions. The loss-cone distribution can acts as a source of free energy for the generation of EIC waves.

In this paper we have conducted a comprehensive mathematical analysis of EIC waves with multi ions plasma (H^+, H_e^+ and O^+) and found how the wave is grow through the inverse landau damping as well as the wave particle interactions. The effect of the general loss-cone distribution function is incorporated in the PSBL region to discuss EIC wave's emissions with multi ions plasma (H^+, H_e^+ and O^+). Our findings may be useful to understand the heating of heavier ions i.e. H_e^+ and O^+ ions supported by Ahirwar [18], Agrwal [15] and Raikwar [19].

6. Conclusions

The concluding remarks of this study are as follows:

1. The theory may be useful to study the electrodynamics of the PSBL region. The EIC turbulence may play an important role in the loss-cone current-potential relationship. It is also suggested that the loss-cone effect can enhance the analomous resistivity for a given turbulence level. The steep loss-cone distribution in the presence of EIC waves with multi ions (H^+, H_e^+ ,O^+) enhance the growth rate, the anomalous resistivity, and transport resulting this instability play a crucial role in the PSBL region.
2. The steep loss-cone structure are analogous to mirror-like devices with a higher mirror ratio, which accelerate the charged particles perpendicular to the magnetic field and that may be a free energy source to excite EIC waves. Thus, more energetic particles may be available to provide energy to the wave by wave-particles interactions. The converging magnetic field lines in the PSBL region may be considered suitable for the use of generalized loss-cone distribution function.
3. The study may also be useful for the experimental devices with current carrying plasma. 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 EIC waves.
4. The present analysis may be useful to explain heating of H_e^+, O^+ ions by particle aspect analysis along with dynamics of EIC instability. The process can be conveyed to the outer magnetosphere at higher altitudes as well as towards the lower ionosphere by wave particle interaction mechanism.
5. It was concluded from the observations by FAST satellites that minor ions play a dramatic role in the modification of the EIC wave spectrum and that they can be strongly energized by the ion cyclotron waves. It is reasonable to assume that if ion cyclotron waves are present in the solar corona, then the heavy ions will strongly affect the ion cyclotron wave spectrum.

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