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Study on EMIC Waves in multi-ions around the Plasmapause Region

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Abstract

Electromagnetic ion-cyclotron (EMIC) waves have been studied by single particle approach. The dispersion relation, growth rate 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 effect of general loss-cone distribution function with temperature anisotropy on EMIC waves in multi-ions is to enhance the growth rate. The results are interpreted for the space plasma parameters appropriate to the plasma-pause region of the earth's magneto-plasma.

Keywords: *Electromagnetic ion-cyclotron waves, Plasma-pause region, solar plasma, General loss-cone distribution function.*

Introduction

The plasma sphere, or inner magnetosphere, is a region of the Earth's magnetosphere consisting of low energy (cool) plasma. It is located above the ionosphere[1]. The outer boundary of the plasma sphere is known as the plasma pause, which is defined by an order of magnitude drop in plasma density. The theoretical studies of ion heating and acceleration perpendicular to the magnetic field are common features in the plasma-pause region. The ion –velocity distributions occur naturally during the generation, confinement, and heating of plasma in confinement and plasma confined in the earth's magnetosphere. Electromagnetic ion-cyclotron waves generated in the equatorial region of earth's magnetosphere as left-handed circularly (LHC) polarized waves propagate field line guided towards the ionosphere. The plasma of the magnetosphere has many different levels of temperature and concentration. The coldest magnetospheric plasma is most often found in the plasma sphere, a donut-shaped region surrounding the Earth's middle.

Electromagnetic ion cyclotron (EMIC) waves in the Pc1 ultra-low frequency wave band (0.2-5Hz) observed in the plasma sphere and magnetosphere are generated by micro-scale instabilities associated with keV energetic protons of ring current origin. The associated cold electron density data show the wave power was confined within the narrow shell of the plasma pause where the electron density gradient decreased from 30-80 cm^{-3} to 20 cm^{-3}. The radial scale size of the wave region is estimated at ~ 0:77 Re. The wave polarization was dominantly left-handed around the equatorial region and inner side of source region, but appeared right-handed close to the outer edge of the plasmapause and at higher latitudes. The Poynting flux and minimum variance analysis indicate that the wave energy was mainly transported towards high latitudes though oblique propagation was seen around the equatorialregion. Enhanced H^+, He^+ and O^+ particle energy fluxes were seen during the wave event over energy range ~25eV-40keV. The observations suggest the waves originated around the equatorial regionin the high density outer plasmasphere-plasmapause which overlaps the ring current; ideal conditions for wave generation by the ion cyclotron instability. The problem is of interest because of the important role that the instabilities play in some of the basic physical processes occurring in plasmas. The interactions are a non thermal feature that can trigger plasma instabilities[2]. We consider a charge neutral plasma with a uniform magnetic field $\hat{z}B$ and no ambient electric field .We also consider a two species, three component plasma, denoting the thermal ion component by the subscript (H^+, He^+ and O^+) for hydrogen, helium and oxygen ions respectively also the subscripts Π and $\perp$ denote parallel and perpendicular to magnetic field B[3].

It is predicted that the propagation of EMIC waves to the ionosphere is strongly affected by the presence of heavy ions (He^+) and (O^+) [4]. Cuperman and Gomberoff,[5] are pointed out the generation of electromagnetic ion –cyclotron (EMIC) waves would pitch-angle scatters protons, subsequently reducing their fluxes. Plasma sheet protons are injected into the magnetosphere during magnetic storm[6]. The development of instabilities in the EMIC modes depends critically on cold plasma characteristics, as noted[7] for ring –current protons at the plasma pause[8].

The main aim of this study is to investigate the generation of EMIC waves in the magnetosphere and see the effect of general loss-cone distribution function with temperature anisotropy in magnetospheric plasma. The parallel magnetic field plays a vital role and explains the observational details of EMIC waves. The detailed description and formulae for the dispersion relation and growth rate is determined in the next section.

Methodology

Distribution function: We consider the cold plasma dispersion relation for the EMIC wave for multi-component plasma[4] as:

$$\frac{c^2k_{\Pi}^{\ 2}}{\omega^2}=\left(\frac{\omega_{p_{H^+}}^{\ 2}}{\Omega_{H^+}^{\ 2}}\right)\left(1-\frac{\omega}{\Omega_{H^+}}\right)^{-1}+\left(\frac{\omega_{p_{He^+}}^{\ 2}}{\Omega_{He^+}^{\ 2}}\right)\left(1-\frac{\omega}{\Omega_{He^+}}\right)^{-1}+\left(\frac{\omega_{p_{O^+}}^{\ 2}}{\Omega_{O^+}^{\ 2}}\right)\left(1-\frac{\omega}{\Omega_{O^+}}\right)^{-1} \quad (1)$$

Where $\omega_{p\alpha}^{\ 2}=\frac{4\pi N_{\alpha 0}e^2}{m_\alpha}$ is the plasma frequency for the ions?

$N\alpha_0$ is the plasma density of particles.

Growth rate: Using the law of conservation of energy

$$\frac{d}{dt}(W_r+W_w)=0$$

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

$$\frac{\partial U}{\partial t}=2\gamma U$$

Where $\frac{dW_r}{dt}=-2\frac{\partial U}{\partial t}$ and $\frac{dW_\alpha}{dt}\sim\frac{\partial U}{\partial t}$

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:

$$\gamma=\frac{\frac{\Omega_{H^+}}{k_{\Pi}V_{T\amalg H^+}}\left[\frac{(\Omega_{H^+}-\omega)}{\Omega_{H^+}}\frac{(J+1)V_{T\perp H^+}^{\ 2}}{V_{T\amalg H^+}^{\ 2}}-1\right]\exp\left[-\frac{1}{V_{T\amalg H^+}^{\ 2}}\left(\frac{\omega-\Omega_{H^+}}{k_{\amalg}}\right)^2\right]}{\left(\frac{ck_{\Pi}}{\omega_{pH^+}}\right)^2\left(\frac{2\Omega_{H^+}-\omega}{\Omega_{H^{+(}}-\omega}\right)+\frac{1}{2}\left(\frac{2\Omega_{H^+}-\omega}{\Omega_{H^{+(}}-\omega}\right)^2}+$$

$$\frac{\frac{\Omega_{He^+}}{k_{\Pi}V_{T\amalg He^+}}\left[\frac{(\Omega_{He^+}-\omega)}{\Omega_{He^+}}\frac{(J+1)V_{T\perp He^+}^{\ 2}}{V_{T\amalg He^+}^{\ 2}}-1\right]\exp\left[-\frac{1}{V_{T\amalg He^+}^{\ 2}}\left(\frac{\omega-\Omega_{He^+}}{k_{\amalg}}\right)^2\right]}{\left(\frac{ck_{\Pi}}{\omega_{pHe^+}}\right)^2\left(\frac{2\Omega_{He^+}-\omega}{\Omega_{He^{+(}}-\omega}\right)+\frac{1}{2}\left(\frac{2\Omega_{He^+}-\omega}{\Omega_{He^{+(}}-\omega}\right)^2}+ \quad (2)$$

$$\frac{\frac{\Omega_{O^+}}{k_{\Pi}V_{T\amalg O^+}}\left[\frac{(\Omega_{O^+}-\omega)}{\Omega_{O^+}}\frac{(J+1)V_{T\perp O^+}^{\ 2}}{V_{T\amalg O^+}^{\ 2}}-1\right]\exp\left[-\frac{1}{V_{T\amalg O^+}^{\ 2}}\left(\frac{\omega-\Omega_{O^+}}{k_{\amalg}}\right)^2\right]}{\left(\frac{ck_{\Pi}}{\omega_{pO^+}}\right)^2\left(\frac{2\Omega_{O^+}-\omega}{\Omega_{O^{+(}}-\omega}\right)+\frac{1}{2}\left(\frac{2\Omega_{O^+}-\omega}{\Omega_{O^{+(}}-\omega}\right)^2}$$

Where $\alpha = \mathrm{i, H^+, He^+, O^+}$ and Using the value of $V_{T\perp\alpha}^{\ 2}=(J+1)^{-1}\frac{2T_{\perp\alpha}}{m_\alpha}$, $V_{T\amalg\alpha}^{\ 2}=\frac{2T_{\amalg\alpha}}{m_\alpha}$ for multi-ions plasma.

Here it is noticed that the J is general loss-cone distribution function has affected the growth rate through temperature anisotropy and change in the energy for the electromagnetic waves propagating parallel to the magnetic field.

Results and Discussion

The characteristics of the EMIC waves were derived the dispersion relation and growth rate by using plasma-pause region parameters.
B_0 = 500nT , $V_{T11H}{}^{+}$=6x10^9cm/s, $V_{T11He}{}^{+}$=6x10^8cm/s, $V_{T11O}{}^{+}$=5x10^8cm/s, $\omega_{pH}{}^{+2}$=8.65x10^7s^{-2} , $\omega_{pHe}{}^{+2}$= 21.65 x 10^6 s^{-2}, $\omega_{pO}{}^{+2}$=5.4 x 10^6s^{-2}
$\Omega_{pH^+}=47.9\sec^{-2}$, $\Omega_{pHe^+}=35.92\sec^{-2}$, $\Omega_{pO^+}=8.98\sec^{-2}$

Figure 1 Shows the variation of frequency of plasma (ω) in sec^{-1} versus wave vector (k_{11}) in cm^{-1} for multi-ions magnetosphere plasma. It is observed that the frequency (ω) is linearly increases with the increasing of the parallel wave vector (k_{11}) cm^{-1} and the variation shows by the straight line on EMIC waves in multi-ions (H^+, $He^+$and O^+) for plasma-pause region. The findings of the investigations may be of importance to the coronal heating and acceleration of solar wind by EMIC waves.

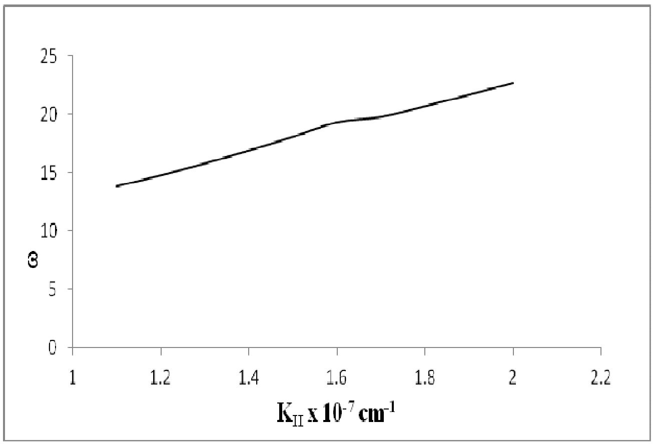

Figure-1
Variation of wave frequency (ω) versus wave vector ($K_{\amalg}$)

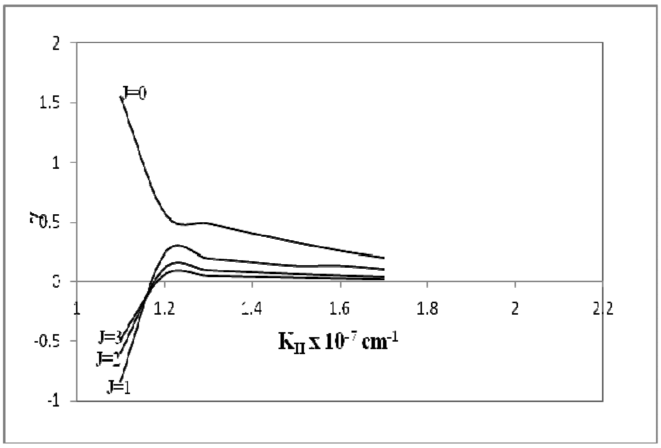

Figure-2
Variation of growth rate (γ) versus wave vector $K_{\amalg}$ cm^{-1} for different general loss-cone distribution function J

Figure 2 predict the variation of the growth rate (γ) with the wave vector (k_{11}) cm^{-1} for the different values of general loss-cone distribution function J. It is observed that the graph peak of the growth rate which shifts towards the lower side of the parallel wave vector (k_{11}) then, the growth rate is also decreases. The increasing of the growth rate transferred in the presence of general loss-cone distribution function J for the EMIC waves in the magnetospheric plasma. We have not considered the contribution of heavy ions such as H_e^+ and O^+ which have the major contribution in space plasma, for example in their differential heating. The analysis can be extended including heavy ions in further investigations.

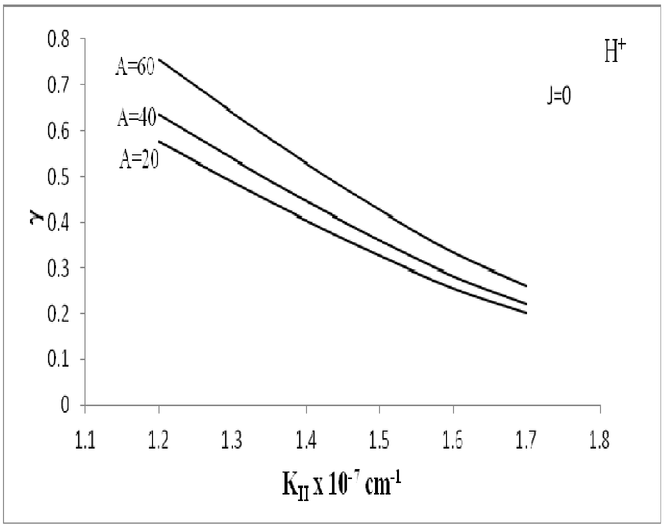

Figure-3
Vreriation of growth rate (γ) versus wave vector K_{II} cm^{-1} for different values of temperature anisotropy A for hydrogen ion at J=0

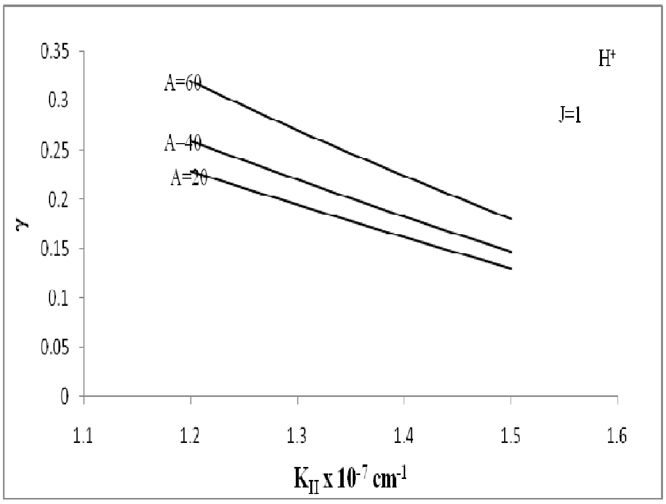

Figure-4
Variation of growth rate (γ) versus wave vector K_{II} cm^{-1} for different values of temperature anisotropy A for hydrogen ion at J=1

Figure 3and4 Depict the variation of growth rate (γ) with the wave vector (k_{11}) cm^{-1} for different values of temperature anisotropy A at J=0and1 for hydrogen ions. It is assumed that the temperature anisotropy is directed from the ionosphere towards the magneto-tail. It is also observed that the effect of increasing the temperature anisotropy of hydrogen ions is to enhance the growth rate rapidly.

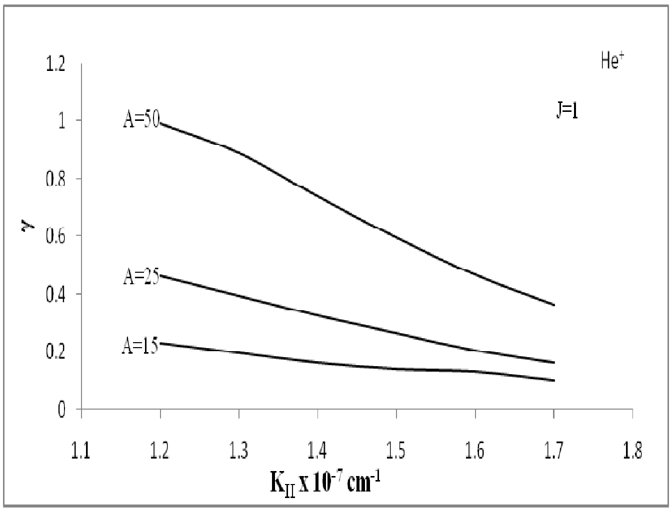

Figure-5
Variation of growth rate (γ) versus wave vector K_{II} cm^{-1} for different values of temperature anisotropy A for helium ion at J=1

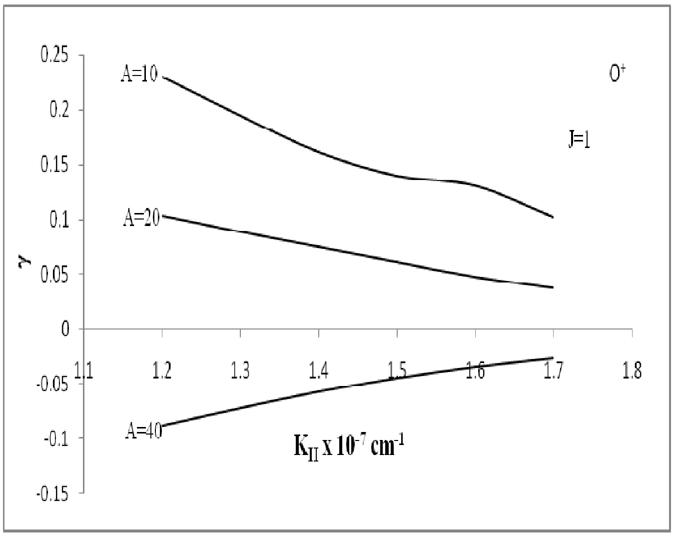

Figure-6
Variation of growth rate (γ) versus wave vector K_{II} cm^{-1} for different values of temperature anisotropy A for oxygen ion at J=1

Figure-5 Shows the variation of growth rate (γ) versus the wave vector (k_{11}) cm^{-1} for different values of temperature anisotropy A at J=1 for helium ions. It is assumed that the effect of increasing the temperature anisotropy of helium ions is to enhance the growth rate but the increment is low with comparison to the H^+ hydrogen ions. It is also seen that the peak of the growth rate which shifts towards the lower side of the parallel wave vector (k_{11}) then, the growth also decreases.

Figure-6 Shows the variation of growth rate (γ) with wave vector (k_{11}) cm^{-1} for different values of temperature anisotropy A at J=1. It is seen that the nature of the graph the growth rate is increases with the increasing of plasma ions temperature for oxygen ions. The variation in growth rate (γ) with wave vector (K_{11}) cm^{-1} for oxygen ions is sharp compare to the helium (He^+) ions and the peak of the growth rate which shift towards the lower side of parallel wave vector (k_{11}) and the growth rate decreases. The peak of the growth rate is decreases with increase of plasma ions temperature for oxygen ions.

Conclusion

In the present work, we have study of an electromagnetic ion-cyclotron wave in multi-ions magnetospheric plasma. It is found that the growth rate enhance with effect of general loss-cone distribution function with temperature anisotropy in H+, He^+ and O^+ ions the plasma-pause region to explain the waves emission.

The effect of increasing general loss-cone distribution function on electromagnetic ion cyclotron waves in H^+, He^+ and O^+ ions enhance the growth rate, may be due a sub-storm phenomena. The growth rate increases with $K_{11,}$ attains a peak and decrease again in all cases. i. The behavior studied for the EMIC waves may be of importance in the electromagnetic emission in the plasma-pause region. The result of the study is also applicable to the plasma devices that have the steep loss-cone distribution. ii. The effect of temperature anisotropy is to enhance the grow the wave emission and the energy of multi-ions H^+, He^+ and O^+ the wave energy propagation outside and inside in plasma magnetosphere unidirectional and bidirectional. iii. The interpreted may be applicable to explain the ion heating in the solor wind as well as plasma-pause region.

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