

# Influence of Beam on EMIC Waves using Kappa Distribution in Jupiter's Magnetosphere

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**ABSTRACT:** The Electromagnetic Ion-Cyclotron (EMIC) Waves are propagated under the influence of beam which are observed in Jupiter's Magnetosphere with varying temperature anisotropy, ions energy density, number density and for different propagation angles with respect to the direction of magnetic field. Voyager-2 space-craft by NASA showed that Jupiter's plasma Magnetosphere contained huge amount of high energy particles in its tail. Thus, for the systems of Jovian type, using the Kinetic Theory approach and method of characteristic solution with the influence of cold plasma beam the growth rate for EMIC waves is computed and the dispersion relation is calculated. Because of the constraint mentioned above, we use Kappa distribution in place of Maxwellian distribution. These computations are mainly focused on parallel and oblique propagations of beam influenced EMIC waves and from the plotted graphs, it is found that beam influenced EMIC waves for oblique propagation has significantly grown more than beam influenced EMIC waves for parallel propagation and with the increase in the ratio of number density of cold plasma to hot plasma, there is increase in the growth rate of EMIC waves under the influence of beam and also, more growth is observed with the injection of high intense beam. Results obtained are much appropriate for the applications pertaining to the environment of space plasma and magnetosphere and also for the planetary comparative study of the solar system.

**KEYWORDS:** Electromagnetic Ion-cyclotron (EMIC), Jupiter, Kappa distribution, Plasma, Magnetosphere.

## I. INTRODUCTION

For the systems of Jovian type, using the Kinetic Theory approach and method of characteristic solution, the growth rate for cold plasma beam influenced EMIC waves propagating parallelly and obliquely to the direction of magnetic field is computed and the dispersion relation is calculated. Here, we use Kappa distribution in place of Maxwellian distribution. Analysis reveals that, with the increase in the ratio of number density of cold plasma to hot plasma, there is increase in the growth rate of beam influenced EMIC waves and also, more growth is observed with the injection of high intense beam.

## II. LITERATURE SURVEY

In solar wind, the presence of Electromagnetic Ion-Cyclotron waves emissions are predicted [1], which are spread into the planetary magnetospheres [2]. Because of the ability of ion cyclotron waves to heat and accelerate ions, their investigations are set to the higher priority. Also in the space explorations, the electromagnetic fluctuations are considered to be an interesting topic [3-5]. The instability of Electromagnetic Ion-Cyclotron (EMIC) waves which is driven by temperature anisotropy, propagates parallel to the magnetic field, which is nimity of transverse kinetic energy of ions [6]. Voyager-2, during its closest approach to the giant planet Jupiter in 1979 observed such high energetic ions and electrons [7]. In July 1979, Voyager-2 spacecraft was launched by NASA to explore various planets of solar system. The space craft detected various phenomena related to the wave-particle interactions and radio emissions when Voyager 2 traversed magnetosphere of Jupiter [8]. Research Work by Cheng et al. [9], explains high

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

energetic ion and electron phase space densities, which declares magnetosphere of Jupiter as an active planetary magnetosphere that exhibits substorm activities, followed by Earth and Mercury. These energetic populations are dealt by generalized function called Lorentzian velocity-distribution function, also known as Kappa distribution function [10]. In Jovian magnetosphere, Suprathermal tails have been predicted and kappa distribution is found suitable for satellite data observations [7, 11]. This helps us in studying high energetic particles with Kappa distribution function in the Jupiter's magnetosphere and also we study theoretically, influence of beam on the Electromagnetic Ion-Cyclotron instabilities existing in Jupiter's magnetosphere. Thus, the growth rate and dispersion relation is calculated for beam influenced EMIC waves propagating parallelly and obliquely to the direction of magnetic field for better comparison.

### III. PROPOSED METHODOLOGY

A homogeneous collisionless anisotropic plasma with external magnetic field  $\mathbf{B}_0 = B_0 \hat{e}_z$  and an electric field  $\mathbf{E}_0 = E_0 \sin(\nu t) \hat{e}_z$  are assumed to obtain the dispersion relation. Following the technique of Pandey et al. [12], the growth rate and real frequency expressions for the beam influenced EMIC waves propagating parallel and oblique to the direction of magnetic field are as follows:

$$\frac{\gamma}{\omega_c} = \frac{\frac{\sqrt{\pi}}{\tilde{k}} \left( \frac{(k-1)! k^{k-1/2}}{(k-3/2)!} \right) (A_T - K_4) K_3^3 \left\{ - \left( \frac{k_3}{\tilde{k}} \right) \right\}^{-2k}}{1 + X_4 + \frac{k}{k-3/2} \left[ \frac{(1+X_4)\tilde{k}^2}{2K_3^2} + \frac{\tilde{k}^2}{K_3} (A_T - K_4) \right] - \frac{X_{1e}}{X_{1i}} K_3^2 + \frac{(\delta-1)K_3^2}{(1-X_3)^2(1+X_4)}}$$

$$X_3 = \frac{\omega_r}{\omega_{ci}} = \frac{\tilde{k}^2}{\delta\beta} \left[ \frac{X_{1i}(1+X_4)}{X_{1i} - X_{1e}(1+X_4)} + \frac{A_T \beta X_{1i}}{2(1+X_4)(X_{1i} - X_{1e}(1+X_4))} \right]$$

$$\frac{\gamma}{\omega_c} = \frac{\frac{\sqrt{\pi}}{\tilde{k} \cos \theta} \left( \frac{(k-1)! k^{k-1/2}}{(k-3/2)!} \right) (A_T - K_4) K_3^3 \left\{ - \left( \frac{k_3}{\tilde{k}} \right) \right\}^{-2k}}{1 + X_4 + \frac{k \cos^2 \theta}{k-3/2} \left[ \frac{(1+X_4)\tilde{k}^2}{2K_3^2} + \frac{\tilde{k}^2}{K_3} (A_T - K_4) \right] - \frac{X_{1e}}{X_{1i}} K_3^2 + \frac{(\delta-1)K_3^2}{(1-X_3)^2(1+X_4)}}$$

$$X_3 = \frac{\omega_r}{\omega_{ci}} = \frac{\tilde{k}^2 \cos^2 \theta}{\delta\beta} \left[ \frac{X_{1i}(1+X_4)}{X_{1i} - X_{1e}(1+X_4)} + \frac{A_T \beta X_{1i}}{2(1+X_4)(X_{1i} - X_{1e}(1+X_4))} \right]$$

Where,

$$K_3 = 1 - X_3 + X_4 ; K_4 = \frac{X_3}{1 - X_3 + X_4} ; X_{1i} = \theta_{li}^2 - \frac{\nu \Gamma_{Xi} \theta_{li}}{\omega_{ci}^2 - \nu^2} \sqrt{\pi} ; X_{1e} = \theta_{le}^2 - \frac{\nu \Gamma_{Xe} \theta_{le}}{\omega_{ce}^2 - \nu^2} \sqrt{\pi}$$

### IV. PLASMA VALUES

The growth rate for beam influenced EMIC waves in the magnetosphere of Jupiter is computed using Lorentzian-Kappa with the following plasma values. Magnetic field  $B_0 = 51 \times 10^9 \text{ T}$ , Electric field  $E_0 = 0.1 \times 10^3 \text{ V/m}$  and density of electron is given by  $n_0 = 3 \times 10^5 \text{ m}^3$ . Temperature anisotropy ( $A_T$ ) is varying from 1.25 to 1.75. The thermal energy of electrons ( $K_b T_{1e}$ ) is taken to be 0.3 eV and that of energetic ions ( $K_b T_{1i}$ ) be 1000 eV.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

## V. EXPERIMENTAL RESULTS

The Figure 1(a) shows, the growth rate ( $\gamma/\omega_c$ ) varying with  $\tilde{k}$  for different values of the temperature anisotropy ratio ( $T_{\perp}/T_{\parallel}$ ) varying from 1.25 to 1.75. For the value of  $T_{\perp}/T_{\parallel}=1.25$ , the growth rate=0.00588; for  $T_{\perp}/T_{\parallel}=1.5$ , the growth rate=0.00961; for  $T_{\perp}/T_{\parallel}=1.75$ , the growth rate=0.0155 and the growth rate is maximum for  $\tilde{k} = 0.25, 0.25$  and  $0.3$  respectively. This graph clearly indicates that there is increase in the growth rate as the temperature anisotropy is increased which in turn gives rise to the free energy which is responsible for the beam influenced EMIC waves propagating parallel to the direction of the magnetic field in the Jupiter's Magnetosphere.

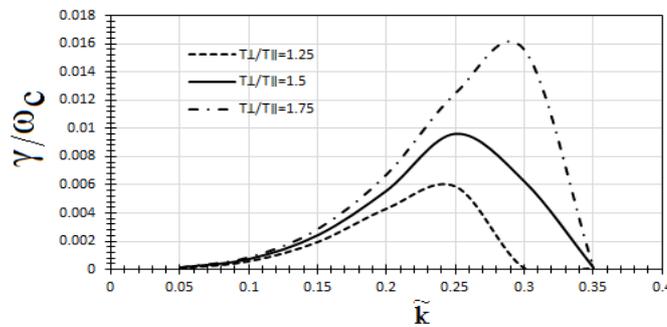


Fig.1 (a)

**Fig.1 (a):** Varying Growth Rate ( $\gamma/\omega_c$ ) with  $\tilde{k}$  for different values of  $T_{\perp}/T_{\parallel}$  at  $K_b T_{\parallel i} = 1 \text{keV}$  with given plasma values for beam influenced EMIC waves propagating parallel to the direction of the magnetic field.

The Figure 1(b) shows, the growth rate ( $\gamma/\omega_c$ ) varying with  $\tilde{k}$  for different values of thermal energy of ions ( $K_b T_{\parallel i}$ ) varying from 1keV to 3keV. For the value of  $K_b T_{\parallel i} = 1 \text{keV}$ , the growth rate=0.00588; for  $K_b T_{\parallel i} = 2 \text{keV}$ , the growth rate=0.0241; for  $K_b T_{\parallel i} = 3 \text{keV}$ , the growth rate=0.0459 and the growth rate is maximum for  $\tilde{k} = 0.25, 0.4$  and  $0.5$  respectively. This graph indicates that there is increase in the growth rate of beam influenced parallelly propagating EMIC waves as the energy of the ions is increased.

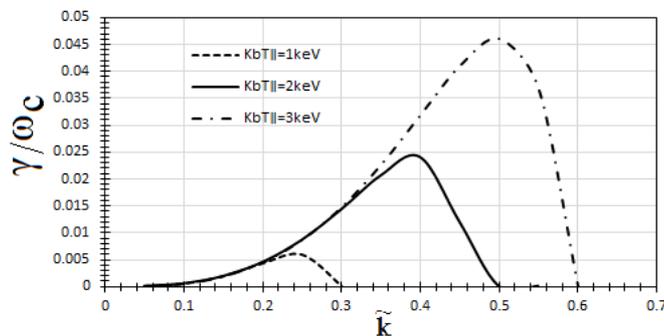


Fig.1 (b)

**Fig.1 (b):** Varying Growth Rate ( $\gamma/\omega_c$ ) with  $\tilde{k}$  for different values of  $K_b T_{\parallel i}$  at  $T_{\perp}/T_{\parallel} = 1.25$  with given plasma values for beam influenced EMIC waves propagating parallel to the direction of the magnetic field.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

The Figure 1(c) shows, the growth rate( $\gamma/\omega_c$ ) varying with  $\tilde{k}$  for different values of number density ratio( $n_c/n_w$ ) varying from 10 to 20. For the value of  $n_c/n_w=10$ , the growth rate=0.00588; for  $n_c/n_w=15$ , the growth rate=0.00710; for  $n_c/n_w=20$ , the growth rate=0.00792 and the growth rate is maximum for  $\tilde{k} = 0.25, 0.3$  and  $0.35$  respectively. This graph clearly indicates that there is increase in the growth rate of beam influenced parallelly propagating EMIC waves as the ratio of number density of cold plasma to hot plasma is increased.

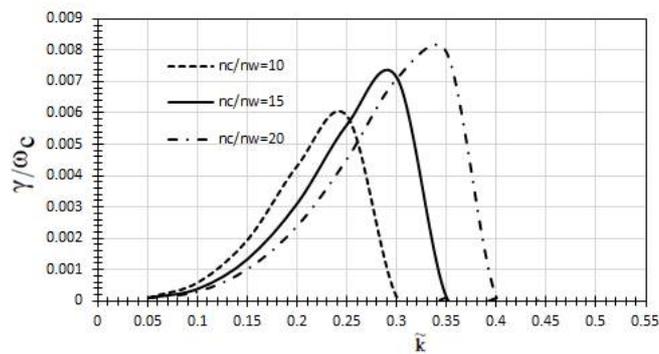


Fig.1 (c)

**Fig.1 (c):** Varying Growth Rate( $\gamma/\omega_c$ ) with  $\tilde{k}$  for different values of  $n_c/n_w$  at  $T_{\perp}/T_{\parallel} = 1.25$  with given plasma values for beam influenced EMIC waves propagating parallel to the direction of the magnetic field.

The Figure 2(a) shows, the growth rate( $\gamma/\omega_c$ ) varying with  $\tilde{k}$  for different values of the temperature anisotropy ratio( $T_{\perp}/T_{\parallel}$ ) varying from 1.25 to 1.75 for beam influenced obliquely propagating EMIC waves to the direction of the magnetic field. For the value of  $T_{\perp}/T_{\parallel}=1.25$ , the growth rate=0.00595; for  $T_{\perp}/T_{\parallel}=1.5$ , the growth rate=0.00971; for  $T_{\perp}/T_{\parallel}=1.75$ , the growth rate=0.0161 and the growth rate is maximum for  $\tilde{k} = 0.25, 0.25$  and  $0.3$  respectively. This graph clearly indicates that the condition of the resonance changes as the growth rate of the beam influenced obliquely propagating EMIC waves increases with increase in the temperature anisotropy.

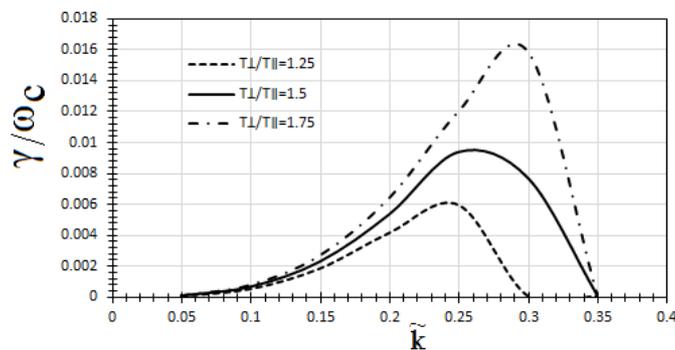


Fig.2 (a)

**Fig.2 (a):** Varying Growth Rate( $\gamma/\omega_c$ ) with  $\tilde{k}$  for different values of  $T_{\perp}/T_{\parallel}$  at  $K_{\perp}T_{\parallel}=1\text{keV}$  with given plasma values for beam influenced EMIC waves propagating oblique to the direction of the magnetic field.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

The Figure 2(b) shows, the growth rate( $\gamma/\omega_c$ ) varying with  $\tilde{k}$  for different values of thermal energy of ions ( $K_b T_{\parallel i}$ ) varying from 1keV to 3keV for the beam influenced obliquely propagating EMIC waves to the direction of the magnetic field. For the value of  $K_b T_{\parallel i}=1\text{keV}$ , the growth rate=0.00595; for  $K_b T_{\parallel i}=2\text{keV}$ , the growth rate=0.0252; for  $K_b T_{\parallel i}=3\text{keV}$ , the growth rate=0.0461 and the growth rate is maximum for  $\tilde{k} = 0.25, 0.4$  and  $0.5$  respectively. This graph shows significant changes in the bandwidth as there is increase in the growth rate of beam influenced obliquely propagating EMIC waves when the energy of the ions is increased.

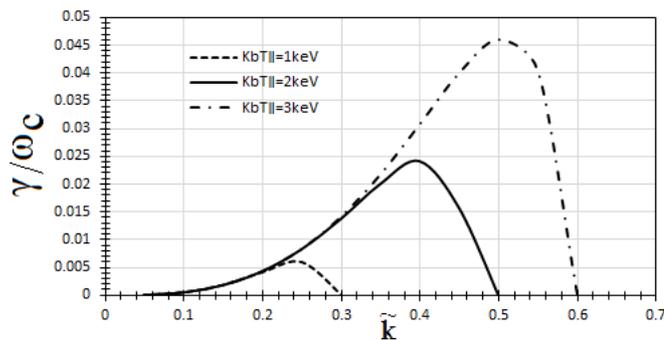


Fig.2 (b)

**Fig.2 (b):** Varying Growth Rate( $\gamma/\omega_c$ ) with  $\tilde{k}$  for different values of  $K_b T_{\parallel i}$  at  $T_{\perp}/T_{\parallel} = 1.25$  with given plasma values for beam influenced EMIC waves propagating oblique to the direction of the magnetic field.

The Figure 2(c) shows, the growth rate( $\gamma/\omega_c$ ) varying with  $\tilde{k}$  for different values of number density ratio ( $n_c/n_w$ ) varying from 10 to 20. For the value of  $n_c/n_w=10$ , the growth rate=0.00595; for  $n_c/n_w=15$ , the growth rate=0.00721; for  $n_c/n_w=20$ , the growth rate=0.00811 and the growth rate is maximum for  $\tilde{k} = 0.25, 0.3$  and  $0.35$  respectively. This graph clearly indicates that there is increase in the growth rate of beam influenced obliquely propagating EMIC waves as the ratio of number density of cold plasma to hot plasma is increased.

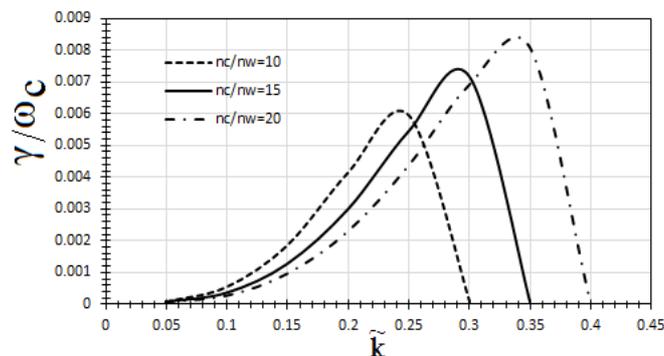


Fig.2 (c)

**Fig.2 (c):** Varying Growth Rate( $\gamma/\omega_c$ ) with  $\tilde{k}$  for different values of  $n_c/n_w$  at  $T_{\perp}/T_{\parallel} = 1.25$  with given plasma values for beam influenced EMIC waves propagating oblique to the direction of the magnetic field.

The Figure 2(d) shows, the growth rate( $\gamma/\omega_c$ ) varying with  $\tilde{k}$  for different values of propagation angle( $\theta$ ) varying from  $10^{\circ}$  to  $30^{\circ}$  for the oblique propagation of the EMIC waves to the direction of the magnetic field under the influence of

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

the beam. For the value of  $\theta=10^\circ$ , the growth rate=0.00589; for  $\theta=20^\circ$ , the growth rate=0.00578;  $\theta=30^\circ$ , the growth rate=0.00589; and the growth rate is maximum for  $\tilde{k} = 0.24, 0.27$  and  $0.27$  respectively. This graph shows increasing values of the growth rate with the increase in the oblique propagation angle( $\theta$ ) of the highly energetic ions. For propagation angle, greater than  $30^\circ$ , an instability with non-resonance takes place by replacing the electromagnetic energy with electrostatic energy in the Jupiter's magnetosphere.

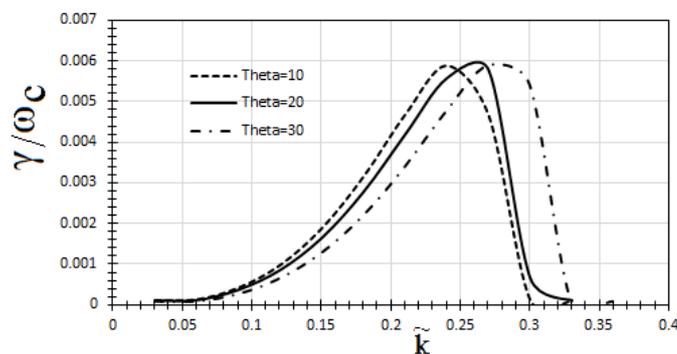


Fig.2 (d)

**Fig.2 (d):** Varying Growth Rate( $\gamma/\omega_c$ ) with  $\tilde{k}$  for different values of propagation angle  $\theta$ , at  $T_\perp/T_\parallel = 1.25$  and  $K_B T_\parallel = 1\text{keV}$  with given plasma values for beam influenced EMIC waves propagating oblique to the direction of the magnetic field.

## VI. CONCLUSION

These computations are mainly focused on parallel and oblique propagations of beam influenced EMIC waves with varying temperature anisotropy, ions energy density, number density and for different propagation angles with respect to the direction of magnetic field. For Jupiter's magnetosphere, it is observed that the above parameters support the growth rate of beam influenced EMIC waves. From the plotted graphs, it is found that beam influenced EMIC waves for oblique propagation has significantly grown more than beam influenced EMIC waves for parallel propagation. Analysis also reveals that, with the increase in the ratio of number density of cold plasma to hot plasma, there is increase in the growth rate of EMIC waves under the influence of beam and also, more growth is observed with the injection of high intense beam. Results obtained are much appropriate for the applications pertaining to the environment of space plasma and magnetosphere and also for the planetary comparative study of the solar system.

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