EFFECT OF PARALLEL ELECTRIC FIELDS ON WHISTLER MODE WAVES IN AN ANISOTROPIC JOVIAN MAGNETOSPHERIC PLASMA

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Abstract. The effect of parallel electrostatic field on the amplification of whistler mode waves in an anisotropic bi-Maxwellian weakly ionized plasma for Jovian magnetospheric conditions has been carried out. The growth rate for different Jovian magnetospheric plasma parameters for $L = 5.6\,R_j$ has been computed with the help of general dispersion relation for the whistler mode electromagnetic wave of a drifted bi-Maxwellian distribution function. It is observed that the growth or damping of whistler mode waves in Jovian magnetosphere is possible when the wave vector is parallel or antiparallel to the static magnetic field and the effect of this field is more pronounced at low frequency wave spectrum.

Introduction

Khosa *et al.* (1984) have discussed the effect of a parallel electric field on the propagation of whistler mode waves in the Jovian magnetosphere for an isotropic one component electron plasma. They have computed the growth rate of the whistler mode instability for different plasma parameters at $3 < L < 10\,R_j$ and have shown its variation with Jovian latitude. Gurnett *et al.* (1979a) have carried out the study of the propagation of VLF waves in the whistler mode through the Jovian magnetosphere and have reported significant information about the spatial and temporal variations in the Jovian magnetospheric fields and plasma parameters. Although there is no direct experimental evidence for the existence of a parallel electric field in Jovian magnetosphere. The reported observations of auroral hiss in its magnetosphere made by instruments on board Voyager 1 can be taken to be directly related to the regions of parallel electric field and auroral particle precipitation there (Gurnett *et al.*, 1979b). Also, there are strong theoretical arguments in support of the existence of field aligned currents at abrupt gradients near the inner edge of the plasma Io torus.

In this communication the effect of an electrostatic field on the amplification of whistler mode waves in an anisotropic bi-Maxwellian weakly ionized plasma for the Jovian magnetospheric condition has been briefly discussed. The growth rate of the whistler mode instability in an anisotropic Jovian magnetospheric plasma for different parameters at $L = 5.6\,R_j$ has been computed with the help of general dispersion relation for the whistler mode wave for a drifted bi-Maxwellian distribution function (Misra *et al.*, 1979).

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Formulation, Results and Discussions

The electron gyrofrequency used in this study has been chosen from the magnetometer experiment (Gurnett *et al.*, 1979a) and other plasma parameters for the Jovian magnetospheric condition have been taken from the planetary radio astronomy experiment (Warwick *et al.*, 1979). The parallel electrostatic field has been assumed to be $|E_0| \leq 20$ m V/m so that the relaxations are assumed to be Maxwellian and the velocity distribution function remains time independent. In an anisotropic low density magnetospheric plasma in presence of collisions a weak electrostatic field does not lead to run away effect of the electrons. In absence of these conditions in fully ionized plasma the presence of even a weak parallel electric field is sufficient to move the electrons and the distribution function becomes time variable which can be expressed (cf. Misra *et al.*, 1979) as

$$f_0 = \frac{n_0}{(2\pi)^{3/2}\alpha_\perp \alpha_\parallel} \exp\left[-\frac{V_\perp}{2\alpha_\perp^2} - \frac{(V_\parallel - V_D)^2}{2\alpha_\parallel^2} \right], \tag{1}$$

where n_0 is the electron density; $\alpha_\parallel = (KT_\parallel/m)^{1/2}$, parallel thermal velocity of electron; $\alpha_\perp = (KT_\perp/m)^{1/2}$, perpendicular thermal velocity of electron; K, Boltzmann constant; m, electronic mass; V_D, drift velocity of the electron due to the electric field. The applied electric field parallel to the magnetic field has the effect of modifying the thermal electron velocity in that direction which is equivalent to saying that the temperature $T_\parallel$ in the direction of magnetic field modifies to the complex temperature $T_{\parallel c}$ as

$$T_{\parallel c} = T_\parallel (1 - jeE_0/kKT_\parallel), \tag{2}$$

where k is the wave number and e is the charge of electrons. The dispersion relation is expressed as (Misra *et al.*, 1979)

$$\frac{c^2k^2}{\omega^2} = 1 - \frac{\omega_p^2}{\omega}\left[\frac{\omega z(\xi)}{2^{1/2}k\alpha_\parallel}(1 - kV_D/\omega) + A(1 + \xi Z(\xi)) \right], \tag{3}$$

where

$$A = (T_\perp/T_\parallel) - 1, \qquad \omega_p = (n_0 e^2/m\epsilon_0)^{1/2},$$

$$Z(\xi) = j\pi^{1/2}\exp(-\xi^2) - \frac{1}{\xi}\left(1 + \frac{1}{2\xi^2}\right).$$

The drift velocity of the electrons is much smaller than the phase velocity of the wave and in the magnetosphere the normalized collision frequency (ν/ω) does not effect the growth rate significantly. In view of these facts, the expression for ξ can be written as

$$\xi = (\omega - \omega_H)/2^{1/2}k\alpha_\parallel .$$

In the above expression ϵ_0 is the dielectric constant of free space, ω the frequency of the wave and $\omega_H = eB_0/m$ is the electron gyrofrequency and B_0 is the uniform magnetic field. The growth rates in Jovian magnetosphere have been computed from the following expression valid for smaller temperature anisotropy $A \leqslant 1$ (Misra *et al.*, 1979)

$$\gamma = \frac{\left[\frac{1}{\tilde{k}}\left(\frac{\pi}{2}\right)^{1/2}\left(A - \frac{\tilde{k}^2}{\beta}\right)\left(1 + \frac{\tilde{k}^2}{\beta}\right)^{-3}\exp\left\{-2\tilde{k}^2\left(1 + \frac{\tilde{k}^2}{\beta}\right)\right\}^{-1} + \tilde{K}\tilde{k}^2\left(1 + \frac{\tilde{k}^2}{\beta}\right)\right]}{\left[1 + \tilde{k}^2\Big(1 + \frac{\tilde{k}^2}{\beta} - 2\tilde{k}^2\left(1 + \frac{\tilde{k}^2}{\beta}\right)\left(A - \frac{\tilde{k}^2}{\beta}\right)\right]}, \tag{4}$$

where

$$\tilde{k} = \frac{k\alpha_{\|}}{\omega_H}, \quad \beta = \mu_0 n_0 K T_{\|}/B_0^2, \quad \tilde{K} = eE_0/kKT_{\|}\,;$$

and μ_0 is the permeability of free space. The variation in growth rate as a function of $\tilde{k}(k\alpha_{\|}/\omega_H)$ in Jovian magnetosphere has been plotted in Figure 1 and 2 for various values of electric fields and temperature anisotropies $A = 0.5$ and 1.0. It is noted that the effect of electric field on the growth rate is to enhance the range of $\tilde{k}$ values for a given temperature anisotropy (A) towards larger wavelengths. The growth rate increases with corresponding increase in $\tilde{k}$ values and attains a maximum corresponding to $\tilde{k} \approx 0.35$ and then decreases for still higher values of $\tilde{k}$. In an isothermal plasma the growth rate becomes zero for $E_0 = 0$ because of the absence of any source of energy for amplification of wave, but in an anisotropic media the energy is supplied for the growth from the vertical velocity and the cyclotron resonance. The growth rate for a fixed value of $\tilde{k}$ and parallel electric field E_0 is found to be slightly higher corresponding to larger value of the temperature anisotropy. The growth rate is also found to increase slightly with the increase in the strength of the parallel electric field. In Figure 3 we have plotted the variation of growth rate γ with the temperature anisotropy corresponding to the different values of the parallel electric field. From the graph we find that for values of A less than 0.2 the growth rate is almost zero. The variation of growth rate with respect to the electric field has been shown in Figure 4 for the values of temperature anisotropy of 0.5 and 1.0. There is the slow increase in the growth rate as we go to the higher values of parallel electric field. Further, there is an increase in the growth rate with the corresponding increase in the value of the anisotropy number. This is true for all values of the parallel electric field E_0. However, the difference in the growth rate for different values of E_0 decreases as the value of A approaches unity. The growth rate exhibits a sharp peak around $\tilde{k} = 0.35$ and it sharply decreases from the maximum at $\tilde{k} = 0.3$ and $\tilde{k} = 0.4$. The whistler mode is stable for $\tilde{k} < 0.3$ and > 0.4 in both cases of temperature anisotropy of $A = 0.5$ and $A = 1.0$ parallel electric field is responsible for stabilizing the wave. Further it is clearly

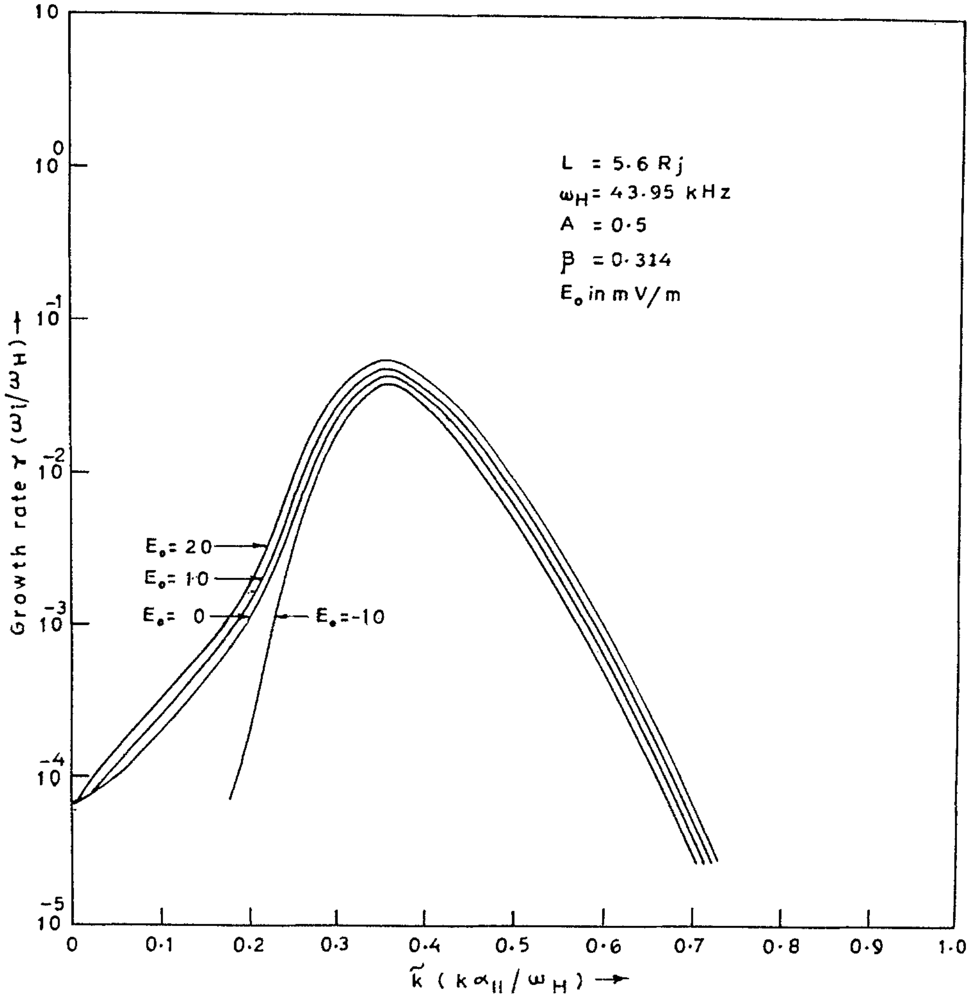

Fig. 1. Variation of growth rate γ with $\tilde{k}\,(k\alpha_\parallel/\omega_H)$ for different values of E_0, $A(T_\perp/T_\parallel - 1) = 0.5$ at $L = 5.6\,R_j$.

seen from Figure 1 and 2 that the maximum growth rate remains almost same around $\tilde{k} = 0.35$ with the increase of temperature anisotropy. The above computations demonstrate that the whistler waves could be generated by the anisotropic free energy source as the rising narrow band chorus, hiss and whistlers in Jovian magnetosphere.

Our analysis has demonstrated the principal characteristic of electromagnetic signals like whistlers and VLF emissions propagating through the region of parallel or antiparallel electrostatic field in the Jovian magnetosphere using a plasma density model adopted from Sentman and Goertz (1977) and Warwick *et al.* (1979). The close agreement between the observed and computed values of

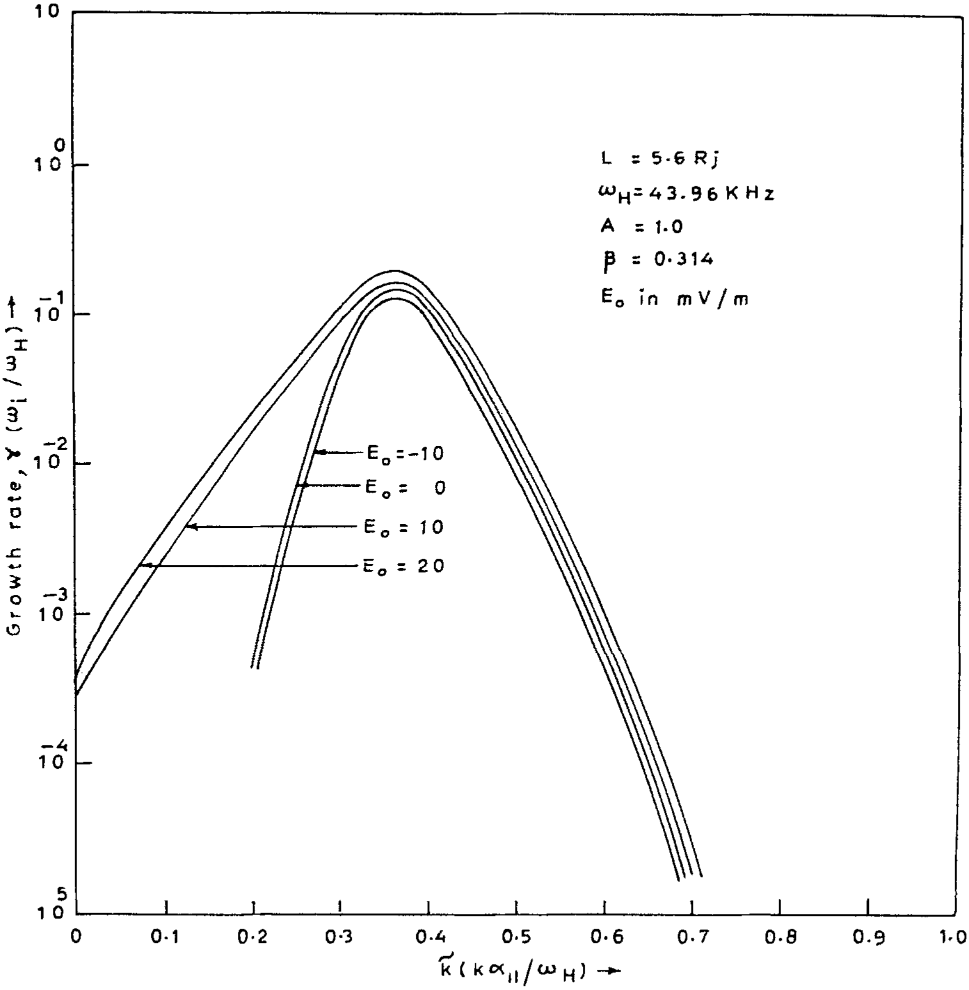

Fig. 2. Variation of growth rate γ with $\tilde{k}\,(k\alpha_{\parallel}/\omega_H)$ for different values of E_0, $A(T_{\perp}/T_{\parallel}-1)=1.0$ at $L=5.6\,R_j$.

whistler dispersions (Menietti and Gurnett, 1980) supports the validity of the Sentman and Goertz (1977) density model outside of the plasma torus and the Warwick *et al.* (1979) model for the electron density inside the plasma torus.

The results obtained clearly show that the electromagnetic signals traversing through the region of parallel or antiparallel electrostatic field may be correspondingly amplified or damped. The direction of $\tilde{k}$ with respect to E_0 may cause at times the dissipation of wave energy which may not propagate beyond the region where parallel electric field exits. The E_0 modified the growth rate of these waves caused by pitch angle anisotropy. The simultaneous presence of parallel and perpendicular fields will cause the diffusion and modification of whistler mode

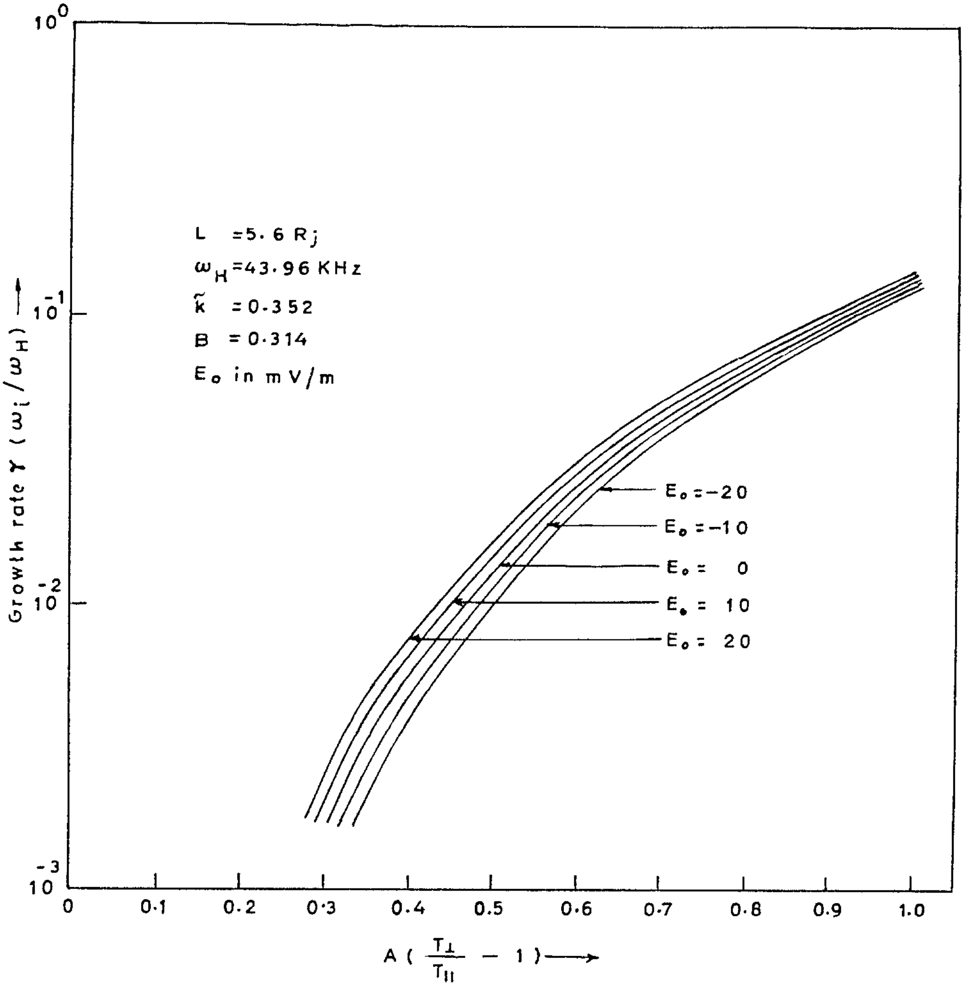

Fig. 3. Variation of growth rate γ with temperature anisotropy, $A(T_{\perp}/T_{\parallel} - 1)$ for different values of E_0, $\tilde{k} = 0.352$ at $L = 5.6\,R_j$.

energy. Recently Ahmad *et al.* (1992) have carried out theoretically the absorption of very low frequency (VLF) waves in Jovian ionosphere during day and night times. It is concluded with the help of their results that the VLF signals can be more easily observed in the night side of Io plasma torus resembled those found in earth's plasma-sphere.

Our results indicate how the features in the whistler wave spectrum may be affected with well-defined effect of parallel electric field on whistler mode waves in anisotropic Jovian magnetospheric plasma. For instance, hiss band was able to cause significant pitch-angle diffusion for electrons with $E \simeq 1$–5 KeV (Scarf *et al.*, 1981). The hiss detected throughout the Io torus region leads to the loss of

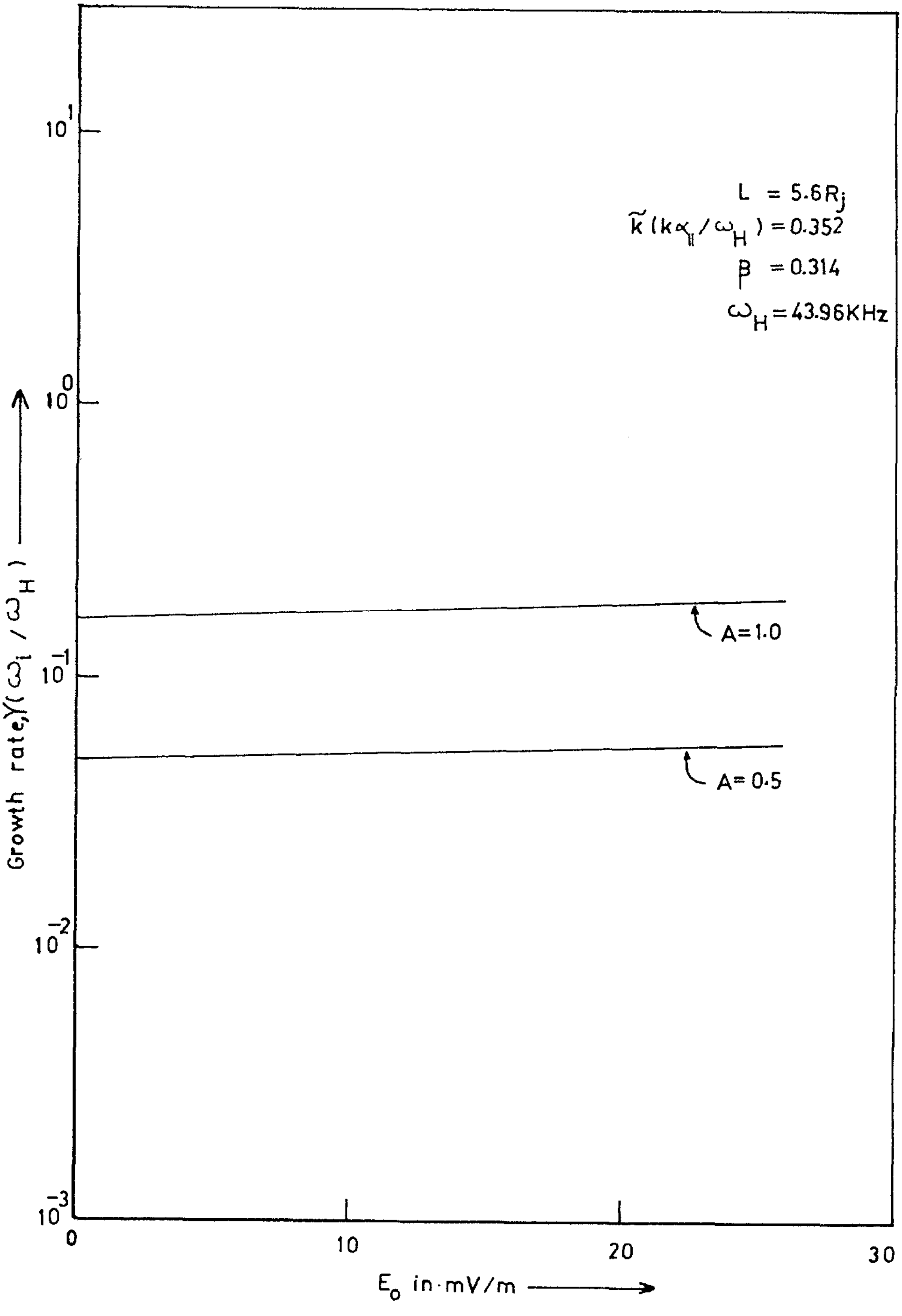

Fig. 4. Variation of growth rate γ with electric field E_0 for $A = 0.5$ and 1.0, $\tilde{k} = 0.352$ at $L = 5.6\,R_j$.

$E > 100$ KeV electrons, which deposit their energies relatively low in the atmosphere, while the discrete higher-frequency waves detected near the magnetic equator lead to the precipitation of the softer electrons, which do generate the auroral emissions. The plasma wave instruments on Voyager 1 and 2 operated during the Jupiter encounters acquired an enormous amount of new information on wave-particle interactions and electromagnetic radiation of importance with respect to magnetospheric dynamics (Scarf *et al.*, 1979; Thorne *et al.*, 1979; Coroniti *et al.*, 1980). The anticipated continuum radiations was also detected, and the measurements were used to evaluate the electron density profiles (Gurnett *et al.*, 1979b; Scarf *et al.*, 1979; Gurnett *et al.*, 1980; Gurnett *et al.*, 1981). A few intense E fields with peaks near saturation were detected (Scarf *et al.*, 1981). The wave-particle interactions at the inbound bow shock and in the upstream region were also structurally similar to those detected near the earth. This brief report touches on only a few aspects of the effect of parallel electric fields on whistler mode waves in an anisotropic Jovian magnetospheric plasma.

Thus we conclude that simultaneous measurements of parallel electric fields and whistler wave parameters in the magnetosphere should help to establish correlation between the two which could explain some of the observed features of VLF emissions in Jovian magnetosphere.

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