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Effect of parallel electric fields on whistler mode waves in Jupiter's magnetosphere

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Abstract. Observation of auroral hiss at Jupiter by Voyager I has been suggested as being directly related to regions of parallel electric field and auroral particle precipitation. The effect of a parallel electric field on whistler mode propagation in Jupiter's magnetosphere has been studied. The dispersion relation for whistler mode waves in an isothermal one-component electron plasma in the presence of a parallel electric field has been used to study the growth of whistler mode waves propagating in the Jovian magnetosphere. The growth rates have been computed by using the observed plasma parameters at $5.6\,R_j$. The growth rate, which is found to be a maximum in the equatorial magnetosphere, is reduced to zero in the absence of the electrostatic field. This has lead us to conclude that, in the case of isothermal magnetosplasma, the growth rate is induced by the electrostatic field.

Key words. VLF waves – Jovian magnetosphere – Auroral hiss – Electric field – Plasma torus – Growth rate – Cyclotron resonance

Introduction

The propagation of VLF waves in the whistler mode through the Jovian magnetosphere is well established (Gurnett et al., 1979a). A detailed study of this class of low frequency emissions in the Jovian magnetosphere reveals significant information about its structural and dynamical features. In particular the study of the propagational features of the observed whistlers yields valuable information about the spatial and temporal variations in the magnetospheric field and plasma parameters. During the last two decades electrostatic field measurements in the earth's ionosphere and magnetosphere have been carried out by a number of workers using instruments on board rockets and satellites. Although in most cases the reported electrostatic field measurements revealed the existence of a transverse component, the existence of a parallel component of the electric field in the earth magnetosphere was confirmed by experimental measurements and theoretical considerations only in the last decade. It is believed that the variability in the current system flowing parallel to the field lines gives rise to a corresponding variability in the transverse magnetic field which in turn generates a parallel component of the electric field. Further, because of turbulence, the plasma conductivity parallel to the field lines becomes finite and anomalous and thereby sustains the parallel component of the electric field. Although there is no direct experimental evidence for the existence of a parallel electric field in Jupiter's magnetosphere, the reported observations of auroral hiss in Jupiter's magnetosphere made by instruments on board Voyager I can be taken to be directly related to the regions of parallel electric field and auroral particle precipitation there (Gurnett et al., 1979b). Further, there are strong theoretical arguments in support of the existence of field aligned currents at abrupt density gradients near the inner edge of the Io plasma torus.

In the present paper we discuss briefly the effect of a parallel electric field on the propagation on whistler mode waves in the Jovian magnetosphere. The growth rate of the whistler mode instability for different plasma parameters at $3<L<10\,R_j$ has been computed and its variation with latitude discussed making use of the dispersion relation for the whistler mode waves in an isothermal one component-electron plasma in the presence of a parallel electric field (Misra and Singh, 1977).

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Results and discussion

The plasma parameters chosen for the Jovian magnetospheric conditions at equatorial altitude have been taken from the planetary radio astronomy experiment (Warwick et al., 1979) and electron gyrofrequency obtained from the magnetometer experiment (Gurnett et al., 1979a). The electrostatic field has been assumed to be $|E_0| \leqq 20\,\mathrm{mV/m}$ and the Jovian magnetic field lines have been assumed to be dipolar (Gurnett et al., 1979a). In this field configuration the ratio of electron density to the magnetic field can be assumed to be invariant along the equatorial plane so that the electron density and magnetic field can be written as

$$N(R,\phi)=3.5\times 10^4\, B(R,\phi)\cos^2\phi/(1+3\sin^2\phi)^{1/2} \tag{1}$$

and

$$B(R,\phi)=B_0(R_j/R)^3\,(1+3\sin^2\phi)^{1/2}. \tag{2}$$

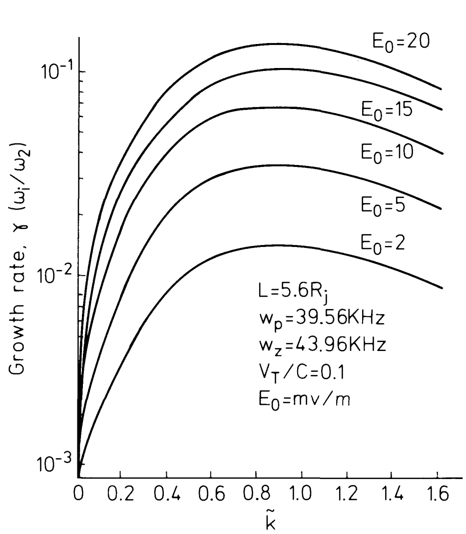

Fig. 1. Variation of growth rate $\gamma(\omega_i/\omega_z)$ with $\tilde{k}(k \cdot V_T/\omega_z)$ at $5.6\,R_j$

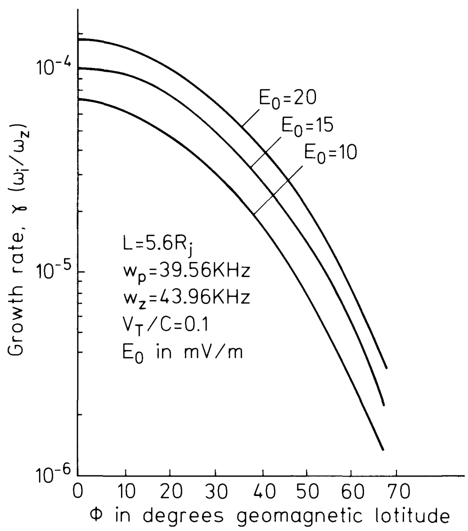

Fig. 2. Variation of growth rate $\gamma(\omega_i/\omega_z)$ with ϕ at $5.6\,R_j$

Where ϕ is the geomagnetic latitude, B_0 is the magnetic field at the ground and R_j is the radius of the Jupiter.

The Jovian distance R is related to the Jovian latitude by

$$R = R_j \cos^2\phi/\cos^2\phi_j \tag{3}$$

with the help of this expression we evaluate the variation of plasma and gyrofrequency along the field lines for a particular L-value. The growth rate has been computed from the following expression (Misra and Singh, 1977):

$$\gamma = \frac{E_0}{B_0 V_T}\left[\frac{\tilde{k}(1+\tilde{k}^2/\beta)}{1+\tilde{k}^2(1+\tilde{k}^2/\beta)}\right]. \tag{4}$$

Where

γ = growth rate
E_0 = eldctric field
B_0 = magnetic field
V_T = thermal velocity of the electron
$\tilde{k} = \frac{k V_T}{\omega_z}$ and $\beta = \frac{\mu_0 n_0 K T}{B_0^2}$
k = wave number
ω_z = the electron gyrofrequency
μ_0 = permeability of free space
n_0 = electron density
K = Boltzmann constant
T = the temperature in the direction of magnetic field

The variation in growth rate as a function of $\tilde{k}(k V_T/\omega_z)$ is shown in Fig. 1. From the figure it is clear that for $\beta = 0.3$, when the electric field is parallel to the magnetic field direction, the growth rate increases with corresponding increase in $\tilde{k}$ values and attains a maximum ($\simeq 0.8$) and then decreases for still higher values of $\tilde{k}$. When $E_0 = 0$, the growth rate is zero, which is evident because there would be no source of energy for the growth in an isothermal plasma. However in an anisotropic plasma the energy is supplied for the growth from the vertical velocity and the cyclotron resonance. When E_0 is antiparallel γ becomes negative resulting in the attenuation of the wave. This suggests that when E_0 and B_0 are both in the same direction (k direction), the whistler mode wave experiences an ampilification. The variation of growth rate with the Jovian latitude ϕ is plotted in Fig. 2, which indicates that the maximum occurs at equatorial heights $\phi = 0$. Hence it is concluded that there is a greater possibility of the generation of VLF hiss in the equatorial heights by a wave ampilification process taking place in the Jovian magnetosphere in the presence of a parallel electrostatic field. This result is consistent with the fact that the auroral hiss is observed over a very small spatial region with very sharply defined cut-off frequencies in the equatorial heights (Gurnett et al., 1979 b).

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References

Gurnett, D.A., Shaw, R.R., Anderson, R.R., Kurth, W.S., Scarf, F.L.: Whistlers observed by Voyager I: Detection of lightning on Jupiter. Geophys. Res. Lett. **6**, 511–514, 1979a

Gurnett, D.A., Kurth, W.S., Scarf, F.L.: Auroral hiss observed by Voyager I near the Io plasma torus. Nature **280**, 767, 1979b

Misra, K.D., Singh, B.D.: Electric field induced instability in the magnetosphere. J. Geophys. Res. **82**, 2267–2270, 1977

Warwick, J.W., Pearce, J.B., Riddle, A.C., Alexander, J.K., Desch, M.D., Kaiser, M.L., Thieman, J.R., Carr, T.D., Gulkis, S., Boischot, C.C., Harvey, Pederson, B.M.: Voyager I planetary radio astronomy observations near Jupiter. Science **204**, 995, 1979

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