Indian Journal of Radio & Space Physics
Vol. 16, April 1987, pp. 232-235

Drift Wave Instability in the Plasmasphere

G RENUKA & E SREEVALSAN
Department of Physics, University of Kerala, Trivandrum 695 581
and
PHILOMINA JOSEPH
Department of Physics, Mercy College, Palghat 678 006

Received 30 *March* 1984; *accepted* 3 *February* 1986

An analysis of the drift wave instability in the plasmasphere during magnetically active and magnetically quiet periods is made. It is found that even though a stabilization effect owing to the admixture of cold electrons is possible, the condition for exciting the ion acoustic wave is satisfied in the plasmasphere. The dependence of growth rate of this excited wave on electron temperature is carried out for various values of the McIlwain parameter L and electron and ion temperatures T_e and T_i, respectively. The results of the numerical calculation show that the growth rate is very small in magnetically quiet period and increases during magnetically active periods and becomes considerable at high electron temperatures.

1 Introduction

The low frequency wave instabilities in high-β plasma of earth's magnetosphere have been studied by several workers[1-4]. Dobrowolny and Negrini[5] studied the dynamics of drift waves in a weakly collisional and inhomogeneous low-β plasma, in the presence of a coherent electrostatic wave propagation parallel to the magnetic field lines. The effect of magnetospheric electric field on the drift velocity of typical proton and electron in Mead and Mead—Williams type geomagnetic field is investigated by Renuka[6]. The turbulence spectrum, the energy flux and the impurity transport of ion Landau damping of drift waves calculated from non-linear theory are compared with experimental results of Hasselberg and Rogister[7]. The particle motion and energization due to combined magnetic and electric drift of non-adiabatic ions in the earth's geomagnetic tail current sheet are investigated by Beard and Cowley[8].

The magnetospheric plasma near synchronous orbit during magnetic storms can be considered to be a mixture of a hot inhomogeneous plasma and a large cold plasma background. For such a two-component plasma, low-frequency compressional waves are excited through drift mirror and drift compressional instabilities. The compressional wave modes are coupled to shear Alfven waves due to effects of magnetic field gradient and curvature. Approximating the geomagnetic field by dipole field, Ng *et al.*[9] studied the properties of the drift.compressional instability in a magnetosphere with a two-component plasma. Studies of Lin and Cheng[10] on drift mirror Alfven instability show that the instability growth rate decreases when the geomagnetic tail field strength increases. Using a statistical model, Minardi[11] studied the thermodynamic fluctuation levels of drift modes and transport coefficients destabilized by the toroidal geometry of the Tokamak.

In this paper, an analysis of the drift wave instability due to the coupling between the electron drift mode and the ion acoustic mode in the plasmasphere is made in magnetically active and magnetically quiet periods.

2 Drift Wave Instability at Plasmapause

The drift wave instabilities produced by the low energy plasma are stabilized by the inertia of cold electrons[12]. This effect can be estimated by comparing the size of the dielectric constants ε_1 and ε_2 of low energy protons and of cold electrons, respectively, at the threshold frequency $\omega = \omega_e^*$, where ω_e^* is the low energy electron drift wave frequency. The stability condition is given by

$$R_e[\varepsilon_1(\omega_e^*) + \varepsilon_2(\omega_e^*)] > 0 \quad \ldots(1)$$

Here

$$\varepsilon_1(\omega) \sim (\omega_{P_{ih}}/kv_{T_{ih}})^2 \quad \ldots(2)$$

and

$$\varepsilon_2(\omega) \sim -(\omega_{P_{ec}} k_\parallel/\omega\, k)^2 \quad \ldots(3)$$

where k, $k_\parallel$ and v_T are the wave numbers in absolute value, wave number in the parallel direction and thermal velocity, respectively, P stands for plasma and subscripts i, e, h and c indicate ion, electron, low energy (hot) and cold components respectively. For low energy plasma, the conditions of drift wave instability are

$$v_{T_{ih}} \ll \omega_e^*/k_\parallel \ll v_{T_{eh}} \quad \ldots(4)$$

and

$$k_\perp v_{T_{ih}}/\omega_{ci} \sim 1 \quad \ldots(5)$$

For cold plasma, the conditions of drift wave instability are

$$v_{T_{ic}} \ll \omega/k_\parallel \ll v_{T_{ec}} \quad \ldots(6)$$

and

$$k_\perp v_{T_{ic}}/\omega_{ci} \lesssim 1 \quad \ldots(7)$$

Hasegawa[13] applied the drift wave theory to the plasma pause assuming the contribution of low energy particles to the plasma dielectric constant to be negligible and treated the plasmapause as consisting of only one kind of plasma with the temperature of a few electron volts. Also,

$$v_{T_i} \ll \omega/k_\parallel \ll v_{T_e} \quad \ldots(8)$$

When the ratio of plasma pressure to the magnetic pressure (β) is comparable with the mass ratio of electron to proton, the dispersion relation for drift wave can be deduced as

$$[(1+\omega^*_e/\omega)\{1+i(\pi/2)^{\frac{1}{2}}\,\omega/(k_\parallel v_{T_e})\}$$

$$-(k_\parallel^2 T_e/\omega^2 m_i)(1-\omega^*_i/\omega)$$

$$\times \exp(-\lambda_i) I_0(\lambda_i)]$$

$$\times [\omega^2 - \{v_A^2 k_\parallel^2 \lambda_i/[1-\exp(-\lambda_i) I_0(\lambda_i)]\} - \omega^*_e\omega]$$

$$= (\lambda_i T_e/T_i)(k_\parallel v_A)^2(1-\omega_i^*/\omega) \quad \ldots(9)$$

where I_0 is the modified Bessel function, v_A is the Alfven speed and

$$\lambda_i = (k_\perp v_{T_i}/\omega_{ci})^2 \quad \ldots(10)$$

The solution of Eq. (9) gives the ion acoustic, Alfven, electron drift and ion drift modes. If $k_\parallel v_A > 2^{\frac{1}{2}}\omega_e^*$, the ion asoustic wave is excited and if $k_\parallel v_A < 2^{\frac{1}{2}}\omega_e^*$, the Alfven wave is excited.

3 Numerical Results and Discussion

The magnetic field **B** was represented by the dipole field

$$\mathbf{B} = (B_0/L^3 \cos^6 \lambda_b)(1+3\sin^2\lambda_b)^{\frac{1}{2}} \quad \ldots(11)$$

where L represents the McIlwain parameter, B_0 is the equatorial magnitude of the magnetic field and λ_b is the geomagnetic latitude. The different parameters used in our calculations were as follows

B_0 = 0.31 Gauss
L = 2, 3 and 4
λ^b = 0°
T_e = 1 eV − 10 eV
T_i = 0.1 eV − 1 eV

It is found that for the chosen values, the condition for exciting the ion acoustic wave is satisfied. The growth rate of the excited ion acoustic wave is given by

$$\gamma = \lambda_i(\omega_e^*)^2(\pi/2)^{\frac{1}{2}}\,(1+T_e/T_i/(k_\parallel v_{T_e}) \quad \ldots(12)$$

The growth rate is calculated both for the possible minimum and maximum values of $k_\parallel$. The minimum value of $k_\parallel$ is given by

$$k_\parallel \gtrsim \pi/l \quad \ldots(13)$$

where l is the length of the field line at the region considered. The maximum value of $k_\parallel$ is given by

$$k_\parallel \ll \omega_e^*/v_{T_i} \quad \ldots(14)$$

At $L=2$, $T_e=1$ eV and $T_i=0.1$ eV, the growth rate for the ion acoustic wave is found to be $1.936\times10^{-5}\text{s}^{-1}$ for minimum value of $k_\parallel$ and $4.887\times10^{-6}\text{s}^{-1}$ for maximum value of $k_\parallel$.

Taking into account the well known fact that electron heating occurs during magnetically active times, the growth rate is calculated for electron temperature $T_e=10$ eV to get the values as $1.936\times10^{-3}\text{s}^{-1}$ for minimum and $4.887\times10^{-4}\text{s}^{-1}$ for maximum value of $k_\parallel$. At $L=3$ also, the same calculations are done to get the values as $1.924\times10^{-3}\text{s}^{-1}$ and $9.831\times10^{-5}\text{s}^{-1}$, respectively for minimum and maximum values of $k_\parallel$ when $T_e=1$ eV, whereas the values are $1.924\times10^{-1}\text{s}^{-1}$ and $9.831\times10^{-3}\text{s}^{-1}$ when $T_e=10$ eV, for the growth rate of the excited ion acoustic wave. Similar calculations at $L=4$ gives values of growth rate as $4.92\times10^{-3}\text{s}^{-1}$ and $2.765\times10^{-4}\text{s}^{-1}$ for $T_e=1$ eV, and $4.92\times10^{-1}\text{s}^{-1}$ and $2.765\times10^{-2}\text{s}^{-1}$ for $T_e=10$ eV. Calculations also show that the growth rate at $L=4$ for a particular value of T_e is greater than that at $L=2$ for the same value of T_e.

For $T_i=1$ eV and $T_e=1-10$ eV, the growth rate γ and the ratio (γ/ω_e^*) are calculated at $L=2$,3 and 4. Fig. 1 shows the plot of (γ/ω_e^*) versus $\delta(=T_e/T_i)$. It is found that (γ/ω_e^*) increases with δ. Thus when the electron temperature increases the growth rate also

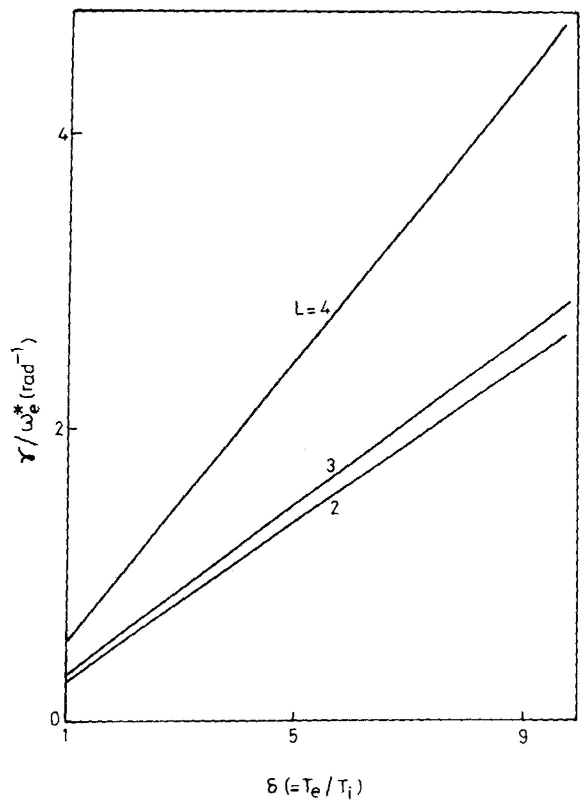

Fig. 1—Plot of (γ/ω_e^*) versus $\delta(=T_e/T_i)$ for $k_{\parallel}=10^{-7}$ m^{-1} and $L=2,3$ and 4

increases and the wave is found to have maximum growth at $L=4$.

For $T_e=1,5$ and 10 eV, ω_e^* and γ are calculated at $L=2,3$ and 4. The drift wave frequencies at $L=2$, 3 and 4 for $T_e=1$ eV are 0.23×10^{-3}, 1.09×10^{-3} and 1.63×10^{-3} Hz, respectively, whereas the GEOS observed value[14] at $L=6.6$ is ~ 2mHz. The results are plotted in Fig. 2. It is found that the drift wave frequency and the growth rate of the excited wave increase with L values. It is also found that the growth rate is very large for larger values of electron temperature compared to lower electron temperature.

The growth rate is calculated for a number of $k_{\parallel}$ values between its minimum and maximum at the corresponding regions, for $L=2,3$ and 4 and the results of calculation are shown in Fig.3. It is found that the growth rate decreases with increase in wave number. Thus shorter waves will have less growth rate or the growth rate will increase with wave length. Again it is found that for the same $k_{\parallel}$ value, the growth rate of the ion acoustic wave will be larger for larger L values.

Thus it can be concluded that the ion acoustic wave is predominantly excited for the conditions chosen. The frequency and growth rate of the excited wave increases with increase in L value or the frequency and growth rate are larger in the outer magnetosphere. For $T_e=1$ eV, the calculations show the frequency as

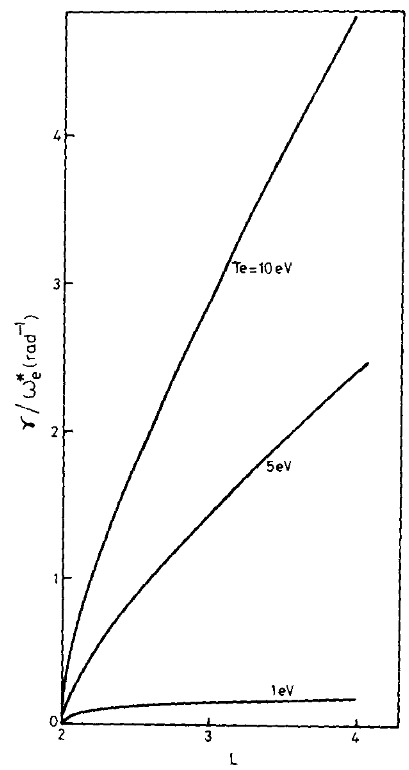

Fig. 2—Plot of (γ/ω_e^*) versus L for $k_{\parallel}=10^{-7}$m^{-1}, $T_i=1$ eV, $T_e=5,10$ and 1 eV

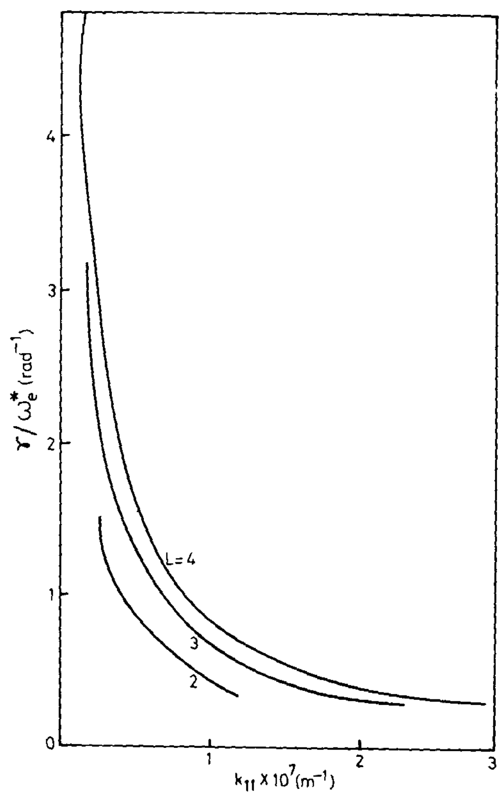

Fig. 3—Plot of (γ/ω_e^*) versus $k_{\parallel}$ tor $T_e=1$ eV, $T_i=1$ eV and $L=2,3$ and 4

0.23 and 1.63 mHz for $L=2$ and 4, respectively. This is in agreement with the experimental observations of drift waves in the outer magnetosphere. The growth rate is found to decrease with increase in the value of $k_{\parallel}$.

References

1 Hasegawa A, *Phys Rev Lett* (*USA*), **27** (1971) 11.
2 Ng P H & Patel V L, *Geophys Res Lett* (*USA*), **10** (1983) 17.
3 Patel V L, Ng P H & Cahil C J, *J Geophys Res* (*USA*), **88** (1983) 5677.
4 Migliuolo S, *J Geophys Res* (*USA*), **89** (1984) 11023.
5 Dobrowolny M & Negrini P, *J Plasma Phys* (*GB*), **6** (1971) 527.
6 Renuka G, *Indian J Radio &Space Phys*, **7** (1978) 186.
7 Hasselberg G & Rogister A, in *Radiation in plasmas*, edited by B McNamara (World Sci Pub Co, Singapore), Vol II, 1984, 870.
8 Beard D B & Cowley S W, *Planet &Space Sci* (*GB*), **33** (1985) 773.
9 Ng P H, Patel V L & Chen S, *J Geophys Res* (*USA*), **89** (1984) 10763.
10 Lin C S & Cheng C Z, *J Geophys Res* (*USA*), **89** (1984) 10771.
11 Minardi E, *Plasma Phys &Cont Fusion* (*GB*), **27** (1985) 873.
12 Gary S P, *J Plasma Phys* (*GB*), **30** (1983) 75.
13 Hasegawa A, *J Geophys Res* (*USA*), **76** (1971) 5361.
14 Walker A D M, Junginger H & Bauer O H, *Geophys Res Lett* (*USA*), **10** (1983) 757.