

BEAM GENERATED 'LEFs' IN THE AURORAL PLASMA

S.S. Mistry and R. Bharuthram

Department of Physics, University of Durban-Westville, Durban 4000, South Africa

Abstract

A theoretical investigation is carried out of the instabilities associated with a model applicable to the auroral acceleration region consisting of an ion beam, precipitating electrons and stationary background electrons. The kinetic dispersion relation is solved numerically without any approximations for auroral plasma parameters. It is shown that low-frequency plasma instabilities are present, which can generate the low-frequency electric field fluctuations (LEFs) that have been observed in the auroral acceleration region. A detailed parameter study of the instability as a function of plasma parameters, such as particle densities and drift speeds, is conducted.

1. Introduction

Ground-based, satellite and spacecraft observations of the auroral region of the earth's magnetosphere (altitude of 6000 - 12000 km) indicate the presence of upward and downward propagating charged particle beams, ion conics, low frequency electrostatic wave fluctuations (LEFs), in addition to other phenomena such as shocks and double layers [1-4]. Since both electron streams parallel and anti-parallel to the local magnetic field have been observed [5], in this paper we investigate the generation of LEFs by counterstreaming ion and electron beams. This investigation is an extension of the work by Lakhina [6], who presented approximate solutions to the dispersion relation.

2. Theory

Our model for the auroral acceleration region consists of a three component plasma : an ion beam moving upward away from the earth along the auroral field lines, cool background electrons and a hot precipitating electron component which streams downwards in a direction opposite to the ions. All species are considered magnetized and the kinetic dispersion relation is solved numerically without any approximations. The instability is driven by the drift \mathbf{V}_{oh} of the hot electrons and \mathbf{V}_{oi} of the ions along the external equilibrium geomagnetic magnetic field $B = B_o \hat{z}$. The velocity distribution of the cool electrons is taken to be Maxwellian and that of the hot electrons and ions the appropriate drifting Maxwellians.

The kinetic dispersion relation for electrostatic modes in such a plasma is given by

$$1 + \sum_j \chi_j = 0, \quad (1)$$

where

$$\chi_h = \frac{1}{k^2 \lambda_{dh}^2} \left[1 + \frac{\omega - k_{\parallel} V_{oh}}{\sqrt{2} k_{\parallel} C_h} \sum_{p=-\infty}^{\infty} Z([\omega - k_{\parallel} V_{oh} - p \Omega_e] / \sqrt{2} k_{\parallel} C_h) \Gamma_{ph} \right], \quad (2)$$

$$\chi_c = \frac{1}{k^2 \lambda_{dc}^2} \left[1 + \frac{\omega}{\sqrt{2} k_{\parallel} C_c} \sum_{p=-\infty}^{\infty} Z([\omega - p \Omega_e] / \sqrt{2} k_{\parallel} C_c) \Gamma_{pc} \right], \quad (3)$$

and

$$\chi_i = \frac{1}{k^2 \lambda_{di}^2} \left[1 + \frac{\omega - k_{\parallel} V_{oi}}{\sqrt{2} k_{\parallel} C_i} \sum_{p=-\infty}^{\infty} Z([\omega - k_{\parallel} V_{oi} - p \Omega_i] / \sqrt{2} k_{\parallel} C_i) \Gamma_{pi} \right]. \quad (4)$$

Here $\omega = \omega_r + i\gamma$ is the wave frequency, Z is the plasma dispersion function, $\Gamma_{pj} = e^{-\alpha_j} I_p(\alpha_j)$ with $\alpha_j = \frac{k_{\perp}^2 C_j^2}{\Omega_j^2}$ for $j = c, h, i$, $C_j = \sqrt{\frac{T_j}{m_j}}$ is the thermal speed of the j^{th} species, $\lambda_{dj} = (T_j / 4\pi n_j e^2)^{1/2}$ is the associated Debye length, I_p is the modified Bessel function of order p , $k_{\parallel}(k_{\perp})$ is the component of the wave vector \mathbf{k} along (perpendicular to) the external magnetic field $\mathbf{B}_o = B_o \hat{\mathbf{z}}$.

3. Numerical Results and Discussion

The dispersion relation (1) is numerically solved for parameters corresponding to the auroral acceleration region [6]. Standard values are: $T_h = 1 \text{ KeV}$, $T_c = 1 \text{ eV}$, $T_i = 10 \text{ eV}$, $n_{ho} = 1.0 \text{ cm}^{-3}$, $n_{co} = 0.001 \text{ cm}^{-3}$, $\Omega_i = 628 \text{ rad/s}$ ($f_i = \Omega_i / 2\pi = 100 \text{ Hz}$). Results are presented in normalized form: distance by $\lambda_d = (T_c / 4\pi n_o e^2)^{1/2}$, time by $\omega_{pi}^{-1} = (4\pi n_o e^2 / m_i)^{-1}$ and speed by $C_s = (T_c / m_i)^{1/2}$.

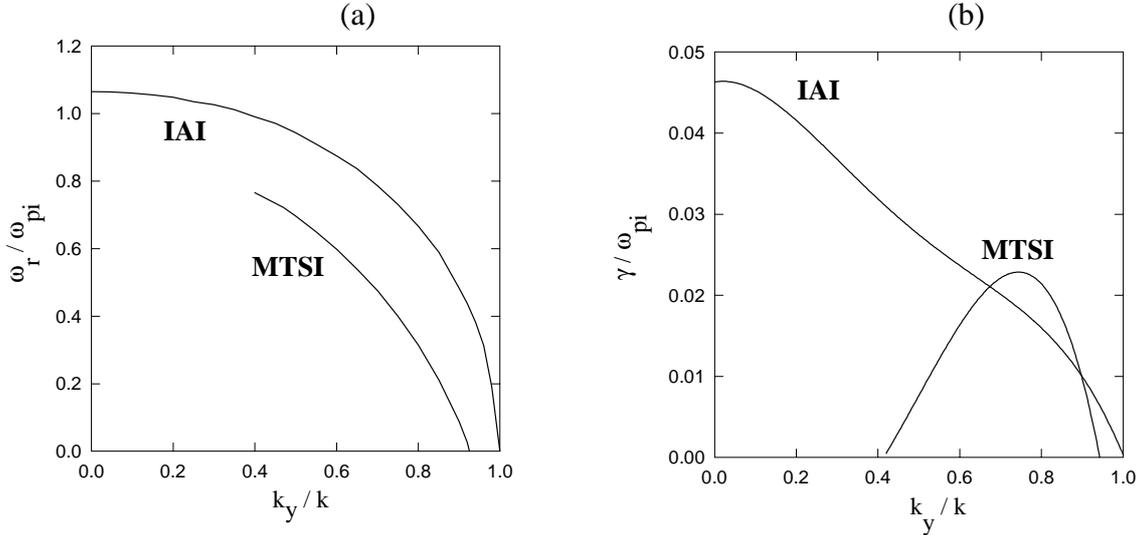


Figure 1. (a) Normalized real frequency vs. k_y/k for $V_{oi}/C_s = 140$; (b) normalized growth rate vs. k_y/k for $V_{oi}/C_s = 140$.

Figure 1. shows the growth rate for a ion beam drift speed of $V_{oi} = 140 C_s$ and $k\lambda_d = 0.01$. Mode 1 is identified as the slow beam ion acoustic instability (IAI) satisfying $\omega_r = k_z C_s / \sqrt{1 + k^2 \lambda_d^2 + k_{\perp}^2 \rho_s^2}$, while Mode 2 is the modified two-stream instability (MTSI). It is found that the IAI has an onset drift speed of $V_{oi} = 30 C_s$, while the MTSI has an onset beam

speed of $V_{oi} = 140 C_s$. In the range $140 C_s < V_{oi} < 180 C_s$, both modes are unstable, while for $V_{oi} > 180 C_s$ only the MTSI has positive growth. Moreover, it turns out that the IAI is unstable for almost all angles of propagation, while the MTSI for a restricted range oblique to B_o .

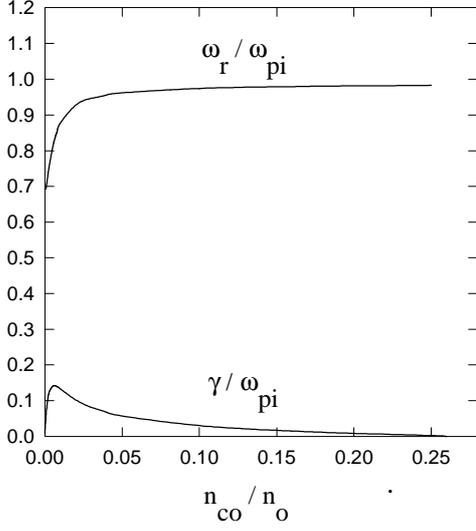


Figure 2. Normalized ω_r and γ vs n_{co}/n_o for $V_{oi} = 100 C_s$.

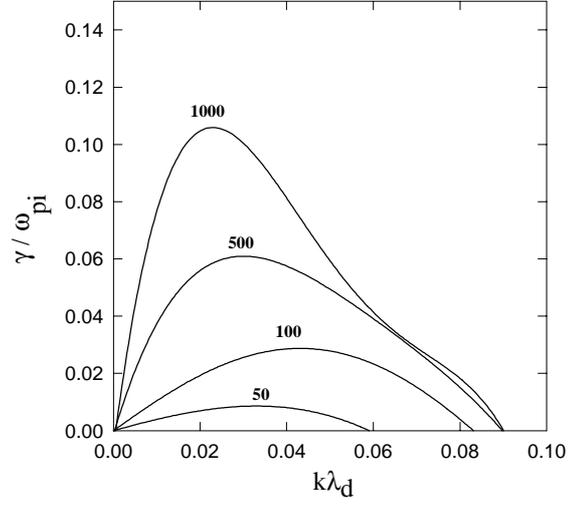


Figure 3. γ vs $k\lambda_d$ for different values of T_h/T_c , with $V_{oi} = 100 C_s$.

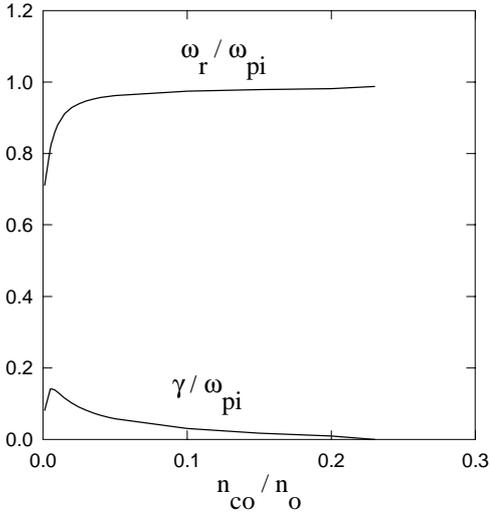


Figure 4. Normalized ω_r and γ vs n_{co}/n_o for $V_{oi} = 100 C_s$ and $V_{oh} = -100 C_s$.

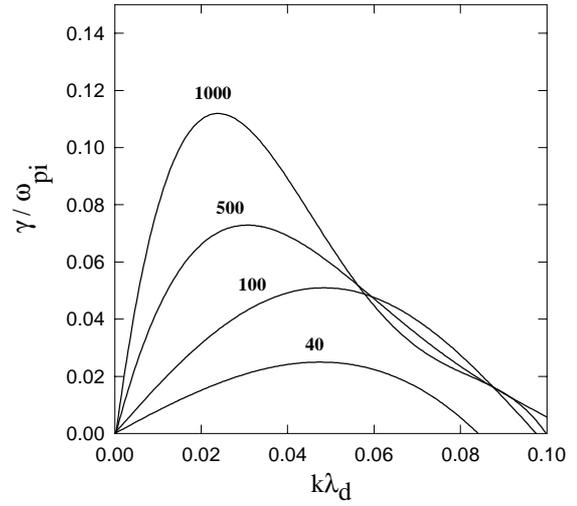


Figure 5. γ vs $k\lambda_d$ for different values of T_h/T_c , with $V_{oi} = 100 C_s$ and $V_{oh} = -100 C_s$.

In Figure 2, the effect of the density of the cool electrons on the IAI is shown for $V_{oi} = 100 C_s$. For the chosen fixed parameters, the growth rate γ is a maximum for a very small cool electron concentration, $n_{co}/n_o = 0.006$, with the instability dying away for $n_{co} > 0.25 n_o$. As the hot electron temperature is increased (Figure 3), the IAI growth rate increases due to enhanced inverse Landau damping. The range of k -values for wave growth also increases, with γ_{max} shifting to lower k -values. The opposite effect is noted when the ion beam temperature T_b is varied. As T_b increases, ion Landau damping is enhanced, causing lower growth rates. For $T_b > 250 T_c$, the IAI is found to be totally damped. Figures 4 and 5 show the additional presence

of a counter-streaming hot electron component ($V_{oi} = 100 C_s, V_{oh} = -100 C_s$). Comparing with Figures 2 and 3, it is seen that instability is enhanced when the hot electrons are drifting. This is not surprising as the net drift between the beam ions and the counter-streaming hot electrons is increased, resulting in more free energy to drive the instability.

References

- [1] Temerin, M.: J. Geophys. Res. **83**, 2609 (1978).
- [2] Hultqvist, B., R. Lundin et al.: J. Geophys. Res. **93**, 9765 (1988).
- [3] Kaufmann, R.L.: Space Sci. Rev. **37**, 313 (1984).
- [4] Holback, B., R. Bostrom et al.: EOC **74**, 526 (1993).
- [5] Sharp, R.D., E.G. Shelly et al.: J. Geophys. Res. **85**, 92 (1980).
- [6] Lakhina, G.H.S.: Annales Geophysicae, **11**, 705 (1993).