PLASMA INSTABILITIES GENERATED BY STREAMING PARTICLES

Mats André
Kiruna Geophysical Institute, University of Umeå
S-901 87 Umeå, Sweden

It is well known that particles streaming along the ambient magnetic field in space plasmas may generate waves with frequencies of the order of the local ion gyrofrequency (ion waves), (Kindel and Kennel 1971). In this study we analyze the dispersion relation of these waves numerically and discuss mechanisms for damping and instability. All numerical results in this report are obtained with the computer code WHAMP (Rönnmark 1982a,b), which solves the dispersion relation of linear waves in a homogeneous plasma for a complex frequency as a function of a real wavevector. As a specific example we consider the S3-3 satellite observations of banded electrostatic ion waves, associated with streaming particles (Kintner et. al. 1979, Cattell 1981).

1. DISPERSION SURFACES

In order to compare wave observations with theory, it is important to have an adequate display of all the wave modes which may be excited. Hence, we present dispersion surfaces, i.e. plots of the frequency f versus wavevector components k_z parallel and $k_\perp$ perpendicular to the ambient magnetic field (fig:s 1 and 2). The magnetic field strength in the model is 0.07G, and the plasma consists of 1.5 protons/cm^{-3} with temperature T_p=2eV and an equal number of electrons with temperature T_e=1keV. The proton gyrofrequency is denoted by f_{cp} and the Larmor radius of 2eV protons by ρ_p. Waves that are heavily damped, e.g. because they are close to a harmonic of f_{cp}, are excluded from the figures.

When the electron temperature is decreased, the electromagnetic modes shown in the figures are essentially unaffected. This is also true for the electrostatic waves with small k_z (C and D in fig 1). However, the banded electrostatic modes at large k_z(B) become heavily Landau damped when $T_e \sim T_p$. The ion-acoustic wave (A) also becomes damped when T_e is lowered, and the phase velocity v_{ia} decreases in agreement with the well known relation $v_{ia}^2 = T_e/m_p$, where m_p is the proton mass.

M. R. Kundu and G. D. Holman (eds.), Unstable Current Systems and Plasma Instabilities in Astrophysics, 309–312.

https://doi.org/10.1017/S007418090007577X Published online by Cambridge University Press

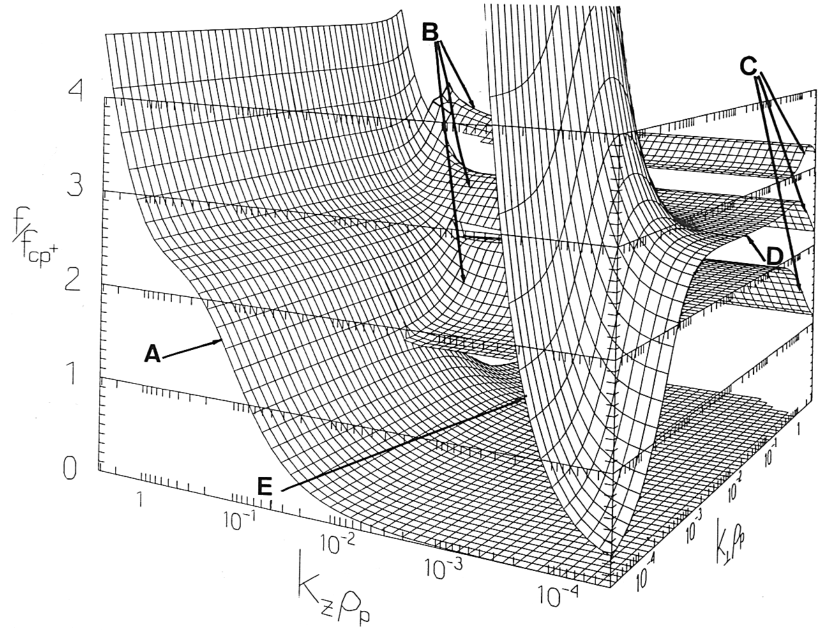

Fig.1 Dispersion surfaces for the first harmonic bands. The plasma model is given in the text. A Ion-acoustic mode (electrostatic). B Banded electrostatic waves, sometimes called Bernstein-like modes or electrostatic ion cyclotron (EIC) waves or, specifically for this plasma composition, electrostatic hydrogen cyclotron (EHC) waves. C Banded electrostatic waves, also called ion cyclotron harmonic (ICH) modes. D Lower hybrid "plateau" (electrostatic for large $k_\perp$, electromagnetic for small $k_\perp$). E Right circulary polarized mode, sometimes called the compressional Alfvén wave. The frequency of this mode approaches zero in the limit of small wavevector.

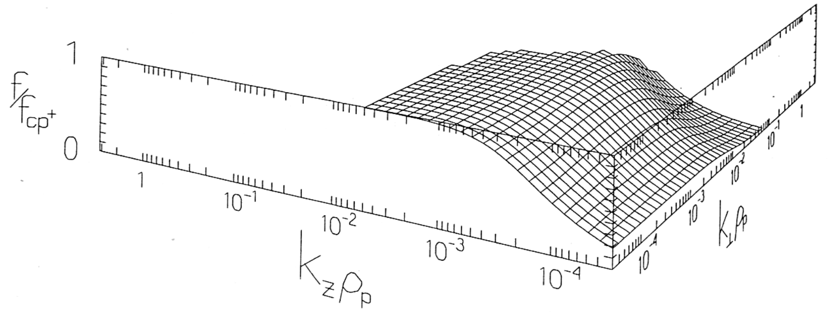

Fig.2 This dispersion surface exist simultaneously with the modes in fig.1, but is shown separately for the sake of clearness. For propagation parallel to the ambient magnetic field this surface represents the left circulary polarized mode, also called the shear Alfvén wave, which approaches zero in the limit of small k_z. This mode gradually becomes electrostatic when $k_\perp$ increases.

2. PARTICLE BEAM INSTABILITIES

Kaufmann and Kintner (1982) study an S3-3 event in which emissions between the first few harmonics of f_{cp} are observed. In their fig. 7 they consider a plasma model including an observed ion beam, and find an electrostatic instability near $1.5f_{cp}(k_{\perp}\rho_p\sim1.5,\ k_z\rho_p\sim0.15)$. However, our calculations show that this model gives an additional, strong, broad-band instability of ion-acoustic waves, which are not observed. This is not surprising, since the temperature of the only electron component is taken to be rather high (1keV), (Kindel and Kennel 1971, Bergmann 1982). By lowering this temperature to the measured value (250 eV) and including some cool electrons in the model, the ion-acoustic waves can be surpressed. These changes in the model damp also the wave at $f\sim1.5f_{cp}$ unless the total density is simultaneously decreased by an order of magnitude. Model 1 presented in Table 1 containes the components observed by Kaufmann and Kintner, a low density 2 eV proton distribution and a mixture of warm and cool electrons. An instability at $f\sim1.5f_{cp}$ is obtained in this model, but the ion-acoustic waves are stable.

The model including a measured ion beam does not predict the observed instabilities between higher harmonics of f_{cp}. Currents are often detected during electrostatic wave events on S3-3 (Cattell 1981) and drifting low energy electrons, carrying field aligned currents, are a plausible energy source for ion waves (Kindel and Kennel 1971, Ashour-Abdalla and Thorne 1978, Bergmann 1982). Using Model 2 of Table 1 we find unstable electrostatic waves in two bands, around $1.2f_{cp}$ and $2.2f_{cp}$, and no ion-acoustic instability. The observed ion beam is not essential for this current driven instability but rather the fact that not too many cool, damping electrons are present. When the temperature of 40 % of the non-drifting electrons in Model 2 (0.8 cm^{-3}) is lowered to 10 eV, the growthrate in the first harmonic band is not significantly decreased, but the wave at $f\sim2.2f_{cp}$ is damped.

In the examples given here we assume that the cool particles have a temperature of a few eV. We present models where banded electrostatic ion waves are generated by proton or electron beams with a drift velocity less than the thermal speed of the cool electrons and also less than the Alfvén speed. When constructing such models some basic facts have to be considered e.g. 1) Too many non-drifting cool electrons may damp all ion waves, 2) The ion-acoustic mode, rather than banded ion waves, may be destabilized when only a few cool electrons (drifting or not) are present, and 3) The growth rate of the ion-acoustic wave is decreased when some of the ions have a temperature of the same order as the warm electrons. Both models in Table 1 include warm protons and cool electrons and hence no ion-acoustic waves are destabilized. In model 1. the ion beam density is a large fraction of the total density and we thus obtain an instability, although cool damping electrons are present. In model 2 the drifting cool electrons generate the instability. Using this kind of models we can get some information about the plasma composition from wave observations.

Model 1

	p	p	p	e	e
T(eV)	2	50	1069	250	10
$n(cm^{-3})$	1	0.55	0.34	1.59	0.3
v_D	0	3.3	0	0	0

$f/f_{cp}=1.5$ $k_\perp \rho_p=0.6$ $k_z\rho_p=0.2$ $\tau=0.1s$ $D_\perp=1$ km $D_z=3$ km

Model 2

	p	p	e	e
T(eV)	10	250	10	250
$n(cm^{-3})$	2	2	2	2
v_D	0	0	0.7	0

$f/f_{cp}=1.2$ $k_\perp \xi_p=1.2$ $k_z\xi_p=0.1$ $\tau=0.02s$ $D_\perp=0.1$ km $D_z=0.3$ km

$f/f_{cp}=2.2$ $k_\perp \xi_p=2$ $k_z\xi_p=0.12$ $\tau=0.1s$ $D_\perp=0.2$ km $D_z=2$ km

Table 1. The temperature (T), density (n) and drift velocity along the ambient magnetic field, normalized to the thermal speed of the drifting component (v_D), for protons (p) and electrons (e). The frequencies and wavevectors given correspond to maximum growth in each band. The magnetic field strength is 0.07G and the Larmor radius of 2eV and 10eV protons are denoted ρ_p and ξ_p respectively. The time for one e-folding of wave amplitude is given by τ. Since the instabilities are convective we introduce the distances $D_\perp$ and D_z which show how far the group velocity takes the wave perpendicular and parallel to the ambient magnetic field during one e-folding.

REFERENCES

Ashour-Abdalla M. and Thorne R.M.:1978,J.Geophys.Res. 83,pp 4755-4766
Bergmann R.:1982,UCB Space Sciences Laboratory Preprint No.SSL-82-111-MKI
Cattell C.: 1981, J. Geophys. Res. 86, pp 3641-3645
Kaufmann R.L. and Kintner P.M.: 1982, J.Geophys.Res. 87,pp 10487-10502
Kindel J.M. and Kennel C.F.: 1971, J. Geophys. Res. 76, pp 3055-3077
Kintner P.M.,Kelley M.C.,Sharp R.D.,Ghielmetti A.G.,Temerin M.,Cattell C Mizera P.F. and Fennel J.F.: 1979, J. Geophys. Res. 84, pp 7201-7212
Rönnmark K.: 1982a, Plasma Phys. 25, pp 699-701
Rönnmark K.: 1982b, WHAMP-Waves in Homogeneous Anisotropic Plasmas, Kiruna Geophysical Institut Report no. 179.