BANDED ELECTRON CYCLOTRON HARMONIC
INSTABILITY - A FIRST COMPARISON
OF THEORY AND EXPERIMENT

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Abstract. A study, which is the first of its kind, uses information derived from simultaneously measured wave spectra and particle distributions as the input to a theoretical linear instability model of an electrostatic cyclotron harmonic wave event recorded on GEOS-1. The presence of a hot loss cone component of the particle distribution is established experimentally, and the model accounts reasonably for the observed frequencies and relative strengths of the \((n + \frac{3}{2})f_c\) and upper hybrid emission features.

1. Introduction

In this paper we report results of a first attempt to compare GEOS-1 spectra of magnetospheric wave instabilities with the prediction of a linear theory of electron cyclotron (ECH) wave instability. The novel feature of this work lies in the fact that the input parameters used for the theoretical model, in particular, the electron distribution function, are derived whenever possible from measurements made concurrently with those of the wave spectra.

The understanding of magnetospheric instabilities with frequencies above the electron gyrofrequency \((f_c = \Omega_c/2\pi)\) has been seen as an important problem since the detection of strong (electric fields > 1 mV m\(^{-1}\)) electrostatic emissions between low gyroharmonics by the OGO-5 electric field experiment (Kennel et al., 1970). Subsequent observations from OGO-5 (Fredricks and Scarf, 1973) and from IMP-6 by Shaw and Gurnett (1975) enriched this observational base and provided the stimulus for further theoretical effort. The literature on ECH wave instability is extensive, though much of the early work, e.g. Dory et al. (1965), Hall et al. (1965), Brambilla (1970), Tataronis and Crawford (1970a,b) is oriented to laboratory plasmas. It is with the paper by Fredricks (1971) that the problem of explaining the occurrence of the so called \('(n + \frac{3}{2})f_c'\) magnetospheric emissions began to be tackled. From this and the subsequent work of Young et al. (1973), Karpman et al. (1975), Ashour-Abdalla et al. (1975), Ashour-Abdalla and Kennel (1976, 1978) the basic requirements for a reasonable (in the sense that plausible magnetospheric electron velocity distributions are used) linear stability theory have emerged. These are basically that a plasma containing at least two components should exist—a hot, weak loss-cone component (density \(n_A\)), and a cooler...
component (density $n_e$). Put somewhat crudely, the hot component, which con-
tains regions of velocity space where $\partial f/\partial v_\perp > 0$, contains the free energy for the
instability, while the cool component aids destabilization and controls, to a large
degree, the dispersion of the waves. The role of the cool plasma upper-hybrid
frequency ($f_{uhc}$) is particularly important in that strong instability is predicted in
its vicinity.

The development of a good linear theory has more than intrinsic interest since it
forms the basis for an understanding of quasi-linear and non-linear effects
associated with the instability. In fact, the quasi-linear pitch angle and energy
diffusion of kilovolt electrons has been discussed by Lyons (1974) in relation to
the generation of diffuse aurorae, and by Ashour-Abdalla and Kennel (1978) as a
wave stabilization mechanism.

Because the earlier satellites lacked the direct methods for the measurement of
important plasma parameters available on GEOS-1, the models discussed above
have been constructed more or less independently of direct experimental input,
other than spectral information. This in turn has emphasised emissions between
low harmonics of the electron gyrofrequency – the so called $\frac{3}{2}$, and $\frac{5}{2}f_c$
instabilities. Since instability is expected close to $f_{uhc}$, and in gyroharmonic bands below it, the
models presuppose a rather low value of the cool plasma density, and by setting
the ratio $n_e/n_A \leq 0.2$ have tended to treat what might be called ‘nightside’
phenomena, where the cool component, presumably of ionspheric origin, is
dominated by the hot component composed of electrons convected from the tail.

From the GEOS-1 observations (Christiansen et al., 1978) it is known that
ECH wave instability also occurs close to the geomagnetic equator, on the
dayside, where the cool plasma is dense $f_{uhc}/f_c > 1$, and dominant, and in which
signals are observed occupying the bands between gyroharmonics all the way up
to $f_{uhc}$. This case is treated briefly by Karpman et al. (1975) and more recently by
Hubbard and Birmingham (1978) who model various spectral types of ECH wave
emissions seen in IMP-6 data and argue that the spectra can be used as a plasma
diagnostic of the cool electron density $n_e$.

The approach adopted in this paper is rather different, since we emphasize the
use of directly measured plasma parameters and thus hope to avoid the difficulty
of dealing with a large number of variable input parameters which besets
theoretical work in this area.

The paper is arranged as follows; in Section 2 we describe various experimental
inputs which are used for the theory, which is described together with the model
velocity distribution in Section 3. The predictions of this model are discussed in
relation to measured wave spectra in Section 4.

2. Experimental

The data used for this study is taken from the 25th August 1977, in a short period
from 09:50-09:53 UT. In order to orient the reader, a grey scaled spectrogram,