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THE AURORAL KILOMETRIC RADIATION: DE 1 DIRECTION FINDING STUDIES

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Abstract. We have determined the directions of arrival of auroral kilometric radiation during three separate intervals using data from the DE 1 plasma wave instrument. In the case of the dominant extraordinary mode component, these directions were consistent with generation at the local electron cyclotron frequency on nightside auroral field lines. The ordinary mode component appeared to have a similar source in one case, but in other cases came from different directions. These other cases were consistent with reflection at the plasmapause and the wall of the auroral plasma cavity.

Introduction

Previous work had suggested the presence of both ordinary (O-mode) and extraordinary (X-mode) components of the auroral kilometric radiation (AKR) [Kaiser et al., 1978; Benson, 1984, 1985], but polarization measurements made by the DE 1 Plasma Wave Instrument (PWI) have recently provided the first detailed measurements of radiation in the two different modes [Shawhan and Gurnett, 1982; Mellott et al., 1984]. The DE measurements indicate that, although the two modes often occur separately, they are sometimes observed together, and when both modes are present, the left-hand polarized O-mode AKR is generally weaker and of lower frequency. This behavior is illustrated in Figure 1 where plasma wave data from a pass over the northern hemisphere auroral zone are presented. The electric field intensity is shown in the upper panel: the intense high frequency emission is auroral kilometric radiation and the funnel-shaped emission at lower frequencies is auroral hiss. The polarizations of the various components are shown in the lower panel, where right-hand polarization is coded black and left-hand polarization is coded white. The X-mode AKR (black) was clearly dominant within the auroral zone (crossed at roughly 1940 UT) while the O-mode was observed at earlier local times and higher magnetic latitudes. These observations are generally consistent with an X-mode source at or near the local electron cyclotron frequency (f_g) on nightside auroral field lines, but the source of the left-hand polarized ordinary-mode emissions is not yet clear. We seek to establish the source(s) of both components and in this paper we have attacked the problem using direction of arrival measurements made with the DE 1 Plasma Wave Instrument.

Much effort has already gone into attempts to define the AKR source region [Gurnett, 1974; Kurth et al., 1975; Kaiser and Alexander, 1976; Alexander and Kaiser, 1976 and 1977; Green et al., 1977; Gurnett and Green, 1978; Alexander et al., 1979; Benson and Calvert, 1979; Gallagher and Gurnett, 1979; James, 1980; and Calvert, 1981a]. This previous work included both direction finding studies and statistical studies of wave amplitude as a function of altitude and local time. The general conclusion was that the predominant AKR source was located at relatively low altitudes (1-3 R_e) on evening sector auroral zone field lines.

However, these studies were all made before routine direct polarization measurements were available and thus without the ability to distinguish between the ordinary and extraordinary mode components. The present study in contrast uses data from the DE 1 PWI which has a capability of distinguishing the two modes. We also employ a new direction finding technique which relies on analysis of the relative phase between signals from two correlated orthogonal antennas [Calvert, 1985]. The DE measurements, which are described below, are consistent with the expected source for the extraordinary mode AKR, but indicate several apparent sources for the ordinary mode component.

Instrumentation and Method of Analysis

The high-altitude DE 1 is in a polar orbit with a 90° inclination, an apogee of 4.65 R_e geocentric, a perigee altitude of 675 km, and an or-

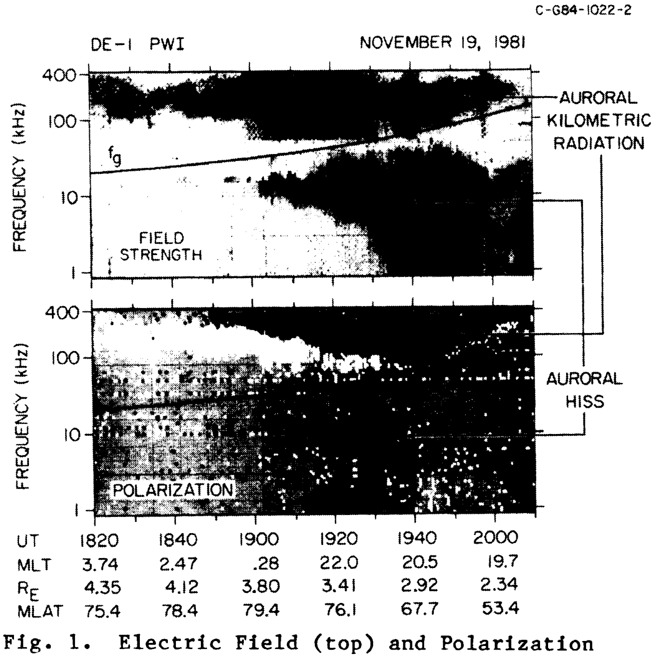

Fig. 1. Electric Field (top) and Polarization (bottom) Spectrograms. The dark regions in the electric field spectrogram correspond to the most intense emissions. In the polarization plot right-hand polarized waves are coded black, and white corresponds to left-hand polarized signals.

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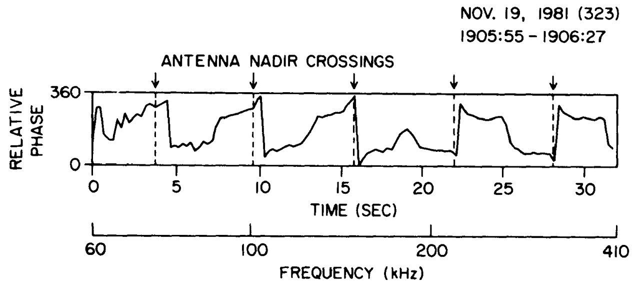

Fig. 2. Phase Plot. The relative phase between the signals from two orthogonal electric field antennas is plotted as a function of time (or equivalently, frequency).

bital period of about 7 hours [see Hoffman et al., 1981, for details of the spacecraft and orbital characteristics]. The DE 1 Plasma Wave Instrument makes spectral and polarization measurements over a frequency range of 2 Hz to 400 kHz [Shawhan et al., 1981]. The instrument uses two dipole antennas for electric field measurements, one oriented along the spin axis (EZ) and another which rotates in the spin plane (EX). The spacecraft spins in a "reverse cartwheel" mode, with its spin axis perpendicular to the orbital plane.

We have used data from the Sweep Frequency Correlator of the DE 1 PWI, concentrating in particular on the behavior of the relative phase between signals from the two electric field antennas. Details of the analysis procedure are presented in a separate paper [Calvert, 1985] and we review only certain pertinent results here. The phase between signals from these two antennas varies as a function of the spin phase of the EX antenna in a manner which depends upon the ellipticity and direction of arrival of the waves, and upon the sense of polarization of the radiation. An example of the pattern which results when this phase difference is plotted as a function of time is shown in Figure 2, where data from one full frequency sweep made near the center of the time interval shown in Figure 1 are presented. The satellite completed a little more than five rotations during the sweep, as indicated by the dotted lines, which mark EX antenna nadir crossings. The observed pattern may to zero order be described as a square function which alternates between the values of 90° and 270°. The polarization of the observed radiation is directly reflected in this pattern, and can be quickly de-

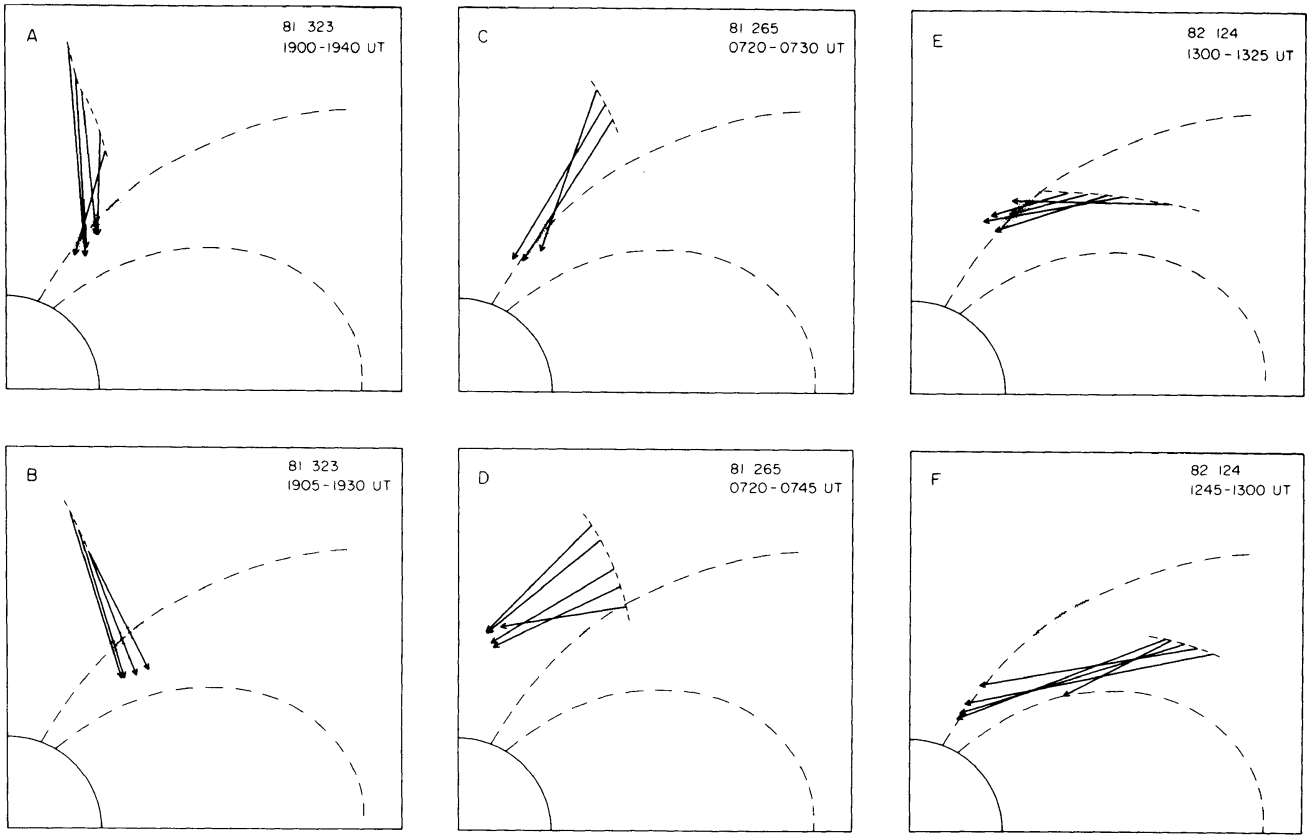

Fig. 3. Direction of Arrival Studies. The arrows indicate the spin plane directions of arrival for three different intervals of AKR activity with extraordinary mode observations presented in panels A, C and E, and ordinary mode in B, D, and F. Each arrow represents an average over five minutes of data and is shown originating at the median satellite position during that interval. A nominal L = 4 plasmapause is indicated for reference. The shaded bars indicate hypothetical sources at the local electron cyclotron frequency on the 70° invariant magnetic latitude field line where $f_g \sim f_{AKR}$. The ranges of observed frequencies were (A) 80-150 kHz, (B) 150-300 kHz , (C) 50-100 kHz, (D) 100-180 kHz, (E) 70-140 kHz and (F) 150-400 kHz.

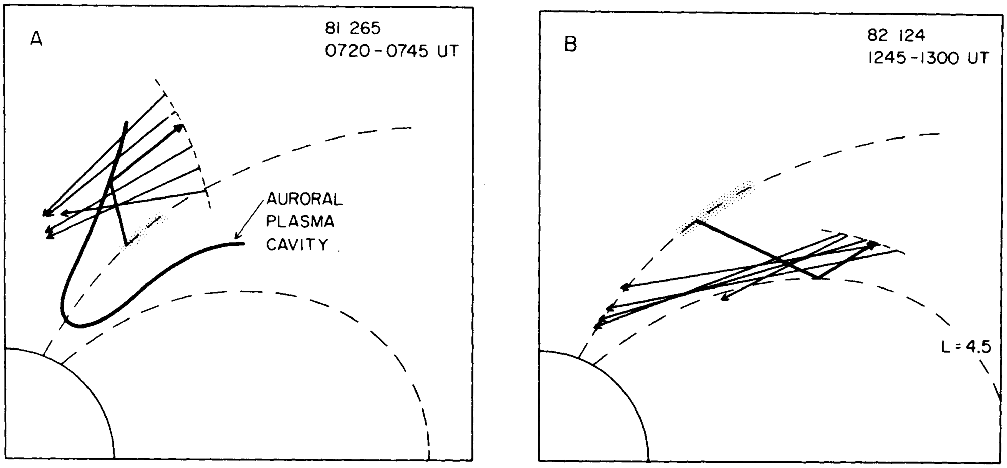

Fig. 4. Reflection Geometries. Possible ray paths for reflection from the auroral plasma cavity wall (A) and the plasmapause (B). The auroral plasma cavity is indicated by the 10 particle/cm^3 profile from Calvert [1981b].

termined by checking the phase difference at times ± 1/4 spin from the nadir: a 90° phase difference at nadir + 1/4 spin corresponds to left handed waves and 270° corresponds to right handed radiation [Shawhan and Gurnett, 1982; Calvert, 1985]. In the illustrated case a transition between the two patterns occurs approximately 19 seconds into the time period: the lower frequency radiation (60-180 kHz) was left-hand polarized and the higher frequency signals (180-400 kHz) were right-hand polarized.

Fits to the shape of this curve provide us with further information about the direction of arrival of the radiation. The feature of interest in these calculations is the sudden phase transistions which give the curve its sawtooth appearance, and which occur when the EX antenna sweeps through the direction of arrival of the incoming radiation. In the spin plane the angle between the direction of arrival and the nadir direction can be found directly by measuring the displacements of the phase transitions from the nadir crossings. The shape of the variation can also be used to estimate the out-of-plane angle. This shape factor primarily affects the slope of the phase transitions, and hence the squareness of the curve. When the slope is relatively steep, as it is here, the radiation is traveling primarily within the spin plane.

We determine average values for the two angles using routines which fit the data points within a given frequency range for a specified time interval. The data presented in this paper were collected over five minute long intervals and over frequency ranges on the order of 50-100 kHz, depending on the bandwidth of the O and X-mode signals in the individual cases.

Observations

This study was limited to observations from the evening sector (1800-2400 LT) and to cases in which the radiation appeared to arrive within ± 20° of the spin plane. Figure 3 shows the measured directions of arrival in this plane (which corresponds to the plane of the figure). The directions, which are indicated by the arrows, are shown originating from the satellite position at the time of the observation. Extraordinary mode measurements are on the top (Figures 3a, 3c and 3e) and ordinary mode on the bottom (Figures 3b, 3d and 3f). The barred regions correspond to positions on the 70° invariant latitude magnetic field line appropriate to generation of X-mode AKR at the local electron cyclotron frequency. Also shown is a nominal plasmapause.

In all three cases the X-mode radiation arrived at the satellite from directions consistent with the hypothesized source. The O-mode radiation on the other hand had several apparent sources. In one case it appeared to come from appropriate altitudes for X-mode AKR generation on the 70° field line (Figure 3b), but in other cases the ray paths either failed to intersect the field line at all (Figure 3d), or else intersected it at much different altitudes than predicted (Figure 3f).

Discussion and Conclusions

The DE 1 direction finding measurements indicate that the extraordinary mode component of the auroral kilometric radiation is generated at the local electron gyrofrequency on evening sector auroral zone field lines. These measurements are generally consistent with the basic hypothesis of most modern AKR theories which concur that the radiation is produced through Doppler-shifted cyclotron resonance with certain features of auroral zone electron distributions [Melrose, 1976; Wu and Lee, 1979].

Although the ordinary mode AKR appears to come from several different locations, we suggest that the directions of arrival are all nonetheless consistent with generation of the radiation on the 70° field line. This would be possible if the radiation in Figures 3d and 3f had not traveled directly to the spacecraft, but had rather been reflected towards the satellite. Two plausible paths for such reflections are sketched in Figure 4. In constructing the sketches we assumed an X-mode AKR source on the 70° field line at an altitude where the local electron gyrofrequency was equivalent to the frequency of the observed radiation. We then constructed the ray paths which would have resulted if the radiation were reflected by the walls of the auroral plasma cavity (Figure 4a) and the plasmapause (Figure 4b). The constructed ray paths match the observed directions of arrival very well, although it was necessary in the second case to use a relatively high value (L = 4.5) for the plasmapause location. A reasonable alternative reconstruction could have been made assuming the lower latitude O-mode source suggested in the results of Oya and Morioka [1983] and Benson [1984, 1985]. These results thus leave open the question of the ultimate source of the ordinary mode AKR: it is not yet clear whether the O-mode component is directly driven in a manner similar to that of the X-mode, or whether it results only as a by-product of a predominantly X-mode source [Calvert, 1982], as suggested by the correlation between O and X-mode amplitudes reported by Mellott et al. [1984] and by recent simulations [Pritchett and Strangeway, unpublished manuscript, 1985].

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