GEOPHYSICAL RESEARCH LETTERS, VOL. 9, NO. 9, PAGES 913-916, SEPTEMBER 1982

POLARIZATION MEASUREMENTS OF AURORAL KILOMETRIC RADIATION BY DYNAMICS EXPLORER-1

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Abstract. The Plasma Wave Instrument (PWI) on the Dynamics Explorer-1 has been used to measure Polarization of auroral kilometric radiation (AKR) at frequencies of 50 to 400 kHz in both the northern and the southern nightside auroral regions at altitudes of 1 to 3 R_E above the AKR source regions. The AKR polarization sense is found to be the same as the right hand polarized auroral hiss found in the frequency range of 0.8 to 6.4 kHz. Consequently, these unambiguous direct polarization measurements of AKR lead to the conclusion that AKR escapes the magnetosphere in the R-X mode. Since DE-1 is close to the source region, it can be inferred that AKR is generated predominately in the R-X mode.

Introduction

It is generally accepted that auroral kilometric radiation (AKR) from the earth is generated on auroral field lines at ~ 1 R_E altitude in association with discrete auroral arcs. Emission is at kilometric wavelengths (50 kHz to 1 MHz in frequency) and the radiation fills a broad emission cone centered on the nightside 70° invariant latitude field line. These observational characteristics were generally recognized by Gurnett (1974) and have been substantiated by subsequent detailed observations.

Several theories have been proposed to relate the observed particle distribution functions on auroral field lines to these AKR characteristics. A review of many current theories is given by Grabbe (1981). The theories differ in the mode of the emission in the source region--either the left hand polarized-ordinary (L-O) mode or the right hand polarized-extraordinary (R-X) mode is possible. Consequently, a discriminating observational parameter to use in evaluating the theories is the polarization of the AKR close to the source region.

The polarization of AKR has been inferred from the observed propagation cutoff frequencies near the plasmapause with Hawkeye-1 (Gurnett and Green, 1978) and near the source region with ISIS-1 (Benson and Calvert, 1979 and James, 1980). A more direct measurement of wave polarization was made with orthogonal monopole antennas by Voyagers 1 and 2 at ~ 100 R_E range as they left the vicinity of the earth near the equatorial plane (Kaiser et al., 1978). The Hawkeye, ISIS and Voyager measurements are consistent with AKR escaping from the source regions in the R-X mode. However, these polarization measurements have been criticized by Oya and Morioka (1981). Using the Jikiken satellite (EXOS-B), Oya and Morioka observe some wave components at the L-O mode cutoff near the equatorial plasmapause which may be consistent with a Z-mode to L-O mode emission mechanism.

Instrumentation on the Dynamics Explorer-1 spacecraft provides the capability to make unambiguous direct measurements of the AKR polarization close to the source region (Shawhan et al., 1981). These measurements are a significant improvement over the previous measurements for the following reasons: (1) Orthogonal dipole electric antennas are utilized which are oriented so that they become perpendicular to the wave propagation vector (approximately the local magnetic field vector) twice each spin period (6 seconds); (2) DE-1 is in a polar orbit which passes close to the high latitude auroral source regions (at 1 to 3 R_E altitude) so that the measured local polarization can be inferred to be the polarization of the emission in the source region; and (3) Polarization sense of AKR can be compared to that of known whistler-mode (right hand polarized) noise such as hiss so that the sense is absolutely calibrated on-orbit. This paper reports the polarization measurement method utilized on a sample of AKR and hiss data.

Measurement Technique

Details of the Dynamics Explorer spacecraft and orbit characteristics are given by Hoffman et al. (1981). DE-1 is in a polar orbit (90° inclination) with an apogee of 4.65 R_E geocentric and perigee of 675 km altitude with an orbital period of about 7 hours. DE-1 includes a plasma wave and quasi-static electric field instrument (PWI) with the capability to make spectral and polarization measurements over a frequency range of 2 Hz to 400 kHz. A complete description of the instrumentation is given by Shawhan et al. (1981). A sample color spectrogram from one Step Frequency Receiver (SFR) is shown in Figure 1. AKR occurs above 100 kHz and above the local electron gyrofrequency (white line). Auroral hiss occurs below 20 kHz.

For the AKR and hiss measurements reported here, orthogonal dipoles (EX and EZ) and the correlating SFRs are utilized. The EX electric dipole antenna is 200 meters tip-to-tip located perpendicular to the spin axis so that it rotates through the magnetic field direction (approximately) twice per spin period (6 seconds). The EZ dipole antenna is 9 meters tip-to-tip. It is oriented parallel to the spin axis and perpendicular to the orbital plane as shown in Figure 2. Each antenna is connected to an SFR with a noise level of 10^{-16} $V^2m^{-2}Hz^{-1}$ for EX and 10^{-14} $V^2m^{-2}Hz^{-1}$ for EZ and a dynamic range of 100 dB. For each SFR a 128 point log spectrum from 100 Hz to 400 kHz takes 32 seconds using four ganged receivers with a 1% bandwidth.

Simultaneous with the spectral sweep, the two SFR outputs are correlated producing in-phase

Paper number 2L1290.
0094-8276/82/002L-1290$3.00

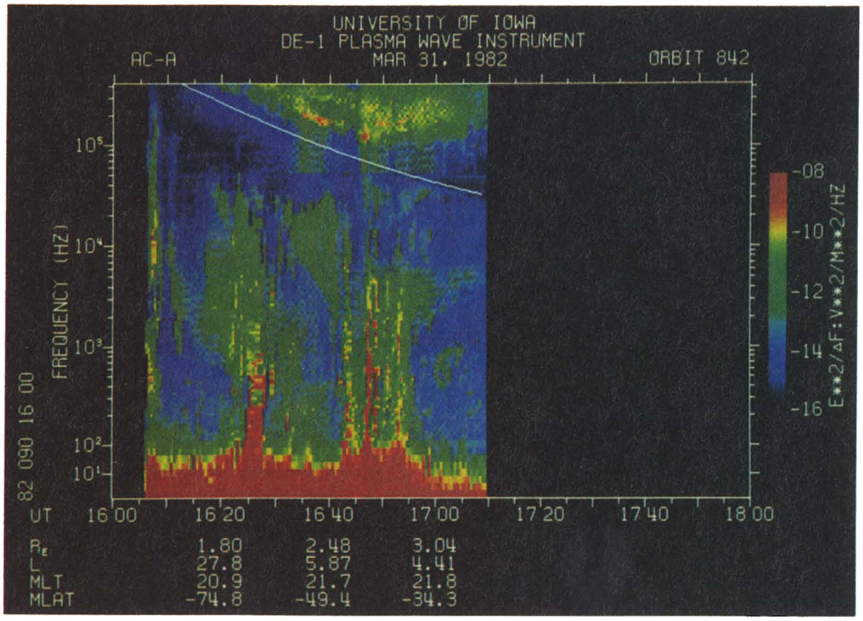

Fig. 1 Color spectrogram of AKR above 100 kHz and auroral hiss below 20 kHz. White line marks electron gyrofrequency.

and quadrature-phase outputs. From these outputs are derived the absolute correlation of the signals $0 < \rho < 1$ and the phase between the signals $0° < \Theta < 360°$ for each frequency step. For AKR and whistler-mode noise, the waves are predominately circularly polarized so that the phase angle should be near 90° or 270° depending on the spin phase of the EX antenna, on the direction of the earth's magnetic field $\vec{B}$ and on the polarization sense of the particular mode. In Figure 2 the spacecraft is depicted over a southern hemisphere AKR source at about 2 R_E.

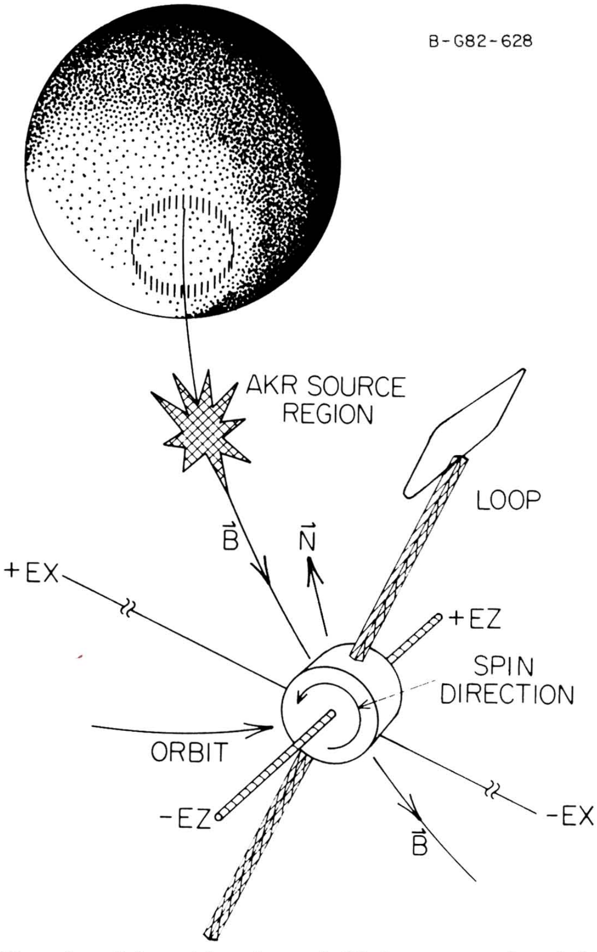

Fig. 2 Schematic view of DE-1 spacecraft with respect to southern hemisphere auroral AKR source region.

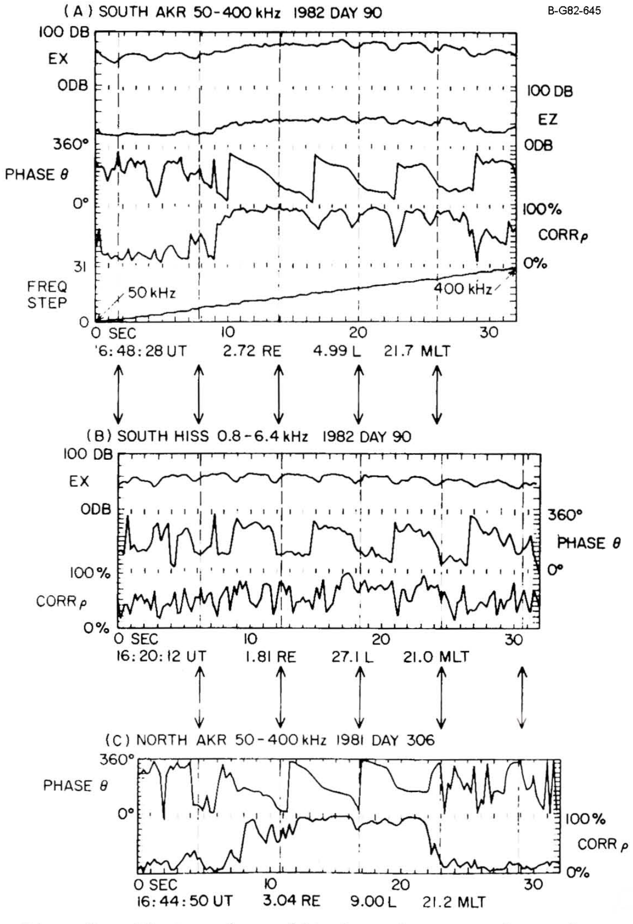

Fig. 3 Plots of amplitude, phase angle and correlation for (a) southern hemisphere AKR, (b) southern hemisphere auroral hiss and (c) northern hemisphere AKR.

Using horizon sensors the spacecraft detects the nadir direction $\vec{N}$ which occurs 75° before the EX antenna is perpendicular to the nadir vector (which is approximately parallel 10° to the local magnetic field vector $\vec{B}$). The optimum orientation for polarization measurements occurs when EX and EZ are perpendicular to the direction of wave propagation which is approximately parallel to $\vec{B}$.

Polarization Results

In Figure 3a is a 32 second sample of AKR when the spacecraft was located above the southern auroral region on 1982 Day 90. This AKR is seen on the spectrogram of Figure 1. One of the four SFR receivers logarithmically sweeps in frequency from 50 kHz to 400 kHz over 32 seconds with a 1 second hold on each of the 32 steps as indicated in the FREQ STEP panel. Independent of frequency, the EX response shows nulls of 20 dB or greater as the EX antenna spins approximately parallel to the magnetic field direction as expected for electromagnetic waves. Amplitude on EZ is less but the correlation is nearly 100% between second ticks 9 and 29. The phase angle variation between nadir marks (vertical lines) shows a consistent pattern of ~ 90° just after nadir switching to ~ 270° after one-half spin.

Only the right hand polarization mode can exist for whistler mode waves in this frequency range above the ion cyclotron frequency (45 Hz maximum) and below the lower of the electron plasma frequency (~ 100 kHz) or electron gyrofrequency (~ 90 kHz)--see Stix (1962). Consequently, the phase change for a whistler-mode wave such as the auroral hiss in Figure 3b defines the phase change with spin for a right hand polarized wave in the southern magnetic hemisphere. This hiss example in the frequency range of 0.8 to 6.4 kHz exhibits spin modulation and a phase change from ~ 90° just after the nadir to ~ 270° 1/2 spin later. Since this phase sense is known to be righthand, the AKR must also be righthand polarized.

For the case of AKR in Figure 3a at the condition that EX $\perp$ $\vec{B}$ at 75° after the nadir mark, the phases read 240°, 255°, 260°. One-half spin later the values become 80°, 90°, 100° respectively. The departure of 10°-15° from 270° and 90° expected for purely circular polarized waves can be due to a calibration bias still to be resolved or to the presence of weak radiation of the opposite polarization sense. A phase shift of 15° could be caused by a 2% (-35 dB) oppositely polarized component.

For plasma waves the polarization sense is defined by the direction which electrons gyrate around the magnetic field--right hand polarized or the direction that ions gyrate--left hand polarized (Stix, 1962). This apparent direction reverses between the southern and the northern magnetic hemisphere as illustrated in Figure 3a and 3c. The phase and correlation plot for 1981 Day 306, a northern hemisphere case, in Figure 3c is compared to the 1982 Day 90 southern hemisphere case of Figure 3a. These records have been aligned according to the nadir crossings to emphasize the phase differences (see vertical arrows). The S-hemisphere case in Figure 3a shows a 90° level after the nadir with a shift to 270° 1/2 spin later. The N-hemisphere case exhibits the opposite phase--first 270° after the nadir, changing to 90°. Since B is reversed, AKR is in the R-X mode in the northern hemisphere, too.

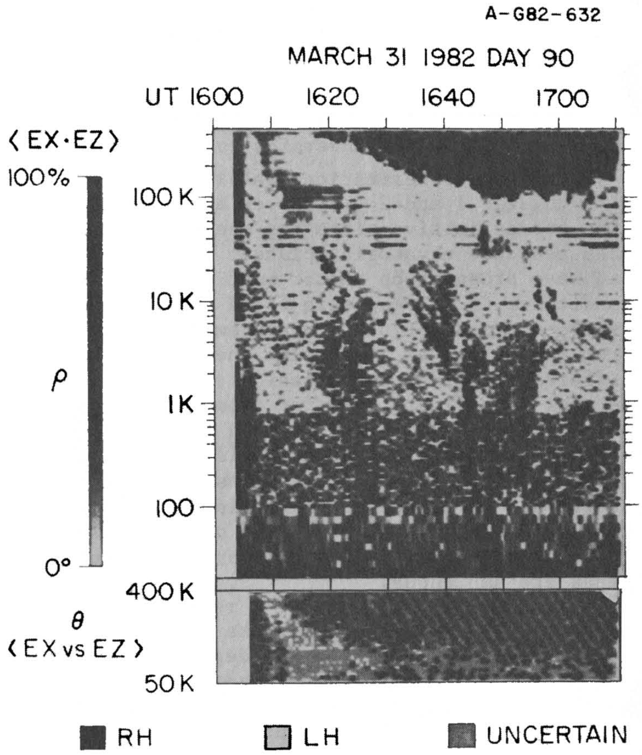

Fig. 4 Correlogram and phase spectrogram in which AKR appears highly correlated and right-hand polarized (black) above 100 kHz.

The ρ ⟨EX • EZ⟩ correlogram and the Θ (EX vs EZ) phase spectrogram are shown in Figure 4 for a 90 minute segment of 1982 Day 90. The dark regions of the correlogram indicate the frequency-time domains in which the phase results are reliable. The phase spectrogram is coded black if all the conditions for a right hand wave (R-X) mode are met--90° ± 75° in the 1/2 spin period just after the nadir mark and 270° ± 75° for the second 1/2 spin period in the southern hemisphere. Uncertain phase values are coded gray and left hand polarized values for L-O waves are coded as white.

For periods and frequencies of high correlation, the AKR and hiss exhibit the predominately R-X mode polarization which is consistent with the selected results of Figure 3.

Discussion

The DE-1 AKR polarization results agree with previous observations using propagation cutoffs by Gurnett and Green (1978), Benson and Calvert (1979) and James (1980) and with direct polarization measurements of Kaiser et al. (1978). However, Oya and Morioka (1982) point out that these measurements do not exclude the possibility that emission at the source is in the Z-mode which converts to the L-O mode for escape from the magnetosphere. For example, the propagation cutoff technique is not definitive since Oya and Morioka (1982) demonstrate that the Z-mode wave can appear to be cut off near the local electron gyrofrequency which is also the R-mode cutoff for the observed case that the plasma frequency is much less than the gyrofrequency. Consequently, the waves cut off at the R-mode cutoff could either be R-X mode waves *or* Z-mode waves before conversion to L-O mode waves.

The direct polarization measurements made with Voyager 1 and 2 (Kaiser et al., 1978) are also not definitive since the measurements were made near the equatorial plane. In this case the wave propagation vector must be nearly perpendicular to the magnetic field direction which is non-optimum for phase measurements; sources from just above to just below the equator have different apparent polarization. Also, since Voyager 1 and 2 are very far from the source regions (~ 100 R_E) Oya and Morioka (1982) argue that the measured polarization is not necessarily the polarization of the emission at the source due to a changing magnetic field direction between the source and the observing location. Consequently, even the Voyager measurements are ambiguous.

Measurements made with DE-1 resolve the ambiguities cited by Oya and Morioka (1982). Polarization determinations do not depend on cutoff frequencies; the direct polarization measurements can distinguish between R-X, L-O and Z-mode waves. DE-1 measurements are on auroral field lines just above the source region where the wave vector is very nearly parallel to the local $\vec{B}$ vector and parallel to the $\vec{B}$ vector in the source region. Consequently, there is no polarization ambiguity as with Voyager near the equator or with a possible change in $\vec{B}$ direction as with Voyager far from the source. The consistency of the magnetic vector dependence is borne out by DE-1 measurements in both the southern and the northern hemisphere. In addition the sense of polarization is determined absolutely by comparison with known right hand polarized whistler-mode hiss.

Oya and Morioka (1982) conclude from observations with EXOS-B and deduced propagation mode cutoffs that the L-O mode is present in AKR although the R-X mode may also exist. It has been noted that the DE-1 measurements are consistent with a left hand polarized component at the 2% power level. Gurnett et al. (1982) show examples in the DE-1 spectrograms of Z-mode bands especially at latitudes above the auroral zone; L-O mode radiation could be present also. It is suggested that EXOS-B may see the weaker L-O radiation because the radiation penetrates into the plasmaspheric region where EXOS-B orbits whereas the stronger R-X radiation is refracted out of the plasmasphere--the plasmapause may act as a mode filter. This hypothesis can be tested with further analysis of the DE-1 polarization data at the plasmapause.

Acknowledgements. We wish to thank Miles Bailey, Dan Odem and Richard Huff for their effort in designing, testing and calibrating the correlating SFR system. We also thank Richard Huff for his many hours at the DE Sigma-9 terminal to process and display the polarization data. This research is supported by NASA/GSFC Contract NAS5-25690.

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(Received June 1, 1982;
accepted August 12, 1982.)