AKR SOURCES POSITIONS - INTERBALL-2 VS CLUSTER OBSERVATIONS

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Abstract

Interball-2 (Auroral Probe) Polrad triaxial spectropolarimeter was used to determine positions of AKR source footprints on the auroral oval. Our findings are consistent with AKR beams narrowly confined to a plane tangent to the source magnetic latitude circle and containing the local magnetic field vector, in agreement with Mutel et al. [2008]. Our approach is based on dynamic spectra data analysis on much longer time scale of two-minute moving averages, as compared to AKR microbursts tens of milliseconds long analyzed by Mutel et al. We show detailed AKR visibility maps for a given position of the spacecraft - that allow determination of both the azimuth and elevation of the AKR beam in question for every measured AKR source position. For long data runs of the order of one hour we see apparent motion of the AKR sources as measured by Polrad, following spacecraft motion along the orbit in such a way, that the spacecraft remains within the radiation beam obeying geometric constraints reported by Mutel et al.

1 Introduction

Auroral Kilometric Radiation (AKR) beaming pattern was subject of investigations since many years. Statistical analysis of the data led to two basic models proposed as an explanation of observations: AKR radiation confined to filled [Green, 1977; Green and Gallagher, 1985] or hollow emission cones [Calvert, 1981; 1987]. Cyclotron maser instability (CMI) widely accepted as AKR generation mechanism favors effective generation of X mode close to the local electron gyrofrequency at the source [Wu and Lee, 1979; Treumann, 2006]. That implies upward AKR refraction and explains limited spatial extent of the AKR beam. AKR is generated in thin cavities extended in longitudinal direction and characterized by low electron density (as compared to the surrounding plasma). Louarn and Le Quéau [1996a, 1996b] deduced from theoretical reasoning and Viking V4H experiment data possibility of AKR beaming parallely with respect to longer longitudinal cavity dimension. Using more recent data from FAST mission, accompanied by numerical

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simulations of AKR generation in the auroral cavity, Pritchett et al. [2002] found that AKR beaming “along the track” tangent to the auroral oval is much more probable than beaming perpendicular to the oval. Schreiber [2005] found, that some structures in the AKR dynamic spectra can be produced by spatially limited radiation beams.

2 Tangent Plane Beaming Model

Quite recently Mutel et al. [2008] showed that AKR beams are strongly confined (within $\pm 20°$) to a plane containing the magnetic field vector at the source and tangent to a circle of constant latitude. Observations of four Cluster mission spacecraft in the VLBI mode were used for localization of the AKR source footprints on the auroral oval [Mutel et al., 2003; Mutel et al. 2004], assuming rectilinear propagation from the source. Rays are strongly refracted upwards on the first $100 - 200$ km of their path [de Feraudy and Schreiber, 1995; Schreiber et al., 2002; Mutel et al., 2008], and average refraction angle attains values between 70° and 80° [Mutel et al., 2008]. Mutel et al. results are based on measurements of single “elementary“ AKR sources beams and are not contaminated by summing of contributions from many such sources, as happens for the swept-frequency receivers integrating AKR signal over frequency and time. Within the frame of the tangent plane beaming model for a given spacecraft location only small part of the auroral oval can be sampled. AKR rays reaching spacecraft location must fulfill geometric constraints imposed by the model.

3 Interball-2 Observations - Direction Finding

Interball-2 was launched on 29 August 1996 with apogee altitude equal 19140 km, perigee altitude 772 km, and inclination to the equator 62.8°. The Polrad spectropolarimeter was operating within the frequency range 4 kHz - 1 MHz with sweep duration 6 or 12 s, and frequency resolution 4 kHz. Nine channel receiver measured all four Stokes parameters of the radiation. Antenna system consisted of two crossed dipoles (22 m each) and 1 monopole (11 m) perpendicular to the crossed dipoles plane.

In our paper we applied already established direction finding method [Panchenko, 2003]. It is based on measurements of the electric field component intensities of the incoming wave received on the three Polrad orthogonal antennas with assumption that the AKR is fully circularly polarized radio emission originating from a point source. Assuming that AKR observed at a frequency f originates at altitude, where the local electron gyrofrequency f_c is equal to f, the magnetic field line passing through the source is found from intersection of the direction vector of wave arrival with surface $f = f_c$ determined from IGRF geomagnetic field model. The source position is subsequently recalculated in coordinates of magnetic local time (MLT) and dipole invariant latitude. Single position was determined for every frequency sweep in 50 kHz frequency window. For satisfactory positioning of the AKR source on the auroral oval we performed signal analysis in the windows 10 min long and 50 kHz wide using two-minute moving average smoothing of the single positions. In this paper we present results for AKR storm observed on December 16, 1996 (1600 - 1700 UT) - Fig.1.

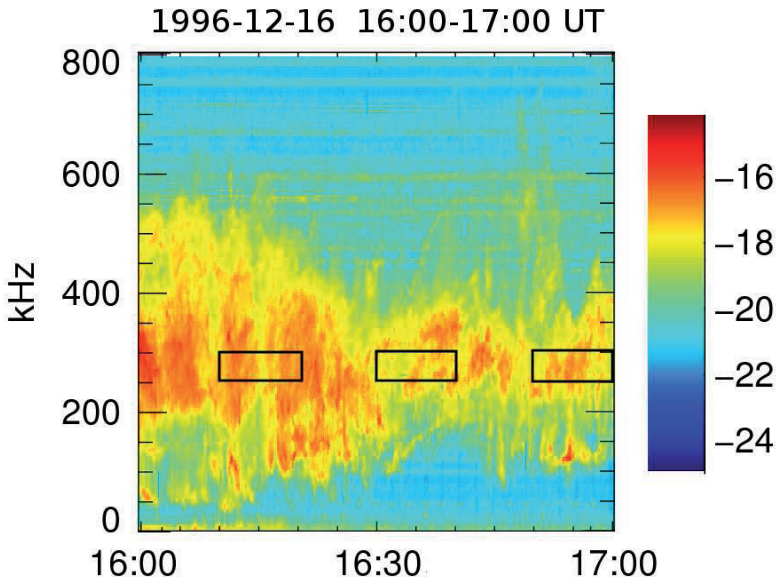

Figure 1: Dynamic spectrum of the AKR storm taken by Interball-2 Polrad experiment on December 16, 1996, intensity scale in log($Wm^{-2}Hz^{-1}$), boxes correspond to the data windows.

4 AKR Visibility Maps and Results

Mutel et al. [2008] introduced joint "visibility maps". For assumed AKR beam size geometry they calculated loci of all hypothetical AKR source footprints on the polar oval, which can simultaneously illuminate all four spacecraft. In this paper we propose AKR visibility maps for a single spacecraft with no assumptions about beam geometry. For a given time and satellite position in the magnetic coordinates and for fixed electron gyrofrequency at the AKR source we calculate emission and azimuth angles for a broad bunch of magnetic field lines covering part of the hemisphere 40° wide (50° invariant latitude to the magnetic pole). The emission angle (90° - refraction angle) is measured from the line tangent to the source magnetic field line, and the azimuth angle from the plane tangent to the auroral cavity. Mapping these angles onto invariant latitude - MLT coordinates gives a detailed picture of the emission geometry of possible AKR sources on the auroral oval. Emission angles confined to [0°,90°] interval correspond to the full range of the refraction possible for AKR R-X mode, while azimuth intervals [0°,+180°] and [0°,−180°] cover all possible azimuth angles. Tangent plane beaming model favors regions between successive +20° and −20° or +160° and −160° lines. Maps are produced in magnetic dipole coordinates and are calculated on the basis of the exact analytical solution. Using our maps we can determine current geometric parameters of the AKR beam hitting the spacecraft. For three cases presented here, determined positions of the AKR sources fall within the azimuth range $\sim \pm 20°$ with respect to the plane tangent to the auroral oval (Fig.2, Fig.3, and Fig.4), confirming results of Mutel et al. [2008]. Shift of the apparent positions of AKR sources, clearly seen in the subsequent figures, can be interpreted as a result of the spacecraft movement along its orbit. Our emission angles are also in agreement with Mutel et al. findings.

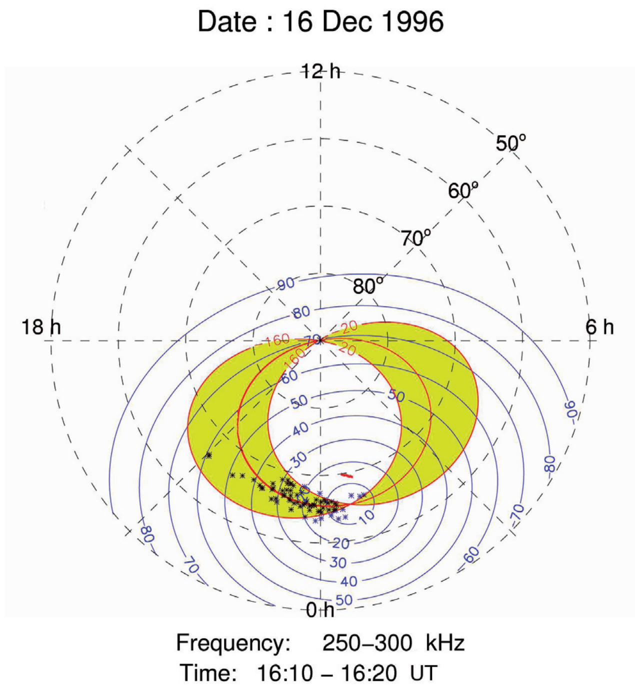

Figure 2: AKR visibility map for 1610-1620 UT time interval. Gray area corresponds to ±20° AKR beam deflection from the plane tangent to the auroral oval, solid circles mark deflection of the beam from the direction tangent to the local magnetic field direction in the AKR source (emission angle equal to 90° - refraction angle). AKR frequency is chosen equal to 275 kHz. Black streak represents spacecraft positions for ten minutes time interval. Black asterisks represent single AKR source positions.

Cluster/VLBI measurements isolate single AKR bursts while Polrad integrates signal in the specified time-frequency window. Since the vector direction method needs long averaging periods, it can not spot individual AKR bursts.

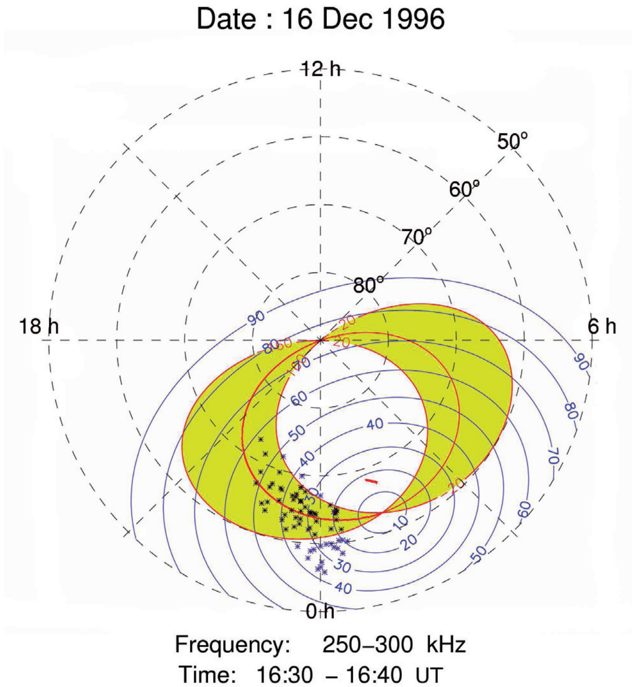

Figure 3: AKR visibility map for 1630-1640 UT time interval.

5 Conclusions

AKR source positions have been derived for a case of an AKR storm on Dec. 16, 1996 with an Interball-2/Polrad spectropolarimeter, using a method of direction finding [Panchenko, 2003]. The determined source directions are consistent with Cluster/VLBI findings [Mutel et al., 2008] regardless of different approaches to the position determinations. Like in case of Cluster/VLBI the determined AKR source projections on the auroral oval are distributed roughly within ±20° around the plane tangent to the source magnetic latitude circle and containing the local magnetic field vector. This result confirms the Mutel's model of radio emission beamed in directions nearly tangent to the source magnetic latitude circles. A tendency of AKR apparent source positions to follow the spacecraft movement along the orbit can clearly be seen as well. Refraction angles are also in agreement with Mutel et al. findings.

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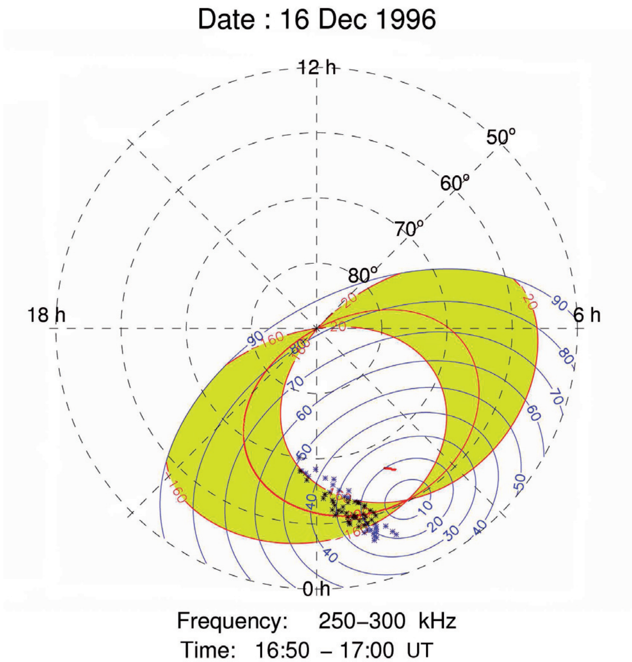

Figure 4: AKR visibility map for 1650-1700 UT time interval.

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