*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-2.088 (2007)*

Experimental and numerical investigations of mechanisms for Auroral Kilometric Radiation

S.L. McConville[1], D.C. Speirs[1], K. M. Gillespie[1], R. Bingham[1,2], K. Ronald[1], A.W. Cross[1], A.D.R. Phelps[1], C.W. Robertson[1], C.G. Whyte[1], R.A. Cairns[3], I. Vorgul[3] and B.J. Kellett[2]

[1] *SUPA Department of Physics, University of Strathclyde, Glasgow, G4 0NG, Scotland*

[2] *Space Physics Division, CCLRC, Rutherford Appleton Laboratory, Didcot, OX11 0QX, England*

[3] *School of Mathematics and Statistics, University of St. Andrews, St. Andrews, KY16 9SS, Scotland*

Introduction

Magnetic field lines at the Earth's poles create regions of increasing field which magnetically compresses electrons as they descend towards the ionosphere. This produces a horseshoe shaped distribution function in velocity space which has been observed by satellites [1]. Research has shown this distribution to be unstable to a cyclotron maser type instability [2] and the emitted radiation is observed to be polarised in the extraordinary mode. We present results of experimental and computational investigations [3] of radiation emissions from an electron beam with a horseshoe distribution in velocity space to compare with the astrophysical observations. Results are presented using an electron beam of energy 75keV with a cyclotron frequency of 4.45GHz and 85keV and 11.7GHz frequency, compressed using magnet coils to mimic the naturally occurring phenomenon. The radiation output from the experiment which was observed to be close to the cyclotron frequency and electron transport measurements confirmed that the horseshoe distribution function was obtained. Experimental measurements of the antenna pattern radiated from the output window allowed the TE mode structures excited by the beam to be analysed demonstrating the radiation to be polarised and propagating perpendicular to the static magnetic field and the efficiency was estimated to be ~2% in close agreement to the predictions of the 2D and 3D versions of the PiC code KARAT. The efficiency was also comparable with estimates of the astrophysical phenomenon.

Method and Apparatus

To investigate the driving mechanisms believed to cause the process of auroral kilometric radiation in a controlled environment, use has been made of the fact that the theoretical models of the beam wave interaction process predicts that the process scales with the

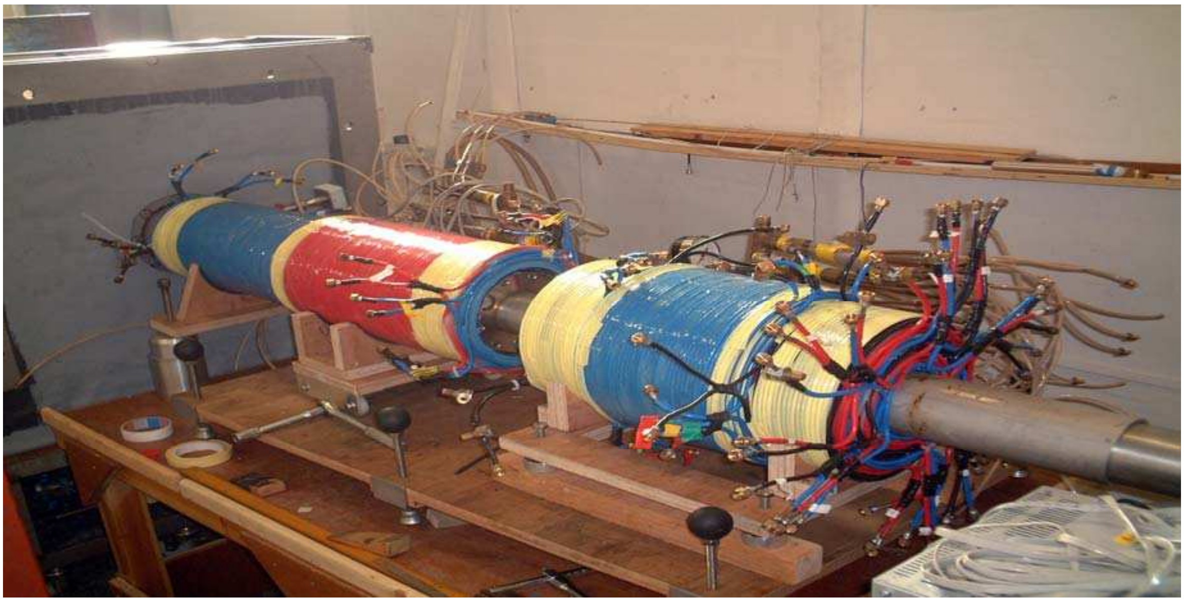

Figure 1: Photograph of the experimental apparatus in the laboratory

cyclotron frequency. Since it is possible to produce large volume magnetic fields of around 0.75T in the laboratory with simple and configurable water-cooled electromagnets, it is feasible to scale the phenomenon to the microwave frequency range and build an experimental apparatus. In the apparatus, figure 1, electrons were injected from an accelerator designed to produce an initial spread in electron velocity distribution placed in a low fringing field of the solenoid system and experience a strong increase in the magnetic flux density (up to a factor of 30 in magnetic mirror ratio) as they are transported into a region where they interact with a microwave field. The progressive magnetic compression of the beam mirrors the auroral behaviour and the radiation resonance is arranged to be with near cut-off TE modes as these have similar polarisation and propagation properties to the X-mode. Electron

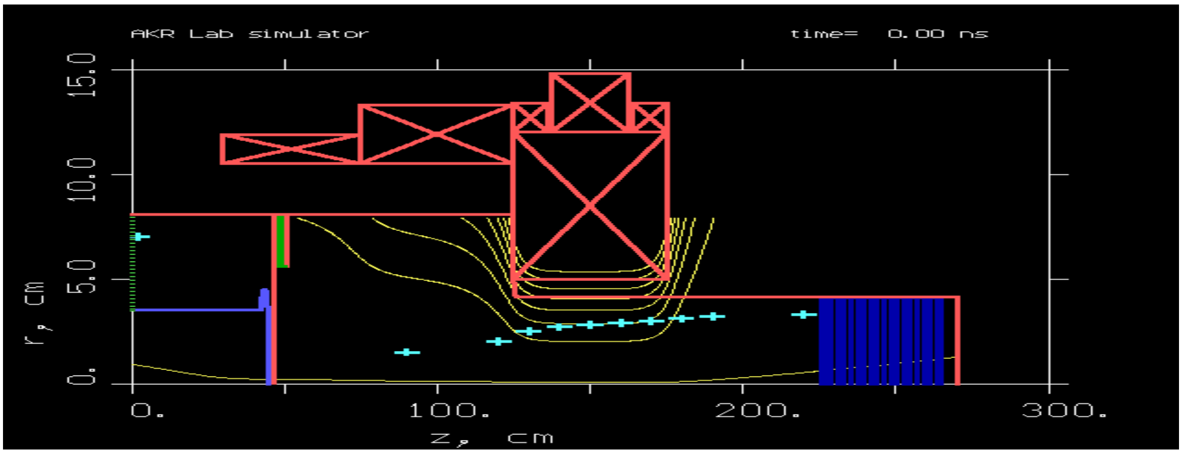

Figure 2: KARAT representation of the geometry in 2D showing electron accelerator, magnetic field solenoids and flux lines

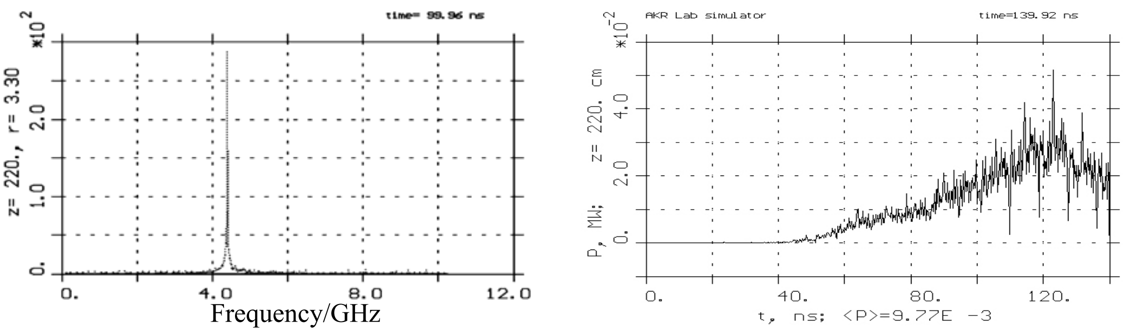

Figure 3: Results from 2D simulations in KARAT of the spectral and temporal structure of the output radiation

beam voltage and current were measured using a combination of shunt resistors, Rogowski belts and Faraday cups. The electron velocity distribution was measured using a Faraday cup downstream of the peak magnetic field and exploiting the process of progressive magnetic mirroring as the mirror ratio was adjusted. Microwave output power was measured using calibrated rectifying receivers in the far field of the output antenna and integrating over the antenna patterns. The radiation spectrum was measured by a combination of FFT of a directly captured AC waveform and the use of waveguide cut-off filters.

The beam transport system of the experiment was designed with the aid of the 2D PiC code KARAT, figure 2, and this code has also been used to simulate the beam wave interaction with $TE_{0,n}$ radiation modes, figure 3. More detailed analysis of the interaction dynamics have also recently been undertaken with the 3D version of KARAT, figure 4(a).

Results

The experiment has been operated in two regimes, one at 4.45GHz resonance with the near cut-off $TE_{0,1}$ mode of the 8.28cm diameter interaction space of the apparatus and the other at 11.7GHz near the cut-off of the $TE_{0,3}$ mode. In both cases the radiation frequency, mode content (see figure 4(b)) and power were analysed and the beam current measured. The results were found to be in good agreement with the numerical simulations. The lower frequency resonance allowed the mapping of the electron line density in velocity pitch angle and the variation of the output power with this density was measured. The 2D PiC simulations were adjusted to produce comparable line density distributions and yielded reasonable agreement with the radiation power, efficiency and spectrum. The lower frequency experiment illustrated harmonic output not predicted by the 2D simulations, but with the implementation of the 3D simulations it is now possible to demonstrate this behaviour numerically. The high frequency experiments had a complex radiation spectrum and strong evidence of mode competition.

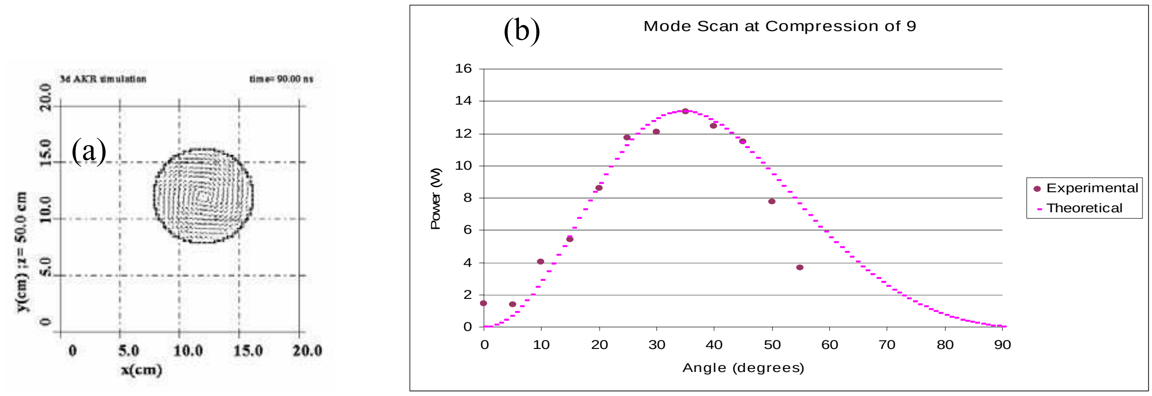

Figure 4: (a) 3D simulations in KARAT of the 4.45GHz mode structure of the apparatus and (b) the antenna pattern measured from the experiment

This was also simulated in the 3D simulations since they can account for modes with azimuthal structure.

The powers and efficiencies, spectral content and polarisation and propagation behaviour of the radiation predicted by the simulation codes are in good agreement with those obtained in the experiment, and they are also comparable with the auroral behaviour. This appears to confirm the energy source for the phenomenon of auroral kilometric radiation to be the transverse motion of the earthbound auroral electron flux.

Acknowledgements

This research was supported by the EPSRC and the STFC centre for fundamental physics. Thanks are due to Mr. I.S. Dinwoodie for making the apparatus and Prof. V.L. Tarakanov for advice with the PiC codes.

References

[1] J. Strangeway et al, “FAST observations of VLF waves in the auroral zone: Evidence of very low plasma densities”, Geophys. Rev. Lett., 25, 2065-2068 (1998).

[2] I. Vorgul et al, “Analysis of a cyclotron maser instability in cylindrical geometry”, Physics of Plasmas, 12, 1-8, (2005).

[3] D.C. Speirs et al, “A laboratory experiment to investigate auroral kilometric radiation emission mechanisms”, Journal of Plasma Physics, 71, 665-674, (2005).