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A laboratory experiment to investigate auroral kilometric radiation emission mechanisms

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Introduction

If an initially mainly rectilinear electron beam is subject to significant magnetic compression the conservation of the magnetic moment results in the ultimate formation of a horseshoe distribution in phase space. A similar situation occurs where particles are accelerated into the auroral region of the earth's magnetic dipole. Such a distribution has been shown to be unstable to a cyclotron resonance maser type of instability and it has been postulated that this may be the mechanism required to explain the production in these regions of auroral kilometric radiation (AKR) and also possibly radiation from other astrophysical objects such as stars with a suitable magnetic field configuration [1,2]. In this paper we describe a laboratory experiment to investigate the evolution of an electron beam subject to a magnetic compression of up to a factor of 30.

Experimental Configuration

Figure 1 shows the design of the apparatus. A large diameter stainless steel anode tube encompasses the centrally located co-axial cathode. A velvet ring is secured to the face of the cathode and provides electron emission as a result of the plasma formed on the tips of the velvet material when energised by a 50kV pulse from a Blumlein power supply. A low, fringing, magnetic field is generated by solenoid 1 and ensures that the electrons have a spread in their pitch factors (as the angle presented by the cathode to the magnetic field lines is a function of the radius). The electrons are subject to compression as they pass through coil 1 into coil 2 and reach the maximum of the magnetic field in the centre of coil 3. The variation of the axial component of the magnetic field on the axis of the experiment was calculated using a Maple programme and is illustrated in figure 2. The Maple programme was also used to fine tune the coil configuration with the addition of shimming coils to obtain a long plateau region whilst minimising the power drive required for the coil assembly (approximately 60kW).

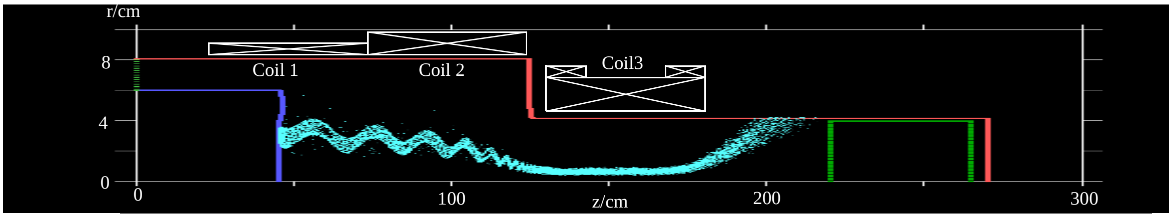

Figure 1: *Configuration of the experiment as described in KARAT, colour scheme, anode:red, cathode:blue, magnets:white, RF absorber:green, macro-electrons:cyan*

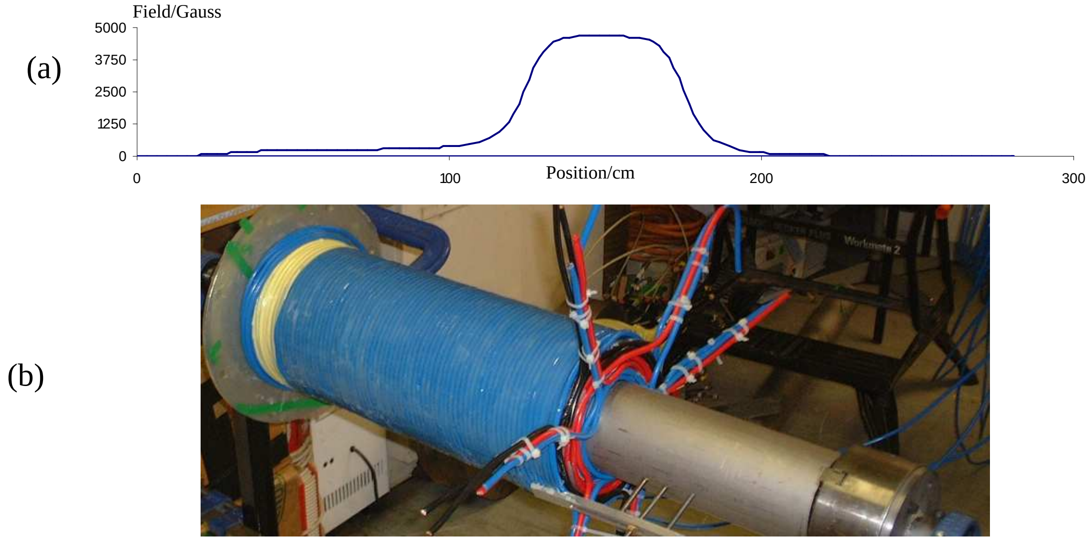

Figure 2: *(a) Calculated axial magnetic field used by KARAT for Div.B expansion, (b) photograph of coil 3 on the winding jig at the halfway point of construction*

Numerical Simulations

To simulate the experiment the time dependent PiC code KARAT has been used. The simulation was given the dimensions of the vacuum vessel and electrodes and the axial magnetic fields estimated by the Maple code. It calculated the magnetic field over all of space based on a Div-B expansion and self-consistently simulated the space charge limited emission of the electrons from the cathode under the action of the applied electric field (50kV between cathode and anode) giving a beam current of 12A. The geometry is illustrated in Figure 1. Using the 2D implementation of the code gave fast execution for a given accuracy of the model and because of the R-Z symmetry of the apparatus produced very illustrative phase space plots. As the electron beam passed into the smaller diameter region, EM waves are excited as it undergoes resonance with the near cut-off modes of the cylindrical waveguide, in this case the $TE_{0,3}$. Figure 3 illustrates the transverse against axial velocity of the electron beam at two positions along the experimental axis and shows the horseshoe distribution function as the electrons propagate into the high magnetic field region. As the interaction progresses one can see the filling in of the horseshoe distribution as transverse energy is extracted from the electrons.

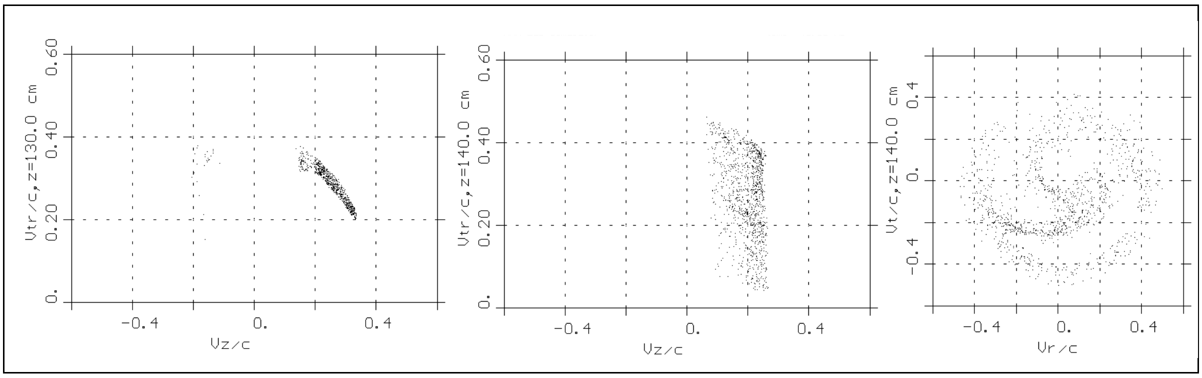

Figure 3: *Evolution of the electron velocity phasespace ($v_{tr(ansverse)}$ against $v_{z(axial)}$ and $v_{t(heta)}$ against $v_{r(adial)}$) as the horseshoe distribution interacts with the RF wave after 40ns*

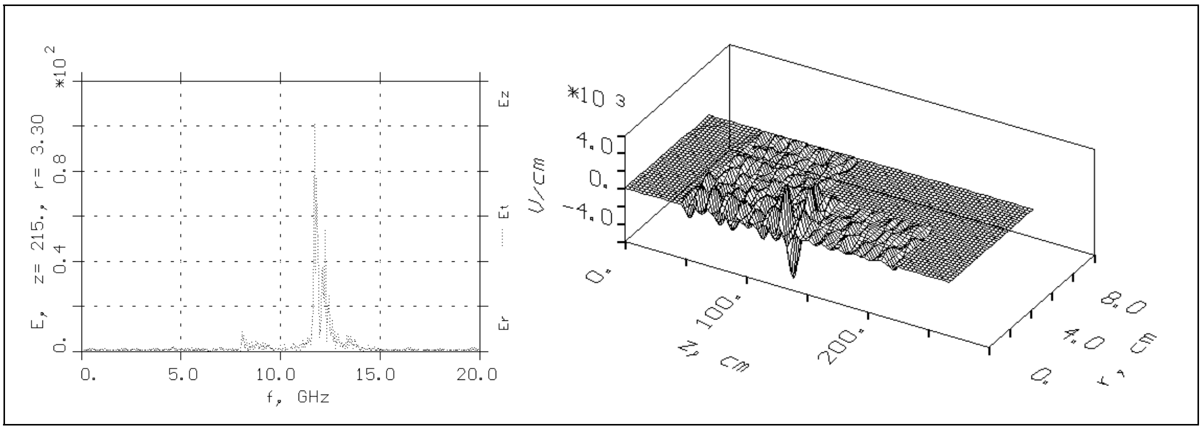

Figure 4: *Spectrum of RF emissions from the electron beam and plot of the theta component of the electric field showing the excitation of the near cut-off $TE_{0,3}$ mode after 50ns*

Figure 3 also shows the azimuthal and radial components of the electron velocity during the interaction with the EM wave. Initially fairly evenly distributed, the RF interaction impacts on their energy and thus their cyclotron frequency resulting in bunching of the electron beam. Deceleration of the bunches as shown in the $v_r/v_{t(heta)}$ distribution yields energy to the EM wave. Phase trapping occurs rapidly, a feature that can be compared with the short 5-10cm axial e-folding gain length predicted in our recent theoretical work [3]. Figure 4 shows the azimuthal electric field distribution in the radial and axial ordinates and the spectrum of the emitted radiation, close to the cyclotron frequency and the cut-off of the operating $TE_{0,3}$ mode wave.

Experimental work in progress

The magnet solenoids have been wound (figure 2b) from thick wall, insulated, 7mm diameter OFHC copper tubing and will be cooled by water driven through the tube core at a pressure of 25Bar. Fabrication of the vacuum envelope has been completed and it has been evacuated to a pressure ~ 10^{-6}mBar. Experiments will shortly commence with the electron beam. The authors will study the electron beam current as a function of the degrees of magnetic compression and pitch angle spread which will be varied both by axial adjustment of the cathode location and the current flowing in the magnet solenoids. The electron beam parameters will be measured using a copper sulphate solution voltage divider and a Rogowski belt to determine the beam energy and total current and the beam propagation into the plateau region will be measured by means of a beam-intercepting Faraday cup feeding a current shunt monitor installed in the centre of the interaction space with an assistant solenoid wound with short length cable to provide a large and adjustable magnitude of mirroring field. Theory and simulation predict that the experiment will generate radiation at or close to the cyclotron frequency of the electron beam. This radiation will be measured by launching it out of the end of the 8cm diameter tube and studying it with WG18 cut-off filters and spectrometers, rectifying diodes and by monitoring the output antenna pattern.

Summary

An experiment to investigate the mechanism of auroral kilometric radiation has been devised by scaling to centimetric wavelengths and laboratory dimensions. A magnetic field configuration has been created offering a compression ratio of up to 30. The apparatus has been simulated numerically using the PiC code KARAT which has demonstrated that in spite of the non-adiabatic compression necessitated by the laboratory scale dimensions and the practical limits of the magnetic system, the required horseshoe distribution of the electron phase space is still generated. The simulations show ECM type behaviour in the interaction with near-cut-off waveguide modes at close to the cyclotron frequency. The construction of the experimental apparatus is nearing completion. One issue with the research is that the experiment is bounded by metallic surfaces, this is not the case in the auroral situation. The experimental results will therefore be compared with numerical simulations having reflective and non-reflective boundaries and with new theoretical work at St. Andrews on the instability behaviour in the presence of metallic boundaries [3].

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References

[1] R. Bingham and R. A. Cairns, Physics of Plasmas, 7, 3089, 2000

[2] R. Bingham, R. A. Cairns and B. J. Kellett, Astron. and Astrophys. 370, 1000, 2001

[3] I. Vorgul et al, these Proceedings, paper P2-077