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EXPERIMENTAL AND NUMERICAL SIMULATION OF AURORAL CYCLOTRON RADIATION MECHANISMS

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The phenomenon of Auroral Kilometric Radiation arises in the polar magnetosphere in regions of reduced background plasma density called the Auroral Density Cavity where the cyclotron frequency exceeds the plasma frequency by around an order of magnitude. The spectrum of the radiation (~300kHz) implies it is due to cyclotron instability in a non-thermal, highly energetic element in the electron population [1-5]. This population is accelerated towards the auroral zones of the ionosphere and as it descends it acquires an increasing component of rotational momentum due to conservation of the magnetic moment in the increasing magnetic field. Progress will be reported in an experiment [6, 7] which has been constructed to establish if there is sufficient free energy in the descending electron flux to explain the observed radiation power of up to 1GW requiring the unusually high efficiency for a natural phenomenon of around 1%. The experiment exploits the prediction of theoretical analysis that the process scales with the cyclotron frequency to increase the magnetic field to the range 0.1-0.5T to give cyclotron resonance in the experimentally convenient microwave regime. 2D and 3D simulations of the electrodynamics have also been undertaken. The experiments have realised an efficiency of a few percent depending on the exact configuration of the electron beam and the cyclotron detuning, in reasonable agreement with the astrophysical observations [8-10]. The simulations have also shown good agreement with the experiment, accurately predicting the efficiency and spectra, and in the case of the 3D calculations the polarisation modes of the radiation generated [11, 12]. The results are also in good agreement with the evolving theoretical understanding of the electrodynamics [13]. The results are therefore highly supportive of the postulate that the auroral kilometric emissions arise from cyclotron instabilities in the descending energetic electron population [14].

The scaled laboratory apparatus was based around a system of electromagnets, illustrated in Figure 1. The electromagnets were constructed in a series of six coils. Each coil consisted of

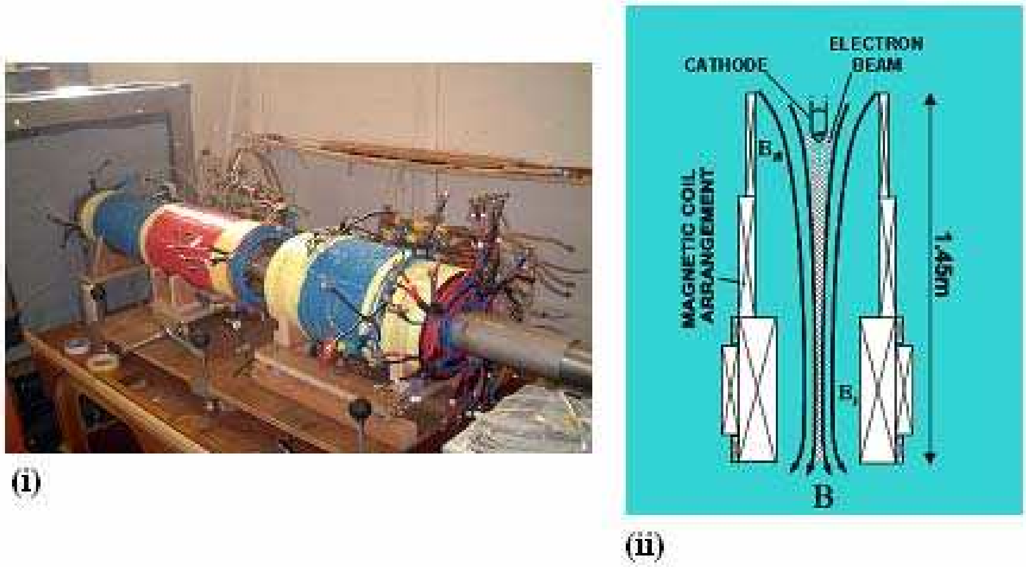
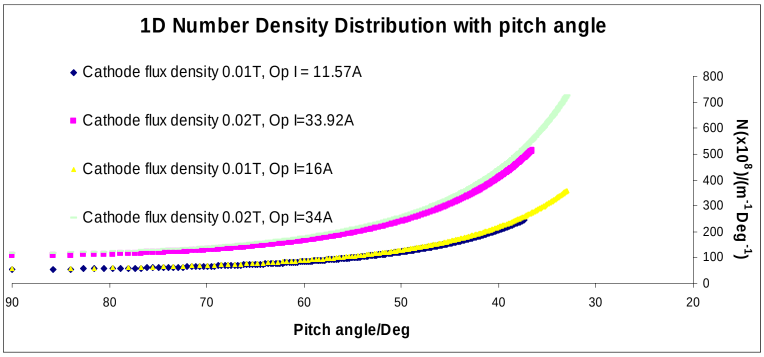


Figure 1:(i) Experimental and solenoid assembly (ii) Schematic of experimental apparatus.

an even number of layers wound to cancel any azimuthal components of the flux density. Figure 1(i) shows the experimental system of solenoids, whilst the apparatus is illustrated schematically in Figure 1(ii), here the electron beam being injected from the cathode is seen passing through the solenoids and being magnetically compressed. The electrons need an initial spread in pitch angle in order to produce a horseshoe distribution in the electron velocity distribution; this was achieved by placing the electron injector into the low, fringing, magnetic field of the electromagnets to ensure an initial spread in electron velocity and high magnetic mirror ratio [8].

High voltage pulses from the power supply caused electrons from the cathode to be emitted through field emission from the velvet fibre tips. The field emission led to the formation of a plasma cloud which provided for space charge limited electron emission [8]. As the magnetospheric EM emissions are polarised and propagate in the X-mode the electrons were brought to cyclotron resonance with TE modes of a waveguide co-axial with the solenoids. These modes have both the propagation and polarisation vectors normal to the waveguide axis and thus the static magnetic field and are therefore similar to the X-mode [10]. The experimental measurements demonstrating an electron beam with a velocity distribution comparable to those observed in the magnetosphere are illustrated in figure 2 [8, 9]. Such a beam was brought to resonance at 4.42GHz and 11.7GHz with the $TE_{0,1}$ and $TE_{0,3}$ modes of the cavity respectively. The resonant experiments have shown that electron kinetic energy may be converted to wave field energy with an efficiency of a few percent [9,10], and good agreement has been achieved with simulations of the 4.42GHz resonance when the electron



For cathode flux density 0.01T

Exp	Num
I_{out}=11.57A	I_{out}=16A
RF_{out}=19kW	RF_{out}=20kW

For cathode flux density 0.02T

Exp	Num
I_{out}=33.92A	I_{out}=34A
RF_{out}=35kW	RF_{out}=50kW

Figure 2: Illustration of the variation of electron density with pitch angle in bopth experiments (blue and magneta) and simulations for two different configurations of the electron injector; comparison of the predicted and measured RF output at 4.42GHz [9]

distribution functions match closely, figure 2 [9]. The radiation spectra were confirmed by capturing the microwave waveform in real time and transforming it whilst the output antenna pattern allowed the polarisation and propagation direction to be deduced. Figure 3 illustrates the antenna patterns produced when the experiment was tuned for resonance at 11.7GHz.

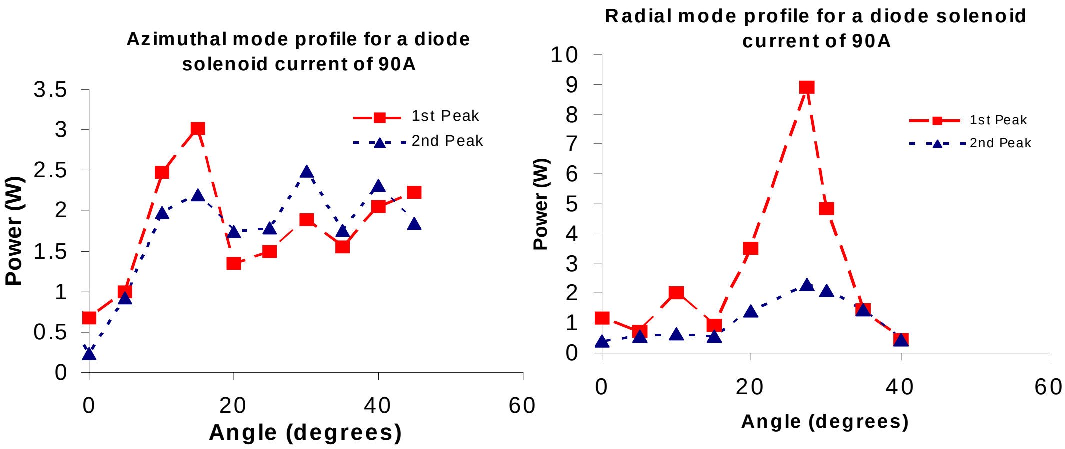


Figure 3: Antenna patterns recorded from the experiment when tuned for 11.7GHz resonance with a field of 0.03T on the cathode

The measured spectra and antenna patterns were consistent with the excitation of near cut-off TE modes, specifically the $TE_{0,1}$ mode at 4.42GHz and a mixture of the $TE_{0,3}$ and $TE_{2,3}$ modes at 11.7GHz frequency, figure 3. The high frequency measurements were confirmed with 3D PiC simulations which predicted these two modes would be strongly generated, figure 4

In summary both experiment and simulation successfully reproduced major aspects of auroral cyclotron emissions. Radiation emission efficiencies close to those observed in the

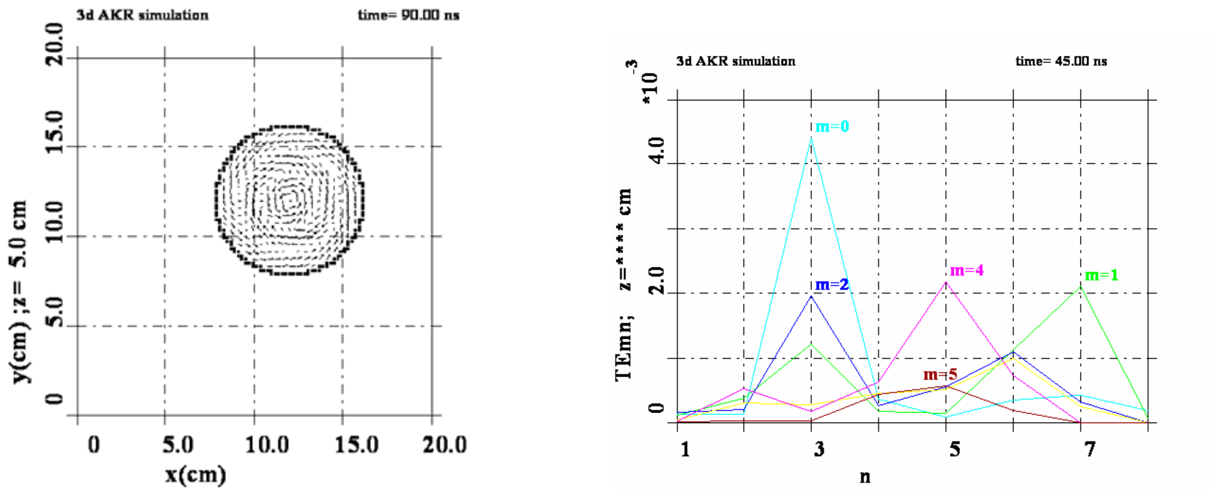


Figure 4: 3D PiC code predictions of the modes excited in the experiment at 11.7GHz showing the transverse E field pattern of a $TE_{0,3}$ mode and the spatial Fourier analysis of the modes excited showing strong generation of the $TE_{2,3}$ and $TE_{0,3}$ modes

magnetosphere confirm that these distributions have sufficient free energy to account for the auroral process. The modes excited in the experiment were consistent with propagation and polarisation of the EM waves perpendicular to the static magnetic field.

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