Modelling of the anomalous Doppler resonance for a laboratory experiment

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Abstract

The anomalous Doppler resonance is an instability that occurs due to coupling between an electromagnetic wave and a negative harmonic of the electron cyclotron frequency, as such this regime is only achievable in slow-wave media, including plasma.[1-2]

In magnetic confinement fusion experiments the generation of fast electrons by Lower Hybrid Current Drive can lead to the criterion for which the anomalous Doppler resonance is fulfilled.[3] A simulation of non-thermal electrons drifting at relativistic velocities along a magnetic field with a background plasma has been developed in the 3D Particle-in-Cell code VORPAL. By tailoring the fast electron distribution so that the number density decreases as the velocity of the electrons increases suppression of the two-stream and Cherenkov instabilities can be achieved. From these experiments indications of the anomalous Doppler instability have been observed.

An experiment to test the prediction of simulations is being developed at University of Strathclyde, with current work focussing on the production of energetic electrons to mimic the energetic tail critical to the anomalous Doppler instability. The results of the experiment will benchmark the code and be used to inform further simulations which will have parameters relevant to magnetic confinement fusion and astrophysical phenomena.

Background

The anomalous Doppler instability is the wave coupling regime in which the negative cyclotron harmonic of an electron and an EM wave interact. This is important when considering tokamaks where a tail distribution of superthermal electrons can be generated during the heating process. High energy electrons drift along a magnetic field interact with the field components of the wave, this results in an increase of gyrational energy but with a greater loss of translational energy. Providing the beam drift velocity exceeds the wave velocity, the pumping of the translational to rotational energy exceeds the dissipation of rotational energy by the *E* field.

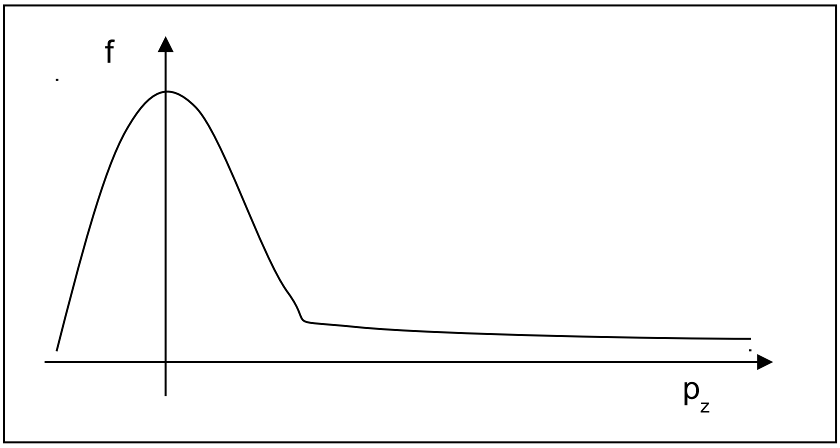

Figure 1: Electron distribution with super thermal tail

Electrons are retarded along the axis of propagation and move inside the constant energy contour as their transverse momentum grows. Energy extraction in this way can be efficient as no bunching is required before energy is extracted from the tail. The upper-hybrid mode provides a suitable EM wave for coupling of a high energy electron and the energy given up by this interaction may be absorbed by the bulk plasma.

Simulations

Numerical simulations of the tail distribution have been conducted using an idealised system using 3D particle in cell code VORPAL. A neutral PiC plasma is generated with 10% of the electrons forming a high energy tail in the z direction which also has a static magnetic field of 0.1T. The density of the tail electrons reduces as their velocity is increased with a maximum relativistic velocity of two thirds the speed of light.

Four separate distributions are defined to generate the tail to allow for more detailed analysis of the tail electrons. The system has periodic boundaries to keep a constant number of particles in the simulation, these are combined with perfectly matched layers to remove boundary conditions on EM waves moving through the periodic system.

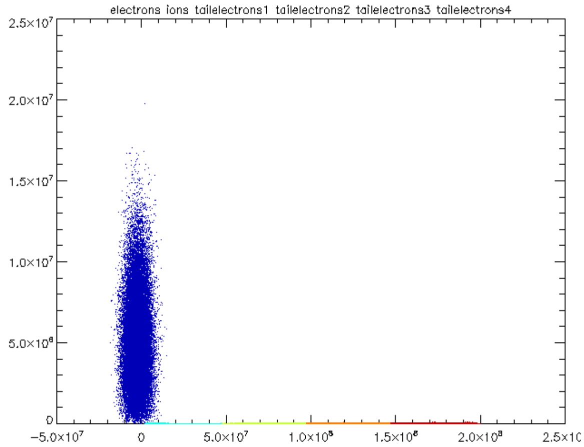

Figure 2: Initial velocity distribution of tail electrons, showing the bulk electrons and superthermal tail

Simulations have shown indications of the anomalous Doppler instability. The tail electrons lose momentum along z and gain perpendicular momentum. The energy of the tail distribution is reduced while the energy of bulk plasma is increased.

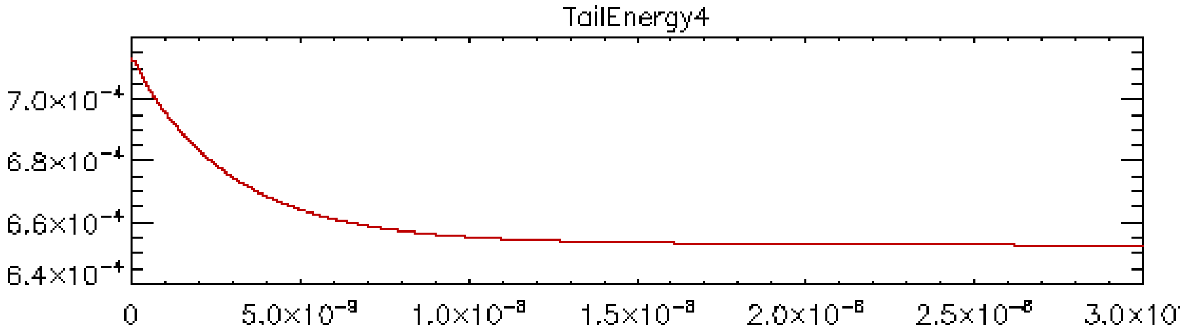

Figure 3: The energy of the fastest electrons in the tail distribution over time

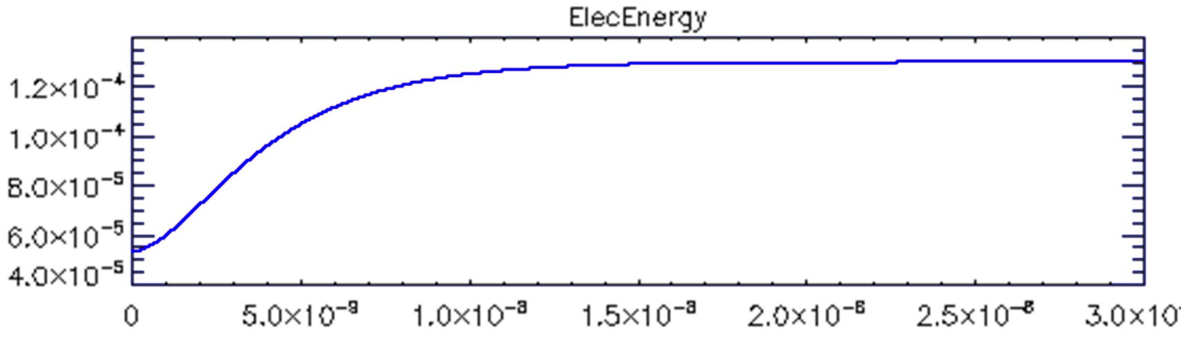

Figure 4: The energy of the bulk plasma electrons over time

Experiment

Building on previous work on auroral kilometric radiation (AKR) [4-10] an experiment will be conducted using a high energy electron beam injected into a partially ionised plasma contained in a penning trap. A magnetic field of 0.1T will be generated along the beam axis. An energy spread will be introduced into the high energy electrons to suppress other plasma instabilities such as the two stream instability.

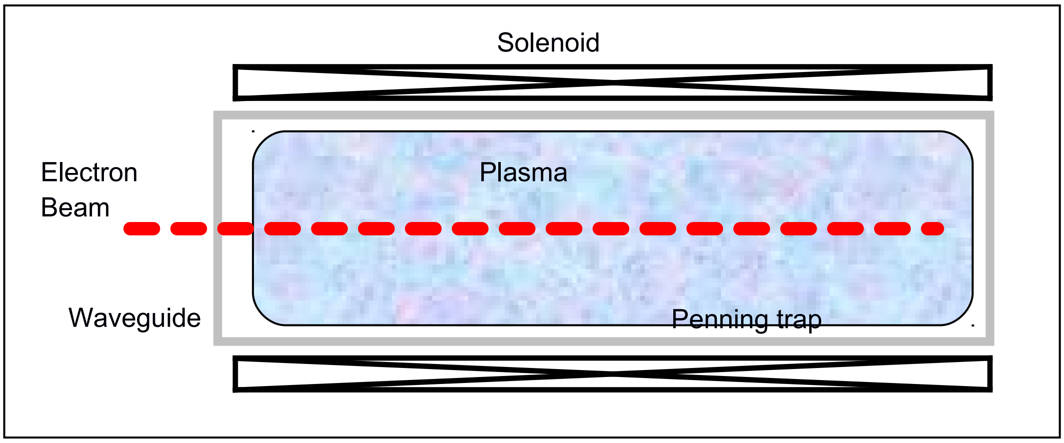

Figure 5: Diagram of experiment set up

Summary

Simulation work using 3D PiC code shows indications of the anomalous Doppler instability with an experiment under development to test these predictions.

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