Laboratory and numerical investigation of mechanisms for magnetospheric cyclotron emissions

K. Ronald*[1], D.C. Speirs[1], K.M. Gillespie[1], M. King[1], K. Matheson[1], S.L. McConville[1], A.D.R. Phelps[1], C.G. Whyte[1], C.W. Robertson[1], A.W. Cross[1], R. Bingham[1,2], M.E. Koepke[1,3], R.A. Cairns[1,4], I. Vorgul[4] & B. Kellett[2]

[1] SUPA & Department of Physics, University of Strathclyde, Glasgow, G4 0NG, Scotland (corresponding author, K.Ronald@strath.ac.uk)

[2]STFC Rutherford Appleton Laboratory, Harwell, Oxford, Didcot, OX11 0QX, England (corresponding author Bob.Bingham@stfc.ac.uk)

[3] Department of Physics, West Virginia University, Morgantown, WV 26506-6315, USA (corresponding author Mark.Koepke@mail.wvu.edu)

[4] School of Mathematics and Statistics, University of St Andrews, KY16 9SS, Scotland (corresponding author rac@st-andrews.ac.uk)

Abstract

Cyclotron coupling between electrons and waves is thought to occur in both polar and equatorial regions of the Earth's magnetosphere. The cyclotron emissions from an electron beam moving into a waveguide with an increasing magnetic field have been investigated in an experiment[1], scaled to microwave frequencies, supported by numerical simulation[2,3] and theoretical analysis, to reproduce aspects of the magnetospheric environment. Magnetic compression produces an electron distribution with a high, quantified, degree of velocity spread[4], as may be expected in the natural environment. The measurements[1,5] and simulations[2] indicate wave production efficiencies which are consistent with the magnetospheric observations and with theoretical predictions (typically ~ few %), preferentially polarised and propagating nearly perpendicularly to the magnetic field, at frequencies close to the cyclotron frequency (in the experiments between 2 and 11GHz)[5]. The effectiveness of the wave generation mechanism is shown to be mitigated by the addition of a quasi-neutral background plasma through the use of a Penning discharge (plasma frequency ~100-300MHz, reflecting the auroral density cavity ratio ω_{ce}/ω_{pe} ~10 or more[6]) in two distinct ways: The efficiency is reduced, whilst the emission acquires an increasingly variable nature, where nominally identical experiments can either generate strong cyclotron signals, or very weak signals indeed, suggesting alternative competing near-threshold mechanisms. Simulations have shown a similar effect on the wave production efficiency, but so far have not provided an explanation for the statistical variability where there are conditions where no radiation is generated at all. The project has also considered the generation of signals in radiation modes where the wavevector has a significant component parallel to the bias magnetic field. Strong wave emission continued to be observed close to (but slightly downshifted from) the cyclotron frequency, with the E-field polarised perpendicular to the bias B-field. These measurements may have relevance to the radiation belts. Simulations, benchmarked against the experiments, have been used to study cyclotron emissions from beams in unbound environments, particularly relevant to the polar magnetosphere[7,8], and these results will also be presented.

References

1. McConville, S. L. et al., 2008, Plasma Phys. Control. Fusion, **50**, art. 074010

2. Speirs, D. C. et al., 2008, Plasma Phys. Control. Fusion, **50**, art. 074011

3. Gillespie, K.M., et al, 2008, Plasma Phys. Control. Fusion, **50**, art.124038

4. Ronald K., et al, 2008, Plasma Sources Sci. Tech., **17**, art.035011

5. Ronald K., et al 2008, Phys. Plasmas, **15**, art.056503

6. McConville S. L. et al, 2012, Plasma Phys. Control. Fusion,**53**, art. 124020

7. Speirs D.C. et al., 2013, J. Plasma Physics, **79**, pp999-1001

8. Bingham R. et al., 2013, Space Science Rev., **178**, pp695-713