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ECE MEASUREMENTS USING DOPPLER-SHIFTED OBSERVATIONS

RODRIGUEZ L.; AUGE N.; GIRUZZI G.; JAVON C., LAURENT L.; TALVARD M.

Association Euratom-CEA, Centre d'Etudes Nucleaires de Cadarache,
13 - Saint-Paul-lez-Durance (FR). Dept. de Recherches sur la Fusion
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L. Rodriguez, N. Augé, G. Giruzzi, C. Javon, L. Laurent, M. Talvard

Association EURATOM-CEA sur la Fusion
DRFC - C.E.N. de Cadarache
13108 Saint Paul-lez-Durance (FRANCE)

1 Introduction.

Electron Cyclotron Emission (ECE) diagnostics are today routinely employed on various tokamaks to measure the electron temperature of thermal discharges because the plasma is optically thick at the second harmonic extraordinary mode. The frequency broadening arising from the magnetic field variation determines a direct relationship between plasma position and frequency.

ECE diagnostics are also used to study fast electrons. There is a strong interest focused on non thermal electron physics, correlated mainly with investigations of non inductive current driven by RF waves. When suprathermal electrons are present in the plasma the direct relation between frequency and position is lost. For standard ECE diagnostics with lines of sight in the mid-plane normal to the magnetic field, this is due to the relativistic shift. It is difficult to deduce directly the maximum energy of the electrons or their location (the power deposition profile) from the observed spectra. Therefore the interpretation of ECE spectra has to be done by appropriate simulation codes, in our case a 3-D Fokker-Planck code /1/ coupled to a radiation code /2/. However the result remains ambiguous.

More information can be obtained from several lines of sight, using both the relativistic shift and the Doppler effect. In the present paper, plasmas with both inductive and Lower Hybrid Current Drive are analysed with this technique.

2 Experimental set-up.

On Tore Supra, the plasma is observed simultaneously from the low field side along three horizontal chords located in the equatorial plane :

- The first one (M0) makes an angle $\theta = 90°$ with the magnetic field.
- The second one (BS) crosses the first one on the magnetic axis. It is slightly oblique: $\theta = 79°$ at the magnetic axis but because of the finite aspect ratio θ varies between θ_{min} on the low field side and θ_{max} on the the high field side in the plasma. $\theta_{min} = 74°$, $\theta_{max} = 82°$.
- The third one (RS) is symmetric. $\theta = 101°$, $\theta_{min} = 98°$, $\theta_{max} = 106°$.

The antenna angular acceptance is 2°. Radiation is analyzed by three Martin-Puplett type Michelson interferometers with InSb cryogenic detectors. Absolute *in situ* calibration has been performed independently for the three spectrometers. For each one, a spectrum is recorded every 22 ms. The frequency shift is given by:

$$\nu(R) = \nu_0(R)\frac{\sqrt{1-\beta^2}}{1-\beta_{//}\cos\theta} \qquad (1)$$

where ν_0 is the rest cyclotron frequency, R the major radius, and $\beta = v/c$. The factor in the numerator always shifts the frequency downwards while the effect of the denominator depends of the sign of $\beta_{//}\cos\theta$.

For $\theta = 79°$, it can be shown that $\nu > \nu_0$ only if the electrons are located in velocity space in the ellipse shown in figure 1. This ellipse contains electrons flowing in the drift direction. For that reason we call the associated Michelson Blue Shift (BS). For $\theta = 101°$ (Red Shift) the same diagram is obtained with $v_{//}$ changed to $-v_{//}$. For $\theta = 90°$ ν is always smaller than ν_0. In the following the spectra for $\theta = 101°, 90°, 79°$ are represented respectively by dotted, heavy and dashed lines.

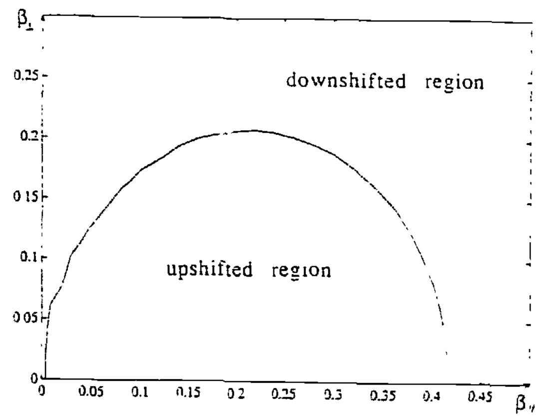

Figure 1

3 Ohmic discharges

Figure 2b shows the superposition of the three spectra recorded 3.0 s after plasma formation. The parameters are B = 3.85 T, I_p = 1.2 MA, $<n_e> = 3\ 10^{19}\ m^{-3}$, V_{loop} = 1V. Figure 2a shows the cyclotron harmonics and cut-off frequencies as a function of minor radius. The most striking observation is that the BS spectrum is above the RS and M0 spectra in the 200 - 350 GHz range. This effect is systematic and cannot be attributed to calibration effects since it has been observed at different toroidal fields (2.6, 3., 3.5 and 4T). This is unexpected for thermal plasmas since only a small broadening (2.5-3. GHz) is expected because of Doppler effect. In other frequency domains like the second harmonic, low frequency (160-200 GHz) and third harmonic, high frequency (350-390 GHz) the amplitudes are identical for the three lines of sight.

The differences must be related to asymmetries in the distribution function in $v_{//}$. Similar non thermal features in EC and X-Rays during typical thermal shots have been observed in several machines /3-5/. However, the effect of the DC electric field cannot account for such asymmetries as checked by Fokker-Planck simulations. Two interpretations can be proposed :

a) Downshifted/upshifted second harmonic: The non thermal feature has been attributed to anomalous transport due to magnetic fluctuations, which cause a distortion of the distribution function /6/. Following this model the observation could be explained by the presence of a small number of moderate energy electrons slightly accelerated by the DC field (i.e. located in the ellipse of figure 1). Their second harmonic emission can be seen by BS line because, due to the upshift , they are resonant between the antenna and the optically thick thermal cyclotron layer). Conversely, they cannot be seen by RS or M0 because the downshift makes them resonant behind the thermal layer.

b) Downshifted third harmonic: Another possible interpretation is to introduce a small number of high energy electrons in the range 200 - 300 keV, in the inner plasma region. Their downshifted 3rd harmonic emission is seen by BS at 200 GHz and above. This determines the maximum energy of electrons. Nothing is seen on RS and M0 because red shift due to the Doppler and/or relativistic effects makes these electrons radiate just below the optically thick 2nd harmonic.

4 RF assisted discharges

During lower hybrid current drive experiments or slide away discharges, two large peaks appear at the same frequencies in the three spectra (50-100 and 110-175 GHz as shown in Fig.2c). If the position and shape of the peaks were determined by equation (1) a significant difference between the three spectra would be observed: the peaks would move downwards in RS spectrum and upwards in BS spectrum. A better agreement is obtained assuming that electrons with a broad energy spectrum cause radiation between 50 and 175 GHz. The shape of the spectrum is rather determined by the cut-off and absorbing layers as can be seen by comparison of Fig 2a and 2c.

The existence of ECE at low frequency implies a substantial number of electrons with energies over 500 keV. Because of the accessibility condition, the lower-hybrid tail cannot extend so far. A possible explanation relies upon the combined effects of the lower hybrid power and of the residual Ohmic electric field, stretching the lower hybrid tail to higher energies. This was checked by means of the Fokker-Planck code; good agreement is found between the experimental and simulated spectra only when the dc field is included, i.e., very similar spectra for the three lines of sight. This interpretation needs confirmation in fully non-inductive long duration discharges.

A RF power scan between 0.1 to 3 MW has been made. The plasma current is kept constant, i.e., the loop voltage decreases for increasing RF power. The two peaks exihibit different behaviour. The amplitude of the highest frequency peak varies linearly with the power, because the number of the moderate energy electrons is mainly determined by their interaction with the lower hybrid wave. The amplitude of the low frequency peak shows a slower increase with RF power because the dynamics of high energy electrons is also governed by the electric field which decreases with RF power.

5 Conclusion

We have reported experimental evidence for asymmetries in ECE spectra measured along oblique lines of sight during Ohmic discharges. These could be attributed to small deviations from the Maxwellian distribution, due either to anomalous transport or to an energetic electron population. A clear interpretation of such asymmetries requires further experimental investigation.

During LHCD experiments, intense peaks appear in the optically thin low-frequency region of the ECE spectrum in windows between cut-off layers. The effects of the inductive electric field and RF power on ECE spectra have been investigated using a Fokker-Planck code. The interpretation is consistent with observations at different power levels.

/1/ R.L.Meyer, G. Giruzzi, V. Krivenski, Comp. Phys. Comm. **40** (1986) 153.

/2/ G. Giruzzi, Nucl. Fusion **28** (1988) 1413.

/3/ A.V. Gurevich et al., JETP Lett. **26** (1977) 569.

/4/ J.E. Rice et al., Phys. Rev. **A25** (1982) 1645.

/5/ G. Taylor et al., Plasma Phys. **31** (1989) 1957.

/6/ H.E. Mynik and J.D. Strachan Phys.Fluids **24**(4) 1981

Figure 2

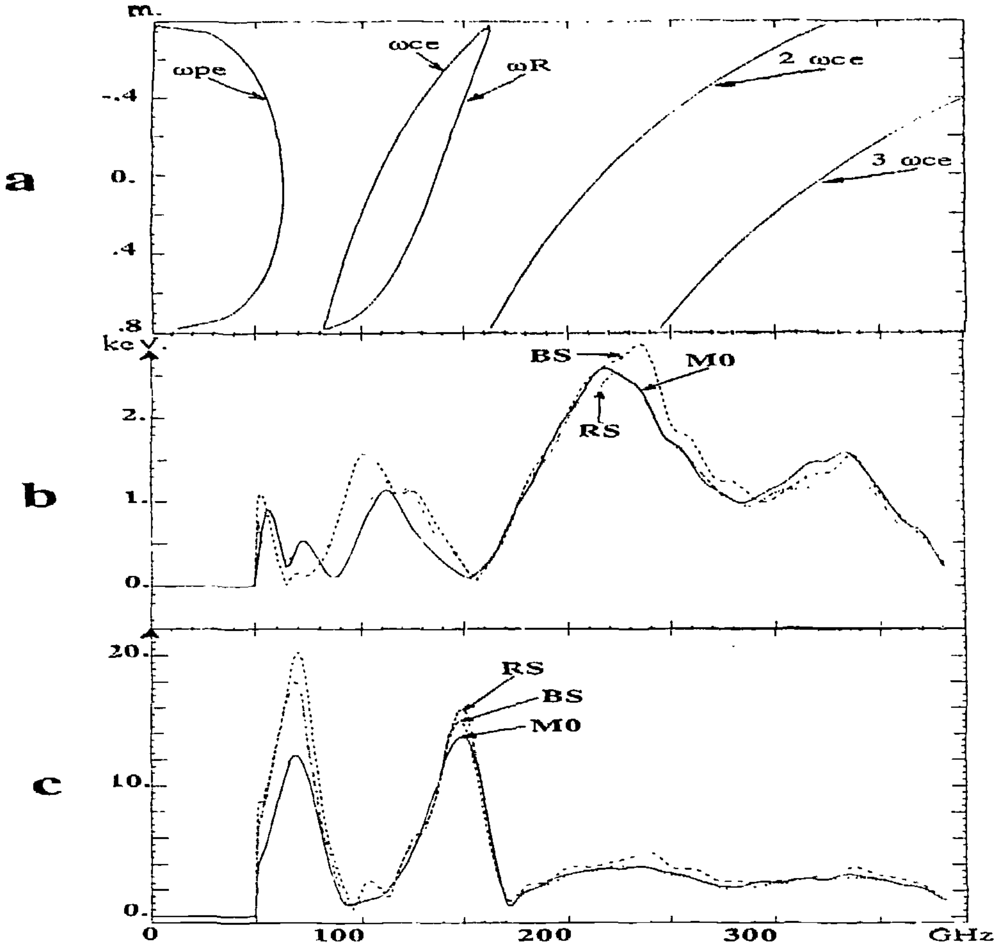

Figure 3