

# CROSS-POLARISATION SCATTERING EXPERIMENTS ON THE RTP TOKAMAK

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## 1. Introduction

Magnetic turbulence can play an essential role in thermonuclear plasma transport. However, information on its characteristics in the hot central plasma is scarce. At present it seems likely that only cross-polarisation scattering (CPS) diagnostics [1] can provide direct information. CPS is based on the change of polarisation - or mode conversion - of a probing wave under scattering off either perpendicular magnetic or parallel velocity fluctuations.

In this context, the observations on O- to X-mode conversion in the RTP tokamak during ECR heating experiments (60 GHz, 160 kW, 40 ms) with the waves injected from the low field side in O-mode are of interest [2]. A strong X-mode component (up to several percent of the O-mode transmitted power) was observed by receiving antennae located at the high field side opposite the launcher at different poloidal and toroidal angles. The effect was observed when the ECR deposition was located around the plasma centre ( $-3 < r_{dep} < +2$  cm). The amplitude of the X-mode diminished strongly with increasing density. However, the phenomenon was not investigated in detail and the cause for the high level of the X-mode signals was not clear.

In this paper the experimental results obtained in a recent series of experiments on RTP are presented. These results will be compared with theoretical estimations.

## 2. Measurement set up

The ECR beam is probed at the high field side by a cross of 9 horns in front of the launcher at poloidal angles  $\theta = 0, \pm 19$  and  $\pm 39^\circ$  and at toroidal angles  $\psi = 0, 3, 6, -4$  and  $-8^\circ$  [2]. Positive  $\theta$  corresponds to the upper part of the torus, negative  $\psi$  coincides with the plasma current direction. From the central horn both X- and O-mode components were measured simultaneously by an ellipsometer with a mode selection of  $\approx 25$  dB. All other channels were used for receiving X-mode power only. The detecting part has been calibrated in situ with an overall accuracy of 15%.

## 3. Experimental results

All X-mode measurements ( $R_0 = 0.72$  m,  $a = 0.164$  m) have been done in discharges with  $I_p = 60$  kA,  $T_e \approx 500$  eV in the Ohmic phase,  $n_e(0) = (1.5 - 2) \cdot 10^{19}$  m<sup>-3</sup>,  $B = 1.85 - 2.35$  T. The 60 GHz power was launched in the O-mode from the low field side (100 kW, 40 ms).

During ECR heating in the plasma core, large X-mode signals are observed (up to 5% of the O-mode transmitted power), on especially the central horn. These signals, measured with fine time resolution 2  $\mu$ s, are strongly fluctuating with amplitude modulation up to 100%. The ratio of the maximum value to the average level is typically (2 - 10). The signals

are detected in a narrow band of  $\pm 10$  MHz around the injected frequency. Fig. 1a,b,c,d show time traces of the X-mode signals from different antennae and the ECRH pulse in the same discharge (time resolution is 50  $\mu$ s). The measured signals always start at a low level at the beginning of the gyrotron pulse. Under certain conditions, there is a transition to a noticeably higher level after some time delay. The transition itself occurs on a short time scale in the order of 10  $\mu$ s. High level X-mode signals are modulated by sawteeth during central heating.

Scanning the ECR deposition from  $-10$  cm to  $+7$  cm shows that, for the central horn, the high level X-mode signals are observed only when the power deposition radius is smaller than  $\sim 3.5$  cm, i.e. inside the  $q=1$  surface. Fig. 2a,b,c,d present dependencies on ECR position of the signals from different antennae. The most pronounced “profile” is observed from the central horn in X-mode (a). Experiments with a ramp down of the toroidal magnetic field show that typically the signal level changes over 0.5-1 cm. The amplitude of the X-mode diminishes strongly with increasing density. An effective O- to X-mode conversion coincides with a decrease (about 20%) of the O-mode transmitted power in the same central zone (Fig. 2b). Shapes of these two profiles are very similar. For comparison, dependencies of  $T_e(0)$  versus  $R_{res}-R_0$  and  $T_e$  versus vertical position  $Z$  (for the discharge of Fig. 1) are presented in Fig. 2e,f (Thomson scattering results). It is clear that there is a good correlation between dependencies (a,b) and (e,f).

The profile of antenna “ $\theta=0^0$ ,  $\psi=-4^0$ ” is more gradual and asymmetric (Fig. 2c). The vertical bars represent the variation of the signal during a single ECRH pulse. One can see that the behaviour of the signals from the central horn (a,b) is more stable than from horn (c). Even more chaotic is the signal from channel “ $19^0$ ,  $0^0$ ” (d). The central zone is slightly visible, moreover, there is a considerable growth of the signal in the range  $R_{res}-R_0 = 7$  cm. X-mode signals from the other antennae have an even lower level or are not registered at all. So the observed mode conversion shows poloidal as well as toroidal asymmetry.

It is important to notice that a time delay (up to 20 ms) between the start of the ECRH pulse and X-mode signals is observed. This time delay differs for various horns (see Fig. 1a,b,c). There is a correlation between the behaviour of the scattered signals and the ECE signal from the central channels. In Fig. 1e,f time traces of  $T_{e ECE}$  for channels  $r = 0$  and  $+2$  cm are shown. The maximum in  $T_{e ECE}$  is observed by channel  $+2$  cm in this discharge ( $B = 2.25$  T,  $R_{res}-R_0 = +3$  cm). It is clear that the time  $t_1$  of the start of the signal from the central horn (a) coincides with the first change of  $dT_{e ECE}/dt$  for both ECE channels. Time  $t_2$  (b) corresponds to the second change of the temperature derivative. Simultaneously sawteeth oscillations begin at this moment. Finally  $t_3$  (c) coincides with the beginning of a plateau in ECE channel  $r = +2$  cm (e) and with an increase of the sawteeth level on ECE channel  $+4$  cm. A similar correlation is registered between the X-mode and soft X-ray signals. Notice that the observed time delays strongly depend on the discharge parameters. In other discharges the order and value of  $t_1$ ,  $t_2$ , and  $t_3$  can change.

Frequency spectra of the observed signals have a broadband structure with a maximum around 60 kHz and a typical width of 100 kHz (similar spectra are registered by the cross-correlation ECE radiometry for  $T_e$  fluctuations [3]). X- and O-mode frequency spectra are very similar in shapes but the ratio of the root mean square to mean level for X-mode signals is several times higher than for O-mode. The difference between spectra taken before or after the transition to the high level is that sawteeth modulation (2 kHz) is observed only after the transition.

#### 4. Discussion and conclusions

Measurements with the high spatial resolution ( $\Delta r/r = 0.02$ ) Thomson scattering diagnostics in RTP have revealed the existence of small-scale structures or filaments in the central core of the plasma during ECR heating [4]. The  $T_e$  and  $n_e$  profiles are measured along a vertical chord through the center of the plasma. Up to 5 (but more typically 3) narrow and hot filaments could be observed simultaneously. The typical filament radius ranges between 0.2 and 0.5 cm whereas the filament  $T_e$  could be higher than the ambient  $T_e$  by a factor of 2. The range of plasma parameters for which the cross-polarisation scattering is observed correlates strongly with the regime of pronounced filaments. Moreover, the X-mode signal profiles for the central horn and the sawteeth modulation show that an effective O- to X-mode conversion is associated with the central zone for which  $q < 1$ . Therefore a theoretical study [5] has been started to see whether or not these filaments could be the cause of the enhanced CPS. According to [5] these  $T_e$  filaments should be accompanied by plasma current and magnetic field perturbations which could then lead to the cross-polarisation scattering effect. Currently a model is being worked out by two of the authors (EZG & LC) to calculate the cross-polarisation efficiency.

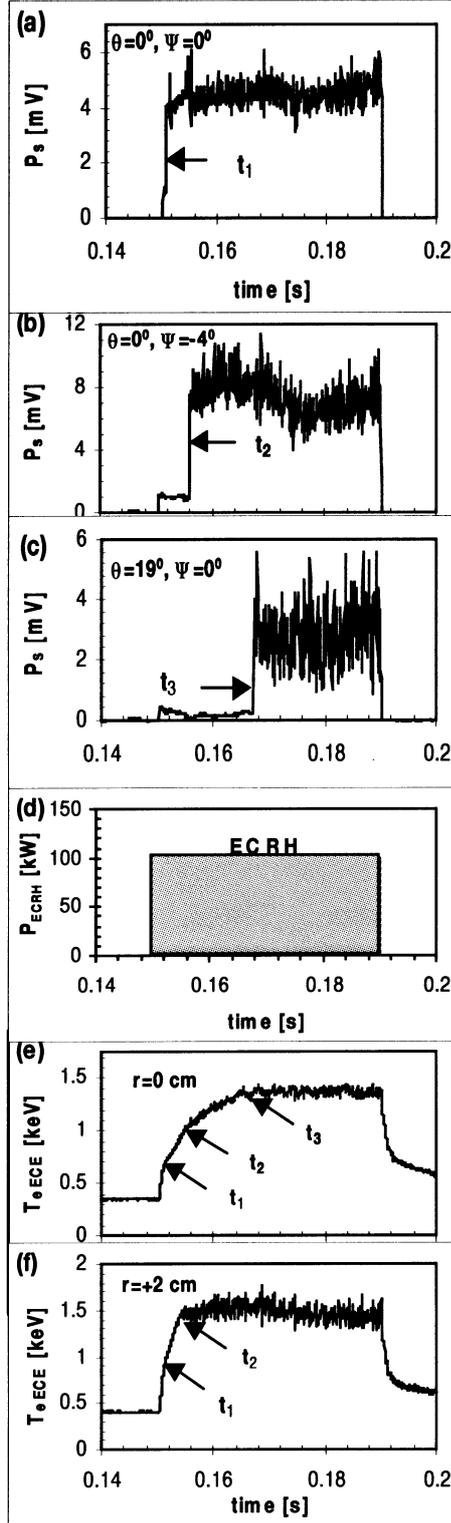
A preliminary estimation of the O- to X-mode conversion caused by fluctuations of the magnetic field and plasma current essential in the electron cyclotron frequency range shows that the efficiency depends crucially on the number of filaments  $N$ , the filament width  $\delta$  and current  $I_f$ . The maximal X-mode power produced by  $N$  filaments is given by  $N^2 P_x$ , whereas the average power is given by  $NP_x$ . In the case  $NI_f = 11$  kA,  $\delta = 0.4$  cm,  $N = 10$ ,  $\rho_0 = 2$  cm and  $n_e(0) = 2 \cdot 10^{19} \text{ m}^{-3}$  we get for the maximal bursts of X-mode radiation  $N^2 P_x / P_0 \approx 5 \cdot 10^{-2}$  and for the average level  $NP_x / P_0 \approx 5 \cdot 10^{-3}$  close to the experimentally observed values. The same values could be reached with  $\delta = 0.2$  cm,  $N = 10$  and smaller total current in filaments:  $NI_f = 3$  kA.

It should be noted that filament current values  $NI_f$  necessary for explanation of observed X-mode power level, are of the same order as the total current inside the zone  $q < 1$  ( $\approx 17$  kA). Also the consequences of so many and so closely packed strong current filaments with respect to the magnetic topology and the equilibrium have to be investigated. At this moment it only seems likely that both the electron temperature filaments and the anomalous cross-polarisation effect are the footprints of current carrying filaments existing in the central zone of the discharge in the presence of ECRH.

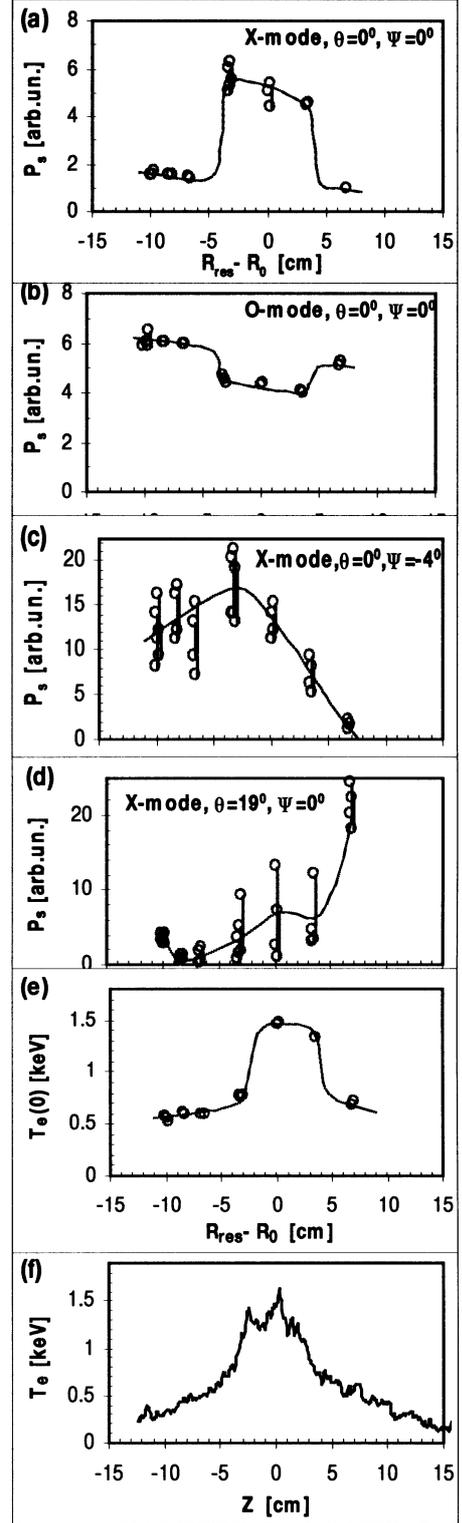
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**Fig. 1.** Time traces of X-mode signals at different poloidal and toroidal angles (a,b,c), ECRH pulse (d) and ECE signals at different minor radii (e,f) in the same RTP discharge.  $B = 2.25 \text{ T}$ ,  $(R_{res} - R_0) = +3 \text{ cm}$ .



**Fig. 2.** Dependencies of scattered signals and  $T_e(0)$  on ECR position (a,b,c,d, and e) and  $T_e$  profile (f).