Anomalous wave scattering in magnetic islands detected by CTS diagnostic in FTU tokamak

A.Bruschi[1], G.Grossetti[2], G.Grosso[1], L.Lubiako[3], F.Orsitto[4], E.Peluso[4], U.Tartari[1], W.Bin[1], A.Botrugno[4], P.Buratti[4], G.Calabrò[4], O.D'Arcangelo[1], G.Granucci[1], G.Pucella[4], A.Moro[1], O.Tudisco[4]

[1]*Istituto di Fisica del Plasma, EURATOM-ENEA-CNR Association, Milano, Italy*

[2]*Karlsruhe Institute of Technology, Assoc. KIT-EURATOM, Karlsruhe, Germany*

[3]*Institute of Applied Physics, Russian Academy of Sciences, Niznhy Novgorod, Russia*

[4]*Associazione EURATOM-ENEA sulla Fusione, CR Frascati, Italy*

Introduction

The Collective Thomson Scattering (CTS) diagnostic has been conceived to measure the velocity distribution function, resolved in space and time, of the ion species collecting the electromagnetic radiation from a high-power gyrotron beam scattered by the plasma electrons. This goal is shared by the 140 GHz CTS diagnostic system installed on FTU, characterized by wave propagation below the electron cyclotron (EC) resonance, with the ordinary (O) and extraordinary (X) modes that propagate at plasma densities up to 2.4 and 4.8×10^{20} m^{-3}, respectively. In early experiments however [1,2], anomalous spectra were observed (Fig.1, left), some of which could be ascribed to gyrotron perturbations due to back-reflections on the X-mode cutoff surface, close to the EC resonance located in the port shadow. This interpretation was later confirmed both by inspection of the last mirror, showing localized damage, and by spectra obtained during test shots carried out in absence of plasma [3]. Recently, the interest in these results was revived by unexpected phenomena detected by the CTS diagnostics in TEXTOR and correlated with the presence of magnetic islands [4]. Moreover, the proposed interpretation of these new findings in terms of a parametric-decay instability (PDI), occurring in particular plasma conditions such that the PDI threshold is strongly lowered [5], opened the way to the possibility of testing such interpretation under different accessibility conditions, using the CTS setup already available on FTU. The interest for such experiment is increased by the possibility that FTU offers of investigating such phenomena in conditions of density and EC wave injection approaching those envisaged in ITER.

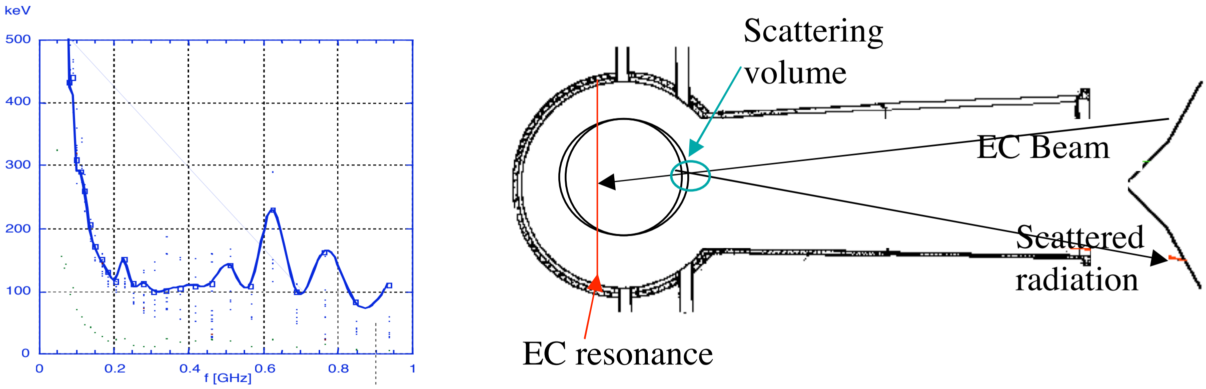

Fig.1 Left: Example of anomalous spectrum observed with the early CTS diagnostics of FTU. Right: New setup for the experiments aimed at investigating the possible occurrence of anomalous scattering or other similar phenomena..

Experimental setup and results

The probe beam was launched and the scattered radiation received using the equatorial ECH launcher [6] of FTU (Fig.1, right). A tract of the EC line allowed to connect the receiving line to the single sideband, 32 channels, 1.2 GHz bandwidth radiometer currently used for CTS. In spite of a high insertion loss, this connection was suited to our purposes, the detected signals being expected to be rather strong. A beam power of about 400 kW at 140 GHz was used.

The magnetic field and the scattering geometry were such that the scattering volume crossed the q=2 surface on the low-field side, while the EC resonance was conveniently set on the high-field side to absorb the EC radiation and significantly reduce the stray radiation level. This configuration was obtained with B=4.8T, I=500kA and line-averaged density n_e=0.6-0.8 $10^{20}m^{-3}$.

The required MHD activity was induced by injecting neon during the flat-top of the plasma current. After neon penetration, a pre-existing magnetic island rotating at a frequency of about 10 kHz was observed to grow, eventually causing either a minor or a major plasma disruption. The probe beam was injected 100 ms after the neon injection, and the plasma was probed for no more than 100 ms, just before the disruption occurred.

In order to prevent reflection of the probe beam into the antenna, the probe and the receiving lines were toroidally tilted by about 10°, with a scattering angle of ≈165° and scattering volume elongated along the major radius R. The fixed time constant of the filter bank limited the time resolution of the collected spectra to about 0.5 ms. Therefore, should the detected signals originate from a rotating island, then the rotation effect would be visible only provided the rotation frequency of the island is less than 1 kHz. In a number of shots the timing of the neon injection was varied in the attempt of synchronizing the island growth with probe injection.

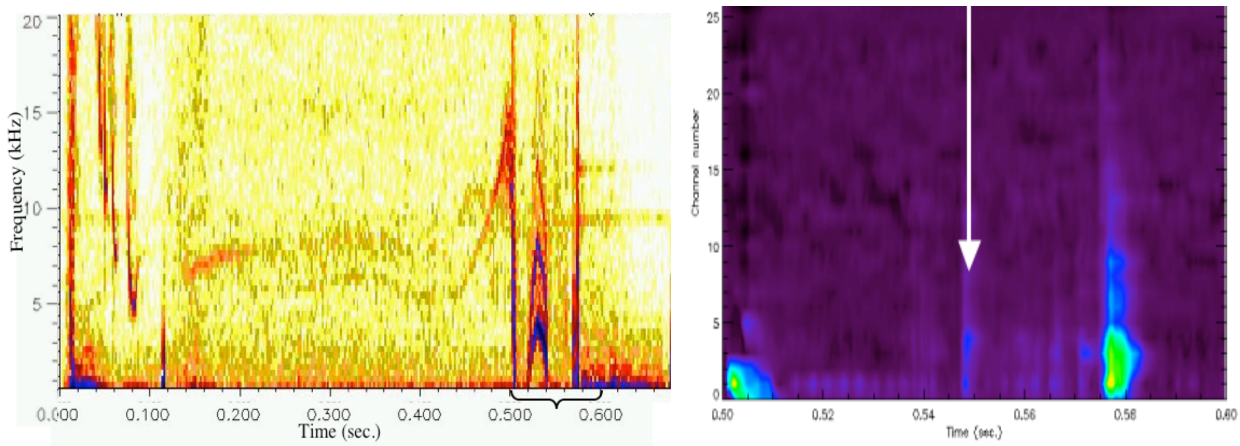

Fig.2; Left: Spectra of magnetic fluctuations for shot #33373. Right: Spectral features observed during the last 100 ms of the same shot: the white arrow points to the most interesting feature. The signals at t=0.5 and t=0.578 are signatures of the gyrotron frequency shift that occurs at pulse start and of the final plasma disruption, respectively.

Strong line signals at frequencies close to the gyrotron frequency were detected by the receiving system in some shots and in all cases this behavior could be correlated with the presence of a well-developed m:n=2:1 rotating island in the scattering volume. The signals are detected only when the mode has sufficiently grown and is slowing down.

In particular we analyzed shot #33373, characterized by a complex magnetic activity (Fig.2, left) in the last 75 ms, starting from t=0.5 s. In this shot neon was injected at 0.4 s, leading to the growth of a pre-existing magnetic island that reaches a rotational frequency higher than 10 kHz and suddenly locks to the wall at t~0.5 s then starts rotating and finally locks again at t=0.55, about 20 ms before plasma disruption. Investigating in more detail the second locking phase, temperature oscillations linked to the rotating island were found in the ECE emission close to R=1.164m, in the radial position corresponding to the expected island location. Similar oscillations were also observed in the interferometric line-integrated density (Fig.3, left). In the subsequent phase the island slows down rapidly and a burst of scattered radiation is detected in two channels shifted respectively 54 and 73 MHz from the probe frequency (Fig.3, middle). This low frequency shift is a distinctive feature with respect to TEXTOR measurements. Considering the mutual locations of the ECE and CTS diagnostics, the position of the O point at the time of the burst is found close to the scattering volume. A specific analysis of the density profiles at the times of the density maxima of Fig.3,left was carried out first averaging the line-density profiles at many times of maxima at the two radii, then by Abel inversion of the averaged density signals.

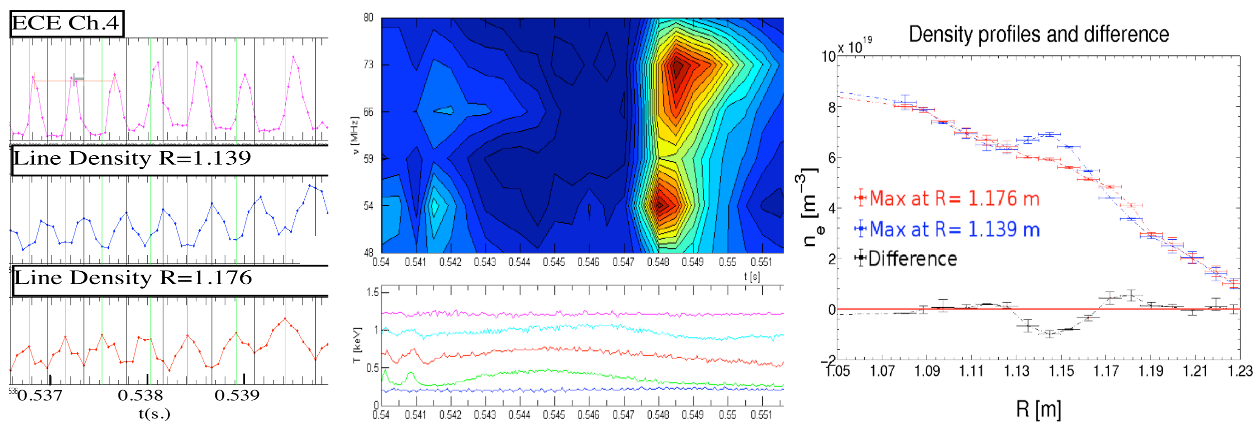

Fig.3; Left: ECE and density signals during island slowing down; the time shift between maxima allows the reconstruction of the island O-point position vs. time. Middle: scattering spectrum and temperatures in the locking phase. Right: Density profiles reconstructed using time of maxima at R=1.139 and R=1.176, and their difference.

The analysis further shows a reversal of the density gradient at the island location, the typical condition cited in [5] (even if injected in sensibly different experimental conditions: O-mode, first harmonic) for the parametric decay of the injected wave. In the next experimental campaign a planned increase of the time resolution of the diagnostic planned for will allow to follow the island rotation up to 10 kHz. Improved signal dynamics and higher spatial resolution will be also available thanks to the use of new EC antennas [7,8], which also implies a new receiving line.

Conclusions and final remarks

The unusual strong line signals observed in an experiment purposely implemented in FTU provide further support both to the observations described in [4] and to the interpretation proposed in [5]. They are accordingly more likely ascribable to a PDI than to anomalous scattering as initially assumed. If confirmed, these new phenomena will change the scenario of the CTS experiments since on one side they make available information of primary interest on the plasma behavior but on the other they introduce a ‘perturbation’ with respect to the more conventional goal of inferring the ion velocity distribution of the bulk plasma.

References

[1] F. Orsitto et al., Rev. Sci. Instr. **70** (1999), 1158
[2] U. Tartari et al.,Rev. Sci. Instr. **78**, 043506 (2007)
[3] U. Tartari et al., Nucl. Fusion **46** (2006) 928-940
[4] E. Westerhof et al. Phys. Rev. Lett. **103**, 125001 (2009)
[5] E. Z. Gusakov and A.Yu. Popov, Phys. Rev. Lett. **105**, 115003 (2010)
[6] A. Bruschi et al., Fusion Eng. and Des. **53** (2001) 431-441
[7] A. Bruschi et al, Fusion Sci. and Techn. **55** (2009) 94-107
[8] W. Bin et al., Fusion Eng. and Des. **84** (2009) 451-456