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The UHR cross-polarization scattering experiment at the FT-2 tokamak

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Magnetic component of small-scale plasma turbulence can play an important role in electron transport disturbing the system of nested magnetic surfaces and causing huge energy losses along the field lines. The cross-polarization scattering (CPS) diagnostics utilizing microwave probing and observation of the scattering spectra perpendicular to the tokamak magnetic field provides a unique opportunity for measuring relatively low magnetic turbulence level in the hot plasma core because intensive density fluctuations do not contribute to the CPS signal in this experimental geometry [1]. The CPS effect was firstly used for the diagnostic development at the Tore Supra tokamak [2], where the extraordinary to ordinary mode ($X \rightarrow O$) conversion was studied in the presence of the probing wave cutoff protecting the O-mode receiving antenna from the high level X-mode radiation forward scattered off the long scale density fluctuations. The alternative scheme of the experiment utilizing the CPS effect in the Upper Hybrid Resonance (UHR) of the probing microwave was applied at the FT-1 tokamak, where the RADAR scheme [3] was used to provide the diagnostic wave number selectivity. Just recently the UHR CPS scheme has been assembled at the FT-2 tokamak (R=55 cm, a=7.9 cm, B_T=(1.8-2.2) T, I_p= (19-35) kA, $n_e(0)$= $(0.5\text{-}6)\times 10^{13}$, T_e=(300-500) eV) where a double antenna set (X-mode for $y_a = 0$ mm; O-mode for $y_a = 15$ mm), shown in fig. 1, was installed at the low magnetic field side in the same poloidal cross-section, but opposite to the movable focusing X-mode antennae, used for UHR microwave backscattering investigation [4]. The plasma was probed by X-mode from the high field side and both O-mode and X-mode spectra were studied with the double antennae set for different values of plasma density, current and probing antenna vertical position. The experiments performed with this scheme have provided a number of evidences in favor of the CPS effect and UHR

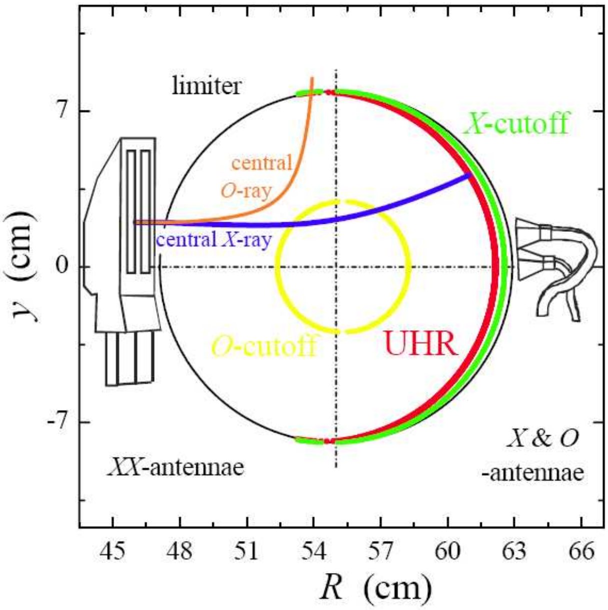

Fig. 1. *UHR cross section, Antennae set up.*

origin of the signal received by the O-mode antenna situated at the low magnetic field side of the torus [4]. Those evidences are as follows: 1) The difference in the spectra received by the O and X-mode antennae at central density $n_e < 4\times10^{13}$ cm^{-3} ; 2) Different dependencies on probing frequency for spectra registered by O and X antennas; 3) Excess of the O-mode broad spectra signal over the X-mode signal observed in high density discharge under condition when the narrow line at the probing frequency in the O-mode spectrum is suppressed (most likely due to reflection from the cut off of the spurious O-mode generated by the probing antenna at the level less than 1% at the O-mode cut off). (see the experiment geometry in fig. 1), 4) The last and most persuading confirmation of the UHR origin of the signal was provided by the first radial correlation measurements [4], which proofed a high wave number of fluctuations contributing to the CPS.

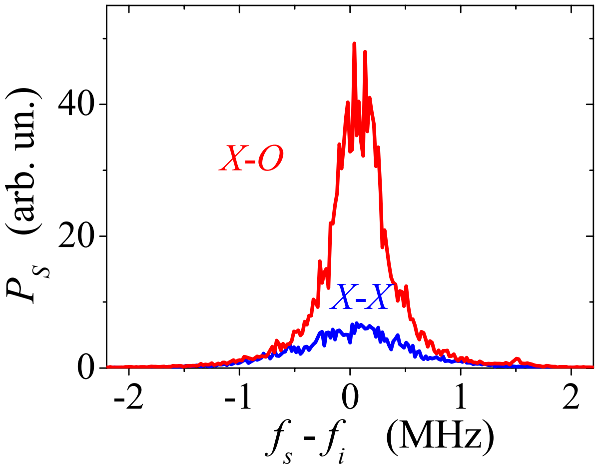

Fig. 2. *Spectra for $n_e \geq 6\times10^{13}$ cm^{-3}.*

In the present paper the detailed radial correlation measurements performed with for O- and X- mode antenna signals in different FT-2 regimes are reported. The plasma was probed simultaneously at two frequencies by *X*-mode wave in *V*-band from the high field side and both *O*-mode (at different vertical positions) and *X*-mode (in equatorial plane) signals were studied with new antennae sets for different exciting antenna vertical positions. One of generators probing at constant frequency (reference channel) defines the UHR position whereas the second generator frequency is changing on discharge to discharge basis. The scattering signals at both probing frequencies are stored by the data acquisition and used for computation of the cross-correlation function (CCF). The first correlation measurements were performed at the reference frequency F_1=62.4 GHz in the high density ohmic discharge (I_p = 25 kA, $n_e \geq 5.5\times10^{13}$ cm^{-3}) where the signal registered by the O-mode antenna exceeded substantially the X-mode antenna signal (see the corresponding spectra shown in Fig.2).

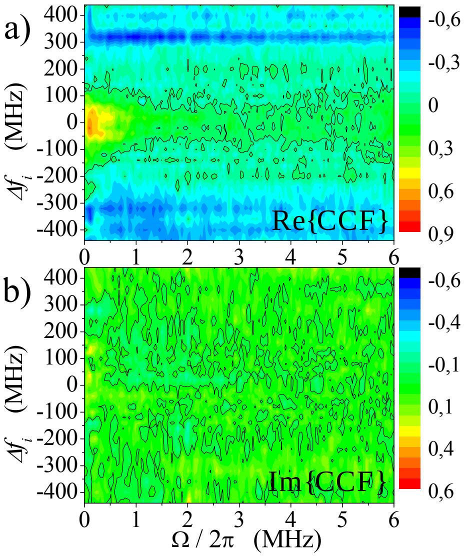

Fig. 3. *CCF for $n_e \geq 5.5\times10^{13}$ cm^{-3}*

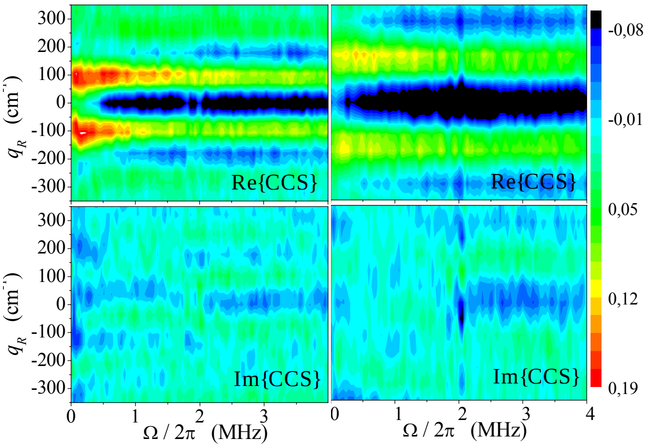

Fig. 4. *CCS for O and X receiving antennae.*

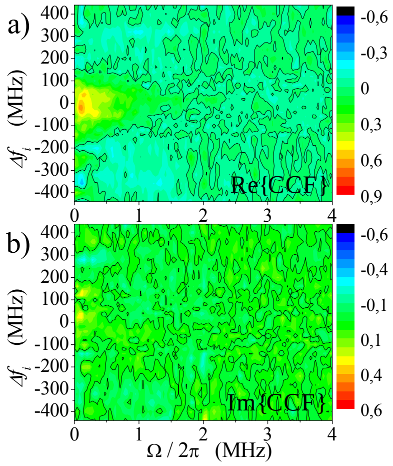

Fig. 5. *Recalculated CCF .*

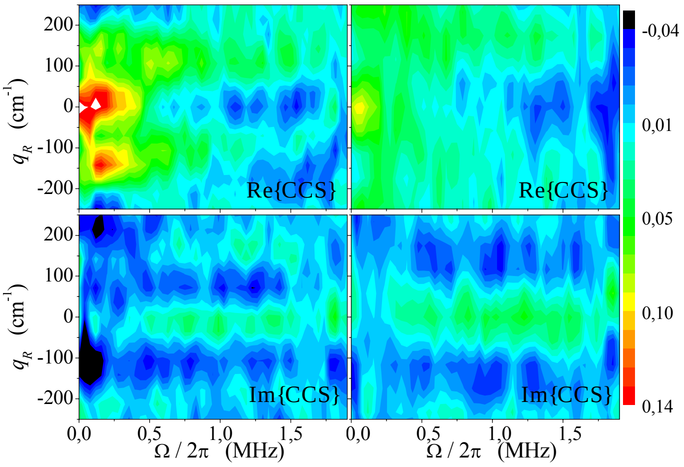

Fig. 6. *CCS for O and X mode antennae.*

The channel frequency difference $\Delta F = F_1 - F_2$ was varied from -440 to 440 MHz that allowed resolving fluctuation wave numbers down to 15 cm^{-1}. The real and imaginary parts of the O-mode signal CCF are presented in fig.3 The Fourier transformation of the CCF dependence on the channel frequency difference dF$_i$ proportional to the UHR spatial separation, gives the cross correlation spectra (CCS), which are presented for O and X mode antennae signals in fig.4. As it is seen in this figure, both spectra possess a similar structure periodic in radial wave number q strongly pronounced at frequencies higher than 2 MHz where no valuable signal was observed according to fig. 2. This structure is not dependent on turbulence frequency and may be presumably related to the spurious O-mode radiation received by O and X mode antennae after multiple reflections by tokamak vessel and cut offs. To suppress this contribution we subtracted from the CCF its value averaged in the frequency range 2-6 MHz. The recalculated CCF for O-mode signal is shown in fig. 5. The corresponding CCS for both O and X-mode cases are presented in fig. 6. It is important to note that the real part of the CCS especially in the case of the O-mode signal is much larger than the imaginary one, which should be zero in theory [5]. Moreover, it should be mentioned that unlike the case of X-mode CCS a pronounced small scale contribution at q=150 cm^{-1} is clearly observable in the O-mode CCS at low frequency of about 100-200 KHz. A similar small scale CCS component was observed also in plasma discharge at lower density

$n_e < 4\times10^{13}$ cm^{-3} for two values of plasma current. These observations taken together may be considered as a confirmation of the UHR origin of the CPS signal. Supposing the signal to be generated due to CPS off the magnetic fluctuations we may determine their wave number and frequency spectrum multiplying the O-mode spectrum of fig.6 by the homodyne spectrum corresponding to fig. 2 and by the CPS efficiency, according to [6], proportional in the UHR to q^2. The obtained radial wave number spectra possessing a knee-like form are shown in fig.7 for different frequencies. In case of high density (fig.7a), the spectrum quickly decays with growing wave number, being proportional to q^{α}, where $\alpha_1 = -2.1$ at $(12 < q < 150)$ cm^{-1} and $\alpha_2 = -5.6$ at $q > 150$ cm^{-1}. For low density (fig.7b) a similar behavior is found with $\alpha_1 = -2.2$ at $(12 < q < 150)$ cm^{-1}, however the same spectrum can be interpreted in a more complicated manner, as possessing a plateau at $40 < q < 80$ cm^{-1}.

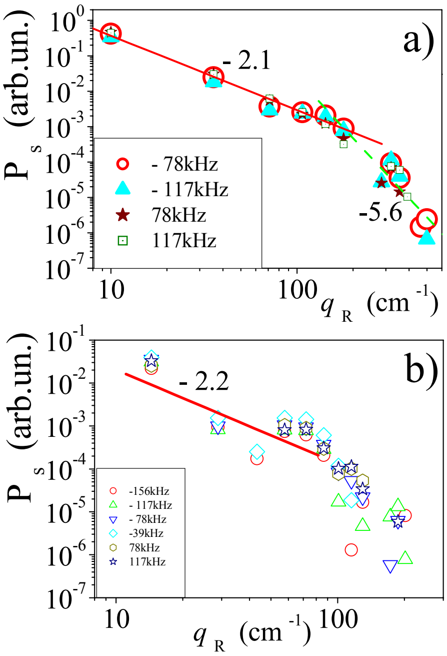

Fig. 7. *The magnetic fluctuation wave number* spectra *for* *a)* $n_e \geq 5.5\times10^{13}$ *cm*$^{-3}$, *b)* $n_e < 4\times10^{13}$ *cm*$^{-3}$

As it is seen in fig.6 the correlation measurements provide data also on longer scale fluctuations, possessing 12 cm^{-1} $> q$ however in this case the CPS take place not in the UHR and both the wave number and spatial resolution of the diagnostic become not sufficient for quantitative conclusions. Nevertheless, the minimal wave number (12 cm^{-1}) at which the reliable and localized measurements are performed in the paper are only a factor of 2 higher than the ω_{pe}/c - maximal value for excitation domain of magnetic fluctuations [7]. Thus the obtained spectra can be used for estimation of the magnetic fluctuation level after absolute calibration of measurements.

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