STUDIES OF TOKAMAK CORE SMALL-SCALE TURBULENCE IN DIFFERENT REGIMES OF T-10, TEXTOR AND FTU TOKAMAKS

Vershkov V for T-10, TEXTOR and FTU teams

RRC "Kurchatov Institute", 123182, Moscow, RF, E-mail: vershkov@nfi.kiae.ru

The investigation of the physical mechanisms of small-scale tokamak turbulence draw significant attention last decade, because the real control of the anomalous turbulent transport in "advanced tokamak" regimes became an important issue, which suggest the clear understanding of both the physical turbulence mechanisms and the conditions of its stabilisation. Unfortunately the experimental turbulence spectra may have footprints of the physical turbulence mechanisms only in linear, or quasi-linear stage, but they should disappear in the strong non-linear turbulence stage. Thus variation of from marginally stable up to strong turbulence needed to identify turbulence physical mechanisms.

This paper presents the results of turbulence investigation with correlation reflectometry, multipine Langmuir probes and HIBP in T-10 tokamak [1,2,3]. The area of investigations was significantly extended by means of development correlation reflectometry at TEXTOR [4] and FTU [5] tokamaks. A common experiment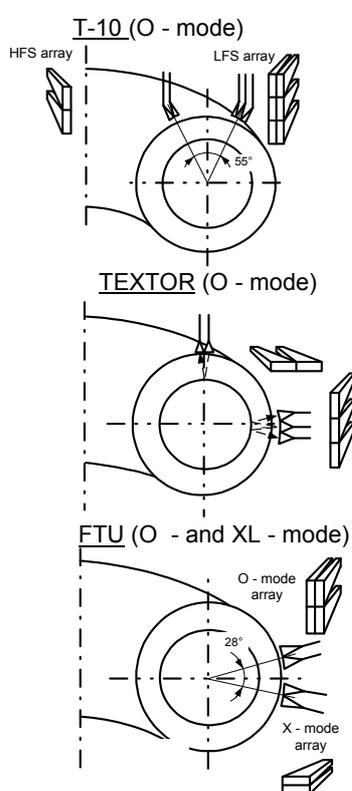 greatly increases the range of toroidal magnetic fields from 1.5 to 8 T and densities from 0.08 to 3×10^{20} m^{-3}. The turbulence characteristics were investigated over the whole plasma column in OH and L-mode ECRH discharges in T-10 and co/counter NBI in TEXTOR. The schematics of correlation reflectometry antennas in T-10, TEXTOR and FTU are shown in Fig.1. The main common feature was the presence of two antenna arrays, enabling long and short distance poloidal and radial correlations. The O-mode were used in T-10 and TEXTOR and both O and lower X mode in FTU. The experimental spectra were similar and they are illustrated by T-10 case in Fig. 2. The results of the complex correlation analysis of fluctuation of the signals reflected from two poloidally separated points, including amplitude Fourier spectra of the first signal (top traces), cross-phase (middle) and coherency (bottom) are shown. The core
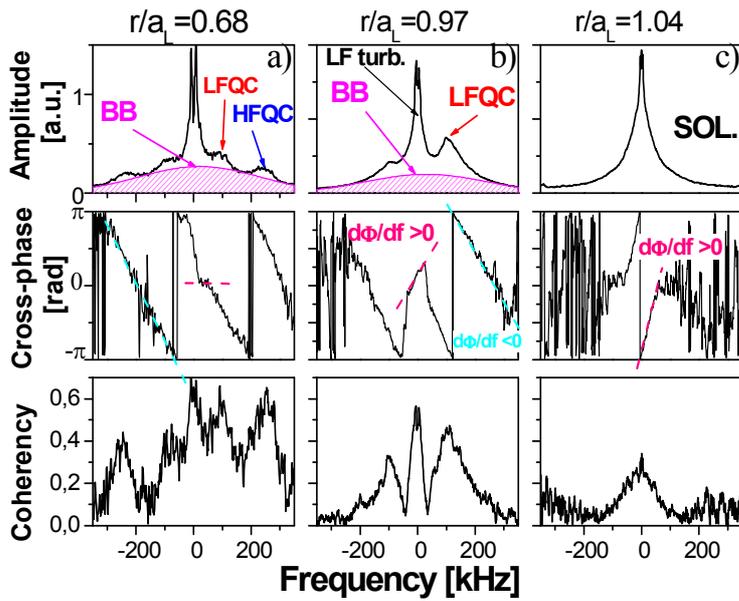

Figure 1.

Figure 2.

turbulence rotates in electron diamagnetic drift direction and has complex structure [8]. It includes the background "Broad Band" (BB) fluctuation, High Frequency (HF) and Low Frequency (LF) "Quasi-Coherent" (QC) spectral maxima and "Low Frequency" (LF) peak at zero frequency The experimental data evidenced that HF and LF QC arise due to the excitation of rational surfaces with high poloidal m-numbers [9]. They are similar to the "eddies", found in the 3D gyrokinetic simulations [10]. The LF QC oscillations have the features of the "streamers" [11] as they have long radial correlation length with zero phase shift. A special fluctuations at 15 – 30 kHz (not shown in Fig. 1) are also seen at low densities near rational surfaces 2 and 3 [2, 12,13]. The oscillations at 15 – 30 kHz are highly correlated at any poloidal separation of reflection points with zero phase shift. The potential fluctuation level is much higher then that of the density. Their properties are similar to the predicted by theory Geodesic Acoustic Modes [14], which are the branch of "zonal flows" [11].

The typical core amplitude spectrum of fluctuations, shown in Fig. 2, exhibits two spectral
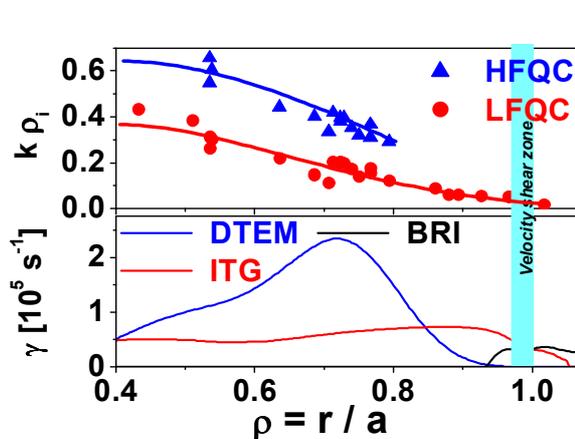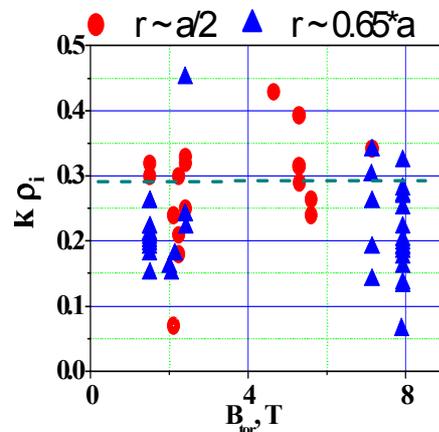

Figure 3.

Figure 4

maxima. The LF QC usually observed at 70-120 and HF QC at 150-250 kHz. The strong difference of their spatial structure is proved by the data in Fig. 3a. A single maximum of QC turbulence was observed at frequency of 200 kHz at LFS, while both maxima clearly seen at LFS. The radial scan of $k\times\rho_i$ values for both QC types together with the linear estimations of increments of ITG [6], DTEM [6,15] and BRI [16] instabilities are presented in Fig. 3a,b respectively. Experiment showed only LF QC at the edge plasma (0.8 <r/a<1), where only ITG is unstable, while in the plasma core both LF and HF QC maxima are seen also in accordance with the increments of ITG and DTEM. It should be stressed that the appearance of HF QC at r/a=0.8 just coincides with the rise of DTEM increment. It is important that in core plasma the $k\times\rho_i$ values approach 0.3 for LF QC and 0.7 for HF QC as are expected from theoretical estimations. The turbulence modes radial distribution showed that LF QC exists near centre and at periphery, while HF is maximal at a/2 in accordance with ITG and DTEM increments. This correspondence is also supported by the values of $k\times\rho_i$ for LF QC in discharges with different toroidal magnetic field strength from 1.5 to 8 T plotted in Fig.4. Such scan was obtained by comparison of T-10, TEXTOR and FTU results. For radius=a/2 all values are near to 0.3 in the wide range of magnetic field, as predicted for ITG. Figure 5 shows the angular rotation of LF QC versus radius for T-10 OH (Fig. 5a) and for OH, counter and co NBI injection in TEXTOR. In both OH cases turbulence rotation are remarkably constant over radii (rigid body rotation) and coincide with the MHD m/n=2/1 rotation. It suggests the presence of the global mechanism, which forced all fluctuations to rotate together with MHD m=2 island. Nevertheless this interaction may be easily overcome in co-NBI heating, which forced core turbulence rotate in opposite direction. The equality of the turbulence and m/n=2/1 island rotations were proved in dynamics in FTU experiment with m/n=2/1 ECRH stabilization. The recent T-10 experiment with temporal ITB formation
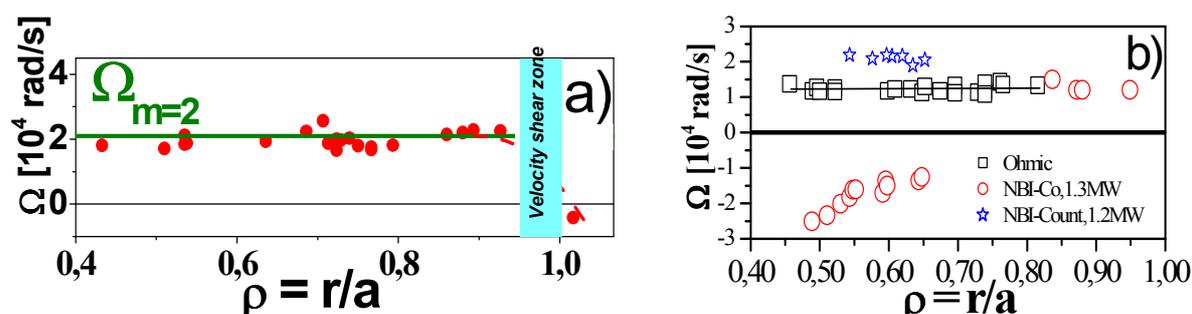
Figure 5.

after off axis ECRH switch off clearly demonstrate the local decrease of the turbulence amplitude and coherency, which proved the experimentally observed decrease of electron heat transport in spit of the steep gradient of electron temperature with R/Lt=16. The disappearance of the core QC turbulence was observed in T-10 experiment with the quick cooling of the edge, accompanied with the rise of the cental SXR emission. Such non-local transport observation may be explained by the suppression of QC turbulence by the temporal velocity shear, providing the decrease of the transport.

References

[1] V.A. Vershkov *et al* RSI, 1999, V. 70, N. 3, p. 2903.

[2] M.V. Osipenko, Nuclear Fusion, **43**, (2003) 1641.

[3] A.V. Melnikov et al, 30 EPS Conference on Contr. Fusion and Plasma Phys., St. Petersburg, Russia (2003) ECA Vol. 27A, P-3.114.

[4] A.Kraemer-Flecken et al, 30 EPS Conference on Contr. Fusion and Plasma Phys., St. Petersburg, Russia (2003) ECA Vol. 27A, P-2.135.

[5] V.A.Vershkov *et al,* 28 EPS Conf. Plas. Phys.Cont. Fus, Funchal, ECA, V.25A (2001) 65

[6] J. Weiland, H. Nordman, Nuclear Fusion, **31**, (1991), 390.

[7] B.B. Kadomtsev, O.P. Pogutse, Rev. Plasma Phys., Vol. 5, Chapter 2

[8] V.A. Vershkov et al, 19 IAEA Fus. Energy Conf., Lyon, France, 2002, CN-94/EX/P3-04

[9] V. A. Vershkov *et al*, 26 EPS Conf. Plas. Phys. Cont. Fus, Maastricht, V. 23J (1999) 825.

[10] R. E. Walts *et al* Phys. Plasmas **1**, 2229, (1994)

[11] G. Manfredi et al, Plasma Phys. Contr. Fusion, **43**, (2001) 825-837.

[12] V.A.Vershkov *et al,* 28 EPS Conf. Plas Phys. Cont. Fus, Funchal, ECA,V.25A (2001) 1413

[13] S.V. Soldatov et al, Proc. 24 EPS Conf. Plasma Phys. Cont. Fusion, Berchtesgarden (1997), Vol. 21A, Part 2, p. 673.

[14] N. Winsor et al, The Physics of Fluids, 11, (1968) 2448.

[15] Tokar M. Z. *et al* 2000, Phys. Rev. Lett. **84** 895

[16] M.V. Osipenko *et al* Physika Plasmy V. 26, N. 12, (2000), 1