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Evolution of the ETG mode turbulence frequency and wave number spectra in dynamic experiments at FT-2 tokamak

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Fine scale component of drift wave turbulence excited by the ETG instability is discussed nowadays as a possible candidate for explanation of the anomalous electron energy transport in tokamak plasmas, in particular in transport barriers [1]. In spite of this the experimental information related to this mode is not detailed. Only recently new experimental techniques based on the microwave scattering effect have been developed to fill in the gap at several tokamaks and first results confirming excitation of the ETG mode scale turbulent fluctuations sensitive to electron temperature gradient have been obtained at FT-2, DIII-D and NSTX tokamaks [2-7]. In particular, two (low and high frequency) small-scale modes identified as TEM and ETG mode were demonstrated in ohmic discharges at FT-2 under conditions when the ETG instability should be above the threshold [3]. The temporal evolution of the small-scale TEM mode component at the plasma edge was studied in dynamic current ramp up (CRU) experiments [7, 8], where the correlation of the observed exponential wavenumber spectra parameters and electron thermal diffusivity had been demonstrated. In the present paper we report results of systematic investigations of the ETG mode turbulence evolution in the gradient discharge region, where it dominates, performed in the CRU experiment.

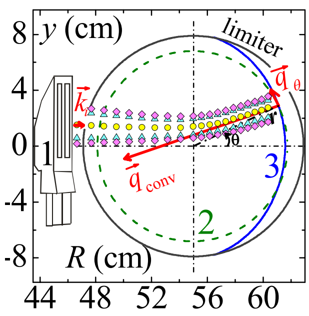

Fig. 1. FT-2 poloidal cross section: 1 – movable antennae; 2 – magnetic surface; 3 – UHR. Probing beam: circles - 0 dB; triangles - 1.5 dB; rhombuses - 3 dB power suppression levels.

The experiment was carried out at the small research FT-2 tokamak ($R_0 = 55$ cm, $a = 7.9$ cm, B=2.2 T, $T_e(0) = 500$ eV) The central electron density was smaller than in [6] $n_e(0) = 2\times10^{19}$ m^{-3}, that allowed central measurements of turbulence using the correlative enhanced scattering (ES) technique [2] utilizing for local diagnostics of small-scale plasma fluctuations the effect of growth of wave vector and electric field of the probing extraordinary (*X*-mode) wave in the upper hybrid resonance (UHR), where condition $f_i^2 = f_{ce}^2 + f_{pe}^2$ is fulfilled for the probing frequency f_i.

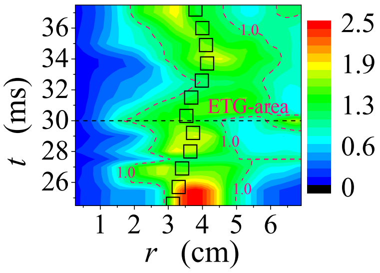

Fig. 2. Temporal behavior of the ETG mode threshold. Squares gives the UHR trajectory for f_i = 65 GHz

To study the small-scale turbulence the movable focusing double antennae set, allowing off equatorial plane plasma *X*-mode probing with the maximal vertical displacement $y_a = \pm 2$ cm was installed at FT-2 at the high magnetic field side (see Fig. 1). The probing was performed at low power level of 20 mW at frequencies 65, 64 and 57 GHz allowing study of drift wave turbulence at 3-4.5 and 5.5-6.5 cm accordingly. The plasma current was ramped up from 22 kA to 32 kA at the 30th ms of discharge which resulted in the evolution of the plasma parameters profiles and correspondingly to variation of ETG instability threshold and growth rate. The evolution of parameter $(R/L_{Te})\,/\,\max\{0.8R/L_n;\ (1+Z_{eff}T_e/T_i)(1.33+1.91s/q)(1-1.5r/R_0)\}$ determining, according to [1], the ETG instability threshold provided by the ASTRA code modeling is shown in Fig. 2. As it is seen the threshold parameter experiences substantial variation along the trajectory of the 64 GHz probing wave UHR point, being however always higher than unity. The GS2 modelling performed for the selected temporal points have confirmed the positive growth rate value there. From Fig. 2 we could also conclude that the ETG instability is mostly below the threshold at the plasma edge. Unfortunately a poor accuracy of electron density and temperature determination in this region makes this conclusion not reliable.

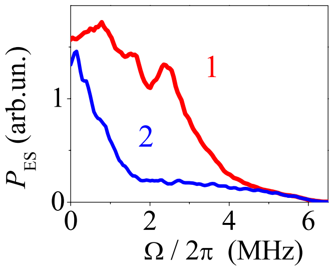

Fig. 3. ES Ω-spectra for f_i=65 GHz (1), 57 GHz (2).

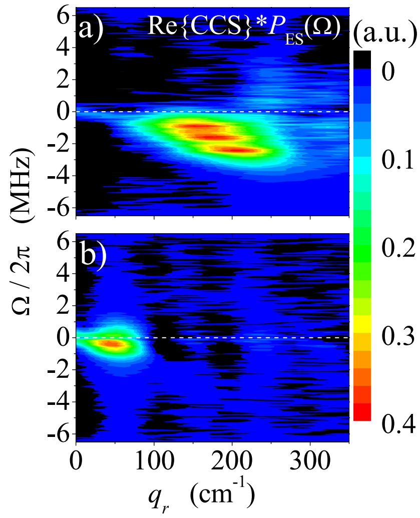

Fig. 4. ES signal spectra for 65 (a) and 57 GHz (b) probing.

The ES frequency spectra $P_{ES}(\Omega)$ measured in the stationary stage of the tokamak discharge (36th ms) at probing frequencies f_i = 65 GHz and 57 GHz, corresponding to r = 3.8 cm and 5.9 cm are shown in Fig. 3 by curves 1 and 2. As it is seen the frequency shift, as well as structure of the ES spectra, in these cases is very different which corresponds to different origin of turbulence producing the signal (ETG and TE modes accordingly). To measure the turbulence wavenumber spectrum we applied the correlation ES diagnostics [2]. Two signals at close probing frequencies with difference $|f_2 - f_1| = \{10, 20,..400\}$ MHz, corresponding to two slightly separated UHR layers in plasma, where the ES by fluctuations occurs, were measured simultaneously using the asymmetric correlation scheme [2].

The cross-correlation function (CCF) of two ES signals, according to [2] is related to the turbulence spectrum $|n|^2_{q_r,\Omega}$ by equation

$$CCF_\Omega(f_1,f_2)=\int I_{q_r,\Omega}\exp\left\{iq_r\left[(f_1-f_2)\partial x_{\mathrm{UH}}/\partial f\right]\right\}dq_r\,,$$

where the ES spectrum $I_{q_r,\Omega}=|n|^2_{q_r,\Omega}\,S_{\mathrm{ES}}(q_r)$ and $S_{\mathrm{ES}}(q_r)$ is ES efficiency [2]. The determined dependence of the normalized CCF of two ES signals on f_2 - f_1 (proportional to the corresponding UHR spatial separation) was Fourier transformed and multiplied by the ES homodyne spectra (Fig. 3) to get the ES spectra $I_{q_r,\Omega}$ shown in Fig. 4. As it is seen, the wavenumber of fluctuations contributing to the ES signal in the central zone and at the edge differs by a factor of 3-4 indicating different physical origin of turbulence in these regions.

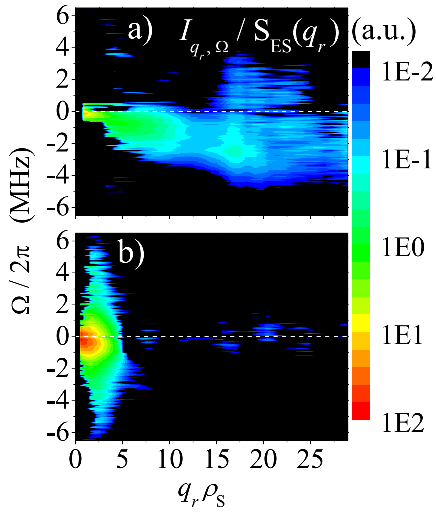

Fig. 5. Turbulence spectra obtained by 65 (a) and 57 GHz (b) probing.

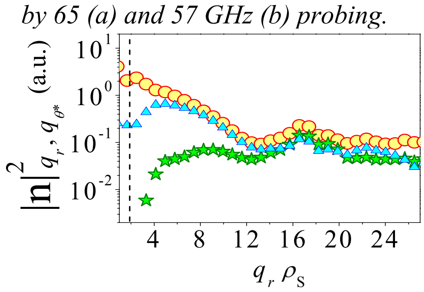

Fig. 6. Turbulence q-spectra at r = 3.8 cm, t=36 ms.

The turbulence spectra $|n|^2_{q_r,\Omega}$ can be obtained from ES spectra of Fig. 4 after accounting for the strong ES efficiency dependence on fluctuation wavenumber [2]. As it is seen in Fig. 5a, in central zone the turbulence spectrum is very wide both in frequency and in radial wavenumber. It occupies the entire ETG instability domain ($20 > q_r\rho_s > 2$), whereas at the plasma edge the turbulence is exponentially decaying with growing wavenumber, being only observable at $q_r\rho_s < 5$. The ETG turbulence wavenumber spectra obtained from Fig. 5a following values maximal in frequency (yellow points) or cutting at 2 and 4 MHz (blue and green points, correspondingly) are shown in Fig. 6. They demonstrate rather weak (less than two orders of magnitude) spectrum variation with growing wavenumber and thus confirm the above conclusions. The temporal behaviour of the ETG turbulence density perturbation $\delta n\sim\int|n|^2_{q_r,\Omega}\,dq_r d\Omega$

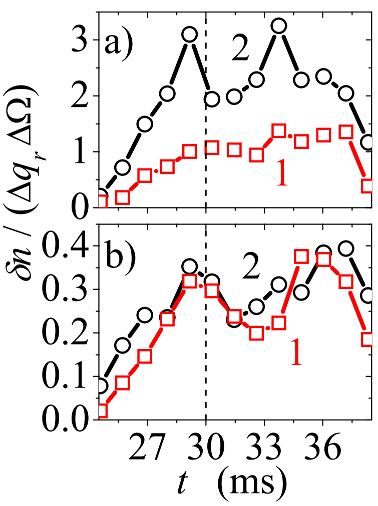

Fig. 7. Integrated turbulent density perturbation for 65 GHz (1) and 64 GHz (2) probing.

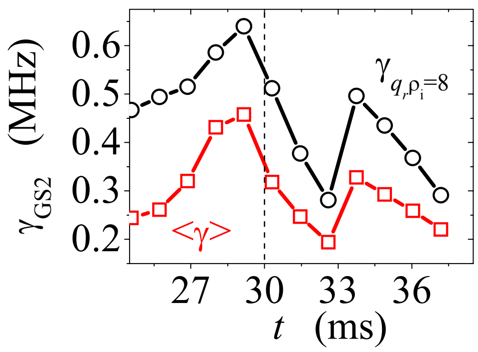

Fig. 8. The growth rate behavior calculated with the GS2 code for linear modes.

integrated over all the wavenumber and frequency domain where it was measured ($\Delta q_r \rho_s$ =[2..16]; $\Delta\Omega/2\pi$ = [-3.7 .. -0.4] MHz) is shown in Fig. 7a for probing frequencies 65 and 64 GHz. As it is seen, in both cases the turbulent density perturbation is growing at t < 29.2 ms and decaying at t > 33.7 ms, whereas at 29.2 ms < t < 33.7 ms its behavior is non monotonous. Similar evolution is typical also for the small-scale, high frequency component ($\Delta q_r \rho_s$ =[5..16]; $\Delta\Omega/2\pi$ = [-3.7 .. -1.8] MHz), as it is seen in Fig. 7b.

It is important to note that this behavior well correlates with the ETG mode instability growth rate evolution, as provided by the GS2 code [9]. The corresponding dependencies are plotted on Fig. 8 for the growth rate $<\gamma>$ averaged over the interval 0.1< $q_r \rho_i$ <10 (squares) and the growth rate calculated for $q_r \rho_i$ =8 (circles).

Conclusions

Summarizing the paper results it is worth to underline that measurements of the small-scale turbulence component performed in the gradient FT-2 discharge zone where the ETG mode is definitely unstable both according to the threshold conditions [1] and to the GS2 computation have resulted in observation of wide radial wavenumber spectra at 2 < $q_r \rho_s$ < 16. It is shown that temporal evolution of the turbulence level in the dynamic CRU discharge follows the behavior of the ETG instability growth rate as provided by the GS2 code, thus giving additional confirmation of its ETG mode origin.

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1. Jenko F., Dorland W., Kotschenreuther M. and Rogers B.N. 2000 *Phys. Plasmas* **7** 1904
2. E.Z. Gusakov, A.D. Gurchenko, A.B. Altukhov et al. 2006 *Plasma Phys. Control. Fusion* **48** A371
3. A.D. Gurchenko, E.Z. Gusakov, A.B. Altukhov et al. 2007 *Nucl. Fusion* **47** 245
4. T.L. Rhodes, W.A. Peebles, J.C. DeBoo et al. 2007 *Plasma Phys. Control. Fusion* **49** B183
5. E. Mazzucato, D.R. Smith, R.E. Bell et al. 2008 *Phys. Rev. Lett.* **101** 075001
6. E. Mazzucato, et al. http://www-pub.iaea.org/MTCD/Meetings/FEC2008/ex_10-2ra.pdf
7. E. Gusakov, et al. http://www-pub.iaea.org/MTCD/Meetings/FEC2008/ex_10-2rb.pdf
8. A.D. Gurchenko, et al., *35 EPS Conf. on Plasma Physics, Hersonissos, 2008*, ECA Vol.32D, O-4.046.
9. M. Kotschenreuther, G. Rewoldt, W.M. Tang, *Comp. Phys. Comm.* **88**, 128 (1995)