STUDIES OF EDGE TURBULENCE IN THE URAGAN-3M TORSATRON

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Spatial and temporal behavior of the edge fluctuations and their correlation with plasma density behavior inside the confinement region of the Uragan-3M torsatron are investigated. The key role of the radial electric field in turbulent transport suppression is shown.

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1. INTRODUCTION

Electrostatic turbulence-driven anomalous particle and heat transport in the edge plasma is generally believed to have a determinative effect on plasma confinement in magnetic fusion devices (see, e. g. [1]).

Highly important characteristics of edge plasma turbulence, such as the fluctuation amplitude, spectra, skewness, kurtosis, turbulence-induced transport, are investigated in the Uragan-3M (U-3M) torsatron, using high resolution measurements of density (ion saturation current, $\tilde{I}_s$) and potential (floating potential, $\tilde{V}_f$) fluctuations with the help of movable Langmuir probe arrays.

A strong electric field shear impact on turbulence suppression is found.

Changes in the radial turbulent particle flux near the plasma boundary [2,3] and their correlation with plasma density behavior inside the confinement region are a good indicator of transition to improved confinement modes.

2. EXPERIMENTAL CONDITIONS AND MEASUREMENT TECHNIQUES

In the l/m=3/9 U-3M torsatron (R_0 = 1 m, $\bar{a} \approx 0.12$ m, $\iota(\bar{a}) \approx 0.3$) the whole magnetic system is enclosed into a 5 m diameter vacuum chamber, so that an open natural helical divertor is realized. Schematic draft of U-3M helical coils (top view) with indication of disposition of RF antenna and diagnostics are shown in Fig. 1.

The toroidal magnetic field is B_ϕ = 0.7 T. A "currentless" plasma is produced and heated by RF fields ($\omega \lesssim \omega_{ci}$, 8.8 MHz). The RF power irradiated by the frame-type antenna is $\lesssim$ 200 kW in the 30...60 ms pulse.

The working gas (hydrogen) is admitted continuously into the vacuum chamber at the pressure of ~10^{-5} Torr. The line-averaged electron density is $\bar{n}_e \sim 10^{12}$ cm^{-3}, and the electron temperature (estimated by 2nd harmonic ECE) attains $T_e(0) \approx 600$ eV and falls to ~50 eV (ECE, probes) at the edge. A two-temperature ion energy distribution (T_{i1}~50…80 eV, T_{i2}~250…400 eV) with a suprathermal tail is formed [4] (hereinafter, the hotter and suprathermal ions are named as "fast ions", FI).

The poloidal cross-section where edge fluctuations, $\tilde{I}_s$ and $\tilde{V}_f$, are measured using a movable four-tip Langmuir probe array (MP, denoted by ∗) [5] is depicted in Fig. 2.

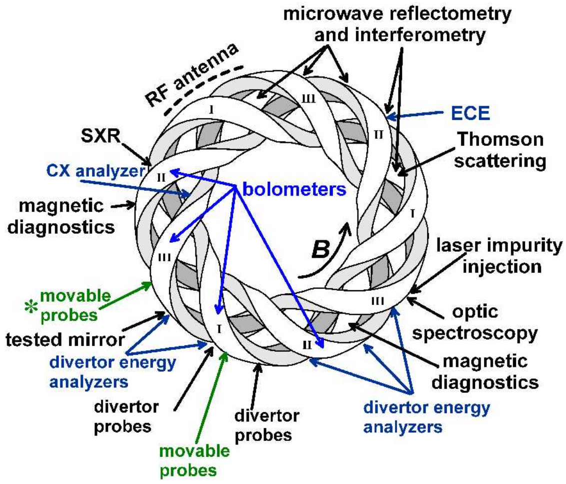

Fig. 1. Magnetic coils I, II, III and diagnostics. Position of MP used in the experiment is denoted with asterisk

The probe array consisting of four single probes 1-4 (shown in Fig. 2 as seen from the center outward) is moved parallel to the torus midplane 1 cm above it, from 0.6 cm inside to 2 cm outside LCFS (its calculated position r = 10 cm).

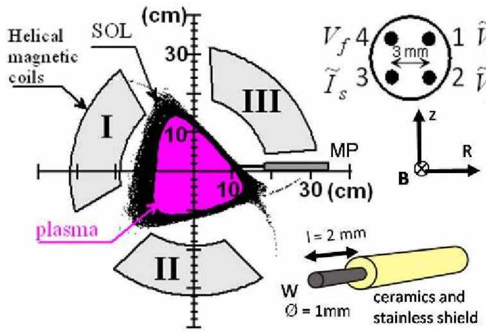

Fig. 2. Poloidal cross-section where the movable probes 1-4 are positioned, with the calculated edge field line structure and the sketch of one probe

A simultaneous registration of one $\tilde{I}_s$ and two $\tilde{V}_f$ signals together with the equilibrium potential V_f is made. As a recording facility, a 12 bit ADC with 1.6 μs sampling rate/channel is used.

To estimate the radial turbulent flux $\tilde{\Gamma}$, the relation $\tilde{\Gamma}(t) \propto \tilde{I}_{s3}(t)[\tilde{V}_{f1} - \tilde{V}_{f2}(t)] \tilde{V}_f$ is used.

3. STUDY OF E_r SHEAR INFLUENCE ON EDGE TURBULENCE

In the experiment presented, beginning with some threshold RF power ~170 kW, the active stage of the RF discharge can be divided into three phases, each of them is characterized by a stronger or weaker edge E_r shear (Fig 3). The stronger electric field gradient in phases 1 and 3 results from burst-like fast ion loss at the start of phase 1 and at the end of phase 2 [6].

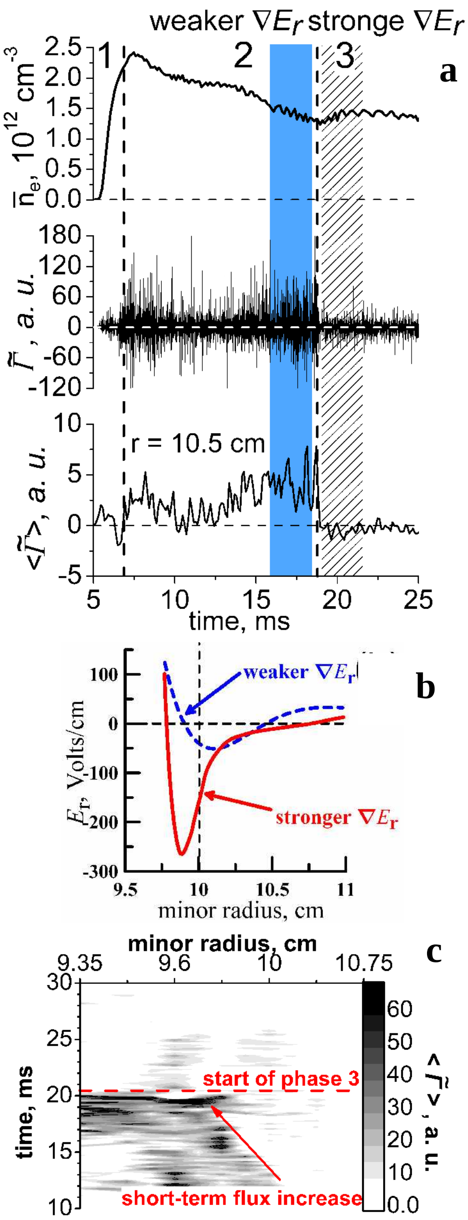

Fig. 3. (a) Plasma density (top), turbulent flux (middle) and average turbulent flux (bottom); (b) qualitative behavior of E_r radial profiles; (c) average turbulent flux space-time evolution

Qualitative behavior of the E_r radial profiles (estimated from V_f measurements) before and after the transition from phase 2 to phase 3 are shown in Fig. 3, b.

A higher E_r shear and, consequently, a higher $E\times B$ velocity shear at phases 1 and 3, result in decrease of turbulence-induced anomalous transport (Fig. 3 a,c, middle and bottom curves).

An obvious correlation between $\bar{n}_e$ and $<\tilde{\Gamma}>$ is observed. The faster density decay inside the confinement region corresponds to the stronger edge turbulent flux, whereas the better plasma confinement corresponds to a weaker turbulent flux (Fig. 3, a).

In Fig. 3, c, before the start of phase 3, a significant short-time increase of the turbulent transport ($r \approx 9.7$ cm) correlates with the burst-like fast ion loss [2,3].

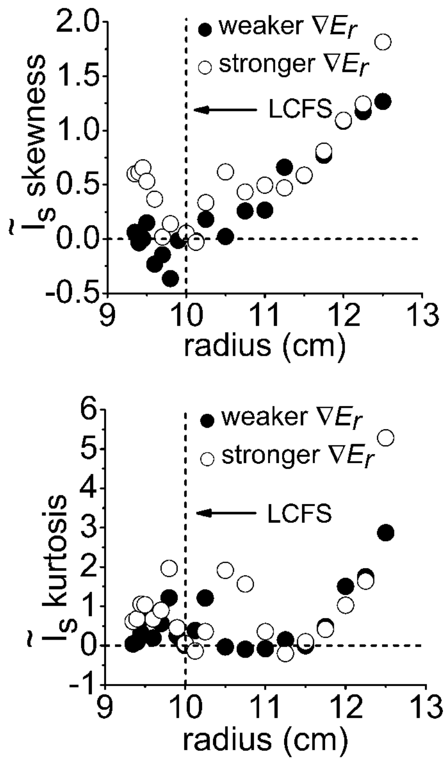

Fig. 4. Skewness and kurtosis as functions of small radius

In Fig. 4 $\tilde{I}_s$ skewness (S) and kurtosis (K) are presented as functions of minor radius. When E_r shear is weaker, $\tilde{I}_s$ fluctuations are negatively skewed (holes) close to the LCFS. After transition to phase 3 the holes disappear. These data were obtained for the same positions of MP (compare with [7]).

The universal character of the parabolic relation between K and S of $\tilde{I}_s$ in magnetically confined plasmas was confirmed for the data obtained in U-3M with the following fit parameters [8]: $K=1.54S^2 + 2.68$.

That means that in U-3M, the edge transport strongly differs from the diffusive picture associated with the Gaussian distribution.

Earlier, it was shown in [9] that the probability density functions of $\tilde{I}_s$ and $\tilde{V}_f$ measured in the edge plasma of U-3M can be classified as stable Lévy distributions.

In Fig. 5 time-frequency evolution of the $\tilde{I}_s$ power spectrum is depicted in two space locations, close (Fig. 5, a, r = 10.5 cm) and more distant (Fig. 5, b, r = 12.0 cm) relative to LCFS.

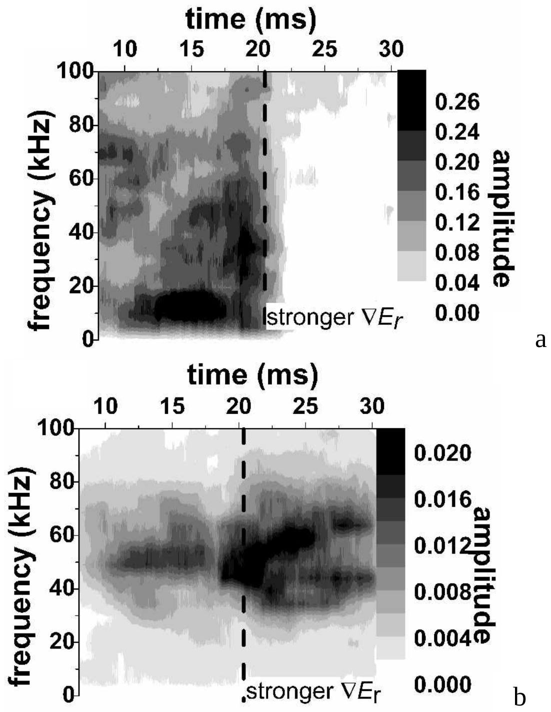

Fig. 5. P_s *power spectrum evolution*

After transition from phase 2 to phase 3, the increase of electric field shear results in decrease of fluctuation power in all the spectral range close to the LCFS (a higher electric field gradient), while more distant from the LCFS the power spectrum does not change significantly (a lower electric field gradient).

SUMMARY

1. The radial electric field shear strongly affects edge turbulent transport in the Uragan-3M torsatron.
2. In the U-3M, the edge transport strongly differs from the diffusive picture associated with the Gaussian distribution. For the U-3M data the universal statistical relation $K=1.54S^2 + 2.68$ is satisfied.

The U-3M edge turbulence data are included into the International Stellarator/Heliotron Edge Turbulence Data Base.

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ИССЛЕДОВАНИЯ ГРАНИЧНОЙ ТУРБУЛЕНТНОСТИ В ТОРСАТРОНЕ УРАГАН-3М

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Исследована динамика флуктуаций вблизи границы плазмы и их корреляция с поведением плотности внутри объема удержания в торсатроне Ураган-3М. Показана основная роль радиального электрического поля в подавлении турбулентного потока.

ДОСЛІДЖЕННЯ ГРАНИЧНОЇ ТУРБУЛЕНТНОСТІ У ТОРСАТРОНІ УРАГАН-3М

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Досліджено динаміку флуктуацій поблизу межі плазми та їх кореляція з поведінкою щільності усередині об'єму утримання в торсатроні Ураган-3М. Показана основна роль радіального електричного поля в пригнічені турбулентного потоку.