Scrape-off layer turbulence modulated by Mirnov oscillations *)

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1 Introduction

In some tokamak discharges, natural or externally applied magnetic oscillations can modulate electrostatic turbulence and change the scrape-off layer characteristics and particle transport [1–4]. In TCABR tokamak, we analyze the scrape-off layer plasma turbulence for discharges with electrostatic fluctuations, spontaneously modulated by Mirnov oscillations. Numerically, we estimate that the contribution of the Mirnov oscillations frequency range to the total turbulence-driven particle transport is significant. Experimentally, we confirm the importance of this contribution to plasma discharges with turbulence modified by a DC-biased electrode inside the plasma [5–7] or an ergodic magnetic limiter (EML) [8]. Our study is based on wavelet power spectral analysis and distributions of intermittent bursts [9–12] of plasma potential and density fluctuations, measured by a set of Langmuir probes and Mirnov magnetic coils.

2 Experimental set-up

The experiment is performed in a hydrogen circular plasma in TCABR [13] (major radius $R = 0.61\,\mathrm{m}$ and minor radius $a = 0.18\,\mathrm{m}$). The plasma current is

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100 kA, the current duration 100 ms and the toroidal field $B_t = 1.1$ T. The multipin Langmuir probe measures the fluctuations of floating potential and ion saturation current, and mean density, temperature, and plasma potential. Magnetic fluctuations are obtained from the Mirnov coils at ≈ 45 degrees from the probe system. The time-series measurements are recorded at a sampling rate of 1 MHz. To examine the time behavior of the fluctuations, we split the data into consecutive segments of 1024 data points (≈ 1.02 ms) and apply wavelet analysis to each segment. In the scrape-off layer, at $r/a = 1.17$, the mean values of density, temperature, and plasma potential are $n_e \approx 1.5 \times 10^{18}\,\mathrm{m}^{-3}$, $T_e \approx 5$ eV, and $V_p \approx 17$ V.

The DC voltage is applied to an electrode, which is located inside the plasma, at $r/a = 0.89$, at ≈ 90 degrees from the probe system. More details about the DC biasing are described elsewhere [5, 6]. For the analyzed discharges the pulse of +470 V is applied during a time interval of 30 ms. The ergodic magnetic limiter (EML) is installed inside the vacuum vessel at ≈ 10 degrees from the probe system. It was projected to create $m = 3$ magnetic perturbations at the plasma edge. The current used for the analyzed data was 1.7 kA, during 30 ms of the discharge. More details about the EML are described elsewhere [8].

3 Electrostatic turbulence modulated by Mirnov oscillations

A peculiarity of our data is the modulation of electrostatic turbulence by Mirnov oscillations. Figure 1 shows the oscillations on the Mirnov coil signal and fluctu-

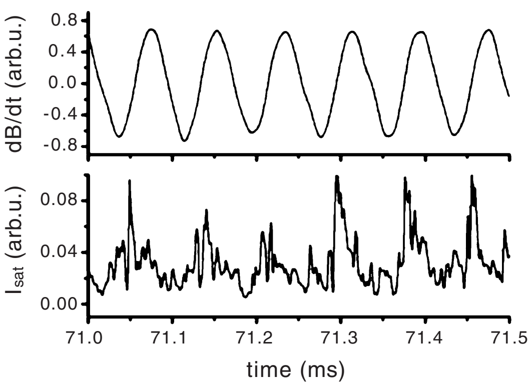

Fig. 1. Oscillations on the Mirnov coil signal and fluctuations of the ion saturation current, for a chosen time interval.

ations of the ion saturation current so that the modulation can be easily seen. Figure 2 shows the dominant modes of the MHD spectrum. Figure 3 shows the superposition of the spectra of the electrostatic fluctuations and the Mirnov oscillations at around 10 kHz. The observed partial spectra superposition, characteristic of TCABR tokamak, is the object of the present investigation. For that, we analyze the data with and without bandpass filtering for the frequency interval from 8 to 15 kHz. Thus, we apply this numerical filter to the plasma potential fluctuations to

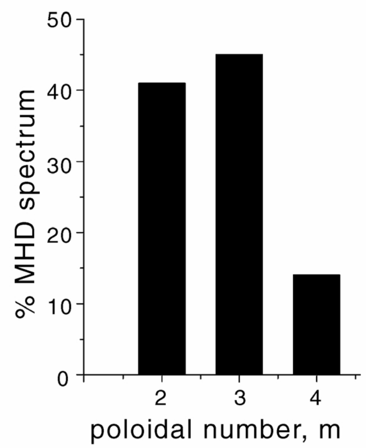

Fig. 2. MHD spectrum of Mirnov oscillations

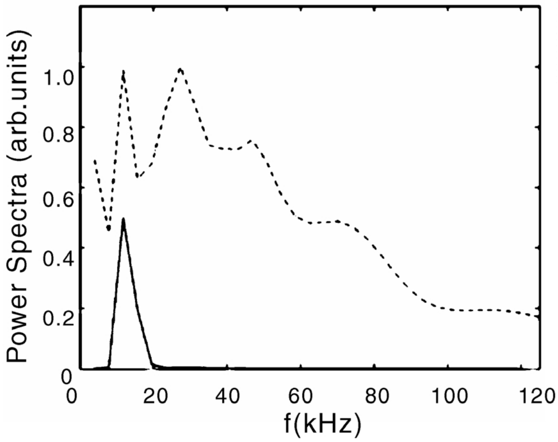

Fig. 3. Superposition of the spectra of Mirnov oscillations (——) and fluctuations of potential (- - - -) at $r/a = 1.17$.

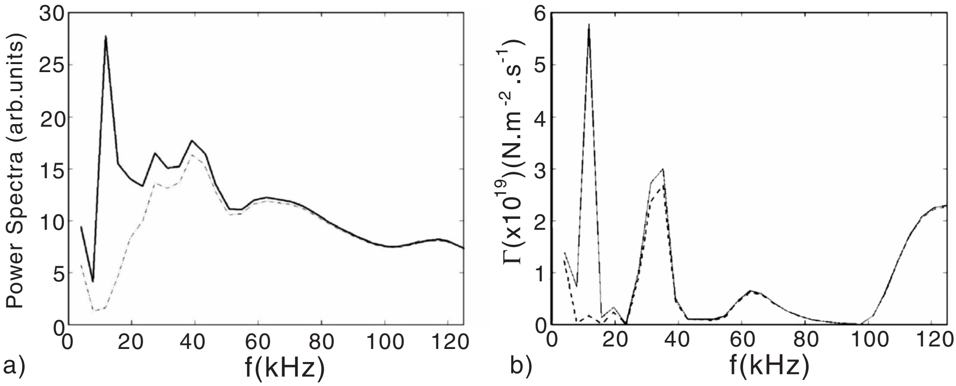

Fig. 4. Superposition of a) the potential fluctuation spectrum and b) the particle transport spectrum (——), and the respective filtered spectra without the frequencies corresponding to Mirnov oscillations (- - - -), for a time interval of 1.02 ms at $r/a = 1.17$.

obtain Fig. 4a, which shows a good concordance of the spectra for high frequencies outside the filtered region. To show the influence of Mirnov oscillations on the turbulence, driven particle transport, we calculate it from the fluctuating density, $\tilde{n}_e$, and radial velocity, $\tilde{v}_{\mathrm{r}}$, obtained from the measured potential and ion saturation current fluctuations:

$$\Gamma = \langle \tilde{n}_{\mathrm{e}} \tilde{v}_{\mathrm{r}} \rangle \, .$$

We compare, in Fig. 4b, transport spectra with and without data excluded by the bandpass filtering for the frequency interval from 8 to 15 kHz, indicating a significant transport in the frequency components of the magnetic oscillations outside the considered range. The difference between particle transport with and without filtering is $\approx$ 10% of the total transport, indicating that significant part of the turbulence-driven transport occurs in the frequency range of the Mirnov oscillations. Thus, alteration on the Mirnov oscillations may influence the turbulence and its associated particle transport.

4 Turbulence control

To experimentally check the conjectured influence of Mirnov oscillations on the transport, we investigate plasma discharges, for which the turbulence is modified by external perturbations produced by DC biasing or an ergodic magnetic limiter. Initially, we show in Fig. 5a the superposition of transport spectra without and with DC bias. As in other discharges analyzed in this work, the DC biasing reduces the transport driven by high frequency components. In the example of Fig. 5a, the transport reduction is $\approx$ 25%, however, this reduction may be even higher for optimized machine conditions (up to $\approx$ 70%). This reduction could be related to the observed increase of phase coupling between wavelet turbulence components with frequencies f_1 , f_2 , and $f = f_1 + f_2$. To demonstrate that, we combine wavelet and bispectral analysis, calculating the summed and the total wavelet-bicoherence. Thus, Fig. 5b shows the superposition of cross-summed bicoherence for potential and density fluctuations without and with DC bias, with magnetic filtering. The reason for the observed transport reduction could be the shear-layer displacement to a inner position due to the electric field created by the DC biasing. In fact, it has been recently reported that the shear-layer, on the last closed plasma magnetic surface, changes its position as the magnetic configuration is modified [3,7]. In spite of the above results, we stress that the DC biasing does not modify the turbulence-driven transport on the Mirnov frequency range, so in TCABR the effectiveness of DC biasing to control transport is partially limited by the action of the Mirnov oscillations. Data obtained with the perturbation by the ergodic magnetic limiter

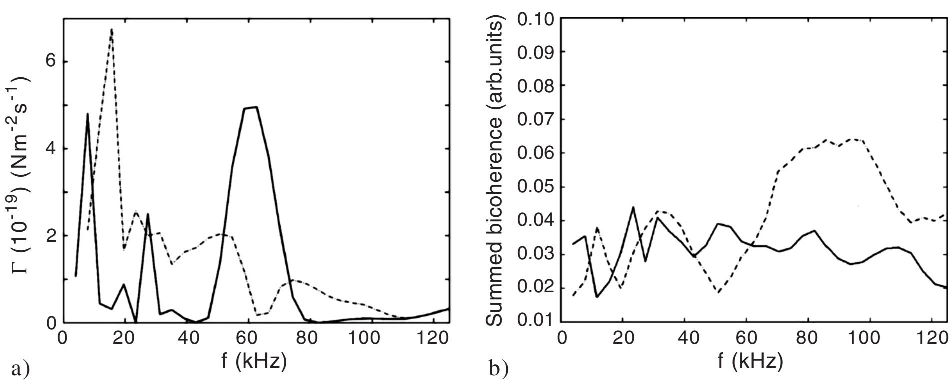

Fig. 5. Superposition of a) the particle transport spectra and b) of filtered summed cross-bicoherence between potential and ion saturation current fluctuations, without (——) or with (- - - -) DC biasing, for time intervals of 1.02 ms at $r/a = 1.17$.

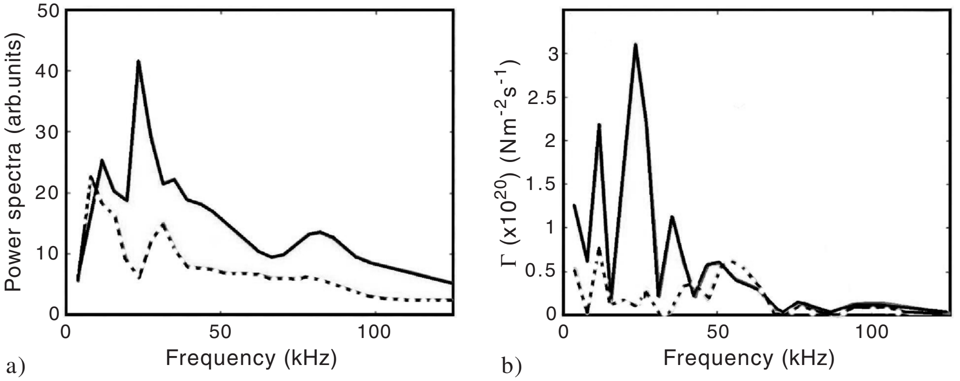

Fig. 6. Superposition of a) the potential fluctuation spectra and b) the transport spectra, without EML (——) or with (- - - -) EML perturbation.

also indicate a transport reduction as that one obtained with DC biasing. Figure 6a shows the superposition of the potential fluctuation spectra without or with EML perturbation, indicating a considerable reduction of fluctuation amplitudes. Figure 6b shows the superposition of the transport spectra without or with EML application with a reduction of 70% due to the EML action. The influence of Mirnov modulation in this reduction is $\approx 20\%$ of the total transport. The study of nonlinear coupling shows the same results as those obtained with DC bias and indicates that it is almost not affected by Mirnov modulation.

5 Conclusion

In the TCABR plasma discharges analyzed in this work, the electrostatic turbulence is modulated by the Mirnov oscillations in the frequency range around 10 kHz. This modulation increases the particle transport in the frequency range of the Mirnov oscillations. This effect is observed even for the externally controlled turbulence achieved by using the DC external perturbation or the ergodic magnetic limiter. Furthermore, we show that, for these modified discharges, the transport reduction is more effective for the turbulent fluctuations with frequencies higher than those of Mirnov oscillations. Finally, the non-diffusive radial transport due to the intermittent bursts is not significant in the Mirnov frequency ranges, but only in the broadband spectrum.

Our results indicate that the Mirnov oscillations influence the electrostatic turbulence and plasma transport cannot be neglected in tokamaks for which a partial superposition of magnetic and electrostatic spectra occurs.

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