

POTENTIAL TURBULENCE IN TOKAMAK PLASMAS

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Abstract

Microscopic potential turbulence in tokamak plasmas are investigated by a multi-sample-volume heavy ion beam probe. The wavenumber/frequency spectra $S(k,\omega)$ of the plasmas potential fluctuation as well as density fluctuation are obtained for the first time. The instantaneous turbulence-driven particle flux, calculated from potential and density turbulence has oscillations of which amplitude is about 100 times larger than the steady-state outwards flux, showing sporadic behaviours. We also observed large-scale coherent potential oscillations with the frequency around 10-40 kHz.

1. Introduction

Local measurement of plasma turbulence in a toroidal magnetic confinement device has been the target of the intensive experimental research, since the anomalous particle/energy confinement may be caused by the microturbulence in the plasma. The heavy ion beam probe (HIBP) is particularly suited for the local study of the turbulence of tokamak plasmas because of the potentiality for density and potential measurement. It is, however, difficult to measure by HIBP potential fluctuations due to the microintability in the tokamak plasmas, since the fluctuating potential is smaller than the acceleration voltage of a probing beam by many orders. Therefore, the measurement of the potential turbulence in the core region of the tokamak plasma by HIBP tends to have a low signal-to-noise ratio (SNR) and only a few results were published so far [1]. In addition, the large-amplitude quasi-coherence modes with the frequency to 30 to 40 kHz, complicate the potential turbulence of small scale oscillations. To tackle these difficulties we enhanced the sensitivity of the measurement by increasing the beam current and by the employment of a multiple-detector system. By these improvements we are now able to obtain the wavenumber/frequency spectra $S(k,\omega)$ of the density and potential turbulence, and the wavenumber-resolved fluctuation-driven particle flux in the high temperature region of JIPP T-IIU tokamak plasma [2].

2. Experimental apparatus

a) Tokamak system.

The JIPP T-IIU tokamak was operated at 3 tesla. Its major radius is 93 cm with a minor radius of 23 cm. Nearly perpendicular neutral beam injection (NBI), with the injection line tilted in the co-direction (the direction of the plasma current) by only 9 degrees, is employed. The main diagnostics are a YAG Thomson scattering apparatus with 28 spatial measurement points and a 100 Hz repetition rate for detailed profiles of plasma density and electron temperature, an 8-channel-ECE polychromator, a 6-channel-FIR interferometer and a charge recombination spectrometer using NBI for ion temperature profiles.

b) a heavy ion beam probe

For the measurement of potential microturbulence, we have to use stable power supplies for the acceleration of the beam and for the energy analyzer of the secondary beam. We connected a very stable power source (up to 500 kV) originally developed for the electron microscope, to the electrostatic acceleration column of the accelerator. The chromatic aberration of the electron microscope is induced by the ripple of its high-voltage power source. The ripple in our case is reduced to less than 2 Volt for 500 kV. We also reduced the high-frequency

ripple on the upper electrode of the parallel-plate energy analyzer to about 0.02 V out of 100 kV by use of an LC filter in SF₆ gas.

This parallel plate analyzer is intrinsically suitable for multiple sets of the entrance slit and detector (many sample volumes) since the electric field is uniform. We installed 7 sets of an input slit and 7 sets of detectors. The signals from 6 input slits are usually available without careful adjustment. A 500 keV thallium beam of a few tens of microamps can be focused to a diameter of about 2 millimeters in the tokamak by a cylindrical deflector and two electrostatic quadrupole lenses (doublet).

Each plate is made of stainless-steel and is connected to low-noise amplifiers. The sampling rate at 12 bits AD conversion is 2 MHz and the frequency band width of the detector amplifier shows the 3 dB decrease of gain at 300 kHz.

The displacement of the beam center in the poloidal direction (the change of the plasma potential at the sample volume) is detected by the difference of the upper ($s_u(t)$) and lower detector currents ($s_u(t)$, $s_d(t)$) normalized by sum of them (ND) by the following equation [3],

$$nd_{p, j}(t) = \frac{s_u(t) - s_d(t)}{s_u(t) + s_d(t)}.$$

The local density at the sample volume may be proportional to the sum of the detector currents and expressed by

$$s_j(t) = s_u(t) + s_d(t)$$

3. Potential and density turbulence

a) Quasi-coherent mode

First of all we want to emphasize that the potential measured by a heavy ion beam probe has fairly large potential fluctuations at 30 to 40 kHz. Figure 1 shows Expanded view and Fourier spectra of the sum of the secondary current s , normalized ratio of upper and lower plates (nd_p) proportional to the local potential change at the sample volume.

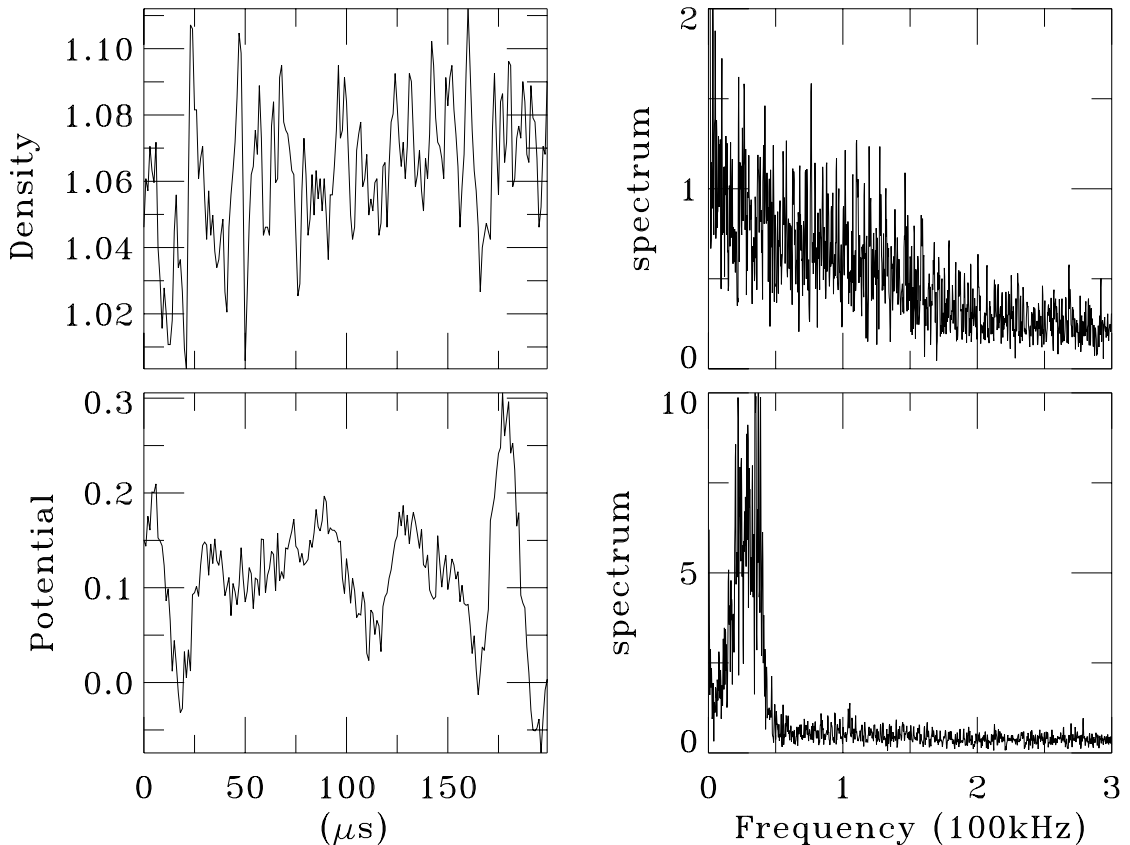


Figure 1. Expanded view and Fourier spectrum of the sum of the secondary beam intensity (proportional to local density) and nd (proportional to potential) at $r/a_p = 0.5$. Conversion ratio is $\times 600V$ in this case.

The sample volumes are around $r/ap = 0.5$. The density turbulence extends to higher frequency while the oscillations with around 40 kHz are dominant in the potential fluctuations. The potential fluctuation or beam energy fluctuation from Fourier spectrum of nd_p in Fig. 1 is about $60 V_{p-p}$ since the conversion rate from nd to plasma potential change is $600V/nd$. These potential fluctuation of the large amplitude in this frequency range were originally discovered in HIBP measurement at the TEXT tokamak[3].

The correlations of density (sum of the secondary beam), potential (change of the beam energy) $nd_{p,j}$, s_j is very small. The mode number of the potential oscillation can be estimated to be $m=0$ since the phase shift of the cross correlation coefficient $\rho(nd_{p,1}, nd_{p,j})$ is almost zero and the peak values are almost 1. Accordingly, we can conclude that these potential fluctuations are large-scale and quasi-coherent. The correlation between density and potential turbulence is small.

In order to verify that these oscillations are not induced by several power supplies of high and low voltage in HIBP we checked the ripple of all power supplies. In addition, these oscillations are not observed when the plasma is replaced by the gas. Because of the fairly high injection energy of 300 kV to 500 kV, the injected Tl^+ ions are easily ionized to Tl^{++} by the puffed helium neutral gas in the tokamak vacuum vessel. Under the comparable detector currents by the intensive helium gas puffing, this large amplitude oscillations of 30-40 kHz disappears.

Our present conclusion is as follows. At the certain layer near the plasma boundary, there occurs regularly the potential fluctuations of the very large amplitude. Since the potential tends to the surface quantity because of the very high electric conductivity along the magnetic field line of force and the potential is an integral of the electric field across the magnetic field from the vacuum vessel to the certain magnetic surface, we can explain the $m=0$ property and no signals in the outer plasma area. Also, the ECE and soft x-ray pin diode signals comes out of rather hot area inside the certain layer, we can not find the correlation with ECE and soft x-ray.

b) high frequency turbulence

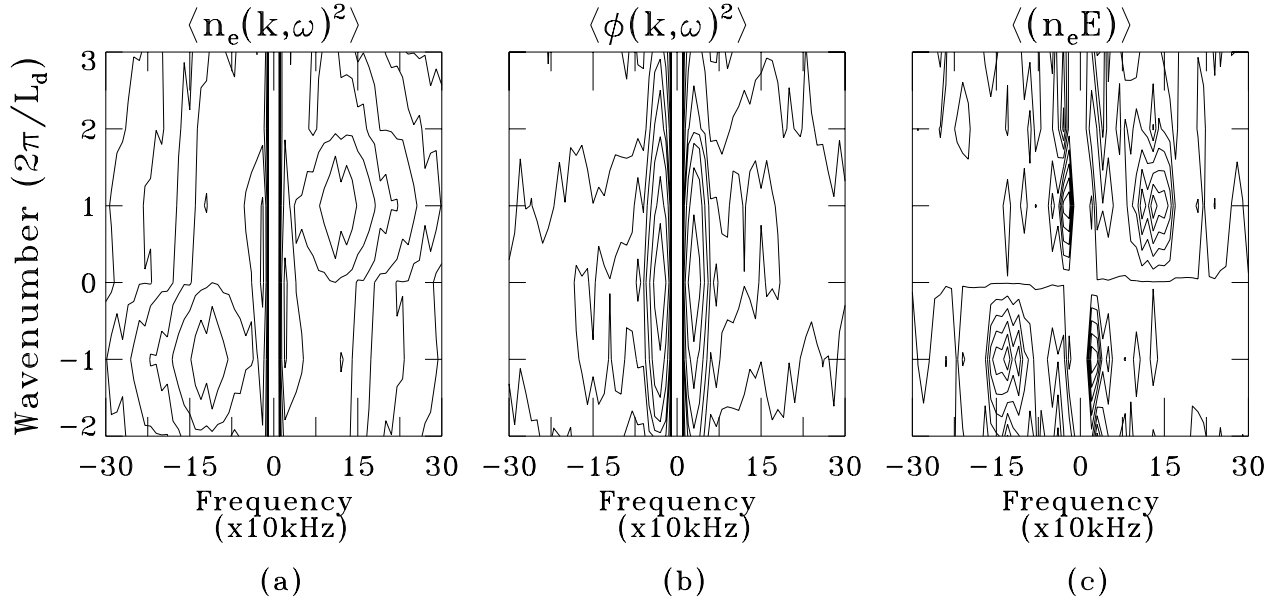


Figure 2. Contours of the two-dimensional (space/time) Fourier spectra of density and potential turbulence (a), (b). and $\langle n_e E \rangle$ proportional to the particle flux driven by the turbulence, (c). $L_d = 2.5$ cm.

Figure 2 shows the contours of two-dimensional (wavenumber/frequency) spectra of the density $S_{n_e}(k, \omega) = \langle n_e(k, \omega)^2 \rangle$, (a), potential $S_{\Phi}(k, \omega) = \langle \Phi(k, \omega)^2 \rangle$, (b), and the quantity proportional to the turbulent-driven particle flux, $\text{real}[\langle n_e(k, \omega) E(k, \omega) \rangle]$, (c), at the position of

about $r/a_p = 0.5$ and $\theta=0$ (weaker B_t field side). The particle flux $\langle nv \rangle$ driven by the turbulent electric field is proportional to $\langle nE \rangle$ through E/B particle drift. $S\Phi(k,\omega)$ is noisy but similar to $S_{ne}(k,\omega)$. Fig. 2(c) and detailed analysis shows that the oscillations around 150 kHz mostly cause the turbulence-driven particle flux. This flux is outwards and its magnitude corresponds to the particle confinement time of about 5 ms under the assumption of the uniformity of the flux on the magnetic surface.

Figure 3(a) shows the calculated turbulence-driven instantaneous total particle flux $\overline{n_e(t) v(t) = n_e(t) \overline{E(t)} / B_t}$ at each sampling time of $1 \mu s$ for the case of Fig. 2. Figure 3(b) shows a time behaviour of the turbulence-driven total particle flux of Fig. 3(a) averaged for $100 \mu s$. The characteristics of the wave forms are much similar in (a) and (b) even though the time scale is $1 \mu s/\text{div.}$ for the instantaneous particle flux (a) and $100 \mu s/\text{div.}$ for the averaged flux. The difference is that we are able to observe the averaged negative flux (outwards) readily among the large fluctuations in Fig. 3(b).

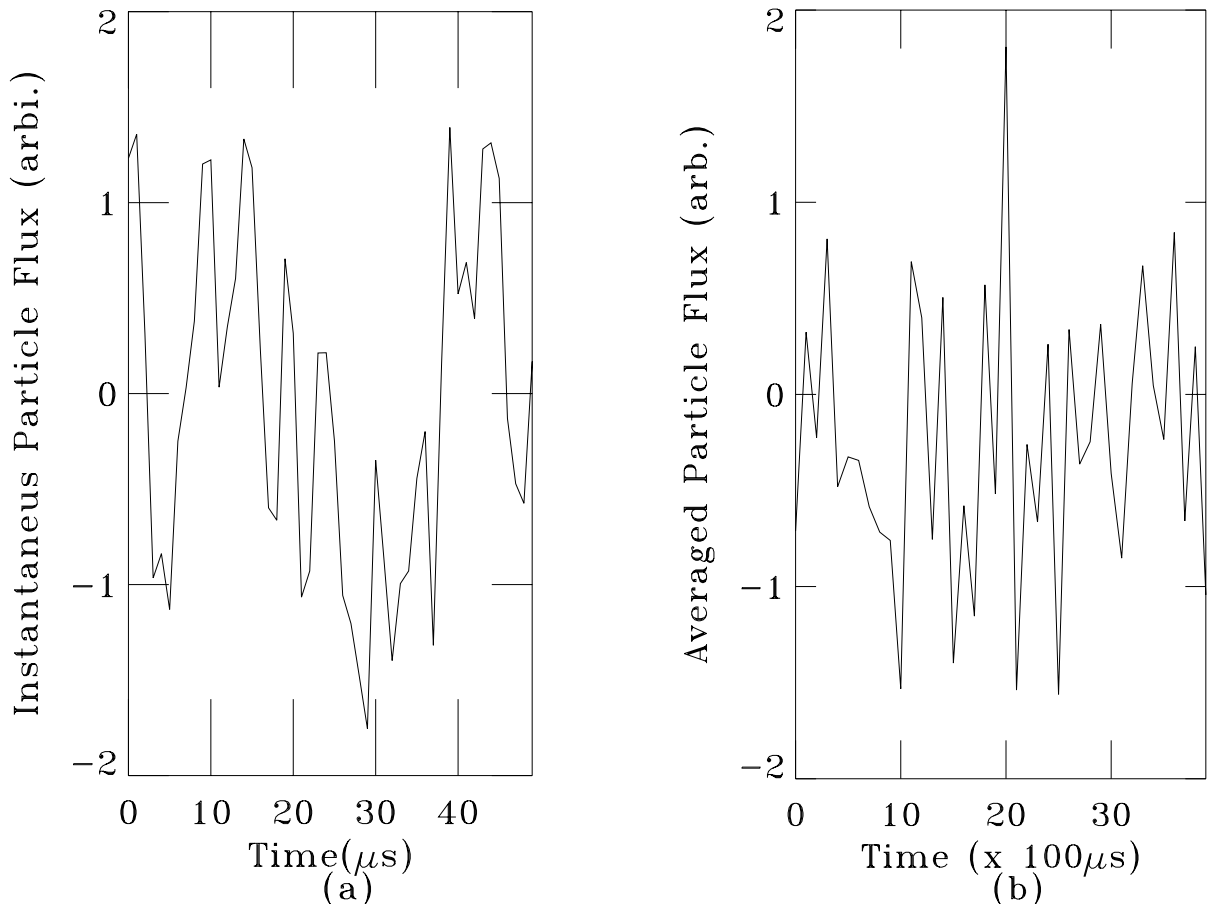


Figure 3. The instantaneous turbulence driven-particle total particle flux, (a) and the averaged(for $100\mu s$) instantaneous particle flux, (b). Both have arbitrary vertical scales, but the vertical scale of (a) is 100 times larger than that of (b).

The appearance of the quasi-steady flux in Fig. 3(b) can be understood, since the main density turbulence has the correlation time of a few microseconds. The ratio of the instantaneous flux to the average flux is so large (about 100) and the polarity of the instantaneous flux is always changing. We may call these signals as sporadic or intermittent behaviour.

Reference

- [1] Forster, J. C., et al., Trans. Plasma Sci. **22** (1994) 359.
- [2] HAMADA, Y., et al., Nucl. Fusion **36** (1996) 515 , 1047, **37** (1997) 999.
- [3] Tsui, H.Y.W. et al., Phys. Fluids **B5** (1993) 1274.