Spatio-temporal evolutions of plasma turbulence fluctuations on LMD-U

H. Arakawa[1], S. Inagaki[2], Y. Nagashima[3], T. Yamada[3], K. Kamataki[2], T. Kobayashi[1], S. Sugita[1], M. Yagi[2], N. Kasuya[4], A. Fujisawa[4], S. -I. Itoh[2] and K. Itoh[4]

[1] *Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, 6-1 Kasuga-Koen, Kasuga 816-8580, Japan*

[2] *Research Institute for Applied Mechanics, Kyushu University, 6-1 Kasuga-Koen, Kasuga 816-8580, Japan*

[3] *Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa 277-8561, Japan*

[4] *National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan*

Introduction

For the realization of a thermonuclear fusion reactor, the turbulence-driven transport is one of the most important issues to be clarified. Drift wave turbulence and structural formation of turbulence thus have been investigated extensively. It is known that the fluctuations of various spatial and temporal scales co-exist in turbulent plasmas [1]. However, only a few observations of turbulence dynamics have been reported. We investigate the growing and damping of fluctuations and their time scales in linear magnetized plasma confined in LMD-U device. By use of a poloidal probe array, spatio-temporal structure of density fluctuations are studied.

In this study, we observed the existence of two structures in power spectrum of density fluctuation. The peaks of coherent modes in each structure satisfy ω/k = constant ($\omega = 2\pi f$: angular frequency, $k = m/r$: poloidal wave number, where m is poloidal mode number and r is radius.). Here, ω/k indicate the phase velocity including $E \times B$ velocity. The delay time of response between modes at growing or damping phase are measured using the frequency filter and the cross correlation technique. The delay time is considered to be very useful to deduce the direction of energy transfer between modes.

Experimental Setup

The turbulence excitation experiments were performed on the Large Mirror Device Upgrade (LMD-U) [2, 3]. Cylindrical plasma with diameter of approximately 0.1 m and axial length of 3.74 m is produced by the RF wave and radially confined by the magnetic field (z : axial, r : radial, θ : poloidal direction). The operational conditions are 3 kW RF power, 900 G magnetic field, 5 mTorr neutral gas (argon) pressure. Peak electron density is 6×10^{18} m^{-3} and electron temperature is 3 eV. A 64-channel poloidal Langmuir probe array [4] is used to observe the

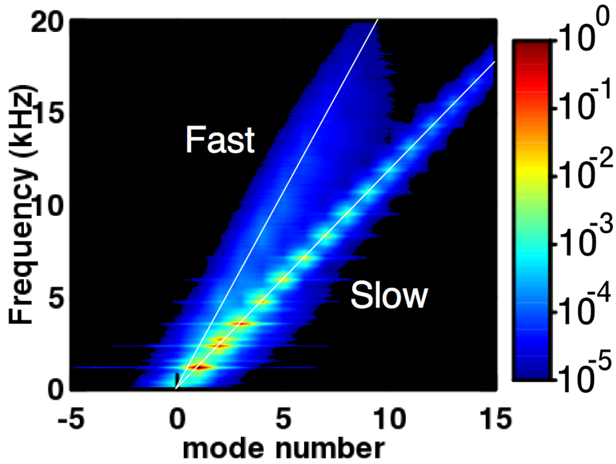

Figure 1: Power spectrum S(m,f) of 5 mTorr neutral pressure and 900 Gauss magnetic field condition. The time window of the spectrum is 8192 μs and the 840 ensembles are averaged.

poloidal structure of turbulence. The axial and radial position of the 64-channel probe array are 1.885 m from source and r = 4 cm (probe tips are 0.39 cm apart) from center, respectively.

Observation of fluctuations with different phase velocities

Figure 1 shows power spectrum of $\tilde{I}_{\rm is}$ measured with the 64-channel poloidal probe array [4, 5]. The time window for FFT is 8192 μs and the 840 ensembles are averaged. Positive poloidal mode number ($m > 0$) means that a mode propagates in the electron diamagnetic direction. There are many peaks in power spectrum and they aligned on two straight lines. A line labeled as "Slow" or "Fast" denote phase velocity is slow or fast compared with the other one. The phase velocities of fluctuations on "Fast" and "Slow" are 5×10^2 m/s and 3×10^2 m/s, respectively. The peaks on a line labeled "Fast" are broad and weak and on "Slow" are narrow and strong.

Discrimination of time evolutions of each modes

It is important to clarify whether the turbulence structures characterized by different phase velocity co-exist or compete each other. Thus, discrimination of modes not only in frequency but also in wave number is required. We combined the (i) frequency filter, (ii) the instantaneous mode amplitude technique [6, 7] and (iii) cross-correlation method.

1. Frequency filter

   To discriminate the phase velocities which have same poloidal mode number and different frequency peaks, we use the frequency filter around the frequency peaks. We use Hann [8] window for frequency filter.

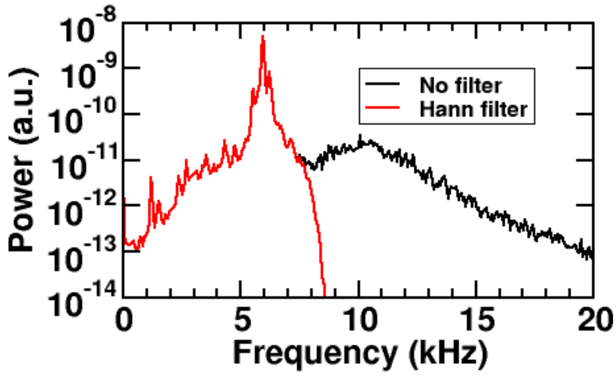

Figure 2: The characteristics of frequency filter by using Hann window. The black line indicate the non-filtered poloidal mode number $m = 5$ spectrum and the red line indicate low pass filtered (< 8 kHz) spectrum.

2. The instantaneous mode amplitude technique

   Fourier transform in the poloidal wave number is applied to the frequency filtered data with 64-channel poloidal probe array. Then the instantaneous signals of ion saturation current, $I(\theta,t)$, is converted into $\hat{I}(m,t)$. Where, θ is the poloidal angle and m is the poloidal mode number. [6, 7]

3. Cross-correlation

   Cross-correlation functions between time-series data for two different modes are analyzed as in [7]. In this study, the frequency band path width is 3 kHz, the time window of cross-correlation function is 200 msec, respectively.

Results

Typical time evolutions of power of $m = 4 - 7$ modes (ensembled) components both in the “Fast” and “Slow” branches are shown in Fig. 3. The cross-correlation function analysis indicates that modes in the “Fast” and “Slow” branches tends to compete each other. Concerning lower-m modes, it is difficult to discriminate individual modes because frequency-difference is close to the band-path width. The power of higher-m modes in “Fast” branches are too weak to analyze.

Summary

In summary, modes with two-different phase velocities (including $E \times B$ velocity) are observed in LMD-U (low temperature, high neutral pressure plasmas). We discriminated modes in the frequency and wave number domains and investigated the dynamics of each modes. The $m = 4 - 7$ modes with slow phase velocity and fast phase velocity tend to compete each other.

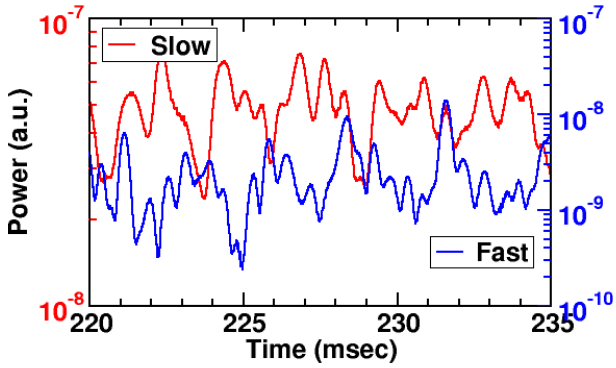

Figure 3: Typical time evolutions of $m = 4 – 7$ modes power with fast phase velocity (blue line) and slow phase velocity (red line).

References

[1] S.-I. Itoh and K. Itoh, Plasma Phys. Control. Fusion **43**, 1055 (2001).

[2] S. Shinohara et al., Proc. 28th Int. Conf. on Phenomena in Ionized Gases, Prague, Czech Republic, 1P04-08 , 354 (Institute of Plasma Physics, AS CR, Prague, 2007).

[3] T. Yamada et al., Nature Phys. **4**, 721 (2008).

[4] T. Yamada et al., Rev. Sci. Instrum. **78**, 123501 (2007).

[5] T. Yamada et al., Plasma Fusion Res. **3**, 044 (2008).

[6] A. Latten, T. Klinger, A. Piel, and T. Pierre, Review of Scientific Instruments **66**, 3254 (1995).

[7] H. Arakawa et al., Plasma Phys. Controll. Fusion **51**, 085001 (12pp) (2009).

[8] J. Donaldson and P. Tryon, *STARPAC: The standard times series and regression package*, 1987.