20aB-1

Future Direction of Plasma Turbulence Studies

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The research of plasma turbulence enters into a new era after establishing a modern view of plasma turbulence. Further understanding based on the modern view requires development of a new diagnostics that can measure the whole plasma with fine resolution up to micro-scale. A candidate of such diagnostics is tomography, and a prototype is constructed in linear cylindrical plasma to provide successful and promising results. Therefore, in order to advance the plasma turbulence suffering from topological effects of confinement magnetic field, it is necessary to construct a special toroidal that allows such tomography measurement to cover the whole plasma with fine resolution from micro-scale to macro-scale fluctuations.

1. Introduction

Plasma turbulence is ubiquitously observed in nature and its study provides a scientific base to understanding nature. Moreover, plasma is an indispensable tool used for nano-technology and others to sustain the modern civilization. Particularly, the research of magnetically confined plasma has been internationally carried out to realize a nuclear fusion reactor, and has made a great progress in understanding of plasma confinement and turbulence.

At present, ITER is being constructed to demonstrate a burning state of plasma and feasibility of a nuclear fusion reactor. However, the first-principle understanding of the plasma turbulence is still necessary to predict plasma performance precisely, which should contribute to reducing future experimental costs. Therefore, physics experiments to aim at the physics understanding of plasma turbulence are absolutely necessary to be continued.

The paper reviews the recent experiments to achieve the modern view of plasma turbulence, and introduces the newly developed diagnostics that can measure the whole plasma with fine spatio-temporal resolution to catch the fluctuations and structure in meso- and micro-scales simultaneously with macroscale structures, and to present the initial results of the prototype of the proposed diagnostic system installed in PANTA, finally discuss the feasibility and future applications.

2. Physics Issues in Modern View of Plasma Turbulence

The discovery of zonal flows has established a view that the plasma turbulence should be regarded as a system of micro-scale fluctuations (such as drift waves) and meso-scale structures, such as zonal flows and streamers generated from the background micro-scale fluctuations [1,2]. Recently, the view has been extended further to include macro-scale fluctuations, by the discovery of macro-scale fluctuating structure spreading over the most of the whole plasma radius in LHD [3]. Finally, the plasma turbulence should be a system of micro-, meso- and macro-scale fluctuating structures interacting with each other.

On this modern view, the energy partition and interactions between the fundamental fluctuations and structures (drift-waves, zonal flows, and macro-structures) determine the properties of turbulent plasmas and the resultant transport, since each structure has its own transport characteristics. The modern paradigm also suggests an important role of zonal flows in addition to shearing effect of electric field on transport barrier formation, as is demonstrated in the observation of intermediate states between L-and H-mode, and the limit-cycle-oscillation just before L-to-H transition [4].

To advance the understanding of plasma turbulence, the modern view requires the simultaneous observation of micro-scale fluctuations, meso- and macro-scale structures, and their interactions and dynamics with high spatio-temporal resolution, *that is*, superior experimental observations that can cover the whole plasma with fine resolution to meso-and micro scale of fluctuations.

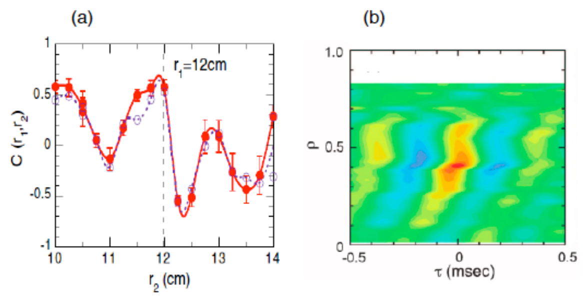

Fig. 1. Analyses of (a) zonal flows and (b) macroscopic fluctuating structure with cross-correlation functions.

3. Plasma Experiments in Low Temperature Device

Plasma devices of low temperature provide excellent environment for turbulence experiments since the devices own high accessibility, high flexibility, easy controllability of plasma, moreover, advantages to use traditional probes and to develop new diagnostics systems. A number of excellent experiments have been done to identify the spatio-temporal evolution of structure and understand turbulence phenomena based on the modern view in such devices with clever use of various probes.

For instance, in a linear plasma device in Kyushu University PANTA device, temporal evolution of blob-like phenomena is efficiently inferred using simultaneous cross-correlation analysis at 3x32 points using 32ch of azimuthal probe array and 3 ch. radial movable probe, as is shown in Fig. 2 [5]. Other examples include the energy transfer between zonal flows and drift-waves [6], the localization of turbulence and its resultant transport [7], the interaction or competition between electron temperature gradient mode and drift waves modes [8], and so on.

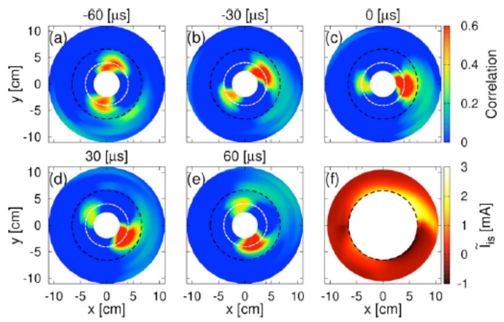

Fig.2. An example of physics results obtained by efficient use of probes in low temperature device. Here, the temporal evolution of blob-like behaviors is deduce.

4. Turbulence Tomography

Traditional probe is a useful tool to make multichannel measurements, however, it is difficult to cover the whole plasma cross-section. Therefore, some other methods should be developed. One of such diagnostics is computed tomography (CT) for plasma emission. For measuring the turbulence structure with CT, a large number of spatial channels should be necessary to resolve such fine structure in space and time, comparable to ion Lamor radius and drift wave frequency, respectively. Therefore, the proposed tomography system should need a large number of the detectors to achieve sufficient spatio-temporal resolution.

A prototype of such tomography system has been made in PANTA. In the system four sets of 33 ch., totally 132 detectors, is set at 4 azimuthal positions separated by 45 degree each other. Figure 3 shows an example of initial results of tomography. The reconstructed image in Fig. 3a shows the centrally peaked emission of ArII line, and local turbulence spectrum at position A to show sharp peaks approximately at 1 and 2 kHz. The wavelet analysis reveals intermittent behaviors of these modes, and the fluctuations around 5 kHz. The initial results demonstrate the promising ability of tomography as local turbulence diagnostics.

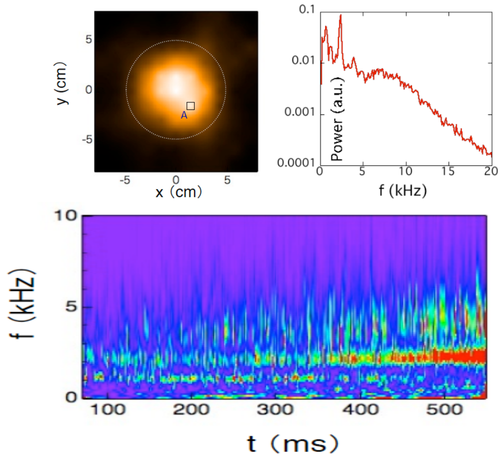

Fig.3. An example of tomography results in PANTA. (a) Distribution of ArII emission, (b) local fluctuation spectrum at and (b) temporal evolution of wavelet spectrum point A in Fig. 3(a).

5. Concluding Remarks

Now the research of plasma turbulence is coming into a new phase, and the plasma turbulence should be investigated with the modern view of turbulence. To advance the understanding of plasma turbulence, the necessary step is to develop a new method to measure the turbulence in the whole plasma region with a high spatio-temporal, that is, micro-scale resolution. A prototype of such diagnostics is successfully developed in linear cylindrical plasma where toroidal effects are not included. Finally, it is absolutely necessary that toroidal devices allow us to realize such diagnostics for understand the plasma turbulence in the first-principle.

Acknowledgements

This work is supported by the Grant-in-Aids for Scientific Research (No. 23246162) and the Grant-in-Aids for Scientific Research (No. 21224014).

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