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Dynamics of global transport and turbulence noise force - an experimental analysis on plasma turbulence

乱流ノイズ力と大域的輸送ダイナミクス―プラズマ乱流の実験解析

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Results from “extreme” measurement and analysis in a plasma turbulence are presented. Two azimuthal probe arrays, which cover the whole area of azimuthal direction of an inhomogeneous magnetized plasma column, realize simultaneous measurement of “dynamics” of global particle and momentum transports driven by micro-scale turbulence for the first time. Non-Gaussian probability density functions (PDF) of the azimuthally averaged transports are observed, and we confirm that the transition from the point-wise PDFs to averaged ones. The change in the particle flux leads that in the momentum flux, demonstrating that the momentum flux is induced by the relaxation of density gradient.

1. Introduction

Pursuit of the “extreme” in existing techniques and methods sometimes explores new discovery and opens the way to breakthrough of research fields. This talk presents a challenge to “extreme” experimental research on turbulence.

The research target is probability density function (PDF) and dynamics of global transport by plasma turbulence. Stochastic process of turbulence fluctuation and transport often shows intermittent property and significant deviation from Gaussian PDF. It is considered that the non-Gaussianity of the PDF of turbulence is one of the key elements that characterize the far-non-equilibrium states [1]. The intermittency may play an important role in triggering transition phenomena [2]. Although progress of study of the non-Gaussian PDF of point-wise particle flux has been noticeable in experiment [3], measurements of the global transport by turbulence are required because relaxation of the plasmas depends upon the global transport. In addition, the global momentum flux, essential for the generation of global axial vector field by turbulence, is also important because the global vector fields have considerable effect on the relaxation [4]. Furthermore, the momentum transport may have the direct link to the particle transport [5]. Therefore, simultaneous observations of statistics (PDF) and dynamics (fine time evolutions) of the global particle and momentum transports are required to understand structural formation in magnetized plasmas.

As a result of “extreme” experiment, we show the first simultaneous observation of statistics and dynamics of the azimuthally averaged particle and momentum fluxes by turbulence in magnetized plasmas [6]. We made efforts to prepare “extreme” number of electrodes/probes to fulfill the observation. Measurement of spatially minute structure of turbulence transport requires fine spatial arrangement of electrodes in the probes. The "global" flux measurements also require that the probes cover the whole azimuthal range of the two-dimensional plasma turbulence. In addition, to detect small probability of intermittent flux events with sufficiently high precision, we paid attention on obtaining "extremely" large amount of data.

2. Experiment

The target plasma is fully-developed drift-wave turbulence in a linear device (the Large Mirror Device-Upgrade, LMD-U [7]). Magnetic field strength is fixed at 0.09 T in the center of the vessel, and the ion cyclotron frequency is ~ 34 kHz. (The sampling rate is 1 MHz.) Auto-power spectra of the ion saturation current and floating potential fluctuations have broadband property at 7 - 8 kHz (fundamental drift-wave) [8]. Two probe arrays were used to measure the momentum and particle fluxes, respectively. The radii of the observation with the two arrays are fixed at r = 4 cm where the local momentum transport had a maximum. (Radius of the cylindrical plasma is 5 cm.) Our main interest is origin of the momentum flux, therefore, we chose the radius r = 4 cm as the observation location. The momentum flux (Reynolds stress, RS) was measured with 16 channel RS probe array (16ch-RSP) [9]. The 16ch-RSP has 16 units, and the units are arranged approximately at regular intervals in the azimuthal direction. The particle flux was simultaneously measured with the 64ch azimuthal probe array [10]. Average ion saturation current has finite radial gradient around r = 4cm. Turbulent fluxes are mainly driven by fluctuations in the frequency range less than 10 kHz.

3. PDF analysis

First, we describe results of observed PDFs of the global particle and momentum transports. The observed PDFs of the fluxes are characterized by non-Gaussianity featured with the positive tail. In particular, the difference between the local PDFs and azimuthally-averaged PDFs was significant. We obtained the tail exponent of the PDF of the azimuthally-averaged RS as 1.208. The PDF tail follows the stretched Gaussian law (deviated from the Gaussian, where the exponent is 2). In the exponent calculation, the probability covers three or four orders of magnitude as a result of the large amount of data, thus the exponent is precisely determined. We also found that the tail exponents of the PDF varied from 0.6 (point-wise) to 1.2 (averaged), as the spatial length of averaging became longer. When the spatial range is close to half wavelength of the fundamental drift-wave, the tail exponent starts to converge. The origin of the difference between the local PDF and the spatially averaged PDF is the internal structure of the flux event. This is the evidence that the local turbulence transport events are not independent, and have long range correlation. This result demonstrates that the mixing of these microscopic dynamics constitutes the PDF for the azimuthally averaged flux.

4. Correlation between the both fluxes

Next, to investigate the dynamical link between the global particle and momentum transports, we show the results from correlation analysis between the both transports. The time delay from the correlation analysis may provide clues to origin of the momentum transport and causal relationship between the flux events in particle and momentum. The particle flux mainly leads the RS by 25×10^{-6} s, higher than the time resolution of the sampling rate. Time delay caused by the difference of locations between the two probe arrays is negligible. Therefore, the observation of the significant time delay of 25×10^{-6} s shows the causal relationship between the particle and the momentum fluxes in this plasma turbulence. We have confirmed that the change in the particle fluxes leads that in the momentum flux, demonstrating that the momentum flux is induced by the relaxation of density gradient.

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