SV-2

Experimental Developments on Long Range Correlation of Plasma Turbulence

S. Inagaki[1,2], K. Ida[2,3], A. Fujisawa[1,2], N. Tamura[3], S. Tokuzawa[3], S.-I. Itoh[1,2], K. Itoh[2,3]
[1]RIAM, Kyushu Univ., [2]Itoh Research Center for Plasma Turbulence, Kyushu Univ., [3]NIFS

1. Introduction

In magnetized toroidal plasmas, understanding of turbulence structure and its role on transport is an urgent issue to be clarified. It has been presumed that local turbulence caused by a local micro-instability (e.g. drift instability) drives local transport. In this local picture, fluxes are tied to gradients of thermodynamic variables at the same location. In the "local expression" of flux-gradient relation, widely separated regions of the plasma don't significantly interact with each other. When edge and core interact, they do so diffusively. However, phenomena which demonstrate violation of "local expression" of flux-gradient relation have been observed in many tokamaks and helical devices during the course of the last two decades. Examples are: Temperature perturbation applied at the plasma edge region propagates inwards at a speed which is 10-50 times faster than what would be expected from local diffusive transport models [1,2]. Rapid propagation of the change in transport coefficient is also observed after the L–H transition [3]. The violation of local closure in the transport is clearly observed for the period of the transient phenomena and thus these issues are so-called "transient transport problem" and a mystery for the past quarter century of magnetically confined plasmas. A model of "interaction between edge and core transport" can explain these phenomena qualitatively. In future experiments on thermonuclear fusion, such as the Internal Thermonuclear Experimental Reactor (ITER), the performance of plasmas are predicted and designed on the basis of such a "local transport picture". While knowledge of the time scale of the change in transport and the establishment of reliable control algorithms are required because a large heat pulse due to the rapid change in transport should be avoided. Thus, local (and empirical) approach to ITER prediction should be replaced by more advanced understanding of turbulent transport.

Recently, meso-scale structures, such as zonal flows and streamers, have been found to be nonlinearly generated by micro-scale fluctuations (multi-scale coupling) and to play an important role in determining the turbulent transport. The multi-scale coupling of fluctuation is proposed as a possible mechanism to produce the interaction between edge and core transport. A coupling between local micro-turbulence and macro-structures is ascribed so as to link the edge and core transport (non-local transport picture). In this report, we take it as a working hypothesis and characterize macro-structures observed in LHD. These results will open the way to understand underlying physical mechanics of turbulence transport. Here, we focused on the non-locality in heat transport. Most recently, linkages between heat and momentum transport were addressed [4].

2. Interaction between the core flux and edge gradient

The violation of the local closure in the transport is not clearly observed in steady-state plasmas except for the period of the transient phenomena. This is because, even if the non-local contribution is as large as local (or diffusive) ones, the usually observed profile resilience (stiffness) introduces a collinearity between temperature gradients at different locations, so that a separation of the "non-local effect" from the others becomes difficult in steady state. Thus we consider flux-gradient relation in the transient phenomena then we estimated the heat flux perturbation from the perturbed energy balance equation.

The flux-gradient relation during core temperature rise induced by TESPEL injection in a low density LHD plasma shows hysteresis which means non-diffusive transport i.e. heat flux is not proportional to temperature gradient (violation of Fick's law) [5]. For further understanding of the flux-gradient relation from the global point-of-view, cross-correlation between flux and gradient are reconsidered. Two-point two-time correlations between the flux and gradient indicates the existence of interaction between flux and gradient at far distant. The radial distance of the observed interaction is of the order of plasma radius. This result gives us hints for a more general formulation of flux-gradient relation in turbulent plasma.

3. Discovery of long range modes

The long distance correlation of turbulence is our working hypothesis, which can explain the interaction between core and edge transport. There are some possible mechanisms which can produce long distance correlation of turbulence. Meso-/Macro-scale fluctuations with long radial correlation can be excited by background turbulence. Zonal flows, GAMs and streamers are examples of meso-scale fluctuating structures. Such long-range fluctuations can produce long distance correlation of micro-turbulence.

Recently, fluctuations with long radial correlation (long-range modes) are discovered by using global correlation measurements between fluctuations or their envelope obtained from a multi-channel ECE system, a microwave reflectometer and a magnetic probe array arranged over the entire range of the LHD [6]. The radial correlation length is of the order of the plasma radius. The fluctuations propagate from the centre to edge region. The propagation is ballistic and the radial phase velocity is extremely fast, 1 km/s on radial average, and is of the order of diamagnetic drift velocity. The toroidal/poloidal mode structure is found to be n/m = 1/1 or 1/2. The cross-bi-coherence analysis shows the non-linear coupling between long-range modes and micro-turbulence. Dynamic behaviors of the long-range mode during the transient transport phenomena are also observed and they support the link between the long-range modes and the edge-core interaction of transport.

4. Summary and future perspective

We discussed the interaction between edge and core transport, which is a mystery for the past quarter century of magnetically confined plasmas. Here we reported the followings: 1) The global flux-gradient relation is indicated in the edge-core interaction of transport. 2) Low frequency temperature fluctuation with long distance radial correlation is discovered and Bi-coherence analysis indicates that the long-range mode is non-linearly coupled with micro-turbulence. 3) A coupling between local micro-turbulence and macro-structures is ascribed so as to link the edge and core transport.

More recently, the dynamical response of turbulence to the low frequency power modulation is observed. The response of turbulence intensity is found to be composed of jumps between states of heating-on and -off [7]. This can be understood with the conjecture that the long-range modes mediate between the direct effects of heating [8] at the center and micro-turbulence at two third of plasma radius. The non-local picture will give a deep understanding of the basic mechanism of turbulent transport and a control algorithm of the burning state of plasmas in ITER.

This work is partly supported by a grant-in-aid for scientific research of JSPF, Japan (21224014, 23360414, 23244113) and by the collaboration programs of NIFS (NIFS07KOAP017, NIFS10KOAP023) and of the RIAM of Kyushu University and Asada science foundation.

[1] M. W. Kissick et. al., Nucl. Fusion **34** (1994) 349
[2] K. W. Gentle et. al., Phys. Plasmas **2** (1995) 2292
[3] J. G. Cordey et. al., Nucl. Fusion **35** (1995) 505
[4] K. Ida et. al., 24th IAEA Fusion Energy Conference, San Diego, USA, 2012, OV/3-4
[5] S. Inagaki et. al., Plasma Phys. Control. Fusion **52,** 075002 (2010)
[6] S. Inagaki et. al., Phys. Rev. Lett. **107**, 115001 (2011)
[7] S. Inagaki et. al., 24th IAEA Fusion Energy Conference, San Diego, USA, 2012, EX/10-1
[8] S.-I. Itoh and K. Itoh,, Sci. Rep. (2012) in press