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Axial and Azimuthal Flows Driven by Turbulence in a Linear Plasma Device

S. Inagaki[1], F. Kin[2], Y. Kosuga, T. Kobayashi[3], Y. Nagashima, T. Yamada[4], M. Sasaki, K. Yamasaki, K. Hasamada[2], H. Arakawa[5], N. Kasuya, A. Fujisawa

[1] RIAM, Kyushu University, Japan, [2] IGSES, Kyushu University, Japan, [3] NIFS, Japan, [4] FAS, Kyushu University, Japan, [5] Teikyo University, Japan

Introduction

Magnetically confined plasma is one of the typical non-equilibrium systems and is characterized by strong spatiotemporal inhomogeneities. Free energy owing to the spatial inhomogeneities excite waves and instabilities. Multi-scale fluctuations co-exist and interact each other, i.e. plasma becomes turbulent and the turbulence drives transport and relaxes the spatial inhomogeneities. This mechanism forms thermo-dynamical structure where gradients, flows and turbulence co-exist. Structure formation has a broad interest in the non-equilibrium systems and widely recognized as key issues to be solved in the non-linear physics.

Linear plasma experiment

Structure formation in magnetized plasma is experimentally investigated by using a linear magnetic device. Cylindrical argon plasma (radius of 6 cm and axial length of 4 m) is generated by 3-6 kW rf (7 MHz) power and radially confined by homogeneous axial magnetic field (0.09 T) [1]. Typical parameters measured by YAG-Thomson scattering and laser induced fluorescence are $n_{e0} \sim 1.0\text{x}10^{19}$ m^{-3}, $T_{e0} \sim 3$ eV and $T_{i0} \sim 0.3$ eV. By means of Langmuir probe and Mach probe, the spatial structure of flows and turbulent fluctuation are measured. Low frequency (1-5 kHz) drift waves are excited and nonlinear couplings between drift waves are evaluated by the bi-coherence analysis.

Axial and Azimuthal flow generation

Here we discuss how turbulence generates axial and azimuthal flows in the magnetized plasma. The zonal flow is one of the flow structures driven by turbulence in the universe and it is discovered to be formed in the magnetically confined plasmas [2]. Radial Reynolds stress of azimuthal flow is evaluated in the linear plasma experiments [3]. It is found that the Reynolds force driven by drift waves generates azimuthal flow shear and the energy of drift waves is transferred to the zonal flow.

This mechanism allows to generate axial flow shear. In fact, strong axial flow shear is generated in the central region of linear plasma. In addition, the strong shear is accompanied by reversal of axial flow [1]. The radial Reynolds force of axial flow is also confirmed to be able to drive observed axial flow structure.

Interaction between particle and momentum transport

Curie dissymmetry principle does not allow thermos-dynamical interactions between scalar field force (e.g. pressure gradient) and vector field force (e.g. stress tensor) in linear systems due to symmetries. In the nonlinear turbulent plasma, this symmetry is usually broken. And thus the momentum and particle transports can interact each other through turbulence in the magnetized plasma. Here we discuss how the flows interact with particle gradient.

The strong axial flow shear formation is accompanied by excitation of D'Angelo mode, which is Kelvin-Helmholtz-type instability excited by axial flow shear. D'Angelo mode is usually stable but is destabilized in the central region of the linear plasma by synergy effect with drift waves [4]. D'Angelo mode is found to drive an inward radial particle flux which contribute to increase the pressure gradient. The pressure gradient excites the drift waves which contributes to destbilzse D'Angelo mode through flow shear. In this way, particle and momentum transports interact through turbulence.

The axial flow structure and spectral of fluctuations are changed by controlling of axial flow velocity of neutral Ar gas. Slow mass flow condition of Ar gas (realized by low injection velocity and low pumping velocity) makes the axial flow shear stronger. The neutral gas can contribute both to the drag of axial flow and excitation of instabilities. Effect of neutrals on the axial flow will be determined by competition between such processes. Understanding of interactions between axial flow, turbulence and neutrals will contribute to further study on divertor plasma control.

References

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