# 19PA-053

# Non-Equilibrium and Extreme State –
# Excitation of a small vortex in solitary drift wave on LMD-U
# 非平衡極限 - LMD-Uにおけるドリフト波孤立波中に発生する小渦の観測

H. Arakawa[1)], S. Inagaki[2,3)], M. Sasaki[2,3)], Y. Nagashima[2,3)], T. Yamada[3,4)], T. Kobayashi[5)],
A. Fujisawa[2,3)], N. Kasuya[2,3)], M. Lesur[2)], Y. Kosuga[6)], S.-I. Itoh[2,3)] and K. Itoh[3,5)]
荒川弘之[1)]，稲垣滋[2,3)]，佐々木真[2,3)]，永島芳彦[2,3)]，山田琢磨[3,4)]，小林達哉[5)]，
藤澤彰英[2,3)]，糟谷直宏[2,3)]，Maxime Lesur[2)]，小菅佑輔[6)]，伊藤早苗[2,3)]，伊藤公孝[3,4)]

1) *Teikyo University, 6-22 Misakimachi, Omuta 836-8505, Japan*
帝京大学 〒836-8505 福岡県大牟田市岬町6-22
2) *Research Institute for Applied Mechanics, Kyushu University, 6-1 Kasuga-Koen, Kasuga 816-8580, Japan*
九州大学応用力学研究所 〒816-8580 春日市春日公園6-1
3) *Research Center for Plasma Turbulence, Kyushu University, 6-1 Kasuga-Koen, Kasuga 816-8580, Japan*
極限プラズマ研究連携センター 〒816-8580 春日市春日公園6-1
4) *Faculty of Arts and Science, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan*
九州大学基幹教育院 〒819-0395 福岡市西区元岡744
5) *National Institute for Fusion Science,322-6 Oroshi-cho, Toki 509-5292, Japan*
核融合科学研究所 〒509-5292 土岐市下石町322-6
6) *Faculty of Arts and Science, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan*
九州大学高等研究院〒812-8581 福岡市東区箱崎6-10-1

Dynamic interactions between a solitary drift wave structure and zonal perturbations in a linear cylindrical device have been observed. The temporal behavior of solitary drift wave structure on an azimuthal cross-section is observed by applying a new method. The instantaneous two-dimensional structure shows the excitation of a small vortex, which is modulated by the zonal perturbation. New finding of spatiotemporal structure of the small vortex should be very useful to understand the energy transfer process between drift wave turbulence and zonal flow.

## 1. Introduction

Role of turbulence, zonal flow, mean flow on dynamics of transport is one of the most important issues to be clarified. Dynamic interactions between a solitary drift wave structure and zonal perturbations in a linear cylindrical device have been observed in our previous work [1]. In the previous work, we have shown a dynamic interaction between the solitary wave and zonal flows cause the emission of the 'splash' (fluctuations with higher frequency than that of the fundamental drift waves and short life time). In this study, the solitary drift wave structure on an azimuthal cross-section is analyzed. A new analytic method for reconstructing instantaneous two-dimensional structure of the solitary drift wave with using 64-channel azimuthal Langmuir probe array and a radially movable Langmuir probe is shown. The reconstructed structure demonstrates that a small vortex is excited synchronously with the period of the zonal perturbation.

## 2. Experimental Setup

Turbulence excitation experiments were performed on the Large Mirror Device Upgrade (LMD-U). Cylindrical helicon plasma with a diameter of approximately 0.1 m and an axial length of 3.74 m is produced by the RF wave in a quartz tube and is radially restricted by the axial magnetic field (z: axial, r: radial, θ: azimuthal direction). The operational conditions are 3 kW RF power, 900 G magnetic field and 5 mTorr argon gas pressure. The major diagnostic tools are a 64-channel azimuthal Langmuir probe array and a radially movable Langmuir probe. The axial and radial positions of the 64-channel probe array in the LMD-U are z = 1.885 m and r = 4 cm, respectively. In this probe array, each probe measures the ion saturation current. The radially movable probe is installed at the axial position 1.375 m and measures the ion saturation current of $r = 1.5 - 6$ cm. These diagnostic tools are measured simultaneously during the discharge.

## 3. Analytic method

To show the temporal behavior of solitary drift wave structure on an azimuthal cross-section, we applied a new method by using of a 64-channel azimuthal Langmuir probe array and a radially movable Langmuir probe. A small vortex, in which the density is peaked periodically in synchronization with a periodic change of zonal perturbation, is identified by azimuthal probe array by the conditional averaging method [2]. The time at the peak of density in each period, $t_0$, is detected and the time from trigger for each period, $\tau$, is defined as $\tau = t - t_0$. The azimuthal location of each peak, $\theta_p(\tau)$, and ion saturation current of radially movable probe, $I_{is}(\theta_0,r,\tau)$, are also detected. If the zonal perturbation is coherent, the $\theta_p$ ($\tau = 0$) is unchanged. However, the $\theta_p$ ($\tau = 0$) is changed randomly due to the change of frequency of zonal perturbation. Thus, $\theta_p$ ($\tau = 0$) will cover the entire region of azimuthal angle after many cycles. By assembling 2214 periods of signals, we reconstructed the two-dimensional structure of the solitary wave and the small vortex, $\delta I_{is}(\theta_p-\theta_0, r, \tau) = I_{is}(\theta_p-\theta_0, r, \tau) - \bar{I}(\theta_p-\theta_0, r)$, where $\bar{I}(\theta_p-\theta_0, r)$ is time averaged $I_{is}(\theta_p-\theta_0, r, \tau)$.

## 4. Instantaneous two-dimensional structure of the solitary wave and the small vortex

Figure 1 show the temporal behavior of the reconstructed two-dimensional structure of the solitary wave and the small vortex. The temporal change demonstrates that a small vortex is excited and suppressed synchronously with the periodic change of the zonal perturbation. Dotted circles in the Fig. 2 (b), (c) and (d) denote the excitation of the small vortex. The vortex is excited around the node of flow shear of zonal perturbation [1] and the phase velocity (in the azimuthal direction) of it in the laboratory frame (i.e. including E × B velocity) is close to that of the solitary drift wave. The instantaneous azimuthal decomposition [3] indicates that the excitation of the small vortex is accompanied with an increase in the amplitude of $m = 3$ mode, where $m$ is azimuthal mode number. The changes of amplitudes of $m = 1$ and 2 modes and the delays between the $m = 1$-3 modes are also observed. Therefore, nonlinear interactions between a solitary drift wave structure and zonal perturbations would cause the excitation of the small vortex.

## 5. Summary

In summary, temporal behavior of solitary drift wave structure on an azimuthal cross-section is observed in the LMD-U linear magnetized plasma. We discovered an excitation of a small vortex synchronously with the periodic change of the zonal perturbation at the node of flow shear of zonal perturbation. The small vortex is accompanied with an increase in the amplitude of $m = 3$ mode.

## Acknowledgments

This work is supported by the grant-in-aid for Scientific Research of JSPS (21224014, 20560767), by the collaboration programs of RIAM of Kyushu University and of NIFS (NIFS10KOAP023), and by Asada Science Foundation.

[1] H. Arakawa et. al., Plasma Phys. Control. Fusion **53** (2011) 115009

[2] S. Inagaki et.al., Plasma Fusion Res. **9** (2014) 1201016

[3] H. Arakawa et. al., Plasma Phys. Control. Fusion **51** (2009) 08500

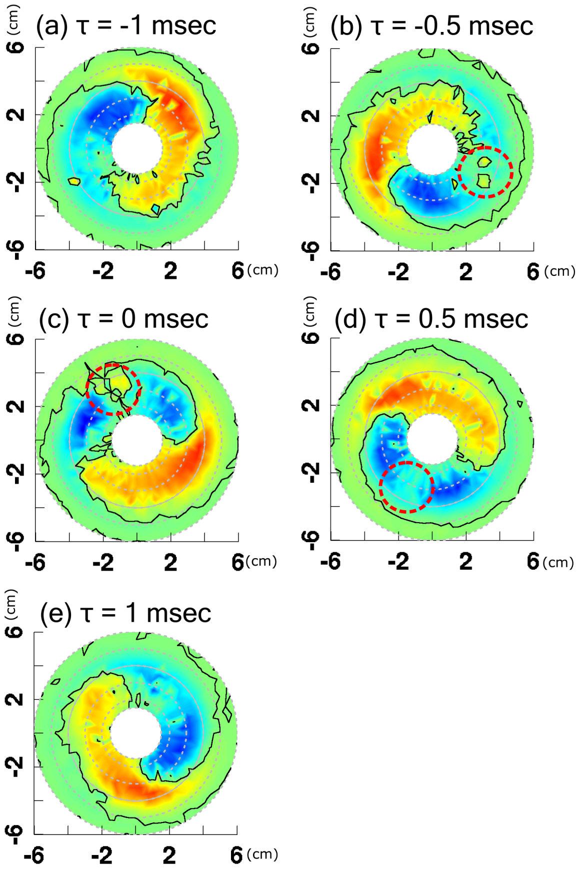

Fig.1 Temporal behavior of two-dimensional structure on the solitary wave and the small vortex. Dotted circle indicates the position of the excited small vortex.