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# Observation of a Long Range Correlated Fluctuation using Langmuir Probes in Heliotron J

## ヘリオトロンJにおける静電プローブによる長距離相関揺動の観測


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A toroidally symmetric electric field fluctuation is found inside the last closed flux surface (LCFS) in low density ECH plasmas of Heliotron J. The fluctuation has a symmetric structure in the toroidal direction and the dominant frequency component is less than 4 kHz. The characteristics are quite similar to those of zonal flows, however, its radial wavelength is, unlike those in other devices, comparatively large. The electric field fluctuation generates the velocity shear synchronized with the fluctuation around LCFS since the fluctuation amplitude sharply increases inside LCFS. Cross-correlation analysis indicates that turbulence structure drastically changes at the boundary of LCFS, which results in the steep increase of Reynolds stress inside LCFS. Consequently, radial shape of the Reynolds stress is similar to that of the symmetric fluctuation amplitude and the resultss imply that the coupling exists between the long range correlated fluctuation and Reynolds stress.


### 1. Introduction

Meso-scale structures including zonal flows are ubiquitously observed in a variety of experimental devices in the field of plasma physics and fusion science [1-3]. The importance of these phenomena is recognized as critical to confinement performance since the turbulence-driven phenomena can regulate turbulence level through the process of energy partition and/or the generation of electric field shearing.

In this study, we report about the first observation of a symmetrical fluctuation similar to zonal flows in a helical system, Heliotron J and its characteristics [4].

### 2. Experimental Set Up

This experiment was conducted in an advanced helical axis heliotron device, Heliotron J. The device has the major and minor radii of 1 m and 0.17 m, and the magnetic field strength B= 1.25 T on axis. In this experiment, the plasma was produced and sustained by a 70 GHz second-harmonic X-mode ECRH with the power of up to 0.3 MW. The plasma density was kept low with $n_e \sim 0.3\times10^{19}$ m$^{-3}$ to suppress the heat load to the probes and to avoid disturbance to plasma discharges. Main diagnostics in this experiment are multiple Langmuir probes (LPs) installed at different toroidal/poloidal sections. In this study, two sets of LPs have mainly been used to measure edge plasma parameters and these fluctuations by scanning the radial position from inside to outside LCFS.

### 3. Experimental Results and Discussions

A high correlation between floating potential signals measured with two probes located at different toroidal sections was observed in the low frequency range less than 4 kHz. Radial structure of the fluctuation was

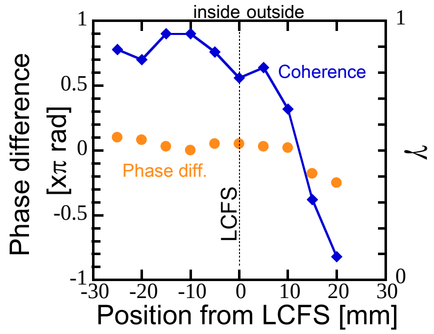


Fig. 1 Radial profile of phase difference and coherence γ at the frequency of 1 kHz between floating potential signals measured with a fixed probe and scanned probe around LCFS.

investigated by fixing one probe inside LCFS and by scanning the other probe around LCFS in radial direction on a shot-to-shot basis, as shown in Figure 1. Clearly, a quite high coherence of ~0.95 is observed inside LCFS at the frequency of 1 kHz, and the value quickly decreases outside LCFS. The phase difference in toroidal direction is almost zero in the observation range where a high correlation exists, which means that the radial wave number is rather small. In other words, radial scale length appears to be much larger than that of the typical zonal flow being reported to be the radial wave length ~ 1 cm in other experiments [1-3]. In addition, this fluctuation cannot be considered to be precursor of transition since any transition phenomena are not observed in this operation regime of Heliotron J.

It is worthwhile to compare the structures of background turbulence to that of the long-range correlation. The normalized cross correlation function is shown in Fig. 5(a). The correlation between $\delta Er$ and $\delta E_\theta$ fluctuations is important to examine the behavior of the Reynolds stress in the generation process of zonal flows. Obviously, the oscillatory structure with the time scale of 0.02-0.03 ms can be seen inside LCFS,

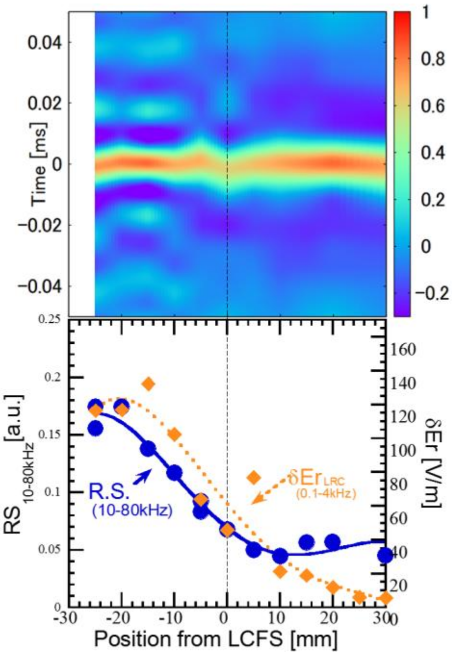


Fig. 2 (a)Cross-correlation between $\delta Er$ and $\delta E_\theta$ in the frequency range of 10 to 80 kHz. (b) Reynolds stress calculated from the in the same frequency range. $\delta Er_{LCR}$ is also shown in the same figure for comparison.

indicating the microscopic fluctuations having weakly periodic structure exist inside LCFS with keeping a certain correlation time. On the other hand, the appearance of the correlation function changes at the boundary of the LCFS. Outside LCFS, the correlation function shows a steep peak around the timing of $\tau \sim 0.0$ ms only, and then rapidly dissipates in the time scale of ~0.01 ms. This result indicates that any periodic structures of fluctuations do not exist at that location and $\delta Er$ and $\delta E_\theta$ fluctuations decorrelate quickly outside LCFS within the time scale of ~0.01 ms. In other words, the broadband turbulent fluctuation disappears, and only the spiky and intermittent fluctuation remains outside LCFS. The above result shows that microscopic fluctuation exhibits different characteristics at the boundary of LCFS, which should also have influences on the behavior of Reynolds stress.

Radial profile of the Reynolds stress driven by broadband fluctuation is compared with the profile of long range correlation in Fig. 5(b). The Reynolds stress was evaluated using $\delta Er$ and $\delta E_\theta$ in the frequency range of 10-80 kHz. The Reynolds stress increases inside the boundary of LCFS, and it is attributed to the increase of $\delta Er$ and $\delta E_\theta$ fluctuation amplitudes and the increase of the cross-correlation.

In summary, a toroidally symmetric $E_r$ fluctuation, which is coupled with Reynolds stress, is observed in Heliotron J device. The fluctuation has quite similar characteristics to zonal flows except for the structure in radial direction, and can produce strong oscillating velocity shear.


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