Nonlinear Coupling of Drift Waves and High Frequency Fluctuation on PANTA

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A new type of nonlinear coupling among multi-time scale of fluctuations is observed on the linear plasma device, PANTA. The low frequency drift waves (DWs), a few kHz and a high frequency fluctuation (the HF fluctuation) (∼ 30 kHz) are simultaneously observed. These fluctuations nonlinearly couple with each other confirmed by bi-coherence analysis. The characteristics of HF fluctuation are also discussed.

Keywords: nonlinear coupling, multi-time scale, drift wave

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In fusion plasma, multi scale turbulence is important subject to understand the behavior of plasma. Turbulence interacts with each other through nonlinear coupling. Especially the couplings between the drift waves (DWs) and other turbulence are widely studied. For instance, the nonlinear coupling between DWs-DWs [1], DWs-Streamers [2], DWs-Zonal Flows (ZFs) [3] and DWs-electron temperature gradient modes (ETG) [4] have been reported. These nonlinear couplings are a key to understand dynamics of turbulent plasmas. Here we report the observation of a new combination of nonlinear coupling with DWs on the linear plasma device, PANTA. The coupling we describe here is between drift waves and a fluctuation of higher frequency (the HF fluctuation) compared to the drift frequency. This HF fluctuation coexists with DWs, which is confirmed by the spectrum analysis. The bi-coherence analysis reveals nonlinear couplings between DWs and the HF fluctuation. Relation of the HF fluctuation to those observed on detachment experiment is also discussed [5, 6].

We produce an argon plasma by using the helicon wave (3 kW) at the frequency of 7 MHz in PANTA. PANTA has a cylindrical vacuum chamber, 4000 mm in axial length and 450 mm in inner diameter. The axial magnetic field (B) is almost constant along the axis. The plasma diameter is about 100 mm. The peak ion density is about $10^{19}\ \mathrm{m}^{-3}$. The floating potential and the ion saturation current are used as indexes of the plasma potential fluctuation and the electron density fluctuation, respectively. These fluctuations are measured with a 64-channel azimuthal probe array [7] located at $r = 40$ mm and at the axial position $z = 1875$ mm. Note that $r = 40$ mm is the location of the maximum density gradient. Radially movable probe is also located at $z = 1375$ mm to measure radial structure. In this paper we performed experiment at the condition where $B = 800$ G and the neutral gas pressure $P_n = 1.5$ mTorr.

Features of each fluctuation in low frequency range (a few kHz) and high frequency range (around 30 kHz) are presented here. Figures 1 (a) and (b) show the normalized auto power spectrum density (APS) of the density, n, and potential, ϕ, and the squared cross coherence among them, $\gamma^2_{n\phi}$, respectively. Figure 1 (a) shows that multi-time scale fluctuations coexist on the potential fluctuation. In the low frequency range, there are several clear peaks. Their power is in same order. Fluctuations in the low frequency range have finite azimuthal mode number, m, which is measured from the 64 ch probe. In particular, the fluctuation at 2 kHz is a typical DW. On the other hand, in the high frequency range, a broad peak is confirmed at around 30 kHz on the potential fluctuation as shown in Fig. 1 (a). This is the HF fluctuation. The HF fluctuation appears strongly on the potential fluctuation. However, $\gamma^2_{n\phi}$ around 30 kHz is not significant as shown in Fig. 1 (b). By the cross coherence analysis of the data measured with azimuthally-separated probes, the frequency characteristic and the azimuthal mode number of HF fluctuation can be seen. Figures 1 (c) and (d) show the APS of potential fluctuation measured with two azimuthally-separated probes of 64 ch

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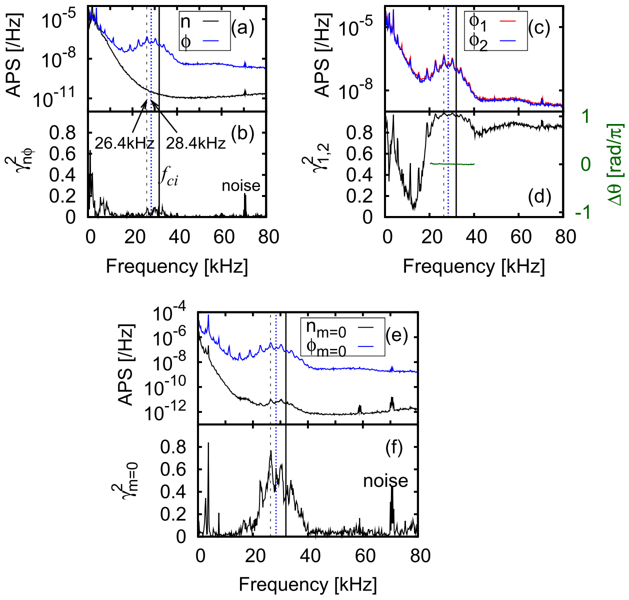

Fig. 1 (a) The normalized Auto Power Spectrum density (APS) of density, n, and potential, ϕ. (b) The squared cross coherence among them. The two vertical dotted lines denote 26.4 kHz and 28.4 kHz, respectively, and the vertical solid line shows ion cyclotron frequency f_{ci}. The sharp peaks at 70 kHz are noise. (c) The APS of potential fluctuation measured by the two probes which are 7.9 mm away in azimuthal direction (ϕ_1, ϕ_2), and (d) the squared cross coherence (black line), $\gamma_{1,2}^2$, and the cross phase (green line), $\Delta\theta$, between those two probes. (e) The APS with $m = 0$ of density fluctuation, $n_{m=0}$, and potential flucutation, $\phi_{m=0}$. (f) The squared cross coherence between those $m = 0$ components, $\gamma_{m=0}^2$.

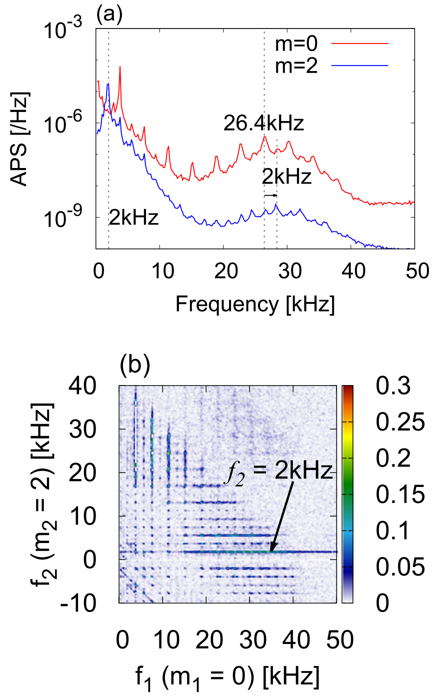

Fig. 2 (a) The azimuthally decomposed auto power spectrum of potential fluctuation with $m = 0$ (red line) and $m = 2$ (blue line), respectively. (b) Contour plot of the squared cross bi coherence among the potential fluctuation with $m = 0$ and $m = 2$. The horizontal line shows the frequency f_1 of $m = 0$ and the vertical line shows the frequency f_2 of $m = 2$.

probe array, ϕ_1 and ϕ_2, the squared cross coherence, $\gamma_{1,2}^2$, and the cross phase, $\Delta\theta$, between the two probes, respectively. These two probes are 7.9 mm away in azimuthal direction. $\gamma_{1,2}^2$ is significant from 20 kHz to 40 kHz, as shown by Fig. 1 (d) black line. This indicates that the HF fluctuation is coherent in broad frequency range. In addition to this, Fig. 1 (d) green line shows that the phase delay in azimuthal direction is 0 from 20 kHz to 40 kHz. This represents that the HF fluctuation is $m = 0$. Thus the components of $m = 0$ are extracted as shown in Figs. 1 (e) and (f). Figure 1 (e) shows the APS with $m = 0$ of density and potential fluctuation described as $n_{m=0}$ and $\phi_{m=0}$, and (f) shows the squared cross coherence between those $m = 0$ components, $\gamma_{m=0}^2$. The HF fluctuation is clearly seen on $m = 0$ potential fluctuation. $\gamma_{m=0}^2$ is significant and broad around 30 kHz as shown in Fig. 1 (f). This also supports that the HF fluctuation is a broad-band fluctuation, and points out that actually, the broad-band characteristic also appears in density fluctuation.

DWs with $m = 2$ and HF fluctuation with $m = 0$ can nonlinearly interact with each other. A possible process is via the three wave coupling, where a beat wave results. For this process, the matching condition on the frequency and the azimuthal wave number has to be satisfied: $(m, f) = (m_1, f_1) + (m_2, f_2)$. In order to confirm this, we compared azimuthally decomposed spectra of $m = 0$ and $m = 2$ as shown in Fig. 2 (a). The red line and the blue line show $m = 0$ and $m = 2$ spectra of the potential fluctuation, respectively. From the figure, we see that $(m, f) = (2, 2\,\text{kHz})$ mode can couple with (0, 26.4 kHz), and (2, 28.4 kHz). In addition, from the amplitude, it is indicated that the dominant components are DWs with $m = 2$ and HF fluctuation with $m = 0$, and the HF fluctuation with $m = 2$ is the beat wave due to the nonlinear coupling: $\mathrm{DW}(2, 2\,\text{kHz}) + \mathrm{HF}(0, 26.4\,\text{kHz}) \rightarrow \mathrm{HF}(2, 28.4\,\text{kHz})$. To verify this coupling further, we have calculated cross-bi-coherence between azimuthally decomposed spectra of $m = 0$ and $m = 2$. First the signals measured from 64 ch probe array are azimuthally decomposed. Then the cross-bi-coherence between $m = 0$ and $m = 2$ components are calculated. Figure 2 (b) shows contour plots of the squared cross-bi-coherence between $m = 0$ and $m = 2$ modes of the potential fluctuation. The horizontal line and the vertical line show the frequency with $m_1 = 0$ and $m_2 = 2$, respectively. The coupling between DWs and HF fluctuation is indicated by the arrow. The HF fluctuation widely couples with the DWs from about 15 kHz to 50 kHz. Thus the new type of multi-time scale nonlinear coupling was observed. This nonlinear coupling is also confirmed by the band-pass filtered signal which is from 20 kHz to 40 kHz. The HF fluctuation is modulated by DW.

Characteristics of HF fluctuation are described here. This HF fluctuation has the frequency around ion cyclotron frequency. However, the result of B scan indicates that this fluctuation is not ion cyclotron wave. The parameter window on B and P_n in which the HF fluctuation can occur is confirmed by parameter scan. We also note that similar HF fluctuation is measured on basic experiments on plasma detachment. Further measurements on the spatial structure, light emission, detachment, etc, will be performed in future.

In summary, a new type of multi-time scale nonlinear coupling is observed in PANTA. Experimental observations show (i) the coexistence of the HF fluctuation of $m = 0$ and DWs, (ii) the $m = 0$ HF fluctuation nonlinearly couples with DWs directly. Identification of the HF fluctuation is still on-going and left for future.

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