§1. A Coupling between Zonal Flows and Turbulence in CHS

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The zonal flows have been an urgent issue to be studied for fundamental understanding of anomalous transport that has been well known in magnetically confined plasmas. The zonal flow structure has been found in CHS, using twin Heavy Ion Beam Probes (HIBPs) [1]. A remaining issue of the zonal flow identification is that the zonal flow structure is driven by turbulence, in other words, the coupling between the zonal flows and the turbulence should be established. In order to confirm this linkage between zonal flow and turbulence, we have performed the wavelet analysis [2] on the electric field fluctuations measured with the HIBPs.

Figure 1 shows time evolution of electric field fluctuation power as a function of frequency together with the zonal flow waveform. In Fig. 1(a) the power of the fluctuations is shown to be predominant in the frequency regime around 50 kHz. Obviously, the power of this frequency range is modulated by a frequency, and the modulation appears to be obeyed with the phase of zonal flows shown in Fig. 1(b). In fact, it is shown in Fig. 1(c) that the zonal flow frequency is consistent with the frequency of the modulation.

In order to confirm this linkage between the phase of zonal flows and turbulence power, a conditional averaged turbulence powers are calculated for the zonal flow phase. The result is shown in Fig. 1(d). The figure demonstrates that the turbulence power (around 50 kHz) is larger when zonal flow is in the direction of ion diamagnetic direction, while the turbulence power is lower when the zonal flow is in the opposite direction. Note that the waves in the frequency range around 50 kHz are found to propagate in electron diamagnetic direction. The clear difference in turbulence power between two different phase of zonal flow shows that the turbulence is affected by the zonal flows.

We have also performed the wavelet bicoherence analysis on the electric field fluctuations. The analysis shows that the coupling constant between elemental waves of turbulence becomes larger to generate zonal flows when the zonal flow is in the phase of top and bottom (see Fig. 1(b)), while the coupling is insignificant when the zonal flow is in the average or zero [3]. Furthermore, it is confirmed that the zonal flow energy increases (or decreases) with a decrease (or an increase) in turbulence energy [2]. These experimental results demonstrate the linkage between zonal flows and turbulence, and the effect of zonal flows on plasma transport.

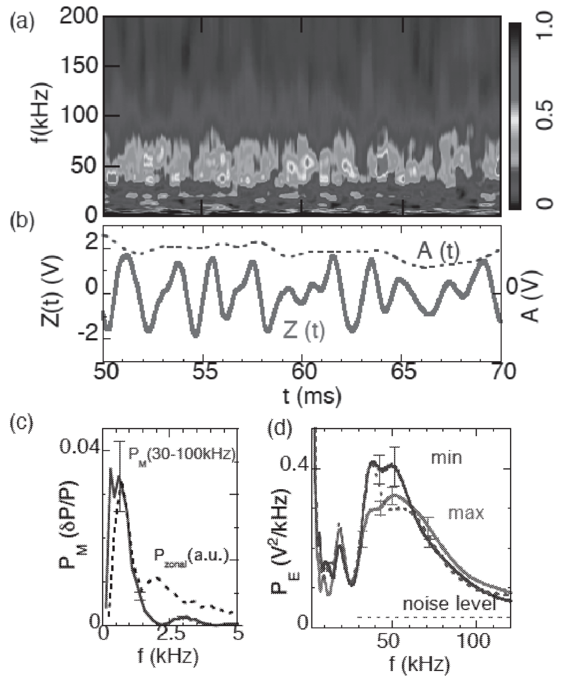

Figure 1: (a) Evolutions of wavelet spectrum of electric field fluctuations as a function of frequency. The unit of the color bar is in V^2/kHz. (b) Evolution of zonal flow. The waveform of zonal flow is the electric field numerically filtered in the frequency range around $f \sim 0.5$ kHz. The blue dashed line indicates the evolution of zonal flow amplitude using the wavelet analysis. (c) The FFT spectrum of wavelet power in the frequency range from 30 to 100 kHz. The electric field fluctuation in the zonal flow range, for comparison, is shown by the black dashed line. (d) Conditional averaged spectra of wavelet power around the local maxima and minima of the zonal flow. The grey dashed line represents the conditional averaged spectrum when $|Z(t)| \sim 0$.

References

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