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Experimental Identification of Zonal Flows in CHS

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Zonal flow in toroidal plasmas is a band-like structure that has poloidal and toroidal symmetry (m=n=0) with a finite radial wavelength (k_r)[1,2]. The study of zonal flow is now becoming a central issue in both fusion research and plasma physics, since it is a mechanism that determines turbulent level and the resultant transport through nonlinear interaction of turbulence. A number of simulation works (e..g., [3,4]) have shown the existence of zonal flow and its important role in determination of the turbulence characteristics. On the other hand, only indirect signs of zonal flow have been obtained in several experiments [5,6]. This paper reports the first direct measurement of zonal flows in a toroidal plasma.

The experiments were performed in a toroidal helical device of medium size, Compact Helical System (CHS); major radius ~1 m, averaged minor radius ~0.2 m. In CHS, a heavy ion beam probe (HIBP) has been used to investigate physics of radial electric field, bifurcation and transport barrier [7]. Recently, another HIBP has been installed, and these double HIBP systems have begun to work to study plasma turbulence and spatio-temporal evolution of plasma structure.

Two HIBPs are located apart from each other approximately by 90 degrees in the toroidal direction. Each one is capable of measuring potentials, denoted as ϕ_1, ϕ_2 ϕ_3, at three adjacent positions (~1.5cm apart from each other) in the plasma. The potential difference between the neighboring channels, e.g., $\Delta\Phi_1=-\phi_1+\phi_2$, can represent a local electric field.

The first trials to identify the zonal flow are performed in electron cyclotron resonance heated (ECRH) plasmas [8]. The plasma parameters are; magnetic field strength B=0.88T, density n_e~5×10^{12}cm^{-3}, electron temperature T_e~1keV, ion temperature T_i~ 0.1keV, ion Larmor radius ρ_i~0.1mm, and energy confinement time τ_E ~ 2-3 ms (or characteristic frequency of global confinement $\tau_E^{-1}/ 2\pi \sim 0.1$ kHz).

Figure 1(a) shows spectra of the *electric field* fluctuation (or perpendicular flow to the magnetic field) at radial position of r_{obs}~12 cm (or ρ~0.6) in the frequency of <30 kHz. The spectra are obtained with the Fast Fourier Transform (FFT) technique applied on the stationary period of ~ 80ms for the discharge duration of ~ 100ms; here the data sampling rate of 2 μs gives the Nyquist frequency of 250 kHz. The spectrum is an average of more than a dozen shots, and the result is significantly above the noise level. The *electric fields* between two toroidal location shows a high coherence (~0.6) in the region of low frequency (f<1 kHz). The phase difference between these two electric fields shows no difference if the observation points are on the same magnetic flux surface. Accordingly, the *electric field* in this range of frequency is the zonal flow.

A clear sharp peak at ~17kHz is found in electric field spectrum; the width of this mode is evaluated as ~0.5kHz with a Gaussian fitting. Figure 1(b) is the expanded view of the peak. A long-range correlation of the fluctuation at the frequency is also confirmed in potential that has a larger signal-to-noise ratio. This mode can be the Geodesic Acoustic

Mode (GAM). The definite conclusion is left in future. Figure 1(c) is the same power spectrum in linear scale as a function of the frequency normalized by ion Larmor frequency. Note that the essential characteristics of the spectrum are found to be very similar to those of simulation results in Ref. [4].

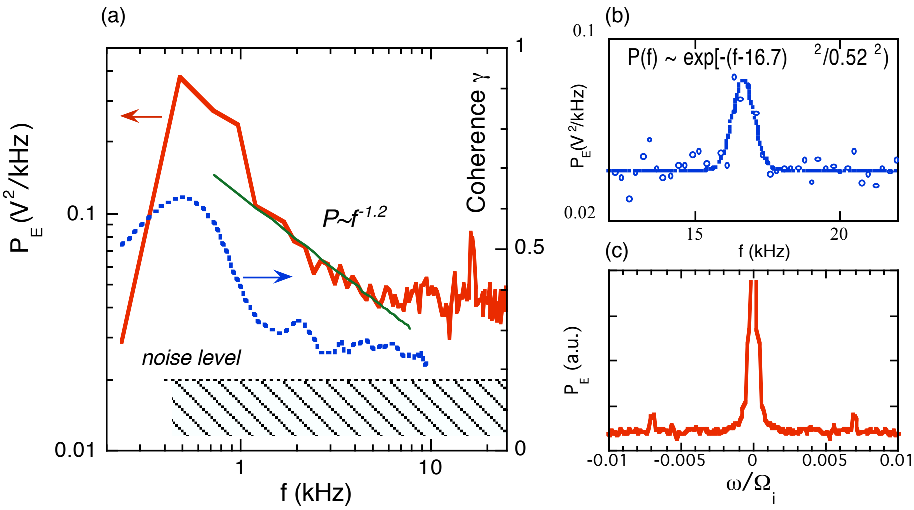

Figure 1: (a) Power spectrum and coherence of electric field fluctuation in CHS. (b) An expanded view of a peak around 17kHz, which is inferred as GAM. (c) The same spectrum in linear scale. The frequency is normalized by ion gyro-frequency.

The radial structure of the zonal electric field (or flow) is inferred by the phase difference between electric fields in two locations. The phase variation of zonal flow activity in radial direction can be evaluated by varying the observation position of the second HIBP, r_2, while fixing the observation point of the first HIBP. The FFT analysis of cross-power spectrum allows us to estimate the phase variation. The analysis demonstrates a radial structure changing sinusoidally with the wavelength of ~1.5 cm, that corresponds to ~$15\rho_i$. Our measurements clearly demonstrate both a long-range correlation and rapidly varying radial structure. Therefore, these studies identify the zonal flow for the first time.

Finally, zonal flows are ubiquitous in nature; the Jovian belts and zones, the terrestrial atmospheric jet stream, the Venusian atmosphere and the solar tachocline. Now, the presence of zonal flows in toroidal plasmas is confirmed. This study of zonal flows in toroidal plasmas in a laboratory can give a new insight on the thermal evolution and structural formation in the universe.

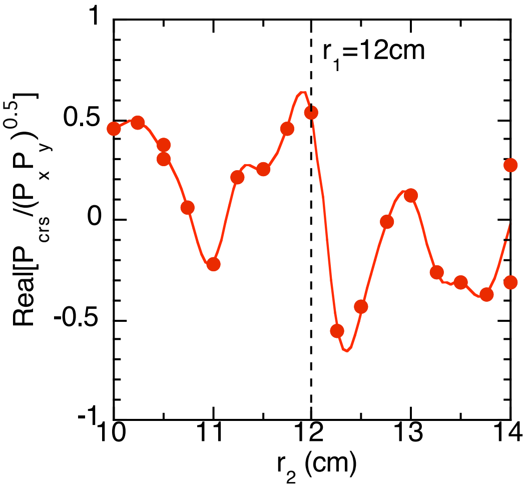

Figure 2. Phase difference of zonal flow in radial direction. The plotted points are the real part of the normalized cross power spectrum ($\gamma\cos\theta$) between electric fields from the two HIBPs. In the measurements, the observation point of an HIBP is radially varied with the other fixed

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References

[1]A. Hasegawa, C. G. Maclennen, and Y. Kodama, Phys. Fluids **22**, 2122 (1979)

[2]P. H. Diamond, et al. in Proceedings of the 17th IAEA fusion energy conference, Yokohama,1998 vol. **4** 1421-1428. (International Atomic Energy Agency, Vienna, Austria, 1999).

[3] K. Hallatschek, Phys. Rev. Lett. 84, 5145 (2000).

[4] T S Hahm , K H Burrell, Z Lin, R Nazikian and E J Synakowski, Plasma Phys. Control. Fusion **42** (2000) A205.

[5] M. G. Shats, W. M. Solomon, Phys. Rev. Lett. **88**, 045001 (2002).

[6] G. R. McKee, et al., Plasma Phys. Control. Fusion **4**5, A477 (2003).

[7] A. Fujisawa et al., Phys. Plasma **7** 4152 (2000)

[8] A. Fujisawa et al., submitted to Phys. Rev. Lett.