Overview of recent results on long-range correlations and zonal flows in the edge of TEXTOR tokamak

Y. Xu[1], I. Shesterikov[1], M. Van Schoor[1], M. Vergote[1], R. R. Weynants[1], A. Krämer-Flecken[2], D. Reiser[2], S. Zoletnik[3], and the TEXTOR team

[1] *Laboratory for Plasma Physics, Ecole Royale Militaire/Koninklijke Militaire School, Euratom-Belgian State Association, Avenue de la Renaissance 30, B-1000 Brussels, Belgium**
[2] *Institute of Energy and Climate Research - Plasma Physics, Forschungszentrum Jülich, Association EURATOM-FZJ, D-52425 Jülich, Germany**
[3] *KFKI RMKI, Association Euratom, Budapest, Hungary*
* *Partner in the Trilateral Euregio Cluster* (*TEC*):

1. Introduction

Zonal flows have stimulated a great interest in fusion research due to their potential capability of regulating the turbulence level and associated transport, and thus, to enhance the prospect of burning plasmas in a fusion reactor like ITER [1]. In the last 2 years, long-range correlations (LRCs) in turbulence and zonal flows (ZFs) have been intensively investigated in the TEXTOR tokamak using Langmuir probes, Correlation Reflectometry [2] and Lithium-Beam Emission Spectroscopy [3]. A wealth of significant and consistent results has been obtained. In this paper, we report primarily on the study of LRCs and ZFs detected by two sets of toroidally separated Langmuir probe arrays.

2. Experimental setup

The experiments were performed in ohmic deuterium discharges in TEXTOR with the following parameters: R=175cm, $a\approx$48cm, B_T=(1.9-2.25)T, I_p=(200-250)kA and line-averaged densities $\bar{n}_{e0}$=(1.5-3.0)$\times 10^{19}$m^{-3}. For measuring the LRC of edge fluctuations along the toroidal direction, two movable Langmuir probe arrays were installed at two nearly opposite locations of the torus (over a distance ~7 m) in the midplane of the low-field side. Both arrays were operated to detect the floating potential (V_f) and ion saturation current (I_s) and their fluctuations at a sampling rate of 500kHz. In each discharge, one array is stationary while the other is fast reciprocating. From shot to shot, the radial position of the stationary probe can be altered. The toroidal cross-correlation between the signals *x* and *y* measured on the stationary and fast probe is defined as $C_{xy}(\tau)=<[x(t)-\bar{x}][y(t+\tau)-\bar{y}]>/\sqrt{<[x(t)-\bar{x}]^2><[y(t)-\bar{y}]^2>}$, where τ is the time lag. In the TEXTOR-DED (Dynamic Ergodic Divertor) experiments, the impact of Resonant Magnetic Perturbation (RMP) on the LRCs has been surveyed using two perturbation modes (poloidal/toroidal= m/n =6/2 and 3/1). In the edge biasing experiment, a polarization voltage (V_{bias}=300-700V) between the limiter and a graphite electrode inserted at r$\approx$41cm has been applied during the stationary phase of the discharge to reach a confinement improvement regime.

3. Results and discussion

In ohmic TEXTOR discharges, LRCs on potential, density and velocity fluctuations have been widely observed by various diagnostics. The LRC exhibits features consistent with the geodesic acoustic mode (GAM) [1]. For probe measurements, the typical results of the LRC detected in I_s and V_f fluctuations ($\tilde{V}_f$) are depicted in Fig. 1. Figure 1(a) shows that the fast probe plunges from outside into the plasma edge at one

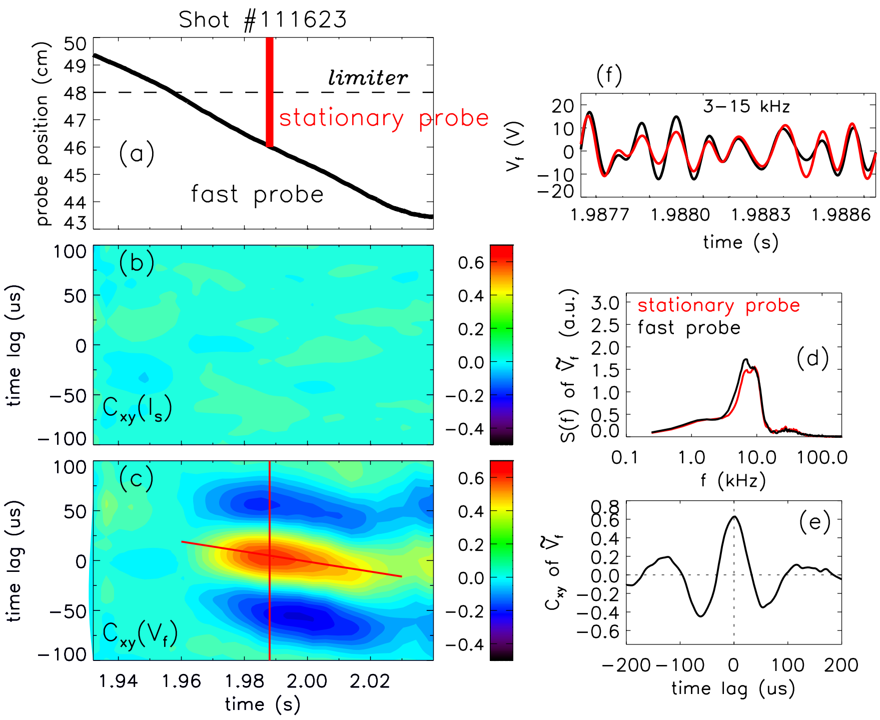

FIG. 1 (a) Time trace of fast/stationary probes; (b) contour plot of cross-correlation between I_s fluctuations measured by two distant probe arrays; (c) contour plot of cross-correlation between V_f fluctuations measured by two distant probe arrays. The vertical red line indicates the time when the two probes are at the same radial location; (d) power spectrum of V_f detected by fast/stationary probe at the same radial location (r≈46 cm); (e) cross-correlation function on V_f measured by the fast/stationary probe at r≈46 cm; (f) waveforms of V_f at r≈46cm in two toroidally distant positions (the red is for the stationary probe and the black is for the fast probe). Both signals are filtered in the frequency range of 3-15 kHz.

toroidal position while the stationary probe stays at r≈46cm (as reference) at another toroidal position. Figures 1(b) and (c) show nearly no correlation on I_s signals whereas on $\tilde{V}_f$ a large cross-correlation occurs when the two toroidally separated probes are localized around the same radial position inside the last closed flux surface. The absence of LRCs on I_s and its presence on V_f fluctuations are both consistent with theoretical predictions for the GAM, which is predicted to have *m*=1 and *m*=0 mode on density and potential fluctuations, respectively. As seen in Figs. 1(c) and (e), the maximum cross-correlation in $\tilde{V}_f$ measured at r≈46cm has approximately a zero delay time, indicating an *n*=0 mode structure of GAMs. Plotted in Fig. 1(d) are the power spectra of the $\tilde{V}_f$ detected at the maximum C_{xy} location. The spectra on the two probes are very similar and a prominent peak is found about *f*≈9kHz, in agreement with GAM waveforms shown in Fig. 1(f). The experimentally detected GAM frequencies are also in accordance with the theoretical expectation of the f_{GAM} dependence on local sound speed [1], i. e., $f_{GAM} \approx C_s(2+q^{-2})^{0.5}/2\pi R$, as reported in Ref. [4]. In addition, bi-spectral analysis reveals that the GAM zonal flows are nonlinearly coupled with broad-band ambient turbulence via three-wave interactions [4, 5]. The radial correlation structures of GAMs on $\tilde{V}_f$ are estimated from the cross-correlation between two probe signals at a zero delay time, C_{xy} (r_1, r_2, τ=0), where r_1 and r_2

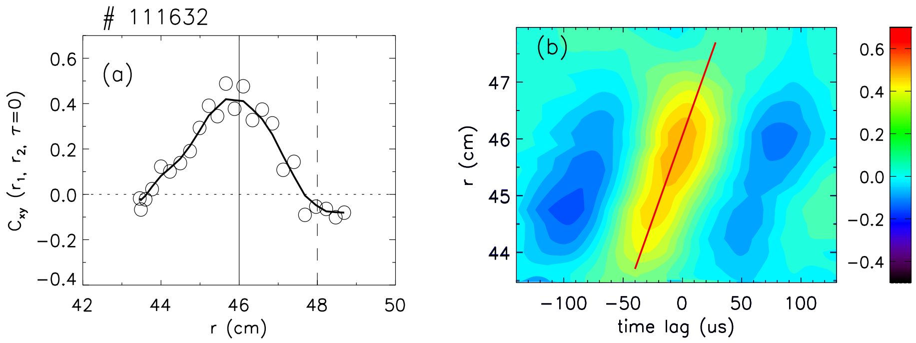

FIG. 2. (a) The radial structure of GAM correlations, estimated from the cross-correlation of V_f signals at a zero-delay time, C_{xy} (r_1, r_2, τ=0), measured by two toroidally distant probes. The vertical dashed line denotes the limiter position; (b) contour-plot of cross-correlation (C_{xy} on V_f) showing the radially outward propagation of GAMs at a speed of V_r ≈0.6 km/s.

represents the radial position of the stationary (reference one) and fast probe, respectively. Figure 2(a) plots the radial profile of C_{xy} (r_1, r_2, τ=0) with the reference probe fixed at r≈46cm. It shows a sinusoidal structure (the innermost measurement is limited by the probe accessibility and we assume that the full waveform is sinusoidal) with λ_r ≈9 cm or k_r≈0.7 cm^{-1}. In our experiments, the k_r changes in a range of (0.5-0.7) cm^{-1} under different plasma conditions. Moreover, as illustrated in Fig. 1(c), the maximum value of C_{xy} on $\tilde{V}_f$ exhibits a clear radial propagation. To estimate the radially moving phase speed of GAMs, we convert the time trace to radial loci. Shown in Fig. 2(b) is the contour-plot of C_{xy} as a function of radius and time lag, from which one can see that the GAM moves radially outward at a velocity of V_r ≈0.6 km/s. The local GAM frequency is f_{GAM}=5.8 kHz. Thus, the GAM phase velocity is $f_{GAM} \times \lambda_r$ = 0.52 km/s, close to the V_r deduced in Fig. 2(b).

In the RMP experiments at TEXTOR, the DED system resonates at q≈3 surface and ergodizes the edge magnetic field lines with various perturbation modes (m/n=6/2 and 3/1). With increasing DED current the ergodization is expected to be stronger. In Fig. 3 the maximum values of the LRC on $\tilde{V}_f$ are shown for three different DED currents. One can clearly see that the LRCs and GAMs are gradually reduced with increasing DED current, as observed also by reflectometry [2]. Such effects by RMP might be linked to parallel dynamics for the development of GAMs. Without RMP, The $k_{//}$ ≈0 is subject to strong instabilities of modes, whereas with RMP the GAM modes are damped by resistivity due to nonzero $k_{//}$ and B_r [6]. It has

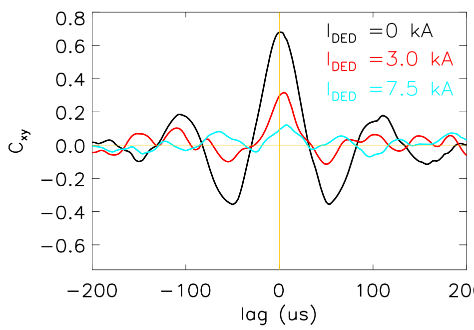

FIG. 3. Maximum values of the LRC on V_f fluctuations measured under different DED currents (I_{DED}=0, 3.0 and 7.5kA) in an m/n=6/2 DED configurations at the edge (r/a=0.95) of TEXTOR [edge safety factor q(a)=5.0].

been found that without RMP the GAM related low-frequency (<10 kHz) fluctuations give nearly a zero contribution in the turbulence-driven flux. But with RMP, the suppression of GAMs provokes a large turbulent flux in low-frequency components.

The LRC has also been investigated in the proximity of the density-limit in TEXTOR. Plotted in Fig. 4 are the maximum values of the LRC on $\tilde{V}_f$ detected in different line-averaged density discharges. At low densities ($\langle n_e \rangle \leq 2\times10^{19}m^{-3}$) the LRCs are quite large and vary only slightly with increasing density. However, at higher densities when $\langle n_e \rangle > 2\times10^{19}m^{-3}$), the LRCs reduce rapidly with increasing plasma density. In the density-limit discharges, the increase of plasma density usually induces a reduction of edge temperature and consequently a change in collisionality. Meanwhile we found a reduction in the edge mean radial electric field E_r. These results suggest the possible role of collisionality and the impact of mean $E_r\times B$ flow shear as well on the development of GAM zonal flows.

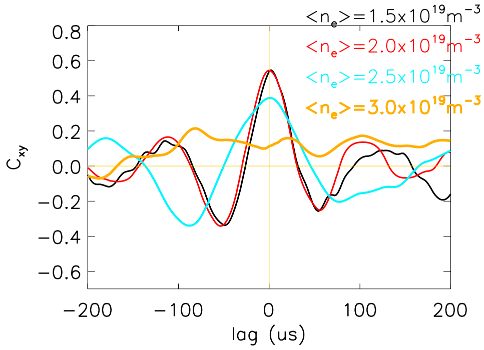

FIG. 4. Maximum values of the LRC on V_f fluctuations measured in different density plasmas at the edge (r/a=0.95) of TEXTOR [edge safety factor q(a)=5.9], showing reduction of the LRC with increasing plasma density toward density-limit.

In edge biasing experiments at TEXTOR, a biasing voltage (V_{bias}=300-700V) between the limiter and a graphite electrode was applied during the stationary phase of the ohmic discharge. It is found that in the biasing-induced improved confinement regime the LRC on $\tilde{V}_f$ is always amplified, suggesting an intimate interplay between the mean and zonal flows [7]. These LRCs are not attributed to GAMs. They are dominated by low-frequency fluctuation components (f <5 kHz). This result agrees with several observations in other devices [6], and thus, suggests the importance of both mean and oscillating sheared flows in the L-H transition physics.

4. Conclusion

The long-range correlation and zonal flows have been studied in TEXTOR in several regimes. In normal ohmic plasmas the GAMs are routinely observed. The damping effects by RMP and plasma density on the GAMs have been surveyed in the TEXTOR-DED and density-limit discharges. In biasing experiments, an amplification of LRCs is seen in the improved confinement. The results provide wealthy evidence for understanding the characteristic of zonal flow and its interaction with turbulence.

Reference:

[1] P. H. Diamond et al., Plasma Phys. Controlled Fusion 47, R35 (2005).
[2] A. Krämer-Flecken et al., J. Plasma Fusion Res. SERIES, Vol. 8 (2009) 44-49.
[3] L. Bardoczi, S. Zolentnik et al., this conference, P1. 065.
[4] Y. Xu et al., submitted to Plasma Phys. Controlled Fusion.
[5] I. Shesterikov et al., Proc. 37th EPS Conf. on Plasma Physics (Dublin,2010), P1. 1090.
[6] Y. Xu et al., Nucl. Fusion 51, 063020 (2011).
[7] Y. Xu et al., Phys. Plasmas 16, 110704 (2009).