Mean and fluctuating E×B shear flows on the ISTTOK edge plasma

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1. Introduction

The possible link between radial electric fields, long-range correlations and edge plasma transport has been previously investigated in several devices, both in edge biasing experiments and spontaneous L-H mode transitions [e.g. 1, 2]. It has been found that the long-range correlation increases during bias induced enhanced confinement regimes and when approaching the spontaneous confinement transitions, highlighting the possible role of zonal-flows in edge transport bifurcations. Recent experiments on the ISTTOK tokamak have also identified long-distance correlations in plasma potential fluctuations consistent with the geodesic acoustic mode (GAM) [3], which are also modified in the presence of externally imposed radial electric fields.

The present work aims at investigating the evolution of both mean and fluctuating E×B flow shear in the ISTTOK edge plasma. The evolution of the radial and long-range correlations as well as the mean and fluctuating flow shearing rates was measured and the interplay between them investigated during confinement enhancement induced by electrode biasing.

2. Experimental set-up

Measurements were carried out in the tokamak ISTTOK, a large aspect ratio circular cross-section tokamak (R = 46 cm, a = 8.5 cm, B_T = 0.5 T, $I_p \approx$ 4-6 kA) equipped with two probe systems for edge fluctuations studies: (i) a 8-pin poloidal array of Langmuir probes with a resolution of 2 mm, installed in an equatorial port; and (ii) a 8-pin radial array of Langmuir probes (rake probe) with 3 mm spatial resolution, toroidally located at 120º from the poloidal array and installed near the top of the poloidal cross-section. Such an experimental arrangement allows the investigation of the three dimensional characteristics of the edge fluctuations. Biasing experiments were performed using either an emissive or a graphite electrode and the bias applied between the electrode and the vacuum vessel [4].

3. Mean and fluctuating shear rates

On ISTTOK, the edge plasma fluctuations are dominated by low frequency oscillations consistent with the geodesic acoustic mode, which is expected to have a frequency of ~20 kHz

(T_i = T_e = 20 eV) [3]. It has been found that the floating potential fluctuations exhibit a significant toroidal correlation at large distances (~1 m) that can be attributed to GAMs.

The radial profile of the mean floating potential, V_f, in the ISTTOK edge plasma is shown in figure 1 together with the evolution of the V_f fluctuations radial profile in the GAM frequency region (15-25 kHz). A shear layer is observed around the limiter position being the mean shear rate in the region just inside the limiter in the order of $\gamma_{E\times B}^{Mean} \approx \Delta V_f^{Mean}/\Delta r^2 B \approx 40/(0.01)^2 \times 0.5 \approx 8 \times 10^5\ s^{-1}$. As illustrated in figure 1, the GAM shearing rate is more modest: the amplitude of the oscillations is around 20 V and the spatial scale around 1.5 cm given a shearing rate of $\gamma_{E\times B}^{GAM} \approx \Delta V_f^{GAM}/\Delta r^2 B \approx 20/(0.015)^2 \times 0.5 \approx 2 \times 10^5\ s^{-1}$. The estimate value for the GAM shearing rate is comparable to the decorrelation rate of the floating potential fluctuations, $\tau_c \sim 3 \times 10^5\ s^{-1}$, calculated as the inverse of the auto-correlation time. The GAM shearing rate is therefore lower (by a factor of ~ 4) than the mean flow but comparable to the turbulent decorrelation rate, suggesting that both the time-varying flow and mean flow are important to stabilize turbulence by shearing decorrelation mechanisms.

The GAM shearing rate can also be evaluated by estimating its radial structure. The *S(k,w)* function was applied to compute the radial structure of the edge fluctuations using rake probe floating potential signals from two radial location separated by 6 mm. As shown in figure 2, the *S(k_r)* spectrum at GAM frequency has a peak at $k_r \approx 1.5$ cm^{-1}, which can be identified as the

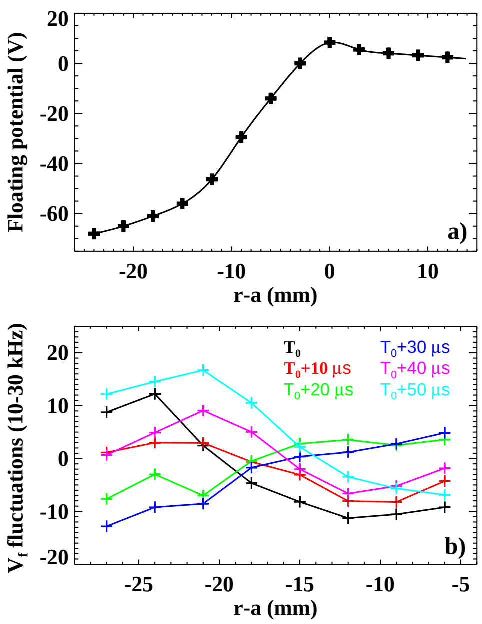

Figure 1: The V_f radial profile in the edge plasma together with the evolution of the V_f fluctuations radial profile in the GAM frequency region (15-25 kHz).

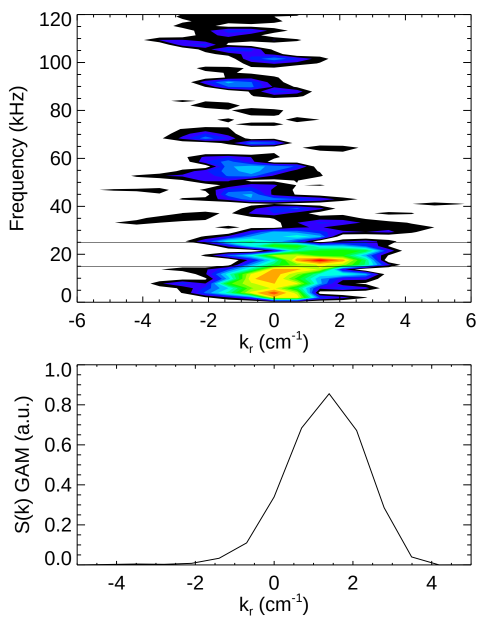

Figure 2: *S(k_r,w)* spectrum of V_f fluctuations and *S(k_r)* spectrum at GAM frequency.

GAM component of the radial fluctuations. Taking the shearing rate to be approximately $\gamma_{E\times B}^{GAM} \approx k_r^2 \Delta V_f^{GAM}/B$, the shearing rate is therefore $\gamma_{E\times B}^{GAM} \approx 4 \times 10^5\ s^{-1}$.
The amplitude of the GAM was found to be strongly bursty, leading to a modulation of the turbulent transport amplitude [4]. This intermittence is also reflected in the fluctuations dispersion relation, as potential structures with $k_r \approx 0$ are observed (see figure 2) for low frequencies (f < 15 kHz). A competition between GAMs and intermittent-like turbulent transport is therefore observed on the ISTTOK edge plasma, leading to a dynamic view of plasma transport. It should be noted that the dispersion relation $k_r(w)$ is not linear both in the low frequency range and in the ambient turbulence range and therefore the propagation velocity is not well defined.

4. Interplay between mean and fluctuating shear flows

GAMs are expected to have a complex spatial pattern, exhibiting structures on the scale of 10 - 20 ρ_i, contrary to mean radial electric field, which change smoothly. Furthermore, mean electric fields can persist in the absence of turbulence contrary to GAMs that are exclusively driven by turbulence. Mean flows can therefore suppress GAMs by shearing apart the turbulence. This offers possible mechanisms for energy exchange between GAMs and mean flows. External plasma biasing can be used in the experiment to control the radial electric field offering the possibility to study its effect on GAMs.
Electrode biasing experiments have been previously investigated on ISTTOK [3], revealing that a large radial electric field is induced for both polarities (up to ±15 kV/m) and a significant improvement in particle confinement observed particularly for negative bias. A clear modification in the V_f fluctuations spectrum is observed for both polarities (see figure 3). A significant reduction in the low frequency fluctuations (< 100 kHz) is observed for negative bias, while for positive bias a more modest reduction is observed and limited to the 5 – 70 kHz frequency range. The decrease in the low frequency fluctuations observed for negative bias is consistent with the reduction in the intermittent events, which are characterized by large amplitude low frequency fluctuations. Figure 4 presents the floating potential radial profile for positive, negative and without electrode biasing.

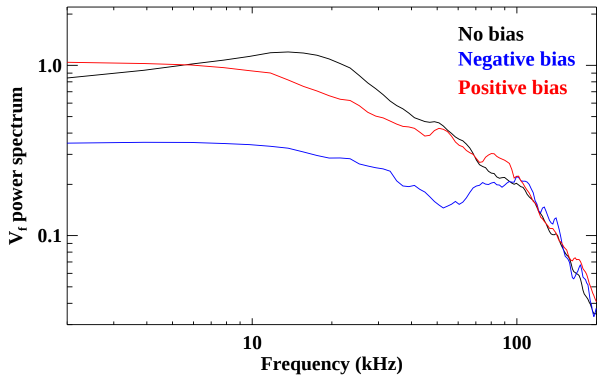

Figure 3: V_f Frequency spectra for positive, negative and without biasing.

Also shown, is the amplitude of the GAM fluctuations estimated as $rms(V_f^{GAM}) \times \gamma^{GAM}$, where $rms(V_f^{GAM})$ is the root-mean-square of the V_f fluctuations with GAM frequency (15-25 kHz) and γ^{GAM} is the long-range coherence for this frequency range. It is typically observed that positive bias leads to a 10-20% increase of γ^{GAM} in the edge plasma, while negative bias leads to a significant reduction (up to 50 %). As a consequence, we observe that positive bias leads to a small reduction of the GAM fluctuations amplitude, being the reduction significantly larger for negative bias (up to a factor of 5). As expected for large enough mean shear flows, GAMs are suppressed as their driving mechanism (turbulence) is sheared apart.

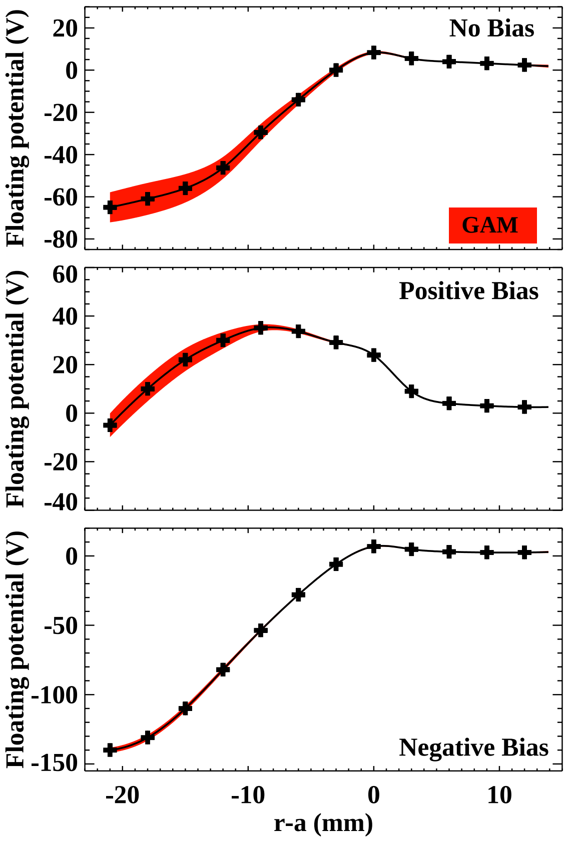

Figure 4: V_f radial profile for positive, negative and without electrode biasing together with the amplitude of the GAM fluctuations.

5. Conclusions

The mean and fluctuating E×B shear flows have been investigated in the ISTTOK edge plasma. The GAM shearing rate was found to be lower (by a factor of ~4) than that of the mean flow but comparable to the turbulent decorrelation rate, suggesting that both the time-varying flow and mean flow are important to stabilize turbulence. External radial electric field was found to modify the GAM amplitude particularly for negative bias where the fluctuations are strongly reduced and consequently the GAMs are suppressed. For positive bias a small reduction of the GAM amplitude is observed in spite of the increase in the long-range correlation.

References

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