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Characterization of geodesic acoustic modes in the ISTTOK edge plasma

C. Silva[1], P. Duarte[1], H. Fernandes[1], H. Figueiredo[1], I. Nedzelskij[1], C. Hidalgo[2], M.A. Pedrosa[2]

[1]*Associação Euratom/IST, Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, 1049-001 Lisboa, Portugal;* [2]*Asociación Euratom/Ciemat, 28040 Madrid, Spain*

1. Introduction

Large scale structures as the zonal flows (ZFs) and the associated geodesic oscillations are universally observed in turbulent systems such as magnetically confined plasmas. It is now widely recognized that fluctuating small scale $\boldsymbol{E} \times \boldsymbol{B}$ shear flows, such as ZFs, can be generated by turbulence and regulate the turbulence in return [1 and references within]. Understanding the mechanisms driving plasma turbulence is essential to optimize experimental results and predict the performance of future devices. The experimental characterization of ZFs is particularly important as it may offer a possibility to control turbulence.

In this paper we build on the previous ISTTOK results [2] aiming at a detailed characterization of the GAM radial, poloidal and toroidal structure and its influence on turbulence and transport. Edge potential and density fluctuations are measured simultaneously with two Langmuir probe systems that allow the investigation of the three dimensional characteristics of the edge fluctuations with high temporal resolution.

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, $r_{vessel} = 10$ cm, $B_T = 0.5$ T, $I_p \approx 4\text{-}6$ kA) with poloidal graphite limiter. As illustrated in figure 1, ISTTOK is equipped with two probe systems that allow the investigation of the edge fluctuations: (i) a 8-pin poloidal array of Langmuir probes with a resolution of 2 mm, installed in an equatorial port (figure 1a); and (ii) a 8-pin radial array of Langmuir probes (rake probe) with a spatial resolution down to 3 mm toroidally located at about 120º from the poloidal array and installed near the top of the poloidal cross-section (figure 1b). Such an experimental arrangement allows the investigation of the three dimensional characteristics of the edge fluctuations.

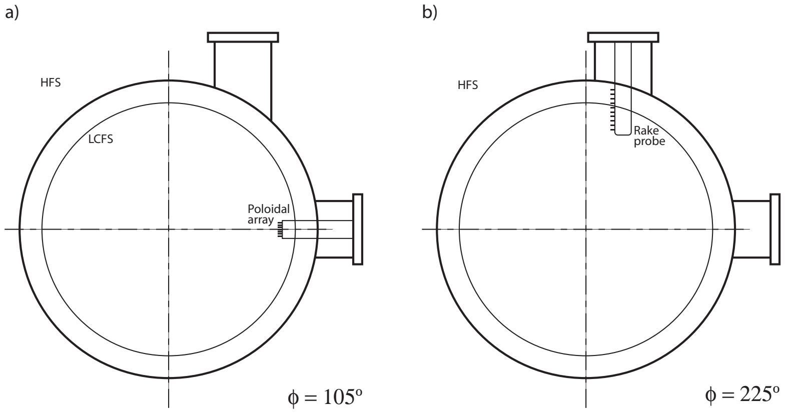

Figure 1: Schematic illustration of ISTTOK (cross-section) showing the two probe systems: (a) poloidal and (b) radial arrays. Both probe systems can be moved radially from shot-to-shot.

3. Results

On ISTTOK, the edge plasma fluctuations are dominated by low frequency oscillations consistent with the geodesic acoustic mode, which for the ISTTOK edge plasma is expected to have a frequency of ~20 kHz ($T_i = T_e = 20$ eV). In this section, a characterization of the GAM structure is presented together with its influence on turbulence.

3.1 Characterisation of the fluctuations poloidal structure

The floating potential and the ion saturation current have been measured across the ISTTOK boundary plasma ($0.74 < r/a < 1.1$) using the poloidal array of probes allowing the investigation of the poloidal structure of the fluctuations. Figure 2 shows the $S(k_\theta, w)$ function, estimated using the two-point statistical dispersion relation, and the associated frequency and poloidal wavenumber (k_θ) spectra for SOL and edge plasma potential fluctuations. In the SOL poloidal wavenumbers in the range of $k_\theta < 3$ cm^{-1} are observed with a broad frequency spectrum that is consistent with the typical ambient turbulent fluctuations. In the edge plasma the wavenumbers are smaller $k_\theta < 1.0$ cm^{-1} and the spectrum is dominated by a broad peak at ~20 kHz with a 10 kHz width. Furthermore, k_θ is found to be roughly zero for frequencies below 50 kHz suggesting the existence of a poloidally symmetric structure.

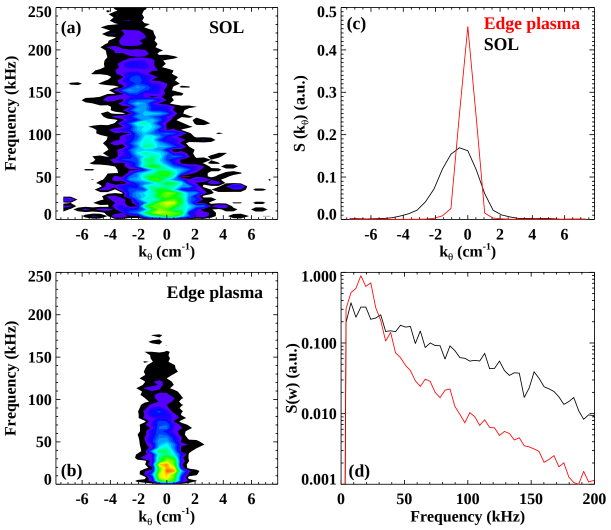

Figure 2: $S(k_\theta, w)$ spectrum of the V_f fluctuations in the SOL (a) and in the edge plasma (b), and the corresponding wavenumber (c) and frequency (d) spectra.

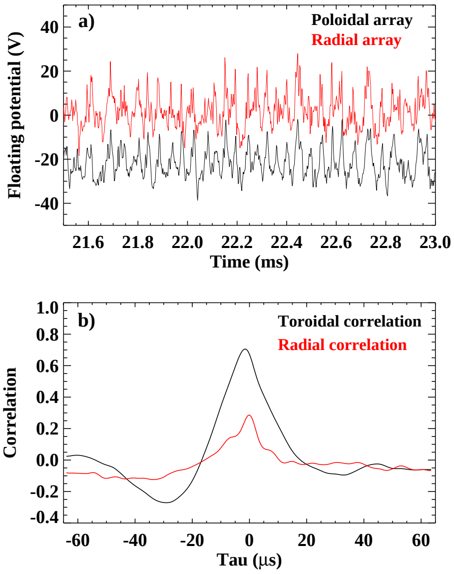

Figure 3: Time evolution of: (a) V_f measured simultaneously in two toroidal positions at r-a= -10 mm; and (b) correlation between V_f signals from toroidally (1 m) and radially (12 mm) separated probes.

3.2 Long-range correlations

The similarity between floating potential signals measured simultaneously at different toroidal locations has been quantified computing their cross-correlation. Raw data for potential signals evolution are shown in figure 3 together with the toroidal cross-correlation. As illustrated in figure 3a, a clear similarity is observed between floating potential signals measured in the edge plasma by the two probe systems and consequently a high toroidal cross-correlation is found (figure 3b). As no significant phase shift is observed between the poloidally and toroidally distant measurements, results suggest that the potential has a $m = 0$,

$n = 0$ structure compatible with GAMs. The radial correlation between rake probe potential signals separated by 12 mm (both pins in the edge plasma) is also shown in figure 5b for comparison. As illustrated, the radial correlation is smaller than the toroidal one in spite of the significantly larger toroidal separation, ~1 m, indicating that GAMs have a fine radial structure.

3.3 GAM radial localization

In order to estimate the GAM radial location the long-range cross-correlation between V_f signals has been computed for different probe positions (figure 4). The correlation has been performed between signals measured simultaneously at different radial positions by the rake probe and one pin of the poloidal array located at r-a= -10 mm. The amplitude of the toroidal correlation is small in the SOL (where the GAM is not predicted to exist), increases rapidly towards the edge plasma reaching the maximum 10 - 15 mm inside the LCFS. A small decrease in the correlation is observed at the inner most probe position. Results suggest therefore that GAMs are localized just inside the LCFS position and have a radial extension of at least 1.5 cm. The radial profile of the amplitude of the potential fluctuations with GAM frequency ($|V_f|_{GAM}$) is also shown in figure 4. The magnitude of $|V_f|_{GAM}$ is small in the SOL and around the LCFS, increases steeply around r - a = - (5 – 10) mm, reaches a maximum about 10 – 15 mm inside the LCFS and then decreases slowly. The remarkable similarity between the two profiles shown in figure 4 constitutes further evidence that the long distance correlations are dominated by GAMs.

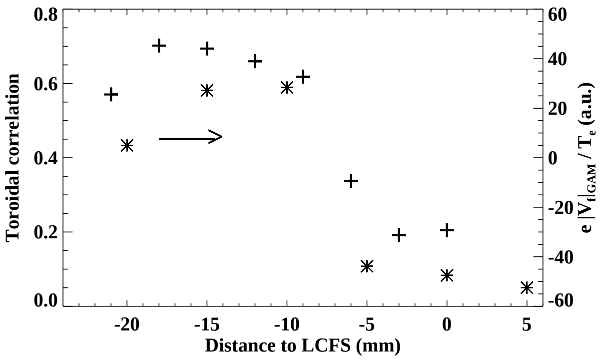

Figure 4: Radial profile of the toroidal cross-correlation for floating potential signals measured between the poloidal probe located at r-a= -10 mm and the rake probe together with the normalized spectral power of the V_f fluctuations in the range 10 – 25 kHz.

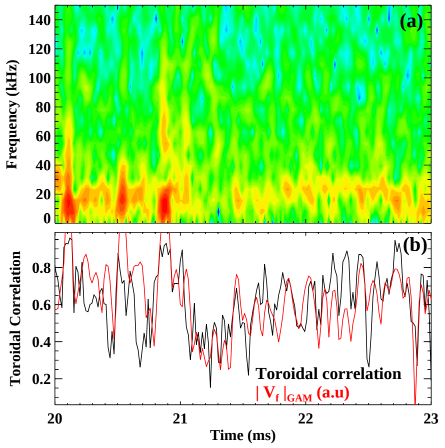

Figure 5: Time evolution of: (a) V_f spectrogram; and (b) toroidal correlation between V_f signals together with the amplitude of the V_f power spectrum in the range 10-25 kHz.

3.4 GAM intermittence

Figure 5 shows the V_f spectrogram calculated using a moving FFT together with the time evolution of the toroidal cross-correlation between V_f signals measured in the edge plasma by the two probe systems. Signals are dominated by a ~20 kHz oscillation with time varying amplitude (figure 5a). Also shown in figure 5b is the amplitude of the V_f power spectrum in the GAM range (10 - 25 kHz). Both long-range correlations and the amplitude of the large scale fluctuations show a significant degree of intermittency and a good correlation between them is found. This observation demonstrates that the GAM amplitude is modulating the long-range correlations. The amplitude of the GAM intermittency (fluctuation level) is typically 30% and the lifetime is estimated to be $\lesssim$ 100 μs, which is compatible with the spectral width of the GAM peak, ~10 kHz.

The relationship between the GAM amplitude and that of the ambient turbulence has been investigated. Figure 6 presents the time evolution of the integrated V_f power spectrum in GAM (10-25 kHz) and ambient turbulence (60-200 kHz) ranges. It is clear that signals are anti-correlated as demonstrated also by the cross-correlation between the two curves (figure 6b). When the GAM amplitude is reduced the ambient turbulent fluctuations are enhanced suggesting the existence of energy transfer between them.

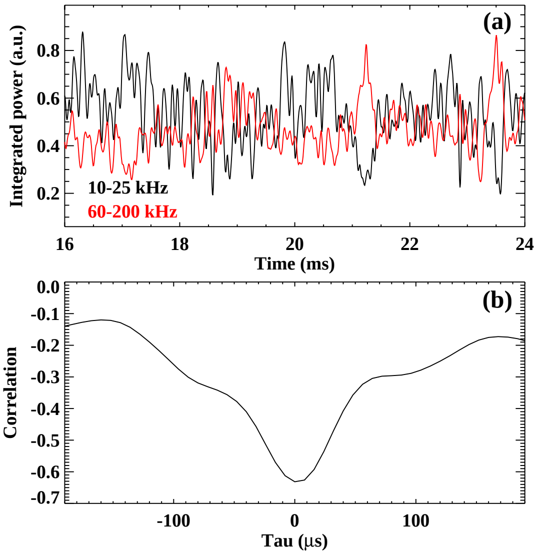

Figure 6: (a) Amplitude of the V_f power spectrum in the range 10-25 kHz and 60-200 kHz. (b) Cross-correlation between V_f (10-25 kHz) and V_f (60-200 kHz).

4. Summary

The fluctuations in the ISTTOK boundary plasma have been investigated using two probe systems that allow the simultaneous measurement of the long distance correlation in the toroidal and poloidal direction as well as the radial structure of the fluctuations with high temporal resolution. The GAM properties have been investigated, being the following observations reported in this paper: (i) The fluctuations in the edge plasma potential are dominated by low frequency oscillations that are consistent with a symmetric structure in the toroidal and poloidal directions, characteristic of the GAM; (ii) Radially resolved measurements indicate that GAMs are localized just inside the LCFS position in a region with at least 1.5 cm of radial extension; and (iii) The GAM amplitude and the long-range correlations are highly intermittent. Experimental evidence is presented suggesting that GAMs modulate the long-range correlations and the ambient turbulent fluctuations.

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