# Structure of the ISTTOK edge plasma fluctuations

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## Introduction

Transport in magnetically confined plasmas is generally accepted to be driven by plasma turbulence. The dynamics underlying the turbulence processes have been therefore extensively investigated with the aim of understanding and enhancing the confinement in fusion plasmas.

The shear in the macroscopic radial electrical ($\boldsymbol{E} \times \boldsymbol{B}$), varying slowly in time when compared with the turbulent eddy turnover time, is well known to be responsible for the suppression of turbulence and consequently the confinement enhancement in magnetically confined plasma devices [1,2]. On the other hand, it is now widely recognized and accepted that fluctuating $\boldsymbol{E} \times \boldsymbol{B}$ shear flows, such as Zonal Flows (ZFs), can be generated by turbulence and regulate the turbulence in return [3-5]. Large scale structures as the ZFs and the associated geodesic oscillations are universally observed in turbulent systems such as magnetically confined plasmas.

## 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) with a poloidal graphite limiter. Around the limiter radius the electron temperature is about $T_e$=20 eV and the electron density is 0.5-1×$10^{18}$ $m^{-3}$. ISTTOK is equipped with two probe systems that allow the investigation of the edge fluctuations: (i) a 8-pin radially movable 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 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. Such experimental arrangement allows the investigation of the three dimensional characteristics of the edge fluctuations. Both Langmuir probe systems can be operated in floating potential ($V_f$) or ion saturation current ($I_{sat}$) mode. The poloidal array can also be operated in mixed mode (one pin measuring $I_{sat}$ and the remaining $V_f$) so that the cross-field fluctuations induced particle flux, $\Gamma_{ExB}$, can be evaluated. Density and plasma potential fluctuations are evaluated from $I_{sat}$ and $V_f$ respectively neglecting electron temperature fluctuations effects. Plasma parameters are measured in the scrape-off layer (SOL) and in the core periphery (region just inside the last closed flux surface, LCFS). Data were simultaneously sampled at 2 MHz and the analyses performed during the discharge flat top (~20 ms).

## Poloidal structure of the edge fluctuations

It has been found that the ISTTOK edge fluctuations have distinct characteristics for r>a (SOL) and $r \lesssim a$ (core periphery). Figure 1 shows the $V_f$ cross-correlation for pins poloidally separated by 4 and 8 mm, measured in the SOL and in the core periphery, as well as the $V_f$ autocorrelation. In the SOL, the fluctuations are characterized by short correlations both in space and time (poloidal correlation length, $\lambda_c$~10 mm and autocorrelation time, $\tau_c$~3-4 μs, respectively). A poloidal propagation velocity of about 5 km/s can be estimated by the time delay between poloidally separated probes. In the core periphery, the autocorrelation time is significantly larger, $\tau_c$~10 μs, and the poloidal cross-correlation only shows a small reduction across the 14 mm extension of the poloidal array ($\lambda_c$ >> 14 mm).

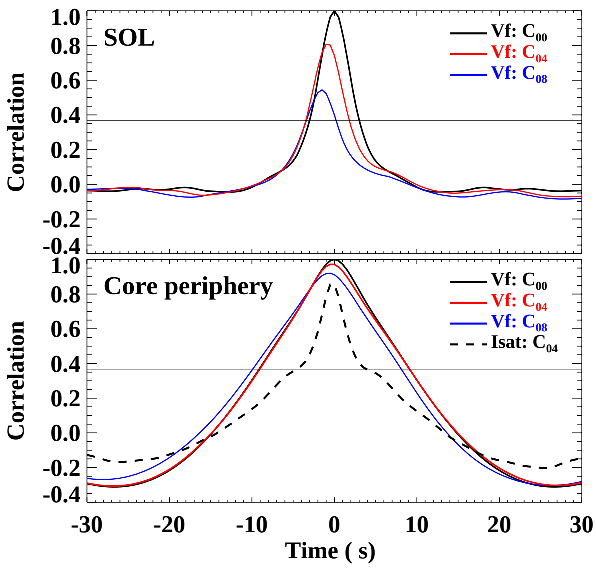


***Figure 1**: Floating potential cross-correlation for pins poloidally separated by 4 ($C_{04}$) and 8 mm ($C_{08}$) in the SOL and in the core periphery. The $V_f$ auto-correlation is also shown ($C_{00}$) as well as the $I_{sat}$ cross-correlation in the core periphery.*

Figure 2 presents the $V_f$ and $I_{sat}$ frequency spectrum together with the poloidal wavenumber spectrum ($k_\theta$) estimated using the two-point statistical dispersion relation ($S(k_\theta,w)$ function). Poloidal wavenumbers in the range of $k_\theta$ < 3 $cm^{-1}$ and a broad frequency spectrum are observed in the SOL. Assuming a poloidally uniform structure, these wavenumbers correspond to poloidal mode numbers up to $m$ = 25. In the core periphery the wavenumbers are smaller, $k_\theta < 1.0$ cm$^{-1}$, and the spectrum is dominated by low frequency components (10-25 kHz). Furthermore, $k_\theta$ is very small ($k_\theta < 0.2$ cm$^{-1}$) for frequencies below 50 kHz, corresponding to $m < 1.5$.

The $I_{sat}$ fluctuations have also been investigated and comparable results obtained. However, as shown in figure 2a the amplitude of the $I_{sat}$ low frequency fluctuations (10-25 kHz) is significantly smaller than that of $V_f$. As a consequence the $I_{sat}$ fluctuations are, in general, dominated by the turbulence time and spatial scales. In the core periphery, where $V_f$ is dominated by low frequency components, $I_{sat}$ shows evidence of both turbulent and low frequency scales, clearly visible in the cross-correlation (figure 1b).

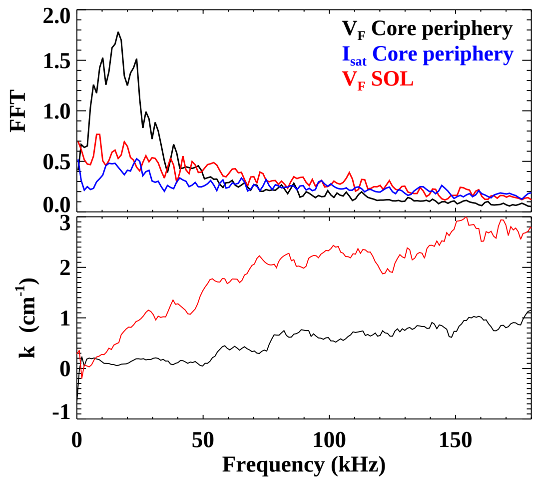


*Figure 2: Frequency spectrum of $V_f$, $I_{sat}$ and poloidal wavenumber in the SOL and core periphery.*

Results indicate that the characteristics of the potential fluctuations in the SOL are consistent with the typical broadband turbulent fluctuations while in the core periphery they are dominated by low frequency oscillations consistent with a symmetric structure ($k_\theta \sim 0$) in the poloidal direction, characteristic of 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). Furthermore, the amplitude of the density fluctuation in the 15-25 kHz range is significantly smaller than that of the potential as expected from the GAM theoretical predictions. Results suggest therefore the existence of GAMs on ISTTOK but more detailed measurements and analysis are required, in particular with respect to the toroidal structure that are presented below.

## Long range correlations

In order to estimate the GAM radial location the $V_f$ toroidal cross-correlation has been computed for different probe positions. Figure 3 shows the cross-correlation between the rake probe signals measured at different radial positions and those of the poloidal array located at r-a= -10 mm. A significant correlation (up to 0.7) has been found in the core periphery between probe systems toroidally apart measuring floating potential, which increases when probes are approximately at the same radial location. A similar correlation profile is obtained when the correlation is performed between pins (of both probe systems) located at approximately the same radial location. The amplitude of the toroidal correlation is small near the LCFS, reaches the maximum value 10 to 15 mm inside the LCFS and then decreases further inside. Results suggest therefore that GAMs are localized in a narrow region just inside the LCFS position.

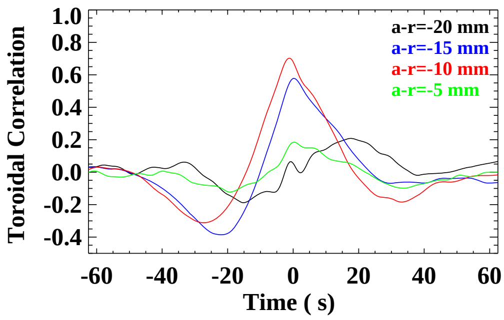


***Figure 3**: Cross-correlation function for floating potential signals measured between the poloidal probe located at r-a= -10 mm and some of the pins of the rake probe.*

The phase and coherence between toroidally separated probe signals have been evaluated from the cross-spectrum. Spectral analysis reveal that the coherence at long distance is significant (.7-.9) for frequencies around 10-30 kHz and that the cross-phase is close to zero only for this frequency range confirming the symmetric structure of the potential oscillations.

## Summary

The floating potential fluctuations in the ISTTOK core periphery exhibit a significant correlation at long distances that is consistent with the geodesic acoustic mode. This conclusion is also in agreement with the observation that core periphery fluctuations are dominated by low frequency oscillations with a symmetric structure in the toroidal and poloidal directions.

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