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# On the Radial Structure of Fluctuations and Turbulence Induced Flows

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## Abstract

Comparative studies of the structure of turbulence have been carried out in stellarator plasmas with low (TJ-IU) and medium (L2-M) magnetic shear. In both devices, the value of the radial coherence of fluctuations is bursty. In the plasma edge region, the radial coherence is dominated by low frequency fluctuations (< 200 kHz) in TJ-IU, whereas in L2-M, the radial coherence is due to high frequency fluctuations (> 100 kHz). Numerical calculations of resistive ballooning turbulence show that in the non-linear phase, the correlation length is of the order of the width of the linear mode poloidal components, whereas in the linear phase, the correlation length is related to the width of the envelope. Toroidal coupling effects appear to be relevant in the nonlinear phase in the proximity of instability thresholds. The electrostatic Reynolds stress shows a radial gradient close to the velocity shear location in the TJ-IU torsatron, thus suggesting that this mechanism can drive poloidal flows.

## Keywords:

stellarator, anomalous transport, flows, L-H transition

## 1. Introduction

A relevant issue for the question, whether transport exhibits a Bohm or gyro-Bohm scaling, is the understanding of the mechanisms that determine the radial correlation length of fluctuations. The closeness to turbulence thresholds [1], the type of instability driving the turbulence and the presence of sheared flows [2] are considered critical elements to determine the transition between different transport regimes as well as to account for a rapid change of transport coefficients [3].

In the framework of the physics of poloidal flows and fluctuations, it has been argued that the average poloidal flow profile can be modified by plasma fluctuations via radially varying Reynolds stress [4-5]. This mechanism might be involved in the L-H transition.

The goal of the present investigation is threefold. Firstly, to compare the statistical properties and the radial structure of fluctuations in the plasma boundary region of stellarator plasmas with low (TJ-IU) and medium (L2-M) magnetic shear. Secondly, the investigation of the radial structure of resistive ballooning turbulence using numerical calculations for both the linear and non-linear phase versus beta. Finally, to investigate flows driven by fluctuations (Reynolds stress) in the TJ-IU plasma boundary region.

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## 2. Comparative Studies of Plasma Turbulence in Stellarator Plasmas

Measurements of fluctuations and turbulent flux have been carried out in the plasma boundary region of the TJ-IU torsatron ($P_{ECRH}$=200 kW, $\iota(0) \approx 0.23$, $R$= 0.6 m, $\bar{a} \approx 0.1$ m, $\bar{n}_e \approx 0.5 \times 10^{19}$ m$^{-3}$, $B_t$=0.67 T) [6] and of the L2-M stellarator ($P_{ECRH}$= 200 kW, $\iota(0) \approx 0.20$, $\iota(a) \approx 1$, $R$=1.0 m, $\bar{a} \approx 0.11$ m, $\bar{n}_e \approx 1.5 \times 10^{19}$ m$^{-3}$, $B_t$= 1.2 T) [7]. Turbulence has been investigated using Langmuir probe arrays and signal processing tools described elsewhere [8].

In both devices, the ion saturation density current increases and the floating potential becomes more negative as the probe is inserted into the plasma edge region. As observed in other devices, the radial electric field is sheared in the proximity of the (computed) location of the last closed flux surface (LCFS). The radial structure of fluctuations has been investigated both in the edge ($r < a_s$) and in the scrape-off layer ($r > a_s$) regions, $a_s$ being the location of the velocity shear layer (Fig. 1). The radial position of the last closed flux surface ($r_{LCFS}$) is very close to the velocity shear location ($a_s$). In the L2-M stellarator the level of ion saturation current fluctuations is of the order $\tilde{I}_s/I_s \approx 5\%$ for $r/r_{LCFS} < 0.8 - 0.9$ and about 20% near the location of the LCFS. In the TJ-IU edge plasma region, the level of fluctuations is $\tilde{I}_s/I_s \approx (15 - 20)\%$, which is about a factor of three higher than in L2-M.

In the TJ-IU torsatron, the value of the radial coherence of fluctuations decreases when increasing radial distance between probes. The value of the radial coherence associated with fluctuations and turbulent transport is intermittent, and the turbulent flux exhibits a smaller radial coherence than the one associated with fluctuations. The statistical properties of the probability distribution function of fluctuations in pressure gradients have been also investigated. To date, evidence has not been found for non-gaussian features in the plasma gradient fluctuation distribution that are related with the presence of critical gradients.

In the TJ-IU torsatron, the radial and poloidal frequency resolved coherence of fluctuations are quite similar (*i.e.*, isotropic in terms of frequencies) and dominated by frequencies below 200 kHz. However, in the L2-M stellarator, the radial and poloidal coherence structure of the fluctuations are different at the plasma

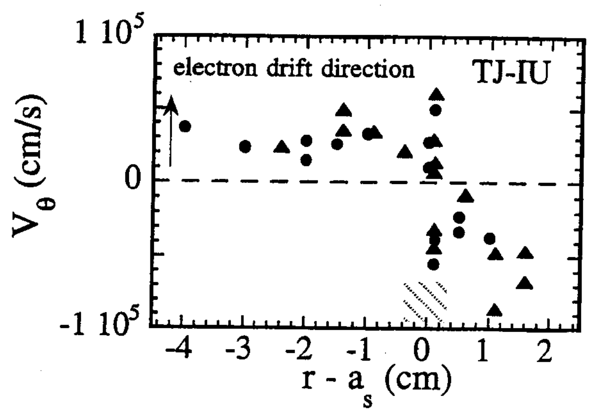


Fig. 1 Poloidal phase velocity of fluctuations versus radius in the plasma boundary region of the TJ-IU torsatron, using the velocity shear location ($a_s$) as a point of reference.

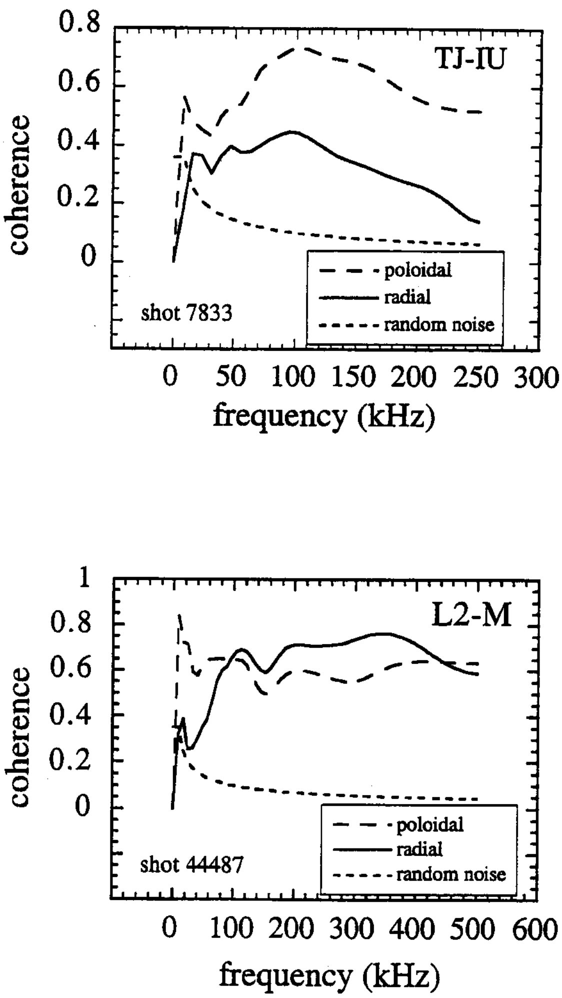


Fig. 2 Frequency resolved radial and poloidal coherence of fluctuations in TJ-IU and L2-M devices. Experiments were done in the plasma edge region ($r/a_s < 1$) and probes were separated $\Delta_r \approx \Delta_\theta \approx 7$ mm both in the radial ($\Delta_r$) and poloidal ($\Delta_\theta$) direction.

edge, the radial coherence being dominated by high frequencies (larger than 100 kHz) and the poloidal coherence dominated by low frequencies (less than 100 kHz) (Fig. 2). In addition, in the TJ-IU torsatron, the apparent radial velocity of fluctuations is about 1 km/s, whereas in the L2-M stellarator, it is much higher (20 – 40 km/s). These results can be interpreted in terms of the influence of linear coupling effects and magnetic shear on plasma turbulence [9].

## 3. Numerical Calculations of Resistive Ballooning Turbulence

The results of numerical calculations of resistive ballooning turbulence show that the correlation length in the nonlinear phase is of the order of the width of the linear mode poloidal components, as opposed to the linear phase, where the correlation length is related to the width of the envelope. However, in low beta plasmas, toroidal coupling effects appear to be relevant in the nonlinear phase, and as a consequence the radial correlation increases [10]. A combined (experimental/theoretical) effort is in progress to investigate the statistical properties of the radial structure of fluctuations versus the proximity to the turbulent thresholds for different plasma instabilities (*e.g.*, pressure gradient driven instabilities).

## 4. Fluctuation Induced Flows

The radial profile of the electrostatic Reynolds stress has been measured in the plasma boundary region of the TJ-IU torsatron using a multiple array of Langmuir probes. The spatial orientation of the Langmuir probe array provides a measurement of radial ($\tilde{E}_r$) and poloidal ($\tilde{E}_\theta$) electric field fluctuations in a plasma volume smaller than the typical correlation volume of fluctuations. There is a significant reduction in the radial coherence of fluctuations in the vicinity of the velocity shear layer location, whereas the poloidal coherence of fluctuations and the root mean squared (rms) level of fluctuations change slightly in the region close to the shear location. The measured Reynolds stress (proportional to $<\tilde{E}_\theta \tilde{E}_r>$) shows a radial variation around the velocity shear location, suggesting that such a mechanism can drive poloidal flows in the edge region of the TJ-IU torsatron (Fig. 3). On the contrary, the magnetic component of the Reynolds stress is negligible, due to the relative phase ($\approx \pi/2$) between poloidal and radial fluctuating components of the magnetic field [11]. Further studies are in progress to quantify the importance of Reynolds stress induced flow as a drive for poloidal rotation, a mechanism which might be involved in the L-H transition.

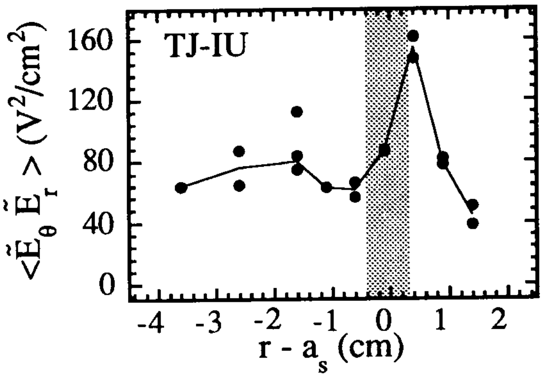


Fig. 3 Radial profile of the electrostatic Reynolds stress in the plasma boundary region of the TJ-IU torsatron.

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