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Turbulence measurements with cold and emissive probes in ISTTOK

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Abstract: Emissive probes are particularly suitable for turbulence studies as they are able to deliver a more accurate measure of the plasma potential. Thus probe arrays with emissive probes were developed for simultaneous measurements of the poloidal electric field, the density and their fluctuations in the edge plasma of ISTTOK. From these parameters the radial fluctuation-induced particle flux (the "turbulent flux") can be derived. The statistical properties of the poloidal electric field and of the turbulent flux, measured with cold and emissive probes, were compared. Both, the root mean square of the poloidal electric field and the turbulent flux were found to be significantly larger when measured with the emissive probes, indicating that temperature fluctuations are important in the ISTOK edge plasma, and they influence the evaluation of the particle flux from probe measurements. The probability distribution function of the turbulent flux was also found to be more peaked and asymmetric when measured with the emissive probes.

The main source of large anomalous particle transport in the edge region of toroidal fusion plasmas is the fluctuation-induced radial particle flux or simply the "turbulent flux":

$$\Gamma_r = \langle \tilde{n}\tilde{v}_r \rangle = \langle \tilde{n}\tilde{E}_\theta \rangle / B . \qquad (1)$$

Here the radial velocity v_r is approximated by the $E_\theta \times B$ velocity, n is the plasma density and $\langle\rangle$ a suitably defined average. This flux can be measured by cold Langmuir probes (CPs), assuming that the fluctuations of the plasma potential, $\tilde{\Phi}_{pl}$, are equal to those of the floating potential, $\tilde{V}_{fl}$. The plasma density is inferred from the ion saturation current I_{is} to a CP. This results in an ambiguity in determining the turbulent flux since both V_{fl} and I_{is} depend also on the electron temperature T_e. More specifically we can write:

$$\Phi_{pl} = V_{fl,c} + \alpha_c \frac{T_e}{e} = V_{fl,c} + \ln\left(\frac{I_{es}}{I_{is}}\right)\frac{T_e}{e} \qquad \text{and} \qquad I_{is} = enA_{ip}\sqrt{T_e/m_i} \qquad (2/3)$$

Here $V_{fl,c}$ is the floating potential of a CP, $\alpha_c = \ln(I_{es}/I_{is})$ the ratio of the electron to the ion saturation current for a CP, A_{ip} the effective probe area for ion collection, m_i the ion mass. In the edge region of a toroidal plasma α_c is typically 2,5 [1].

From equations (2) and (3) we derive the measured turbulent flux Γ_m [2] as

$$\Gamma_m = \frac{1}{B}\left\langle \Delta V_{fl,c} \frac{1}{eA_{ip}} \sqrt{\frac{m_i}{k_B T_e}} I_{is} \right\rangle \approx \Gamma_r + \frac{1}{2eB}\left\langle \Delta\tilde{V}_{fl,c}\tilde{T}_e \right\rangle \frac{n_0}{T_{e0}} + \frac{\alpha_c}{eB}\left\langle \tilde{n}\Delta\tilde{T}_e \right\rangle, \quad (4)$$

where $\Delta V_{fl,c}$ is the difference between the floating potentials of the two CPs divided by their poloidal separation and approximates the electric field E_θ. Thus Eq. (4) elucidates the influence of electron temperature fluctuations on the turbulent flux measured by CPs.

Emissive probes (EP) offer the advantage of reducing the influence of the electron temperature on the floating potential [3], thereby delivering a closer approximation to the plasma potential and its fluctuations. For an EP Eq. (2) becomes:

$$\Phi_{pl} = V_{fl,h} + \alpha_h \frac{T_e}{e} = V_{fl,h} + \ln\left(\frac{I_{es}}{I_{is} + I_{em}}\right)\frac{T_e}{e}, \quad (5)$$

with $V_{fl,h}$ being the floating potential of a heated and therefore emissive probe, $\alpha_h = \ln[I_{es}/(I_{is} + I_{em})]$ where I_{em} is the current of emitted electrons. So in principle by a sufficiently large emission current it is possible to reduce the deviation of $V_{fl,h}$ from Φ_{pl} to zero. However, from previous works it is known that for EPs the formation of a space charge by the emitted electrons and other effects lead to a correction of the α-factor [4,5,6]. Instead of a value of $\alpha_c \approx 2{,}5$ for the CP, we have to use here an α_h, which is not zero but around 1,15 according to measurements in CASTOR [1].

Measurements of the turbulent flux were done with two probe set-ups. The first set-up, A, is described in detail in [7] (see Fig. 1a). A new set-up, B, consists of four EPs above each other in the poloidal direction and one CP (see Fig. 1b). All probes are made of 0,2 mm diameter tungsten wire. In the following we define as "CPs" also the loop probes when they were not heated, and as "EPs" when they were heated to electron emission.

Probe array B (Fig. 1b) permits a comparison between the determination of the poloidal electric field with CPs and EPs even simultaneously and for various distances between the probes, depending which probes are heated. For both probe arrays, E_θ was always inferred from $\Delta V_{fl,\mathrm{nm}} = (V_{fl,\mathrm{n}} - V_{fl,\mathrm{m}})/d_{\mathrm{nm}}$, where n and m indicate the numbers of two probes positioned poloidally above each other. In case of array A, e.g., n = 2 and m = 1. However, in the following we discuss the results of flux measurements with both probe arrays.

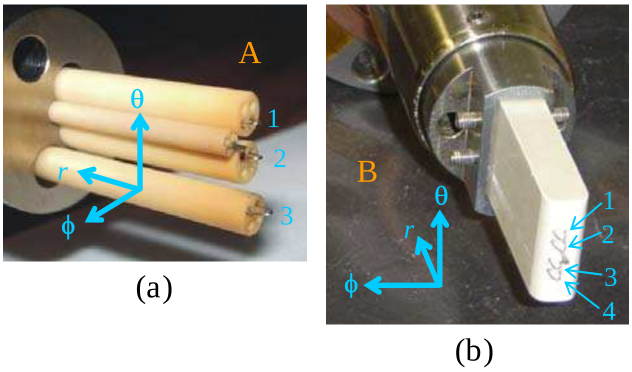

Fig. 1: Probe arrays of EPs and one CP for ISTTOK; (a) 3 EPs, one CP; EP#3 is radially protruding so that in principle also the radial electric field can be derived. (b) four EPs on a poloidal meridian, one CP in between.

Fig. 2 shows the power spectra (Fig. 2a) of $\tilde{E}_\theta$ and the coherence function $\gamma_{n,E}$ (Fig. 2b) measured with EPs and CPs. A clearly enhanced coherence is observed in the low frequency range when the EP data are considered (Fig. 2b), suggesting a good correlation between density and temperature gradient fluctuations, as can be interpreted from Eq. (4).

As a consequence of the higher power density of $\tilde{E}_\theta$ (Fig. 2a) and the increase of the correlation between $\tilde{n}$ and $\tilde{E}_\theta$ (Fig. 2b), the turbulent flux measured with EPs is significantly larger than measured with CPs, as shown in Fig. 3. The results of Fig. 3 suggest that in ISTTOK edge plasma temperature fluctuations are important for the estimation of the turbulent flux and therefore the standard method based on CP measurements is not applicable.

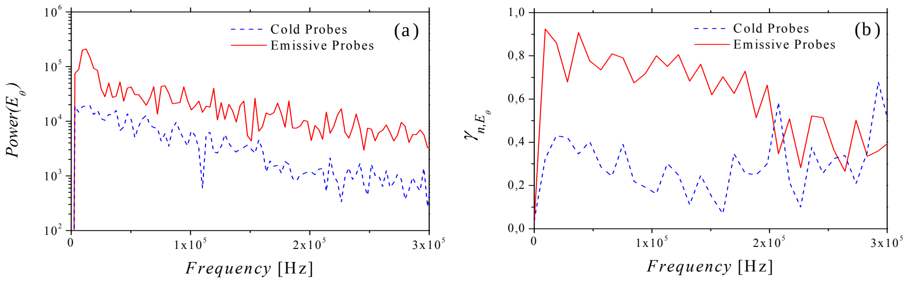

Fig. 2: (a) Power spectrum of the poloidal electric field fluctuations measured with CPs (blue dashed line) and EPs (red solid line; (b) time averaged cross coherency spectrum of the poloidal electric field and the density fluctuations, measured at r – a = –8 mm inside the scrape-off layer (SOL)

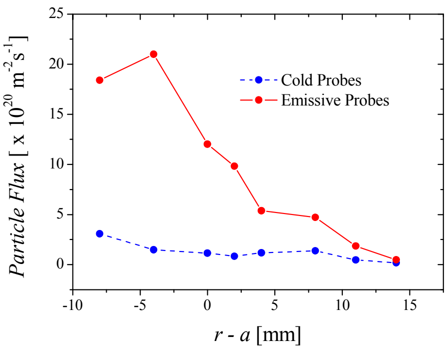

Fig. 3: Radial profile of the turbulent flux measured with the cold probes (dashed line – blue dots) and the emissive probes (solid line – red dots).

The statistics of the fluctuations were investigated by computing their probability distribution functions (PDF) (Fig. 4). The PDF of $\tilde{E}_\theta$, measured with EPs for $r - a = -8$ mm (with a being the minor radius) shows only a minimal change compared to the measurements with CPs. However, the PDF of the turbulent flux, as measured with EPs, is significantly more skewed and peaked than those measured by the CPs. In particular with EPs the skewness increases from 4,6 to 6,2, and the kurtosis from 27 to 48. Thus not

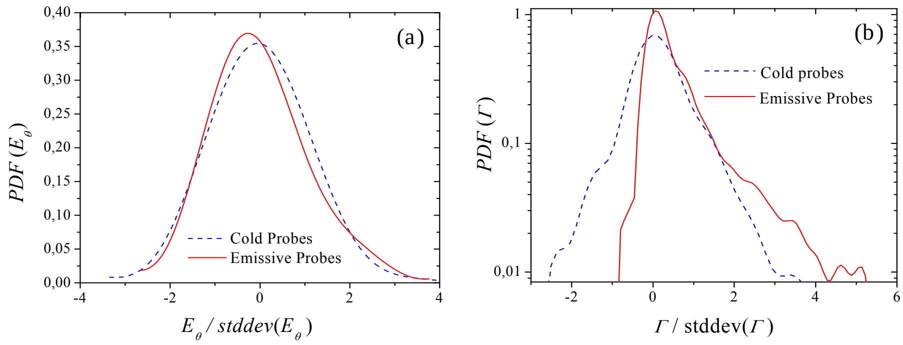

Fig. 4: Probability distribution functions of (a) the normalized poloidal electric field fluctuations and (b) the turbulent flux at $r - a = -8$ mm, once measured with the probes unheated (dashed blue line) and once with the probes emissive (solid red line).

only the turbulent flux is measured to be larger with EPs, but also the statistics of the transport are influenced by the method of measurement. It should be noted that the more skewed transport PDF is in better agreement with turbulence modelling [8,9]. Both features we interpret as a sign that the measurement with emissive probes delivers more reliable results.

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