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Intermittent temperature fluctuations in the edge region of the SINP tokamak

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Coherent localized structures in the edge plasmas of toroidal and linear magnetic confinement devices have received much attention in recent years because of their role in the intermittent transport of plasma across the magnetic field. They cause enhanced cross-field particle and heat fluxes, exceeding what would be expected from a diffusive transport process. The probability distribution functions (PDF's) of the fluctuations have been reported to deviate from the Gaussian distribution in the scrape-off layer (SOL) [1] and this has been attributed to intermittent events (formation and decay of plasma structures). In this paper, we present the results of the measurements on such intermittent events, taking electron temperature fluctuations into account explicitly.

The experiments were performed in the SINP tokamak which is a small ohmically heated tokamak having R = 0.3 m and a = 0.065 m defined by a movable limiter. The SOL extends upto the wall (r = 0.085 m). The discharge parameters were B_t = 1.0 T, $I_p \approx$ 20 kA with ~8 ms duration of flat top, $q_a \approx 4.7$ and filling pressure = 5×10^{-4} Torr (hydrogen). The vacuum vessel is routinely conditioned by an audio frequency discharge cleaning system.

A square array of Langmuir probes inserted radially into the plasma has been used to obtain simultaneously the floating potential ϕ_f, the ion saturation current I_s and the electron temperature T_e at the same spatial location. A poloidal array and a radial array of probes have been employed to study the propagation of the plasma structures in the respective directions.

The typical time behaviour of n, T_e, E_θ and Γ_r as obtained from the 4-probe array is shown in Fig. 1 at r = 0.074 m. The radial particle flux $\Gamma_r = \tilde{n}\tilde{E}_\theta / B_t$ has been calculated taking temperature fluctuations into account because $\tilde{T}_e$ is not negligible in this tokamak ($\tilde{T}_e / T_e \sim$ 20% in the SOL). Large and intermittent bursts, exceeding several times the standard deviation, are seen in all the signals and are often correlated. The PDF's of n and Γ_r are non-Gaussian, as reported by previous authors. We find that $\tilde{T}_e$ also exhibits an asymmetric PDF (Fig. 2) which has been reported in only few experiments [2]. A Gaussian fit with the PDF shows that positive fluctuations of T_e occur more frequently than negative ones. The skewness of the PDF is a measure of this asymmetry and found to be S = 0.8 – 1.4 at different radii. The PDF of E_θ is close to a Gaussian one.

The conditional averaging (CA) technique has been used to study the radial and poloidal propagations. Taking the innermost probe as the trigger source and 2.5 times the rms value as the threshold level, ion saturation currents from the radial array have been conditionally averaged. The time delays between the peaks from the successive probes clearly indicate the propagation of a plasma structure moving radially outward with a velocity of ~ 4.5 km/s. The structure is seen to reduce in amplitude and smear out while moving outward. A gradually developing 'dip' is also noticeable in the signals from probes near the wall, possibly indicating the change of the structure to a dipole-like shape having ragions with a higher and lower than average density. From the decay of the peak heights, the radial correlation length is found to be λ_r~ 5 mm.

Similar CA measurement from the poloidal probe array gives the poloidal propagation velocity of the structures to be ~ 4 km/s. The poloidal correlation length is λ_θ ~1.5 cm. By moving the poloidal array in steps of 2 mm in the radial direction (from r=5.9 to 8.3 cm), an observation space of 1.5 cm × 2.4 cm has been scanned in the poloidal cross-section. Conditionally averaged floating potentials from the poloidal array has shown [3] that the plasma structures are localized in the r-θ plane, are elongated in the poloidal direction and can have both positive and negative polarities. The lifetime of the structure exceeds the autocorrelation time of $\tilde{\phi}_f$ (τ_{auto} = 3-4 μs).

CA analysis done on the data obtained from the 4-probe array reveals further properties of the plasma structures. Taking density as the primary signal to identify the intermittent events, Fig. 3 shows the results of the CA procedure for positive density fluctuation events (blobs). It is found that the plasma density inside the blobs is about two times the background plasma density. T_e inside is also about 30% higher than that of the background plasma. The potential of the blob is positive with respect to the surrounding plasma. It therefore has an internal electric field in the outward direction and therefore an internal **E**×**B** rotation of the plasma exists, i.e., it resembles a vortex structure. E_θ is also higher inside the blob by a factor of 2. It has been suggested by theoretical models that this E_θ is caused by the **B**×∇**B** polarization of the blobs [4]. The negative density fluctuation events (voids) are found to have lower potentials and lower temperatures than the surrounding plasma.

Considerable temperature fluctuations are present in the SOL of the SINP tokamak ($\tilde{T}_e / T_e \sim 20$ %) and have an intermittent behaviour (Fig. 1). The effect of $\tilde{T}_e$ on anomalous particle transport has been reported earlier [5]. However, $\tilde{T}_e$ has an effect on the heat transport also. The total heat flux due to the electrons is given by $Q_{tot} = (3/2B).\langle \tilde{E}_\theta \tilde{P} \rangle$ where $\tilde{P}$ is the electron pressure fluctuation (assumed isotropic) and is dependent on $\tilde{T}_e$. The convected heat flux is given by $Q_{conv} = (5/2).\overline{T}_e \Gamma_r$ where $\overline{T}_e$ is the time-averaged electron temperature. The time behaviours of Q_{conv} and Q_{tot} as obtained from the measurements by the 4-probe array at the LCFS are shown in Fig. 4 for a 500 μs time window. Both Q_{conv} and Q_{tot} are seen to exhibit intermittent nature. The PDF of Q_{conv} is the same as that of Γ_r . The conducted heat flux $Q_{cond} = Q_{tot} - Q_{conv}$ is shown in Fig. 4 and also shows intermittent nature. The PDF's of both Q_{tot} and Q_{cond} are non-Gaussian and are partly due to the non-Gaussian PDF of the temperature fluctuation (in addition to those of n and E_θ).

CA has been performed on the Q_{cond} and Q_{conv} signals and the result is shown in Fig. 3(e,f). For higher n and higher E_θ inside the blob, there is a cross-field transport of particles in the outward direction (positive peak of CA of Γ_r), causing a positive peak of CA of Q_{conv}. The intermittent structures therefore cause a bursty heat transport by convection. CA of Q_{cond} however exhibits a negative peak inside the structure, causing the total heat Q_{tot} to be less than the convected part. The magnitudes and the phase relationship between $\tilde{E}_\theta$ and $\tilde{T}_e$ may be the cause of this. Such behaviour of conditionally averaged Q_{cond} has been noticed at all radii in the SOL. From the time variation (Fig. 4) also, it can be seen that sometimes positive fluctuation of Q_{conv} do correspond to negative fluctuation of Q_{cond}.

At the LCFS, the steady state $Q_{tot} \sim 5.0$ kW/m^2 and the conducted heat flux is only 10% of the total heat flux. Q_{tot} exhibits episodes of high amplitude bursts, the peak being sometimes even more than 20 times the steady state value. Such bursts may be of concern in fusion devices because of the localised high thermal load on the limiter and the wall, causing enhanced erosion. The bursty nature and the non-Gaussian PDF of T_e may play a role here.

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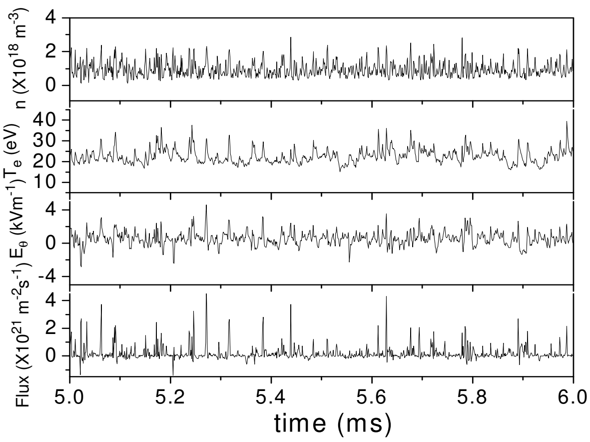

Fig.1. Time behaviours of the plasma parameters in the SOL: (from the top) n, T_e, E_θ and Γ_r.

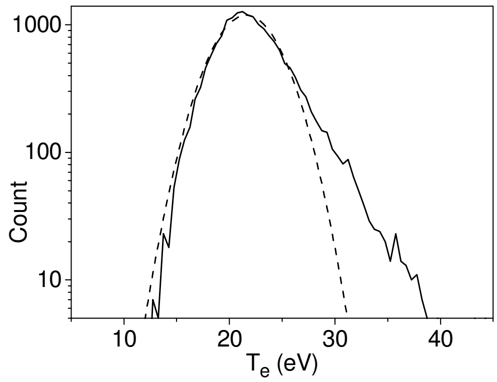

Fig.2. PDF of T_e (solid line) and the Gaussian fit (dashed line) with it.

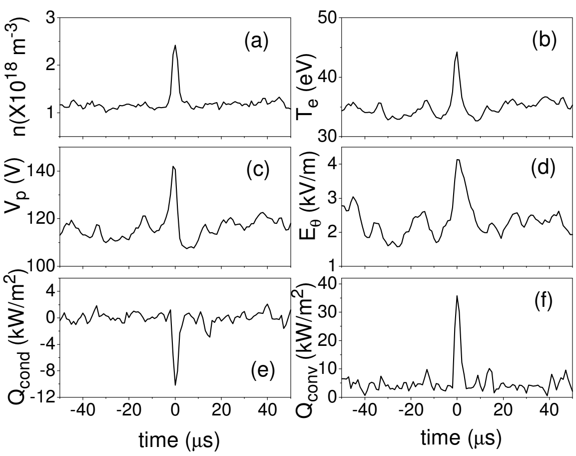

Fig. 3. Conditional averages for positive density fluctuation events at r = 6.5 cm : density (a), electron temperature (b), plasma potential (c), poloidal electric field (d), conducted heat flux (e) and convected heat flux(f).

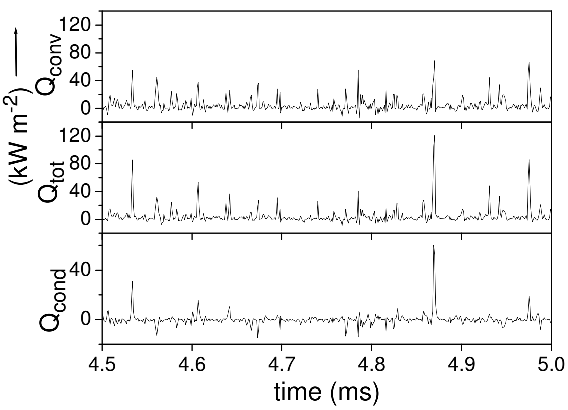

Fig. 4. Time dependences of (from the top) convected, total and conducted heat flux at r = 6.5 cm.