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Radial propagation of turbulent fluctuation structures in the SOL of Alcator C-Mod

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Abstract

This paper reports on the experimental characterization of the poloidal and radial propagation of turbulent structures in the scrape-off layer of the Alcator C-Mod tokamak. Turbulent structures are tracked using turbulence imaging diagnostics, which views the D_α emission of a localized gas puff in a poloidal cross section of the scrape-off layer with an ultra fast camera system. Large-amplitude turbulent structures are extracted from the small-amplitude background fluctuations and their velocity is extracted by two-dimensional cross-correlation technique. It is demonstrated that the poloidal velocity is mainly with background E×B plasma rotation. Radial velocities of structures are found to lie in the range $\leq$5% of the ion sound speed, thereby causing large radial transport events.

A common feature of turbulence is the formation of fluctuation structures [1, 2]. In turbulent plasmas structure formation is of particular strong interest. The fluctuation induced transport across the magnetic field in fusion devices is generally characterized by large transport events [3], which are ascribed to turbulent structures. The paradigm of the transport mechanism is the cross-field advection of plasma in potential vortices. In the last few years cross-field transport by direct radial propagation of turbulent structures, so-called 'blobs', has been observed in tokamak edge and scrape-off layer (SOL) plasmas[4, 5, 6, 7]. Blobs are plasma pressure structures propagating radially over distances larger than the blob spatial scale, thereby causing large intermittent transport events. The detailed characterization and understanding of the dynamics of blobs is a crucial task for divertor heat loads and first wall recycling phenomena. In this paper the propagation features of blobs in the SOL of Alcator C-Mod is investigated.

All the results presented in this paper were obtained in lower single null ohmic L-mode discharges in Alcator C-Mod with a toroidal magnetic field of $B_t = $5.4T, the plasma current was $I_P = $630kA, resulting in a safety factor $q_{95} = 6$, and the line averaged density was $\int n\,\mathrm{d}l = 1 \cdot 10^{20}\,\mathrm{m}^{-2}$. An overview over the SOL diagnostics used is shown in Fig. 1.

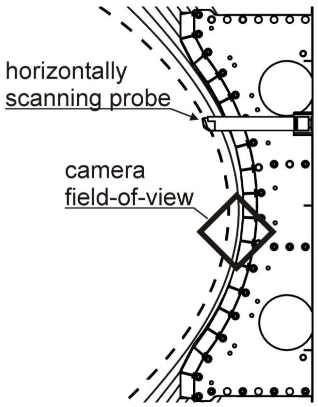

Figure 1: Overview over the SOL diagnostics arrangement used: horizontally scanning Langmuir probe and the field of view of the ultra fast camera system.

A multi-tip Langmuir probe scans horizontally across the SOL and provides time averaged profiles of the electron density, electron temperature, and plasma potential. For fluctuation measurements an ultra fast framing camera (Princeton Scientific Instruments, Inc. PSI-5, 250kHz, 300 frames) views the D_α emission intensity of a localized gas puff in a 6cm$\times$6cm vertical-radial cross section of the SOL [5, 6]. For constant neutral density, the D_α emission is a function of density and electron temperature. Assuming that electron temperature fluctuations are correlated with density fluctuations, the D_α emission is direct measure of the dynamics of plasma pressure fluctuations in poloidal and radial direction simultaneously. The data analysis is mainly based on correlation analysis. The camera frames are pre-processed for further evaluation. First, the time average for each pixel is subtracted from the pixel time series to separate the fluctuations from the time averaged emission. Second, to account for pixel to pixel variations a two-dimensional median filter over 3$\times$3 pixel is applied. This procedure reduces the spatial resolution of the camera images to $\Delta s \approx 20\rho_s$, where ρ_s is the effective ion gyroradius. One result of this procedure is shown in Fig. 2. The sequence of color-coded plots shows the evolution of density fluctuations in the camera field of view for four consecutive time instants with a temporal resolution of $\Delta t = 4\mu$s. It is clearly observed that a blob forms close to the separatrix (strong plasma pressure gradient region), grows in amplitude while propagating radially

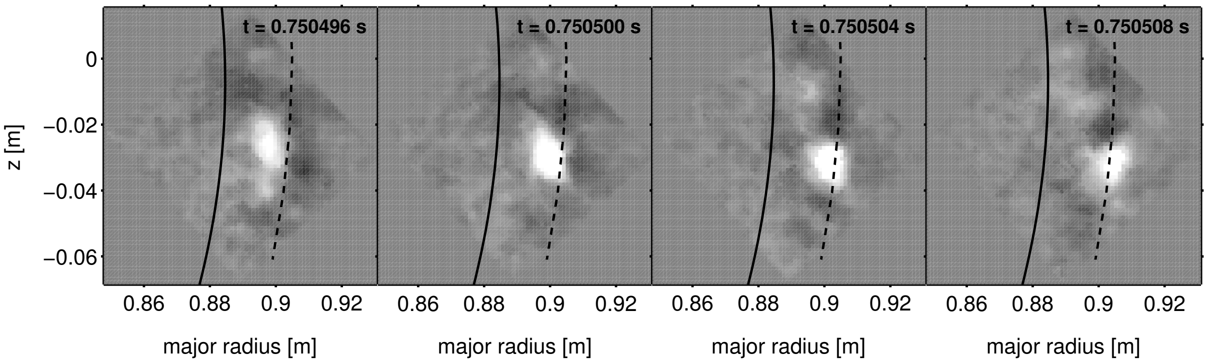

Figure 2: Series of four camera snap shots showing the radial propagation of a blob. Bright color corresponds to positive, dark to negative fluctuations. Superimposed are the separatrix (solid line) and the edge of the limiter (dashed line).

outwards, and subsequently decays in the limiter shadow. To separate the blob from the small amplitude fluctuations a threshold is applied to the amplitude and spatial size of the individual camera images. A blob is identified if its amplitude exceeds 1.5σ, where sigma is the two-dimensional standard deviation of the entire frame, and if the threshold forms a closed contour with an enclosed area of $A \geq 50$pixel. The poloidal and radial velocity of the extracted blobs are determined by calculating the two-dimensional cross correlation of two consecutive frames for each detected blob, which provides the blob's poloidal and radial displacement $(\Delta p, \Delta r)$ and poloidal and radial velocities are obtained as $v_p = \Delta p/\Delta t$ and $v_r = \Delta r/\Delta t$, respectively, where Δt is the time between the two frames. In Fig. 3 the poloidal and radial velocities as obtained from the camera data evaluation are depicted. Shown are the number distribution of velocities for one shot of all 300 camera frames. In poloidal direction the distribution is skewed towards negative velocities, which corresponds to propagation in time-averaged E×B drift direction (downwards) in this representation, which is i parallel to the ion diamagnetic drift direction. In radial direction no events are found to show a significant propagation inwards, which leads to a strongly skewed distribution towards positive radial velocities (outwards). The number of blobs with radial velocities $v_r \geq 700$m/s strongly decreases and the maximum radial propagation speeds are ≈ 1.2km/s. Two features of blob propagation are apparent. First, the radial velocity of blobs have a broad distribution. Second, only a fraction of blob events show significant propagation, indicated by the peaked distributions at $v_r, v_p = 0$. A relatively large number of blobs are found, which form and decay without showing any radial propagation. This feature is supposedly linked to the blob generation mechanism itself. Models for radial blob propagation indicate that the radial velocities are determined by the vorticity associated with the blob

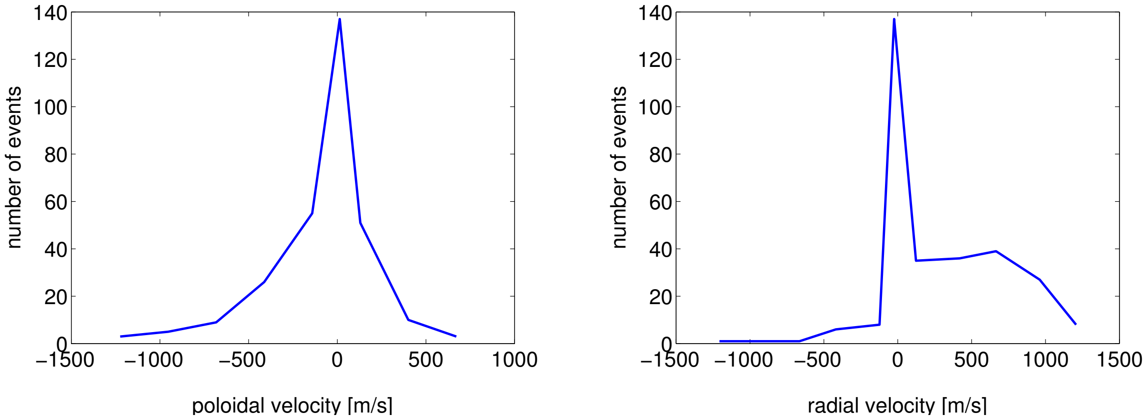

Figure 3: Number distribution of poloidal and radial blob velocities. Positive velocities correspond to poloidally downwards and radially outwards propagation, respectively.

[8, 9, 10]. The Based on those models the experimental findings indicate that the vorticity associated with a blob has a statistical distribution leading to the observed veloctiy distribution for the radial propagation and is probably linked to the blob generation process.

To summarize, the propagation of turbulent fluctuation structures is analyzed by two-dimensional (vertical-radial) imaging of D_α intensity fluctuations. Cross correlation analysis reveals that the poloidal propagation of blobs is in direction of E×B plasma rotation. The radial velocities are generally larger than the poloidal velocities and show a broad distribution with values of $v_r \leq 1.2$km/s corresponding to $v_r \leq 5\% C_s$, with C_s being the ion sound speed.

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