Parallel correlation of turbulent fluctuations in the SOL of Alcator C-Mod

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Abstract

The results of correlation measurements along the magnetic field in the scrape-off layer (SOL) of Alcator C-Mod are presented. For the specific magnetic field configuration the plunge of a reciprocating probe, located close to the lower X-point, is magnetically connected to a poloidal-radial array of optical views at the outer midplane. The correlation structure at the outboard midplane has a radial and poloidal correlation length of 1.2 cm, which corresponds to the typical size of spatiotemporal SOL fluctuation structures. Over a connection length of 2.8 m high correlations of pressure fluctuations are observed with a maximum correlation amplitude of 76%. The observed time delay of the maximum correlation is found to be much smaller than expected from a sound speed response along the magnetic field and is consistent with a parallel propagation on the order of the electron thermal speed.

It is widely accepted that the radial propagation of spatiotemporal fluctuation structures in the tokamak SOL is due to a dipolar potential, which gives rise to a radial $E \times B$ drift of turbulent structures. Several models have been proposed to describe the formation of the electric field, which are either based on polarization of the structure [1, 2] or on the intrinsic interchange instability drive [3]. The resulting dipolar potential structure associated with the plasma pressure perturbation has been experimentally verified [4, 5]. The model approaches assume the primary drive of these fluctuation structures is in the bad curvature region at the outboard midplane. However, radial propagation of spatiotemporal structures is also observed far away from the outboard midplane close to the lower X-point [6]. The spatial structure and propagation features are identical to the observations at the outer midplane if the magnetic flux surface expansion is taken into account. The question arises if those fluctuations form as field-aligned filaments spanning all along the magnetic field to the divertor plate or if they form rather localized in the outboard midplane region and propagate parallel to the magnetic field towards the divertor. For the present study a number of lower single null discharges are analyzed with moderate densities in the range $n/n_{GL} = 15 - 35\,\%$, where n_{GL} denotes the Greenwald density limit. The

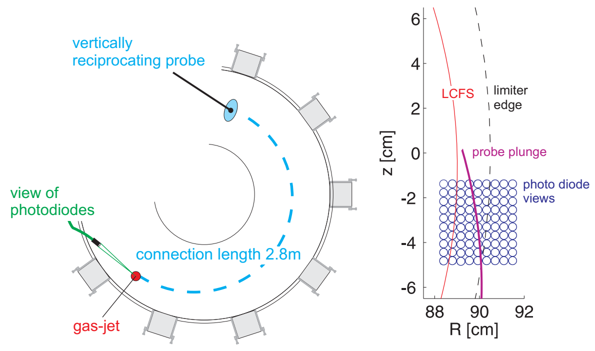

Figure 1: Magnetic connection between the vertically reciprocating probe and the diode FOV. The left figure shows the toroidal projection of the connection around half of the toroidal circumference, the figure to the right the projection of the probe plunge to the diode FOV.

mid-SOL densities and electron temepratures vary in the range $(1-4)\cdot 10^{19}\mathrm{m}^{-3}$ and 15-30 eV, respectively. Two key diagnostics are used for the correlation studies: A two-dimensional 10x9 array of views coupled to fast optical detectors (avalanche photodiodes) images the D_α emission of a toroidally localized gas puff at the outboard midplane in a poloidal cross section of approx. 4×4 cm [7]. An outer gap is chosen that the field-of-view (FOV) covers the entire SOL width from the last closed flux surface (LCFS) to the limiter-shadow edge. The second diagnostics is a multi-tip fast scanning probe, which is located toroidally 198° away from the diode viewing area close to the lower X-point and measures ion saturation current and floating potential fluctuations. Despite the detailed dependencies of the individual quantities on the plasma parameters, in the following analyses the ion saturation current and D_α intensity fluctuations are taken as proportional to plasma pressure fluctuations, and floating

potential to plasma potential fluctuations. For a specific magnetic field configuration at relatively high $q_{95} = 5.5$ the probe plunge is magnetically mapped across the array FOV and both diagnostics measure the fluctuation characteristics at the same magnetic flux tube. The magnetic mapping is depicted in Fig. 1 showing the toroidal projection of the magnetic connection and particularly the probe plunge projection along the magnetic field to the array FOV. The connection length is $L_{\|} = 2.8\,\mathrm{m}$, which is approximately one order of magnitude larger than the electron mean free path for Coulomb collisions. The result of the cross-correlation analysis just within

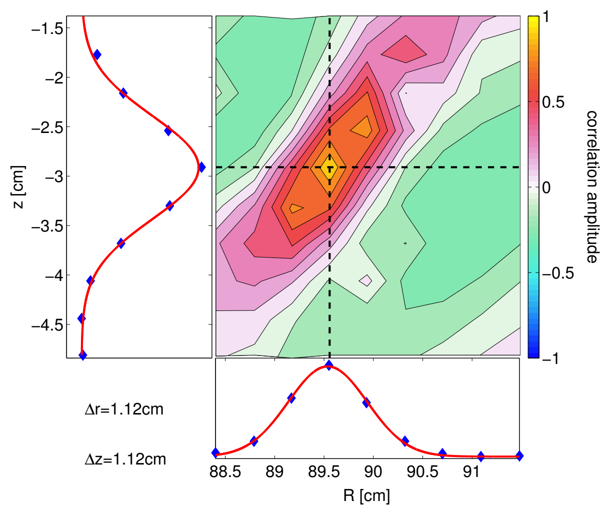

Figure 2: Two-dimensional cross correlation structure within the diode FOV together with radial and poloidal cuts indicating the respective correlation lengths.

the array FOV is shown in Fig. 2. The correlation structure is poloidally tilted and spans diagonally across the entire FOV. In radial and poloidal direction the correlation structure has a nearly Gaussian shape with a correlation length in both directions of $l_p = l_r = 1.2\,\text{cm}$. These lengths are consistent with the typical size of spatiotemporal fluctuation structures as measured with turbulence imaging diagnostics [8]. The temporal evolution of the correlation pattern is also consistent with the observed motion of spatiotemporal structures, i.e it propagates poloidally in direction of the background $E \times B$ drift and radially outwards, which indicates the dominance of fluctuation structures in the correlation results. Parallel to the magnetic field a high correlation of 76% between plasma pressure fluctuations close to the lower X-point as measured with the reciprocating probe and at the outboard midplane as measured with the diode array is found, shown in Fig. 3. The observed correlation pattern has a similar shape and extent when compared to the midplane situation and peaks at the intersection point of the projected probe plunge with the array of diode views. The correlation structure is of predominant monopolar shape. High correlation amplitudes are also observed if the pressure fluctuations at the midplane are correlated with the near-X-point potential fluctuations, shown in Fig. 3 as contour lines for positive (red) and negative correlation amplitudes (blue). The peak correlation amplitude here is 50%. The monopolar pressure correlation structure is associated with a dipolar potential structure, which yields a poloidal electric field and gives rise to a radially outward propagation due to $E_{pol} \times B$ drift. The maximum correlation between

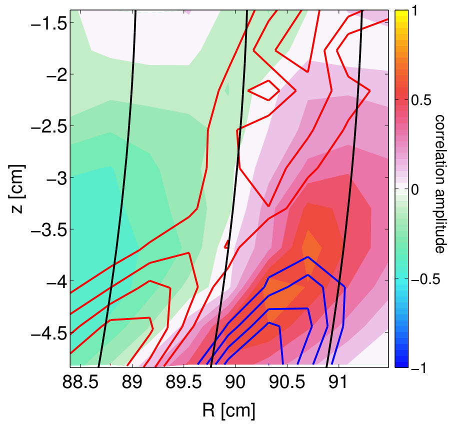

Figure 3: Spatiotemporal cross-correlation pattern between pressure fluctuations (color coded) across the array FOV. The cross-correlation between fluctuations of the potential and pressure is shown by the contour lines, the flux surfaces as black lines.

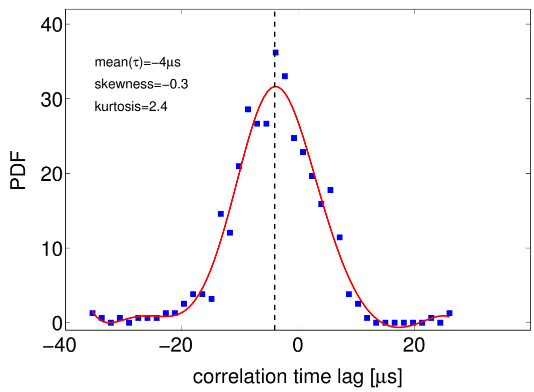

Figure 4: Probability distribution function of the correlation time lags for maximum correlation.

the near-X-point fluctuations and the outboard midplane is found at non-zero correlation time lags, i.e. fluctuations do not occur simultaneously along the entire magnetic flux tube but propagate along the magnetic field. The distribution of the correlation time lags for maximum correlation for a series of 10 discharges is shown in Fig. 4. The mean time lag of $-4\mu s$ indicates that fluctuations occur first at the midplane before reaching the X-point region. This distribution is more peaked when compared to a Gaussian but almost symmetric, with a FWHM of approx. $15\mu s$. No dependence of the correlation time lag on the SOL density in the range under consideration is observed. The propagation along the magnetic field is, however, much faster than expected for parallel particle diffusion on a sound speed scale, which would result in time lags of $\tau \geq 100\mu s$, and is much closer to the electron thermal speed, which yields a delay time of $\tau \approx 1\mu s$. Thus, the picture emerges that fluctuations are predominantly driven at the outboard midplane. This finding is consistent with the structure shape and velocities measured in the near-X-point region [6] and has also been discussed theoretically, e.g. in [9]. The associated potential fluctuations propagate on the electron time scale along the magnetic field and the observed plasma pressure fluctuations close to the X-point are most likely a result of local convection within the radial plasma pressure gradient due to the perturbed potential.

References

[1] D. A. D'Ippolito *et al.*, Phys. Plasmas **9**(1), 222 (2002).

[2] D. A. D'Ippolito *et al.*, Contrib. Plasma Phys. **44**(1-3), 205 (2004).

[3] O. E. Garcia *et al.*, Phys. Rev. Lett. **92**(16), 165003 (2004).

[4] O. Grulke *et al.*, Phys. Plasmas **13**, 012306 (2006).

[5] N. Katz*et al.*, Phys. Rev. Lett. **101**(1), 015003 (2008).

[6] J. L. Terry*et al.*, Journal of Nuclear Materials **390-91**, 339 (2009).

[7] I. Cziegler*et al.*, Phys. Plasmas **17**, 056120 (2010).

[8] J. L. Terry *et al.*, Phys. Plasmas **10**(5), 1739 (2003).

[9] D. Ryutov, Phys. Plasmas **13**, 122307 (2006).