The Edge Turbulence in the W7-AS Stellarator: 2 d Characterization by Probe Measurements

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Introduction

In the edge region of the W7-AS stellarator spatially and temporally resolved measurements of turbulent electrostatic fluctuations are performed using Langmuir probe arrays. They are intended to explore the limits of our physical model based on former investigations of the scrape-off layer of ASDEX [1]. A very high correlation of the ion saturation current fluctuations $\parallel \mathbf{B}$ was observed implying that the interaction between plasma and target plates must be taken into account. The sheath conditions are added to a 2d fluid model which includes magnetic curvature, $\mathbf{E} \times \mathbf{B}$, and diamagnetic drifts. In linear order its predictions agree with the experiment in a wide range of discharge parameters [1].

Another interesting subject is the investigation of the nonlinear dynamics of the saturated turbulent state. The latter is characterized by an unpredictable formation and decay of structures. Observing the evolution of structures should therefore offer insights into the nonlinear dynamics. Simple global properties, as average velocities, can be determined from the spatial-temporal correlation function. More detailed information, e. g. concerning the question whether typical structures exist, may be obtained by studying individual structures. Our starting point of a quantitative classification of structures is the decomposition of fluctuation data in a sum of simple "events" (pulse-shaped in space and time) with individually determined spatial and temporal position, velocity, size, lifetime, and amplitude. A search for statistically significant deviations from the spatially and temporally uniform distribution of the events follows. An analysis of that kind was applied to spatially 1d plus time dependent data taken from measurements with a poloidal probe array: In the environment of events with a high magnitude/size ratio the floating potential exhibits a dipole-like conditional average which is oriented such that in its center the $\mathbf{E} \times \mathbf{B}$ drift is directed radially outwards. Because the conditional average of the ion saturation current has a maximum there a very high local particle flux must be associated with these structures [2].

Of course, without a minimum knowledge about the radial behaviour it would remain uncertain to what extent the 1d poloidal properties describe the fluctuations. Especially the possibility of radially moving structures must be considered. New measurements at W7-AS with a right-angled probe array consisting of 20 tips in poloidal and 8 tips in radial direction are addressed to these questions.

Correlations

Basic space-time characteristics of the fluctuations are contained in the correlation function

$$\rho(\mathbf{d},\tau) = \frac{\left\langle \tilde{s}(\mathbf{d},t)\, \tilde{s}(\mathbf{x}+\mathbf{d},t+\tau)\right\rangle}{\sqrt{\left\langle \tilde{s}^2(\mathbf{x},t)\right\rangle\left\langle \tilde{s}^2(\mathbf{x}+\mathbf{d},t+\tau)\right\rangle}} \tag{1}$$

where $\mathbf{x}$, $\mathbf{x}+\mathbf{d}$ are the spatial positions of two probes and $\tilde{s}$ denotes the fluctuating part of a random process $s := \tilde{s} + \bar{s}$ as given by the measured quantities (e. g. floating potential). For the present analysis time intervals with constant discharge conditions and negligible probe movement were chosen. Thus, $\tilde{s}$ may be regarded as stationary. Estimates of (1) are based on temporal averaging.

Correlation ∥ B

To study the behavior of the fluctuations along the field lines simultaneous measurements of the floating potential with a radially movable Langmuir probe array of 19 tips extending in poloidal direction and a static Langmuir probe at a distant toroidal position were carried out. Because the poloidal positions of the probes are fixed the rotational transform of the magnetic field ι had to be adjusted such that the field line bundle crossing the fixed probe passed the accessible poloidal-radial range of the movable probe array. (By numerical field line tracing it was estimated that this constraint requires a rotational transforms near $\iota = 0.253$ which is somewhat smaller than typical values for W7-AS.) The corresponding connection length between the 19 tips array and the distant probe is about 6 m. Other plasma conditions relevant to these measurements are: B = 1.25 T, gas H_2, line averaged central density 1×10^{19} m^{-3}, ECR heating: 170 kW.

Between the 19 tips array and the distant probe a correlation of 0.92 was found representing a lower limit for the actual maximum correlation parallel **B**. It might be even higher, if the field line was not hit precisely. Within the temporal resolution (0.5 μs) the peak of the correlation function with the highest peak value is centered around $\tau = 0$. Apart from that the poloidal-temporal correlation function between the 19 tips array and the distant probe looks very similar to the correlation function obtained from the 19 tips array itself. Correlation lengths, correlation times and propagation velocities are the same. A comparison of such correlation lengths ∥ **B** to the correlations lengths ⊥ **B** in the order of 1 cm suggests an essentially 2-dimensional structure of the fluctuations. Obviously the physical process responsible for the fast balancing along the field lines has only very little tendency to spread ⊥ **B**.

Correlation in the radial-poloidal plane

Measurements concerning the radial-poloidal structure of the fluctuations are performed with a right-angled probe array consisting of 20 tips in poloidal and 8 tips in radial direc-

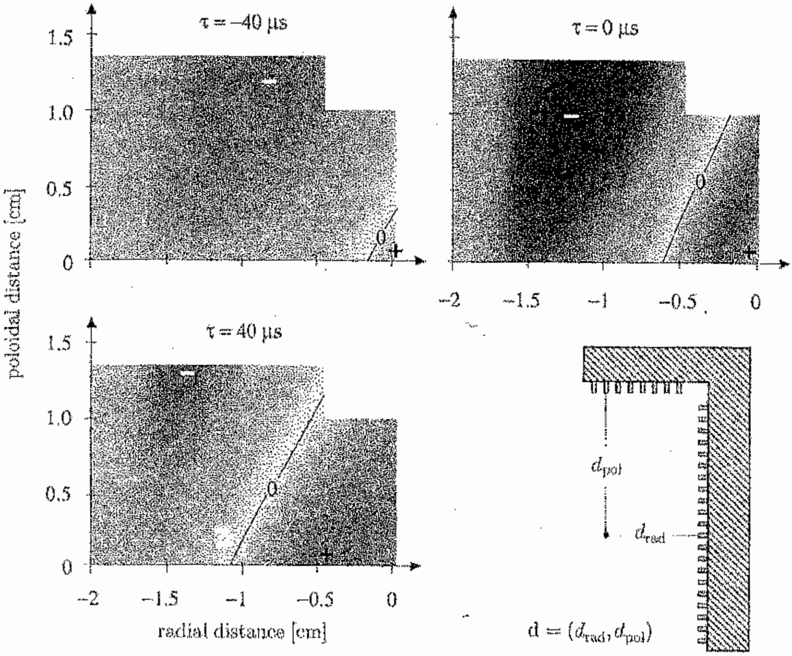

Figure 1: *Cuts through the spatially 2-dimensional correlation function of the floating potential for constant* τ.

tion. The distance between adjacent tips is 0.25 cm; the diameter of the tips is 0.09 cm. From such time series discrete estimates of the 2-point-correlation function $\rho(\mathrm{d}_{ij}, \tau)$ can be calculated where $\mathrm{d}_{ij} = \mathrm{x}_j - \mathrm{x}_i$ denotes the radial-poloidal distance vector between the i-th and j-th probe. Due to poloidal homogeneity $\rho(\mathrm{d}_{ij}, \tau)$ is only a function of the poloidal probe distance whereas inhomogeneity in radial direction implies that $\rho(\mathrm{d}_{ij}, \tau)$ depends not only on the radial distance but also on the radial position. For the right-angled array the d_{ij} form a rectangular grid. Figure 1 shows cuts through the discrete 2-point-correlation function of the floating potential for constant values of τ. Discharge parameters were: B = 2.53 T, gas: D_2, line averaged central density 1×10^{19} m^{-3}, ECR heating: 300 kW. Smoothness was obtained by interpolation between the spatial grid points. The 2d spatial cut through the correlation function at $\tau = 0$ exhibits an oblique structure which may be attributed to an oblique orientation of the fluctuations. Movies, i. e. τ-sequences, of such 2d spatial cuts indicate further that the fluctuations propagate as well in radial as in poloidal direction. In figure 1 a propagation to the left, i. e. radially inwards, can be seen. These findings have important consequences for the interpretation of spatially 1d resolved measurements: Radial velocity components of oblique structures appear as poloidal motion, if only the poloidal direction is observed which explains the similarity between the radial-temporal and poloidal-temporal correlation functions. Velocity components perpendicular to the direction of observation lead to apparently smaller correlation times or lifetimes of individual structures.

It should be noted that figure 1 reflects the situation at one certain radial probe position a few centimeters outside the confinement region. Radial profiles of parameters associated with the poloidal correlation function show the well known velocity shear layer where the sign of the poloidal velocity changes and the correlation lengths and times exhibit minima. Accordingly at other radial positions different spatially 2d correlation functions are observed.

Conclusion

In the edge region of the W7-AS stellarator fluctuations of the floating potential show a very high correlation along the field lines over distances in the order of 10 m with zero time delay similar to former results for the ion saturation current in the scrape-off layer of ASDEX. This confirms the idea that in the shadow of a limiter the turbulence is essentially a 2-dimensional process under the far-reaching control of the sheath conditions. A poloidal *and* radial propagation of the fluctuations seen in the 2d spatial correlation function sheds light on the limits of spatially 1d resolved measurements.

References

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[2] G. Theimer et. al., Proc. 22nd EPS Conference on Controlled Fusion and Plasma Physics, Bournemouth 1995, volume 19C, part I, pp. 301–304