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The impact of magnetic shear on the spatial structure of edge fluctuations in Wendelstein 7-AS

In the edge and scrape-off layer (SOL) plasma of the Wendelstein 7-AS (W7-AS) stellarator, fluctuations in floating potential $\tilde{\Phi}_{fl}$ and ion saturation current $\tilde{I}_{sat}$ have been observed with different arrangements of Langmuir probe tips [1, 2]. For most measurements, poloidal arrays of 16 tips with probe tip separation of 2 to 2.5 mm were used, but several measurements were performed with an angular array of 20 tips arranged in the poloidal direction and 8 tips arranged in the radial direction (Fig. 1).

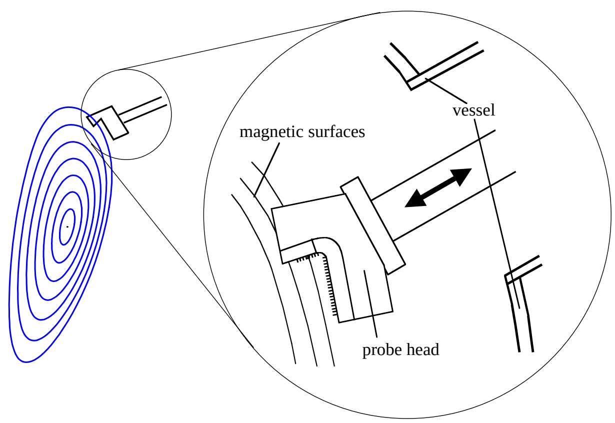

Fig. 1. Arrangement of the angular Langmuir probe array on a reciprocating probe drive, depicted together with flux surfaces of W7-AS for rotational transform $\iota \approx 0.33$.

The aim of the measurements was to characterize the three-dimensional (3-D) spatial and temporal structure of the fluctuations, to determine their contribution to the anomalous radial transport (for results see Ref. [3]), and to study the impact of variations in discharge parameters on the properties of the fluctuations.

Fluctuations in $\tilde{\Phi}_{fl}$ and $\tilde{I}_{sat}$ exhibit qualitatively similar behavior, although they may differ in their typical lifetime and poloidal scale length. Here we discuss only $\tilde{\Phi}_{fl}$ results.

1. Radial-poloidal structure of the fluctuations

Since a limited spatio-temporal subwindow of raw fluctuation data always represents the realization of a random process, we characterize the fluctuations by means of their correlation function in order to average over typical fluctuation "events." If $f(\boldsymbol{x}, t)$ are the raw data, then

$$\phi(\boldsymbol{x}, \boldsymbol{x}_0, \tau) = \int f(\boldsymbol{x}, t+\tau) f(\boldsymbol{x}_0, t)\, dt\,,$$

and we use in the following the normalized version of ϕ,

$$\varphi(\boldsymbol{x}, \boldsymbol{x}_0, \tau) = \frac{\phi(\boldsymbol{x}, \boldsymbol{x}_0, \tau)}{\sqrt{\phi(\boldsymbol{x}_0, \boldsymbol{x}_0, 0)\phi(\boldsymbol{x}, \boldsymbol{x}, 0)}}\,.$$

If the integration in time is to be useful, the fluctuations must be stationary during the time interval investigated. Similarly, if the fluctuations are homogeneous along some direction in space, φ depends only on the separation $\boldsymbol{x} - \boldsymbol{x}_0$ in the corresponding coordinate, and the integration can also be applied along this coordinate. In the plasma edge, this is sometimes the case for the poloidal direction, as long as the poloidal interval is small compared with the poloidal circumference. In contrast, in the radial direction the fluctuations are never homogeneous, since their radial scale length is comparable with the profile decay lengths in the plasma edge.

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From data taken with the angular probe array shown in Fig. 1, one can reconstruct two of the four quadrants in the radial-poloidal plane of the radial-poloidal correlation function $\varphi(r_0, d_r, d_\theta, \tau)$ where r_0 is the radial reference position. In this reconstruction, we take advantage of the radial reciprocation of the probe head, which positions, during different time windows, either the poloidal row of tips or different tips of the radial row on the reference position r_0 [1,2]. A typical result is shown in Fig. 2 for five different time lags τ

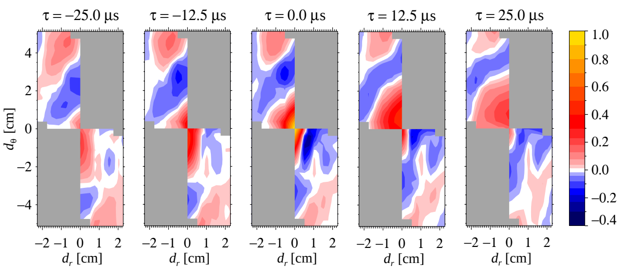

Fig. 2. Radial-poloidal correlation function at five different values of τ from $\tilde{\Phi}_{fl}$ data taken with the angular Langmuir probe array. Typical features include the inclination of the structures in the poloidal-radial plane, the minima and secondary maxima poloidally displaced from the main maximum of the correlation function, and the poloidal propagation of the whole structure.

Apart from the minima and secondary maxima in poloidal direction, which are well known from purely poloidal-temporal correlation functions, and the poloidal velocity visible from the shift of the entire structure in the poloidal direction for different values of the time lag τ, the most striking feature is the inclination of the whole structure in the radial-poloidal plane.

To anyone familiar with the investigation of plasma turbulence in toroidal magnetic confinement devices, two possible reasons for such an inclination will present themselves: the radial shear of the poloidal velocity due to the radial variation of the radial electric field ($\boldsymbol{E} \times \boldsymbol{B}$ shear) and the magnetic shear.

Before we discuss these two candidates in Sect. 3, we shall complement our picture of the spatial structure of the fluctuations.

2. Correlation of the fluctuations parallel to the magnetic field

In Sect. 1 we demonstrated that the typical scale length of the fluctuations in the plane perpendicular to the magnetic field is of the order of a few centimeters (see Fig. 2). In contrast, if we succeed in placing two Langmuir probe tips approximately on the same magnetic field line, we find a very high correlation even if the probe tips are separated by several meters (Fig. 3).

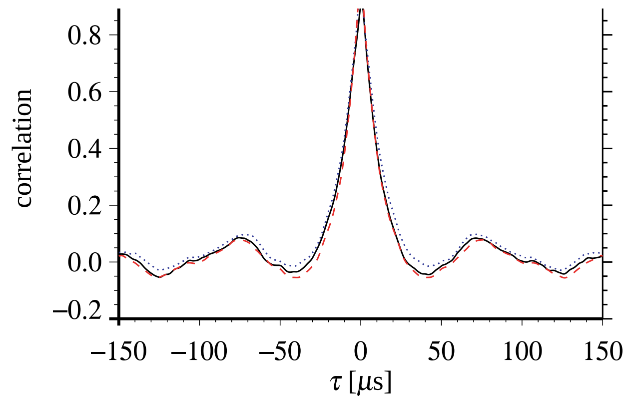

Fig. 3. Cross-correlation function between two probe tips measuring $\tilde{\Phi}_{fl}$ (solid line). The probe tips are separated by 6 m along the magnetic field and are positioned on the same field line within the errors. For comparison, the auto-correlation functions of each of the two probe tips are shown (dotted and dashed lines).

An interesting question is how to reconcile the high correlation along the magnetic field of structures with a size of up to several centimeters perpendicular to $\boldsymbol{B}$ with the magnetic shear: the radial-poloidal cross section of these structures would be distorted because of the magnetic shear in different planes perpendicular to the magnetic field. This is indeed what is predicted by turbulence simulation codes (see, e.g., Refs. [4,5]) for tokamak geometry. There, the principal axis of the turbulence structures are approximately in the poloidal and radial directions in the midplane, and the structures become inclined in one sense when following a flux tube towards the top of the torus and in the opposite sense towards the bottom of the torus, in agreement with what is expected from the magnetic shear.

3. Discussion

If a shear in the poloidal $\boldsymbol{E} \times \boldsymbol{B}$ velocity causes the inclination of the radial-poloidal correlation function, then one would expect this inclination to change for different time lags τ. From a radial profile of the poloidal velocity we find a radial gradient of ~200 $\mathrm{m \cdot s^{-1} \cdot cm^{-1}}$ in the radial region from which the data of Fig. 2 were taken. This would account for a change in inclination of 1 cm in the poloidal direction per centimeter in the radial direction per 50 μs. The development of a kink in Fig. 2 between $\tau = 0$ and $\tau = +25\ \mu$s between $d_r = -1$ cm and $d_r = -2$ cm at d_θ ~3 cm would indeed be of the estimated magnitude and sign.

As for the magnetic shear, one would not expect a change in the inclination with τ; however, the amount and orientation of the inclination would be expected to differ depending on the position of measurement. Although W7-AS is a low-shear stellarator, the attribute “low magnetic shear" refers only to the global magnetic shear. The local magnetic shear within one module is considerable. This is demonstrated in Fig. 4, where we have plotted the poloidal separation d_θ between two magnetic field lines as a function of the position along the magnetic field $d_{||}$. The two field lines have 1-cm radial separation at the position of the angular probe head, and d_θ , $d_{||}$ is set arbitrarily to (0, 0) at this starting position. \

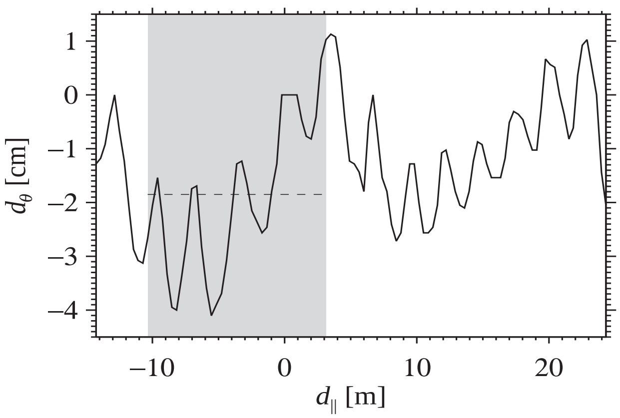

Fig. 4. Poloidal separation d_θ of two magnetic field lines starting 1 cm and 2 cm outside the last closed flux surface (LCFS), with a purely radial separation at the position of the angular probe head, as a function of distance along the magnetic field $d_{||}$, for the vacuum magnetic field of the discharge from which data were used to calculate the poloidal-radial correlation function shown in Fig. 2. Although the field lines approach each other closely even after long distances $d_{||}$ along the magnetic field (low global magnetic shear), they reach large poloidal separations (more than 4 times the original radial separation) in certain sections in between (high local magnetic shear). The data from the grey area are used to calculate an "average poloidal separation" for the torus outboard side, indicated by the dashed line.

The angular probe head was located close to a local extremum of d_θ . If one assumes that the fluctuation structures "strive to be not inclined on the average,'' as is suggested by the 3-D simulation code results, one may average over several modules in the neighborhood of the probe position. We chose to average over the torus outboard side, indicated by the grey area in Fig. 4. We then find that we should expect an inclination of ~2 cm in the poloidal direction per centimeter in the radial direction (the average value is indicated by the dashed line in Fig. 4), which would well account for the observed inclination in Fig. 2, both in magnitude and in orientation.

An interesting qualitative test is the reversal of the magnetic field. Since the poloidal $\boldsymbol{E} \times \boldsymbol{B}$ velocity and also its shear would reverse, one should expect a reversal of the inclination. In contrast, an inclination due to magnetic shear would not reverse, since the magnetic geometry is not affected by the field reversal.

Unfortunately, for technical reasons the magnetic field was never reversed while using the angular probe head. However, a superthermal Li beam generated by laser blow-off [6] was used to calculate radial-temporal correlation functions from the Li line emission along the beam as observed along an angle.

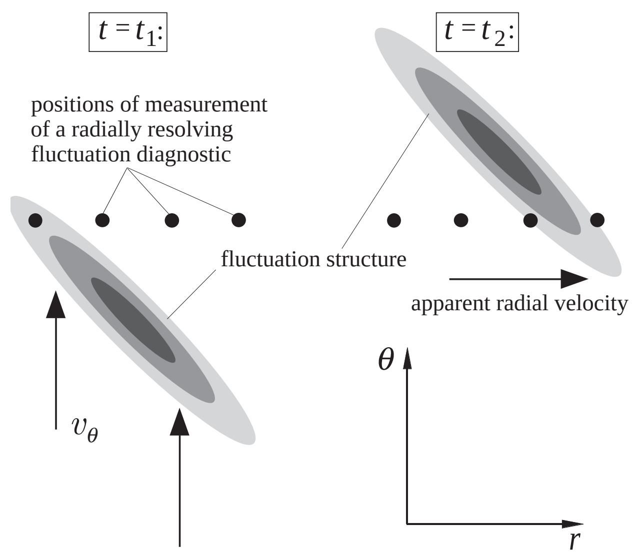

Fig. 5. Inclined structures can give the impression of radial movement when observed with a radial array of detectors, even if they move only in poloidal direction.

Fluctuations in the Li line emission are closely related to density fluctuations [7]. In the measurements with the angular probe head, it had been shown that the radial velocity of the fluctuations is very low, whereas the poloidal velocity is in the range of several 100 m/s [1,2]. In this situation of poloidally moving structures, which are inclined in the radial-poloidal plane, a radial array of detectors will measure a non-zero radial velocity as a projection effect (illustrated in Fig. 5).

If the poloidal velocity reverses and the orientation of the inclined structures remains the same (as it would be expected if the magnetic shear was the reason for the inclination), the projected radial velocity would reverse. If, on the other hand, both the poloidal velocity and the orientation of the inclined structures reverse (as expected if $\boldsymbol{E} \times \boldsymbol{B}$ shear was the reason for the inclination), the projected radial velocity would remain unchanged. In Fig. 6, the radial-temporal correlation functions from the Li laser blow-off diagnostic are shown for two discharges with opposite magnetic field orientation.

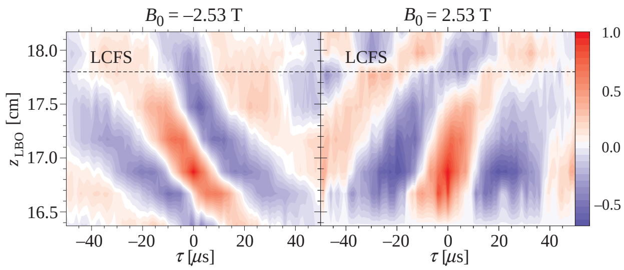

Fig. 6. Radial (along the Li beam coordinate z_{LBO}) temporal correlation function of Li emission for two discharges with opposite magnetic field. The apparent radial velocity of the fluctuations reverses [6].

We find indeed a reversal of the projected radial velocity [6], which indicates again that the magnetic shear is the dominant effect in this type of discharge. However, the magnitude of the projected velocity changes. Although there may be several reasons for this, one of them may be that contributions of both $\boldsymbol{E} \times \boldsymbol{B}$ and magnetic shear exist, which add for one orientation of the magnetic field and subtract for the opposite magnetic field orientation.

4. Conclusion

We have demonstrated that the fluctuation structures in the SOL of W7-AS can be inclined in the radial-poloidal plane. The amount and temporal behavior of this inclination indicate that it is caused in part by the (local) magnetic shear and in part by the radial shear of the poloidal $\boldsymbol{E} \times \boldsymbol{B}$ velocity. For those discharges investigated, the effect of magnetic shear seems to be the dominant contribution.

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References

[1] J. Bleuel, Ph.D. thesis, Technische Universität München, 1998, Max-Planck-Institut für Plasmaphysik report IPP III/235.

[2] J. Bleuel, M. Endler, H. Niedermeyer, M. Schubert, H. Thomsen, and W7-AS Team, New J. Phys. **4** (2002) 38, http://stacks.iop.org/1367-2630/4/38.

[3] J. Bleuel, M. Endler, and W7-AS Team, in *26th EPS Conference on Controlled Fusion and Plasma Physics* (Maastricht), ECA **23J** (1999) 61, http://epsppd.epfl.ch/Maas/web/pdf/or16.pdf.

[4] A. Zeiler, D. Biskamp, J. F. Drake, and P. N. Guzdar, Phys. Plasmas **3** (1996) 2951.

[5] B. Scott, Phys. Plasmas **7** (2000) 1845.

[6] M. Bruchhausen, Ph.D. thesis, Universität Düsseldorf, 2002, Forschungszentrum Jülich report Jül-3993.

[7] S. Zoletnik, S. Fiedler, G. Kocsis, G. K. McCormick, J. Schweinzer, and H. P. Winter, Plasma Phys. Controlled Fusion **40** (1998) 1399.