

PROPERTIES OF DENSITY AND MAGNETIC FIELD FLUCTUATIONS IN THE SOL AND THE EDGE REGIONS OF THE W7-AS STELLARATOR

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Edge and Scrape Off Layer (SOL) electron density fluctuations in the W7-AS stellarator are investigated by Beam Emission Spectroscopy (BES) technique using the 48 keV Li-beam diagnostic[1]. This method enables a non-disturbing, spatially and temporally resolved measurement of correlation functions (and this way fluctuation amplitudes as well) across the SOL and the outer 20-30% of the confinement region. To complement the poloidally localized but radially resolved BES measurement, magnetic field fluctuations were recorded and correlated with Li-light fluctuations using poloidal arrays of Mirnov coils mounted on the vessel wall at three toroidal positions.

1. Experiment and data evaluation

The Li(2p) line radiation induced by collisions of plasma particles with the neutral Li-beam atoms is observed at 28 positions along the beam using a set of photomultipliers. The detection system has a bandwidth of 1 MHz. Although the photon noise on the photomultiplier signals does not decrease below 10% at the above bandwidth even at the maximum of the light profile, correlation functions

$$C^S(Z_1, Z_2, \tau) = \frac{1}{T} \int_0^T \tilde{S}(Z_1, t) \tilde{S}(Z_2, t + \tau) dt \quad (1)$$

can be determined with good accuracy if the integration time T is set longer than about 10 ms. Here $\tilde{S}(Z, t)$ denotes the fluctuating part of the light emission detected at point Z along the beam as a function of time.

Using an appropriate model of the atomic processes taking place in the beam[2] the light emission for any density profile can be calculated. If the beam is only weakly attenuated or the electron density fluctuation amplitude is small ($\leq 10\%$) then the connection between the beam light fluctuations and the electron density fluctuations can be approximated linearly but non-locally:

$$\tilde{S}(Z, t) \approx \int_0^Z \tilde{n}_e(Z', t) h(Z, Z') dZ'. \quad (2)$$

Weak attenuation holds for the SOL, while the condition of low fluctuation level is satisfied for the confinement region. Therefore the above linearization is a good approximation everywhere along the Li-beam for nearly all discharge conditions. By substituting the linear approximation of $\tilde{S}(Z, t)$ into equation (1) one arrives at a linear mapping from the correlation functions of the electron density fluctuations to the correlation functions of beam light fluctuations. By inverting

this mapping as it is described in detail in [3] one can calculate the correlation functions of electron density fluctuations. Normalization of the correlation functions is done by using the fluctuation powers obtained from $C(Z, Z, 0)$.

The time resolution of the correlation functions can be as good as $1\mu s$ but in order to reduce statistical noise it is typically set to about $5\mu s$. Spatial resolution is limited both by the intrinsic time constants of the atomic physics processes in conjunction with the Li-beam velocity and by the diameter of the beam to about 1 cm.

Magnetic field fluctuations are measured by sampling the signals of Mirnov coils with 3-5 μs time resolution. By applying the SVD technique to a poloidally distributed set of Mirnov coils at one toroidal position the dominant spatial and temporal structures are determined[4]. Additionally, the correlation between Mirnov coil signals and Li-beam light signals is calculated. Although this correlation can be different from the correlation between electron density fluctuations and magnetic field fluctuations, it can deliver valuable information as at least for low electron density discharges the beam light fluctuations correlation functions resemble the correlation functions of electron density fluctuations.

2. Results

After analyzing several hundred plasma discharges under various conditions ($t_a = 0.25 \dots 0.55$, $n_e(0) = 1 \times 10^{19} \dots 8 \times 10^{19} m^{-3}$, ECRH, NBI, ICRH and combined heating scenarios) it was found that the observed fluctuation phenomena can be divided into four categories:

1 Turbulent fluctuations in the SOL with relative amplitudes between 10-40%, correlation times between 20-50 μs (decreasing towards the LCFS) and radial correlation lengths typically 1-2 cm. These fluctuations are present in all discharges and not sensitive to magnetic configuration changes. A typical space-time correlation function is shown on Fig. 1/a. The characteristics of these fluctuations are in good agreement with Langmuir probe measurements[5]. No correlation with magnetic fluctuations was observed.

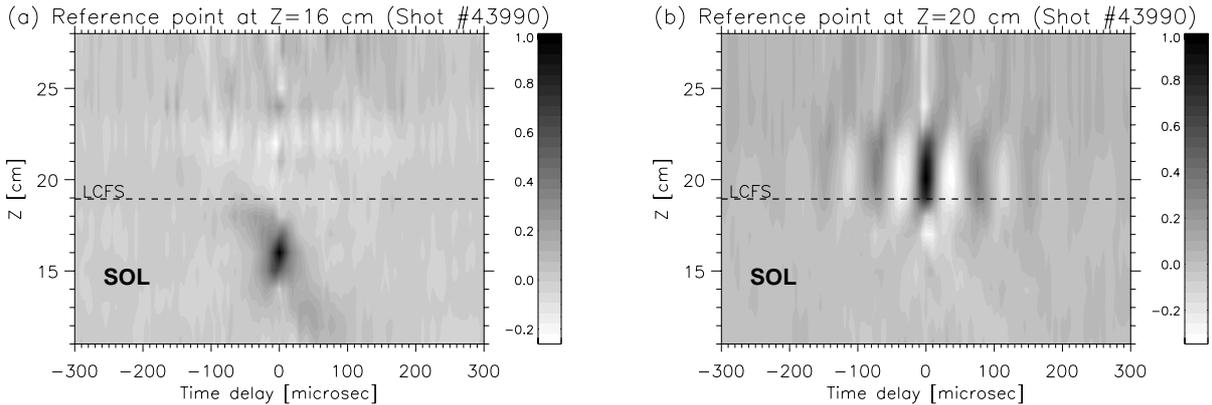


Fig. 1. Normalized Space-time correlation of electron density fluctuations relative to (a) a point in the SOL, (b) relative to a point 1 cm inside the LCFS. Horizontal axis plots time lag, vertical axis is coordinate along the Li-beam.

2 Burst-like fluctuations in the edge plasma. A few cm inside the LCFS one often observes temporally periodic but finite lifetime phenomena (Fig. 1/b). These are not correlated with fluctuations in the SOL, but well correlated with magnetic fluctuations as shown in Fig. 2.

(Correlation 0.2...0.7 is observed, depending on plasma conditions.) The number of periods in the burst can vary from a single peak to about 5-6. The frequency of the burst is in the range of 10-30 kHz. The radial correlation length, number of peaks, frequency and phase structure along the beam sensitively depend on t , electron density and other plasma parameters, although all burst properties are reproducible from shot to shot. Under certain conditions) these fluctuations are absent. SVD analysis of magnetic fluctuations[4] revealed, that the poloidal structure of the associated magnetic fluctuations can be best described by an $m = \text{int}(1/t_a)$ mode perturbation with a correlation time of $100\mu s$ or less, where t_a is the edge rotational transform and int means integer part.

3 Relaxational phenomena. Under certain plasma conditions fluctuations with $200\text{--}500\mu s$ correlation time appear both in the SOL and the edge plasma. They are most characteristic in a small t window around $t_a = 0.523$ where they are the result of sudden flattenings followed by a gradual relaxation of the density profile around the LCFS. This behaviour is reflected by a radial anticorrelation between positions inside and outside the LCFS. The amplitude and extension depends strongly on plasma conditions. For a detailed discussion of such phenomena see [6].

4 Mode activity. In NBI heated discharges periodic fluctuations are observed in the edge plasma. They show periodic autocorrelations for several hundred microseconds and good correlation with magnetic fluctuations. They most probably correspond to GAE modes.

3. Discussion

As it is well known edge plasma phenomena can largely affect plasma confinement, therefore in this section we intend to discuss the relevance of the above phenomena to plasma confinement. Mode activity is not discussed as it appears or disappears without having any effect on the confinement. Relaxational phenomena as seen by the Li-beam diagnostic are merely a response of the density profile to some instability, therefore they are also neglected.

The first question one has to answer is whether SOL turbulence and burst-like fluctuations are merely the two facets of the same instability or they are different, i.e., does the characteristic of the turbulence change at the LCFS or not? Several arguments are found that there is a change at the LCFS:

- For the burst-like fluctuations strong correlation with magnetic fluctuations is observed as it is shown on Fig. 2. On the other hand any attempt to find correlation between magnetic fluctuations and Li-beam light fluctuations in the SOL was unsuccessful. Similar results were published from TEXT[8], where a correlation between Langmuir probe ion saturation current and magnetic field fluctuations was observed only if the probe was inserted inside the LCFS.

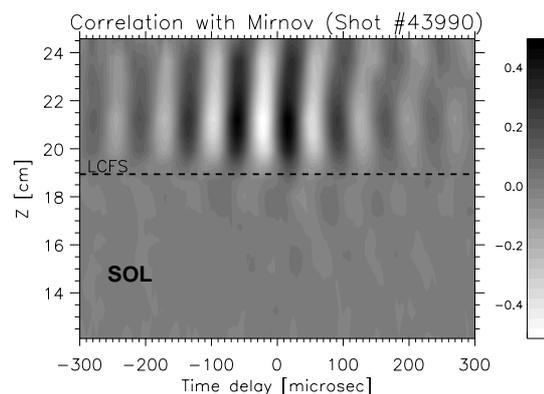


Fig. 2. Normalized correlation of Mirnov coil signal with all Li-beam light signals. The horizontal axis gives time lag, the vertical distance along the beam.

- As characteristics of SOL turbulence measured with the Li-beam diagnostic agree with Langmuir probe measurements, we have good reason to think the two diagnostics measure the same phenomenon. From the Langmuir probe measurements[7] it is known, that SOL turbulence in W7-AS has a typical poloidal wavelength of 5 cm. On the other hand, the poloidal wavelength of the burst-like fluctuations from the low-m structure of the correlated magnetic-field fluctuations is found to be several ten centimeters, nearly an order of magnitude longer than for the SOL turbulence. If additionally to the low-m structure the perturbations would have a local 5 cm poloidal wavelength structure as well, the Li-beam would additionally detect bursts with a frequency of 100-300kHz. This is well within the frequency response of the diagnostic, but was never seen.
- While the SOL turbulence can be seen in all discharges, in some cases the burst-like fluctuations disappear. In these cases the SOL turbulence remains unchanged and similar fluctuations are not detected inside the LCFS.

The above argumentation supports the former finding from ATF[9] that turbulence mechanisms are different on the two sides of the LCFS. However, as both the resolution of the Li-beam diagnostic and the accuracy of the LCFS position determination is around 1 cm, it cannot be ruled out that within one centimeter around the LCFS the same type of turbulence is present.

The importance of SOL turbulence for plasma confinement has already been discussed in the literature. The relevance of the burst-like fluctuations is not yet clear. It was found that at high electron density discharges ($n_e(0) \approx 8 \times 10^{19} m^{-3}$) around $t_a = 0.35$ the energy confinement time depends sensitively on edge t , and the radial correlation length of the burst-like fluctuations increases with decreasing confinement time. However, at low electron density ($n_e(0) \approx 1 \times 10^{19} m^{-3}$) the burst-like fluctuations completely disappear for a certain magnetic configuration without any change in confinement time. In this case the confinement time is insensitive to t_a . These observations indicate, that at low electron density the burst-like fluctuations are not important for confinement, but at high densities they might play a role in confinement.

Theoretical calculations to understand SOL turbulence on the basis of drift wave turbulence are presented in another paper [10]. In these calculations the crossing of the LCFS does not make enough difference to understand the observation that turbulence characteristics change at the LCFS. However, the present version of the simulation might be invalid under the plasma conditions found a few centimeters inside the confinement zone. Thus a direct comparison with theoretical calculations is not available for the whole observation volume at present.

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