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# STATISTICAL ANALYSIS OF FLUCTUATION EVENTS IN THE SOL AND THE EDGE REGIONS OF THE W7-AS STELLARATOR

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Electron density fluctuations in the SOL and edge ($r/a \geq 0.7$) region of the W7-AS stellarator plasma are measured with the Li-beam BES diagnostic[1]. By analysing the correlation functions different phenomena were identified in different regions of the plasma[2]. Disregarding mode activity the observed phenomena all have an autocorrelation function falling close to zero within a few hundred microseconds, suggesting that the fluctuation consists of "events" with finite lifetimes.

Although these investigations revealed both the spatial and temporal characteristics of the phenomena and their RMS amplitude as well they delivered no information on the statistical properties, e.g. amplitude distribution and frequency of the events although these data are essential for identifying the nature of the turbulence.

Finding events in the signal can also be of importance in some cases when the usual correlation functions do not show a correlation between two signals due to some phase jitter. For example let us consider the edge and SOL layers of the W7-AS stellarator. As it was shown previously a phenomenon with wave-like autocorrelation function appears in the edge plasma, while in the SOL the well-known turbulent fluctuations are present[2]. If these two phenomena were strictly phase coupled a correlation would appear between the Li-beam light signals measured in the two regions, as shown on *Fig. 1a.*

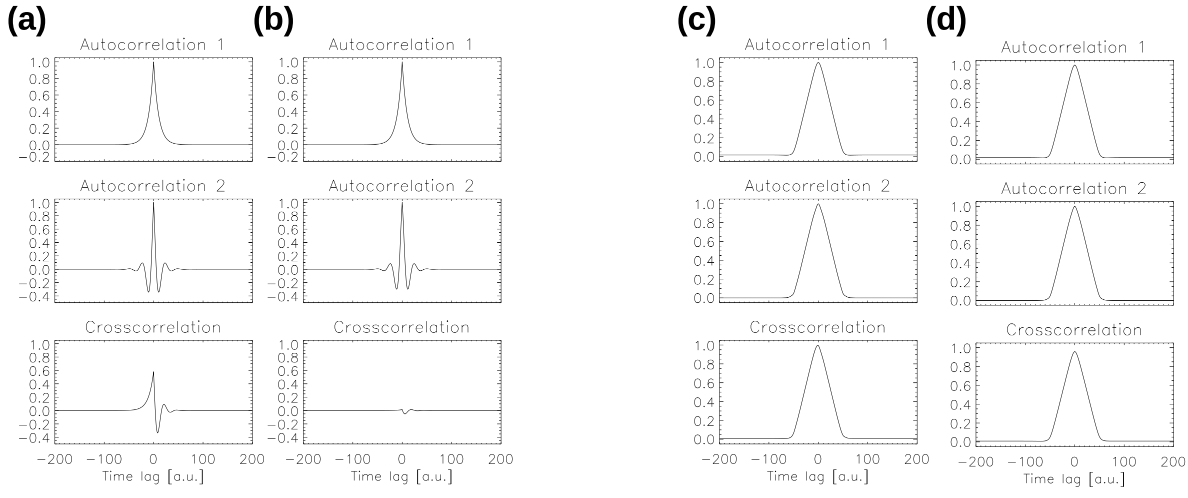


*Fig. 1. Autocorrelation and crosscorrelation functions of a SOL-like and a wave-like simulated fluctuation signal with (a) no phase jitter and (b) random phase jitter. The right two columns show the correlation functions of the event signals obtained from the same simulated raw signals, (c) without jitter, (d) with jitter.*

If the wave-like fluctuation has a random phase jitter from event to event the crosscorrelation practically disappears as shown on *Fig. 1b.* As in the experiment no correlation is seen between SOL and edge plasma fluctuations the question arises whether it is not caused by some phase jitter between fluctuations in the two regions.

To find "events" in the BES signals is even more complicated than finding them e.g. in Langmuir probe signals [3] because the Li-beam BES signals contain a considerable amount of photon statistical fluctuation. The actual fluctuation signal is a few times lower in amplitude than the photon noise. Therefore to identify "events" we developed an algorithm which is not based on the analysis of raw signals [3] but rather on the analysis of the autocorrelation functions calculated from short time intervals.

The numerical procedure.

In the experiment the light of the Li-beam signal is measured at 28 spatial locations along the Li-beam. At low plasma density the measured light fluctuations are nearly proportional to the density fluctuation at the crossing points of the beam and the observation lines of sights[1] therefore in the analysis below we investigate the fluctuation in the Li-beam light signals. According to previous analyses the nature of the fluctuation phenomena changes in space, thus all light signals are analysed independently the following way. The measured signal contains two components:

$$S_i^M = S_i + Z_i \tag{1}$$

where $i$ is the time index, $S_i$ is the light intensity at time $i$ and $Z_i$ is the photon statistical noise at time $i$. Let us assume that $\langle Z_i \rangle = 0$.

We assume that the light signal contains only one phenomenon and that the time evolution (and thus the autocorrelation function) of this is the same for all events. The only quantity assumed to change is the amplitude of the events. We wish to find these events by calculating the similarity between autocorrelation functions calculated from short time interval data and the autocorrelation function calculated from the whole time series. To do so we define the time dependent correlation function as

$$C_i(\tau) = S_i^M S_{i+\tau}^M. \tag{2}$$

The smoothed correlation function with $n$-point smooth length is defined as

$$C_i^S(\tau) = \frac{1}{n} \sum_{j=-n/2}^{n/2} C_{i+j}(\tau). \tag{3}$$

The autocorrelation function for the whole time interval is defined the usual way: $A_\tau = \frac{1}{N} \sum_{i=1}^{N} S_i^M S_{i+\tau}^M$. It is assumed that $N$ is sufficiently large (i.e. the time interval is sufficiently long) that the effect of photon statistical noise is negligible on the autocorrelation function $A_\tau$ for $\tau \neq 0$.

With the above quantities the *event signal* is defined as the correlation between the autocorrelation function and the smoothed time dependent correlation function at different $i$ time instances:

$$E_i = \sum_{\tau=\tau_1}^{\tau_2} A_\tau C_i^S(\tau). \tag{4}$$

It can be shown that $\langle E_i \rangle$ at every $i$ time instance is independent of the photon noise amplitude and depends only on the $S_i$ light intensities.

The amplitude of $E_i$ describes the amplitude of the phenomenon (in arbitrary units) characterized by $A_\tau$ correlation function around time instance $i$. If the smooth length $n$ is selected to be about the length where the autocorrelation function falls to zero, than temporally separated events can be detected and the photon noise contribution for the event signal is much less than for the original raw signal. It should be noted that the described method is not selective in the sense that if two or more phenomena appear in the signal with different autocorrelation functions it will respond to both, albeit with different sensitivity.

*Fig. 2.* shows the result from a simulation where the raw signal was generated numerically and processed with the described algorithm. The light fluctuation was determined in a way that both the autocorrelation function and the RMS light fluctuation amplitude relative to the photon noise RMS level were the same as in an actual experiment at the W7-AS stellarator. The amplitude of the events was fixed. The algorithm finds the events and even their amplitude is recovered except for the case when two events overlap.

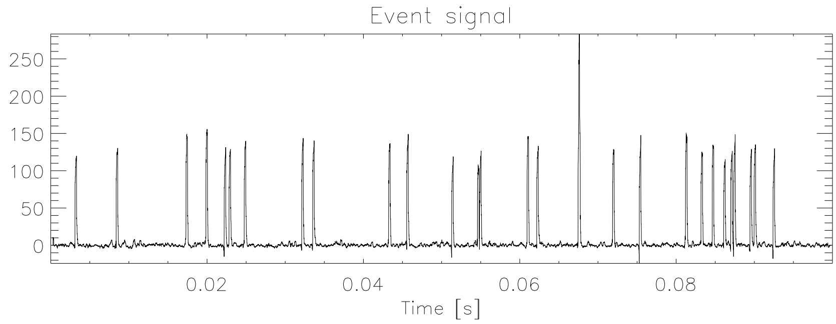


*Fig. 2. Event signal calculated from a simulated raw signal containing randomly distributed identical events and photon noise. The autocorrelation function and signal to noise ratio were fitted to an experimental result.*

The possibility to use the event function to detect correlation between different events with a phase jitter was also tested numerically on the same data set where the usual correlation analysis failed and the result is shown on *Fig. 1 (c),(d).* The correlation between events is clearly recovered.

Experimental results.

The above described event signal was used for roughly determining the repetition rate of the events in experimentally measured signals. To do this a histogram of the event signal amplitude distribution (or Probability Distribution Function, PDF) was calculated. An example is plotted on *Fig. 3.*

Unfortunately this plot is not usable for the derivation of the event amplitude distribution directly as it contains the rising and falling part of the signal during an event and also because events might overlap in time. Nonetheless, the PDF of simulated event functions with different event repetition rates can be compared with the shape of the experimentally determined PDF.

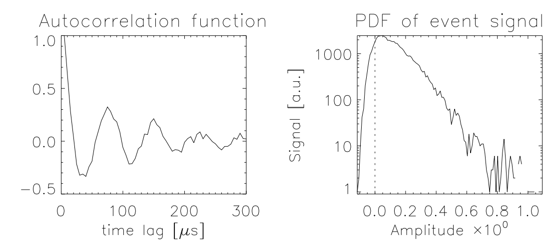


*Fig. 3. Autocorrelation function and PDF of the event signal in the edge plasma in a low-density ECRH discharge.*

It was found that an agreement can be reached only if the average event repetition time is set to about 50 $\mu s$, which is shorter then the lifetime of the event (see the autocorrelation function). In this case the events overlap in time and no statement can be made on the shape of the event amplitude distribution. Repeating this procedure for signals obtained from different regions of the plasma under various plasma conditions the result was always the same: the events overlap in time and it is not possible to resolve individual ones.

Although the above finding prevents us from using the event signal as a time marker for conditional averaging of various signals as it was done with probe signals [4] we can use it to investigate the temporal correlation between different types of fluctuations in different plasma regions. To do so we calculate the event signal for all Li-beam BES channels and correlate these the same way as usually correlation functions are calculated: $C(Z_1, Z_2, \tau) = \langle E_{Z_1}(t) E_{Z_2}(t+\tau) \rangle$, where $E_Z(t)$ is the event function calculated from the light signal measured at position $Z$ along the Li-beam. Selecting one channel as reference one can plot the spatiotemporal event correlation function $C(Z_0, Z, \tau)$ as it is shown on *Fig. 4.* for the SOL. As one can clearly see there is no correlation between events in the SOL and the ones in the edge plasma although the autocorrelation functions on the left side indicate that fluctuations are clearly present there as well.

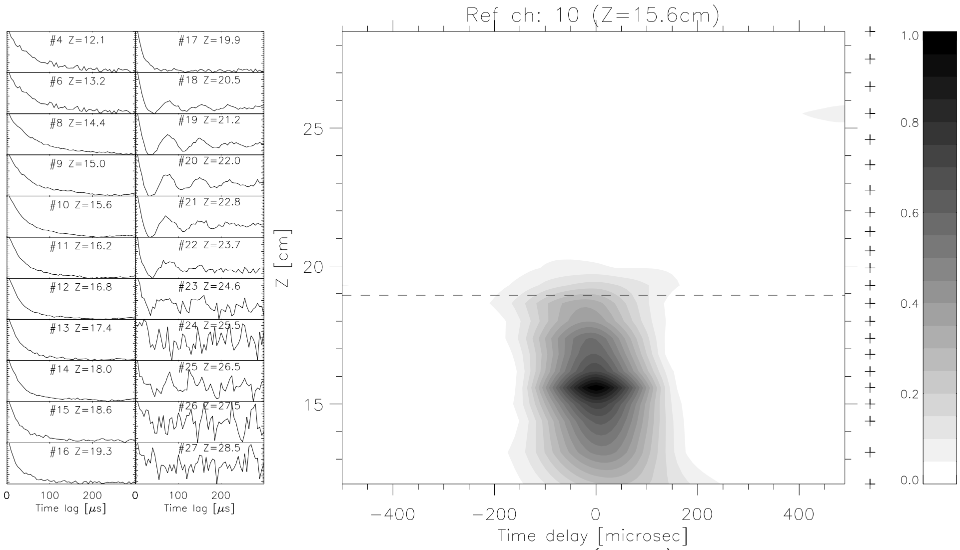


*Fig. 4. Spatiotemporal correlation function of events(right) and autocorrelation functions (left) at different locations. Horizontal axis is time lag, vertical is coordinate along the Li-beam (Z). SOL is at the bottom, the position of the LCFS is indicated by dashed line.*

Conclusions. The analysis of events in Li-beam BES fluctuation signals revealed that the turbulence consists of overlapping small events rather than of well separated large ones. No correlation is detected between events on the two sides of the LCFS although fluctuations exists both in the SOL and the edge plasma.

References

[1] S. Zoletnik, *et al. Plasma Phys. Control. Fusion* 40 1399 (1998)

[2] S. Zoletnik, *et al. ICPP& 25th EPS Conf. Prague* ECA Vol. 22C 407 (1998), also submitted to *Phys. Plasmas*

[3]M. Endler, *et al. Physica Scriptra* 51 610 (1995)

[4]H. Johnsen, *et al Phys. Fluids.* 30 2239 (1987)