

**The origin of the long time correlations of the density fluctuations
In the Scrape off Layer of the Tore Supra Tokamak**

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In this paper we investigate experimentally the origin of long range correlations observed on the auto-correlation function of the turbulent signal in the SOL of Tore Supra [1]. To this purpose, the bursts, their magnitude and the waiting times between them are selected by a threshold method and we perform a correlation analysis between them. For the first time we measure a clear correlation between burst magnitude and waiting times in the turbulence of a fusion device[2].

The scenario of the plasma is the following: $R= 2.38$ m, $a=0.71$ m, $I_p=0.6$ MA, $q(a)=7$, mean density $n= 1.48 \cdot 10^{19} \text{ m}^{-3}$. Lower Hybrid Power $P_{LH}= 1.54$ MW. The shot lasts for more than 100 s and all the parameters presented above are kept perfectly constant. The probe used for this work is located on a Lower Hybrid grill at a distance of 46 mm from the plasma LCFS in the low field side region 330mm above the middle plane. Data are obtained during a series of shots with Lower Hybrid heating and pellets injection but also with Ohmic plasmas. Since the analysis performed for these 2 types of plasmas yields similar results, both types will be used in the following. The probe is dc biased at -100 V to collect the Ion saturation current (I_{sat}). As the current measured by the probe is rather small (the collected current scales from several mA to several tens of mA) it is necessary to amplify it by a factor of 50 before recording. As far as the noise is concerned, it is observed only at high frequency and is removed from the signal by filtering out the components above 400 kHz.

This current and its fluctuations are recorded at 1 MHz. The I_{sat} fluctuations can be considered as a good approximation of the density fluctuations as they only depend on the square root of the electron temperature. In order to obtain better statistics, up to 9 triggers separated by 1 s are used. For each trigger a time series of 16000 samples is recorded. After checking the stationarity and invariance of the data (same power Spectra, RMS value, skewness etc.), the time series are concatenated to obtain a time series of length 144000 data points. Such a procedure introduces a short time discontinuity at the junction of the different time series, but with respect to the number of samples does not have any impact on the analysis presented below. A typical sample representing the fluctuations of the signal, i.e. ($I_{sat} - \langle I_{sat} \rangle$) is shown on Figure 1a. At this radial position, the turbulence is almost entirely

composed of large bursts superimposed to a weak turbulent background. The auto-correlation function (ACF) of the signal (Figure 1 b) shows a long tail extending beyond 50 μ s. The Probability distribution function (PDF) of the fluctuations in figure 1c shows that the PDF cannot be fitted by a Gaussian above one standard deviation $\sigma(\text{isat})$, (defined relative to the most probable value of the PDF) so that it can be considered as being intermittent everywhere above this value. In order to analyse the data, we choose a threshold level at least at this value to extract the bursts from the background turbulence. We have used in the analysis several thresholds and we find that they can be chosen in a range extending from $\sigma(\text{isat})$ to $2 \sigma(\text{isat})$ where $\sigma(\text{isat})$ stands for the standard deviation of the signal (0.167 in our case) defined relative to the most probable value of the PDF. The choice of the threshold allows us to generate a new time series where any point above the threshold are ascribed a value of 1 while all others are set to zero, we create in this way a gate function Z . This time series Z is then used to calculate the sequence of time duration of the bursts (τ_b) and the waiting times between them (Δt_b) in sequential order. A third sequential series is calculated for the magnitude of the bursts (I_b). The initial raw data is convoluted with the gate signal Z and we obtain another time series which corresponds to the raw data with all the points below the threshold set to zero. We use this last series to calculate the sum of the amplitudes within each burst that we define as the magnitude of the bursts I_b . The output of this procedure is a waiting time $\Delta t_b(k)$ associated to a burst duration $\tau_b(k)$ and magnitude $I_b(k)$. Because in these series the quantities are issued in temporal order, it is possible to calculate the correlation between them using standard correlation functions. To calculate the correlation between the magnitude of the bursts I_b and the waiting time between bursts Δt_b , we first subtract the mean value from these sequential series. We present in Figure 2 the cross-correlation function of these two quantities:

$$c(\Delta k) = \langle I_b(s) \Delta t_b(s + \Delta k) \rangle$$

where Δk is no more a time lag in μ s but an integer standing for the shift between the 2 sequential series. Figure 2 displays the correlation function in Ohmic at threshold $\sigma(\text{isat})$ and during LH for $\sigma(\text{isat})$ and $2 \sigma(\text{isat})$. The result is that the magnitude of the individual bursts and the time intervals between them are anti-correlated. As this result is obtained in Ohmic and LH heating, it is a generic property of the density fluctuations. Although this level of correlation is rather small (slightly above 0.1 both in Ohmic and during LH Heating), it is clearly out of the noise as can be seen in Figure 2a. The correlation functions displayed in

Figure 2 are peaking at a Δk of one, but another very important information is that the anti-correlation peak has a width of several points which are clearly above the noise level.

The meaning of Figure 2 is the following: A burst of large magnitude (i.e. greater than the mean magnitude) tends to be surrounded by a number of small time intervals (smaller than average) equal to the number of points in the anti-correlation peak. It is equivalent to say that the bursts tend to appear in packs on the probe and that they are separated within the packs by time intervals smaller than the average. Thus, the result of the cross-correlation plotted in figure 2 exactly defines what we call “packs”, namely a number of peaks separated by waiting times smaller than the average waiting time. Three points in the anti-correlation peak indicates that the bursts tend to be measured in packs of four. The correlation function of Figure 2 underlines the existence of a weak temporal organization of the bursts. The existence of groups or packs of peaks in the data has consequences for the interpretation of the wings observed on the auto-correlation function of the Isat fluctuations displayed in Figure 1b. The different peaks within a pack are going to be correlated between themselves and this will produce long wings on the auto-correlation function of the signal.

To emphasize this point further, we compare the auto-correlation function of the gate signal Z with the one of the raw data. The gate function is composed of windows of 0 and 1 that do not exceed $40 \mu\text{s}$ at most. Therefore, there cannot exist long range correlations above $40 \mu\text{s}$ others than the correlations between the different windows. Before calculating the auto-correlation function of Z , we subtract its mean value. Figure 3 shows that the correlation function of the gate signal Z displays the same long wings as the one obtained with the raw time series, so that in fact, all the long range correlation properties of the signal are preserved in the temporal distribution of the windows of the gate function. This demonstrates that the long range correlation of the turbulent density (above $40 \mu\text{s}$) is in fact the correlation of different peaks within their pack.

In turbulence models, packs of bursts may be observed when the turbulence is in two limiting states. The first state corresponds to a situation where the coupling of the turbulent poloidal electric field with the turbulent density is strong. In that case, the poloidal electric field induced by the density bursts may dominate over the ambient electric field. The density tends to be sheared apart and does not propagate on long radial distances [3]. Density bursts tend to split and develop radial fingers in the (r, θ) plane, which rotate poloidally due to the diamagnetic drift. The observed packs of bursts might correspond to several such fingers. The second state corresponds to moderate coupling between density and potential. The auto-correlation time of the electric potential is then larger than the time duration of a single

density burst and several bursts may propagate along the potential valleys, and lead to the sequences of bursts observed in Tore Supra. The lack of spatial resolution of the diagnostic used for this work does not allow the two mechanisms to be discriminated.

References:

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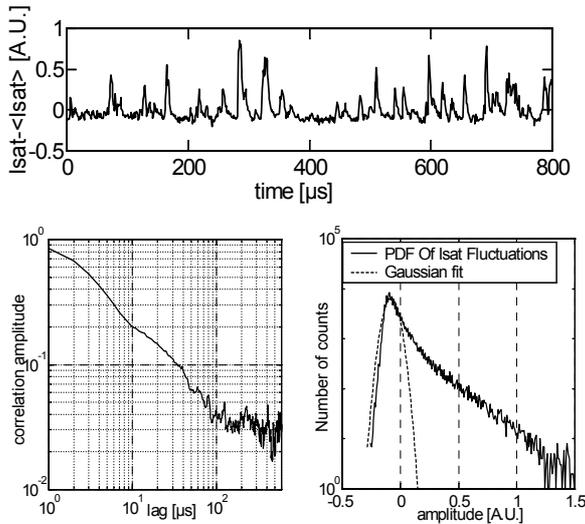


Figure 1: Top: time trace of I_{sat} fluctuations measured on the probe. **Bottom left:** Temporal auto-correlation function of I_{sat} fluctuations in log-log scale. **Bottom right:** PDF of I_{sat} fluctuations, also plotted on the same figure, the best Gaussian fit that was found for this case.

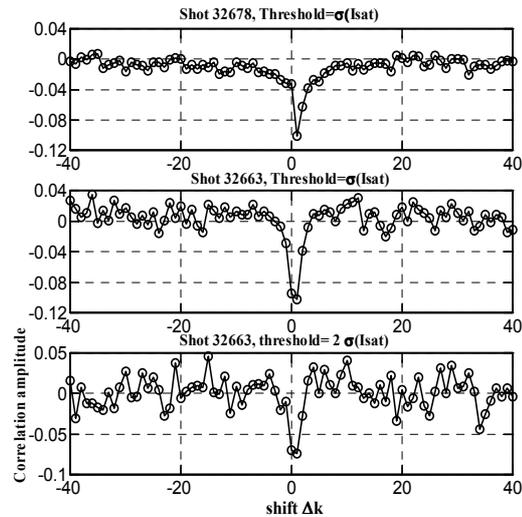


Figure 2: cross correlation function of burst magnitude I_b with time between bursts Δt_b . **Top:** Ohmic shot, threshold for bursts= $\sigma(isat)$. **Middle:** shot with LH heating, threshold for bursts= $\sigma(isat)$, **Bottom:** same shot during LH heating, threshold = $2\sigma(isat)$.

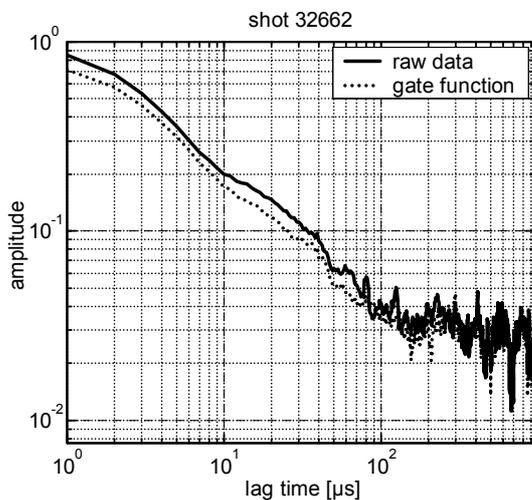


Figure 3: Comparison of the 2 temporal correlations functions (I_{sat} fluctuations and gate signal Z) plotted in log-log scale.