30th EPS Conference on Contr. Fusion and Plasma Phys., St. Petersburg, 7-11 July 2003 ECA Vol. **27A**, P-1.76

Effects of the density fluctuation characteristics on the phase fluctuation spectrum obtained from a reflectometer

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Introduction: The previous studies [1] in reflectometry devoted to the connection between the phase fluctuation spectrum and the radial wave-number spectrum of the density fluctuation use a homogeneous turbulence model. In the case of O-mode and X-mode reflectometers we study here with full-wave simulations the modification introduced by the nature of the density fluctuations. The presented studies show the responses of different characteristics of the turbulence emission as a burst emission (intermittency) with different repetition rates and time widths. Other simulations show that it is possible to obtain information on the spatial amplitude distribution of the density fluctuations in the density profile by using a sliding window in the data processing analysis of the phase fluctuations. Finally, we show that the radial wavenumber spectrum evolution in the radial direction can also be determined to some extent. For the moment this method gives only a relative (radial evolution of the density fluctuations., not the absolute value. Further development. has to be made to obtain the absolute value of the amplitude of the density fluctuation.

Signature of a homogeneous turbulence: In previous study [1],], it was shown that the phase fluctuation spectrum is related to the density fluctuation spectrum. In the case of a wide k-spectrum of the density fluctuations, this present analysis shows that all wavenumbers up to the Bragg detection limit ($k_f < 2k_o$ incident wave-number) contribute to the phase fluctuations. The different contributions come from localised zones of the density profile and, as expected, the main part comes from the vicinity of the cut-off layer. The phase fluctuations dependencies with k_f and L (length of the density gradient) found in the literature for the O-mode, the dependencies are the same in both cases ($\alpha\, k_f^{-1/2}$), and have been completed for the X-mode. The X-mode phase dependencies are different for low k_f values (oscillation of the cut-off $\alpha\ k_f^{-1/2}$) and for the higher k_f values (Bragg backscattering domain $\alpha\ k_f^{-3/4}$). In the simplest situation of a FM reflectometer (linear density profile, weak amplitude of the density fluctuations) a transfer function can be obtained. Some works have to be done to take into account the non linear effects in the transfer function to extract the radial wavenumber spectrum. Figure 1a shows an example of such a reconstruction of the density fluctuation spectrum. The density fluctuation are built with a chosen wavenumber spectrum on the average over several hundred samples, here a flat spectrum, cut at $k/k_o = 3.3$. This simulation confirms that only the wavenumbers up to the Bragg detection limit contribute to the phase fluctuations.

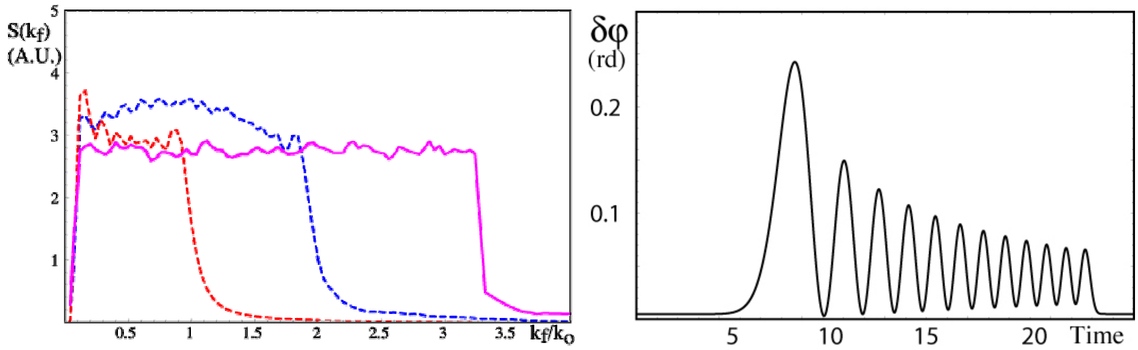

Figure 1:a) left size Comparison of reconstructed wavenumber spectra of density fluctuations for ordinary (red), extraordinary (blue) modes and input spectrum (magneta) b) right size Phase variations associated to a narrow burst.

Response associated to a burst emission: We consider the case where narrow bursts are emitted and do not overlap (for strong overlapping, the average spectrum looks like homogeneous turbulence). As shown analytically, the phase response changes if the width of a burst is lower than a critical width $w_c = (k\ L\ k_o^{-2})^{1/2}$ [2], which gives typical phase signatures if only separate bursts exist in the probing zone. The average spectrum of the density fluctuations can always be deduced from the previous method. However the phase variation contains additional information. For example, for a single burst of width smaller than w_c, the phase fluctuation has a characteristic Ai^2-like variation. If there are at the same time in density profile are more than two bursts with a width smaller than w_c, the phase response is a mixing of Ai^2 function with different origins corresponding to different radial position of the burst In this situation, a statistical approach can be made on the distance between two adjacent bursts to obtain a pdf and compare to models or such simulation. When the burst spatial width increases the spectral effects disappear and the phase variations become more and more connected to the spatial regime [2] and the Ai^2 signature disappears. In the case of high level of density fluctuations, the situation is more complicated because the response becomes non linear and we have to distinguish the phase jumps due to the signal lost and those given by an index plateau or hill-hole density variation as it can be found in case of MHD activity [3] .

Radial evolution of the density amplitude from density profile reflectometer:

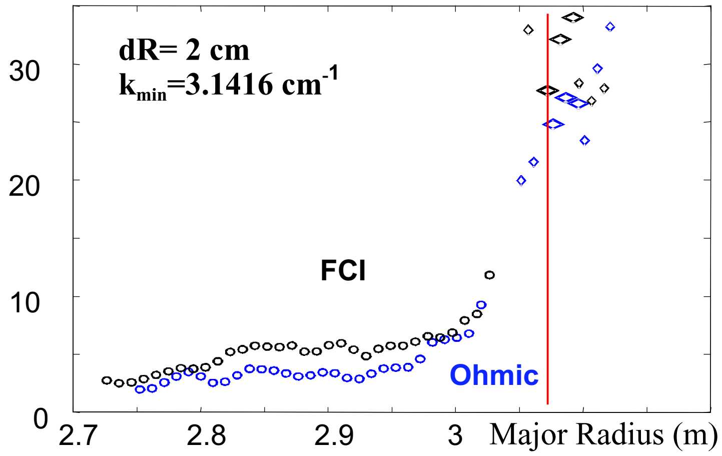

Figure 2: Radial evolution of the density fluctuation amplitude (in arbitrary units) with and without IRCH heating deduced from the Tore Supra FM reflectometer data.

Simulations of a swept X-mode reflectometer have shown that information on the local density amplitude can be obtained. The method is based on the integration over a fixed wavenumber range of the average k-spectrum associated to a radial sliding window. For each radial position of the sliding window, a relative evaluation of the density fluctuation amplitude can be made. The wavenumber range can be associated to a probing zone with a known width if the density profile is determined. The amplitude obtained by this way is an average value over the probing zone. The choice of the wavenumber range corresponds to a region near the cut-off layer. To interpret these results, we have made the assumption here that the k-spectrum is the same over all the plasma because the radial evolution of the k-spectrum is unknown. If the k-spectrum radial evolution is known (see the next paragraph), some correction could be made to reach the density fluctuation amplitude versus radial position. This method has been applied on the Tore Supra and seems to give expected results that is to say an increase of the density fluctuation amplitude near the edge and a higher level of the density fluctuations when the plasma is heated. These results should be confirmed in better defined experiments on TS.

Radial evolution of the k-spectrum: The radial evolution of the k-spectrum can be studied by processing the phase fluctuations given by a FM reflectometer. The simulations have permit to shown that is possible to reach the radial evolution of the k-spectrum. The data processing method is the following: a sliding window is applied on the phase fluctuations expressed as a function of the radial position and a fast Fourier transform of the phase data contained in the sliding window is computed. Then the above-mentioned correction in wavenumber and gradient length is applied [1] assuming that on the probing zone the amplitude and the density gradient length are constant. A quasi-local k-spectrum is then obtained for each radial position of the sliding window. The wavenumber resolution depends on the number of points used to define the sliding window. To demonstrate the feasibility of the method we have used two different types of k-spectrum which overlap in the central part, r=a/2 (see fig 3 left). Experimentally the method needs more than 4000 points per frequency ramp and 100 ramps to have a good average. The center of the plasma is not reach due to the choice of the upper frequency. But in the case of the X-mode it is possible to access the center and beyond. This kind of data processing applied to FM reflectometer data might be used to analyse the modification of the k-spectrum induced the transport barrier formation.

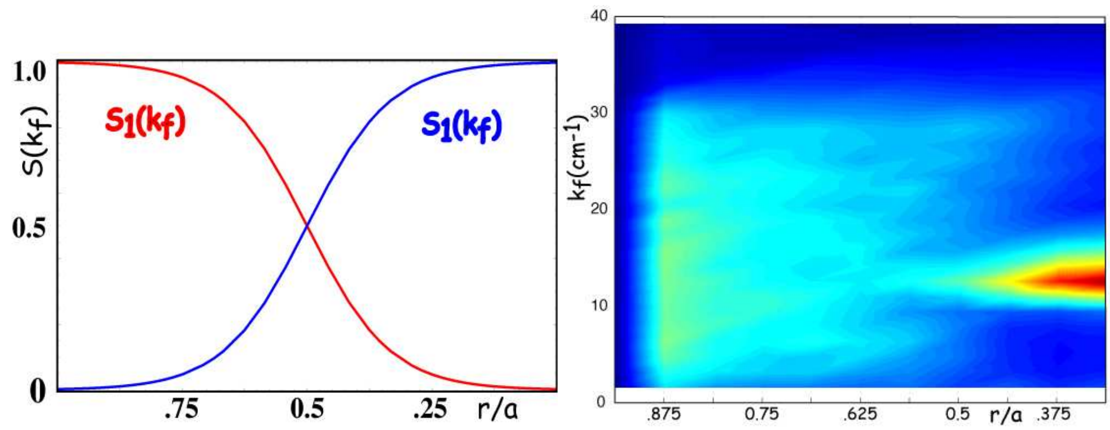

Figure 3. Radial evolution of the wavenumber spectrum recovered from phase variations obtained by a FM reflectometer (Gaussian spectrum (blue) at the center and experimental [4] at the edge (red) with a given envelop shown on the left side)

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