ANALYSIS OF UP-DOWN ASYMMETRIES OF DENSITY FLUCTUATIONS IN TORE SUPRA

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1. Introduction

Anomalous transport in fusion devices is a major problem to plasma confinement. It is known to be mainly due to microscale fluctuations. In the circular cross-section tokamak TORE SUPRA, measurements of density fluctuations with the CO_2 laser scattering diagnostic ALTAIR have shown that this turbulence can be separated into two components: a bulk turbulence and a larger magnitude edge turbulence. In the latter region, fluctuations play an important role by controlling particle and energy loads on plasma facing components. Most of the previous investigations were focused on the relation between turbulence and global plasma parameters and, in few cases, local parameters through the radial component. Only small effort has been put on the analysis of poloidal asymmetries, although qualitative observations have been made in some tokamaks (TEXT, ALCATOR, CCT, ASDEX).

In Tore Supra, where heat and particle control is based on the use of a set of modular limiters, of inner wall and of an ergodic divertor, up-down asymmetries of density fluctuation power δn_e^2 have regularly been observed with the CO_2 laser scattering diagnostic ALTAIR [1]. They are difficult to interpret, but their investigation may not only help to understand the origin, the propagation and development mechanisms of the edge turbulence, but also provide additional information on edge plasma transport. First qualitative analyses [2] seemed to show that these asymmetries are correlated to the plasma leaning point position: lower limiter(s), outboard limiter or inner wall. Dedicated experiments have been performed to thoroughly investigate the mechanisms underlying the asymmetry behaviour. New experimental results and possible theoretical explanations are presented.

2. Experimental set-up

The experimental set-up of the infra-red laser scattering diagnostic ALTAIR has been described in details in Ref. [2], and only some features necessary for the understanding of this specific analysis are summarized hereafter. ALTAIR measures density fluctuations with an heterodyne detection which allows to determine the direction of the plasma turbulence propagation. Moreover, two intermediate frequencies allow to observe simultaneously two independent wave vectors which can be adjusted between 3 and 15 cm^{-1} in any direction perpendicular to the vertical probing beam in the plasma. In order to compare the turbulence

coming from the upper part of the probing chord to the lower one, on a same plasma and at the same instant, we used a configuration based on the simultaneous measurements of two wave vectors $\mathbf{k_1}$ and $\mathbf{k_2}$, adjusted with the same wave number but different orientation.

3. Experimental observations

3.1. Plasma configuration and edge safety factor effects

Figure 1 illustrates the up-down asymmetry at $k_\theta = 10$ cm^{-1} versus the edge safety factor q(a), in various geometric configurations: plasma leaning on the inner wall, on the outboard limiter, on lower limiter(s) and multiple plasma configuration. In the latter configuration, the plasma is close to many points in the vessel. The asymmetry strongly depends on the edge safety factor: it increases with q(a) towards the lower part of the plasma, whatever limiter(s) being used (see the dashed line in Fig. 1). But the clearest effect on the asymmetry level is observed when the plasma is leaning on a lower limiter placed in the vicinity of the measurement volume. In that case, the level of density fluctuations at the lower part of the plasma reaches a value six times larger than at the upper part. A saturation effect at higher q(a) is also observed.
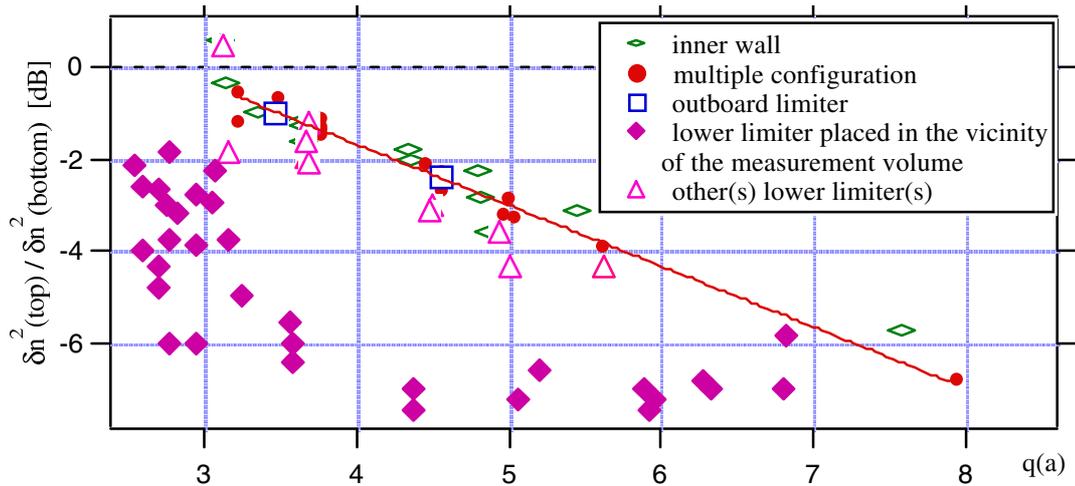

Figure 1. Up-down asymmetry observed versus the edge safety factor $q(a)$, k_θ =10cm^{-1}.

3.2. Line average density

Figure 2 presents the top and bottom fluctuations power versus the line average density, at $k_\theta = 10$ cm^{-1} and in the case where the plasma is leaning on the lower limiter situated nearby the measurement chord (see Fig.1, dark lozenges). There is a weak dependence on the line average density until a MARFE occurs for nl ~ 5.5 10^{19} m^{-2}. During the MARFE, located at the inside edge of the plasma (high field side) and above the midplane, the top fluctuation power strongly increases by more than a factor of twenty, whereas the bottom one is weakly reduced.
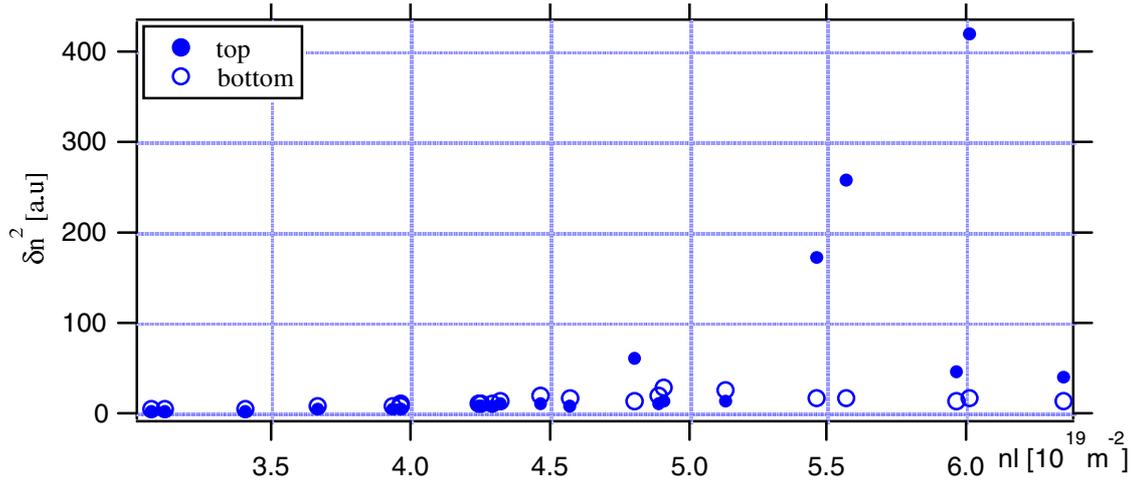
Figure 2. Top and bottom fluctuation power versus line average density, $k_\theta=10 \text{cm}^{-1}$.

3.3. k power spectra

In the case where the plasma is leaning on the lower limiter situated nearby the measurement chord (see again Fig.1, dark lozenges), **k** power spectra have been recorded simultaneously at the top and the bottom of the plasma for wave numbers ranging from 3 to 13 cm^{-1}. Figure 3 shows that the top fluctuation power decreases with k faster than the bottom one, showing respectively a $k^{-4.7}$ and a k^{-3} average dependences, i.e. the k-spectrum slope is lower where the turbulence level is higher.
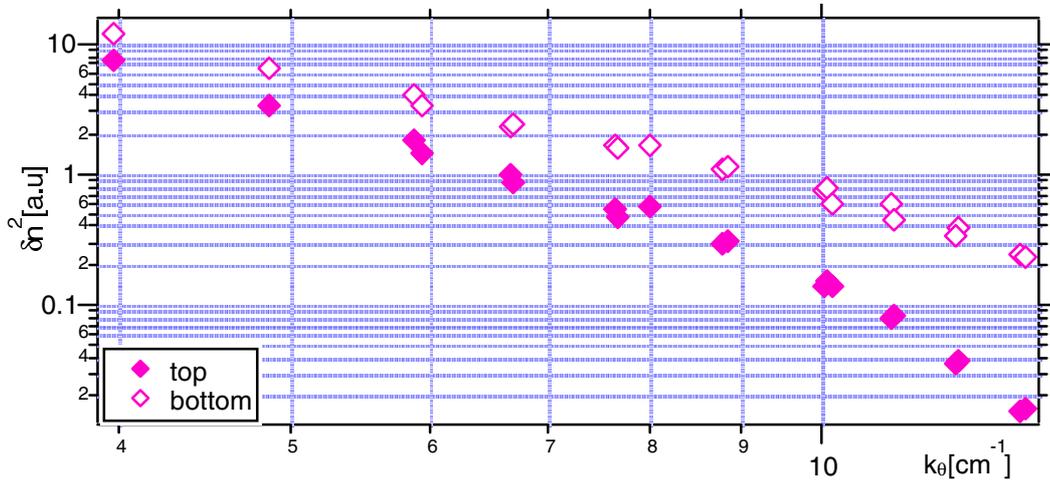

Figure 3. Top and bottom k-spectra, plasma leaning on the limiter placed in the vicinity of the measurement volume.

3.4. Frequency spectra

The frequency spectra present two features differentiated by a Doppler shift due to the electric drift [3]. This allows to distinguish two regions of the plasma located on both sides of the

electric shear layer. One corresponds to the plasma bulk and the other to the plasma edge and the scrape-off layer. The asymmetry appears to mainly develop beyond the radial electric shear layer i.e. in the extreme edge of the plasma and the scrape-off layer, as seen in Ref. [3].

4. Modeling and concluding remarks

Most of the turbulence models do not predict a strong up-down asymmetry of the fluctuation level, but rather a higher fluctuation level in the low field side than in the high field side. Thus, the up-down asymmetry modeling is a difficult task but it enhances new insights into the understanding of edge plasma turbulence. Three groups of turbulence models provide a possible theoretical explanation. The first one refers to the hypothesis of a poloidally asymmetric equilibrium. For instance, assuming that the perturbed density is proportional to the perturbed electric potential (Boltzmann relation) and considering a poloidal inhomogeneity of the equilibrium density, one obtains an asymmetry on density fluctuations. The largest density regions then exhibit a maximun turbulence level. Vertical drift effects lead to such up-down asymmetries of equilibrium quantities, but they are too weak to explain the measurements. However, considering an asymmetric ionization or diffusion source (in this case, the strong turbulence regions are those of strong recycling) this model predicts a dependence on edge safety factor for δn_e^2 and asymmetries levels in agreement with the experimental values. The second turbulence model type is related to standard turbulence theories with additional effects such as a sheared rotation inducing a ballooning angle variation and then leading to an asymmetry rotation. Finally, the last model type introduces additional instability mechanisms with an asymmetrical source leading to asymmetrical growth rates such as ionization, radiative, sheath, rippling and Kelvin-Helmholtz instabilities.

All these models are now under deeper investigation and new dedicated experiments will be soon realized to provide additional information. As a whole, they lead to up-down asymmetries extending with the edge safety factor: in fact, as q(a) increases, the characteristic connection lengths (between radial opposite regions) increase and transit effects along magnetic field lines are reduced, leading to an increase of the asymmetry level. However, they do not necessarily exhibit a sensitivity to the direction of the plasma current as observed in TEXT [4], where the asymmetry reverses with the plasma current. The latter feature provides a severe constraint on the invoked models: among the various edge instabilities, only the rippling and the Kelvin-Helmholtz instabilities are sensitive to the plasma current direction.

References

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