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Characterization of the up-down asymmetry of density fluctuations induced by a lower modular limiter in Tore Supra

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1. Introduction

In magnetic fusion devices, the effect of plasma facing components on plasma turbulence is a key issue for several reasons. Firstly, the edge turbulence controls the power deposition on plasma facing components. Secondly, the possible influence of the edge parameters on the core fluctuations is a central question, since the core turbulent transport is responsible for the confinement degradation. It is in practice difficult to determine whether the plasma core influences the edge, or the opposite. We show here that spatial edge asymmetries of density fluctuations, and particularly up-down asymmetries, provide a powerful tool to investigate this problem. Up-down asymmetries have already been observed in TEXT [1], ALCATOR [2], CCT [3] and TORE SUPRA [4]. Nethertheless, only TEXT and TORE SUPRA measurements show a permanent asymmetry, which reverses with the plasma current direction in TEXT. In TORE SUPRA, previous scaling analyses with various plasma parameters have emphasized that a very clear effect on the asymmetry level appears when the plasma leans on the lower modular limiter located close to the measurement chord [4]. We present here recent measurement results concerning that specific case. They tend to show that the limiter configuration has some effect on the core turbulence.

2. Experiment

The measurements were performed on a set of steady state deuterium ohmic discharges, which parameters are $I_p = 0.9$ MA, $B_\phi = 3.1$ T, $<n_e> \sim 2\times10^{19}\,m^{-3}$, $a = 0.72$ m and $R_0 = 2.35$ m. The plasma current and toroidal field directions are parallel, and both in the anticlockwise direction with respect to the vertical axis when seen from above. Data are taken during the stationary phase of plasma discharges.

Density fluctuations are measured with the CO_2 laser coherent scattering diagnostic ALTAIR, which is described in detail in [5]. The apparatus can measure simultaneously two independent wavenumbers of the density fluctuations contained in the plasma cylinder crossed by the laser beam. An heterodyne detection is used, allowing to determine the direction of the fluctuation propagation. The setup is such that the recorded bottom and top fluctuations are mainly localized in the outer halves of the discharges. Details on the spatial localization can be found in [5-6].

3. The limiter effect on density fluctuations

In the experiment reported here, the plasma leans on a modular limiter located in the equatorial plane (outboard limiter), far from the laser probing chord. Shot to shot, the lower modular limiter located close to the measurement chord is introduced into the scrape-off layer.

3.1. Top and bottom fluctuation levels

When the plasma leans on the outboard limiter, a weak up-down asymmetry of density fluctuations is observed (but larger than the experimental error bars). Introducing into the srape-off layer a lower modular limiter located close to the measurement chord has a dramatic effect. Figure 1 shows the fluctuation level δn_e^2 at the top and the bottom of the plasma versus the distance between the lower limiter and the LCFS ($r_{lim} - r_{LCFS}$), for $k_\theta = 10\ cm^{-1}$. The transition is sharp: when the distance between the lower limiter and the LCFS is close to one centimeter, the fluctuation level increases significantly at the bottom of the plasma whereas it remains unchanged at the top. This leads to the onset of an up-down asymmetry with a higher level of turbulence at the lower part of the plasma. When the limiter reaches the LCFS, the fluctuation level at the bottom is 2.5 times larger than at the top.

3.2. Frequency spectra associated to fluctuations located in the lower part of the plasma.

During this experiment, the density fluctuation frequency spectrum at the bottom of the plasma exhibit a striking behaviour. In TORE SUPRA, density fluctuation frequency spectra exhibit typically two bumps, centered on positive and negative frequencies [6-7]. These double bump shape is attributed to a differential Doppler shift due to the sign reversal of the radial electric field in the plasma edge, at a normalised radius r_s/a close to 0.9 [7]. This property allows to discriminate between core and edge fluctuations located on both side of the radial electric shear layer, respectively ($r_s > r > a/2$) and ($r > r_s$). Both fluctuation contributions can be determined using the time derivative phase of the complex signal [8]. Figure 2 illustrates the frequency spectra measured at the bottom of the plasma for $k_\theta = 10\ cm^{-1}$, before the transition (r_{lim} - r_{LCFS} > 1 cm, figure 2a), at the transition (r_{lim} - r_{LCFS} = 1 cm, figure 2b), and finally after the transition ($r_{lim} = r_{LCFS}$, figure 2c). It is remarkable that at the transition (see figures 2a and 2b) a new spectral component with a large amplitude appears in the spectrum, at high positive frequency (figure 2b). This additional bump could be due to the Doppler effect associated with a large local electric field appearing when the limiter approaches the LCFS. It could also correspond to the onset of a new source of fluctuations. The associated fluctuations drift in the ion diamagnetic direction, and are therefore located in the plasma edge ($r > r_s$) [6-7]. When the limiter is introduced further into the plasma and reaches the LCFS (figure 2c), the bump broadens and merges with the bulk spectrum. It has to be stressed here that no significant change is observed in the top fluctuation frequency spectrum. Thus, this experiment suggests that an additional turbulence appears at the bottom of the plasma because of the limiter introduction.

3.3. Edge and core fluctuations

Performing the specific analysis [8] on the bottom fluctuation frequency spectra, both core ($r_s > r > a/2$) and edge ($r > r_s$) fluctuation levels δn_e^2 are determined (figure 3). When the limiter distance to the LCFS is equal to 3 cm, an excess of edge fluctuations clearly appears. When the limiter reaches the LCFS ($r_{lim} = r_{LCFS}$), an increase of the core fluctuations occurs, showing that the asymmetry develops primarily in the scrape-off layer and spreads into the core. This stresses that the edge fluctuations due to the limiter influences the core fluctuations.

3.4. Characterization of the observed asymmetry

Several features characterize the asymmetry. Previous analyses showed that it increases with the edge safety factor , and that the wavenumber spectra are not the same at the top and the bottom of the plasma, with power laws being respectively $k^{-4.7}$ and $k^{-2.9}$ [4]. These features suggest that the fluctuations generated by the lower limiter are charaterized by short correlation lengths along the magnetic field lines, and the connection lengths play some role.
We interest now to the relation between the asymmetry and the plasma current direction, wich is important to discriminate between different theories. Indeed, among the various possible theoretical models, only the rippling [9] and Kelvin-Helmholtz [10] instabilities are sensitive to the plasma current direction. When the plasma current direction is reversed, more turbulence is observed at the top than at the bottom of the plasma, so the up-down asymmetry inverts with the plasma current direction (figure 4) as observed in TEXT [1]. However the level of asymmetry is weaker in this case and does not depend on the value of the edge safety factor, in contrast with the case where the plasma current and toroidal field are oriented in the same direction [4].

4. Conclusions

Introducing a lower limiter into the TORE SUPRA scrape-off layer, close to the measurement chord, has a dramatic effect. A new spectral pattern with large amplitude appears in the frequency spectrum, at high positive frequency. This induces a strong up-down asymmetry of density fluctuations, with a maximum of turbulence at the bottom of the plasma. The asymmetry is observed primarily in the plasma edge, then spreads in the core when the limiter reaches the LCFS. Several features characterize the asymmetry. It increases with the edge safety factor, reverses with the plasma current direction, and the wavevector spectra are not the same at the top and the bottom of the plasma. These observations stress that a limiter can induce locally an additional turbulence with small correlation length along the magnetic field lines. This asymmetric edge turbulence affects the core turbulence, and therefore likely the core confinement.

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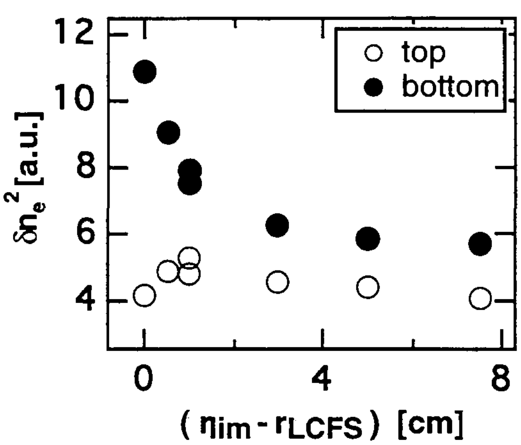

Figure 1. Top and bottom squared density fluctuation level δn_e^2 versus the lower modular limiter distance to the LCFS.

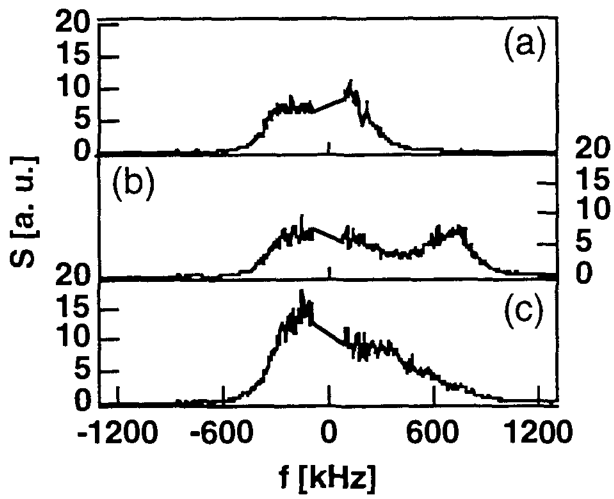

Figure 2. Frequency spectra measured at the bottom of the plasma, for distinct lower limiter positions: (a) $r_{lim} - r_{LCFS} = 7$ *cm, (b)* $r_{lim} - r_{LCFS} = 1$ *cm, and (c)* $r_{lim} = r_{LCFS}$.

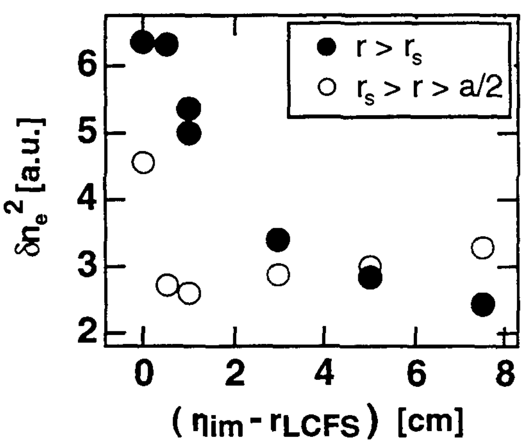

Figure 3. Core ($r_s > r > a/2$*) and edge (*$r > r_s$*) squared density fluctuation level* δn_e^2 *at the bottom of the plasma, versus the lower limiter distance to the LCFS.*

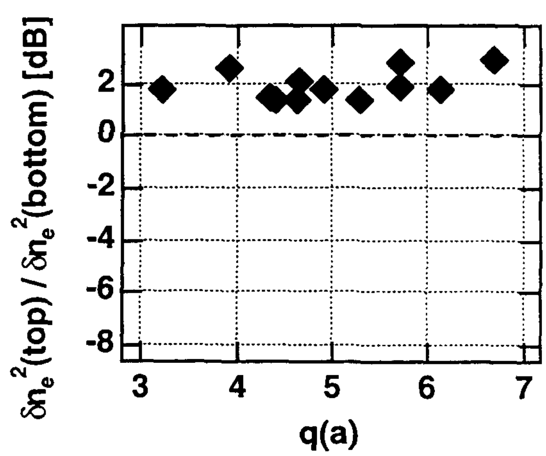

Figure 4. Up-down asymmetry for reversed plasma current versus the edge safety factor q(a), with plasmas leaning on the lower limiter located close to the measurement chord.