Velocity shear layer formation and turbulence characteristics measured by reflectometry in TJ-II

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Introduction

Reflectometry measurements carried out in TJ-II plasmas show an inversion in the perpendicular rotation velocity of the turbulence from positive to negative (from ion to electron diamagnetic direction) when the plasma collisionality exceeds some critical value [1, 2]. HIBP measurements indicate that the inversion in the perpendicular rotation velocity of the turbulence is dominated by the inversion in the radial electric field [3]. A second reflectometer channel working in the same frequency band enables the measurement of the radial correlation properties of the turbulence. Changes in the correlation characteristics associated with changes in the rotation velocity of the turbulence are discussed.

Experimental arrangement

The reflectometer installed at TJ-II is a two channel fast frequency hopping system [4] working in X-mode in the frequency range from 33 to 50 GHz, covering densities from about 0.3 to 1.5×10^{19} m^{-3}. The reflectometer uses standard antennas not perfectly aligned to the cut-off surfaces resulting in Doppler shifted asymmetric spectra [1]. In the actual arrangement both channels share the waveguides and antennas allowing for radial correlation measurements of the plasma turbulence. The frequencies of the channels can be programmed independently: one channel can be kept constant while the other one is swept in steps. Typically, eight frequency steps with a frequency separation of $\delta f = 0.2$ GHz and a time duration of 4-5 ms per step, provide suitable conditions to evaluate the spectral coherence and correlation lengths.

Experimental results

The experimental results have been obtained in plasmas created and heated by ECH (two gyrotrons, each one with a power of up to 300 kW). Figure 1 shows the line-averaged plasma densities (figure 1.a) and the density profiles measured by Thomson scattering (figure 1.b) in two discharges heated with ECH at 400 kW. Also in figure 1.a and 1.b the time sequence of the reflectometer probing frequencies and the corresponding cut-off densities are displayed. The direction of the rotation velocity of the turbulence, as

determined by the asymmetry in the complex amplitude spectra of the reflectometer signals, is positive in the low plasma density discharge (0.55×10^{19} m^{-3}) and negative in the high density one (0.65×10^{19} m^{-3}). The correlation length (L_c) is calculated as the radial separation between the reflectometer cut-off frequencies at which the mean coherence drops to 1/e. As it is shown in figure 2.a, the correlation length increases as more internal radial positions are probed and is shorter for the low-density plasma; the comparison with the local values of the density gradient scale length is shown in figure 2.b.
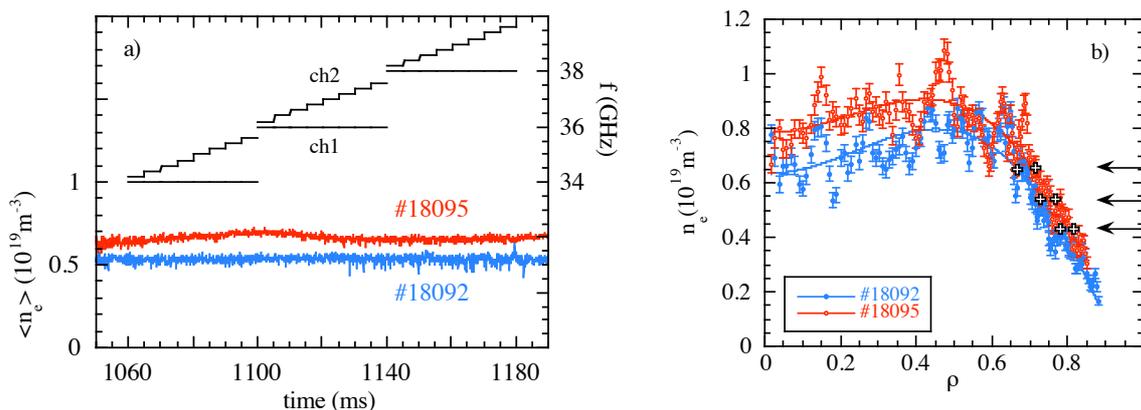

Figure 1: (a) Time evolution of line-averaged density in discharges #18092 and #18095 (blue and red traces, respectively) and probing frequencies of channel 1 and channel 2. (b) Density profiles measured by Thomson scattering; cut-off densities are marked as crosses in the profiles.
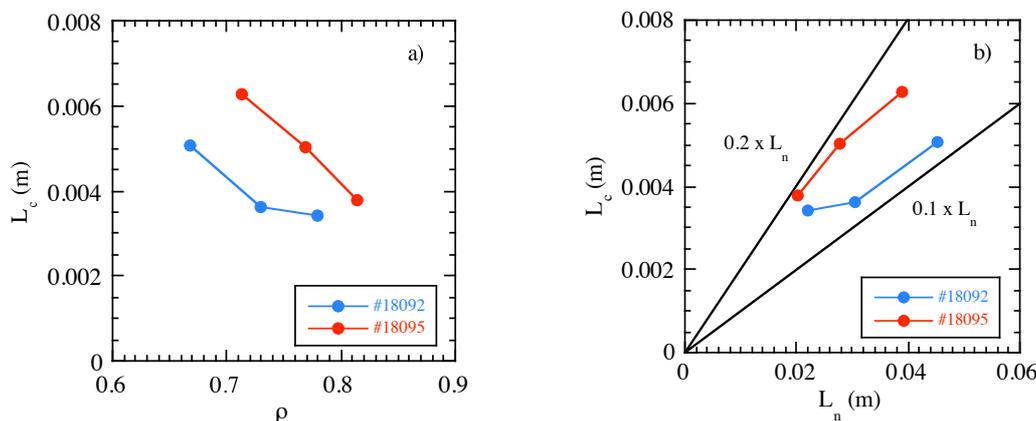

Figure 2: Correlation length at different radial positions (a) and comparison with the local density gradient scale length.

As it has been already mentioned, the correlation lengths are obtained from the decay of the mean coherence, which is calculated weighting the spectral coherence with the power spectrum in the whole frequency range. However, it can be also evaluated for different spectral intervals, providing the correlation length for the different frequencies. Figure 3

shows the frequency dependence of the correlation length $L_c(\omega)$ for the same discharges and for the three probing frequencies.
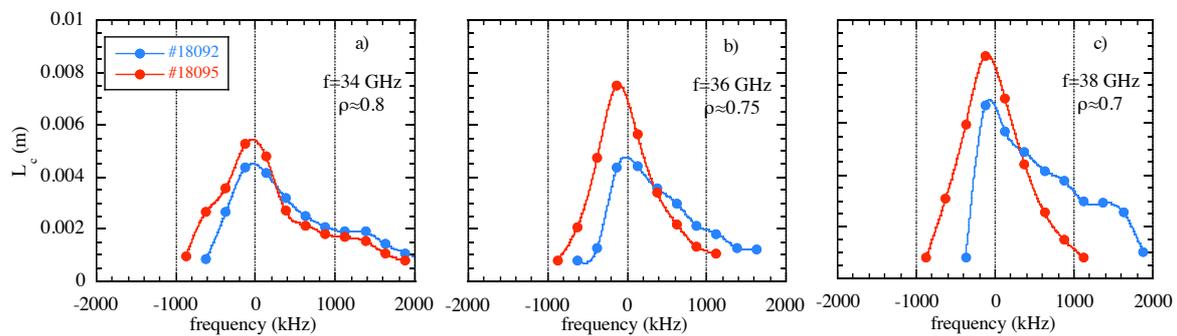

Figure 3: Correlation length for different spectral frequencies and at different radial positions (a-c).

The correlation length reflects the asymmetry of the power spectra, and, as it is expected, the longer correlation lengths appear at the lower frequencies. Furthermore, significant spectral coherence is found at very high frequencies (between 1 and 2 MHz), being more pronounced at the inner radial position ($\rho\approx0.7$). Similar behaviour is found in discharges with the same plasma density but heated with different ECH power levels. An increase in the ECH power produces a decrease in the collisionality and consequently, the perpendicular rotation velocity can change from negative to positive. Two discharges are selected, both with 0.65×10^{19} m^{-3}, and with nominal ECH power of 415 kW (negative perpendicular rotation velocity) and 470 kW (positive velocity). The correlation length for different spectral frequencies and the power spectrum for the two discharges are shown in figure 4.
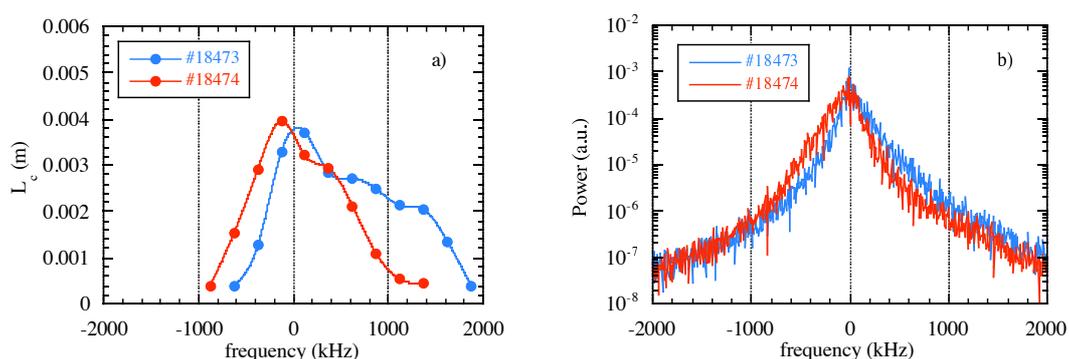

Figure 4: Correlation length for different spectral frequencies (a), and power spectra (b) in two discharges, both with density 0.65×10^{19} m^{-3} and with different ECH power: 415 kW (#18474, red) and 470 kW (#18473, blue).

The same behaviour is observed: while the asymmetry in the correlation length reflects that of the power spectrum in both discharges, significant correlation is found at very high

frequencies in the discharge with collisionality below the critical one. These two discharges are part of an ECH power scan experiment performed at constant plasma density. In this experiment, as the plasma is heated with higher ECH power (up to 600 kW), the correlation lengths at high turbulence frequencies further increases (see figure 5).
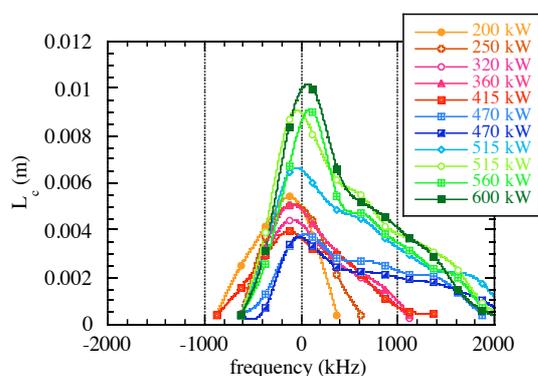

Figure 5: Correlation length in discharges with density 0.65×10^{19} m^{-3} and with different ECH power (it includes the discharges with 415 and 470 kW, shown in figure 4).
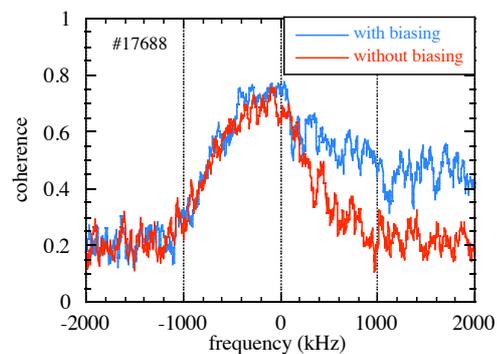

Figure 6: Spectral coherence in a discharge with density 1×10^{19} m^{-3} and with P_{ECH}=400 kW, before (red) and during (blue) edge plasma biasing.

Changes in the radial electric field at the plasma edge have been also induced by means of electrode biasing [5]. An example is shown in figure 6: a positive bias voltage is applied at the plasma edge of a discharge with line density 1×10^{19} m^{-3} and heated with P_{ECH}=400 kW. In this discharge, the radial electric field is negative in the plasma edge region (the collisionality is above the critical one) but becomes positive as the bias voltage is applied. For this experiment the frequencies of the two reflectometer channels were held fixed preventing radial correlation length measurements; however, the probing frequencies are close enough to measure high coherence. Once more, significant coherence is measured at high frequencies associated with a positive radial electric field.

In summary, significant correlation lengths have been measured at very high turbulence frequencies, associated with positive perpendicular rotation velocities, i.e. positive radial electric fields.

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