Impact of collisionality on fluctuation characteristics of micro-turbulence on Tore Supra

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In the present paper, we investigate the effect of the normalized collisionality on fluctuation characteristics of micro-turbulence during dedicated ν^* scan experiments in which only ν^* is varied while the other dimensionless parameters such as ρ^*, β and the plasma shape are kept constant. These kind of experiments constitute an excellent framework for comparisons between observed characteristics of micro-turbulence and the results from simple theoretical predictions and gyrokinetic simulations. Measurements of density fluctuations are performed using Doppler backscattering system [1], which allows us to access different spatial scales of density fluctuations and then to extract the perpendicular wavenumber spectrum. In addition, this technique also gives detailed information about the dynamics of density fluctuations and the dispersion relation of micro-turbulence by resolving the representation of the perpendicular velocity as a function of the wavenumber.

A. Shape of the wavenumber spectrum

The wavenumber spectrum observed in typical Ion Cyclotron Resonnace Heated L-mode plasma performed on Tore Supra is composed of two regions : at the smaller wavenumbers ($k\rho_s < 0.7$), a region of energy injection from the main instability/instabilities in which the spectrum is rather flat and/or decreases slowly, and at larger wavenumbers ($k\rho_s > 0.7$), a region of energy transfer in which the spectrum decreases in a regular power-law-like fashion [2]. In the range of small k , the shape of the spectrum is well represented by a Gaussian function. The justification of the Gaussian function comes from the shape of the linear growth rate of the main instabilities. The quasi-linear approach, which involves balancing the linear growth with a quasi-linear transfer rate, gives a spectrum in the linearly driven region and explains roughly the shape of the spectrum near the region of the drive ($k_\perp\rho_s \lesssim 0.5$). At larger k, the form can be described by the simple form $k^{-3}/\left(1+k^2\right)^2$(from a solution of a disperate scale interaction cascade model [3, 4]) suggesting that the interactions between large scale flow structures and fluctuations may play an important role in determining the wavenumber spectrum shape in this energy transfer region.

B. Impact of ν^* on the shape of the wavenumber spectrum

The shape of the perpendicular wavenumber spectrum has been studied during the dedicated ν^* scan experiments, in which the entire radial profile of collisionality has been varied by more than a factor of 4 [5].

In order to quantify the effect of the collisionality on the wavenumber spectrum shape we use a fitting processes. The best agreements occur when treating the two wavenumber ranges $k\rho_s < 0.7$ and $k\rho_s > 0.7$ of the spectrum separately using Gaussian $A_2e^{-\xi k^2}$ function for the low k region and a generalized expression of the spectral model for drift waves for higher k region derived in Ref. [3] :

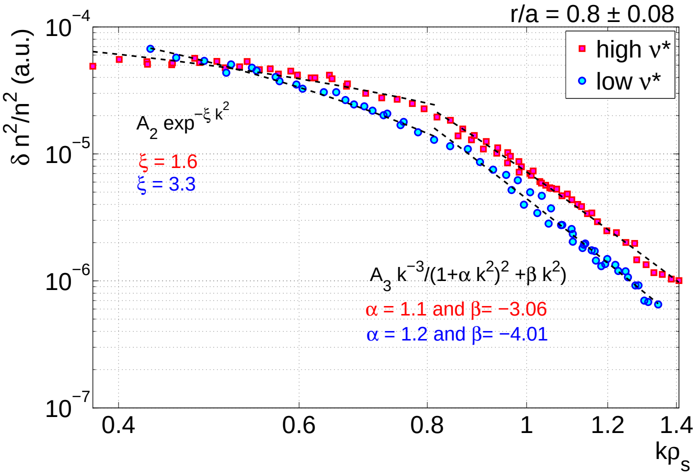

Figure 1: Fitting of the wavenumber spectra using Gaussian function and a generalized expression of the spectral model for drift waves considering respectively the wavenumber range $k\rho_s < 0.7$ and $k\rho_s > 0.7$ for both high and low ν^* discharges

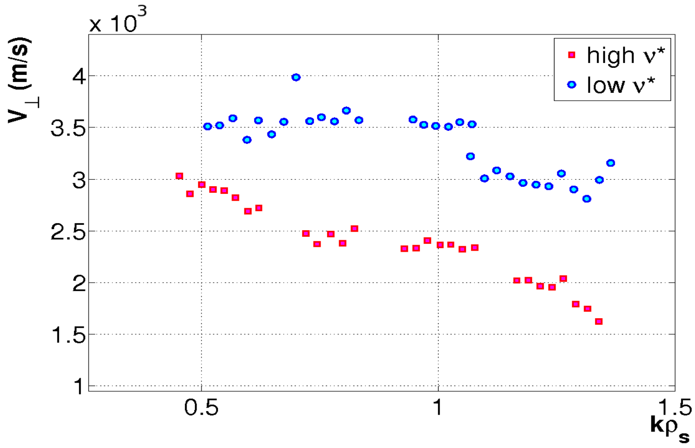

Figure 2: Evolution of the mean perpendicular velocity of density fluctuations (in electron diamagnetic direction) versus the normalized perpendicular wavenumber at $r/a = 0.8 \pm 0.025$

$$A_3 \frac{k^{-3}}{(1+\alpha k^2)^2 + \beta k^2} \tag{1}$$

The results from the fitting processes for both low and high collisionality cases are presented in figure 1. For the smaller wavenumber range ($k\rho_s < 0.7$), the spectrum is well described, for both cases, by Gaussian . and is affected by thechange of the value of ν^* in such a way that decreasing ν^* the spectrum decreases faster. This effect can be quantified by comparing the fitting parameters of the Gaussian function ξ : for the low ν^* discharge $\xi = 3.3$ while for the low $\nu*$ discharge $\xi = 1.6$. In the higher wavenumber range, the spectrum is well fitted using the generalized form of the spectral shell model (eq. 1) and is almost not affected by the variation of ν^*. Comparing the parameters from shell model expression, $\alpha = 1.1$ and $\beta = -3.6$ for the high ν^* case while $\alpha = 1.2$ and $\beta = -4$ for the low ν^* case.

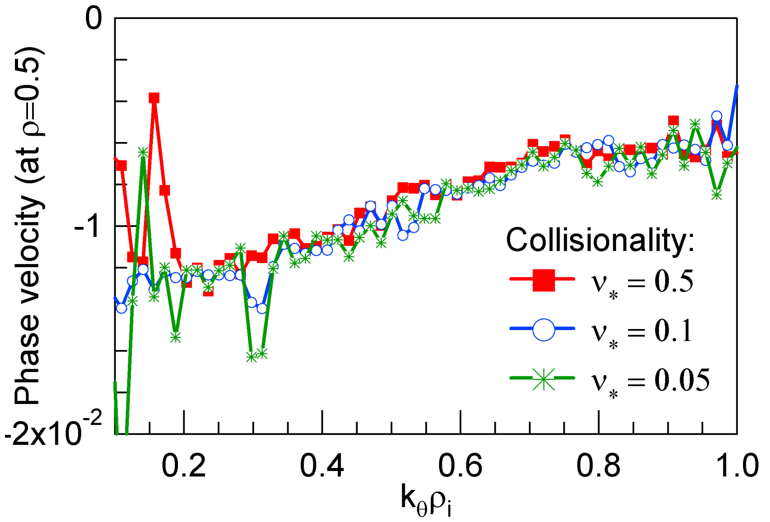

Figure 3: Phase velocity normalized to the thermal velocity in the case of pure ITG regime for different values of collisionality obtained from GYSELA code. Here negative sign corresponds to ion direction.

C. Evolution of the dispersion relation

The Doppler shift of the spectral density power $S_{k,r}(f)$ gives the perpendicular velocity of density fluctuations in the laboratory frame : $V_\perp = v_{E\times B\perp} + v_{fluc}$, where $v_{E\times B\perp} = -E_r/B$ (E_r being the radial electric field) and v_{fluc} is the mean phase velocity of the density fluctuations. The perpendicular wavenumber $k_\perp$ dependence of the measured Doppler velocity $V_\perp$, for the both dischargesare shown in figure 2. A clear difference in $V_\perp(k_\perp)$ is observed between both discharges : for the high ν^* discharge, $V_\perp$ decreases with increasing $k_\perp$ while $V_\perp(k_\perp)$ remains rather flat in the case of the low ν^* discharge [5].

In the case of the high ν^* discharge, the linear stability gives ion direction mode (probably ITG modes) as the most instable mode in the range of $k\rho_s = [0.05 - 0.8]$ while from $k\rho_s = 0.8$ the most unstable mode is in electron direction (probably TEM modes and ETG at higher k). During the low $\nu*$ discharge, the stability picture is more complex and the appearance of hybrid modes (a mixed mode with a frequency changing from electron direction to ion directions) is observed. In the case of pure ITG regime, the effect of collisionality on the phase velocity has been studied using GYSELA simulations extracted from [5]. No impact of changing collisionality is observed on the phase velocity suggesting that the observed modification of the perpendicular velocity as a function of the perpendicular wavenumber (figure 2) is due to the presence of electron modes.

Non-linear simulations including electron dynamic have been performed using the GENE code[6]. Simulations discussed in the following are performed in the local approximation (i.e., gyroradius small compared to machine size), considering MHD equilibria provided from EFIT and local gradient lengths (temperature and density) and collisionality from the experiments. However, equilibrium $E\times B$ shear flows are not taken into account here and could potentially lower the low k growth rates and other spectral features. In order to compare results from non-linear simulations with the experimental observations (figure2), the phase velocity, deduced from the first moment of the electrostatic potetiel frequency spectrum, is considered for each wavenumber and presented in figure 4. In the high ν^* plasma, the dominant mode in the wavenumber range $k\rho_s = [0.5 - 1.5]$ is in ion direction while the succesive changes of the phase velocity sign observed in figure 4seem indicate that the turbulence regime during the low ν^* discharge is a mix of ion and electron modes. These results, in fair agreement with the observations, suggest that the experimental change in the dispersion relation is due to a modification of the turbulence regime from a dominant ITG regime at high collisionality to a mixed regime in which ITG and electron modes (such as TEM) are present. However, several disagreements must be highlighted from these results. First of all, the value of the phase velocities (or its variation over

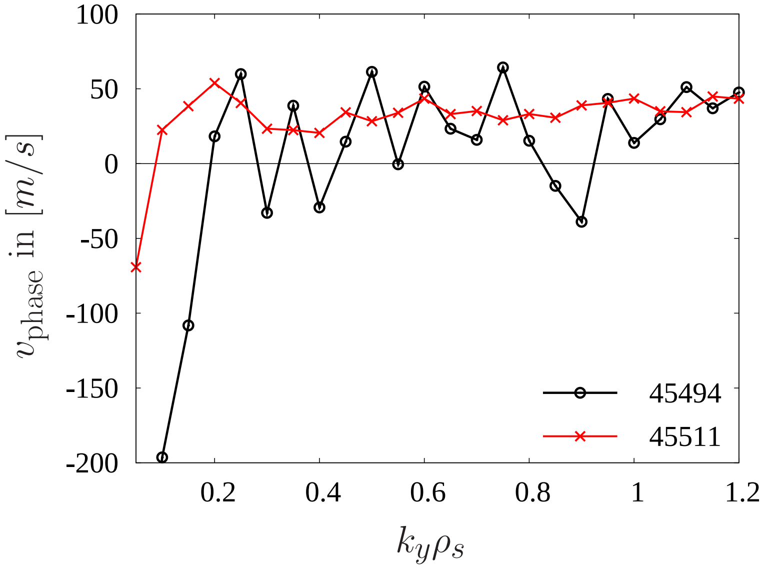

Figure 4: Phase velocities extracted from the first moment of the non-linear frequency spectra of the electrostatic potentiel obtained using the GENE code for both low (#45494) and high (#45511) ν^* discharges. Here positive and negative signs correspond respectively to ion and electron direction.

the entire k range) obtained from gyrokinetic simulations are by a factor 10-20 smaller as compared to the variation of $V_\perp$ as a function of k experimentally measured . In addition, the evolution of the phase velocity, even in the simpler case, for instance the high collisionality case, is not similar to the observation in which a clear increase (in absolute value) is observed. The discrepancies may come from the fact that in these simulations no external $E \times B$ shear is applied. Another possibility is that the existence of strong zonal flow activity (seen in simulations) may influence local measurements of phase velocity by the Doppler method. In general, the development of more elaborate synthetic diagnostics will be investigated. New simulations are planned by adding experimentally measured E_r profile in order to clarify this point and by considering the phase velocity of density fluctuations instead of electrostatic potentiel fluctuations.

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