Turbulence measurements with the Correlation Electron Cyclotron Emission (CECE) diagnostic in TCV

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Introduction

Neoclassical theory severely underestimates heat and particle transport in tokamak plasmas. This is commonly attributed to coupling of multi-field micro fluctuations. A thorough study of these fluctuations becomes then extremely interesting to better comprehend the mechanisms that drive and regulate anomalous transport.

One of the parameters that can influence transport is plasma shaping. Tokamak à Configuration Variable, or TCV (major radius R = 0.88 m, minor radius a = 0.25 m), is the ideal machine to study these effects due to its unparalleled shaping capabilities, versatile heating systems and array of available diagnostics.

It has been found, in particular, that negative triangularity (δ) discharges show improved confinement properties, like halved values of electron heat diffusivity χ_e with respect to positive triangularity plasmas. [1]. Despite δ reducing quickly when moving from the edge inside the plasma, the improvement in χ_e seems to extend well into the minor radius ($\rho_{vol} > 0.4$). One possible explanation is based on the distinction between regions of different stiffness inside the plasma. A region around the plasma mid-radius (tipically $0.5 < \rho_{vol} < 0.8$), where the T_e and n_e scale lengths are generally insensitive to various plasma parameters, including edge triangularity, is considered stiff. Outside that a non- stiff region is identified, characterized by constant gradients that change for different plasma conditions. In this paper the same definition of stiffness used in [5] is considered. Thus, when comparing the temperature of discharges with comparable density and the same heating power, with positive and negative δ, it is found that the T_e ratio at $\rho_{vol} = 0.8$ remains constant over the whole stiff region, leading to an increased core temperature of negative triangularity discharges. This provides a possible explanation of how a triangularity, rapidly decreasing in the plasma core, can influence confinement properties over a large fraction of the plasma radius.

Previous fluctuations studies

It has been suggested that one of the possible causes of the observed improved confinement in $\delta < 0$ discharges could be a change in the fluctuations characteristics with triangularity. This possibility has been investigated both with numerical simulations and experimentas.
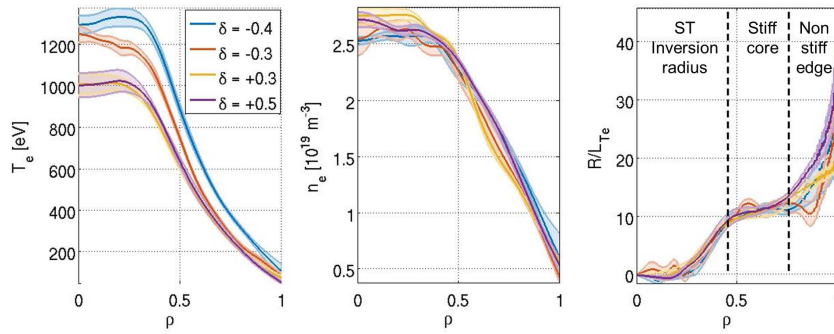
Figure 1: Profiles of the model discharges for the four different shapes. (a) Electron Temperature. (b) Electron density. (c) Normalized temperature scale length

Local, non-linear gyrokinetic simulations with the GENE code have confirmed that the dominant instabilities are TEM in all cases [3]. A different level of stiffness for different radial positions (decreasing closer to the plasma edge) is found, in agreement with [5]. Higher critical gradients for $\delta < 0$ with respect to $\delta > 0$ discharges are predicted.

On the experimental side, discharges with positive and negative triangularity with comparable density profiles and the same heating power have been studied with the aid of the Tangential Phase Contrast Imaging (TPCI) diagnostic, able to measure density fluctuations with wavenumbers $1.1 < k < 9.4 cm^{-1}$, over a wide fraction of the plasma profile. The measurements show a strong suppression of the fluctuations, in the $\delta < 0$ cases, for $0.45 < \rho_{vol} < 0.95$ [2].

Triangularity effects on temperature fluctuations

In 2016, new experiments were performed in which fluctuations diagnostics, in particular the Correlation Electron Cyclotron Emission (CECE), were available. The CECE system of TCV has recently been upgraded with a new Intermediate Frequency (IF) section containing six frequency tunable YIG filters. This, combined with a steerable line of sight and the flexibility of TCV, allowed the measurement of small ($< 1\%$) electron temperature fluctuations, with poloidal $k_\theta < 1.12 cm^{-1}$, over a large fraction of the plasma cross-section.

The effects of triangularity on relative fluctuations amplitude were studied in ohmic discharges with $I_p = 225 kA$, comparable density profiles with line averaged density of $2 * 10^{19} \ m^{-3}$, and $\delta = +0.5, +0.3, -0.3, -0.4$. The electron temperature was left free to evolve, resulting in higher values over the whole profile for the $\delta < 0$ cases. The measured profiles are shown in figure 1. The ratio between T_e in the $\delta = +0.5$ and $\delta = -0.4$ discharges is shown in figure 2 (a). From that and the temperature logarithmic gradient profile in figure 1 it is easy to distinguish a central, flat, zone that corresponds to the stiff region defined in [5]. In this study we will focus on measurements taken outside this stiff region ($\rho_{vol} > 0.75$), where we expect most of the δ

effects, and inside it ($0.45 < \rho_{vol} < 0.75$), where the plasma should become insensitive to edge conditions. They are represented with different colours in figure 2.

After the development of a target for the four different shapes, each of them was repeated, with different frequency settings for the CECE channels, obtaining measurements from plasma volumes covering the region $0.3 < \rho_{vol} < 0.95$ and $0.3 < \rho_{vol} < 0.85$ for the positive and negative triangularity discharges, respectively. The position of the emission volume for each channel is calculated via ray tracing, using the TORAY code. Correlation is calculated for all adjacent channels over a 500 ms window, which corresponds to a minimum detectable fluctuation $\delta T_e/T_e \sim 0.22\%$.

Figure 2: (a) T_e ratio between $\delta < 0$ and $\delta > 0$ plasmas. (b) Radial profiles of $\delta T_r ad / T_r ad$ for different δ. The same data are plotted against R/L_{T_e} (c) and R/L_{n_e} (d).

The profiles of relative temperature fluctuations, $\delta T_e/T_e$, shown in in figure 2(b), clearly show a strong suppression of the fluctuations in the $\delta < 0$ case, especially close to the edge. At $\rho_{vol} \sim 0.8$ the fluctuation level in the $\delta = -0.4$ case is less than one third of that in the $\delta = 0.5$ case. For radial positions closer to the plasma core the difference quickly decreases. However, also in this case, as it has been observed for density fluctuations, the $\delta > 0$ discharges exhibit higher relative fluctuations amplitude down to $\rho_{vol} = 0.55$, where plasma triangularity has already decreased to less than $\sim 40\%$ the edge value. The dependence of the relative fluctuations on the normalized density and temperature scale lengths, $R/L_{T_e} = R/\nabla log(T_e)$ and R/L_{n_e}, has also been studied, as shown in figure 2 (c) and (d). It is found that, for positive triangularity discharges, a critical gradient for both temperature and density can be defined for $\delta T_{rad}/T_{rad}$. From this series of discharges it looks as if the negative triangularity discharges do have a higher critical gradients with respect to the positive triangularity ones, in agreement with the results of the gyrokinetic simulations [3]. Usually critical gradients are defined as the local values of gradients after which further increase corresponds with a growth of the local heat flux (stiff profiles). In this case, instead, they refer to the onset of fluctuations, and they are evaluated from the whole set of measurements.
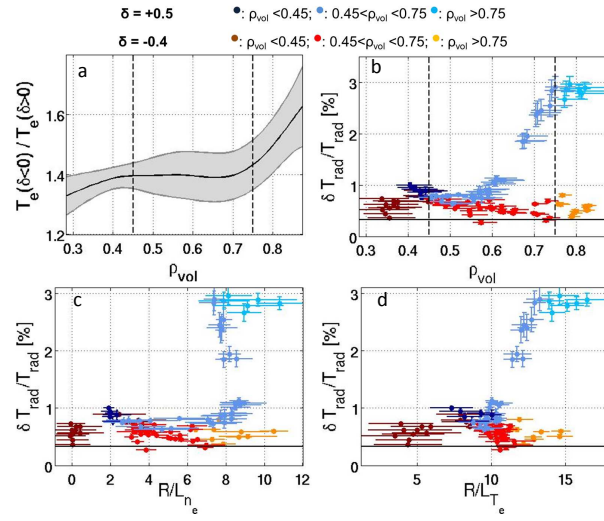
Cross-correlation analysis between the different CECE channels provides the means to estimate the radial correlation length of the observed fluctuating structures, defined as the $1/e$ folding length for the correlation coefficient ρ at time delay $\tau = 0$ calculated for a set of couples of channels with different radial separation. As shown in figure 3, larger structures are observed for $\delta > 0$ compared to $\delta < 0$ plasmas. Smaller correlation lengths are associated with better confinement [4]. Possible explanations include higher shear flows disrupting the fluctuating structures reducing their impact on transport.

Figure 3: Correlation coefficient, at time delay $\tau = 0$, for couples of channels at distance Δr, and fits for radial correlation lengths.

Acknowledgments

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[5] O. Sauter, S. Brunner, D. Kim, G. Merlo, R. Behn, Y. Camenen, S. Coda, B. P. Duval, L. Federspiel, T. P. Goodman, A. Karpushov, A. Merle, and Tcv Team. On the non-stiffness of edge transport in L-mode to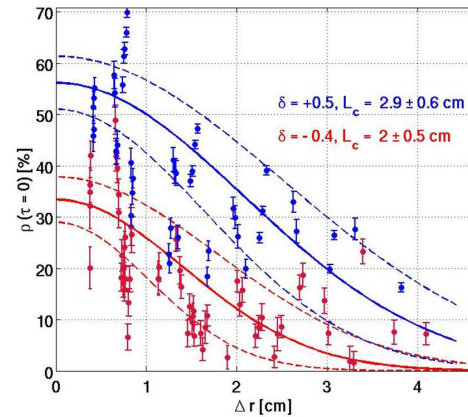kamak plasmas. *Physics of Plasmas*, 21(5):055906, May 2014.