Poloidal asymmetry and dynamics of perpendicular flow in Tore Supra plasmas

L. Vermare, P. Hennequin, Ö. D. Gürcan, C. Honoré, P. Morel, A. Storelli
Ecole Polytechnique, LPP, CNRS UMR 7648,91128 Palaiseau, France

P. Donnel, X. Garbet, J. C Giacalone, and the Tore Supra Team
CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France

The mechanism at the origin of the poloidal asymmetry observed in the perpendicular flow measured in the Tore Supra plasmas is investigated. For a wide range of plasma conditions, the perpendicular velocity, measured using Doppler backscattering technique in the core of limited L-mode plasmas is larger in the equatorial plane at the low field side ($\theta \sim 0°$) than in the vertical one at the top of the plasma ($\theta \sim 90°$). Among the possible explanations of such poloidal asymmetry, the generation of convective cells by the ballooned structure of the underlying turbulence has been proposed. In this present paper, experimental evidence of such convective cells is investigated through the dynamics of the measured perpendicular velocity.

A. Context

While turbulent transport is partly responsible for reducing tokamak performances, large scale flows radially inhomogeneous are known to play a key role in reducing the turbulent transport by shearing the turbulent structures. Vortex shearing due to mean flows or time dependent zonal flows that are generated by turbulence, is commonly invoked as one of the key aspects of the formation of transport barriers [1]. However, what determines (i.e. sets up and sustains) large scale flows and their gradient is not fully elucidated. In a standard view, the neoclassical theory predicts that non ambipolar fluxes generate a radial electric field in order that the resulting charge transport stays ambipolar [2, 3]. As a result, the mean equilibrium flow is expected to be mainly symmetric in both poloidal and toroidal direction. In addition, turbulence is known to generate zonal flows, which are by definition also symmetric. This would imply that the mean perpendicular flows are poloidally symmetric in the confined region of the plasma. However, the radial profiles of the mean perpendicular velocity of density fluctuations measured in Tore Supra plasmas exhibit a robust and large poloidal asymmetry. Among several possible explanations, the turbulent generation of large scale flows similar to zonal flows but poloidally asymmetric has been studied. Generation of asymmetrical flows from the tilting of turbulent structures by magnetic and mean flow shears, combined with turbulence ballooning is considered. In this case, a balance of the turbulent Reynolds stress with Landau damping leads to a poloidal velocity that is proportional to the local intensity of turbulence (radially and poloidally) and therefore stronger in the equatorial plane. For ITG turbulence, the velocity that is generated is found to be in the electron diamagnetic direction and to decrease from the equatorial plane towards the top of the device. The order of magnitude is in agreement with the observation, which is an indication that this mechanism may be a plausible explanation of the observations [4]. Recent improvement of the theoretical derivation (rigorous derivation of the gyrokinetic equation coupled to the Poisson equation retaining only the passing particles contribution), confirms the generation of *poloidal convective cells* in addition to zonal flow at low frequency and GAMs at higher frequency [5]. These convective cells are found to have a $m = 1$ structure with an in-out phase (i.e. with maxima close to the the equatorial plane). In the light of to these results, the existence of these "poloidal convective cells" and the link between them and the observed poloidal asymmetry of the mean flow is investigated experimentally.

B. Experimental set-up and observation of a poloidal asymmetry of the perpendicular flows

The poloidal asymmetry of the mean perpendicular flow has been observed comparing the radial profile of the mean perpendicular velocity of density fluctuations at two poloidal locations. This study has been performed for a wide range of L-mode plasma parameters using two independent Doppler Backscattering (DBS) diagnostics simultaneously, one at the low field side (LFS), the other at the top of the machine. Doppler backscattering (DBS) is a diagnostic technique, which can be used to probe density fluctuations at given scales. The measured frequency spectra are Doppler shifted due to the motion of density fluctuations perpendicular to the field lines, in the $\hat{\mathbf{b}} \times \hat{\mathbf{r}}$ direction [6]. This shift of the peak of the spectrum provides the mean Doppler shift frequency $\omega_{DBS} = \mathbf{k}_{sc}\mathbf{v}_{\perp}$ at a given radial location (an area of a few centimeters width) and at a given wavenumber, where $\mathbf{v}_{\perp} = \mathbf{v}_{\mathbf{E}\times\mathbf{B}} + \mathbf{v}_{ph}$ is the perpendicular velocity of density fluctuations in laboratory frame, mainly due to the $E \times B$ drift velocity, written as : $\mathbf{v}_{\mathbf{E}\times\mathbf{B}} = \frac{\mathbf{E}\times\mathbf{B}}{B^2}$ plus fluctuation phase velocity $\mathbf{v}_{ph}$. Depending of the data analysis applied, this system gives access to the mean perpendicular velocity corresponding to the motion of density fluctuations integrated over typically few ms or to an *instantaneous* velocity corresponding to a short time integration (around $6.4\mu s$). The comparison of the radial profiles of the *mean* perpendicular velocity of density fluctuations at different poloidal locations ($\theta \backsim 0°$ and $\theta \backsim 90°$) exhibits a clear poloidal asymmetry such as density fluctuations move faster in the equatorial plane (in this case by a factor 3) than in the vertical plane, in the region $0.7 \leq \rho \leq 0.95$ (see for example figure 1, in which the equatorial velocity is about 3 time larger than the top one). Note that this asymmetry, which is systematically observed in all discharges in which data from top measurements are available, remains in most of the plasma conditions even applying corrections related to the $B \propto \frac{1}{R}$ dependence and related to the effect of Shafranov shift. The only case for which this "equilibrium asymmetry" correction may explain the asymmetry is an Ohmic discharge where the asymmetry is about 50% while the correction is about 33%.

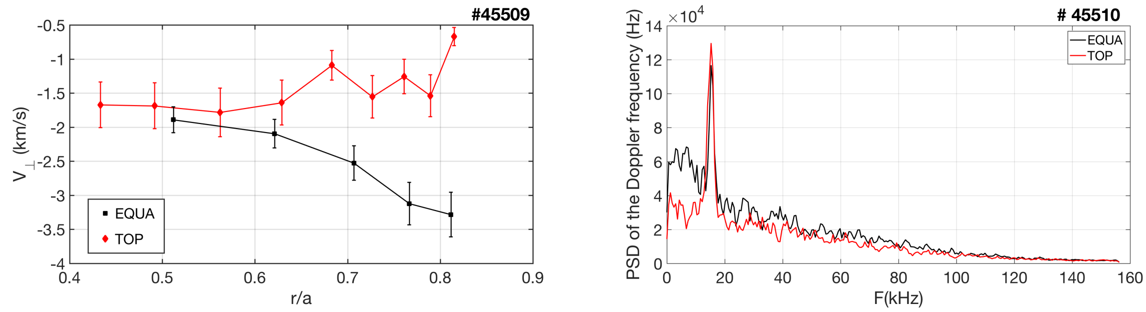

Figure 1: Illustration of a strong poloidal asymmetry and higher level of low frequency flow in the equatorial plane. Left figure : radial profiles of the mean perpendicular velocity of density fluctuations measured using DBS at the two poloidal locations (top plane and equatorial plane) and right figure : frequency spectra of the "instantaneous" Doppler frequency (i.e. perpendicular velocity of density fluctuations) for the same both locations

C. Dynamics of the perpendicular flow

As mentioned above, the asymmy(figure1) is observed for the mean perpendicular velocity obtained from the DBS frequency spectra averaged over typically few ms. In order to access to the temporal evolution of the flow velocity, or in other words, the instantaneous velocity, several data analysis techniques can be used. In the context of Geodesic Acoustic Modes (GAMs) studies [7], the MUltiple SIgnal Classification (MUSIC) algorithm has been compared to more standard techniques (sliding FFT and phase derivative method) and used successfully on DBS data. This algorithm appears as a powerful data analysis method to follow the Doppler frequency (and then the density fluctuations velocity) with a high temporal resolution. Taking advantages of this method, we use this data analysis approach to investigate low frequency flows (with a frequency lower than GAMs) that should be related to the *poloidal convective cells* generated by turbulence. Figure 1 shows the radial profiles of the mean velocity and the frequency spectra of the *instantaneous* velocity for the top and the equatorial locations. Spectrum from both locations exhibits a clear peak around 15kHz, with a similar amplitude, which are associated to GAMs (which has a m=0 structure for the velocity). In addition, at lower frequency (between 1kHz and 15kHz), the flow measured in the equatorial plane appears stronger than the one from the top system. This picture agrees with the theoretical derivation of the convective cells mentionned above [5]. The remarkable point is that this tendency is systematically observed in all discharges in which a poloidal asymmetry of the mean velocity, stronger than the one coming from the equilibrium, is observed. On the contrary, in the Ohmic discharge, in which the poloidal asymmetry is weaker and seems explained by the "equilibrium asymmetry", the frequency spectra are similar for both locations (see Figure 2). These results are in line with expectations from theory about convective cells generated by Reynold stress with an m=1 structure and an in-out asymmetry.

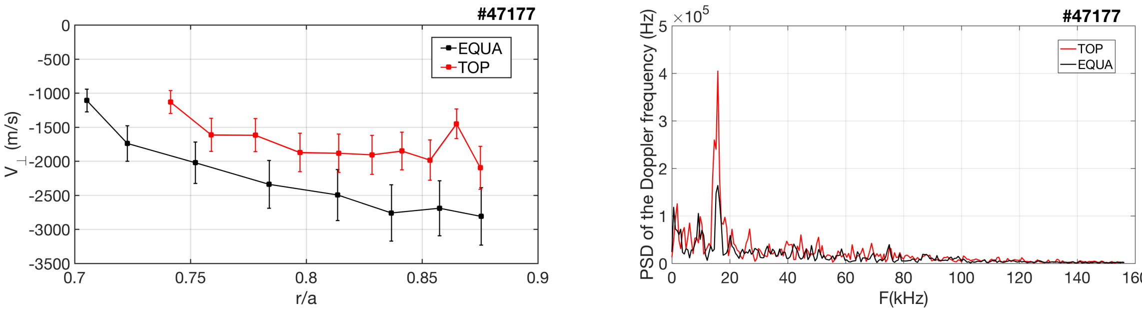

Figure 2: Illustration of a weak poloidal asymmetry possibly explained by equilibrium asymmetry and an equal level of low frequency flow in both top and equatorial plane. Left figure : radial profiles of the mean perpendicular velocity of density fluctuations measured using DBS at the two poloidal locations (top plane and equatorial plane) and right figure : frequency spectra of the "instantaneous" Doppler frequency (perpendicular velocity of density fluctuations) for the same both locations

D. Discussion

The analysis of the dynamics of the perpendicular velocity shows interesting consistency the theoretical prediction that motivates to investigate this possible explanation further. However, the link between these convective cells and the strong poloidal asymmetry of the mean perpendicular flow observed is not rigorously established. The next step will be to quantify, via gyrokinetic simulations, the impact of the convective cells in the mean velocity. In parallel, it should be emphasized that the possible explanations of the mean flow asymmetry, such as the contribution of the phase velocity, the spreading of poloidal flow asymmetries from the far edge towards the plasma core, and the ripple induced neoclassical friction require also deeper investigations.

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