The effect of SOL flows on edge and core radial electric field and rotation in Tore Supra

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Introduction

Plasma flows, parallel to the magnetic field, that can reach plasma sound speed, are known to exist in the Scrape-Off Layer (SOL) region in tokamaks. These flows are commonly observed to be highly asymmetric and their flow direction depend on magnetic configuration whether a limited or a diverted plasma is considered. While several mechanisms may be important in the generation of such asymmetry (large scale drifts, Pfirsch–Schlüter currents, ... etc), the strong ballooning of the radial transport seems to play the dominant role [1, 3]. All these flows are known to impose boundary conditions which can affect the core plasma rotation . In Alcator C-Mod, it was shown that flow momentum can couple across the separatrix inducing co or counter current increment in central plasma rotation of the same sign of the flow in the SOL. The exact underlying mechanisms and their influence on spontaneous rotation are still not completely understood [1, 2]. In particular, the possible link between perpendicular ($E \times B$ drifts) and parallel flows remains an open question.

On Tore Supra, we use a flexible limiter configuration to change the contact points and reverse the SOL flows [3]. In this paper, we focus on the changes observed between configurations with reversed parallel flow (as measured at the top of the device), when the contact point is moved from the top to the bottom of the outboard limiter. To study the effect of SOL flows on core rotation, we have monitored both parallel SOL flows using a Mach probe (in SOL), perpendicular $E \times B$ velocity using Doppler reflectometry (over SOL, edge and core), and toroidal velocity using Charge eXchange Recombination Spectroscopy (from edge to core).

Plasma and boundary conditions

Tore Supra has various limiters to define the Last Closed Flux Surface (LCFS): an axisymmetric Toroidal Pumped Limiter (LPT) at the bottom, an outboard limiter (LPA) plus 3 antennas with their protections on the low field side, as well as 6 pairs of inner bumpers. The magnetic field and the plasma current are oriented clockwise as viewed from the top of the machine. B

was set around 3.6T (adjusted for a good spatial coverage of the edge by reflectometry), and I_p was varied in the range (700<I_p<1100 kA), edge safety factor (3.3 <q_a< 5) in this set of experiments.

The parallel Mach number $M_{\|}(= V_{\|}/c_s)$ is measured using the movable Mach probe located at the top of the machine. The asymmetry of the parallel flow has been extensively studied on Tore Supra [3] by moving the contact point of the plasma poloidally using the different limiters positions. It was shown in particular that the distribution of the parallel flow (especially the location of the stagnation point relative to the position of the limiters) is mainly determined by the strongly ballooning of outboard transport.

The perpendicular velocity is measured from the Doppler reflectometry system [4], which detects the field back-scattered on fluctuations close to the cut-off layer. The probing beam frequency defines the measurement location; the probing beam incidence selects the wave-number (in therange $3 < k_\perp < 25$ cm^{-1}). The 50-75 GHz O-mode channel provides measurements in the core ($.5 < r/a < .9$ depending on density profile), while the 75-110 GHz X mode channel covers SOL and edge, roughly on the equatorial plane. The perpendicular velocity of plasma density fluctuations is obtained from the Doppler shift of the frequency spectrum $\Delta\omega = k_\perp v_\perp$. This velocity is the sum of the fluctuation phase velocity and the $\vec{E} \times \vec{B}$ drift velocity induced by the radial electric field E_r, which is the dominant term in most cases. The radial electric field is usually strongly sheared near the separatrix, pointing outwards in the SOL and becoming negative in the plasma edge. In the core of the Tore Supra, non ambipolar particle flux induced by ripple loss, have been shown to be dominant mechanism that sets the radial electric [6]

The toroidal velocity profile is measured via Charge eXchange Recombination Spectroscopy [5] (from CVI impurity line analysis). In these experiments 11 tangential views cover the plasma from r/a 0.25 to 0.9 in the equatorial plane (2 cm spatial resolution at the plasma edge and 6 cm at the plasma core). The diagnostic neutral beam power is low therefore the momentum input is negligible. The toroidal rotation is usually counter current in Ohmic.

In the series shown here, TS was operated in ohmic with mostly circular plasmas, with the contact point on the low field side, on the top (blue) or the bottom (red) of the outboard limiter (Fig. 1 left). The profile of the Mach number in the SOL is shown on Fig.1 (right panel). The value of $M_{\|} \sim 0.5$ is typical of the configuration with contact point at the bottom: the ballooning of the radial flux displaces the stagnation point from the top roughly to the outer midplane. It corresponds to co-current direction. This asymmetry extends in the far SOL but $M_{\|}$ becomes negative (counter-current) close to the separatrix. When the contact point is moved to the top, the flow is reversed (counter-current) in the whole SOL.

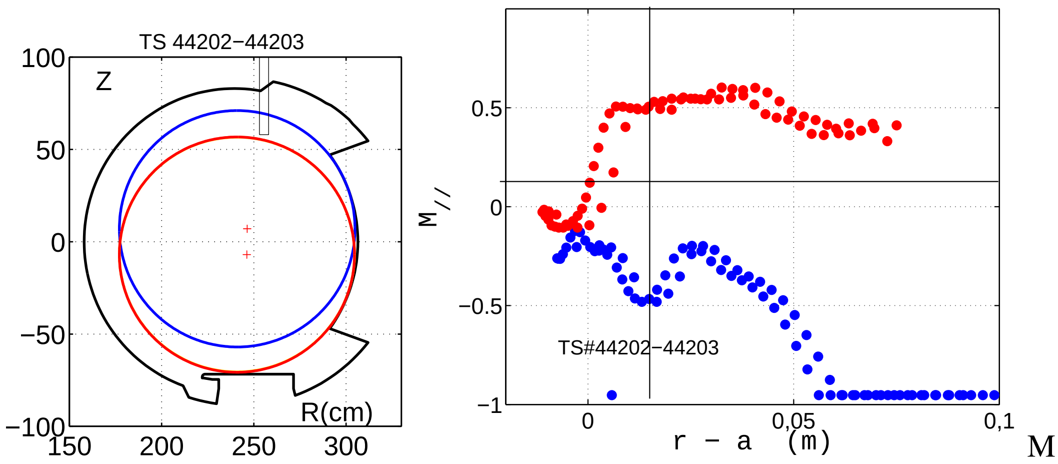


Figure 1: *left: Poloidal cross section showing the contact point at the bottom (red) and at the top (blue) of the outboard limiter. right: Profile of the parallel Mach number* $M_{\parallel}$.

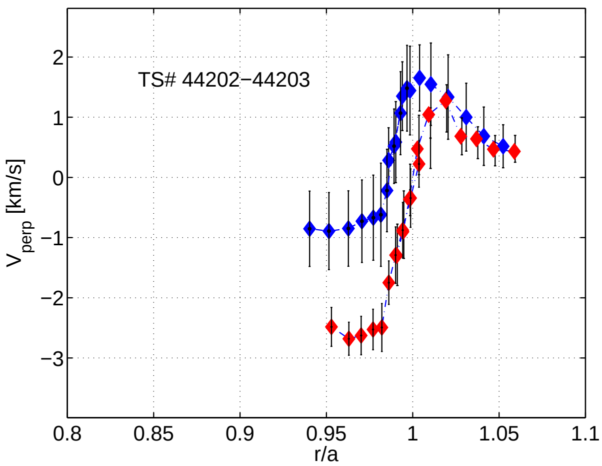
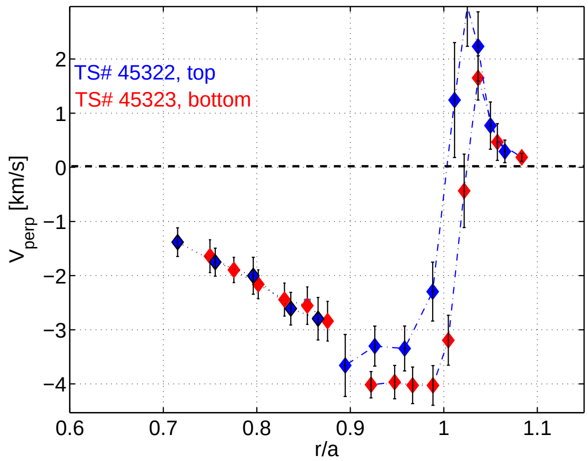


Figure 2: *Perpendicular velocity profile from Doppler reflectometry (top and bottom).*

The perpendicular velocity $V_{\perp}$ ($\equiv E_r/B$) profile is shown in Fig 2. Both the location of the shear layer and the amplitude of the $V_{\perp}$ inversion at the separatrix are modified, affecting the edge perpendicular velocity profile. This suggests a coupling between parallel flows in the SOL and perpendicular flows at the edge.

To investigate the radial extend of the perturbation, measurements were performed in higher density plasmas (around 5 10^{10} m^{-3}) to get a better spatial coverage of the Doppler measurements in the core (O mode). In the case shown in Figure 3, the perpendicular velocity profile is still different at the edge between top and bottom configurations, but this difference is reduced. Note also that the maximum velocities are higher than in the shot of Fig. 1, even though the magnetic configuration is identical. The reason for this difference is still unclear. The core perpendicular velocity profile remains similar for both configurations, up to r/a > 0.8, suggesting that the effect of ripple induced loss is likely to be dominant in the core.

An effect is also visible on the toroidal velocity profile, mostly at the edge (r/a > 0.8): when the contact point is at the bottom, the SOL parallel flow (above equatorial plane) should be co-current, which induces a co-current increment of the toroidal velocity at the edge. When the contact point is moved above the equatorial plane, the far SOL parallel flow is reversed to counter-current direction (though we don't know the exact location of the stagnation point), the toroidal velocity also becomes more counter-current.



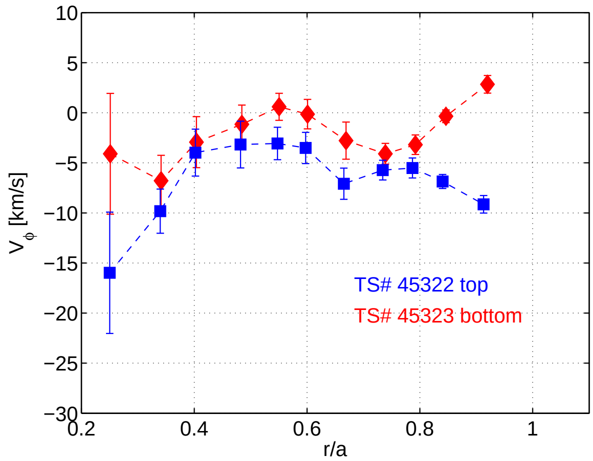


Figure 3: *left: perpendicular velocity profile from Doppler reflectometry (here* $V\perp < 0$ *corresponds to* $E_r < 0$*). right: toroidal velocity profile from CXRS.*

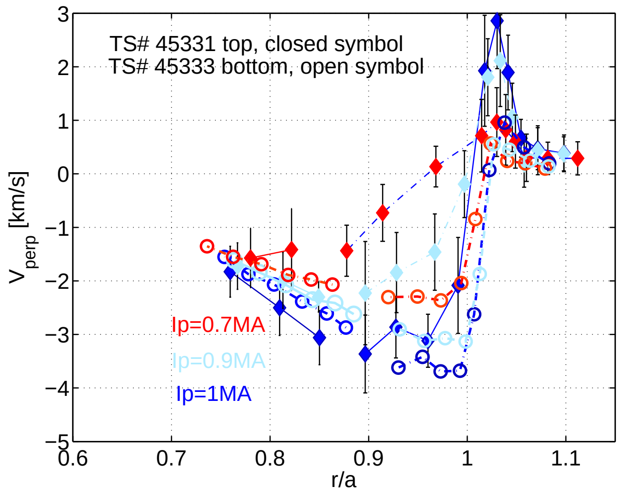


Figure 4: *Perpendicular velocity profiles (top and bottom), at different current values.*

Figure 4 compares perpendicular velocity profiles in top and bottom configurations at different plasma currents, that is, different connections of the outboard limiters. At low current, the magnetic field lines can intersect the different outboard limiters, which tends to symmetrize the toroidal configuration. The difference between the maximum values of the perpendicular velocity at top and bottom configuration is always visible, but increases at low current. The form of the profile (stiffness of the $V_\perp$ inversion at the separatrix) is strongly affected by the current value, indicating a sensitivity to the detail of configuration.

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