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Observation of a localized radial electric field inversion in Tore Supra plasmas

E. Trier[1], P. Hennequin[1], C. Fenzi[2], Ö. D. Gürcan[1], R. Sabot[2], P. Maget[2], J. Bucalossi[2], X. Garbet[2], F. Clairet[2], L. Vermare[1], C. Bourdelle[2], Z.O. Guimarães-Filho [3], G. Falchetto[2], G. Huysmans[2]

[1] *LPP, Ecole Polytechnique, CNRS, UPMC, Route de Saclay, 91128 Palaiseau, France.*

[2] *CEA, IRFM, F-13108 Saint Paul Lez Durance, France.*

[3] *Equipe DSC, PIIM, CNRS-Université de Provence, F-13397 Marseille Cedex 20, France.*

Introduction

Plasma rotation is of interest for several reasons; one of them being that the L-mode plasma rotation can change the L-to-H mode transition threshold [1]. A better knowledge of momentum sources in the edge and the core is therefore useful. In particular, rotation in L-mode shows unexplained phenomenology such as rotation reversal observed in TCV [2]. This paper presents observations by Doppler Reflectometry in Tore Supra of a localized radial electric field (E_r) inversion in the mid-plasma zone (r/a~0.5), during experiments in L-mode ohmic plasmas without external momentum input.

In a previous work [3], it has been checked that the measured radial electric field in Tore Supra agrees well at mid-radius with ripple-induced E_r predicted by neoclassical theory [4], suggesting that the main contribution in the ambipolarity condition determining E_r comes from the ripple-trapped thermal ions. Consequently, both measured and predicted radial electric fields are negative inside Tore Supra plasmas (no external momentum input). Observing a positive radial electric field in the mid-plasma zone is something unusual in Tore Supra.

Experimental conditions and Diagnostics

Tore Supra operates in limiter configuration and the vacuum magnetic field in this series of experiments is 1.9T. Plasmas are ohmic. The ellipticity and triangularity are near the maximum possible value for Tore Supra (which usually operates with circular plasma shape): ellipticity b/a <1.17 and triangularity δ<20%. Doppler Reflectometry measurements presented here have shown good reproducibility in a set of 11 discharges with similar plasma conditions. The representative shot #43413 will be described in more details in the following part. All these discharges presents low edge safety factor ($2.8 < q_a < 3.8$), plasma current in the range (500<I_p<650 kA), plasma major and minor radius R_0=2.35m and 60<a<65cm.

The diagnostic used for measuring E_r is Doppler Reflectometry. It allows measurements of the perpendicular velocity of the density fluctuations from the Doppler shift of the backscattered signal frequency spectrum. This velocity is the sum of two terms, $v_\perp = V_{E\times B} + v_{fluc}$; v_{fluc} is the phase fluctuation velocity, usually small compared to the $E \times B$ drift velocity induced by the radial electric field, $V_{E\times B}$. Doppler Reflectometry operates with microwave beam in O-mode and X-mode polarization. The beam incidence selects a wave number in the range $k_\perp \sim$ 4-20 cm^{-1}. The probing frequency and the antenna angle are scanned, which allows radial profile measurement [5].

Radial electric field inversion

Scenario of discharge #43413 is shown in figure 1. During the current ramp (500 kA to 650 kA), the edge safety q_a factor decreases from 3.6 to 2.8. A short (400ms) and low-power (<400 kW) NBI pulse at t=9s allows the measurement of C^{6+} temperature and toroidal velocity by CXRS. At each Doppler Reflectometry measurement time, the probing frequency is scanned in 10 steps in both O-mode (between 49 and 57 GHz) and X-mode (between 73.5 and 85.5 GHz). The measurements points are located in the zone 0.45< r/a < 0.75, on the low field side.

While q_a decreases, a positive perpendicular velocity (i.e. positive E_r) is detected for some of the scanning frequencies (mainly 53.4GHz) in O-mode. It is also visible in X-mode, but in this case it is more difficult to extract a Doppler shift frequency from the spectrum. The E_r inversion appears (figure 2) when t>6s (q_a< 3.2). The radial location of this inversion evolves progressively from $r/a=0.6$ (t=7.5s) to $r/a=0.5$ (t=10.5s). For the others probing frequencies, the perpendicular velocity remains negative: the radial electric field inversion is local (figure 3). Unfortunately, the inversion zone is located close to the most inner radii accessible by Doppler Reflectometry, making it difficult to measure the value radial electric field value beyond this point. However, enough evidence from the various discharges is available showing that this inversion zone does not go up to the plasma centre.

The CXRS toroidal velocity measurements show no rotation inversion. At all radii the plasma rotates in the counter-current direction but a perturbation of V_Φ is seen at the E_r inversion radius: absolute value of V_Φ locally drops by ~30% (figure 4). This feature was common for all the shots where V_Φ was measured (#43410 to #43413). The associated local change of the $V_\phi B_\theta$ term in the radial force balance equation is not sufficient to explain the E_r inversion.

MHD activity

MHD activity, which is strong in these discharges since q_a~3, appears as the most plausible explanation for the origin of the electric field inversion. In #43413, modes with toroidal number n=1 (m=1,2,3) are detected using Mirnov coils signal analysis. Safety factor calculation by the CRONOS code shows that the E_r inversion is located between the q=1 and q=3/2 surfaces (figure 6). During a short acquisition at t=8.5s, fast ECE measurements located in the central region (approximately r/a<0.55) detects, for some sawtooth crashes, a strong and long duration (~10ms) low frequency mode (~1 kHz) inside q=1. Moreover, fast Interferometry observes a mode at 2.7 kHz, which may be located in the outer part of the plasma (since it is not detected by fast ECE). Reflectometry detects time-of-flight jumps associated with flattenings of the density profile (i.e. islands, probably). It was not possible to locate it precisely due to the absence of edge Reflectometry measurements, but rough estimations of the cut-off layer location shows that the presence of an island in the E_r inversion region is possible.

Conclusion

Similar E_r inversion observations have already been made in the vicinity of an island during H-mode discharges in the edge of the TUMAN-3M Tokamak [6]. Vortex-like flows have also been detected inside large islands in LHD [7]. Magnetic turbulence [8], or island-induced "zonal-flows" [9] have been suggested as some possible explanation for such E_r inversion.

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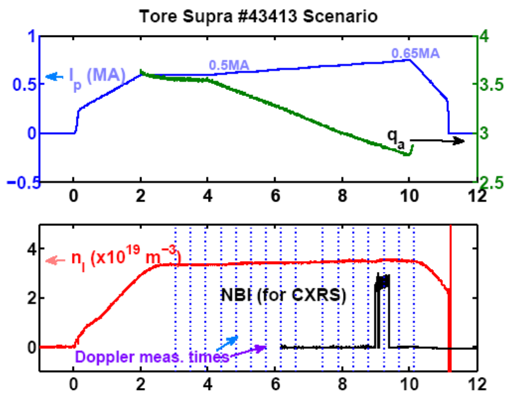

Figure 1 *Scenario of discharge #43413. Up: plasma current (blue) and edge safety factor (green). Down: line density (red), with time of Doppler Reflectometry (dashed vertical lines) and CXRS (black).*

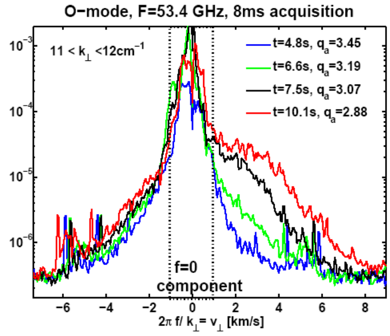

Figure 2 *Doppler Reflectometry $v_\perp$ spectrums, showing appearance of a positive $v_\perp$ (#43413).*

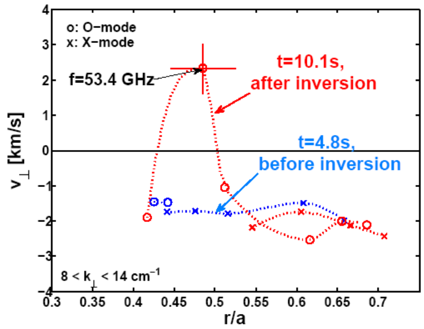

Figure 3 *Doppler-measured perpendicular velocity before (t=4.8s, blue) and after (t=10.1s, red) the radial electric field inversion (#43413).*

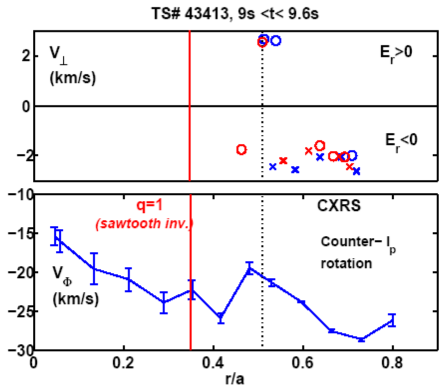

Figure 4 *Perpendicular velocity (up) for 9<t<9.6s, and CXRS-measured toroidal velocity (#43413)*

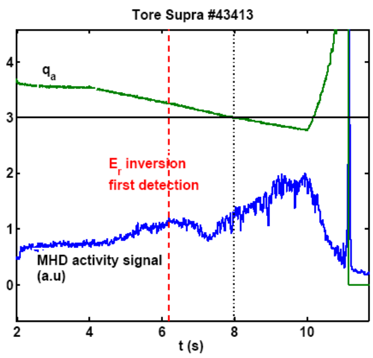

Figure 5 *MHD activity signal and the appearance of E_r inversion(#43413)*

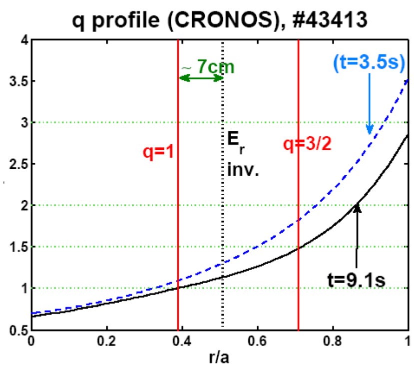

Figure 6 *Location of E_r inversion at t=9s, comparison with rational surfaces location calculated by CRONOS (#43413).*