

DEPENDENCE OF TURBULENCE ON COLLISIONALITY IN TORE SUPRA

T. Gerbaud, C. Bourdelle, L. Vermare¹, T. Aniel, A. Casati, F. Clairet, G. Falchetto,
C. Fenzi-Bonizec, X. Garbet, P. Hennequin¹, S. Heuraux², F. Imbeaux, J-L. Ségui
CEA-Cadarache, CEA/IRFM 13108 St Paul-lez-Durance, France
¹ LPTP, CNRS-Ecole Polytechnique, 91128 Palaiseau Cedex, France
² LPMIA, CNRS 7040, Univ. Henri Poincare Nancy I,
BP239, 54506 Vandoeuvre cedex, France

It is well known that collisionality plays an important role in turbulence. This paper reports the experiments performed in Tore Supra dedicated to the scan of the normalized collisionality parameter ($\nu^* = \nu_{ei} (m_e/eT_e)^{1/2} qR/\epsilon^{3/2}$), varying in the range of ~ 4.7 (Fig. 1a). For the first time, the radial profiles of density fluctuation have been measured in such experiments. These experiments have been carefully prepared, in order to keep the same radial profile of the other dimensionless parameters (variations $<15\%$): ρ^* , β , q , density and temperature gradients (Fig. 1b,1c,1d). At the edge plasma, an increase of $\delta n_e/n_e$ observed from two measurement techniques, while there is no clear dependence in the central region ($r/a < 0.5$).

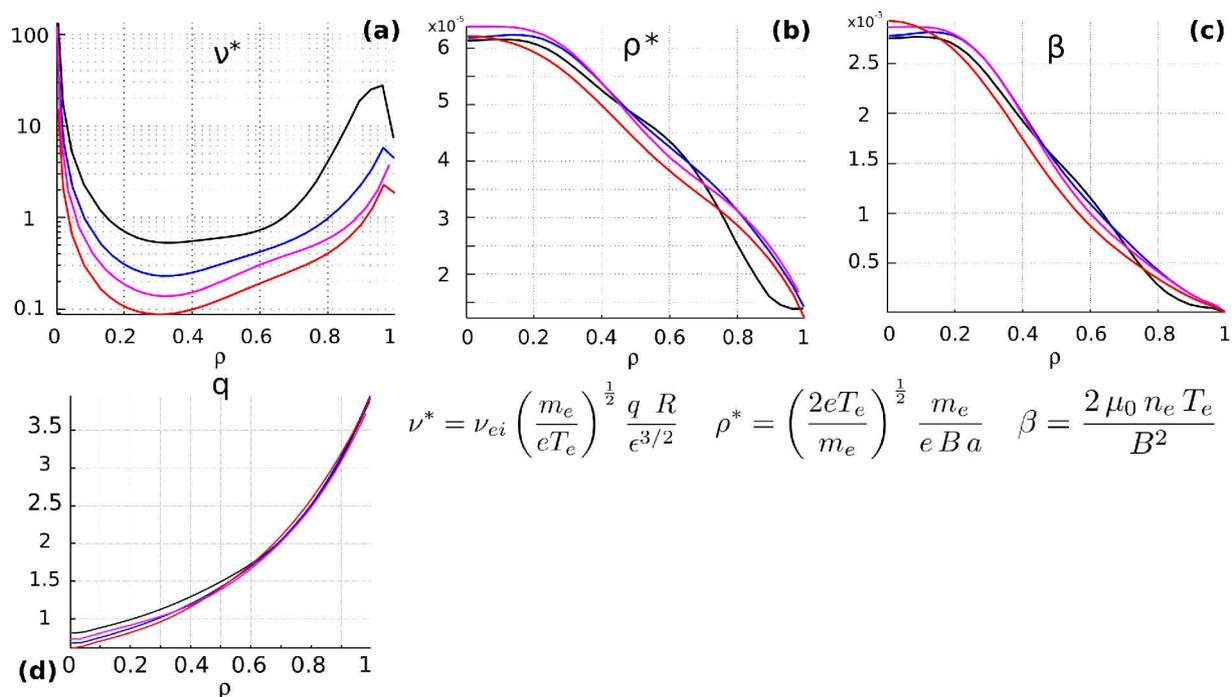


Figure 1: Profiles of dimensionless parameters for the Tore Supra shots #39598, #39611, #39648, #39596. (a) normalized collisionality ; (b) normalized toroidal Larmor radius ; (c) kinetic pressure normalized to magnetic pressure ; (d) safety factor profile.

Experimental conditions

Four discharges have been performed by varying the magnetic field from 2.40 T – 3.87 T, using ICRH in the H-minority scheme ($P_{\text{ICRH}} = 0.5\text{-}0.6$ MW), with plasma current $I_p=0.8\text{-}1.2$ MA, central line density $n_l = 4.5 \cdot 10^{19}$ m⁻³, $T_e(r/a=0) = 1.1\text{-}2.4$ keV and $T_i(r/a=0) = 1\text{-}1.7$ keV.

Radial profiles of electron density are measured by the fast-sweeping reflectometers and by interferometry (for the case of 2.4 T). Electron temperature profiles are provided respectively by 32 channels of ECE and Thomson scattering. The ion temperature profiles are measured by 8 chords of charge exchange diagnostic. The variation of the ratio T_e/T_i and Z_{eff} are less than 30%. The safety factor profiles are provided by the CRONOS code [1], constrained by the Faraday angles from polarimetry.

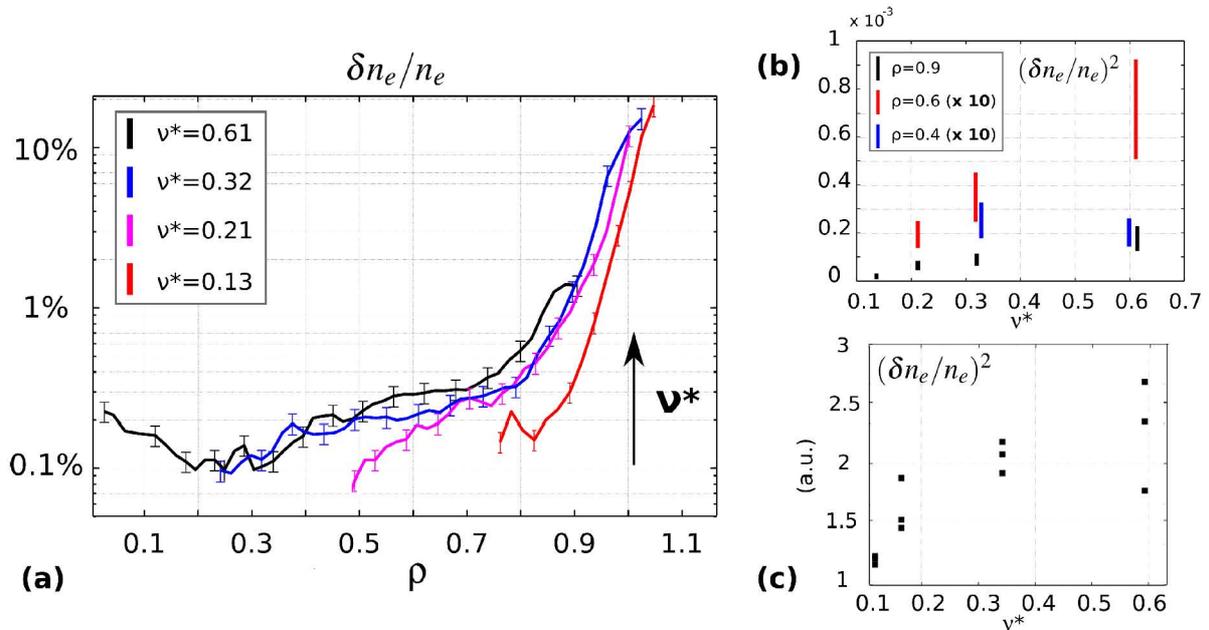


Figure 2: (a) Radial profiles of $\delta n/n$ extracted from fast-sweeping reflectometry signals, error bars estimated at 15%. (b) Local evolution of $(\delta n/n)^2$ from signals fast-sweeping reflectometry for $r/a = 0.4$ (blue), 0.6 (red) and 0.9 (black); factor-of-10 correction applied for $r/a = 0.4$ and 0.6. (c) $(\delta n/n)^2$ values extracted from Doppler reflectometry signals, for 3 different probing wave frequencies, for $r/a=0.7\text{-}0.8$ and $k_\theta = 6\text{-}8$ cm⁻¹.

Turbulence measurements

Local measurements of density fluctuations were performed by two different reflectometry techniques : fast-sweeping reflectometry and Doppler reflectometry. Fast-sweeping reflectometers are operated in the range of 50-110 GHz in X-mode, performing a frequency sweeps each 25 μ s [2]. The absolute value of density fluctuation intensity is obtained from the integration of local spectra $S[\delta n](r, k_r)$ between 1-10 cm⁻¹ [3]. Relative error

of $\delta n/n$ is estimated to be around 15%. Doppler reflectometer is operated between 50-110 GHz in O mode and measures δn spectra in poloidal wave-number k_θ [4]. The turbulence intensity is measured for wave-numbers $k_\theta = 6-8 \text{ cm}^{-1}$, and at the radial position $r/a = 0.7-0.8$.

Radial profiles of density fluctuations, by varying v^* , provided by fast-sweeping reflecto-meters are displayed on Fig. 2. In Fig. 2a, one can see that there is no significant dependence of $\delta n/n$ on v^* in the core region $r/a < 0.5$. While at the plasma edge, $r/a > 0.7$, the v^* dependence is clearly pronounced. As shown in Fig. 2b, $(\delta n/n)^2$ varies by a factor of $\sim 4-25$ for $r/a > 0.8$ when varying for a v^* from ~ 0.1 to 0.6. These results are consistent with the measurements of δn^2 in the region $r/a = 0.7-0.8$ by Doppler reflectometer. In Fig. 2c, the variation of $(\delta n/n)^2$ from Doppler measurements increases by a factor of 2-3.

These results are correlated with the behaviour of the effective thermal diffusivity obtained from the power balance analyses and defined as :

$$\chi_{\text{eff}} = - (q_e + q_i) / (n_e \nabla T_e + n_i \nabla T_i)$$

where q_e and q_i are the electron and ion heat fluxes respectively. Here, we assume that $\nabla T_i = T_i / T_e \nabla T_e$. The local thermal diffusivity is usually predicted to scale as the turbulence intensity, i.e. $\chi_{\text{eff}} \sim (\delta n/n)^2$. The power balance analyses have been performed within $0.3 < r/a < 0.8$ because of large uncertainty at the edge (P_{rad} , Z_{eff} , ..) and central core (sawtooth, heat

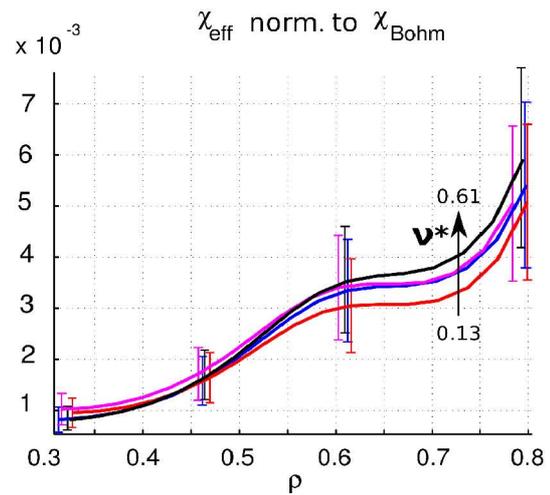


Figure 3 : Effective thermal diffusivity coefficient from CRONOS normalized to Bohm thermal diffusivity.

source). The radial profiles of χ_{eff} normalized to the Bohm diffusion coefficient ($\chi_b = T/B$) are shown in Fig.3 . In this figure, weak variations can be seen within the error bars (30 %).

This result is consistent with micro-instability simulations of the considered discharges using the non-linear gyrokinetic code GYRO [5]. Indeed, these simulations expect a weak decrease of χ_{eff} ($\sim 20\%$), at $r/a = 0.5$. Linear stability analysis performed with QuaLiKiz [6] show no clear effect of v^* on growth rates, but highlights the predominant effect of Z_{eff} variations.

Global energy confinement

Experimental observations of turbulence are confirmed by the evolution of the global energy confinement time $B_0\tau_E$. Additional points are included for global analysis in order to confirm the global trend in the behaviour of $B_0\tau_E$ with v^* (Fig 4-a,b). Best matches are found when separating the ohmic and ICRH heated plasma discharges,

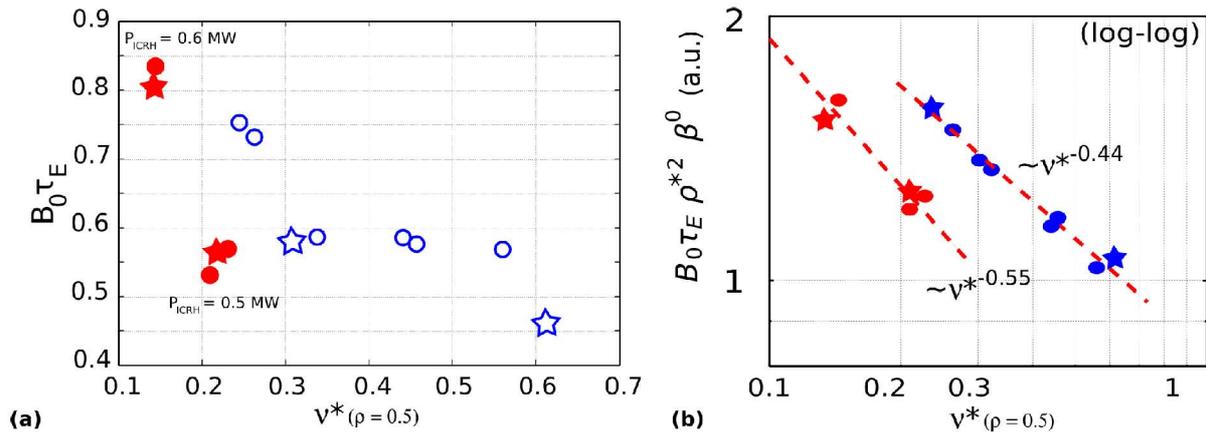


Figure 4: Normalized confinement time against collisionality at radial position $r/a=0.5$. Ohmic shots are empty blue symbols, ICRH heated shots are filled red ones. Additional shots (*circles*) present dimensionless parameters slightly varying from the ones of the TS #39596, #39598, #39611, #39648 discharges (*stars*). (a) When non-zero, ICRH power is expressed in MW ; (b) log-log plot of $B_0\tau_E \rho^{*2} \beta^0$ versus v^* , fits in red dashed line.

Summary

No clear dependence of $\delta n/n$ upon v^* is observed for $r/a < 0.5$. This is correlated with χ_{eff} from the power analyses and micro instability simulations. Contrarily at the edge $\delta n/n$ varies significantly when increasing v^* by a factor of 4.7. The global energy confinement exhibits a degradation when increasing v^* : $B_0\tau_E \sim v^{*-0.5}$. These results suggest an important role of the edge transport in the degradation of energy confinement when increasing v^* .

References

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