INVESTIGATION OF DIMENSIONLESS SCALING LAWS AND NON LOCAL TRANSPORT IN TORE SUPRA

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Abstract

Similarity experiments have been performed in Tore Supra to investigate the dimensionless scaling of transport in stationary regimes. Local and global analyses have shown that in ***L*** regimes the electron transport is nearly gyro-Bohm, electromagnetic, and weakly collisional, while in ohmic regimes it is gyro-Bohm, electromagnetic, and strongly collisional. The gyro-Bohm behaviour and electromagnetic nature of the electron transport have been confirmed by the density and magnetic fluctuation measurements. Edge cooling experiments have been carried out in Tore Supra to investigate the transport mechanism. The non local transport phenomenon has been observed in both OH and LH regimes. Thresholds have been obtained for the non local transport appearance on the plasma density, current and the pellet size. This effect is significantly enhanced in the LH heating regime. Experimental observations suggest that the mechanism governing the non local transport is unlikely to be linked to the current effects including the spatial redistribution and the magnetic shear, and the low wavenumber MHD.

1. INTRODUCTION

Heat transport, an important issue for magnetic confinement fusion, can be investigated in two different situations : stationary and transient. Studies of these two regimes are complementary in order to better understand the transport mechanisms in tokamaks. The similarity approach is an excellent method to investigate the dimensionless scaling laws in the stationary regime [1]. These dimensionless scaling laws present a major interest for extrapolating existing results to next step devices such as ITER, in order to predict their performances. The features of electron transport in stationary regimes are diffusive, electro-magnetic, with short correlation length. However in transient regimes, the electron transport is not always compatible with a simple diffusive model, since large scale transport events are observed with a propagation time smaller than a diffusion time. Recently a surprising phenomenon of non local transport (NLT) has been evidenced in TEXT [2], and is described by a controversial picture : a strong cooling in the edge plasma provokes a significant heating in the central plasma core within a time much smaller than a diffusion time. This non-diffusive, long-range and reversed polarity response due to an edge temperature perturbation raises the basic problem of locality for the "standard" (local and turbulent) transport model. Investigating the mechanism behind this new phenomenon presents a great interest for the understanding of transport mechanism.

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2. SIMILARITY EXPERIMENTS

Similarity experiments have been performed in Tore Supra. Dimensionless transport scalings have been investigated as a function of the gyro-radius $r^* \equiv \sqrt{2 m_e T_e}/(-q_e B a)$, the beta number $b \equiv n_e T_e/(B^2/2m_0)$ and the collisionality $n^* \equiv \text{const}\,(R/a)^{3/2} q_a\, R\, n_e / T_e^2$: $c / c^B \propto (r^*)^{xr} (b)^{xb} (n^*)^{xn}$, where $c^B \equiv T_e/(-q_e B)$ is the Bohm diffusivity. From the local analysis, it has been shown that in ***L*** regimes the electron transport is nearly gyro-Bohm ($x_\rho \approx 1$), electromagnetic ($1 < x_\beta < 2$) and weakly collisional ($0 < x_\nu < 0.5$), the ion transport is rather Goldston-like [3]. These results are confirmed by the global analysis where a dimensionless scaling has been obtained : $\left\langle c^L \right\rangle / c^B \propto (r^*)^{0.4\pm0.2} (b)^{1.3\pm0.2} (n^*)^{0.1\pm0.2}$ (Fig.1). In the last expression, the effective diffusivity $\langle c \rangle$ is defined as a^2/t_E, where t_E is the confinement time. It should be noted that $\langle c \rangle$ includes both electron and ion contributions. In OH regimes the internal electron transport scaling is different and given by $c^{OH} / c^B \propto (r^*)^1 (b)^{-2} (n^*)^1$. The electron transport is thus weakly collisional in L regimes and strongly collisional in OH regimes. The r^*-scaling shows that the electron transport is nearly gyro-Bohm in both regimes. This gyro-Bohm behavior has been confirmed by density fluctuation measurements [3] and is consistent with turbulence numerical simulations when the gradients are well above the instability threshold. The strong dependence in b indicates that the turbulence which causes this transport is electromagnetic in both regimes. This is corroborated by the magnetic fluctuation measurements where a good agreement has been found between the experimental heat flux and that estimated from magnetic fluctuations [4]. In Fig.2 the electron heat flux induced by magnetic turbulence ($Q_e^{mag} \equiv -n_e c_e^{mag} \nabla T_e$) is plotted versus the temperature gradient ∇T_e, and c_e^{mag} is given by $c_e^{mag} = L_c v_{the} (\tilde{B}/B)^2$ where L_c is the correlation length, v_{the} is the electron thermal velocity and $\tilde{B}$ is the magnetic fluctuation. From this figure a critical temperature gradient is clearly observed, and its value $(\approx 2.5\, keV/m)$ is very close to that obtained from profile analysis [5]. Thus in stationary regimes the features of electron transport are diffusive, electromagnetic, with short correlation length compared to the plasma size.

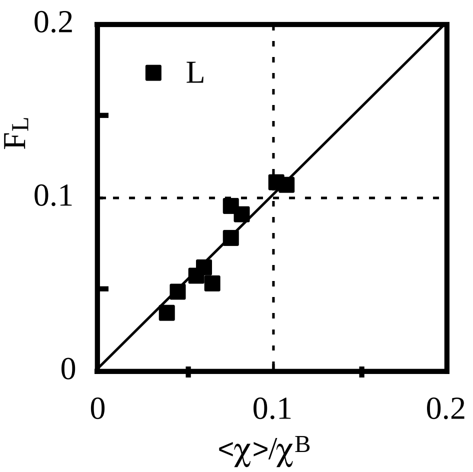


Fig.1 Dimensionless scaling of transport versus the experimental values of $\langle c \rangle / c^B$ in L regimes with $F_L = K (r^*)^{0.4} (b)^{1.3} (n^*)^{0.1}$.

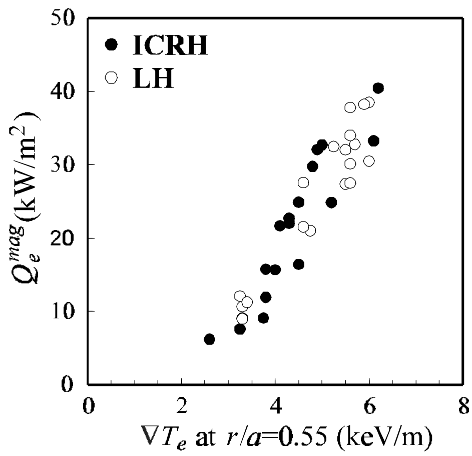


Fig. 2 Magnetic fluctuation-induced heat flux plotted as a function of ∇T_e at r/a=0.55.

3. NON LOCAL TRANSPORT EXPERIMENTS

Edge cooling experiments have been performed in Tore Supra using the oblique pellet injection and the impurity injection by laser. The electron temperature perturbations are measured with a multichannel electron cyclotron emission (ECE) heterodyne system. Results obtained with impurity injection are very similar to those reported in TEXT [2] and in TFTR [6], where a significant temperature increase has been observed in the central core during the impurity injection, with a reaction time much smaller than the heat diffusion time. The NLT features (drop at the edge and rise in the centre for T_e) have also been confirmed in the ohmic regime with pellet injections, and the results are similar to those reported in JIPPT-IIU [7] and in RTP [8]. Fig. 3a presents the diagram of the non local transport appearance. A threshold on the line average density and current $\bar{n}_e / I_p^{1/2}$ is clearly observed from this figure : $\bar{n}_e / I_p^{1/2} \le 1.0\times 10^{19}\ m^{-3} / MA^{1/2}$. Furthermore from this figure a threshold on the relative density variation caused by the pellet injection has also been observed : $\Delta\bar{n}_e / \bar{n}_e \le 0.5$.

Significant enhancements have been observed for the NLT feature in the Lower Hybrid (LH) heating regimes. These results differ from those obtained in TFTR and TEXT, where this effect tends to disappear with additional heating (NBI, ECRH). The limit on $n_e / I_p^{1/2}$ is now extended : $\left[n_e / I_p^{1/2}\right]_{crit} = 1.4\times 10^{19}\ m^{-3} / MA^{1/2}$, and no limit has yet been observed for $\Delta n_e / n_e$ in LH regimes (Fig. 3b). In the latter case large relative density variation $\Delta n_e / n_e$ can not be reached due to the reduced pellet fuelling efficiency, which is directly linked to the more peripheral pellet penetration caused by suprathermal electrons.

Fig.4 presents a pellet injection experiment in a fully non-inductive current regime, where the plasma current is fully carried by the suprathermal electrons created by LH waves. During this phase, the sawtooth activity has been fully suppressed as shown in Fig. 4a. Furthermore, there is no variation during this pellet injection for the loop voltage V_{loop}, the radiation power P_{rad}, the input LH power P_{LH} and the hard x-ray (HXR) signals, which are a measurement of the central non-inductive current level at two different energy channels [9] (Fig. 4b). Lastly no excitation of low wavenumber MHD modes has been observed contrary to that reported in TFTR.These observations indicate clearly that the mechanism governing

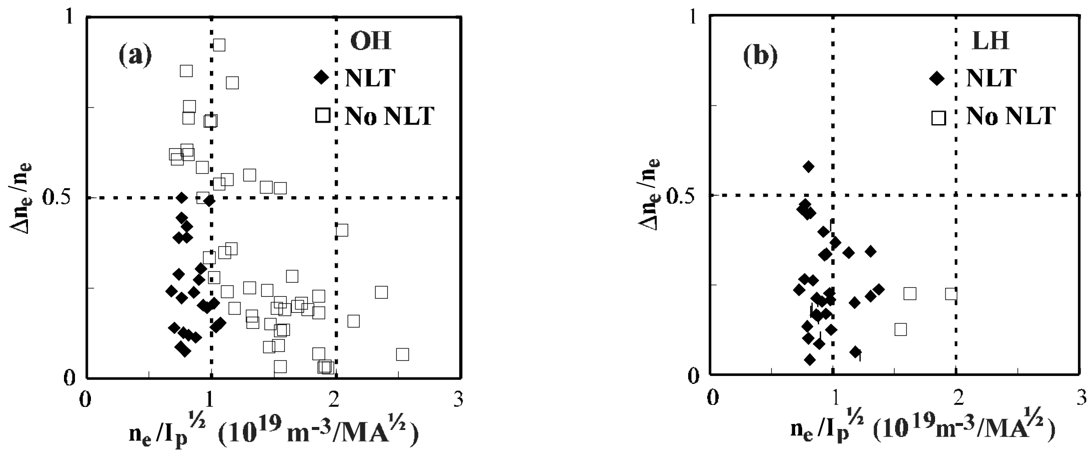
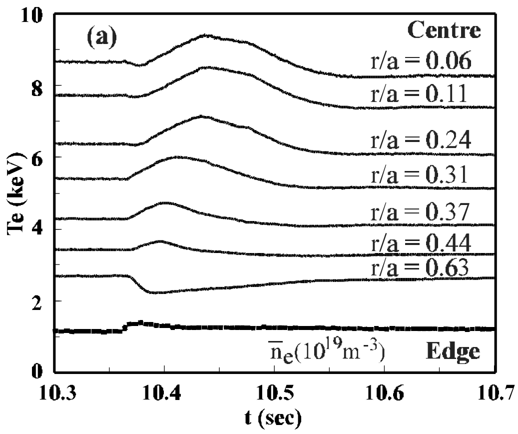


Fig. 3 Diagram for the non local transport in pellet injection experiments. ◆ (□) corresponds to the case where the non local transport effect is (not) observed. (a) in OH regimes. (b) in LH-heating regimes.



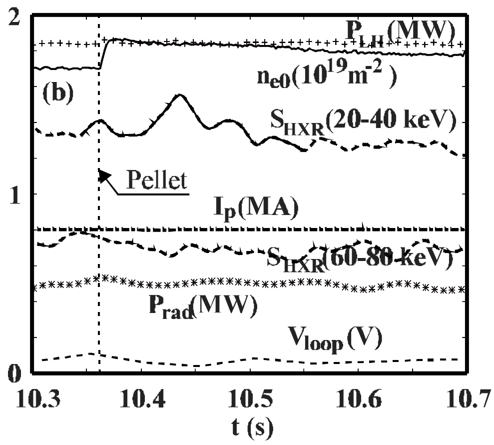


Fig. 4 Pellet injection experiment in the fully non-inductive current regime with LH wave. (a) ECE temperature response and the line average density $\bar{n}_e$. (b) Time evolution of the current I_p, the central density n_{e0}, the LH input power P_{LH}, the radiation power P_{rad}, the loop voltage V_{loop} and the HXR signals (A.U.).

the non local transport is not correlated with the change of current profile. Moreover the characteristic time of the current change is much slower than that observed in the NLT phenomenon. Thus the mechanisms based on spatial redistribution of the plasma current, or modification of the magnetic shear, may be excluded for the non local transport.

4. CONCLUSIONS

Local and global analyses of similarity experiments in Tore Supra have shown that in L regimes the electron transport is nearly gyro-Bohm, electromagnetic and weakly collisional. The gyro-Bohm behaviour and electromagnetic nature of the electron transport have been confirmed by the density and magnetic fluctuation measurements.

The non local transport phenomenon has been observed in the edge cooling experiments. Thresholds have been obtained for the NLT appearance on the plasma density, plasma current and the pellet size. The NLT effect is significantly enhanced in the LH heating regime. Experimental observations suggest that the mechanism governing the non local transport is unlikely to be linked to the current effects including the spatial redistribution and the magnetic shear, and the low wavenumber MHD.

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