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Electron Transport Dynamics in LHD Core Plasmas

S. Inagaki[1], K. Ida[1], N. Tamura[1], K. Tanaka[1], T. Tokuzawa[1], S. Kubo[1], T. Shimozuma[1], Y. Nagayama[1], K. Kawahata[1], S. Sudo[1] and LHD experimental group[1]

[1] *National Institute for Fusion Science, Toki, Japan*

Introduction

Magnetically confined toroidal plasmas exhibit various transport dynamics e.g. spontaneous internal transport barriers (ITBs) formation, transition of low to high confinement mode in the edge region and abrupt core-edge interactions [1, 2, 3]. The observed dynamics has different time and space scales. Plasma transport is dominated by turbulence, and thus the exhibited time and space scales of transport dynamics is considered to be resulted from the turbulence-transport interactions. To achieving a predictive capability of turbulence transport, therefore, understanding of the dynamics is crucial.

ITB formation and non-local events in LHD

An spontaneous electron ITB (eITB) formation and a non-local electron temperature, T_e, rise have been observed in the Large Helical Device (LHD), which has negative magnetic shear and is free of net current [4, 5]. Neutral beams with a power of 2-4 MW are injected to initiate and sustain the plasma. The fundamental and the second harmonics of ECH is added with a power of 0.5-1 MW. Figure 1(a) shows a typical time evolution of T_e at the spontaneous eITB formation. A decrease in the density triggers an eITB formation in LHD. Electron ITB formation event propagates core to edge and then stopped near the low order rational surface (m/n = 2/1) as well as in tokamaks. The time scale of the ITB event propagation is 50 ms and is comparable to the energy confinement time of this discharge. A typical T_e response to the edge cooling in LHD by a tracer encapsulated solid pellet (TESPEL[6]) injection is shown in Fig. 1(b). Although the TESPEL affects only on the edge plasma, a sudden rise of T_e takes place in the central region ($\rho \leq 0.4$). Unlike the ITB formation, the plasma starts to go back to normal condition 30 ms after TESPEL injection as in tokamaks. Radial propagation of T_e rise is unclear because it takes place almost simultaneously in the core region ($\rho \leq 0.4$).

Comparison of Dynamic Behaviors

The heat flux perturbation, δq_e, is determined from,

$$\delta q_e(\rho,t) = -\frac{1}{S(\rho)}\int_0^{\rho}\frac{3}{2}n_e\frac{\partial \delta T_e(\rho,t)}{\partial t}dV, \tag{1}$$

where S is the surface area of the closed flux surface, V is the volume and δT_e is the electron temperature perturbation. The perturbations of convection, heating power are neglected.

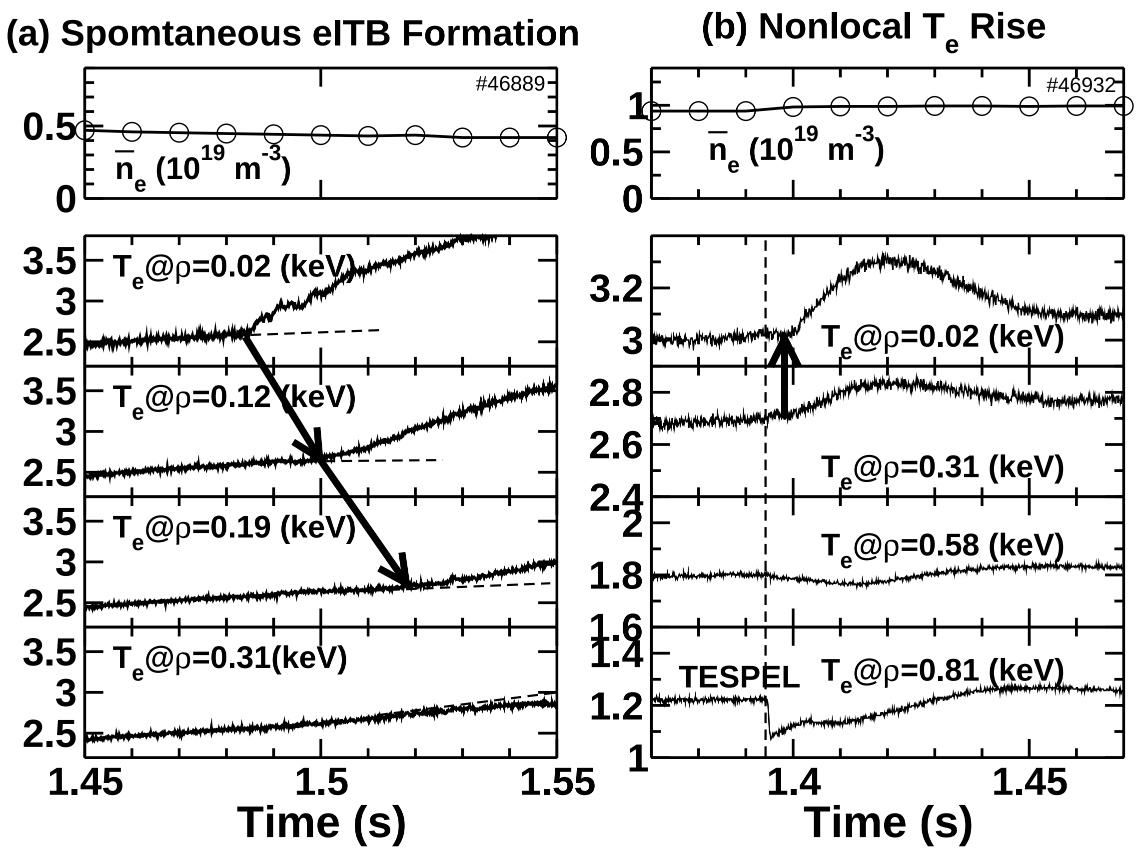

Figure 1: Typical time evolutions of line-averaged density and electron temperature at different radii in LHD plasmas with (a) the spontaneous ITB formation and (b) the non-local T_e rise (a major radius at the magnetic axis of 3.5 m, an averaged minor radius of 0.56 m and a magnetic field at the axis of 2.829 T).

A flux-gradient diagram is obtained for the ITB formation and it indicates that the heat flux jump (forward transition) takes place at $\rho = 0.02$ first as shown in Fig. 2(a). The ∇T_e increases after the jump. The time derivative of T_e at ρ = 0.02 drops corresponding to abrupt rises in the time derivative of T_e (ITB evolution) at ρ = 0.12 and 0.19 at $t = 1.508$ s and 1.525 s, respectively (see Fig. 2(b)). The flux-gradient diagram indicates multi-minor back transition as indicated by an arrow in Fig. 2(a) (a minor back transition at $t = 1.508$ s is unclear due to a large oscillation). These back transition events implies a spatial coupling of transport (non-locality) and a presence of multi-stable states in transport barriers. The flux-gradient diagram outside the ITB region indicates a diffusive behavior (the thick line corresponds to the thermal diffusion relation with χ_e = 0.7 m^2/s). A small flux jump is also observed.

Flux jump is observed for the non-local T_e rise as shown in Fig. 3(a). The diagram also indicate the back jump of flux, and thus the flux-gradient diagrams reveal a hysteresis. Unlike

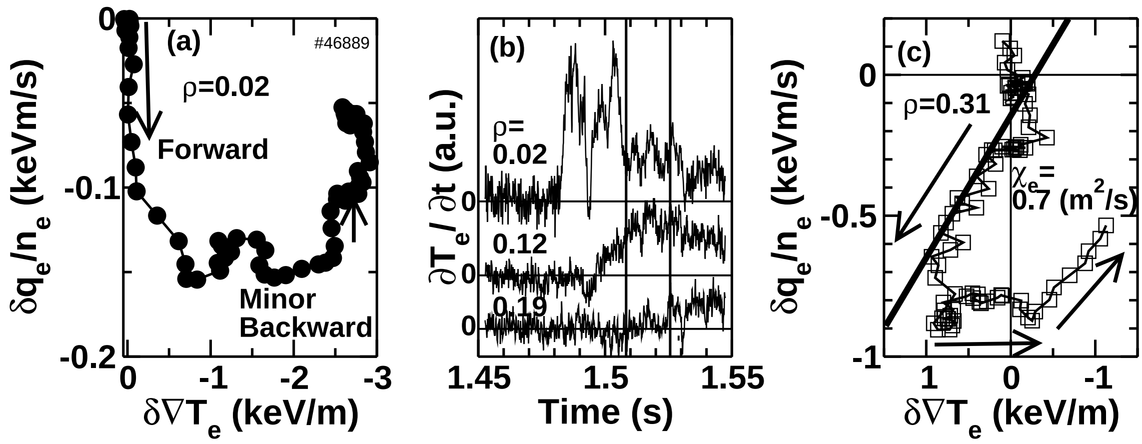

Figure 2: Flux-gradient diagrams of Fig. 1(a) at (a) ρ = 0.02 (inside the ITB) and (c) ρ = 0.31 (outside the ITB). (b) Time evolution of time derivative of T_e at different radii (averaged 50 data points). The arrows in (a) and (c) denote the direction of variation. An oscilation observed in the time derivative of T_e at ρ = 0.02 is removed in the flux estimation by Eq. (1).

spontaneous ITB formation, the flux jump takes place simultaneously in a wide region of plasma ($\rho \leq 0.61$) [5]. The spontaneous eITB formation and the non-local T_e rise takes place in the low-n_e and high-T_e (low collisionality) regime in LHD. The responses of T_e to the change in the line averaged density are shown in Fig. 3(b). The critical density for non-local T_e rise ($1.5 \times 10^{19}\text{m}^{-3}$) is 2-3 times larger than that for eITB formation ($0.6 \times 10^{19}\text{m}^{-3}$). The T_e changes discontinuously at the critical value. On the other hand, an increase in T_e induced by TESPEL injection gradually increases with decrease in the density.

Discussion and Summary

The time and space scales of two phenomena are quite different. The spontaneous eITB formation in LHD is characterized by narrow in radial region and slow in propagation time scale. On the other hand, the non-local T_e rise is characterized by wide in radial region and fast in propagation time scale.

The flux-gradient diagrams are obtaind for the spontaneous eITB formation and the non-local T_e rise experimentaly. The flux jumps may be explained by the 'first-order' transition models [7]. In the spontaneous eITB formation, a decrease in n_e increases q_{e/n_e}, however, it is not possible to establish a simple link the increase in edge n_e and the change in the core flux in the non-local T_e rise. By an adequate choice of the change of the critical gradient scale length in the 'second-order' transition models [8], it may be possible to explain the obtained flux-gradient diagrams. The physical mechanism responsible for the critical gradient scale length, however,

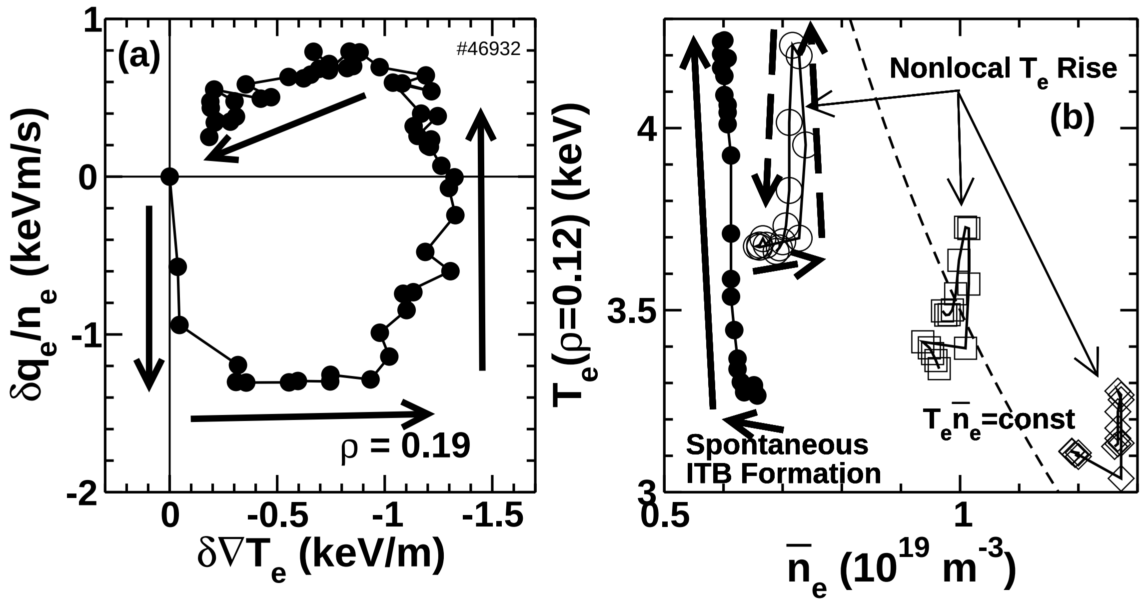

Figure 3: (a): Flux-gradient diagrams of Fig. 1(b) at ρ = 0.19. (b): line-averaged density dependence of change in core T_e. The arrows denote the direction of variation. The dashed line corresponds to the core electron pressure = constant.

has not been fully clarified yet. More convincing theoretical explanation is strongly required.

Acknowledgments

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References

[1] S. V. Neudatchin *et al* , *Plasma Phys. Control. Fusion* **44**, A383 (2002)

[2] J. G. Cordey *et al* , *Plasma Phys. Control. Fusion* **36**, A267 (1994)

[3] K. W. Gentle *et al* , *Phys. Rev. Lett.* **74**, 3620 (1995)

[4] T. Shimozuma *et al* , *Nucl. Fusion* **45**, 1396 (2005)

[5] S. Inagaki *et al* , *Plasma Phys. Control. Fusion* **48**, A251 (2006)

[6] S. Sudo *et al* , *Plasma Phys. Control. Fusion* **44**, 129 (2002)

[7] V. B. Lebedev and P. H. Diamond, *Phys. Plasmas* **4**, 1087 (1997)

[8] F. Ryter *et al* , *Phys. Rev. Lett.* **86**, 5498 (2001)