**Summary**

- New aspects of nonlocal \( T_e \) rise from LHD
  - Observation in net-current free plasma
  - Time response of nonlocal \( T_e \) rise can take on a variety of forms
  - Time response of core \( T_e \) rise is quickened by larger edge perturbation (shorter \( T_e \) gradient scale length?)
  - Delay of nonlocal \( T_e \) rise increased with...
  - Increase in collisionality in the core
  - Increase in \( T_e \) gradient scale length at the edge
  - Nonlocal rise of \( T_i \) as well as \( T_e \) has been observed after rapid edge cooling
  - Transient response analysis for electron heat transport suggests
    - Strong coupling between the edge and the core
    - Complex relationship between flux and gradient
    - Transitions between “nonlocal” and “local”

**Characteristics of nonlocal \( T_e \) rise in LHD (I)**

- **Significant rise of core \( T_e \) in response to edge cooling in LHD**
  - Edge cooling experiment of LHD shows a significant rise of core \( T_e \)
    - No change in low-\( m \) MHD modes
    - No density peaking like PEP, RI-mode
  - Electron heating dominates (\( T_e/T_i > 1 \))
  - Difference between \( T_e \) measured and that simulated based on simple diffusion model is pronounced in the core (\( \rho < 0.6 \)) little at the edge (\( \rho > 0.6 \))

- **What plasma can have a nonlocal \( T_e \) rise?**
  - Nonlocal \( T_e \) rise observed in...
    - ECH plasma (i.e. net-current free plasma)
      - Toroidal plasma current and high-energy ion are not a factor
    - NBI plasma (still \( T_e/T_i > 1 \))
      - High-energy electron is also not a factor
    - CERC plasma
      - Even inside transport improved region, \( T_e \) rise appears
  - \( \Rightarrow \) High heat flux required!

---

**Motivation**

- Full understanding of electron heat transport is necessary for achieving a good predictive capability for burning plasmas
- Experiments on toroidal plasmas show nonlocality
  \[ q_e(\rho_1) = f(\nabla T_e(\rho_1), \nabla T_e(\rho_1 - \delta \rho), \nabla T_e(\rho_1 + \delta \rho), \ldots, T_e(\rho_1), T_e(\rho_1 - \delta \rho), \ldots) \]
  in electron heat transport

- Profile resilience
- Fast plasma response (non-diffusive, ballistic)
- Phase inversion of cold pulse polarity

- Possible theoretical interpretation is “nonlocality” in turbulence (e.g. turbulence spreading)
- Observations in LHD heliotron give new insight into nonlocal transport
  - Because LHD has
    - Different magnetic configuration (normally negative magnetic shear)
    - No tokamak-like stiffness in \( T_e \) profile

---

**Experimental study on nonlocal electron heat transport in LHD**

N. Tamura\(^1\) (ntamura@LHD.nifs.ac.jp), S. Inagaki\(^2\), K. Tanaka\(^1\), C. Michael\(^1\), T. Tokuzawa\(^1\), K. Ida\(^1\), M. Yoshinuma\(^1\), T. Shimozuma\(^1\), S. Kubo\(^1\), R. Sakamoto\(^1\), T. Fukuda\(^3\), K. Itoh\(^1\), Y. Nagayama\(^1\), K. Kawahata\(^1\), S. Sudo\(^1\), A. Komori\(^1\) and LHD team\(^1\)

\(^1\)National Institute for Fusion Science, \(^2\)Kyushu University, \(^3\)Osaka University
Characteristics of nonlocal $T_e$ rise in LHD (II)

- **Condition for nonlocal $T_e$ rise**
  - Inverse relationship between increment of core $T_e$ due to nonlocal effect and $n_e$ observed
    - Same as in tokamaks
    - In LHD, no differences among heating methods (however, almost electron heating is dominant)

- **Variety of time response**
  - Repetitive hydrogen pellet injection shows clearly heat flux dependence of nonlocal $T_e$ rise, also no impurity effect

- **Dependence of delay time**
  - Favorable condition for delay of nonlocal $T_e$ rise
    - Higher collisionality $\nu_T^*$ in the core
    - Longer $T_e$ gradient scale length at the edge
  - Plasma is heated with NBI (n-NBI 3.6 MW + p-NBI 5.4 MW) and ECH (0.3 MW)
    - $T_e/T_i$ seems to be still larger than unity
    - TESPEL (doubled accidentally) is deposited outside $\rho \sim 0.9$
  - Ti is increased nonlocally as well as $T_e$ after rapid edge cooling
    - At $\rho \sim 0.7$, increment of $T_i$ is slightly larger than that of $T_e$
    - not just e-i collisional coupling
  - No change in $V_p$ is seen

Ti response to nonlocal $T_e$ rise

- High time-resolved (2.5ms) charge exchange spectroscopy system allows us to measure a Ti response to nonlocal $T_e$ rise
Transient Analysis

- Transient analysis suggests strong coupling between the core and the edge.

- Heat flux perturbation: $\delta q_e(r, t) = -\frac{3}{2} n_e \frac{\partial T_e(r, t)}{\partial t} \rho d\rho$

- Strong negative correlation between the edge $\delta V T_e$ and the core $\delta q_e/n_e$ is obtained.
  - The region with strong negative correlation appears around $\rho \sim 0.6$.

- Complex relationship between heat flux and $T_e$ gradient:
  - Reduction of $\delta q_e/n_e$ is not accompanied by changes in local $\nabla T_e$.
  - Evidence against "standard transport theory" (local & diffusive).
  - Turn-back of $\delta q_e/n_e$ is also independent of local $\nabla T_e$.

- How can we understand nonlocal $T_e$ rise in LHD?
  - Reduction of normalized heat flux due to nonlocal effect takes place in a wider region.

- Clue from LHD experiment:
  1. Nonlocality in e-transport revealed by edge cooling.
  2. Transitions between "nonlocal" and "local" in e-transport also revealed.

- Physical mechanisms of not only transition between "nonlocal" and "local" also nonlocality itself are unclear.

- However, that of nonlocality should have characteristics as follows:
  - Response delayed with higher $v_b^*$ & longer $T_e$ gradient scale length.
  - Radial extent close to plasma minor radius, $a$. 