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Experimental study on nonlocal electron heat transport in LHD

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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 quicken 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”

Motivation

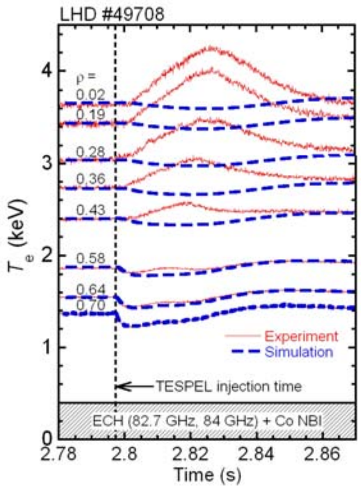
- ✓ Full understanding of electron heat transport is necessary for achieving a good predictive capability for burning plasmas
- ✓ Experiments on toroidal plasmas shows nonlocality
  $q_e(\rho_1) = f(\nabla T_e(\rho_1), \nabla T_e(\rho_1-\delta\rho), \nabla T_e(\rho_1+\delta\rho), \ldots, T_e(\rho_1),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

Profile resilience | Fast plasma response (non-diffusive, ballistic) | **Recently observed in LHD**: Phase inversion of cold pulse polarity

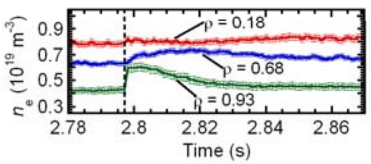
- ✓ Possible theoretical interpretation is “nonlocality” in turbulence (e.g. turbulence spreading)
- ✓ Observations in LHD heliotron give new insight into nonlocal transport
  - ● Because LHD has
    - – different magnetic configuration (normally negative magnetic shear)
    - – no tokamak-like stiffness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

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 (ρ < 0.6)
  - ● little at the edge (ρ > 0.6)

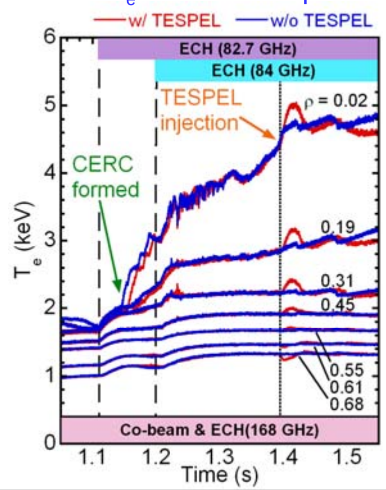
◆ What plasma can have a nonlocal T_e rise?

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

⇒ **High heat flux required!**

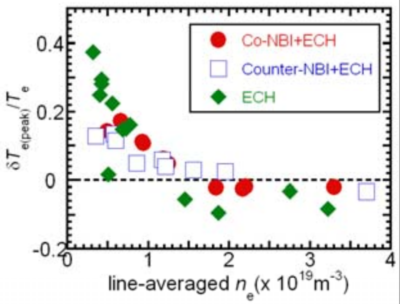
Nonlocal T_e rise in CERC plasma



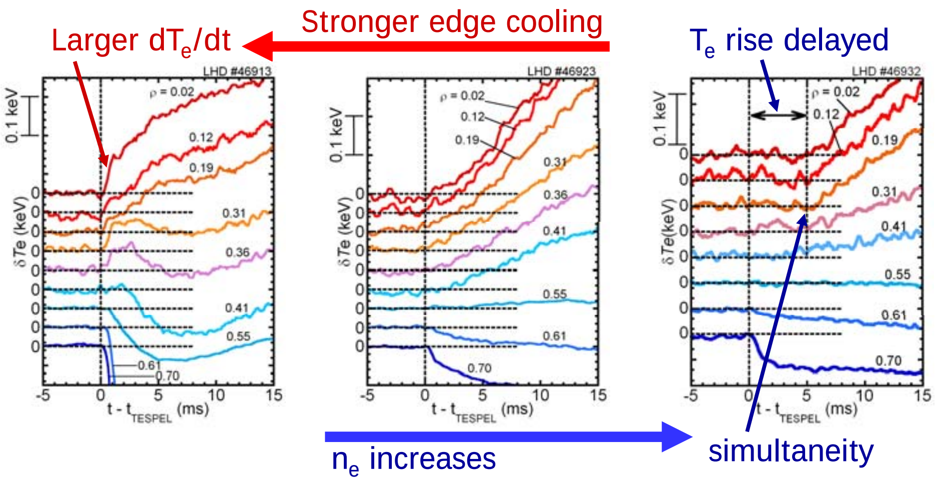
Characteristics of nonlocal T_e rise in LHD (II)

◆ 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)

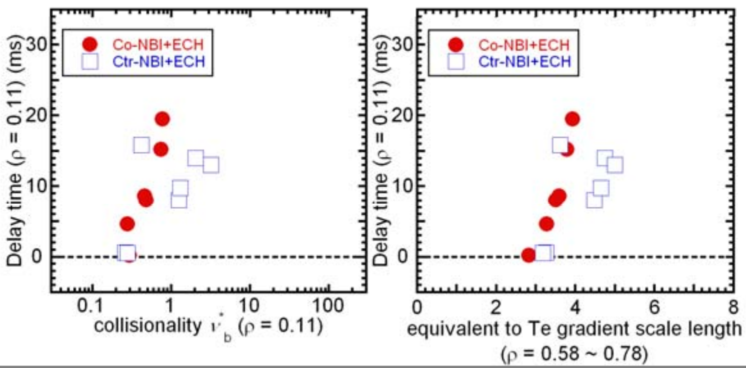


◆ Variety of time response

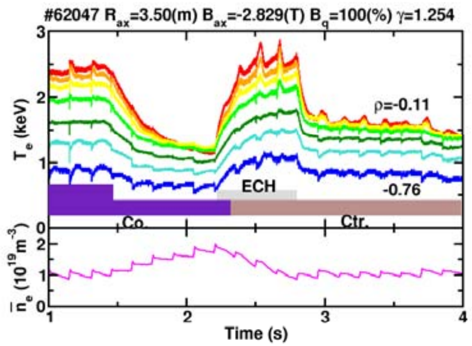


◆ Dependence of delay time

✓ Favorable condition for delay of nonlocal T_e rise
- Higher collisionality ν_b^* in the core
- Longer T_e gradient scale length at the edge

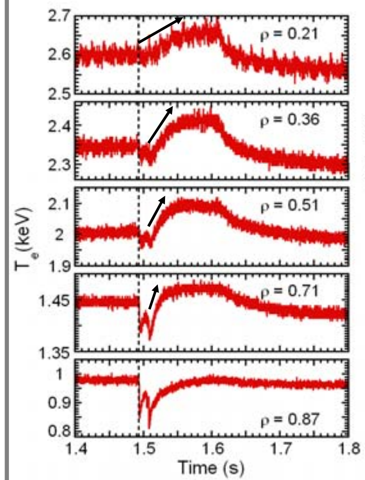


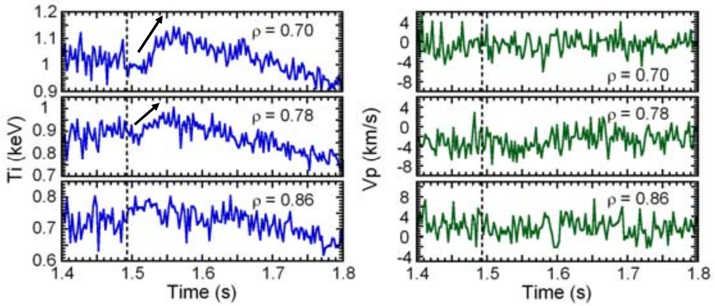
✓ Repetitive hydrogen pellet injection shows clearly heat flux dependence of nonlocal T_e rise, also no impurity effect



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





✓ 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 ρ ~ 0.9

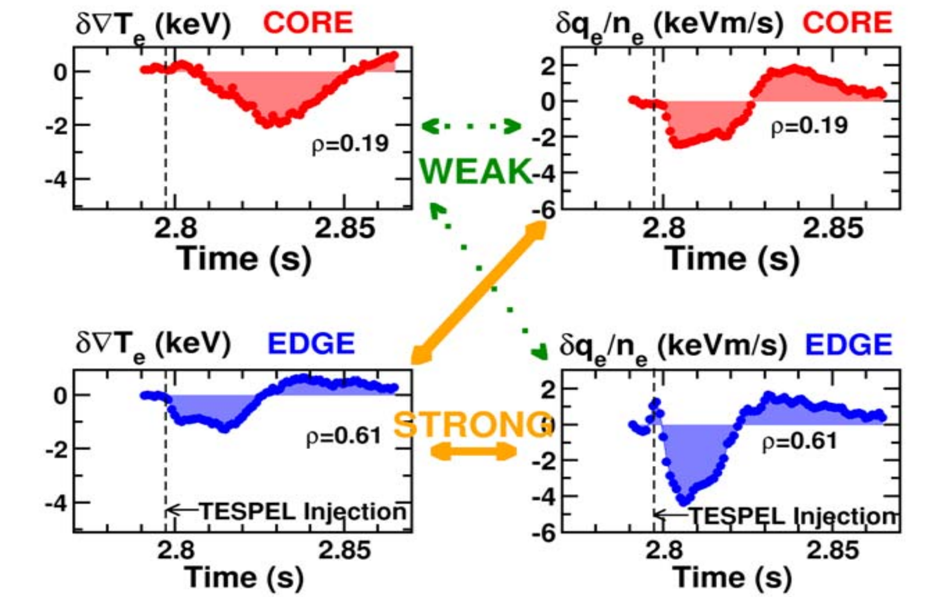
✓ Ti is increased nonlocally as well as T_e after rapid edge cooling
- At ρ ~ 0.7, increment of T_i is slightly larger than that of T_e
- not just e-i collisional coupling

✓ No change in V_p is seen

Transient Response Analysis

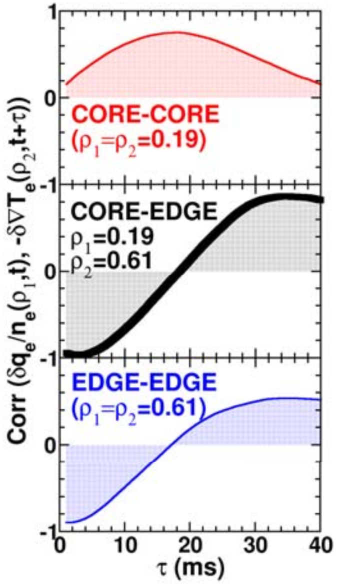
✓ Transient analysis suggests strong coupling between the core and the edge

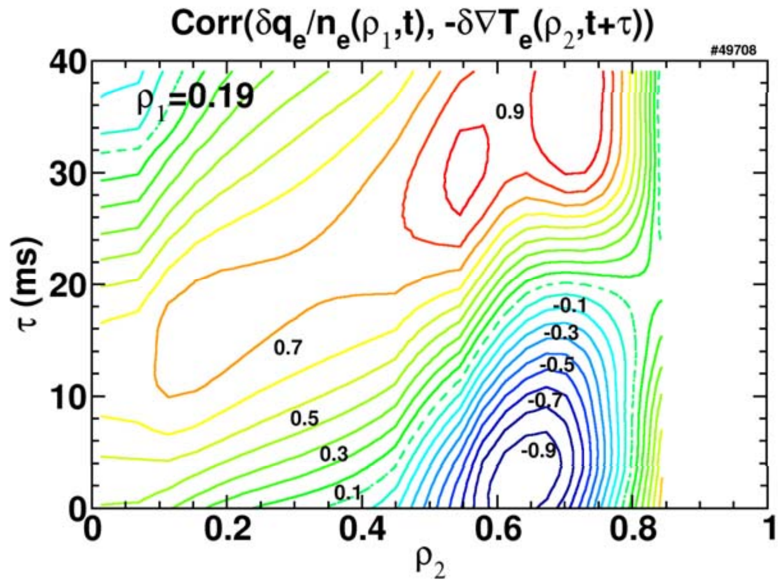
✓ Heat flux perturbation $\delta q_e(r,t) = -\frac{1}{r}\int_0^r \frac{3}{2} n_e \frac{\partial \delta T_e(r,t)}{\partial t} \rho d\rho$



✓ Strong negative correlation between the edge $\delta\nabla T_e$ and the core $\delta q_e/n_e$ is obtained

- The region with strong negative correlation appears around ρ ~ 0.6





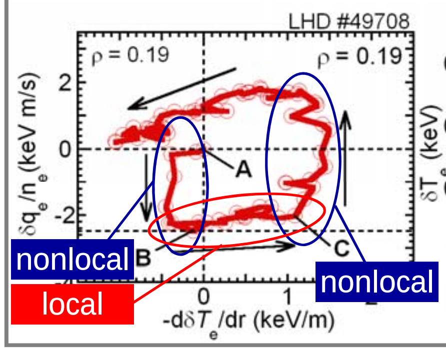
◆ Complex relationship between heat flux and T_e gradient

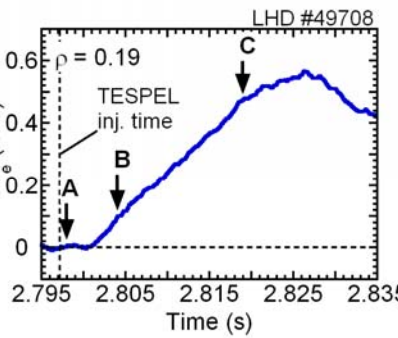
✓ Reduction of $\delta q_e/n_e$ is not accompanied by changes in local ∇T_e

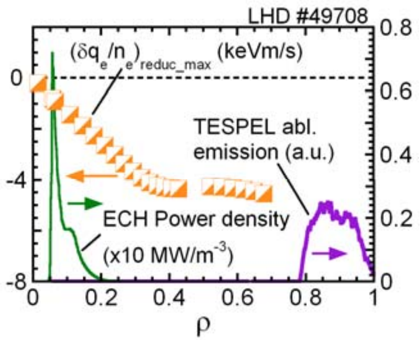
- Evidence against "standard transport theory" (local & diffusive)

✓ Turn-back of $\delta q_e/n_e$ is also independent of local ∇T_e

✓ Reduction of normalized heat flux due to nonlocal effect takes place in a wider region







◆ How can we understand nonlocal T_e rise in LHD?

✓ Clue from LHD experiment

1. Nonlocality in e-transport revealed by edge cooling
2. Transitions between "nonlocal" and "local" in e-transport also revealed

nonlocal → local → nonlocal

✓ 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 ν_b^* & longer T_e gradient scale length
- Radial extent close to plasma minor radius, a

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